ISSUED AUGUST 26, 1953

VOL. LXXXVII **PART I**

JOURNAL AND PROCEEDINGS
OF THE
ROYAL SOCIETY
OF NEW SOUTH WALES

FOR
1953
(INCORPORATED 1881)

PART I
OF
VOL. LXXXVII

Containing List of Members, Report of Council, Balance Sheet, Obituary Notices, Presidential Address and Papers read in April, 1953.

EDITED BY
G. D. OSBORNE, D.Sc., Ph.D.
Honorary Editorial Secretary

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

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

1953

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SYDNEY
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Royal Society of New South Wales

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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.

FORM OF BEQUEST.

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.

Volumes XI to LIII (that is to 1919)
,, LIV ,, LXVI (1920 to 1932)
,, LXVIII (1936)
,, LXX ,, LXXXII (1938 to 1948)
,, LXXXIII and LXXXIV

Volumes I to X (to 1876) and LXVII and LXIX (1935 and 1937) are out of print.

Reprints of papers are available.

LIST OF THE MEMBERS

OF THE

Royal Society of New South Wales

as at April 1, 1953

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.*, F.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., c/o Box 30, P.O., Chatswood.
1948	P	2	Andrews, Paul Burke, 5 Conway-avenue, Rose Bay.
1948			Arnold, Joan W. (Mrs.), 202 Separation-street, Northcote, Victoria.
1930	P	1	Aston, Ronald Leslie, B.Sc., B.E. *Syd.*, M.Sc., Ph.D. *Camb.*, A.M.I.E. *Aust.*, Senior 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., c/o Royal Geographical Society, Kensington Gore, London, S.W.7.
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.
1951			Banks, Maxwell Robert, B.Sc., Lecturer in Geology, University of Tasmania, Hobart, Tasmania.
1946	P	1	Barclay, Gordon Alfred, Chemistry Department, Sydney Technical College, Harris-street, Broadway, Sydney ; p.r. 78 Alt-street, Ashfield.
1919			Bardsley, John Ralph, 29 Walton-crescent, Abbotsford.
1951			Basden, Kenneth Spencer, A.S.T.C., Technical Officer, Department of Mining and Applied Geology, N.S.W. University of Technology, Broadway, Sydney.
1950			Baxter, John Philip, B.Sc., Ph.D., A.M.I.Chem.E., The Director and 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.*, Professor of Organic Chemistry, University of Sydney, Sydney.
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., 6 Wolseley-road, Lindfield.
1948			Blanks, Fred Roy, B.Sc. (Hons.), Industrial Chemist, c/o Australian Department, I.C.I. Ltd., London, S.W.1, England.
1946			Blaschke, Ernest 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.)

Elected.		
1951		Booker, Frederick William, M.Sc., c/o Geological Survey of N.S.W., Mines Department, Sydney.
1920	P 9	Booth, Edgar Harold, M.C., D.Sc., F.Inst.P., " Hills and Dales," Mittagong. (President, 1936.)
1951		Bosson, Geoffrey, M.Sc. *Lond.*, Professor of Applied Mathematics, N.S.W. University of Technology, Broadway, Sydney.
1939	P 26	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., Sydney ; p.r. 52 Beechworth-road, Pymble. (President, 1951.)
1938		Breckenridge, Marion, B.Sc., Department of Geology, The University of Sydney ; p.r. 19 Handley-avenue, Thornleigh.
1946	P 1	Breyer, Bruno. M.D., Ph.D., M.A., F.R.A.C.I., Senior Lecturer in Agricultural Chemistry, Faculty of Agriculture, The University of Sydney.
1952		Bridges, David Somerset, Schoolteacher, 14 Mt. Pleasant-avenue, Normanhurst.
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 10	Browne, Ida Alison, D.Sc., Geology Department, The University of Sydney.
1913	P 23	‡Browne, William Rowan, D.Sc., 51 Nelson-street, Gordon. (President, 1932.)
1952		Bryant, Raymond Alfred Arthur, A.S.T.C., Lecturer in Mechanical Engineering, N.S.W. University of Technology ; p.r. 32 Bruce-street, Brighton-le-Sands.
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., Ph.D., Sc.D., 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.
1952	P 1	Burke-Gaffney, Rev. Thomas Noel, S.J., Director, Riverview College Observatory, Riverview, N.S.W.
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.
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. *Syd.*, Ph.D. *Liverpool*, Senior Lecturer, Organic Chemistry, N.S.W. University of Technology ; p.r. " Alwilken," Coral-road, Cronulla.
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.
1952		Chapman, Dougan Wellesley, Surveyor, 3 Orinoco-street, Pymble.
1951		Charlwood, Joan Marie, B.Sc., Biochemist, 184 Queen-street, Concord West.
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., Ph.D., c/o Propulsion Research Laboratories, Box 1424H, G.P.O., Adelaide.
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., Professor in Physiology in the University of Sydney.
1909	P 7	‡Cotton, Leo Arthur, M.A., D.Sc., Emeritus Professor of Geology, Sydney University ; 113 Queen's Parade East, Newport Beach. (President, 1929.)
1941	P 1	Craig, David Parker, Ph.D., Professor of Physical Chemistry, University of Sydney.
1951		Crane, Roslyn Ann, B.Sc., Librarian, Australian Leather Research ; p.r. 6 Chesterfield-road, Epping.
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-Craig, 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.
1951		Darvall, Anthony Roger, M.B., B.S., D.O., Medical Practitioner, Royal Prince Alfred Hospital, Missenden-road, Camperdown.
1952		Davies, George Frederick, A.M.I.E.T. *Britain*, Engineer, 57 Eastern-avenue, Kingsford.
1952		Davison, Clem Newton, A.S.T.C., B.E. (Mining Engineering), c/o Territory Enterprises Pty. Ltd., Rum Jungle, N.T.
1952		Day, Alan Arthur, B.Sc., c/o Department of Geophysics and Trinity College, Cambridge, England.
1919	P 2	de Beuzeville, Wilfred Alex. Watt, J.P., " Melamere," Welham-street, Beecroft.
1952		Debus, Elaine Joan, Chemist, 62 Tarrant's-avenue, Eastwood.
1928		Donegan, Henry Arthur James, A.S.T.C., A.R.A.C.I., A.R.I.M.M., Senior Analyst, Department of Mines, Sydney ; p.r. 18 Hillview-street, Sans Souci.
1947		Downes, Alan Marchant, B.Sc.
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.
1951		Dunn, Thomas Melanby, B.Sc., c/o Chemistry Department, University College, Gower-street, London, W.C.1.
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. 15 Calvert-parade, Newport Beach.
1934	P 58	Dwyer, Francis P. J., D.Sc., Senior Lecturer in Chemistry, University of Sydney, Sydney.
1945		Eade, Ronald Arthur, B.Sc., 21 Steward-street, Leichhardt.
1951		Edgar, Joyce Enid (Mrs.), B.Sc., 16 Cooper-street, Cessnock.
1950		Edgell, Henry Stewart, 8 Barkly-crescent, Forrest, Canberra, A.C.T.
1946	P 1	El Nashar, Beryl, B.Sc., Ph.D., Dip.Ed., 9 San Francisso de Sales 5o C, Moncloa, Madrid, Spain.
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 Tyron-road, Lindfield.
1940		Emmerton, Henry James, B.Sc., 37 Wangoola-street, East 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.

Elected.		
1950		Fallon, Joseph James, B.Ec. *Zurich*, Photographer, 1 Coolong-road, Vaucluse.
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, Palaeontologist, Australian Museum, College-street, Sydney.
1949		Flinter, Basil Harold, B.Sc., Colonial Geological Survey, Federation of Malaya, Batu Gajah, Malaya.
1932		Forman, Kenn P., M.I.Refr.E., Box 1822, G.P.O., Sydney.
1943		Frederick, Robert Desider Louis, B.E., 1540 High-street, Malvern, Victoria.
1950		Freeman, Hans Charles, M.Sc., 43 Newcastle-street, Rose Bay.
1951		French, Oswald Raymond, Research Assistant, University of Sydney ; p.r. 66 Nottinghill-road, Lidcombe.
1940		Freney, Martin Raphael, B.Sc., 27 Wycombe-road, Neutral Bay.
1944	P 2	Friend, James Alan, M.Sc. *Syd.*, Ph.D. *Camb.*, Biochemistry Unit, Wool Textile Research Laboratories, 343 Royal parade, Parkville, N.2, Victoria.
1945		Furst, Hellmut Friedrich, B.D.S. *Syd.*, D.M.D. *Hamburg*, Dental Surgeon, 158 Bellevue-road, Bellevue Hill.
1952		Garan, Teodar, Geological Professional Officer, 1/22nd Street, Warragamba Dam, N.S.W.
1935	P 2	Garretty, Michael Duhan, D.Sc., " Surry Lodge ", Mitcham-road, Mitcham, Victoria.
1939	P 4	Gascoigne, Robert Mortimer, Ph.D. *Liverpool*, Department of Organic Chemistry, N.S.W. University of Technology, Broadway, Sydney.
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., Ph.D., A.R.I.C., 103 Bland-street, Ashfield.
1947		Gill, Naida Sugden, B.Sc., Ph.D., 45 Neville-street, Marrickville.
1947		‡Gill, Stuart Frederic, Schoolteacher, 45 Neville-street, Marrickville.
1948		Glasson, Kenneth Roderick, B.Sc., Geologist, 70 Beecroft-road, Beecroft.
1945		Goddard, Roy Hamilton, F.C.A.Aust., Royal Exchange, Bridge-street, Sydney.
1951		Goldstone, Charles Lillington, B.Agr.Sc. *N.Z.*, Lecturer in Sheep Husbandry, N.S.W. University of Technology, c/o East Sydney Technical College, Darlinghurst.
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	P 1	Gray, Charles Alexander Menzies, B.Sc., B.E., 75 Woniora-road, Hurstville.
1952		Gray, Noel Mackintosh, B.Sc. *W.A.*, Geologist, Research Sub-Branch, M.W.S. and D. Board, 341 Pitt-street, Sydney.
1952		Griffin, Russell John, B.Sc., Geologist, c/o Department of Mines, Sydney.
1952		Griffith, James Langford, B.A., M.Sc., Dip.Ed., Senior Lecturer in Applied Mathematics, N.S.W. University of Technology, Broadway, Sydney.
1938		Griffiths, Edward L., B.Sc., A.R.A.C.I., A.R.I.C., Lot 7, Kareelah-road, Hunters Hill.
1946	P 1	Gutmann, Felix, Ph.D., F.Inst.P., M.I.R.E., N.S.W. University of Technology, Broadway, Sydney.
1948	P 8	Gyarfas, Eleonora Clara, M.Sc. *Budapest*, Ph.D. *Syd.*, Research Assistant, Chemistry Department, University of Sydney.
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.

Elected		
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 6	Harris, Clive Melville, B.Sc., A.S.T.C., A.R.A.C.I., Lecturer in Inorganic Chemistry, N.S.W. University of Technology, Broadway, Sydney ; 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.
1951		Heard, George Douglas, B.Sc., Maitland Boys' High School, East Maitland, N.S.W.
1919		Henriques, Frederick Lester, Billyard-avenue, Elizabeth Bay.
1952		Hewitt, John William, B.Sc., Geologist, Main Roads Department ; p.r. 31 Wetherill-street, Narrabeen.
1945		Higgs, Alan Charles, Colonial Sugar Refining Co. Ltd., Pyrmont ; p.r. 29 Radio-avenue, Balgowlah.
1938	P 4	Hill, Dorothy, D.Sc. *Q'ld.*, Ph.D. *Cantab.*, Department of Geology, University of Queensland, St. Lucia, Brisbane, Queensland.
1936		Hirst, Edward Eugene, A.M.I.E., Vice-Chairman and Joint Managing Director, British General Electric Co. Ltd. ; p.r. " Springmead," Ingleburn.
1948	P 6	Hogarth, Julius William, B.Sc., 8 Jeanneret-avenue, Hunters Hill.
1952		Holm, Thomas John, Engineer, 524 Wilson-street, Redfern.
1951		Holmes, Robert Francis, 15 Baden-street, Coogee.
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.
1923	P 3	‡Hynes, Harold John, D.Sc.Agr., M.Sc., Assistant Director, Department of Agriculture, Box 36A, G.P.O., Sydney ; p.r. " Belbooree," 704 Pacific-highway, Killara.

1943		Iredale, Thomas, D.Sc., F.R.I.C., Reader, Chemistry Department, University of Sydney ; p.r. 96 Roseville-avenue, Roseville.

1942	P 1	Jaeger, John Conrad, M.A., D.Sc., Professor of Geophysics, Australian National University, Canberra, A.C.T.
1951		Jamieson, Helen Campbell, A.S.T.C. ; p.r. 3 Hamilton-street, Coogee.
1951		Johnson, William, Geologist, c/o The Supervising Engineer, Warragamba Dam, N.S.W.
1949	P 1	Joklik, Gunther F., B.Sc., c/o Bureau of Mineral Resources, Canberra, A.C.T.
1951		Jones, Roger M., Laboratory Assistant, Sydney Technical College ; p.r. 69 Moore Park-road, Centennial Park.
1935	P 6	Joplin, Germaine Anne, B.A., Ph.D., D.Sc., Geophysics Department, Australian National University, Canberra, A.C.T.
1948	P 1	Jopling, Alan Victor, B.Sc., B.E., Geology Department, N.S.W. University of Technology, Broadway, Sydney.

1935		Kelly, Caroline Tennant (Mrs.), Dip.Anth. ; p.r. " Avila," 17 Heydon-avenue, Warrawee.
1940		Kennard, William Walter, 9 Bona Vista-avenue, Maroubra.
1924	P 1	Kenny, Edward Joseph, Under Secretary of the 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.
1952		Kirkpatrick, Colin Bruce, M.Sc. *Syd.*, Senior Lecturer in Applied Mathematics, N.S.W. University of Technology, Broadway, Sydney.

Elected.		
1948		Knight, Oscar Le Maistre, B.E. *Syd.*, A.M.I.C.E., A.M.I.E.Aust., Engineer, 10 Mildura-street, Killara.
1948		Koch, Leo E., Dr.Phil.Habil *Cologne*, Research Lecturer, N.S.W. University of Technology, Broadway, Sydney; p.r. "Shalford," 21 Treatt's-road, Lindfield.
1939	P 3	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, B.Sc., 17 Clifford-street, Gordon.
1951		Lawrence, Laurence James, B.Sc., Lecturer in Geology, N.S.W. University of Technology; p.r. 28 Church-street, Ashfield.
1936		Leach, Stephen Laurence, B.A., B.Sc., A.R.A.C.I., British Australian Lead Manufacturers Pty. Ltd., Box 21, P.O., Concord.
1947		Le Fevre, Raymond James Wood, D.Sc., Ph.D., F.R.I.C., Professor of Chemistry, University of Sydney.
1936	P 2	Lemberg, Max Rudolph, D.Phil., F.R.S., 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; p.r. 160 Alt-street, Haberfield. (President 1946-47.)
1940		Lions, Jean Elizabeth (Mrs.), B.Sc., Dip.Ed., 160 Alt-street, Haberfield.
1951	P 3	Livingstone, Stanley Edward, A.S.T.C. (Hons.), A.R.A.C.I., B.Sc., Lecturer in Organic Chemistry, N.S.W. University of Technology; p.r. 5 Parker-street, Rockdale.
1947		Lloyd, James Charles, B.Sc. *Syd.*, N.S.W. Geological Survey, 41 Goulburn-street, Liverpool.
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, B.Sc., "Bodleian," 26 Kenneth-street, Longueville.
1951	P 1	Lovering, John Francis, B.Sc., Assistant Curator, Department of Mineralogy and Petrology, Australian Museum, College-street, Sydney.
1950		Low, Angus Henry, B.Sc., 74 Turnbull-street, Merewether.
1947		Lowenbein, Gladys Olive (Mrs.), B.Sc. *Melb.*, F.R.I.C. *Gt.Brit.*, A.R.A.C.I., 9 "Churchill," Botany-street, Bondi Junction.
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	P 1	McElroy, Clifford Turner, B.Sc., 147 Arden-street, Coogee.
1940		McGregor, Gordon Howard, 4 Maple-avenue, Pennant Hills.
1948		McInnes, Gordon Elliott, B.Sc., Ewan House, Billyard-avenue, Wahroonga.
1944	P 7	McKenzie, Hugh Albert, B.Sc., 52 Bolton-street, Guildford.
1943	P 3	McKern, Howard Hamlet Gordon, A.S.T.C., A.R.A.C.I., Senior Chemist, Museum of Applied Arts and Sciences, Harris-street, Broadway.
1947		McMahon, Patrick Reginald, M.Agr.Sc. *N.Z.*, Ph.D. *Leeds*, A.R.I.C., A.N.Z.I.C., Professor of Wool Technology, N.S.W. University of Technology, Broadway.
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.
1947		Magee, Charles Joseph, D.Sc.Agr. *Syd.*, M.Sc. *Wiss.*, Chief Biologist, Department of Agriculture; p.r. 4 Alexander-parade, Roseville. (President, 1952.)
1950		Mahoney, Albert John, B.Sc., Industrial Chemist, 112 Archer-street, Chatswood.
1951		Males, Pamela Ann, 13 Gelding-street, Summer Hill.

Elected.		
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.
1951		Mallaby, Hedley Arnold, B.Sc. (For.), Dip.For. *Canberra*, 114 Kurrajong-avenue, Leeton.
1940		Malone, Edward E., 33 Windsor-road, St. Marys.
1947	P 14	Mapstone, George E., M.Sc., A.R.A.C.I., M.Inst.Pet., Coal Research Section, C.S.I.R.O., Chatswood.
1949		Marshall, Charles Edward, Ph.D., D.Sc., Professor of Geology, The University of Sydney.
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. p.r. 18 Courallie-avenue, Pymble.
1951		Minty, Edward James, B.Sc., " Roseneath," Lynch-street, Parkes, N.S.W.
1922	P 33	Morrison, Frank Richard, F.R.A.C.I., F.C.S., Deputy Director, Museum of Applied Arts and Sciences, Harris-street, Broadway, 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.
1950		Mortlock, Allan John, M.Sc., 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, B.Sc., Chief Geologist, c/o Snowy Mountains Hydro-Electric Authority, Cooma, N.S.W.
1946		Mulholland, Charles St. John, B.Sc., Government Geologist, Department of Mines, Sydney.
1915		‡Murphy, Robert Kenneth, Dr.Ing.Chem., A.S.T.C., M.I.Chem.E., F.R.A.C.I., 68 Pindari-avenue, North Mosman.
1951		Murray, James Kenneth, B.Sc., 464 William-lane, Broken Hill, N.S.W.
1950		Murray, Patrick Desmond Fitzgerald, M.A., D.Sc., Professor of Zoology, University of Sydney.
1930	P 7	Naylor, George Francis King, M.A., M.Sc., Dip.Ed. *Syd.*, Ph.D. *Q'ld.*, Senior Lecturer in Psychology and Philosophy, University of Queensland, Brisbane.
1943		‡Neuhaus, John William George, 32, Bolton-street, Guildford.
1932		Newman, Ivor Vickery, M.Sc., Ph.D., F.R.M.S., F.L.S., ; p.r. 1 Stuart-street, Wahroonga.
1950		Ney, Michel, B.Sc.
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.
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, 42 Milroy-avenue, Kensington.
1940	P 25	Nyholm, Ronald Sydney, M.Sc. *Syd.*, Ph.D., D.Sc. *Lond.*, Associate Professor of Inorganic Chemistry, N.S.W. University of Technology, Broadway.
1951		‡O'Dea, Daryl Robert, A.S.T.C., Box 68, P.O., Broadway.
1947		Old, Adrian Noel, B.Sc.Agr., Chemist, Department of Agriculture ; p.r. 4 Springfield-avenue, Potts Point.
1921	P 12	Osborne, George Davenport, D.Sc. *Syd.*, Ph.D. *Camb.*, F.G.S., Reader in Geology in the University of Sydney. (President, 1944.)
1950		Oxenford, Reginald Augustus, B.Sc., 9 Cambridge-street, Singleton, N.S.W.

Elected.		
1951	P 1	Packham, Gordon Howard, B.Sc., 61 Earlwood-avenue, Earlwood.
1920	P 79	Penfold, Arthur Ramon, F.R.A.C.I., F.C.S., Director, Museum of Applied Arts and Sciences, Harris-street, Broadway, Sydney. (President, 1935.)
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., 4 Morella-road, Clifton Gardens.
1935		Phillips, Orwell, 55 Darling Point-road, Edgecliff.
1946		Pinwill, Norman, B.A. *Q'ld.*, The Scots College, Bellevue Hill.
1943	P 8	Plowman, Ronald Arthur, B.Sc., Ph.D. *Lond.*, A.S.T.C., A.R.A.C.I., Chemistry Department, University of Queensland, Brisbane.
1919		Poate, Sir 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.
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 Thirlow-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, B.E. (Mining), Mining Engineer, Finlay-road, Turramurra.
1935	P 3	‡Quodling, Florrie Mabel, B.Sc., Lecturer in Geology, University of Sydney.
1922	P 6	Raggatt, Harold George, D.Sc., Secretary, Department of National Development, Acton, Canberra, A.C.T.
1919	P 3	Ranclaud, Archibald Boscawen Boyd, B.Sc., B.E., 57 William-street, Sydney.
1947		Ray, Reginald John, Plastics Manufacturer and Research Chemist; p.r. "Treetops," Wyong-road, Berkeley Vale.
1931	P 1	Rayner, Jack Maxwell, B.Sc., F.Inst.P., Deputy Director, Bureau of Mineral Resources, Geology and Geophysics, 485 Bourke-street, Melbourne, Vic.
1951		Rector, John, B.Sc., Research Officer, Engineering Production, Metrology Division, C.S.I.R.O.; p.r. 46 Sir Thomas Mitchell-road, Bondi Beach.
1947		Reuter, Fritz Henry, Ph.D. *Berlin*, 1930, F.R.A.C.I., Associate Professor of Food Technology, N.S.W. University of Technology; p.r. 94 Onslow-street, Rose Bay.
1946		Rhodes-Smith, Cecil, 261 George-street, Sydney.
1950		Rickwood, Frank Kenneth, Senior Lecturer in Geology, The University of Sydney.
1947	P 1	Ritchie, Arthur Sinclair, A.S.T.C., Lecturer in Mineralogy and Geology, Newcastle University 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; p.r. 249 West Botany-street, Rockdale.
1939	P 19	Ritchie, Ernest, M.Sc., Senior Lecturer, Chemistry Department, University of Sydney, Sydney.
1939	P 3	Robbins, Elizabeth Marie (Mrs.), M.Sc., Waterloo-road, North Ryde.
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;
1949	P 6	Robertson, William Humphrey, B.Sc., Astronomer, Sydney Observatory, Sydney.
1951		Robinson, David Hugh, A.S.T.C., Chemist, 21 Dudley-avenue, Roseville.
1940		Rosenbaum, Sidney, 23 Strickland-avenue, Lindfield.
1948		Rosenthal-Schneider, Ilse, Ph.D., 48 Cambridge-avenue, Vaucluse.
1945		Rountree, Phyllis Margaret, D.Sc. *Melb.*, Dip.Bact. *Lond.*, Royal Prince Alfred Hospital, Sydney.
1952		Rutledge, Harold, B.Sc. *Dunelm*, Ph.D. *Edin.*, Geology Department, University of Sydney.

Elected.		
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. ; p.r. 10 Buena Vista-Avenue, Clifton Gardens.
1948	P 3	Schafer, Harry Neil Scott, B.Sc., C.S.I.R.O., Coal Research Section, P.O. Box 3, Chatswood ; p.r. 18 Bartlett-street, Summer Hill.
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, Technical Officer, School of Mining Engineering and Applied Geology, N.S.W. University of Technology, Broadway ; p.r. 9 Fairlight-street, Manly.
1933		Selby, Esmond Jacob, Dip.Com., Sales Manager, Box 175D, G.P.O., Sydney.
1950		Sergeyeff, William Peter, Mining Geologist and Engineer, c/o P.O. Yerranderie, via Camden, N.S.W.
1948		‡Sharp, Kenneth Raeburn, B.Sc., c/o S.M.H.E.A., Cooma, N.S.W.
1936	P 4	Sherrard, Kathleen Margaret Maria (Mrs.), M.Sc. *Melb.*, 43 Robertson-road, Centennial Park.
1945	P 3	Simmons, Lewis Michael, B.Sc., 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 2	Simonett, David Stanley, M.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	P 1	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.
1952		Slade, Milton John, B.Sc., New England University College, Armidale, N.S.W.
1940		Smith, Eric Brian Jeffcoat, 1 Rocklands-road, Wollstonecraft.
1947	P 2	Smith-White, William Broderick, M.A. *Cantab.*, B.Sc. *Syd.*, Department of Mathematics, University of Sydney ; p.r. 28 Canbrook-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, M.Sc., Lecturer in Geology, The University of Sydney, Sydney ; p.r. 42 Hopetoun-avenue, Mosman.
1916		‡Stephen, Alfred Ernest, F.C.S., c/o Box 1158HH, 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 3	Stevens, Neville Cecil, B.Sc., Mining Museum, Sydney ; p.r. 12 Salisbury-street, Hurstville.
1951		Stevens, Robert Denzil, 32 Menangle-road, Camden.
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. Gladswood House, Gladswood Gardens, Double Bay. (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. ; p.r. 26 Rosslyn-street, Bellevue Hill.
1951		Stuntz, John, B.Sc., 511 Burwood-road, Belmore.
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.* ; 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.
1952		Thomas, Penrhyn Francis, A.S.T.C., Optometrist, Suite 22, 3rd Floor, 49 Market-street, Sydney.

Elected.		
1946	P 2	Thompson, Nora (Mrs.), B.Sc. *Syd.*, c/o Mines Department, Wau, T.N.G.
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., M.B., B.S., Manning River District Hospital, Taree.
1949		Trebeck, Prosper Charles Brian, A.C.I.S., F.Com.A. *Eng.*, F.F.I.A., A.A.A., J.P., P.O. Box 76, Moree.
1951		Tugby, Mrs. Elise Evelyn, B.Sc.; p.r. 76 Bream-street, Coogee.
1943		Turner, Ivan Stewart, M.A., M.Sc., Ph.D.; p.r. 120 Awaba-street, Mosman.
1952		Ungar, Andrew, Dipl.Ing., Dr.Inq., 6 Ashley Grove, Gordon.
1949	P 1	Vallance, Thomas George, B.Sc., F.G.S., Geology Department, University of Sydney; p.r. 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. "Avila," 17 Heydon-avenue, Warrawee. (President, 1930.)
1948		Walker, Donald Francis, Surveyor, 13 Beauchamp-avenue, Chatswood.
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.)
1948		Ward, Judith, B.Sc., c/o 68 Upper-street, Bega, South Coast, N.S.W.
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.)
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.; p.r. "Hazelmere," Chelmsford-avenue, Lindfield. (President, 1937.)
1944		Watkins, William Hamilton, B.Sc., Industrial Chemist, c/o Cablemakers (Aust.) Pty. Ltd., Illawarra Road, Liverpool, N.S.W.
1911	P 1	‡Watt, Robert Dickie, M.A., B.Sc., Emeritus Professor of Agriculture, Sydney University, "Garron Tower," 5 Gladswood Gardens, Double Bay. (President, 1925.)
1921		‡Watts, Arthur Spencer, "Araboonoo," Glebe-street, Randwick.
1951		Weatherhead, Albert Victor, F.R.M.S., F.R.P.S., Technical Officer, Geology Department, N.S.W. University of Technology, Broadway; p.r. 3 Kennedy-avenue, Belmore.
1949		Westheimer, Gerald, B.Sc., F.S.T.C., F.I.O., Optometrist, 727 George-street, Sydney.
1943		Whiteman, Reginald John Nelson, M.B., Ch.M., F.R.A.C.S., 143 Macquarie-street, Sydney.
1951		Whitley, Alice, B.Sc., Teacher, 39 Belmore-street, Burwood.
1951	P 3	Whitworth, Horace Francis, M.Sc., Mining Museum, Sydney.
1949		Williams, Benjamin, A.S.T.C., 18 Arkland-street, Cammeray.
1949		Williamson, William Harold, Hughes-avenue, Ermington.
1943		Winch, Leonard, B.Sc.
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., 28 Calbina-road, Northbridge. (President, 1926.)
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.
1952		Wynn, Desmond Watkin, B.Sc., Geologist, c/o Department of Mines, Sydney.
1950		Zehnder, John Oscar, B.Sc., Geologist, c/o Australasian Petroleum Coy., Port Moresby, Papua.

HONORARY MEMBERS.

Limited to Twenty.

Elected.	
1949	Burnet, Sir 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.
1952	Firth, Raymond William, M.A., Ph.D., London School of Economics, Houghton-street, Aldwych, W.C.2, England.
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.
1912	Martin, Sir Charles J., C.M.G., D.Sc., F.R.S., Roebuck House, Old Chesterton, Cambridge, England.
1935	O'Connell, Rev. Daniel, J.K., S.J., D.Sc., D.Ph., F.R.A.S., Director, The Vatican Observatory, Rome, Italy.
1948	Oliphant, Marcus L., B.Sc., Ph.D., F.R.S., Professor of Physics, The Australian National University, Canberra, A.C.T.
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, 1952-53.

1906	William Dixson.
1906	Arthur Marshall McIntosh.
1896	Roland James Pope.
1893	Cecil Purser.

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 Prolonged 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.
1951. "The Ore Minerals and their Textures." By A. B. Edwards, D.Sc., Ph.D., D.I.C.

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.
1951	Stillwell, Frank Leslie, D.Sc., C.S.I.R.O., Melbourne.
1952	Wood, Joseph G., Ph.D. *Cantab.*, D.Sc. *Adel.*, Professor of Botany, University of Adelaide, South Australia.

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.
1951 Gregg, Norman McAlister, M.B., B.S., 193 Macquarie-street, Sydney.
1952 Waterhouse, Walter L., M.C., D.Sc.Agr., D.I.C., F.L.S., "Hazelmere," Chelmsford-avenue, Lindfield.

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.
1951 Bolton, John G., B.A., C.S.I.R.O., Division of Radiophysics, Sydney.
1952 Wardrop, Alan B., Ph.D., C.S.I.R.O., Division of Forest Products, South Melbourne.

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.
1951 Penfold, Arthur Ramon, F.R.A.C.I., F.C.S., Director, Museum of Applied Arts and Sciences, Sydney.
1952 No award made.

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.
1952 A. L. G. Rees, D.Sc., C.S.I.R.O., Division of Industrial Chemistry, Melbourne.

Royal Society of New South Wales

REPORT OF THE COUNCIL FOR THE YEAR ENDING 31st MARCH, 1953.

Presented at the Annual and General Monthly Meeting of the Society,
1st April, 1953, in accordance with Rule XXVI.

The membership of the Society at the end of the period under review stood at 382. Twenty-one new members were elected during the year, nineteen members were lost by resignation, and one member was removed from the register.

Four members have been lost to the Society by death since 2nd April, 1952 :

William Dixson (elected 1906).
Arthur Marshall McIntosh (elected 1906).
Roland James Pope (elected 1896).
Cecil Purser (elected 1893).

During the year nine General Monthly Meetings were held, the average attendance being thirty-six. Thirteen papers were accepted for reading and publication by the Society, six less than the previous year.

Lecturettes given during the year were as follows :

7th May :

" Chemical Weed Control." The speakers were B. Cortis-Jones, M.Sc., and Kelvin Green, B.Sc.Agr.

2nd July :

" The Heat Pump ", by R. C. L. Bosworth, D.Sc. (Adel.), Ph.D. (Camb.).

" Soil Conditioning Problems with particular reference to " Krilium ", by T. H. John, M.Sc.

3rd September :

" Aboriginal Rock Carvings : Their Techniques and Significance ", by F. D. McCarthy, Dip.Anthr.

Two meetings were devoted to Symposia, at which the following addresses were given :

4th June :

" Symposium on Sulphur "—

" The Occurrence and Commercial Sources of Sulphur ", by G. D. Osborne, D.Sc. (Syd.), Ph.D. (Camb.), F.G.S.

" The Present Industrial Position of Sulphur ", by T. G. Hunter, D.Sc., Ph.D. (Birmingham).

" The Biological Production of Sulphur ", by E. J. Ferguson-Wood, M.Sc., B.A.

6th August :

" Symposium on Time "—

" Cosmological Time ", by K. C. Westfold, M.A., B.Sc., D.Phil.

" Geological Time ", by A. V. Jopling, B.Sc., B.E.

" Measurement of Time ", by H. Wood, M.Sc., F.R.A.S.

The meeting devoted to the Commemoration of Great Scientists was held on 1st October. The following addresses were given :

" The Curies ", by Dr. D. P. Mellor.

" Emil Fischer ", by Professor A. J. Birch.

" Leonardo da Vinci ", by Dr. I. Rosenthal-Schneider.

A Film Evening was held on 5th November and, through the courtesy of the Department of External Affairs (Antarctic Division) and the Sydney Scientific Film Society, two very interesting films were shown :

" Macquarie Island ", with an address by Mr. J. Bunt.

" Science and Cinematography ", with an address by Dr. A. R. Michaelis.

Five Popular Science Lectures were delivered during the year :

15th May : " Science of Washing ", by Professor A. E. Alexander.

19th June : " Electrons and Arithmetic ", by Professor D. M. Myers.

18th September : " Science versus Waste : Food Storage and Transport for a Hungry World ", by Dr. R. N. Robertson.

16th October : " Queer Fish ", by Mr. A. N. Colefax.

20th November : " The Enjoyment of Architecture ", by Mr. A. A. Gamble.

The thanks of the Society are due to the five gentlemen who gave these lectures.

The Annual Dinner of the Society was held in the Withdrawing Room of the University Union, Sydney, on 26th March, 1953. There were present forty-seven members and friends.

The Section of Geology had as Chairman Mr. R. O. Chalmers and as Hon. Secretary Mr. T. G. Vallance. The Section held eight meetings during the year, including a symposium, lecturettes, notes and exhibits. The average attendance was twenty members and seven visitors.

The Council of the Society held eleven ordinary meetings and one special meeting during the year. The average attendance at the meetings was twelve.

On the Science House Management Committee the Society was represented by Mr. H. A. J. Donegan and Mr. F. R. Morrison ; substitute representatives were Dr. R. C. L. Bosworth and Mr. H. O. Fletcher.

The representatives of the Society on Science House Extension Committee were the President, Dr. C. J. Magee, and the Hon. Treasurer, Mr. H. A. J. Donegan.

During the year one of our Vice-Presidents, the Rev. Dr. D. J. K. O'Connell, was appointed Director of the Vatican Observatory. Mr. H. Wood was elected to fill the vacancy caused by Father O'Connell's departure, at the Council meeting held on 24th September.

Following a request from the Conservator of the Muogamarra Sanctuary for representation of this Society on the proposed Trust, Miss Joyce Vickery, M.Sc., was appointed to occupy this position.

Raymond William Firth, M.A., Ph.D., was elected an honorary member of the Society at the Annual and General Monthly Meeting held on 2nd April, 1952.

The Liversidge Research Lecture for 1952 was delivered by Dr. A. L. G. Rees on 17th July in the Chemistry School of the University of Sydney.

The title of the lecture was " Electron Diffraction in the Chemistry of the Solid State ".

The Clarke Medal for 1953 was awarded to Dr. A. J. Nicholson, Chief of Division of Entomology, C.S.I.R.O., Canberra, for his distinguished contributions to Australian entomology, particularly his studies on mimicry and insect populations.

The Edgeworth David Medal for 1952 was awarded to Dr. Alan B. Wardrop for his outstanding contributions in the field of botany, particularly his work on cell-wall organization of timbers.

The James Cook Medal for 1952 was awarded to Professor W. L. Waterhouse for his outstanding contributions in the field of agricultural science, particularly his work on the breeding of rust-resistant wheats.

During the year the Council entertained the distinguished scientist Professor E. A. Guggenheim, of the University of Reading, on the occasion of his visit to this city.

The financial position of the Society, as disclosed in the annual audit, is still difficult. Despite Council's efforts to keep expenditure within income, the deficit for the current year is £212 8s. 8d. This, however, is a great improvement on the deficit of £736 incurred in the previous year. An important factor in the improvement has been the generous grant of £400 from the Rural Credits Development Fund of the Commonwealth Bank of Australia, for which the Society is deeply grateful. The second main factor in the relative improvement is the increase made in members' subscriptions. Although the outlook is distinctly better than in recent years, the financial position is one that demands constant attention.

A new typewriter for the office has been purchased, and the old one traded in.

At the General Meeting held on 1st October, the following clause was added to Rule IX :

" The Council shall have the power to reduce to one and a half guineas the annual subscription of any member who is absent from Australia and who makes application in writing for a reduction. Such reduction may be granted for a period not exceeding two years."

The Society's share of the profits from Science House for the year was £495, an increase of £65 on the previous year.

The grant from the Government of New South Wales of £400 continues, and the Society appreciates very much the Government's continued interest in its work.

At the Special Meeting held on the 11th November, 1952, Council appointed a standing committee to advise the Council on library matters.

It is with regret that I have to report the resignation of Mrs. M. Golding, who has rendered such valuable service as library assistant. She has been succeeded by Mrs. B. Sommerville, who has had previous library experience in New Zealand and the McMaster Laboratory.

The Library. The amount of £60 15s. 5d. has been spent on the purchase of periodicals and £107 18s. 6d. on binding. A wash-basin has been installed in the library.

Exchange of publications is maintained with 420 societies and institutions, an increase of three.

The number of accessions entered in the catalogue during the year ended 28th February, 1953, was 2,654 parts of periodicals.

The number of books, periodicals, etc., borrowed by members, institutions and accredited readers was 336.

Among the institutions which made use of the library through the inter-library scheme were : National Standards and Radiophysics Laboratory, Waite Agricultural Research Institute, Fisher Library, Colonial Sugar Refinery, McMaster Laboratory, Sydney Technical College, Forestry Commission of N.S.W., Sydney Hospital Library, Department of Health, N.S.W., Department of Public Works, N.S.W., Food Preservation Laboratory, Homebush, Standard Telephones and Cables, Department of Agriculture, N.S.W., Bureau of Mineral Resources, M.W.S. and D. Board, N.S.W., C.S.I.R.O. Division of Industrial Chemistry, Division of Fisheries, Division of Entomology, Building Research, Highett, Plant and Soils Laboratory, Brisbane, Wool Textile Research Laboratory, Regional Pastoral Laboratory, Snowy Mountains Hydro-Electric Authority, Taubman's Ltd., University of Melbourne, Queensland Institute of Medical Research, Kraft Walker Cheese Co., Melbourne, Museum of Applied Arts and Sciences, Sydney County Council, Australian National University, Canberra, National Museum, Victoria, Hydro-Electricity Commission, Tasmania, University of Western Australia, University of Queensland, State Library of Tasmania, Timbrol Ltd., N.S.W. University of Technology, Australian Leather Research Association, Wollongong Technical College, School of Public Health and Tropical Medicine, Sydney.

C. J. MAGEE,
President.

THE ROYAL SOCIETY OF NEW SOUTH WALES.

BALANCE SHEET AS AT 28th FEBRUARY, 1953.

LIABILITIES.

1952.		1953.					
£		£	s.	d.	£	s.	d.
270	Accrued Expenses				111	3	3
23	Subscriptions Paid in Advance				34	13	0
113	Life Members' Subscriptions—Amount carried forward				135	12	0
	Trust and Monograph Capital Funds (detailed below)—						
	Clarke Memorial	1,896	10	2			
	Walter Burfitt Prize	1,111	13	9			
	Liversidge Bequest	700	0	0			
	Monograph Capital Fund	3,752	10	0			
7,428					7,460	13	11
24,088	ACCUMULATED FUNDS				23,851	4	6
	Contingent Liability (in connection with Perpetual Leases.)						
£31,922					£31,593	6	8

ASSETS.

1952.		1953.					
£		£	s.	d.	£	s.	d.
573	Cash at Bank and in Hand				168	7	4
	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	2,860	0	0			
9,360					9,360	0	0
	Debtors for Subscriptions	122	11	6			
—	*Less* Reserve for Bad Debts	122	11	6			
					—		
14,835	Science House—One-third Capital Cost				14,835	4	4
6,800	Library—At Valuation				6,800	0	0
325	Furniture—At Cost—*less* Depreciation				402	15	0
24	Pictures—At Cost—*less* Depreciation				23	0	0
5	Lantern—At Cost—*less* Depreciation				4	0	0
£31,922					£31,593	6	8

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 29th February, 1952 . .	1,800	0	0	1,000	0	0	700	0	0	3,000	0	0
Revenue—												
Balance at 29th February, 1952	141	16	9	81	16	8	44	5	1	659	18	4
Income for Twelve Months . .	53	15	2	29	17	1	20	18	1	92	11	8
	195	11	11	111	13	9	65	3	2	752	10	0
Less Expenditure	99	1	9	—			65	3	2	—		
Balance at 28th February, 1953	£96	10	2	£111	13	9	—			£752	10	0

ACCUMULATED FUNDS.

				£	s.	d.
Balance at 29th February, 1952				24,088	1	2
Less—						
Increase in Reserve for Bad Debts . .	£20	4	0			
Deficit for twelve months (as shown by Income and Expenditure Account)	212	8	8			
Bad Debts written off	4	4	0			
				236	16	8
				£23,851	4	6

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, 1953, as disclosed thereby. We have satisfied ourselves that the Society's Commonwealth Bonds and Inscribed Stock are properly held and registered.

HORLEY & HORLEY,
Per Conrad F. Horley, F.C.A. (Aust.),
Chartered Accountants.

Prudential Building,
39 Martin Place,
Sydney, 11th March, 1953.

(Sgd.) H. A. J. DONEGAN,
Honorary Treasurer.

INCOME AND EXPENDITURE ACCOUNT.
1st March, 1952, to 28th February, 1953.

1951-2. £		1952-53. £	s.	d.	£	s.	d.
	To Annual Dinner—						
	Expenditure	70	16	6			
20	*Less* Received	68	12	0			
					2	4	6
32	,, Audit				31	10	0
41	,, Cleaning				70	10	0
19	,, Depreciation				18	3	0
11	,, Electricity				22	12	4
6	,, Entertainment Expenses				4	2	8
12	,, Insurance				11	3	2
66	,, Library Purchases and Binding				61	7	2
100	,, Miscellaneous				87	18	3
76	,, Postages and Telegrams				93	9	4
	,, Printing and Binding Journal—						
	Vol. 85	700	8	3			
	Vol. 86, Parts I and II	293	8	7			
755					993	16	10
145	,, Printing—General				116	9	5
107	,, Rent—Science House Management Committee	74	16	2			
	Less Receipts from Subletting	47	16	8			
					26	19	
128	,, Reprints				—		
—	,, Repairs				46	14	6
783	,, Salaries				886	13	3
25	,, Telephone				31	11	4
£2,326					£2,505	5	3

1951-2. £		1952-53. £	s.	d.
633	By Memberahip Subscriptions	973	17	6
10	,, Proportion of Life Members' Subscriptions	11	11	0
400	,, Government Subsidy	200	0	0
—	,, Commonwealth Bank—Special Grant	400	0	0
430	,, Science House—Share of Surplus	495	0	0
117	,, Interest on General Investments	109	5	7
—	,, Other Receipts—Sale of Reprints	103	2	6
1,590		2,292	16	7
736	,, Deficit for Twelve Months	212	8	8
£2,326		£2,505	5	3

ABSTRACT OF PROCEEDINGS

OF THE SECTION OF

GEOLOGY

Chairman : R. O. Chalmers, A.S.T.C.
Hon. Secretary : T. G. Vallance, B.Sc., F.G.S.

Meetings. Eight meetings were held during the year, the average attendance being twenty members and seven visitors.

April 18th.—Address by Dr. G. D. Osborne on " Spilites of New South Wales and the Spilite Problem ". The speaker reviewed the occurrence of Palæozoic true spilites and spilitoid rocks in N.S.W., and dealt with the serpentine-spilite association. Tectonic, petrological and environmental implications of spilite lavas were mentioned and it was concluded that there is no justification for the conception of a primary spilitic magma. The idea of a close connection, in space and time, between invasion of peridotites and the irruption of spilites was questioned.

May 16th.—Short talks, illustrated by Kodachrome slides, on the following areas of geological interest : (*a*) Victorian Alps (Mr. N. C. Stevens) ; (*b*) Northern Queensland (Dr. H. Narain) ; (*c*) Hart's Range, Central Australia (Mr. G. F. Joklik) ; (*d*) Braidwood district, N.S.W. (Mr. G. E. McInnes).

June 20th.—Contributions to Geology from the N.S.W. University of Technology. Short talks by (*a*) Prof. D. W. Phillips on " Structures Produced by Mining Operations " ; (*b*) Dr. L. E. Koch on " Observations on the So-called ' Sunburn ' of Basalts and its Technical Implications " ; (*c*) Mr. L. J. Lawrence on the " Petrology and Ore Deposits of the Mole Tableland " (northern N.S.W.) ; (*d*) Mr. A. V. Weatherhead on " Some Recent Observations in the Micro-Petrology of Clays as Revealed by a New Technique ".

July 18th.—Address by Dr. H. Rutledge on " The Petrology of the Southern Part of the Loch Doon (Galloway, Scotland) Plutonic Complex ". An abstract of this work is given in *Proc. Geol. Soc. London,* No. 1484, 1952.

August 15th.—Short address by Dr. L. E. Koch entitled " On the Adhesiveness of Minerals and Rocks and its Technical Applications ". The speaker mentioned such phenomena as desert varnish and the ' streak ' produced on polished glass surfaces by certain minerals, as well as the utilization of this physical property of ' adhesiveness ' in such operations as froth flotation.

September 19th.—Symposium on Some Aspects of the Geology of the Sydney District. (*a*) " Subdivision of the Triassic ", by Dr. W. R. Browne. (*b*) " The Volcanic Necks ", by Dr. G. D. Osborne. (*c*) " Observations on the Wianamatta Group ", by Mr. J. F. Lovering. Dr. Browne believed that the usually recognized divisions of the Triassic (Narrabeen, Hawkesbury and Wianamatta) in the Sydney district were true series established on the evidence of the contained fossils by David in 1932. Dr. Osborne referred especially to the breccia masses which display evidence of tilting or downward-drag of the well-bedded tuff or breccia and to the pleonaste-pyroxene symplectites in gabbroic cognate xenoliths in the basalt of some necks. Mr. Lovering presented a suggested stratigraphical sequence of eight formations (based on lithological features) which comprise the Wianamatta Group.

October 17th.—Address by Mr. F. K. Rickwood on " The Structure of the Central Highlands of New Guinea ".

November 21st.—Address by Mr. E. O. Rayner entitled " Some Geological Observations in Central and Northern Australia ". The speaker gave an account of the geological field investigations of the Australian Museum Expedition to Northern Australia in April-August, 1952.

Obituary

William Dixson, who was elected a member of the Society in 1906. was born at Sydney on the 18th April, 1870, and received his education at All Saints' College, Bathurst.

Leaving Sydney in 1889, he served his time in Scotland as an engineer, and returned to Australia in 1896 and took a position within the family business of Dixson and Sons, Ltd., tobacco merchants. He soon rose to important executive positions in the firm.

He was created a Knight in 1939.

He had a very deep interest in the materials of Australian history, of which he made, during his lifetime, a great collection, second only to that of David Scott Mitchell on the bibliographical side ; on the pictorial side Dixson's was the greater.

His books, manuscripts and pictures are bequeathed to the Trustees of the Public Library to form a Dixson Library, for which he has provided a generous endowment, the full extent of which will not be known until the bequest is handed over to the Trustees of the Public Library. The Dixson Wing of the Public Library, opened in 1929, contains the magnificent pictures and other material which he presented during his lifetime.

He died at the age of 82 on the 17th August, 1952.

Arthur Marshall McIntosh was elected a member of the Society in 1906, shortly after he was registered, in 1905, as a dentist for New South Wales. He practised until his retirement in 1949, his registration being terminated, at his request, in 1950.

He died on the 7th March, 1952, at the age of 72.

Roland James Pope, who joined the Society in 1896, and died on the 27th July, 1952, aged 88 years, was an ophthalmic surgeon. He ceased practising some twenty-five years ago, and thus was not well known in his profession in recent decades. During his career he was an Honorary Ophthalmic Surgeon for a considerable period.

Cecil Purser, one of the greatest physicians this State has known, died on the 13th January, 1953, aged 90 years, full of honour and profoundly respected by a host of friends in the medical and academic worlds.

He was born on the 13th January, 1862, at Castle Hill, and educated in that district. He entered Sydney University and graduated as follows : B.A. 1885, M.B., Ch.M. 1890. He did his medical courses in those historic days when Sir Thomas Anderson Stuart was establishing the Sydney Medical School. Soon after his graduation he gained such experience, and made such a mark on his contemporaries, that he was soon occupying positions of trust and responsibility.

A full list of his appointments would take too much space, but we record his appointment as Resident Medical Officer at Royal Prince Alfred Hospital, and later (1891–93) a most successful Medical Superintendent. He was Hon. Assistant Physician, 1896–1898, Hon. Senior Physician, 1898–1912, Hon. Consulting Physician from 1912 until his death.

His great administrative ability displayed itself in his election as a Director of the Board of Management of R.P.A. Hospital, followed by being Vice-Chairman 1920–23 and finally Chairman 1924–33.

In addition to these great services, he contributed much effective work upon various boards and committees of medical institutions.

Th other great field of his honorary service was the University of Sydney. He was elected to the Senate in 1909, retiring in 1929 after twenty years as a Fellow, during which time he was Vice-Chancellor (under the old scheme) in 1917, 1918 and 1923, and Deputy-Chancellor 1924–25.

He was a great supporter of the College Scheme of University residence, and entered St. Andrew's College as a student, later being elected to its Board of Trustees. He also helped in the foundation of Wesley College, and was appointed a Foundation Trustee. The latest extension at Wesley has been named the Cecil Purser Wing.

Purser was truly a great man, full of sympathy for the under-privileged. In spite of his many official commitments, he developed a very great practice and was the " family doctor " to numbers of folk who drew from him understanding and sympathy in their illnesses, both of body and of spirit.

PRESIDENTIAL ADDRESS

By C. J. MAGEE, D.Sc.Agr. (Syd.), M.Sc. (Wis.).

Delivered before the Royal Society of New South Wales, April 1, 1953.

PART I. WORK OF THE SOCIETY.

The Annual Report of Council records a year of useful activity. The programme of meetings has been of fairly wide interest, but considering our membership of 383, average attendance at meetings continues to be poor. This is doubtless largely due to the high degree of specialization that exists in Science today and the many other societies members also now support. It has been my observation, however, that when our business paper includes an item of wider interest than usual, either as a contributed paper or lecturette, attendance improves. Symposia are regarded by members with favour and the two symposia which were held during the year were well attended. So was the film evening. Improvement in the design of meetings should continue to be a special consideration for the incoming and future Councils, since it is most desirable that our Society, besides its other activities, remains a meeting place for scientists of all disciplines.

Special attention was given during the year by Council to the Society's Library, which is fast exhausting its filing capacity. A sub-committee consisting of Messrs. F. N. Hanlon, A. V. Jopling and H. Wood was appointed in May to enquire into the composition of the library, the amount of use made of it, and to estimate its storage life. The sub-committee presented a valuable report, which influenced Council in calling a special meeting in November to discuss the present-day function of the library and to formulate a policy to be adopted for its development. A Standing Committee was appointed, consisting of the President, Professor K. E. Bullen (Hon. Sec.), Mr. F. N. Hanlon (Hon. Librarian), Mr. H. Wood, Mr. A. V. Jopling, Dr. D. P. Mellor and Dr. G. H. Briggs, to advise Council during the next few years on library matters. Council also recommended that the Library Standing Committee be reviewed each year to ensure that each branch of science retains representation. It is clear that there are many engineering, medical and other journals in the library which are no longer received by the Society and could appropriately be disposed of by gift, loan or sale to other libraries, and that there is still unnecessary duplication of filing with the library of the Linnean Society of New South Wales. The present day purpose of the library was defined by Council, and with the assistance of the Standing Committee it will be possible to institute a number of improvements and greatly extend the storage life of our existing premises. It is of interest that about 38 per cent. of the publications received by the Royal Society library are not available elsewhere in Sydney.

It is gratifying to record that the financial position of the Society remains sound during this difficult period of inflation, in which all costs have risen steeply, particularly publication costs and salaries. Although our Income and Expenditure Account for the year shows a deficit, it is the smallest deficit the Society has had for several years and payment was made for the printing of six parts of our Journal instead of the usual four. The action taken at the end of the previous financial year of increasing members' subscriptions has greatly assisted the Society this year, and the grant of £400 received from the Rural Credits Development Fund of the Commonwealth Bank of Australia has been of special value. I wish to record my thanks to the Governor of the Bank for the support given to our Society in a very difficult period. The Government of New South Wales has again given generous help and made a grant of £400 towards our activities, but an amount of £200 only appears in our Balance Sheet, as this year the grant was made in quarterly instalments. Council has practised numerous economies, but it has adhered to the Society's policy of not declining to publish any scientific paper of merit because of cost alone. This policy over the last few difficult years has, without doubt, been the main contributor to the fall in value of the accumulated funds of the Society from £26,081 in 1949 to the present figure of £23,851. Nevertheless, it is considered that the financial position of the Society is still secure enough for maintenance of the policy.

The Liversidge Research Lecture for 1952, sponsored by this Society, was delivered on 17th July at the University of Sydney by Dr. A. L. G. Rees, Division of Industrial Chemistry, C.S.I.R.O., Melbourne. He chose as his subject " Electron Diffraction in the Chemistry of the Solid State ". The Royal Society of New South Wales co-operated with the University of Sydney in arranging the Pollock Memorial Lecture, which was held on 15th September at the University of Sydney. The lecture, entitled " Post-War Physics ", was given by Professor H. S. W. Massey, Quain Professor of Physics, University College, London. I presided at both meetings, which were well attended, particularly by young scientists, and I could not help feeling how perfectly the lectures fulfilled the wishes of Liversidge and Pollock in being lectures " to encourage research and draw attention to research that should be done ".

There has been much public and scientific interest during the year in the discovery of substantial deposits of uranium ore in Northern Territory. These appear to be of sufficient importance to influence strongly Australia's future. An Atomic Energy Commission has been appointed by the Commonwealth Government, and we take pride in the fact that Professor J. P. Baxter, a valued member of Council, is one of the three members of this Commission.

The year was notable in that the 29th Meeting of the Australian and New Zealand Association for the Advancement of Science was held in Sydney from 20th to 27th August, and many members of our Society participated actively in its proceedings. The meetings of the fifteen sections of the Association, which were open to the press and members of the public, could not have failed to widen the appreciation of science in this State. The tenth General Assembly of the Union Radio-Scientifique Internationale was also held in Sydney, for the first time in Australia, from 11th to 23rd August. The A.N.Z.A.A.S. and U.R.S.I. meetings, in addition to their main functions, were of special benefit in that they brought to Sydney many eminent overseas scientists.

Many members of the Society took part also in the Centenary Celebrations of the University of Sydney, which were held on 26th to 31st August. The University of Sydney was founded in 1852 and early members of our Society, particularly Dr. Henry Gratton Douglass and Dr. Charles Nicholson, played a prominent part in its foundation.

The Annual Dinner of the Society was held again this year and was attended by 47 members and guests. The function was a most enjoyable one. The original minute book of the Philosophical Society of Australasia, from which the Royal Society of New South Wales stems, was exhibited at the dinner. This historical relic was discovered in 1921 (see THIS JOURNAL, Vol. LV), but its whereabouts in recent years has been unknown. It is a pleasure to record that it is now filed under call number D.142 at the Mitchell Library, Sydney.

I wish to take this opportunity to thank members of Council, and indeed the general membership of the Society, for the co-operation I have received during the year. In particular I wish to thank members of the Executive Committee for their help and guidance and the Hon. Librarian for his attention to the library. This Society is indebted, too, to a wide circle of friends in this and other States who have assisted during the year in the refereeing of contributed papers, in serving on selection committees, in helping with symposia and popular science lectures, and I wish to make grateful acknowledgement to them.

It is with regret that I have to record the deaths of the following members :

Sir William Dixson, who was elected a member of the Society in 1906.

Arthur Marshall McIntosh, who was elected to membership of the Society in 1906.

Dr. Roland James Pope, who was elected a member of the Society in 1896.

Dr. Cecil Purser, who was elected a member in 1893.

PART II. SOME ASPECTS OF THE BUNCHY TOP DISEASE OF BANANA AND OTHER *MUSA* SPP.

(Plates I–VI.)

Our rules do not contain any instruction that the President shall deliver an address, but it has become traditional for him to do so. It has become traditional, too, for your President to take the liberty of occupying this portion of the Annual General Meeting with a consideration of scientific matters in which he has a special interest and to invite members to join him in appreciating their significance. For almost 30 years I have maintained an interest in one of the plant virus diseases, namely the bunchy top disease of bananas and other *Musa* spp., and as I have had the opportunity of observing it in a number of countries besides Australia, it is thought that this would be a suitable occasion to present a review of some of my observations. Tonight I will deal with its history and distribution, and since the establishment of its distribution rests on recognition of symptoms, I will discuss the variability of its symptoms and the confusion which exists regarding identity of the disease in certain species.

The genus *Musa* is one of the most important groups of plants in tropical regions and provides a staple food, bananas and plantains, for several hundreds of millions of people. These plants surpass all other food crops in yields per acre and possess the special advantages that they are perennials and with their aid areas of land can be brought into food production in a comparatively short time. The food they supply also is non-seasonal in its harvest, obviating the need for storage and lessening the risk of famine. During the last century or so, peoples living in temperate climates have also come to regard bananas with favour, and there are now large industries based on their culture in the tropics and sub-tropics and their shipment to regions or countries with temperate climates.

Bananas and plantains are plants of great antiquity, and some philosophers consider that they were one of the first foods of man and among the first crops to be cultivated by him (Reynolds, 1951). All scientific evidence (Sands, 1925 ; Hill, 1926 ; Harland, 1928 ; Howes, 1928) points to the banana and plantain being indigenous to the Indo-Malayan region, whence they have been distributed to Africa, the Americas and to the Pacific region. Linnæus, who named two of the most important species of the genus, has perpetuated legends which surround these important food plants. The legend reached Europe that the sages of India reposed in the shade of the banana tree and refreshed themselves with its fruit.

Linnæus has preserved this myth in his *Musa sapientum.* An eastern legend also held that the banana flourished in the Garden of Eden, being in fact the tree of knowledge (a more acceptable supposition than the apple tree, although neither is mentioned in Genesis) and this legend is believed to have influenced Linnæus in naming his *Musa paradisiaca.* All the most important varieties of bananas and plantains appear to belong to these species and to one other species, erected by Lambert in 1836, *M. cavendishii.* The classification of *Musa* spp. is, however, still rather tentative but is being proceeded with at the Imperial College of Tropical Agriculture, Trinidad, a most worthy task in view of their importance in food production and commerce.

All the species of *Musa* producing edible seedless fruit, and all the fertile or seed-bearing species which have been examined, are subject to attack by the bunchy-top virus. I will refer especially tonight to symptoms of the disease on two of the seed-bearing species : the Abyssinian banana, *M. ensete* Gmel., a tall-growing ornamental and shade plant, and *M. textilis* Née, from which abaca or manila hemp fibre is extracted. An important industry in the Philippines is based on this latter species.

Early History and Geographical Range.

Fiji.

The bunchy top disease of the banana first attracted notice in the islands of the Fiji Group, where it seriously interfered with the development of an important export industry. Several references to the disease were published in the *Fiji Times* during 1889. Short accounts of the early efforts which were made to determine its cause are given in the *Kew Bulletin* of 1890 and 1892. Two interesting letters have been preserved at the Royal Botanic Gardens, Kew, and extracts of these are worthy of quotation because of their bearing on the early history of the disease. These quotations are made with the permission of the Director.

Under date December 6, 1890, the Governor of Fiji, Sir John Thurston, reported as follows to the Colonial Office : " In or about 1879, *M. cavendishii* growing in the island of Moturiki were attacked with a disease. In time all the bananas were killed off and the disease attacked the more robust indigenous plantains and killed them. From Moturiki it spread all over the group to leeward. Then by careless transporattion of plants it got to windward and the disease is now everywhere. No such disease was ever known before. Its attacks appear capricious for in a banana plantation the individuals do not suffer from propinquity or apparently not ; healthy and apparently healthy plants growing among those diseased. There appears to be no difference between plants in old plantations, new plantations, virgin soil, forest land, littoral or inland district . . . "

" In 1878 our first coolie ship came from India and landed at depots built on a small island close to Moturiki, named Yanuca, and it is opined that all bananas were there and then attacked and that the disease was blown across the few yards of water that divided the one island from the other. Is it possible that some pest came with Indian rice, curry stuffs and baggage generally ? "

In February, 1891, Sir John wrote as follows to the Colonial Office : " Perhaps the most singular character of the disease is its capriciousness. It does not and has not (Moturiki excepted) attacked all plants in contiguity but only some of them. Healthy and unhealthy plants may sometimes be seen rising from the same stool. The state of the land whether old or new, virgin soil or well exhausted is not in question. The disease in its capricious way attacks plants in every condition as regards soil, and here and there even individuals of the order *Musa* growing wild in the forest . . . "

" The disease, whatever it may be, causes both plants to appear constricted or choked at what may loosely be described as the junction of the leaves and the stem. The stem of the banana is really nothing more than the strong sheathing bases of the petioles and it is just where the petioles rise from these bases that appearance of constriction presents itself. I enclose a photograph of a half-grown plant and its sucker showing the leaves crowded and compressed together in the centre or line of growth. Also another showing the manner in which suckers finally grow. They attain no height, bear narrow, lanceolate leaves, fail to flower and ultimately decay and rot away . . . "

" I also find that as the disease increases the petioles of the leaves become dry and brittle and will snap or break off shortly and show the inner cellular structure dry and almost entirely wanting in sap or moisture. The conclusion at which I have arrived is that the seat of the disease is below the surface of the ground—that the root feeders are in some way affected and the plant rendered unable to elaborate the sap necessary to the formation of healthy cells and cell contents. The plant so affected therefore grows feebly, abnormally in habit, and soon dies. Planters cut down and root out every plant as soon as the least sign of disease appears, and this plan has the effect at least of retarding the spread of the disease . . . "

" It is not likely that the banana export will be seriously affected or brought to an end by this disease, but it is needless to say that the cost of production and the anxiety of the planters are much increased. At the suggestion of the Kew authorities I am sending them the roots, stem and leaves of a diseased plant preserved in a clear pickle of salt and water, and it is not improbable that the highly trained intelligence at Kew may detect that which is beyond our observation here."

Reproductions of the photographs enclosed by Thurston in his second despatch are shown in Plate I, Figs. 1 and 2, and together with his description they leave little doubt of the identity of the Fijian disease. Further confirmation of this was obtained by me in discussions with old residents of the Colony during a visit to Fiji in 1937. The specimens Thurston sent to Kew Gardens were examined in August, 1891, by Arthur E. Shipley, of Christ College, Cambridge, who reported[1] that there was " no evidence of any foreign organism " in the specimens.

Thurston somewhat underestimated the dangers of the disease as a few years later it reached epiphytotic form and seriously upset the industry.[2] Some idea of the disastrous effects of the disease is obtained from a study of the export figures[3] for bananas about this time. The banana industry in Fiji dates back to 1877, in which year 3,100 bunches were shipped. Within ten years exports had grown to 359,000 bunches, and by 1892 a peak of 788,000 bunches was reached. During the next three years, primarily as a result of floods and the rapid spread of bunchy top, production steeply declined and in 1895, 114,000 bunches only were exported, about one-seventh of the 1892 total. Then, from 1896 onwards an improvement occurred, 463,000 bunches being shipped in 1899, although by 1905 exports had fallen to the low figure of 147,000 bunches.

The reasons for the temporary recovery of the industry around 1896 have never been chronicled, and a search I made of Fijian official records in 1937 brought to light only one likely contributory factor, namely the introduction in 1892 by the Fijian Government of two cases of suckers of the Gros Michel

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[1] Fiji Despatches from the Secretary of State, 1891. At Colonial Secretary's Office, Suva, Fiji.

[2] Minute Paper No. 1069 of 1893. At Colonial Secretary's Office, Suva, Fiji.

[3] Council Paper No. 23. Legislative Council, Fiji, 1906.

variety from Jamaica, in the hope that this variety would prove resistant to the disease. It is probable that the gradual distribution of this variety, which we now know to be highly resistant to bunchy top, was partly responsible. The tall growing Gros Michel, however, did not prove the most satisfactory for Fijian conditions owing to its greater liability to hurricane damage than the dwarf Cavendish and it did not entirely displace the latter variety. The Gros Michel also was found to be more susceptible to Sigatoka disease or leaf spot (*Cercospora musæ*) than the Cavendish.

The revival of banana growing in Fiji from 1912 to 1916,[4] when exports of 1½ millions of bunches were the rule, does not appear to have been caused by any organized attempt to control bunchy top by eradicatory measures, but to the extension of plantations into new districts and islands. In 1918 the industry received a new check because of shipping difficulties and later tariff changes on the Australian market, and has not since recovered.

The disease is still widespread in Fiji, and surveys I made in 1937 showed that at that time from 5 to 30 per cent. of plants in all plantations and gardens were infected, depending on the care and supervision of the owners. It is remarkable, however, that no plantings which were 100 per cent. infected were then seen and it is thought this must be attributed to the use of the Gros Michel and Veimama varieties. There is a special feature about the resistance of the Veimama variety. This is thought to be of an acquired type following recovery or partial recovery from an attack of the disease (Magee, 1948).

Although bunchy top first came into prominence in Fiji, it is improbable in view of the history of its gradual spread there and its known wide geographical range, that it had its origin in that colony. Thurston's suggestion that the disease was imported with the baggage of early immigrants from India has not received any support from recent studies on its distribution in that region. These immigrants would have been recruited in south-western India, probably in Bombay, but there is no very early record of bunchy top in this part of India. The disease is now known to be present in Travancore-Cochin and also in the State of Bombay, but it has attracted attention there only during the past ten years. Simmonds (1931), who had much experience in Fiji, has suggested that the disease was imported into Fiji from Tanna in the New Hebrides with an "immune" strain of suckers in 1886. There have been no reports in recent years of the presence of the disease in the New Hebrides, but no authoritative surveys have been made.

Mediterranean Region.

Bunchy top occurred in Egypt at least as early as 1901 (Fahmy, 1924) and has since been a limiting factor in banana production. While returning from England in 1928 I made an inspection[5] of banana plantations in Lower Egypt on behalf of the British Government and was able to identify the disease with the one I had previously studied in Australia. Recent correspondence (Soliman, 1951) indicates that bunchy top is still a disease of major importance in Egypt. The origin of the disease in Egypt is not known.

There were reports some years ago that bunchy top had been introduced into Israel from Egypt but the disease is now stated not to be present there (Reichert, 1952).

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[4] Council Paper No. 107. Legislative Council, Fiji, 1917.

[5] Report on bunchy top in Egypt. To Director, Commonwealth Mycological Institute, London, 1928.

Ceylon.

Bunchy top first appeared in Ceylon about the middle of 1913 (Petch, 1913 ; Bryce, 1921). It was confined to the Colombo district for some time but gradually spread to neighbouring districts and became well established in the Central and Western Provinces, destroying most of the banana plantings and a plot of manila hemp at Peradeniya. Surveys[6] I made in Ceylon in 1928, on behalf of the Government of Ceylon, showed that, while the disease was widespread in these two Provinces, it was absent from other parts of the island visited, suggesting that the introduction into the Colombo district or Peradeniya was the primary focus for its distribution. An investigation of the disease by Hutson and Park (1930) demonstrated that its vector (the banana aphid *Pentalonia nigronervosa* Coq.) in Ceylon is the same as that in Australia. The source from which the disease reached Ceylon is not known, although it has been stated (Harland, 1928) that it was probably introduced from Fiji.

Australia.

The early history of the bunchy top disease in Australia is recorded in reports by Darnell-Smith (1919), Darnell-Smith and Tryon (1923), Darnell-Smith (1924) and Magee (1927). The disease was introduced into New South Wales in 1913 in infected banana suckers from Fiji at a time when the foundations of the industry were being laid in this State. Rapid expansion of banana planting occurred towards the end and after World War I, primarily as a result of disruption in the continuity of supplies of Fijian bananas to Australian markets brought about by shipping difficulties, and the encouragement given to repatriated soldiers to adopt banana growing as a livelihood. Several soldiers' settlements were established in banana areas. Further impetus to development came in 1921 when the Commonwealth Government imposed a heavy duty on the importation of bananas as a protection to soldier settlers. As planting progressed, the disease gradually spread, this being facilitated, as we now know, by the distribution of infected planting stock. Production reached a peak in 1922, but two years later the industry had collapsed. The hardship caused by the disease was intense and led to special Commonwealth and State action. An investigation of the disease was made and its virus nature and its vector were discovered. A scheme of control based upon eradication and replanting with disease-free stock was instituted and as a result of the co-operative efforts of banana growers and the Departments of Agriculture of New South Wales and Queensland over the past twenty years, the industry has been completely rehabilitated (Magee, 1936 ; Eastwood, 1946). The area over which the disease originally spread has been progressively reduced, the industry has greatly expanded and in most districts at the present time bunchy top affected plants can be found only by searching for them.

Pacific Islands.

In the Pacific region, in addition to the occurrence of the disease in Australia, and almost all the inhabited islands of the Fiji group, bunchy top has been recorded from the Ellice Island (Campbell, 1926), Wallis Islands (Simmonds, 1933) and Bonin Island (Gadd, 1926). A complete survey of the Pacific would doubtless show a wider distribution, although it is of interest that Samoa has apparently so far escaped the disease (Simmonds, 1933) and also the Hawaiian Islands (Jensen, 1946). During 1951 I carried out a survey of virus diseases of plants in the Territory of Papua and New Guinea on behalf of the Commonwealth Government, paying particular attention to bananas, without seeing any evidence of bunchy top in this plant. It seems likely that these islands, too, in which

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[6] Report on visit to plantain areas of Ceylon. To Director of Agriculture, Ceylon, 1928.

bananas are such an important item in the diet of the natives, have not yet had the disease introduced to them. There have been newspaper reports of the occurrence of the disease in the neighbouring Solomon Islands, but these have never been fully investigated.

In the Philippine Islands, there is a disease of abaca or manila hemp (*Musa textilis*), which is very similar to or identical with banana bunchy top. This disease has been present in the Philippines at least since 1910, although it did not cause serious losses until 1923. (Ocfemia, 1926, 1930.) The identity of this disease with banana bunchy top will be discussed later.

In 1946 and again in 1950 the opportunity was given me of examining an outbreak of a destructive disease in a number of large abaca estates on the Semporna Peninsula of North Borneo. The disease presented a number of puzzling features in relation to symptoms (Reinking, 1950) and the pattern of its spread inwards from the margin of the estates bordering the jungle which I was unable to interpret fully. The disease was affecting bananas as well as abaca and I formed the opinion that the virus was the same as that which has caused losses in Australia, or a closely related strain. The estates in which the disease occurred were planted by a Japanese company prior to World War II with planting stock which it is presumed came from Mindanao, Philippine Islands. I was unable to establish how the disease originated in North Borneo, but it is probable it was introduced along with the planting stock. It spread throughout the estates during and after the war and has since led to their eradication and replanting.

Malaya.

Whether the disease occurs in Malaya is uncertain. It is my opinion, however, that certain foliar symptoms I saw in a plot of abaca at Serdang Agricultural Experiment Station, near Kuala Lumpur, during a one day's visit in 1950 were caused by a mild chronic infection of the bunchy top virus. The foliage was upright and narrow, isolated chlorotic areas occurred in the leaves, and as leaves matured their margins became chlorotic and later brown and parchment-like. The abaca plants were named varieties of Philippine origin and some local hybrids.

India.

An endeavour has been made by correspondence during the past year to determine the distribution of bunchy top in the Indian sub-continent. Reports have been received of the occurrence of the disease in Travancore-Cochin State, Bombay State, Western Hyderabad and in Orissa, Assam and East Pakistan. The worst outbreak has occurred in Travancore-Cochin State in the Cochin, Kottayam and Quilon districts. The disease is believed to have been introduced about 1940 from Ceylon and is now known to occur over some hundreds of square miles (Samraj, 1952). Photographs received from Travancore show typical symptoms of the disease. In Bombay, the worst affected areas have been observed in east Khandesh at Shendurni, Jalgaon and Nasirabad (Vasudeva, 1952). An outbreak in the Aurangabad district of Hyderabad State is reported to have originated from planting stock introduced from east Khandesh and to have been dealt with by eradication. In Assam, Orissa and East Pakistan the disease is reported as occurring in many gardens, but there is still some doubt about its identity. I have received official reports from the respective governments that the disease is not present in United Provinces, Central Provinces, Madras, Mysore, Rajasthan and West Pakistan. The disease position in West Bengal and Bihar is uncertain but there have been unconfirmed reports of its occurrence in both States.

No full investigation of bunchy top appears to have been carried out in India, and it is possible that in some States there is confusion between it and the less serious mosaic disease. Nevertheless, the importance of the disease is generally realized and in several States there is legislation against the introduction of planting stock from areas in which it is known or thought to occur and also for its eradication (Mehta, 1952 ; Ramachandran Nair, 1944).

Regions not so far Invaded.

The important banana exporting countries such as the West Indies, Central and South America, the Canary Islands and most parts of Africa appear to have escaped bunchy top. It is known that surveys have been made in some of these countries in search of the disease, without success. There have also been no reports of the disease from Java, Sumatra, Formosa, Burma, Siam, Indo-China or China. Where bunchy top originated is uncertain, although it is clearly a disease of the Eastern Hemisphere, the accepted place of origin of the banana and plantain.

Variability of Symptoms of Bunchy Top in Different Musa Species.

The present published descriptions of symptoms of the bunchy top disease of bananas only inadequately cover the range the virus is capable of causing and consequently there occur opportunities for error in its diagnosis in different *Musa* spp. and varieties. Further detailed investigations of the symptoms caused by this virus are clearly necessary. Such studies should include field symptoms, as well as those normally observed under glasshouse conditions, as there is already evidence of the existence in mature plants of some varieties and species of a mild chronic form of the disease. It is proposed, however, merely to indicate how the symptoms described for some varieties and species cannot be accepted for all.

When the symptoms of bunchy top were first described (Darnell-Smith, 1924 ; Magee, 1927) much reliance was placed on the occurrence of dark green streaks, either continuous or morse code-like in pattern in the petioles and along the main and subsidiary veins of the laminæ of leaves, as a crucial symptom in deciding whether or not the plant was infected with the virus. The need to refer to a well-defined symptom of this type arises frequently in field work because congestion of leaves at the apex of plants, which is a field symptom that gave the disease its name, or another constant symptom, chlorosis of the last emerged leaves, may also be caused by unfavourable environment or malnutrition. When it was shown (Magee, 1939) that the green streak symptom was caused by tissue alterations in the phloem and adjacent regions of vascular bundles and that the derangement of the phloem was primarily the cause of upset in health of plants, its value in diagnosis seemed undisputed. In the Cavendish and Gros Michel groups of banana varieties (Cheesman, 1934) the usefulness of the green streak symptom is still unquestioned. In these varieties of edible bananas green streaks are the first symptom of infection both in field and in glasshouse studies and they generally persist throughout the life of infected plants. In some of the fertile or seed-bearing species of *Musa* to which bunchy top has been transmitted experimentally, this symptom is also a reliable diagnostic one, but in certain others, *e.g. M. ensete* and *M. textilis*, the green streak symptom occurs so rarely as to lose nearly all its value as an aid in diagnosis. Further, in at least one variety in the Cavendish group, namely the Veimama of Fiji, there is an acute and a mild chronic phase of the disease (Magee, 1948), and plants in the latter phase (partially-recovered) display the green streak symptom only in some leaves, and when present, in a much reduced distribution. Thus, in deciding the health of such partially-recovered plants, the green streak symptom is useful when present, but in practice close study of the plants throughout their growth becomes necessary.

Symptoms of Banana Bunchy Top in Musa ensete *Gmel.*

In this species bunchy top takes the form of a " yellows " disease, and when observed for the first time its identity with bunchy top of edible bananas could easily be doubted. Green streaks have been observed only twice in several hundreds of plants of *M. ensete* which were successfully inoculated under glass-house conditions and then only to a minor extent in the petioles. Following infection, the first-symptom leaf shows either a general or localized chlorosis and the youngest (right) half of the lamina fails to unroll completely after emergence from the pseudostem (Plate II, Fig. 1). The base of this half of the leaf usually shows a water-soaked or membranous area which later collapses, resulting in malformation. Whether further leaves emerge from the pseudostem or not depends on the severity of the disease, and in a high percentage of cases rotting (" heart rot ") occurs in the central cylinder. This is the result of a general collapse of the young developing leaves within the pseudostem. In other cases one or more leaves may emerge after the first-symptom leaf, but these are usually small and malformed (Plate II, Fig. 2).

The symptoms shown by *M. ensete* are of interest in view of their close resemblance to those described for the bunchy top disease of abaca (Ocfemia, 1930).

Symptoms of Banana Bunchy Top in Abaca (M. textilis) *Née.*

Transmission of the banana virus to abaca results in slightly different symptoms, depending on whether seedlings or vegetatively propagated material is employed. The variation is a difference in the extent of chlorosis in the first-symptom leaf and the compactness of the rosette of leaves subsequently formed ; a difference apparently conditioned by the relative robustness of the plants. The first symptoms shown by young abaca seedlings very closely resemble those I have described for *M. ensete* seedlings. The disease can be first detected from 29 to 42 days in the third or fourth leaf that emerges from the pseudostem after inoculation. The young furled heart leaf, when about half emerged, shows white streaks or areas towards its base. Sometimes the whole basal portion is white in colour. On unfurling, the leaf shows marginal chlorosis and indefinite chlorotic areas or chlorotic bands extending from the margin of the lamina towards the midrib, and varying degrees of upward rolling of one or both sides of the lamina (Plate II, Fig. 3). Sometimes the chlorosis is confined to the right side of the leaf only when viewed from its adaxial surface. Examination of the leaf in transmitted light reveals a translucency or clearing of some or many of the main and sub-main veins which is visible from both sides of the leaf. As the leaf matures portion of the chlorotic areas may collapse, becoming membranous and later light brown in colour.

There is considerable variation in the degree of abnormality shown by the first-symptom leaf depending apparently on the stage of development at which the leaf comes under the influence of the virus. The first symptoms shown by some seedlings are very mild, consisting merely of a slight marginal chlorosis of the leaf and the appearance of faint yellowish streaks in the lamina (Plate II, Fig. 4), while others early show a severe reaction to infection. In the latter cases chlorosis is pronounced ; most of the veins are cleared, white and then membranous areas appear in the leaf and when these collapse the leaf is badly deformed (Plate III, Fig. 1). In still other cases an intermediate reaction is shown by the first-symptom leaf in which chlorosis is restricted to the margin of the lamina and vein clearing is the most definite sign that infection has occurred.

The leaf which emerges after the first-symptom leaf is usually shorter, narrower and highly chlorotic, with one or several membranous areas near the margin of the lamina (Plate III, Fig. 2). Both sides of the lamina may be rolled upwards. The next three or four leaves, which emerge slowly, may be of similar type but without the extreme chlorosis and membranous areas and if cultural conditions are good, slightly larger leaves then appear. The general effect of this restricted growth is to produce a rosette of narrow leaves, but the rosette is of a looser type than that observed in banana varieties.

The course of the disease in a vegetative offset of abaca is illustrated in Plate IV. The effect of the virus in the variety studied is less marked than in young seedlings, but this would be expected to vary with the variety. Following an initial check in growth in which one to three shortened leaves with chlorotic margins, cleared venation and chlorotic areas are formed subsequent leaves tend to increase in length as though a tolerance to the virus has been built up. This prevents the formation of a tight rosette, but all leaves are narrower than normal and show a characteristic upturning of their margins.

Green streaking of the vascular traces of the leaf, the most important diagnostic symptom of bunchy top in bananas, is observed to a very minor extent in abaca, and then usually in the petiole and midrib only of some of the first infected leaves. Green streaks are occasionally observed also along a few of the veins of the lamina. In abaca the clearing or translucency of the main and some of the subsidiary veins of the first-symptom leaf and most subsequent leaves is, however, almost as useful diagnostically as the green streak symptom in the case of the banana, particularly in glasshouse studies (Plate III, Fig. 3). Cleared venation is an associated symptom also of bunchy top in banana varieties (Magee, 1927 ; Plate IV, Fig. 1), but is not an early symptom, and because of the prominence of the green streaks has been overlooked in descriptions of the disease.

A comparison of the symptoms just described in *M. ensete* and *M. textilis* with published descriptions of the bunchy top disease in edible bananas reveals many variations, and in the absence of transmission studies it would be easy to conclude that more than one virus is involved. There is no single symptom or group of symptoms on which a definite diagnosis could be based in all cases. The characteristic green streaks or cleared venation are reliable criteria for diagnosis when present, but the symptoms of chlorosis shown by *M. ensete* and *M. textilis* are too indefinite for a firm decision to be made without clinical study, unless the observer has had much experience with the disease. The position is complicated, too, by the fact that there is at least one other virus disease of *Musa* spp. which is relatively common in tropical and sub-tropical countries, namely mosaic or infectious chlorosis (Wellman, 1934 ; Ocfemia and Celino, 1938 ; Magee, 1940*a*) caused by the widespread cucumber mosaic virus. Although this is clearly a mosaic type rather than a yellows type disease, rosetting or bunching of the leaves may be associated, leading sometimes to the disease being wrongly diagnosed as bunchy top. Symptoms of the chronic mild form of this disease consisting of bands of mosaic tissue extending from the mid-rib to the margin of otherwise apparently normal leaves could also be mistaken for chronic symptoms of bunchy top in certain varieties of bananas and abaca.

The high percentage of infected *M. ensete* seedlings which develop heart rot in glasshouse inoculations is of particular interest since this symptom has been one of the barriers against accepting the identity of banana and abaca bunchy top. Heart rot is a well recognized secondary symptom of bunchy top in abaca in the Philippines (Ocfemia, 1930 ; Ramos, 1933) but is less frequently observed in bananas, its incidence fluctuating with climatic conditions.

The tendency of infected abaca plants to show at first a severe and later a milder reaction to the virus (Plate IV) was strikingly different from the behaviour of the Cavendish and other varieties of bananas I had previously studied. It was not, however, until a few years later, when the remarkable behaviour of the Veimama variety in making a partial recovery from bunchy top was examined (Magee, 1948), that the importance of the tendency of abaca to grow out of the disease especially attracted my attention. The significance of this was further emphasized in 1950 when I was commissioned to report[7] on the health status of abaca planting stock in a series of estates in North Borneo. Here it was observed that suckers of the Tangongon and Bangkura varieties of abaca could be selected from stools which were badly affected with the disease and if replanted under favourable conditions would make fairly vigorous growth, giving rise to stools of generally healthy appearance (Plate V, Figs. 1 and 2). During this field survey I formed the opinion that some varieties of abaca at least are able to tolerate a chronic infection in much the same manner at the Veimama banana. There was no opportunity of making a clinical study of the partially-recovered abaca plants while in Borneo, but I will briefly refer to two of the symptoms which they showed. Many stools were seen which were of normal habit of growth, but close examination showed the presence of chlorotic bands of a characteristic type in the lamina of some of the leaves (Plate V, Fig. 3). Also, if a search were made, dark brown streaks or stripes were occasionally to be found in the mid-rib and petioles of some leaves (Plate V, Fig. 4). These stripes are quite different in nature from the green streaks referred to earlier, but like them are associated with modification of the phloem and adjacent tissues. A histological examination of the stripes reveals that they are caused by the phloem and neighbouring tissues of some of the more superficial vascular bundles becoming partially or wholly impregnated with brown gum. Gum stains are to be seen also in some epidermal and hypodermal cells in many superficial fibre bundles. Other pathological changes of the type normally associated with the bunchy top disease (Magee, 1939) are also present in the phloem of the gum-blocked vascular bundles. The effect of the gum accumulations is to give an external display of dark brown stripes in the mid-rib and petiole. The green streak symptom, on the other hand, is caused by the development of abnormal chlorophyll-bearing tissue adjacent to deranged phloem tissues.

THE QUESTION OF IDENTITY OF BANANA AND ABACA BUNCHY TOP.

The successful transfer of bunchy top from banana to abaca (Magee, 1927) confirmed the observation made by Bryce in 1918 on the susceptibility of this plant in the field in Ceylon. During the banana investigation, reports were received of a serious disease which was destroying the abaca crop in Cavite Province, Philippine Islands. The symptoms of the malady corresponded so closely to those of banana bunchy top that the opinion was expressed that the diseases were identical. About the same time, Ocfemia (1926, 1927, 1930) was successful in transmitting the abaca disease in the Philippines by means of *Pentalonia nigronervosa* Coq., the vector also of banana bunchy top, and concluded that the same virus was causing destruction in both Australia and the Philippines.

Later, however, doubt arose regarding the identity of the diseases. Ocfemia and Buhay (1934) observed that Philippine varieties of banana growing in proximity to diseased abaca did not contract bunchy top and that experimental attempts to transmit abaca bunchy top to several banana varieties were unsuccessful. In a series of communications with Professor Ocfemia, the identity or otherwise of the two diseases was discussed without finality. In addition to the apparent non-transmissibility of abaca bunchy top to banana, there was the

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[7] Report to Colonial Development Corporation, Singapore, 1950.

symptom of heart rot associated with a high percentage of infected abaca plants which was not then an accepted symptom of the banana disease.

During 1936, 1937 and again recently, I made further studies on the transmission of banana bunchy top to abaca, using both seedling and vegetatively-propagated material, and confirmed that the banana virus could be transmitted at will from banana to abaca and back to banana. This transmission was performed several times by using groups of 20 apterous aphids (*P. nigronervosa*) which had fed during their *nymphal* stages on *recently* infected plants. The variety of banana used was the Cavendish. Young and vigorous plants only of each species were employed. During these transmissions a further study of the symptoms of banana bunchy top in abaca was made. A comparison of these symptoms with those described by Ocfemia (1930) strengthened my opinion that the same virus was involved in both countries. An endeavour was made to make a closer study of the diseases, but an export ordinance of the Philippine Government prevented me obtaining living abaca plants infected with bunchy top for comparison with diseased plants in Australia, so that the question of identity has not been settled.

Comparison of the Phloem Abnormalities in Australian and Philippine Material.

Through the courtesy of Professor Ocfemia in supplying some preserved material of abaca bunchy top, I was enabled in 1938 to make a further comparison of the diseases. Histological preparations were made of the Philippine material and also of tissues of similar age from abaca plants infected with the Australian virus. All material was fixed in formol-acetic-alcohol and stained in Haidenhain's iron-alum-hæmatoxylin and light-green. Studies of these preparations showed that the primary effect of the virus, or viruses, in upsetting the normal development of the phloem is very similar indeed.

The banana bunchy top virus in abaca causes a derangement of the phloem very like that described for the banana (Magee, 1939), but with the difference that the hyperplastic changes are not so general, either within the phloem or in the surrounding ground tissue. In Plate V, Fig. 1, is depicted a phloem strand of abaca affected with banana bunchy top. The phloem is almost entirely replaced by an abnormal tissue, composed of hypertrophic and hyperplastic cells. As in the banana (*loc. cit.*), hypertrophic or " giant " cells reach their greatest development in the abaxial region of the strand, where they may be associated with areas of obliteration or necrosis. These abnormal changes, which commence during the early differentiation of the phloem, may involve portion or the whole of the fibrous sheath and result in its replacement by hypertrophic cells.

Plate V, Figs. 2 and 3, show the same type of phloem malformation in the Philippine material. The normal phloem and fibrous sheath are replaced by hypertrophic and hyperplastic cells, and several areas of obliteration are present. In the Philippine material, besides the infiltration of gum into the areas of obliteration or necrosis, the lumina of certain of the cells of the phloem were blocked with gum. Whilst this was found, to some extent, in Australian material both of banana and abaca, the heavy gum deposits were more characteristic of the Philippine material (see also Plate V, Fig. 4).

In the abnormal phloem strand shown in Plate V, Fig. 3, there is to be seen an extension of the hyperplastic influence to the ground tissue, resulting in the formation of a miniature-celled tissue. This was observed to occur only rarely in both the Australian and Philippine abaca material, but its occurrence in the latter is of special interest since hyperplasia of the ground tissue adjacent to the phloem is such a prominent feature of the effect of the Australian virus on the

Cavendish banana. On the rare occasions when extension of hyperplasia to the ground tissue occurs in abaca it is considered it would become visible externally, as it does in banana, as a green streak.

Plate V, Fig. 4, shows in longitudinal section the structure of the phloem of abaca infected with the Philippine virus. Here again is evident a point of similarity in the effect of the Australian virus in both abaca and banana. Many of the cells which constitute the abnormal phloem tissue contain the same type of hypertrophied nuclei as has been described in the case of bunchy top of the Cavendish banana.

The Heart-Rot Symptom in Abaca and the Philippine Reports of the Failure of Transmission of the Abaca Virus to the Banana.

In the Philippines, a high percentage of abaca plants infected with bunchy top later develop a rot of the centre of the pseudostem, which may extend down as far as the rhizome, and cause death of the plants. Heart-rot was at one time considered to be a specific disease in the Philippines, and was the subject of much investigation and speculation as to its cause.

Following his investigation of bunchy top of abaca, Ocfemia (1930) concluded that 11 to 17 per cent. of abaca plants infected with bunchy top ultimately die of heart-rot, and later Ramos (1933), in assessing the different causes of heart-rot disease in Laguna and Cavite Provinces, placed the bunchy top figure at 10 to 22 per cent., and those cases where heart-rot was secondary to injury from beetle borer (*Cosmopolites sordidus* Germar) at 53 to 90 per cent.

Heart-rot is not a symptom of bunchy top of Cavendish bananas in Australia, but I have observed occasional bunchy top affected bananas dying of heart-rot in Ceylon and Fiji (Plate I, Fig. 3). The symptom is regarded as a purely secondary one, and Ocfemia, too, has indicated that the onset of heart-rot is dependent on weather conditions and represents an extreme case of collapse of chlorotic tissues and their subsequent invasion by bacteria. This is clearly the origin of heart-rot when Australian bunchy top is inoculated to *M. ensete*. It is considered that the absence of heart-rot in association with outbreaks of bunchy top in any country cannot be regarded as evidence of the presence of a distinct virus.

The most formidable barrier to the acceptance of the identity of the banana and abaca virus is the fact that Philippine banana varieties have been reported by Ocfemia (1930) and Ocfemia and Buhay (1934) not to succumb to abaca bunchy top when growing in close proximity to infected plants in the field. Further, attempts to transmit the abaca disease experimentally to a number of banana varieties, including the Cavendish variety, have proved unsuccessful. How much importance should be attached to the negative field observations is difficult to judge. Many instances of apparent non-infectiousness of bananas infected with bunchy top have been observed in the field in Australia, and, before the nature of the disease was understood, this was a subject of much speculation. It is of interest that the capricious nature of the spread of the disease was commented on by the Governor of Fiji as early as 1891. Even under severe epiphytotic conditions in an established Cavendish plantation in Australia, diseased and healthy stools may remain side by side for months, or even a year or two, without symptoms of the disease being detected in the healthy plants. In the case of the Gros Michel variety, with its greater resistance to the disease, many disconcerting observations have been made, such as groups of stools having been surrounded for years by infected Cavendish stools without contracting the disease. Further data on the range of the Philippine observations, and the varieties and circumstances, would be helpful.

In reference to the attempts of Ocfemia and Buhay (1934) to transmit abaca bunchy top to banana experimentally, it is doubtful whether the negative evidence should be accepted as final. Two of the three experiments concerned are open to criticism. In these experiments, infective aphids (unchecked for infectivity to abaca) were transferred to each of two, or four, banana suckers standing in water in battery jars, and were killed after feeding for 48 hours. The plants were then planted in pots of soil and their further growth observed. Since there is always a lapse of two or three weeks before suckers without roots establish themselves, it is questionable whether this method of inoculation would prove successful even in a small percentage of a large number of trials, because of the condition of the plants at the time of inoculation.

In the third experiment ten healthy suckers each of the Latundan, Bungulan, Saba, Lacatan and Cavendish varieties growing in pots and ten suckers of each variety growing under field conditions were used. To each plant 50 *adult* wingless aphids which had been allowed to feed on diseased abaca plants for 5 days to acquire the virus were transferred and allowed to feed for 10 days. Though at first sight it may seem most unlikely that negative results should occur in all plants in this experiment, if the virus involved is the banana bunchy top virus there are conditions under which it could occur. From studies on the acquisition of the virus by adult and nymphal aphids (Magee, 1940*b*) it is known that even with recently-infected banana plants acquisition of the virus by adults is of a low order as compared with nymphs, and if, as occurs in the banana, availability of the virus in abaca falls with ageing and loss of vigour, the employment by Ocfemia and Buhay of anything but recently-infected sources of inoculum would be expected to give negative results with adults. No details of the sources of inoculum are given, and check inoculations to abaca to prove infectivity for the aphids were apparently not made.

It is felt that further field observations must be made on bananas growing in abaca plantations in which bunchy top is spreading actively and further experimental inoculations to bananas must be carried out using as vectors aphids which have fed as nymphs on a recently-infected source of the virus before it can be accepted that the Philippine virus is distinct, or even a distinct strain, from that which occurs in Australia and Ceylon. In view of the remarkable behaviour of the Veimama banana in making a partial recovery from the disease and the robust plants formed by suckers taken from diseased stools of the abaca varieties in North Borneo, the possibility cannot be overlooked that some of the Philippine bananas may be also partially-recovered plants. It is known (Magee, 1948) that Veimama plants of this type display an acquired resistance to re-infection.

One other point of similarity between the Australian and Philippine disease should be mentioned. In both cases there is an incubation period in the vector. This need not be evidence for identity, but it is relatively rare for there to be an incubation period with viruses transmitted by aphids. In the case of abaca bunchy top, using groups of 25 aphids, Ocfemia and Buhay (1934) found that between 24 and 48 hours must elapse after feeding on an infected source before the aphids were capable of infecting healthy seedlings. The duration of this period for banana bunchy top depends on the individual aphid and varies from a few hours to 48 hours (Magee, 1940*b*).

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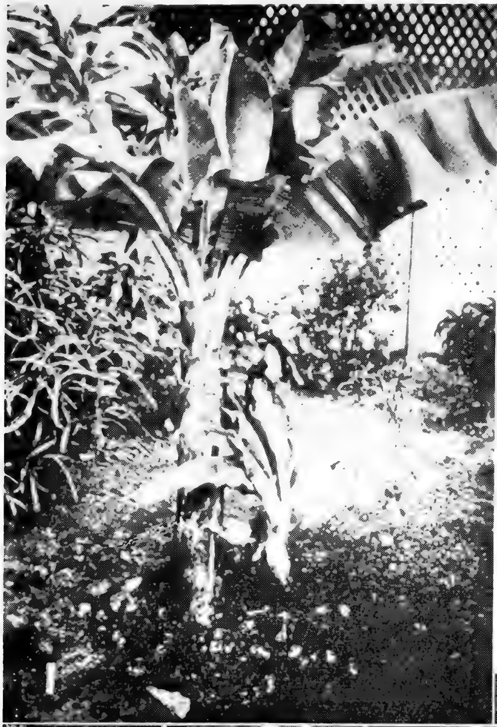
The aspects of the bunchy top disease I have selected for consideration this evening are a challenge for further investigation. We do not know where the disease originated, and in view of the variable symptoms which may be caused by the virus there are difficulties to be cleared away in establishing its incidence and identity in different countries. Further studies of symptoms should be made by inoculating the virus to a wider range of *Musa* species and varieties and by following the subsequent behaviour of inoculated plants in the field. This could be done without risk in the field, provided the infected plants are regularly treated with one of the modern insecticides to prevent colonization of the vector on the plants. It is probable that the question of the identity of banana or plantain bunchy top and the abaca disease could be resolved by an interchange of infected material. Sufficient is known about the diseases to enable a safe comparative study to be made under quarantine conditions in either the Philippines or in Australia, although all risks would be removed if the study were made in Australia where abaca is never likely to be a crop of economic importance.

My desire for a more complete knowledge of the bunchy top disease arises from the belief that in addition to the Veimama variety other varieties of bananas and some varieties of abaca can carry the virus almost symptomlessly, and because of this a danger exists of their spreading the disease to new territories and countries. There is little doubt that the entry of bunchy top into North Borneo, where it now occurs in both bananas and abaca, resulted from the introduction of abaca planting stock which carried a chronic mild infection. In endeavouring to account for the present world distribution of the disease, it is thought that special scrutiny should be given to early importations of abaca planting stock. It is not known how the disease penetrated into Ceylon, but Bryce's report that the disease destroyed a plot of abaca at the Peradeniya Experiment Station in 1918 might be relevant, as the plot was probably a trial of introduced material and Peradeniya is many miles from Colombo, where the disease was first reported in 1913. Chronic infections in bananas might also have played a part in spreading the disease in the past, and we should not pass over Simmonds' suggestion that bunchy top was introduced into Fiji in " immune " stock from one of the Pacific Islands until more is known about the distribution of the disease in the many islands in this region.

The great importance of chronic and often symptomless infections with plant viruses is now being realized. Evidence is accumulating that they constitute an insidious threat even where there are well organized plant quarantine barriers against the introduction of new diseases. For instance, the disaster which befell the citrus industries in Argentine and Brazil in recent years, when nine million citrus trees succumbed to the Tristeza disease, is attributed to the introduction of trees or budwood from South Africa (Costa, Grant and Moreira, 1950). It is now known that such trees or buds would have carried the Tristeza virus symptomlessly. Also, recent surveys carried out by Fraser (1952) in New South Wales show that this virus is almost universal in its distribution in our coastal citrus areas, and probably has been for many years, so that the Tristeza disease could easily have been introduced to South America from Australia. The Tristeza virus has also penetrated into Californian citrus areas, again, presumably, in symptomless planting stock or budwood;

The importance of bananas and plantains as food crops in the tropics is strong reason for the continuance of investigations on the bunchy top disease, and also for organized surveys to determine its geographical range. Special attention should be given to such surveys in the Pacific region, and this might be a project that could be appropriately taken up by the South Pacific Commission. From the Australian point of view, and considering our political commitments, it would be a calamity if the disease were to penetrate into the Territory of Papua and New Guinea because of the important part bananas play in the diet of the natives of this territory. As a first step in protecting New Guinea, surveys should be conducted in the Solomon Islands, New Hebrides and other island linkages with the Fiji Group and the Ellice Islands where bunchy top occurs.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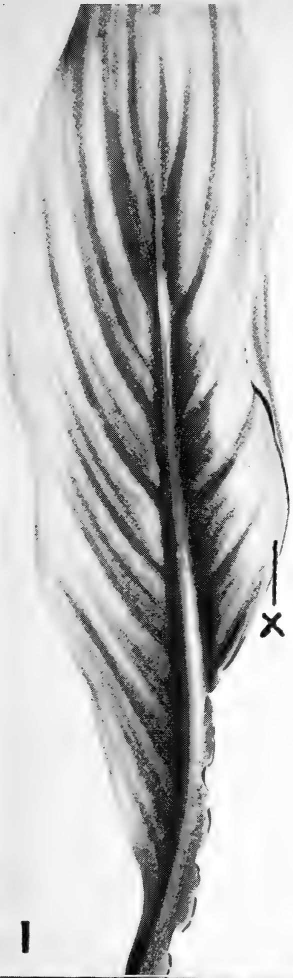

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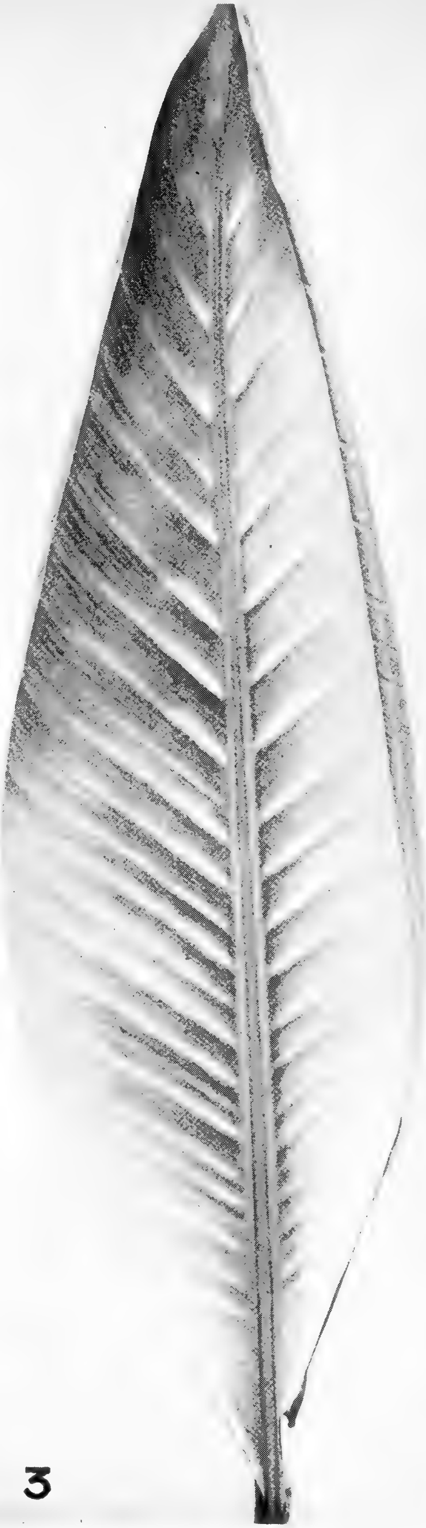

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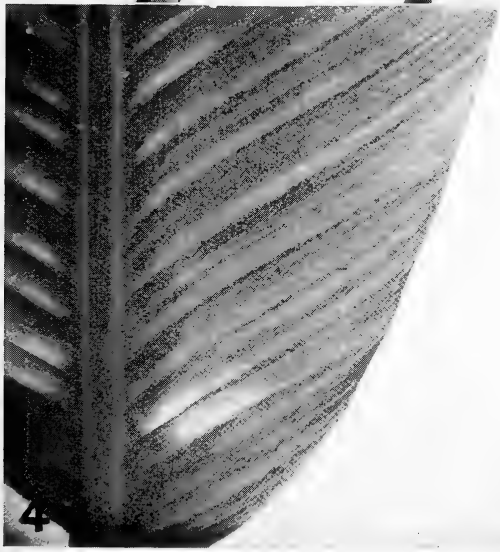

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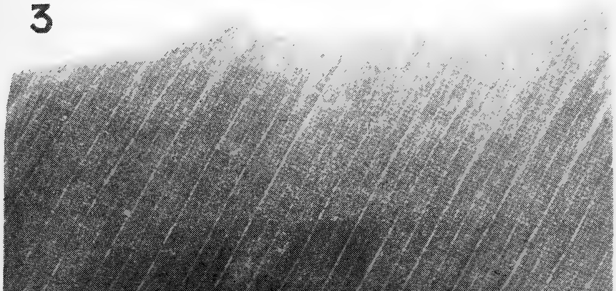

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Journal Royal Society of N.S.W., Vol. LXXXVII, 1953, Plate V


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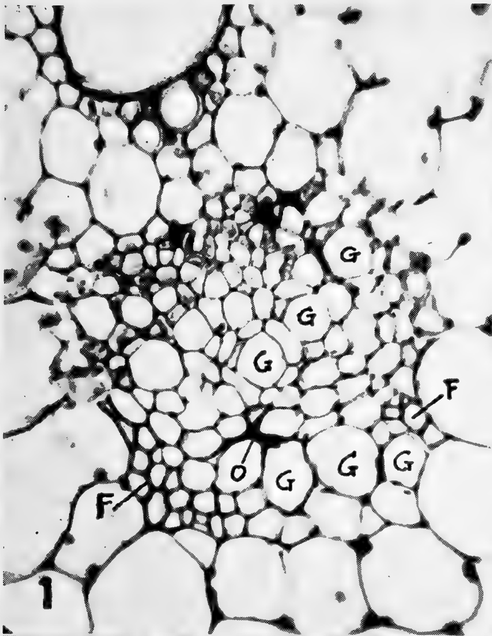
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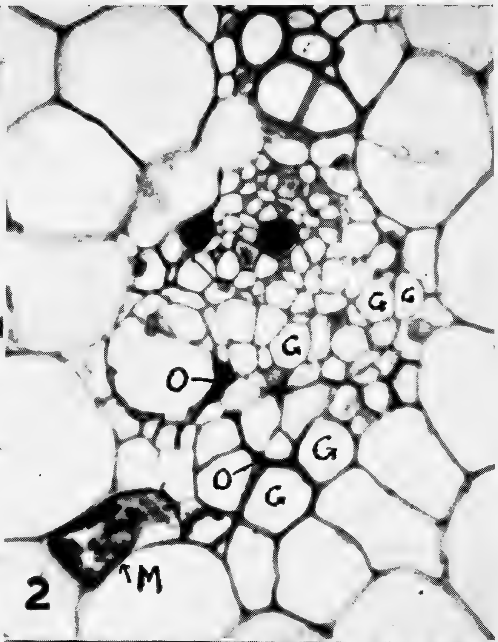
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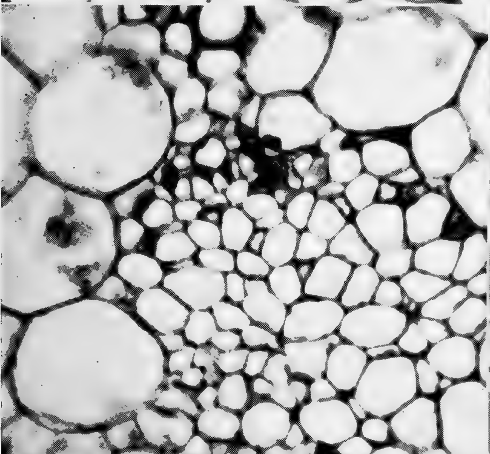
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EXPLANATION OF PLATES.

PLATE I.

Figs. 1 and 2.—Reproductions of photographs enclosed by the Governor of Fiji in a despatch to the Colonial Office in 1891. The plants are of the Cavendish variety and the symptoms shown leave no doubt of the identity of the disease which destroyed the Fijian industry about this time. Reproduced by permission of the Director, Royal Botanic Gardens, Kew.

Fig. 3.—Bunchy top stool of the Cavendish variety, Fiji, 1937, showing dieback of plants following heart-rot. Photo. by B. E. Parham, Department of Agriculture, Fiji.

PLATE II.

Figs. 1 and 2.—Symptoms of bunchy top in a seedling of the Abyssinian banana, *Musa ensete*, showing chlorosis, membranous areas, X, and malformation of leaves. Fig. 1, first symptom-leaf and Fig. 2 the following leaf.

Fig. 3.—First symptom-leaf of abaca (*M. textilis*) infected with banana bunchy top. The leaf is chlorotic ; the right side of the lamina has failed to unfurl completely and a membranous area is developing near its base. Two-thirds natural size.

Fig. 4.—Another type of first-symptom commonly shown by abaca seedlings affected with banana bunchy top. The leaf is slightly chlorotic and faint yellowish streaks are present towards its base. Such streaks are sometimes visible before the leaf unfurls. Natural size.

PLATE III.

Fig. 1.—Severe symptoms shown by the first-symptom leaf of an abaca seedling infected with banana bunchy top. Most of the main veins are cleared, the lamina is highly chlorotic, particularly towards its margin, and is malformed as the result of the collapse of membranous areas. Natural size.

Fig. 2.—Second infected leaf of an abaca seedling to which the banana bunchy top virus has been transmitted, showing the type of symptom commonly displayed. Symptoms are usually more severe than in the first-symptom leaf. Note cleared veins, severe chlorosis, and the malformations of the lamina caused by collapse of membranous areas. Two-thirds natural size.

Fig. 3.—Portion of abaca leaf affected with banana bunchy top showing nature of the cleared vein symptom when viewed from the under-surface of the leaf. Clearing is to be seen in both the main and subsidiary veins of leaves which emerge after the first-symptom leaf but may be present also in the first-symptom leaf. The clearing is either continuous or broken into dots and dashes. Natural size.

PLATE IV.

Vegetatively propagated abaca plant infected with banana bunchy top illustrating type of growth which occurs subsequent to infection. The central plant was inoculated at the fifth-leaf stage and the other two plants are infected suckers which have arisen as offsets. The lowest leaf, X, of the parent plant is the last healthy leaf formed and the first-symptom and next two leaves are indicated at 1, 2 and 3. Note that leaves formed later than these instead of becoming shorter as occurs in infected bananas, proceed to increase in length. The leaves, however, remain narrow, upright and have slightly upturned margins. A similar behaviour is to be seen in the sucker on the right, where the later-formed leaves are also beginning to increase in length.

PLATE V.

Figs. 1 and 2.—Showing in Fig. 1 a twenty-months-old stool of the Bangkura variety of abaca and in Fig. 2 a twelve-months-old stool of the Tangongon variety which grew from suckers selected from stools that became badly affected with bunchy top during a period of rapid spread of the disease on Tiger Estate, North Borneo, in 1950. Note apparently normal foliage and vigour. Close examination of such stools revealed symptoms which are considered to indicate that they had a mild chronic form of bunchy top disease similar to that reported in the case of the Veimama variety of Fiji.

Fig. 3.—Portion of abaca leaf showing yellow bands which were associated with a suspected mild chronic form of bunchy top in North Borneo. The bands may be broad and conspicuous or narrow and fleeting. Note on the left side of the leaf the yellow bands are well defined only near the margin. Photo. by Mr. N. Young.

Fig. 4.—Illustrating the dark brown stripe symptom which was associated with a severe outbreak of bunchy top in abaca in North Borneo. Although the symptom was a capricious one, even in badly diseased stools, it was occasionally seen in plants with the mild chronic form of the disease. Photo. by Mr. N. Young.

PLATE VI.

Fig. 1.—Australian material. Phloem strand from petiole of abaca infected with the banana virus, showing replacement of the phloem and portion of its fibrous sheath by morbid tissue. F, fibrous sheath ; G, hypertrophic or " giant " cells ; O, region of obliteration or necrosis. ×370.

Fig. 2.—Philippine material. Phloem strand from petiole of abaca infected with the abaca virus, showing replacement of the phloem and its fibrous sheath by morbid tissue and blocking of the lumina of two cells with gum. F, remnant of fibrous sheath ; G, hypertrophic or " giant " cells ; O, regions of obliteration ; M, mucilage duct. ×370.

Fig. 3.—Philippine material. Abnormal phloem strand of abaca infected with the abaca virus showing extension of hyperplasia into the parenchyma to form a miniature-celled tissue. ×370.

Fig. 4.—Philippine material. Longitudinal section of portion of a phloem strand from a petiole of abaca infected with the abaca virus showing hypertrophic nuclei and accumulations of gum. ×700.

OCCULTATIONS OBSERVED AT SYDNEY OBSERVATORY DURING 1952.

By K. P. SIMS, B.Sc.

Manuscript received, February 3, 1953. Read, April 1, 1953.

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. 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 1952, 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 —0·00152 hours was applied before entering the ephemeris of the Moon. This corresponds to a correction of —3″·0 to the Moon's mean longitude.

TABLE I.

Serial No.	N.Z.C. No.	Mag.	Date.	U.T.	Observer.
				h m s	
244	337	5·7	Feb. 2	11 27 50·7	W
245	1547	3·8	Mar. 10	11 36 26·5	S
246	1315	6·9	Apr. 4	13 09 12·5	W
247	1754	6·9	May 6	9 30 40·7	S
248	1815	4·8	June 3	10 24 57·9	S
249	2039	5·6	June 5	7 33 25·0	W
250	2045	6·4	June 5	8 50 51·5	W
251	2051	5·7	June 5	9 37 49·3	W
252	1885	7·4	July 1	10 37 24·2	S
253	2109	6·1	July 3	7 50 57·2	W
254	2268	4·8	July 4	12 06 31·8	R
255	2273	5·9	July 4	12 51 05·2	W
256	2084	6·5	July 30	12 39 23·3	W
257	2650	4·7	Aug. 30	13 55 51·4	W
258	2809	4·9	Aug. 31	10 14 40·2	W
259	2575	6·8	Sept. 26	11 09 53·0	R
260	3196	6·1	Sept. 30	8 43 48·0	R
261	2872	6·2	Oct. 25	10 27 03·3	W
262	2875	6·1	Oct. 25	10 37 47·2	W
263	3308	6·2	Oct. 28	13 42 43·5	W
264	3311	7·0	Oct. 28	14 08 35·6	W
265	65	7·3	Dec. 24	9 56 40·8	S

Table I gives the observational material. The serial numbers follow on from those of the previous report (Robertson and Sims, 1952). The observers were H. W. Wood (W.), W. H. Robertson (R) and K. P. Sims (S). In all cases the phase observed was disappearance at the dark limb. Table II gives the results of the reduction, 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.	Luna-tion.	p	q	p^2	pq	q^2	$\Delta\sigma$	$p\Delta\sigma$	$q\Delta\sigma$	Coefficient of	
										$\Delta\alpha$	$\Delta\delta$
244	360	+ 97	+24	94	+23	6	—0·2	—0·2	0·0	+11·5	+0·57
245	361	+ 96	—29	92	—28	8	—1·2	—1·2	+0·3	+10·7	—0·69
246	362	+ 53	+85	28	+45	72	+1·0	+0·5	+0·8	+11·0	+0·62
247	363	+ 96	+27	93	+26	7	+0·6	+0·6	+0·2	+14·7	—0·21
248	364	+ 97	—26	93	—25	7	—1·3	—1·3	+0·3	+11·1	—0·67
249	364	+ 91	—42	82	—38	18	+0·8	+0·7	—0·3	+ 9·9	—0·72
250	364	+ 62	—78	39	—49	61	+0·8	+0·5	—0·6	+ 4·3	—0·95
251	364	+ 89	—46	79	—41	21	+0·8	+0·7	—0·4	+ 9·5	—0·75
252	365	+ 98	+18	97	+18	3	+1·8	+1·8	+0·3	+14·2	—0·26
253	365	+ 66	—75	44	—50	56	+0·4	+0·3	—0·3	+ 5·5	—0·92
254	365	+ 97	+24	94	+23	6	+0·7	+0·7	+0·2	+13·6	+0·04
255	365	+ 69	+72	48	+50	52	+0·5	+0·3	+0·4	+11·2	+0·57
256	366	+ 97	+26	93	+25	7	+1·1	+1·1	+0·3	+14·1	—0·07
257	367	+ 89	—46	79	—41	21	—2·4	—2·1	+1·1	+12·4	—0·37
258	367	+100	— 5	100	— 5	0	+1·9	+1·9	—0·1	+13·5	+0·15
259	368	+100	—10	99	—10	1	+1·1	+1·1	—0·1	+13·3	—0·06
260	368	+ 91	—41	83	—37	17	—0·5	—0·5	+0·2	+14·6	+0·01
261	369	+ 92	—40	84	—37	16	—1·3	—1·2	+0·5	+13·6	—0·17
262	369	+ 84	—54	71	—45	29	+0·6	+0·5	—0·3	+13·1	—0·31
263	369	+ 50	+87	25	+43	75	—0·3	—0·2	—0·3	+ 0·9	+1·00
264	369	+ 85	+53	72	+45	28	—0·8	—0·7	—0·4	+ 7·8	+0·85
265	371	+ 69	+72	48	+50	52	+0·6	+0·4	+0·4	+ 4·4	+0·95

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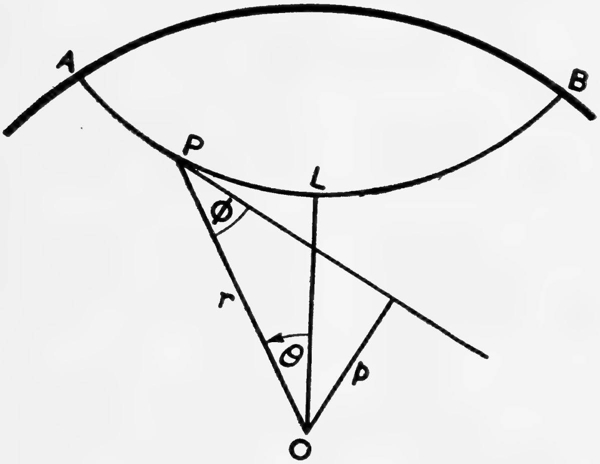
Robertson, W. H., and Sims, K. P. THIS JOURNAL, **86**, 20 ; Sydney Observatory Papers No. 18.

PARAMETERS OF SEISMIC RAYS.

By K. E. Bullen, M.A., Sc.D., F.R.S.

Manuscript received, February 18, 1953. Read, April 1, 1953.

1. In the standard theory of seismic rays, it is customary to use polar coordinates r, θ, taken as in the Figure, where P is any point of the ray AB, L is the lowest point of the ray, and O is the centre of the Earth, here taken to be spherically symmetrical. The purpose of this note is to show that there are advantages in using (p, r) coordinates, where p is the perpendicular from O to the tangent at P. In particular, the salient properties of the parameter of a seismic ray (taken as λ below) are derived very directly.



2. The shape of rays for a given velocity distribution, $v(r)$ say, is commonly determined (Jeffreys, 1952) by using the analogue of Fermat's principle in the form that the time T along a ray, given by

$$T=\int\frac{ds}{v}, \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where s is the arc-length AP, is stationary when the distance AB is assigned. In polar coordinates, (1) becomes

$$T=\int\frac{1}{v}\left\{\left(\frac{dr}{d\theta}\right)^2+r^2\right\}^{\frac{1}{2}}d\theta, \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

and the condition that the integral in (2) is stationary leads to the usual Euler differential equation, which is then solved to give various properties of the ray.

In (p, r) coordinates, (1) becomes

$$T=\int_q^{r_0}\frac{2rdr}{v\sqrt{(r^2-p^2)}}, \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

where r_0 is the Earth's radius and q is the value of p at the point L of the ray. The interesting and simplifying feature in using (3) is that the integrand formally contains no derivative, as does (2) through the presence of $dr/d\theta$. The integral in (3) has to be made stationary subject to the condition that the angle Δ subtended by AB at O is assigned. This condition needs a second integral to describe it, namely

$$\begin{aligned}\Delta &= \int d\theta \\ &= \int_q^{r_0} \frac{2p\,dr}{r\sqrt{(r^2-p^2)}}, \qquad \text{(4)}\end{aligned}$$

where Δ is assigned. The use of (p, r) coordinates thus converts the original variation problem into an isoperimetrical one, to be solved using an undetermined multiplier, λ say.

Writing

$$T-\lambda\Delta = \int_q^{r_0} \psi\, dr, \qquad \text{(5)}$$

so that

$$\psi = 2\left(\frac{r}{v} - \frac{\lambda p}{r}\right)(r^2-p^2)^{-\frac{1}{2}}, \qquad \text{(6)}$$

a necessary condition that the travel-time is stationary is then given by

$$\frac{\partial\psi}{\partial p} = 0, \qquad \text{(7)}$$

where the parameter λ will be constant along a particular ray. The condition (7) leads by simple differentiation and reduction to the formula

$$\frac{p}{v} = \lambda, \qquad \text{(8)}$$

which is the form of Snell's law of refraction relevant to a spherical Earth. (For refraction at a spherical surface of discontinuity, (8) shows that $v^{-1} \sin \varphi$ is unchanged, φ being as in the Figure.)

3. Substituting from (8) into (6) gives

$$\psi = 2(rv)^{-1}(r^2-p^2)^{\frac{1}{2}}, \qquad \text{(9)}$$

which by (5) immediately gives another standard formula, namely

$$T = \lambda\Delta + 2\int_q^{r_0} r^{-1}(\eta^2-\lambda^2)^{\frac{1}{2}} dr, \qquad \text{(10)}$$

where $\eta = r/v$.

4. The formula

$$\frac{dT}{d\Delta} = \lambda, \qquad \text{(11)}$$

connecting the parameter λ with the travel-time-distance relation, can now be readily deduced independently of the more geometrical process usually followed. Since $r=p$ at the lowest point L, it follows by (9) that $\psi_{r=q}$ is zero. Hence, by (5),

$$\begin{aligned}\frac{d}{d\lambda}(T-\lambda\Delta) &= \int_q^{r_0} \frac{d\psi(\lambda, p)}{d\lambda} dr \\ &= \int_q^{r_0} \frac{\partial\psi(\lambda, p)}{\partial\lambda} dr,\end{aligned}$$

where $\psi(\lambda, p)$ is expressed in the form (6), $\partial\psi(\lambda, p)/\partial p$ being then zero by (7). Thus

$$\frac{d}{d\lambda}(T-\lambda\Delta)=\frac{\partial}{\partial\lambda}(T-\lambda\Delta)\;;$$

i.e.

$$\frac{dT}{d\lambda}-\Delta-\lambda\frac{d\Delta}{d\lambda}=-\Delta,$$

which gives (11).

The derivation of all three of the results (8), (10) and (11) in this way throws more light on the parameter λ than the usual methods. (Cf. Bullen, 1947, pp. 108-111.)

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A NOTE ON THE COMPOSITION OF THE ESSENTIAL OIL OF *EUCALYPTUS CITRIODORA* HOOK., TYPE.

By H. H. G. McKern, A.A.C.I.,
and (Mrs.) M. C. Spies, A.A.C.I.

Manuscript received, February 20, 1953. Read, April 1, 1953.

Notwithstanding the many analyses which have been made on the essential oil of *Eucalyptus citriodora* and its forms, there appears to be little reliable information about the minor constituents of oil of the "Type" (65-85% *dl*-citronellal). Apart from the identification of the major component citronellal by Schimmel & Co. (1888), the only other chemical examination of this oil appears to be that of Chiris (1925). Chiris reported the presence of citronellol, geraniol and acetates of these alcohols, as well as citronellyl butyrate and citronellate, pinene, cineole, isopulegol and unidentified sesquiterpene compounds, whereas a recent examination of authentic samples by ourselves failed to detect the presence of geraniol, butyric acid or cineole.

As the studies in progress at the Museum of Applied Arts and Sciences, Sydney, on the essential oils of *E. citriodora* Type and its various physiological forms (Penfold *et al.*, 1951) call for knowledge of the minor constituents, it has been found necessary to examine freshly distilled oils from naturally occurring trees in Queensland, and from cultivated specimens in New South Wales.

The aldehyde contents of the oils examined ranged from 65·8 to 77%, and the constituents found (other than citronellal) were isopulegol, citronellol, the formic, acetic and citronellic acid esters of these alcohols, α-pinene, β-pinene, and *iso*valeric aldehyde. No evidence could be found for the presence of geraniol, cineole, propionic, butyric or valeric acids in any of the oils examined.

EXPERIMENTAL.

Samples of oil used in this work were steam-distilled from freshly-cut leaves and terminal branchlets of *Eucalyptus citriodora* Hook., both from naturally-occurring trees at Cordalba, Queensland, and from cultivated specimens near Sydney, N.S.W. After drying with anhydrous sodium sulphate, the physico-chemical constants of the oils fell within the following ranges: d_{15}^{15} 0·8660 to 0·8752; $n_D^{20°}$ 1·4528 to 1·4582; α_D ±0·0° to +3·51°; ester No., mg. KOH/g., 12·5 to 18·5; ester No. after acetylation 264 to 300; citronellal content, 65·8 to 77·0%; soluble in 0·5 to 1·5 volumes of 70% W/W alcohol. The oils examined are thus seen to possess physico-chemical constants falling within the range quoted by Penfold *et al.* (1951, *loc. cit.*) for the "Type" oil, *i.e.* the oil marketed commercially (E. Guenther, "The Essential Oils", Vol. 4, p. 473). It is not proposed to quote at length all the experimental data gained on every oil examined, since much of it is repetitive, and some results secured for a typical case only will be given.

Crude oil of *E. citriodora* was obtained in 0·52% yield on steam-distillation of fresh leaves and terminal branchlets of Type trees growing near Sydney. The oil had d_{15}^{15} 0·8752; n_D^{20} 1·4582;

α_D —0·25° ; soluble in 1·3 volumes of 70% W/W alcohol ; ester No., 12·5 ; after acetylation, 264 ; citronellal content, 65·8%. One litre of this oil was submitted to fractional distillation at 20 mm., the lower boiling (terpenic) fractions only being taken off, as shown in the table.

Fraction.	Boiling Range, 20 mm.	Volume.		$d_{15}^{15°}$	$n_D^{20°}$	α_D
		Mls.	%			
Vapour trap, aqueous	—	4	0·4	—	1·3346	—
Vapour trap, non-aqueous	—	3	0·3	—	—	—
1	53°	6	0·6	0·8574	1·4672	—8·50°
2	53°–60°	15	1·5	0·8588	1·4652	—4·45°
3	60°–65°	11	1·1	0·8584	1·4664	—5·3°
4	65°–69°	6	0·6	0·8604	1·4714	—9·65°
5	69°–96°	9	0·9	0·8531	1·4702	—3·45°

After fraction 5, oxygenated constituents (citronellal and isopulegol) began to appear and fractionation was stopped. A vapour-trap immersed in an acetone-dry-ice freezing mixture was interposed between the fractionation assembly and the vacuum pump.

Aqueous distillate (4 ml.), although giving a positive test with Schiff's reagent, failed to give a significant quantity of 2,4–dinitrophenyl-hydrazone, and from the refractive index appeared to be mainly water.

Determination of Iso-valeric Aldehyde. Refractionation of the non-aqueous phase collected in the vapour-trap, together with fractions 1, 2 and 3, gave 1 ml. of first runnings. It was a colourless mobile liquid (n_D^{20} 1·4053) of choking odour and gave a strongly positive Schiff test. It yielded a *p-nitro phenyl hydrazone* (yellow needles) of m.p. 113·5°, and admixture with an authentic specimen of *iso-valeric aldehyde p-nitro phenyl hydrazone* of m.p. 110·5° gave a m.p. of 112·5°.

Found : C, 59·45%, 59·64% ; H, 6·72%, 7·06% ; N, 19·01%.

Calculated for $C_{11}H_{15}O_2N_3$: C, 59·69% ; H, 6·83% ; N, 18·99%.

Determination of α-pinene. Refractionation of fractions 1, 2 and 3 gave a fraction b_{93}, 90–96° ; $d_{15}^{15°}$, 0·8618 ; n_D^{20}, 1·4695 ; α_D —11·35° which yielded a nitrosochloride, m.p. 109°. Oxidation of the fraction (6 g.) with cold neutral permanganate (potassium permanganate, 12·6 g. ; water, 150 ml. ; ice, 57 g.) yielded an oily acid which formed a *semicarbazone*, m.p. 202°, from methanol. Admixture with an authentic specimen of *pinonic acid semicarbazone* of m.p. 205° raised the m.p. to 204°.

Determination of β-pinene. Refractionation of fractions 4 and 5 gave a fraction having b_{93} 92–100° ; d_{15}^{15}, 0·8650 ; n_D^{20}, 1·4744 ; α_D, —11·5. Oxidation of the fraction (7 ml.) with alkaline permanganate (potassium permanganate, 14 g. ; sodium hydroxide, 3 g. ; water, 180 ml.) gave a good yield of white crystals, m.p. 127°, from benzene. Admixture with an authentic specimen of *nopinic acid* produced no depression of m.p.

Determination of Acids. Another specimen of crude oil (500 g.) from the same source was saponified with alcoholic potash (0·5N ; 4·5 litres) at room temperature for 3 days. Dilution of the reaction mixture with water enabled the saponified oil to be removed.

Citronellic Acid. After reduction to a small bulk, acidification of the aqueous solution of potassium salts with sulphuric acid (5N), followed by steam-distillation, resulted in the collection of a colourless oily acid (12 ml.) of characteristic " fatty acid " odour. After drying it had b_{10} 140–143° ; d_{15}^{15} 0·9303 ; n_D^{20} 1·4549 ; α_D +0·5° and yielded a *p-phenylphenacyl ester*, m.p. 38°, and a *S-benzylthiuronium salt*, m.p. 143°, both undepressed by admixture with specimens prepared from an authentic sample of *citronellic acid.*

Neutralization equivalent: 169·0.

Calculated for citronellic acid: 170.

Formic and Acetic Acids. The aqueous portion of the distillate from the steam-distillation of the acidified mixture of potassium salts was collected in three fractions. Fraction 1 was shown to contain a considerable amount of formic acid and attempts to prepare a silver salt resulted in rapid reduction to metallic silver. In order to determine other acids, the formic acid was destroyed by boiling with alkaline permanganate in the usual way. The residue obtained on evaporating the reaction mixture to dryness was distilled with syrupy phosphoric acid to yield a *liquid acid* of pungent odour from which the silver salt was prepared. 0·1396 g. yielded 0·0904 g. Ag, equivalent to 64·76%. Fraction 2, also containing formic acid, was similarly treated, and the silver salt of the residual acids prepared. 0·1400 g. silver salt yielded 0·0906 g. Ag, equivalent to 64·71%. Fraction 3 contained only a small amount of acids, and the silver salt prepared therefrom after destruction of the formic acid could not be rigorously purified. 0·0432 g. Ag salt gave 0·0283 g. Ag, equivalent to 65·5%. Silver acetate requires 64·67%; silver propionate would require 59·67%. No evidence for the presence of appreciable quantities of the butyric or valeric acids was observed, either in this oil or any others examined.

Determination of Alcohols. The saponified oil, after separation of the acids, was washed free of alkali and treated with hydroxylamine as described by Penfold *et al.* (1952) to convert all citronellal present to its high-boiling oxime. Four hundred and thirty grammes of this oximated oil was then fractionally distilled at 3 mm.

Isopulegol. The first fraction (b_3 60–66°; d_{15}^{15} 0·9131; n_D^{20} 1·4732; α_D —0·25°) had the characteristic odour of isopulegol and gave with α-naphthyl *iso*cyanate an *α-naphthyl urethane* m.p. 120° from methanol undepressed by an authentic specimen of *isopulegol α-naphthyl urethane.*

[In order to confirm the presence of isopulegol as an original constituent of the freshly-distilled crude oil of this species, another oil (d_{15}^{15} 0·8692; n_D^{20} 1·4545; α_D +3·51°; ester number, 18·5; ester number after acetylation, 300; citronellal content, 75%) was oximated at 0° without any other preliminary treatment and fractionally distilled at 10 mm. The fraction boiling at 95° again yielded an α-naphthyl urethane, m.p. 119°.]

Citronellol. A portion of the oximated oil boiling at 67–93° at 3 mm. (33 g.) was refluxed 2 hours with equal weights of phthalic anhydride and benzene, after which water was added. The reaction-mixture was brought to neutrality with sodium hydroxide solution and extracted with ether to remove unreacted material. On acidification the acid phthalate ester was separated and steam-distilled with excess sodium hydroxide solution. A colourless oil (10 ml.) of pleasant rose-odour was obtained, having physical constants (d_{15}^{15} 0·8678; n_D^{20} 1·4574; α_D —0·55°) closely corresponding to those of citronellol. It yielded an allophanate which on recrystallization from benzene melted at 107°, undepressed by an authentic specimen of *citronellyl allophanate.*

Sesquiterpenes. Still pot residues from the various fractional distillations gave the usual colour tests for sesquiterpenes, but owing to the small quantities present they were not further investigated.

ACKNOWLEDGEMENTS.

We wish to express our thanks to the Trustees and Director (Mr. A. R. Penfold) of the Museum of Applied Arts and Sciences for permission to publish this Note.

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The Museum of Applied Arts and Sciences,
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A SYSTEM OF INDEPENDENT AXIOMS FOR MAGNITUDES.

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1. INTRODUCTION.

Let S be a set of elements $a, b, c, \ldots$ in which are defined (i) an *order relation* (for any a, b, $a<b$ is either true or false), (ii) an *addition operation* (any a, b determine a unique sum $a+b$); a second operation (iii) *multiplication by a natural number* $\varkappa$ can be defined, inductively, in terms of (ii) $(1.a=a, (\varkappa+1)a=\varkappa a+a)$.

The condition for S to be isomorphic [with respect to (i), (ii)] to a subgroup G of the (additive) group R of the real numbers is well known: S must be an archimedean-ordered group.[1] The following related question is of interest: under what conditions is S isomorphic to the set G^+ of the positive elements of such a group G? When S is a set of *magnitudes* like lengths, areas, volumes, weights, times, etc., this amounts to the problem of measuring the magnitudes by means of positive real numbers. It will be shown that such a set S may be characterized by the following system of independent axioms:

$\begin{matrix}(\mathrm{I}a)\\(\mathrm{I}b)\end{matrix}$ For any a,b at $\begin{matrix}\text{least}\\\text{most}\end{matrix}$ one of $a<b$, $a=b$, $b<a$ holds (trichotomy law).

(II) $(a+b)+c=a+(b+c)$ (associative law).

(III) If $a<b$, then the equation $a+x=b$ has at least one solution x (right inverse law).

(IV) $a<a+b$ (right law of positivity).

(V) To any a,b, a natural number $\varkappa$ exists such that $b\leqslant\varkappa a$ (law of Archimedes).

The necessity of these laws is obvious; their sufficiency will be proved in Nos. 2 and 3, their independence in No. 4.

2. CONSEQUENCES OF THE AXIOMS.

(VI) $b<b'$ implies $a+b<a+b'$ (right monotonic law).

Proof: $b+x=b'$; by (III); $a+b<(a+b)+x=a+(b+x)=a+b'$, by (IV), (II).

(III*) $a+x=b$ has at most one solution x, i.e. $a+x=a+y$ implies $x=y$ (right cancellation law).

Proof: By (I*a*) it is sufficient to exclude $x\lessgtr y$; $x\lessgtr y$ implies $a+x\lessgtr a+y$, by (VI), which contradicts $a+x=a+y$, by (I*b*).

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[1] O. Hölder, *Ber. sächs. Akad. Wiss., Leipzig. Math. phys. Kl.* 53, 13–14 (1901); R. Baer, *J. reine u. angew. Math.* 160, 212–218 (1929); H. Cartan, *Bull. Sci. Math.* (2), 63, 201–205 (1939); F. Loonstra, *Proc. Ned. Akad. Wet.* 49, 41–46 (1945); see also G. Birkhoff, "Lattice Theory", revised edition, 1948, p. 226.

(VII) $a<b$, $b<c$ imply $a<c$ (transitive law).

Proof: $a+x=b$, $b+y=c$, by (III); $a<a+(x+y)=(a+x)+y=b+y=c$, by (IV), (II).

(VIII) For any a, the correspondence $\varkappa \longleftrightarrow \varkappa a$ is an isomorphism of the sets $\{1, 2, 3, \ldots\}$ and $\{a, 2a, 3a, \ldots\}$.

Proof: $a<2a<3a<\ldots$, by (IV), (VII); $(\varkappa+\lambda)a=\varkappa a+\lambda a$, by (II).

(V*) If $a \leqslant b$, then λ exists such that $\lambda a \leqslant b<(\lambda+1)a$.

Proof: $b \leqslant \varkappa a$, for some $\varkappa$, by (V); $\varkappa a<(\varkappa+1)a$, by (IV); $b<(\varkappa+1)a$, by (VII). If $\varkappa'$ is the least number with $b<\varkappa' a$, then $2 \leqslant \varkappa'$, and $\lambda=\varkappa'-1$ satisfies (V*).

(IV′) $b<a+b$ (left law of positivity).

Proof: By (Ia) either $b<a$ or $a \leqslant b$. If $b<a$, then (IV) implies $b<a+b$, by (VII); if $a \leqslant b$, then $\lambda a \leqslant b<(\lambda+1)a=a+\lambda a \leqslant a+b$, by (V*), (VIII), (VI), (VII).

(VI′) $a<a'$ implies $a+b<a'+b$ (left monotonic law).

Proof: $a+x=a'$, by (III); $b<x+b$, by (IV′); hence $a+b<a+(x+b)=(a+x)+b=a'+b$, by (VI), (II).

3. Sufficiency of the Axioms.

We distinguish two cases:

3a. *S possesses a smallest element e,* i.e.

(IX) $e \leqslant a$ for all a.

By (V*), λ exists for every a such that $\lambda e \leqslant a<(\lambda+1)e$; this implies $\lambda e=a$, as $\lambda e<a$ leads to $\lambda e+x=a$, by (III), and $a<(\lambda+1)e=\lambda e+e \leqslant \lambda+x=a$, by (IX), (VI), (VII), contradicting (Ib). S thus is the set $\{e, 2e, 3e, \ldots\}$ which, by (VIII), is isomorphic to the set $\{1, 2, 3, \ldots\}$ of the positive integers.

3b. *S possesses no smallest element,* i.e.

(X) No element a exists such that $a \leqslant b$ for all b.

It follows that, to every a, an element b exists such that $a \nleqslant b$, i.e. $b<a$, by (Ia). Moreover, b' exists such that $2b' \leqslant a$; for $b<a$ leads to $b+x=a$, by (III), and if $b'=\min(b,x)$,[2] then $2b'=b'+b' \leqslant b'+x \leqslant b+x=a$, by (VI), (VI′), (VII).

(XI) $a+b=b+a$ (commutative law).

Proof: By (Ia), it is sufficient to exclude $a+b \gtrless b+a$. Suppose $a+b<b+a$. By (III), $(a+b)+x=b+a$. Choose y, by (X), such that $2y \leqslant x$, and put $z=\min(a, b, y)$[2]; then $z \leqslant a$, $z \leqslant b$, $2z=z+z \leqslant z+y \leqslant y+y=x$, by (VI), (VI′), (VII). By (V*), $\varkappa$, λ exist such that

$$\varkappa z \leqslant a<(\varkappa+1)z, \qquad \lambda z \leqslant b<(\lambda+1)z,$$

whence, by (VI), (VI′), (VII), (VIII), (II)

$$b+a<(\lambda+1)z+(\varkappa+1)z=\varkappa z+\lambda z+2z \leqslant a+b+x=b+a,$$

in contradiction to (Ib).

(XI) implies the validity of the remaining left laws; and by adjunction of the elements 0 and $-a$, in the usual manner, S may be extended to form an archimedean-ordered group which is isomorphic to a subgroup G of R; S itself is isomorphic to G^+.

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[2] The minimum of a finite number of elements exists in virtue of (I), (VII).

4. INDEPENDENCE OF THE AXIOMS.

The independence of the axioms will be proved by exhibiting, for each of the six axioms, the example of a set satisfying all but this particular axiom.

Example 1*a*. Let $S=\{2, 3, 4, \ldots\}$ with the usual addition, and define $a<b$ to mean the existence of x in S such that $a+x=b$. As $2\neq 3$, and neither $2+x=3$ nor $3+x=2$ have a solution in S, (I*a*) is false. The other axioms are easily verified.

Example 1*b*. Let $S=\{0, \pm 1, \pm 2, \ldots\}$ with the usual addition, and define $a<b$ to hold between *any* a, b. All axioms hold except (I*b*).

Example 2. Let S be the set of all real numbers $a>1$ with the usual order, the " sum " of two elements a,b being given by a^{b}. (II) is false, as $(a^{b})^{c}\neq a^{b^{c}}$; the other axioms are easily verified.

Example 3. Let $S=\{2, 3, 4, \ldots\}$ with the usual addition and order. All axioms hold except (III) (the equation $2+x=3$ has no solution).

Example 4.[3] Let $N=\{1, 2, 3, \ldots\}$ and let a be any transformation which maps N in a one-one-manner on a subset $Na=N'$ of N whose complement $N-N'$ is infinite. Let $T=\{a, b, c, \ldots\}$ be the set of all such transformations. The product ab of two transformations is obtained by first applying a then b. Multiplication clearly satisfies the associative law (i) $(ab)c=a(bc)$. Moreover, the following two properties hold : (ii) $\mu\neq\nu$ implies $a^{\mu}\neq a^{\nu}$; for, by the definition $Na^{\mu+1}$ is a proper part of Na^{μ} so that $Na, Na^{2}, Na^{3}, \ldots$ and hence $a, a^{2}, a^{3}, \ldots$ are all different. (iii) The equation $ax=b$ has a solution for any a, b. x is found thus : Let a map $\varkappa$ on $\varkappa a=\varkappa'$, and let b map $\varkappa$ on $\varkappa b=\varkappa''$; defining $\varkappa' x=\varkappa''$, we get $\varkappa ax=\varkappa b$; x is then defined for all $\varkappa'$ in $N'=Na$, its range being $N''=Nb$; the definition of x on $N-N'$ is arbitrary provided its values lie in $N-N''$ and omit an infinite part of $N-N''$. $ax=b$ thus has an infinity of solutions ; a special one can be singled out and called the special quotient b/a. From T an enumerable subset $S=\{a_1, a_2, a_3, \ldots\}$ satisfying (i), (ii), (iii) can be selected by starting with any element a_1 and constructing the subset generated from a_1 by the multiplication and special quotient operations. Defining $a_1<a_2<a_3<\ldots$ (and using the multiplicative instead of the additive notation in S), S satisfies (I*a*), (I*b*), (II) (trivially), (III) (as *every* equation $ax=b$ has a solution), and (V) as $a, a^{2}, a^{3}, \ldots$ are all different and any $b=a_{\lambda}$ exceeds a finite number $(\lambda-1)$ of elements only. As $a+x=a$ has a solution, (IV) is false.

Example 5. Let S be the set of all ordinal numbers greater than 0 and less than ω^{2} with the usual addition and order. All axioms hold except (V) $(\varkappa\cdot 1<\omega$ for all $\varkappa)$.

5. CONCLUSION.

The present system of axioms is only one of many similar ones. A more systematic investigation of the various possible systems, as well as their relation to the problem of isomorphism with the full subgroups G of R (and also Hölder's[4] axioms for sets isomorphic to R^{+}) will be the subject of a subsequent paper.

The merits of the present system may be described as follows : Only the one-sided laws (III), (IV) are used, whereas the investigations of ordered semigroups usually assume both right and left inverse and monotonic laws. The

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[3] I am indebted to Dr. B. H. Neumann for drawing my attention to this adaptation of an example given by R. Baer and F. Levi (*Sitz. ber. Heidelberg Akad. Wiss. Math.-naturwiss. Kl.* 1932, 2, Abh., 7–8).

[4] *Loc. cit.* footnote 1, 4–7. Parts of the proof in Nos. 2, 3 of the present paper are taken from Hölder ; but he assumes both inverse and both positive laws.

restriction to the one-sided laws appears particularly natural when applied to physically irreversible magnitudes like time-intervals. An axiomatic treatment of time was given by H. Weyl[5]). His treatment assumes the existence of clocks which are described as systems which return, after a while, to a prior state and hence are periodical; this would imply a directly numerical measurement of time. For the present system of axioms an aperiodic (hence somewhat simpler and more fundamental) type of clock is required: a clock is a system which may be started at any given moment from a standard initial state and whose subsequent states are all different (*e.g.*, a sample of radio-actively decaying matter), so that the various states a', b', c', . . . of the clock represent the time intervals a, b, c, . . . elapsed since the clock was started. It is assumed that of two different states a', b' one can be recognized as the earlier state; it is also assumed that all clocks, wherever and whenever used, always behave in exactly the same manner. $a<b$ then means that the state a' is earlier than b'; and the sum $c=a+b$ of two time intervals is obtained by starting a clock A, starting a second clock B when A has reached the state a', and observing the state c' of A when B has reached the state b'. The laws (Ia), (Ib), (II) and (IV) are direct consequences of these definitions; and the equation (III) $a+x=b$ may be solved by starting a clock X when A has reached the state a' and observing its state x' when A reaches b'. The corresponding left equation $y+a=b$ can not be solved in this way as this would require the determination of a state y' of a clock Y such that a clock A, started when Y is in the state y', reaches the state a' when Y reaches b'; as the process is irreversible, the state y' which depends on a later event cannot be found. Similarly, the left law of positivity (IV′) $b<a+b$ is not an *a priori* consequence of the definitions. The law of Archimedes (V) plays an exceptional role; it has to be added, as a further natural law, to the assumptions made about the clocks.

Department of Mathematics,
University of Melbourne,
March, 1953.

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[5] "Space, Time, Matter" (London, 1922), Introduction.

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CLARKE MEMORIAL LECTURE*

SOME PROBLEMS OF TERTIARY GEOLOGY IN SOUTHERN AUSTRALIA.

By Martin F. Glaessner, Ph. D., D.Sc.
Department of Geology, University of Adelaide.

With three text-figures.

Contents.

Introduction.

We are assembled to honour the memory of the Rev. W. B. Clarke, who has been called the Father of Australian Geology. It is particularly appropriate to honour a pioneer in geological science because it is the fundamental philosophy of geology to look back in time, to gain that insight into the nature of things which is needed in order to plan and make the next step forward. Looking back at the work of our pioneers, we are impressed with their freshness of outlook, their random sampling of data from the unlimited number presented by nature, their determination to gather information and record it as found, and most of all their ability to recognize facts as such. In the years which have passed we have gone a long way. Where we stand now we are deeply troubled by uncertainty about facts, an attitude which would have appeared strange indeed to the pioneers. We doubt whether a granite is a plutonic igneous rock or a migmatite, whether a sandstone is a greywacke, a subgreywacke or an arkose, whether a sedimentary basin is a mobile shelf, a miogeosyncline or a paraliageosyncline, and whether an orogeny builds mountains or pushes the earth's surface downward. This is partly the result of living in an age of uncertainty and confusion, affecting all branches of human activity, and among them every branch of science. But it is not altogether a bad or deplorable state of affairs. Our untroubled predecessors have unearthed facts in such prodigious quantities, prodigious particularly when we compare the conditions of their work with the manpower and technical and transport facilities available to us. Their observations have since been grouped and built into a framework of hypotheses and theories. New facts are no longer gathered indiscriminately but are immediately weighed against or assessed in terms of current theories.

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* Delivered to the Royal Society of New South Wales, June 18, 1953.

Principles of Tertiary Geology.

Those who are familiar with the history of exploration of the Tertiary strata of southern Australia will agree that it would be futile to attempt to summarize its course as an introduction to current or new problems in this field. It will suffice to say that very significant contributions have been made by such indefatigable searchers for facts and fossils as Tate and Howchin in South Australia, and McCoy, Wilkinson, Dennant, Hall and Pritchard, Chapman, Singleton, Miss Crespin and others in Victoria. If discussions became somewhat confused in the earlier days and somewhat acrimonious at various stages, this can be taken as proof of the lively interest and great enthusiasm of the workers in this field. The study of the record shows that the great majority of authors of contributions to the study of the Tertiary of Australia are or were palæontologists. This means that the abundant and beautifully preserved large and small fossils in these rocks have for many years attracted far more interest than the rocks themselves. This means also, though it does not detract from what has been achieved, that much was left undone. And while it would be absurd to suggest that the scope of the work on fossils should be reduced, I feel the time has come to advance on a broader front if we want to clarify the record of Tertiary time in Australia and extract from it all the data of theoretical and practical value which it contains.

There is no need to say much about the practical side of Tertiary geology as the facts are well known. The brown coal developments in Victoria, the lignite resources of Moorlands in the Murray Basin and near St. Vincent Gulf in South Australia need only be mentioned. They are receiving constant attention from geologists and mining experts. A considerable portion of the subterranean water resources of Australia, perhaps the most valuable economic mineral deposits of the continent, is contained in Tertiary strata. Looking further afield and optimistically ahead we remember that most of the world's petroleum production comes from Tertiary reservoir rocks, and while no immediate objectives are known here I feel that the last word has not been said and that hopes for finding oil or gas in these rocks in southern Australia should not be abandoned. Any new discoveries in this field should be closely scrutinized for favourable indications. Lastly, Tertiary rocks form the environment of much of our civilization, and particularly agriculture, contributing to the soil of vast fertile areas ; and just as London, Paris, Vienna, Budapest and Rome came to grow up, for good reasons, in Tertiary basins, so did Perth, Adelaide and Melbourne. From a practical point of view, from the point of view of gaining all possible benefit from our environment and at the same time understanding how it came into being, Tertiary basins are an important object of geological studies.

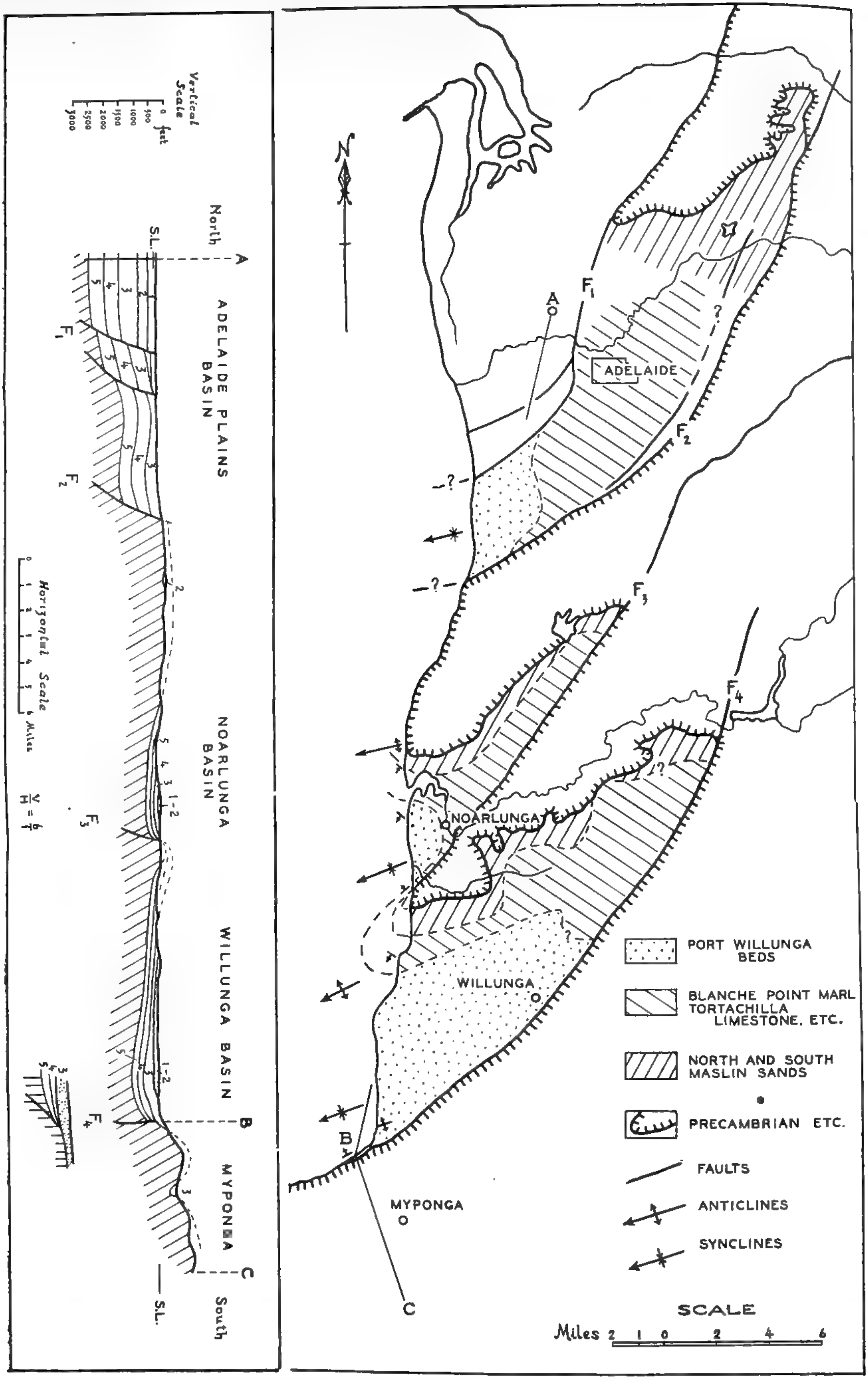
From a theoretical point of view, that of advancing our knowledge of fundamental geological processes and thereby advancing the science of geology itself, they are no less important. That they have been somewhat neglected by geologists and have attracted less attention than they deserve is due, among other causes, to two misconceptions. One is that the Tertiary period is a short span of geological time, somewhat of the same order as the Quaternary, so that Tertiary rocks can form only a rather insignificant veneer on the really important older rocks. This is patently incorrect as we know now that the Tertiary Period lasted some 70 million years, against one million years of the Quaternary. The other ingrained misconception is that Tertiary rocks are unfolded and basically undisturbed except by irregular fracturing, so that nothing can be gained from their study for the understanding of the structure of the earth and the nature of earth movements. We are just beginning to find that this, too, is quite incorrect.

Tertiary geology is as much a study in four dimensions as the study of any other part of the geological record. They are the three dimensions of space and the dimension of time ; every one is essential and no single one can tell the full story. We need the linear dimension of the stratigraphic column, the two dimensions of the geological map, the third dimension of subsurface study, and the careful placing of the record against the relative or absolute scale of geological time to give a full account of geological history.

STRATIGRAPHIC SEQUENCE OF THE ADELAIDE BASIN.

We have selected the Adelaide Basin as the proving ground for the soundness of this approach. The Adelaide Basin is a geological feature of a respectable size, some 130 miles long and about 50 miles wide. Over half of this area is covered by the shallow waters of the Gulf St. Vincent. This represents a valuable reserve fund of information on sedimentation and it is hoped that an investigation of its sediments will be carried out in the not too distant future. The land area can be divided into the Adelaide Plains Basin and its northern extension to about 100 miles north of the city, the Tertiary areas on Yorke Peninsula where detailed studies have not yet been carried out, the marginal basins south of Adelaide known as the Noarlunga and Willunga Basins, and isolated outcrops on Kangaroo Island and in the southern Mount Lofty Ranges. The Adelaide Plains area is poor in natural outcrops, but being an artesian basin its subsurface geology is known from many bores and the available information was recently ably summarized in detail by Dr. K. R. Miles (Miles, 1952). Only one bore in the deepest part of the basin reached the pre-Cambrian bedrock, at a depth of 2,242 feet, in 1892, revealing the entire Tertiary sequence. Structural conditions make it possible to study this sequence in the coastal sections south of the city, and the first phase of the investigation involved the detailed survey of these sections leading to the construction of measured stratigraphic columns. They show the following units :

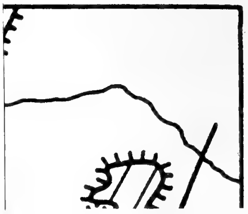
Firstly, there is a series of cross-bedded quartz-sands up to 60 feet thick containing plant remains in intercalated clay lenses, with a few sponge remains and poorly developed foraminifera in laminated sands near the top indicating brackish water conditions. This unit is known as the *North Maslin Sands.* These sands rest on lateritized pre-Cambrian or on Permian tillite, and are capped with ironstone in some places. In a quarry north of Maslin Beach the next unit is seen to follow with an angular unconformity. This unit, the *South Maslin Sand,* is a fine quartz sand with glauconitic and limonitic pellets and interstitial calcareous and glauconitic clay. Its colour is purplish, green or brown. Marine fossils occur sporadically. It is at least 100 feet thick in Maslin Bay, but thin or absent elsewhere. After a slight unconformity, with a pronounced cut-and-fill effect, follows the *Tortachilla Limestone,* 6–10 feet thick, glauconitic, with limonitic material derived from the underlying beds. Its lower part is polyzoal, its upper part shelly, with a rich fauna of mollusca, echinoids and foraminifera. It grades upward into glauconitic marl which is, according to Reynolds (1953), the basal member of the *Blanche Point Marls.* In this bed, which is 7–14 feet thick, Parr found Eocene foraminifera including *Hantkenina.* The next member of the Marls is distinctly banded, being developed as an alternation of soft argillaceous and hard siliceous marls. These are followed by soft marls with few hard bands. The Blanche Point Marls, about 100 feet thick, are very rich in sponge remains, a fact which is genetically related to the occurrence of siliceous bands. *Turritella aldingæ* Tate is a common fossil throughout this formation. It is overlain by the *Chinaman's Gully Beds,* a very distinctive formation which is only four feet thick in the coastal sections. It contrasts vividly with the underlying and overlying strata by its sandy composition and green, yellow and red colours. The top is a cross-bedded, limonite-cemented quartz grit. This formation, which is unfossiliferous, is considered as non-marine. Above it are



Text-fig. 1.

Explanation of Map: Distribution and structure of Early and Middle Tertiary formations in part of the Adelaide Basin. F_1, Para Fault; F_2, Eden-Burnside Fault; F_3, Clarendon (Moana) Fault; F_4, Willunga Fault.

Explanation of Section: A, Croydon Bore (Adelaide); B, 1½ miles south of Sellick's Beach; C, south of Myponga. 1, Recent and Pleistocene; 2, Pliocene; 3, Port Willunga Beds including subsurface Miocene strata; 4, Blanche Point Marls, Tortachilla Limestone and equivalents; 5, North and South Maslin Sands. Inset shows relations of sediments adjacent to Willunga Scarp at the end of the deposition of the Port Willunga Beds. Precambrian and Palæozoic basement shaded.



over 100 feet of predominantly bryozoal beds, calcarenites and clays with nodules and pellets, with pronounced current-bedding at the base and intermittently at higher levels. These are the *Port Willunga Beds.*

All these Tertiary formations are cut off up-dip by about 20 feet of partly fossiliferous sandy limestones, sands and sandy clays. The marine fauna in these beds is of Pliocene age. There is an angular unconformity between the Pliocene which shows a dip of 1° and the underlying formations which dip at 2° in a general direction to the south-south-west. As the dips are very regular, the unconformity becomes very pronounced over the great length of coastal exposures. It was recognized as such by early observers, though not fully appreciated in its general significance.

Marginal Basins.

The next step following upon the detailed mapping of the coastal traverses and construction of stratigraphic columns was the mapping of the inland extension of the different formations. This was carried out at the scale of two inches to one mile by B. Daily and G. Woodard (unpublished). In the available time only the Tertiary formations could be mapped, and neither the pre-Tertiary nor the post-Pliocene could be studied closely. Obviously, the more detailed the stratigraphic subdivision of the standard section into mappable formations, the greater the structural detail which can be revealed by areal mapping. Tate's original stratigraphic division into " Eocene " and " Miocene " produced no recognizable structural picture. The later division into " Oligocene freshwater beds ", " Miocene limestones " and, along the coast, a strip of unconformable marine Pliocene led to the picture of tilted fault blocks which was developed gradually by Benson, Howchin, Mawson, Fenner and Sprigg. It was known that at the southern end of the fault blocks which revealed the standard sections the beds were tilted up to dip north-westward, but this was explained as " drag on the faults ". When the southern margin of the Noarlunga Basin was mapped the oldest instead of the youngest beds of the Tertiary sequence were found exposed and the structure was recognized as a syncline instead of a tilted block. It is, however, very asymmetric, with a very narrow southern limb and considerable thinning of strata towards the southern edge. There are no drag effects such as distortion of fossils or sliding on bedding planes. The southern margin of the Willunga Basin has pre-Pliocene strata exposed only in the sea cliffs south of Sellick's Beach. This is six miles south of the point where the pre-Pliocene unconformity disappears below sea level. As it has a fall of 25 feet per mile between this point and the northern edge of the basin (Reynolds, 1953), it should be 150 feet below sea level at its southern end, according to the concept of tilted blocks. Instead, outcrops of marine fossiliferous Pliocene have now been found there above sea level, overlying Port Willunga beds. When next seen, above the Cambrian basement of the southern margin of the basin, these beds rise steeply, with dips increasing to vertical and then moderating upwards to about 40°. These magnificent exposures were described by Howchin (1911). But instead of the expected drag effects and faulted contact we found a flexure in the well-bedded Port Willunga Beds, sigmoidal in vertical plane, with a transgressive basal breccia. Even the most fragile fossils are virtually undistorted. The most impressive proof of undisturbed transgressive contact is supplied by the occurrence of infillings of fossiliferous Tertiary limestone in fissures in the underlying Cambrian, which are up to 15 feet deep. The Port Willunga Beds occur also as isolated remnants in the higher country to the south, at Myponga and above Hindmarsh Falls, where they were found by Madigan and Howchin (at an elevation of about 900 feet). Here they rest either on pre-Cambrian or on Permian beds. As the older members of the Tertiary sequence occur neither here nor on the southern edge of the Willunga Basin, they must wedge out somewhere under the Basin. We shall see that there is evidence for a shoreline in this position, over which the Willunga Beds transgressed, as they transgressed in the coastal sections over the preceding non-marine Chinaman's Gully Beds.

Marine Pliocene is found outcropping only within a short distance of the present coastline. The most distant surface occurrence is probably in the grounds of the University of Adelaide, about six miles from the coast. Lithologically similar deposits found further inland are unfossiliferous and probably non-marine. They are mostly quartz sands and well-rounded quartz gravels, with sandy limestones occurring nearer to the shoreline. These deposits were laid down on a peneplaned surface which probably had acquired a gentle seaward slope by the time of the Pliocene transgression. This surface and the covering marine and non-marine Pliocene deposits were further disturbed by gentle warping and strong faulting.

Subsurface Conditions.

The variations in thickness of strata in different bores proved puzzling from the earliest days of exploration. Variations in facies were recognized more recently. These conditions call for detailed stratigraphic analysis. In this work, micropalæontological examination of samples from bores provides very valuable data. It is fortunate that some samples from the Croydon bore, the only bore in the Adelaide Plains area which reached bedrock, have been preserved. The study of the foraminifera from these samples is being carried out together with the study of surface samples taken from the measured coastal sections and of selected other bore material. It is not yet completed, but data obtained have enabled us to make a rough correlation of strata in the Croydon bore and to compare them with bores on the next higher fault block, across the Para Fault. Combining palæontological data and correlations with the lithological descriptions we find that the missing thickness of pre-Pliocene marine strata on the upthrown block represents an erosional interval on an unconformable contact, corresponding to that which is so well exposed along many miles of coastal cliffs. As the pre-Pliocene marine Tertiary beds preserved in the Kent Town bore contain the foraminiferal fauna which is found near the base of the marine section of the Croydon bore, we find that about 1,300 feet of strata were removed from this site on the upthrown block. This was the amount of pre-Pliocene or early Pliocene movement on the fault in this vicinity, as the surface of Pliocene deposition was almost level (peneplaned). That this level surface was further disturbed in late or post-Pliocene time is shown by the fact that in the Croydon bore it is about 600 feet deep (550 feet below sea level), while in the Kent Town bore it is approximately at sea level. This indicates the later faulting in this cross-section.

Subsurface investigations provide information not only of structural but also of facies development. Bores in the Adelaide Basin at some distance from the coast have encountered lignites which do not outcrop in the coastal cliffs. In some bores two lignitic series were found, separated by fossiliferous marine rocks. A bore put down to a depth of 680 feet in the Willunga Basin produced a log which seemed to have little resemblance to the columnar section of the coastal cliffs only three or four miles to the west. It is obvious that facies changes are greater from west to east than in a meridional direction, where there is little change in ten miles of section. It is not surprising that the plant-bearing deltaic North Maslin Sands become lignitic inland, but it is interesting that in several instances the proven lignite areas end abruptly against faults, without reappearing as expected in the upthrown continuation of the same formation. This means that during the deposition of the lignite a scarp formed the boundary of the swampy basin. It was probably a fault scarp formed by earlier movement, as Sprigg (1942, 1945, 1946) has shown clearly that Late Tertiary to Recent movements occurred on earlier, probably Palæozoic faults. A revival of movement would then turn the boundary scarp again into a fault.

A study of bore records from the Adelaide and Willunga Basins and outcrop observations suggest that the upper lignites (which do not seem to be of economic importance here) are related to the Blanche Point Marls. This may seem surprising as along the coast this formation is not only entirely marine but also rich in sponges and free from coarse clastic material suggesting uniform still-water conditions. But still water is not necessarily deep water, and even deep water is not necessarily far from land. In outcrops we see unfossiliferous fine micaceous sands appearing in this formation, and in bores the same sand with gravels and lignite occurs in equivalent positions, above the glauconitic beds with the *Hantkenina*-fauna and either above or below the *Turritella* and sponge-spicule fauna of the Blanche Point Marls. The glauconitic beds overlap the basement, cutting out the Maslin Sands. This is taken as evidence of a shoreline in the eastern part of the basins or, in other words, at the foot of the present Ranges. A reflection of a more widespread regressive phase is seen on the coast in the development of the thin non-marine Chinaman's Gully Beds above the Blanche Point Marls, and this regression also provides the explanation of the absence of Tertiary strata older than the Port Willunga Beds south of the Willunga Basin, in the Myponga area. Pre-existing structural lines influenced sedimentation in the basins not only as shoreline trends but also as boundaries of relatively high or less subsiding areas. Evidence for this is seen in thinning against these highs which were wrongly interpreted as subsequently upthrown basement blocks. The Blanche Point Marls are less than 100 feet thick in the coastal sections which were measured down the flanks of two of these blocks, while they are over 200 feet thick in the Willunga bore, which is in the axial part of the basin.

We have seen that the Port Willunga Beds are transgressive. Their subsurface distribution in the basins under the cover of soil, alluvium or Pliocene has been traced with the aid of bore records. Erosion has confined them to the axial portions of the basins near the coast, confirming synclinal folding in pre-Pliocene time. There is no evidence of these beds having ever covered the whole of the Mount Lofty Ranges, and the suggestion has been made that the transgression followed structurally low zones. A lignite band was found in this formation in the Myponga bore.

Under the conditions here described, shoreline, lignitic, non-marine, and particularly conglomeratic formations of different ages, must be expected to occur and to be so similar in composition and appearance that their dating becomes an exceedingly difficult and in some instances impossible task. In the subalpine Tertiaries of Europe much of the diastrophic history of the mountains can be worked out from the evidence of such formations. Their dating is often assured by abundant vertebrate fossils. As the vertebrate population of the Australian continent must have been extremely poor in numbers throughout the Tertiary these methods cannot be applied here, but it is hoped that meticulous field and subsurface stratigraphic studies together with investigations of sedimentary petrology and palæobotany will supply some of the missing clues.

TIME STRATIGRAPHY.

Stratigraphy, from its beginnings in history, means the study of the succession of strata and their dating in terms of the geological time scale. Neither of these aspects is sufficient in itself. A study of the rocks alone is bound to overlook gaps in the succession and the influence of contemporaneous events in other areas, and the naming and dating of fossil collections without regard to the full sedimentary record does not produce a statement of geological history. If properly collected, identified or described, and interpreted, the fossils provide a framework of time data which is indispensable for the study of Tertiary geology. Much work on our own collections and those of our predecessors, particularly Tate and Howchin, remains to be done, and I do not propose to discuss here palæontological or biostratigraphic problems.

Palæontological work to date has provided some fixed points for an outline of geological history of the area. They are Mawson and Chapman's discovery of a flora of Tertiary aspect in the North Maslin sands, Parr's discovery of the Eocene *Hantkenina*-fauna at the base of the Blanche Point Marls which showed that the flora cannot be younger than Eocene (and may be older), and the discovery of *Austrotrillina*, of Lower Miocene age, by Miss Crespin in bryozoal limestones in the upper part of the pre-Pliocene Tertiary section of bores near Adelaide. This fossil was also found in similar limestones from Yorke Peninsula by Howchin. The Myponga bore shows *Lepidocyclina*, of the same age, occurring in a bryozoal limestone overlying 242 feet of similar strata which can be correlated with the Port Willunga Beds of the type section. There is little doubt that the fossiliferous zone of Lower Miocene age is missing from the coastal sections because of later Miocene denudation. No index fossils of similarly world-wide significance have been found in the upper part of the Blanche Point Marls or the lower part of the Port Willunga Beds. I have stated (Glaessner 1951) that I consider these parts of the sequence as Oligocene (including equivalents of the Aquitanian) and I have not materially altered my opinion. The subject will remain controversial until the succession of faunas which have been found is fully described and analysed.

Geological History.

The observations made in the Adelaide area can now be summarized in an outline of geological history of Tertiary time in ten stages. Some of the stages and events in the geological history of the area which we have studied in detail are also apparent throughout southern Australia, and we shall briefly review the more significant points.

1. At the beginning of Tertiary time there was an eroded land surface composed of folded pre-Cambrian and Cambrian strata and in some places also of essentially unfolded remnants of unconsolidated Permian glacial deposits. There is evidence of lateritization of the surface of the older rocks. The difference in resistance to erosion between them and the glacial deposits in South Australia must have had a considerable influence on the configuration of the land surface. The contribution made by later erosion of the soft sands to Tertiary sediments must be considered when the distribution of the glacial strata before the Tertiary is reconstructed. Under these conditions the nature of the pre-Tertiary land surfaces is doubtful and it would be premature to make assumptions, such as complete peneplanation, on local evidence alone.

2. The beginning of deposition of angular, often coarse and gravelly current-bedded sands indicates rejuvenation of the land surface in early Tertiary time. Lignites were formed in structural lows adjacent to fault scarps. There is evidence of deltas laid down in proximity to the sea shore and of a lateritized surface of these beds.

3. The next phase is characterized by marine ingression, by the appearance of glauconite and of detrital limonite which occurs in a form suggesting denudation of earlier laterites from highs. Sedimentation, still deltaic with strong

cross-bedding, seems to have been confined to low areas. Lateritization may have continued during this time. This is the last phase of laterite formation which can be proved to have occurred prior to the end of the Pliocene.

The events leading up to the appearance of the first widespread marine transgression of Upper Eocene age have undoubtedly influenced large areas of south-eastern Australia. The deposition of angular gravels and coarse sands on an old land surface, and of lignites in structural lows with thicknesses varying according to rates of subsidence, the occurrence of marine ingressions and the formation of glauconite are features commonly found throughout southern Australia. There is a long span of time available for this paralic phase, from the beginning of Cainozoic time or even earlier (depending on whether the flora is really Tertiary or Late Cretaceous), to the end of the Eocene or, where the Late Eocene marine phase is missing, even Oligocene. The dating of the Pebble Point fauna of western Victoria as Paleocene or Lower Eocene does not fix the age of similar facies elsewhere within this range. One might point to possible correlations between the North Maslin Sands, in which the Noarlunga lignites occur, the Pebble Point beds of western Victoria, the Eastern View Coal Measures and the Lower, if not the Lower and Upper, Latrobe Valley Coal Measures, which contain the Yallourn coals, but there is as yet no palæontological proof of these correlations.

Similarly, one would be inclined to think of the South Maslin Sands as possible equivalents of the Demon's Bluff Formation, formerly known as Anglesean, and its equivalents, but again there is no decisive palæontological evidence though its stratigraphic position was clarified by Raggatt and Crespin (1952). There is clearly a long pre-Upper Eocene period of paralic deposition including coal formation. It begins usually with a series of coarse clastics.

4. A pronounced marine phase follows. It transgresses in the Adelaide Basin over the sands on to the basement rocks on the margins of the highs. The sediments are glauconitic and calcareous, with a rich shelly fauna preserved in deposits of the sublittoral zone. This is the first distinctive fauna of foraminifera, mollusca and echinoderms in the Basin. It indicates Upper Eocene age. The small number of planktonic foraminifera compared with that of similar deposits on the open coasts of Victoria suggests deposition in a basin with restricted access to the open sea.

The Upper Eocene marine transgression can be traced on the evidence of its marine fauna, as yet largely undescribed, westward through the northern part of Kangaroo Island and part of Yorke Peninsula to the lower limestones of the Nullarbor basin, and eastward into the Cape Otway area. This raises two questions: What corresponds to it in the south-east of South Australia and western Victoria? Why has it not been found west of Cape Otway? These questions will be left undecided. I have collected in both areas marine rocks containing a *younger* marine fauna resting on paralic (and in Victoria also on volcanic) facies. Whether these facies extend upwards to include equivalents of the marine Upper Eocene or whether marine Upper Eocene is missing on unconformities such as those observable at Knight's quarry near Mt. Gambier, Airey's Inlet and elsewhere, cannot yet be decided.

5. Conditions become more uniform throughout the Adelaide Basin, with still-water deposition of dark, less glauconitic calcareous muds rich in sponge remains. This brings to mind Woolnough's interesting speculations (Woolnough 1942) on the influence of the denudation of a lateritized peneplaned continent on composition of the surrounding seas and on life and sedimentation in them. Woolnough suggested that radiolarites would be formed, but it appears that less extreme conditions in early to mid-Tertiary time favoured the growth of

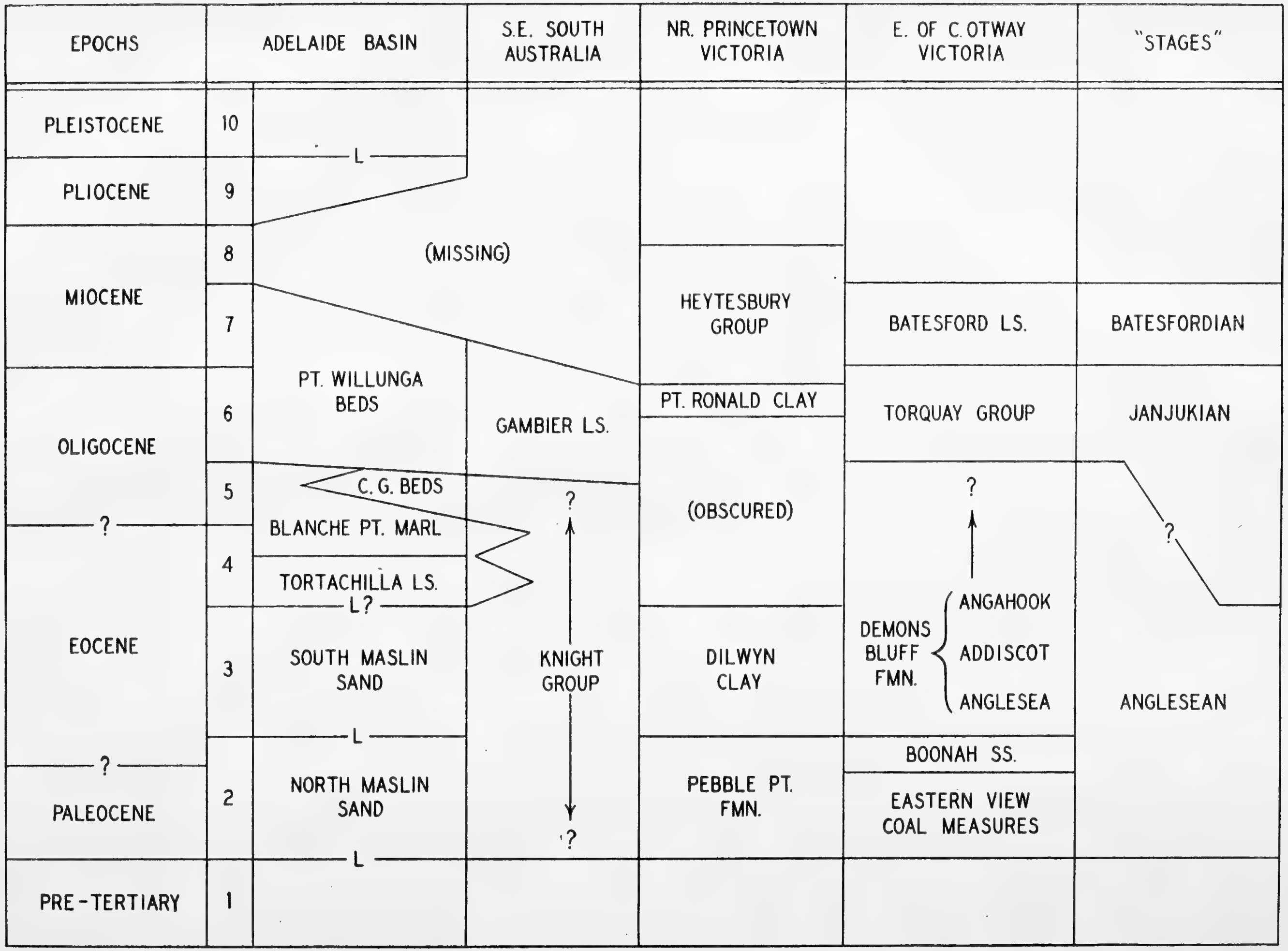


Fig. 2.—Stratigraphic Relations of Tertiary Formations.
1–10, Phases of regional geological history (see text). L, Horizons of observed lateritization. C.G.B., Chinaman's Gully Beds. Anglesean-Janjukian " Stage " boundary drawn to indicate fluctuations of usage. Princetown column after G. Baker.

siliceous sponges. The marine sediments grade inland into deposits of sandy lagoons and swamps where some lignites were formed, and there is evidence of regression of the sea.

Equivalents of the Blanche Point Marls of the Adelaide Basin can be traced in both shell- and plant-bearing facies to Yorke Peninsula, but not definitely beyond. In Western Australia a careful comparison with the Plantagenet beds which are similarly rich in sponges has yet to be made. The observed relations between the Blanche Point Marls and the upper lignites of the Adelaide Basin is significant. It is possible that favourable conditions for the formation of lignites younger than those formed during the basal Tertiary paralic phase extended over a large area.

6. A second very widespread marine phase follows. It transgresses over some of the highs, with the development of a thin bed of basal breccia. The muds are still glauconitic and calcareous but organic sedimentation dominates. Bryozoa which made a brief appearance at the beginning of the first marine phase are now the main rock-forming organisms, but mollusca, echinoderms, brachiopods and foraminifera are common and form a distinctive marine assemblage.

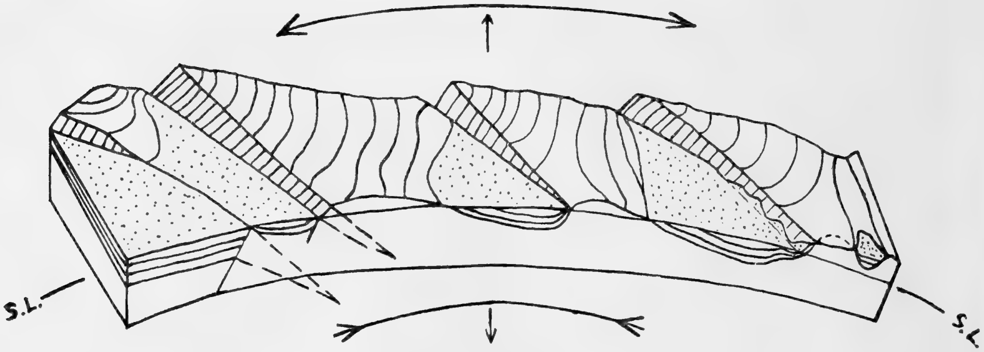
7. The upper part of this bryozoal limestone and clay stage contains the well-known Lower Miocene fauna with *Austrotrillina* and *Lepidocyclina* and associated smaller foraminifera constituting the third distinctive marine fauna of the basin.

The marine phase which transgresses as Port Willunga Beds over the margins of the Adelaide Basin can be recognized over large areas. Faunal correlations can be made between them, the Gambier Limestones and parts of the Torquay Group (formerly known as Janjukian). Palæontological work on these faunas and their correlations is now in progress. What is significant geologically is not the exact age of these beds in terms of the general stratigraphic time scale but the fact that the marine transgression does not appear to have reached all areas at the same time. In other words, it appears to be a progressive overlap affecting various fault-bounded or warped basement blocks at various times. At Mt. Gambier the exposed base of the Gambier Limestone resting unconformably with a nodule bed on the exposed paralic series may correspond with the base of the Port Willunga Beds where they overlie the Chinaman's Gully Beds, but elsewhere it may be older. On the Gellibrand River near Princetown in Victoria a phosphate deposit marks a break in deposition followed by strata which are slightly older than the first appearance of the Lower Miocene foraminiferal fauna (Parr, in Baker, 1944). On the Aire Coast the Calder River limestones and clays (Singleton, 1941, p. 75) are similarly transgressive. From the Nullarbor area complete sections are not yet available, but Lower Miocene limestones which are widespread overlie 110 feet of lignitic " lacustrine " strata near Pidinga (King, 1951). In the Murray Basin the base of the limestones overlying the paralic deposits previously assigned to the Oligocene is not likely to be an exact time-stratigraphic horizon.

8. After the deposition of these beds the entire area, highs as well as lows, is affected by regression and mild diastrophic movements. There is considerable movement on normal faults which have since become the major boundary faults of the Mount Lofty Range, and there is gentle folding movement in the basins following lines indicated by old faults. The subsiding areas in which greater thicknesses of sediment accumulated become now more definite synclines and the relatively rising areas with thinner sedimentary cover become anticlines. Erosion strips the sedimentary cover from the anticlinal cores and reduces the entire observable area to a peneplain. There is, however, no renewed lateritization.

The widespread Middle to Late Miocene regression and phase of slight movement which affected the Adelaide Basin has regional significance over the greater part of southern Australia, though possibly not in east Gippsland. Throughout the Murray Basin the Pliocene rests disconformably on Miocene, as it does at Hamilton in western Victoria. Some of the folding of the Tertiary may be older, as on the Aire Coast. We have seen that some is younger. But the regression appears to have been general, starting in Middle Miocene time, and deposition and subsequent removal before the Pliocene transgression of any great thickness of Middle or Upper Miocene is unlikely. The " Cheltenhamian " Upper Miocene may have been confined to the Port Phillip area and Gippsland.

9. Deposition takes place again in the Adelaide area on a peneplaned surface. It is marine in the vicinity of the present coast, grading into non-marine sands and gravels landward. The marine fauna indicates Pliocene age, but its position within the Pliocene is still undecided. In accordance with the concept of peneplanation the gravels consist of well-rounded quartz pebbles indicating transport from a distant and possibly preformed source. The Pliocene sea extended to Eyre Peninsula and possibly to the Nullarbor Plain and also through the Murray Basin.



Text-fig. 3.—Block diagram showing structural relations of basement and Tertiary cover in the area between Adelaide (left) and Myponga (right). Not to scale.

10. Movements continue, more or less along the old lines. The surface on which the Pliocene deposits rest subsides further along the boundary fault of the main Adelaide basin and in the vicinity of the axes of the pre-Pliocene synclines, and the anticlinal highs continue to rise. The faults which run in parallel curves from the Mt. Lofty Ranges southward and then westward towards the coast show near the coast either no displacement or a minimum amount of displacement. In the ranges where the uplifted pre-Pliocene surface is recognizable, it is displaced by these faults up to at least 600 feet. This type of hinge faulting requires compression near the coast, where gentle up- and down-warping is observed, and tension in the Ranges, where normal faulting occurs in a number of pronounced steps. To some extent the movement was rotational, following the curved structural trend from the Mt. Lofty Ranges towards Kangaroo Island. This concept explains the observed southward tilting of each of the blocks in the hills which was the basis for the hypothesis of tilted fault blocks. It accounts equally well for the observed stratigraphic and structural relations of the Tertiary formations in the coastal zone including the synclinal nature of the basins and the flexured transgressive contact at Sellick's Beach, which are contrary to the tilting hypothesis. A further advantage of the new concept is

that it eliminates the need for the postulated graben-type faulting of St. Vincent Gulf, for which there is no geological evidence.

The time of inception of the strong scarp-forming movements is marked by the appearance of the remarkable fanglomerate or outwash gravel and breccia which forms cliffs up to 200 feet high at the foot of the Willunga scarp at Sellick's Beach, resting on fossiliferous Pliocene without apparent break, and by scattered patches of boulder beds along the foothills. There is also evidence that the movement continues, in a less violent form, to the present day.

The ultimate deformations of the Tertiary rocks resulting from movements during and after the Tertiary, have not been studied elsewhere in so much detail as in South Australia. Complex fault patterns are now being revealed in south-western Victoria (Boutakoff, 1952), in the Port Phillip area and in Gippsland. Folding can be clearly seen on the east coast of Yorke Peninsula, where at Port Julia a large anticline in equivalents of the Port Willunga Beds shows dips of 8° on both flanks and at Meninie Hill south of Ardrossan, where another anticline exposes Blanche Point Marls dipping similarly north-east and south-west. Both anticlinal axes pitch south-eastward under St. Vincent Gulf. Anticlinal folding with dips of 10–20° is clearly seen east of Castle Cove on the Aire Coast (Victoria), and four anticlines are visible in 20 miles of coastline from Airey's Inlet to Torquay. This folding is comparable in intensity with that south of Adelaide, where three faulted anticlines occupy 24 miles of coastline. The recent account of the brown coals of Victoria by Thomas and Baragwanath (1949–1950) shows folding (Morwell anticline, Baragwanath anticline) and faulting in Gippsland. Post-Pliocene faulting on Eyre Peninsula was recently described by Miles (1952*a*). Tertiary and post-Tertiary folding, similar in different areas in amplitude and in the spacing of fold axes, is widespread, but there are also unfolded or very weakly folded Tertiary strata. There has been in the past some reluctance to admit the occurrence of " genuine " folding in the Tertiary. This should now be recognized and the significance of its distribution determined. There has also been a tendency to consider all disturbance of Tertiary strata as basically due to faulting and to refer the movements to the Kosciusko epoch. This term refers to post-Pliocene movements. Its application to the deformation of pre-Pliocene strata which may have occurred either during their deposition or in the Late Miocene is bound to confuse the record and should be discontinued. In the Adelaide area there were " Kosciusko " movements in the sense defined by Andrews (1910) and followed by David and Browne, but there were also earlier and later movements. The nature and significance of these movements and their relation to sedimentation will be the final topics in this discussion.

BASEMENT AND TERTIARY SEDIMENTARY COVER.

The relation of deformations of sedimentary rocks at the surface to movements of crystalline or metamorphic basement rocks at depth is one of the fundamental problems of geology. Obviously an area where contacts between pre-Cambrian or Cambrian rocks and Tertiary sediments are exposed over miles of coastal cliffs can provide valuable information for the discussion of this problem. While these investigations were in progress, the Presidential Address to the Geological Society of London, entitled " Foreland Folding ", by G. M. Lees, was published (Lees, 1952). This fundamentally important paper states the problem clearly. Lees, on the basis of his great experience and penetrating analysis, comes to the conclusion that " the cover of sedimentary rocks plays a passive role and accommodates itself to movements of the basement beneath " and that " a crystalline basement complex can flexure and form the cores of anticlines with, in some cases, little or no faulting ". He gives an example of compression in a flexured shield area in Nigeria where anticlines with basement cores were formed in a sedimentary basin, and concludes that in rift valleys compression is dominant. In the Gulf of Suez area " the basement is deformed in a pattern of anticlines and synclines, complicated by faults it is true, but nevertheless showing a behaviour very different from the rigid pattern of tilted fault-blocks usually ascribed to rift-valley tectonics ". In the sections described by Lees the sedimentary cover is about ten times thicker than in southern Australia. I do not think this affects the validity of the comparison. The Australian examples confirm the statements quoted here and add to the picture the important observation that Tertiary and post-Tertiary movements occurred on lines of weakness which, as Sprigg has shown, date back to the original deformation of the Adelaide Geosyncline, that is, to Palæozoic time. The persistent control of structural development by such lineaments was recently postulated in Victoria by Boutakoff (1952). We are at present unable to explain the apparent inactivity of these lineaments during the long span of Mesozoic time and the sudden resumption of activity at the beginning of the Tertiary. The results of recent work in the Leigh Creek Triassic coal basin (Parkin 1953) indicate folding of a similar nature to that in the Tertiary. It may well be that when detailed stratigraphic and structural studies are extended to other Mesozoic areas the periods of complete quiescence will be shortened and the varying intensity of movement may be found to reflect normal cycles.

We have answered the question of the nature of the Tertiary structure by stating that it indicates essentially a revival (or a continuation) of compressive stresses acting on old lines of weakness. The movement of the basement may be either flexuring or fracture, to which the sedimentary cover adjusts itself. What is the nature of the resulting sedimentation? Sedimentation over a large area is comparable with that of a continental terrace (Nullarbor, Gambier Sunklands, Gippsland), with inland extensions (Adelaide Basin, Murray Basin, Port Phillip Sunkland) which may be compared with intermontane basins as their structures conform at least in part with folded mountain zones. Both the continental terrace and the inland basins show unusual features which are due to the fact that their inception does not follow in the usual manner soon after the formation of the mountain zones on the continent. Theirs is not the relation of the Molasse and the attached Vienna and Pannonian Basins to the Alps, or of the Northern European basins to their Saxonic and Variscan background. Neither is it comparable to the history of the Atlantic and Gulf Coastal terrace of North America which commences in the Jurassic or Lower Cretaceous, not so very long after the Late Palæozoic folding. The long time during which the folded mountains were worn down, the Late Palæozoic and the Mesozoic, reduced the amount of terrigenous material available for sedimentation in the Tertiary. The only significant amounts of coarse clastics are found at the beginning, when much weathered material was available on the old eroded surface, and at the end when renewed uplift had formed a relief which was possibly somewhat more prominent than that seen to-day. It is interesting that the only really thick Tertiary section found, reaching in the Nelson bore a depth of over 7,000 feet, is thick in the Lower Tertiary portion, which corresponds probably only to the first paralic phase. Later sedimentation is starved of detrital terrigenous material, because of low relief on the continent. During Middle Tertiary time it is dominantly organic, with bryozoa as the main rock-building organisms. In the intermontane basins the foraminiferal plankton, which at that time could have been rock-forming (*Globigerina* marls), is poor owing to restricted access to the open ocean. The main contribution from the continent is clay, which often becomes glauconitic, and at an earlier stage silica which is used by sponges. Subsiding areas, on downfaulted blocks of the terrace and in downwarps in the basins, collect greater thicknesses of these sediments.

The area of Tertiary deposits in southern Australia is essentially a "mobile shelf" in the sense of Bubnoff, which makes it a miogeosyncline in Stille's terminology. These terms and others which could be equally well applied to the area, are useful for general orientation, but its peculiarities must not be overlooked under the cover of a convenient geotectonic label. They are firstly the intense fracturing of some areas, which follows old lineaments, the fact that apparently only the "hinge belt" of the basin is visible while its greater part is under the waters of the Southern Ocean, and secondly the poor supply of terrigenous sediment which is due to the enormous time lag between the last mountain building on the continent and the beginning of paralic sedimentation. These unusual conditions make the problem difficult, but they also make the study of Tertiary geology a worthwhile contribution both to the history of the continent and to fundamental geological knowledge.

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A NEW AMMONOID FROM THE EASTERN AUSTRALIAN PERMIAN PROVINCE.

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(Communicated by F. K. Rickwood.)

With Plate VII and two Text-figures.

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Abstract.—*Pseudogastrioceras pokolbinense,* n.sp., is described from the upper part (Farley Formation) of the Lower Marine Group of New South Wales. The evidence of this species points towards an Artinskian age of these beds.

Stratigraphical Occurrence.

Ammonoids are so rare in the Eastern Australian Permian province that every new find must be regarded as something of a sensation. The only previously described Permian ammonoid from eastern Australia is *Adrianites* (*Neocrimites*) *meridionalis* Teichert and Fletcher (1943) from the lower part (" Branxton Stage ") of the so-called " Upper Marine Group " of New South Wales. Two additional specimens of ammonoids have recently come to light during a reorganization of the palaeontological collections in the Geology Department of the University of Sydney, and I am greatly indebted to Messrs. F. K. Rickwood and P. J. Coleman for making these important finds available to me for study. The specimens which represent a new species of *Pseudogastrioceras*, here described as *P. pokolbinense*, were collected not later than in 1932.

The specimens come from micaceous sandstones of the Farley Formation, probably not more than a few hundred feet below the top of the " Lower Marine Group ".[1] The type locality is situated near the southern extremity of the structure known as Lochinvar Dome, only 17 miles south-west of the locality where *Adrianites* (*Neocrimites*) *meridionalis* was found on the east flank of the same structure (Fig. 1). Stratigraphically the two species are separated by the Greta Coal Measures, which are only 200 feet thick, but the exact vertical distances of the occurrences of the ammonoids in relation to the coal measures are unknown. The two species may, therefore, be several hundred feet, perhaps even more than 1,000 feet, apart stratigraphically.

For exact map references, the reader is referred to David (1907), and more particularly to the more recent work of L. J. Jones (1939). The latter has given a detailed description of the Greta Coal Measures of the Lochinvar Dome. The general stratigraphy of the area was described by Walkom in 1913, and the detailed sequence of the Lower Marine Group by Osborne (1949).

Significance for Correlation of New South Wales Permian.

A detailed comparison of *Pseudogastrioceras pokolbinense* (see below) with other species of the same genus suggests that its affinities are with Artinskian

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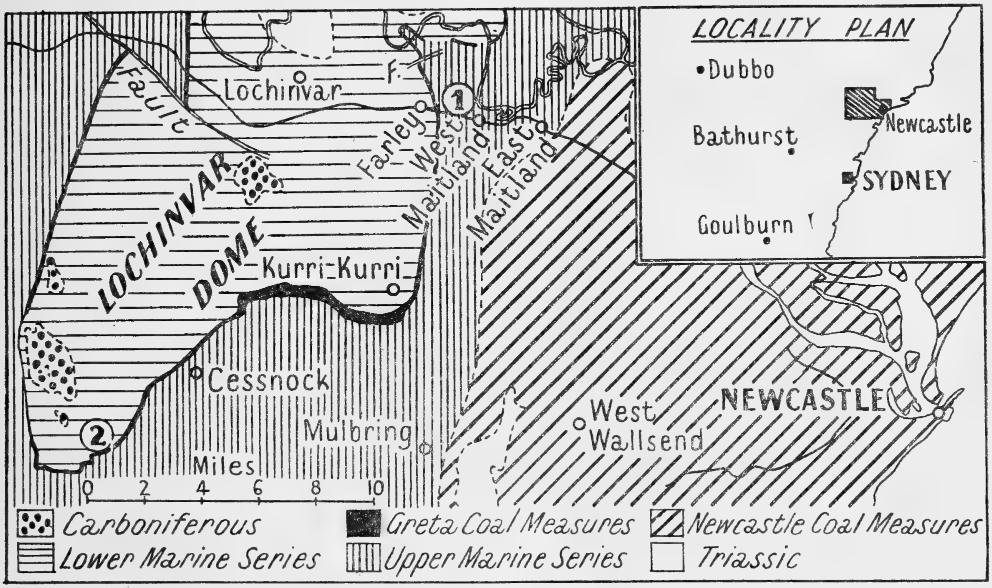
[1] Formerly this was known as " Lower Marine Series " and its subdivisions, which have formational rank, were called " Stages ". It is proposed to follow Voisey (1952) in his tentative reclassification of the Permian rocks of New South Wales.

and younger forms. *Pseudogastrioceras*, in the more restricted sense here applied, does not seem to appear before the Artinskian.

Pseudogastrioceras pokolbinense belongs to a group of ammonoids which presents taxonomic difficulties (see Miller and Furnish, 1940 ; Teichert and Glenister, 1952), because its members represent an almost completely intergrading morphological series ranging from openly umbilicate shells with depressed whorl section and strong transverse ribs on the umbilical wall (*Paragastrioceras*) to involute shells with compressed whorls and weak longutidinal ribs (*Altudoceras*, *Pseudogastrioceras*), and finally to keeled forms in which the ribs are practically restricted to the ventral and ventro-lateral regions (*Strigogoniatites*). It is possible that this morphological series also represents a succession in time.



Text-fig. 1.—Geological sketch-map of the country west of Newcastle, New South Wales. The numbers indicate the occurrences of (1) *Adrianites* (*Neocrimites*) *meridionalis* Teichert and Fletcher, (2) *Pseudogastrioceras pokolbinense* Teichert, n.sp.

Typical broad-whorled, evolute *Paragastrioceras* appears in the Sakmarian (Maximova and Ruzhencev, 1940 ; Ruzhencev, 1950), whereas compressed and involute *Pseudogastrioceras* and keeled *Strigogoniatites* are characteristic of the Sosio Limestone of Sicily and the Basleo beds of Timor. Intermediate forms represented by *Altudoceras* and more openly coiled species of *Pseudogastrioceras* are perhaps more typical of the Artinskian and equivalent beds, although they continue into younger strata. *Uraloceras*, which occurs both in the Sakmarian and Artinskian, is probably outside this lineage, because of the different course of the growth-lines and constrictions of its shell.

Pseudogastrioceras pokolbinense represents an advanced stage along the line from *Paragastrioceras* to *Pseudogastrioceras*. It is similar to typical *Pseudogastrioceras* in the absence of transverse ribs and in the compressed whorl section, but differs from advanced species of the genus in the weakness of the longitudinal ribs and the less involute coiling of the shell. On the whole, the morphological characters of *Pseudogastrioceras pokolbinense* agree most closely with those of a majority of Artinskian species of that genus. This trend of evidence is in harmony with that derived from the detailed study of the Upper Marine ammonoid, *Adrianites* (*Neocrimites*) *meridionalis* Teichert and Fletcher (1943) and both the upper part of the Lower Marine Group and the lower part of the Upper Marine Group are placed in the Artinskian.

There is now complete unanimity of opinion among Australian stratigraphers that all the rocks between the base of the Lower Marine Group and the top of the Newcastle Coal Measures, together with their equivalents elsewhere in Australia and in Tasmania, should be placed in the Permian System. In David's " Geology of the Commonwealth of Australia " (1951) the section below the Farley " Stage " is correlated with the Sakmarian, which most geologists include in the Permian.

In recent years several South American geologists have published correlation tables in which not only the Lower Marine Group, but also the Upper Marine Group of New South Wales are placed in the Carboniferous, sometimes rather low in that system. Thus Fossa-Mancini (1944) places the Lower Marine in the Viséan and the Upper Marine in the Moscovian, but his discussion of the significance of the occurrence of " *Agathiceras* " and of " *Paralegoceras* " in Australia is not in harmony with present knowledge. Frenguelli (1946) seems to accept the same correlations. More recently, Maack (1952), without discussing the matter in detail, places in the Upper Carboniferous the whole of the Lower Marine as well as the basal Upper Marine, that is, those beds in which, as we now know, Artinskian ammonoids occur.

DESCRIPTION.

Pseudogastrioceras Spath.

Pseudogastrioceras pokolbinense Teichert, n.sp.

(Plate VII, Figs. 1-4, Text-fig. 2.)

Description of Holotype.—The holotype is an internal cast of a complete specimen. It is discoidal and moderately evolute. About one and a half whorls are preserved. One-third of a whorl is taken up by the body chamber, which seems to be preserved in its entirety. The maximum diameter of the specimen is 57·5 mm. The umbilicus is 15 mm. wide. At the aperture the shell is 23·5 mm. wide and 27 mm. high and the height of the venter above that of the last whorl is 16 mm. The ventral side is evenly rounded and the flanks are slightly convex. The umbilical shoulder is narrowly rounded and smooth and the umbilical wall is steep. The shell is not preserved, but the surface of the internal cast, especially on the body chamber, shows fine lirae, spaced about half a millimetre apart. No umbilical ribs or nodes or other transverse ornamentations are present.

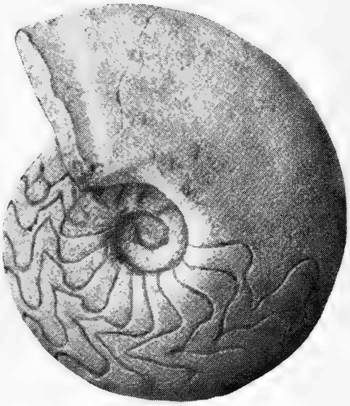
Quite close to the aperture the cast is very slightly constricted. The constriction is relatively broad (about 3 mm. wide) and quite shallow and the aperture is slightly flared. Across the flanks the course of the constriction is gently concave ; it runs across the ventro-lateral zone, swinging slightly forward and forming a shallow ventral lobe.

The septa are closely spaced. The mature sutures form a broad ventral lobe, divided by a large ventral saddle. Each of the two prongs of the ventral lobe is slightly wider than the adjoining lateral lobe, which is situated in the middle of the flanks. There is a small pointed umbilical lobe. The internal suture has not been studied, but is known from the paratype (see below).

Paratype.—The second specimen is a smaller fragment of a phragmocone of which nearly two whorls are preserved. Its maximum diameter is 27·3 mm. the width of the umbilicus 6·5 mm. At the adoral end the width of the conch is 14 mm. and the height of the whorl 12·5 mm. The surface of the shell is

1

2



3

4

smooth. Where the height of the whorl is 11 mm., the whorl is constricted by a narrow transverse groove whose course is slightly concave across the flanks and curved slightly backward across the venter.

Repository.—Holotype: No. 866. Paratype: No. 867. Both in the Department of Geology, University of Sydney.

Locality.—In Portion 74 of the Parish of Pokolbin, New South Wales. This locality is about three miles south-west of Cessnock and 29 miles almost due west of Newcastle.

Horizon.—Farley Formation of the Lower Marine Group. Judging from L. J. Jones' map (1939) the beds within Portion 74 should range from about 370 to about 950 feet below the top of the Lower Marine Series. The total thickness of the Farley " Stage " is given as 800 feet, so that the possibility cannot be altogether excluded that the specimen may have come from the top beds of the next lower Lochinvar " Stage ".

Text-fig. 2.—Suture of *Pseudogastrioceras pokolbinense*, n.sp. (The exact shape of the internal lateral lobes has not been accurately determined.)

Affinities.—The Australian species is very close to the genotype of *Pseudogastrioceras*, *P. abichianum* Möller (see Miller, 1944, pl. 44, figs. A and B). Since the umbilicus of *P. pokolbinense* is slightly wider, this species is somewhat intermediate between the genotype and *P. roadense* Böse. The latter was referred to *Altudoceras* by Teichert and Glenister (1952), but may with equal right be included in *Pseudogastrioceras* s. str. *Gastrioceras altudense* Böse (1917), on which Ruzhencev (1940) established the genus *Altudoceras*, has a still wider umbilicus than *Gastrioceras roadense* and it has prominent transverse ribs on the umbilical shoulders. The scope of *Altudoceras* is more or less identical with Böse's " Group of *Gastrioceras zitteli* ", which Plummer and Scott (1937) referred to *Paragastrioceras*. However, the only figures of *Gastrioceras zitteli* reproduced by them (pl. 22, figs. 10-11) are those of an immature individual taken from Gemmellaro's monograph (1887, pl. 6, figs. 22, 23). Mature specimens are almost three times as large and the last one and a half to two whorls lack ribs on the umbilical shoulders. Also the longitudinal ribs become strongest in the ventral and ventrolateral regions and almost disappear from the flanks. The venter becomes quite narrowly rounded and on the whole, mature specimens of *Gastrioceras zitteli* are quite similar to forms which Miller (1944) included in *Strigogoniatites* (e.g. *S. kingi* Miller). These conditions, previously overlooked, further emphasize the many transitions which connect all the " genera " concerned.

Pseudogastrioceras pokolbinense is undoubtedly quite close to the true *Pseudogastrioceras* end of this morphological series. Closely related species are *Pseudogastrioceras karpinskii* Frédérix and *P. suessi* Karpinsky, from the Artinskian of the Urals, from both of which it differs by a somewhat narrower umbilicus. *Pseudogastrioceras goochi* Teichert (1942) from the Permian of Western Australia is a much bigger species, has flat flanks, and its whorl-section is broadest near the umbilical shoulder.

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EXPLANATION OF PLATE VII.

Figs. 1-4.—*Pseudogastrioceras pokolbinense* Teichert, n.sp. 1-3. Lateral and apertural views of holotype (No. 866). 4. Lateral view of paratype (No. 867). All natural size.

ON THE INTERPRETATION OF CERTAIN LAPLACIAN OPERATOR FUNCTIONS.

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SUMMARY.

Assuming that the operator ∇ is defined by

$$\nabla^2 w(x, y) \equiv \frac{\partial^2 w(x, y)}{\partial x^2} + \frac{\partial^2 w(x, y)}{\partial y^2},$$

then expressions of the following type are determined :

$$\left[\frac{\sin z\nabla}{\nabla}\right] w(x, y) = \frac{1}{2\pi}\int_0^{2\pi}\int_0^z \frac{s w(x - is\cos\varphi,\, y - is\sin\varphi)}{(z^2 - s^2)^{\frac{1}{2}}} ds d\varphi,$$

$$J_0(z\nabla) w(x, y) = \frac{1}{2\pi}\int_0^{2\pi} w(x - iz\cos\varphi,\, y - iz\sin\varphi) d\varphi.$$

Section 7 is devoted to a brief discussion of the algebra of the operator ∇.

PREFACE.

In the determination of the solution of Laplace's equation

$$\frac{\partial^2\varphi}{\partial z^2} + \nabla^2\varphi = 0$$

$$\left(\text{where } \nabla^2 \equiv \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}\right),$$

and similar equations, especially the equation of elasticity, one of the most popular methods is to use the two-dimensional Fourier transformation (equations (1.5) and (1.6) of this paper). The use of this method demands that the functions considered should be small at infinity.

In particular, the adoption of this method immediately eliminates all those functions $\varphi(x, y)$ for which the equation

$$\nabla^{2n}\varphi(x, y) = 0 \qquad (n \text{ integral}) \quad \ldots\ldots\ldots\ldots\ldots \quad (\text{P.1})$$

holds.

We may proceed to solve the equations using the symbol ∇ as a differential operator. The use of this method demands that at every step the functions considered must be expressed in the form

$$\sum_{n=0}^{\infty} a_n \nabla^{2n} w(x, y), \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (\text{P.2})$$

where $w(x, y)$ is a suitably restricted function. The method will certainly not prevent discussion of functions which are solutions of equation (P.1). In fact, it will be seen that the ∇-method is particularly suited for the treatment of such functions. Section 7 of this paper presents some remarks on types of functions which may be introduced.

Now it is obvious that, in certain cases, a problem may be solved by the ∇-method and by the two-dimensional Fourier method. A means of identifying the results is necessary and this is provided by equation (1.11).

In this paper the author has determined some definite integral expressions for some of the more elementary expressions of the type (P.2).

I. INTRODUCTION.

If we consider the two-dimensional operator ∇ defined by

$$\nabla^2 \equiv \frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1.1)$$

we observe that Laplace's equation

$$\frac{\partial^2 \varphi}{\partial z^2}+\nabla^2\varphi=0$$

possesses formal solutions of the type

$$\varphi=\left[\frac{\sin z\nabla}{\nabla}\right]u(x, y)+[\cos z\nabla]w(x, y) \quad \ldots\ldots\ldots\ldots \quad (1.2)$$

where the symbolic expressions in square brackets are defined by the formal power series

$$\frac{\sin z\nabla}{\nabla} \equiv \sum_{n=0}^{\infty} \frac{(-1)^n z^{2n+1}\nabla^{2n}}{(2n+1)!} \quad \ldots\ldots\ldots\ldots \quad (1.3)$$

and

$$\cos z\nabla \equiv \sum_{n=0}^{\infty} \frac{(-1)^n z^{2n}\nabla^{2n}}{(2n)!}. \quad \ldots\ldots\ldots\ldots\ldots \quad (1.4)$$

In this paper, integral expressions are found for certain functions defined by $f(\nabla)w(x, y)$.

The methods of finding the results will involve the use of the two dimensional Fourier Transform defined in the form

$$F_2[w(x, y)] \equiv \bar{w}(\xi, \eta)=\frac{1}{2\pi}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} e^{i(\xi x+\eta y)}w(x, y)dxdy, \quad \ldots\ldots\ldots \quad (1.5)$$

which has the inverse transformation

$$F_2^{-1}[\bar{w}(\xi, \eta)] \equiv w(x, y)=\frac{1}{2\pi}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} e^{-i(\xi x+\eta y)}\bar{w}(\xi, \eta)d\xi d\eta. \quad \ldots\ldots \quad (1.6)$$

Corresponding to equation (1.5) we have the convolution formula

$$F_2^{-1}[\bar{f}(\xi, \eta)\bar{g}(\xi, \eta)]=\frac{1}{2\pi}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} f(x-x_1, y-y_1)g(x_1, y_1)dx_1dy_1 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1.7)$$

$$=\frac{1}{2\pi}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} f(x_1, y_1)g(x-x_1, y-y_1)dx_1dy_1.$$

Now if $w(x, y)=w(R)$ where $R^2=x^2+y^2$ (i.e. w is a radial function) then $\bar{w}(\xi, \eta)=\bar{w}(\rho)$ (where $\rho^2=\xi^2+\eta^2$) (i.e. $\bar{w}$ is also a radial function [B.C. p. 167] and in addition (1.5) and (1.6) reduce to Hankel Transforms of order zero. Thus

$$\bar{w}(\rho)=\int_0^{\infty} Rw(R)J_0(\rho R)dR \equiv H_0[w(R)] \quad \ldots\ldots\ldots\ldots \quad (1.8)$$

and

$$w(R)=\int_0^{\infty} \rho\bar{w}(\rho)J_0(\rho R)dR \equiv H_0^{-1}[\bar{w}(\rho)]. \quad \ldots\ldots\ldots\ldots \quad (1.9)$$

Assuming that $w(x, y)$ and its derivatives are suitably restricted, equation (1.5) gives

$$F_2[\nabla^2 w(x, y)] = -(\xi^2+\eta^2)\bar{w}(\xi.\eta) = -\rho^2\bar{w}(\xi, \eta),$$

or more generally, if

$$f(\nabla^2) \equiv \sum_{n=0}^{\infty} c_n \nabla^{2n},$$

then

$$F_2[f(\nabla^2)w(x, y)] = f(-\rho^2)\bar{w}(\xi, \eta) \quad \ldots\ldots\ldots\ldots \quad (1.10)$$

In this paper we will treat only those functions which may be expressed as a power series involving even powers of ∇, so equation (1.10) may be written as

$$F_2[g(\nabla)w(x, y)] = g(i\rho)\bar{w}(\xi, \eta) \quad \ldots\ldots\ldots\ldots\ldots \quad (1.11)$$

where $g(\nabla) \equiv f(\nabla^2)$,
i.e.

$$g(\nabla)w(x, y) \equiv F_2^{-1}[g(i\rho)F_2 w(x, y)] \quad \ldots\ldots \quad (1.12)$$

2. INTEGRAL EXPRESSIONS FOR $[(\sinh z\nabla)/\nabla]w(x, y)$ AND $[(\sin z\nabla)/\nabla]w(x, y)$.

Using equation (1.11) we obtain

$$F_2\left\{\left[\frac{\sinh z\nabla}{\nabla}\right]w(x, y)\right\} = \frac{\sin z\rho}{\rho}\bar{w}(\xi, \eta). \quad \ldots\ldots\ldots\ldots\ldots \quad (2.1)$$

Since $(\sin z\rho)/\rho$ is radial, equation (1.9) gives

$$F_2^{-1}\left[\frac{\sin z\rho}{\rho}\right] = \int_0^\infty J_0(R\rho)\sin z\rho d\rho = \begin{cases} (z^2-R^2)^{-\frac{1}{2}} & z>R \\ 0 & 0<z<R \end{cases} \quad \ldots\ldots \quad (2.2)$$

[W.B.F., p. 405.]

Now combining equations (2.1), (2.2) and the two-dimensional Fourier convolution theorem (equation (1.7)) we obtain the first part of

Theorem (2.1).

If (*a*) $F_2[w(x, y)]$
and (*b*) $[(\sinh z\nabla)/\nabla]w(x, y)$ exist,
then

$$\left[\frac{\sinh z\nabla}{\nabla}\right]w(x, y) = \frac{1}{2\pi}\int_A\int \frac{w(x-x_1, y-y_1)}{(z^2-x_1^2-y_1)^{\frac{1}{2}}}dx_1 dy_1 \quad \ldots\ldots\ldots \quad (2.3a)$$

$(z>0)$.

(A being the interior of a circle with centre the origin and radius z.)

$$= \frac{1}{2\pi}\int_0^{2\pi}\int_0^z \frac{sw(x-s\cos\varphi, y-s\sin\varphi)}{(z^2-s^2)^{\frac{1}{2}}}ds d\varphi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.3b)$$

$(z>0)$.

$$= \frac{z}{2\pi}\int_0^{2\pi}\int_0^1 \frac{sw(x-zs\cos\varphi, y-zs\sin\varphi)}{(1-s^2)^{\frac{1}{2}}}ds d\varphi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.3c)$$

(all real z).

Equation (2.3*b*) follows from equation (2.3*a*) by an obvious change of variable. Equation (2.3*c*) also follows by change of variable, but, in addition, obviously holds over the extended range of z.

We now proceed formally from (2.3*c*) and derive an integral expression for $[(\sin z\nabla)/\nabla]w(x, y)$ by replacing z by zi.

Stated fully, the new result is

Theorem (2.2).

If (*a*) $w(u, v)$ is analytic in both u and v in the region $h \geqq Im\, u \geqq -h$, $h \geqq Im\, v \geqq -h$, where $h > |z|$

and (*b*) $w(u, v) \to 0$ uniformly, as $Re\, u$ and $Re\, v \to \pm\infty$ in such a way that $F_2[w(x+ix_1, y+iy_1)]$ exists (absolutely) for $0 \leqq |x_1| < h$ and $0 \leqq |y_1| < h$

then

$$\left[\frac{\sin z\nabla}{\nabla}\right]w(x, y) = \frac{z}{2\pi}\int_0^{2\pi}\int_0^1 \frac{sw(x-izs\cos\varphi,\ y-izs\sin\varphi)}{(1-s^2)^{\frac{1}{2}}}dsd\varphi \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.4a)$$

$$= \frac{1}{2\pi}\int_0^{2\pi}\int_0^z \frac{sw(x-is\cos\varphi,\ y-is\sin\varphi)}{(z^2-s^2)^{\frac{1}{2}}}dsd\varphi \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.4b)$$

for $z > 0$.

$$= \frac{1}{2\pi}\int_A\int \frac{w(x-ix_1,\ y-iy_1)}{(z^2-x_1^2-y_1^2)^{\frac{1}{2}}}dx_1dy_1 \qquad \ldots\ldots\ldots\ldots \quad (2.4c)$$

for $z > 0$.

(where A is the area described after equation (2.3*a*)).

Clearly equations (2.4*b*) and (2.4*c*) are obtainable from equation (2.4*a*) by change of variable.

Proof.—Since $F_2^{-1}[(\sinh z\rho)/\rho]$ does not exist, the results cannot be obtained directly from the convolution theorem.

Proceeding from the right side of equation (2.4*c*):

$$L \equiv F_2\left[\frac{1}{2\pi}\int_A\int \frac{w(x-ix_1,\ y-iy_1)}{[z^2-x_1^2-y_1^2]^{\frac{1}{2}}}dx_1dy_1\right]$$

$$= \frac{1}{4\pi^2}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}\int_A\int \frac{w(x-ix_1,\ y-iy_1)}{[z^2-x_1^2-y_1^2]^{\frac{1}{2}}}e^{i(\xi x+\eta y)}dx_1dy_1dxdy$$

$$= \frac{1}{4\pi^2}\int_A\int\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} \frac{w(x-ix_1,\ y-iy_1)}{[z^2-x_1^2-y_1^2]^{\frac{1}{2}}}e^{i(\xi x+\eta y)}dxdydx_1dy_1$$

(the interchange of the order of integration being justified by absolute convergence),

$$= \frac{1}{4\pi^2}\int_A\int \frac{e^{-(\xi x_1+\eta y_1)}}{[z^2-x_1^2-y_1^2]^{\frac{1}{2}}}dx_1dy_1\int_{-\infty-iy_1}^{+\infty-iy_1}\int_{-\infty-ix_1}^{+\infty-ix_1} w(u, v)e^{i(\xi u+\eta v)}dudv$$

(by change of variable $u = x-ix_1$ and $v = y-iy_1$).

Since w is analytic in the region quoted in the hypothesis, we can change the path of integration to the real axes.

$$L = \frac{1}{4\pi^2}\int_A\int \frac{e^{-(\xi x_1+\eta y_1)}}{[z^2-x_1^2-y_1^2]^{\frac{1}{2}}}dx_1dy_1\left[\lim_{p,\, q,\, r,\, s\to+\infty}\left(\int_{-p-iy_1}^{-p} + \int_{-p}^{q} + \int_{q}^{q-iy_1}\right)\right]\cdot$$

$$\left(\int_{-r-ix_1}^{-r} + \int_{-r}^{s} + \int_{s}^{s-ix_1}\right)w(u, v)e^{i(\xi u+\eta v)}dudv.$$

Since $w(u, v) \to 0$ as $Re\, u$ and $Re\, v \to \pm\infty$, the first and last integrals in the curved brackets vanish so

$$L=\frac{1}{4\pi^2}\int_A\int \frac{e^{-(\xi x_1+\eta y_1)}}{[z^2-x_1^2-y_1^2]^{\frac{1}{2}}}dx_1dy_1\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} w(u, v)e^{i(\xi u+\eta v)}dudv$$

$$=\frac{\bar{w}(\xi, \eta)}{2\pi}\int_0^z\int_0^{2\pi}\frac{te^{-\rho t\cos(\theta+\alpha)}}{(z^2-t^2)^{\frac{1}{2}}}d\theta dt$$

(by an obvious change of variable, where $\tan\alpha=-\eta/\xi$).

Then by a change of origin in the θ-integral, we obtain

$$L=\frac{\bar{w}(\xi, \eta)}{2\pi}\int_0^z\int_0^{2\pi}\frac{te^{-\rho t\cos\theta}}{(z^2-t^2)^{\frac{1}{2}}}d\theta dt$$

$$=\bar{w}(\xi, \eta)\int_0^z\frac{tI_0(\rho t)}{(z^2-t^2)^{\frac{1}{2}}}dt \tag{2.5}$$

(by [W.B.F., p. 79] where $I_0(t)$ is the Bessel function of the first kind with imaginary argument).

Using the series expansion for the Bessel function

$$L=\bar{w}(\xi, \eta)\int_0^z\sum_{n=0}^{\infty}\frac{\rho^{2n}t^{2n+1}}{(z^2-t^2)^{\frac{1}{2}}\{\Gamma(n+1)\}^2 2^{2n}}dt$$

$$=\bar{w}(\xi, \eta)\sum_{n=0}^{\infty}\frac{\rho^{2n}z^{2n+1}}{2^{2n}\{\Gamma(n+1)\}^2}\int_0^{\frac{\pi}{2}}\sin^{2n+1}\beta d\beta$$

(by the substitution $t=z\sin\beta$).

By using the well-known formula for the integral

$$L=\bar{w}(\xi, \eta)\sum_{n=0}^{\infty}\frac{\rho^{2n}z^{2n+1}}{2^{2n}\{\Gamma(n+1)\}^2}\cdot\frac{2^{2n}\{\Gamma(n+1)\}^2}{\Gamma(2n+2)}$$

$$=\bar{w}(\xi, \eta)\sum_{n=0}^{\infty}\left(\frac{z^{2n+1}\rho^{2n+1}}{(2n+1)!}\right)\frac{1}{\rho}$$

$$=\frac{\sinh z\rho}{\rho}\bar{w}(\xi, \eta). \tag{2.6}$$

Finally, our assumptions and equation (1.11) together with equation (2.6) show that $[(\sin z\nabla)/\nabla]w(x, y)$ exists and equals the right side of (2.4*c*) which we aimed to prove.

3. INTEGRAL EXPRESSIONS FOR $[\cosh z\nabla]w(x, y)$ AND $[\cos z\nabla]w(x, y)$.

By integrating the right side of (2.3*b*) by parts we obtain

$$\left[\frac{\sinh z\nabla}{\nabla}\right]w(x, y)=\frac{1}{2\pi}\int_0^{2\pi}[-(z^2-s^2)^{\frac{1}{2}}w(x-s\cos\varphi, y-s\sin\varphi)]_0^z d\varphi$$

$$+\frac{1}{2\pi}\int_0^{2\pi}\int_0^z(z^2-s^2)^{\frac{1}{2}}\frac{\partial w(x-s\cos\varphi, y-s\sin\varphi)}{\partial s}dsd\varphi$$

$$=zw(x, y)+\frac{1}{2\pi}\int_0^{2\pi}\int_0^z(z^2-s^2)^{\frac{1}{2}}\frac{\partial w(x-s\cos\varphi, y-s\sin\varphi)}{\partial s}dsd\varphi. \tag{3.1}$$

Now from the series definition we observe that

$$\frac{\partial}{\partial z}\left[\left(\frac{\sin z\nabla}{\nabla}\right)w(x, y)\right]=(\cos z\nabla)w(x, y) \tag{3.2}$$

The boundedness and differentiability of $w(x, y)$ allows us to differentiate equation (3.1)to obtain

Theorem (3.1).

If (*a*) $F_2[w(x, y)]$
and (*b*) $[\cosh z\nabla\,]w(x, y)$ exist,
then

$$[\cosh z\nabla\,]w(x, y)$$

$$=w(x, y)+\frac{1}{2\pi}\int_0^{2\pi}\int_0^z\frac{z}{(z^2-s^2)^{\frac{1}{2}}}\;\frac{\partial w(x-s\cos\varphi,\, y-s\sin\varphi)}{\partial s}\,ds\,d\varphi \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\quad (3.3a)$$

$(z>0)$.

$$=w(x, y)+\frac{1}{2\pi}\int_0^{2\pi}\int_0^1\frac{1}{(1-s^2)^{\frac{1}{2}}}\cdot\frac{\partial w(x-zs\cos\varphi,\, y-zs\sin\varphi)}{\partial s}\,ds\,d\varphi \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\quad (3.3b)$$

(all real z).

Proceeding from equation (2.3*b*) analogously we have

Theorem (3.2).

Under the assumptions of Theorem (2.2)

$$[\cos z\nabla\,]w(x, y)$$

$$=w(x, y)+\frac{1}{2\pi}\int_0^{2\pi}\int_0^z\frac{z}{(z^2-s^2)^{\frac{1}{2}}}\;\frac{\partial w(x-is\cos\varphi,\, y-is\sin\varphi)}{\partial s}\,ds\,d\varphi \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\quad (3.4a)$$

$(z>0)$.

$$=w(x, y)+\frac{1}{2\pi}\int_0^{2\pi}\int_0^1\frac{1}{(1-s^2)^{\frac{1}{2}}}\;\frac{\partial w(x-izs\cos\varphi,\, y-izs\sin\varphi)}{\partial s}\,ds\,d\varphi \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\quad (3.4b)$$

(all real z).

4. REMARKS ON THE RESULTS OBTAINED IN SECTIONS 2 AND 3.

The equation of Theorems (2.1), (2.2), (3.1) and (3.2) have been derived with the assumption that $w(x, y)$ has a two-dimensional Fourier transform. It will be seen that this is not necessary.

We will assume that $w(u, v)$ is an analytic function in the neighbourhood of $u=x$ and $v=y$. That is to say that for certain positive P and Q

$$w(x+a, y+b)=\sum_{n=0}^{\infty}\frac{1}{n!}\left(a\frac{\partial}{\partial x}+b\frac{\partial}{\partial y}\right)^n w(x, y) \quad\ldots\ldots\ldots\ldots\quad (4.1)$$

for all a and b so that $|a|<P$ and $|b|<Q$.

We will assume that

$$|z|<\min(P, Q). \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\quad (4.2)$$

So examining equation (3.4*a*), we proceed :

$$M\equiv\int_0^{2\pi}\int_0^1\frac{ds\,d\varphi}{(1-s^2)^{\frac{1}{2}}}\cdot\frac{\partial w(x-izs\cos\varphi,\, y-izs\sin\varphi)}{\partial s}$$

$$=\int_0^{2\pi}\int_0^1\frac{ds\,d\varphi}{(1-s^2)^{\frac{1}{2}}}\cdot\frac{\partial}{\partial s}\sum_{n=0}^{\infty}\sum_{p=0}^{n}\frac{\cos^p\varphi\,\sin^{n-p}\varphi}{\Gamma(p+1)\Gamma(n-p+1)}\,(-izs)^n\,\frac{\partial^n}{\partial x^n\partial y^{n-p}}w(x, y)$$

$$=\sum_{n=1}^{\infty}\sum_{p=0}^{n}\frac{(-1)^n 8nz^{2n}}{\Gamma(2p+1)\Gamma(2n-2p+1)}\;\frac{\partial^{2n}}{\partial x^{2p}\partial y^{2n-2p}}w(x, y)\int_0^1 s^{2n-1}(1-s^2)^{-\frac{1}{2}}ds$$

where the order of integration and summation has been inverted (the convergence being uniform). In the integration with regard to φ it has been observed that terms involving odd powers of $\sin\varphi$ or of $\cos\varphi$ disappear after integration.

After simplification we have

$$\begin{aligned} M &= \sum_{n=1}^{\infty}\sum_{p=0}^{n}(-1)^n z^{2n}\frac{2\pi\Gamma(n+1)}{\Gamma(2n+1)\Gamma(p+1)\Gamma(n-p+1)}\cdot\frac{\partial^{2n}}{\partial x^{2p}\partial y^{2n-2p}}w(x,y)\\ &=2\pi\sum_{n=1}^{\infty}(-1)^n\frac{z^{2n}}{(2n)!}\sum_{p=0}^{n}\frac{\Gamma(n+1)}{\Gamma(p+1)\Gamma(n-p+1)}\cdot\frac{\partial^{2n}}{\partial x^{2p}\partial y^{2n-2p}}w(x,y)\\ &=2\pi\sum_{n=1}^{\infty}(-1)^n\frac{z^{2n}}{(2n)!}\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}\right)^n w(x,y)\\ &=2\pi\{[\cos z\nabla\,]w(x,y)-w(x,y)\}. \end{aligned}$$

So

$$[\cos z\nabla\,]w(x,y)=w(x,y)+\frac{1}{2\pi}M$$

as required.

The other results may be treated similarly, so

Theorem (4.1).

If (*a*) $w(x+a,\ y+b)=\sum_{n=0}^{\infty}\frac{1}{n!}\left(a\frac{\partial}{\partial x}+b\frac{\partial}{\partial y}\right)^n w(x,y)$

for $|a|<P$ and $|b|<Q$,

and (*b*) $|z|<\min(P,Q)$,

then the conclusions of Theorems (2.1), (2.2), (3.1) and (3.2) hold.

5. INTEGRAL EXPRESSIONS FOR $[I_0(z\nabla\,)]w(x,y)$ AND $[J_0(z\nabla\,)]w(x,y)$.

An alternative method of deriving formulae of the type we have been considering is to use the integral formulae for $[I_0(z\nabla\,)]w(x,y)$ and $[J_0(z\nabla\,)]w(x,y)$ where again $I_0(t)$ and $J_0(t)$ are the Bessel functions discussed in [W.B.F., pp. 79 and 48] respectively.

If we write $\delta(t)$ for the Dirac impulse function we have

$$\int_0^{\infty}\left[\frac{\delta(z-R)}{R}\right]J_0(\rho R)R\,dR=\delta_0(\rho z).$$

Then referring back to equations (1.8) and (1.9) we obtain formally

$$\begin{aligned} F_2^{-1}[J_0(\rho z)]&=H_0^{-1}[J_0(\rho z)]\\ &=\frac{\delta(z-R)}{R}. \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.1) \end{aligned}$$

From equation (1.9)

$$F_2\{[I_0(z\nabla\,)]w(x,y)\}=J_0(z\rho)\overline{w}(\xi,\eta).$$

Thus from the convolution theorem

$$\begin{aligned} [I_0(z\nabla\,)]w(x,y)&=\frac{1}{2\pi}\int_0^{\infty}\int_0^{2\pi}w(x-R'\cos\varphi,\ y-R'\sin\varphi)\left\{\frac{\delta(z-R')}{R'}\right\}R'\,d\varphi\,dR'\\ &=\frac{1}{2\pi}\int_0^{2\pi}w(x-z\cos\varphi,\ y-z\sin\varphi)\,d\varphi. \quad\ldots\ldots\ldots\ldots (5.2) \end{aligned}$$

Replacing z by zi in the equation (5.2) we have

$$[J_0(z\nabla\,)]w(x,y)=\frac{1}{2\pi}\int_0^{2\pi}w(x-iz\cos\varphi,\ y-iz\sin\varphi)\,d\varphi \quad\ldots\ldots (5.3)$$

As in section 4, we may prove equations (5.2) and (5.3) by using the Taylor expansion and obtain

Theorem (5.1).

If $w(u, v)$ satisfies the conditions of Theorem (4.1), then equations (5.2) and (5.3) hold.

Now the formula

$$\frac{\sin zk}{k}=\int_0^z \frac{sJ_0(sk)}{(z^2-s^2)^{\frac{1}{2}}}ds \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (5.4)$$

where k is a constant can be easily obtained. So formally

$$\left[\frac{\sin z\nabla}{\nabla}\right]w(x, y)=\int_0^z \frac{s}{(z^2-s^2)^{\frac{1}{2}}}[J_0(s\nabla)]w(x, y)ds$$

$$=\int_0^z \frac{sds}{(z^2-s^2)^{\frac{1}{2}}}\int_0^{2\pi} w(x-is\cos\varphi, y-is\sin\varphi)d\varphi$$

as previously obtained.

Considering (5.4) as an identity in power series we may write

$$\frac{\sin z\nabla}{\nabla}\equiv\int_0^z \frac{sJ_0(s\nabla)}{(z^2-s^2)^{\frac{1}{2}}}ds.$$

Equations (5.2) and (5.3) are extremely important theorems in the development of the theory of the ∇-operator.

6. THE PREVIOUS RESULTS SPECIALISED FOR RADIAL FUNCTIONS AND HANKEL TRANSFORMS OF ORDER ZERO.

If we assume that $w(x, y)$ is radial, the formulae we have derived may be simplified. If the Hankel transform exists, then the result may be expressed in this form.

$$\left[\frac{\sinh z\nabla}{\nabla}\right]w(R)=\frac{z}{2\pi}\int_0^{2\pi}\int_0^1 \frac{rw(R_1)drd\theta}{(1-r^2)^{\frac{1}{2}}}$$

$$\left\{=H_0^{-1}\left[\frac{\sin z\rho}{\rho}\,.\,\overline{w}(\rho)\right]\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2.3r)$$

$$\text{with } R_1^2=R^2+z^2r^2-2Rzr\cos\theta. \quad \ldots\ldots\ldots\ldots \quad (A)$$

$$\left[\frac{\sin z\nabla}{\nabla}\right]w(R)=\frac{z}{2\pi}\int_0^{2\pi}\int_0^1 \frac{rw(R_2)drd\theta}{(1-r^2)^{\frac{1}{2}}}$$

$$\left\{=H_0^{-1}\left[\frac{\sinh z\rho}{\rho}\overline{w}(\rho)\right]\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2.4r)$$

$$\text{with } R_2^2=R^2-z^2r^2-2iRzr\cos\theta. \quad \ldots\ldots\ldots\ldots \quad (B)$$

$$[\cosh z\nabla]w(R)=w(R)+\frac{1}{2\pi}\int_0^{2\pi}\int_0^1 \frac{1}{(1-r^2)^{\frac{1}{2}}}\,\frac{\partial w(R_1)}{\partial r}drd\theta$$

$$\{=H_0^{-1}[\cos z\rho\,.\,\overline{w}(\rho)]\}. \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.1r)$$

$$[\cos z\nabla]w(R)=w(R)+\frac{1}{2\pi}\int_0^{2\pi}\int_0^1 \frac{1}{(1-r^2)^{\frac{1}{2}}}\,\frac{\partial w(R_2)}{\partial r}drd\theta$$

$$\{=H_0^{-1}[\cosh z\rho.\overline{w}(\rho)]\}. \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.2r)$$

$$[I_0(z\nabla)]w(R) = \frac{1}{2\pi}\int_0^{2\pi} w(R_3)d\theta$$

$$\{=H_0^{-1}[J_0(z\rho)\overline{w}(\rho)]\} \tag{5.2r}$$

$$\text{with } R_3^2 = R^2+z^2-2Rz\cos\theta. \tag{C}$$

$$[J_0(z\nabla)]w(R) = \frac{1}{2\pi}\int_0^{2\pi} w(R_4)d\theta \tag{5.3r}$$

$$\{=H_0^{-1}[I_0(z\rho)\,.\,\overline{w}(\rho)]\}$$

$$\text{with } R_4^2 = R^2-z^2-2iRz\cos\theta. \tag{D}$$

It is clear that equations (2.3r) and (formally) (5.2r) are direct consequences of the Hankel Convolution formula

$$H_0^{-1}[\overline{f}(\rho)\overline{g}(\rho)] = \frac{1}{2\pi}\int_0^{2\pi}\int_0^{\infty} rf(R_0)g(r)drd\theta$$

$$= \frac{1}{2\pi}\int_0^{2\pi}\int_0^{\infty} rf(r)g(R_0)drd\theta \tag{6.1}$$

$$\text{with } R_0^2 = R^2+r^2-2Rr\cos\theta$$

These last formulae may be derived easily from formulae (1.7) by change of variable.

7. Some Remarks on the Algebra of the Operator ∇.

Suppose that we have two series

$$f(\nabla) \equiv \sum_{n=0}^{\infty} a_n \nabla^{2n} \tag{7.1}$$

and

$$g(\nabla) \equiv \sum_{n=0}^{\infty} b_n \nabla^{2n} \tag{7.2}$$

and a set of functions $w(x, y)$ which are to act as operands.

In order to obtain the unique product

$$f(\nabla)[g(\nabla)w(x, y)] = g(\nabla)[f(\nabla)w(x, y)] \tag{7.3a}$$

$$= [g(\nabla)f(\nabla)]w(x, y) \tag{7.3b}$$

$$= \left[\sum_{n=0}^{\infty}\left\{\sum_{p=0}^{n} a_p b_{n-p}\right\}\nabla^{2n}\right]w(x, y) \tag{7.3c}$$

we will assume the sufficient condition: the double series

$$\sum_{n,p} a_n b_p \nabla^{2n+2p} w(x, y) \tag{7.4}$$

is absolutely convergent. *This condition will be assumed to hold whenever we write* $f(\nabla)g(\nabla)w(x, y)$.

Now in order to obtain a meaning for $[f(\nabla)]^{-1}$ we will proceed as follows: If we assume that we are given

$$f(\nabla) \equiv \sum_{n=0}^{\infty} a_n \nabla^{2n},\ a_0 \neq 0 \tag{7.5}$$

then we can derive the unique power series

$$g(\nabla) \equiv \sum_{n=0}^{\infty} b_n \nabla^{2n},\ b_0 = \frac{1}{a_0} \tag{7.6}$$

with the property

$$\sum_{p=0}^{n} a_p b_{n-p} = 0, \quad n > 0. \qquad \ldots\ldots \quad (7.7)$$

Thus if the double series (7.4) is absolutely convergent then

$$[f(\nabla)g(\nabla)]w(x, y) = w(x, y) \qquad \ldots\ldots \quad (7.8)$$

or for the set of functions $w(x, y)$

$$f(\nabla)g(\nabla) = 1. \qquad \ldots\ldots \quad (7.9)$$

Thus we define

Definition (7.1).

If
$$f(\nabla) \equiv \sum_{n=0}^{\infty} a_n \nabla^{2n}, \quad a_0 \neq 0$$

and
$$g(\nabla) \equiv \sum_{n=0}^{\infty} b_n \nabla^{2n}, \quad b_0 = \frac{1}{a_0}$$

where
$$\sum_{p=0}^{n} a_p b_{n-p} = 0, \qquad n \neq 0$$

then $g(\nabla) \equiv [f(\nabla)]^{-1}$ is defined to be the inverse of $f(\nabla)$.

As a simple example of an inverse as defined above we see that

$$(1 - \nabla^2)^{-1} \equiv \sum_{n=0}^{\infty} \nabla^{2n}. \qquad \ldots\ldots \quad (7.10)$$

This inverse can be used to demonstrate the necessity of examining the operand before applying the definition (7.1).

If the operand is e^x

then
$$(1 - \nabla^2)e^x = 0,$$
$$\left(\sum_{n=0}^{\infty} \nabla^{2n}\right)[(1 - \nabla^2)e^x] = 0 \neq e^x.$$

But

$$(1 - \nabla^2)e^{\frac{1}{2}x} = \frac{3}{4}e^{\frac{1}{2}x}$$

$$\left(\sum_{n=0}^{\infty} \nabla^{2n}\right)(1 - \nabla^2)e^{\frac{1}{2}x} = \left(\sum_{n=0}^{\infty} \nabla^{2n}\right)\frac{3}{4}e^{\frac{1}{2}x}$$
$$= \frac{3}{4}\left(1 + \frac{1}{4} + \frac{1}{16} + \ldots\right)e^{\frac{1}{2}x}$$
$$= e^{\frac{1}{2}x}.$$

Now it is clear that in special cases there may be alternative power series which could act as inverses. For example, if $w(x, y)$ is any biharmonic function then

$$1 + \nabla^2 + \sum_{n=2}^{\infty} b_n \nabla^{2n}$$

for arbitrary b_n is an inverse for $1 - \nabla^2$.

We may then state

Definition (7.2).

If
$$g(\nabla)f(\nabla)w(x, y) = [f(\nabla)]^{-1}f(\nabla)w(x, y) = w(x, y) \qquad \ldots\ldots \quad (7.11)$$

for a set of functions $w(x, y)$ then $g(\nabla)$ is defined to be a particular inverse of $f(\nabla)$ for the set of functions $w(x, y)$.

As a result of the foregoing analysis we are able to solve

$$f(\nabla)w(x, y)=h(x, y) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (7.12)$$

where $f(\nabla)$ is a function of the type (7.5). We have simply

$$[f(\nabla)]^{-1}f(\nabla)w(x, y)=[f(\nabla)]^{-1}h(x, y)$$
$$w(x, y)=[f(\nabla)]^{-1}h(x, y)$$

or we may replace $[f(\nabla)]^{-1}$ by any other particular inverse.

It is to be emphasised that if $a_0=0$, then $f(\nabla)$ does not possess an inverse, in the sense here defined.

We now proceed to derive formally some integral formulae.

Taking $K_0(t)$ to be the Bessel function of the second kind with imaginary argument and understanding that the integral represents a power series, we have

$$\begin{aligned}\int_0^\infty sK_0(as)I_0(bs\nabla)ds &= \sum_{n=0}^{\infty}\int_0^\infty sK_0(as)\frac{s^{2n}b^{2n}}{(n!)^2 2^{2n}}\nabla^{2n}ds, \quad a>0\\ &=\sum_{n=0}^{\infty}\frac{b^{2n}\nabla^{2n}}{(n!)^2 2^{2n}}\int_0^\infty K_0(as)s^{2n+1}ds\\ &=\sum_{n=0}^{\infty}\frac{b^{2n}\nabla^{2n}}{(n!)^2 2^{2n}}\cdot\frac{2^{2n}(n!)^2}{a^{2n+2}}\end{aligned}$$

[W.B.F., p. 388]

$$\left.\begin{aligned}&=\frac{1}{a^2}\sum_{n=0}^{\infty}\frac{b^{2n}}{a^{2n}}\nabla^{2n}\\ &=(a^2-b^2\nabla^2)^{-1}.\end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (7.13)$$

Similarly,

$$\int_0^\infty sK_0(as)J_0(bs\nabla)ds=(a^2+b^2\nabla^2)^{-1}. \quad \ldots\ldots\ldots\ldots \quad (7.14)$$

Thus using the results of section 5 we obtain

$$[a^2-b^2\nabla^2]^{-1}w(x, y)\frac{1}{2\pi}\int_0^\infty\int_0^{2\pi} sK_0(as)w(x-sb\cos\varphi,\ y-sb\sin\varphi)d\varphi ds \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (7.15)$$

$$[a^2+b^2\nabla^2]^{-1}w(x, y)=\frac{1}{2\pi}\int_0^\infty\int_0^{2\pi} sK_0(as)w(x-isb\cos\varphi,\ y-isb\sin\varphi)d\varphi ds. \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (7.16)$$

Now from [W.W., p. 135] we obtain

$$\begin{aligned}u\operatorname{cosec} zu &=\frac{1}{z}+\sum_{n=-\infty}^{\infty}{}'\left(\frac{u}{uz-n\pi}+\frac{u}{n\pi}\right)(-1)^n\\ &=\frac{1}{z}+\sum_{n=1}^{\infty}\frac{(-1)^n 2u^2 z}{u^2z^2-n^2\pi^2}\end{aligned} \quad \ldots\ldots\ldots\ldots \quad (7.17)$$

where Σ' indicates that the term in $n=0$ is omitted from the sum.

Considered as a function of u, the series (7.17) can be rearranged to give a power series. If now u is replaced by ∇ we have the formal inverse of $(\sin z\nabla)/\nabla$. However, the form of the series in equation (7.17) allows us to proceed to

$$\nabla\operatorname{cosec} z\nabla=\frac{1}{z}+\sum_{n=1}^{\infty}2z\nabla^2(-1)^{n+1}\int_0^\infty sK_0(n\pi s)I_0(sz\nabla)ds \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (7.18)$$

i.e.

$$[\nabla \operatorname{cosec} z\nabla\,]w(x, y)=\frac{1}{z}w(x, y)$$

$$+\frac{z\nabla^2}{\pi}\sum_{n=1}^{\infty}(-1)^{n+1}\int_0^{\infty}\int_0^{2\pi} sK_0(n\pi s)w(x-sz\cos\varphi,\, y-sz\sin\varphi)d\varphi ds. \qquad \ldots\ldots (7.19)$$

An interesting form occurs when we adopt the same procedure for

$$(\sin z\nabla\,)/(\sin c\nabla\,),\ |z|<c.$$

From the same section of [W.W.] we obtain

$$\frac{\sin zu}{\sin cu}=\frac{z}{c}+\sum_{n=-\infty}^{+\infty}{}'\left\{\frac{1}{u-\dfrac{n\pi}{c}}+\frac{1}{\dfrac{n\pi}{c}}\right\}(-1)^n\sin\frac{n\pi z}{c} \qquad |z|<c$$

$$=\frac{z}{c}+\sum_{n=1}^{\infty}(-1)^n\left\{\frac{2n\pi c}{c^2u^2-n^2\pi^2}+\frac{2c}{n\pi}\right\}\sin\frac{n\pi z}{c}.$$

So again replacing u by ∇ and using the result (7.13) we obtain

$$\frac{\sin z\nabla}{\sin c\nabla}=\frac{z}{c}+\sum_{n=1}^{\infty}(-1)^{n+1}\left[2n\pi c\int_0^{\infty}sK_0(n\pi s)I_0(cs\nabla\,)ds-\frac{2c}{n\pi}\right]\sin\frac{n\pi z}{c} \qquad \ldots\ldots (7.20)$$

Putting the operand in this result, we find the Fourier series

$$\left[\frac{\sin z\nabla}{\sin c\nabla}\right]w(x, y)=\frac{z}{c}w(x, y)$$

$$+c\sum_{n=1}^{\infty}(-1)^{n+1}\left[n\int_0^{\infty}\int_0^{2\pi}sK_0(n\pi s)w(x-cs\cos\varphi,\, y-cs\sin\varphi)d\varphi ds-\frac{2w(x, y)}{n\pi}\right]$$

$$\sin\frac{n\pi z}{c}. \qquad \ldots\ldots (7.21)$$

8. Acknowledgement.

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JURASSIC FISHES OF NEW SOUTH WALES (MACROSEMIIDÆ) WITH A NOTE ON THE TRIASSIC GENUS *PROMECOSOMINA*.

By R. T. Wade, M.A., Ph. D.

(With Plates VIII and IX and two Text-figures.)

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INTRODUCTION.

In 1941, in an account of the Jurassic fishes of New South Wales, I included a preliminary note on *Uarbryichthys latus*, a new Jurassic macrosemiid. At that time the head was in London in the care of Professor D. M. S. Watson, and it remained in his careful custody till after the war ended. On its return to me this head was placed in the Australian Museum, where it is catalogued as No. F.43258 (*a*), the trunk of the same fish receiving the number F.43258 (*b*). Together with that fossil Professor Watson returned to the Museum a nearly complete fish now listed as No. F.43606, to which I have given the name *Uarbryichthys incertus*.

I am thus once again indebted to Professor Watson for encouragement and advice, and to the authorities of the Australian Museum for many forms of help they have given me there. In particular I am grateful to Mr. Howard Hughes, who made the photographs, and to Mr. G. P. Whitley, who drew Text-fig. 2.

Family **Macrosemiidæ**.

Genus **Uarbryichthys**

Plate VIII, Text-figs. 1, 2.

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Diagnosis. Small Macrosemiidæ rather deeply fusiform in shape. Heads rather large, triangular, with somewhat pointed snout; orbit small, placed well back; suspension forwardly inclined; gape small. Conspicuous ornament of branching rugæ on many external bones of the head. Frontals long; wide behind orbits, tapered in front. Parietals small, roughly quadrangular. Tabular bones possibly in two pairs, the outer quadrangular, the inner triangular. Operculum nearly twice as deep as long. Sub-operculum much smaller than operculum, having an antero-dorsal triangular extension overlapped by operculum; interoperculum small; preoperculum short where adjacent to operculum, longer and turning somewhat forward before the suboperculum and interoperculum. Branchiostegal rays not numerous. Six infraorbitals of varied shapes and sizes. Suborbital area apparently undivided. Maxilla small, comparatively deep near gape, tapering rapidly towards snout; posterior margin sigmoidal. Mandibles fairly robust, having greatest depth in coronoid region, thence tapering rapidly anteriorly; very slight droop at symphysis of the mandibles. Supraorbital sensory canal probably ends at back of frontal.

Single long continuous dorsal fin, arising only slightly behind head; pelvics midway between pectorals and anal; anal about midway between pelvics and caudal. Fin rays have long proximal portions, but thereafter are divided into small joints, and distally branch. Fulcra absent. Pectorals have scaleless lobes with at least five long slender basals. Scaly upper lobe of tail is small.

Scales thick, " rhombic ", ganoine covered; on anterior trunk are deeper than long; ventrally and on the produced upper lobe of the tail they are as deep as long; in the caudal region longer than deep, elaborately ornamented with short irregular rugæ on anterior trunk, with fewer rugæ posteriorly.

Genotype. *U. latus* Wade.

Uarbryichthys latus.

Diagnosis. As for genus.

Holotype. A somewhat incomplete fish in partial counterpart in the Australian Museum, Sydney (No. F.43258 (*a*), (*b*)).

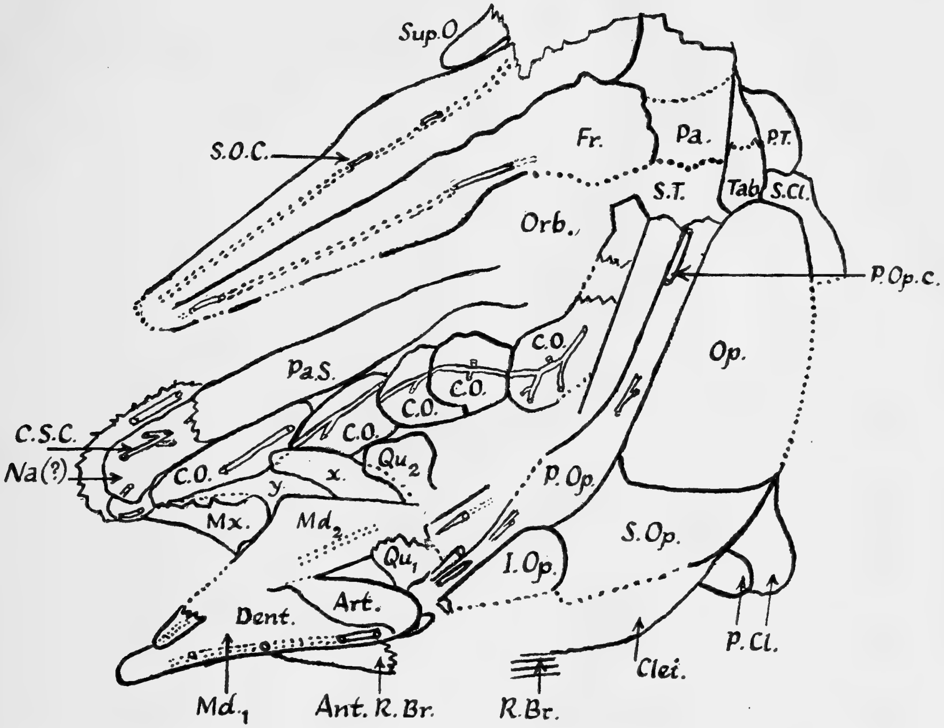
Material. The holotype and several fragments in the Australian Museum, Sydney.

The matrix is a close-grained highly siliceous chert, impregnated with iron oxides. All bone has disappeared but imprints are heavily stained by iron oxide and there are some casts. Because of the fine texture of the original mud, many details are very clearly preserved. The crushing together of the bones of the head, followed by the irregular cleavage of the chert block in recovering the specimen, have made exact delimitation of bones difficult or impossible.

Measurements. The measurements of the holotype are as follows: Length from tip of snout to base of tail, 190 mm.; maximum depth of trunk, 65 mm.; depth at origin of caudal fin, 22 mm.; length of head with opercular apparatus, 65 mm. Maximum depth of head, 58 mm.

The Head (Text-fig. 1). The bones of the cranial roof were thick and so firmly sutured that under crushing its anterior has moved as a unit to a short distance from the rest of the head. The frontals make up most of the covering, which is wide behind and just in front of the orbits, but more anteriorly tapers rapidly. In this region the suture of the frontals is straight, but from a point between the orbits undulates gently before reaching the parietals. In No. F.43258 (*a*) the outer margin, behind the orbit of one of the frontals, has been deeply pressed into the matrix, perhaps by the neurocranium, and its outer limit is not determinable. However, the counterpart, F.43258 (*b*), preserves almost certainly the outer segment of a frontal bearing a channel and cast of a supraorbital canal parallel to its outer margin, to which it is very close, and extending to the junction of frontal and parietal.

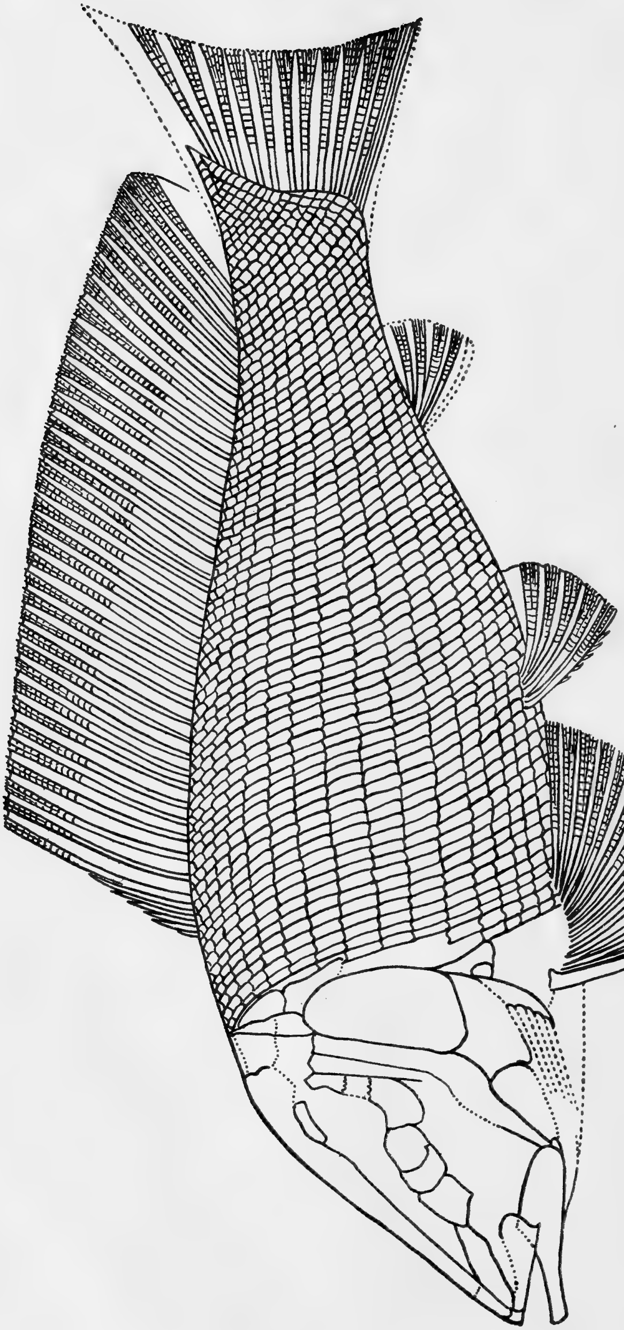
In No.43258 (*a*) part only of the second frontal is preserved behind the orbits. One parietal is almost completely delimited. Its width almost equals its length. Its anterior margin has nearly straight junction line with about three-quarters of the posterior margin of the adjacent frontal. Its common suture with the other parietal, estimated from the distribution of ornamental rugæ, is gently concave to the midline of the head. Its junction with the supratemporal is uneven and the parietal is shorter there than on its inner side. Posteriorly it is slightly convex backward where it lies in contact with the triangular tabular, but above that its margin is not clearly determinable. Near the posterior margin of the parietal, and about half its width from its inner margin, there is a small area from which an ornament of rugæ radiates. In almost the centre of this area there is a cylindrical cast 1·5 mm. long which probably represents a sensory pore.



Text-fig. 1.—Head of *Uarbryichthys latus* Wade. Genotype. No. F.43258 (*a*) (×3/2), Australian Museum, Sydney.

Ang.=Angular.
Ant.R.Br.=Anterior branchiostegal ray or gular.
Clei.=Cleithrum.
C.O.=Circumorbitals.
C.S.C.=Casts of sensory canal.
Dent.=Dentary.
Fr.=Frontal.
I.Op.=Interoperculum.
Md. 1 and 2=Mandibles.
Mdc.=Mandibular sensory canal.
Mx.=Maxilla.
Na. ?=Nasal ?.
Op.=Operculum.
Orb.=Orbit.
Pa.=Parietal.
Pas.=Parasphenoid.
P.Cl.=Post-cleithral scales.
P.Op.=Preoperculum.
P.Op.C.=Fragments of preopercular sensory canal.
P.T.=Post-temporal.
Qu. 1 and 2.=Quadrates.
R.Br.=Branchiostegal rays.
S.Cl.=Supracleithral scale.
S.O.=Supraorbital.
S.Op.=Suboperculum.
S.O.C.=Supraorbital sensory canal.
S.T.=Supratemporal.
Sym.=End of symplectic (?).
Tab.=Tabular or extrascapular.
x=Unplaced bone.
y=Surface damage.

Serrated lines indicate damage in the specimen.



Text-fig. 2.—*Uarbryichthys latus* Wade. Reconstruction based on specimen No. F.43258, (×3/4 approx.) Australian Museum, Sydney. Fin rays stylized after a comparatively small number whose condition could be observed.

In F.43258 (*b*) it seems that small bones, the outer polygonal, the inner triangular (with curved sides), make up each triangular tabular row of about 10 mm. wide, but one cannot be quite certain. Triangular post-temporals, slightly less wide than the tabular row, are connected by irregular scales or small supra-cleithrum to scales behind the opercula. At the outer margin of the nearly complete parietal described above there is the posterior segment of an incompletely determinable supratemporal, whose anterior has been destroyed by crushing.

The parasphenoid seems to have been turned in the crushing movement so as to show much of its width. The impression in No. F.43258 (*a*) is 32 mm. long and 6 mm. deep. It is damaged both anteriorly and posteriorly ; ventrally it was pressed deep into the matrix, and since bony material has disappeared a deep, very narrow trench bounds the impression there. Nearer the hinder end the ventral margin dips somewhat, forming an arc which is concave downwards, and then ends abruptly at a break in the specimen.

Extending forwards some 10 mm. from beneath the damaged anterior margin of the parasphenoid there is an impression 5 mm. wide, having parallel dorsal and ventral margins, and at its anterior end a margin which is an arc convex outwards. The impression as a whole is a shallow trough, concave upwards, being more depressed close to its anterior margin. It is lightly ornamented by very small sharply pointed projections. It bears a calcitic internal cast of branching sensory canal slightly to the dorsal side of the midline of the bone and turning upwards as it approaches the anterior end of the impression, and embedding its end there. Along the midline there is the merest suggestion of a suture. A small fragment of sensory canal is present near the antero-ventral margin of the impression. Having in mind the position of this impression, i.e. extending back from the very tip of the snout ; its comparatively large size ; its width, which equals that of the anterior end of the frontals, the position of its sensory canal as it lies close to a midline in such a way that it could easily continue the similarly placed canal of a frontal, the author considered that there is here evidence of paired nasals which extended between the tip of the snout and the cranial roof. The fact that the impression is covered posteriorly by the parasphenoid is probably due to the rolling motion of the crushing which moved the cranial roof and turned the parasphenoid so as to show much of its base.

The bones of the snout were crushed deep into the matrix and much broken when the specimen was uncovered. Impressions of the parts that remain are situated partly below the probable nasals but separate bones cannot be distinguished. Parts of internal calcitic casts of the sensory canal are lying ventral to the nasals, but issuing from a greatly crushed bone, which must have been the anterior circumorbital of the other side of the head. Anterior to the nasals is the rounded anterior of the snout, which was probably a rostral as it carries some of an internal cast of sensory canal.

Although exact delimitation is not possible, the circumorbital bones are for the most part satisfactorily determinable. One of them, a supraorbital, which bears a conspicuous ornament of rugæ nearly concentric with the orbital margin of the bone, is 8·5 mm. long, about 3 mm. deep, and is placed in the orbit immediately behind the widest part of the cranial roof. Then behind the orbit and deeply impressed into the matrix there was a bone of which only a large fragment remains. This is roughly rectangular in shape, 7 mm. deep and 3·5 mm. long, greatly ornamented, but preserving nothing of sensory canal. A break in the specimen, which damaged that bone, damaged also the upper margin of a large bone that lies partly behind and partly below the orbit. In this is preserved very prominently an internal cast of part of the infraorbital sensory canal which branches several times. Anterior to this bone there are four bones below the orbit, each channelled and carrying the calcitic cast of the infraorbital sensory canal. The first of the four, roughly oval in shape, is about 10 mm. deep and 10 mm. long ; the second, of the same depth, is only about half as long and has both interior and posterior margins concave backwards ; the third, wide behind and throughout most of its length, becomes pointed anteriorly ; finally, carrying the sensory canal into the snout, there is the fourth bone, about 22 mm. long and 4 mm. where deepest, and tapering towards each end from its maximum depth.

The operculum is 28 mm. deep, 14 mm. long near its ventral margin, but only 10 mm. long at about one-third of its depth. The suboperculum is a much smaller bone, only about half as deep as the operculum. Its anterior margin is gently concave forwards, its upper margin more deeply concave upwards, and the two margins form an acute angle in front of the antero-ventral margin of the operculum. The almost triangular interoperculum is 16 mm. × 6·5 mm., and in the specimen is damaged ventrally. This damage has affected, also, nearly the whole branchiostegal region, so that only short lengths (the longest 7 mm. long) of four narrow strap-like branchiostegals lie ventral to the impression of the cleithrum. A triangular impression about 7 mm. long but much deeper at its broken posterior end than any other preserved branchiostegal fragment is either an anterior branchiostegal ray or small gular.

Much of the preoperculum is clearly distinguishable, but conditions in some parts of it are obscure. In its middle section, i.e. where it lies adjacent to about three-quarters of the anterior margin of the operculum, the anterior and posterior margins of the bone, and also its general shape, are clearly indicated, and it bears a part of the internal cast of the preopercular sensory canal. The upper section of the bone is very narrow, but it widens considerably in front of the suboperculum, where also the bone is bent at a wide obtuse angle. But at the junction of suboperculum and interoperculum the latter (which is there somewhat in advance of the suboperculum, as though it had been pushed forwards at the time of crushing) greatly diminishes the width of the preoperculum. From that point the preoperculum tapers very rapidly till its anterior end reaches the mandible. In this latter section two fragments of interval cast of sensory canal mark the triangular preopercular area with certainty.

The area that borders the post-orbitals is slightly ornamented at its upper end, which is in relief, by very small short rugæ of varied lengths, but conspicuously wrinkled into two or three very small ridges and furrows very close to the post-orbitals, where its margin is straight and gives the impression of truncating the posterior margins of those bones. There are no recognizable subdivisions of this area. At about half the depth of the area in relief there is the false appearance of a cast of sensory canal, but the fragment is that of a highly ornamented bone whose undersurface produced the smooth impression now revealed.

In the region of the cheek impressions of parts of bones occur at different levels. Near the lower mandible the preoperculum is at the lowest level. On the next level above it, and resting against the mandible, there is a large segment of quadrate. From the base of this fan-shaped bone, and directed backwardly, there is a conical 5 mm. of calcite with some circular grooves round it. From its position this may be the anterior end of a symplectic.

At this same level, about 4 mm. away there is a smaller calcitic cone parallel to the first and resting in a groove on the triangular impression of part of a possible preoperculum. On the next level there is a nearly complete fan-shaped impression of a second quadrate.

There are impressions of the mandibles of both sides of the head, having their anterior ends not widely separated. The lower impression is about 27 mm. long, and has a well-marked longitudinal depression near its ventral margin, close beside which the course of the mandibular sensory canal is indicated by some calcitic casts of canal and sensory pores. Dorsally it is overlapped by a damaged impression of the second of the mandibles. This latter has a dorsal margin which rises to a pronounced hump at about half the length of the bone, measuring from the posterior margin, and then descends rapidly anteriorly. In both instances the ventral margins display a slight anterior droop.

The maxilla of the specimen is folded along the margin of the mouth and it is damaged at points along its inner margin. It is deepest near its posterior margin, from which it tapers to a very narrow projecting anterior end as it enters the snout. The posterior margin is sigmoidal, convex outwards throughout most of its course but changing to form a curve of slight concavity or notch near the margin of the mouth. There are no indications of a supramaxillary or of teeth.

The ornamentation on dermal bones of the head comprises rugæ of varying lengths sometimes branching, radiating from a centre, or fanning out from a point or points near a margin. It is conspicuous on the cranial roof behind the orbits, but not anterior to them; possibly the smooth surfaces are those of undersides of the bones. The opercular bones, too, and the circumorbitals were heavily ornamented.

Much of the sensory canal system of the head has been preserved as external casts or calcitic segments of internal casts. The supraorbital canals are very clear in the frontals to points just behind the orbits. Mention has already been made above of the probable preservation of a portion of the canal as it ends back in the posterior margin of a frontal (No. F.43258 (*b*)). No trace of canal appears on the parietals, but merely a small sharply pointed calcitic projection suggesting a sensory pit in the original bone. The preservation of parts of the sensory canal system in bones of the snout, in the circumorbitals, in the preoperculum and in the mandible has been described above.

Appendicular Skeleton. Of the bones of the pectoral girdle, the cleithrum is in great part determinable from external casts. It is arcuate and excavated somewhat at the insertions of the pectoral fin. The upper end of the nearly vertical arm is slender and not clearly delimited, the nearly horizontal lower arm seems stout and sharply convex outwards. Two highly ornamented post-cleithral scales are preserved in specimens No. F.43258 (*a*), and an irregularly shaped scale is observable below the post-temporal, but, although the region is completely preserved in No. F.43258 (*b*), nothing definite can be determined about conditions between these two parts.

The pectoral fin rays fringed a scaleless fleshy lobe which is reinforced by long, slender basals. Casts of six of these basals are clearly discernible in specimens No. F.43258 (*a*) and (*b*). The fan-shaped pectoral fin (partly damaged distally) comprises about fourteen rays, of which the most anterior is robust with an expanded head at its insertion. The eighth and ninth rays are nearly complete and no doubt show the characteristics of fin rays of any of the fins. A long smooth proximal shaft is continued by a section divided into very small joints. Division of the ray into two closely jointed branches takes place, and in some instances there is most distally a further subdivision into four. There is no indication of fulcra on the anterior ray of the pectoral fin, but it is possible that some are obscurely shown on the small pelvic fin (five rays). As preserved in No. F.43258 (*b*), the anal fin is very small and may have had no more than five or six rays, but the long dorsal fin, comprising at least thirty-seven rays, is very prominent. Its point of insertion is at about the tenth scale row behind the head, where there are four or five sharply pointed rays of increasing length before the robust anterior ray. Because of a break in the specimen all the rays of the dorsal fin are distally curtailed except for a few posterior rays. No endoskeletal fin supports are preserved.

The caudal fin is far from complete. The tip of the produced upper scaly lobe is missing, as are the distal ends of all rays, the proximal ends of about eight rays, and in their entirety the rays which fringed the upper lobe.

From a small area at the extremity of the lower caudal lobe some scale-casts have been broken away, revealing about eight slender irregular endoskeletal ray supports. However, fragments large or very small indicate that the tail comprised more than twelve rays.

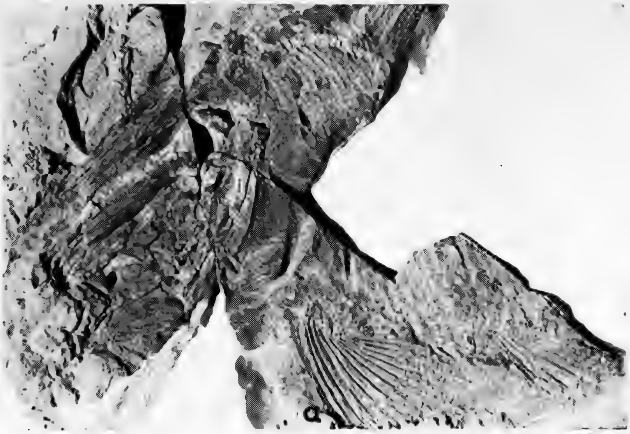
The thick rhombic or rhomboidal ganoid scales which covered the whole trunk were ornamented by an intricate pattern of small irregular rugæ, very numerous on the scales of the anterior trunk but reduced to a few longitudinal rugæ near to and on the caudal region. Scales of most of the anterior flank are appreciably deeper than long (measurable scales reach 6 mm. × 2·5 mm.). Measurable scales near the base of the tail are 2 mm. long by 1·5 mm. deep. On the produced upper lobe they are still smaller and apparently equilateral. The dorsal margin of the incomplete upper lobe is capped by several small scute-like scales.

Remarks. In respect of the trunk, *Uarbryichthys latus* has a somewhat deeper body than macrosemiid genera other than *Histionotus.* It has the single long dorsal fin of *Macrosemius* and *Distichiolepis* and other fins and fin rays of a type common to the family. Its scales, of one kind only, are thick, ganoid, completely covering the trunk, which is not the case in *Macrosemius* or *Distichiolepis* ; they are appreciably deeper than long over most of the trunk, as in *Histionotus* ; they are profusely ornamented and not at all pectinated. Finally, the suspensorium is forwardly directed to the extent true of *Histionotus*, with the accompanying resemblances to that genus of small mouth, pointed snout, sloping parasphenoid and slight mandibular droop observable in that genus.

In the dermal bones of the head, however, it stands apart from any of the known Macrosemiidæ. The pair of frontals, which forms the greater part of the cranial roof, extend back well behind the orbits. The roof as a whole, which is wide anterior to the orbits, tapers thence anteriorly to a place not far from the tip of the snout. The parietals are comparatively small bones.

In the upper orbital area, part only of the region is occupied by one well-developed kidney-shaped supraorbital. Just behind the orbit there is a somewhat rectangular bone, and at the infero-posterior corner a well-developed circumorbital. Both of these have similarly shaped and placed counterparts in *Ophiopsis guigardi* (Saint-Seine, 1949) and also in the eugnathid *Caturus Porteri* (D. H. Rayner, 1948). In *Macrosemius helenae* there are three circumorbitals, which are placed below the posterior two-thirds of the orbit ; in *Distichiolepis fourneti* there are two only, and they are beneath and before the orbit. However, in *Uarbryichthys* the complete series of five are well defined and clearly marked out by a prominent infraorbital canal ; moreover the most anterior of them is large and reaches forward to the snout, in contrast with the conditions observable in *Ophiopsis*, *Macrosemius* and *Distichiolepis.*

Like *Macrosemius helenae*, no supramaxilla is present in *Uarbryichthys latus*, but, unlike that species, the maxilla of *U. latus* has a sigmoidal posterior margin such as is seen in *Ophiopsis guigardi.* In the mandible the coronoid process is situated at about half the bone measured from the posterior margin and is only moderately prominent, and although the bone is much less deep anterior to the process than behind it there is not the great difference observable in *Macrosemius helenae* and others.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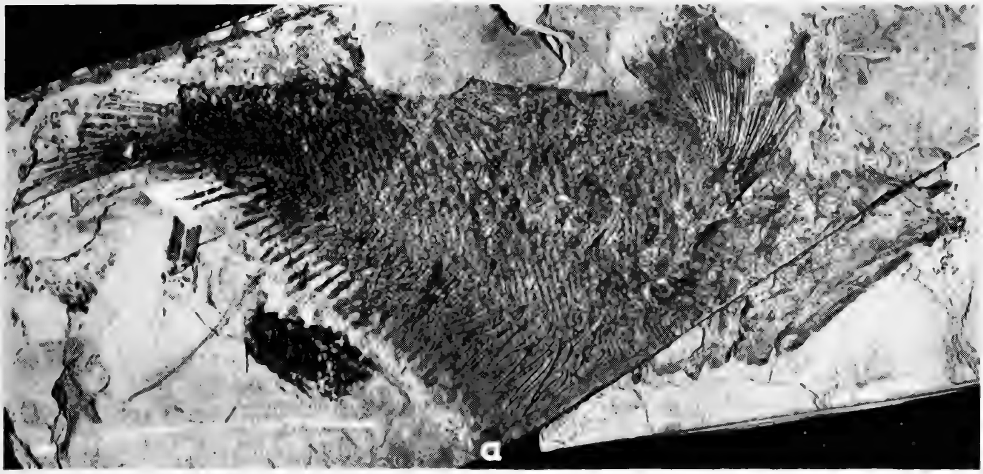
b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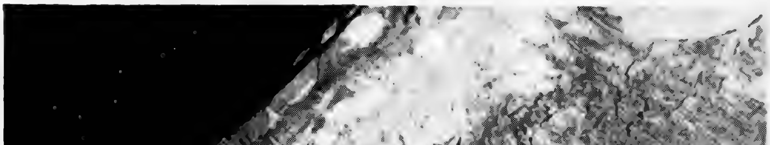
b

Except for the operculum, which is somewhat like that of *Macrosemius helenae*, the opercular bones differ considerably in size and shape from those in *Macrosemius*, *Distichiolepis* or *Ophiopsis*. The region between the upper end of the preoperculum and the two post-orbitals shows no indication of subdivision.

The division of the tabular into two small plates has been observed in one specimen only, and may be due to an accident in crushing. Again, for the position of the supraorbital sensory canal, viz. near the outer margin of the frontal and ending at the junction of frontal and parietal, there is only the evidence of a fragment of cranial roof preserved in No. F.43258 (*b*).

In the above there is evident a general simplicity of design in the head of *Uarbryichthys latus*. If the two post-orbitals and the sigmoidal posterior margin of the maxilla are eugnathid characters shared with *Ophiopsis guigardi*, the pattern of the cranial roof, the structure of jaws, of the supraorbital region, of the suborbital region do not follow *Macrosemius*, *Distichiolepis* or *Ophiopsis* in any degree of agreement with the Eugnathidæ. On the other hand the infraorbital row, especially the most anterior of these, resembles some Eugnathidæ. As for the trunk, the proportions of it, its scales, its fins (except the dorsal) and fin rays quite resemble *Eoeugnathus*, and the shape of the head, the inclined suspension, small eye and small mouth recall *Histionotus* and *Heterolepidotus*. Whatever the ancestor which *Uarbryichthys* shared with the other Macrosemiidæ, it has developed differently in the fresh waters of eastern Australia.

Uarbryichthys incertus sp. nov.

(Plate IX.)

Diagnosis. A *Uarbryichthys* having maximum depth of trunk about the length of the head and contained about three times in the total length of the fish. Produced upper caudal lobe nearly one-third the length of the upper part of the caudal fin and at its base about one-third of the total depth of the tail. Number of fin rays approximately as follows: pectorals, 18; pelvics, 5; dorsal, 42; anal, 5; caudal, 20. Transverse scale rows are more numerous on dorsal than ventral parts of the caudal region of the trunk.

Holotype. A nearly complete fish with greatly crushed head in the Australian Museum, Sydney (No. F.43606).

Material. The unique holotype. It is preserved in the same kind of material and in the same condition as *U. latus* (No. F.43258), but the bones of the head are more completely crushed together, all the fins are defective in some particulars, and the scale rows of the anterior half of the trunk are considerably disarranged.

Description. The measurements of the holotype are as follows: length to base of caudal pedicle, 265 mm.; maximum depth of trunk, 90 mm. (?); length of head with opercular apparatus, 90 mm. (?); depth at origin of caudal fin, 25 mm. (?). These measurements are all approximate because of the difficulty (due to crushing) of determining exact margins. The produced upper lobe is certainly 22 mm. long and has a depth, at its junction with the tail as a whole, of 9 mm.

The Head. As in *U. latus*, crushing caused the anterior part of cranial roof to move away from the rest of the head. But in this case the frontals were separated from each other slightly and somewhat of their anterior inner margins can be seen. A number of other bones are identifiable but no useful description can be given of them.

The Fins. In the dorsal fin many of the fin rays have been split proximally and in crushing there has been some displacement. This is especially in evidence near the origin of the fin, so that one cannot be quite certain as to the exact number of fin rays. Again, there is some damage distally throughout much of the length of the fin, but two or three rays most posteriorly placed are nearly complete and resemble small whips of four, six or eight lashes on a short handle. The pectoral fins, larger than those of *U. latus*, are also more completely divided into small joints and have shorter undivided proximal segments. In both pelvic and anal regions the surface of the specimen is greatly damaged and neither their exact position nor the number of rays in them is known.

The caudal fin is much more satisfactorily preserved. Fulcral scales and fulcral rays border its dorsal margin, the proximal undivided parts of the rays are very short, and each ray is divided into many small joints. A few rays of the upper part of the fin, somewhat crowded together, are well preserved almost to their distal ends. In the rest of the fin the rays are more widely spaced and there has been considerable damage to the specimen.

Although the produced upper lobe has received slight damage not far from the tip, it is very well preserved. One long narrow rectangular scale, from which a long fin ray runs backward, covers the extreme tip. Two small scales are placed just before this, and thereafter the scaly area increases and the fin grows larger as fin rays are added at the under margin and fulcral scales along the upper.

The Scales. Over the caudal area posterior to the anal fin scale impressions are well preserved, and the greater number of transverse rows on the dorsal region is very noticeable; at intervals a row resembling a wedge of small, narrowing scales pushes down from the dorsal margin to the mid flank, where the scales are much larger. As regards the rest of the trunk, it is highly probable that before the fish was deeply covered by sediment deterioration of the flesh had occurred, so that crushing, when it came, greatly disarranged the rows of scales and the scales in the rows. But a sufficient number of measurements has been possible to show the much shorter lengths of dorsal transverse rows and therefore the greater number of rows necessary to cover the fish there. The state of preservation prevents a definite computation of the exact relationship of the number of dorsal and flank or ventral rows that corresponded, but quite clearly the conditions in general show considerable similarity to that known in *Districhiolepis fourneti* (Saint-Seine, 1949).

The similarity extends also to the thinness of scales near the dorsal margin, particularly in the region above that between the pelvics and the anal fin, where a few endoskeletal ray-supports can be made out.

NOTE ON THE TRIASSIC GENUS *Promecosomina*.

Literature.

1941. Australian Triassic Fishes. THIS JOURNAL, Vol. LXXIV.

1952. Lehman, Jean-Pierre. Etude Complémentaire des poissons de l'Eotrias de Madagascar. *Kungl. Sven. Vet. Hand. Fjärde Serien*, Band 2, No. 6.

In the latter work Lehman, in a discussion of Parasemionotidæ that includes new genera *Stensionotus*, *Jacobulus*, *Thomasionotus* with characteristic preopercula, gives it as his opinion that (page 185) " il apparaît en réalité que *Promecosomina* est un Parasemiontide à préopercule divisé."

This writer agrees with this conclusion and readily withdraws the family name Promecosominidæ which he set up in 1941.

EXPLANATION OF PLATES.

PLATE VIII.

(*a*) Head of *Xarbryichthys latus* Wade. Specimen F.43258 (*a*). (×1/2.)
(*b*) Trunk of *Xarbryichthys latus* Wade. Specimen F.43258 (*b*). (×5/6.)

PLATE IX.

(*a*) Complete specimen of *Xarbryichthys incertus* sp. nov. Wade. Specimen F.43606. (×2/5.)
(*b*) Caudal region of *Xarbryichthys incertus* sp. nov. Wade. Specimen F.43606. (×4/5.)

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THE ASSEMBLAGES OF GRAPTOLITES IN NEW SOUTH WALES

By KATHLEEN M. SHERRARD

With Plates X and XI and two Text-figures.

Manuscript received, July 15, 1953. Read, October 7, 1953.

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INTRODUCTION AND ACKNOWLEDGMENTS.

In New South Wales, as in other countries, it has become apparent that similar suites of graptolite species or "assemblages of graptolites" occur repeatedly in the various localities where graptolite-bearing Ordovician and Silurian rocks outcrop. The graptolites making up the assemblages in New South Wales are not always the same, however, as those which are found in assemblages in other places such as Victoria, New Zealand, Great Britain, Bohemia, Sweden and North America.

It has been found elsewhere that different assemblages correspond to differences in age, constituting "zones" within the Ordovician and Silurian sedimentary rocks. In a few cases in New South Wales the different assemblages of graptolites occur in a series where by superposition their age relations can be observed directly in the field, but in general, the age of the rocks containing graptolites, often steeply folded, has to be determined by correlation of their graptolites with those of known age from other places.

In carrying out the work described in this paper, it was possible through the courtesy of Professor W. B. R. King, F.R.S., to conduct some of the correlations by means of direct comparison with the graptolite collections of the Sedgwick Museum, Cambridge, where Miss G. L. Elles kindly advised me in the work. Professor C. E. Marshall, D.Sc., Ph.D., of the University of Sydney; Mr. H. O. Fletcher, Palaeontologist to the Australian Museum; Mr. H. F. Whitworth, Curator of the Mining Museum, Sydney; Dr. N. H. Fisher, of the Bureau of Mineral Resources, Canberra; and Mr. D. G. Moye, Senior Geologist to the Snowy Mountains Authority, have been good enough to allow me to examine graptolites in collections in their charge. Mr. N. C. Stevens has been particularly generous in allowing me to study graptolites from his extensive collecting, and Mr. R. A. Keble, F.G.S., Mr. G. H. Packham, Mr. H. W. Williamson, Mr. K. Crook and Mr. M. MacKellar have also kindly made available others, all of which have extended greatly the collections I have made myself.

As a result, assemblages typical of different zones have been selected for New South Wales and are given in this paper. Graptolites from over one hundred localities within the boundaries of the State and excluding the Australian Capital Territory are correlated with these typical assemblages. A list of these localities not otherwise referred to is given on page 93.

Geographical Distribution of Graptolite-Bearing Rocks.

Keble and Benson (1939) referred to all localities in New South Wales from which graptolites had been recorded when they wrote. Those localities and others in which graptolites have been found since that time lie mainly within three areas in the State.

(1) The Southern Highlands where both Silurian and Ordovician graptolites occur at numerous places within a broad strip running south-south-west from Tallong, Goulburn and Crookwell to Tumbarumba, Geehi and the County of Wellesley;

(2) an area in the Central West where both Silurian and Ordovician graptolites occur in a strip running north from Mandurama to Tomingley and Wellington;

(3) a narrow strip running north from Wagga through Ariah Park to Yalgogrin and Weja, in which Ordovician graptolites have been obtained.

Lying away from these three areas are occurrences on the South Coast near Cobargo and Bermagui (Brown, 1931). The oldest known Ordovician graptolites occur near Narrandera. There is little doubt that more graptolite-bearing localities remain to be discovered.

Lithology of Graptolite-Bearing Rocks.

Graptolites of Ordovician age from New South Wales are generally preserved as chitinous or pyritic films in a highly compressed condition in strongly folded slates, usually dark-blue or greyish in colour, but occasionally bleached white as at Geehi and Woodstock. Metamorphism has sometimes caused the development of chiastolite in the slate. Dr. G. A. Joplin (1945) made chemical analyses of a number of graptolite-bearing slates, finding an unusually high percentage of silica (about 80%) in them. It may or may not be significant that the slate with the highest percentage of silica (87%) among those analysed, is also one of the slates (Loc. 17, Yass River) with the oldest graptolites in the analysed group. However, the correlation cannot be carried further, since the slate from Yalgogrin, placed in a high graptolite zone, has a higher silica percentage than some of the slates with older graptolites, for example that from Gygederick Hill, Berridale.

Although the majority of Ordovician graptolites in New South Wales are preserved as films on slates, there are a few instances of casts of graptolites preserved in quartzites from which they stand out in slight relief, for example in the Shoalhaven Gorge (Sherrard, 1949) and in the Malongulli Formation near Mandurama (Stevens, 1952). Finally, some Ordovician graptolites occur in a calcareous matrix (Stevens, 1950) and some in a leached limestone in the Mandurama district.

Silurian graptolites are found generally in New South Wales in gently dipping sandy rocks, sometimes in slight relief and sometimes as compressed films. More rarely they occur as films in strongly folded argillaceous rocks, as near Goulburn.

Graptolite Zones.

Certain assemblages of graptolites have long been recognized in Britain as typical of strata of a definite age and have enabled the recognition of graptolite zones each "characterised by a *special association* of Graptolites . . . and . . . that form in this association which apparently combines restricted vertical range with wide horizontal distribution is most conveniently selected as the index of the zone" (Elles and Wood, 1914, p. 515). However the typical species or index graptolite selected in other places to name the zone cannot always be recognized in the assemblages examined from New South Wales, so that other types have had to be chosen. It is noticeable that a few distinctive species characterize each group, but these may be accompanied by other species persisting from older groups. New species can be observed to make their appearance in the new group and though the old species persist, they have often changed materially in size or other character. Miss G. L. Elles of the Sedgwick Museum, Cambridge, has frequently insisted that this "coming in of new species marks an advancement in graptolite development only to be accounted for by the passage of time" (1925).

By comparison of the graptolite assemblages found in rocks in New South Wales with those in other places the following zones are recognized in this State:

Silurian.

Ludlow.

Zone of *Monograptus scanicus.*
Zone of *Monograptus nilssoni.*

Wenlock.

Zone of *Monograptus testis.*
Zone of *Cyrtograptus insectus.*

Llandovery.

Zone of *Monograptus crispus.*
Sub-zone of *Monograptus triangulatus.*
Zone of *Monograptus gregarius.*

Ordovician.

Caradoc.

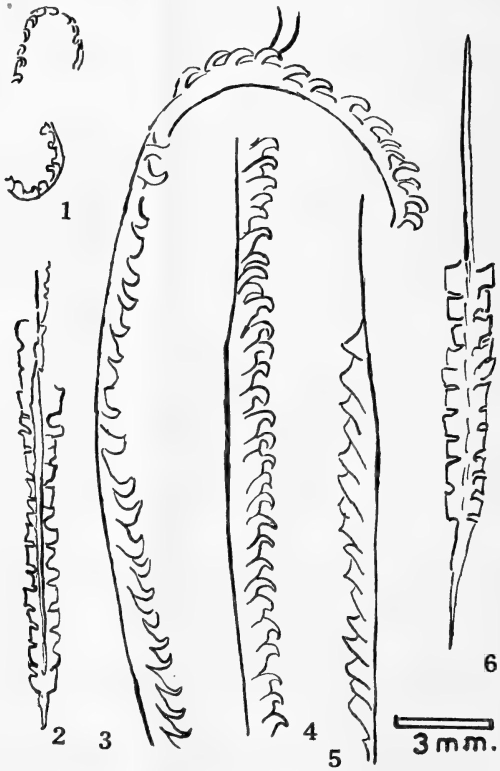
Zone of *Orthograptus quadrimucronatus* and *Pleurograptus linearis.*
Zone of *Orthograptus calcaratus* and *Plegmatograptus nebula.*
Zone of *Climacograptus wilsoni.*
Zone of *Climacograptus peltifer.*

Llandeilo.

Zone of *Nemagraptus pertenuis.*
Zone of *Glyptograptus teretiusculus.*

Arenig.

Zone of *Tetragraptus quadribrachiatus.*



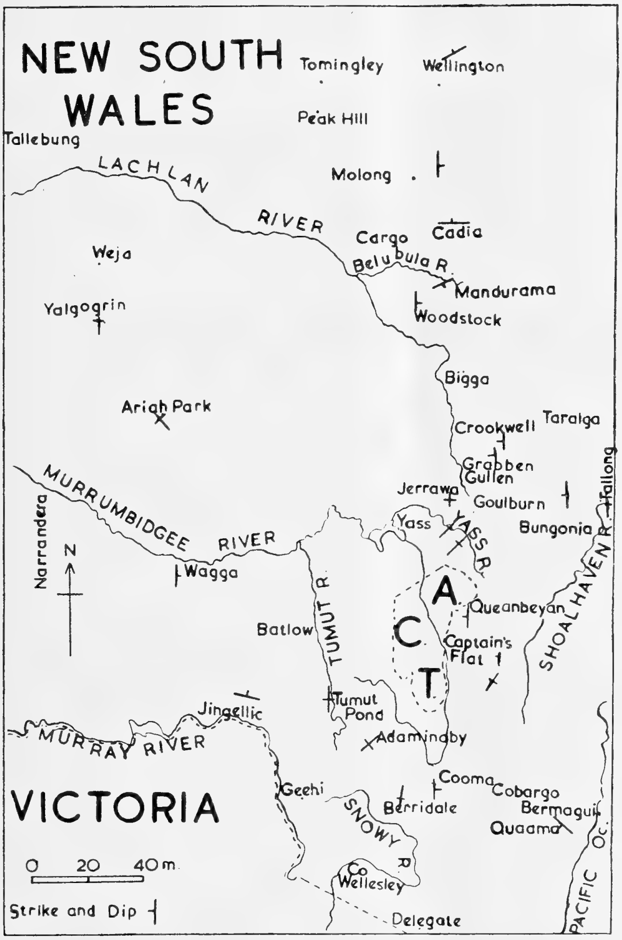
Text-fig. 1.

1. *Monograptus exiguus* (Nich.), Four Mile Creek.
2. *Climacograptus antiquus* Lapw., Digger's Creek, Cadia (F.3417, Mining Museum).
3. *Cyrtograptus* aff. *insectus* Boucek, Four Mile Creek.
4. *Monograptus marri* Perner, Four Mile Creek.
5. *M. dubius* (Suess), Four Mile Creek.
6. *Amplexograptus arctus* Elles and Wood, Cadia (F.29896, Australian Museum).

(Nos. 1, 3, 4, 5 collected by Messrs. Stevens and Packham.)

Equal importance cannot be attached to all the zones selected for New South Wales; for example only one occurrence of the *Tetragraptus quadribrachiatus* zone is known so far. In the Caradoc all zones but that of *Climacograptus wilsoni* are widely distributed. That zone is included with some doubt, as is explained below. *Orthograptus calcaratus* and *Plegmato-*

graptus nebula selected as joint index fossils for one zone are not restricted to that zone, as is desirable for an index fossil. These graptolites are, however, particularly well developed in assemblages assigned to their zone. The *Nemagraptus* zone is included in the Caradoc in Britain (Pocock and Whitehead, 1948) and in Sweden (Hede, 1950), and in Czechoslovakia, the zone with *Glyptograptus trubinensis* (related to *G. teretiusculus*) is included in the Caradoc (Kettner and Boucek, 1936; Pribyl, 1951). However, since in New South Wales, *Didymograptus caduceus* survives into the *Nemagraptus pertenuis* zone, this zone is retained in the Llandeilo. *Glyptograptus teretiusculus* is very wide-spread in this zone, but *Dicranograptus* and *Nemagraptus* occur with it in the Walli district and indicate the coming in of a later zone than that of *Glyptograptus teretiusculus*.



Text-fig. 2.

Sketch-map showing position of localities from which graptolites have been obtained and direction of fold axes of Ordovician strata at some localities.

In the cases of two of the Silurian zones, those of *Monograptus testis* and *Cyrtograptus insectus*, their nearest counterparts occur in Czechoslovakia and accordingly zones set up there have been selected for New South Wales (Kettner and Boucek, 1936).

The graptolite zones recognized in this paper correspond approximately to only seven of the fifteen Ordovician zones recognized in Britain and to six of the twenty Silurian zones set up there. In Victoria, the extensive occurrence of Lower Ordovician graptolites has enabled the division of the rocks of that age into more zones than have been recognized in Britain. In general the trend of the strike in Victoria is sub-meridional, which means that the same beds may be expected to crop out to the north in New South Wales. However, north of a line running east and west approximately from Elmore to Charlton in Central Victoria, the Lower Palaeozoic rocks are covered by Post-Tertiary deposits which extend to the boundary of the State and continue further north into New South Wales masking older rocks. So far the outcrop near Narrandera of the *Tetragraptus quadribrachiatus* zone is the only representative of a low zone in the Ordovician known in the State. Except for the record from Tallebung on about the same longitude this is to the west of other graptolite-bearing strata in New South Wales but to the east of the main Lower Ordovician localities of Victoria. It seems not unlikely that further inliers of low Ordovician age will be found in the future in this part of New South Wales.

The zones from that of *Nemagraptus pertenuis* to that of *Pleurograptus linearis* approximate fairly closely to the zones making up the Gisbornian, Eastonian and the lower part of the Bolindian of Victoria. Dr. Ruedemann (1947) has pointed out similarities between high Ordovician graptolites of Western America and of Australia.

In the Silurian, the instructive sections at Yass and Cadia, where several zones are found in superposition, have enabled a more satisfactory zoning of this period than has yet been possible in Victoria (Thomas, 1947). Similarities between the Wenlock of New South Wales and Bohemia and between the Ludlow of New South Wales, Oklahoma and Sweden are also apparent.

Graptolite Assemblages.

For each of the zones, a typical locality has been selected and its assemblage of graptolites is given. The assemblages from any other localities placed in the zone follow or are given in Tables I–IV. It will be seen that in most cases graptolites occur in the corresponding table which have not been identified in the typical locality. The localities are arranged in the tables in the order of decreasing variety in their assemblages. Assemblages with only one or two species such as that from Tumbarumba in the *Cl. peltifer* zone and those from Trunkey and Taralga in the *O. quadrimucronatus* zone are included with some doubt.

Ordovician.

Arenig.

Zone of *Tetragraptus quadribrachiatus.*

Graptolites of this zone, the oldest so far found in New South Wales, occur in a chiastolite slate inlier in Portions 56 and 57, Par. Corobimella, 15 miles S.S.W. of Narrandera. *Tetragraptus quadribrachiatus* (F 39696–7, Australian Museum) from this locality is in a state of fair preservation and has been described and figured (Keble and Macpherson, 1941). The accompanying graptolites are incomplete. Most are wide forms, some with a well-marked central tube, some with spines. They can be identified only approximately. The assemblage may be:

Tetragraptus quadribrachiatus,
cf. *Glossograptus acanthus*
cf. *Trigonograptus ensiformis*
? *Amplexograptus confertus*
? *Glyptograptus dentatus*

This zone is equivalent to either zone 3, 4 or 5 of the British succession, to the Middle Ordovician as recognized in Victoria (Harris and Thomas, 1938), to the lowest graptolite horizon of the Pittmann Formation of the Ordovician in the Australian Capital Territory (Öpik, 1954); and to the Lower Didymograptus zone of Sweden (Hede, 1950).

Llandeilo.

Zone of *Glyptograptus teretiusculus.*

This zone occurs typically in siltstone in several localities in the Parish of Clarendon in the Cadia District (Locs. 12, 12a, 13, 13a, g_1, g_2). Apart from traces of dendroids, the only graptolite found after wide collecting is *Glyptograptus teretiusculus* or its affiliates (Stevens, 1954).

It often occurs in slight relief when its dimensions vary from those seen in the compressed state. *Glyptograptus teretiusculus* seems generally the best attribution, but its dimensions under some conditions link it with *Orthograptus apiculatus* or with *Mesograptus foliaceus* (*sensu stricto*, Elles and Wood, 1907, p. 259) which is also generally recorded without associates. For example from locality g_1, Portion 113, Par. Clarendon (south-west corner), near Cadia, have been obtained numerous specimens up to 4 cm. long though generally incomplete, and up to 3 mm. wide, though usually 2·5 mm., gradually tapering to 0·7 mm. There are 12 thecae in 10 mm. almost invariably, which are inclined at 40 degrees to the vertical. These are best called *Mesograptus foliaceus* (*s.s.*). The rhabdosomes are seen in differing aspects, the thecae changing from the shape of a leaf with both apertural and ventural margins convex, to the shape of a cup or bracket with the apertural margin concave and the ventral margin sigmoidally curved. Sometimes scalariform aspects of the rhabdosome are seen so that it appears as an almost bare stipe with very faint outlines of thecae on one side only. This "monograptid" aspect was seen in Glyptograptids from Badgery's Crossing, Shoalhaven Gorge, and its true nature pointed out by Miss G. L. Elles (Sherrard, 1949).

Collections from Locs. 12, 18 and 19 Shoalhaven Gorge, from Mandurama Ponds Creek and from Junction Reefs, Belubula River, between Mandurama and Lyndhurst are also placed in this zone. Graptolites from the last locality were described by T. S. Hall (1900) as *Diplograptus manduramae* and *Climacograptus affinus*, both new species which Hall explained he was erecting with some doubt. Comparison of the holotypes of these species, now in the Mining Museum, Sydney, with descriptions and plates in "British Graptolites" published after T. S. Hall's paper, enables the correlation of *D. manduramae* and *Cl. affinus* with *G. teretiusculus*, which name has priority. The assemblage for this zone is therefore:

Glyptograptus teretiusculus
G. rostratus
Mesograptus foliaceus s.s.
Dendroids.

Zone of *Nemagraptus pertenuis.*

The type area for this zone is Licking Hole Creek, 500 yards south-west of Malongulli Trig, between Mandurama and Walli (Stevens, 1952), where graptolites are piled in profusion on dark, calcareous slate. The assemblage is:

Isograptus (*Didymograptus*) *caduceus* var. *tenuis* (rare)
Nemagraptus explanatus var. *pertenuis* (common)
Climacograptus cf. *antiquus* (rare)
Dicellograptus cf. *divaricatus*
Glyptograptus teretiusculus
Retiograptus geinitzianus
Thamnograptus sp.

Since it is commonly found on a much lower horizon (Castlemainian), the occurrence of a variety of *Isograptus caduceus* is noteworthy. Only one specimen has been identified. It occurs on the same slab as *Nema. pertenuis.* It is recorded from one locality in the Gisbornian division of the Ordovician in Victoria (Harris, 1924; Thomas, 1932) with a somewhat similar assemblage.

A rather different assemblage occurs at "Trilobite Hill", near Walli (Grid reference 845468), also in the Malongulli Formation:

Dicellograptus cf. *divaricatus*
Dicranograptus zic zac var. *minimus*
Glyptograptus teretiusculus (very common)
Climacograptus cf. *antiquus*
? *Thamnograptus* sp.

Bryozoa, sponge spicules, brachiopods, gasteropods and trilobites are associated with graptolites at both these localities. Similar assemblages and associates are recorded from Llandrindod, Wales (Elles, 1940), and Sweden (Hadding, 1913).

The puzzling assemblage at Captain's Flat railway station is included in this zone. It may be:

Mesograptus cf. *multidens*
cf. *Orthograptus calcaratus* var. *acutus*
Cryptograptus tricornis
Nemagraputs pertenuis

The first member of this assemblage is of different dimensions from those of any graptolites seen elsewhere in New South Wales or known at the Sedgwick Museum, Cambridge. The first collection from this locality was made by Messrs. H. W. Williamson and Glasson and consisted of fragments of diplograptid forms from 3·5 to 5·3 mm. wide with a very broad virgular tube (0·6 mm.). Thecae were 8–10 in 10 mm. up to 3·5 mm. long with two-thirds overlap. These were tentatively correlated with *Orthograptus calcaratus* var. *vulgatus.* Later collections made for the Bureau of Mineral Resources contained diplograptids up to 11 mm. wide and 4·5 cm. long (Plate XI, fig. 13) and obviously related to the earlier collections. There was in addition in the later collections a form up to 10 cm. long with an almost non-existent periderm. It has been suggested that this may be a scalariform view of the first. It is hard to imagine such a wide graptolite coming to rest on its side. Like the *Mesograptus* it is too poorly preserved to be the holotype of a new species and it is compared with *Orthograptus calcaratus* var. *acutus.* Ruedemann (1947, p. 111) commenting on another species says "it has in its large size a peculiarly Australian character". The country rock is a highly compressed blue slate which dips west at about 85 degrees. The Captain's Flat area is strongly folded, heavily faulted and highly mineralized and the rolling out to a greater width of a convexo-concave graptolite such as a *Mesograptus* can be visualized. The increase in length of a graptolite contained in folded strata to one and a half times its usual length is recorded from Victoria (Hills and Thomas, *Geol. Mag.,* 1944, p. 218).

The collection from Tomingley (Dun, 1898; Hall, 1902), is remarkable for its wealth of dendroids. These also occur sparingly in other collections placed in this zone. Though the Tomingley assemblage has many species characteristic of the *Climacograptus peltifer* zone of Britain, it has been retained in the *Nemagraptus pertenuis* zone because of the complete absence in a large, well-preserved collection of any member of the *Climacograptus bicornis* family including *Cl. peltifer.*

Slates with ? *Nemagraptus pertenuis* from Portion 169, Par. Talagandra, Nanima-Bedulluck district, to the east of Loc. 63 may indicate this zone.

The Kiandra Beds (Opik, 1952) at their outcrop about 1700 feet above the Tumut Pond Camp of the Snowy Mountains Authority contain graptolites of this zone. They were also found in the core from a hole drilled not far from the outcrop, which after passing at an angle of 45 degrees for 235 feet through unfossiliferous rocks penetrated graptolite-bearing Kiandra Beds.

Caradoc.

Zone of *Climacograptus peltifer.*

The type area for this zone is in the Shoalhaven Gorge at its junction with Bungonia Creek (Loc. 11, Sherrard, 1949). Various collections from other parts of the Gorge fall into this zone, while the collection from the Tolwong Mine described by T. S. Hall in 1902 seems to belong here also.

The assemblage at Bungonia Creek mouth is:

Dicranograptus nicholsoni (very common)
Climacograptus bicornis
Cl. peltifer (very common)
Cl. tridentatus
Corynoides calicularis
Orthograptus calcaratus
O. pageanus var. *abnormispinosus*
O. apiculatus
Glossograptus hincksii
Cryptograptus tricornis
Mastigograptus sp.

Climacograptus bicornis shows spines of most diverse form, ranging from very stiff and straight hairs to a pitchfork shape. In one case the two long, thick, stout, straight spines and the rhabdosome together make a figure like the Three Legs o' Man. The rhabdosome may be as long as 4·5 cm. but is usually shorter. *Cryptograptus tricornis* is up to 1·5 cm. long, which is unusual in this species in New South Wales. The variations in the appendages to *Cl. peltifer* have been commented on before (Sherrard, 1949). This graptolite is not common elsewhere in New South Wales. This assemblage has many species in common with the total assemblage from Balclatchie, Scotland (Bulman, 1947) but it does not correspond precisely with any of the separate bands.

The assemblage collected by Mr. R. A. Keble from near Tumbarumba occurs in a blue-black micaceous mudstone which is intruded by granite. The rock does not cleave parallel to the bedding and though graptolites are

TABLE I.

Localities in Zone of Nemagraptus pertenuis.

Column	1	2	3	4	5	6	7	8	9	10
Isograptus caduceus var. *tenuis* Harris	×	cf.								
Leptograptus validus Lapw.. .						cf. (Loc. 8)	cf. L. sp.			
Nemagraptus explanatus (Lapworth)				×						
N. explanatus var. *pertenuis* (Lapw.)	×			×				?		×
Dicellograptus divaricatus Hall	cf.	×		cf.	cf.		var.		D. sp.	
D. divaricatus var. *salopiensis* E. & W.		×	×					×		
D. patulosus Lapw.. . ..		×								
D. angulatus E. & W. ..		×						×		
D. sextans Hall							×			
Dicranograptus ziczac var. *minimus* Lapworth ..					×	×		×		
Climacograptus scharenbergi Lapw.			×							
Cl. antiquus Hall	cf. (rare)	×		×	cf.	cf.				
Cl. brevis E. & W.				×						
Mesograptus multidens E. & W *s*			×				M. sp.			cf.
M. foliace.u (Murchison) ..	×	×				×				
Orthograptus apiculatus (E. & W.)		×							×	
O. whitfieldi Hall		×								
O. calcaratus var. *acutus* Lapw.		×								cf.
Glyptograptus teretiusculus (His.)	×	×	×	×	v.c.	cf.				
Amplexograptus arctus E. & W.			×	cf.						
A. perexcavatus Lapw. ..		×		×						
Retiograptus geinitzianus Hall	×	×	?					×	×	
Lasiograptus mucronatus (Hall)		×	×							
L. mucronatus var. *bimucronatus* (Nich.)			×							
Cryptograptus tricornis (Carr.)							×			×
Dendroids	×	v.c.		×	×			×		

v.c. = very common.

Column

1	Mandurama-Walli, Licking Hole Creek, Cliefden Caves.
2	Tomingley.
3	Tumut Pond.
4	Cadia. Australian Museum Collection.
5	Mandurama, " Trilobite Hill ".
6	Mandurama, Localities 7 and 9.
7	Greenwich Park-Towrang Road. (Naylor, 1950.)
8	Parish of Lawson, County of Wellesley.
9	Cargo.
10	Captain's Flat. Railway Station.

common, they are difficult to determine and the assemblage may not belong to this zone.

The Yass River assemblages in this zone are rich in small dicellograptids which are identified as *D. angulatus* and small climacograptids, taken as *Cl.*

brevis. Small dicellograptids, such as *D. pumilus* and small examples of *Cl. minimus* are common in higher zones in the Yass River district.

The assemblage from Loc. 62, near Piccaree Hill, Nanima-Bedulluck, has been placed in the *Orthograptus calcaratus* zone, but at this locality there seems to be a passage down from a typical *O. calcaratus* assemblage to one in which small *Climacograptus bicornis*, *Cryptograptus tricornis* and *Lasiograptus harknessi* predominate, that is down to the *Cl. peltifer* zone.

TABLE II.

Localities in Zone of Climacograptus peltifer.

Column	1	2	3	4	5	6	7	8	9	10
Dicellograptus morrisi Hopk.			cf.			cf.				
D. caduceus Lapw.			×							
D. angulatus E. & W.				×						
Dicranograptus nicholsoni Hopk.	v.c.	cf.	×	×	×				? D. sp.	
D. ramosus var. *hians* (T. S. Hall)		×	×		×					
D. ramosus var. *spinifer* Lapw.		×								
D. ziczac Lapw.		×		×						
Climacograptus bicornis (Hall)	×	×	×	×	×	×	?		×	×
Cl. peltifer (Lapw.)	v.c.									
Cl. tridentatus (Lapw.)	×			×	×		?			
Cl. caudatus Lapw.		×	×							
Cl. brevis E. & W.		×		×						
Cl. scharenbergi Lapw.				?					?	
Orthograptus calcaratus Lapw.	×		var.			O. sp.				
O. pageanus Lapw.		×	×				cf.			
O. pageanus var. *abnormispinosus* E. & W.	×		×							
O. apiculatus (E. & W.)	×	×		×				cf.	cf.	
Cryptograptus tricornis (Carr.)	×	×	×	v.c.						
Glossograptus hincksii (Hopk.)	×							×		
Plegmatograptus nebula E. & W.		×								
Lasiograptus harknessi (Nich.)				×					?	var.
Corynoides calicularis Nich.	×									
Mastigograptus sp. indet. Ruedemann	cf.									

Column	
1	Shoalhaven Gorge, Loc. 11.
2	Shoalhaven Gorge, Locs. 16, 17.
3	Shoalhaven Gorge, Tolwong Mine.
4	Yass River, Locs. 17, 24, 34.
5	Snowy Mountains, Por. 95, Par. Bullenbalong.
6	Gygederick Hill, Berridale.
7	Tumbarumba-Jingellic.
8	Molong (*a*).
9	Molong (*b*).
10	Grabben Gullen.

Zone of *Climacograptus wilsoni.*

Graptolites occur in a slate dipping east at 80 degrees which has been quarried on Wagga Common, 20 chains west of Moorong Trig, Parish of Uranquinty, about three miles west of the town of Wagga. Graptolites, all diplograptids, are so prolific that in one case 50 can be counted in a space of four square inches. They are obscured, however, by the development of chiastolite, which frequently masks thecal character and proximal ends. In addition the slate does not cleave evenly. All diplograptids increase in width very gradually to a maximum of 3 mm., and are up to 6·5 cm. long. In many cases the rhabdosomes are not preserved in true profile, thecae on one side being climacograptid and on the other orthograptid in shape. Of a large number examined, only one is complete proximally with a thread-like virgella 3 mm. long.

The assemblage is considered to be best described as:

cf. Climacograptus wilsoni var. *tubularis*
Orthograptus calcaratus var.

The horizon may be somewhere about that of *Cl. wilsoni.* This attribution is supported by the wealth of diplograptids and absence of other families.

The assemblage of diplograptids poorly preserved in andalusite slate from Mt. Tallebung, 47 miles north-west of Condobolin (Raggatt, 1950) may belong to this zone.

Zone of *Orthograptus calcaratus* and *Plegmatograptus nebula.*

The assemblage in the lower beds on the eastern side of Wambrook Creek, Portion 40, Par. Lake, 11 miles west of Cooma, has been selected as the type for this zone. This assemblage is comparable with that of the British zone of *Dicranograptus clingani*, though no dicranograptid has been found at the type locality. *Dicranograptus ramosus* occurs in a collection in the Australian Museum made from this vicinity where graptolites are prolific. The assemblage is:

Dicellograptus caduceus
D. morrisi
Climacograptus bicornis
Cl. peltifer (very rare)
Cl. caudatus
Orthograptus calcaratus
O. cf. *apiculatus*

Plegmatograptus nebula, though not found at the type locality, is common in other outcrops of this zone, for example at Stockyard Flat Creek, County of Wellesley in the remote south-east of the State on the Victorian border (Dun, 1897; T. S. Hall, 1902). Dr. Hall described a new species, *Climacograptus hastata* from this locality. The holotype is in the Mining Museum, Sydney (F 3400). It is 8 cm. long, including virgula and a virgella of 1·2 cm. of which 0·5 cm. is covered by a membrane. The rhabdosome is 0·6 mm. wide proximally, increasing to 1·7 mm. after 1 cm., then to 2·2 mm. and no more. There is a very wide virgular tube (0·5 mm.) which can be seen within the rhabdosome before it emerges at the distal end to continue 1·1 cm. to the edge of the slab. Thecae are 9 in 10 mm. with their ventral walls convex at first and then pressed in their lower part into a concave curve. Thecal apertures usually show a sinuous curve. Four strong spines are attached to the basal thecae. *Cl. hastata* seems more satisfactorily placed in *Orthograptus calcaratus* (Plate XI, fig. 17). This species had not been raised above the rank of a variety of *Diplograptus foliaceus* when Hall wrote in 1902.

Hall also erected *Dicellograptus affinus* from material at Stockyard Flat Creek (Holotype F 3402, Mining Museum). Two dicellograptids are on the slab (Plate X, fig. 7) of which the right-hand one is that figured by Hall in Plate XIII, fig. 1 (Hall, 1902). The holotype carries a paper label between the stipes of the right-hand specimen "*Dicell. affinus* Type fig.". Hall gave no dimensions with his description other than "thecae . . . about 10 in 10 mm.", and he noted that the hydrosome resembled *D. morrisi* Hopk. The graptolite on the left-hand side of the slab has a hand-written paper label "fig. specn. F 3402". It is apparently the original of Plate XIII, fig. 3; *Dicellograptus* cf. *divaricatus*. However, its dimensions correspond with *D. morrisi*. In 1909 in referring specimens from Tolwong Mine to *D. affinus*, Hall wrote (p. 340) "the differences between *Dicello. elegans* and *D. affinus* are very slight, and I am not sure whether *D. affinus* is more than a variety with longer basal spines". A new description of *D. affinus* was issued by Keble and Harris in 1925 which showed that in the absence of dimensions in Hall's original diagnosis, new attributions to *D. affinus* differed considerably from Hall's holotype. The new description, for instance, gave maximum width for stipes of 0·6 mm. and their total length as usually less than 1 cm., whereas both graptolites on Hall's holotype have stipes more than 5 cm. long and the width of the stipes of the right-hand specimen increases from 0·6 cm. to 0·8 mm., which, with its other dimensions, shows that Hall was right in 1909 when he wrote that *D. affinus* was but a variety of *D. elegans*.

Hall (Plate XII, fig. 1, 1902) figured *Pleurograptus*(?) from Stockyard Flat Creek. On this slab (F 3412, Mining Museum) this graptolite is entangled in the long, drooping spines (1·2 cm. long) of *Cl. bicornis* (Plate X, fig. 1). It may be *Amphigraptus divergens* var. *radiatus*. Four very thin stipes (0·4 mm. wide) radiate from nearly the same point, 10 thecae occur in 10 mm., each being about 1·5 mm. long and overlapping for half its length. The association of this leptograptid with *Cl. bicornis* recalls the conditions at Wambrook Creek, Cooma, where *Pleurograptus linearis* occurs 25 feet stratigraphically above *Cl. bicornis* in the type locality of this zone, and a zonal boundary has been drawn between them. It may be that in New South Wales, leptograptids of the *Pleurograptus* and *Amphigraptus* type occur in lower strata than elsewhere and that no zonal boundary should be placed in Wambrook Creek. Other leptograptids, such as *Leptograptus capillaris* occur in association with *Orthograptus pageanus* and *Climacograptus bicornis* at Loc. 13, Shoalhaven Gorge, placed in this zone.

Zone of *Orthograptus quadrimucronatus* and *Pleurograptus linearis*.

Both index graptolites do not occur in all assemblages of this zone. *Orthograptus quadrimucronatus* is more widely distributed than *Pleurograptus linearis*. The assemblage at the Municipal Quarry, Portion 42, Par. Queanbeyan, 145 chains south of the Queanbeyan railway station, has been selected as the type for the zone. The graptolites occur in a blue-grey slate dipping west at 85 degrees and splitting along the bedding to almost paper-thin layers. Harris and Keble (1929) described a small collection from this locality which was erroneously stated in that paper to be within the Australian

TABLE III.

Localities in Zone of Orthograptus calcaratus *and* Plegmatograptus nebula.

Column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Amphigraptus divergens var. *radiatus* Lapw.								?									
Le.ptograptus flaccidus (Hall)				×	×		×		×		×						
L capillaris Carr.							×						×				
D.cellograptus morrisi Hopk.	×	×	×					×		×		×	cf.	×	D. sp.		
D caduceus Lapw.	×	×	×	cf.	×	×	×	cf.	cf.	×	×	×					
D˙ elegans Carr.		×	×	×				×		cf.	cf.						
D˙ pumilus Lapw.		×		×	×	×							×	cf.			
D. forchammeri var. *flexusosus* Lapw.		cf.					×	×					×	×			
Dicranograptus ramosus (Hall)			×							×	×					D. sp.	
D. ramosus var. *hians* (T. S. Hall)					×		×				×	×	×				×
D. nicholsoni Hopk.									×	×	×		×				
Climacograptus bicornis (Hall)	×		×	×	×	×	×	×		×		×		×		×	cf.
Cl. peltifer (Lapw.)	×																
Cl. tridentatus (Lapw.)						×		×	×								
Cl. caudatus Lapw.	×		×				×	×	×	×	×	×	×				×
Cl. minimus (Carr.)				×	×	×	×			×	?	×	×	×			cf.
Orthograptus calcaratus Lapw.	×	×	×	×	×			×	×	×	var.	var.	×	×	×	var.	
O. calcaratus var. *basilicus* Lapw.													×				
O. calcaratus var. *vulgatus* Lapw.		×	×	×											×		
O. pageanus Lapw.							×										
O. pageanus var. *abnormispinosus* E. & W.							×						×				
O. truncatus var. *pauperatus* E. & W.						×		×							×	×	
O. apiculatus (E. & W.)	cf.	×		×							×	×			×		
Glossograptus hincksii (Hopk.)			×									×	×				
Cryptograptus tricornis (Carr.)						×	×	×				×	×				
Plegmatograptus nebula E. & W.						×	×	v.c.					×				
Lasiograptus harknessi (Nich.)							×					×	×				
Corynoides sp. indet.							cf.					?					
Dendroid				×													

Column

1	Wambrook Creek, east side (lower beds), Por. 40, Par. Lake.
2	Wambrook Creek, west side (lower beds), Por. 47, Par. Lake.
3	Wambrook Creek, Australian Museum Collection.
4	Woodstock.
5	Yass River, Locs. 1, 11, 13, 16, 28, 32.
6	Shoalhaven Gorge, Loc. 9.
7	Shoalhaven Gorge, Locs. 13, 14.
8	Stockyard Flat Flat, County of Wellesley.
9	Tingaringi, County of Wellesley.

Column

10	Snowy Mountains, Locs. P.326, 486, 495.
11	Por. 42, Par. Lake, Cooma.
12	Nanima-Bedulluck, Locs. 61, 62, 63, 64.
13	Tallong, Locs. 3, 5, 8.
14	Five miles from Delegate.
15	Wellington.
16	Apsley.
17	Parish of Jinjera, south of Captain's Flat.

Capital Territory. Collections from this locality in the Australian Museum provide a representative assemblage, which is:

Leptograptus flaccidus
Dicellograptus caduceus
D. morrisi (very common)
D. elegans
D. pumilus
Climacograptus tubuliferus (very common)
Orthograptus quadrimucronatus
O. calcaratus
Mesograptus ingens

Each of these species except *Mesograptus ingens* and *Dicellograptus caduceus* occurs in Zone 13 of the British succession. Much the same assemblage is found in the Eastonian of Victoria, and the Mt. Peel beds, New Zealand (Keble and Benson, 1929) are also perhaps comparable.

The very large diplograptid, *Mesograptus ingens* (T. S. Hall) is confined to this horizon. Its development is probably related to that of large diplograptids found in other countries on high Ordovician horizons. *Orthograptus calcaratus* var. *basilicus* from the Hartfell Shales (A 19916, Sedgwick Museum, Cambridge) in the zone of *Pleurograptus linearis* is 12 cm. long and 4 mm. wide, with 10 to 8 thecae in 10 mm. The virgula is over 1 mm. wide and 2·5 cm. long. The thecae are long tubes with everted apertures but without visible spines. *Glossograptus quadrimucronatus* var. *paucithecatus* Decker from Arkansas (Decker, 1935; Ruedemann, 1947) is of the same great width and length, and occurs in uppermost Ordovician with *Dicellograptus complanatus* and *D. anceps* as associates. Pribyl (1951) records *Diplograptus vulgatus* up to 3·5 mm. wide and Boucek (1937) notes from the same uppermost Caradoc of Bohemia (Bohdalec Beds) a Mesograptid whose thecae resemble *Diplograptus multidens* and whose general form is like *Meso. modestus.*

This zone is also found on the Hume Highway in various road cuttings 8 to 10 miles east of Goulburn and near the intersection of the road to Brayton, where the assemblage is:

Pleurograptus linearis,
Climacograptus tubuliferus
Cl. supernus
Orthograptus quadrimucronatus.

These graptolites occur in steeply dipping bleached shales, which are in close proximity to shales with Silurian graptolites of the *Monograptus nilssoni* zone or Zone 33 of the British succession.

Naylor (1939, 1950) records from Ordovician outcrops in the same vicinity, assemblages of species which, though somewhat different from those given here, also belong to the *O. quadrimucronatus* zone.

P. linearis has also been collected at Wambrook Creek, 11 miles west of Cooma (Opik, 1952), in dark-blue slate dipping north at 50 degrees. Its only associate is a small *Dicellograptus caduceus* with stipes 1·5 cm. long which do not always cross. The slate at this locality conformably overlies slate with an assemblage belonging to the *Orthograptus calcaratus* zone. It has already been pointed out that the advent of *Pleurograptus* here may not indicate passage to a higher zone.

TABLE IV.

Localities in Zone of Orthograptus quadrimucronatus *and* Pleurograptus linearis.

Column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Leptograptus flaccidus (Hall)	×		2, 50	×		×				L. sp.		×	?					
Pleurograptus linearis Carr.							×		×									
Dicellograptus morrisi Hopk.	v.c.	×	×	×	×	×				×		cf.		? D. sp.			D. sp.	
D. caduceus Lapw.	v.c.	×	31 only						× small									
D. forchammeri Gein.				×	cf.								×					
D. elegans Carr.	×		×	×	×	×				×	cf.	cf.	×					
D. pumilus Lapw.	×		×	×	cf.	×				×	×							
Dicranograptus ramosus (Hall)			31 only										D. sp.					
D. ramosus var. *hians* (T. S. Hall) ..	very rare	×	41 only					×										
D. nicholsoni Hopk.		×																
Climacograptus tubuliferus Lapw.	v.c.	×	×	×	cf.	×	×				C. sp.	×	×					?
Cl. minimus (Carr.)		×	×	×				×		cf.								
Cl. supernus E. & W.							×											
Cl. caudatus Lapw.			×	×						×		×						
Orthograptus calcaratus Lapw.	×			×							var.	var.						
O. quadrimucronatus (Hall)	×	v.c.	×	×	cf.	×	×	×		×		cf.		×	×	?	×	cf.
O. quadrimucronatus var. *spinigerus* Lapw.		×									×							
O. truncatus var. *pauperatus* E. & W. ..			×			×												
O. pageanus Lapw.												×	?					
Mesograptus ingens (T. S. Hall)	×	×	50 only		×	×							×		×		?	×
Glossograptus hincksii Hopk.			41 only	×							?		cf.					
Retiograptus pulcherrimus K. & H. ..							×											
R. yassensis Sherrard and Keble			2 only															
Cryptograptus tricornis Carr.			×															
Plegmatograptus nebula E. & W.				×														

Column	
1	Queanbeyan.
2	Yalgogrin.
3	Yass River, Locs. 2, 3, 4, 31, 37, 41, 50, 52.
4	Tallong, Loc. 4.
5	Geehi River.
6	Hume Highway, 9 miles east of Goulburn.
7	Hume Highway, junction with Brayton Road.
8	Harman, one-half mile east of Railway Cutting.
9	Wambrook Creek, east side (upper beds), Por. 40, Par. Lake.
10	One and one-half miles west of Berridale, Por. 49, Par. Myack.
11	Snowy Mountains, Loc. P.767.
12	Portions 65, 111, Par. Coolrington, west of Cooma.
13	Abercrombie Range.
14	Brayton Road, one mile north of Hume Highway
15	Ariah Park.
16	Trunkey.
17	Taralga.
18	Cobargo.

Other Ordovician Occurrences.

In addition to the graptolites whose state of preservation has enabled them to be allotted to one of the zones in the Ordovician recognized in New South Wales, poorly preserved graptolites have also been obtained from a number of other localities.

The following occurrences can probably be assigned to a zone in the Caradoc:

1. Site of Adaminaby Dam, Snowy Mountains Authority, Parishes of Nimmo and Eucumbene, 8 miles south-south-west of Adaminaby. *Diplograptus* sp., *Climacograptus* sp., *Dicellograptus* sp., ?*Leptograptus* sp.
2. Localities near the Murrumbidgee River, about 13–14 miles east of Adaminaby; Portion 79, Par. Brest; Portion 64, Par. Backalum. *Diplograptus* sp. or *Climacograptus* sp.
3. Between the Murrumbidgee River and Adaminaby; Portion 87, Par. Bolaira.
   Diplograptus sp. (broad).
4. About 5 miles south-south-east of Berridale; Portion 28, Par. Bobundara.
   Diplograptus sp., *Climacograptus* sp. and *Dicellograptus* sp.
5. About 8 miles west of Cooma; Portion 153, Par. Coolringdon.
   Diplograptus sp. and *Climacograptus* sp.
6. Headwaters of Bundara Creek.
   Diplograptus sp. (broad).
7. Quaama; Por. 17, Par. Cadjangarry, 3 miles east of Quaama. *Diplograptus* sp.
8. About ¾ mile north-west Narira Trig, North of Cobargo.
   Diplograptus sp., *Climacograptus* sp. and *Dicellograptus* sp.
9. Weja, 3 miles north of railway station.
   Diplograptus sp.
10. 30 miles north-west of Crookwell, on road to Bigga between Markdale and Blanket Flat.
    Dicranograptus sp.

The following occurrences can probably be assigned to a zone in the Llandeilo:

1. North-west corner Portion 139, Par. Carlton, Cadia District
   Diplograptid.
2. Cadiangullong Creek, Grid: 937547, Canowindra sheet, Military Map.
   Glossograptus cf. *hincksii*
   Diplograptus or *Climacograptus*.
3. Belubula River near junction with Merrimalong Creek, Grid: 911496, Canowindra sheet, Military Map.
   cf. *Glyptograptus teretiusculus*.
4. North of Forest Reefs, 6 miles west of Millthorpe
   ?Glyptograptid.

Probable graptolite traces have been obtained from Buddong Falls, near Batlow.

Ordovician graptolites are reported from the following localities but have not been examined:

Cox's River, south-west of Katoomba (David and Browne, 1950, p. 156).
East of Braidwood (verbal communication).

Silurian.

Six graptolite zones can be recognized in the Silurian of the State. These correspond to Zones 19, 23, 28(?), 31(?), 33 and 34 of the British Silurian succession. In spite of the gaps in the zonal succession as recognized in Britain, the first four have been found in a conformable series dipping west at from 30 to 70 degrees at Four Mile Creek near Cadia (Stevens and Packham, 1953), and near Hatton's Corner, Yass, the last three zones occur in a conformable sequence (Brown and Sherrard, 1952).

Llandovery.

Zone of *Monograptus gregarius.*

The oldest zone in the Silurian recorded in New South Wales until the present is that of *M. gregarius* occurring at the bottom of the Four Mile Creek sequence, where the assemblage is:

M. gregarius
Climacograptus sp.

Sub-Zone of *Monograptus triangulatus.*

A collection made by Mr. N. C. Stevens (1954) on Angullong Property in Portion 112, Par. Carlton, several miles south of Four Mile Creek village, belongs either to the *M. triangulatus* sub-zone of the *M. gregarius* zone or possibly to a slightly higher zone. It contains:

Climacograptus hughesi
Glyptograptus tamariscus
G. sinuatus
Mesograptus sp.
Petalograptus sp.
Orthograptus insectiformis
Monograptus intermedius
M. triangulatus
? *Rastrites longispinus*
R. aff. *approximatus*

Zone of *Monograptus crispus.*

Twenty feet stratigraphically above the zone of *M. gregarius* at Four Mile Creek the zone of *M. crispus* is well represented with the following:

M. exiguus
M. marri
M. cf. *variabilis*
M. cf. *nodifer*
M. (?) *galaensis*
Retiolites geinitzianus.

The same zone is recorded from Bungonia (Naylor, 1935) with *M. exiguus* and *M. barrendei.* This zone is widely represented in Victoria (Keble and Harris, 1934; Thomas, 1947).

Wenlock.

Zone of *Cyrtograptus insectus.*

Some hundreds of feet of conformable strata separate the last zone from that of *Cyrtograptus insectus* at Four Mile Creek, where the following assemblage is recorded:

Cyrto. aff *insectus,*
Monograptus priodon,
Monograptid of *vomerinus* group.

The zone of *Cyrto. insectus* is recognized in Bohemia (Kettner and Boucek, 1936) between the British zones of *Cyrto. murchisoni* and *M. riccartonensis*. *Cyrto. insectus*, while similar to *Cyrto. symmetricus* and *Cyrto. rigidus*, is differentiated by the conspicuous thecal spines seen in some aspects under strong magnification.

Zone of *Monograptus testis*.

This zone, characteristic of beds at the top of the Wenlock in Bohemia, is represented in the Bedulluck area by the following assemblage (Sherrard, 1952):

Monograptus flemingii var. *elegans*
M. flemingii var. *compactus*
M. vomerinus
M. testis var. *inornatus*.

M. vomerinus has also been collected in other parts of the Yass District (Brown and Sherrard, 1952), notably at the bottom of the Hatton's Corner graptolite sequence.

The beds at the top of the conformable series at Four Mile Creek must be equivalent to this zone, since they contain the following assemblage:

M. dubius
M. cf. *vulgaris*.

M. flemingii var. *primus* found in Portion 134, Par. Carlton, to the south of Four Mile Creek, denotes the same zone.

Ludlow.

Zone of *Monograptus nilssoni*.

Shale with graptolites of this zone outcrops more or less persistently round the asymmetrical trough into which the Silurian at Yass is folded. It forms the middle member of a conformable series of three graptolite zones (Brown and Sherrard, 1952). Brachiopods, lamellibranchs and eurypterids are associated with the graptolites. An association with similar shelly fossils is recorded for this graptolite zone in Sweden (Hede, 1918). The assemblage at Yass is:

Monograptus nilssoni (including "*Linograptus*")
M. bohemicus
M. roemeri
M. crinitus
Dictyonema sp.

A similar graptolite assemblage is described from Oklahoma (Decker, 1935). The assemblage at Yass is found in a greyish-brown sandy shale dipping west-south-west at 7 degrees, but much the same assemblage is found in a very different facies at the junction of the Hume Highway with the Brayton road, 8 miles east of Goulburn, where *M. nilssoni* and *M. bohemicus* occur in white shale with an almost vertical dip (Naylor, 1939). *M. bohemicus* has also been recorded from near the town of Goulburn (Naylor, 1950) and with *M. chimaera* from east of Taralga (Naylor, 1938).

Zone of *Monograptus scanicus*.

The type area for this zone is Silverdale, Portion 34, Par. Derrengullen, 2 miles east-north-east of Bowning. The first record of graptolites from New

South Wales was from Bowning (Mitchell, 1886), but it is not known if they were from this locality. The assemblage at Silverdale is:

Monograptus salweyi
M. cf. *tumescens*
Dictyonema sp.

M. salweyi has also been found about 9 miles to the south-south-east at the junction of Taemas and Good Hope roads, Portion 15, Par. Hume, 1½ miles south-south-west of Yass railway station, where sandstone containing it conformably overlies shale with graptolites of the *M. nilssoni* zone. It is also found in other localities near Yass (Brown and Sherrard, 1952). In all cases, small brachiopods and crinoid stems occur on the same slabs as the graptolites.

M. salweyi has not been recorded from Victoria, but varieties of the Swedish form, *M. uncinatus,* to which it is closely related (Tullberg, 1882), occur widely (Thomas, 1947).

Stratigraphical Relationship Between Graptolite Zones.

A conformable passage from slates with graptolites of the *Orthograptus calcaratus* zone up to slates with those of a higher zone can be observed in Wambrook Creek, 11 miles west of Cooma, as has been explained. Elsewhere stratigraphical relationships are not so clear. The Yass River localities Nos. 2 and 24 with graptolites of the *Orthograptus quadrimucronatus* zone and the *Climacograptus peltifer* zone respectively are less than a quarter of a mile apart (Sherrard, 1943). The slates containing them are not in contact, but both dip at 40 degrees to the north-west and must be quite conformable. Apart from minor faults which are frequent within the series, all the Ordovician slates in the Yass River region appear conformable, although containing graptolites of three different zones.

In the Shoalhaven Gorge, graptolites of the zone of *Glyptograptus teretiusculus* have been collected recently by Messrs. K. Crook and M. Mackellar in quartzite at locality 18 on the right bank of Barber's Creek at its junction with the Shoalhaven River. Graptolites of the zone of *Orthograptus calcaratus* were collected almost immediately opposite on the left bank of the same creek in a cliff of blue-black slate dipping east (downstream) at 75 degrees (Loc. 9, Sherrard, 1949). These slates must overlie the quartzite with *Glyptograptus.* The junction is probably hidden by the great load of debris, mostly granite boulders 6 to 8 inches in diameter brought down by Barber's Creek, and dropped at its mouth.

Near Berridale, two zones have been recognized in outcrops about 3½ miles apart. Graptolites of the *O. quadrimucronatus* zone occur in spotted shales striking north-north-east and dipping almost vertically, which outcrop 1½ miles west of the town, while 2½ miles north-east of the town on Gygederick Hill, silicified slate dipping nearly west at 60 degrees, with graptolites probably of the *Climacograptus peltifer* zone has been collected. The structural relation between these slates has not been determined. Dr. W. R. Browne has pointed out (1944) that a record of *Didymograptus* and *Tetragraptus* from Berridale was an error.

In the Mandurama-Canowindra district, beds with graptolites of the *Glyptograptus teretiusculus* and *Nemagraptus* zones are widespread, but their relationship to slates with graptolites of younger zones at Woodstock and Wellington is not known. Conformable relations are pictured between strata in the Goulburn district which contain Ordovician graptolites from more than one zone (Naylor, 1950).

STRUCTURAL RELATIONSHIP BETWEEN ORDOVICIAN AND SILURIAN GRAPTOLITE-BEARING ROCKS.

In a number of places, such as Nanima-Bedulluck (Yass District), near Cadia and near Bungonia, rocks with Ordovician graptolites outcrop in fairly close proximity to rocks with Silurian graptolites, but the relations between the rocks of the two periods are never plain. At Piccaree Hill in the Nanima-Bedulluck area (Sherrard, 1952) steeply folded and denuded Ordovician slates occur as "islands" whose stratigraphical relation to the nearest Silurian rocks has not been determined after careful search. Locality 64 in this neighbourhood with Ordovician graptolites is about 5 miles north-north-west of locality 71 with Silurian graptolites of the *Monograptus testis* zone. The dips and strikes of the sedimentary rocks between them, where not hidden by igneous rocks or alluvium, seem quite concordant.

The relation between Ordovician and Silurian graptolite-bearing rocks is apparently also obscure near Cadia (Stevens and Packham, 1953). A faulted junction has been recognized in one place (Stevens, 1954).

In the district east of Goulburn, Naylor (1950) has postulated an overfolded anticline involving Ordovician and Silurian sedimentary rocks and apparently causing the Silurian to dip beneath the Ordovician in exposures near the intersection of the Hume Highway with the road to Brayton and on the Goulburn to Bungonia road. The structure, whatever it is, has to account for the close proximity of shales with Ordovician graptolites of Zone 13 to shales with Silurian graptolites of Zone 33 at the first locality and of Zone 23 at the second.

GRAPTOLITE-BEARING LOCALITIES.

Details of some localities have been given in the paper, others were listed in previous publications (Sherrard, 1943, 1949, 1952; Brown and Sherrard, 1952). Particulars of others referred to in the paper are as follows:

Apsley: near railway station, Portions 109, 281, Par. Wellington.

Ariah Park: 5 miles south-west of railway station, Portion 29, Par. Windeyer, Co. Bourke.

Cadia: Localities near Orange-Angullong road, near turn-off to Four Mile Creek Post Office: Loc. 12: 1¼ miles east of P.O.; Loc. 12a: 1½ miles north-east of P.O.; Loc. 13: 1⅜ miles south-east of P.O.; Loc. 13a: 1⅛ miles south-east of P.O.; Loc. g_1: south-west, Portion 113, Par. Clarendon; Loc. g_2: north-west, Portion 160, Par. Clarendon.

Cargo: Portion 98, Par. Cargo.

Cobargo: 7 miles east of Cobargo, on Bermagui road, Portion 176, Par. Bermaguee.

Geehi River: between Geehi River and Bogong Creek, Portion 15, Par. Hume, Co. Selwyn.

Grabben Gullen: Portion 152, Par. Grabben Gullen; Portion 194 or 195, Par. Lampton.

Jinjera, Parish of: 6½ miles south of Captain's Flat on Cooma Road, Portion 34.

Mandurama-Walli:

(*a*) Licking Hole Creek: Grid reference, Military Map, Canowindra Sheet: 818450.

(*b*) "Trilobite Hill": Grid reference, same sheet: 845468.

(*c*) Loc. 7: south of Belubula River, west of Cliefden Caves; Grid 856481.

(*d*) Loc. 8: north bank of Belubula River, north of Cliefden Caves: Grid 865487.

Molong:

(*a*) half-way between Molong and Euchareena, Parish of Copper Hill.

(*b*) 5 miles north-west of Euchareena, Portions 4, 10, 84, Par. Nubrigyn.

Quaama: 3 miles east of Quaama, on Pipeclay Creek, Portion 17, Par. Cadjangarry.

Shoalhaven Gorge: (Locs. 1–12 in Sherrard, 1949)

Loc. 13: Barber's Creek, about 1 mile upstream from junction with Shoalhaven River.

Loc. 14: about 100 yards downstream from Loc. 13.

Loc. 15: Barber's Creek (not *in situ*).

Loc. 16: Shoalhaven River, about 200 yards downstream from mouth of Bungonia Creek.

Loc. 17: Shoalhaven River, about 100 yards downstream from mouth of Bungonia Creek.

Loc. 18: right bank of Barber's Creek, in quartzite, near mouth.

Loc. 19: Bungonia Creek, upstream almost to limestone.

Snowy Mountains:

Loc. P.495. Centre of C.P.L. 85, Par. Backalum, Co. Wallace, about $3\frac{1}{4}$ miles north of Backalum Creek.

Locs. P.486, 326, north-east corner, Portion 84, Par. Backalum.

Loc. P.767, right bank Snowy River, north, Portion 113, Par. Beloka, Co. Wallace.

Taralga: 6 miles from Taralga on Bannaby road.

Tomingley: mine dump in village.

Trunkey: near Wilson's Reef, between Trunkey and Newbridge.

Tumbarumba: Carboona Gap, in road cutting, 18 miles south-west of Tumbarumba and 10 miles north-east of Jingellic.

Tumut Pond: south of Tumut River, south-east of camp, 1700 feet above it. Grid Reference: Military Map, Toolong Sheet: 295163.

Wellington: Res. 6, Par. Nanima, $1\frac{1}{2}$ miles north-west of Wellington on Wuuluman Road.

Woodstock: 1 mile north of Woodstock. Grid Reference: Military Map, Canowindra Sheet: 810305.

Yalgogrin: 3 miles north of Yalgogrin North, Portion 30, Par. Murrengrew (S.E.) and Portion 11, Par. Brolga (N.E.).

SYSTEMATIC DESCRIPTIONS.

Order Graptoloidea.

Family Isograptidæ.

Genus **Isograptus**

Isograptus caduceus var. *tenuis* Harris, 1933.

Plate X, fig. 5.

Graptolites (*Didymograpsus*) *caduceus* (*Salter*), McCoy, 1874, Prod. Pal. Vic. Dec. 2; 30, Pl. XX, figs. 3–5.

Isograptus caduceus var. *tenuis* Harris, 1933, 93, figs. 53, 54.

Horse-shoe shaped rhabdosome, stipes diverging downward first at 115 degrees, then upward at 300 degrees; stipes up to 1 mm. wide. Thecæ almost conical, 0·5 mm. wide at aperture but 0·25 mm. initially; 10 thecæ in 10 mm. 2·2 mm. long, inclined at 15 degrees, overlap one-fifth, apertures everted with strong denticle. Sicula stout and blunt.

Associates: *Nemagraptus explanatus* var. *pertenuis*, Dendroid.

Locality: Licking Hole Creek, Mandurama.

Family LEPTOGRAPTIDÆ.

Genus **Leptograptus.**

Leptograptus capillaris (Carruthers).

Plate XI, fig. 8.

Leptograptus capillaris (Carr.), Elles and Wood, 1903; 112; Pl. XV, figs. 4, a–d.

Stipes crowded and interlocked on slabs. Curved into almost complete circles. Stipes 0·4–0·6 mm. wide. Thecæ 10 in 10 mm., about 1·5 mm. long, overlap one half, ventral walls sigmoidally curved; apertures with denticles sometimes forming semi-circular excavation, sometimes introverted. No sicula seen.

No associate on same slab.

Locality: Public Reserve, Long Point, Tallong (Loc. 5, Sherrard, 1949).

Leptograptus flaccidus (Hall).

Plate X, fig. 3.

Leptograptus flaccidus (Hall), Elles and Wood, 1903, 106; Pl. XIV, figs. 1, a–g.

Stipes diverge at 215 degrees then after horizontal development of first theca, bend till 140 degrees between stipes, which may be over 8 cm. long when broken on edge of slab. Width 0·6 mm. proximally, 1·2 mm. distally. Sicula 2 mm. long. Thecæ, 8–10 in 10 mm., proximal thecæ being more widely spaced, each 2 mm. long, overlap one-third. Ventral margins, sigmoidally curved. Apertures often introverted, forming semi-circular excavation.

Locality, Associates: *Orthograptus calcaratus*, *Climacograptus bicornis* (at Yass River, Loc. 1); none at Barber's Creek, Shoalhaven River.

Nemagraptus explanatus var. *pertenuis* (Lapworth).

Plate X, fig. 2.

Nemagraptus explanatus var. *pertenuis* (Lapworth), Elles and Wood, 1903, 134; Pl. XIX, figs. 7, a–f.

Rhabdosomes incomplete. Very slender, gracefully curved stipes, dorsally flexed describing almost semi-circles, 0·25–0·35 mm. wide Angle of divergence 60 degrees, square axil. Stipes about 1·5 cm. preserved. Thecæ 9–11 in 10 mm. Thecæ 1·5–2 mm. long, almost no overlap, apertures apparently introverted. Thin branches about 1 cm. long rarely project from a theca.

Associates: *Retiograptus geinitzianus*, *Glyptograptus teretiusculus*.

Locality: Licking Hole Creek, Mandurama.

Family DICRANOGRAPTIDÆ.

Genus **Dicranograptus.**

Dicranograptus ramosus var. *spinifer Lapworth.*

Plate X, fig. 4.

Dicranograptus ramosus var. *spinifer* Lapworth, Elles and Wood, 1904, 176; Pl. XXIV, figs. 8, a–c.

Biserial section 2 cm. long, fusiform in shape, 1·0 mm. wide proximally, 3 mm. wide at 6 mm., decreases to 2·5 mm. near bifurcation. All biserial thecæ spined, 14 thecæ in first 10 mm. Virgella 0·5 mm. long. Spines generally appear apertural, sometimes mesial, up to 1 mm. long. Thecæ with curved ventral wall, 2 mm. long, overlap one-half, apertures generally slightly introverted. Uniserial stipes enclose angle of 40 degrees, they are 2 mm. wide, 11 thecæ in 10 mm., each 2 mm. long, overlap one-half, ventral walls curved, introverted apertures, no spines. Uniserial stipes broken at 3·5 cm.

Associates: *Dicranograptus ramosus* var. *hians, Plegmatograptus nebula.*

Locality: Shoalhaven River, 100 yards downstream from mouth of Bungonia Creek (Loc. 17).

Dicranograptus ramosus var. *hians* (T. S. Hall).

Dicranograptus hians T. S. Hall, 1905, Proc. Roy. Soc. Vict. (n.s.), XVIII; 24; Pl. VI, fig. 6.

Biserial section 3 mm. long, 1·5 mm. wide, with four thecæ on each side, each with rounded ventral walls. Uniserial stipes enclose angle of 110 degrees, they are 0·8 mm. wide and curve back towards one another slightly in 5 cm. or more of length. Thecæ 10 in 10 mm., each 2 mm. long, with ventral wall curved, overlap one-quarter. Well-marked septum in biserial section. Spines seldom seen. This species is identical with specimens A 19567 a, b in the Sedgwick Museum, Cambridge, labelled *Dicranograptus ramosus* var. *deflexus* Elles m.s. and regarded as equivalent to *Dicranograptus spinifer* var. *geniculatus* Ruedemann, 1908. T. S. Hall's published name takes precedence.

Associates and Locality: as for *D. ramosus* var. *spinifer.*

Family Diplograptidæ.

Genus **Climacograptus.**

Climacograptus wilsoni var. *tubularis* Elles and Wood.

Plate XI, fig. 18.

cf. *Climacograptus wilsoni* var. *tubularis* Elles and Wood, 1906, 199; Pl. XXVI, fig. 13.

Rhabdosome up to 6·5 cm. long, not including virgula. Width, 0·5 mm. proximally, 2·5 mm. distally, virgella thread-like 3 mm. long, though seldom retained. Basal spines sometimes seen. Thecæ 14–12 in 10 mm. each 1·5–2 mm. long, 0·4–0·6 mm. wide. Thecæ impressed below, aperture concave, denticle at apertural angle, overlap one-half. Exvacation marked, Septum incomplete. Thecæ alternate.

Associates: Diplograptids.

Locality: Wagga Common.

Genus **Diplograptus.**

Sub-genus **Orthograptus.**

Orthograptus pageanus var. *abnormispinosus* Elles and Wood.

Plate XI, fig. 11.

Orthograptus pageanus var. *abnormispinosus* Elles and Wood, 1907, 226; Pl. XXVIII, fig. 5a.

Rhabdosomes about 3 cm. long, width 1 mm. proximally, increasing to 4 mm. distally. Thecæ 12 in 10 mm., each 2·5 mm. long, ventral walls sigmoidally curved, each with fine spines but 9th and 10th or 13th and 14th thecæ have spines 5 mm. long. Basal spines also pronounced. Broad tube within rhabdosome. Virgula 5 mm. long where broken.

Localities: Shoalhaven Gorge, Locs. 11, 13, 15.

Associate: *Climacograptus bicornis.*

Orthograptus calcaratus var. *acutus* Lapw.

Plate XI, fig. 14.

Orthograptus calcaratus var. *acutus* Lapw., Elles and Wood, 1907, 242, Pl. XXX, figs. 3, a–c.

Rhabdosomes up to 6 cm. long and 4 mm. wide. Proximal end blunt. Thecæ 11–9 in 10 mm. normally, but 5 in 10 mm. in distorted forms. Each theca 3–5 mm. long, many with pronounced flange at angle of apertural and ventral walls. The long, thin forms from Captain's Flat seem best compared with this species. At this locality rhabdosomes up to 10 cm. long where broken distally. Complete proximally, 1·5 mm. wide proximally, 3·3 mm. wide at 2 cm., 4·0 mm. at 3·5 cm., which width is maintained. Short faint virgella in one specimen. Two curved basal spines, basal theca 1 mm. long with ventral wall horizontal for half length then curved vertically downward ending in basal spine. Later thecæ with half ventral wall vertical then bent in right angle and curving sigmoidally downward. Early thecæ 2 mm. long. Overlap about one-third. Apertures slightly everted. Proximal thecæ 10 in 10 mm. Periderm very thin but visible. At 3·5 cm. from proximal end, thecæ 4½ in 10 mm. At this distance the periderm is absent, lists outline thecæ. A very strong parietal list, ogee in shape, which is thicker on one side of rhabdosome than other, is joined to a fainter but distinct pleural list marking outer ventral wall and hour-glass-like in shape. Faint septal strands, apparently zig-zag can also be discerned. At this distance from proximal end, all thecæ at least 3 mm. long, overlap apparently slight. Where parietal and pleural lists meet a denticle is formed.

In spite of its greater length and tenuous periderm it bears comparison with normal specimens of *O. calcaratus* var. *acutus* from Tomingley. The greater length may be due to distortion. It also suggests *Retiograptus*.

Associate: *Mesograptus* cf. *multidens*.

Localities: Tomingley, Captain's Flat.

Sub-genus "**Mesograptus**".

Mesograptus ingens (T. S. Hall).

Plate XI, fig. 9.

Diplograptus ingens T. S. Hall, 1906, Rec. Geol. Surv. Vict., 1, 276; Pl. XXXIV, fig. 7.

Glossograptus quadrimucronatus var. *paucithecatus* Decker, 1935, 703; figs. 2, i–k.

Mesograptus ingens (T. S. Hall), Keble and Benson, 1939, 81.

Rhabdosomes large, F 30418, Aust. Mus. from Queanbeyan, 6 cm. long where cut off at edge of slab. Width at broad proximal end is 3 mm., 3·3 mm. at 1 cm., 4·5 mm at 3 cm. Thin virgella produced 4 mm., two mesial spines, curved, on basal thecæ, each 2 mm. long. Ventral edges of basal thecæ arranged horizontally. 11 thecæ in 10 mm., each 2 mm. long, ventral walls sigmoidally curved, apertures introverted, overlap one-half. Specimen from Loc. 50 Yass (Pl. XI, fig. 9), 2 cm. long, 2 mm. wide at blunt proximal end, increasing to 7 mm. wide at 1 cm. and decreasing to 6 mm. distally. Thecæ 9 in 10 mm., each straight tube with everted apertures and suggestion of short spine on some. Curved basal spines 2 mm. long. Virgula broken off at edge of slab. Another specimen from Queanbeyan shows a fragment of *M. ingens*, 9 cm. long, crossing a slab of slate from side to side with neither proximal nor distal

end visible. It is 3 mm. wide throughout and is traversed by a broad, virgular tube. Thecæ of typical undulate shape are 9 in 10 mm. with faint spines.
Associate: *Dicellograptus morrisi.*
Localities: Queanbeyan; Loc. 50, Yass River; Yalgogrin.

Mesograptus multidens Elles and Wood.

Plate XI, fig. 13.

cf. *Mesograptus multidens* Elles and Wood, 1907, 261; Pl. XXXI, figs. 9, a–d.

Rhabdosomes up to 4·5 cm. long, complete proximally but not distally; from 4·5 to 11 mm. wide with the average 8–9 mm. wide. Rhabdosomes widen rapidly from initial breadth of 2 mm. at the broad proximal end. Short, basal spines. Thecæ 8 in 10 mm., each about 4 mm. long and 0·5 mm. wide, overlap one-third. Test very attenuated, graptolite preserved as network with strongly developed parietal lists. Central virgular tube conspicuous, which is typical of *M. multidens*, though width of rhabdosomes too great and thecæ per 10 mm. too few for typical *M. multidens.* However, the slate at Captain's Flat in which cf. *M. multidens* occurs, has suffered intense pressure, which could have caused a graptolite which is convexo-concave in cross-section (as all *Mesograpti* are) to roll out to a great width. The dimensions of this graptolite under description agree more closely with those of *M. ingens*, but *M. ingens* does not occur with *Cryptograptus tricornis* and *Nemagraptus explanatus* var. *pertenuis* (of more or less normal width) which have been collected from the same locality though not on the same slabs as the *Mesograptus.*

Associate (on same slabs): cf. *Orthograptus calcaratus* var. *acutus.* At the same locality on different slabs *Cryptograptus tricornis, Nemagraptus explanatus* var. *pertenuis.*
Locality: Railway station, Captain's Flat.

Sub-genus **Glyptograptus.**

Glyptograptus tamariscus Nicholson.

Plate XI, fig. 19.

Glyptograptus tamariscus Nicholson, Elles and Wood, 197, 247; Pl. XXX, figs. 8, a–d.

Rhabdosome 5·5 mm. long of which virgella, which is complete, occupies 0·5 mm., increases in width from 0·6 to 1·4 mm., then slightly decreases. Thecæ alternate, 9 on each side, ventral wall with flowing sigmoidal curvature, thecæ up to 1·5 mm. long, overlap one-quarter to one-third. Excavation one-quarter width of rhabdosome. Apertural margins concave.
Associate: *Monograptus intermedius.*
Locality: Cadia district.

Glyptograptus teretiusculus (Hisinger).

Plate XI, fig. 16.

Glyptograptus teretiusculus (Hisinger), Elles and Wood, 1907, 250; Pl. XXXI, figs. 1, a–e.

Rhabdosomes up to 3 cm. long, seldom complete but one or two with conspicuous virgella 2 mm. long, and short basal spines. Virgula sometimes conspicuous, up to 2·5 mm. long. Well marked septum. Proximal width 0·5 mm. increasing to not more than 2 mm. Thecæ up to 16 in 10 mm., alternate, 1·5 mm. long, overlap one-sixth to one-third, ventral wall sigmoidally curved, drawn out to denticle. Excavation pouch-like, taking up one-half ventral margin and one-third width of rhabdosome. This graptolite differs from

Glyptograptus teretiusculus var. *euglyphus* in having far more thecæ per 10 mm.

Associates: *Isograptus caduceus, Nemagraptus explanatus* var. *pertenuis, Dicranograptus zic zac.*

Localities: Mandurama District, Cadia, Tumut Pond.

Family GLOSSOGRAPTIDÆ.

Genus **Retiograptus.**

Retiograptus geinitzianus Hall.

Plate XI, fig. 20.

Retiograptus geinitzianus Hall, Elles and Wood, 1908, 316; Pl. XXXIV, figs 7, a–d.

Rhabdosomes up to 8 mm. long and 2 mm. wide, exclusive of spines. Longest spines are 1·5 mm. long, occurring in central part of rhabdosome, where they are twice as long as others. Rhabdosomes devoid of test, except for slight indications in proximal portions up to about 3rd theca. Each rhabdosome formed of clathria of horizontal and vertical lists outlining thecæ which are diplograptid in shape and measure 15 in 10 mm., overlapping about three-fifths of length. Thecæ about 1·5 mm. long and 0·75 mm. wide, with two spines at intersection of apertural and ventral margins of thecæ, one stiff and straight, one drooping. Along mid-line of rhabdosome appears another set of thecæ as though the cross-section were cruciform. Stout virgella visible.

Associates: *Glyptograptus teretiusculus, Nemagraptus explanatus* var. *pertenuis.*

Localities: Licking Hole Creek, Mandurama, Tomingley.

Genus **Lasiograptus.**

Lasiograptus mucronatus var. *bimucronatus* (Nicholson), Elles and Wood.

Lasiograptus mucronatus var. *bimucronatus* (Nicholson), Elles and Wood, 1908, 323; Pl. XXXIII, figs. 8, a–e.

Rhabdosome up to 4 cm. length revealed, increasing in width from 1·5 mm. to 4·5 mm. Thecæ 14 in 10 mm., about 3 mm. long, apertural margins concave, apertural angles slightly introverted, slender spines visible on some. Very pronounced excavation, one-third width of rhabdosome. In one case a membrane connects many of the elongated spines giving the appearance of a flag 2·5 mm. long and 0·6 mm. wide flung out from either side of the rhabdosome. These represent the scopulate processes seen in this variety. The rhabdosome has a lax appearance.

Locality: Tumut Pond.

Family MONOGRAPTIDÆ.

Genus **Monograptus.**

Monograptus triangulatus (Harkness).

Plate XI, fig. 22.

Monograptus triangulatus (Harkness), Elles and Wood, 1913, 471; Pl. XLVII, figs. 4, a–f.

Rhabdosome incomplete, convexly curved, 7 mm. long, width including thecæ 1·5 mm. 9 triangular thecæ, scarcely in contact, each about 2 mm. long, with ventral (lower) edge crescentic, very slightly recurved at tip. Greatest width of theca 0·5 mm.

Associates: *M. intermedius, ?Rastrites longispinus.*

Locality: Portion 112, Par. Carlton. Cadia district.

Monograptus intermedius (Carruthers).

Plate XI, fig. 21.

Monograptus intermedius (Carr.), Elles and Wood, 1913, 485; Pl. XLIX, figs. 3, a–c.

Rhabdosomes incomplete, 1·5 cm. long; 0·6 mm. wide including barb, ventral curvature, thecæ 10 in 10 mm., each about 1·5 mm. long, overlap one-half, ventral margin sigmoidally curved with recurved barb.
Associates and locality: as for *M. triangulatus*.

Rastrites longispinus (Perner).

Plate XI, fig. 21.

?*Rastrites longispinus* (Perner), Elles and Wood, 1914, 489; Pl. L, figs. 2, a–g.

Distal fragment 5 mm. long, shows slight convex curve and is not more than 0·25 mm. wide. Thecæ 4 in 5 mm., on convex side of rhabdosome, each 4 mm. long with reflexed apertural termination.
Associates and locality: as for *M. triangulatus*.

SUMMARY.

Rocks from over one hundred localities in New South Wales containing graptolites have been placed in seven zones of Ordovician age and six zones and one sub-zone of Silurian age on the basis of the assemblages of graptolites they contain. Correlations with graptolite-bearing strata in other countries are suggested. Some of the localities have not been recorded previously as possessing graptolite-bearing strata, and some of the graptolites are recorded and described for the first time for New South Wales. Lists of assemblages of graptolites identified from each locality are given. The localities are shown on a sketch-map, on which is shown also, where possible, the direction of the general fold axes of the Ordovician strata.

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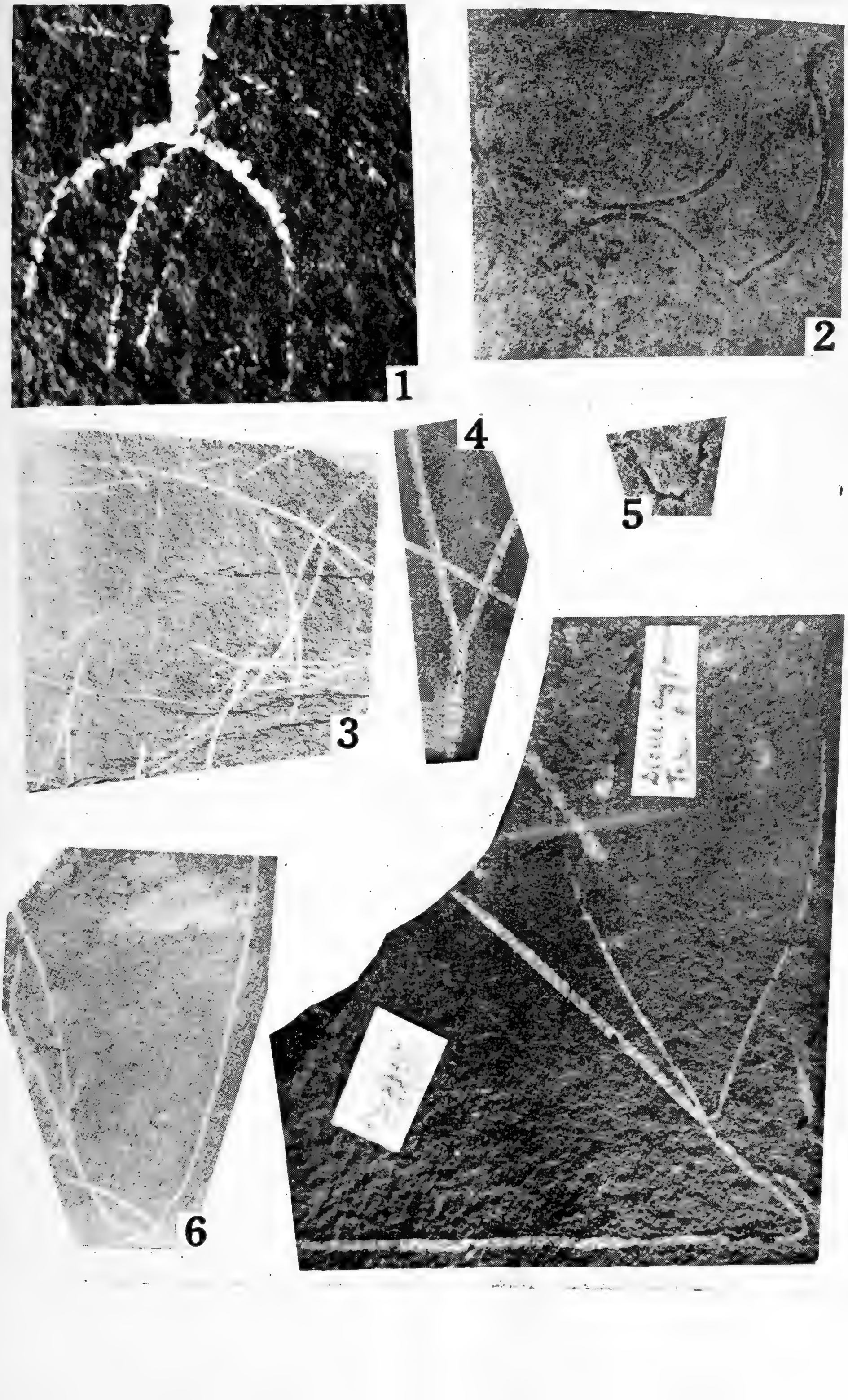
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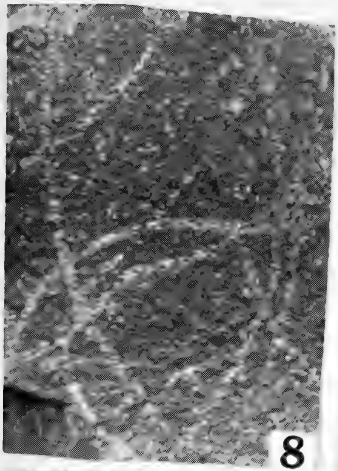

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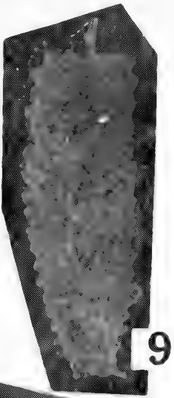

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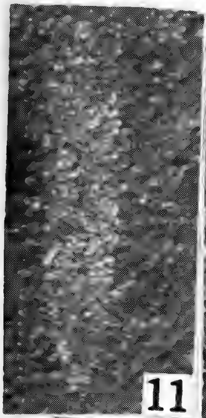

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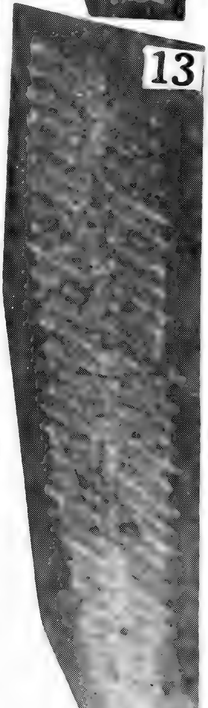

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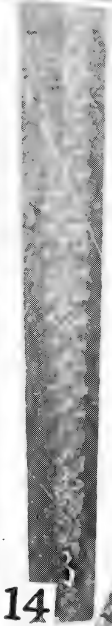

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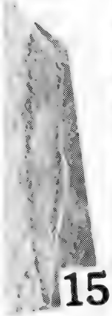

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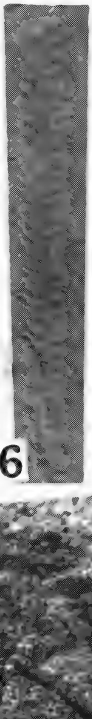

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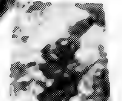

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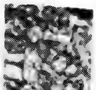

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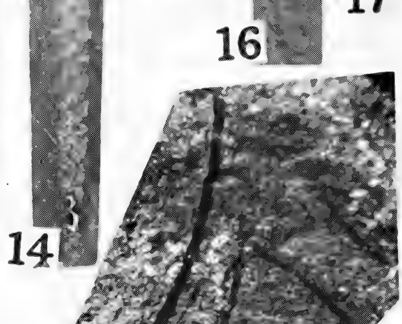

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EXPLANATION OF PLATES.

PLATE X.

Fig. 1.—*Cf. Amphigraptus divergens* var. *radiatus* Lapw. and *Climacograptus bicornis* (Hall), Stockyard Flat Ck. (F.3412, Mining Museum). Mag. ×4.

Fig. 2.—*Nemagraptus explanatus* var. *pertenuis* (Lapw.), Licking Hole Ck. Mag. ×3.

Fig. 3.—*Leptograptus flaccidus* (Hall), Barber's Ck., Shoalhaven Gorge. Mag. $\times\frac{2}{3}$.

Fig. 4.—*Dicranograptus ramosus* var. *spinifer* Lapworth, Loc. 17, Shoalhaven Gorge. Mag. ×1.

Fig. 5.—*Isograptus caduceus* var. *tenuis* Harris, Licking Hole Ck. Mag. ×1.

Fig. 6.—*Dicellograptus elegans* Carr., Loc. 31, Yass River. Mag. ×1.

Fig. 7.—*Dicellograptus elegans* and *D. morris*, holotype of "*Dicellograptus affinus*" T. S. Hall, Stockyard Flat Ck. (F.3402, Mining Museum). Mag. ×1.

PLATE XI.

Fig. 8.—*Leptograptus capillaris* (Carr.), Long Point Lookout, Tallong. Mag. ×2.

Fig. 9.—*Mesograptus ingens* (T. S. Hall), Loc. 50, Yass. Mag. ×2.

Fig. 10.—*Dicellograptus morrisi* Hopk., Wambrook Ck., Cooma. Mag. ×1.

Fig. 11.—*Orthograptus pageanus* var. *abnormispinosus* E. & W., Barber's Ck., Shoalhaven Gorge. Mag. ×2.

Fig. 12.—*Mesograptus foliaceus* (Murch.), Loc. gl, Cadia. Mag. ×3.

Fig. 13.—*Mesograptus cf. multidens* or *ingens*, Captain's Flat. Mag. ×2. Coll. Bureau of Mineral Resources.

Fig. 14.—*Cf. Orthograptus calcaratus* var. *acutus* Lapw., Captain's Flat. Mag. ×1.

Fig. 15.—*Hallograptus mucronatus* (Hall), Tumut Pond. Mag. ×1.

Fig. 16.—*Glyptograptus teretiusculus* (His.), as for Fig. 2. Mag. ×3.

Fig. 17.—*Orthograptus calcaratus* ("*Climacograptus hastata*", T. S. Hall, holotype), F.3400, Mining Museum. Mag. ×1.

Fig. 18.—*Climacograptus wilsoni* var. *tubularis* E. & W., Wagga. Mag. ×1.

Fig. 19.—*Glyptograptus tamariscus* Nich., Portion 113, Par. Carlton, Cadia. Mag. ×3.

Fig. 20.—*Retiograptus geinitzianus* Hall, Loc. as for Fig. 2. Mag. ×3.

Fig. 21.—*Monograptus intermedius* (Carr.) and ? *Rastrites longispinus* (Perner), Loc. as for Fig. 19. Mag. ×3.

Fig. 22.—*Monograptus triangulatus* (Hark.), Loc. as for Fig. 19. Mag. ×3.

Note.—Nos. 2, 5, 8, 12, 16, 19, 20, 21, 22 collected by Mr. N. C. Stevens.
Nos. 3, 4, 11 collected by Messrs. M. MacKellar and K. Crook.

THE ESSENTIAL OIL OF *BACKHOUSIA MYRTIFOLIA* HOOKER *ET* HARVEY.

PART II. THE OCCURRENCE OF PHYSIOLOGICAL FORMS.

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SUMMARY.

The essential oils from foliage of four trees of *Backhousia myrtifolia* Hooker *et* Harvey from Fraser Island, Queensland, have been examined. One of the oils corresponded to the form originally described by Penfold (Part I, 1922) in containing elemicin as the major constituent. Two oils contained *iso*-elemicin as major constituent, whilst the fourth consisted principally of methyl *iso*-eugenol. The detection of methyl eugenol in substantial amount, together with the foregoing phenol ethers, in an oil distilled from a " bulk-cut " of foliage from the same population indicates the probable existence of a third physiological form within this species. A biosynthetic mechanism appears to be in operation in this species, similar to that in *Melaleuca bracteata* F. Muell. (Penfold *et al.*, 1950).

The occurrence of *iso*-elemicin in nature is recorded for the first time.

INTRODUCTION.

In Part I, Penfold (1922) showed that the essential oil obtained on steam-distillation of the foliage of *Backhousia myrtifolia* Hooker *et* Harvey collected from the vicinity of Sydney and southwards to Currowan, N.S.W., consists of 75 to 80 per cent. of elemicin (1,2,6-trimethoxy-4-allylbenzene), no other phenol ether being detected. Recently, however, a consignment of mixed foliage collected from several trees of the same species from Fraser Island, Queensland, was steam-distilled, and the essential oil was found to differ markedly from the elemicin form previously described, which is now designated the Type.

The essential oil from this bulk cut of foliage (Part *A* in the Experimental section), like that from the Type, was heavier than water ; but, in addition to elemicin, it contained methyl *iso*-eugenol as a major constituent, together with methyl eugenol and *iso*-elemicin. The presence of the asarones was suspected from the high refractive index of the *iso*-elemicin fraction, but the quantity of material available did not permit separation. Associated with the phenol ethers are small amounts of terpenes (principally α-pinene), unidentified esters, paraffins, and an alkali-soluble substance.

In order to determine whether these trees all produce the above mixture of compounds, or whether the population is made up of a number of physiological forms, samples of leaf from individual trees were secured, and the oils submitted to separate examination (Part *B* of the Experimental section). It was found that it is highly probable that individual trees produce oils containing as a major constituent a single phenol ether only. The occurrence of different but closely related compounds as major constituents in individual trees of the same species is very interesting from the biogenetic point of view, particularly as a similar series of compounds has been found in *Melaleuca bracteata* F. Muell. (Penfold *et al.*, 1950). Apparently a similar biosynthetic mechanism is in operation in both species.

The occurrence in nature of *iso*-elemicin is of interest, since this is the first instance of which the authors are aware.

Further work on this species is in progress, since the presence of further forms in other localities is suspected.

EXPERIMENTAL.

(All melting points are uncorrected.)

(*A*) *Mixed Foliage.*

The foliage used consisted of air-dry leaves and terminal branchlets weighing 184·5 lb., which on steam-distillation yielded 0·35% of an amber-coloured heavier-than-water oil, possessing the following characteristics:

Specific gravity at 15°/15°	1·031
Refractive index at 20° C.	1·5368
Optical rotation, 100 mm. tube	Too dark to read
Do., after NaOH wash	+0·29°
Solubility in 70% (W/W) alcohol	1·0 volume
Acid number, mg. KOH/g.	1·2
Ester number, mg. KOH/g.	6·6
Do., after acetylation	6·8

The crude oil (160 ml.) was shaken twice with aqueous sodium hydroxide solution (10%; 100 ml.), twice with brine (15%; 100 ml.) and finally with water (50 ml.). The pale amber-coloured oil had d_{15}^{15} 1·031, n_D^{20} 1·5372 and α_D +0·29°, after drying with anhydrous magnesium sulphate. From the alkaline extract was obtained 0·665 g. of a viscous liquid of phenolic odour and giving a fugitive dirty violet colour with alcoholic $FeCl_3$ solution. Its identity could not be determined.

Fractional Distillation (see Table 1). 135 ml. of the alkali-washed oil were fractionally distilled at 10 mm., using a dry-ice and acetone trap between the fraction take-off and the vacuum pump.

TABLE 1.

Fraction.	Boiling Range.	Volume.	d_{15}^{15}	n_D^{20}	α_D
Trap	—	1·6 ml.	0·8664	1·4742	Inactive.
1	42°– 60°	8·6 „	0·8590	1·4743	Inactive.
2	60°– 80°	2·0 „	0·8584	1·4792	+2·6°
3	80°–115°	4·7 „	0·9104	1·4775	+3·1°
4	115°–126°	6·3 „	0·9747	1·5110	—1·6°
5	126°–136°	29·0 „	1·040	1·5444	Inactive.
6	136°–140°	43·5 „	1·060	1·5544	Inactive.
7	140°–144°	12·5 „	1·069	1·5436	Inactive.
8	144°–151°	8·5 „	1·074	1·5391	Inactive.
9	151°–157°	10·0 „	1·083	1·5519	+0·21°
Residue	—	4·8 „	—	1·543 (approx.)	—

Determination of α-pinene. The 1·6 ml. from the trap was mixed with fraction 1 and the first 7 ml. (b.p. 156°–165°) slowly distilled off at 760 mm. This yielded a *nitrosochloride,* m.p. 103°–104° (decomp.), undepressed on admixture with an authentic specimen of *α-pinene nitrosochloride* of m.p. 103°. Each was then recrystallized to 107° and 107·5° respectively, and no depression of m.p. of the mixed product was noted. A final recrystallization to m.p. 110° and 109° respectively showed a mixed m.p. of 109·5°.

A further portion of this fraction (4 ml.) was oxidized in the usual way with permanganate to furnish an *acid* which failed to crystallize, and which was converted directly to a *semicarbazone* of m.p. 207°, undepressed by admixture with an authentic specimen of dl-*pinonic acid semicarbazone.*

Other Terpenes. Fraction 2, terpenic in nature, failed to yield either a nitrosite or a bromide. Limited quantity of material prevented further investigation.

Determination of Methyl Eugenol. From fraction 5 was prepared, on re-fractionation, a fraction having d^{15}_{15} 1·028, n^{20}_{D} 1·5348, α_D ±0°. The fraction (2 ml.) when brominated by the method of Underwood, Baril, and Toone (1930) yielded white needles, m.p. 77° from absolute alcohol, undepressed on admixture with an authentic specimen of *bromoeugenol methyl ether dibromide.* Another portion of the fraction (7 ml.), oxidized with aqueous potassium permanganate according to Wallach and Rheindorff (1892), yielded *veratric acid,* m.p. 181·5°, undepressed on admixture with an authentic specimen.

Determination of Methyl Iso-eugenol. Fraction 6 was re-fractioned to give a main fraction b_{10} 139°–140°, d^{15}_{15} 1·058, n^{20}_{D} 1·5589, α_D, ±0°, also yielding veratric acid on permanganate oxidation as just described, but in addition yielding by Underwood, Baril and Toones' (*loc. cit.*) procedure a *dibromide,* m.p. 102° from dry ether, undepressed on admixture with an authentic specimen of *methyl iso-eugenol dibromide.*

Determination of Elemicin. Fractions 7 and 8 were combined, and on re-fractionation a fraction was obtained b_9 143°, d^{15}_{15} 1·070, n^{20}_{D} 1·5372, α_D ±0°. Seven ml. were oxidized with alkaline aqueous potassium permanganate solution ($KMnO_4$, 15·4 g. ; KOH, 2·1 g. ; H_2O, 490 ml., and ice 490 g.). From the reaction mixture, after removal of MnO_2 and acidification, was isolated *trimethyl gallic acid,* m.p. 169° from alcohol, undepressed on admixture with an authentic specimen. Ether extraction of the mother-liquor from the precipitation of this acid yielded *trimethyl homogallic acid,* m.p. 118·5°–119°, undepressed by an authentic specimen.

Determination of Iso-elemicin. Fraction 9 (5 g.) was oxidized with $KMnO_4$ according to Fabinyi and Széki (1906). A good yield of *trimethyl gallic acid* was obtained, m.p. 170°, undepressed on admixture with authentic material. 0·4092 g. required 19·2 ml. 0·1 N NaOH. Neutralization equivalent, 212·7. Calculated for $C_{10}H_{12}O_5$, 212·2. No trimethyl *homo*gallic acid could be found among the products of oxidation. Fraction 9 (1·2 g.), brominated by the procedure of Semmler (1908), yielded 1·0 g. of a white crystalline *dibromide,* m.p. 91° from petroleum ether. A duplicate preparation gave a product m.p. 90·5°. Found : C, 39·37, 39·14% ; H, 4·35, 4·48% ; Br, 43·0, 43·2%. Calculated for $C_{12}H_{16}O_3Br_2$: C, 39·15% ; H, 4·38% ; Br, 43·42%.

Occurrence of Paraffins. From the residue (4·8 ml.) in the still-pot a small quantity of a light waxy deposit precipitated which could not be purified to constant melting point. It appeared to be a mixture of higher paraffins.

(*B*) *Individual Trees.*

Four trees, forming part of the population from which the mixed foliage described in (*a*) was collected, were selected at random and the foliage therefrom steam-distilled to furnish the oils shown in Table 2. Phenol ether contents, calculated as the major phenol ether subsequently found, were determined by the Zeisel method for alkoxy groups.

On fractional distillation *in vacuo,* each of the above oils gave a major fraction of fairly constant boiling point. Data for this fraction only are given in each case.

Tree No. 1. b_{11} 143°–144° ; d^{15}_{15} 1·054 ; n^{20}_{D} 1·5659 ; α_D, inactive. Bromination as previously described for methyl *iso*-eigenol yielded a *bromide,* m.p. 102°, undepressed by *methyl* *iso-eugenol dibromide.* Oxidation by permanganate gave a white crystalline *acid,* m.p. 182°, undepressed on admixture with *veratric acid.*

Tree No. 2. $b_{10\cdot5}$ 142°–150° ; d^{15}_{15} 1·067 ; n^{20}_{D} 1·5312 ; α_D inactive. Seven grammes of the fraction, oxidized by alkaline permanganate, gave two *solid acids,* m.p. 170° and m.p. 118°–119°, undepressed by *trimethyl gallic acid* and *trimethyl homogallic acid* respectively. Neither the fraction nor the still-residue could be induced to give a solid bromide.

Tree No. 3. b_{10} 153°–160° ; d^{15}_{15} 1·079 ; n^{20}_{D} 1·5474 ; α_D inactive. Seven grammes oxidized by alkaline permanganate gave a solid *acid* m.p. 170·5°, undepressed by *trimethyl gallic acid.* No trimethyl *homo*gallic acid could be found. Bromination yielded a *dibromide* m.p. 91°, undepressed by *iso-elemicin dibromide.*

TABLE 2.

Tree Number.	1	2	3	4
Weight of leaf	53 lb.	25·5 lb.	44 lb.	35·5 lb.
Yield of oil	0·71%	0·40%	0·28%	0·10%
Sp. gr. at 15°/15°	1·028	1·027	1·047	1·045
Refr. index, 20° C.	1·5489	1·5181	1·5332	1·5411
Opt. rot., 100 mm.	+1·0°	+1·2°	Inactive.	Inactive.
Solubility in 70% W/W alcohol ..	0·8 vol.	0·8 vol.	0·8 vol.	0·7 vol.
Phenol ether content	80·7% (calc. as methyl *iso*-eugenol).	72·1% (calc. as elemicin).	78·4% (calc. as *iso*-elemicin)	77·5% (calc. as *iso*-elemicin)

Tree No. 4. Only six grammes of oil were obtained from this tree, and this could only be roughly resolved into a main fraction, b_{10} 148°–156° ; d^{15}_{15} 1·066 ; n^{20}_{D} 1·5449 ; α_D, inactive. It gave, however, a copious yield of a white crystalline *dibromide,* m.p. 91°–91·5°, undepressed by *iso-elemicin dibromide.* Insufficient material prevented oxidation from being carried out, but this was done for the material from tree No. 3.

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NARRABEEN GROUP: ITS SUBDIVISIONS AND CORRELATIONS BETWEEN THE SOUTH COAST AND NARRABEEN–WYONG DISTRICTS.

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With one Text-figure.

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INTRODUCTION.

The nomenclature of the Mesozoic rock units in the Cumberland Basin has been dealt with by Hanlon, Joplin and Noakes (1952), the revised nomenclature being as follows:

Wianamatta Group.
Hawkesbury Sandstone.
Narrabeen Group.

These beds are probably of Triassic age.* The present paper deals with the further subdivisions of the Narrabeen Group.

It is not proposed to review the literature in detail, as this has already been done in the paper referred to above. However, one point which needs clarifying arises from doubts which have been expressed as to whether the "Upper Narrabeen" of Raggatt (1938) should be included in the Narrabeen Group, or whether all the beds above the so-called "Chocolate Shales" should be regarded as part of the Hawkesbury Sandstone. As long ago as 1885 Wilkinson (1885) referred to fossil plants found by himself and David in "the shale beds immediately underlying the Hawkesbury Sandstone on the coast at Narrabeen". The fossiliferous shale beds are above the so-called "Chocolate Shales" and Wilkinson would have included the Upper Narrabeen of Raggatt in the Narrabeen Group. Most authors have followed this procedure in recent years.

The authors of this paper have been or are interested mainly in different areas. One (H.G.R.) has worked mostly from the Hawkesbury River northwards through Gosford and Wyong to the Broke-Denman area. The results of this work were embodied in a thesis (Raggatt, 1938) presented to Sydney University for the degree of Doctor of Science. In the thesis the Narrabeen Group was referred to as the Narrabeen Series and subdivided into Upper, Middle and Lower Narrabeen. Another author (F.N.H.) has been concerned with the stratigraphy of the Narrabeen Group mainly in the Southern Coalfield, where he is conducting a geological re-survey, and neighbouring areas, as well as in the North-western Coalfield to the north-west of Murrurundi. The third author (G.D.O.) has worked in the Pittwater area south of the Hawkesbury

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* The possibility that the upper part of the Wianamatta Group may be Jurassic needs to be envisaged.

River and in the National Park-Clifton district (Osborne, 1948), his work thus serving, to some extent, as a link between that of the other authors.

The present subdivisional names do not accord with the principles laid down in the Australian Code of Stratigraphic Nomenclature. The purpose of the present paper is to revise the nomenclature and to indicate the probable correlation between the rock units of the South Coast and the Narrabeen-Wyong districts.

Proposed Nomenclature.

The proposed nomenclature and the correlation between the Narrabeen-Wyong and South Coast districts are set out in Table I. Comparative sections from the South Coast through Sydney to the Wyong district are shown in Figure 1. From this it will be seen that there is a general thinning from north to south which applies particularly to the Gosford Formation.

Table I.

Subdivisions of the Narrabeen Group, showing Correlation between the Narrabeen-Wyong and South Coast Districts.

	Narrabeen-Wyong District.	South Coast District.
Gosford Formation.	Mangrove Sandstone Member. Ourimbah Sandstone Member. Wyong Sandstone Member.	No members named at this stage.
Clifton Sub-Group.	Collaroy Claystone.	Bald Hill Claystone.
	Tuggerah Formation.	Bulgo Greywacke.
		Stanwell Claystone.
	Munmorah Conglomerate.	Scarborough Greywacke.
		Wombarra Shale. Otford Greywacke Member.
		Coalcliff Greywacke.

It will be noted that in the above table the rock unit name of " Sub-Group " has been used. The use of this term in cases where no alternative is practicable was approved recently by the A.N.Z.A.A.S. Standing Committee on Stratigraphic Nomenclature (Raggatt, 1953). In this case the necessity to use the term arises from the desire to alter accepted terminology as little as possible. Present knowledge indicates that the lower part of the Triassic System along the Central Coast of N.S.W. comprises one rock group from the top of the Newcastle Coal Measures to the top of the so-called " Upper Chocolate Shales ", separated in many areas from the overlying Hawkesbury Sandstone by a formation which in most places at least is lithologically distinct from both. As the term " Narrabeen Shale Beds " (Wilkinson, 1887) includes the top beds of the " Upper Chocolate Shales " *and* the overlying fossiliferous shales ; and the term " Narrabeen " is generally accepted as including all beds down from the base of the Hawkesbury Sandstone as exposed at Narrabeen to the top of the Newcastle Coal Measures, considerable confusion would probably be caused if the term " Narrabeen " were restricted to either the basal group or the overlying formation. Under these circumstances it is considered advisable to classify the basal unit as a " Sub-Group " and include it and the overlying formation in the Narrabeen Group.

GOSFORD FORMATION.

The formation is typically developed in the Gosford District and is named after the town of Gosford, located in latitude S. 35° 25′ and longitude E. 151° 21′. It comprises mainly shales, shaley sandstones and sandstones and was referred to by Raggatt (1938) as the Upper Narrabeen. This author (H.G.R.) was principally concerned with structural geology and, for this reason, only the prominent members in the Gosford Formation which were used as horizon markers for structural control were named.

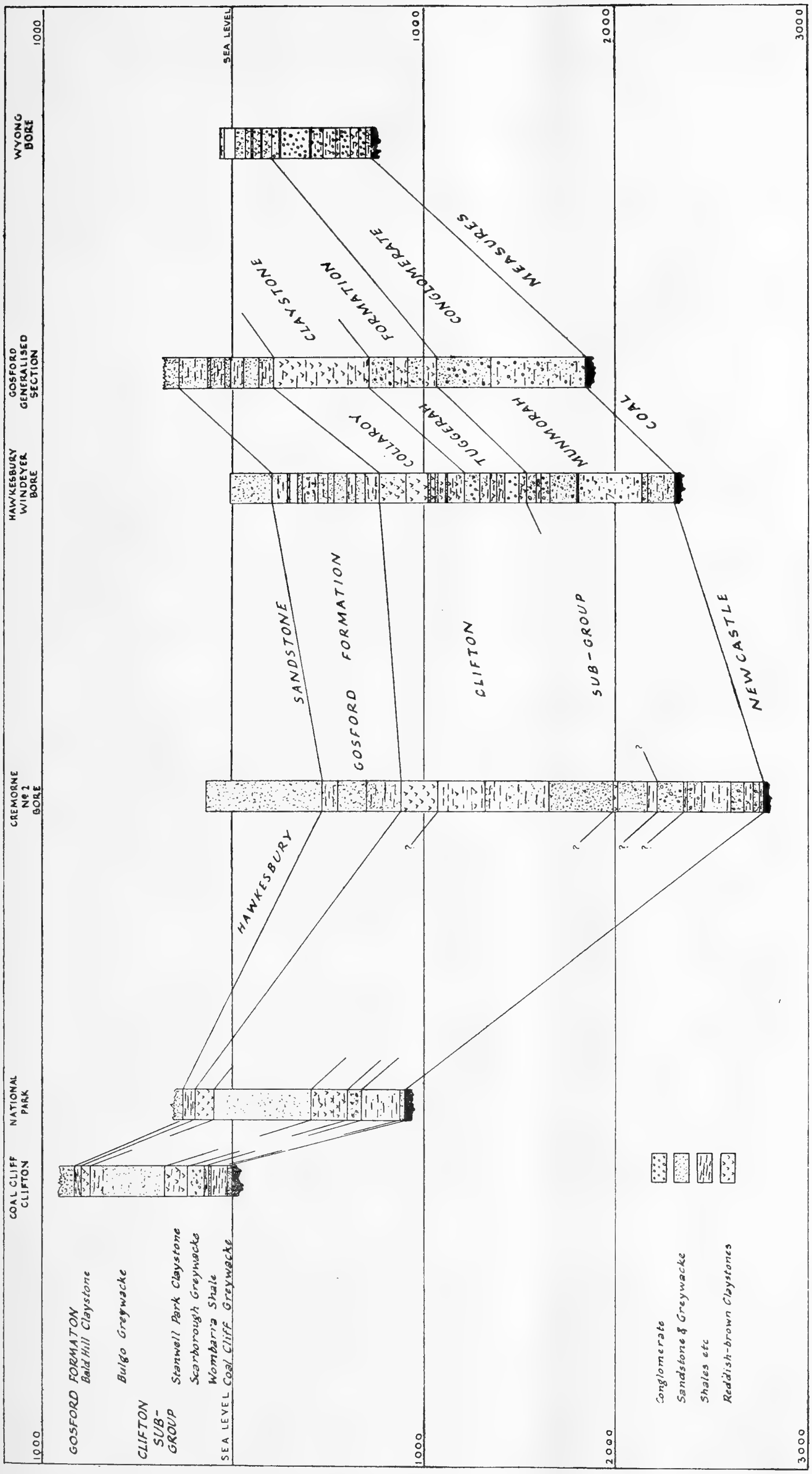
The difference between the Gosford Formation and the overlying Hawkesbury Sandstone in the Gosford District will be apparent from the detailed descriptions given below. Generally speaking, the sandstones contain a much larger proportion of matrix than in the typical Hawkesbury Sandstone and tend towards greywackes in composition.

The Gosford Formation crops out in the Narrabeen-Pittwater area, along the lower reaches of the Hawkesbury River to the coast near Gosford, and thence through Ourimbah and to the west of Wyong. It forms the bold coastal cliffs from Box Head to the Skillion at Terrigal. On the near South Coast in the Stanwell Park-Bald Hill area, the upper part of the steep, talus-covered slopes below the mural escarpment formed by the Hawkesbury Sandstone and above the top of the Clifton Sub-Group, comprises sandstones, underlain by shales and siltstones. The maximum thickness of these beds is about 100 feet. The sandstones are typically quartzose and are being mapped by one of us (F.N.H.) as the Undola Sandstone Member at the base of the Hawkesbury Sandstone. The shales and siltstones are probably the equivalent of the Gosford Formation. Further along the coast towards Sydney, to the north of Garie Beach, the section is so similar in many respects to that at the base of the Gosford Formation in the Pittwater District, that there can be little doubt the beds are equivalent. However, to the west of Sydney in the Warragamba area the lithology of the Gosford Formation closely resembles that of the Hawkesbury Sandstone (Browne, Waterhouse and Moye, 1951) and it is difficult to separate the two formations.

It is proposed to give five sections for comparative purposes, namely a generalized section of the beds in the Gosford District, a natural section measured partly at Kangy and partly on the Lisarow-Mt. Elliott Rd., the section recorded in the log of Windeyer's Hawkesbury River Bore, a section from the Pittwater District, and one from north of Garie Beach on the South Coast.

Generalized Section—Gosford District (Raggatt, 1938).	Thickness in Feet.
Shale and shaley sandstone. Fossil plants common	120–150
Mangrove Sandstone Member. Commonly well-bedded and with pebbly base, yellow in colour; cavernous weathering ..	20– 30
Shaley sandstone and shale	65– 70
Ourimbah Sandstone Member. Fine to medium sandstone.. ..	30
In places mainly shale with abundant plant impressions, chiefly in lower half; also shaley sandstone	70– 80
Wyong Sandstone Member. Medium to coarse sandstone, passing into grit. Usually makes bold outcrop	60–100
Shale and shaley sandstone	75–100
Total	500–600

The *Wyong Sandstone Member* forms a most useful horizon for geological mapping. It is a massive coarse to pebbly sandstone which usually makes bold outcrops, rendered all the more conspicuous by the shaley lithology of the underlying strata. It forms the cap to the reservoir hill in Wyong township and thence to the south-west, west and north.



Narrabeen Group.
Correlation between South Coast, Sydney and Wyong Districts.

The *Ourimbah Sandstone Member* forms a small cliff in the type locality and on the catchment of Ourimbah Creek, but is not a persistent horizon like the Wyong and Mangrove Sandstones.

The *Mangrove Sandstone Member* is also a rather distinctive bed and has been used for geological mapping along Mangrove Creek and its tributaries, the headwaters of Wyong Creek, and along Murray's Run Creek. This sandstone is usually well-bedded, commonly yellow in colour, and weathers into caverns.

Natural Section measured partly at Kangy and partly on the Lisarow-Mt. Elliott Road. (Raggatt, 1938.)

	Thickness in Feet
Base of Hawkesbury Sandstone.	
Shale	50
Shaley sandstone	100
Shale	25
Mangrove Sandstone Member. Shaley sandstone, pebbly base	30
Shale	15
Sandy and ferruginous shale with some sandstone	50
Ourimbah Sandstone Member	30
Shaley sandstone and shale	60
Hard white sandy shale	20
Wyong Sandstone Member. Sandstone, coarse to pebbly	60
Total	440

Section from Windeyer's Hawkesbury River Bore. (Depth 214 ft. 6 in. to 776 ft.)

	Thickness Ft.	In.
Shaley sandstone	2	6
Shale	3	0
Shaley sandstone	17	0
Broken shaley sandstone	13	3
Sandstone and shale	14	0
Sandstone	11	6
Shaley sandstone	3	6
Shale	2	3
Shaley sandstone	2	3
Sandstone	10	3
Shaley sandstone		6
Chocolate shale	17	9
Shaley sandstone	5	9
Shale	3	9
Shale and sandstone	5	9
Sandstone	3	6
Shaley sandstone	2	6
Chert		9
Shaley sandstone		9
Shale		6
Shaley sandstone	1	2
Chocolate shale	4	10
Sandstone and shale	12	0
Sandstone (probably *Mangrove Sandstone Member.* H.G.R.)	22	0
Sandstone, shale and conglomerate	12	3
Sandstone and conglomerate	12	3
Shaley sandstone	12	2
Chocolate shale	5	7
Shaley sandstone	21	9
Sandstone and shale	25	0
Sandstone	12	9
Shaley sandstone	13	0
Sandstone	16	9
Shaley sandstone and sandstone layers	10	2
Shale		6

		Thickness	
		Ft.	In.
Shaley sandstone and sandstone layers		15	10
Sandstone		4	0
Grey shale		10	6
Fine grey sandstone (*Ourimbah Sandstone Member* (?). H.G.R.)		39	9
Shale and sandstone		1	9
Sandstone		22	9
Shaley sandstone		3	0
Shale		4	9
Shale and sandstone		33	0
Grey sandstone	(Probably *Wyong Sandstone Member*. H.G.R.)	6	0
Sandstone		8	6
Conglomerate		1	0
Sandstone		30	6
Shale, sandstone and conglomerate		4	6
Conglomerate			7
Hard shaley sandstone		11	2
Shaley sandstone and sandstone layers		12	3
Sandstone		12	6
Shaley sandstone and sandstone layers		12	6
Grey shale		6	3
Shale and sandstone		10	0
Sandstone		7	3
Total		561	6

Section, Pittwater District. (Osborne, 1948.)

		Thickness in Feet
Sandy shales and flaggy sandstone		90
Sandstone, massive (*Bilgola Sandstone Member*)		46
Shales and sandstones, rhythmically banded		35
Sandstone, brown		15
Conglomerate lenses		12
Shale	3	15
Sandstone	1	
Shale	3	
Sandstone	2	
Shale	1	
Sandstone	1½	
Shale	1	
Pebbly ironstone	2½	
Sandstone, finely laminated, current-bedded, " slump " and " rill " structure, honeycomb weathering		9
Shale	2	24
Sandstone	2	
Shale	3	
Sandstone	1	
Shale	2	
Sandstone	4	
Shale	3	
Sandstone	2	
Shale	1	
Sandstone	4	
Sandy shale, finely laminated, with plant remains		5
Sandstone, purplish, with odd shale fragments and swirl marks		1
Sandstone, purplish, alternating with shale		4
Sandstone, coarse, with washouts and pockets of carbonaceous shale		3
Sandstone, fine, with little purplish shale breccia. Ripple marks well developed		6
Clayshale		1
Shales, fine, black, with good ripple marks and plant remains		20
Sandstone, fine, shaley with ripple marks		6
Sandstone, red, climatically banded		2
Shale, flaky, sandy		10
Shale, swirl-marked		2

	In.	Thickness in Feet
Sandstone, shaley, fine current-bedded		3
Shale, black		1
Sandstone, laminated, ripple-marked		2
Shale, sandy, fine, with plant remains		3
Sandstone, black and ironstone nodules		2
Worm tracks in quartzitic sandstone		3
Shale, sandy, rhythmically bedded		4
Ironstone shales		1
Sandstone and shales		2
Sandstone, fine, laminated		4
Sandstone, shaley, with cylindrical sand-casts		3
Ironstone	8	6
Sandstone	10	
Shale	2	
Sandstone	12	
Shale with siderite	3	
Sandy shale, current-bedded	9	
Sandstone	4	
Shale	4	
Sandstone	2	
Shale	8	
Sandstone	10	
Sandstone, purplish, fine, ripple-marked		10
Total		350

The *Bilgola Sandstone Member* is evenly bedded, finely laminated and in places cross-bedded. It commonly crops out in large freestone beds and is exposed in the quarry just above and to the south of Bilgol a Beach. It is a very useful key horizon for mapping and will probably be found to be equivalent to the Mangrove Sandstone Member.

Section on the coast about two miles north of Garie Beach. (Hanlon, 1952).

	Thickness Ft.	In.
Greywacke, fine, interbedded with shales as below ; slump bedding in band near middle	2	0
Shale, dark grey to black, being finely laminated in places, abundant plant remains	8	0
Claystone, grey, grading up into siltstone	7	6
Siltstone, light grey, indurated		9
Claystone, grey to dark grey	2	9
Siltstone, rhythmically bedded	8	0
Greywacke, fine to siltstone, indurated, honeycomb weathering	1	0
Shale, dark grey, rhythmically interbedded with fine greywacke. Abundant reed casts on some horizons	6	6
Siltstone, grey to reddish-brown, two thin pebbly bands composed mainly of quartz and chert	5	6
Greywacke, fine, rhythmically interbedded with shale—proportions vary laterally	3	0
Siltstone, grey	9	0
Greywacke, coarse grey, similar to topmost bed of Bald Hill Claystone	1	6
Claystone, grey, indurated, sideritic	5	0
Total	60	6

Clifton Sub-Group.

The beds are well developed in both the northern and southern areas and comprise the Middle and Lower Narrabeen of Raggatt (1938). The sub-group has been named after the town of Clifton (latitude S. 34° 16′; longitude

E. 150° 58′) on the South Coast because the best complete natural sections are exposed in the cliff faces in this area between Clifton and Bulgo Headland.

It is proposed to describe and name the formations which make up the sub-group in the South Coast district first and then in the Narrabeen-Wyong area, pointing out probable correlations.

South Coast District (Hanlon, 1952).

A generalized section of the Clifton Sub-Group in the Clifton District is included in Figure 1. Preliminary examination of bore logs indicates that the formations named will generally be recognizable as far south as Mt. Kembla, but beyond that area identification may not be possible everywhere.

The beds comprise greywackes, claystones, shales and greywacke conglomerates. The pronounced rhythmical character of the sedimentation, on both a major and minor scale, has previously been pointed out by one of the authors (Osborne, 1948). The most outstanding feature of the sediments is the reddish-brown colour which characterizes many of the claystones and shales, and to a lesser extent some of the greywackes. Claystones and shales in various shades of green are also common. In the Gosford District green beds are almost as common as those coloured reddish-brown. The tuffaceous nature of these beds has been referred to by several authors and, at least in part, they appear to represent redistributed tuffs.

The beds referred to as greywackes have always been described previously as sandstones. However, recent work by one of the authors (Hanlon, 1952) has caused him to conclude that greywacke is a preferable designation, because the quartz content of these sediments in the Clifton-Bulgo area is less than 50% and generally in the range 10%–20%. Grains of chert, jasper and chalcedonic material are abundant, but claystone, felspar and volcanic rock fragments are also common. The matrix is generally siliceous and clayey and the colour characteristically grey or greenish grey, although to a lesser extent it may be yellowish-grey, green or reddish. Southwards, and particularly westwards, the arenaceous sediments become more quartzose, and in the Burragorang area the Clifton Sub-Group is represented by sandstones with certain beds tending towards arkose or greywacke in composition. In the northern area also the arenites appear to be greywackes rather than sandstones. However, in the absence of any recent collection and examination of the complete sequence the old terminology has been retained. The term greywacke is used purely in a descriptive sense and not in a genetic sense as implying any particular mode of origin for the sediments.

Bald Hill Claystone.—This formation has been previously referred to as the " Chocolate Shales ", " Upper Chocolate Shales " and " Upper Red Beds ". It comprises mainly reddish-brown claystones, with some mottled claystone and reddish-brown greywacke bands in places. A detailed section is given below. The colour is hard to describe exactly—a reddish-brown being perhaps the best general description. It is certainly not a true chocolate colour. Comparison of specimens with the " Rock-Colour Chart " distributed by the National Research Council, Washington, D.C., shows that the colour lies between very dusky red (10R2/2) and greyish-red (10R4/2), the numerical designation 10R3/2 probably being the closest approximation to the normal colour. This is also the colour of the equivalent beds at the top of the Clifton Sub-Group in the Narrabeen District.

The thickness of the formation is about 50 feet in the type area at Bald Hill, to the north of Stanwell Park, after which it has been named and where it forms conspicuous outcrops. Under the microscope some bands appear to be tuffaceous and the formation as a whole may represent redistributed tuffs.

Section Bald Hill Claystones and upper portion of Bulgo Greywacke—above Bulgo Headland.

	Thickness	
	Ft.	In.
Breccia, grey and cream, lower part indurated along joints	6	0
Claystone, reddish-brown, numerous small solution cavities	3	6
Claystone, reddish-brown, few cavities, occasional greyish-cream areas up to about 6 inches diameter	6	0
Claystone, mottled, reddish-brown and light grey	2	6
Claystone, reddish-brown, slightly mottled, represents gradual transition between zones above and below	6	0
Claystone, reddish-brown, fine-grained grey mottling, sudden lateral colour changes	4	0
Claystone, reddish-brown	12	0
Claystone, light reddish-brown, mottled	1	0
Claystone to fine greywacke, reddish-brown	11	0
Base of *Bald Hill Claystone*—Top of *Bulgo Greywacke*. Thickness of Bald Hill Claystone, 52 feet.		
Greywacke, fine to medium, light grey, pale, reddish-brown in places	8	6
Breccia, medium	1	3
Greywacke, fine to medium, light grey, pale reddish-brown in places	2	3
Shale, reddish-brown		2
Greywacke, fine to medium, light grey, pale reddish-brown in places, laterally shows rhythmical interbedding with reddish-brown shale		3
Claystone, reddish-brown, mottled in part	1	0
Greywacke, fine, greenish-grey, odd reddish-brown bands	1	9
Shale, reddish-brown		3
Greywacke, greenish-grey, finely bedded	2	6
Shale, reddish-brown		3
Greywacke, fine to medium, light grey	9	0
Shales, reddish-brown	7	0
Greywacke, fine to medium, light grey	2	6
Claystone, reddish-brown, few grey and greenish-grey bands	4	6
Greywacke, fine, light greenish-grey	6	0
Greywacke, rhythmically interbedded reddish-brown and greenish-grey	1	0
Greywacke, fine to medium, greenish-grey	8	0
Greywacke, fine, rhythmically interbedded reddish-brown and greenish-grey	4	0
Greywacke, fine, light grey	6	0
Shale, reddish-brown with odd greenish bands	3	0
Greywacke, fine, light grey, up to 18 inches at base softer and shaley	9	6
Greywacke, fine to medium, irregular breccia band about 1 foot from base	7	0
Greywacke, reddish-brown and greenish-grey	1	0
Claystone, silty, grey, greywacke bands near centre	8	0
Greywacke, medium	2	0
Claystone, silty, greenish-grey	2	0
Greywacke, medium	20	0
Total	170	8

In the Burragorang Valley area the beds which are equivalent to the Bald Hill Claystone differ considerably from those on the coast and in many places there are no reddish-brown claystones in the Narrabeen sequence.

Bulgo Greywacke.—The Bulgo Greywacke comprises approximately 390 feet of sediments consisting mainly of greywacke and has a somewhat banded appearance due to the weathering of soft greywacke and claystone bands. It forms very prominent outcrops in the Bulgo area, after which it has been named, and northwards towards National Park and southwards in the Coal Cliff-Clifton area.

Down to 40 feet particularly, and to almost 100 feet from the top in places, there are a few intercalated beds of reddish-brown claystone and greywacke. However, as these beds would only be mappable in restricted areas, and as they appear to die out in a southerly direction, they have been included in the Bulgo Greywacke and not in the Bald Hill Claystone, which has been restricted so as to include only the main reddish-brown beds which are readily mappable as a unit.

It appears likely that the proportion of reddish-brown beds in the upper part of the formation increases northwards and their lower limit may extend further down the sequence. It is for this reason that in the correlation shown in Table I and Figure I the Collaroy Claystone is regarded as equivalent to the upper part of the Bulgo Greywacke as well as the Bald Hill Claystone.

A detailed section of the upper part of the Bulgo Greywacke has been given above. No useful purpose would be served by giving a detailed section of the lower part of the formation because it consists of a number of lenticular beds of somewhat different lithology, but generally similar to the overlying and underlying beds.

Stanwell Park Claystone.—This formation has been previously known as the "Cupriferous Tuffs", "Lower Chocolate Shales" and "Lower Red Beds". It outcrops at Stanwell Park and along the bed of Stanwell Creek. It has been named after this locality, although the best natural sections are exposed at Bulgo (see below) and between Coal Cliff and Clifton (see below), which has been taken as the type section. The formation comprises reddish-brown and greenish-grey claystones, greywackes and tuffs, the ratio of claystones to the other rock types being in general about three to one. Greenish and bluish calcareous tuffs have been described by one of the authors (Osborne, 1948).

Type Section of Stanwell Park Claystone—between Coal Cliff and Clifton.

	Thickness	
	Ft.	In.
Claystone, reddish-brown, green and grey	18	6
Greywacke, greenish	3	0
Claystone, reddish-brown, green and grey	33	0
Greywacke, greenish	3	0
Claystone, reddish-brown	6	0
Greywacke, greenish-grey	7	0
Claystone, green and reddish-brown	6	0
Greywacke, greenish-grey	2	6
Claystone, reddish-grey	4	0
Greywacke, greenish	1	0
Claystone, grey, green and reddish-brown	6	0
Greywacke, fine, speckled	1	6
Greywacke, fine, grey and reddish-brown, much speckled	6	0
Claystone, reddish-brown and grey with greywacke bands	16	6
Greywacke, argillaceous, grey with reddish-brown speckling on weathered surface	7	0
Total	121	0

Section, Stanwell Park Claystone at Undola.

	Thickness	
	Ft.	In.
Claystone, greenish-grey to reddish-brown	20	0
Greywacke, coarse and pebbly at base, grading to medium at top	13	0
Claystone, reddish-brown and greenish-grey	7	0
Greywacke, medium, fawnish-grey	1	6
Claystone, reddish-brown and greenish-grey	3	6
Greywacke, medium to fine, greenish and fawn	4	0
Claystone, reddish-brown and greenish-grey, with thin greywacke bands	9	0
Greywacke, fawn, greenish-grey, iron-stained	6	0

	Thickness Ft.	In.
Claystone, reddish-brown, green and grey, grading upwards into fine greywacke	14	0
Greywacke, medium, greenish-grey, with reddish-brown claystone	6	0
Greywacke, fine, greenish-grey	10	0
Greywacke, medium, greenish-grey	7	0
Claystone, fawn, grey, green and reddish-brown	41	0
Claystone, green, grey and reddish-brown, iron-stained	15	0
Shale, grey, starchy fracture	8	0
Greywacke (6 to 9 inches thick) and alternating shale bands	9	0
Total	174	0

Scarborough Greywacke.—The name of the formation is taken from Scarborough Station, above and north of which it forms prominent outcrops. The formation consists essentially of greywackes and greywacke conglomerates (see section below). It is approximately 80 feet thick and forms prominent cliffs in the Clifton, Coal Cliff, Stanwell Park and Bulgo areas.

Section, Scarborough Greywacke—between Coal Cliff and Clifton.

	Thickness Ft.	In.
Greywacke, medium to coarse, with pebbly bands	24	0
Greywacke conglomerate, fine, multi-coloured pebbles, grades into greywacke above	15	6
Greywacke, medium to coarse, irregular conglomeratic bands, particularly basal 4 feet	44	0
Total	83	6

Wombarra Shale.—This formation has been named after the village of Wombarra, through which it passes above and to the west of the railway line. It is generally obscured by soil and talus cover. Good natural sections can be seen in the Coal Cliff-Clifton area and the type section given below is taken from this area. It comprises shales, claystones and siltstones with intercalated greywackes and ranges in thickness from 100 to 120 feet. About 20 feet from the top there is a bed of greywacke which forms prominent outcrops from Scarborough northwards through Clifton to Coal Cliff and which can be readily identified in bores at Stanwell Park and Otford. It has been named the *Otford Greywacke Member*. The thickness averages about 20 feet, but varies somewhat due both to lenticularity of individual beds and sharp lateral facies changes of the upper and lower beds to shales. It tends to become conglomeratic in places.

Section, Wombarra Shale—between Coal Cliff and Clifton.

		Thickness Ft.	In.
Shale, light grey		3	3
Greywacke, greenish-grey		1	9
Shale, grey, starchy fracture		13	0
Otford Greywacke Member	Greywacke, medium, with few pebbly bands, greenish-grey, soft	11	6
	Greywacke, medium to coarse, with pebbly bands	10	0
	Greywacke conglomerate, fine, mostly greenish, multi-coloured pebbles	1	3
Shale, grey, reddish-brown in places, starchy fracture		44	0
Greywacke, argillaceous		2	9
Shale, grey, starchy fracture, few greywacke bands		11	9
Shale, grey, with numerous greywacke bands		19	0
Total		118	3

The beds described as shales comprise also claystones, laminated siltstones and very fine greywackes. It is probable that the basal 19 feet of the section given above may pass laterally into greywackes, and these beds could be the stratigraphical equivalents of the top portion of the Coal Cliff Greywacke at points where the latter is thickest.

The shales and claystones are generally greyish in colour, but reddish-brown beds are present in some places. This could lead to incorrect correlations between sections in the Illawarra district and those of adjoining districts in places where the Stanwell Park Claystone is not recognizable.

Coal Cliff Greywacke.—This formation consists essentially of medium to coarse greywacke with pebbly bands and forms prominent outcrops in the Scarborough-Clifton-Coal Cliff area. The basal section immediately overlying the Bulli Coal Seam commonly consists of fine to very fine greywacke, indurated in places, and passes into shales in some localities. The thickness ranges from 30 feet at Coal Cliff to over 50 feet at Scarborough, partly due to variable thickness of individual beds and partly due to lateral facies changes similar to that referred to in the description of the Wombarra Shale.

Section, Coalcliff Greywacke—between Coalcliff and Clifton.

	Thickness Ft.	Thickness In.
Greywacke, light grey, medium to fine	3	0
Shale, silty, light grey, indurated bands*	6	6
Greywacke, medium to coarse, pebbly bands, ironstone concretions in places	22	0
Greywacke, very fine, argillaceous, indurated, dark near underlying coal seam	1	2
Total	32	8

* This band passes laterally into greywacke in a southerly direction.

Narrabeen-Wyong District (Raggatt, 1938).

A generalized section of the Clifton Sub-Group in the Gosford area is given below.

Formation.	Thickness in Feet.	Lithology.
Collaroy Claystone ..	400–550	Mainly red and green shales with sandstone beds up to 10 feet thick.
Tuggerah Formation	100–150	Sandstone and fine conglomerate.
	45–100	Red and green shales.
	75–100	Sandstone and fine conglomerate.
	40–100	Mainly red and green shales.
Munmorah Conglomerate	280	Sandstone and fine conglomerate with some green shales.
	500	Red, green and grey shales and sandstone with fine conglomerate.

Continuous complete natural sections, such as those around Clifton on the South Coast, are not available and therefore it has been necessary to take sections from bores as types for the formations comprising the Clifton Sub-Group in the Narrabeen-Wyong area.

Collaroy Claystone.—The Collaroy Claystone includes the original " Chocolate Shales " described from Long Reef in the Collaroy area, previously included as part of the Narrabeen District. However, only the uppermost beds are exposed in this area and it is proposed to take the type section from the log of Windeyer's Hawkesbury River Bore, given below.

Section, Collaroy Claystone—Windeyer's Hawkesbury River Bore. (Depth 776 ft. to 1,224 ft. 6 in.)

	Thickness Ft.	In.
" Chocolate " and grey shale	26	0
" Chocolate " shale	12	6
Grey shale	2	0
Shale and sandstone	5	6
Sandstone	4	10
" Chocolate " shale	58	2
" Chocolate " shale and sandstone	3	0
" Chocolate " shale	7	0
Grey shale and sandstone	9	9
Sandstone	12	6
Soft grey shale	1	6
" Chocolate " shale	13	0
" Chocolate " shale and sandstone	7	6
" Chocolate " shale	49	9
Grey shale	1	0
" Chocolate " shale	13	0
Fine grey sandstone	2	0
" Chocolate " shale	23	3
Sandstone	18	3
" Chocolate " shale	12	6
" Chocolate " and grey shale	8	9
Grey shale and sandstone	4	6
Sandstone	10	0
" Chocolate " and grey shale	35	6
" Chocolate " shale	1	0
Grey shale	3	6
Sandstone	10	0
" Chocolate " and grey shale	14	0
Sandstone	1	6
Grey shale	9	9
Sandstone	14	9
" Chocolate " shale	4	6
Grey shale and sandstone	15	0
Sandstone	10	0
Shale and sandstone	3	0
Sandstone	9	6
" Chocolate " and grey shale and sandstone	10	3
Total	448	6

The beds are well exposed on the lower slopes of the hills around Wyong and form the valley bottoms over much of the country west and north of the township. Good partial sections are to be seen in the cutting to the south of Wyong Railway Station and on the coast between Wamberal Headland and Toowoon Bay.

Tuggerah Formation.—This formation comprises red and green shales, sandstones and fine conglomerates. It crops out around Tuggerah Lakes after which locality it has been named. The type section of this formation is also taken from Windeyer's Hawkesbury River Bore and is given below.

Section Tuggerah Formation—Windeyer's Hawkesbury River Bore. (Depth 1,224 ft. 6 in. to 1,547 ft. 6 in.)

	Thickness Ft.	In.
Sandstone	21	9
Sandstone and conglomerate	55	6
Sandstone, conglomerate and grey shale	14	0
Sandstone	20	3
Sandstone and shale	7	3
" Chocolate " shale	4	9
Shaley sandstone	10	6
Sandstone	7	6
" Chocolate " and grey shale	20	0
" Chocolate " shale	4	0

	Thickness	
	Ft.	In.
Grey shale	6	0
Sandstone	11	0
Sandstone, shale and conglomerate	7	0
Sandstone and conglomerate	3	0
" Chocolate " shale	13	6
Shaley sandstone		6
Sandstone	7	0
Shaley sandstone		9
Fine conglomerate	38	6
Grey shale and sandstone	6	0
" Chocolate " shale	3	9
" Chocolate " and grey shale	1	3
Shaley sandstone	2	9
Sandstone	6	0
Fine conglomerate	6	9
" Chocolate " and grey shale	38	3
Grey shale	2	3
" Chocolate " shale	1	9
Grey shale	1	6
Total	323	0

Munmorah Conglomerate.—The Munmorah Conglomerate comprises conglomerates, sandstones and red, green, blue and grey shales. The conglomerates are, for the most part, characterized by evenness in size of the pebbles, which are from ½ in. to ¾ in. in diameter. They contain lenses of sandstone, but these are rarely persistent. The conglomerates become more conspicuous and coarser northwards from Wyong and north-westerly up the Hunter Valley. Southwards towards Gosford and Sydney the formation is much less pebbly.

The formation crops out in the country between the Great Northern Railway north of Warnervale and Lake Macquarie. The higher sandstones and conglomerates may be seen between The Entrance, Tuggerah and Toowoon Bay, and the lower around the foreshores of Lake Munmorah (after which the formation has been named) and the southern end of Lake Macquarie. The type section is taken from the log of the Wyong Bore, which is given below. The base of the formation rests on the Wallarah Coal Seam, which is the topmost bed of the Newcastle Coal Measures.

Section Munmorah Conglomerate—Wyong Bore. (Depth 274 ft. 4 in. to 787 ft. 6½ in.)

	Thickness	
	Ft.	In.
Conglomerate with jasper pebbles	7	6
Blue and red shales, thin beds conglomerate	16	4
Fine brown and grey conglomerate	13	4½
Green and grey shales with *Phyllotheca*	12	9½
Conglomerate with jasper pebbles, green and blue shales, sandstone and fine conglomerate	68	10
Conglomerate with jasper pebbles, and three beds of greenish shale, and a little sandstone	81	6
Green shales	11	9
Conglomerate and green shales	53	0½
Green shale and sandstone	21	0
Coarse conglomerate	8	7
Greenish sandstone, green and red shales, fine and coarse conglomerate, with jasper pebbles	33	6
Red, green and blue shales	30	9
Conglomerate with jasper pebbles	48	7
Green, red and brown shales	38	8
Fine and coarse conglomerate with beds of dark shale	40	0
Sandstone and shale	27	0
Total	513	2½

SUMMARY.

The Narrabeen Group is subdivided into the Gosford Formation and the Clifton Sub-Group. In the South Coast the latter comprises the Bald Hill Claystone, Bulgo Greywacke, Stanwell Park Claystone, Scarborough Greywacke, Wombarra Shale and Coal Cliff Greywacke. In the Narrabeen-Wyong District it comprises the Collaroy Claystone, Tuggerah Formation and Munmorah Conglomerate. The group thins generally from north to south. The tops of the Bald Hill Claystone and Collaroy Claystone are probably equivalent horizons and the bases of the Stanwell Park Claystone and Tuggerah Formation may be equivalent.

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A NEW SPECIES OF HADROPHYLLUM FROM THE GARRA BEDS AT WELLINGTON, N.S.W.

By G. H. Packham.
University of Sydney.

With one Text-figure.

Manuscript received, September 24, 1953. Read, October 7, 1953.

This species of *Hadrophyllum* occurs in richly fossiliferous shale of the Garra Beds in Por. 50, Parish Curra. The locality is on the east bank of Curra Creek three hundred yards south of where the Wellington-Arthurville road crosses Curra Creek. Hill (1942) described a number of corals from the same portion. They are *Eddastrea expansa* Hill, *Phillipsastrea aperta* Hill, *P.* sp. cf. *P. speciosa* Chapman and *P. linearis* Hill, *Favosites bryani* Jones and *F. allani* Jones. In addition Basnett and Colditz (1945), who described the general geology of the area, record *Stromatopora* sp., *Atrypa* sp., *Leptæna* sp. Brachiopods are the most common fossils at the point from which *Hadrophyllum* was collected.

The genus *Hadrophyllum*, which has not yet been recorded from Australia, is widely distributed ; it occurs in the Devonian rocks of North America, Europe and south-east Asia and in the Carboniferous rocks of North America.

Family **Hadrophyllidæ** Stumm, 1949.

Genus **Hadrophyllum** Edwards and Haime, 1850.

The genus is described by Bassler (1937, p. 197) as follows : " Cushion or top-shaped, short thick coralla, with calyx restricted to convex upper surface and extended into a peduncle terminating sharply or bluntly beyond the centre, opposite the counter fossula. The calyx shows a broad excavated cardinal fossula, a distinct but narrow counter fossula, two less conspicuous alars, all of which delimit four groups of smooth septa with several of each group united to the one outlining the fossula. Minor septa short, generally united to the major ; cardinal and counter septa well developed. The thick elevated corallum with the calyx presenting four well developed fossulæ and the base a conspicuous peduncle of attachment, characterize this genus."

Hadrophyllum wellingtonense n.sp.

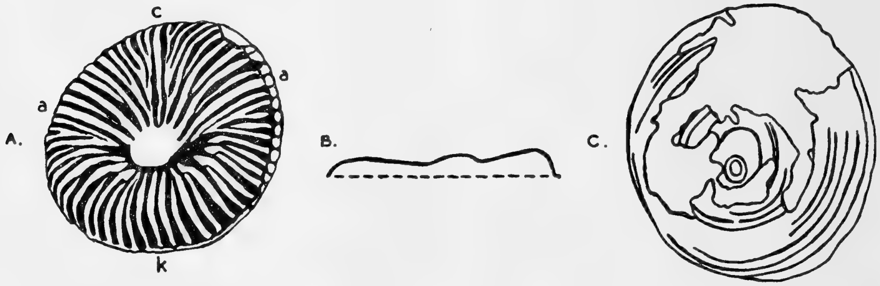
Material. Holotype 7100, paratypes 7101–7104. All specimens are in the collection of the Department of Geology, University of Sydney.

Diagnosis. Discoid *Hadrophyllum* lacking peduncle of attachment. Counter septum flanked on either side by a major septum which has no associated minor septum.

Description. Coral slightly elliptical, elongated in the counter-cardinal direction. Mean diameter about sixteen millimetres and maximum thickness two and a half millimetres. Upper surface slightly convex, base flat with well developed growth lines of varying size. Scar of attachment small and eccentric, lying on the counter side of the geometrical centre.

There are fifty-two to fifty-six smooth septa in the mature individual varying in degree of development; both major and minor septa are large in the region of the counter septum, while on the cardinal side of the alar septa the major and minor septa are strongly differentiated. All the minor are joined to the major septa at their axial ends. On the third to sixth major septa from the counter septum there are slight prominences at the junction of the major and minor septa. Reduction in the size of septa occurs in the fossulæ. In the alar fossulæ on the counter side of the alar septa one of the septa is reduced in size to that of its associated minor septum. The next major septum is less reduced and the third is not reduced at all. A similar phenomenon occurs on either side of the cardinal septum in the cardinal fossula. A counter fossula is not developed. The first four to six septa of these fossular regions are pinnate and further away become radial.

The alar septa are the best developed in the coral and have a minor septum associated with each of them on the counter side. The cardinal septum is long and slender. The counter septum is shorter and stouter. On either side next to it is a stout but slightly shorter major septum which has no associated minor septum. These are possibly the counter laterals.



A. Upper surface of holotype (specimen slightly distorted). *a*, Alar septum. *c*, Cardinal septum. *k*, Counter septum.
B. Profile of section along cardinal septum (on left) raised axial area and counter septum (on right).
C. Lower surface of paratype (7101) showing eccentric growth lines.
All drawings twice natural size.

The major septa on the cardinal side of the alar septa are long and merge into an axial raised area separated from the septa on the counter side of the alars by a slight depression. The raised area is not in the geometrical centre of the coral but on the counter side of it.

The microstructure of the septa is poorly preserved but appears to be entirely fibrous. The fibres are apparently normal to the base of the coral radiating upwards and outwards to the top of the septa.

Remarks. *H. wellingtonense* has affinities with two species, *H. brancai* (Frech) and *Microcyclus intermedius* Bassler. This group of three species is intermediate in characters between the two genera. All of them have the flat discoid form of *Microcyclus* and all have alar fossulæ; that of *M. intermedius* is better developed than any other species in the genus. The two species of *Hadrophyllum* have eccentric growth lines on the base, and lack a large smooth axial area, *H. wellingtonense* has a small raised axial area in a broader axial depression. Some specimens of *H. brancai* from Indo-China figured by Mansuy (1916) show this feature, but those of Yin (1938) from China show no sign of any axial structure. *M. intermedius*, on the other hand, has concentric growth lines and a large smooth axial area occupying nearly half the width of the coral.

A counter septum flanked on either side by a major septum which has no associated minor septum occurs in *H. wellingtonense*, *M. intermedius*, *M. discus*, *M. lyrulatus* and possibly in *H. pauciradiatum.* Another type of septal arrangement where the counter septum has a minor septum adjacent to it on either side then alternating major and minor septa further away occurs in *H. brancai*, and is the most common in the two genera.

H. wellingtonense has been placed in the genus *Hadrophyllum* because of the three well developed fossulæ, the absence of a large smooth axial region and the presence of eccentric growth lines on the base.

The microstructure, although not well preserved, seems to be a simple arrangement of fibrous material. This suggests the possibility of some relation to the Streptelasmidæ of Wang (1950).

Age. The closely related species *H. brancai* occurs in south-east Asia associated with the *Spirifer tonkinensis* fauna which Yin (1938) considers to be at about the Lower and Middle Devonian boundary. Such an age for *H. wellingtonense* is probable, since Hill (1942) says: " The fauna in Por. 50, Parish of Curra, is comparable with that of the Loomberah limestone of the Tamworth district which is possibly early Couvinian."

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OF
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Plates XII-XV and Index

EDITED BY
F. N. HANLON, B.Sc., Dip.Ed.
Honorary Editorial Secretary

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MEASURES OF DOUBLE STARS ON SYDNEY ASTROGRAPHIC PLATES, DECLINATIONS −52° TO −58°.

By W. H. Robertson.

Manuscript received, September 30, 1953. Read, December 2, 1953.

The stars in the following lists were measured on plates taken for the Sydney Section of the Astrographic Catalogue. The object was to improve knowledge of past positions, and only stars having satisfactory and reasonably separated images have been included. Rectangular coordinates were measured in a machine having a short screw micrometer which could be rotated to deal with the coordinates in turn. Scale and orientation were defined in the first place by the reseau lines on the plate. Adjustments in accordance with the plate constants were used whenever these had been determined. In other cases a mean value for the scale correction was assumed and the orientation correction was found by measuring two stars, separated widely in the field but differing little in declination, on two plates, the one with determined plate constants and the other for which the orientation was required. Then if X_1, Y_1, X_1', Y_1' are the measures of the two stars on one plate, X_2, Y_2, X_2', Y_2' those on the other, and D_1, D_2 the corresponding plate constants the approximate relation is

$$D_1-D_2=\frac{(Y_1-Y_2)-(Y_1'-Y_2')}{X_1-X_1'}.$$

Let α, δ be the equatorial coordinates of the primary star, ξ, η its standard coordinates on a plate centred at A_0, D_0, and $\Delta\alpha$, $\Delta\delta$, $\Delta\xi$ and $\Delta\eta$ the corresponding differences between the coordinates of the secondary and the primary. Then differentiating the usual relations

$$\begin{aligned}\Delta\alpha\cos\delta&=\Delta\xi(1-\xi^2\sec^2 D_0+\tfrac{1}{2}\xi^2\tan^2 D_0-\tfrac{1}{2}\eta^2)\\&\quad+\Delta\eta(\xi\tan D_0+\xi\eta\tan^2 D_0)+\ldots,\\\Delta\delta&=\Delta\eta(1-\tfrac{1}{2}\xi^2\sec^2 D_0-\eta^2)\\&\quad-\Delta\xi(\xi\tan D_0+\xi\eta\sec^2 D_0)+\ldots.\end{aligned}\qquad\ldots\ldots\ (1)$$

Equation (1) is in radians and in the notation of the Sydney Astrographic Catalogue

$$\begin{aligned}\xi&=-\{X-14-A(X-1)-B(Y-30)-C\}300\sin 1'',\\\eta&=\{Y-43-D(X-1)-E(Y-30)-F\}300\sin 1''.\end{aligned}$$

By substituting this in (1) and expressing the result in seconds of arc we obtain

$$\begin{aligned}\Delta\alpha\cos\delta&=-300\Delta X(1-A)+\Delta Y\{300B-0\cdot4363(X-14)\tan D_0\}+\ldots,\\\Delta\delta&=300\Delta Y(1-E)-\Delta X\{300D+0\cdot4363(X-14)\tan D_0\}+\ldots\end{aligned}$$
$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (2)$$

Tables including also terms of second order in X and Y, which in practice were found negligible, were used to assist computation in accordance with (2), after which the position angle and distance were calculated.

TABLE I.

Name	C.P.D.	R.A.	S. Dec.	Epoch	p	d	Mags	Weight
		h m	° ′		°	″		
Hu1551	53°9	0 03·7	52 53	94·72	122·6	8·28	8·3, 11·0	2a
h3360	53°72+3	0 16·7	53 05	20·74	33·5	14·48	9·5, 10·2	2a
h3383	54°153	0 35·6	53 56	92·87	217·6	7·18	9·8, 10·5	2a
h3388	54°159+0	0 38·0	54 40	93·61	238·9	16·70	8·1, 8·3	5a
h 398	52°90+1	0 42·2	52 33	25·96	131·6	28·28	8·8, 9·8	3b
h3402	54°186	0 45·1	54 43	94·78	60·9	12·74	8·2, 11·1	2a
h3412	56°198+9	0 56·9	56 42	94·76	142·3	27·70	8·7, 10·9	2b
				20·80	137·6	28·20		2b
h3422	56°256	1 10·9	56 10	92·73	56·6	13·88	7·6, 11·6	2a
Δ4	54°358	1 34·9	53 57	92·87	104·2	10·46	7·6, 8·2	3b
Hu1554	54°369	1 39·2	54 44	27·87	280·2	5·74	9·5, 9·8	2b
h3514	56°444	2 30·7	56 34	94·71	21·0	30·82	9·4, 10·3	2b
Cor14	53°462	2 35·5	53 23	20·56	128·6	9·32	8·8, 9·3	4b
Δ10	51°361+3	3 01·4	51 43	92·70	69·2	37·65	7·5, 8·3	2b
h3571	[53°674]	3 16·3	53 28	21·16	94·4	20·09	11·5, 12·1	3a
h3575	51°404	3 21·6	51 25	94·75	45·0	35·64	6·6, 10·2	2b
B49	54°556	3 22·4	54 07	92·97	70·0	4·47	9·6, 11·4	2b
Cor22	56°679	4 25·4	56 08	92·97	139·4	6·44	9·3, 9·7	2b
h3669	53°728	4 33·2	53 04	93·95	312·4	13·92	9·6, 9·9	2a
h3680	52°551	4 38·1	52 05	92·85	210·9	10·19	9·4, 9·5	2b
λ43	53°777	4 55·5	53 33	93·46	309·3	8·32	8·4, 9·4	4b
h3731	56°787	5 06·2	56 01	92·79	303·8	10·04	9·2, 11·0	2b
h5450	56°811	5 12·1	56 55	25·95	268·2	6·90	9·3, 9·4	2b
h3777	54°853	5 31·8	54 58	26·09	104·0	11·30	10·0, 12·7	2b BC
h3786	53°904	5 35·6	53 33	94·03	96·0	13·44	9·6, 11·2	2b
h3787	54°867+6	5 35·8	54 37	94·00	248·2	23·82	8·0, 10·3	4b
				24·02	248·0	24·91		5b
h3802	55°864	5 43·4	55 46	92·97	305·0	7·74	8·4, 10·3	2b
h3808	57°894	5 47·9	57 40	94·84	306·8	6·43	9·9, 9·9	3a
h3828	53°990	5 58·1	53 55	94·03	124·4	13·48	9·9, 11·0	2a
				25·21	118·8	13·48		2a
h3837	55°940	6 04·2	55 57	94·05	293·8	11·52	8·0, 12·0	2b
h3854	54°1020	6 18·4	54 28	25·21	126·9	11·39	9·3, 11·6	2b
h3898	56°1181+0	6 49·1	56 07	93·12	309·9	16·73	8·6, 8·9	3a
h3906	55°1102+1	6 54·0	55 28	96·98	223·0	19·28	9·5, 9·9	4a
				24·98	223·3	19·41		6a
Cor47	52°1074	7 03·0	52 28	23·16	90·7	21·08	8·0, 10·4	3b
Hu1421	55°1162	7 06·2	55 14	94·04	31·9	5·99	9·7, 10·0	2b
h3952	53°1302	7 14·0	53 52	92·06	276·1	16·13	7·2, 11·2	4b
h3961	57°1195	7 18·5	57 30	93·96	254·2	13·58	9·0, 11·0	2b
R75	55°1222	7 19·4	55 09	93·12	270·6	5·05	10·0, 10·8	2b AB
	55°1222+1			93·12	261·0	31·25	10·0, 10·4	2a AC
h3971	57°1220	7 22·7	57 44	92·56	190·2	16·89	9·2, 10·4	4a
LP110	57°1263	7 31·8	57 33	20·99	192·2	13·11	9·2, 10·8	2b
h4016	51°1312+3	7 49·1	51 09	92·05	169·4	16·95	9·9, 10·1	2a
				20·15	169·4	17·00		2a
Gls77	53°1480+9	7 52·9	53 20	93·11	340·6	33·84	7·4, 7·9	2b
h4065	53°1567+9	8 10·5	53 45	92·56	44·6	10·90	9·8, 9·7	4a
	57°1484+3	8 17·8	57 21	94·05	337·9	15·75	8·7, 9·0	2a
Cor78	53°1998	8 53·5	53 25	93·19	142·6	10·56	8·1, 8·3	2a
h4177	55°1924	9 01·7	55 56	00·07	262·2	13·96	6·9, 8·8	2b
LP117	52°1957	9 04·6	52 46	00·12	354·0	8·72	9·0, 10·2	2b AB
LP119	56°2039	9 08·7	56 36	24·22	246·1	5·56	9·0, 9·1	3b
h4189	53°2209	9 09·0	53 33	98·53	107·2	19·77	7·9, 11·0	5b
R107	57°1966	9 13·8	57 59	93·12	279·8	9·55	9·0, 10·4	2b
R111	56°2109	9 17·9	56 50	24·03	212·5	9·36	8·9, 9·9	2a
	55°2129	9 20·1	55 34	93·09	225·7	11·32	9·5, 9·7	5a AB
				93·08	176·6	18·97	9·7, 11·5	4a BC
h4207	54°2238+9	9 20·5	54 28	92·83	128·2	16·14	9·7, 9·8	8a
Cor83	52°2346	9 22·4	52 49	94·04	150·5	19·36	7·1, 9·7	2b
LP120	53°2397	9 22·7	53 28	93·05	174·4	4·35	9·8, 10·2	2b
I830	56°2212	9 25·0	56 54	93·05	56·8	17·74	7·9, 9·9	2b
R120	55°2269	9 28·8	55 35	23·39	215·6	9·28	8·9, 9·2	2a
Syd	56°2300	9 29·7	56 39	95·08	23·1	11·24	7·4, 10·4	2b

TABLE I.—*Continued.*

Name	C.P.D.	R.A.	S. Dec.	Epoch	p	d	Mags	Weight
		h m	° ′		°	″		
Cor86	52°2512	9 30·0	53 01	95·59	131·0	14·37	9·0, 9·4	5a
h4221	52°2515	9 30·0	53 00	93·19	129·6	5·90	9·0, 12·8	2b
Cor88	56°2383	9 35·0	56 30	94·27	148·6	13·26	8·2, 9·8	2b
				24·16	148·8	12·83		2b
h4234	51°2496+5	9 37·3	51 50	00·22	216·8	22·56	9·6, 10·3	2b
h4260	57°2367	9 47·0	57 45	94·13	118·6	13·20	7·9, 10·5	2b
Cor93	52°2885	9 47·7	52 43	93·35	227·7	12·05	8·8, 9·6	5b AB
				24·10	227·2	12·00		2b
				92·05	307·6	7·06	9·6, 12·8	2b BC
R137	54°2821+2	9 49·7	54 33	93·06	47·8	14·78	8·9, 10·4	4a
h4266	51°2761	9 51·2	51 37	96·90	89·1	12·93	9·2, 10·2	5a
Cor98	53°3177	10 04·6	54 17	93·19	112·6	6·84	9·3, 10·2	2a
				23·39	112·0	6·76		2a
h4297	54°3269	10 08·4	54 38	00·14	301·9	10·88	9·9, 10·4	2a
				23·26	303·0	10·77		4b
h4319	53°3793	10 22·3	53 23	93·19	122·7	12·40	7·0, 10·8	3a
Cor103	51°3322	10 24·3	52 03	20·19	287·0	5·49	8·5, 9·2	2b
h4328	51°3358+0	10 27·2	51 22	20·19	109·8	17·68	9·5, 10·1	2b
LP132	53°4311	10 59·3	53 24	92·08	264·0	11·67	8·9, 9·4	2b
h4401	54°4294	11 00·4	54 42	92·08	228·6	14·47	9·6, 9·9	2a
h4411	52°4251	11 04·2	52 27	24·35	260·0	7·60	10·3, 10·8	2a
h4417	54°4397	11 09·1	54 53	93·19	147·0	19·84	8·8, 9·7	2b
R172	55°4402+3	11 24·7	55 24	24·16	107·2	26·38	9·4, 9·8	3a
h4446	51°4266	11 27·2	51 54	94·28	298·6	10·75	8·6, 8·6	2b
	54°4812	11 47·6	54 23	92·10	140·1	14·22	9·1, 9·6	4a AB
				92·10	267·3	11·89	9·1, 13·5	3b AC
h4492	54°4935	11 58·7	54 09	00·22	272·6	15·66	7·4, 11·2	2b
LP133	54°5046	12 07·5	54 47	20·36	274·2	6·90	9·6, 10·2	2b
h4508	55°4936+7	12 09·6	55 14	20·36	33·6	24·20	8·8, 9·2	2b
h4511	54°5103	12 12·7	54 58	20·36	297·4	8·67	9·1, 9·5	2a
h4534	57°5607+6	12 32·6	57 34	94·28	281·1	15·55	9·2, 9·2	2a
R205	57°5611+0	12 33·5	57 43	92·37	270·2	24·94	10·4, 11·0	2a
R206	55°5203+2	12 38·6	55 21	24·27	275·2	16·44	8·8, 9·0	2b
h4546	52°5847	12 39·2	52 13	97·34	223·4	15·17	7·4, 9·2	5a
Δ127	55°5316+7	12 53·9	55 22	93·36	125·5	16·69	8·4, 8·6	3a
Cor146	57°5852+1	12 55·4	57 36	94·30	351·9	14·42	8·8, 8·9	2a
h4564	55°5343	12 56·8	55 08	94·26	219·1	22·21	8·3, 9·5	2b
h4573	55°5439	13 07·6	55 44	24·27	57·3	7·58	9·9, 10·7	2b
LP138	54°5516	13 11·0	54 17	94·22	345·7	8·20	8·8, 9·6	2b
h4615	57°6313+4	13 43·2	57 34	23·29	150·9	15·38	8·6, 10·4	2a
Cor162	57°6347	13 45·2	57 56	94·30	68·4	17·36	8·7, 9·2	2a
Δ151	55°5793+4	13 50·7	55 33	94·27	22·6	13·72	8·1, 9·5	2a
				20·35	38·0	18·28		2a
Δ155	53°5879+0	14 01·1	53 13	93·19	21·4	21·50	8·9, 9·4	2a
h4673	51°6793	14 15·8	51 58	92·18	144·6	12·15	10·6, 11·5	2a
h4675	54°5998	14 18·9	54 21	94·27	337·2	8·62	9·8, 9·8	2b
	56°6723	14 31·5	57 19	94·35	8·6	11·94	9·1, 10·6	2a
h4691	55°6094	14 32·0	55 16	94·33	274·0	11·89	8·6, 9·3	2a
LP148	54°6102	14 33·3	54 57	94·33	330·8	9·91	9·6, 10·1	2a
h4709	55°6233	14 46·6	55 48	94·27	222·4	20·74	9·4, 11·8	2a
	54°6260	14 54·2	54 34	20·35	226·8	8·54	9·8, 11·1	2a
h4747	55°6451+0	15 07·9	55 21	94·27	341·0	17·44	10·1, 10·6	2a
h4754	57°7024	15 13·9	57 38	24·31	306·9	6·18	9·7, 10·3	2a
φ58	54°6559	15 24·8	54 23	25·36	124·0	6·55	8·5, 11·0	2b
h4778	52°8475+4	15 25·0	52 32	18·41	205·9	13·02	9·0, 9·4	2a
	55°6624	15 27·8	55 20	94·26	146·2	6·40	10·4, 10·9	2b
h4789	54°6599	15 29·6	54 10	25·36	90·2	13·48	9·0, 9·3	2a
φ59	54°6603	15 29·8	55 01	94·26	354·1	5·86	9·6, 11·6	2b
h4794	51°8448	15 36·1	51 31	94·53	145·7	12·76	9·9, 11·4	2a
h4806	54°6705	15 42·4	54 27	20·35	326·2	14·87	8·8, 10·6	2b
Cor200	55°7659	16 34·8	55 59	20·40	302·0	6·52	9·2, 9·5	2a
LP161	52°10471	17 01·8	52 16	20·56	146·3	11·56	8·8, 9·4	2a
R294	54°8105	17 05·6	54 18	23·61	115·8	14·28	9·3, 9·4	2a
h4938	56°8154+5	17 12·3	56 19	94·33	109·2	25·12	8·8, 9·1	2a

Table I.—*Continued.*

Name	C.P.D.	R.A.	S. Dec.	Epoch	p	d	Mags	Weight
		h m	° ′		°	″		
h4950	57°8577	17 21·5	57 28	94·35	307·4	10·46	9·6, 10·4	4b
h4959	55°8221+2	17 27·8	55 34	23·48	294·9	19·56	9·2, 9·3	6a
h4994	52°10927+6	17 49·3	52 11	95·42	209·0	13·80	9·9, 10·1	2a
h5027	54°8761	18 05·5	54 23	94·46	102·4	12·24	8·0, 9·2	2a
h5050	57°9126	18 30·8	57 29	23·43	107·0	12·12	9·0, 9·5	2b
h5447	54°9530	19 48·4	54 22	92·62	267·2	9·56	9·3, 11·0	2a
h5193	57°9677	20 18·2	57 03	94·52	332·0	17·91	9·0, 10·2	2b
h5239	55°9506+5	20 56·8	55 44	92·70	212·0	12·80	8·6, 9·4	2a
h5241	55°9515	20 59·5	55 53	92·70	40·1	12·41	10·0, 10·4	2a
h5290	54°9934	21 37·6	54 36	92·62	291·3	11·10	9·5, 10·8	2a
Hu1542	54°10019	22 00·4	54 16	92·76	119·0	5·70	9·5, 12·7	2a
	56°9854+5	22 10·0	56 13	94·54	13·2	16·86	11·2, 12·0	2a
h5364	57°10150	22 44·3	57 01	94·54	98·0	10·52	9·2, 9·7	2a
h5379	56°9991+0	22 57·6	56 50	20·61	328·6	12·00	10·3, 10·7	2a
h5424	56°10166	23 45·0	56 26	26·82	57·3	11·28	9·9, 11·7	2b

Note.

The position angles of the following stars conform to the *Southern Double Star Catalogue* but appeared different by 180° on the plates.

Star	R.A.	Star	R.A.
h4016	7 49·1	Δ155	14 01·1
h4401	11 00·4	h4754	15 13·9
R205	12 33·5	h4959	17 27·8

Table II.

Barton	C.P.D.	R.A.	S. Dec.	Epoch	p	d	Mags.	Weight
		h m	° ′		°	″		
2018	54°364	1 38·2	54 28	92·84	137·2	5·15	11·4, 12·0	2b
				27·87	136·7	5·39		1b
2019	52°306	2 24·3	52 28	92·85	220·0	5·58	10·5, 11·8	2b
				19·76	219·0	5·30		2b
2025	52°1082	7 04·8	52 32	23·33	200·8	3·75	11·0, 11·5	1b
3115		7 25·3	57 32	91·97	228·4	3·72	11·8, 11·8	2a
2028	53°1388	7 35·7	53 22	23·34	249·8	3·90	10·9, 11·5	2b
3116		7 38·0	56 10	92·08	68·0	4·48	11·6, 12·2	2a
2537	54°1424	7 50·4	54 40	26·18	151·0	4·58	11·9, 12·7	1b
3117	58°1043	8 02·1	58 04	94·05	301·6	4·36	11·7, 12·3	2b
3118		8 07·2	58 08	93·12	354·0	3·63	12·0, 12·2	1b
2029	53°1668	8 22·2	53 33	94·03	159·2	4·88	11·2, 11·7	2b
				24·02	157·4	4·72		2a
3119		8 29·6	56 17	25·08	1·0	3·90	11·4, 11·8	2b
3122		8 33·0	56 50	25·08	294·6	3·52	11·8, 11·8	1a
2541	54°1814	8 44·0	54 44	94·04	120·1	3·93	11·0, 11·8	1a
2542	54°1818	8 44·6	54 38	94·04	1·0	4·19	11·4, 11·4	1a
Rst	57°1883	9 05·3	57 44	24·22	348·6	3·42	11·4, 12·2	2b
3125		9 14·5	55 52	26·10	323·7	4·84	11·8, 12·2	1a
2546		9 21·2	56 18	93·08	159·9	4·39	12·4, 12·6	1a
2037		9 26·8	54 03	92·08	155·9	4·35	11·4, 12·2	1a
2039		9 31·8	52 26	20·15	292·6	5·29	11·0, 11·6	2a
2550	56°2417	9 36·8	56 12	94·27	234·8	4·06	12·0, 12·4	1
3127	58°1632	9 41·6	58 09	24·30	249·2	4·13	11·3, 11·9	1a
3130	56°2614	9 50·0	56 28	24·12	199·5	4·61	12·0, 12·5	3a
2042		9 52·1	52 11	92·05	235·2	4·49	12·3, 12·5	2a
				24·36	237·5	3·95		3a
2555	56°2680	9 53·5	56 41	24·14	19·8	3·41	12·3, 12·5	4a
2557		9 54·2	57 53	24·10	227·4	4·36	12·2, 12·6	1a
2044	53°3131	9 55·5	53 30	24·35	238·8	3·78	11·7, 12·1	2a
2045	53°3136	9 55·8	53 23	24·35	32·9	4·92	12·0, 13·0	2a

TABLE II.—*Continued.*

Barton	C.P.D.	R.A.	S. Dec.	Epoch	p	d	Mags.	Weight
		h m	° ′		°	″		
2558	57°2523	9 56·6	57 28	24·10	114·4	3·54	12·0, 13·0	1b
2046	54°3002	9 56·8	54 19	92·08	145·3	4·96	12·1, 12·7	2b
2047		9 57·0	54 06	92·08	119·6	3·02	12·2, 12·4	2a
2559	57°2535	9 57·2	57 48	93·15	135·2	4·13	11·8, 12·8	1b
φ	53°3192	9 58·3	53 55	92·08	165·5	5·82	11·3, 13·3	2a
3133	55°2829	9 59·3	55 19	24·16	72·3	4·32	12·2, 12·2	2a
3134		9 59·4	58 08	93·15	203·7	4·48	11·8, 12·2	1b
2562	56°3268	10 20·8	56 26	94·27	299·0	4·91	10·7, 10·9	1a
2052	53°3817	10 23·3	53 59	92·08	54·8	4·03	11·6, 12·2	2b
2053		10 25·9	54 04	92·08	167·2	3·20	12·2, 12·2	2b
2563	54°3751	10 26·6	54 57	93·19	26·2	4·22	11·6, 11·7	2a
				26·09	27·6	4·03		2a
2564		10 30·8	55 36	26·09	240·7	3·27	11·8, 12·4	1a
3146	58°2530	10 37·0	58 42	24·30	219·5	4·97	11·2, 11·8	2a
2055	53°4192	10 47·1	53 59	92·08	162·5	3·43	11·2, 11·2	1a
3153	56°3923	10 47·3	56 58	24·16	68·3	4·65	11·2, 12·2	1b
3154		10 48·8	57 51	93·15	127·4	4·49	12·0, 12·2	1a
2569	54°4161	10 51·3	54 56	96·67	320·9	5·32	10·8, 11·3	2a
				25·15	323·2	5·06		1a
3156		10 51·4	56 37	24·16	235·6	4·86	11·6, 12·2	2a
2062		11 10·5	53 47	92·08	1·9	5·24	11·8, 12·2	2a
2064		11 14·0	54 08	92·08	76·9	4·83	12·0, 12·4	2b
2065	54°4455	11 14·0	54 22	92·08	357·8	4·70	11·6, 11·6	2b
2577	54°4486	11 16·6	54 59	20·21	139·3	4·26	10·9, 11·3	2b
3166		11 49·7	55 47	94·25	179·8	3·98	12·2, 12·2	2a
2075	53°5827	13 53·7	53 21	18·41	210·6	3·96	11·7, 12·1	2a
2077	52°7207	14 18·0	52 22	18·40	54·8	5·24	11·4, 11·6	2a
2814		14 41·2	57 01	94·18	142·8	4·93	12·0, 12·2	1a
2815		15 05·6	56 38	24·27	120·1	4·06	11·8, 12·2	2a
2083	52°8744	15 34·3	52 22	94·53	190·9	5·47	11·2, 11·9	2b
2819	57°8006	16 18·3	57 39	24·44	214·5	3·53	12·0, 12·4	1b

NOTE.

Attention is drawn in the case of the following stars to the C.P.D. identification which was incorrect or marked as doubtful in Barton's lists.

No.	R.A.	No.	R.A.
3117	8 02·1	2042	9 52·1
2037	9 26·8	3134	9 59·4
2550	9 36·8	3154	10 48·8

The stars in Table I were chosen from Innes' *Southern Double Star Catalogue*, and those in Table II from among the doubles discovered by S. G. Barton in published Sydney catalogues. Column 1 gives the name of the star or Barton's number, column 2 the C.P.D. number, and columns 3 and 4 the position (1900·0). The C.P.D. numbers given by Barton have been altered in a few cases noted at the end. Columns 5, 6 and 7 give respectively the epoch, position angle and distance ; in cases where two or more plates differed in epoch by only a few years the results have been combined. Column 8 gives the magnitudes of the stars. In Table I these are taken from Innes' Catalogue. In Table II they were estimated from the plates adjusted in the case of C.P.D. stars, so that the combined magnitude equalled the C.P.D. magnitude with the corrections given in Harvard Annals, Vol. 80, No. 13. Column 9 gives the number of images measured and an estimate of the quality of a single measure depending on the size and shape of the images and the separation and magnitude difference of the components. The probable error in distance was 0″·13 for a measurement of a single image pair of quality *a* and 0″·17 for quality *b*.

THE THERMAL METAMORPHISM OF PORTIONS OF THE WOOLOMIN GROUP IN THE ARMIDALE DISTRICT, N.S.W.

PART I. THE PUDDLEDOCK AREA.

By ALAN SPRY, M.Sc.

With Plate XII and two Text-figures.
(Communicated by S. WARREN CAREY.)

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ABSTRACT.

A portion of the intrusive contact between the New England batholith, and the eugeosynclinal Woolomin Group occurs near Puddledock, in northern New South Wales. The igneous complex comprises mainly quartz monzonite with subordinate hypersthene diorite, pyroxene granite, biotite porphyrite and dolerite. The sedimentary group originally consisted of greywacke, quartzite and basic lava, which are now represented by biotite hornfels, saccharoidal quartzite and a group of rocks rich in calc-silicate minerals.

INTRODUCTION.

The great New England batholith is a multiple intrusion of subsequent type which extends for over two hundred miles through the eastern highlands of northern New South Wales and southern Queensland as a meridional belt. It is chiefly acid in character, although there are variations from basic to ultra-acid types.

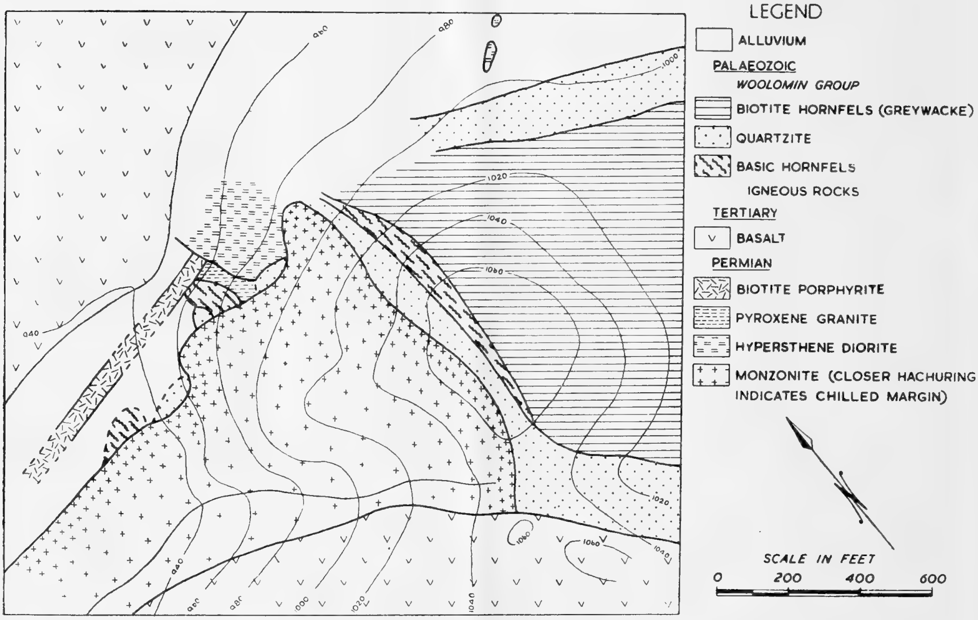
The intruded rocks around Armidale consist of a thick and broadly folded eugeosynclinal series consisting of greywackes (as defined by Pettijohn, 1949), polymictic breccias, sub-greywackes, quartzites, jaspers and basic lavas which has been named the Woolomin Series by Benson (1918) and Voisey (1942). These rocks are referred to here as the Woolomin Group, rather than the Woolomin Series, in accordance with the Code of Stratigraphic Nomenclature (Raggatt, 1950) because the length of time involved in their deposition is at present unknown, hence the " rock " term *group* is preferred to the " time-rock " term *series*. Due to the lack of diagnostic organic remains, the age of these rocks is not known, but they are regarded as probably Silurian-Devonian. Regional metamorphism is lacking unless the silicification which gave rise to the widespread jaspers can be regarded as a low-grade regional metasomatic process. Thermal metamorphism by both the Epi-Silurian (?) and Permian batholiths is rather slight, and restricted to fairly narrow contact aureoles. Metasomatism associated with the intrusions is uncommon, although scapolitization of the basic lavas has been found in two localities. These rocks are well shown in the area described, which is about half a mile north-east of the Puddlecock Dam and 10 miles north-east of Armidale. A portion of the intrusive contact is exposed in an area of about two acres, which is entirely surrounded by flat-lying Tertiary basalts. Mapping was done by plane-table on a scale of 200 feet to 1 inch, and the contours shown on Figure 1 are taken from a purely arbitrary 1,000 feet datum level.

The Igneous Rocks.

The main body is a quartz monzonite with a chilled margin and a steeply dipping sharp contact with the sediments. The other igneous rocks are found in small bodies and their mutual relations are somewhat obscured by soil cover and consequently the intrusive sequence could not be established definitely. The probable order is as follows :

(1) Biotite porphyrite.
(2) Hypersthene diorite.
(3) Quartz monzonite.
(4) Pyroxene granite.
(5) Dolerite.

The biotite porphyrite occurs as an elongated, dyke-like body about 30 feet wide and 800 feet long. It appears to be cut off at one end by the hypersthene diorite and consequently is regarded as the earliest intrusive. It is a light grey porphyritic rock with a very fine-grained groundmass rich in poorly twinned albite crystals and contains phenocrysts of biotite, hornblende and andesine (Ab_{65}).



Text-fig. 1.—A geological map showing the relations of the igneous and metamorphic rocks at Puddledock.

The hypersthene diorite is a coarse-grained brownish rock consisting of almost equal amounts of felspars and ferromagnesian minerals. The relative amounts of orthoclase and plagioclase are variable and the rock might be termed diorite in some specimens and monzonite in others. Plagioclase is most abundant (35%) as subhedral crystals which are often strongly zoned (oligoclase Ab_{70} to andesine Ab_{50}) and twinned on combinations of the Albite and Carlsbad laws. Orthoclase is present in quantities up to 30% and appears as slightly perthitic crystals which are frequently moulded on plagioclase giving a monzonitic fabric. The dark minerals are augite, hypersthene, hornblende and biotite. The pyroxene is chiefly augite, accompanied by quite abundant hypersthene, and the two may be intergrown or surrounded by a corona of hornblende or biotite. There is about 5% quartz occurring as tiny intergranular crystals or as blebs and myrmekitic growths in the orthoclase. A striking feature is the presence of about 2% of apatite which occurs as aggregates of rod-like prisms frequently radiating outwards from the pyroxene. As this intrusion is early in the sequence, the coronas of hornblende and biotite and also the growths of apatite could be interpreted as being due to the thermal metamorphism of the rock by later intrusions, but it is thought they are most probably the result of deuteric crystallization.

The quartz monzonite is a light coloured, medium-grained rock becoming dark coloured and fine-grained in the chilled marginal zone. Near the contact the rock is a micro-monzonite, generally even grained, or slightly porphyritic with larger plagioclase phenocrysts set in a slightly finer grained matrix containing felspar with biotite, augite, hornblende and occasional hypersthene. It is usually a mid-andesine, but may be zoned from oligoclase Ab_{85} to andesine Ab_{50}. Dusty orthoclase is present in amounts up to about 20% and quartz may be almost absent or up to 15%. The most abundant ferromagnesian mineral is biotite. Green augite and hypersthene are usually fringed with biotite or pale green hornblende.

The normal quartz monzonite differs from the border phase in its coarser grain and lack of pyroxene. It is a medium to coarse grained rock containing plagioclase, orthoclase and biotite with a little hornblende and quartz, and shows a monzonitic fabric. The plagioclase is well formed and is andesine, but shows zoning from Ab_{70} to Ab_{55}. Orthoclase is anhedral and dusty and surrounds the plagioclase. Quartz is present up to 20% as grains or vermiculate growths with felspar. Biotite is abundant and often intergrown with pale hornblende.

The pyroxene granite occurs as a few small outcrops located between the monzonite, diorite, porphyrite and hornfels. It does not show any significant relation towards them and there is nothing to indicate whether it was intruded before or after the neighbouring rocks. It is only about 50 feet by 30 feet in area. It is a coarse-grained, leucocratic rock containing perthitic orthoclase (65%), quartz (24%), augite (8%), sphene (3%) and a very little plagioclase (oligoclase Ab_{80}). The augite is green and slightly pleochroic while sphene is remarkably abundant as brown prisms and grains.

The dolerite is a fine-grained greenish-grey rock which occurs in a very small outcrop in the east end of the central basic hornfels mass. It occurs only a few feet from the monzonite and intrudes the Group B hornfelses. It has an intergranular texture with laths of albite up to 0·1 mm. long forming an imperfect mesh enclosing the ferromagnesian minerals. These are entirely secondary and consist chiefly of pale green, almost isotropic chlorite, tiny needles of tremolite (?) and a very little brown hornblende. Epidote occurs as scattered small grains, and ilmenite is very abundant with a great deal of finely granular sphene. This dolerite has many affinities with the spilites and was at first considered to have been a pre-granite intrusion associated with the Woolomin volcanism. However, as it occurs within basic rocks which have been strongly metamorphosed and which contain garnet, pyroxene, wollastonite, etc., it is unlikely, in view of its unmetamorphosed character, that it could have been in position prior to the emplacement of the monzonite, and consequently it is placed at the end of the intrusive cycle.

The texture, composition and dyke-form of the biotite porphyrite are more in keeping with the later phases of emplacement of the batholith, and it was at first considered to be part of the widespread system of dykes of porphyry and lamprophyre which are a feature of the last phases of this intrusive cycle. The field evidence appears to preclude this view, and indicates that the dyke invaded the sediments first, and was followed and partly obliterated by the later hypersthene diorite. The diorite was followed by the major intrusion of quartz monzonite which cuts across all the other rocks. This has a chilled margin and the mineralogical differences from the edge inwards indicate the trend of crystallization. The micro-monzonite has less quartz, less hornblende and a more basic plagioclase and contains augite and hypersthene, which are absent from the quartz monzonite. The position of the rather basic pyroxene granite in the sequence is not known, but from the abundance of quartz and orthoclase it has been tentatively regarded as the last plutonic unit to form. The abundance of such minerals as pyroxene (augite and hypersthene) apatite and sphene in the hypersthene diorite and pyroxene granite suggests that they may have been contaminated by absorbing some spilite, but no field evidence was found to support this hypothesis.

The Metamorphic Rocks.

The rocks which have been altered by the intrusion were originally fine grained greywacke, quartzite and spilite. These have been altered to varying degrees, but because of their widely different chemical compositions it was not possible to find zones of decreasing grade of metamorphism away from the intrusion. Both greywackes and spilite attained the amphibolite facies of Turner (1948), but the latter may have reached the pyroxene hornfels facies in one place.

The Basic Hornfelses.

The most interesting of the thermally altered rocks are those derived from the basic lava flow. It has been observed in several localities around Armidale that basalts have been altered to rocks of spilitic nature prior to the intrusion of the batholith and that the thermal metamorphism operated on the spilitic mineral assemblage. There are two major groups which have different mineralogical and textural characteristics and each of these groups is subdivided into varieties.

A. Those showing original igneous texture.
    (1) Hornblende rich.
    (2) Diopside rich.
    (3) Scapolite or prehnite rich.

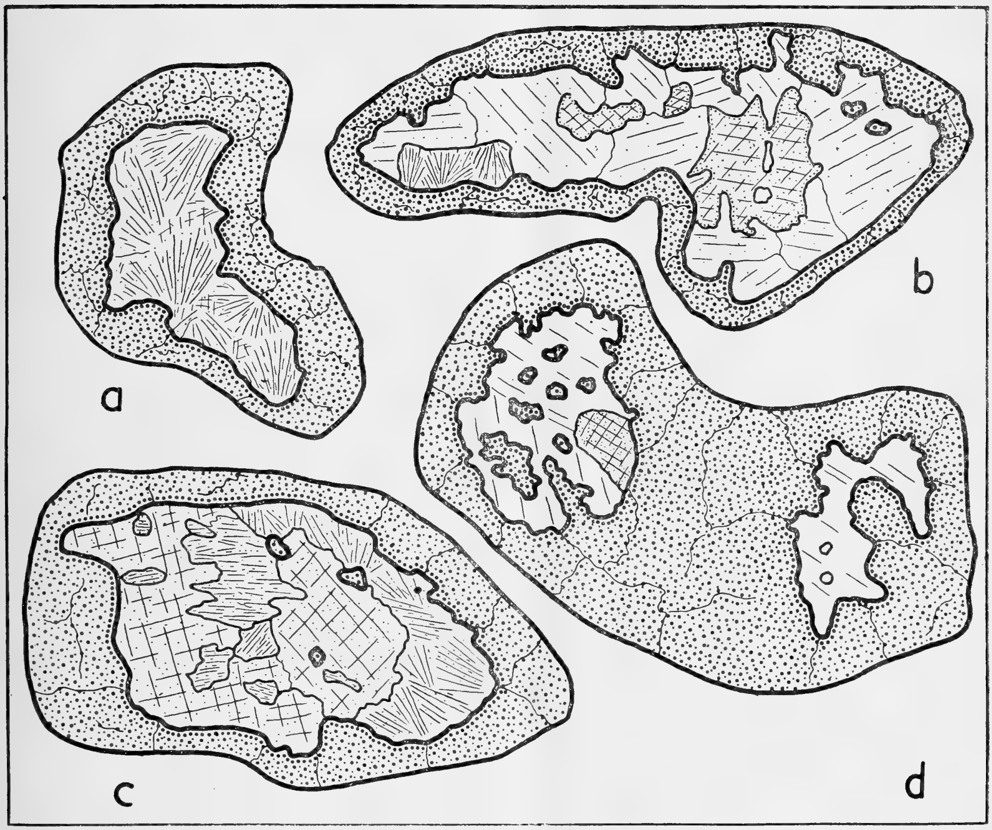
B. Those not showing original igneous texture.
    (1) Calcite quartz bearing.
    (2) Wollastonite bearing.

Group A.

The spilite which occurs as the narrow band shown in the upper central part of Figure I is less altered and still retains some of the original igneous (amygdaloidal and intergranular) texture. The three varieties show differing original composition and degree of alteration with the typical associations hornblende-albite, diopside-andesine and diopside-scapolite (or prehnite).

The hornblende rich variety is a dense green rock which appears to show least alteration. Blasto-intergranular texture is shown by radiating laths of original poorly twinned albite with fresh pale yellowish-brown to dark brown hornblende and colourless diopside crystallizing between the felspar. Secondary plagioclase (andesine Ab_{60}) occurs only in amygdales, where it may be accompanied by diopside and sphene.

The diopside-rich variety is pale greenish grey in the hand specimen and it is common to find the diopside and hornblende rich varieties together, even in one hand specimen. The intergranular texture is not shown so well as in the previous variety, but the albite laths form radiating growths with diopside granules between. Secondary fresh plagioclase (albite to basic andesine) is sporadic and is usually found in amygdales, although in parts the original basaltic texture is replaced by a granoblastic aggregate of plagioclase and diopside. The amygdales were probably originally filled with calcite, and during metamorphism there has been a migration, chiefly of lime out from the amygdale and alumina, silica, etc., into the amygdale from the surrounding rock. This resulted in a zone of grossular ringing the amygdale, with a central zone containing one or more of the following minerals : calcite, plagioclase, scapolite, prehnite, diopside or apatite, as shown in Figure 2. The texture is often diablastic with growths of calcite and andesine, calcite and grossular, diopside and andesine, etc. Some of the grossular is birefringent. Scapolite and prehnite are restricted to amygdales in this variety but become abundant in the mass of the rock in the third type.



Text-fig. 2.—Sketches of some amygdales in the basic hornfelses of group A showing a rim of grossular in each case with a filling of (*a*) prehnite, (*b*) plagioclase, calcite and prehnite, (*c*) calcite, scapolite, prehnite and garnet, (*d*) plagioclase, diopside and garnet. ×46 approximately.

Where scapolite or prehnite become very abundant, they replace original albite laths over large areas. The primary basaltic texture is obliterated as the scapolite envelops the plagioclase and forms comparatively large crystals with sutured margins. These areas contain unaltered diopside granules whose mutual relations still show the intergranular texture to some extent. Growth of other minerals from the amygdales outward tends to give a coarse granoblastic texture.

The amygdales contain similar assemblages to the diopsidic variety mentioned previously, untwinned or poorly twinned plagioclase being notable. The scapolite and prehnite both form from plagioclase and the scapolite may alter to prehnite. The scapolite is a mizzonite Ma_{65} with $N_{\varepsilon}=1\cdot546$, $N_{\omega}=1\cdot574$, D.R. $=0\cdot028$. These values were measured by immersion methods on fragments of a large crystal from an amygdale, but measurements with a Berek Compensator on the groundmass scapolite in thin sections indicated generally a more sodic dipyre Ma_{35} with D.R. averaging $0\cdot012$. In one specimen where calcite was abundant, a lime-rich scapolite occurred and was greatly altered to wollastonite suggesting that the scapolite and wollastonite may not be stable together, the latter mineral representing a higher grade of metamorphism.

The three varieties probably do not indicate differing grades of metamorphism, but rather differing compositions which may be original or due to metasomatism. The mineral assemblages indicate that equilibrium has not been established, thus enabling a series of metamorphic changes to be recognized.

Group B.

The mineral assemblage of this group is quite different from that of the preceding one, both because the original basic rock was much richer in calcite and also because the metamorphic grade is higher. This richness in calcite has been observed in unmetamorphosed spilites which contain closely packed amygdales filled with calcite so that the rock contains at least 50% of that mineral. Calcite also has replaced plagioclase by a premetamorphic process. Rocks of this group occur in a small patch surrounded by quartz monzonite, pyroxene granite and biotite porphyrite and their elevation to at least the cordierite-anthophyllite sub-facies of the amphibolite facies and possibly to the pyroxene hornfels facies is a reflection of the proximity of igneous rock almost completely surrounding the hornfels. Complete recrystallization has taken place and no vestige of the igneous structure remains. The structure is coarse and irregular with diablastic and poikiloblastic textures common. The minerals present include calcite, quartz, wollastonite, diopside-hedenbergite and grossular. Members of this group are divided into two classes, depending on the presence of calcite plus quartz or wollastonite, and thus a division is made between rocks of different metamorphic grade.

The lower grade hornfels is typically light coloured with large bladed crystals of both plagioclase and calcite up to 3 cms. long, containing pyroxene or garnet poikiloblastically. The garnet, which is pale brown and probably grossular, sometimes constitutes up to about 90% of a dark, heavy garnet-rock. The pyroxene is deep greenish-brown in colour with a relief close to that of grossular and a D.R. of $0\cdot027$, and thus is an iron-bearing diopside as distinct from the colourless diopside in the group A hornfelses. Calcite and quartz grow diablastically without any tendency to form wollastonite. Sphene and scapolite or prehnite occasionally occur, while a greenish-brown fibrous amphibole replaces the pyroxene as a retrograde product in some rocks. The plagioclase is a basic andesine.

Those hornfelses which contain wollastonite instead of calcite plus quartz usually have a coarse and irregular texture or are granoblastic aggregates of wollastonite, pyroxene, garnet and plagioclase (as basic as labradorite Ab_{40}).

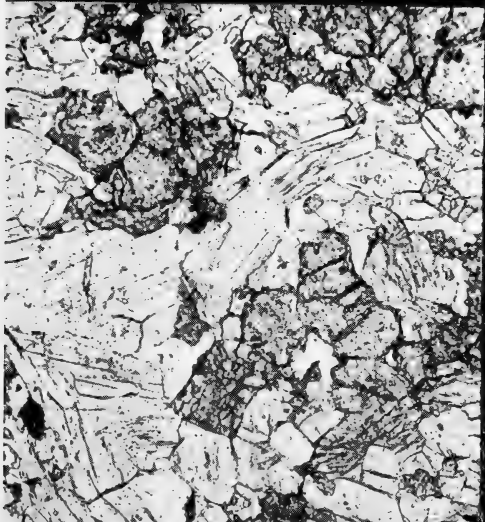
Some hornfelses of this group are indistinguishable from calc-silicate rocks derived from lime-rich sediments. They are presumed to be the products of metamorphism of calcite rich basic igneous rocks rather than sediments for the following reasons :

(*a*) No limestones have been found in the Woolomin Group.

(*b*) They occur in the line of strike of the basic lava.

1

2



3

4

They are frequently porphyroblastic with large grossular crystals set in a decussate growth of wollastonite with abundant tiny pyroxene crystals. Calcite may occur where there was not sufficient silica to allow the complete change to wollastonite.

SEDIMENTARY HORNFELSES.

The metamorphosed sediments found here are regarded as having been derived from fine-grained greywackes and quartzite. The most common hornfels is a black, saccharoidal, rather soft rock which is spotted with biotite flakes growing along the bedding. The texture is porphyroblastic with large flakes or aggregates of biotite set in a very fine granoblastic aggregate of quartz, felspar and biotite. Each of the large biotite crystals is surrounded by a zone barren of mica, from which the ferromagnesian material has been derived. Quartz and felspar are usually equally abundant and each constitutes about 40% of the rock. The felspar is quite fresh and is chiefly untwinned plagioclase varying in composition from oligoclase to andesine (Ab_{60-70}). The freshness and range of composition suggest that the plagioclase is metamorphic and has been derived from the cloudy felspar common in the unaltered Woolomin greywackes. A few crystals which have a cloudy core and a fresh peripheral zone represent partially recrystallized felspar. A little chlorite and poorly crystallized muscovite may occur with apatite as accessories. One hornfels contains abundant tiny granules of diopside in groups with quartz and oligoclase.

The coarse white saccharoidal quartzite is very pure and has a granoblastic to sutured texture. It contains only minute amounts of minerals other than quartz ; tiny crystals of muscovite, epidote, apatite, pyrite, magnetite and rutile occur.

DEGREE OF METAMORPHISM.

The rocks show the impress of a moderate grade of thermal metamorphism with a higher grade where there has been repeated intrusion. Metasomatism appears to have been restricted to a little introduction of halogen and water to the basic rocks where scapolite and prehnite were formed from plagioclase. The spilite was much more susceptible to both metamorphism and metasomatism than the sediments. There was a distinct period of retrograde metamorphism when pyroxene altered to hornblende. The mineral assemblages of the basic lava are typical of thermal metamorphism of such rocks. The basaltic rocks of group A originally contained the assemblage augite plus labradorite and this was changed to the spilitic assemblage albite plus hornblende, epidote, calcite and actinolite prior to the thermal metamorphism. The original minerals are not found here but the first process was presumably an alteration of actinolite to hornblende, while the albite was unchanged. At a further stage the albite recrystallized. In rocks which were richer in epidote or calcite, diopside appeared with albite and hornblende. At higher temperatures the assemblage diopside plus andesine was accompanied by grossular. The scapolite and prehnite which earlier were restricted to the amygdales then replaced the groundmass plagioclase over large areas. The processes have been arrested at various stages of completion, and the failure to achieve equilibrium between the minerals is typical of these rocks.

The group B rocks probably originally contained calcite, albite, chlorite, actinolite and a little quartz. The first stage was the production of the assemblage andesine-pyroxene-grossular with calcite plus quartz. The second stage was marked by the combination of calcite plus quartz to give wollastonite with garnet, pyroxene and plagioclase. The hornblende rich members of group A contain hornblende-diopside-albite, which is an unstable assemblage arrested in its trend to hornblende-diopside-plagioclase probably representing the cordierite-anthophyllite sub-facies of the amphibolite facies. Amphibole is not found in the other basic hornfelses, which may extend up into the pyroxene-hornfels facies. The assemblages diopside-plagioclase, diopside-plagioclase-scapolite (prehnite)-grossular, diopside-grossular or diopside-grossular-wollastonite are not critical and may indicate the upper part of the amphibolite or the lower part of the pyroxene hornfels facies. The presence of plagioclase as basic as labradorite Ab_{40} would indicate that some at least of the wollastonite bearing rocks of group B lie in the latter facies. The change from an assemblage in which calcite and quartz occur together to one in which wollastonite is stable marks a definite step in the metamorphic processes and Turner (1948) states that calcite plus quartz is stable over the lower part of the cordierite-anthophyllite sub-facies, while wollastonite is stable over the upper half, thus calcite plus quartz does not extend into the pyroxene-hornfels facies.

In the greywackes, the assemblage quartz plus oligoclase or andesine plus biotite with or without diopside indicates that the sediments reached the same approximate level of metamorphism as the basic rocks in the cordierite-anthophyllite sub-facies. However, some biotite hornfelses contain albite or acid oligoclase with a little muscovite and chlorite, and possibly represent a stage as low as the actinolite-epidote hornfels sub-facies of the albite-epidote-amphibolite facies. The presence of abundant potash which is represented by biotite prevented the appearance of such minerals as cordierite, andalusite or almandine, etc. There is a moderately close relation between the degree of metamorphism of the spilite and the greywackes, but in general the basic rocks contained a mineral assemblage which is susceptible to metamorphism and were permeable, thus suffering considerable alteration, whereas the fine-grained massive greywackes were both structurally and mineralogically more resistant.

Somewhat similar rocks have been found in similar environments at Tilbuster and Dumaresq, some miles to the west, and a description of these other areas will be presented in the second part of this paper.

ACKNOWLEDGEMENTS.

This work was undertaken while the author was on the staff of the New England University College, Armidale, and the author wishes to thank Dr. A. H. Voisey for making this research possible. Appreciation must be particularly expressed to those students who assisted in the field mapping. The work was completed at the University of Tasmania, where Professor S. Warren Carey and his staff have assisted by criticism of the manuscript.

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EXPLANATION OF PLATE.

PLATE XII.

Fig. 1.—Apatite prisms surrounding biotite and pyroxene as radial growths in the hypersthene diorite. ×60.

Fig. 2.—Hornfels of group A containing diopside and plagioclase with the intergranular texture almost destroyed. ×60.

Fig. 3.—Hornfels of group B showing a decussate aggregate of wollastonite with pyroxene and garnet. ×60.

Fig. 4.—Hornfels of group B showing a granoblastic aggregate of diopside and plagioclase. ×60.

SEDIMENTATION OF THE TOMAGO COAL MEASURES IN THE SINGLETON–MUSWELLBROOK COALFIELD: AN INTRODUCTORY STUDY.*

By F. W. Booker, M.Sc.,
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and C. T. McElroy, B.Sc.

With Plates XIII and XIV and three Text-figures.

Manuscript received, October 14, 1953. Read, December 2, 1953.

I. Introduction and Acknowledgements.

For the past few years the authors have studied, both independently and collaboratively, several aspects of the stratigraphy, lithology, petrology, sedimentation and sedimentary tectonics of the Tomago Coal Measures in the Singleton-Muswellbrook Coalfield, Central Hunter Valley, New South Wales.

This paper discusses these matters briefly, and is intended to be the first of a series on sedimentation in certain areas of N.S.W., in which it is hoped the collaboration of field geologist and petrologist will continue.

In this paper the sections on stratigraphy, lithology and sedimentation are the work of Booker. Bursill is responsible for the petrological study of the Bayswater Bore, and McElroy for the petrology of the rocks from the surrounding area.

The authors desire to express their grateful appreciation of the assistance of Mr. H. F. Whitworth, M.Sc., Dr. Paul and Mr. R. O. Chalmers in the preparation of microscopic sections and plates for this paper, of Dr. H. Rutledge for his meticulous reading of the paper and valuable comments thereon, and of Mr. P. McKenzie for his able co-operation during the field investigations. Helpful discussion by Dr. G. D. Osborne is also acknowledged.

II. General Structure.

The Singleton-Muswellbrook Coalfield of Upper Permian Age is situated in the Central Hunter River Valley of New South Wales, embracing the region between these two towns, which are on the Great Northern Railway.

Sediments referable to the Tomago Coal Measures occupy an area of approximately 300 square miles in this field. They occupy a synclinal area between the Muswellbrook Dome on the west, and the Loder and Darlington Domes on the east; they are bounded on the north by the Hunter Overthrust and on the south by the Newcastle Coal Measures, which are in turn overlain by the Triassic, as shown in Fig. 1.

The structure in the Tomago Coal Measures of this field is not a simple syncline. Rather there is a series of anticlines and synclines with more or less meridional axes. The axial planes all appear to dip westerly and are generally arcuate. In the southern part of the area the convexities of the arcs are directed to the east, but in the north there is a tendency to reversal. The axis of the

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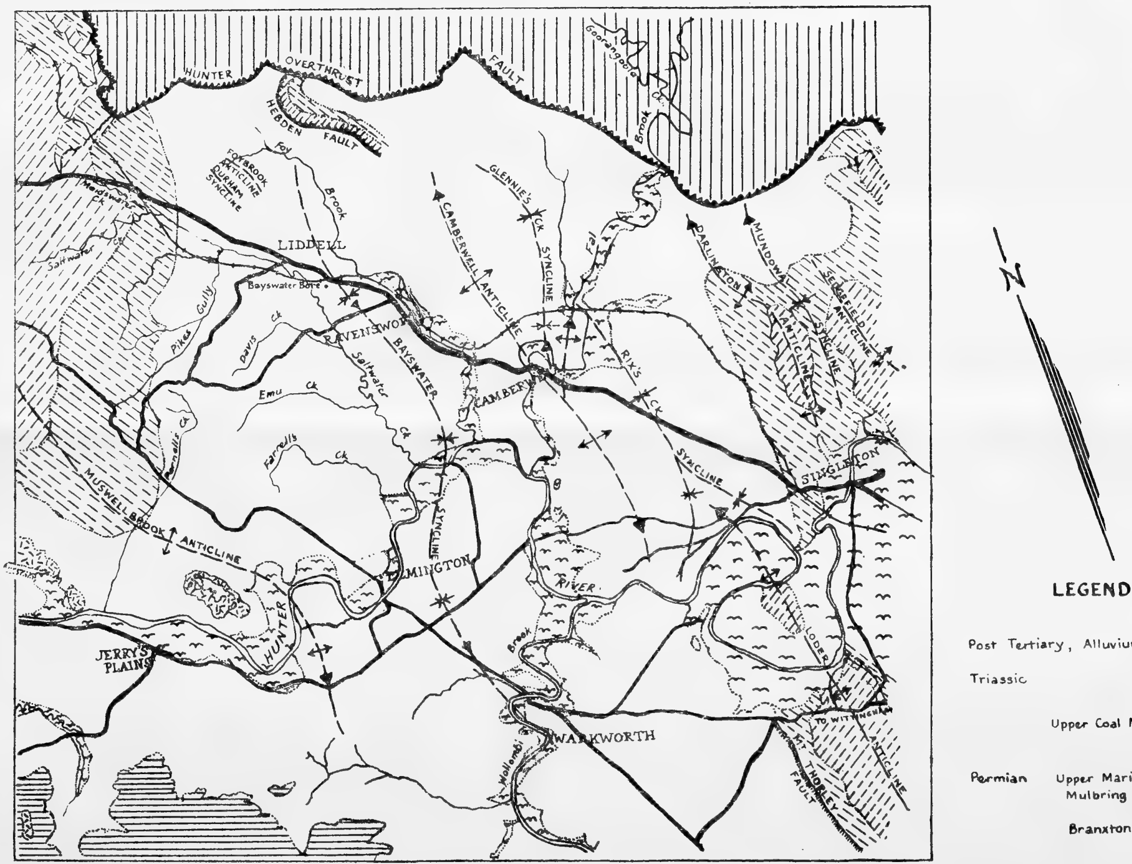

LEGEND

Post Tertiary, Alluvium		▨
Triassic		▤
	Upper Coal Measures	☐
Permian	Upper Marine Series Mulbring Beds	▨
	Branxton Beds	▨
Carboniferous		▥
Igneous		▩

UPPER COAL MEASURES OF SINGLETON-MUSWELLBROOK COALFIELD

Scale

MILES 0 ½ 1 2 4 6 MILES

Muswellbrook Dome is an exception to this generalization. On the north the fold structures are truncated by the Hunter overthrust and its subsidiary, the Hebden Thrust. To the south the intensity of the folding decreases rapidly, and the folds are barely reflected in the Newcastle Coal Measures and the overlying Triassic.

III. General Stratigraphy.

In the Singleton-Muswellbrook Coalfield the Tomago Coal Measures consist of some 1,600 to 1,700 feet of sediments, which can be subdivided into two formations :

(1) *The Bayswater Formation.* Transition beds between the underlying marine Crinoidal Shales or Mulbring Beds of the Upper Marine Group and the Coal Measures proper. They consist of about 200 feet of dark shales containing occasional fragments of *Glossopteris*, and a few pyritic concretions, grading downwards into similar marine shales containing numerous foraminifera and an occasional macro-fossil.

The Bayswater Formation or Bayswater Shales, which are readily recognizable, can be traced over the whole length of both margins of the basin, and have been identified in every bore deep enough to penetrate them. They can only be separated from the underlying marine shales on palæontological evidence, and in this connection the authors here desire to record the valuable work of Miss I. Crespin, B.A., of the Bureau of Mineral Resources, whose micro-palæontological work has been a major contributing factor in delineating these beds.

(2) *The Rix's Creek Formation.* 1,400 to 1,500 feet thick, mainly greywacke, sandstone, shale and siltstone with numerous coal seams. In the north-eastern part of the area there occurs a distinct conglomerate facies.

In the vicinity of Liddell, Ravensworth and Rix's Creek the Rix's Creek Formation consists of a rhythmic succession of greywackes, sandstones, shales, siltstones, claystones and coal seams. Conglomerate is a minor rock type, and when it does occur, is generally as a component of graded bedding in greywacke. As the massive greywackes of the Rix's Creek Formation are traced northwards they pass into conglomerates. The first indication of the change in sedimentation is the occurrence of lines and small irregular lenses and wedges of pebbles in the greywacke, a relationship which at this stage appears to resemble graded bedding (Plate XIII, Fig. 1). The pebbles become larger and more numerous, the lenses and wedges thicken, and the next stage is a series of interlocking lenses of greywacke and greywacke conglomerate.

Further north there is a transition from a massive greywacke with only occasional pebbly bands to a massive conglomerate with minor lenses of greywacke. At this stage the pebbles are relatively small, up to a maximum of two inches in diameter. Still further north, the size of the fragments increases until the conglomerate contains small boulders up to a foot in diameter. This change takes place in a distance of less than four miles.

Excellent exposures of the early stages of the facies change may be seen in the railway cuttings between Nundah and Rix's Creek. The medium and fine conglomeratic stages are exposed in Glennies Creek to the east and north from Glennies Creek Railway Station ; the coarser phases occur in Reedy Creek and Stony Creek, tributaries of Glennies Creek, east of the Singleton-Goorangoola Road. The conglomerate facies of the Rix's Creek formation occupies a sector of a circle bounded by the Hunter Overthrust and extending as far south as Nundah and Glennies Creek, and as far west as Coal Hole Creek, east of Antienne. The coarsest phases lie to the east, grain becoming finer to the south and west.

The conglomerate pebbles comprise a heterogeneous assemblage of the harder and more resistant sedimentary types, such as chert, jasper and chalcedony, as well as resistant igneous rocks. Petrological examination of a number of pebbles from these conglomerates, carried out by Mr. H. F. Whitworth, M.Sc., suggests that all could have been derived from rocks of Carboniferous age outcropping to the north.

Raggatt (1938) made a comprehensive study of the facies of the Muree in this part of the Hunter River Valley, and found a comparable and parallel facies change. He failed, however, to recognize the facies change of the Rix's Creek Formation and referred its conglomerate facies to the Newcastle Coal Measures, under the name of Fal Brook Conglomerates.

IV. SEDIMENTATION.

The Bayswater Bore displays the most complete section of the Tomago Coal Measures in the Singleton-Muswellbrook Coalfield so far available. Thus it may be regarded as typical of the Tomago sedimentation in the Liddell-Ravensworth-Rix's Creek area.

In this bore a thickness of approximately 1,170 feet of strata belonging to the Rix's Creek Formation is made up of the following :

	Feet		%
Greywacke	594	equivalent to	51
Greywacke conglomerate	72	,, ,,	6
Shale, siltstone and mudstone ..	404	,, ,,	35
Coal	100	,, ,,	8

Several of the members included above under the heading of *greywacke* contain minor amounts of conglomerate, as components in the graded bedding.

The sediments represented in the bore are referred to five groups :

(1) Rudites.
(2) Arenites :
  (*a*) Epiclastic.
  (*b*) Pyroclastic.
(3) Lutites.
(4) Rocks containing siderite in characteristic form.

(1) *Rudites.* In hand specimen all of these are very similar, varying from pebbly greywacke through gritty greywackes with scattered pebbles to fine conglomerate of the greywacke type. The overall colour is light to medium grey. The phenoclasts are polygenetic and much the same in all specimens examined, the commoner being :

(1) Very weathered green (?) volcanic rock.
(2) Grey-brown quartzite.
(3) Light brown porphyry.
(4) Various grey to brown cherty rocks.
(5) Rare vein quartz.
(6) Blackish quartzite.
(7) Basalt (?).
(8) Brownish altered sandstone.
(9) Jasperoid and chalcedonic rocks.

Most are commonly rounded to sub-rounded, but a few are sub-angular. They are often well weathered, though indurated in the process of cementation, the rocks thus formed being hard, firmly cemented and not very porous. The diameters of the phenoclasts vary from 0·9 to 3·5 cm. The following specimens selected over a fairly considerable depth range may be regarded as representative of this class of sediment :

Specimen Number.	Approximate Depth. (Feet.)	Phenoclast Diameter. (Centimetres.)
R.W. 24	520	3·5
23	520	2·0
11	184	1·9
22	514	1·6
8	158	1·0
7	146	0·9

Quartz grains, mostly euhedral, are common, but few accessory minerals have escaped alteration. Most of the rock fragments are fine-grained, cherty or quartzose. Specimen R.W. 7 contains a small pebble with a micrographic inter-growth of quartz and felspar.

Cementation occurs by four methods which appear in all specimens :

(1) (*a*) *Reaction.* The boundaries of the grains, particularly between the quartzites and some less easily recognizable grains, are seen to merge into each other indefinitely at their contact.

(*b*) *Recrystallisation* (*or Enlargement*). This is well developed in specimen R.W. 7, in which a chalcedonic cement has formed round and between chalcedonic pebbles.

(*c*) *Degradation.* This is probably the main cause of cementation. The weathered surfaces of pebbles and grains have become homogeneous with a clay-based matrix which has invaded the less resistant grains, particularly the plagioclase felspar.

(*d*) *Carbonation.* This is the normal interstitial infilling by carbonates, and it is found in the more porous specimens. The carbonates may be calcite or siderite or mixed carbonates of iron and lime (ankerite). Frequently they are impure, due to the presence of the clay fraction. They are reactive and occasionally replace entire detrital grains which retain some of their original shape, or invade them, leaving, as in specimen R.W. 23, a curious skeleton-crystal or scopulitic structure. There seems to be no evidence of pressure welding.

(2) *Arenites.* (*a*) *Epiclastic.* The epiclastic arenites in hand specimen are whitish-grey to medium grey in colour. All are hard, compact and not very porous. They have a " pepper-and-salt " appearance, due to the presence of dark rock fragments and carbonaceous material, as well as light-coloured quartz and rock fragments. The more finely grained varieties are very tough. Bedding is rarely apparent, but when present, is irregular. Graded bedding is fairly common in the coarser arenites (Plate XIII, Fig. 1).

Under the microscope the grains are seen to consist of much the same rock types as the rudite phenoclasts with quartz and very few ferro-magnesian or other accessory minerals. The grains vary in shape from elongate to equant, but rarely show the high sphericity of many of the rudite pebbles. Many of the grains are angular to sub-angular, the angularity varying inversely as the size. The quartz grains are fresh and more or less euhedral. These grains are commonly fractured but frequently retain several perfect faces and undamaged coigns. Cherty, chalcedonic and quartzitic fragments are dominant in the rocks. There is much interlocking of grains, the interstices being filled with smaller grains, thus reducing porosity. The fraction below arenite grain size, say 0·12 mm., is quite small, generally under 10% if sideritic material is excluded.

Approximate estimates of the detrital quartz fractions in specimens of arenites from the Bayswater Bores are as follow:

Specimen Number.	Estimated Detrital Quartz.
R.W. 6	7%
20	7%
15	5%
30	8%
33	7%
18	10%
14	10%

The felspar fraction in these rocks is always less than 5% and comprises plagioclase (common) and orthoclase (less common). The felspars, while retaining their euhedral shape, are usually weathered to some extent.

The cementation of the arenites is the same as that of the rudites discussed above. The carbonate cementation, however, takes two forms:

(i) A brown granular cementing material probably composed of clayey ferrous carbonate.

(ii) A crystallised form of the material referred to above, almost invariably consisting of small crystals of mixed carbonates of calcium and iron, and probably magnesium.

(*b*) *Pyroclastic.* Tuffs are relatively common in the section of the Bayswater Bore. They are most conspicuous when they are intercalated with coal or carbonaceous shales. Specimens R.W. 111 from 1,412 feet (Plate XIV, Fig. 6) is an excellent example of a crystal tuff occurring between layers of carbonaceous shale. Carbonaceous shale containing scattered plagioclase crystals breaks off sharply and is replaced by a band of crystal tuff which is perfectly graded upward from incoherent crystals to fine bentonitic clay. The tuff band is only one and a half inches thick. No quartz is present; about 25% of the rock consists of euhedral plagioclase, cracked, embayed and stained; 10% consists of macerated woody material with well preserved cellular structure, and 15% of fine-grained cherty angular rock fragments. The residue is clayey material.

A remarkable rock from a depth of about 1,342 feet, specimen R.W. 104, has the appearance of black welded crystalline ash with its upper surface pitted with circular depressions two to four millimetres in diameter. It is about three inches thick, and has a curious pitted fracture throughout (Plate XIII, Fig. 5). Under the microscope the groundmass is brownish and indeterminate. The rest consists of quartz fragments, often deeply embayed, which could not possibly have survived water transport. Many of the fragments are completely shattered. Some primary calcite, mica and pieces of woody tissue are present (Plate XIV, Fig. 5).

The ashy rock of specimen R.W. 104 may be a form of ignimbrite deposited by a nuée ardente, and the shattering and surface vesiculation may have been caused by cooling in shallow water. The vesiculæ are filled with laminated shale. The presence of woody tissue seems to eliminate any possibility of it being a stringer from a sill.

It is possible that the fresh plagioclase found in the rudites and arenites is derived from pyroclastic material transported by water, but crystal tuffs of the type represented by specimen R.W. 111 could only have been deposited from the air.

(3) *Lutites.* The following specimens chosen over a wide vertical range in the Bayswater Bore are typical of this group of rocks.

Specimen Number.	Maximum Grain Size. (Millimetre.)	Average Grain Size. (Millimetre.)	Approximate Depth. (Feet.)
R.W. 12	0·63	0·10	186
2	0·20	0·12	48
13	0·50	0·26	336
38	0·25	0·09	1,148
37	0·35	0·10	1,131
21	0·30	0·07	204
5	—	0·04	113
19	0·70	0·09	488
103	0·15	0·04	1,342
100	—	—	1,339

Except in grain-size most of these specimens differ little from the arenites. The higher proportion of carbonate cement in some cases reduces the cohesion of the grains, but in others it may produce a uniformly well-cemented and non-porous rock. There is a tendency for the coarser lutites, as well as the finer arenites, to be jointed, but jointing appears to be reduced as the clay fraction increases.

The quartz fraction of the lutites consists of very angular grains, and the proportion increases inversely as the grain size, except in the more clayey specimens. The following table shows the estimated quartz content of selected specimens of lutites from the Bayswater Bore.

Specimen Number.	Estimated Quartz Content.
R.W. 12	15%
2	27%
13	30%
38	50%
37	50%
21	40%
19	30%
5	15%
103	Mainly non-detrital
100	Mainly non-detrital

Plagioclase felspar, biotite, sericite and chlorite are present in all specimens; potash felspar and olivine are rare. The more clayey varieties contain much mica.

It is often difficult to distinguish the clay from the carbonate cementing material. The following are very approximate estimates of the carbonate content of selected specimens.

Specimen Number.	Estimated Carbonate Content.
	%
R.W. 12	5
2	70 (including clay)
13	7
38	Less than 1
37	5 (excluding veinlets).
21	5
19	5
5	Less than 5
103	80 (carbonate and clay)
100	100 (calcium carbonate with devitrified glassy shards)

As in the arenites, the carbonate cementing material is usually complex and present either in a minutely crystalline form or in a granular clayey form. Specimen R.W. 2 is almost a limestone with a fairly large clay fraction and scattered quartz grains. Specimen R.W. 103 is a marl, and R.W. 100 a limestone, possibly containing some tuffaceous material as there are traces of the presence of devitrified glassy shards in it.

(4) *Rocks Containing Siderite in Characteristic Form.* Few of the rocks from the rudites to the clays are without some proportion of siderite. The following specimens consist mainly of siderite and they are arranged in order of the grain size of the small detrital fraction they contain.

Specimen Number.	Approximate Depth. (Feet.)	Form of Siderite.
R.W. 31	861	Equal siderite and clay with scattered quartz and rock fragments.
26	743	As above.
35	1,118	As above.
32	948	Sphærosideritic ironstone.
25	728	Clay ironstone.

The mixed silty or sandy carbonate rock contains ferrous carbonate either as small, ill-defined crystals or as irregularly shaped flocculi, which are finely granular and reticulate, showing a fine network structure. In carbonaceous rocks these flocculi may coalesce into irregular globose masses along the bedding planes, often surrounded by woody tissue, suggesting an origin between layers or within vegetable tissue. These flocculi can also occur scattered along the bedding planes of the arenites. Specimen R.W. 32, a dense black ironstone, is a beautiful example of sphærosiderite, containing perfect zoned spherulites of siderite. Clearly the invasion of some of the siderite into arenites is, and some nodules are, diagenetic ; some of the flocculi are deposited as such along with the detritus, possibly by a co-precipitation process, and others, particularly the globose material and spherulites, are formed authigenically. The reticulate structure may substantiate a flocculous, precipitated origin.

The above summary of the petrology of the Tomago Coal Measures is based almost entirely on the section proved in the Bayswater Bore, but numerous samples collected over a very wide lateral and vertical range only serve to confirm it.

Of the many samples taken from bore cores and outcrops in the area, thirty specimens were selected for microscopic study. The specimens were taken from localities within a zone approximately 13 miles long by five miles wide, the long axis of which trends north-westerly and south-easterly through the Bayswater Bore, which is four miles from the north-western end of the zone.

The majority of the specimens were taken from the cores of diamond drill bores situated from 1½ to 2½ miles west of the Bayswater Bore. They were taken over a maximum vertical range of 630 feet, and the stratigraphic equivalents of the specimens are represented in the Bayswater Bore.

Specimens taken from outcrops of wider lateral distribution than those from the bore cores are representative of beds stratigraphically equivalent to practically the whole vertical range of the Bayswater Bore.

The specimens studied included rudites, arenites and lutites, but the arenites, being the most abundant, received the closest attention.

The arenites from the core of the Bayswater Bore contained up to 55% of rock fragments, the dominant assemblage being cherts, siltstones and quartzites with very subordinate amounts of the igneous rocks. The dominance of this siliceous assemblage, which justifies the use of the term " oligomictic," is maintained in the specimens collected from the zone referred to above. Micrographic intergrowths similar to that recorded in specimen R.W. 7, from the Bayswater Bore, were observed in several localities.

As in the Bayswater Bore, cementation has taken place by the processes of carbonation, and also by a siliceous cement and interstitial primary clay. The siliceous material is in the form of chalcedony and micromosaics of quartz, while the clay minerals form well-defined interstitial, scaly aggregates, sometimes clouded by sideritic material. Specimen M.S. 66, from an outcrop 2½ miles north-east of the Bayswater Bore, exemplifies the skeletal sideritic cementation recorded in specimen R.W. 23 from that bore.

The mineral grains in the rocks are angular to sub-angular, and the rock grains are sub-angular to sub-rounded. The fragmental constituents of the arenites range from 0·1 to 1·0 mm. in diameter and are fairly well sorted.

The estimated percentage of quartz in the arenites from surrounding localities are higher than those in the Bayswater Bore, up to 31% having been determined. The felspar content of the rocks is somewhat higher, up to 12% having been determined.

Over the whole of the zone studied, the great majority of the rocks of any particular class show similarity of texture and composition, both laterally and vertically.

In summing up prevailing views, Pettijohn (1949) concluded that induration and dark colour were necessary for the correct use of the term " greywacke." Large, very angular detrital grains, mainly quartz, felspar and rock fragments in a sericitic and chloritic matrix, were also requisite.

The rocks from the Tomago Coal Measures are classed as greywackes as defined by Condon (1952), but it is felt by the authors that it would be preferable to erect a new name for these mildly indurated, light-coloured arenites.

Such a name must imply sandy texture and composition dominantly quartz and rock fragments, but it must not convey previously accepted implications not applicable to these rocks. In the meantime the use of the term greywacke to describe these rocks merely implies that they are arenites having the mineral composition of greywackes.

From the above description it will be seen that the log of the Bayswater Bore represents superficially a very uniform example of sedimentation. In reality the keynote of the sequence is restless instability, alternating with long periods of quiescence.

The greywackes which constitute the major part of the sequence show every sign of having been rapidly removed from the source area and rapidly poured into the area of deposition with little or no winnowing. The heterogeneity of the constituent rock types, the comparative freshness of the felspar and the occurrence of inclined or foreset bedding are all evidence of rapid deposition and quick burial. The occurrence of graded bedding in rocks deposited under such conditions is somewhat difficult to explain in view of the generally accepted theories as to its origin (Pettijohn, 1949) and its occurrence can merely be recorded in a paper of this nature (Plate XIII, Fig. 1). The rapid change of facies from conglomerate to greywacke, siltstone and shale in a matter of four miles may be accepted as proof of proximity to high, rapidly rising source areas, and the affinities of the constituent rock fragments are strong evidence that the source areas were composed of rocks comparable with those of the Carboniferous outcropping immediately to the north.

The greywackes of the area have been deposited in a series of interlocking lenses, of which the horizontal axes are not always parallel to the true bedding, and there is frequently an angular difference of as much as 30 degrees between the true bedding as represented by a shale bed or a coal seam and that of the greywacke lenses. Examples of this may be seen in Foy Brook Open Cut and Pyke's Gully Open Cut at Liddell.

In Pyke's Gully Open Cut the junction of the overlying greywackes with the Liddell Seam is exposed. The photograph shown in Plate XIII, Fig. 2, was taken before extraction of the coal had begun, and the floor of the cut is virtually the roof of the seam. Here the foreset beds of the Liddell Sandstone (Greywacke) are inclined at an angle of about 30 degrees to the bedding of the coal seam. Above the seam is a few feet of shale, on to which the greywacke detritus has been poured. The weight of the material and the forward slumping of the great bulk of rapidly introduced sediment has crumpled the shale overlying the seam and even the topmost plies of the coal itself.

Lenticular sedimentation of this nature is the rule in the Singleton-Muswellbrook Coalfield and applies equally to the Greta as to the Tomago Coal Measures. Consequently wide variations of interseam thicknesses are everywhere in evidence, making it impossible to accept interseam thickness or lithology as reliable criteria in seam correlation.

Cone-in-Cone Structure. The lenticulation of the coarser sediments occurs also in the argillaceous deposits. An interesting form of cone-in-cone structure is apparently associated with this feature and with the presence of tuffaceous clays and recrystallising carbonates. The structure is always associated with bentonitic clays or shales, and generally with clay ironstones. It consists of thin calcareous bands up to one foot thick, of no great lateral extent. The bands themselves comprise a succession of minutely plicated veins and veinlets of calcite, often traversed by secondary veins. The small plications imprison lenticles of clay. Both the clay and the calcite may be partially sideritized. The bands usually rest upon grey, blue-grey, or white bentonitic clay or shale, and are frequently overlain by a band of clay ironstone. The plicated veins may be contorted to such an extent that they form conical structures which may be associated with slickensiding or apparent chatter marks in the clay.


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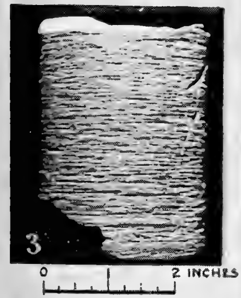
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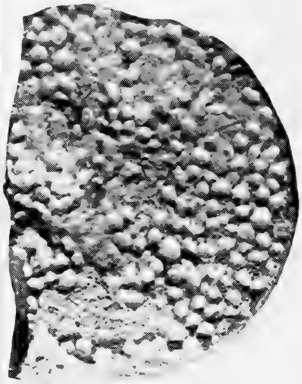
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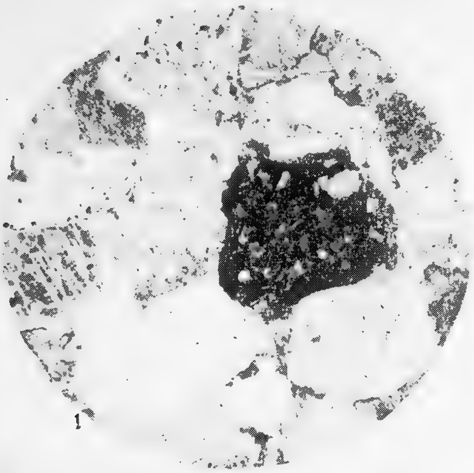

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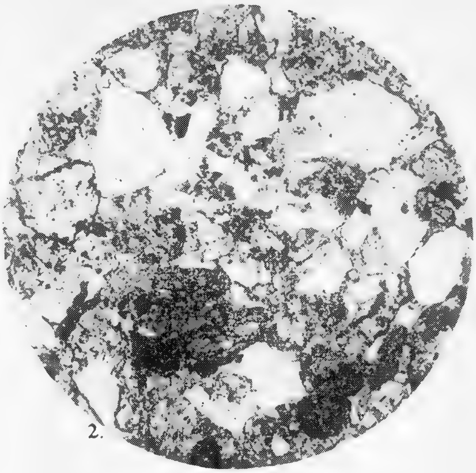

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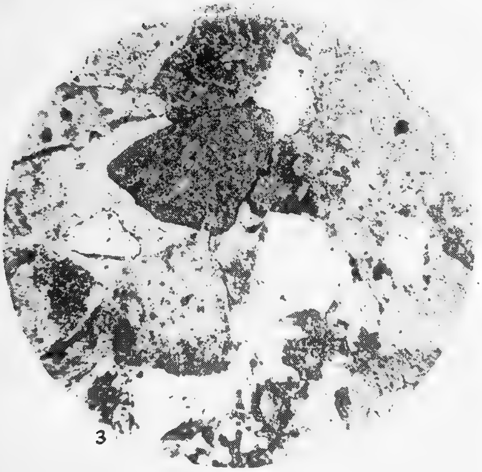

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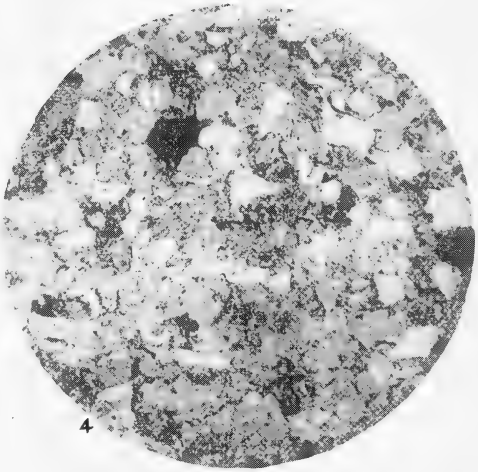

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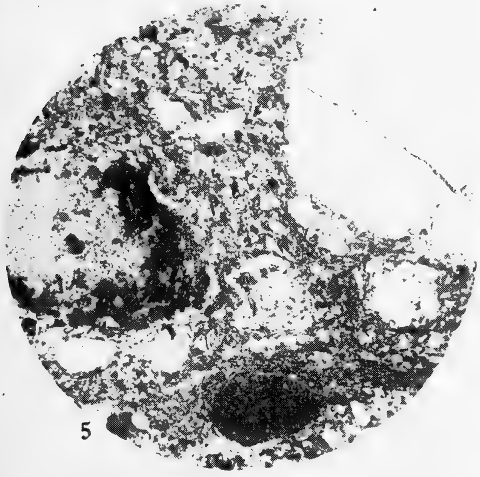

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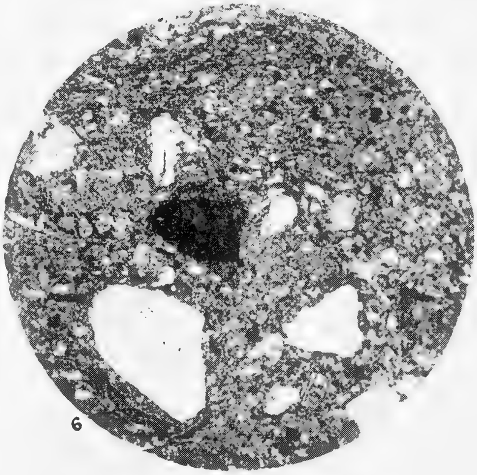

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This type of structure, which has not hitherto been described in detail from this area, may have been referred to by David (1884) when he described a portion of a bore core from East Maitland as follows : " Five inches of soapy clay shale with fibrous calcareous veins " and " eight inches of clay shales, soapy, with irregular calcareous veins one-eighth to one and one-half inches thick."

During a boring campaign by the Commonwealth Bureau of Mineral Resources in the Newcastle District, the phenomenon was noticed in several bores, particularly in the Buchanan-Maitland area, but always in sediments referable to the Tomago Coal Measures, never in the Newcastle Coal Measures.

The fact that the structure is found in almost every stage of development may throw some light on the growth of cone-in-cone structure. It is suggested that the conditions necessary for the formation of the initial plicate structure depend on minute lenticulation of alternate sideritic and possibly ashy clay that becomes altered to bentonitic clay in time. The lenticles of siderite above and below the clay layer meet from time to time, forming nodes which act as centres of crystallization of the siderite. The outward growth of crystalline siderite will then naturally have a conical tendency, as nodes further and further from the centre become incorporated, while the clay lenticles are isolated entirely.

It seems likely that at an early stage the siderite may be replaced by calcite, which may be contributed in part at least from the clay.

Stages in the development of cone-in-cone structure ranging from slight sideritic plications to elaborate calcite cones have been observed (Plate XIII, Figs. 3 and 4). The " chatter marks " may result from movement of the clay as crystallisation alters the volume, or they may be merely small isolated lenticles of clay which simulate the effects of movement. The association of slickensiding does, however, substantiate to some extent the occurrence of movement, probably of the " stick-slip " type. It should be noted that lenticles of bentonitic clays are found in which the lenticle boundaries are coated with secondary carbonate (ankerite), and this may suggest an alternative method of growth.

Cyclic Sedimentation.

The sedimentation of the Rix's Creek Formation as a whole presents a picture of alternating instability and quiescence. The numerous and thick coal seams must be deemed to have required long periods of stability under conditions favouring the prolonged existence of coal swamps for their formation. In contrast, the interseam sedimentation, with its thick, lenticular greywackes and conglomerates, foreset bedding and rapid lateral variation, suggests rapid accumulation and rapid burial of the deposits. This occurred under conditions requiring the abrupt rejuvenation of the source areas and rapid sinking of the depositional areas, possibly accompanied by water level variations, between each period of coal formation. The log of the Bayswater Bore (Text-fig. 2) shows a rhythmic sequence of greywackes, mudstones, siltstones, shales and coal seams forming a cyclic suite. Four major cycles of sedimentation can be identified in a depth of 1,250 feet, and on these are superimposed many minor cycles. Similar cycles can also be identified in most other bores in the area.

Cycles or rhythms in sedimentation are a world-wide phenomenon.

Text-figure 3 (*a*) (Raistrick and Marshall, 1939), illustrates a cycle or coal measure " unit " from the Carboniferous Coal Measures of England. It is described as " a unit cycle of sedimentation related to depth of water and supply of sediment in a deltaic area," and is the result of the shoaling and filling of the depositional area and the formation of coal swamps. The section might well have been taken from the log of almost any bore in the Singleton-Muswellbrook Coalfield, except that the marine phases of the cycle are not there represented.

Cyclic sedimentation in the Pennsylvanian of America was recognized by Udden as early as 1906. In 1912 he described cyclic sediments in the Pennsylvanian of the Peoria Quadrangle of Illinois. The study of cyclic sedimentation in the Pennsylvanian has since been developed by Weller, Wanless, Shepard and others until to-day the literature on the subject is extensive.

In the Pennsylvanian of America the equivalent of the coal measure " unit " is the cyclothem, defined by Weller (1930) in the following terms : " A series of beds deposited during a single sedimentary cycle of the type that prevailed during the Pennsylvanian Period."

Under ideal conditions the cyclothem contains ten members, five fresh-water and five marine. The concept of the " ideal " cyclothem was developed to represent the optimum succession of deposits during a complete sedimentary cycle. Weller defined an ideal cyclothem for the State of Illinois, which is reproduced in Text-fig. 3 (*b*).

A comparison of the figures reproduced will demonstrate the essential similarity of the coal measure " unit " and the cyclothem. Variations in tectonic intensity and periodicity and its relationship to both source and depositional areas must influence the nature and succession of cyclic deposits, and the relationship of the area of deposition to the source area alone can be responsible for major variations in the sedimentation of a cycle. Text-fig. 3 (*c*) after Wanless and Shepard (1936), shows three types of cyclothem ranging from near-source to shallow marine conditions. Text-fig. 3 (*d*) shows a cycle from the Tomago Coal Measures of the Singleton-Muswellbrook Coalfield and a comparison of this section with those shown in Text-fig. 3 (*c*) suggests a strong similarity between it and the piedmont type of cyclothem.

Although the cycles of sedimentation in the Tomago Coal Measures have many features in common with the coal measure " units " of the Carboniferous of England and the cyclothems of the Pennsylvanian of America, there are, however, differences which cannot be overlooked in any comparison.

First, while the English and American cycles range in amplitude from marine to fresh-water, the examples from the Tomago Coal Measures are restricted to fresh-water conditions.

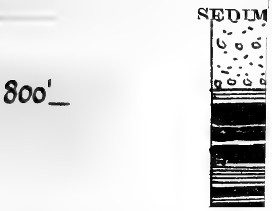
Secondly, the English and American examples commence and terminate with unconformity. So far intraformational unconformity has not been found in the Tomago Coal Measures.

Thirdly, the complete coal measure " unit " or cyclothem is nowhere represented in the Tomago Coal Measures, or for that matter in any of the coal measure sediments in New South Wales.

Fourthly, in the Pennsylvanian of America individual cyclothems have been identified over wide areas and have been suggested as a basis of coal seam correlation (Weller, 1930). The cycles in the Tomago Coal Measures of this area have not yet been established as continuous over any great area.

Fifthly, Weller assigns the rank of formations to the cyclothems of the Pennsylvanian, but similar ranking of the Tomago cycles does not appear to be warranted. It will be appreciated, therefore, that although the cyclic sedimentation of the Tomago Coal Measures has much in common with that of the Carboniferous of England and the Pennsylvanian of America, there are so many points of difference that it would be unwise at this stage to draw more than general inferences from a comparison.

Numerous hypotheses have been advanced from time to time in explanation of the phenomena of cyclic sedimentation. In 1936 Wanless and Shepard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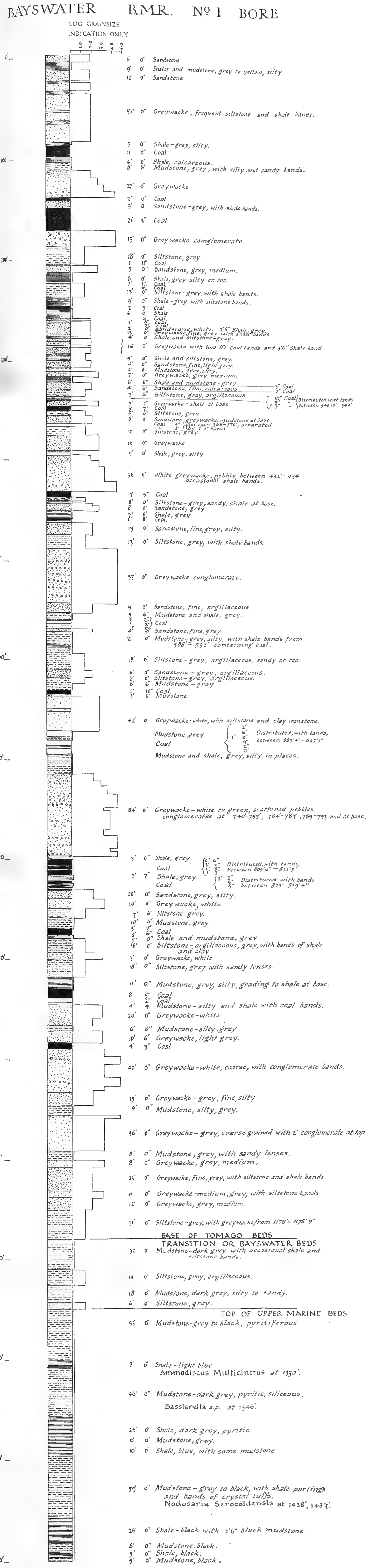

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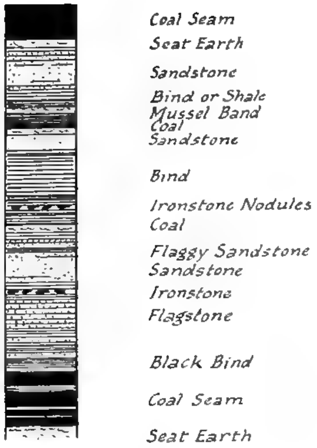
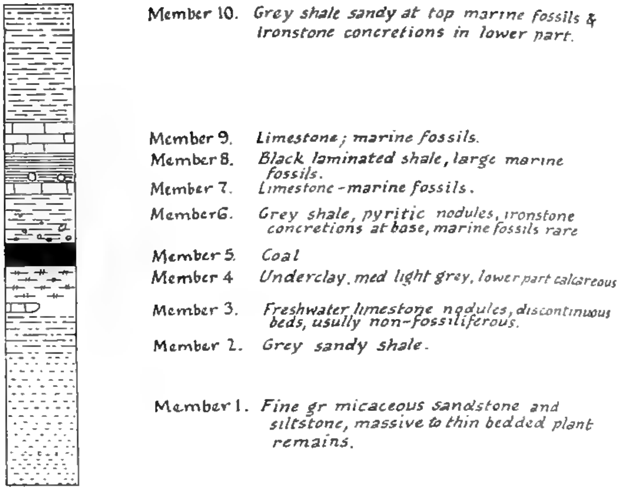


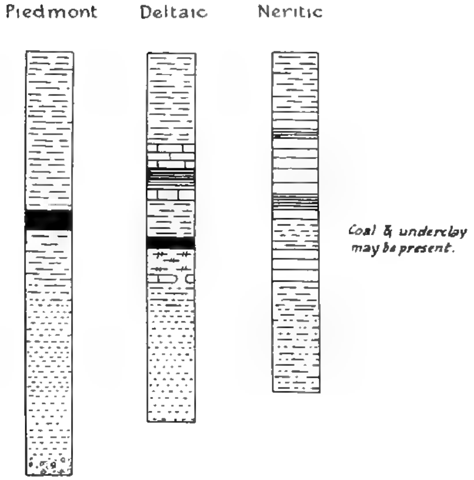
Detail of Coal Measure Unit (*after Raistrick & Marshall*)

Fig. "a"



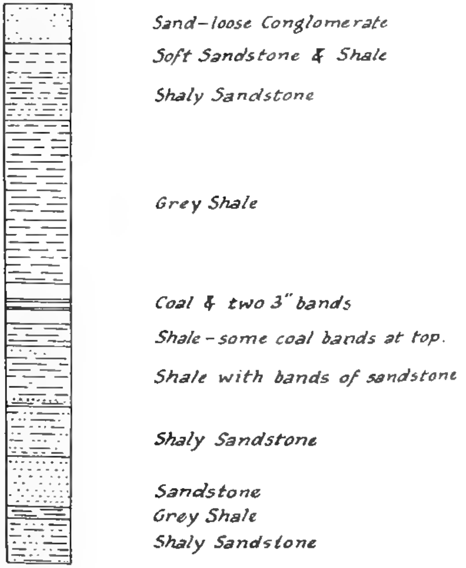
The ideal cyclothem (*adapted from Wilman & Payne Ill. Geol. Survey Bull. 66. 1942. & other sources.*)

Fig. "b"



Three types of cyclothems showing change from near-source areas to shallow fluctuating marine conditions. (Adapted from Wanless & Shepard Geol Soc. Am. Bull 1938.)

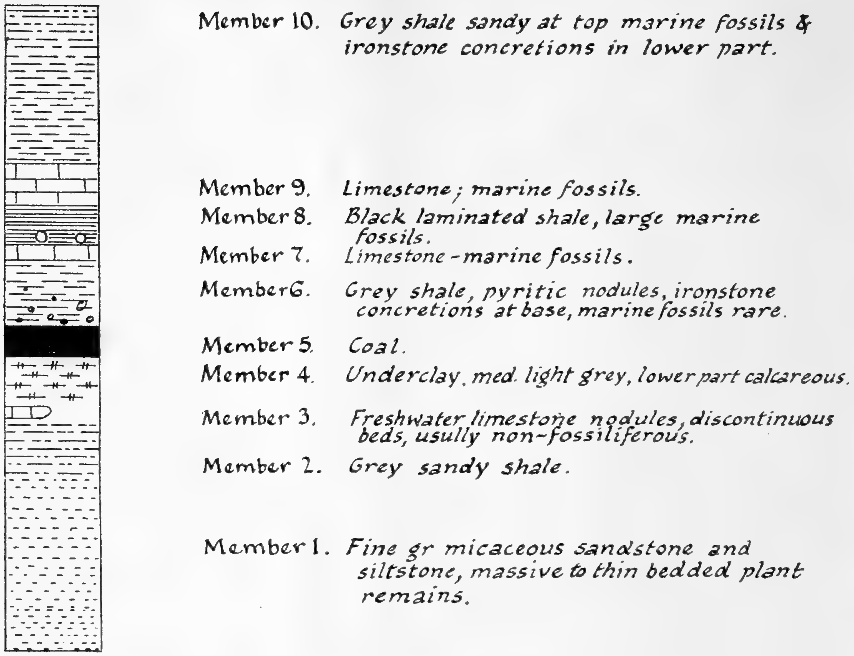
Fig. "c"



Detail from Nº1 Bore Ravensworth State Coal Mine Reserve.

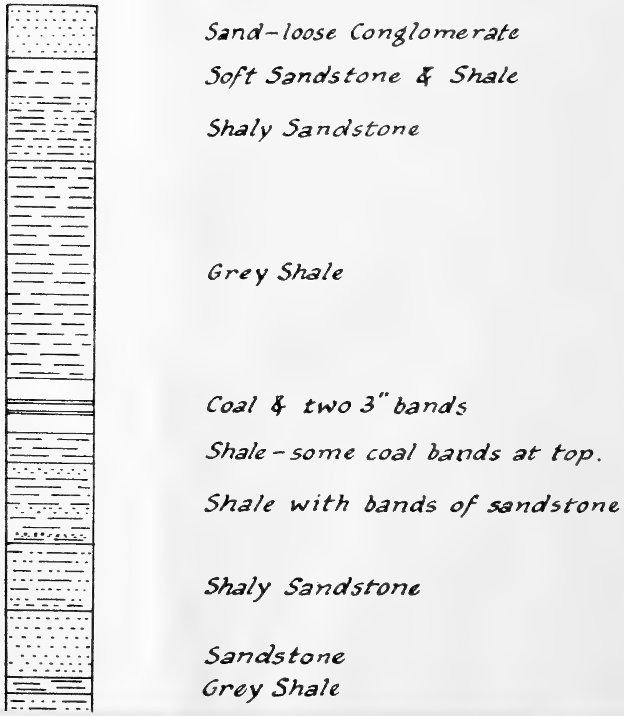
Fig. "d"

Text-figure 3.



The ideal cyclothem (adapted from Wilman & Payne Ill. Geol. Survey Bull. 66. 1942. & other sources.

Fig. "b"



examined the various hypotheses which may be summarized as (1) the hypothesis of intermittent subsidence, and (2) the hypothesis of alternate subsidence and uplift, and proposed a third hypothesis of sea-level fluctuations. Included in their hypothesis is a postulation of glacial control of sea-level fluctuations as a factor in cyclic sedimentation.

As this is the first record of cyclic sedimentation in the coal measures of New South Wales, it is considered premature at this stage to attempt to theorize as to its causation. Any or all of the hypotheses referred to above might be applicable. The suggestion of glacial control of sea-level fluctuations is, however, of more than passing interest in view of the widespread glacial conditions known to have existed in the Permian of the Hunter River Valley of New South Wales.

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EXPLANATION OF PLATES.

PLATE XIII.

Fig. 1.—Graded bedding in greywacke, No. 6 Bore, Ravensworth State Coal Mine Reserve.

Fig. 2.—The Liddell Sandstone resting on shales overlying the Liddell Seam, Pyke's Gully Open Cut. The shales overlying the seam and the topmost plies of the seam itself have been crumpled by the weight and the forward slumping of the overlying sediments.

Fig. 3.—Minute lenticles in shale, Bayswater Bore.

Fig. 4.—Well developed cone-in-cone structure, Bayswater Bore. ×1.

Fig. 5.—Surface pitting on ignimbrite (?), Bayswater Bore. The pitting may be due to deposition in shallow water or, more probably, rain prints. ×1.

PLATE XIV.

Fig. 1.—Arenite from No. 6 Bore, Ravensworth State Coal Mine Reserve. ×40. Specimen No. M.S.6.

Fig. 2.—Arenite from No. 8 Bore, Ravensworth State Coal Mine Reserve. ×40. Specimen No. M.S. 160.

Fig. 3.—Arenite from the Bayswater Bore. ×40. Specimen No. R.W.20.

Fig. 4.—Lutite from the Bayswater Bore. ×40. Specimen No. R.W. 37.

Fig. 5.—Ignimbrite (?) from the Bayswater Bore. ×40. Specimen No. R.W. 104.

Fig. 6.—Crystal tuff from the Bayswater Bore. ×40. Specimen No. R.W. 111.

GEOLOGY AND SUBSURFACE WATERS OF THE MOREE DISTRICT, NEW SOUTH WALES.

By J. Rade*

With four Text-figures.

Manuscript received, October 23, 1953. Read, December 2, 1953.

Introduction.

The Moree district is situated in the north of New South Wales immediately south of the Queensland border and forms part of the area included in the eastern lobe of the New South Wales section of the Great Artesian Basin. It has been selected for description on account of its importance in regard to the stratigraphy and structure of the Great Artesian Basin. It occupies an area of approximately 6500 square miles between Goondiwindi, Mungindi and Narrabri.

Previous references to the artesian water of this district are to be found in Symmonds (1912), Water Conservation and Irrigation Commission's Artesian Investigations (1939, 1940) and David (1950).

In compiling the present paper full use was made of bore data collected by the Water Conservation and Irrigation Commission of N.S.W. The boundaries of the Cretaceous series were determined from the data obtained by Miss Irene Crespin of the Mineral Resources Bureau, Canberra, during an examination of microfossils from samples taken from several bores in the area between 1940 and 1946. The writer made a number of visits to the district for purposes of field investigation.

The country contains but few rock outcrops, being mostly covered by Pleistocene and Recent black soil and waste; the surface is very flat with a slight slope to the west and the rivers traversing it have very shallow and meandering courses. Hence all the information as to the geology has been gained from the logs of artesian and subartesian bores. Since these are numerous it has been possible to obtain a fairly accurate idea of the strata below the surface, though the boundaries shown in the maps and section can only be regarded as tentative. It has been more difficult to determine the depth of bedrock because many bores were not carried down to it, and in the compilation of the bedrock map (Fig. 1) only the most significant bores were taken into account. However, though there may be errors of detail, it is considered that the countours obtained help to throw some light on the structure of the basement complex.

Some trouble was taken to determine as exactly as possible the boundary between Cretaceous and Jurassic beds because of the probability that the variations in this surface reflect variations in the bedrock surface. Less importance was attached to the Cretaceous Roma and Winton Series.

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STRATIGRAPHICAL GEOLOGY.

Apart from some Tertiary basalts and a probable thin cover of Tertiary freshwater sediments overlying the Winton series near the Queensland border, the rocks in the Moree district are Palaeozoic and Mesozoic. As shown by the bores the bedrock consists of Palaeozoic shales, conglomerates, felspar-porphyries and granites. Partly as the result of a study of the Warialda Intake Area, now under investigation by the writer, it is thought that the beds underlying the main aquifers may be chiefly Triassic, Permian, Carboniferous and Devonian, and partly Silurian and Ordovician. The granites intersected by bores in the south-western part of the district are Palaeozoic and are referred tentatively to the Kanimblan orogeny, but the possibility must not be excluded that late Permian intrusions are present in the extreme east.

In the Warialda Intake Area, some 50 miles east of Moree, are Triassic beds consisting of conglomerates, sandstones and shales resting on the Palaeozoic basement and overlain by sandstones of the Jurassic Walloon Series. In shales interbedded with sandstones and bituminous shales on the banks of Warialda Creek N.W. of Delungra, the writer recently found a well-preserved flora including *Thinnfeldia odontopteroides,* and *Johnstonia* sp., plants characteristic of the Triassic Ipswich Series of Queensland. From the available bore logs it would appear that the Triassic beds occur only on the eastern margin of the district and thin out quickly towards the west, so that the Walloon strata rest directly on the older rocks.

The Walloon Series varies considerably in thickness from place to place because of its deposition on an irregular surface not far from the shoreline, and changes in lithological facies are observed within the limits of the district. The lower part of the series is composed of shales which are correlated with the Purlawaugh Beds of Mulholland (1950), while the upper part consists of the porous sandstones known as the Pilliga Beds. With these through change of facies some shales are interstratified and gradually they assume a shaly character. The thickest shale intercalations are found in the deeper parts of the basin, as for example in Boronga No. 2 bore 53 miles N. of Moree.

The maximum thickness about 1500 feet of the Walloon Series was disclosed in the Dolgelly bore, 40 miles N. of Moree, and the minimum recognized thickness of about 170 feet was found in the Coonal bore, 31 miles W. of Moree. The average thickness of the series is estimated to be about 700 feet. Apart from some indeterminable plant-remains, no fossils have been found in the beds.

According to David (1950, p. 459) the Marburg and Bundamba beds of Queensland and the soft Upper Coal-measures of the Walloon Series are not represented in the New South Wales part of the Great Artesian Basin.

Of great interest is the transition from the Walloon Series to the Lower Cretaceous. David (1950, p. 484) correlates outcrops in the far north-west of N.S.W. with the Lower Cretaceous Blythesdale Series of Queensland, which is regarded as lacustrine. In several bores in the Moree district there are sandy shales with lignite and coal and intercalations of sandstone between Jurassic sandstones and Cretaceous marine shales; these beds, which have yielded no microfossils, the writer regards as equivalents of the Blythesdale Series. In the Walloon bore 20 miles N.W. of Moree a coal-seam 1′ 3″ thick between beds of shale was recorded at a depth of 1650 feet. In the Talmoi bore, 26 miles N.W. of Moree, at a depth of 2640 feet 8 feet of shale were found with small seams of coal, associated with sandy shale, white shale, grey sandstone and clay. The average thickness of the series is thought to be about 600 feet.

The Blythesdale Series in N.S.W. has yielded plant-remains. Walkom (1918, p. 58) refers to fragments of *Taeniopteris spatulata* obtained at 1630 feet in the Walloon bore. This plant has a considerable vertical range, and according to David (1950, p. 502) reaches its highest stratigraphical level in the Upper Cretaceous Styx River beds of Queensland.

The Blythesdale beds are overlain by the marine Roma Series, consisting of light bluish-grey shales or shaly mudstones. The lithological character is very persistent, and intercalations of sandstone and sandy shale are but few. The series may attain a considerable thickness, estimated to be about 1300 feet in the Boronga No. 2 bore and 1095 feet in Neargo No. 2 bore. The average thickness is approximately 700 feet.

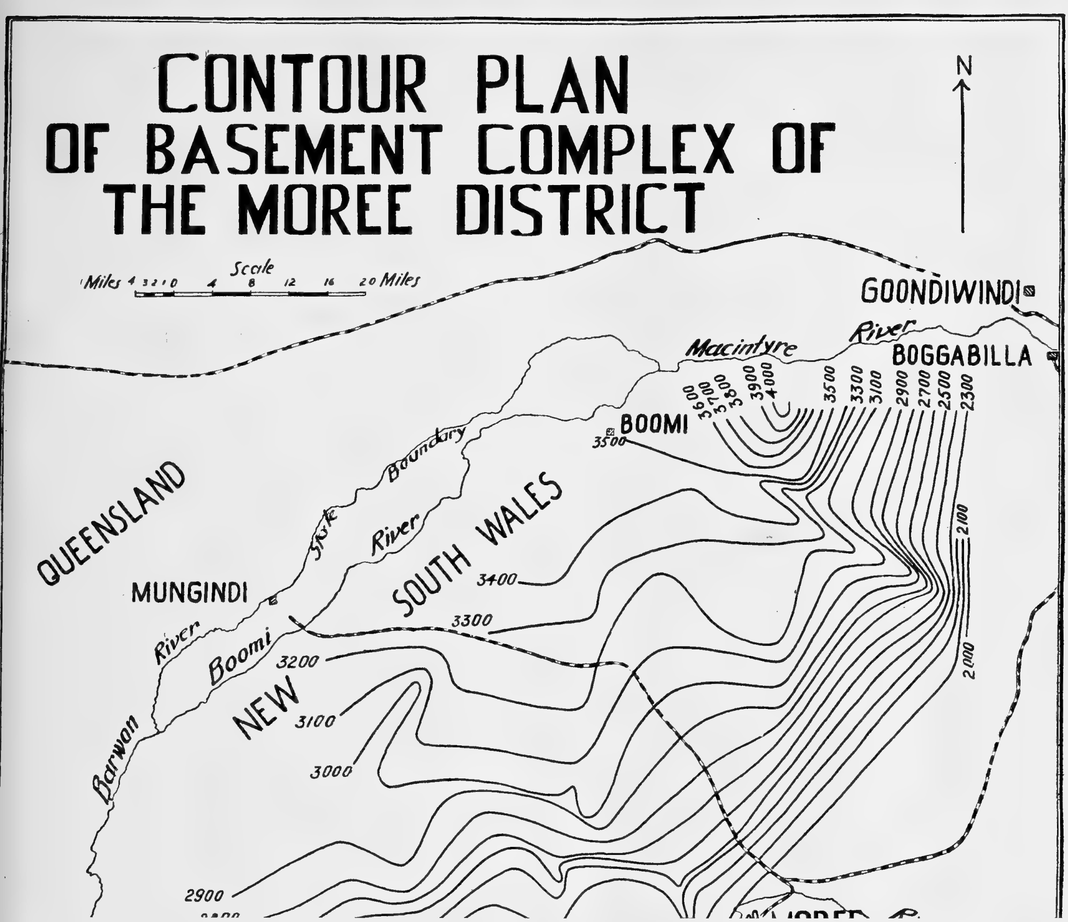
In the Roma beds a rich foraminiferal fauna has been found (Crespin, 1944, 1945, 1946). Many of the forms are identical with those of the Lower Cretaceous of Western Australia (Crespin, 1937), and some are found in the Upper Cretaceous of the North-west Basin (Crespin, 1938). According to Miss Crespin the sandstones and gravels in Boronga No. 2 bore between 25 and 75 feet are Tertiary. From 100 to 250 feet clay was reported, containing fine angular quartz grains, limonite and fragments of Bryozoa referable to genera characteristic of Upper Cretaceous and Tertiary, as, for example, *Hornera, Cribrilina, Retepora beaniana* and *Filisparsa.* At 275 feet the bore passed into sediments of definitely Cretaceous age, in which fossils were found from 752 to 2054 feet. From 902 feet down a persistent assemblage of foraminifera was encountered, dominated by arenaceous genera including *Ammobaculites, Haplophragmoides, Trochammina* and *Arenobulimina* together with the following: *Anomalina* sp., *Arenobulima puschi, Cassidulina* cf. *subglobosa, Cibicides lobatulus, Crithionina, Globigerinoides trilobus, Globigerina* sp., *Glomospira, Gyroidina umbilicata, Haplophragmium aequale, Heronallenia* sp., *Hyperamminoides* sp., *Lagena globosa, Lenticulina* cf. *gibba, L.* cf. *rotulata, Marginulina bullata, Nodosaria subtertenuata, Reophax, Rzehakina, Spiroplectammina* cf. *scott, Spiroplectoides, Textularia* sp., *Verneuilina polystropha.*

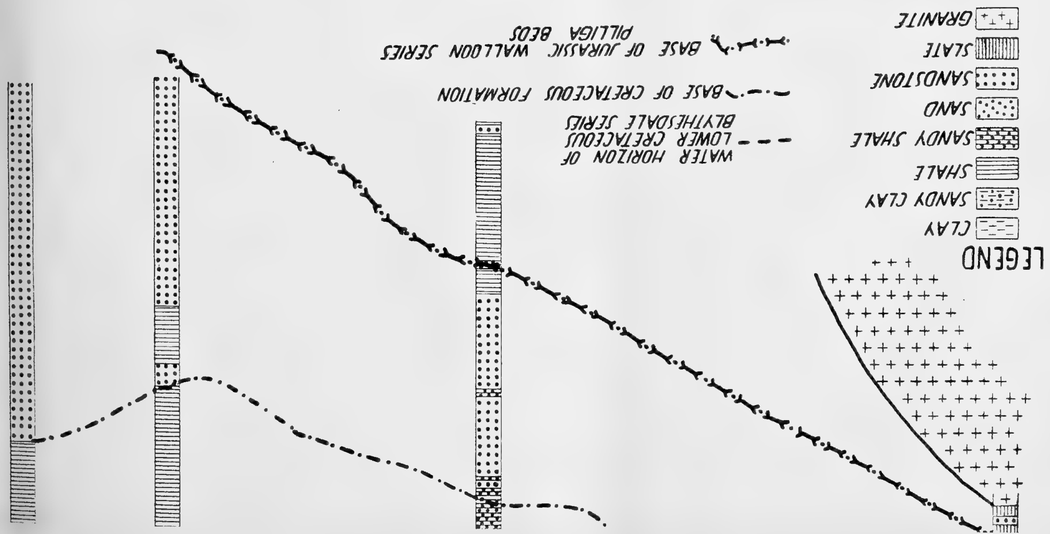
The writer would place the boundary of the Winton and Roma Series in Boronga No. 2 bore at 752 feet, and the boundary of Roma and Blythesdale Series at approximately 2195 feet.

Another bore of the Moree district examined by Miss Crespin for microfossils was Neargo, in which a typical assemblage of Lower Cretaceous foraminifera was present from 355 to 1450 feet.

According to Walkom (1918, p. 58) Lower Cretaceous rocks with marine fossils were encountered to 1500 feet in the Walloon bore; this depth approximately determines the boundary of Roma and Blythesdale Series.

Above the Roma Series lies the Upper Cretaceous Winton Series, representing a return of freshwater lacustrine conditions following the disappearance of the Roma sea. Into the Winton Lake flowed rivers from the highlands of New England bringing sand and mud, and at frequent intervals the occurrence of swampy conditions resulted in deposits of lignite. The town of Moree is approximately on the old shore-line of the Winton Lake. In the Moree artesian bore carbonaceous shale 29 feet 6 inches thick was encountered at 673 feet, and at 806 feet lignite alternating with dark shale, clay and sandstone, to a total thickness of 116 feet. The sequences begin with sandy layers, which pass up into clay and shale, reflecting the conditions prevailing in





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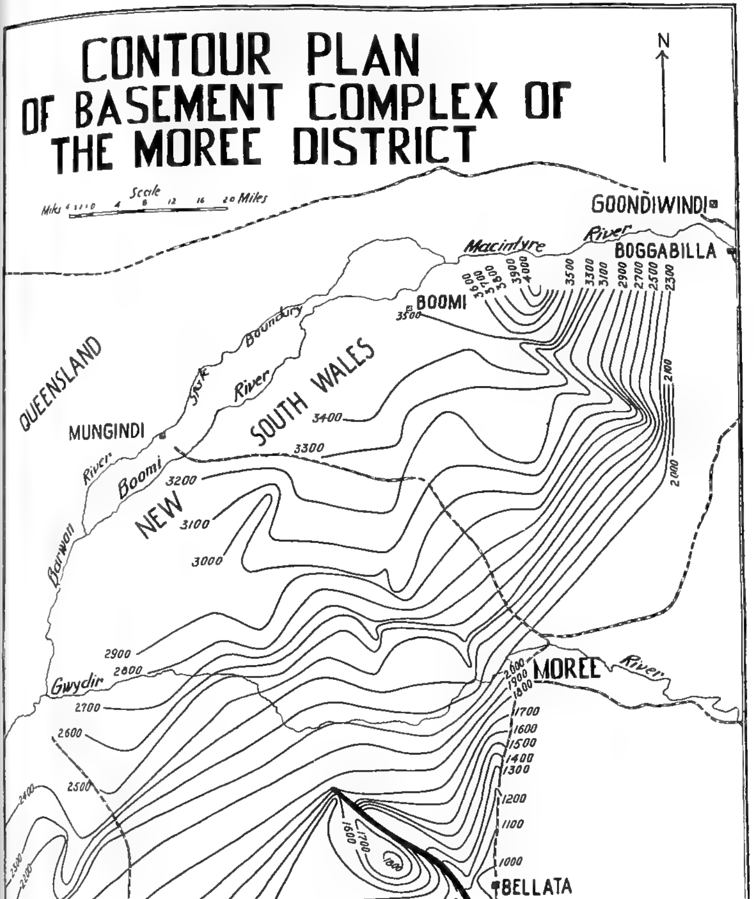

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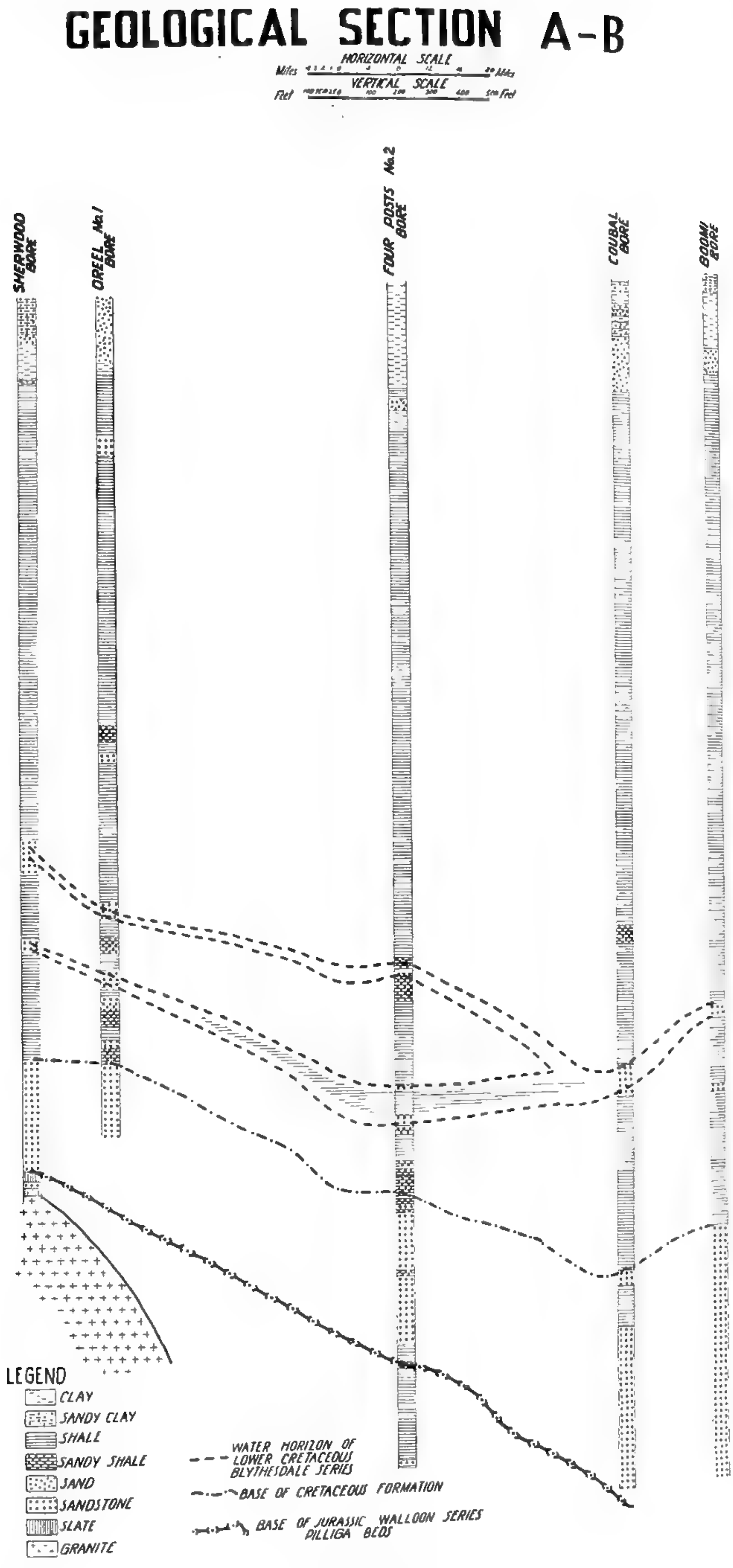

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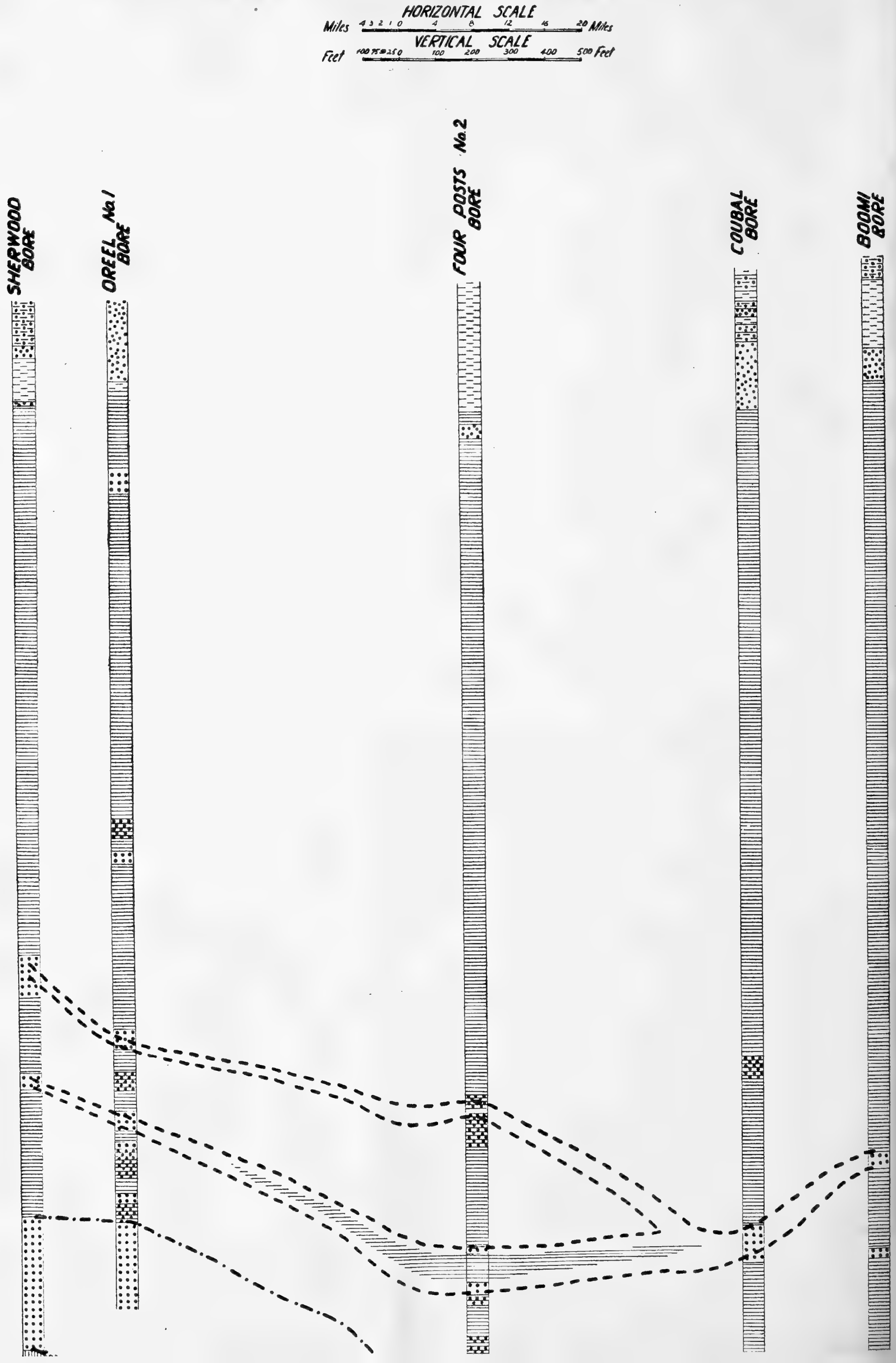
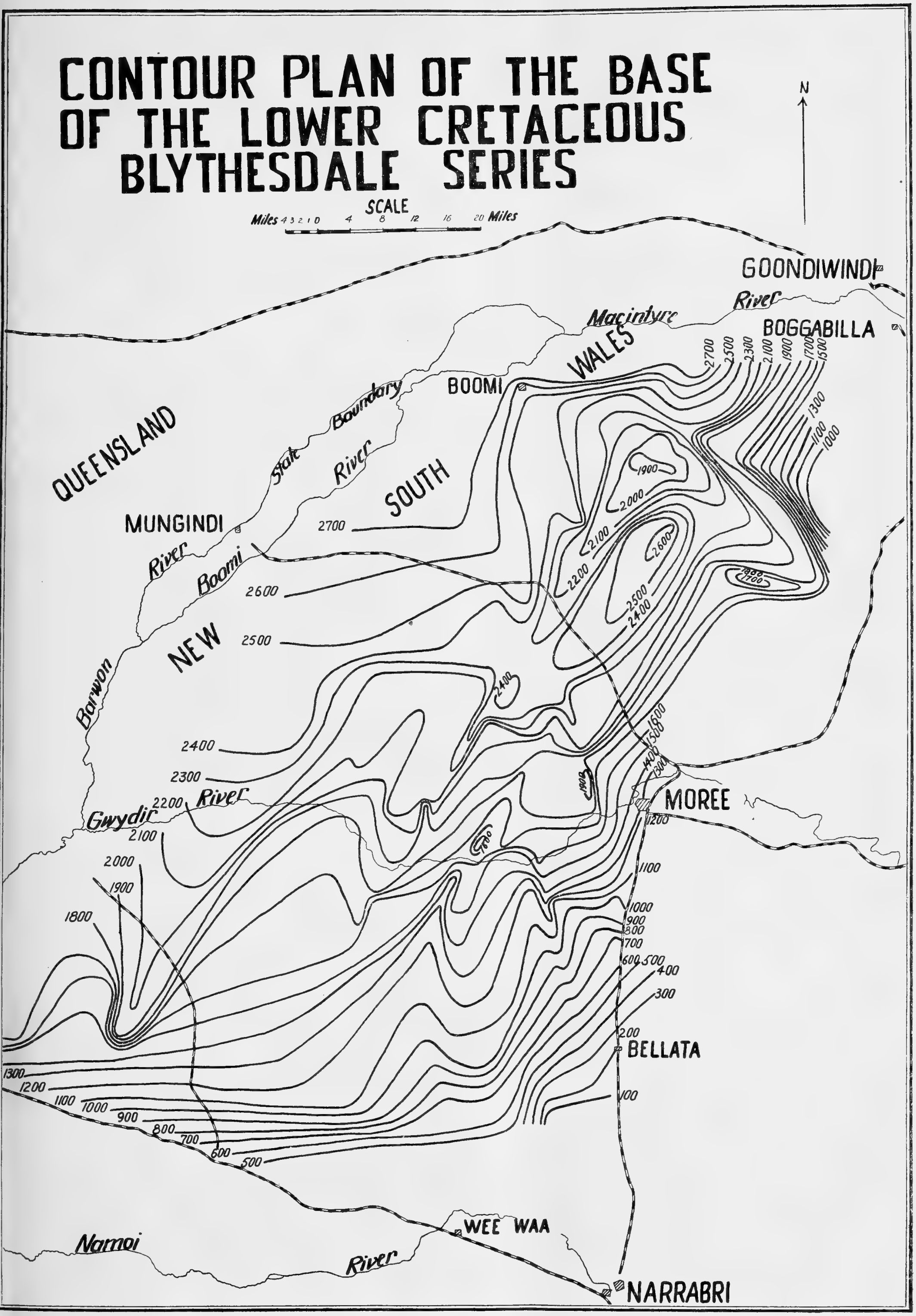
GEOLOGICAL SECTION A-B





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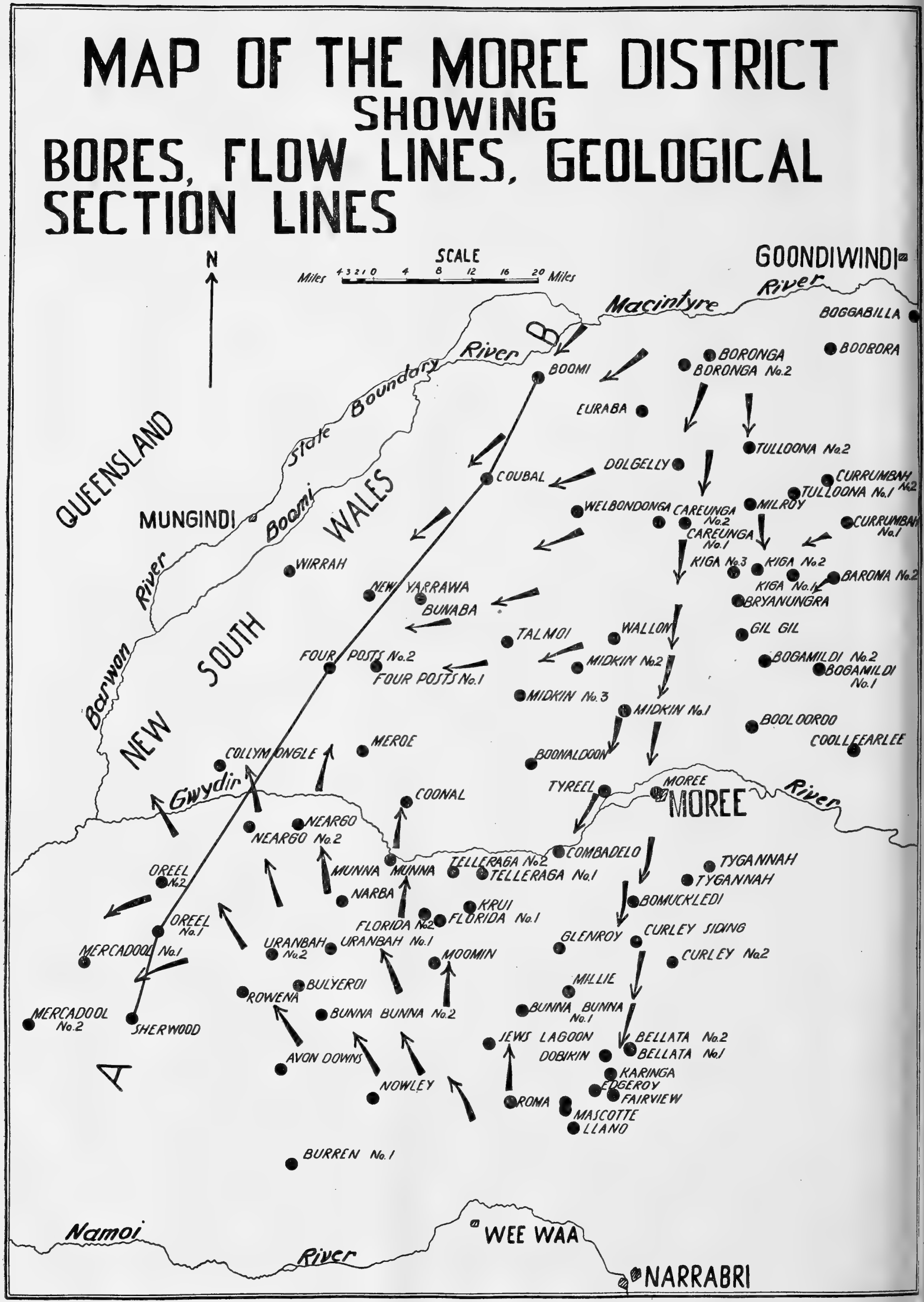

Text-figure 4.

Winton time, the lignite and carbonaceous shale having been deposited in a much more tranquil environment than the coarser sediments. The carbonaceous shale beginning at 673 feet is underlain by 1′ 6″ of sand and gravel, possibly deposited by rivers in a shallow lake. It is suggested that the lignite layers beginning at 806 feet were laid down in the deltaic region of a river entering the Winton Lake; they are underlain by 40 feet of sandstone with streaks of lignite, and these may have been laid down in a tranquil part of the delta occasionally inundated by floodwaters. As time went on the conditions changed and the deposits were more of a swampy lacustrine character with very fine deposits of clay and shale.

According to David (1950, p. 489) Winton beds to a thickness of 900 feet and consisting of shale, carbonaceous shale and shaly sandstone with plant-fragments, were found in the Walloon bore, resting on the marine Cretaceous beds. On the bore-data available the thickness of the series in the Dolgelly bore north of Moree may be placed at about 800 feet.

Structural Geology.

It is not proposed to consider the structure of the bedrock in detail here as the author hopes in a later paper to deal with this question for the whole area of the Great Artesian Basin within New South Wales.

From the contour-map (Fig. 1) it would appear that in the Moree district a number of trends are expressed as valleys and ridges in the bedrock, the most prominent being north-east and north-north-west respectively. Some of the structures, possibly due to faulting, were apparently imposed in post-Cretaceous time, since they are shown not only in the bedrock contours but also in those of the base of the Lower Cretaceous, as in the S.W. and N.E. parts of the district.

A fault striking W.N.W. is shown west of Bellata, evidence for which was found in the Karinga bore, 4 miles S.W. of Bellata, where signs of strong shearing were detected in shale samples recovered from the boring.

Groundwater Hydrology.

Some salt water aquifers are met at depths between 60 and 200 feet, but these are of no practical value. The first artesian flows are found in the Blythesdale Series ,and the highest flow is at approximately 2400 feet in the western part of the district; for example in the Wirrah bore 53 miles N.W. of Moree it was struck at 2435 feet. In the northern part this flow was at its greatest known depth of 2844 feet in Boronga No. 2 bore. The second flow in the Blythesdale Series is often small and may be only a trickle. In many places, particularly in the western part of the district, it is really two separate flows.

The aquifers are in the sandstone beds. That from which the highest flow is derived is between 30 and 100 feet thick, while the aquifer from which the second flow comes varies considerably but averages between 40 and 50 feet in the western part of the district. This is split by a bed of shale into two aquifers, as is seen on the geological section forming Fig. 2, in Four Posts No. 2 bore, 43 miles N.W. of Moree, where the shale is 79 feet thick. In the west the interval between the aquifers of the highest and the second flows is between 170 and 340 feet.

The waters of these two flows differ greatly from those of the flows in the Walloon Series in containing a markedly greater percentage of total solids. The composition of the Blythesdale waters is illustrated in the

TABLE I.

	A.		B.		C.		D.		E.	
	Grains per Gallon.	In 1,000 Parts.	Grains per Gallon.	In 1,000 Parts.	Grains per Gallon.	In 1,000 Parts.	Grains per Gallon.	In 1,000 Parts.	Grains per Gallon.	In 1,000 Parts.
Na_2CO_3 ..	56·484	0·8069	59·282	0·8469	30·748	0·4392	56·664	0·8095	36·367	0·5195
K_2CO_3	Absent	Absent	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace
$CaCO_3$	0·750	0·0107	1·000	0·0143	0·674	0·0094	0·875	0·0125	1·000	0·0143
$MgCO_3$ ..	0·296	0·0042	0·159	0·0023	Trace	Trace	0·265	0·0038	0·212	0·0030
NaCl	25·952	0·3707	17·376	0·2552	6·185	0·0883	14·737	0·2105	6·340	0·0906
Na_2SO_4 ..	0·136	0·0019	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent
SiO_2	2·044	0·0292	2·380	0·0340	1·988	0·0284	1·624	0·0232	1·960	0·0280
Fe_2O_3 Al_2O_3 } ..	0·196	0·0028	Trace	Trace	0·070	0·0010	Trace	Trace	Trace	Trace
Boric acid ..	Trace		Faint trace		Trace		Trace		Trace	
Total	85·858	1·2264	80·688	1·1527	39·665	0·5663	74·165	1·0595	45·879	0·6554
Date of analysis	30.6.10		30.5.12		28.11.12		26.8.13		16.12.13	

A. Bryanungra Bore, 26 miles N.E. of Moree, Blythesdale aquifer at 2,075 feet.
B. New Yarrawa Bore, 43 miles N.W. of Moree, Blythesdale aquifer at 2,335–2,345 feet.
C. New Yarrawa Bore, 43 miles N.W. of Moree, Walloon (Pilliga) aquifer at 3,590 feet.
D. Wirrah Bore, 53 miles N.W. of Moree, Blythesdale aquifer at 2,452 feet.
E. Wirrah Bore, 53 miles N.W. of Moree, Walloon (Pilliga) aquifer at 3,578 feet.

accompanying table. The high percentage of total solids is due in part to the carbonates occurring abundantly in the beds of the Blythesdale Series.

The main aquifers of the Moree district are situated in the Walloon sandstones. The average depth of the first aquifer below the deepest Blythesdale aquifer is between 200 and 400 feet. Since from the practical point of view it is important to know the depth to the first main flow, a contour-map of the base of the Blythesdale Series has been prepared (Fig. 3). The contours are, of course, only tentative, but the error cannot be very great because the top of the Walloon Series is marked fairly distinctly by the occurrence of sandstones containing small intercalations of shale. The first main aquifer is further below the base of the Blythesdale Series in some places than in others, being overlain by some thickness of sandstone: in the Boomi bore 53 miles N.W. of Moree this overlying sandstone is about 100 feet thick, in the Midkin No. 3 bore 21 miles N.W. of Moree it is about 160 feet, and the greatest known thickness of 300 feet is found in the Roma bore, 42 miles S.W. of Moree.

The Walloon sandstone is very porous, and therefore very favourable for the accumulation and movement of underground water. To judge from Mulholland's (1950, p. 126) investigations in the Coonamble area, only some of the sandstones belonging to the Pilliga beds are permeable—usually friable sandstones separated by relatively impermeable beds of harder sandstone and sandy shale.

The water in the Walloon Series is softer than that in the Blythesdale Series. Its chemical composition is illustrated in the table above.

It is of interest to note the relation between the chemical composition of the artesian waters in the Moree district and the structural features of the basement complex. For this purpose we may take Plan No. 11 accompanying the Water Conservation and Irrigation Commission's Artesian Investigations, 2nd Interim Report (1940), which shows total mineral content in grains per gallon in the bores east of the Narran River; this may be compared with the contour-plan of the basement complex of the Moree district forming Fig. 1 of the present paper. On both maps it is possible to recognize at once the main thalweg of the artesian water, stretching from southern Queensland into the eastern part of the Moree district. It is characterized by water containing from 40 to 45 grains per gallon of total solids, which moves from the deeepest part of the basin in the vicinity of Boronga No. 2 bore, south past Moree to the bores of Bellata and Fairview, where, to the N.W. of Bellata, it is blocked by the Bellata fault. Areas whose waters have a higher content of total solids are situated west of the main thalweg, and the water with highest content of mineral matter is found in the N.E. part of the district just at its boundary with the Warialda intake beds, as in Currumbah, Marlow, Baroma No. 2 and Coolleearlee bores. Since the movements of the water are indicated by the differing content of total solids from place to place, we may infer that the Warialda intake beds have only subordinate significance in regard to the supply of water to the Moree district. These intakes yield water containing 61 grains per gallon and upwards of total solids, and it is thought that these high figures may be related to a possible thin cover of Blythesdale overlying the Walloon beds on the western margin of the Warialda intake beds; if the beds were strongly fractured the solution products of the calcareous layers might well leak down into the Walloon sandstones and affect the chemical composition of the main flows. However, the water with the high content of mineral matter very soon joins the main body of water coming from Queensland, so that its content of total solids is much reduced.

The water derived from the intake beds about Narrabri and to the west of it moves in a N.W. direction, as shown in Fig. 4.

SUMMARY.

The strata in the Moree district are mainly Mesozoic and Palaeozoic. Palaeozoic trends are dominant in the structure of the basement complex. The highest artesian flows are in the Lower Cretaceous Blythesdale Series, but the main flows come from the Jurassic Walloon Series. In chemical composition the waters of the Blythesdale Series differ greatly from those of the Walloon Series, the latter having a smaller content of total solids. The chemical composition of the main flows is related to the movements of the water, which in turn are governed by the geological structure of the basement complex.

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MINERALIZATION OF THE ASHFIELD SHALE, WIANAMATTA GROUP.

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Department of Mineralogy and Petrology, The Australian Museum, Sydney.

With Plate XV and one Text-figure.

Manuscript received, October 30, 1953. Read, December 2, 1953.

Contents.

Abstract.

Barite, pyrite, marcasite, kaolinite, siderite and calcite occur associated with the sideritic mudstone bands in the Ashfield Shale, basal formation of the Wianamatta Group.

Authigenic processes have formed syngenetic siderite and pyrite under neutral to alkaline conditions. Epigenetic processes, with the agency of acid supergene waters, have reprecipitated siderite, converted pyrite to marcasite and sedimentary mica to kaolinite, deposited barite and calcite. Some processes (e.g. redistribution of iron sulphide as marcasite) are apparently still in progress. A hydrothermal episode, associated with the early Tertiary basic alkaline intrusions of the Sydney district, is suggested as the source of the massive vein barite.

Introduction.

In this work a suite of minerals, including barite, associated with the Ashfield Shale, is described along with the various physical and chemical techniques used to elucidate their origins. D and F numbers refer to registered specimens in the Australian Museum collections.

Barite crystals have been recorded previously from the "Wianamatta Shales" at Macdonaldtown and St. Peters, near Sydney (Anderson, 1905) and from the Hawkesbury Sandstone at Cook's River (Smith, 1891) Fivedock and Pyrmont (David, 1894); Northmead (Hodge-Smith, 1930). From the descriptions given it seems that the occurrences in the "Wianamatta Shales" were limited to crystals of epigenetic barite deposited in joint planes in the Ashfield Shale.

The Lithological Environment.

The Ashfield Shale (Lovering, 1953) is a black shale, in places humic and sandy, with a maximum thickness of 200 feet, lying directly on top of the Hawkesbury Sandstone of the Triassic System, Sydney Basin. Small vitrainous lenses are abundant in the shales, but the most important variant is a sideritic mudstone ("clay ironstone") forming bands and lenses at irregular intervals throughout the sequence. The 40 feet thick section in the brick quarry at Ashbury (Sydney 1 inch : 1 mile military sheet reference 120123) shows nine such bands varying in thickness from one to ten inches. Associated with the bands are cylindrical shaped masses isolated within the black shales.

Siderite, a major constituent of this sideritic mudstone, occurs as rounded pellets set in a base of indeterminate clay material. Partial analyses of four sideritic mudstones (Lovering, 1953) shows ferrous carbonate between 39·5–48·7%. The absence of barium is of importance.

These sideritic mudstone bands are the host rock of a suite of minerals (barite, pyrite, marcasite, kaolinite, siderite, calcite) which reflects a series of mineralization episodes commencing in syngenetic deposition and continuing up to the present time.

Mineral Paragenesis.

The mineral paragenesis is consistent over the whole areal extent of the Ashfield Shale. The minerals are, in general, restricted to the sideritic mudstones. They occur in several environments.

(*a*) Concretionary structures: Hollow, spherical (diameter <3 cm.), concretionary structures are found in the sideritic mudstones. On a weathered surface they appear as spherical nodules locally on the same horizontal plane. The hollow cores of these concretions are more or less completely filled with barite, kaolinite, siderite and iron sulphides (Plate XV, Fig. 2).

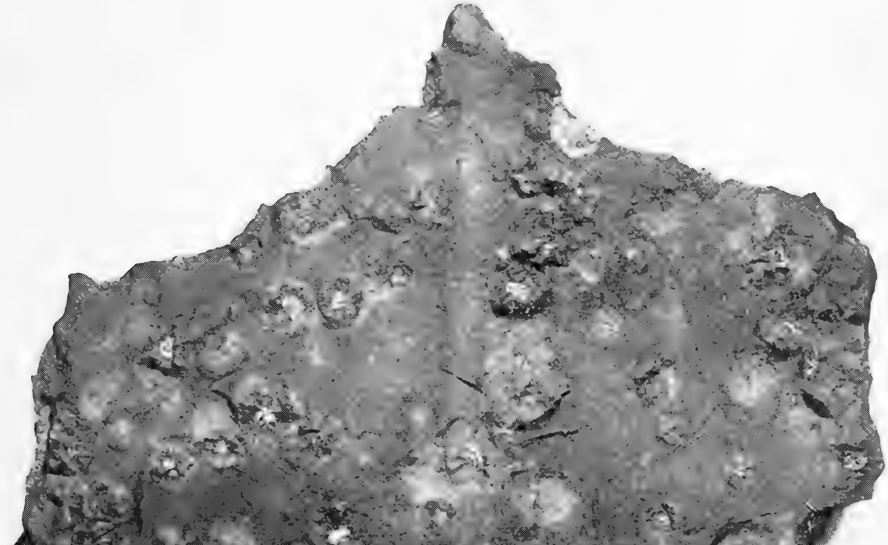
(*b*) Vein fillings: Irregular veins and lenses up to 1 cm. across occur in the sideritic mudstone bands and, particularly, the cylindrical masses. Partly filled veins have allowed crystallization of barite, while others are completely filled with massive barite, iron sulphides and kaolinite.

(*c*) Fault breccia and joint plane fillings: Minor normal faults through the Ashfield Shale often have a localized brecciated zone with which is associated veins and cavities filled with fibrous and crystalline calcite. Thin rosettes of milky barite crystals, as well as single crystals, occur in the vertical joints (striking N. 10° E. and E.-W.) and horizontal joints in the Ashfield Shale.

Barite.

Barite occurs in the concretionary nodules both massive and as short (<5 mm.) tabular and prismatic crystals. When massive, it is white, but the crystals may be clear and colourless, white or even iron stained. Crystals are found also in some of the open veins. Thin sections through concretionary nodules show barite of two generations. The earlier barite occurs on the walls of the nodules and is always clouded by clay inclusions. The later barite occurs towards the centre of the vugh and is relatively clear and free from inclusions.

1



2

The massive barite filling veins may be white and translucent or clear. This massive variety fluoresces strongly under ultra-violet radiation.

Barite also occurs as thin buff-coloured rosettes of platy crystals and as single crystals along joint planes in the sideritic mudstones and normal shales.

Pyrite and Marcasite.

Pyrite and marcasite are intimately associated with each other in the concretionary nodules, the irregular veins, and as isolated crystals and lens-shaped masses in the sideritic mudstone bands.

Mr. R. L. Stanton, from examination of polished sections, has reported in a personal communication that pyrite and marcasite occur in approximately equal proportions. The ideal section of a sulphide vein shows

(1) Inner zone of coarse, platy sulphide.

(2) Intermediate zone of fine-grained sulphide with a rather spongy appearance due to inclusions of sideritic and shaley material.

(3) Outer zone very much broken with these inclusions.

This structure has arisen from the mode of deposition of the sulphide originally filling cracks and veins in the sideritic mudstones. As the deposition continued, the original space was filled and the surrounding shaley material was then more or less replaced by the sulphide.

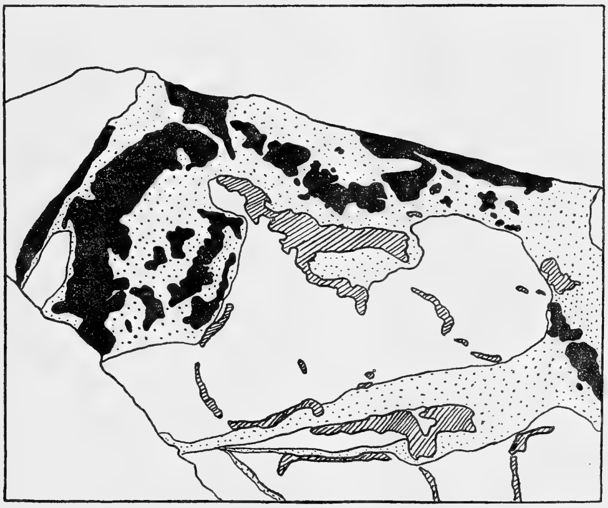


Fig. 1.—Iron sulphide (marcasite after pyrite) veins (black) with some barite (lined) associated with siderite-rich mudstone (dotted) and clay mudstone (white). Camera lucida ×4.

Figure 1 shows the association of the sulphide and barite veins with the siderite-rich and clay mudstones. Lens-shaped masses of sulphide are always horizontal, arising from deposition in horizontal cracks. These lenses are often associated with fish remains (e.g. F43740 *Myriolepis* ? from Thornleigh).

The concretionary nodules may be filled with massive sulphide or contain small cubes and pyritohedra. In all associations pyrite has been the first mineral deposited. A subsequent change in the environment has converted the pyrite to marcasite—a process beginning along cleavage traces in the pyrite and spreading into the body of the crystal.

Kaolinite.

A white clay mineral often fills the centres of the concretionary nodules and is associated with barite in some veins. An X-ray powder photograph shows the characteristic pattern of kaolinite together with three unknown lines at 2·800 Å, 1·896 Å and 1·620 Å.

Siderite.

As well as occurring as a syngenetic constituent of the sideritic mudstone, siderite is found in the concretionary nodules as a result of re-deposition at a later period. The siderite, apparently the last formed mineral in the concretion, occurs with barite and sulphide and always has a radiating structure.

Calcite.

Calcite has been found only in faulted zones in the Ashfield Shale. The calcite occurs mostly as thin veins of fibrous crystals, but in places the faulting has opened up larger cavities which are lined with white to colourless nail-head crystals.

THE GEOCHEMICAL PROCESSES ASSOCIATED WITH DEPOSITION.

Barite—Significance of Fluorescence.

Specimens of barite from each of the three modes of occurrence in the Ashfield Shale were examined under monochromatic ultra-violet light ($\lambda = 2536$ Å) with the following results :

(*a*) Massive and crystalline barite from concretionary nodules gave no fluorescence.
(*b*) Single crystals and aggregates from joint planes gave no fluorescence.
(*c*) Massive vein fillings in the sideritic mudstones gave a strong pale-green fluorescence.

In addition, specimens of barite, of hydrothermal origin at Prospect and the basic breccia filled neck of Dundas, both close to Sydney, gave an identical strong pale-green fluorescence.

The positive or negative fluorescence appears to be dependent on the manner of deposition, and so indicative of the origin, of the barite.

Barite (barium sulphate) is an inorganic crystal phosphor whose luminescence depends essentially on the crystalline nature of the base material (Pringsheim, 1949). Although little is known about the effect specific crystal structures have on luminescence, the so-called layer lattice structures shown by many compounds with large negative ions (such as $SO_4^=$, NO_3^- and I^-) have been suggested as particularly favourable phosphors because interstitial atoms can penetrate easily into the relatively large spacings which separate the tightly packed layer planes. The interstitial atoms causing luminescence may be atoms or ions of either radicle displaced from their lattice positions or they may be impurities. These " foreign activators " may actually quench luminescence by excessive concentration and are normally related to the base as

(1) Ions replacing ions of the base material in the matrix lattice.
(2) Interstitial atoms slightly deforming the surrounding lattice.
(3) Ions or atoms embedded at points of lattice defects.

Semi-quantitative spectrographic analyses made by Mr. D. A. Sinclair, Defence Research Laboratories, N.S.W., of three barite specimens with various fluorescent behaviours, localities and origins, indicate the activators present (Table 1). The three specimens were :

(*a*) D35754. Barite crystals associated with the basic breccia filling volcanic pipe at Dundas, near Sydney. Strong pale green fluorescence. Hydrothermal origin.

(*b*) D38136. Massive barite, filling vein associated with sideritic mudstone in Ashfield Shale, at the Ashfield Brickworks quarry, Milton St., Ashfield. Strong pale green fluorescence. Hydrothermal ?

(*c*) D9440. Flat barite crystals filling joint planes in Ashfield Shale from Macdonaldtown, near Sydney. No fluorescence. Epigenetic.

According to Smith (1944), suitable activators for barium sulphate are Cu, Ag, Au, Mn, Pb, Ni, Sb, Bi, V, U. Of these only Cu is present in the spectrogram of the fluorescent varieties, and is probably partially responsible for the fluorescence as an activator. The absence of Fe is of importance.

TABLE 1.

Spectrographic Analyses of Barite.

Spectrogram Indication of Amount Present.	Barite. Dundas. D 35754. Fluorescent. Hydrothermal.	Barite. Ashfield. D 38136. Fluorescent. Hydrothermal ?	Barite. Macdonaldtown. D 9440. Non-Fluorescent. Epigenetic.
Major element ..	Ba.	Ba.	Ba.
Minor element			Fe.
Strong trace	Sr.		Si Sr, Al, Mg.
Trace		Sr.	Cu Ca.
Faint trace	Ca, Si, Mg.	Si, Al, Mg, Cu.	Ni, Pb ?
Very faint trace ..	Cu, Sn ?, Pb ?		Mn, Sn ?, Ti ?
Not detected	Fe, Al, Mn, Ni, Ti.*	Ca, Fe, Mn, Ni, Sn, Pb, Ti,*	*

* Li, Na, K, Be, Ag, Au, Zn, Cd, Hg, Bi, As, Sb, Cr, Co, V, Mo, W, Zr, P, B. } Were not detected in all samples.

N.B.—Queried indications are of doubtful authenticity.

Analyst : D. A. Sinclair, Defence Research Laboratories, N.S.W.

By contrast the non-fluorescent epigenetic barite contains four possible activators (Cu, Ni, Mn, Pb). The explanation of this apparent anomaly lies in the very high Fe content of the non-fluorescent barite. The effect of this Fe is that of a " poison," quenching the fluorescence of the other activators.

The spectrographic analyses of Table 1 also show the agreement of the nature and concentrations of the trace elements in both fluorescent specimens.

This evidence suggests that the vein barite in the sideritic mudstones has been deposited, like the Dundas barite, from hydrothermal fluids related to the Tertiary basic intrusions of the Sydney district.

The analysis of the epigenetic material from Macdonaldtown is very different, with impurities abundant both in number and concentration. Fe and Si are particularly abundant, reaching the proportions of minor elements. This abundance of impurities is probably a reflection of the origin of the barite.

In deposition from solution, barium sulphate has a remarkable tendency to carry down other salts as it precipitates (Vogel, 1947). This process of co-precipitation is due primarily to impurity absorption on the surface of the primary particles of the crystal. The impurity may become trapped in the spaces of the layer lattice structure of the barium sulphate or may form a solid solution with it. Ions that heavily co-precipitate with $BaSo_4$ are Na^+, K^+, Li^+, Ca^{++}, Sr^{++}, Al^{+++}, Cr^{+++}, Fe^{+++}. Of these Fe^{+++}, Al^{+++}, Ca^{++} and Sr^{++} are all abundant impurities in the epigenetic barite (Table 1). It is only to be expected that the supergene solutions transporting the $BaSo_4$ had dissolved a number of impurities as they percolated through the rocks and these impurities were then co-precipitated with the epigenetic barite.

The normal solubility of barium sulphate is 0·0023 g. per litre. To account for the abundance of this epigenetic barite there would need to be some factor operating to increase the mobility of $BaSo_4$. Palmquist (1938) has proved that Cl^- ion increases solubility, and Old (1942) has shown that supergene water from the Ashfield Shale contains between 378 and 1,555 grains Cl^- per gallon. Increased mobility would also arise from the increased concentration of H^+ ions available from the oxidation of the iron sulphide.

The Iron Sulphide Deposition.

Edwards (1953) has developed a technique based on the work of V. M. Goldschmidt and others by which the likely origin of iron sulphides may be indicated from a determination of the ratio of sulphur to selenium in the mineral. Iron sulphides (i.e. marcasite and pyrite) of hydrothermal origin have ratios of the order S : Se : 10,000 : 1, while those of sedimentary or supergene origin have S : Se ratios of about 200,000 : 1 or greater.

TABLE 2.

S : Se Ratios of Iron Sulphides (FeS_2) from the Ashfield Shale (Wianamatta Group) and Hawkesbury Sandstone.

(Per courtesy of Dr. A. B. Edwards.)

	D 38865. Warragamba Dam Site.	D 38130. Brick Quarry, Midson Road, Eastwood.	DR 7443. Brick Quarry, Thornleigh.
Formation ..	Hawkesbury Sandstone (?)	Ashfield Shale.	Ashfield Shale.
%S	42·99	24·38	20·53
%Se	0·0002	Nil	0·0001
S/Se wt. ..	204,950	250,000 or greater	205,300

Analyst : G. C. Carlos, C.S.I.R.O. Mineragraphic Investigations, Melbourne.

Determinations carried out at the Mineragraphic Section, C.S.I.R.O., of the S : Se ratios of two iron sulphide samples from thin vein fillings in the sideritic mudstones of the Ashfield Shale indicate supergene origin for them (Table 2). Most of this iron sulphide is marcasite, which has more or less completely replaced pyrite.

The evidence suggests that the FeS_2 precipitated by the anaerobic bacteria (see later) has gathered in contraction cracks in the semi-colloidal ferrous carbonate muds and given rise to the sideritic mudstones. In this environment the FeS_2 was deposited as pyrite rather than marcasite, and the pyrite formed the original fillings of the veins and isolated crystals found in vughs in the mudstones, indicating that the environment was neutral or alkaline (Edwards and Baker, 1951).

The changing conditions of the epigenetic environment (from oxidation of the sulphide ?) have converted the pyrite more or less completely to marcasite, indicating that the environment had become acid (Edwards and Baker, 1951).

Some of the marcasite has probably been precipitated as a primary deposit from the supergene waters. Marcasite is still being deposited from the acid supergene waters of the Hawkesbury Sandstone. Coralloidal and stalactitic iron sulphide filling a sub-horizontal shear zone in the Hawkesbury Sandstone (?) about R.L. +30 feet at the site of Warragamba Dam excavation was proved to be marcasite, and is apparently still in the process of being deposited. The S : Se ratio (Table 2) of this marcasite was determined at the Mineragraphic Section, C.S.I.R.O., and is of the order 204,950 : 1, indicative of a supergene origin.

Siderite, Kaolinite and Calcite Deposition.

The siderite is apparently of two generations—syngenetic and epigenetic. As the main constituent of the sideritic mudstones, it is obviously of syngenetic origin. The reducing conditions and neutral to alkaline pH at the depositional site were the factors controlling the concentration and deposition of Fe as ferrous carbonate (siderite).

The later change to acid conditions during the epigenetic stage caused solution of the siderite, followed by reprecipitation as radiating aggregates in the concretionary nodules.

The kaolinite fillings in the concretionary nodules are also a result of the changing environment of epigenetic times. The sedimentary mica, unstable under the acid conditions, has been altered to kaolinite and concentrated in the nodules.

The calcite has been deposited from supergene waters in the latest stage of mineralization—the post-faulting epigenetic stage, and is probably still forming. The calcium carbonate has been dissolved from such calcareous members of the Ashfield Shale as the cone-in-cone horizon (Lovering, 1953).

THE MINERALIZATION EPISODES.

The processes leading to the deposition of the various minerals described in previous sections show the effect of four distinct mineralization episodes.

(1) The Ashfield Shale was deposited under humid lagoonal conditions with restricted circulation and alternating marine-freshwater inundations, with essentially neutral-alkaline pH environment (Lovering, 1953). These conditions led to the formation of humic black shales and sideritic mudstone bands with associated pyrite. The reducing environment and neutral-alkaline pH ensured the formation of pyrite, rather than marcasite (Edwards and Baker, 1951), and iron carbonate rather than oxide.

The iron sulphide was probably deposited by anaerobic sulphur bacteria, which flourish under such conditions (Galliher, 1933). They generate colloidal ferrous sulphide which migrates and fills contraction cracks in the ferrous carbonate muds, partly replaces the walls, and later stabilizes as pyrite, either massive (in the veins) or as tiny cubes and pyritohedra (in the cavities).

Associations of sideritic mudstone bands with black humic shale sequences are of world-wide occurrence. It is usually suggested that the siderite has formed because of an inordinate amount of iron being introduced. This would presuppose an unusual source area as well as a special depositional environment. It is more likely that the conditions associated with the special depositional environment concentrated the incoming iron and precipitated it in a restricted horizon as ferrous carbonate rather than distributing it through the shale sequence as oxide.

(2) With the advent of the epigenetic stage and removal of the sediments from the sedimentary (authigenic) environment, a change of pH conditions occurred. The syngenetic siderite in the mudstones was locally leached, existing cavities enlarged and the concretionary nodules were formed. Existing pyrite became unstable and was converted to marcasite ; sedimentary mica altered to kaolinite ; some barite (with kaolinite inclusions) was deposited ; siderite was reprecipitated as spherical crystal aggregates.

(3) Hydrothermal solutions associated with early Tertiary intrusions of basic alkaline magma around the Sydney district appear to have introduced barite in favourable horizons. This barite is only found in irregular veins, commonly replacing kaolinite formed in the second episode.

(4) Epigenetic mineralization has continued up to the present day. Calcite has been deposited from supergene waters in late Tertiary fault zones. Much barite has been deposited also in this last episode in veins, cavities and joint planes, from waters containing $BaSo_4$ in solution dissolved from the relatively large quantity deposited by the hydrothermal fluids. Marcasite has been, and apparently is still being deposited, from supergene waters below the water table.

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The author would like to record his sincere appreciation of the assistance given to him by Mr. R. L. Stanton, Department of Geology, University of Sydney, by his examination of polished sections ; Dr. A. B. Edwards, Mineragraphic Investigations, C.S.I.R.O. (S : Se ratio determinations) ; Dr. J. A. Ferguson, Division of Building Research, C.S.I.R.O. (X-ray identification of kaolinite) ; officers of the Defence Research Laboratories (preparation of polished sections and spectrographic analyses).

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Explanation of Plate XV.

Fig. 1.—Pyrite-marcasite veins associated with hydrothermal ? barite in sideritic mudstones. D 38145. ×1.

Fig. 2.—Concretionary nodules with pyrite-marcasite, barite, kaolinite, siderite. D 38151. ×½.

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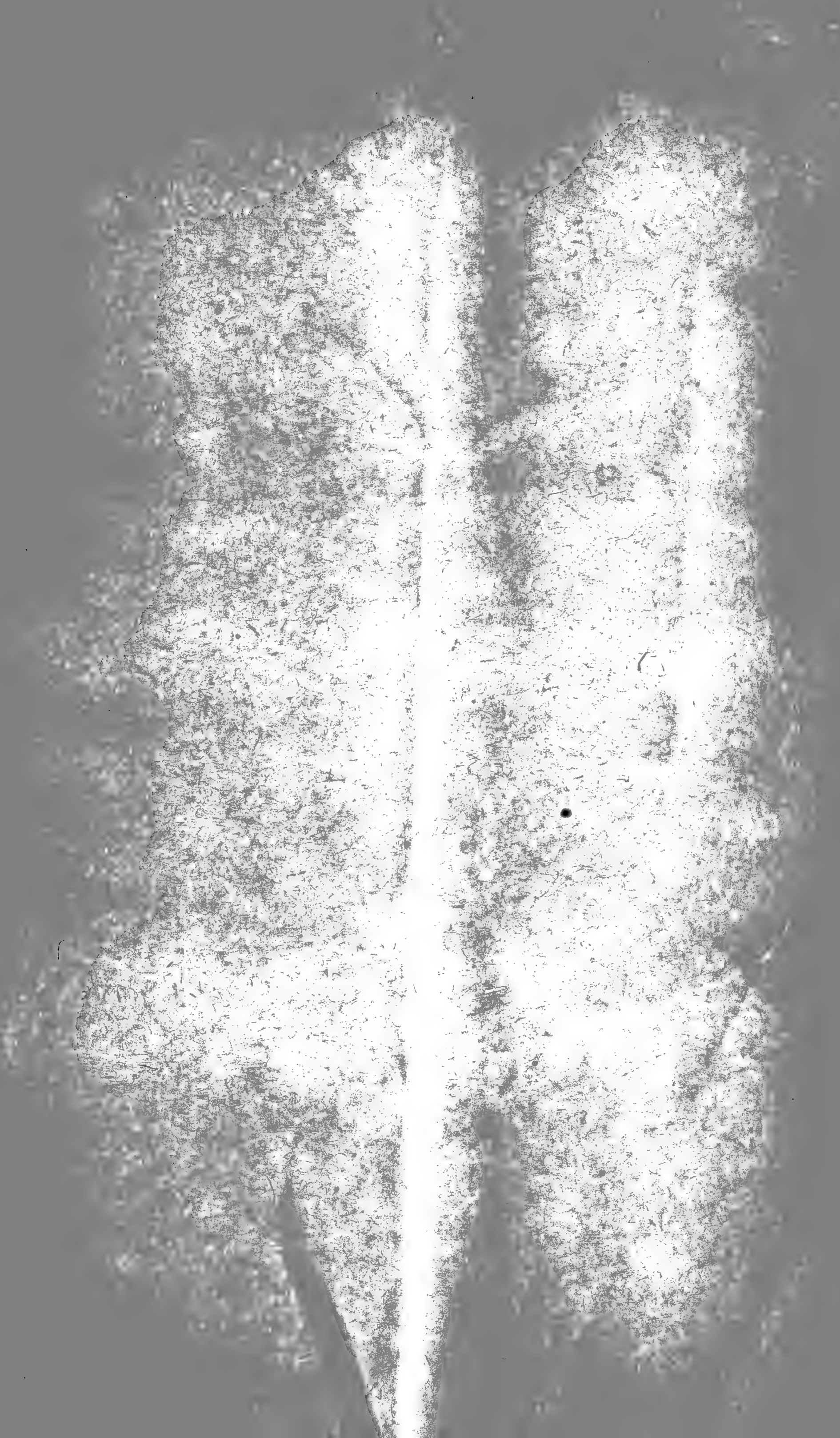

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FIELD MARSHALL SIR WILLIAM SLIM, G.C.B., G.C.M.G., G.C.V.O., G.B.E., D.S.O., M.C.

HIS EXCELLENCY THE GOVERNOR OF NEW SOUTH WALES,
LIEUTENANT-GENERAL SIR JOHN NORTHCOTT, K.C.M.G., K.C.V.O., C.B.

President :

R. S. NYHOLM, D.Sc., Ph.D. (*Lond.*), M.Sc. (*Syd.*).

Vice-Presidents :

R. C. L. BOSWORTH, M.Sc., D.Sc. (*Adel.*), Ph.D. (*Camb.*), F.A.C.I., F.Inst.P.
IDA A. BROWNE, D.Sc.
C. J. MAGEE, D.Sc.Agr. (*Syd.*), M.Sc. (*Wis.*).
PHYLLIS M. ROUNTREE, D.Sc. (*Melb.*), Dip.Bact. (*Lond.*).

Hon. Secretaries :

G. BOSSON, M.Sc. (*Lond.*).
F. N. HANLON, B.Sc.

Hon. Treasurer :

H. A. J. DONEGAN, A.S.T.C., A.A.C.I.

Members of Council :

J. P. BAXTER, B.Sc., Ph.D., A.M.I.Chem.E.
REV. T. N. BURKE-GAFFNEY, S.J.
D. P. CRAIG, Ph.D.
N. A. GIBSON, M.Sc., Ph.D., A.R.I.C.
J. L. GRIFFITH, B.A., M.Sc., Dip.Ed.
M. R. LEMBERG, D.Phil., F.R.S.
F. D. McCARTHY, Dip.Anthr.
P. R. McMAHON, M.Agr.Sc. (*N.Z.*), Ph.D. (*Leeds*), A.R.I.C., A.N.Z.I.C.
G. D. OSBORNE, D.Sc. (*Syd.*), Ph.D. (*Camb.*), F.G.S.
J. S. PROUD, B.E. (Mining).

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.

FORM OF BEQUEST.

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.

Volumes XI to LXVIII (1877–1934)
LXX (1936)
LXXII (1938)

and subsequent issues.

Volumes I to X (to 1876) and LXIX and LXXI are out of print.

LIST OF MEMBERS.

A list of members of the Royal Society of New South Wales up to 1st April, 1953, is included in Volume LXXXVII.

During the year ended 31st March, 1954, the following have been elected to membership of the Society :

Christie, Thelma Isabel, B.Sc., 181 Edwin-street, Croydon.

de Lepervanche, Beatrice Joy, 560 Homer-street, Earlwood.

Golding, Henry George, A.R.C.S., B.Sc., Technical Officer, School of Mining Engineering and Applied Geology, N.S.W. University of Technology, Sydney.

McKenzie, Peter John, B.Sc., Geologist, Geological Survey of N.S.W., Mines Department, Bridge Street, Sydney.

Phillips, June Rosa Pitt, B.Sc., c/o Geology Department, the University of Sydney.

Rade, Janis, M.Sc., Geologist, P.O. Box 70, Alice Springs, N.T.

Veevers, John James, B.Sc., c/o Geology Department, Imperial College, London, England.

During the same period resignations were received from the following :

Arnold, Joan W. (Mrs.).
Barclay, G. A., Ph.D.
Breckenridge, Marion, B.Sc.
Carver, Ashley George.
Clune, Francis Patrick.
Gillis, R. G.
Kennard, William Walter.
Lederer, Michael.
Martin, Cyril Maxwell.
Nicol, A. C., A.S.T.C., A.R.A.C.I.
Still, Jack Leslie, B.Sc., Ph.D.
Warner, Harry, A.S.T.C.
Webb, Gordon Keyes, A.F.I.A., A.C.I.S.
Wogan, Samuel James.

Obituary.

1898	Frank Lee Alexander.
1935	Reginald Marcus Clark.
1919	Wilfred Alex. Watt de Beuzeville.
1938	Edward L. Griffiths.
1892	Henry Ferdinand Halloran.
1952	Harold Rutledge.
1946	Cecil Rhodes-Smith.
1919	Harold Henry Thorne.
1943	Reginald John Nelson Whiteman.

AWARDS.

The Clarke Medal.

1953 Nicholson, Alexander J., D.Sc., Chief of the Division of Entomology, C.S.I.R.O., Canberra.

The James Cooke Medal.

1953 Rivett, Sir David, K.C.M.G., M.A., D.Sc., F.R.S., 11 Eton Square, 474 St. Kilda-road, Melbourne, S.C.2.

The Edgeworth David Medal.

1953 No award made.

The Society's Medal.

1953 Walkom, Arthur Bache, D.Sc., Director, The Australian Museum, Sydney.

The Walter Burfitt Prize.

1953 Bullen, Keith E., M.A., Ph.D., Sc.D., F.R.S., Professor of Applied Mathematics, the University of Sydney.

Royal Society of New South Wales

REPORT OF THE COUNCIL FOR THE YEAR ENDING 31st MARCH, 1954.

PRESENTED AT THE ANNUAL AND GENERAL MONTHLY MEETING OF THE SOCIETY,
7TH APRIL, 1954, IN ACCORDANCE WITH RULE XXVI.

The membership of the Society at the end of the period under review stood at 361. Seven new members were elected during the year, 14 members were lost by resignation, and five members were written off.

Nine members have been lost to the Society by death since 1st April, 1953:

Frank Lee Alexander (elected 1898).
Reginald Marcus Clark (elected 1935).
Wilfred Alex. Watt de Beuzeville (elected 1919).
Edward L. Griffiths (elected 1938).
Henry Ferdinand Halloran (elected 1892).
Harold Rutledge (elected 1952).
Cecil Rhodes-Smith (elected 1946).
Harold Henry Thorne (elected 1919).
Reginald John Nelson Whiteman (elected 1943).

During the year nine General Monthly Meetings were held, the average attendance being 36. Seventeen papers were accepted for reading and publication by the Society, an increase of four on the previous year.

Addresses given during the year were as follows:

6th May: " Recent Researches on the Earth's Interior ", by Professor K. E. Bullen.
" Some Factors Affecting Health and Safety in Mines ", by the visiting English scientist, Professor Ivon Graham.
1st July: " The Chemistry of Ants ", by Dr. G. W. K. Cavill.
5th August: " The Application of Science to Leather Manufacture ", by Dr. H. Anderson, of the Australian Leather Research Association.
2nd September: " Recent Advances in the Fields of Linguistics, Chemistry and Geology." The speakers were Dr. A. Capell, Professor A. E. Alexander and Dr. J. A. Dulhunty.

As part of the Coronation celebrations, the meeting held on 3rd June was devoted to a Symposium on " Science in the Time of the First Elizabeth ". The following addresses were given:

" Physical Science ", by Mr. J. B. Thornton.
" Medical Science and Health ", by Professor Harvey Sutton.

The meeting devoted to the Commemoration of Great Scientists was held on 7th October, and the following addresses were given:

" Wilhelm Ostwald ", by Emeritus Professor C. E. Fawsitt.
" Benjamin Thompson, Count Rumford, Administrator, Statesman and Natural Philosopher ", by Dr. G. H. Briggs.
" Anton de Bary, the Founder of Plant Pathology and Modern Mycology ", by Dr. N. H. White.

A Film Evening was held on 17th September and, through the courtesy of the South Pacific Commission and the N.S.W. Film Council, the following films were shown:

" Kapingamarangi ",
" The River ",
and at the meeting held on 4th November films of general scientific interest were shown.

Two Popular Science Lectures were delivered during the year:

21st May: " The Conquest of the Air ", by Professor A. V. Stephens.
15th October: " Northern Australia's Prospect ", by Professor J. Macdonald Holmes.

In place of the Annual Dinner, a Sherry Party was held in the Society's rooms on Thursday, 25th March. There were present 80 members and friends.

The Section of Geology had as Chairman Dr. J. A. Dulhunty and as Hon. Secretary Mr. R. D. Stevens. The Section held eight meetings during the year, including lecturettes, notes and exhibits. The average attendance was 20 members and five visitors.

The Council of the Society held eleven ordinary meetings and one special meeting during the year. The average attendance at the meetings was 13.

The President represented the Society on the Board of Visitors of the Sydney Observatory.

At the A.N.Z.A.A.S. meeting held this year, the President and Mr. H. W. Wood attended as delegates of the Society.

On the Science House Management Committee the Society was represented by Mr. H. A. J. Donegan and Mr. F. R. Morrison ; substitute representatives were Dr. R. C. L. Bosworth and Mr. H. O. Fletcher.

The representatives of the Society on Science House Extension Committee were the President, Dr. Ida A. Browne, and the Hon. Treasurer, Mr. H. A. J. Donegan.

Election of Councillor.—Mr. F. N. Hanlon was elected to the Council at the meeting held on 29th July, 1953, to take the place of Mr. A. V. Jopling, who had resigned his membership of the Council as he was leaving Australia for an extended trip overseas. At the meeting held on 28th October, 1953, Mr. F. N. Hanlon was appointed to act as Hon. Editorial Secretary following Dr. G. D. Osborne's resignation from this position on the Council owing to illness.

The Rev. Daniel J. K. O'Connell, S.J., D.SC., Ph.D., F.R.A.S., Director of the Vatican Observatory, was elected an Honorary Member of the Society at the Annual and General Monthly Meeting held on 1st April, 1953.

The Clarke Memorial Lecture for 1953 was delivered by Dr. M. F. Glaessner on 18th June. The title of the lecture was " Some Problems of Tertiary Geology in Southern Australia ".

The Clarke Medal for 1954 was awarded to Emeritus Professor E. de C. Clarke for his distinguished contributions to geological sciences.

The Walter Burfitt Prize for 1953 was awarded to Professor K. E. Bullen for his outstanding contributions in the field of geophysics.

The Society's Medal for 1953 was awarded to Dr. A. B. Walkom, Director of the Australian Museum, in recognition of his outstanding services in the organization of Science in Australia and his distinguished contributions in Palæobotany.

The James Cook Medal for 1953 was awarded to Sir David Rivett, K.C.M.G., F.R.S.

Royal Tour.—On the occasion of the Royal visit to Sydney, the Society was represented officially by the President at the luncheon given by the Government of New South Wales in honour of Her Majesty Queen Elizabeth II, and also at the garden party at Government House.

Under the auspices of the Royal Society of New South Wales, the British Astronomical Association and the Institute of Physics, a lecture entitled " The Sun, the Stars and the Nebulæ " was delivered by Professor Otto Struve of the University of California, who is also President of the International Astronomical Union. The lecture was held in the Hall of Science House. on 11th January, and was very well attended.

The financial position of the Society, as disclosed in the annual audit, is not a satisfactory one, the deficit for the twelve months being £184 12s. 8d.

The Society's share of the profits from Science House for the year was £450.

The Society has again received a grant of £400 from the Government of New South Wales. The Government's interest in the work of the Society is much appreciated.

A special grant from the Rural Credits Development Fund of the Commonwealth Bank of Australia, amounting to £200, is gratefully acknowledged.

The Library.—The Library Committee continues to meet, and has been helpful in advising Council on library matters.

The amount of £55 12s. has been spent on the purchase of periodicals and £94 4s. 3d. on binding.

Exchange of publications is maintained with 415 societies and institutions—five less than in the previous year.

The number of accessions entered in the catalogue during the year ended 28th February, 1954, was 2,725 parts of periodicals.

The number of books, periodicals, etc., borrowed by members, institutions and accredited readers was 399—an increase of 63 on last year's figures.

Among the institutions which made use of the library through the inter-library scheme were C.S.I.R.O.—Coal Research Section, Head Office, Melbourne, McMaster Animal Health Laboratory, Division of Fisheries, Division of Industrial Chemistry, Wool Textile Research Laboratories, Animal Genetics Section, Division of Entomology, Division of Plant Industry, Division of Food Preservation, Commonwealth Research Station, Irrigation Research Station, National Standards and Radiophysics Laboratory, Colonial Sugar Refining Co. Ltd., Sydney Technical College, University of Melbourne, Fisher Library, University of Sydney, Forestry Commission of N.S.W., Division of Wood Technology, Granville Technical College, Australian National University, Royal Society of Tasmania, N.S.W. Department of Agriculture, Commonwealth Observatory, University of Queensland, Faculty of Veterinary Science, University of Sydney, Newcastle Technical College, Wollongong Technical College, National Museum of Victoria, W. D. and H. O. Wills, Ltd., Melbourne Public Library, B.C.P.A., S.M.H.E.A., Antarctic Division, Department of External Affairs, Sydney Hospital, University of Adelaide, University of Tasmania, Australian Paper Manufactures Association, Timbrol Ltd., Dental Hospital, Sydney, Lever Bros., Waite Agricultural Research Institute, Australian Museum, M.W.S. and D. Board, Bureau of Mineral Resources, Taubman's Ltd., Queensland Institute of Medical Research, N.S.W. Department of Health, Standard Telephones and Cables Ltd., N.S.W. University of Technology.

IDA A. BROWNE,
President.

THE ROYAL SOCIETY OF NEW SOUTH WALES.

BALANCE SHEET AS AT 28th FEBRUARY, 1954.

LIABILITIES.

1953.		1954.					
£		£	s.	d.	£	s.	d.
—	Australian and New Zealand Bank Ltd.—Overdraft				148	8	5
111	Accrued Expenses				33	9	0
35	Subscriptions Paid in Advance				28	17	6
135	Life Members' Subscriptions—Amount carried forward				124	1	0
	Trust and Monograph Capital Funds (detailed below)—						
	Clarke Memorial	1,809	10	7			
	Walter Burfitt Prize	1,055	14	9			
	Liversidge Bequest	720	17	6			
	Monograph Capital Fund	3,844	19	7			
7,461					7,431	2	5
23,851	ACCUMULATED FUNDS				23,644	4	4
	Contingent Liability (in connection with Perpetual Leases.)						
£31,593					£31,410	2	8

ASSETS.

1953.		1954.					
£		£	s.	d.	£	s.	d.
168	Cash at Bank and in Hand				4	9	10
	Investments—Commonwealth Bonds and Inscribed Stock, 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	2,860	0	0			
9,360					9,360	0	0
	Debtors for Subscriptions	111	7	0			
	Less Reserve for Bad Debts	111	7	0			
—					—		
14,835	Science House—One-third Capital Cost				14,835	4	4
6,800	Library—At Valuation				6,800	0	0
403	Furniture—At Cost—*less* Depreciation				385	8	6
23	Pictures—At Cost—*less* Depreciation				22	0	0
4	Lantern—At Cost—*less* Depreciation				3	0	0
£31,593					£31,410	2	8

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, 1953 ..	1,800	0	0	1,000	0	0	700	0	0	3,000	0	0
Revenue—												
Balance at 28th February, 1953	96	10	2	111	13	9	—			752	10	0
Income for twelve months ..	53	13	11	29	16	5	20	17	6	92	9	7
	150	4	1	141	10	2	20	17	6	844	19	7
Less Expenditure	140	13	6	85	15	5	—			—		
Balance at 28th February, 1954 ..	£9	10	7	£55	14	9	£20	17	6	£844	19	7

ACCUMULATED FUNDS.

	£	s.	d.	£	s.	d.
Balance at 28th February, 1953				23,851	4	6
Add Decrease in Reserve for Bad Debts.. ..				11	4	6
				23,862	9	0
Less—						
Deficit for twelve months (as shown by Income and Expenditure Account) ..	£184	12	8			
Bad Debts written off ..	33	12	0			
				218	4	8
				£23,644	4	4

(Sgd.) HENRY DONEGAN,
Honorary Treasurer.

The above Balance Sheet has been prepared from the Books of Accounts, 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, 1954, as disclosed thereby. We have satisfied ourselves that the Society's Commonwealth Bonds and Inscribed Stock are properly held and registered.

HORLEY & HORLEY,
Per Conrad F. Horley, F.C.A. (Aust.),
Chartered Accountants (Aust.).

Prudential Building,
39 Martin Place,
Sydney, 17th March, 1954.

INCOME AND EXPENDITURE ACCOUNT.

1st March, 1953, to 28th February, 1954.

1952-3.		1953-54.					
£		£	s.	d.	£	s.	d.
	To Annual Dinner—						
	Expenditure	54	15	5			
	Less Received	29	8	0			
2					25	7	5
31	,, Audit				31	10	0
71	,, Cleaning				75	10	0
18	,, Depreciation				22	6	0
23	,, Electricity				35	16	6
4	,, Entertainment Expenses				3	2	5
11	,, Insurance				11	10	9
61	,, Library Purchases and Binding				68	14	5
88	,, Miscellaneous				89	9	7
93	,, Postages and Telegrams				101	9	2
	,, Printing and Binding Journal—						
	Vol. 86, Parts 3 and 4	391	14	9			
	Vol. 87, Parts 1 and 2	360	3	3			
994					751	18	0
116	,, Printing—General				130	5	9
27	,, Rent—Science House Management				36	14	3
47	,, Repairs				19	14	11
887	,, Salaries				991	18	6
32	,, Telephone				30	14	9
£2,505					£2,426	2	5

1952-3.		1953-54.		
£		£	s.	d.
974	By Membership Subscriptions	939	4	6
12	,, Proportion of Life Members' Subscriptions	11	11	0
200	,, Government Subsidy	400	0	0
400	,, Commonwealth Bank—Special Grant	200	0	0
495	,, Science House Management—Share of Surplus	450	0	0
109	,, Interest on General Investments	109	3	0
103	,, Reprints	28	13	9
—	,, Other Receipts—Sale of Furniture, Books, etc.	102	17	6
2,293		2,241	9	9
212	,, Deficit for Twelve Months	184	12	8
£2,505		£2,426	2	5

ABSTRACT OF THE PROCEEDINGS

OF THE SECTION OF

GEOLOGY

Chairman : J. A. Dulhunty, D.Sc.
Honorary Secretary : R. D. Stevens.

Meetings.—Eight meetings were held during the year, the average attendance being 20 members and five visitors.

April 17th.—

(*a*) Mrs. K. Sherrard exhibited a specimen of *Didymograptus* (*Isograptus*) *caduceus* from Licking Hole Creek, Cliefden Caves, near Mandurama.

(*b*) Address by Mr. F. C. Loughnan on the " Coal Measures of the Stroud-Gloucester Trough, N.S.W. ".

May 15th :

(*a*) Address by Mr. T. G. Vallance entitled " Some Observations on Metamorphic Zones ".

(*b*) Address by Mr. P. McKenzie entitled " Studies on Shore-Line Processes along the New South Wales Coast ".

June 19th :

(*a*) Mr. N. C. Stevens exhibited a specimen of epistilbite collected from a pegmatite in a road cutting near the village of Hartley.

(*b*) Address by Sarwar Mahmud on " Water Supply Problems of the Salt Range, Punjab, Pakistan and Adjoining Areas ".

July 17th :

(*a*) Mr. R. O. Chalmers exhibited specimens of rutile in sillimanite schist from the Thackaringa Sillimanite Quarry, and of titanite in an amphibolite from a locality 11 miles S.S.E. of Broken Hill.

(*b*) Dr. W. R. Browne noted the occurrence of prismatic structure in Hawkesbury sandstone near Coal and Candle Creek Road and West Head Road. Dr. Browne also exhibited a photograph of a similar structure from Mt. Irvine.

(*c*) Mrs. K. Sherrard exhibited a Triassic fish fragment collected from a quarry near the road from Appin to Wilton, about 2½ miles S.W. of Appin.

(*d*) Dr. L. E. Koch made further observations on the epistilbite from Hartley, N.S.W.

(*e*) Mr. N. C. Stevens exhibited specimens of hornblendite from Mainmaru, andalusite from Wagga and Reid's Flat, and axinite from Armidale.

(*f*) Mr. T. G. Vallance exhibited Kodachrome slides of the Broken Hill district, and a specimen of sillimanite from Thackaringa.

(*g*) Dr. J. A. Dulhunty exhibited a specimen of a hard black sideritic rock from the South Coast Coal Measures.

August 21st :

Address by Dr. Harold Rutledge on " Beach Sands ".

September 18th :

Address by Mr. L. R. Hall and Mr. R. O. Chalmers on " The Amblygonite-Cassiterite Pegmatite of the Euriowie District ".

October 16th :

Address by Mr. Frank Jeffries on " Oil-field Development in Western Canada ".

November 20th :

(*a*) Address by Mr. R. L. Stanton on " Some Impressions of New Caledonian Geology ".

(*b*) Mr. R. D. Stevens exhibited Kodachrome slides of Tasmania, in particular of the Cradle Mountain-Lake St. Clair, National Park.

(*c*) Mr. N. C. Stevens noted the occurrence of Ordovician limestones south of Cargo and at Canowindra. These limestones were previously thought to have been of Silurian age. Mr. Stevens also exhibited a specimen of a clastic vein in Ordovician sediments from the Belubula River.

PRESIDENTIAL ADDRESS

By IDA A. BROWNE, D.Sc.

With Plate I and two Text-figures.

Delivered before the Royal Society of New South Wales, April 7, 1954.

PART I.

THE SOCIETY'S ACTIVITIES DURING THE PAST YEAR.

The outstanding event of the past year was the Coronation of Her Majesty Queen Elizabeth II in June, 1953, which was followed by the Royal Visit to New South Wales last February.

We join with other citizens in expressing our loyalty to the Crown and our pleasure in the presence of the Queen and the Duke of Edinburgh in our midst. Their graciousness and devotion to duty must be an inspiration and example to us all.

The Annual Report of the Council records another year of progress in the work of the Society.

According to our Rules, " the Object of the Society is to encourage studies and investigations in, and to receive at its stated meetings, and to publish, original papers on Science, Art, Literature and Philosophy, and especially on such subjects as tend to develop the resources of Australia, and to illustrate its Natural History and Productions ".

It is my opinion that the publication of the results of original scientific research is the most important work of the Society. On the one hand, a permanent record of the research is made ; and on the other, the preparation of a paper for publication provides a valuable discipline in the training of a scientist to present his results clearly and concisely.

It seems to me, therefore, that it is unfortunate that during the past two years fewer papers, and on less varied subjects, have been submitted to the Society for publication. The Society has not altered its policy of accepting suitable papers on all subjects included under its first Rule, and up to the present has not rejected any paper solely on account of the cost of printing.

There are differences of opinion regarding the form of presentation of a paper that may be adopted at the general meetings. Some workers prefer to discuss their results in technical terms, but where the subject is highly specialized few, if any, of the audience may be able to appreciate it. In such a case it is surely better to give, in non-technical terms, an account of the objects and results of the research, which should be of interest to the majority of members. This matter and the related one of the pattern of the ordinary monthly meetings and of the popular science lectures were discussed by the Council at a special meeting, and are still under consideration.

The Standing Committee appointed two years ago to advise on Library matters met again during the year, and now that we have a trained Librarian, Mrs. B. Somerville, the Library is being put into proper order.

That the Library is playing an important part in the life of the community is shown by the increasing number of borrowers, among whom the Government

Departments, both Federal and State, teaching and research institutions and private industry are prominent. The Library consists essentially of scientific periodicals, not individual books, and has been built up chiefly by exchange for our own Journal and Proceedings, but also by purchase. A recent survey indicated that nearly 40% of the publications are not available in other libraries in Sydney, so that our library service is a valuable contribution to the needs of scientific research workers here.

During the year this Society was represented at several meetings of other scientific organizations. Sir Douglas Mawson represented it at the Centenary Meeting of the Royal Society of South Australia in September.

The Canberra meeting of A.N.Z.A.A.S. in January, 1954, was attended by a number of our members, many of whom took leading parts in its proceedings. Mr. H. Wood and I were the official delegates of the Society at this meeting. I have to report that during the Canberra meeting it was resolved that the Australian National Research Council should gradually hand over its functions and commitments, partly to A.N.Z.A.A.S. and partly to the newly formed Academy of Sciences, by which it has been superseded. To the new Academy of Sciences we offer our best wishes.

We congratulate Mr. A. R. Penfold, one of our former Presidents, and the recipient of the Society's Medal two years ago, on receiving the Fritzsche Award of the American Chemical Society for outstanding achievements in research on essential oils and related chemicals. Many of Mr. Penfold's papers have been published in our Proceedings.

We offer congratulations to those of our members who have been honoured by the award to them of scholarships and travel grants to enable them to pursue their studies abroad. Prof. K. E. Bullen, Prof. A. J. Birch and Dr. I. S. Turner have been awarded grants from the Carnegie Corporation of New York to visit the United States and Europe under the British Dominion's programme, and several of our younger members, including Dr. T. G. Vallance and Mr. J. F. Lovering, have received Fulbright Scholarships for study in the United States.

Mr. H. B. Carter, who has been a valued member of our Council for several years, leaves us at the end of the month to take up a permanent scientific appointment with the Agricultural Research Council of Great Britain, and will be resident at Edinburgh, Scotland. He takes with him our best wishes for success and happiness.

The financial position of the Society continues to cause concern to the Council. The deficit is about the same as last year, although less than it was a couple of years ago. This apparent improvement is due partly to the publication of fewer papers and partly to the special grant of £200 from the Rural Credits Development Fund of the Commonwealth Bank of Australia, for which we are grateful.

The Government of New South Wales has again made a grant of £400 towards the work of the Society, which has been of considerable benefit to us.

The Society has been fortunate in having the services of a number of guest speakers as well as members at its meetings, and has had the advice of a number of non-members on its various sub-committees. Their assistance is greatly appreciated, and I wish to thank all these gentlemen for their contribution to the work of the Society.

I also wish to thank all members of Council for the cooperation I have received during the year ; each and every one has performed special services for the Society in addition to attending the formal meetings of the Council : I am especially indebted to the members of the Executive and to our Assistant Secretary, Miss M. Ogle, for their help and guidance during my tenure of office.

The death of nine of our members during the year has been announced by the Honorary Secretary. These include Harold Henry Thorne, who was a former member of Council ; also one of our oldest members, Henry Ferdinand Halloran, elected in 1892, and one of our newest members, Harold Rutledge, elected in 1952, whose tragic death in the plane disaster at Singapore shocked us a few weeks ago.

It may not be generally known that it was owing to the generosity of Mr. Halloran that two of the coveted awards of the Society—the Edgeworth David Prize and the James Cook Medal—were instituted. Mr. Halloran very modestly did not wish his name to be associated with the names of the prizes, but I feel that members would wish to record our indebtedness to such a benefactor.

PART II.

A STUDY OF THE TASMAN GEOSYNCLINE IN THE REGION OF YASS, NEW SOUTH WALES.

For the second part of my address I have chosen a subject which has been of special interest to me for more than twenty years, the Palæozoic history of the region surrounding the town of Yass, on the Southern Tablelands of New South Wales, about 150 miles south-west of Sydney. For a long time this region has been known to geologists on account of its interesting structures and its remarkably rich and varied fossil faunas, but until recently (Brown, 1941) no detailed map showing the order of succession of the Silurian beds in the neighbourhood of Yass had been published, and until now there has been no similar map for the even more interesting Devonian sequence developed to the south-west of Yass. My own field work was undertaken in an effort to establish the order of succession and the geographical distribution of the various fossiliferous formations, to study the faunas preserved in them, to make age-correlations with occurrences in other parts of the world, and to work out the geological structure and history of the region.

TASMAN GEOSYNCLINE.

There is general agreement among geologists that the main areas of deposition of marine sediments are geosynclines—elongated troughs—either in the oceans bordering continental masses, or within the borders of the continents themselves. These troughs are somewhat mobile, and appear to subside slowly during periods of sedimentation. Whether the accumulation of great thicknesses of shallow-water deposits in geosynclines is the cause or the result of the subsidence is not yet known, and G. M. Lees (1953) maintains that " no adequate reason for the broad geosynclinal depressions has yet been offered ".

An examination of the geological map of Australia (David, 1932) shows that the marine sediments of lower and middle Palæozoic age, whose fold-axes are approximately meridional, outcrop over a large area of eastern Australia from Tasmania and Victoria through New South Wales to Queensland and that probably the Mesozoic sediments of the eastern portion of the Great Artesian Basin are underlain by older Palæozoic rocks. From this it is inferred that the sea formerly extended over this whole area, and studies of the sediments in various places indicate that land probably existed both to the east and to the west of it. The great trough occupied by this sea was named by Schuchert (1916) the Tasman Geosyncline. Various geologists have described its development in general terms (David, 1950), but much yet remains to be learned of the details of its structure, extent and history. The rocks of the Yass region occur within the site of this geosyncline, and I propose to outline the probable history of the region during a part of the Palæozoic era, as interpreted from the geological formations there.

Pre-Ordovician (?) Sedimentation.

On the far South Coast of New South Wales apparently unfossiliferous altered sediments, strongly folded, outcrop over a considerable area north and south of the Wagonga River, near Narooma. Their geological age is uncertain, but they are known to be pre-Upper Ordovician, and from their lithological similarity to certain rocks at Heathcote, in Victoria, it seems possible that they may be of Cambrian age. These are the oldest known sediments of the Tasman Geosyncline. They were originally sandy or shaly ; no limestones are known to occur with them.

Lithologically similar strata outcrop east of Jerrawa, only about 12 miles east of Yass, and are well exposed in railway cuttings there. In the absence of palæontological evidence to the contrary these may also be regarded as possibly of Cambrian age. Their relations to the younger rocks are not known.

Ordovician Sedimentation.

During the Ordovician period the Tasman Geosyncline extended far to the west of the meridian of Yass, for Lower Ordovician graptolitic slates are known near Narrandera, 140 miles to the west ; from the south-east of Yass, near Canberra, sandy shales, mudstones and argillaceous shales containing Radiolaria and low Middle Ordovician graptolites have been recorded by Öpik (1954). Upper Ordovician graptolitic shales are known from a number of localities between Jerrawa, Canberra and Queanbeyan and the coast near Cobargo.

The Upper Ordovician graptolitic facies is widespread, but the shelly facies, represented by limestones, so far has been recorded only from the Canowindra and Mandurama districts, some 90 miles north of Yass, although it is possible that other limestones mapped as Silurian may be actually of Ordovician age.

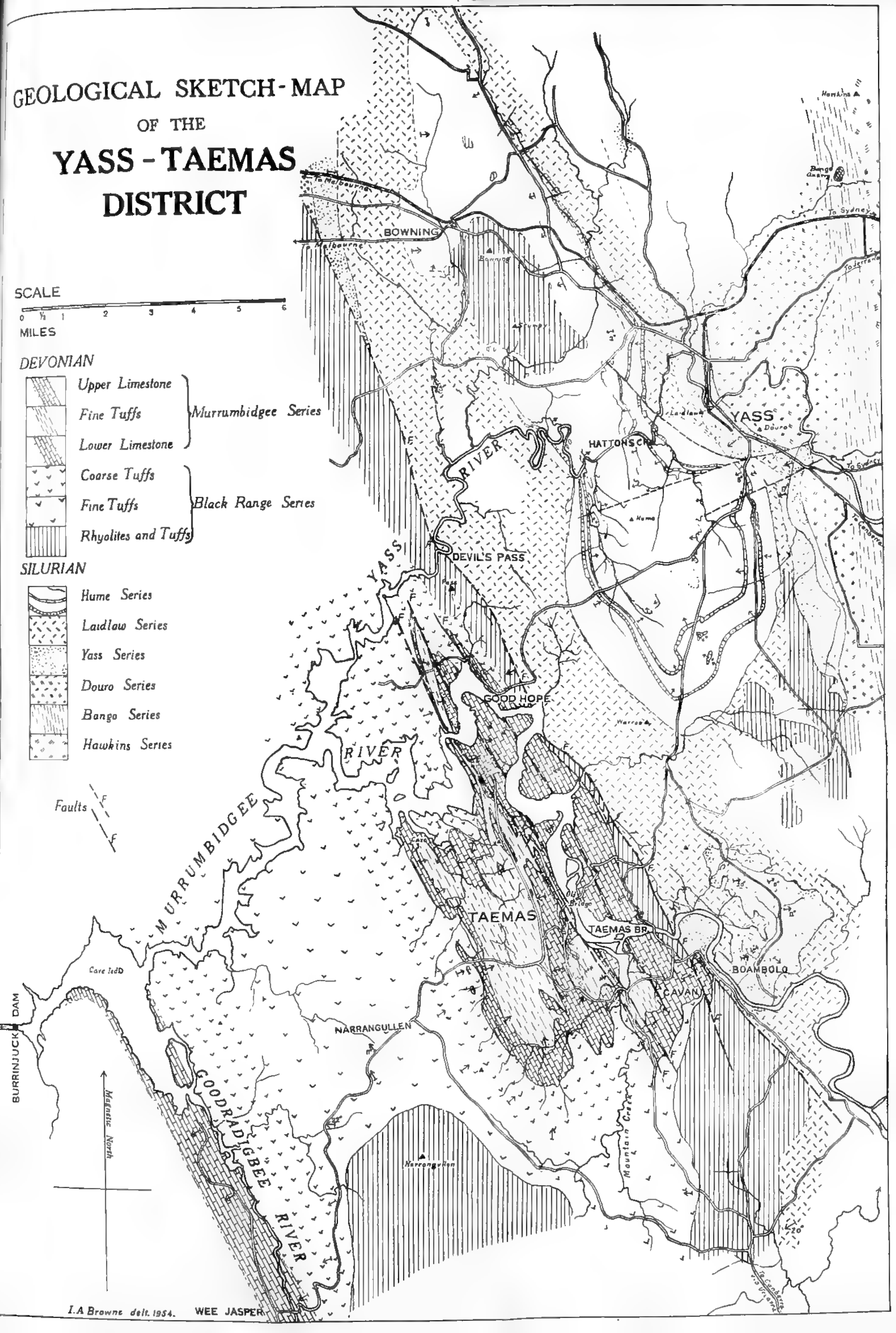
It is not known whether the sea covered the Yass area in Lower and Middle Ordovician times ; the only Ordovician rocks known belong to the Upper Series, the graptolitic black slates of the Jerrawa district east of Yass, which have been described by Mrs. Sherrard (1943), who has identified more than 40 species of graptolites.

There is no evidence of volcanic activity in the Yass district during the Ordovician period unless the rather siliceous black slates are really composed of very fine volcanic dust, as Dr. Joplin (1945) has suggested. In this case the carbonaceous material may represent the remains of floating marine vegetation, such as forms in the Sargasso Sea of the present day, and the graptolites that were associated with it may have been killed off by the showers of fine volcanic ash. To the north of Yass, near Mandurama, lavas and tuffs are associated with the shallow-water limestones of the shelly facies.

The occurrence of a thick series of unfossiliferous sandstones and shales overlying the graptolite beds south-west of Jerrawa indicates a change in the conditions of sedimentation, with uplift and relatively rapid erosion of land to the east. Near the top of this series occurs the Mundoonan Sandstone, which has a more or less uniform dip to the west (Sherrard, 1939). This sandstone is regarded by Mrs. Sherrard as Upper Ordovician, but, since it shows markedly less intense folding than the graptolitic beds and is more or less conformable with the overlying Silurian beds to west, there seems a possibility that it forms the base of the Silurian sequence (Fig. 1).

At or shortly after the close of the Ordovician period there was an epoch of earth-movement and plutonic intrusion, known as the Benambran epoch

Journal Royal Society of N.S.W., Vol. LXXXVIII, 1954, Plate I



(Browne, 1947), during which the Ordovician sediments in the central part of the geosyncline were folded and altered and were elevated to form a geanticline. The Yass region was within the limits of this geanticline. The uplifted Ordovician sediments were subjected to erosion, and after subsidence they formed a more or less rigid basement on which the Silurian formations were later deposited unconformably. The structural relations of the Ordovician and Silurian in the region of the geanticline are thus very different from those in south-central Victoria, where sedimentation continued without interruption and there is no angular unconformity between the Ordovician and Silurian.

No granitic intrusions of Benambran age are known close to Yass, but contaminated granite, somewhat similar to the epi-Ordovician granite of Cooma, intrudes and metamorphoses old sediments west of Cullerin on the Hume Highway, 32 miles east of Yass.

Silurian Sedimentation.

In Silurian time the Tasman Geosyncline was probably more restricted in its width than in the Ordovician, but its true western boundary is obscured by the Cainozoic deposits of the Riverina district. It was a broad, generally shallow sea-way, probably dotted with islands and archipelagoes, with which were associated coral reefs and beach deposits. In the eastern portion of the geosyncline the water was probably much deeper than in the west, and this may account for the known variations of lithological and palæontological facies. Other minor variations might be due to the existence of embayments, channels and terrestrial barriers.

The greater part, if not the whole, of the Silurian sequence was developed in the region of Yass. Naylor (1935) found Lower Silurian graptolites in slates near Bungonia, south-west of Goulburn, and Öpik (1954) records similar forms from near Canberra. Although the shelly faunas of the Yass sequence have not yet been described in detail, they are known to range from the *Halysites* fauna of the Bango limestone, of probable Lower Silurian age, to the fauna of the Upper Trilobite Bed at Bowning, close to the Siluro-Devonian boundary. Graptolites occurring on a number of horizons enable close correlations with parts of the British and North American successions.

The general succession in the Yass district has been described previously (Brown, 1941). Apart from the Mundoonan sandstone, which may form the lowest unit, the sequence, in descending order, is as follows :

	Approx. Thickness (Feet).
Hume Series, including shales with the Upper Trilobite bed, interbedded shales and thin bands of conglomerate, tuffaceous sandstone with *Monograptus flemingi,* shales and sandstones, Middle Trilobite Bed, shale with *M. bohemicus,* Black Bog shales, Lower Trilobite Bed including Hume Limestone, *Barrandella* shales, Bowspring Limestone . .	*c.* 800
Laidlaw Series, fine and coarse tuffs and porphyries	900
Yass Series, sandstones, calcareous shales and mudstones, thin beds of limestone. Richly fossiliferous	800
Douro Series, chiefly coarse tuffs with some (?) porphyry	3,000
Bango Series, marmorised limestone and shales, in part tuffaceous, with *Halysites*	800
Hawkins Series, chiefly coarse tuffs, in part fossiliferous, in part intrusive into Bango shales	2,000
Approximate total thickness	8,300

Of the total thickness nearly three-quarters, about 6,000 feet, consists of igneous material occurring chiefly in three series alternating with the fossiliferous Bango, Yass and Hume Series. Thus there are great rhythms in sedimentation ; smaller rhythms are evident in the repetition of limestones and shales, and minor rhythms are conspicuous within the limestones themselves. While there is general conformity within the succession, in detail there are disconformities or erosional breaks between the various units. (See section, Fig. 1.)

The normal sediments show abundant evidence of their shallow-water origin by the occurrence of fossil rain-prints, ripple-marks and organic remains. They also contain much fine pyroclastic material, which must have been showered over the sea-floor as fine volcanic ash and dust, and which was probably responsible for the death of organisms inhabiting the littoral zone and for their quick burial and preservation as fossils.

The tuffaceous igneous material, although broadly conformable with the associated normal sediments, exhibits locally intrusive relations with them. Much of this material is coarsely crystalline and shows some resemblance to quartz-porphyry in handspecimen, but its clastic character is apparent under the microscope. The apparently intrusive character of these clastic rocks forms one of the major problems of Silurian geology in this State, where " intrusive tuffs " occur over a great area of the Southern and Central Highlands. One broad belt extends from the vicinity of Cooma (Browne, 1929) north along the Murrumbidgee Valley and through the Australian Capital Territory (as at Mt. Ainslie, Yarralumla, Uriarra Crossing) and Queanbeyan to Yass district, and thence far north through Canowindra. Although a number of geologists have studied these tuffs in various places, there is yet no concensus of opinion as to their origin. Associated with the crystal tuffs are dacitic lavas and intrusions of co-magmatic quartz-porphyrite and quartz-porphyry.

Marine conditions in the region of Yass during Silurian times must have been very similar to those around some of the tropical islands of the Pacific Ocean of the present day, with warm, shallow waters favourable to the growth of coral-reefs, and normal sedimentation interrupted intermittently by coastal or submarine volcanic activity.

Perhaps the most interesting part of the succession at Yass is that within the Hume Series. After the prolonged outburst of volcanic activity during the Laidlaw epoch, relatively quiet sedimentation continued for a long time, during which the clear seas favourable for the growth of coral-reefs gave place to muddy waters in which trilobites and other organisms flourished. During the closing phase of this epoch and following the deposition of shales, sandstones and thin bands of interbedded conglomerate, the Upper Trilobite Bed near Bowning Railway Station was deposited. In addition to a number of forms that were abundant earlier, it contains a few that foreshadowed the new forms of life that were to develop in the succeeding period.

The problem of the boundary between two geological systems and periods is one about which there are differences of opinion in every country, since geological time is continuous and earth-movements that produce unconformities or breaks in the deposition of sediments do not occur simultaneously all over the world : in fact, they do not affect the whole of a geosyncline at the same time. Many people regard the palæontological evidence as more reliable, " the incoming of new forms *in abundance* " marking the beginning of a new epoch. As yet, however, insufficient palæontological research has been accomplished to enable a settlement of all difficulties in the application of this criterion.

So here at Bowning there is a problem of determining the Siluro-Devonian boundary, and on the available evidence I consider that the top of the shales containing the Upper Trilobite Bed should be taken as marking the top of the

Fig. 1.

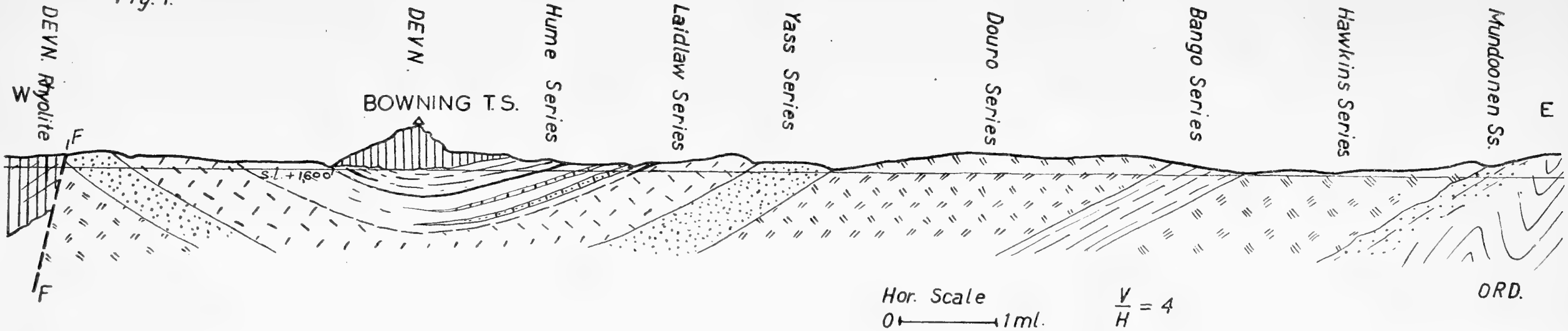


Fig. 2

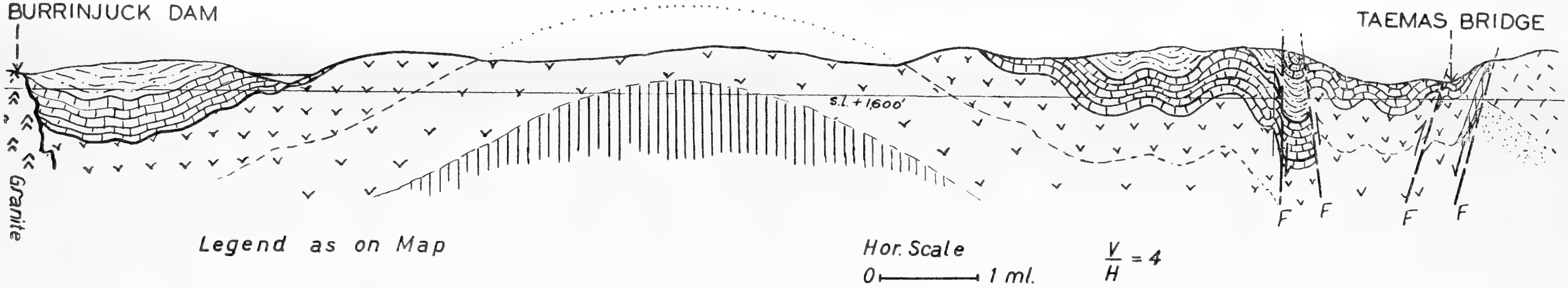


Fig. 1.—W.-E. Geological Section through Bowning Trig. Station. (Modified from Brown, 1941.)

Fig. 2.—Generalized Geological Section from Burrinjuck Dam to Taemas Bridge.

Silurian. The succeeding tuffaceous conglomerate in the neighbourhood of Bowning Hill transgresses unconformably the Hume series, and clearly belongs to the overlying Devonian volcanic sequence.

The Silurian Period was apparently brought to a close by the Bowning orogeny (Browne, 1947) during which the strata in the Yass-Bowning area were gently folded along a north-north-west axis. The Hume Series now forms a closed oval basin surrounding Bowning Hill, and the underlying formations appear in confocal troughs, which become progressively more elongated. The outcrops of Bango limestone appear along a belt roughly parallel to the Siluro-Ordovician boundary. Cross-warping in the vicinity of Boambolo, south of the main basin, has produced an inlier of the Yass Series along the main fold-axis.

No plutonic intrusions related to the Bowning orogeny are known at Yass, but the intrusion of the Gunning granite, which outcrops about 16 miles to the east, possibly took place during that epoch.

Devonian Sedimentation.

After an interval of erosion that followed the Bowning orogeny, ocean waters once again flooded the Tasman Geosyncline and the Devonian Period in the Yass district opened with a great display of volcanic activity. On the sinking shoreline west of Yass this commenced with the deposition of an agglomerate or conglomerate, in which waterworn boulders of hard Silurian tuff and fossiliferous limestone, with volcanic blocks of andesite, are embedded in a coarse tuffaceous matrix. On Bowning Hill this rock is overlain by flows of andesite and beds of tuff, which are succeeded by flows of rhyolite. This occurrence is an outlier of a great suite of volcanic rocks named the Black Range Series (Brown, 1941), which outcrops extensively in the Black Range and in the country between Bowning Hill and Burrinjuck Dam, and through Narrangullen Mountain to the south.

Along the eastern border of the main outcrop the base of the sequence is hidden by heavy faulting, but the series consists of flows of rhyolite and pyroxene-andesite interbedded with fine tuffs, the whole being overlain by a thick sequence of coarse tuffs and volcanic breccias. North of Narrangullen Mountain black shales overlie the rhyolites, but these thin out south of Taemas. Fine, shaly red tuffs are conspicuous near the top of the sequence.

The thickness of the lava flows varies from place to place: a thickness of 1,800 feet has been measured north of Good Hope, and elsewhere it may be greater. The overlying tuffs also vary in thickness and in places taper out and disappear, but it is probable that the thickness of lavas and tuffs is of the order of at least 2,500 feet. The rock-types produced during this epoch of vulcanicity were quite distinct from those of the preceding period, the felsitic rhyolites with small felspar phenocrysts and dense stony groundmass being particularly characteristic, and the experienced field worker has little or no difficulty in distinguishing them from the Silurian igneous rocks. The occasional presence of marine fossils in the tuffs indicates submarine deposition.

To the south and south-west of Yass the Black Range Series is succeeded by a sequence of Middle Devonian sediments called by Süssmilch (1914) the Murrumbidgee Beds and by David (1932) the Murrumbidgee Series and later (1950) the Taemas Series. These sediments, approximately 2,000 feet thick, consist of two great formations of richly fossiliferous limestone separated by fine-grained siliceous clastic sediments. Thus again in the Devonian, as in the Silurian succession, there is evidence of great rhythms in sedimentation.

The lower limestones are well-bedded, and individual beds may be traced for many miles. Harper (1909) described part of the sequence, distinguishing, from the base up, the Bluff Limestone, the Yellow Limestone and the Currajong Limestone, and mentioning some of the fossils occurring therein. Corals are abundant in a few thin bands near the base and in limited bands higher up, but the most abundant organisms are brachiopods, notably spirifers of the gens *Spirifer yassensis* (which range from the base to the top of the sequence), also chonetids, atrypids, small rhynchonellids and meristids ; Mollusca, including lamellibranchs, gastropods and nautiloid cephalopods ; and Bryozoa, sponges and trilobites.

The overlying fine, clastic sediments are mainly unfossiliferous except in their upper portions. Rhythmic alternations of unfossiliferous bands with beds a few inches thick containing myriads of spirifers and chonetids are well seen near the western approach to old Taemas Bridge and along the river bank to the south. Red beds are prominent within these sediments.

The upper limestone, which occurs along the western bank of the Murrumbidgee River, north of old Taemas bridge, contains Bryozoa, brachiopods, corals and cephalopods, and also the plates of ganoid fishes. The specimen of *Dipnorhynchus sussmilchi* described by E. S. Hills (1941) came from this limestone.

As in other parts of the State, the Devonian beds have been extensively folded. In the region south-west of Yass, between the Murrumbidgee and Goodradigbee Rivers, the lavas and tuffs of the Black Range Series outcrop in a great trough or syncline plunging to the south from Illalong Creek Railway Station, in the centre of which a median anticline forming Narrangullen Mountain has raised the rhyolites more than 3,000 feet above sea-level. Around these the overlying shales and tuffs outcrop in a great arc pitching at a low angle to the north, but dipping more steeply to the north-east and to the west, and the beds of the Murrumbidgee Series, eroded off this axis, are now confined to two more or less closed elongated basins, one on either side of the anticline. The western basin is along and to the west of the Goodradigbee River (Fig. 2) and is intruded by the Burrinjuck granite and related igneous intrusions ; the eastern basin extends from the Yass River, below the Devil's Pass, south across the Murrumbidgee River and through the parishes of Taemas and Cavan. The general stratigraphical succession is similar in the two basins, though the thicknesses of strata are different. The similar order of succession of the faunas in the lower beds is very striking and indicates similar conditions of sedimentation and environment over a wide area.

It was chiefly from the lower limestones of the eastern basin in the neighbourhood of Taemas and Cavan that W. B. Clarke and others (D. Hill, 1941) collected fossils that have made the area geologically famous ; and in this area also is the spectacular folding of the limestones that has been illustrated by Süssmilch (1914), David (1950) and others.

However, no detailed map of the whole structure has been made until now, so that it has been almost impossible to place fossils from different localities in their correct stratigraphical horizons.

As may be inferred from the map (Plate I) and geological section (Fig. 2), the eastern basin is really a compound structure, consisting of two synclinoria, the eastern one much broken by faults. The most easterly fault has brought the Black Range Series down against the Silurian (Figs. 1 and 2), while a parallel fault two miles to the west throws down to the east, so that between the faults there is a long narrow belt of downthrown Devonian rocks. Within this are two other faults, between which a central zone has been upthrust.

Of the minor foldings some are symmetrical, others very asymmetrical, and some small elongated domes and basins are developed. The folded and faulted rocks are strongly cleaved.

Since the fossils in the limestones indicate a Middle Devonian age for the sediments, it is probable that their folding and faulting took place at the close of Middle Devonian time, during the epoch of diastrophism which affected much of south-eastern Australia (Brown, 1932), and which is known as the Tabberabberan orogeny (Andrews, 1937-1938). Some of the minor folding and crumbling is closely related to the faulting, and this accounts for the intensity of folding of the Devonian rocks in contrast with the generally gentle, open folding of the Silurian near Yass.

No intrusive igneous rocks occur in the eastern basin, but the granite and quartz-porphyrite of Burrinjuck are probably related to the Tabberabberan orogeny.

Historical Summary.

In the cross-section we have taken of the Tasman Geosyncline in the latitude of Yass district, we have seen that in its early stages, perhaps during Cambrian or Lower Ordovician times, it extended far to the east and to the west of Yass ; during the Ordovician, fine-grained muds were deposited within the geosyncline, and graptolites inhabited its waters. Coral and other shelly faunas lived in the shallower waters north of Yass during Middle and Upper Ordovician times and built up limestones.

At the close of the Ordovician, folding of the sediments, intrusion of granite to the east and the formation of a geanticline within the geosyncline marked the epoch of Benambran orogeny. An interval of erosion was followed by submergence of the region and the transgression of the early Silurian sea.

Silurian sedimentation occurred in a somewhat more restricted geosyncline. The alternations of shallow-water, sandy, muddy and calcareous sediments record fluctuations of sea-level and changes of environment for their enclosed faunas of corals, brachiopods, trilobites and other organisms. The enormous quantities of associated igneous material are evidence of periodic displays of volcanic activity on a tremendous scale.

The Silurian Period closed with the Bowning orogenic epoch, when the Silurian sediments were gently folded and somewhat faulted, and granite was injected into the sediments around Gunning.

A somewhat similar set of conditions was repeated in the Devonian ; great thicknesses of rhyolitic lava, tuff and ash were deposited over the eroded surface of Silurian formations as a result of widespread volcanic activity. In the Middle Devonian conditions became favourable for the formation of extensive coral reefs, which developed on a subsiding floor and produced thick deposits of limestone.

By this time the Tasman Geosyncline in the Yass region contained sediments and products of igneous activity of the order of many thousands of feet thick, Silurian and Devonian alone accounting for at least 12,000 feet. The folding and faulting of the Middle Devonian and the accompanying intrusions of Burrinjuck granite and quartz-porphyrite of the Tabberabberan epoch may have been caused by fracture of the basement of the geosyncline by this enormous load of superimposed sediments.

No Upper Devonian or younger Palæozoic sediments are known in the Yass district, although the widespread distribution of Upper Devonian in other parts of the State suggests that probably they also occurred here, but have been completely worn away.

CONCLUSION.

Although much has been written of the Tasman Geosyncline, much yet remains to be known of the details of sedimentation in various localities ; of changes of facies, both lithological and palæontological ; of migrations of faunas within the geosyncline at different stages in its history ; of distribution in space and time of vulcanicity and igneous intrusion ; of the character and timing of earth-movements which have produced folding, faulting and unconformity within the sediments. The solution of these and other problems lies in the detailed mapping and study of the geology and palæontology of particular areas and the integration and summation of all the knowledge thus obtained.

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EXPLANATION OF PLATE I.

Geological Sketch-map of the Yass-Taemas District.

The Silurian in the N.E. is from the author's map (Brown, 1941) with additional boundaries from K. Sherrard (1939) and information kindly supplied by Mr. A. J. Shearsby of Yass.

The Devonian part of the map is mainly original but incorporates some material from L. F. Harper (1909). Alluvium is omitted.

NOTE ON A PAPER BY J. L. GRIFFITH.

By G. BOSSON, M.Sc.

Manuscript received, November 6, 1953. Read, April 7, 1954.

If $f(x_1, x_2, \ldots, x_n)$ be a harmonic function of n variables, it is well known that the mean of the function taken over the $(n-1)$—dimensional boundary of an n-dimensional sphere is equal to the value of the function at the centre of the sphere. However, the writer has not been able to find, in the literature, any generalization of this theorem for the case of a function which is not harmonic, except that due to Griffith for a function of two variables.

In a recent paper (Griffith, 1954), has shown that, if $f(x, y)$ possesses derivatives of all orders within and on a circle of radius λ whose centre is (x, y), then the mean value of the function taken round the circle

$$\begin{aligned}&=\frac{1}{2\pi\lambda}\int_0^{2\pi} f(x+\lambda\cos\theta,\ y+\lambda\sin\theta)\lambda d\theta\\ &=\frac{1}{2\pi}\int_0^{2\pi} f(x+\lambda\cos\theta,\ y+\lambda\sin\theta)d\theta\\ &=I_0(\lambda\nabla_2)f(x,y), \qquad \ldots\ldots\ldots\ldots\ldots\ldots (1)\end{aligned}$$

provided

$$I_0(\lambda\nabla_2)f(x, y) \text{ exists.}$$

In this theorem $\nabla_2^2\equiv\partial^2/\partial x^2+\partial^2/\partial y^2$ and

$$I_0(\lambda\nabla_2)f(x, y)\equiv\sum_{n=0}^{n=\infty}\frac{(\frac{1}{2}\lambda\nabla_2)^{2n}}{(n!)^2}f(x, y). \qquad \ldots\ldots\ldots\ldots (2)$$

$I_0(\lambda\nabla_2)f(x, y)$ will exist provided the series on the right of (2) is convergent.

In the present paper, a formal derivation of the corresponding theorem for a function of three variables is given together with its application to the solution of the Equation of Wave Motions for three spatial co-ordinates.

Suppose $f(x, y, z)$ possesses derivatives of all orders within and on a sphere of radius λ and centre at a given point (x, y, z). We denote the mean of the function taken over this sphere by $f(x, y, z;\ \lambda)$. We take

$$\begin{aligned}\nabla_3^2&\equiv\partial^2/\partial x^2+\partial^2/\partial y^2+\partial^2/\partial z^2,\\ D&\equiv\partial/\partial z\end{aligned}$$

and assume (i) that $f(x, y, z)$, *qua* function of x and y, satisfies the conditions of Griffith's theorem and (ii) that $f(x, y, z)$, *qua* function of z, possesses a convergent Maclaurin expansion. Then

$$f(x, y, z;\ \lambda)=\frac{1}{4\pi}\int_0^{\pi}\int_0^{2\pi} f(x+\lambda\sin\theta\cos\varphi,\ y+\lambda\sin\theta\sin\varphi,\ z+\lambda\cos\theta)\sin\theta d\varphi d\theta.$$

On use of (1), this takes the form

$$\begin{aligned}
f(x, y, z\,;\ \lambda)\\
&=\tfrac{1}{2}\int_0^{\pi} I_0(\lambda \sin\theta \,.\, \nabla_2) f(x, y, z+\lambda\cos\theta)\sin\theta d\theta\\
&=\tfrac{1}{2}\int_0^{\pi} I_0(\lambda \sin\theta \,.\, \nabla_2) e^{\lambda\cos\theta . D}\sin\theta d\theta . f(x, y, z)\\
&=\int_0^{\frac{\pi}{2}} I_0(\lambda \sin\theta \,.\, \nabla_2)\cosh(\lambda\cos\theta \,.\, D)\sin\theta \,.\, d\theta \,.\, f(x, y, z)\\
&=\int_0^{\frac{\pi}{2}} \sum_{n=0}^{n=\infty}\frac{\lambda^{2n}\sin^{2n}\theta \,.\, \nabla_2^{2n}}{2^{2n}(n!)^2}\sum_{m=0}^{m=\infty}\frac{\lambda^{2m}\cos^{2m}\theta\sin\theta \,.\, D^{2m}}{(2m)!} d\theta f(x, y, z).
\end{aligned}$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

Assuming that it is legitimate to interchange the order of summation and integration, we have now

$$\begin{aligned}
f(x, y, z\,;\ \lambda)\\
&=\sum_{n=0}^{n=\infty}\sum_{m=0}^{m=\infty}\frac{\lambda^{2(m+n)}\nabla_2^{2n}D^{2m}}{2^{2n}(n!)^2(2m)!}\int_0^{\frac{\pi}{2}}\cos^{2m}\theta\sin^{2n+1}\theta d\theta\, f(x, y, z)\\
&=\sum_{n=0}^{n=\infty}\sum_{m=0}^{m=\infty}\frac{\lambda^{2(m+n)}\nabla_2^{2n}D^{2m}}{2^{2n}(n!)^2(2m)!} \,.\, \frac{\Gamma(m+\frac{1}{2})\Gamma(n+1)}{2\Gamma\left(m+n+\dfrac{3}{2}\right)} f(x, y, z). \quad \ldots\ldots\ldots \quad (4)
\end{aligned}$$

On using the duplication formula for the gamma function, equation (4) becomes

$$\begin{aligned}
f(x, y, z\,;\ \lambda) &= \sum_{n=0}^{n=\infty}\sum_{m=0}^{m=\infty}\frac{\lambda^{2(m+n)}\nabla_2^{2n}D^{2m}(m+n)!}{m!n!(2m+2n+1)!} f(x, y, z)\\
&=\sum_{r=0}^{r=\infty}\frac{\lambda^{2r}}{(2r+1)!}\sum_{n=0}^{r}\frac{\nabla_2^{2n}D^{2r-2n}r!}{n!(r-n)!} f(x, y, z)\\
&=\sum_{r=0}^{r=\infty}\frac{\lambda^{2r}(\nabla_2^2+D^2)^r}{(2r+1)!} f(x, y, z)=\sum_{r=0}^{r=\infty}\frac{\lambda^{2r}\nabla_3^{2r}}{(2r+1)!} f(x, y, z).
\end{aligned}$$

Thus

$$\begin{aligned}
f(x, y, z\,;\ \lambda) &= \frac{1}{4\pi}\int_0^{\pi}\int_0^{2\pi} f(x+\lambda\sin\theta\cos\varphi,\ y+\lambda\sin\theta\sin\varphi,\ z+\lambda\cos\theta)\sin\theta d\varphi d\theta\\
&=\frac{\sinh\lambda\nabla_3}{\lambda\nabla_3} \,.\, f(x, y, z). \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)
\end{aligned}$$

It is interesting to note that a well known general solution of the equation of wave motion follows rapidly from this result.

The wave motion equation for three-dimensional space may be written (writing, from now on, ∇ for ∇_3)

$$\frac{\partial^2\psi}{\partial t^2}-c^2\nabla^2\psi=0, \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (6)$$

where $\psi\equiv\psi(x, y, z, t)$ is the " velocity potential ".

Solving this equation formally, as though it were an ordinary differential equation with t as independent variable and ∇ were an algebraic quantity, we have

$$\psi=\cosh ct\nabla \,.\, \psi_0(x, y, z)+\frac{\sinh ct\nabla}{c\nabla} \,.\, \psi_1(x, y, z), \quad \dots\dots\dots\dots \quad (7)$$

where $\psi_0=(\psi)_{t=0}$ and $\psi_1=(\partial\psi/\partial t)_{t=0}$.

If ψ possesses derivatives of all orders and if the series

$$\cosh ct\nabla \,.\, \psi_0\equiv\sum_{n=0}^{n=\infty}\frac{(ct\nabla)^{n}}{(2n)!}\psi_0 \quad \dots\dots\dots\dots\dots\dots \quad (8)$$

and

$$\frac{\sinh ct\nabla}{c\nabla} \cdot \psi_1\equiv t\sum_{n=0}^{n=\infty}\frac{(ct\nabla)^{2n}}{(2n+1)!}\psi_1 \quad \dots\dots\dots\dots\dots \quad (9)$$

are convergent and may be differentiated twice, it is easy to see that (7) is, in fact, a valid solution of (6). Further, on differentiating (9) with respect to t, we have

$$\frac{\partial}{\partial t}\left\{\frac{\sinh ct\nabla}{c\nabla} \cdot \psi_1\right\}=\sum_{n=0}^{n=\infty}\frac{(ct\nabla)^{2n}}{(2n)!}\psi_1=\cosh ct\nabla \,.\, \psi_1,$$

so that, writing ψ_0 in place of ψ_1, we have

$$\cosh ct\nabla \,.\, \psi_0=\frac{\partial}{\partial t}\left\{\frac{\sinh ct\nabla}{c\nabla} \cdot \psi_0\right\} \quad \dots\dots\dots\dots \quad (10)$$

Finally, on using (5), (7) and (10), we have the following well known solution of the wave equation (6) :

$$4\pi\psi=\frac{\partial}{\partial t}\left\{t\int_0^{\pi}\int_0^{2\pi}\psi_0(x+ct\sin\theta\cos\varphi,\ y+ct\sin\varphi,\ z+ct\cos\theta)\sin\theta d\varphi d\theta\right\}$$
$$+t\int_0^{\pi}\int_0^{2\pi}\psi_1(x+ct\sin\theta\cos\varphi,\ y+ct\sin\theta\sin\varphi,\ z+ct\cos\theta)\sin\theta d\varphi d\theta.$$
$$\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (11)$$

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REFERENCE.

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THE ESSENTIAL OIL OF *EUCALYPTUS MACULATA* HOOKER.

PART I.

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SUMMARY.

Essential oils from *E. maculata* have been examined from both Queensland and N.S.W. trees. The latter appear to produce oils of uniform composition, containing as major constituents cineole, (+)-α-pinene, dipentene and (+)-limonene, cadinene, cadinol and a lævo-rotatory sesquiterpene. The Queensland trees so far examined, whilst containing only (+)-α-pinene as the major constituent, show some variations among themselves with respect to the minor constituents. Similar oils have been observed from some of the progeny of the low-aldehyde form of *E. citriodora* (Penfold *et al.*, 1953), and the specific status of the two species is discussed.

INTRODUCTION.

The essential oil of *E. maculata* was first described by Baker and Smith (1920,) who examined two oils, one from southern and one from northern New South Wales. These authors reported the presence of cineole, pinene and sesquiterpene (assumed by them to be aromadendrene) in these oils. They could find no evidence for the presence of citronellal. Since this date no further work on the essential oil of this species has been carried out, owing to the fact that the oil showed no promise of either commercial value or scientific interest.

However, following the discovery by Penfold *et al.* (1948, 1951) of variant oil forms within the species *E. citriodora* Hooker, it has been found necessary to define the essential oil status of *E. maculata* more accurately both in Queensland and New South Wales.

This arises from the fact that some of the progeny from the low-aldehyde form of *E. citriodora* have been shown by Penfold *et al.* (1953) to yield oils strikingly similar in composition to oils from *E. maculata* trees naturally occurring in Queensland. Secondly, although the geographical ranges of these two trees overlap northwards from about latitude 25½° S., each species seems to occupy its own distinct area within this range, and they rarely intermingle to any great extent. Notwithstanding this, several individual trees within well-defined populations of *E. citriodora*, and remote from any occurrences of *E. maculata*, have given oils very similar in composition to *E. maculata* oils.

This evidence has led us to review the relationship between *E. citriodora* and what is known in Queensland as *E. maculata*. Morphologically, the two species, as they occur in Queensland, are remarkably alike, and it is virtually impossible to separate them on these grounds alone. Mueller (1879) maintained there were no morphological differences between the two, and considered *E. citriodora* to be merely a variety of *E. maculata.* Maiden (1922, 1924) agreed, as he considered the two trees did " not differ in important morphological characters ". Blakely (1934) mentions that the pedicels of *E. citriodora* are more slender than those of *E. maculata*, the buds less pointed, and the leaves, on the whole, shorter, but in our experience these characters are too variable to be of much value as specific differences. In addition, a critical examination of the wood anatomy of the two trees, carried out on our behalf by Byrnes (1953), has failed to show any differences between *E. citriodora* and Queensland *E. maculata.* Consequently, it is the opinion of the present authors that the name *E. maculata* has, up to the present time, been employed in Queensland solely to designate those trees whose leaves do not give an odour of citronellal when crushed. In view of what is now known of the occurrence of physiological forms or chemical varieties within a single species (Penfold, 1949), the separation of trees into species on purely chemical grounds can no longer be justified.

It may also be of significance that the oils from the various collections of *E. maculata* so far examined from Queensland sources, although varying somewhat among themselves (e.g. guaiol present in some oils) are all fundamentally different in composition from oils from the tree known in New South Wales as *E. maculata.* The relationship between N.S.W. *E. maculata* and the Queensland *E. maculata-E. citriodora* complex is also at present being examined at this Institution.

THE ESSENTIAL OILS.

The essential oils obtained by steam-distillation of the foliage showed marked variations in composition both between the Queensland and New South Wales samples, as well as within the Queensland samples.

The two N.S.W. oils were similar in composition, consisting principally of cineole, (+)-α-pinene, dipentene, (+)-limonene, cadinene, cadinol, a lævo-rotatory sesquiterpene yielding cadalene on dehydrogenation, and small amounts of an unidentified sweet-smelling substance.

The two Queensland oils, differing from each other and from other Queensland oils in the course of examination, differed markedly from the N.S.W. oils. Although the major constituent in each case was found to be (+)-α-pinene, it was associated, in the case of the Brisbane oil, with *iso*-valeric aldehyde, dipentene, terpinolene, an ester of terpineol (?), a lævo-rotatory and a dextro-rotatory sesquiterpene, both yielding an azulene on dehydrogenation, and a sesquiterpene alcohol fraction giving a mixture of cadalene and an azulene on dehydrogenation. In the case of the Tiaro oil, the pinene was associated with guaiol, together with dipentene, a lævo-rotatory sesquiterpene and a sweet-smelling constituent which could not be identified. The occurrence of guaiol in this oil may be not without significance in the question of the *E. maculata-E. citriodora* relationship, as Harris and McKern (1950) have already demonstrated the frequent occurrence of this compound in oils of the low-aldehyde form of *E. citriodora.* Data for the crude oils are given in Table I.

EXPERIMENTAL.

(In each case the essential oils were obtained by the steam-distillation of leaves and terminal branchlets. All melting points are uncorrected.)

New South Wales Trees.

The oils from Moorebank and Bateman's Bay (see Table I) were examined separately; however, as the oils were subsequently shown to be of similar composition, a typical examination only will be described.

TABLE I.

Characteristics of Crude Oils of E. maculata.

Origin of Material.	Date Received.	Weight of Foliage.	Oil Yield.	d_{15}^{15}	n_D^{20}.	α_D.	Solubility in Aqueous Alcohols.		Acid Number, mg. KOH/g.	Ester Number, mg. KOH/g.	Ester Number After Acetylation.	Cineole Content.
							70% W/W.	80% W/W.				
		lb.	%									
Moorebank, N.S.W.	19/7/51	208	0·49	0·9201	1·4857	+ 6·70°	Insoluble in 10 vols.	Soluble in 1 vol.	1·1	6·1	46·8	27%*
Bateman's Bay, N.S.W.	13/9/51	255	0·78	0·9208	1·4835	+ 2·25°	Insoluble in 10 vols.	Soluble in 8·4 vols.	2·0	6·5	19·6	26%*
Brisbane, Queensland.	6/6/52	200	1·0	0·8758	1·4727	+30·85°	Insoluble in 10 vols.	Soluble in 10 vols. (turbidity).	1·5	6·2	18·9	Absent
Tiaro, Queensland	14/3/51	107	1·1	0·8712	1·4702	+33·62°	Insoluble in 10 vols.	—	1·1	3·4	16·8	Absent

* The cineole contents given for the crude oils were determined by calculation from the cineole found by the *o*-cresol method in the fractions boiling up to 60° at 10 m.m.

Fractional distillation : 475 ml. of oil after washing with alkali to remove acidic and phenolic constituents had d_{15}^{15} 0·9206 ; n_{D}^{20} 1·4861 ; α_{D} +2·40°. On fractional distillation at reduced pressure the fractions described in Table II were obtained.

TABLE II.

Fractional Distillation of N.S.W. E. maculata *Oil.*

Fraction.	Boiling Range.	Pressure.	Volume.	d_{15}^{15}.	n_{D}^{20}.	α_{D}.
		mm.	ml.			
1	40–60°	10	203·0	0·8970	1·4632	+ 9·2°
2	60–110°	9	30·5	0·9109	1·4846	— 5·8°
3	110–112°	9	31·0	0·9149	1·5034	— 9·85°
4	112–113°	9	39·0	0·9181	1·5061	— 0·6°
5	113–125°	9	30·0	0·9239	1·5094	+21·0°
6	125–128°	9	30·0	0·9307	1·5096	+33·0°
7	128–132°	10	22·0	0·9519	1·5080	+ 9·0°
8	120–125°	5	57·0	0·9797	1·5075	—23·0°

Determination of Cineole. Fraction 1 had a cineole content (Cocking method) of 60·5%. The cineole was removed from 190 ml. by repeated extraction with 50% aqueous resorcinol solution. The aqueous solution of the cineole-resorcinol addition compound was steam-distilled with an excess of sodium hydroxide solution to give a colourless oil of camphoraceous odour having d_{15}^{15} 0·9281 ; n_{D}^{20} 1·4607 ; α_{D} ±0°. The identity of the cineole was confirmed by the preparation of the *o-cresol addition compound* of m.p. 56–56·5°, undepressed by an authentic specimen.

The cineole-free oil from fraction 1 was refractionated at reduced pressure to give the fractions described in Table III.

TABLE III.

Fraction.	Boiling Range.	Pressure.	Volume.	d_{15}^{15}.	n_{D}^{20}.	α_{D}.
		mm.	ml.			
A	42–52°	19	11·6	0·8569	1·4681	+30·3°
B	52–58°	19	9·2	0·8529	1·4706	+26·66°
C	58°	17	24·8	0·8450	1·4767	+19·35°

Determination of (+)-*α-pinene.* Fraction A yielded a *nitrosochloride* of m.p. 109°, undepressed by an authentic specimen of *α-pinene nitrosochloride.* Confirmation was obtained by permanganate oxidation of the fraction to an oily *acid* which gave a *semicarbazone* of m.p. 205°, undepressed by an authentic specimen of *pinonic acid semicarbazone.*

Alkaline permanganate oxidation gave no indications for either β-pinene or sabinene.

Determination of Dipentene. Fraction C in glacial acetic acid readily yielded a *bromide* of m.p. 124–125°, undepressed by an authentic specimen of *dipentene tetrabromide.*

Determination of (+)-*limonene.* Using amyl alcohol and ether a second bromide preparation from fraction C gave, on fractional crystallisation, a *bromide* of m.p. 104°, undepressed by an authentic specimen of *limonene tetrabromide.*

The Laevo-rotatory Sesquiterpene. Refractionation of fractions 2, 3 and 4 at reduced pressure gave a fraction $b_{9\cdot5}$ 112–117° ; d_{15}^{15} 0·9082 ; n_{D}^{20} 1·5001 ; α_{D} —22·2°. Dehydrogenation of 10 ml. with sulphur for 2½ hours at 185–220°, followed by extraction with ether and distillation under diminished pressure yielded 3·8 ml. of a greenish-brown oil having d_{15}^{15} 0·9817 and n_D^{20} 1·5680. It gave a good yield of an orange *picrate* of m.p. 116°, undepressed by an authentic specimen of *cadalene picrate.* The fraction yielded also a *nitrosochloride* of m.p. 155° (with decomposition) but a hydrochloride could not be prepared.

Determination of Cadinene. Refractionation of fractions 5 and 6 gave a fraction b_{11} 133–139°; d_{15}^{15} 0·9250; n_D^{20} 1·5097; α_D +43·27°. The fraction gave a good yield of a glistening white *hydrochloride* of m.p. 119°, undepressed by an authentic specimen of *cadinene dihydrochloride.* Dehydrogenation with sulphur gave a green oil b_1 122°; d_{15}^{15} 0·9826; n_D^{20} 1·5747. It gave an orange *picrate* of m.p. 115°, undepressed by an authentic specimen of *cadalene picrate.*

Determination of Cadinol. Refractionating of fraction 8 gave a fraction b_2 124°; d_{15}^{15} 0·9783; n_D^{20} 1·5083; α_D —24·4°. This highly viscous oil yielded a hydrochloride of m.p. 119°, undepressed by an authentic specimen of *cadinene dihydrochloride.* It also was dehydrogenated with sulphur to yield an oil which readily formed a *picrate* of m.p. 116° undepressed by *cadalene picrate.*

Alkali-soluble Constituents. The various consignments of oil contained about 0·2% of acidic and phenolic substances which were not further investigated.

Queensland Trees.

(*a*) *Tiaro District.* Four hundred and twenty-seven grammes of the crude oil (Table I) were fractionally distilled at reduced pressure to give the fractions shown below in Table IV.

TABLE IV.

Fraction.	Boiling Range.	Pressure.	Volume.	d_{15}^{15}.	n_D^{20}.	α_D.
		mm.	ml.			
1	39–40°	11	373	0·8640	1·4662	+39·4°
2	40–55°	9	8	0·8527	1·4782	+19·6°
3	55–120°	9	5	0·9103	1·4840	+ 4·0°
4	120–144°	9	Remainder	solidified.	—	—

The first runnings had an odour of *iso*-valeric aldehyde. Its amount was too small to investigate, but the presence of this aldehyde was demonstrated in the Brisbane oil which will be described later. Refractionating of fraction 1 failed to alter significantly the physical data.

Determination of (+)-*α-pinene.* 32 g. of a fraction having d_{15}^{15} 0·8636; n_D^{20} 1·4668; α^D +39·87° on oxidation with permanganate gave an excellent yield of a crystalline *acid* of m.p. 68·5°, undepressed by an authentic specimen of *pinonic acid.* The *semicarbazone* was prepared and melted at 204°, also undepressed on admixture with an authentic specimen of *pinonic acid semicarbazone.*

Determination of Dipentene and Limonene. Fraction 2 yielded a *bromide* of m.p. 120°, undepressed by admixture with *dipentene tetrabromide* of m.p. 124–125°. It thus appears that both dipentene and (+)-limonene are present. *Fraction* 3 failed to give an α-naphthyl urethane and was not further investigated.

Determination of Guaiol. Fraction 4 solidified to a crystalline mass. The liquid portion was filtered off at the pump and the solid purified first by draining on a porous tile, then by recrystallisation from alcohol to m.p. 91·5°, undepressed by admixture with an authentic specimen of guaiol.

The Laevo-rotatory Sesquiterpene. The filtrate from fraction 4 had d_{15}^{15} 0·9806; n_D^{20} 1·5044; α_D —23·15° and was still heavily contaminated with guaiol. It was redistilled at 8 mm. to give a main fraction of d_{15}^{15} 0·9454 ; n_{D}^{20} 1·5040 ; α_{D} —26°. An attempt to prepare a hydrochloride was unsuccessful.

(*b*) *Brisbane District.* Four hundred and sixty-five ml. of crude oil (see Table I) were fractionally distilled at reduced pressure to give the fractions shown in Table V.

Determination of Iso-valeric Aldehyde. Low-boiling constituents were condensed in a trap immersed in a " dry-ice "-acetone freezing mixture interposed between the fractionation assembly and the manometer. This liquid was distilled directly into a solution of *p*-nitrophenyl hydrazine in alcohol (30 ml.) containing acetic acid (1 g.). Distillation was discontinued when the b.p. had reached 100°. From the above solution was isolated a brown p-*nitrophenylhydrazone* of m.p. 110·5°, undepressed by an authentic specimen of *isovaleraldehyde* p-*nitrophenylhydrazone*.

Found : C, 59·56 ; H, 6·45 ; O, 14·91, 14·95 ; N, 18·98%. Calculated for $C_{11}H_{15}O_2N_3$: C, 59·69 ; H, 6·83 ; O, 14·45 ; N, 18·99%.

TABLE V.

Fraction.	Boiling Range.	Pressure.	Volume.	d_{15}^{15}.	n_{D}^{20}.	α_{D}.
	° C.	mm.	ml.			
Trap	—	10	35·0	0·8640	1·4667	+37·7°
1	38	10	275·0	0·8634	1·4662	+41·5°
2	39	10	42·0	0·8639	1·4669	+37·0°
3	39– 43	10	6·0	0·8664	1·4689	+29·5°
4	43– 51	10	5·0	0·8690	1·4715	+14·9°
5	51– 58	10	20·0	0·8616	1·4745	+ 4·8°
6	58– 61	10	4·0	0·8608	1·4796	+ 2·5°
7	61– 66	10	2·0	0·9251	1·4863	—
8	86– 96	5	5·0	0·9475	1·4870	+10·1°
9	96–108	5	9·0	0·9281	1·4958	— 7·3°
10	108–111	5	10·0	0·9221	1·5002	— 3·4°
11	111–114	5	8·0	0·9241	1·5025	+ 8·0°
12	114–120	5	8·5	0·9279	1·5054	+12·4°
13	120–123	5	7·5	0·9358	1·5088	+12·7°
14	123–125	5	11·0	0·9618	1·5073	+ 5·0°
15	125–126	5	7·0	0·9757	1·5052	+ 5·0°

Determination of (+)-α-*pinene.* Fraction 1 gave on permanganate oxidation an acid of m.p. 68·5°. The semicarbazone of the acid melted at 205°. Alkaline permanganate oxidation of fraction 4 failed to yield any benzene-soluble acidic material.

Determination of Dipentene. Fraction 5 gave a good yield of a *bromide* of m.p. 124–125° undepressed by an authentic specimen of *dipentene tetrabromide.*

Determination of Terpinolene. Fraction 6 yielded a bromide which was fractionally crystallised into two main fractions. The first melted at 120° and was undepressed by an authentic specimen of dipentene tetrabromide. The second fraction melted at 116°, was depressed by dipentene tetrabromide, but undepressed by *terpinolene tetrabromide.*

Terpenyl Ester ? Fraction 8 was saponified with 0·5 N alcoholic potassium hydroxide for 2 hours on a steam-bath. Steam distillation of the reaction mixture gave 3 ml. of a colourless oil of a pronounced terpineol odour and having d_{15}^{15} 0·9395 and n_{D}^{20} 1·4880. Attempts to prepare a crystalline derivative failed.

Sesquiterpenes and Sesquiterpene Alcohols. All of the fractions boiling above 96° C. at 5 mm. were separately dehydrogenated with sulphur. The dehydrogenation products in petroleum ether were chromatographed through an alumina column. On removal of the solvent from the various fractions, the main dehydrogenation product in each case was an intensely royal-blue azulene. The *picrate* in each case formed as very dark olive-green needles melting at 115·5° C.

Attempts to prepare hydrochlorides and trinitrobenzoates failed with all fractions. Water was formed during the dehydrogenation of fractions 14 and 15. The ester number after acetylation indicated 51% of acetylisable constituents.

Fractions 14 and 15, as well as yielding the royal-blue azulene as the main dehydrogenation product, also gave a yellow fraction, which reacted with picric acid to give an orange-yellow *product*, m.p. 114·5° C., identical in physical characteristics with, and undepressed by, admixture with *cadalene picrate*.

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We should like to express our thanks to the District Forester at Bateman's Bay, N.S.W., for securing material from his area. The Queensland Sub-Department of Forestry has given great assistance in arranging collections of material from various localities in that State. Much help in the analytical determinations was given by Mr. R. O. Hellyer, A.S.T.C. (Chem.). Microanalyses are by the Division of Industrial Chemistry of the C.S.I.R.O., Melbourne.

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OCCULTATIONS OBSERVED AT SYDNEY OBSERVATORY DURING 1953.

By K. P. Sims, B.Sc.

(Communicated by the Government Astronomer.)

Manuscript received, February 4, 1954. Read, April 7, 1954.

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 269, 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 1953, 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 —0·00152 hour was applied before entering the ephemeris of the Moon. This corresponds to a correction of —3″·0 to the Moon's mean longitude.

Table I.

Serial No.	N.Z.C. No.	Mag.	Date.	U.T.	Observer.
				h m s	
266	731	5·9	Jan. 25	10 57 20·5	R
267	1117	5·1	Feb. 24	9 45 19·2	S
268	1282	6·6	Apr. 21	11 29 46·1	S
269	1385	6·5	Apr. 22	10 25 43·9	R
270	1486	4·6	Apr. 23	12 06 32·7	W
271	1759	6·5	Apr. 26	9 52 11·3	W
272	1242	6·8	May 18	9 46 38·5	S
273	2039	5·6	May 26	7 40 17·4	W
274	2045	6·4	May 26	8 45 13·6	S
275	2051	5·7	May 26	9 46 42·6	S
276	2108	6·4	June 23	7 31 29·4	W
277	2109	6·1	June 23	8 16 11·8	W
278	1565	6·3	July 15	8 29 39·9	R
279	——	7·4	July 15	8 29 44·4	R
280	1967	5·7	July 19	12 16 11·2	W
281	2084	6·5	July 20	13 05 21·5	W
282	2349	3·1	July 22	11 37 30·8	S
283	2524	6·0	July 23	16 49 00·9	W
284	2652	6·4	July 24	9 07 03·1	S
285	2286	5·4	Aug. 18	11 11 12·8	W
286	2295	7·0	Aug. 18	13 14 37·3	R
287	3320	5·3	Nov. 15	13 44 27·8	W

Table I gives the observational material. The serial numbers follow on from those of the previous report (Sims 1953). The observers were H. W. Wood (W), W. H. Robertson (R) and K. P. Sims (S). In all cases the phase observed was disappearance at the dark 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.*

The star involved in occultation 279 was not included in the *Nautical Almanac* list; it is G.C. 14744. Its apparent place was R.A. 10^{h} 40^{m} 55^{s}·87, Dec. +4° 59′ 27″·0.

TABLE II.

Serial No.	Luna-tion.	p	q	p^2	pq	q^2	$\Delta\sigma$	$p\Delta\sigma$	$q\Delta\sigma$	Coefficient of	
										$\Delta\alpha$	$\Delta\delta$
266	372	+100	+ 3	100	+ 3	0	+0·7	+0·7	0·0	+13·2	+0·11
267	373	+100	+ 3	100	+ 3	0	+1·1	+1·1	0·0	+13·4	—0·19
268	375	+ 69	+73	47	+50	53	—0·7	—0·5	—0·5	+12·5	+0·46
269	375	+ 86	+51	74	+44	26	+0·4	+0·3	+0·2	+14·3	+0·14
270	375	+ 99	+13	98	+13	2	+0·5	+0·5	+0·1	+14·1	—0·31
271	375	+ 60	—80	36	—48	64	+0·3	+0·2	—0·2	+ 2·8	—0·98
272	376	+ 96	—27	93	—26	7	+0·8	+0·8	—0·2	+11·7	—0·55
273	376	+ 89	+46	79	+41	21	+0·5	+0·4	+0·2	+14·2	+0·14
274	376	+100	— 9	99	— 9	1	+2·6	+2·6	—0·2	+13·0	—0·41
275	376	+ 96	+27	93	+26	7	+0·6	+0·6	+0·2	+14·2	—0·06
276	377	+ 45	—89	20	—40	80	+2·5	+1·1	—2·2	+ 2·4	—0·99
277	377	+ 37	—93	14	—34	86	+2·3	+0·9	—2·1	+ 1·3	—1·00
278	378	+ 69	—72	48	—50	52	—0·2	—0·1	+0·1	+ 4·4	—0·95
279	378	+ 68	—73	47	—50	53	+1·5	+1·0	—1·1	+ 4·3	—0·96
280	378	+ 84	+55	70	+46	30	—0·8	—0·7	—0·4	+14·1	+0·21
281	378	+ 96	+28	92	+27	8	—0·3	—0·3	—0·1	+14·1	—0·02
282	378	+ 40	+92	16	+37	84	—1·0	—0·4	—0·9	+ 6·8	+0·86
283	378	+100	— 2	100	— 2	0	+0·6	+0·6	0·0	+13·5	0·00
284	378	+ 55	+84	30	+46	70	—0·7	—0·4	—0·6	+ 6·2	+0·89
285	379	+ 51	+86	26	+44	74	—1·0	—0·5	—0·9	+ 8·7	+0·77
286	379	+ 96	+27	93	+26	7	—0·7	—0·7	—0·2	+13·5	+0·12
287	382	+ 85	—52	73	—44	27	+0·7	+0·6	—0·4	+14·9	—0·10

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Robertson, A. J., 1940. *Astronomical Papers of the American Ephemeris,* **10**, Part II.
Sims, K. P., 1953. THIS JOURNAL, **87**, 19 ; *Sydney Observatory Papers,* No. 19.

GEOLOGY AND SUB-SURFACE WATERS OF THE AREA NORTH OF THE DARLING RIVER BETWEEN LONGITUDES 145° AND 149° E., N.S.W.

By J. RADE.*

With two Text-figures.

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INTRODUCTION.

The present paper deals with that part of the New South Wales portion of the Great Artesian Basin stretching between the Darling-Barwon River and the Queensland border and between longitudes 145° and 149° E. The towns of Bourke and Walgett mark the southern boundary, while the western boundary passes through Yantabulla. The area comprises about 14,200 square miles of flat country, topographic features rarely rising to more than 200 feet above the surrounding country. In the western part of the area the altitude varies from 350 feet above sea level in the south to 500 feet above sea level in the north. Higher country is found to the east, where elevations above sea level vary from 430 feet in the south to 565 feet in the north, the latter being the highest part of the map area.

The area is drained by the northern tributaries of the Darling River. Narran River is an exception, since it flows directly into Lake Narran and thus does not enter the Darling. Such rivers as the Narran, Bokhara, Birric and Culgoa, all located north-east of Bourke, flow in a south-westerly direction, but the more westerly situated Warrego River has a south-south-westerly course.

During the course of the present work, the main effort was directed towards the elucidation of the structure and composition of the Palæozoic basement rocks, since they are of importance in a study of water potentialities of the area and are not well known. Full use has been made of the bore data collected by the Water Conservation and Irrigation Commission, Sydney. However, it should be noted that bore data for this area is not always reliable, despite the intensive boring programmes carried out. Bore logs are generally inadequate, few palæontological studies have been made, and the chemical analysis of water samples are too few. Thus much information which would have been of great assistance in the present study has been lost.

The two contour maps which accompany the present paper were prepared by the author from information gained from artesian and sub-artesian bores. Inaccuracy has been introduced by the inadequate bore records, and doubt as to the exact localities of some of the bores. The contours must thus be regarded as only approximate, but nevertheless they serve to elucidate the structure of the basement in this, the most complex area of Palæozoic basement rocks in the whole of the New South Wales section of the Great Artesian Basin.

GEOLOGY.

The area under consideration consists mainly of Palæozoic and Mesozoic rocks. The Palæozoic rocks form the basement of this portion of the New South Wales part of the Great Artesian Basin, while the overlying Mesozoic rocks form the aquifers for artesian and sub-artesian water.

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The Palæozoic rocks are of Ordovician, Silurian and Devonian age. Granites also form a considerable part of the Palæozoic basement in the western part of the area, while Palæozoic schists and slates are widespread in the central and eastern parts of the area. These Palæozoic basement rocks will be considered below in more detail.

The deepest bores of the whole area were drilled into the structural depressions of the eastern section of the area under consideration, to the north of the town of Walgett. The Gerongra bore, situated 17 miles north of Walgett, reached Palæozoic slates at a depth of 3,053 feet, this being the greatest depth at which the basement has been encountered. The Nullawa bore, situated 69 miles north-north-west of Walgett, encountered Palæozoic granite at a depth of 3,018 feet. Palæozoic quartzite and schist were encountered in the Dungle Ridge bore, situated 49 miles north-north-east of Walgett.

The Palæozoic granite has been encountered widely in many bores drilled in the western part of the area. It has been strongly faulted, so that in some places it forms horsts, with the result that the granite is struck at shallow depths. In the north-western corner of the map area the granite was penetrated at a depth of 1,553 feet in the Brindingabba No. 5 bore, 21 miles north of Yantabulla. However, in the Yantabulla No. 1 bore, located at Yantabulla, faulting has brought the granite to within 180 feet of the surface. Granite is met with at varying depths in the several bores to the north-east and east-south-east of Yantabulla. For example, the Mascotte No. 2 bore, situated 17 miles east of Yantabulla, met granite at a depth of 839 feet, while the Maranoa No. 2 bore, situated 28 miles north-east of Yantabulla, encountered granite at a depth of 1,469·5 feet. Granite was encountered 40 miles east-south-east of Yantabulla at a depth of 742 feet in the Multagoona No. 9 bore, apparently in a horst. In the Grass Hut bore, 46 miles east-south-east of Yantabulla, the granite was struck at a depth of 430 feet. Decomposed granite and schist were encountered in the middle part of the area, not far from the Queensland border, at a depth of 1,595·5 feet in the Dunsandle No. 1 bore, 40 miles east-south-east of Barringun. South-east of Yantabulla the Palæozoic basement also consisted of granite and was encountered at varying depths below the surface; in the Boongunyarrah Springs bore, nine miles south-east of Yantabulla, it occurred at 285 feet, while at the Pirillie No. 8 bore, 16 miles south-east of Yantabulla, it was encountered at 1,330 feet. In the southern margin of the area, 28 miles north-east of Bourke, the granite was struck at a depth of 700 feet.

Slates and schists of Palæozoic age were encountered in the central and western parts of the area concerned; slates were recorded at 1,641 feet in the Maranoa No. 4 bore, situated 25 miles north-east of Yantabulla, at 1,820 feet in the Belalie No. 7 bore, 12 miles south-south-west of Barringum, and at 1,795 feet in the New Eureka bore, 24 miles east-south-east of Barringum. Schistose slate is known from a depth of 1,674 feet in the Weilmoringle No. 7 bore, 57 miles east-south-east of Barringun. The Palæozoic basement, consisting of slates and quartzites, was first struck at a depth of 1,300 feet in the Kerribree No. 2 bore, situated 21 miles south-south-east of Yantabulla. Schist with quartz veinlets was met with at 1,118 feet in the Pirillie No. 9 bore, 30 miles south-east of Yantabulla. Palæozoic slate also forms the basement north-east of Bourke, where it is known at a depth of 1,710 feet in the Gidgea Camp bore, 12 miles north-north-east of Bourke, and also at a depth of 1,898 feet in the Weilmoringle No. 9 bore, 74 miles north-east of Bourke. Slates are known at 1,860 feet below the surface in the Milroy No. 2 bore, 63 miles north-east of Bourke. Schistose slate was recorded from a depth of 1,674 feet in the Weilmoringle No. 7 bore, 76 miles north-east of Bourke.

The depths at which the granites, slates and schists are first encountered may be compared by reference to the data given above. It is clear that the granites occur at much shallower depths than the slates and schists. The granites which form part of the Palæozoic basement occur mostly as batholiths intruding the slates and schists. The slates and schists were more susceptible to processes of denudation, and thus form the deeper portions of the basement surface, while the more resistant granites form the higher basement surfaces.

The Jurassic Walloon Series, consisting of sandstones with intercalations of shales, was deposited on the Palæozoic basement. The intercalations of shale have an average thickness of from 30 to 60 feet in the bores sunk in the area north of Walgett. Conglomerates are also found in the Walloon Series, generally along the flanks of the Palæozoic basement ridges. An example is to be found along the ridge to the north-east of Bourke, stretching in a north-north-westerly direction into the New South Wales portion of the Great Artesian Basin. Sand, sandstone and conglomerate, presumably derived from the abovementioned ridges, was encountered between 1,590 feet and 1,642 feet in the Warraweena No. 4 bore, situated 27 miles north of Bourke. Water-worn quartz gravels were encountered at a maximum depth of 1,070 feet in the Lissington No. 4 bore, 43 miles north-north-east of Bourke. The Warraweena No. 4 bore, mentioned above, is situated above a structural depression in the Palæozoic basement, while the Lissington No. 4 bore is located on the northern slopes of the adjoining ridge. Two cycles of sedimentation are represented in the strata pierced by the Gingie bore, situated 23 miles north-west of Walgett. The sediments in question represent the upper part of the Walloon Series. Each cycle commenced with the deposition of conglomerate, and was terminated with the deposition of shale. The following is the record of the older cycle of sedimentation, taken from the Gingie bore :

1,936	to	1,945	feet below surface	9	feet of	black shale.
1,945	,,	1,985	,, ,,	40	,,	brown shale.
1,985	,,	1,987	,, ,,	2	,,	drift sand.
1,987	,,	2,064	,, ,,	77	,,	sandstone.
2,064	,,	2,072	,, ,,	8	,,	gravel.
2,072	,,	2,084	,, ,,	12	,,	conglomerate.

A gradual transition from sediments of coarser character to sediments of finer character can be clearly seen by the figures above. The occurrence of brown and black shales at the top of the cycle is significant. Black shales containing pyrite are characteristically encountered in the Jurassic deposits of Europe, and it is thought that they are the result of deposition under tranquil conditions. These circles of sedimentation expressed in the Gingie bore may be taken as true reflections of the saltatory uplift of the peninsular-like structure of the Palæozoic basement, the latter stretching from the Lake Narran area in a north-easterly direction into the New South Wales portion of the Great Artesian Basin. The Gingie bore is situated on the south-eastern margin of this Palæozoic ridge, and thus the earth movements which affected the ridge are faithfully reflected by the type of sediment found in the bore.

The thickness of the Walloon Series varies within wide limits according to the sub-surface contours of the Palæozoic basement. Thin sequences of the Walloon Series are found on the basement ridges, but great thicknesses have been recorded in the structural depressions. The average thickness of the Walloon Series is 600 feet in the eastern part of the map area, but thinner sequences are known from the western part of the area.

The Walloon Series is overlain by the Lower Cretaceous Blythesdale Series, consisting largely of shales, but containing intercalations of sandy shales, sandstones, and some thin coal seams. The sediments are of lacustrine origin, and on the whole are more sandy than the overlying marine Roma Series. The average thickness of the Blythesdale Series is about 600 feet.

The Roma Series consists largely of blue-grey shales, but intercalations of sandy shale and sandstone are occasionally encountered. The Roma Series generally accounts for the bulk of the sediments penetrated by the bores. Valuable foraminiferal studies of the Roma Series have been carried out for the Water Conservation and Irrigation Commission by Miss Irene Crespin, of the Bureau of Mineral Resources. As a result of these studies, foraminifera of Lower Cretaceous age have been identified in the marine facies between 325 and 1,181 feet in the Lila Springs No. 8 bore, situated 32 miles north of Bourke. In this same bore the marine facies is replaced at a depth of 1,200 feet by fine-grained fawn-coloured shales containing numerous plant remains and seed pods. Foraminifera and ostracods are no longer found, and it is assumed that this level represents the top of the Blythesdale Series. If this be the case, then the thickness of the Roma Series in this locality is 875 feet, which is taken to be the average thickness.

The overlying Winton Series represents a return to lacustrine deposition. It consists mainly of sandy clays, with occasional seams of clay and lignite. The average thickness of the Winton Series is about 500 feet. In 1945 Miss Crespin conducted a foraminiferal investigation of the Stanford bore, situated 58 miles north-east of Bourke. The strata between 139 and 237 feet were referred to the Upper Cretaceous. The thickness of the Upper Cretaceous Winton Series in this area is thus seen to be less than in other areas. In this connection it is significant that the Stanford bore is situated towards the southern limit of development of the Winton Series. In general, the Winton Series is most widely developed in the vicinity of the Queensland border, while it is absent in the south-western corner of the map area. Kenny (1934, p. 71) states that the Upper Cretaceous sediments are not represented in the West Darling district, although the Lower Cretaceous is represented, probably by the equivalents of the Roma Series of Queensland. The Winton Series is developed in the far north-west corner of the New South Wales portion of the Great Artesian Basin, adjacent to South Australia. According to Jack (1930), the Winton Series is also developed in the adjoining area of South Australia.

Structural Geology.

The accompanying figure (Fig. 1) is a contour map of the surface of the Palæozoic basement. Before this is considered in detail, a summary of previous investigations will be given. Mulholland (1940, p. 22) investigated the geological structure of the area south-west of Bourke and found two sets of fold axes. One of them was stated to vary in strike from meridional to N. 20° W., while the other was stated to vary between N. 40° E. and N. 45° E. Domes were identified at the points of intersection of these trend lines, and a probable fault with a strike of S. 30° E. was detected. From these studies by Mulholland it can be seen that the geological structure of the area to the south-west of Bourke is quite complex. The accompanying contour map (Fig. 1) will show that the Palæozoic basement configuration is also complex between Bourke and Yantabulla.

The major feature of the basement configuration is the peninsular-like ridge which extends in a north-easterly direction into the New South Wales portion of the Great Artesian Basin. It is suggested that this trend may be referred to the Caledonian Orogeny. Lloyd (1936, p. 65) has detected the same north-easterly trend in a synclinal structure located at Mt. Drysdale, between Bourke and Cobar. The same trend can be detected in some of the basement

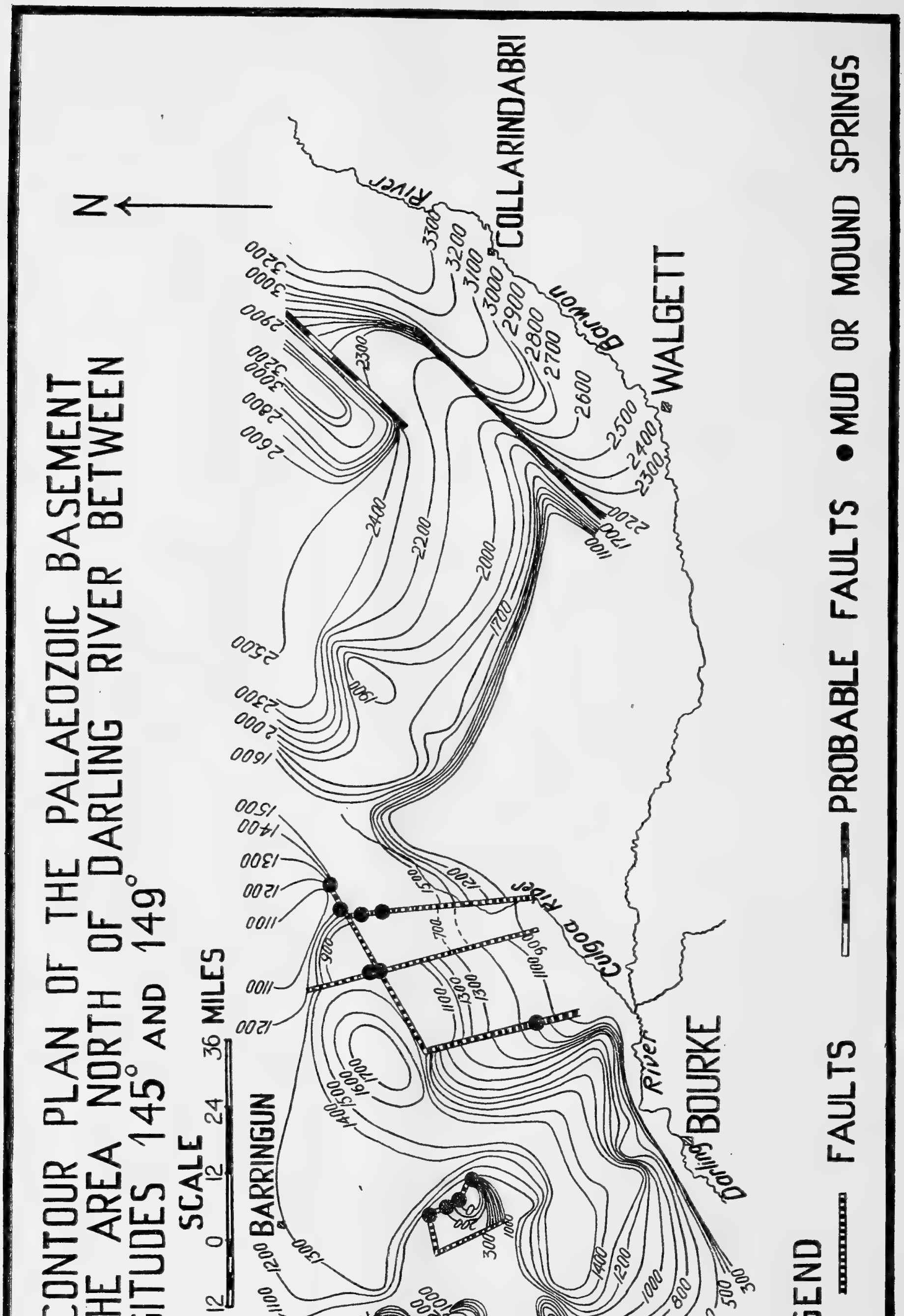
CONTOUR PLAN OF THE PALAEOZOIC BASEMENT IN THE AREA NORTH OF DARLING RIVER BETWEEN LONGITUDES 145° AND 149°
N
SCALE
MILES 12 0 12 24 36 MILES
COLLARINDABRI
WALGETT
BARRINGUN
BOURKE
YANTABULLA
Barwon River
Culgoa River
Darling River
3300
3200
3100
3000
2900
2800
2700
2600
2500
2400
2300
2200
2000
1900
1700
1600
1500
1400
1300
1200
1100
1000
900
800
600
500
400
300
200
0
+200
LEGEND
FAULTS
PROBABLE FAULTS
● MUD OR MOUND SPRINGS

Fig. 1.

faults, such as the probable fault to the north of Walgett (Fig. 1) and other faults in the central and western parts of the map area. The main structural depressions also follow this trend.

The north-north-westerly trend is referred by the present author to the Variscan period of orogeny. It is expressed in the faults which cut the central and western portions of the map area, and is clearly reflected by the alignment of the mound springs. Of particular significance are the mound springs which are located 42 miles north-north-west of Bourke. Here they occur along the eastern margin of a granitic basement horst. A further alignment of the mound springs occurs along a parallel fault to the south-east of Yantabulla. There can be little doubt that these structural lines are true faults, as evidenced by the mound springs and the basement contours. The faults encountered to the north-east of Bourke are also reflected in the courses of the Darling and Culgoa Rivers. The Culgoa River abruptly changes its course when it strikes the south-south-easterly trending fault, and flows along the fault line for some distance. Again, the intense branching of the Darling River, which takes place 25 miles east-north-east of Bourke, coincides in position to the area where the south-south-easterly trending faults strike the line of the river.

The faintest trend found in the map area strikes slightly north of west. It is seen in the fault which bounds the south-eastern corner of the horst located 42 miles to the north-north-west of Bourke, and is clearly expressed in the alignment of the Kullyna and Native Dog mound springs. The structural valley encountered 23 miles north-east of Bourke has the same trend direction. Another small fault having the same strike connects the mound springs of Coonbilly, 20 miles south-east of Yantabulla, with those of Youngarinnia, 15 miles south-east of Yantabulla.

It is clear that these structural trends form a continuation of the trends described from the adjoining areas of Queensland. In the latter area Whitehouse (1945, p. 25) has shown that the bedrock occurs at shallow depths between eastern meridians of longitude 142 degrees and 147 degrees.

The structural geology of the area has not been discussed in detail, since the author is at present engaged in the preparation of a more extensive paper dealing with the structural geology of the whole of the New South Wales portion of the Great Artesian Basin.

HYDROLOGY.

Aquifers are occasionally encountered at shallow depths, but they are saline and are thus of little practical value. Below these are the aquifers of the Upper Cretaceous Winton Series, generally formed above the structural valleys of the Palæozoic basement. They carry sub-artesian water.

The uppermost truly artesian aquifers are located in the sandstone intercalations of the Lower Cretaceous Blythesdale Series, while the most important artesian aquifers are found in the Jurassic Walloon Series. The accompanying contour map (Fig. 2) represents the artesian aquifer of the Lower Cretaceous Blythesdale Series ; however, it must be emphasized that at present the aquifer does not yield artesian water throughout the whole of the map area. This contour plan for the upper artesian aquifer only includes the eastern part of the area under study, mainly the area north of Walgett. In this restricted area the basement contours are fairly regular. Few faults are present. The central and western parts of the map area are different in this respect, since strong faulting in the basement has produced many irregularities in the contours of the aquifer.

On comparing the contour plan of the artesian aquifers of the eastern portion of the area (Fig. 2) with the same portion of the contour plan of the Palæozoic basement (Fig. 1), it becomes evident that the former plan approximately reflects the main structural features of the latter. The contours of the aquifers express the north-easterly trending ridge and the depressions occurring to the north and east of it, just as do the contours of the Palæozoic basement.

The aquifers of the Lower Cretaceous Blythesdale Series occur at the greatest depths in the north-eastern part of Figure 2. Thus in the Goondablui No. 2 bore, 71 miles north-north-east of Walgett, this aquifer was encountered at 2,675 feet below the surface. The main flow from the Jurassic Walloon Series was encountered in the abovementioned bore at a depth of 625 feet below the aquifer of the Blythesdale Series.

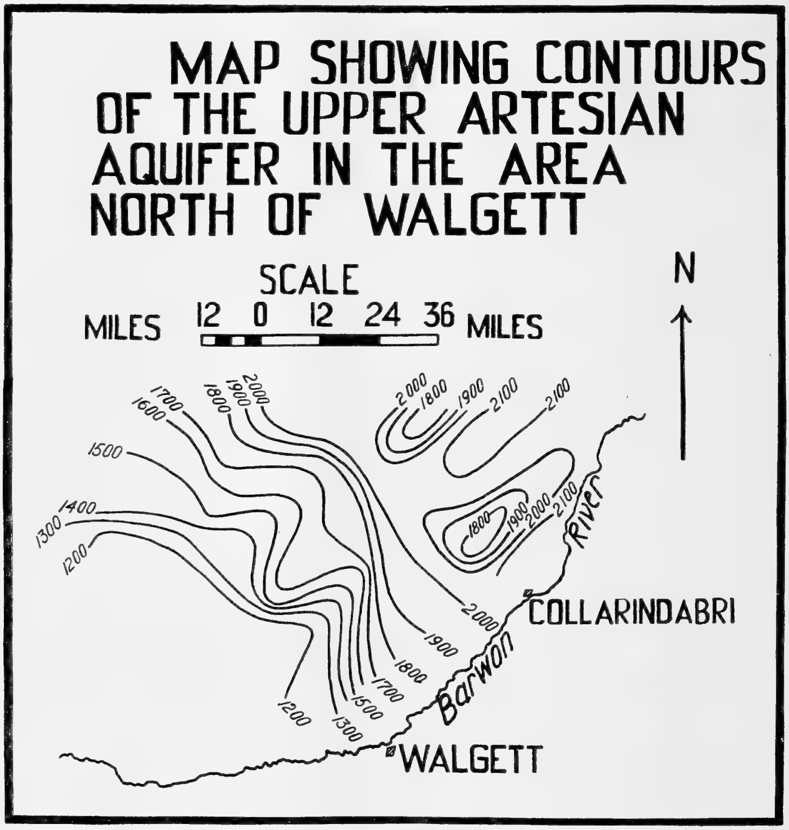

Fig. 2.

The following are analyses of the water obtained from several bores.

From this table it may be clearly seen that the good quality waters of the valuable aquifers in the Walloon Series are located at shallow depths in the vicinity of Yantabulla.

It is usual for the aquifers bearing saline water to occur in the western part of the area. Their distribution may be correlated with the severe faulting, which fractured the strata and permitted leakage of saline water from the shallow aquifers into the deeper aquifers. The long distances which the water must travel from the intake area is also an important factor in a consideration of salinity. The prevailing direction of sub-surface water flow is to the south-west. The water travels in this direction from Queensland to New South Wales

TABLE I.

	A.		B.		C.		D.		E.		F.		G.	
	Grains per Gallon.	In 1000 Parts.	Grains per Gallon.	In 1000 Parts.	Grains per Gallon.	In 1000 Parts.	Grains per Gallon.	In 1000 Parts.	Grains per Gallon.	In 1000 Parts.	Grains per Gallon.	In 1000 Parts.	Grains per Gallon.	In 1000 Parts.
Na_2CO_3 ..	58·681	0·8383	48·156	0·6879	67·455	0·9636	40·306	0·5758	33·320	0·4760	28·731	0·4105	22·103	0·3157
K_2CO_3 ..	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	0·239	0·0039
$CaCO_3$ ..	0·650	0·0093	0·625	0·0089	0·600	0·0086	0·950	0·0136	0·500	0·0071	0·750	0·0107	2·250	0·0321
$MgCO_3$ ..	0·275	0·0039	0·159	0·0023	0·212	0·0030	0·212	0·0030	0·159	0·0023	tr.	tr.	tr.	tr.
NaCl ..	15·731	0·2247	8·168	0·1167	18·506	0·2644	8·362	0·1195	7·882	0·1126	7·768	0·1109	7·539	0·1077
Na_2SO_4 ..	absent	absent	absent	absent	tr.	tr.	tr.	tr.	absent	absent	absent	absent	absent	absent
SiO_2 ..	1·568	0·0224	1·890	0·0270	1·960	0·0280	2·240	0·0320	1·470	0·0210	1·820	0·0260	4·448	0·0064
Fe_2O_3 ..	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.
Al_2O_3 ..	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.
Boric acid	tr.	—	—	—	a strong tr.	—	a faint tr.	—	a trace	—	a trace	—	a trace	—
Total ..	76·905	1·0986	58·998	0·8428	88·733	1·2676	52·070	0·7439	43·331	0·6190	39·069	0·5581	32·579	0·4653
Date of analysis	11.9.11		27.5.15		23.5.11		14.3.12		26.8.13		25.5.11		11.5.11	

A. Dungle Ridge Bore, 49 miles N.N.E. of Walgett, Blythesdale aquifer at 2,566 feet.
B. Dungle Ridge ,, 49 ,, N.N.E. ,, ,, Walloon (Pilliga) aquifer at 2,700 feet.
C. Goondablui 4 ,, 68 ,, N.N.E. ,, ,, Blythesdale aquifer at 2,659 feet.
D. Goondablui 4 ,, 68 ,, N.N.E. ,, ,, Walloon (Pilliga) aquifer at 3,535 feet.
E. Inglewood ,, 39 ,, N.W. ,, ,, Walloon (Pilliga) aquifer at 2,388 feet.
F. Dumble ,, 66 ,, N.W. ,, ,, Walloon (Pilliga) aquifer at 3,034 feet.
G. Kenmare ,, 10 ,, N. ,, Yantabulla, Walloon (Pilliga) aquifer at 1,500 feet.

along the structural depressions of the Palæozoic basement and along the northern margin of the Palæozoic peninsular-like structure described above. This means that in travelling from the intake beds the water must traverse the highly faulted regions where the minerals from the Cretaceous shales are responsible for the " salting " of the water. These considerations are especially applicable to the aquifers of the Blythesdale Series.

The mud or mound springs are of particular interest. They are formed when an artesian aquifer is transected by a fault, especially when an impervious bed blocks the aquifer on the side of the fault opposite to the prevailing direction of flow of the water. This is shown by the horst situated 47 miles east-south-east of Yantabulla, where mound springs are developed along the faults on the eastern side of the horst, but not on the western side. Mound springs are especially common at the point of intersection of two faults, as may be seen in the central map area of Figure 1.

Comparing the movement of the water and the structure of the basement, it appears that in its movement the water uses the deeper strata as the thalweg, and the direction of movement is closely controlled by the configuration of the Palæozoic basement.

SUMMARY.

The strata in the area between longitudes 145° and 149° of the New South Wales portion of the Great Artesian Basin are mostly of Palæozoic and Mesozoic age. Caledonian trends dominate the Palæozoic basement, but Variscan faulting has an important structural control. The shallower artesian flows are from the Lower Cretaceous Blythesdale Series, while the main artesian flows are from the Jurassic Walloon Series. The movement of the artesian water is from Queensland into New South Wales, and is closely controlled by the configuration of the Palæozoic basement.

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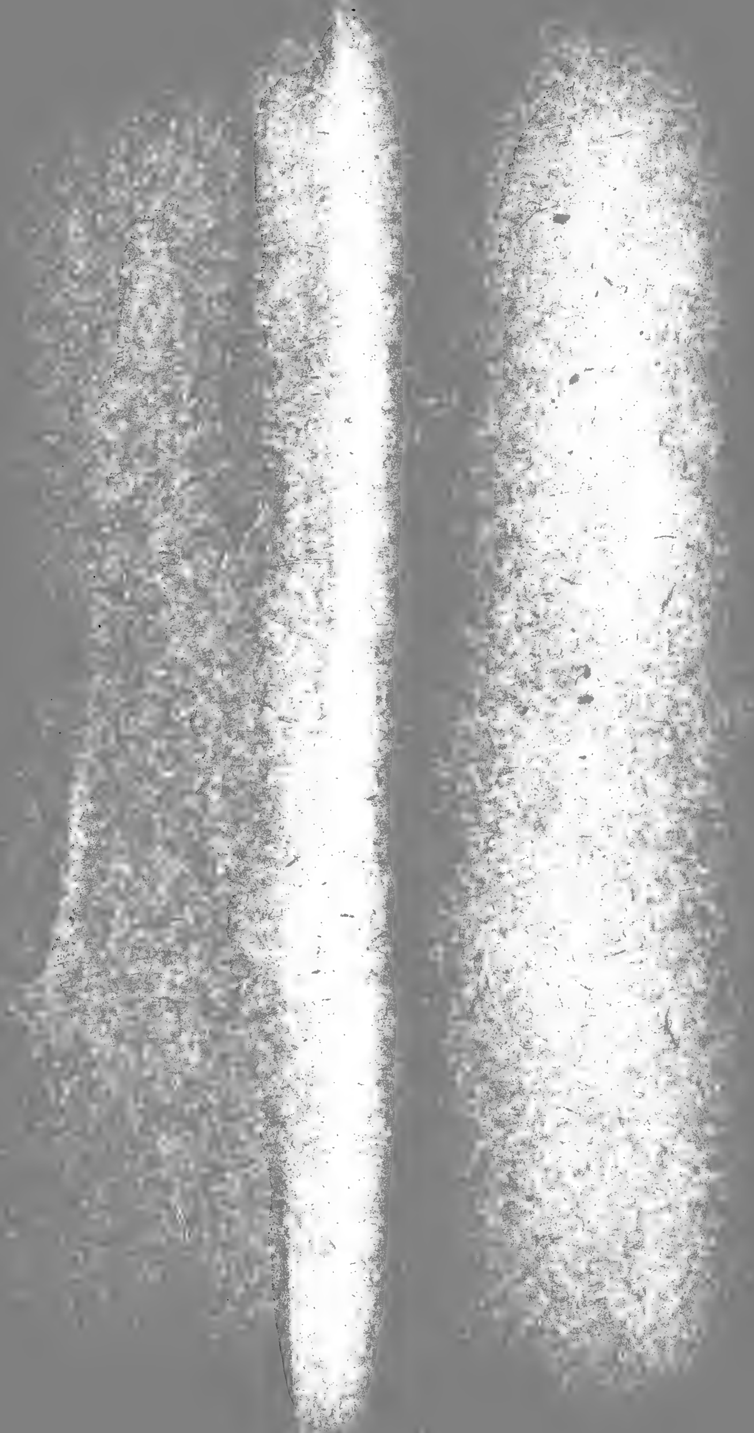

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OF NEW SOUTH WALES
FOR
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PART II (pp. 33-54)
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F. N. HANLON, B.Sc., Dip.Ed.
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D

ORGAN TRANSFORMATION INDUCED BY ŒSTROGEN IN AN ADOLESCENT MARSUPIAL (*TRICHOSURUS VULPECULA*).

By A. Bolliger.

From the Gordon Craig Research Laboratory. Department of Surgery, University of Sydney.

With Plates I-III.

Manuscript received, March 29, 1954. Read, June 2, 1954.

The scrotum of the adolescent male of the marsupial *T. vulpecula* (brush tail phalanger or possum) can be transformed into a persistent mammary pouch by castration and subsequent repeated administration of œstrogens (Bolliger, 1944; Bolliger and Tow, 1947). In the present paper this is confirmed and additional changes brought on by œstrogen administration to a castrated phalanger are described. These will be discussed under the headings of (*a*) cloaca, (*b*) penis, (*c*) scrotomarsupial area, and (*d*) fur.

Animal and Treatment.

A male phalanger (*T. vulpecula*) about five months of age, weighing 510 grms., was castrated (7/3/52). The testicles, which had a diameter of 0·2 cm., were removed through two small lateral incisions in the scrotal sac. Three days later injections of œstradioldipropionate were begun. During the whole experiment the animal remained with its mother.

Details.

0·1	mg.	of	œstradioldipropionate	on	10, 17 and 24 March, 1952.
0·15	,,	,,	,,	,,	7 and 16 April, 1952.
0·2	,,	,,	,,	,,	26 April and 5 May, 1952.
0·3	,,	,,	,,	,,	12 and 19 May, 1952.
0·4	,,	,,	,,	,,	26 May, 2 and 11 June, 21 July, 29 August, 29 September, 29 October, 1952.

The total amount of œstradioldipropionate administered over a period of eight months was 4·4 mg. At the time of the last injection the phalanger was approximately one year and two months old. At this age normal males have reached sexual maturity (Bolliger, 1942). At the age of two years the animal was killed (24/8/53), ten months after the last injection of œstrogen.

(*a*) *Cloaca.*

Penis, cloaca, rectum and pericloacal glands (Bolliger and Whitten, 1948) are contained in a conically shaped hillock (*Colliculus urogenitalis*) with an apical sphincteric orifice which normally only opens for excretory and reproductive functions (Plate I, Fig. 1). This opening leads into a shallow cloaca. In the cloaca can be seen the opening of the penis pocket (*præputium*) and separated by a short perineum, the terminal portions of the rectum. Externally the penis cannot be seen even when the animal urinates. It becomes visible only when in a state of erection. On defæcation the rectum may protrude for a distance of about 1 mm.

This was the state of the external genitalia of our experimental animal as injections with œstrogen were commenced. The cloacal hillock measured about 4 mm. in length. Approximately one month after the first œstrogen administration the urogenital hillock began to swell. Next, the swollen rectum attached to a greatly altered urogenital apparatus became everted, and after another two months it protruded from the opening of the hillock for a distance of 1 cm. It was necessary to cover the exposed rectal mucosa frequently with penicillin ointment in order to protect it against injury and infection.

By this time the originally conical cloacal hillock had taken on a cylindrical elongated shape and measured about 1 cm. in length. It was capped by the protruding, now mushroom-shaped rectum attached to the terminal portion of a modified urogenital canal. The swollen rectal orifice measured 1·1 cm. in diameter (Plate I, Fig. 2). After terminating œstrogen injections the protruded rectum returned almost completely into the cloacal hillock. The cloacal hillock also diminished in size but retained a somewhat swollen appearance for ten months until the animal was killed.

(*b*) *Penis.*

As already mentioned, the penis cannot be seen exteriorly, and even on inspecting the interior of the cloaca it may not be noticed, because it is retracted in the penis pocket or præputium. If the penis is pulled out from the penis pocket, it is noticed that it consists of two sections: distally, an unattached part (*pars libera*), and proximally a part covered by a fibrous tunic (*pars obtecta*) (Van den Broek, 1910). The free unattached part is an undivided cylindrical structure of about 2–3 cms. in length when not erected, and is covered with numerous small horny spicules. At its distal end it is provided with a flagellum which arises near the ventral periphery of the cylindrical shaft. The flagellum is approximately 1 cm. long and near its base is the external opening of the urogenital canal. The relaxed penis is S-shaped, as shown in the diagram (Plate I, Fig. 3) and about 5–6 cms. in total length. This double bend permits large extension, the total length of the fully erected penis being about 12–14 cms. with a diameter of about 1 cm.

About three months after the beginning of œstrogen injections when the rectum had become protruded, it appeared as though the unattached part of the penis with its typical flagellum and horny spicules had disappeared. At this stage there was attached at the distal end of the rectum on its ventral aspect a roughly pyramidal structure (base 1·5; height 0·7 cm.) of fibrous tissue which contained at its apex a pin-sized opening (Plate I, Fig. 2). This was the urinary outlet, and the urinary stream issuing from the small opening was at first of very narrow diameter. This occasioned bladder distension. During the subsequent weeks the opening became wider and adequate for the urinary flow.

The protrusion of the rectum became less obvious about two months after the last œstrogen injection, and finally the anus became retracted almost completely within the cloaca. At the age of two years, when the animal was killed, the urinary outlet was seen within the cloaca as an opening of about 1 mm. diameter. The appearance of the penis and urogenital canal at this stage is described in the post-mortem report.

(*c*) *Scrotomarsupial Area.*

After about three months of œstrogen administration, the scrotum became transformed into a pouch, confirming previous observations (Bolliger, 1944;

Bolliger and Tow, 1947). The pouch thus formed was well developed (Plate I, Fig. 2), but a small remnant of the scrotal tip failed to invert. At the height of its development the length of the pouch opening was 4·5 cm. The inferior recess was 2·0 cm., and the maximum width was 4·0 cm. Some four months after œstrogen administration had ceased the pouch gradually diminished in size but persisted till the animal was killed.

(*d*) *Fur.*

As previously reported (Bolliger, 1944), the male phalanger treated with œstrogen loses its typically brownish male pelage and becomes dark grey, thus presenting an exaggeratedly female appearance.

In the present experiment this was very marked, in as much as the fur of the whole of the posterior half of the body moulted almost simultaneously. The new grey fur which replaced the shed hairs had the typical dark grey female appearance. In addition the line of demarcation between old and new fur was very distinct, as shown in Plate II, Fig. 4. Ultimately the whole of the male animal grew a female pelage, the transformation being much slower and less visible in the anterior region of the body. The distinctive sternal area also exhibited this feminization of the pelage as described in previous experiments (Bolliger and Tow, 1947).

Post-mortem Examination.

The phalanger weighed 1·92 kg. This was approximately normal, but the body length of this œstrogen-treated animal was only three-quarters of that of normal controls. It was correspondingly broader and contained large masses of adipose tissue. The fur was also darker and thicker than in controls (Plate II, Fig. 5). The pouch created by administration of œstrogen was still definitely in evidence, and the scrotal remnant had not increased materially. The cloacal hillock measured about 1 cm. in length and in the cloaca two openings were seen, one leading to the rectum and the other forming the urinary outlet.

Internal Organs.

On opening the abdomen the viscera were found buried in a large deposit of fat. The kidneys were of normal size and weighed 5·3 and 5·0 grm.

A very small fibrous prostate weighing about 0·8 grm. did not show the pigmentation which is always present in the gland of normal males. The Cowper's glands were about one-tenth of the normal size. The " erectores penis and urethræ " were small spherical bodies measuring about 0·1 cm. in diameter. In controls these bodies have a diameter of about 1·0 to 1·5 cm.

No penis could be seen on macroscopic examination, and the structure which had taken the place of the long S-shaped cavernous urethra was a straight short and narrow tube measuring 2 cm. in total length. The distal third had a diameter of about 0·1 cm. and consisted of thin translucent tissue. The proximal two-thirds had thicker walls and measured approximately 0·2 cm. in diameter (Plate II, Fig. 6).

The rectum appeared to be normal. The paracloacal glands were of about the size and appearance found in fully grown females (Bolliger and Whitten, 1948). The oil glands weighed 0·25 grm. and the cell glands 0·16 grm. each.

On microscopic examination of cross sections of the prostate the urethral lumen was found to be branched and narrow. The lining epithelium had undergone metaplasia from a columnar to a stratified squamous type. Tubular vestiges lined by stratified squamous epithelium were comparatively few and most of these contained keratin plugs. The rest of the prostate was mainly composed of fibrous tissue.

The Cowper's glands presented an atrophic picture similar to that seen in the prostate gland.

Serial sections were prepared from the terminal or " cavernous " urethra and three distinct areas (*a*, *b* and *c*) could be recognized.

(*a*) A translucent thin empty tube of about 0·5 cm. in length led into the cloaca. Its wall measured about 0·05 cm. in thickness and consisted of fibrous tissue, muscle and epithelium. It appeared as if this section of the urethra was derived from the original penis pocket or præputium.

(*b*) In the next area the urethral tube contained a body unattached to the wall of the urethra for a distance of about 0·3 cm. The position of this body was comparable with that of the unattached part of the penis. It resembled, however, not a phalanger's undivided penis but had more the characteristics of the female clitoris. A deep narrow groove now divided the former penis structure into two parts (Plate III, Fig. 7). This cleavage is typical of the clitoris of *T. vulpecula* as already pointed out by Van den Broek (1905). The bulk of this clitoris-like structure was composed mainly of a vascular connective tissue containing only small remnants of muscle. The blood vessels had very thin walls and though varying in size, they nowhere assumed the size of cavernous spaces. Epithelial septa protruded into this tissue. The erectile tissue was concentrated on the dorsal periphery forming a distinctive oblong body. This area was much more cellular and contained more muscle and wider cavernous spaces.

In contrast to the undivided and unattached part of the penis this clitoris-like structure was bipartite and possessed neither flagellum nor spicules. It was not endowed with the large amount of muscular tissue typical of the penis of the phalanger and was not pierced by an urethra.

(*c*) Higher up the original penis pocket and the clitoris-like structure began to grow together and a definite urethra was formed. The last third of the cavernous urethra greatly resembled the urogenital canal of the female. The broad submucosa consisted mainly of fibrous tissue and the lumen of the urethra was extensively branched (Plate III, Fig. 8).

The urine is conveyed through this urethra and subsequently through a number of narrow channels situated between clitoris pocket and clitoris into the space beneath the clitoris and ultimately into the cloaca.

Discussion.

In the case of another marsupial, the American opossum (*Didelphys virginiana*), it is already known that by the use of sex hormones it is possible to orient the primordia of the copulatory structures in either the male or the female direction during the first 20 days of pouch existence. Throughout this early period, administration of an androgen to either sex of this marsupial always results in the formation of a precociously differentiated penis. On the other hand, an œstrogen produces a hypertrophic vulva in genetic males or females (Moore, 1941 ; Burns, 1950).

In previous investigations on the effect of sex hormones on the common phalanger or possum (*Trichosurus vulpecula*) it was noticed that the external genitalia of this Australian diprotodont marsupial respond in a manner similar to the American polyprotodont marsupial. In *T. vulpecula*, however, these responses were found to occur even 90 days or later after the birth of the phalanger (Bolliger and Carrodus, 1940).

Furthermore, and in contradistinction to observations of the American workers, the scrotum of the phalanger responded markedly to œstrogen administration by forming a rudimentary pouch (Bolliger and Carrodus, 1939 ; Bolliger and Canny, 1941). Combining œstrogen administration with castration it was possible to convert the scrotum of the phalanger into a typical permanent pouch (Bolliger, 1944 ; Bolliger and Tow, 1947). The experimental demonstration that scrotum and mammary pouch are homologous has been confirmed in the present investigation.

This transformation of an existing organ, not merely of its primordia, presented the question of the response to œstrogens of the male external genitalia of the phalanger in general. In the present and previous experiments, where this subject was not pursued further, a temporary extrusion of the urogenital canal and of the rectum was noted after a few months of œstrogen administration.

Such a reaction could be explained by the intensive growth of periurethral connective tissue and of sinus epithelium ofter œstrogen administration which for example, gives the vulva of the very young opossum *D. virginiana* a remarkably swollen appearance (Burns, 1942). In all probability a similar process also operated in the present experiment, although the animal was much older. The urogenital canal, together with the attached rectum, was thus forced to move caudally, giving the picture of rectal prolapse.

This apparent prolapse lasted for about four months only, after which time a normal cloaca slowly became reestablished and the remnants of the urogenital canal and the rectum were therefore no longer visible in the living animal.

On post-mortem examination, the rectum was similar to that of controls, but the urogenital canal had changed profoundly. The structure which previously was the penis had much diminished in size and was now so small that it could only be examined microscopically.

It must be emphasized that the present experiment was begun when the animal was five months old and when a typical penis of about 3 cm. in length was already present. Sexual maturity is established at the age of one year. At the age of two years there is found within the urethra of the œstrogen-treated phalanger a minute unattached structure which resembles not the free part of the undivided penis, but a bipartite clitoris. The remainder of the original penile urethra also resembles more the urogenital canal of the female than the attached part of the male copulatory organ.

This would suggest that in addition to a severe regression in size a transformation of a male into a female organ had been accomplished. Simultaneously the male scrotum was transformed into a female pouch.

Compared with the penis of the fully grown male, the rudimentary structure found in the œstrogenized animal was probably less than a fiftieth of the normal size, erectile and muscular tissue having atrophied tremendously. The diminution of the amount of erectile tissue was reminiscent of the condition described in the œstrogen-treated 20 days old American opossum, where little erectile tissue remains.

Burrows (1949) pointed out that atrophy of the musculature of the penis of the œstrogen-treated rat is an early and constant reaction. This is also marked in the œstrogen-treated phalangers where, after cessation of the œstrogen treatment, the penis regains its original size and shape. This indicates that in the half-grown phalanger both castration and sex hormone administration are necessary to reestablish that degree of plasticity of the accessory sex organs which exists during embryonic development of higher mammals or which still exists in the American opossum during the first few weeks of life. This restored plasticity not only includes the cloaca (Zuckerman, 1950) but spreads to the scrotomarsupial area, and even the whole skin region in which a sudden well demarcated replacement of the male fur by a female type occurs over the posterior half of the rump.

The resulting transformations of pouch, penis and pelage of the adolescent phalanger are persistent for many months after cessation of œstrogen administration and may therefore be considered permanent.

Compared with controls the ultimate changes produced in the genito-urinary tract were so extensive and the concomitant interference with the lower urinary passages so extreme that survival of the animal must be considered extraordinary.

SUMMARY.

The administration of œstrogen to a practically half-grown castrated male diprotodont marsupial, *Trichosurus vulpecula*, known as the brush tail phalanger or possum, caused a transformation of the scrotum into a permanent pouch, thus confirming previous experiments.

In addition, temporary protrusion of the urogenital canal and the rectum occurred and continued for a period of six months. At this stage the penis had altered its shape and the characteristic unattached part could no longer be distinguished.

Subsequently the rectum regained its normal shape and position but the atrophy of the penis progressed further, and at the age of two years the distal part of the urogenital canal below the Cowper's glands consisted of a narrow urethra containing a small clitoris-like body in its lumen.

These anatomical changes in the distal part of the urogenital canal are interpreted as a transformation of a male organ into its female homologue and are comparable with the conversion of the scrotum into a pouch. Simultaneously the pelage undergoes feminization which is particularly rapid and obvious in the posterior half of the body.

The most remarkable aspect of this transformation process is the fact that these phenomena occurred in the second half of the phalanger's period of adolescence, and, without further œstrogen administration, persisted even when normal sexual maturity would have been established.

Both œstrogen administration and castration are necessary to yield these practically permanent transformations.

ACKNOWLEDGEMENTS.

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Throughout the experiment indispensable assistance was given by Mr. N. T. Hinks.

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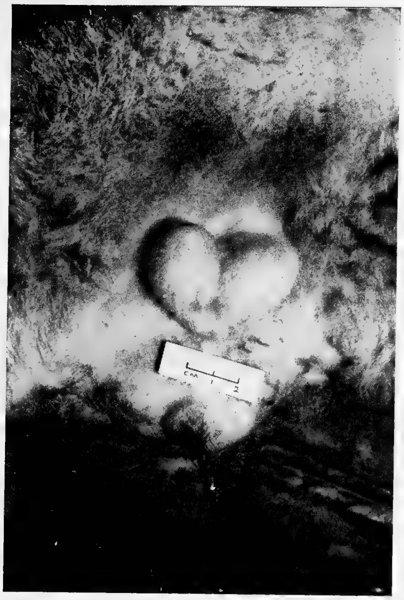
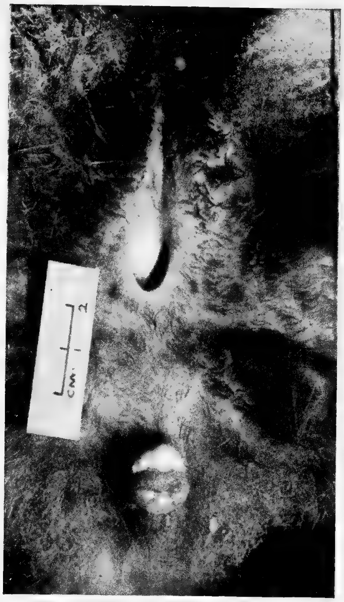


Fig. 1.



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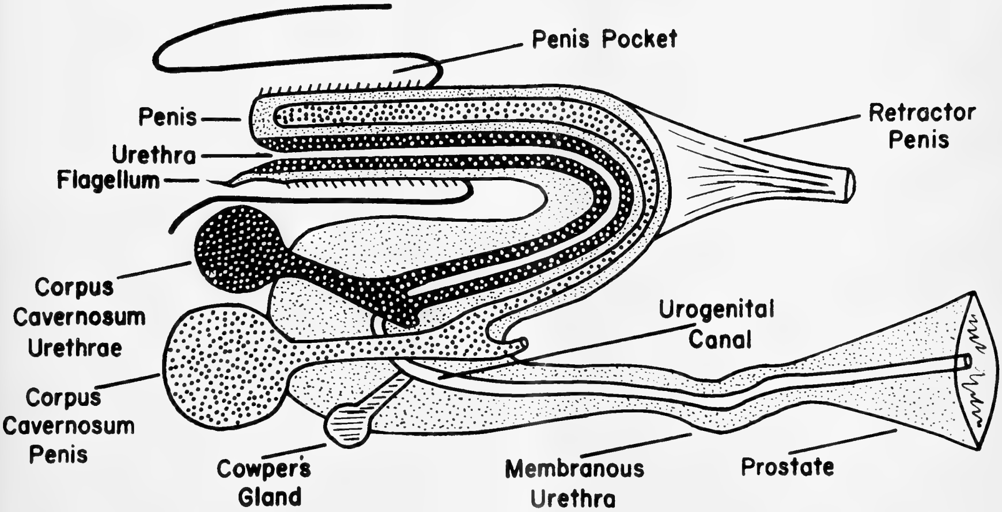

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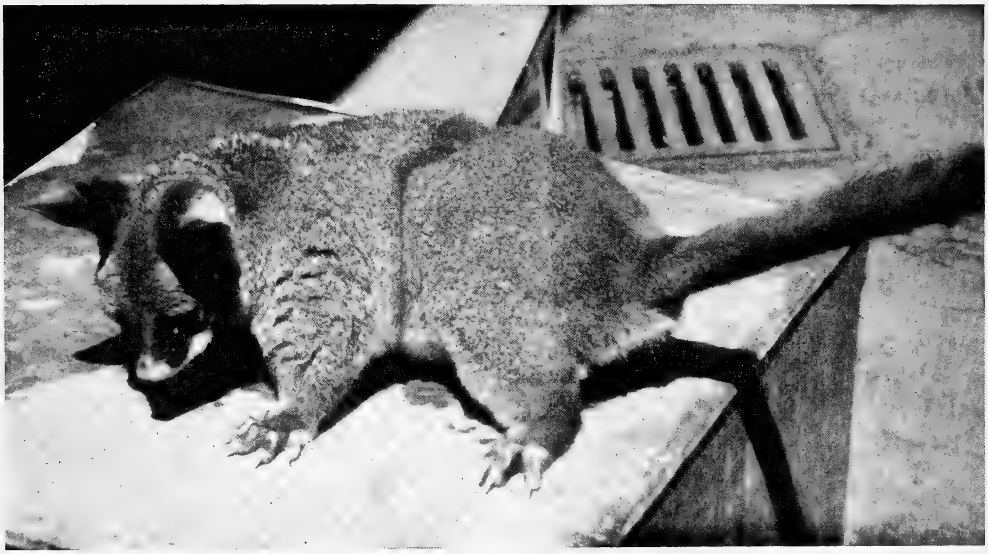

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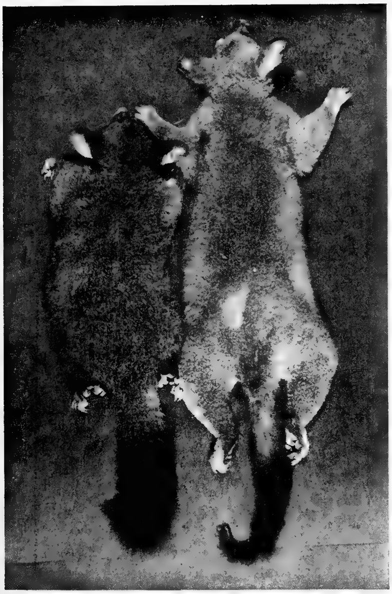

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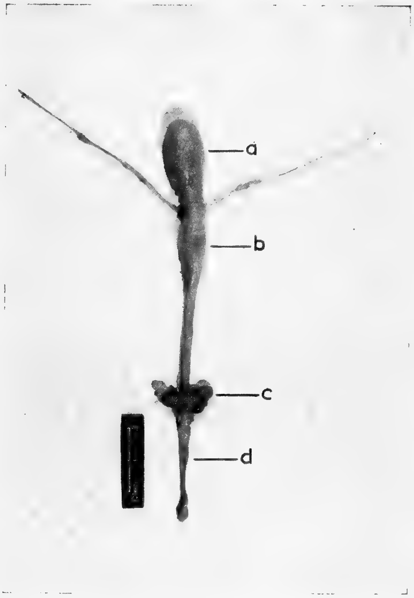

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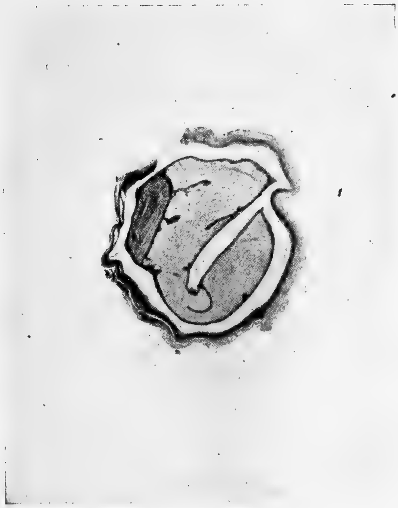

Fig. 7.

Fig. 8.

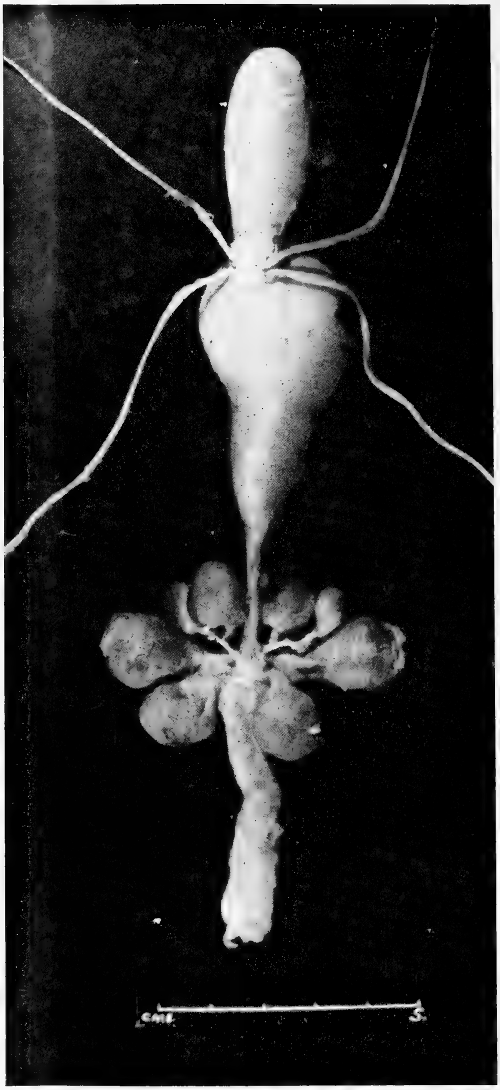

Fig. 9.

Explanation of Plates.

Plate I.

Fig. 1.—Scrotum and cloacal hillock in a normal male.

Fig. 2.—Cloaca and scroto-marsupial area in the castrated male phalanger (*T. vulpecula*) treated with œstrogen for six months. Notice the transformation of the scrotum to a well-developed pouch. Rectum and urogenital canal are protruding from the cloaca and the urethral orifice is visible on the apex of the pyramid-shaped remnant of the free part of the penis which is attached to the rectum.

This condition of rectum and penis as depicted had already persisted for three months.

Fig. 3.—Schematic drawing of the penis of *T. vulpecula*. (Partly after Van den Broek, 1910.)

Notice the spicules on the free part of the penis.

Plate II.

Fig. 4.—The œstrogen-treated phalanger lost the fur from the whole of the posterior half of its body. The new, grey fur which replaced the more brownish shed hairs had the typical dark grey colour of the female. The line of demarcation between old and new fur was very distinct, giving the impression that the rump had been shorn.

Fig. 5.—Compare the short broad body of the œstrogen-treated phalanger with that of a normal male.

Fig. 6.—Atrophic urogenital tract of œstrogen-treated phalanger.
(*a*) Bladder.
(*b*) Prostate.
(*c*) Cowper glands and *erectores penis* and *erectores urethræ*.
(*d*) " Cavernous " urethra.

Compare with normal urogenital tract (Fig. 9). See also Carrodus and Bolliger (1939).

Plate III.

Fig. 7.—Cross-section through clitoris-like body and wall of urethra. Note the deep cleavage in the clitoris-like body. (×20.)

Fig. 8.—Cross-section of " cavernous " urethra near Cowper's glands. Note the branched urethral canal and the broad submucosa. (×20.)

Fig. 9.—Posterior aspect of normal urogenital tract of fully grown phalanger. Note the large prostate, *erectores penis* and *urethræ*, and Cowper's glands. The dissected penis is still somewhat bent and the naturally straight flagellum is hooked. The *vasa deferentia* enter the prostatic urethra in close proximity to the bladder neck and ureters.

WARIALDA ARTESIAN INTAKE BEDS.

By J. Rade.*

With one Text-figure.

Manuscript received, March 18, 1954. Read, June 2, 1954.

Introduction.

The area treated in the present paper comprises about 3,200 square miles of country in the northern part of New South Wales, stretching from Delungra and Warialda in the south to Boggabilla and the Queensland border in the north. The main part of the area is located in Burnett County, but portions of the adjacent counties of Stapylton, Courallie, Murchison and Arrawatta are included. The main purpose of the work is a consideration of the effectiveness of the Warialda intake beds.

Full use has been made of the bore data collected by the Water Conservation and Irrigation Commission, Sydney. The geological investigations of the area concerned were carried out by the writer, following the main creeks on foot and traversing the country in different directions by car.

Topography.

The highest country in the map area is to the east of Delungra, where an elevation of approximately 2,000 feet above sea level is recorded. Much lower country occurs to the north-west, elevations of approximately 700 feet above sea level being recorded in the extreme north-west, and elevations of 900 feet being known from the western map border.

The northern part of the area, near the Queensland border, is drained by the Macintyre and Dumaresq Rivers. West of the Macintyre River, several creeks flow in a north-westerly direction, the largest of them being Ottley's Creek, Yallaroi Creek and Croppa or Cox's Creek. The southern part of the area is drained by westerly trending streams, including Gwydir River, Mosquito Creek and Warialda Creek.

Geology.

The following is a brief outline of the rock types encountered in the map area.

Devonian. Rocks of Devonian age outcrop on the banks of Warialda Creek, south-west of the township of Warialda. They belong to the Upper Devonian Barraba " Series ", and consist of mudstones with intercalations of tuff. David (1950, p. 252) has stated that the Barraba " Series " dip beneath the Jurassic sediments in the Warialda area, but reappear to the north-east of Ashford.

Carboniferous. Rocks of Carboniferous age are exposed along the banks of Warialda Creek east of the point where this creek joins the Gwydir River, and also in the railway and road cuttings at Yagobie and Gravesend. They consist mainly of tuffs and lavas, with shale and slate intercalations.

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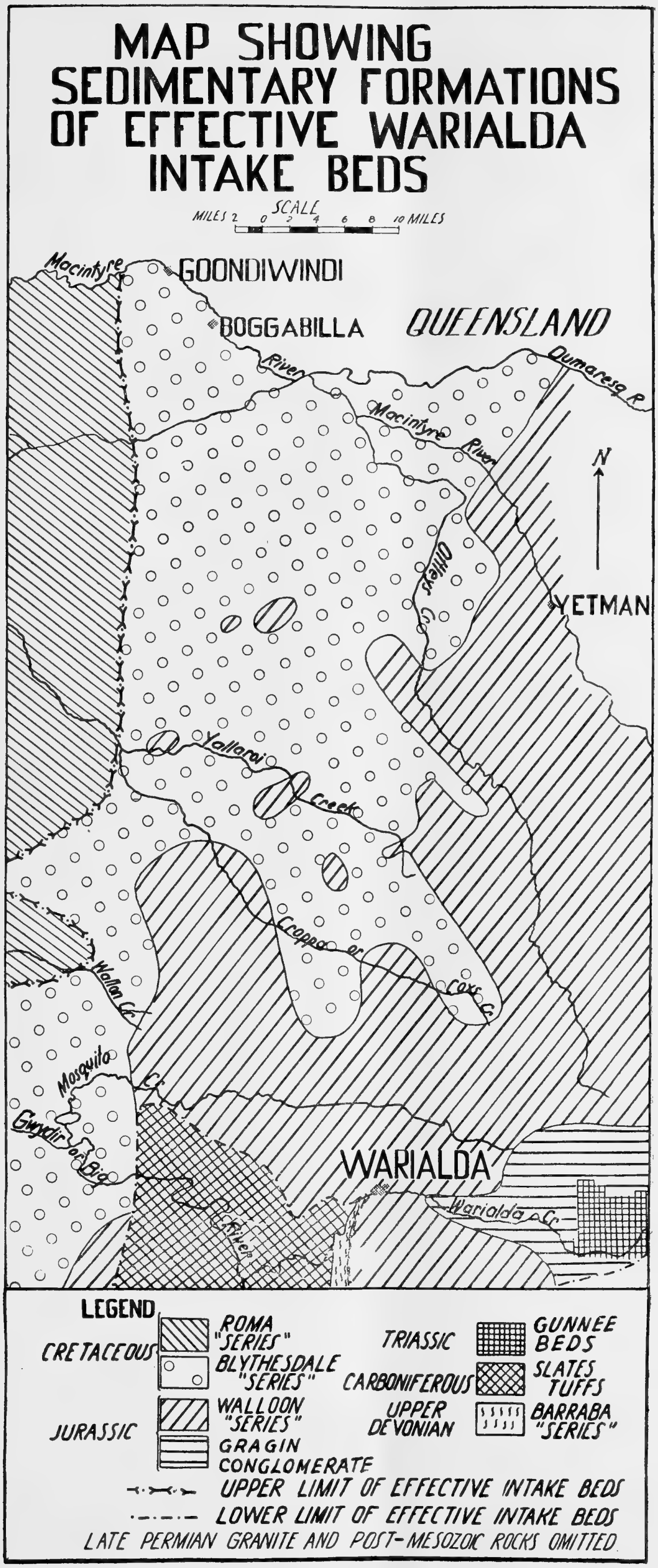
MAP SHOWING SEDIMENTARY FORMATIONS OF EFFECTIVE WARIALDA INTAKE BEDS
SCALE
MILES 2 0 2 4 6 8 10 MILES
Macintyre
GOONDIWINDI
BOGGABILLA
QUEENSLAND
River
Dumaresq R.
Macintyre River
N
Ottleys Cr.
YETMAN
Yallaroi Creek
Croppa or Coxs Cr.
Wallan Cr.
Mosquito Cr.
Gwydir or Big River
WARIALDA
Warialda Cr.
LEGEND
CRETACEOUS
ROMA "SERIES"
BLYTHESDALE "SERIES"
JURASSIC
WALLOON "SERIES"
GRAGIN CONGLOMERATE
TRIASSIC
GUNNEE BEDS
CARBONIFEROUS
SLATES TUFFS
UPPER DEVONIAN
BARRABA "SERIES"
UPPER LIMIT OF EFFECTIVE INTAKE BEDS
LOWER LIMIT OF EFFECTIVE INTAKE BEDS
LATE PERMIAN GRANITE AND POST-MESOZOIC ROCKS OMITTED

Permian. The western portion of the late Permian New England batholith occupies the eastern part of the map area, but is largely covered by Tertiary basalt. Granites outcrop in the banks of Warialda Creek. They are also encountered in several bores drilled into the cores of the north-west trending Palæozoic ridges which will be shown to underly the Mesozoic strata. These granites are best known from bores west of Warialda, and in the vicinity of Gragin Peak, 10 miles east-north-east of the township of Warialda. Spectacular gorges have been formed in the late Permian granites which outcrop along the banks of Warialda Creek, as for example at the Dog Trap, located 4·5 miles east of the township of Warialda. Xenoliths of grey sandstone with contact metamorphosed outer rims are found in the granite which outcrops in Warialda Creek, east of Warialda township. It seems probable that these sandstones represent remains of Palæozoic (probably Carboniferous) sediments which were intruded by the granite, but have since been completely removed by erosion.

Triassic. Much of the area in the northern part of New South Wales and the adjacent portion of Queensland is occupied by the New England granodiorite batholith, and it is clear that this intrusion forms a divide between the Clarence Basin in the east and the area of sedimentation around Moree in the west. The present author has recently recognized a characteristic group of sediments to the west of this divide, in the Delungra area and to the east of Warialda. To them the name " Gunnee Beds " is hereby assigned. They consist of grey gritty sandstone, with shale and carbonaceous shale intercalations. Well-preserved plant fragments were found in a carbonaceous shale which outcrops in the bank of Warialda Creek, north-west of Delungra, Portion 42, Parish of Gunnee, County of Burnett. The following species have been determined by Dr. A. B. Walkom :

Thinnfeldia odontopteroides (Morris).
Thinnfeldia lancifolia (Morris).
Thinnfeldia feistmanteli (Johnston).
Johnstonia coriacia (Johnston).
Stenopteris elongata (Carruthers).

All material is stored in the Australian Museum, Sydney. It is clear that the assemblage is typical of the Ipswich " Series ".

The outcrops of the Gunnee Beds found to the north-west of Delungra occur between outcrops of granite belonging to the New England granodiorite batholith, and it is thus clear that the granites underly the sediments. There is also evidence to suggest that the sediments have been partly infaulted into the granite. The thickness of the Gunnee Beds in this area is not evident, but it is clear that it is greater than 100 feet.

Jurassic. The Gunnee Beds are overlain by a formation, hereby referred to as the Gragin Conglomerate, and correlated with the Bundamba " Series ", of Queensland. It is represented by approximately 200 feet of conglomerates, and outcrops in the banks of Warialda Creek between Delungra and Warialda. Occasional thin sandstone beds are encountered. Most of them are only 1–2 feet in thickness, but a 7-feet thick sandstone bed is found near the top of the conglomerate where it outcrops in Warialda Creek, 3·5 miles east of the township of Warialda. This same area represents the most westerly outcrop of the formation known to the author. The Gragin Conglomerate is also known from several bores to the south of Gragin Peak, but apart from the outcrops in Warialda Creek, no others are known to the west of the New England granodiorite batholith.

Lloyd (1941, p. 96) has, however, recorded the Bundamba " Series " from the Nymboida area to the east of the New England batholith. Here it is represented by 250 feet of conglomerates, overlying sediments which, it is suggested, probably belong to the Ipswich " Series ". It is interesting to note that there is no great discrepancy between the thicknesses of the Bundamba sediments in these two basins.

The equivalents of the Purlawaugh beds of the Walloon " Series " outcrop in the Warialda intake area, and are hereby named the Delungra Shale. They consist mainly of shales, but contain intercalations of sandstone and some coal seams. The Purlawaugh beds of the Coonabarabran-Narrabri intake area, described by Mulholland (1950), bear a close resemblance to these sediments. Outcrops of the Delungra Shale in the Warialda intake area are not numerous, since the formation in question is generally obscured by the overlying Warialda Sandstone. It is, however, encountered in several bores around the margins of the effective intake beds, and are met with in the structural ridges formed by the Palæozoic basement complex. More detailed information of the sections encountered in these bores will be presented in the hydrological portion of the present paper. The greatest thickness of the Delungra Shale is approximately 300 feet. In comparison, Mulholland (1950, p. 125) estimated that the greatest thickness of the corresponding Purlawaugh beds in the Coonamble artesian basin near Coonabarabran is in the vicinity of 200 feet.

The sediments corresponding to the Pilliga Sandstone outcrop more extensively in the Warialda intake area than any of the other Jurassic rock units. They consist of massive, coarse, porous sandstones and grits, are frequently ferruginous, and contain ferruginous concretions surrounding fragments of wood. Conglomeratic intercalations are rare, and occasional beds of clayey sandstone and sandy shale are found. Current bedding is frequently encountered. These sediments are hereby named the Warialda Sandstone.

The Warialda Sandstone outcrops most extensively to the north of Warialda, but is also found in bores to the south-east of Moree. It was in this latter area that David (1950, p. 459) recorded outliers of current bedded sandstone, and quartz conglomerate with thin layers of ironstone, resting with unconformity on the Lower Carboniferous strata.

The Warialda Sandstone has been proved to be 400 feet in thickness in bores to the north of Warialda. Mulholland (1950, p. 126) has stated that the corresponding Pilliga Sandstone in the intake area of the Coonamble artesian basin has a thickness of 600 feet.

Cretaceous. The Jurassic Warialda Sandstone disappears to the north-west and west beneath sediments consisting of shales and sandy shales, with sandstone intercalations and small coal seams. It is clear that the latter are transitional beds between the Warialda Sandstone and the Cretaceous Roma " Series ". The lithology of the Warialda Sandstone indicates that it was deposited in a lake, whereas Crespin (1944, 1945, 1953) has shown the marine affinities of the Foraminifera found in the Roma " Series ". Foraminifera are unknown from the transitional beds. David (1950, p. 484) has suggested that the inliers found in the far north-west of New South Wales may be correlated with the Lower Cretaceous Blythesdale " Series ". Whitehouse (1945) has shown that the Blythesdale " Series " occurs almost as far south as the New South Wales border, and this proximity strengthens the present author's correlation of the transition beds mentioned above with this Lower Cretaceous formation.

The Blythesdale " Series " is considered to be of lacustrine origin. It forms an effective intake bed, since it has been proved to contain artesian horizons further to the west. To the west and north-west, the Blythesdale " Series " is overlain by the Lower Cretaceous Roma " Series " and the Upper Cretaceous Winton " Series ". The former consists largely of blue shales with occasional sandstone intercalation, whereas the latter is more sandy in character, and contains coal seams. The lithology of the Winton " Series " clearly indicates the lacustrine origin of the sediments, and demonstrates a return to lacustrine conditions after the transgressions which were responsible for the marine Roma " Series ".

Cainozoic. Tertiary basalts are widespread, and largely obscure the older sediments. The thickness of the basalt is variable, but bores north of Delungra in the Gragin Peak area, north of Wallangra, north-east of Warialda and in the middle of the Warialda intake beds, have proved it to be greater than 200 feet. In the Warialda intake area, it is evident that the eruptions of the basalt were of the fissure type. As will be shown later in this paper, the fissuring is closely connected with the uplift of the New England block in Tertiary times.

Great thicknesses of alluvium, largely derived from the disintegration of the Jurassic and Cretaceous sediments, are of widespread occurrence. The western and north-western portions of the area under consideration are almost completely covered by these deposits, so that outcrops of the older rocks are rarely seen.

STRUCTURAL GEOLOGY.

In the area occupied by the Warialda intake beds, the Mesozoic strata have a regional dip of a few degrees to the north-west. The trend in the underlying Palæozoic basement is N. 20° W., and is thus the same as that for the Devonian rocks encountered in the classic sections of the Tamworth district.

A north-easterly trend may also be discerned in the north-western portion of the map area, both in the surface outcrops and from the bore data. Numerous geological sections through the Warialda Intake Beds have been constructed for hydrological purposes by the present author. These sections clearly show the presence of the north-west trending sub-surface ridges, and demonstrate that the latter are transected at their north-western extremities by the less well marked north-eastern trends. The result of these two trends is the formation of shallow domes and basins in the north-western part of the map area. The Warialda Sandstone is found close to the surface in the domes, but lies deeply buried beneath the Lower Cretaceous in the basin structures.

According to David (1950, p. 266), all of the Upper Devonian sediments of eastern Australia were folded at the end of the Lower Carboniferous. It can thus be assumed that the north-westerly trending ridges are a product of this Lower Carboniferous period of orogenic activity. Bryan (1925, p. 21) has stated that the north-easterly trend direction may be regarded as older than the north-westerly trend.

After the intrusion of the late Permian New England granodiorite batholith, its western margins were subjected to faulting. Evidence of the faulting may be seen in the area between Delungra and Gragin Peak, where a tongue of the Lower Cretaceous Blythesdale " Series " is infaulted into the granite. The bore data of this area further indicates that the granite escarpments formed by the faulting existed as bold ridges in the lower Mesozoic, and that it was not until the time of deposition of the Warialda Sandstone that the escarpments were partially covered by sediment. It is also suggested that further faulting, and rejuvenation of the faults and consequent uplift was responsible for the coarse Gragin Conglomerate of the Jurassic Bundamba " Series ", while the uniform grain size of the Warialda Sandstone indicates gentle but uniform uplift during the time of deposition of these sediments. Intense uplift of the New England Block occurred in Tertiary times, partially due to the initiation of new fault lines. Tertiary lavas reached the surface along these fracture lines, as shown in the sections between Delungra and Gragin Peak. Hill (1930) has found similar faulting of the intake beds of the Great Artesian Basin of eastern Queensland, and has shown that in some places the Esk " Series " has been infaulted into the underlying Brisbane Schists.

GROUNDWATER HYDROLOGY

Palæozoic Formations.

The water-bearing properties of the Palæozoic formations of the Warialda area are limited. They serve as run-off regions, and do not constitute an important element of the effective intake beds.

Devonian.

Little information regarding the mudstones of the Barraba " Series " is available.

Carboniferous.

Carboniferous rocks occupy the south-western portion of the map area. The comparatively shallow bores (100 feet average) into these rocks generally yield brackish water, but several bores ranging in depth from 150 to 300 feet have failed to yield water.

Late Permian Granite.

Most bores drilled into the late Permian granite fail to produce water. Occasional exceptions do, however, occur where the bores are sunk into alluvium-filled depressions in the granite, or in the beds of creeks. Some of the bores in the valley of Warialda Creek produce water from the joint and fracture systems in the granite. The ridges and cupolas of the late Permian granite possess an interesting character from the hydrological point of view. In no case have these structures produced water, since both they and the sediments which overlie them are denser in structure than the surrounding rocks, and thus act as run-off areas. Typical examples of these structures are found in the vicinity of Gragin Peak, located 10 miles east-north-east of Warialda, and in the area situated 15 miles east-south-east of Warialda. Here the granites are covered by Jurassic sediments and Tertiary basalts. Commonly the percolating water travels through the gently north-westerly dipping Jurassic sandstones, and thus does not reach the cupolas and ridges of the granites. In the past, an intensive boring campaign has been conducted in this area, but most of the bores have proved to be failures.

Granite was struck at a depth of 458 feet on one of the north-westerly trending structural ridges situated 5 miles west-north-west of the town of Warialda, and this bore proved to be unproductive. Another failure bore was drilled in the vicinity of Gragin Peak, 8 miles east-north-east of Warialda. Here granite was encountered at a depth of 504 feet. It was overlain by a thickness of 320 feet of Delungra Shale, this in turn being overlain by 160 feet of Warialda Sandstone. Sixteen gallons per hour were encountered, however, in the Delungra Shale at a depth of 290 feet. The Warialda Sandstone was unproductive, since the strata were deposited on the basement ridge, and their regional dip to the north-west means that favourable conditions for the accumulation of sub-surface water could not occur.

Gunnee Beds.

Several bores to the north of Delungra may have penetrated the Gunnee Beds, but bore logs are incomplete and contain little useful information regarding these rocks.

Gragin Conglomerate.

Bores drilled into the Gragin Conglomerate commonly prove to be non-productive. Excellent examples are the bores located west and north-west of Delungra, and in the vicinity of Gragin Peak. A bore situated nine miles east-north-east of the town of Warialda, in the vicinity of Gragin Peak, was drilled to a depth of 510 feet without providing water. Here the Gragin Conglomerate has a thickness of 199 feet and is overlain by blue and brown shales, sandy shales, clay, and a thin bed of sandstone. The latter sediments represent the Delungra Shale. Small flows of water were encountered at a depth of 214 feet. A partial analysis of the water disclosed the presence of 25·2 grains per gallon of total solids, 12·2 grains per gallon of sodium chloride, and a pH. of 7·6.

It is tentatively suggested that the Delungra Shale overlies the Gragin Conglomerate to the west of the Macintyre River, north of Wallangra. In a 350 feet deep bore, located 14·5 miles north-west of Wallangra, the thickness of the Delungra Shale which overlies the Gragin Conglomerate is 220 feet, the deposits consisting of carbonaceous shales. In a failure bore, 467 feet deep, located 5·5 miles west of Wallangra, the Delungra Shale is represented by 267 feet of grey shale and underlies 200 feet of Warialda Sandstone.

Warialda Sandstone.

The Warialda sandstone forms the main effective intake beds of the Warialda area, and contains several aquifers. The permeable beds are generally seen to be sealed by thin shale intercalations. Shales are, however, not always encountered, and the present author agrees with Mulholland (1950, p. 126) in his conclusions for the Pilliga beds of the Coonamble artesian basin, in that the permeable beds may be sealed by harder sandstone beds which are relatively impermeable.

The Warialda Sandstone and the aquifers it contains have a regional dip to the north-west. Apart from this slight regional dip, the aquifers of the Warialda Sandstone exactly reflect the regional configuration of the underlying basement, and are transected by the N. 20° W. trending ridges of that basement. Thus as a result of the regional dip of the strata and the configuration of the basement complex, the water in the aquifers flows towards the border of Queensland. The flow trend in this direction is reinforced by the sub-surface barrier west of Warialda, the latter having been formed by the north-westerly trending Devonian and Carboniferous ridges. Thus only a small percentage of the water finds its way into the Moree District. Most of the water which does reach the Moree District is derived from the Lower Cretaceous Blythesdale " Series ", and is comparatively high in its content of total solids.

Very few of the bores drilled into the Warialda Sandstone prove to be failures. Some bores are, however, not of sufficient depth to reach the aquifers of the Warialda Sandstone, and other non-productive bores can be seen to lie above the Palæozoic basement ridges, where the cover of Warialda Sandstone is thin. In the latter case the bores penetrate the Delungra Shale and the late Permian granite. The depth to which bores must be sunk is dependent on the structure of the underlying basement surface, and is thus variable.

Two prominent ridges of the basement complex are encountered in the southern portion of the Warialda Intake Beds, where most of the bores penetrate the Warialda Sandstone. The axis of the first ridge is located approximately 5 miles west of the township of Warialda. Here granite is encountered at a depth of 458 feet in a bore of total depth 468 feet. Many of the bores located along the same ridge, in the area between Warialda Creek in the south-east and Mosquito Creek in the north-west, have proved unproductive. They often penetrate 95 to 180 feet of Warialda Sandstone and then encounter the Delungra Shale. The most north-westerly non-productive bore drilled along this ridge is located 16 miles north-west of the town of Warialda. It has a total depth of 220 feet, and ended in Delungra Shale. To the north-west of this point, most of the bores encountered Warialda Sandstone and produced water from between 150 feet and 355 feet beneath surface.

Similar hydrological conditions are found along the second sub-surface basement ridge. It occurs to the north-east of the township of Warialda, where many bores ranging in depth from 300 to 520 feet have proved unproductive. Further to the north-west the aquifers in the Warialda Sandstone were encountered at depths of from 200 to 577 feet. Yields of up to 800 gallons per hour have been recorded, and few failure bores are known.

In the structural valleys of the Warialda Intake Beds (which reflect the configuration of the basement) an aquifer is encountered in the Warialda Sandstone. It is found at depths of from 300 to 400 feet, and yields 400 or more gallons of water per hour.

As a result of the regional north-westerly dip of the Warialda Sandstone and the regional structure of the basement complex, the yield of the aquifers increases considerably in the north-westerly direction. The water yielded by the aquifers of the Warialda Sandstone is fairly pure and contains little saline material.

Cretaceous.

The sandstone intercalations encountered in the Lower Cretaceous Blythesdale " Series " constitute the upper horizons of the effective aquifers. In the north-west part of the area under consideration, several aquifers are found in sandstone intercalations between the sandy shales of the Blythesdale " Series ". As with the lower aquifers, the regional dip of the upper aquifers is to the north-west. Yields average from 300 to 500 gallons per hour, but the water is generally brackish. Saline water is also encountered at more shallow depths. One such aquifer is encountered at a depth of 150 feet, the yield averaging from 100 to 150 gallons per hour.

The structural valleys, the upper portions of which are filled by the Lower Cretaceous Blythesdale " Series ", are important from the hydrological point of view. As pointed out earlier in the present paper, the Blythesdale " Series " has formed in embayments underlain by the Warialda Sandstone. Thus where the Blythesdale " Series " is present, the bores must be deeper so as to drill through the unsatisfactory water horizons in these rocks and penetrate the excellent water horizons of the Warialda Sandstone.

Tertiary Volcanics.

The hydrological conditions which prevail in the Tertiary volcanics have an important economic bearing, since great areas of the Warialda Intake Beds are covered by these Tertiary basalts. Boring has proved that the basalts contain zones of cavities which are capable of storing water. It has become apparent that, in basalt areas, any available ground water is generally located at shallow depths, and the hydrology is dependent on local conditions, of which the topography plays an important role. An example can be found in the country between Inverell and Delungra, where the slight westerly dip of the land surface has an important bearing on the hydrology of the area. The basalt flows have followed the land surface, and thus the zones which contain abundant cavities also dip gently to the west.

Many of the bores drilled into the basalts of the Warialda area have yielded no water. This is because the bores have not penetrated, either one of the cavity zones, or a fracture zone in the more solid basalt flows. Blasting to gain access to the cavity zones or to widen existing fractures in the basalt has been undertaken with considerable success.

Several good aquifers have been encountered in the basaltic rocks of the Warialda intake area. Up to three aquifers have been encountered in a bore with a depth of 250 feet, the yields increasing with depth to 400 gallons per hour for the bottom aquifer. The uppermost aquifer is commonly encountered at a depth of from 80 to 90 feet, the average yield being 160 gallons per hour. However, if the surface of the basalt is weathered and fractured and is covered by a thin layer of alluvial deposit, then the yield from this upper horizon frequently reaches as high as 700 gallons per hour. From the accumulated bore data it may be stated that the maximum depth from which good water supplies can be expected in the basalt does not exceed 300 feet.

Pleistocene and Recent.

Water occurs at shallow depths in the alluvial deposits, which have originated largely from disintegration of the Jurassic sediments. From the point of view of the possibilities for irrigation from these bores which penetrate the alluvium, it seems that the alluvium from the Warialda Sandstone is too fine grained to give up the considerable yields which are necessary for irrigation purposes. Another feature worthy of consideration in this respect is that the creeks which cut into the Warialda Sandstone are generally youthful and thus contain little alluvium. The river flats formed of alluvium derived from this formation are also generally shallow. Similar features have been noticed by the author in the Coonabarabran area, which is the intake area for Coonamble artesian basin. In this area it is the Castlereagh River which traverses the Pilliga Sandstone. Complete similarity in regard to these features thus exist between the Coonamble basin and the Warialda intake beds.

ACKNOWLEDGEMENTS.

The writer is indebted to Dr. A. B. Walkom, Director of the Australian Museum, for the determinations of the fossil plants. Thanks are also due to the Water Conservation and Irrigation Commission, Sydney, for permission to publish this paper.

SUMMARY.

The paper deals with the Warialda intake beds, which outcrop over an area of 3,200 square miles in the northern portion of New South Wales between Delungra, Warialda, Boggabilla and the Queensland border. Sediments of Devonian, Carboniferous, Triassic and Cretaceous age, as well as the late Permian granite and Tertiary volcanics, are described. Consideration is also given to Tertiary and Recent alluvium. The writer records the presence of the Triassic Ipswich " Series " (Gunnee Beds) with its characteristic flora. This is the first time the Ipswich " Series " has been recorded to the west of the late Permian New England granodiorite batholith.

The Mesozoic sediments are shown to have a gentle regional dip towards the north-west, and to be deposited over the north-westerly trending ridges of the Palæozoic basement complex. It is considered that this basement configuration is the result of the Carboniferous orogenic period. The configuration of the basement and the regional dip to the north-west of the Mesozoic sediments is responsible for the movement of the ground water towards the Queensland border. Special hydrological treatment is given to each formation of the Warialda intake beds.

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THE T–PHASE FROM THE NEW ZEALAND REGION.

By T. N. Burke-Gaffney, S.J.

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On January 12 and 13, 1954, three earthquake shocks occurred at a point south of New Zealand. On the seismograms of these from the Sprengnether Vertical Short Period instrument at Riverview there were found waves of very short period and of small amplitude, some seventeen minutes after the P. These are evidently examples of the T-phase, which are of interest inasmuch as this phase does not appear to have been reported previously from the New Zealand region. A careful examination of the other seismograms showed that they were not discernible on the Galitzins, but were quite distinct on the Wiechert, though, since they are superimposed on large surface waves, they could very easily have been overlooked. This circumstance made it worth while to examine earlier records from the same region to see if perhaps the T-phase had been recorded previously and had escaped notice.

Examination showed that, in fact, the phase was to be found on 21 other seismograms, but had not entirely escaped notice, for on five occasions it had been reported as a " small local shock, superimposed on coda of previous shock ". This interpretation is not surprising, since the appearance of the waves is quite similar to those produced by very small local tremors. More surprising, however, is the fact that two of these shocks occurred within six hours one of the other and no one appeared to have noticed the coincidence of each having a " local shock " superimposed and at the same interval after P in each case.

It may be well to recapitulate the history of this phase. It would seem to have been noted first in the Harvard Bulletin 5, on the shock of September 15, 1935, but was first referred to as the T-phase in a discussion of the Earthquakes of the West Indies, by Fr. D. Linehan, of Weston College Observatory. T stands for " third phase ", the P and S phases being the first and second, for it would seem that on the seismograms under discussion the amplitudes were comparable to that of P, thus giving the appearance of being the beginning of another, but smaller shock. On Riverview seismograms, there is no comparison between the amplitudes, those of T rarely being great enough to measure. Fr. Linehan reported the occurrence of the phase, but offered no explanation of it. The period of the waves is of the order of 0·5 sec., so that they stand out readily on the long surface waves which arrive at about the same time. Tolstoy and Ewing discussed the phase at length in a paper published in 1950 and there put forward the theory that the waves are compression waves travelling through the ocean with the velocity of sound in water along the SOFAR sound channel—that is, at a depth of approximately 700 fathoms, where the velocity of sound is least. Subsequently Leet, Linehan and Berger contested this conclusion and offered evidence tending to show that the velocity of T is far from constant and has an average value of 1·70 km./sec., whereas the velocity required on the Tolstoy-Ewing theory is about 1·46 km./sec. Ewing, Press and Worzel replied to this with another detailed paper, in which the conclusion is reached that the velocity of T is 1·46 km./sec. ±0·01.

In view of this controversy, it seems worth while to see what conclusion can be drawn from Riverview seismograms. In Table I are listed the shocks, with date, time at origin, epicentre, distance from Riverview, magnitude, arrival time of T, travel time of T, these last two being divided into the times for the first observed T wave and those for the maxima, distinguished by the subscripts i and m respectively. With these shocks is included another which occurred since the investigation was begun. The epicentres and times at origin are taken from Gutenberg and Richter: "Seismicity of the Earth" (Princeton, 1949), or from the epicentre cards of the United States Coast and Geodetic Survey, except in two or three cases in which neither of these gave an epicentre, when that given by Wellington is used.

Table I.

No.	Date.	Epicentre.	Origin.	Δ	Mag.	T_i.	T_m.	T_i–0.	T_m–0.
			h. m. s.	km.		m. s.	m. s.	sec.	sec.
1	1932, Aug. 13	51 S. 164 E.	20 56 01	2165	6·5	18 18	19 00	1339	1381
2*	1936, Feb. 22	49·5 164	15 31 54	2035	7·2	52 46	54 11	1252	1337
3	1936, Feb. 22	49·5 164	19 22 43	2035			45 19		1356
4	1936, Feb. 22	49·5 164	19 30 06	2035			52 47		1361
5*	1938, Dec. 16	45 167	17 21 25	1910	7	41 35	42 25	1209	1300
6*	1938, Dec. 16	45 167	23 14 54	1910	6	35 06	35 34	1152	1240
7	1939, April 20	46·5 167·5	22 06 35	2035	6	26 47	27 37	1212	1262
8	1943, Aug. 2	45 167	00 46 35	1910	6·75	07 07	07 35	1232	1260
9	1943, Sept. 6	55 159	03 41 30	2445	7·8	06 48	07 22	1518	1552
10	1945, Sept. 1	46·5 165·5	22 44 10	1865	7·2	05 03	05 23	1253	1273
11	1945, Sept. 4	46·3 165·8	17 14 04	1865	5·75	34 34	35 17	1230	1273
12*	1947, Oct. 13	44·2 169·0	07 31 17	1945	6·8	50 47	52 10	1170	1253
13	1948, June 19	43·2 169·1	06 18 36	1880	6·4		40 05		1289
14	1948, June 19	43·2 169·1	07 05 36	1880	6·5	26 23	27 19	1247	1303
15*	1949, May 27	45·3 167·0	08 54 11	1865	6·25		15 02		1251
16	1949, July 2	52 162	11 27 35	2210	6·5		50 20		1365
17	1950, Feb. 5	50 164	01 23 30	2090	6·8	45 51	45 57	1341	1347
18	1950, Feb. 6	48 164	22 53 27	1910	5·75		17 14		1427
19	1950, Aug. 5	50 164	09 16 48	2090	7·3		39 50		1382
20	1950, Oct. 10	46 167	18 42 10	1910	6·2		03 06		1256
21	1951, July 7	44·8 168·2	10 15 23	1900	6		36 11		1290
22	1954, Jan. 12	49 165	14 16 22	2035	6·75	37 52	38 42	1290	1340
23	1954, Jan. 12	49 165	14 20 26	2035	6·75	42 00	42 58	1284	1342
24	1954, Jan. 13	49 165	00 13 06	2035	7·25	33 46	35 22	1240	1336
25	1954, Mar. 23		18 36 28	2035		57 32	58 20	1264	1312

* Reported in Bulletin as small local shock.

Let us assume, first, that the T-phase is water-borne. This requires the further assumption that the phase is not generated at the hypocentre, but is given birth at, or near, the 700-fathom line, otherwise one should expect to find it associated only with shocks which occur near the continental shelf. A consideration of the listed epicentres shows, however, that some of these are quite distant from the shelf, or, rather, from the edge of the ridge upon which New Zealand stands. This being so, it becomes necessary to make a correction to find the true distance travelled as the T-phase and the true travel time. The epicentral distance must be decreased by a quantity equal to the distance from the epicentre to the point at which the T-phase can be generated, at or near the 700-fathom line; the time must be decreased by the time taken for normal P waves to travel this distance. This distance is not easily determined with accuracy. Apart from the fact that there may be an uncertainty in the epicentre, it is not easy to judge where the 700-fathom line runs; the only charts available give the 600-ft. and 6,000-ft. contours, in one case, and 2,000 metres and 4,000 metres in another. At the receiving end, so to speak, a similar correction must be made; it is more easily determinable that the off-shore distance of the

700-fathom line is about 80 km. Less easily settled is the question of the velocity along this land path. For present purposes the quite arbitrary assumption is made that the velocity is that of P waves near the surface, i.e., 14 seconds are required to traverse the latter part of the path. In every case, therefore, the distance must be decreased by 80 km. and the time by 14 sec., while for some shocks greater distances and times must be subtracted from the beginning. The corrections to be made are set out in Table II (A) and the corrected times and distances in Table III. In this latter table the resultant velocities are shown under the section A.

TABLE II.

Corrections to be Applied to Distances and Times in Table I.

No.	Dist.	Time.		No.	Dist.	Time.	
		A.	B.			A.	B.
	km.	sec.	sec.		km.	sec.	sec.
1	—80	—14	—39	14	—200	—29	—95
2	80	14	39	15	120	19	59
3	80	14	39	16	80	14	39
4	80	14	39	17	80	14	39
5	120	19	59	18	80	14	39
6	120	19	59	19	80	14	39
7	120	19	59	20	180	26	85
8	120	19	59	21	180	26	85
9	80	14	39	22	80	14	39
10	80	14	39	23	80	14	39
11	80	14	39	24	80	14	39
12	200	29	95	25	80	14	39
13	200	29	95				

The velocities shown are those for the first observable wave of the series (V_i) and for the maxima (V_m). As is evident, there is a greater uncertainty about the former, since the waves begin very gradually and the beginning may easily be missed, while the maxima stand out clearly and in some cases these only are identifiable. Nevertheless, the standard errors of the means scarcely differ, being 0·014 and 0·013 respectively. The average velocity for V_i is well above that for the minimum for sound in water, and would be yet higher if the excessively low values of Nos. 13, 14, 18 and 21 were omitted.*

It is probable that the velocities in the last four shocks are the most reliable, for these have been taken from the Sprengnether seismograms, which, with higher magnification and faster paper rate, together with the shorter period, make reading easier.

In their second paper Ewing, Press and Worzel suggest that the best values for the velocity of T will be obtained from seismograms of shocks for which no corrections have to be made, that is, for such as occur well away from the continental shelf and are recorded close to the coast. Subject to this criterion one should reject the shocks numbered 5 to 8, 12 to 15, 20 and 21. From the remainder one will obtain a mean velocity for V_i of 1·54 km./sec., or 1·58 km./sec. if the 80 km. correction from coast to observatory be also dropped, and for V_m 1·47 or 1·51 km./sec.

---

* It may be remarked that the distances listed in Table 1 are all calculated from the epicentres. In the cases of those mentioned here the S-P distance is noticeably greater than that used, but for the sake of uniformity the epicentral distance has been used in the calculation of velocities.

To complete the investigation, it is proper to see how these results accord with the views expressed by Leet, Linehan and Berger. From a comparison of the arrival times of T at Weston, Harvard and Ottawa, these authors deduce a velocity of 2·13 km./sec. for the land path. Since, with respect to the shocks here under consideration, there is no other observatory in the same azimuth with Riverview, it is not possible to deduce a land path velocity in a like manner.

TABLE III.

No.	Dist.	A.				B.			
		T_i.	T_m.	V_i.	V_m.	T_i.	T_m.	V_i.	V_m.
	km.	sec.	sec.	km./sec.	km./sec.	sec.	sec.	km./sec.	km./sec.
1	2085	1325	1367	1·57	1·52	1300	1342	1·60	1·56
2	1955	1238	1323	1·58	1·48	1213	1298	1·61	1·50
3	1955		1342		1·46		1317		1·50
4	1955		1347		1·45		1322		1·48
5	1790	1190	1281	1·50	1·40	1150	1241	1·56	1·45
6	1790	1133	1221	1·58	1·48	1093	1181	1·64	1·52
7	1915	1193	1243	1·60	1·54	1153	1203	1·66	1·60
8	1790	1213	1241	1·48	1·45	1173	1201	1·53	1·49
9	2365	1504	1538	1·57	1·54	1479	1513	1·60	1·57
10	1785	1239	1259	1·45	1·42	1214	1234	1·48	1·45
11	1785	1216	1259	1·47	1·42	1191	1234	1·50	1·45
12	1745	1141	1224	1·53	1·43	1075	1158	1·61	1·50
13	1680		1260		1·34		1194		1·41
14	1680	1218	1274	1·38	1·32	1152	1208	1·46	1·39
15	1745		1232		1·41		1192		1·47
16	2130		1351		1·54		1326		1·60
17	2010	1327	1333	1·52	1·51	1302	1308	1·55	1·54
18	1830		1413		1·29		1388		1·33
19	2010		1368		1·48		1343		1·50
20	1730		1230		1·41		1171		1·48
21	1720		1264		1·36		1205		1·43
22	1955	1276	1326	1·53	1·47	1251	1301	1·56	1·50
23	1955	1270	1328	1·54	1·47	1245	1303	1·56	1·50
24	1955	1226	1322	1·59	1·48	1201	1297	1·63	1·55
25	1955	1250	1298	1·57	1·51	1225	1273	1·59	1·54
Mean	—	—	—	1·53	1·47	—	—	1·57	1·49

The velocity given is, therefore, assumed to hold also for these regions and the necessary corrections determined. These are listed in Table II, B, and the values of V_i and V_m subsequently determined in Table III, B. The mean velocity thus found is lower than that found by the authors named.

It seems reasonable to suppose that the beginnings of the T-phase has not always been observed correctly on the Wiechert or Mainka seismograms, for reasons already given. However, since the last four shocks may be taken as typical, and as the ratio V_i/V_m determined from them is constant, or nearly so, it may reasonably be supposed that a truer idea of V_i may be obtained by multiplying V_m by this constant, i.e. by 1·04. When this is done, so as to include all shocks, it is found that the mean value of V_i is unchanged.

Since the maxima are more easily observed than the beginnings, the use of this ratio may be a more certain method of finding the true velocity of T, but a great many good observations will first be required to confirm, or disprove, that it is in fact constant.

It would seem, then, that the mean value for the oceanic path of T is too great to conform with the theory that the waves are water-borne. At the same time, the conclusion does not bear out the contention that the velocity is as high as 1·70 km./sec.

Finally, a few general remarks may be made. Firstly, an inspection of the tables seems to show that there is a tendency for the shorter distances to yield lower velocities. That this is not merely an effect of the corrections introduced is shown by the fact that the same relation holds whatever the correction. A detailed study of more abundant material might be worth while, to see if there is indeed a true correlation.

A second point of interest is that T has not been recorded at Riverview from shocks of magnitude much less than 6 and only rarely for magnitudes greater than 7. There have been several of the latter class for which T has not been found. It is probable that the pens had been moving too rapidly to record them ; for those of magnitude greater than 7 listed here (except No. 24) have had T shown on the Mainka seismograms only. It is remarkable, also, that at the other end of the scale—shocks of magnitude 6 or less—the Mainkas show T more clearly than do the Wiecherts, notwithstanding the fact that the period of the Mainka is 10 seconds and that of the Wiechert seven seconds, and that the latter has also the greater magnification.

SUMMARY.

The T-phase as recorded at Riverview on seismograms of earthquake shocks from the New Zealand region is examined with reference to two opposing theories. Concordance is not found with either theory. No alternative theory is offered, but possible lines of further investigation are adumbrated.

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EDITED BY
F. N. HANLON, B.Sc., Dip.Ed.
Honorary Editorial Secretary

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THE PALÆOZOIC STRATIGRAPHY OF SPRING AND QUARRY CREEKS, WEST OF ORANGE, N.S.W.

By G. H. Packham
and N. C. Stevens.

With two Text-figures.

Manuscript received, May 25, 1954. Read, August 4, 1954.

I. Introduction.

The fossiliferous Silurian limestones of Spring and Quarry Creeks, west of Orange, have been known for many years through the work of Süssmilch, who in 1907 published an account of the Silurian and Devonian strata, with a geological map of the parish of Barton. It includes the type localities for *Arachnophyllum* (?) *epistemoides* and several species of *Halysites* described by Etheridge (1904, 1909). The area was also included in a geological map of the Wellington-Orange-Canowindra region (Joplin, 1952), and the Silurian sediments were assigned to the Gamboola Formation, thought to be of Lower Silurian age.

In the area dealt with in this paper, graptolites have been found at a number of localities, and it is shown that the Silurian strata range from Lower to Upper Silurian. The formations present resemble those at Four Mile Creek (Stevens and Packham, 1953), and some of the same formations have been recognized.

II. Stratigraphy.

(1) *Ordovician.*

The oldest Ordovician rocks are found in the N.W. part of the area. They are shown on the map as " calcareous siltstones etc.", but some sheared andesites and tuffs underlie the siltstones at g_{11}. The calcareous siltstones have yielded *Climacograptus bicornis* at g_{11}, and *Dicellograptus* cf. *forchammeri*, *Dicellograptus* sp. and cf. *Glyptograptus teretiusculus* at g_{13}. As the outcrops are somewhat weathered, the graptolites are not well preserved. The forms present indicate a zone somewhere in the lower part of the Upper Ordovician (usage of David (1950)).

Apparently overlying the calcareous siltstones is a massive limestone (bed D of Süssmilch) which outcrops over a moderately large area between Spring and Oaky Creeks. It is separated from Silurian strata to the east by a strike fault. On its eastern margin the limestone shows traces of bedding planes and a few partly silicified corals and gastropods. Dr. D. Hill has examined one of these specimens and reports (personal communication) that it " contains a silicified *Coccoseris* sp. encrusting a *Propora* sp. The *Coccoseris* has tabularia a little over 0·5 mm. in diameter, spaced the same distance apart, and is, I think, conspecific with a specimen from the Bowan Park limestone of Portion 289, Parish of Bowan. The *Propora* sp. has slightly wider tabularia than the common Bowan Park *Propora* sp., and may or may not be conspecific with it—the material is too poor for certainty. The evidence as far as it goes suggests that the Barton Limestone would be similar or close in horizon to the Bowan Park limestone. The known range of the genus *Coccoseris* is Middle Ordovician to Lower Silurian ; that of *Propora* is Middle Ordovician to Upper Silurian." The Ordovician age of the limestone at Bowan Park (Portion 289, Parish of Bowan) has been recognized by Dr. I. A. Brown (1952).

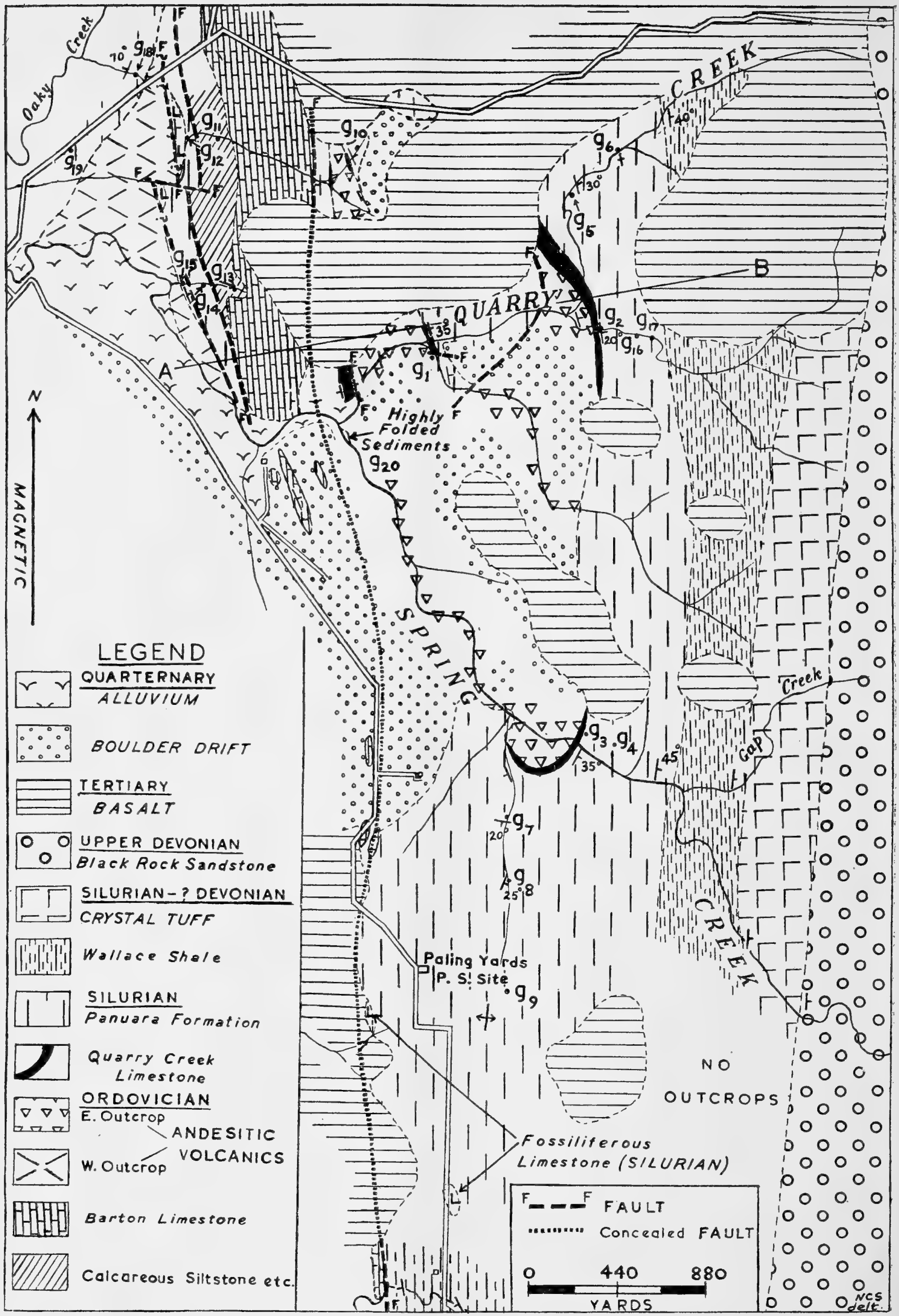

Fig. 1.—Geological sketch-map of Spring and Quarry Creeks. L=limestones of uncertain stratigraphical position.

Andesitic volcanic rocks of Ordovician age outcrop on either side of the Barton Limestone. They are indicated separately on the map as eastern and western outcrops because of lithological differences and probable different stratigraphical position.

The rocks of the western volcanic outcrop are mainly andesites (often amygdaloidal) and tuffs. At g_{15} they are conformably overlain by thin beds of shale and bluish-grey felspathic sandstone with *Climacograptus supernus*, *C.* cf. *inuiti* and *Orthograptus* sp., which suggest a zone near the top of the Ordovician.

East of the Barton Limestone, andesitic lavas, breccias, tuffs and conglomerates outcrop along Quarry and Spring Creeks, underlying Lower Silurian limestone. Calcareous beds with *Favosites* sp., *Halysites* sp., Heliolitids, Streptelasmids and Stromatoporoids occur amongst the volcanic rocks 400 yards N.E. of the junction of Spring and Quarry Creeks.

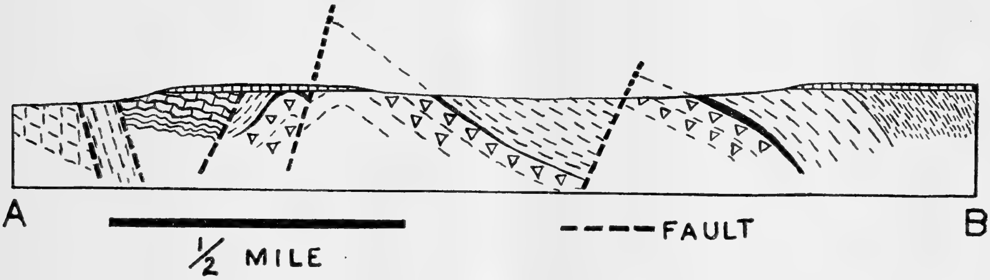

Fig. 2.—Geological section AB (see map). Directions and angles of dip of faults are assumed.

Relations between the eastern and western volcanic outcrops are not observable in the field, but the eastern outcrop is thought to be the younger, since it underlies Lower Silurian limestone, with only a few feet of red sandy shale intervening.

The andesitic conglomerates and breccias in Quarry Creek resemble types in the Upper Ordovician Angullong Tuff of Four Mile Creek (Stevens and Packham, 1953).

The sequence in the Ordovician rocks described above seems to be as follows (the top unit may be partly Silurian):

5. Andesitic volcanic rocks (E. outcrop).
4. Sandstones and shales (g_{15})
3. Andesitic volcanic rocks (W. outcrop).
2. Barton Limestone.
1. Calcareous siltstones, etc. (g_{11}, g_{13}).

Several limestone lenses appear along the eastern margin of the western outcrop of the volcanic rocks. They are unfossiliferous and their stratigraphic position is uncertain. The boundary on which they lie is known to be faulted east of g_{15} and it is possible that a continuation of this fault may pass on either side of the limestone beds.

Silurian.

Panuara Formation. As in the type area (Stevens and Packham, 1953) the Panuara Formation consists of a limestone near the base, followed by shales and fine-grained sandstones, both of which are graptolite-bearing. The thickness of the formation is probably less than 700 feet.

The lowest member of the formation is a bed of red sandy shale with occasional andesite pebbles, which overlies andesitic rocks in Quarry Creek and its tributaries. The presence of this weathered andesitic material is evidence of a time-break between the formations.

The limestone which follows is well-bedded, richly fossiliferous and made up largely of fossil debris, but it lacks the marly layers of the Bridge Creek Limestone of the type area. It is proposed to call this fossiliferous limestone the Quarry Creek Limestone Member.

The section along Quarry Creek is much disrupted by strike faults, resulting in the appearance of the same limestone bed three times. These are beds A, B and C (from east to west) of Süssmilch (1907), whose geological section shows all three beds dipping east, apparently at different stratigraphical horizons. Bed A (Quarry Creek) is the type locality for *Halysites peristephesicus* and *Arachnophyllum* (?) *epistemoides* ; bed C (near the junction of Spring and Quarry Creeks) is the type locality for *H. pycnoblastoides* and *H. süssmilchi*, and *H. lithostrotionoides* has for its type localities bed C and bed A on Spring Creek. Süssmilch records also *H. australis*, *H. cratus*, *Mycophyllum crateroides*, several species of *Favosites*, *Heliolites* and *Cyathophyllum*, *Pachypora*, *Claudopora*, *Zaphrentis*, *Astylospongia* and *Orthosina* (?) from beds A and C. Beds A, B and C have been found to be equivalent, since A and C have similar faunal assemblages, while A and B overlie andesitic rocks and are overlain by beds containing graptolites of similar age.

Fine-grained sandstones with some sponge spicules overlie the Quarry Creek Limestone. *Monograptus* cf. *pragensis pragensis* and dendroid graptolites have been found in these rocks at g_2, a few feet above the limestone, and on Spring Creek at g_3, *M. marri* and dendroids occur about 20 feet above the limestone. There are also dendroid graptolites in these sandstones on either side of an anticlinal fold at g_{10} and g_{20}. The graptolites at g_2 and g_3 are of Upper Llandovery age ; however, the graptolites 50 feet above the Bridge Creek Limestone at Four Mile Creek are of Lower Llandovery age, so that the Quarry Creek Limestone seems to be of a higher horizon.

Above the sandstones, green or brown splintery shales with *M. marri*, *M.* cf. *initialis*, dendroids and *Chonetes* sp. (at g_1) are faulted against outcrop B of the Quarry Creek Limestone. South of Spring Creek, buff-coloured shales at g_7 contain *Gladiograptus* sp., *M.* cf. *griestonensis minuta*, fragments of *Rastrites* sp. or the proximal end of a *M. triangulatus* type and fragments possibly of *M. probosciformis*. In the N.W. part of the area at g_{12}, there are green shales with *M. probosciformis*, *M.* cf. *initialis* and proximal fragments of *M. pandus* or *M. marri*. The shales are faulted against the oldest Ordovician rocks on the east and adjoin a bed of massive limestone of uncertain age on the west. The graptolites at g_1, g_7 and g_{12} are considered to be of the same zone, near the top of the Llandovery.

Grey shales with some calcareous and sandy beds follow. On the eastern tributary of Quarry Creek, a lower Wenlock assemblage of graptolites includes *M. dubius*, *M. priodon* and *M.* cf. *linnarssoni* at g_{16} and *M. dubius* also occurs at g_{17}.

Graptolites at g_4 and g_8, east and south respectively of the outcrop of the Quarry Creek Limestone on Spring Creek, seem to represent a higher horizon. At g_4 grey shales with *M.* aff. *vulgaris* var. *curtus* and *M.* aff. *testis* var. *inornatus* are associated with a thin bed of impure limestone, and at g_8 and g_{19} *M.* aff. *vulgaris* var. *curtus* is present in micaceous siltstones.

Buff-coloured shales at g_{14} and g_{18}, on either side of the western outcrop of the Ordovician volcanic rocks, have yielded *M.* cf. *testis*, and in dark green shale at g_5 on Quarry Creek the same graptolite is associated with a *Monograptus* of the *M. vomerinus* group. The age of these beds is probably Upper Wenlock.

The youngest Silurian strata in which graptolites have been found are grey shales at g_6 on Quarry Creek, and at g_9 near Paling Yards Public School site. At g_6, badly preserved graptolites, probably *M. bohemicus* and dendroids are present, and at g_9 the assemblage includes *M, bohemicus tenuis*, *M. nilssoni*, *M. leintwardinensis* var. *primus* and dendroids.

Two lenses of fossiliferous limestone south of Paling Yards Public School site should, from structural considerations, be near the top of the Panuara Formation, but their fauna (*Halysites*, Cystiphyllids and Mycophyllids) is suggestive of a lower horizon.

TABLE 1.

Stratigraphic Relations of Graptolite Assemblages in the Panuara Formation of Spring and Quarry Creeks.

LOWER LUDLOW.	Panuara Formation	Unnamed Member (interbedded) fine-grained sandstone, siltstone and shale)	*M. bohemicus tenuis*, *M. nilssoni*, *M. leintwardinensis* v. *primus*. *M.* cf. *testis*. *Monograptus* sp.
WENLOCK.			*M. priodon*, *M.* cf. *dubius*, *M.* cf. *linnarssoni*.
LLANDOVERY.			*M. marri*, *M.* cf. *initialis*, *M. probosciformis*, *M.* cf. *griestonensis minuta*, *M.* sp., *Gladiograptus* sp.
			M. marri, *M.* cf. *pragensis pragensis*.
		Quarry Creek Limestone	

Silurian—? Devonian.

Wallace Shale. As in the Four Mile Creek area, the Panuara Formation is conformably overlain by a formation consisting largely of unfossiliferous shales. The shales are poorly bedded ; generally the only indication is the presence of a thin silty band approximately every six inches. The thickness is about 800 feet.

In the upper part of Quarry Creek, green shales overlie a tuff with quartz and orthoclase fragments and some devitrified glass shards in a fine-grained matrix. A similar rock has been noted on Panuara Rivulet at the base of the Wallace Shale (Stevens, 1954). The green shales are overlain by blue-grey shales which locally exhibit calcareous concretions and small-scale contemporaneous deformations.

On Spring Creek, tuffs at the base of the Wallace Shale are overlain by green splintery shales, at the base of which the Silurian trilobite *Encrinurus* cf. *mitchelli* has been found. As Lower Ludlow graptolites are present in the underlying Panuara Formation, it is possible that the Wallace Shale and the underlying tuffs extend into the Lower Devonian.

Crystal Tuffs. A formation of crystal tuffs (red tuffs of Süssmilch, 1907) overlies the Wallace Shale on Spring and Gap Creeks. Rhyolite, considered by Süssmilch to be at a similar horizon, outcrops near the head of Oaky Creek (see Süssmilch's map and columnar sections). The authors believe this to be an extension of the Bulls' Camp Rhyolite of Four Mile Creek.

The tuffs are composed of orthoclase, albite and chlorite together with devitrified glassy material. The grain-size of the mineral fragments is generally about 0·5 mm. The tuffs occur in thick massive beds, through which are scattered dark chloritic patches up to an inch across, containing quartz and felspar phenocrysts. Interbedded with the tuffs on Gap Creek are shales of lithology similar to the Wallace Shale; this suggests that the Wallace Shale type of sedimentation continued between volcanic outbursts.

Above the Wallace Shale on Gap Creek there is an unusual succession. The normal shale lithology is interrupted by about four one-inch bands of silt showing graded bedding (a structure which has not been observed elsewhere in this formation). Then follows an eighteen-inch bed of greywacke. This rock is badly sorted, and contains angular fragments of basic lavas, albite, quartz, orthoclase, chlorite, calcite and acid lavas (in order of abundance), all set in a chloritic matrix. Resting on this with a sharp junction is a boulder-bearing bed, 50 feet thick, which has not been observed at any other localities in the area. Indefinite banding is the only sign of bedding in the rock. A matrix of chlorite and quartz-felspar silt makes up 75% of the rock. Fragments ranging from sand size to boulders 2 ft. 6 in. in diameter, scattered evenly through the bed, make up the remainder. These blocks are of varied type: rhyolite, quartz-felspar-porphyry (similar to the Canowindra Porphyry (Stevens, 1951)), limestone, siltstone and greywacke (somewhat like the underlying bed) have been recognized. The normal crystal tuff follows with a sharp boundary.

The texture of this boulder-bearing bed is not that of a normal sediment and a pyroclastic origin is precluded by the great diversity of the rock fragments. The best explanation seems to be that the material was deposited by a local submarine mud-flow. Terrestrial mudflows, according to Blackwelder (1928), are capable of carrying large blocks of rock which do not sink when the mudflow comes to rest. It is possible that similar conditions could obtain for submarine mudflows, but some degree of dilution could be expected. The graded beds and the greywacke underlying the boulder-bearing bed could have been the result of deposition of turbidity currents generated by the mudflow and flowing ahead of it. If this is the explanation, the mudflow remained as a discrete mass, since the boulder bed has a sharp junction against the underlying greywacke. Unfortunately, there is no sign of any sedimentary structures which would indicate the direction and source of the flow.

Upper Devonian and Younger Formations.

The Upper Devonian rocks have been adequately described by Süssmilch (1907). The basalt which covers some of the area is continuous with the Tertiary lavas of Mt. Canobolas.

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A THEOREM CONCERNING THE ASYMPTOTIC BEHAVIOUR OF HANKEL TRANSFORMS.

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SUMMARY.

Assuming that

$$\bar{f}(u)=\int_0^\infty xJ_\nu(ux)f(x)dx$$

it is proved that, with certain restrictions on the functions and constants,

$$\lim_{u\to\infty}\{u^{2-a}\bar{f}(u)\}=\frac{\Gamma(\frac{1}{2}\nu-\frac{1}{2}a+1)}{2^{a-1}\Gamma(\frac{1}{2}\nu+\frac{1}{2}a)}\lim_{x\to 0+}\{x^a f(x)\}$$

I. INTRODUCTION.

The Hankel transform $\bar{f}(u)$ of a function $f(x)$ is defined by

$$\bar{f}(u)=\int_0^\infty xJ_\nu(ux)f(x)dx, \quad \ldots\ldots\ldots\ldots\ldots\ldots (1.1)$$

where $J_\nu(t)$ is the Bessel function of the first kind of order ν.

Provided that

$$\nu>-\tfrac{1}{2}, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1.2)$$

the inversion formula

$$f(x)=\int_0^\infty uJ_\nu(xu)\bar{f}(u)du, \quad \ldots\ldots\ldots\ldots\ldots\ldots (1.3)$$

is associated with equation (1.1).

In [T.F.I.], theorem 135, it will be found that the integral in equation (1.1) must converge absolutely, while the integral in equation (1.3) may not converge absolutely. In [M.O.], theorem 2, the integral in equation (1.1) is not required to converge absolutely, and that in equation (1.3) is taken to be a Césàro integral.

In this note we shall understand that

$$\int_a^\infty \equiv \lim_{p\to\infty}\int_a^p ; \quad \ldots\ldots\ldots\ldots\ldots\ldots (1.4)$$

where the integral will not necessarily converge absolutely.

It will be unnecessary to assume that both equations (1.1) and (1.3) hold at the same time.

If we refer to [S.F.T.], p. 528, we will find (with a slight change of notation) the transform pair

$$\begin{cases} f(x) = x^{-2}e^{-px} \\ \bar{f}(u) = u^{-1}\{(u^2+p^2)^{\frac{1}{2}} - p\} \end{cases}$$

which is given for $\nu = 1$. It is clear that equation (1.3) will not hold with our definition (1.4) since

$$\bar{f}(u) \to 1 \text{ as } u \to \infty.$$

To avoid this type of difficulty we will assume that (i) if $f(x)$ is given then $\bar{f}(u)$ is *defined* by equation (1.1) and (ii) if $\bar{f}(u)$ is given then $f(x)$ is *defined* by equation (1.3).

When we adopt this procedure, it will be seen that equation (1.2) may be relaxed. If this is done then care must be taken when $\nu = -n$ is a negative integer. The substitution $J_{-n}(x) = (-1)^n J_n(x)$ must be made and the theorems correspondingly modified.

When the theorems are generalized to include discontinuous functions (section 3 and section 4, end) the proofs given demand that condition (1.2) must be applied again.

Reverting now to the result quoted in the summary, it is seen that it can be considered as the analogue of the well known result in the Laplace Transform theory, viz. :

If the Laplace Transform of $F(t)$ is $\bar{F}(s)$ and

$$F(t) \sim Bt^{\beta} \text{ as } t \to 0+$$

then

$$F(s) \sim B\frac{\Gamma(\beta+1)}{s^{\beta+1}} \text{ as } s \to \infty,$$

(see [D.L.T.], p. 200, theorem 12).

II. The Statement of the Theorem when $a > \frac{1}{2}$.

We consider first the case when $a > \frac{1}{2}$.

We then have

Theorem 1.

Assuming that $f(x)$ is a function of x, and that

(i) $\frac{1}{2} < a < 2 + \nu$; .... (2.1)
(ii) $x^{\frac{1}{2}}f(x) \to 0$ as $x \to \infty$; .... (2.2)
(iii) $F(x) \equiv x^a f(x)$ is absolutely continuous in $0 \leqq x < \infty$; .. (2.3)
(iv) $x^{\frac{1}{2}-a}F'(x)$ is absolutely integrable in $0 < \eta \leqq x \leqq \infty$; (all η) ; .... (2.4)

then, as $u \to \infty$

$$u^{2-a}\bar{f}(u) \to K\frac{\Gamma(\frac{1}{2}\nu - \frac{1}{2}a + 1)}{2^{a-1}\Gamma(\frac{1}{2}\nu + \frac{1}{2}a)}, \qquad \text{(2.5)}$$

where $\bar{f}(u)$ is given by equation (1.1) and where

$$K = F(0) = \lim_{x \to 0+} \{x^a f(x)\}. \qquad \text{(2.6)}$$

Proof.

From (iii) it follows that

$$K = F(0) \text{ is finite,}$$

and that $F'(x)$ is absolutely integrable in $(0, \eta)$ for all $\eta > 0$.

Now

$$u^{2-a}\bar{f}(u) = \int_0^\infty u^{2-a}xf(x)J_\nu(ux)dx$$

$$= -\int_0^\infty F(x)\frac{d}{dx}Z(ux)dx. \qquad \text{............ (2.7)}$$

where

$$Z(x) = \int_x^\infty t^{1-a}J_\nu(t)dt.$$

By using the inequality (2.1), we see that this integral converges and

$$Z(0) = \frac{\Gamma(\frac{1}{2}\nu - \frac{1}{2}a + 1)}{2^{a-1}\Gamma(\frac{1}{2}\nu + \frac{1}{2}a)}, \qquad \text{................ (2.8)}$$

([M.O.F.], p. 34).

This obviously implies that there exists a constant M, such that

$$|Z(x)| < M. \qquad \text{.................... (2.9)}$$

Further, if we use the asymptotic expansion for $J_\nu(x)$ with large values of x ([W.B.F.], p. 199) we see that there is a constant N such that

$$|Z(x)| < Nx^{\frac{1}{2}-a} \qquad \text{................ (2.10)}$$

for sufficiently large x.

Thus

$$\begin{aligned} |F(x)Z(ux)| &< |x^a f(x)| \,.\, |Nx^{\frac{1}{2}-a}u^{\frac{1}{2}-a}| \\ &= Nu^{\frac{1}{2}-a}|x^{\frac{1}{2}}f(x)| \\ &\to 0, \end{aligned}$$

as $x \to \infty$ by assumption (ii).

Now reverting to equation (2.7) and integrating by parts,

$$u^{2-a}\bar{f}(u) = \Big[-F(x)Z(ux)\Big]_0^\infty + \int_0^\infty Z(ux)F'(x)dx$$

$$= F(0)Z(0) + \int_0^\infty Z(ux)F'(x)dx. \qquad \text{.......... (2.11)}$$

In order to prove the theorem we must prove that the integral in equation (2.11) vanishes as $u \to \infty$.

For this purpose, we split the range of integration and obtain

$$\left|\int_0^\infty Z(ux)F'x(dx)\right| = \left|\int_0^\eta Z(ux)F'(x)dx + \int_\eta^\infty Z(ux)F'(x)dx.\right.$$

$$< M\int_0^\eta |F'(x)|\,dx + Nu^{\frac{1}{2}-a}\int_\eta^\infty x^{\frac{1}{2}-a}|F'(x)|\,dx$$

$$\text{................ (2.12)}$$

by using equations (2.9) and (2.10).

Recalling that $F'(x)$ is absolutely integrable at $x=0$, it is clear that if we are given $\varepsilon>0$, we may choose η, so that

$$M\int_0^\eta |F'(x)|\,dx<\tfrac{1}{2}\varepsilon.$$

From assumption (iv)

$$\int_\eta^\infty x^{\frac{1}{2}-a}|F'(x)|\,dx \text{ is finite,}$$

and so after the choice of η above we may choose a u_0 so that

$$Nu^{\frac{1}{2}-a}\int_\eta^\infty x^{\frac{1}{2}-a}|F'(x)|\,dx<\tfrac{1}{2}\varepsilon$$

for all $u>u_0$.

Thus

$$\left|\int_0^\infty Z(ux)F'(x)dx\right|<\varepsilon$$

for all $u>u_0$.

Hence

$$\begin{aligned}\lim_{u\to\infty}\{u^{2-a}\bar{f}(u)\}&=F(0)Z(0)\\&=K\frac{\Gamma(\frac{1}{2}\nu-\frac{1}{2}a+1)}{2^{a-1}\Gamma(\frac{1}{2}\nu+\frac{1}{2}a)}.\end{aligned}$$

III. A Generalisation of Theorem 1

Now suppose that $f(x)$ satisfies the conditions of theorem 1 except that there is a finite discontinuity at the point $x=x_0$.

As stated in the Introduction, we add the assumption that

$$\nu>-\tfrac{1}{2}. \qquad \qquad (3.1)$$

Suppose that

$$f(x_0+0)-f(x_0-0)=f_0. \qquad \qquad (3.2)$$

We then construct the function

$$g(x)\equiv f(x)+h(x), \qquad \qquad (3.3)$$

where

$$h(x)\equiv\begin{cases}f_0x^\nu, & 0<x<x_0.\\ 0, & x>x_0.\end{cases}$$

The new function $g(x)$ satisfies the conditions of the theorem and

$$\lim_{x\to0+}\{x^af(x)\}=\lim_{x\to0+}\{x^ag(x)\} \qquad \qquad (3.4)$$

since $\nu>-\frac{1}{2}$ and $a>\frac{1}{2}$.

Now

$$\begin{aligned}\bar{h}(u)&=\int_0^\infty xJ_\nu(ux)h(x)dx\\&=\int_0^{x_0} f_0x^{\nu+1}J_\nu(ux)dx\\&=u^{-1}f_0x_0^{\nu+1}J_{\nu+1}(ux_0)\end{aligned}$$

([S.F.T.], p. 528.)

Then

$$\lim_{u\to\infty}\{u^{2-a}\bar{h}(u)\}=f_0x_0^{\nu+1}\lim_{u\to\infty}\{u^{1-a}J_{\nu+1}(ux_0)\}$$

for all $a>\frac{1}{2}$.

That is

$$\lim_{u\to\infty}\{u^{2-a}\bar{f}(u)\}=\lim_{u\to\infty}\{u^{2-a}\bar{g}(u)\}. \qquad \text{(3.5)}$$

So, since the theorem holds for $g(x)$ it holds also for $f(x)$.

Obviously, this method may be continued to show that if $f(x)$ satisfies the conditions of theorem 1 except that it possesses a finite number of finite discontinuities, then equation (2.5) holds.

IV. Extension of the Theorem to the Case $a<\frac{1}{2}$.

In order to extend the result of equation (2.5) to the case when $a<\frac{1}{2}$, we will state a theorem which contains assumptions on the function $\bar{f}(u)$. It will be observed that the theorem is stated for $a<1\frac{1}{2}$.

Theorem 2.

Assuming that $\bar{f}(u)$ is a function of u, and that

(i) $-\nu<a<1\frac{1}{2}$

(ii) $u^{2+\nu}\bar{f}(u)\to 0$ as $u\to 0$,

(iii) $\bar{F}(u)\equiv u^{2-a}\bar{f}(u)$ is absolutely continuous in $0<u<\infty$ and $\lim_{u\to\infty}\bar{F}(u)=k$;

(iv) $u^{a+\nu}\bar{F}'(u)$ is absolutely integrable in $0<u<\infty$ then as $x\to\infty$

$$x^af(x)\to k\frac{2^{a-1}\Gamma(\frac{1}{2}\nu+\frac{1}{2}a)}{\Gamma(\frac{1}{2}\nu-\frac{1}{2}a+1)} \qquad \text{(4.1)}$$

where $f(x)$ is given by equation (1.3).

It is easily seen that equations (2.9) and (4.1) are identical.

The proof of this theorem, and its generalization to the case when $\bar{f}(u)$ possesses a finite number of finite discontinuities, follows very closely on the lines of theorem 1 and will not be given.

The most important case of our result would be the case when $a=0$. Theorem 2 shows that if $a=0$, then $\nu>0$. So our formula breaks down in the most useful case $a=0$ and $\nu=0$. This situation will be examined further in a note to be presented to this Society later.

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MINOR PLANETS OBSERVED AT SYDNEY OBSERVATORY DURING 1953.

By W. H. ROBERTSON.

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The following observations of minor planets were made photographically at Sydney Observatory with the 13″ standard astrograph. Observations were confined to those with southern declinations in the *Ephemerides of Minor Planets* published by the Institute of Theoretical Astronomy at Leningrad.

On each plate two exposures, separated in declination by approximately 0′·5, were taken with an interval of about 20 minutes between them. The beginnings and endings of the exposures were recorded on a chronograph with a tapping key.

Rectangular coordinates of both images of the minor planet and three reference stars were measured in direct and reversed positions of the plate on a long screw measuring machine. The usual three star dependence reduction retaining second order terms in the differences of the equatorial coordinates was used. Proper motions, when they were available, were applied to bring the star positions to the epoch of the plate. Each exposure was reduced separately in order to provide a check by comparing the difference between the two positions with the motion derived from the ephemeris. The tabulated results are means of the two positions at the average time except in cases 32, 33, 46, 63, 76 where each result is from only one image, due to a defect in the other or a failure in timing it. No correction has been applied for aberration, light time or parallax, but in Table I are given the factors which give the parallax corrections when divided by the distance. The observers named in the last column of Table II are W. H. Robertson (R), K. P. Sims (S) and H. W. Wood (W). I wish to thank Mr. Wood for help in initiating this programme and Mr. Sims for assistance with the computations.

TABLE I

1953 U.T.	Planet	R.A. (1950·0) h m s	Dec. (1950·0) ° ′ ″	Parallax Factors s	″
1 May 14·49466	7 Iris	14 19 35·29	—19 05 48·0	—0·12	—2·3
2 June 5·46904	7 Iris	14 04 37·66	—17 03 03·0	+0·02	—2·5
3 Sep. 8·63040	13 Egeria	0 12 37·66	—21 21 06·5	+0·02	—1·9
4 Oct. 1·53735	13 Egeria	23 49 21·35	—22 00 05·8	—0·02	—1·8
5 May 13·43858	15 Eunomia	11 43 06·50	—14 51 24·0	+0·04	—2·8
6 May 14·41494	15 Eunomia	11 43 00·39	—14 46 39·7	—0·03	—2·8
7 May 26·40390	15 Eunomia	11 43 27·52	—13 57 45·8	+0·04	—3·0
8 June 11·48122	16 Psyche	14 31 47·20	—10 36 30·7	+0·05	—3·4
9 June 16·45689	16 Psyche	14 30 02·08	—10 32 23·4	+0·02	—3·4
10 Aug. 13·47186	18 Melpomene	19 10 40·54	—13 51 54·5	—0·04	—3·0
11 Sep. 8·41811	18 Melpomene	19 08 17·52	—17 26 27·2	+0·02	—2·5
12 May 20·37128	25 Phocæa	10 46 53·18	— 5 26 33·2	+0·01	—4·2
13 June 1·37546	25 Phocæa	10 55 15·55	— 4 16 08·0	+0·10	—4·3

TABLE I—*Continued.*

1953 U.T.		Planet		R.A. (1950·0) h m s	Dec. (1950·0) ° ′ ″	Parallax Factors s	″
14 Aug.	31·40994	26	Proserpina	17 58 36·32	—27 38 29·3	+0·08	—1·0
15 Sep.	8·38566	26	Proserpina	18 04 05·54	—27 30 08·0	+0·06	—1·0
16 July	23·71378	28	Bellona	22 18 11·74	—10 10 03·4	+0·13	—3·6
17 Aug.	13·61232	28	Bellona	22 04 48·50	—12 15 21·2	+0·02	—3·2
18 Sep.	8·53328	28	Bellona	21 45 13·88	—15 01 05·0	+0·04	—2·8
19 June	30·64034	29	Amphitrite	20 23 58·56	—28 07 43·7	—0·06	—0·9
20 July	27·57700	29	Amphitrite	19 57 48·03	—29 09 02·7	—0·10	—0·8
21 Aug.	17·55900	32	Pomona	20 49 13·65	— 8 45 47·0	+0·05	—3·7
22 Aug.	31·49256	32	Pomona	20 39 32·19	— 9 49 52·2	—0·02	—3·6
23 July	15·59270	38	Leda	19 16 02·91	—23 33 56·8	—0·08	—1·6
24 July	23·52408	38	Leda	19 08 46·74	—23 32 06·8	—0·06	—1·6
25 June	15·56180	46	Hestia	17 08 27·48	—19 04 47·8	0·00	—2·2
26 June	29·51198	46	Hestia	16 55 29·04	—18 49 05·5	—0·01	—2·3
27 Aug.	10·38051	51	Nemausa	15 41 24·50	— 7 35 18·9	+0·10	—3·9
28 Aug.	31·36877	51	Nemausa	16 04 02·26	—10 07 02·1	+0·19	—3·6
29 July	29·63476	52	Europa	21 56 01·51	—14 43 07·8	—0·02	—2·9
30 Aug.	18·58358	52	Europa	21 42 02·40	—16 31 59·2	+0·02	—2·6
31 July	1·60404	62	Erato	19 12 09·21	—21 15 12·8	0·00	—1·9
32 July	21·55246	62	Erato	18 55 42·88	—21 50 55·8	+0·05	—1·8
33 June	22·60913	78	Diana	18 20 48·62	—34 42 20·5	+0·06	+0·1
34 July	20·49942	78	Diana	17 53 23·19	—33 45 02·1	+0·01	0·0
35 June	4·39290	79	Eurynome	12 00 55·71	— 0 46 43·1	+0·04	—4·8
36 June	9·40047	79	Eurynome	12 03 03·31	— 0 53 45·9	+0·10	—4·8
37 Aug.	10·63550	91	Ægina	22 11 42·44	—13 43 49·6	+0·14	—3·1
38 Sep.	8·53328	91	Ægina	21 46 29·12	—15 38 08·4	+0·03	—2·7
39 Aug.	24·68382	92	Undina	23 54 44·87	—14 51 51·7	+0·10	—2·9
40 Sep.	10·62310	92	Undina	23 44 03·95	—16 43 02·2	+0·08	—2·6
41 July	30·63948	97	Klotho	22 05 46·88	— 5 42 19·6	—0·02	—4·1
42 Aug.	17·59794	97	Klotho	21 52 41·61	— 7 59 14·7	+0·03	—3·8
43 Aug.	24·64534	109	Felicitas	23 32 39·16	— 8 31 31·0	+0·02	—3·7
44 Oct.	1·50016	109	Felicitas	22 57 17·64	— 9 21 27·9	—0·03	—3·6
45 Sep.	10·65815	110	Lydia	0 50 57·33	— 3 08 45·4	+0·04	—4·5
46 Oct.	1·56258	110	Lydia	0 34 16·90	— 4 33 43·6	—0·04	—4·3
47 Aug.	12·63965	124	Alkeste	22 11 59·92	— 7 46 05·6	+0·08	—3·9
48 Sep.	21·49100	124	Alkeste	21 43 12·56	—11 12 59·6	+0·02	—3·4
49 June	29·62207	128	Nemesis	19 05 22·46	—26 52 57·1	+0·06	—1·1
50 July	21·52932	128	Nemesis	18 44 37·72	—27 59 52·7	0·00	—0·9
51 Aug.	10·66525	130	Elektra	22 57 13·34	—11 28 32·3	+0·04	—3·3
52 Aug.	24·60536	130	Elektra	22 50 08·81	—14 41 29·9	—0·01	—2·9
53 July	1·68752	133	Cyrene	21 04 47·54	—20 24 16·8	+0·02	—2·0
54 July	22·60962	133	Cyrene	20 49 42·46	—20 42 46·2	—0·02	—2·0
55 June	9·65952	144	Vibilia	18 30 27·95	—25 00 52·2	+0·08	—1·4
56 July	14·51514	144	Vibilia	17 56 25·59	—26 17 49·4	0·00	—1·1
57 Aug.	13·52903	154	Bertha	20 00 19·41	—50 12 09·5	+0·04	+2·5
58 Aug.	17·51691	154	Bertha	19 56 58·80	—50 00 16·5	+0·05	+2·5
59 June	11·59324	184	Dejopeja	17 02 03·55	—24 27 38·8	+0·08	—1·4
60 June	22·53957	184	Dejopeja	16 53 12·47	—24 12 16·7	+0·02	—1·4
61 June	9·55270	201	Penelope	16 25 56·38	—12 08 39·7	+0·01	—3·2
62 June	16·52370	201	Penelope	16 19 57·26	—12 01 55·8	—0·01	—3·2
63 July	23·61480	214	Aschera	20 38 24·08	—22 00 45·1	+0·04	—1·8
64 July	30·58956	214	Aschera	20 31 42·25	—22 17 44·4	+0·03	—1·7
65 Aug.	17·63116	241	Germania	22 25 48·62	— 1 42 46·8	+0·06	—4·7
66 July	22·56474	259	Aletheia	19 19 04·07	—29 03 26·9	+0·05	—0·7
67 July	28·52686	259	Aletheia	19 14 22·85	—29 26 39·3	—0·02	—0·6
68 June	9·60262	266	Aline	17 40 00·61	—14 11 48·1	+0·01	—2·9
69 June	18·56482	266	Aline	17 32 01·44	—13 34 02·2	—0·02	—3·0
70 June	30·53152	266	Aline	17 21 44·23	—12 52 25·1	0·00	—3·1
71 June	11·55580	275	Sapientia	15 56 03·07	—13 12 31·0	+0·10	—3·1
72 June	15·51970	275	Sapientia	15 53 20·14	—13 12 46·2	+0·03	—3·1
73 July	23·66960	352	Gisela	21 08 11·31	—10 34 48·4	+0·14	—3·5

TABLE I—*Continued.*

1953 U.T.			Planet	R.A. (1950·0) h m s	Dec. (1950·0) ° ′ ″	Parallax Factors s	″
74	July	15·67975	359 Georgia	21 23 09·95	—25 50 59·1	—0·08	—1·2
75	Aug.	6·60782	359 Georgia	21 04 21·28	—26 50 12·8	+0·08	—1·1
76	July	23·61480	367 Amicitia	20 39 01·34	—21 51 00·7	+0·04	—1·8
77	July	30·58956	367 Amicitia	20 31 34·05	—22 25 01·1	+0·03	—1·7
78	June	8·59070	372 Palma	16 36 22·78	—52 32 20·1	+0·16	+2·7
79	June	29·66232	375 Ursula	20 06 38·73	—38 50 03·2	+0·06	+0·8
80	July	28·56140	375 Ursula	19 37 07·69	—38 14 48·2	+0·05	+0·7
81	June	16·63762	381 Myrrha	18 35 22·06	—12 50 27·0	+0·06	—3·1
82	July	14·54602	381 Myrrha	18 13 47·80	—14 58 10·0	+0·06	—2·8
83	July	21·66763	385 Ilmatar	21 36 52·95	—26 03 54·9	+0·06	—1·2
84	Aug.	24·55140	385 Ilmatar	21 04 59·92	—26 32 33·0	+0·06	—1·1
85	July	7·61489	394 Arduina	19 35 22·61	—29 03 02·0	+0·04	—0·7
86	July	23·55520	394 Arduina	19 20 38·76	—30 15 23·9	+0·02	—0·5
87	July	7·68151	412 Elizabetha	20 51 12·77	—22 57 24·6	+0·08	—1·7
88	July	29·57983	412 Elizabetha	20 33 46·17	—25 53 25·9	—0·01	—1·2
89	June	8·64830	488 Kreusa	18 12 37·94	—24 22 24·6	+0·08	—1·4
90	July	7·50648	488 Kreusa	17 47 53·47	—25 40 36·4	—0·08	—1·3
91	June	29·55973	550 Senta	17 38 50·83	—23 23 21·2	+0·05	—1·6
92	July	9·50516	550 Senta	17 30 32·84	—22 10 49·2	—0·02	—1·8
93	July	15·63001	556 Phyllis	20 17 50·50	—17 44 34·5	+0·06	—2·4
94	July	30·55224	556 Phyllis	20 02 58·96	—18 03 26·9	—0·03	—2·4
95	July	21·71485	595 Polyxena	22 16 29·84	—37 06 50·6	+0·15	+0·4
96	Aug.	6·64274	595 Polyxena	22 03 43·35	—38 16 15·8	—0·09	+0·6
97	Sep.	8·66354	599 Luisa	1 03 02·71	—20 04 41·9	+0·02	—2·1
98	Oct.	1·60898	599 Luisa	0 39 46·41	—19 03 38·8	+0·09	—2·3
99	Oct.	8·56036	599 Luisa	0 32 07·61	—18 13 57·4	+0·02	—2·3
100	June	18·52210	675 Ludmilla	16 36 14·38	—23 58 43·8	—0·03	—1·5
101	July	13·61252	758 Mancunia	19 44 27·92	—22 13 40·7	—0·01	—1·8
102	July	29·54424	758 Mancunia	19 31 56·19	—23 01 30·9	+0·01	—1·6
103	Aug.	13·65487	1303 Luthera	23 20 38·73	—33 04 38·1	+0·02	—0·1

TABLE II.

Comparison Stars	Dependences			
1 Yale *12* II 6019, 5998, 5994	0·30926	0·33202	0·35871	W
2 Yale *12* I 5287, 5286, 5260	0·46404	0·21685	0·31911	R
3 Yale *13* I 39, 56, *14*, 81	0·09164	0·42420	0·48416	W
4 Yale *14* 15874, 15880, 15891	0·33268	0·07540	0·59192	S
5 Yale *12* I 4605, 4599, 4591	0·01999	0·61379	0·36622	S
6 Yale *12* II 4586, 4591, 4599	0·15859	0·20200	0·63940	W
7 Yale *11* 4354, 4356, 4365	0·28129	0·52478	0·19392	S
8 Yale *11* 5114, 5099, 5104	0·79252	—0·00264	0·21012	R
9 Yale *11* 5101, 5104, 5115	0·42218	0·46503	0·11279	W
10 Yale *12* I 7126, 7151 *11* 6680	0·28597	0·52188	0·19216	R
11 Yale *12* II 7092, 7115, 7134	0·13688	0·45079	0·41233	R
12 Yale *17* 4123, 4135, 4148	0·35454	0·13039	0·51506	R
13 Yale *17* 4174, 4175, 4184	0·31194	0·18782	0·50024	S
14 Yale *13* II 11565, 11577, 11579	0·06233	0·90428	0·03339	S
15 Yale *13* II 11656, 11681, 11698	0·51930	0·21723	0·26347	R
16 Yale *11* 7880, 7883, 7889	0·17868	0·43960	0·38172	W
17 Yale *11* 7814, 7822, 7825	0·59451	0·57106	—0·16557	W
18 Yale *12* I 8177, 8183, 8196	0·13401	0·63514	0·23084	W
19 Yale *13* II 13437, 13460, 13489	0·43569	0·22986	0·33445	W
20 Yale *13* II 13133, 13152, 13167	0·36802	0·36682	0·26515	R
21 Yale *16* 7458, 7474, 7494	0·42018	0·35586	0·22396	R
22 Yale *11* 7316, 7318, 7340	0·13722	0·48864	0·37414	S

TABLE II—*Continued.*

Comparison Stars	Dependences			
23 Yale *14* 13424, 13428, 13452	0·47199	0·08448	0·44354	S
24 Yale *14* 13324, 13344, 13358	0·29038	0·46044	0·24918	W
25 Yale *12* II 7008, 7010, 7043	0·35149	0·41484	0·23367	R
26 Yale *12* II 6900, 6921, 6937	0·28155	0·24386	0·47458	W
27 Yale *16* 5479, 5492, 5493	0·37392	0·45580	0·17027	S
28 Yale *16* 5595, 5596, 5604	0·51542	0·35133	0·13325	S
29 Yale *12* I 8225, 8232, 8248	0·33960	0·34975	0·31065	R
30 Yale *12* I 8168, 8169, 8179	0·28511	0·59165	0·12325	R
31 Yale *13* I 8162, 8177, 8192	0·37422	0·46173	0·16405	W
32 Yale *13* I 8009, 8027, *14* 13182	0·35482	0·24189	0·40329	W
33 Cord. C 10172, 10178, 10202	0·38128	0·21704	0·40168	S
34 Cord. C 9811, 9844, 9850	0·24832	0·28430	0·46738	W
35 Yale *21* 3343, 3346, 3348	0·27520	0·64205	0·08274	W
36 Yale *21* 3352, 3353, 3357	0·47183	0·37844	0·14973	R
37 Yale *11* 7864, *12* I 8302, 8303	0·52063	0·30770	0·17166	W
38 Yale *12* I 8177, 8187, 8196	0·09806	0·43686	0·46508	W
39 Yale *12* I 8793, 8795, 8810	0·33512	0·28276	0·38212	S
40 Yale *12* I 8742, 8752, 8755	0·34575	0·28848	0·36577	W
41 Yale *16* 7926, 7928, 7947	0·32270	0·31237	0·36493	R
42 Yale *16* 7860, 7861, 7881	0·23254	0·37592	0·39153	R
43 Yale *16* 8348, 8349, 8357	0·68833	0·17106	0·14061	S
44 Yale *11* 8060, 8074, *16* 8176	0·07244	0·46232	0·46524	S
45 Yale *17* 192, 196, 207	0·47905	0·66169	—0·14074	W
46 Yale *17* 118, 127, 131	0·48732	0·04623	0·46646	S
47 Yale *16* 7962, 7963, 7977	0·21681	0·37195	0·41124	W
48 Yale *11* 7708, 7718, 7730	0·29298	0·58393	0·12308	S
49 Yale *14* 13299, *13* II 12466, 12513	0·45701	0·19267	0·35032	W
50 Yale *13* II 12215, 12246, 12263	0·34541	0·27710	0·37748	W
51 Yale *11* 8067, 8073, 8076	0·56688	0·13027	0·30285	W
52 Yale *12* I 8478, 8482, 8499	0·14936	0·39641	0·45424	S
53 Yale *13* I 9049, 9055, 9072	0·28430	0·48149	0·23421	W
54 Yale *13* I 8943, 8945, 8953	0·00717	0·40570	0·58713	W
55 Yale *14* 12845, 12879, 12890	0·41623	0·28807	0·29570	W
56 Yale *14* 12306, 12321, 12340	0·40044	0·30750	0·29206	S
57 Cape Ft. 18941, 18977, 19000	0·33904	0·25359	0·40737	W
58 Cape Zone 18525, 18548, Cape Ft. 18919	0·46860	0·37139	0·16001	R
59 Yale *14* 11792, 11794, 11827	0·46890	0·23275	0·29835	W
60 Yale *14* 11698, 11704, 11731	0·42167	0·36781	0·21052	S
61 Yale *11* 5690, 5700, 5716	0·46657	0·20614	0·32729	W
62 Yale *11* 5656, 5673, 5684	0·24537	0·45490	0·29974	R
63 Yale *14* 14342, 14357, *13* I 8872	0·33128	0·44198	0·22674	W
64 Yale *14* 14258, 14279, 14296	0·32608	0·21590	0·45802	R
65 Yale *17* 7805, 7809, 7816	0·16928	0·35791	0·47281	R
66 Yale *13* II 12649, 12659, 12673	0·15754	0·36107	0·48139	W
67 Yale *13* II 12586, 12611, 12623	0·26434	0·45210	0·28356	R
68 Yale *11* 6052, *12* I 6365, 6379	0·25488	0·38028	0·36484	W
69 Yale *11* 5998, 6012, 6021	0·56687	0·34559	0·08754	R
70 Yale *11* 5931, 5949, 5952	0·34271	0·31392	0·34337	W
71 Yale *11* 5539, 5540, 5545	0·54809	0·34181	0·11010	W
72 Yale *11* 5516, 5530, 5531	0·22336	0·24528	0·53136	R
73 Yale *11* 7499, 7506, 7519	0·23681	0·42949	0·33370	W
74 Yale *14* 14751, 14761, 14771	0·25813	0·47346	0·26841	S
75 Yale *13* II 13869, 13910, *14* 14613	0·43997	0·25994	0·30009	S
76 Yale *14* 14342, 14357, *13* I 8872	0·00611	0·37802	0·61586	W
77 Yale *14* 14258, 14279, 14296	0·30883	0·37642	0·31474	R
78 GC 22320, LPl A 5611, 5651	0·37190	0·23511	0·39299	W
79 Perth *2* 1372, GC 27941, 28055	0·32055	0·36562	0·31383	W
80 Perth *6* 1650, 1652, 1655	0·24794	0·51467	0·23739	R
81 Yale *11* 6377, 6380, 6388	0·15555	0·25754	0·58690	R
82 Yale *12* I 6610, 6644, 6654	0·34470	0·30110	0·35420	S
83 Yale *14* 14863, 14867, 14883	0·30029	0·35113	0·34858	W
84 Yale *13* II 13899, *14* 14578, 14620	0·21529	0·34908	0·43562	S

TABLE II—*Continued.*

Comparison Stars	Dependences			
85 Yale *13* II 12858, 12860, 12878	0·06922	0·58902	0·34176	R
86 Cord. B 12665, 12702, Yale *13* II 12671	0·33463	0·39791	0·26745	W
87 Yale *14* 14467, 14487, 14496	0·26118	0·22663	0·51218	R
88 Yale *14* 14282, 14298, 14321	0·45119	0·15208	0·39674	R
89 Yale *14* 12598, 12610, 12642	0·18303	0·44397	0·37300	W
90 Yale *14* 12198, 12209, 12228	0·16063	0·37200	0·46737	R
91 Yale *14* 12117, 12120, 12127	0·24553	0·34070	0·41377	W
92 Yale *13* I 7179, 7203, *14* 12070	0·36720	0·19714	0·43566	R
93 Yale *12* II 8693, 8716, *12* I 7658	0·17863	0·32883	0·49254	S
94 Yale *12* II 8601, 8602, 8622	0·44909	0·40406	0·14685	R
95 Perth *6* 1880, 1883, 1886	0·29432	0·20660	0·49908	W
96 Perth *6* 1862, 1864, 1870	0·30124	0·25561	0·44316	S
97 Yale *13* I 264, 281, 283	0·17273	0·39373	0·44354	W
98 Yale *12* II 152, 168, 169	0·11204	0·57414	0·31382	S
99 Yale *12* II 123, 133, 140	0·37563	0·38528	0·23909	W
100 Yale *14* 11528, 11556, 11559	0·34121	0·36345	0·29534	R
101 Yale *14* 13767, 13790, 13812	0·30914	0·51402	0·17684	S
102 Yale *14* 13602, 13621, 13650	0·25600	0·22930	0·51469	R
103 Cord. C 12515, 12539, 12541	0·32531	0·29921	0·37548	W

ROYAL SOCIETY OF NEW SOUTH WALES

SYMPOSIUM

OIL, AUSTRALIA AND THE FUTURE

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1955

CONTENTS.

FOREWORD.

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 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.

Its objects, as set out in the Rules of the Society, include " studies and investigations . . . in Science . . . and especially on such subjects as tend to develop the resources of Australia, and to illustrate its Natural History and Productions ".

The Society publishes original investigations, awards medals to distinguished scientists and arranges for addresses by research workers on specialist topics in Science. In addition, however, the Society is actively concerned with the translation of scientific developments to the general public and holds regular symposia and discussions on topics of interest to the community.

It was decided to hold in 1954 a symposium dealing with the search for oil in Australia and the likely effects of its discovery on Australia's economy. The four speakers invited to address members of the Society and visitors are authorities in their fields. The presentation of their subjects in a manner intelligible to the general public met with an enthusiastic response from the well attended meeting which was held on Wednesday, 4th October, 1954, in the Hall of Science House, Sydney.

The Council of the Royal Society of New South Wales considered that the publication of the addresses would contribute to a broadening of the outlook of the public on this most important subject. It was decided, therefore, to make this publication available to the general public.

The Council takes this opportunity of expressing our appreciation of the contributions made by the four speakers.

R. S. Nyholm,
President.

SEARCH FOR OIL IN AUSTRALIA AND NEW GUINEA: THE GEOLOGICAL BACKGROUND.

By H. G. Raggatt.

It is impossible to discuss the search for oil in Australia without first reviewing the conditions under which oil occurs in the earth. This means, of course, that some of you will have presented to you material similar to that included in an address to the Australian Institute of Mining and Metallurgy in Sydney on the 2nd June, 1954. However, I see no alternative to this method of presentation. If oil had been found in commercial quantities anywhere in Australia or Papua-New Guinea, it might have been possible to adopt a different approach, but that is still in the future.

The search for oil is a research problem on a grand scale. I believe that oil has been found in Western Australia mainly because the investigation was approached basically as a piece of research, and because the Commonwealth and Western Australian Governments accepted the view that this was a long-range problem which ought to be tackled systematically and that no drilling should be done until the facts had been gathered together and critically appraised.

Before a decision was made to concentrate the efforts of the Commonwealth Bureau of Mineral Resources in the Carnarvon and Fitzroy Basins, two propositions were examined:

(1) What are the geological conditions in which oil occurs?
(2) Using criteria deduced from (1), what conclusions may be drawn concerning the oil possibilities of the sedimentary basins of Australia?

I propose to discuss these two propositions and to outline the conclusions reached from examination of them. In doing this we shall see that there is a great deal known about the conditions in which oil occurs in the earth, but that our knowledge of Australian geology is so scanty that the information known about conditions is difficult to apply.

The geological conditions that are regarded as essential for the occurrence of oil in commercial quantities have been stated many times, and confirmed over and over again by experience. Recent research (Smith, 1954) shows " that petroleum is being formed in the present era and that the crude product is nature's composite of the hydrocarbon remains of many forms of marine life ". The research results tend to support the long-held view that both relatively and actually organic matter such as plankton is the major source of oil, though all forms of marine life probably are sources to a greater or lesser degree.

The abundance of organic matter in sediments decreases with increase in grain size; clay contains twice as much organic matter as silts and silts twice as much as sands (Trask, 1934).

Thus, the widely held belief based mainly on field observations, that dark-coloured marine shales are to be regarded as source beds, seems to be pretty well supported by laboratory research. It would be difficult to explain many occurrences of oil on any other hypothesis. For example, it is the general rule to find oil in a particular formation or formations over wide areas, whereas other formations in the same sequence with reservoir characteristics similar to the producing " sands " contain water only. Again, in oilfields such as Goose

Creek, Texas, which is characterized by numerous lenticular sand bodies through a section about 4,000 feet thick, oil is found in some lenses and not in others despite the fact that the lithology of the lenses is similar (Minor, 1925). It seems reasonable to assume that in such cases the oil came from shales adjacent to the oil sands, and not from a common distant source. This and other evidence (Clark, 1934) seems to rule out the migration of oil over long distances, either vertically or laterally, as a common occurrence, though no doubt migration does occur, e.g. along faults and at unconformities. In general, however, source beds should be looked for first, near to where oil is found.

The first essential is, therefore, a sequence which includes fossiliferous marine rocks, among which shales are favoured as likely to contain source material in adequate quantities.

The next essential is that there should be porous rocks into which the oil can move and be stored, because it is rarely that sediments which contain abundant source material are themselves sufficiently porous to serve as reservoirs.

Finally, the reservoir must be sealed by having an impervious cover, such as beds of shale.

In a typical oilfield, therefore, there is usually good development of shale, and many oilfield areas are characterized by more than one formation of shale interbedded with limestone and sandstone, thus providing an alternation of source, reservoir and cap rock.

Western Venezuela, one of the world's largest oil-producing regions, may be taken as an example. Oil is produced mainly from two formations in the Cretaceous, which has a total maximum thickness of about 13,000 feet. Excluding 4,600 feet of sandstone and conglomerate at the base, the section consists of alternations of dark shales, limestone, and glauconitic sandstone (E. Rod and W. Maync, 1954).

A striking feature of some oilfield regions is the association of commercial accumulations of oil with unconformities.

Cunningham and Kleinpell (1934) state that a review of the evidence concerning producing oilfields in the San Joaquin Valley, California, " indicates that the presence of unconformities has caused the accumulation or the availability at drillable depths of the major portion of the commercial oil of the region ". The unconformities to which they refer are either " marine transgressions rarely accompanied by the development of basal conglomerate " (Miocene) or regressions marginal to a rising border or to rising structures within the basin (Pliocene).

Levorsen (1934), referring to oilfields of the mid-continent region of U.S.A. (Kansas, Oklahoma, Arkansas and parts of Texas and Illinois), states that:

> " . . . other things being equal that district which contains the most unconformities has the most traps capable of retaining oil and gas and is consequently the most desirable as prospective oil and gas territory.
>
> " Unconformities mark planes of increased porosity in many places. This may be due to the porosity developed in the leaching and weathering of the underlying formation when it is a limestone or dolomite, or to the accumulation of unassorted fragments, pebbles, sandstones, and conglomerates as the basal member of the overlying formation. This porosity may act as an avenue of migration for oil and gas, or, when developed to the proportions of a reservoir rock and in the form of a suitable trap. it may be the locus of an oil pool.
>
> " Formations which overlie a plane of unconformity are commonly of nearshore or littoral origin. Many geologists believe that petroleum and natural gas originate in such an environment."

Levorsen uses "unconformity"—in its widest sense as defined by Twenhofel—to include erosional, non-sequence and angularly discordant contacts.

We may consider for a moment one of Levorsen's illustrations—a section through the Oklahoma City field—showing the relationship of unconformities to oil and gas production (Figure 1). It will be noted that oil and gas occur in several formations of Ordovician age below an unconformity overlain by a shale of Pennsylvanian age; that is, the Silurian, Devonian and Mississipian are absent.

This example is by no means unique. In the Turner Valley, Western Alberta, oil is produced from limestone of Mississipian age overlain unconformably by shale of Jurassic age; that is, the Pennsylvanian Permian and Triassic are missing. Similar conditions prevail in the Kevin-Sunburst field in northern Montana.

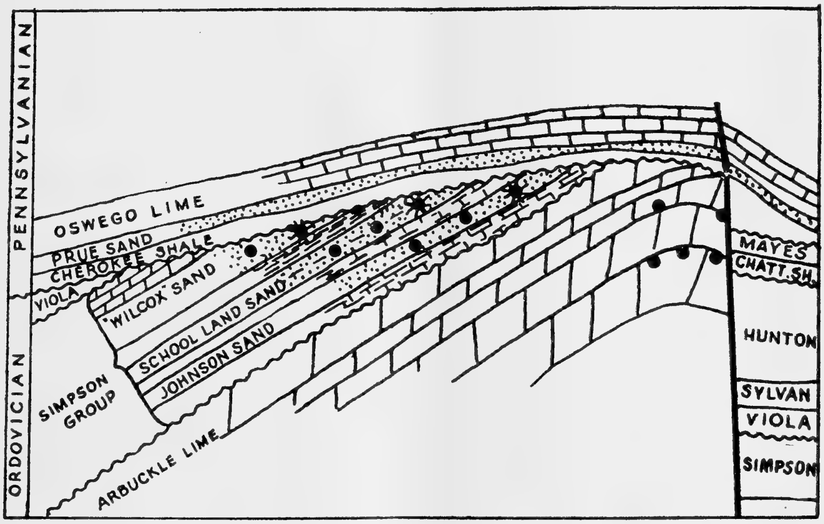

Fig. 1.—Idealized section across Oklahoma City field, Oklahoma, U.S.A., showing relation of unconformities (wavy lines) to occurrence of oil (full circles) and gas (rayed circles). *After* A. I. Levorsen, 1934.

In some of the papers in which the accumulation of oil at unconformities is described the authors do no more than state the relationship but, implicitly or explicitly, the general view seems to be that we should look to the sediments immediately overlying the unconformity for source material. Although there is satisfactory evidence—e.g. gravity of oil—that this applies in many places, it cannot be universally true. It seems unlikely to be true, for example, of the oil occurrences in the Arbuckle limestone illustrated by Levorsen. Rise in the rock temperature with depth of burial may be an important factor in determining the time and rate of migration into and across unconformities in some places.

For our present purpose we need not examine the matter critically, but merely note the fact that unconformities, even where they represent long periods of time, are not unwelcome in the geological record of potential oilfields.

There are two other general points that deserve consideration because of their bearing on the search for oil in Australia:

(1) Is the absence of signs of oil in outcrops, and in water bores, of particular significance?

(2) Is the presence of pressure water inimical to the occurrence of oil?

Absence of indications of oil in outcrops and in the hundreds of bores that have been put down for water in many of the sedimentary basins in Australia, has been cited as discouraging even to the point of proving that no oil exists.

Andrews (1924) wrote down the oil prospects of Australia largely on the absence of indications of oil in outcrops and bore waters. Clapp (1926*a*, 1926*b*) writing about the Carnarvon Basin, stated : " . . . if oil existed in commercial quantities anywhere (in the Basin) it would seem that some trace of oil or gas should have been found in one or more of the numerous wells."

Dr. W. G. Woolnough, however, after a tour of inspection of the oilfields of U.S.A. and Argentine, reported (1931, p. 14) that " almost complete absence of oil seepages in Australia is far from being the unfavourable indication that some people suppose ".

When we visited the United States in 1945, Mr. J. M. Rayner and I made a special point of examining an oil field area where there was no sign of oil in the outcropping sediments. The area selected was Big Horn Basin in Central Wyoming. In the oilfield at Byron (Garland) the principal reservoir rock is the Madison limestone (Mississipian). The wells in the Madison limestone were characterized by large initial production of a low gravity oil (19°), but in the outcrops of the Madison limestone only 30 miles away there are no seeps or oil residues, and the smell when struck with a hammer is no different from that commonly noticed with limestones.

There is an absence of seepages over large areas of the United States which include many important producing oilfields.

It was concluded that lack of evidence of oil in outcrops need not be regarded as particularly significant, and certainly should not be taken as excluding from examination areas that otherwise show promise as potential oilfields.

Now that it is known that oil occurs in the same formation that forms the main artesian aquifer in the Carnarvon Basin, it may seem strange to many that no oil was noted in drilling the artesian wells. Experience at Rough Range shows how difficult it is to find oil, even when it is being sought by a properly planned drilling campaign. Most of the artesian wells were not drilled on structures favourable to the accumulation of oil. One or two were, but they were drilled long ago with unsuitable rigs and by men who were not trained to note the signs of oil. Moreover, once the hole fillted with water the oil would have had to come in against the pressure of the water column in the bore ; and, of course, the structures may not contain oil.

It is impossible to generalize about the effect of water circulation on the accumulation of oil. Krampert (1934) makes some statements concerning the effect of water circulation on distribution and accumulation of oil in Wyoming, Colorado and New Mexico which, no doubt, apply to several areas in Australia. Krampert considers that in the Rocky Mountains region " water circulation is probably a necessary adjunct to oil migration ", but he also reports that " fully 90 per cent. of the structures in the region have been adversely affected by being either completely or partially flushed ". His general conclusion about the area may be quoted :

> " Water circulation in the reservoir sands prevents accumulation of oil and gas in structural traps, when the direction of movement is from the structures toward the basin in which the oil and gas originates. Conversely, accumulation is stimulated when the water movement is from the basin toward the structural trap."

Having thus somewhat sketchily examined the geological conditions in which oil occurs, we may now turn to our second question : Using the criteria deduced from this examination, what conclusions may be drawn concerning the oil possibilities of the sedimentary basins of Australia? We shall see that our main difficulty in answering this question is that we do not know enough about the geology of the basins, and particularly of the subsurface geology in their deeper parts.

In a first appraisal of potentialities, the very general knowledge that we have of the geology of large parts of Australia may be adequate, but the nearer we get to an attempt to assess resources, or indeed, to outline with some precision the areas to which we should give detailed attention, the more we realize how lacking we are in detailed knowledge of the geology of Australia.

I can prove this best by some illustrations from geological investigations of large potentially oil-bearing areas of Western Australia with which I have been personally associated.

The broad outline of the geology of the Carnarvon Basin was established by the Gregory brothers between 1848 and 1861, and by Gibb Maitland between 1911 and 1919. These men did wonderfully good work under very difficult conditions. I am not finding any fault with their work, but it is astonishing, nevertheless, how much has been added to the geological picture since their day.

F. G. Clapp, though he sadly underrated the oil possibilities of the Carnarvon Basin (1926*a*, 1926*b*), made a notable contribution to knowledge by discovering the Cape Range anticline and recording that it consisted of Tertiary rocks (1925).

Rudd and Dee, in 1932, named, described and mapped for the first time a number of formations in the Permian along the Wooramel River. It has since been shown that these formations occur throughout the Carnarvon Basin.

Condit and Rudd, in 1934, showed that the white siltstones which are such a conspicuous feature of the geology of the area are Cretaceous and not Jurassic.

In 1934 (and again in 1935 with Dr. Washington Gray), I spent a considerable time in the area and discovered much that was new, including:

(*a*) That there was not merely one glacial boulder bed but a thickness of over 2,000 feet of fluvio-glacial deposits including at least eight distinct boulder beds and fossiliferous marine deposits;

(*b*) that the Permian section included considerable thickness of shale,* much of which was dark in colour;

(*c*) that the Permian formations thicken from south to north;

(*d*) that there is an angular unconformity between the Cretaceous and the Permian.

Although it seemed that by 1935 the general geology of the area was fairly well known, it can now be seen that all the work that had been done, including my own, amounted only to reconnaissance and not very detailed reconnaissance at that.

It was not until 1948 that systematic detailed work was begun by the Commonwealth Bureau of Mineral Resources. This resulted in many important modifications and additions to the knowledge of the Permian and to the discovery of fossiliferous marine rocks of Devonian and Carboniferous age. These additions to knowledge so changed the geological picture that they led to re-orientation in the views held by Caltex Oil Company (which itself had done some work in the area) concerning the oil possibilities of the Carnarvon Basin. Mr. Follis, Vice-President of Standard Oil of California, when he announced the discovery

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* It is curious that such an experienced observer as Clapp (1926*b*) should have tried to "explain away" references to the occurrence of shale in the Carnarvon Basin when at the same time he published a list of bores ranging in depth from 523 to 3,011 feet and yielding flows of water up to two million gallons per day.

of oil in Rough Range No. 1 well, stated: "It was the extensive exploration efforts of Australia's Department of National Development which led to the leasing of widespread acreage now held by Caltex and Ampol. This work was what encouraged Caltex to return to Australia in the hope of bringing in the Commonwealth's first discovery." (*The West Australian*, 5th December, 1953.)

A similar story could be told about the results of detailed work by the Bureau of Mineral Resources in the Fitzroy Basin. Here, not only has it been proved that the reported showings of oil in bores put down at Price's Creek in 1922 were genuine, but that they occur in limestone of an age—Ordovician—whose presence has never been recorded or even suspected in Western Australia. Not only that, but it has been shown that marine rocks of uppermost Permian and lowest Triassic are present. This is the first record of the occurrence of marine Triassic on the Australian continent.

The lesson to be learnt here obviously is that one cannot begin to discuss Australia's resources of petroleum, or even the possibility of its occurrence in much of Australia, because there is not enough geological information available. It may be thought that these remarks apply only to the remote areas to which I have just referred, but this is not so. Clearly the remarks apply most forcibly to those areas, but there are also serious gaps in our detailed knowledge of the geology of the sedimentary basins of eastern Australia.

Australian stratigraphy suffers from a long history of generalizations because, except in a very few areas, there has been no economic objective to provide the incentive necessary to work out the stratigraphy in detail. Two simple illustrations may be given.

So great an authority as Sir Edgeworth David stated the commonly held view when he wrote (1923) that the red beds of the Narrabeen Group provide the rich soils upon which the citrus orchards of the Gosford district are established. In fact the citrus orchards are not established on soils derived from red beds and the area where these beds crop out to the north and east of Wyong is some of the poorest country in coastal New South Wales. This area is traversed by a railway and a highway connecting the two largest cities in New South Wales. The red beds are exposed at the south end of the cutting at Wyong railway station, where they have a definite southerly dip. Moreover, in a bore at Ourimbah (N.S.W. Mines Department, 1888)—in the heart of the citrus growing region—the first red bed was intersected at a depth of 447 feet. Yet the view expressed by David remained current until the area was mapped by Reeves and myself for Oil Search Ltd. in 1935.

Detailed work carried out in recent years by Miss Crespin and me (1952) in the Torquay area 50 miles south-west of Melbourne, has shown that two stratigraphic units of the Tertiary which, for many years, have been regarded as distinct—the Janjukian and the Balcombian—overlap each other.

It is worth stressing that nearly all this new information has been revealed by examination of rocks at the surface. Many of the areas which are of interest as possibly containing oil are basins or parts of basins covering large areas and have never been tested by deep boring. In many places there is not enough evidence upon which even conjecture can be based as to what rocks lie deep beneath the surface. For example

(*a*) What is the lower part of the Permian like, and what underlies it, beneath Sydney?

(*b*) What underlies the Tertiary rocks at the Victorian-South Australian border, or the structures it is proposed to test near Woodside, Victoria?

(*c*) What underlies the Mesozoic rocks of the Great Artesian Basin, particularly to the west and south-west?

To me this last is one of the most fascinating unknowns in the search for oil in Australia.

Answers must be found to these and many other questions before we can begin to express any reliable opinion on the prospects of finding oil in many parts of Australia.

The first requisite is reliable geological maps on a scale of not less than one inch equals four miles. Happily the preparation and publication of these maps on a co-operative Commonwealth-States basis is already under way, but it will be many years before they will be available in large numbers. These, of course, are not the only geological maps available. State Geological Surveys have been publishing maps for many years, but the four-mile map series represents the first attempt to bring together geological information systematically on an Australian wide basis.

The second requisite is a series of geophysical profiles—magnetic, gravity and seismic—supplemented to the greatest extent possible by scout drilling.

Magnetic surveys can be, and are being speeded up by the use of airborne equipment, but gravity and seismic surveys are relatively slow and seismic more so than gravity. Nevertheless, we would reach our goal more quickly if we followed this methodical approach. As it is, some companies are going ahead with test drilling without having found out anything more than can be deduced from geological surveys of the surface. Moreover, some of this drilling is being done in areas where unconformities exist and where the structure at depth is unknown. A few simple illustrations will indicate how foolish a procedure this is.

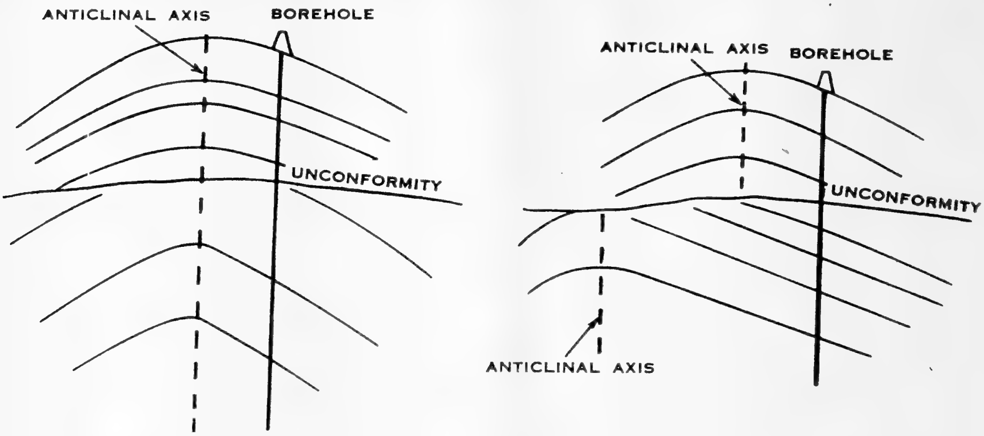
Figure 2 includes three sections across an anticline underlain by an unconformity. In Figure 2.1 the anticlinal axis continues through the unconformity. A well put down to test the surface anticline will be correctly placed to test the anticline below the unconformity. In Figure 2.2 and 2.3, however, a well sited so as to test the surface anticline will be off structure in case 2.2 and will pass from an anticlinal to a synclinal axis in case 2.3. The dip of the beds above and below the unconformity in cases 2.2 and 2.3 are the same and, therefore, determination of dip will provide no clue to the fact that the structural conditions below the unconformity are different from those above it.

This brings me to my next point. Most of the drilling for oil in Australia was done before the modern techniques of geophysical surveying, whether from the surface or in bore holes, were developed; certainly they were not then available in Australia. However, these techniques are available now and there is no excuse for not using them. The structural conditions I have just illustrated can be worked out by geophysical surveys, the results of which may also provide other evidence of value in working out the subsurface geology.

Magnetic methods are useful where the buried ridge type of structure is suspected, particularly if the basement ridge is made up of rocks with relatively high magnetic susceptibility, e.g. basalts. Gravity methods are also useful for elucidating this type of structure and for giving a measure of the probable thickness of sediments above bedrock.

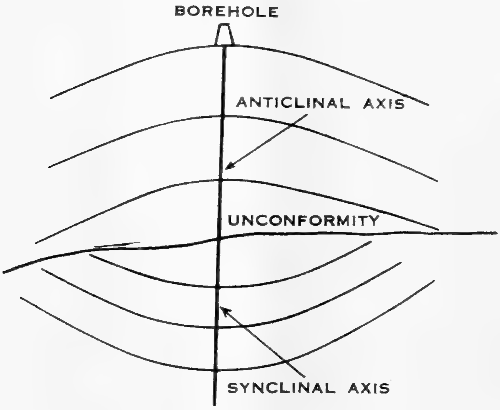
However, it is the seismic method that has been found most useful in exploration for oil, because it provides a means of actually mapping structures beneath the surface. A good example of the value of seismic surveys is provided by a traverse by the Bureau of Mineral Resources across the Giralia anticline in the Carnarvon Basin (Figure 3). It will be seen from the illustration given that the survey confirmed the existence of an unconformity between the Cretaceous and Permian rocks (see page S9) and showed that the structure below the unconformity extended to considerable depth.

Geophysical logging of bore holes is now standard practice. The electrical characteristics generally logged are resistivity and self-potential. With a single-electrode probe, logs of resistivity and potential are recorded simultaneously and are useful for correlation and identification of geological strata.



1. Borehole in same structural position above and below Unconformity

2. Borehole well down flank below Unconformity as compared with position above it.



3. Borehole on Anticlinal Axis above Unconformity passes into Synclinal Axis below it

Fig. 2. Structure above and below Unconformity.

Multi-electrode resistivity logging techniques provide the possibility of making a quantitative interpretation in terms of the porosity and saturation of reservoir sands.

Gamma-ray logging records natural radioactivity of sediments. Neutron logging records the gamma-ray activity artificially generated in the sediments by neutrons emitted from a source lowered into the hole.

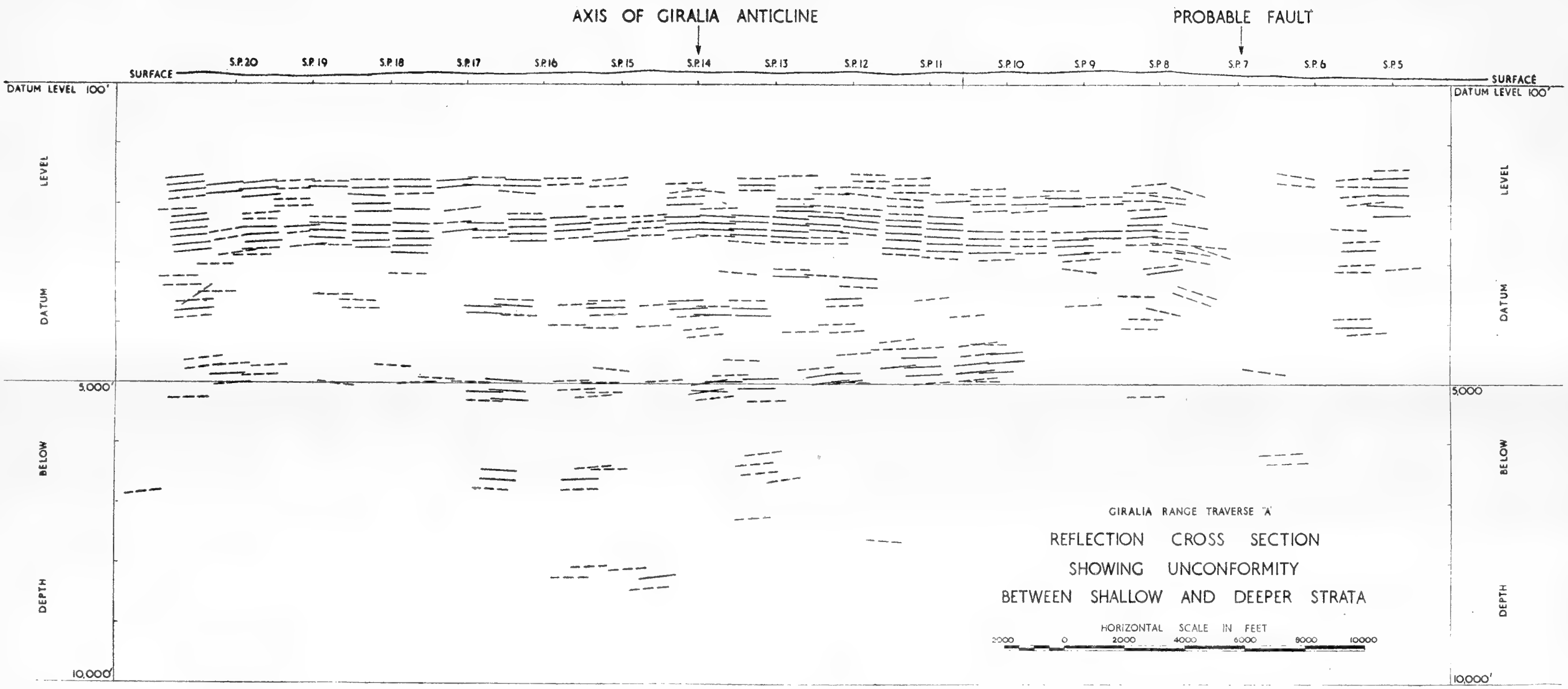


Fig. 3.—Traverse across Giralia Anticline showing unconformity. The unconformity lies at a depth of approximately 3,000 feet. It will be noted that in several places the dips (indicated by broken lines) are not parallel above and below the surface of unconformity.

In general, relatively high natural radioactivity is shown by shales, particularly oil shales, and by bentonite and volcanic ash. Low gamma-ray activity is shown by pure limestones, dolomites and quartz sands. Absolute identification of formations is generally not possible from a gamma-ray log but the log is useful in areas where the general features of the stratigraphic section have already been established.

The chief value of the neutron log lies in the fact that the gamma-ray output of rocks during irradiation with neutrons is closely related to hydrogen content of the rock. Low response signifies high hydrogen content which might imply presence of water- or oil-saturated formations.

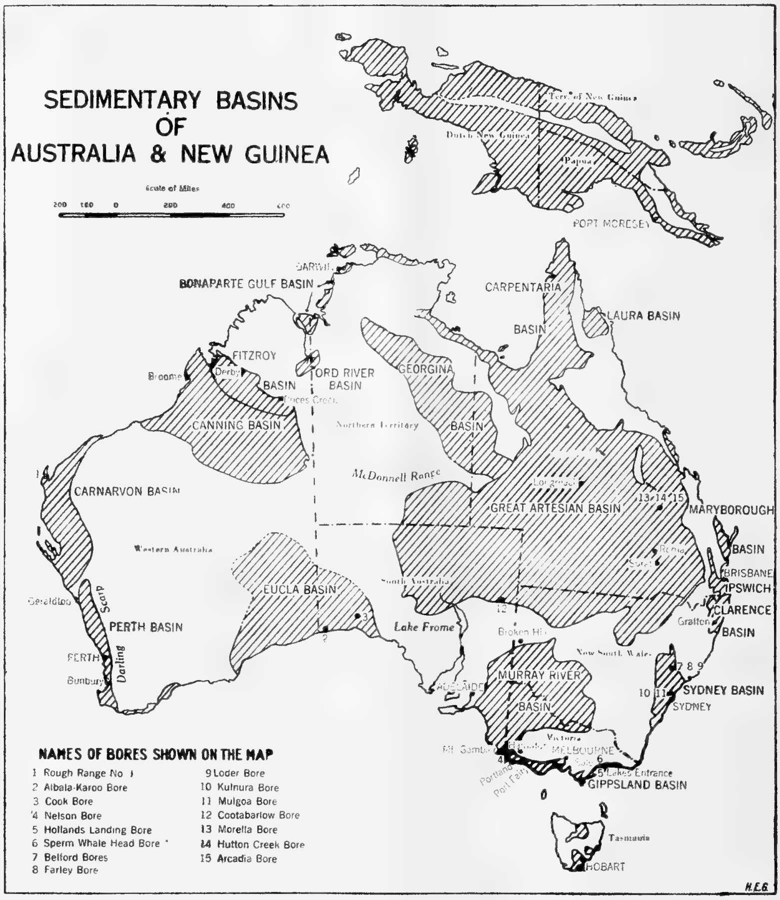


Fig. 4.

It is to be hoped that the government departments responsible for the administrative oversight of the current oilfield exploration programmes will do all they can to ensure that modern exploration survey and drilling techniques are used.

It is to be hoped also that they will see to it that all companies keep adequate records and samples which should be available as a permanent reference because, undoubtedly, in the future ideas will undergo change and interpretation of evidence will be revised many times.

Having stressed the difficulties in advance we may now go on to discuss some of the sedimentary basins that may be considered as having oil prospects. This discussion will be somewhat uneven because I wish to avoid repeating most of what was said in my address to the Australian Institute of Mining and Metallurgy. It is proposed to refer to

(1) Carnarvon Basin,
(2) Bonaparte Gulf and Ord River Basins,
(3) Fitzroy and Canning Basins,
(4) Gippsland Basin,
(5) Sydney Basin;
(6) Great Artesian Basin,
(7) Papua.

CARNARVON BASIN.

There is no part of Australia where the geological conditions outlined earlier in this address are so well met as in the Carnarvon Basin. The geology of the area is briefly described in my address to the Australian Institute of Mining and Metallurgy and a report on it by Mr. Alan Condon, Acting Chief Geologist, Bureau of Mineral Resources is in the press. Here I wish to add only some further speculation concerning the origin of the oil struck in Rough Range No. 1 well.

The three possibilities discussed in my address to the Australian Institute of Mining and Metallurgy were:

(1) Birdrong Formation,
(2) Formation above the Birdrong—the Muderong Shale,
(3) The Palæozoic rocks.

Possibility (3) was favoured with a preference for the Permian, but in the light of further study of published work, some of which has been referred to in this address, it seems at least as likely that the oil formed in the eroded surface of the Palæozoic from material deposited in the early Cretaceous seas, and that later flushing by water may have played an important part in determining the emplacement of oil in structural and, perhaps, other traps. The reported occurrence of oil and gas in shale in Cape Range No. 1 well (Shothole Canyon) suggests that the possibility of origin in the Cretaceous cannot be excluded.

If the oil did originate in the Permian rocks that underlie the Birdrong at Rough Range, experience suggests that the source should be sought first close at hand to the east, that is in the opposite direction to the movement of the artesian water.

Those of you who have been to Rough Range or have seen samples of the oil will know that it is not fluid at surface temperature. It is, of course, quite fluid at the rock temperature at a depth of 3,605 feet. It is conceivable, therefore, that during the geological past the oil may have existed in a non-fluid state and that it only began to migrate (or began to migrate again) and collect in commercial quantities with the rise in rock temperature due to depth of burial; at the least, this must be a factor to be taken into consideration in examining the mechanics of the accumulation of oil.

BONAPARTE GULF AND ORD RIVER BASINS.

In my Australian Institute of Mining and Metallurgy address I referred to the fact that seepages are still active in the Ord River area and that they appear to be bringing up an oil residue from the underlying rocks which, in this area, may be basalt or Proterozoic sediments. It was stated that the view was held that the oil possibly originated in Middle Cambrian sediments and later found its way down into the basalt, whence it is now moving upwards again. Since that address was given I have seen for the first time the section of Proterozoic rocks in the Ord Valley. These rocks include a considerable thickness of dark-coloured shales which dip at low angles and are not metamorphosed; in fact, a Sydney geologist would be pardoned for mistaking them for Wianamatta. It is known that the shales are marine in origin (Traves, 1954) and, therefore, despite their great age they cannot be excluded from consideration as source rocks. Accordingly, I suggest that these shales may be the source of the asphaltite now found in the Cambrian basalts, and that they have to be taken into account in considering the oil prospects of several parts of Australia, e.g. the Fitzroy and Great Artesian Basins.

Fitzroy and Canning Basins.

In my earlier remarks on these basins there was an inference that the prospects of the area rested mainly upon the possibility of oil having been formed in the fossiliferous marine rocks and having remained therein or accumulated at unconformities. There are two points I wish to add here:

(1) That the possibility of the occurrences of oil at unconformities should also be examined in the light of the abundant information from other countries to some of which I have referred in this address. Unconformities of the type that have produced oil in other countries are present between the Proterozoic and the Ordovician, the Ordovician and the Devonian and between the Devonian and the Permian. The conditions that prevailed when the Permian deposits were laid down upon the Devonian reef structures must have been generally similar to those that prevailed when the Jurassic deposits were laid down upon the Mississipian in western Canada and north-western United States.

(2) For reasons outlined in discussing the Ord River area, the unconformity between the Palæozoic and the Proterozoic cannot be excluded as a possible target in drilling for oil.

Gippsland Basin.

Renewed interest in this Basin probably makes it worth while to speculate further concerning the origin of the oil and of the bearing of the conclusion reached on the possibility of finding oil in commercial quantities. The shaft that was put down by the Commonwealth Government on the recommendation of Mr. Leo Ranney provided an opportunity for examining the glauconitic sandstone in which most of the bores in this area struck oil. The sandstone is not known to crop out anywhere in Gippsland. Examination of the crosscut from this shaft strongly suggested that the oil occurs in small lenses and the probability, therefore, is that the oil originated in the lenses themselves or in the adjacent rock in much the same way as is suggested for the oil sands of Goose Creek, Texas, and other similar fields. Mr. L. C. Noakes (1947), who, with Mr. R. F. Thyer made a special study of the distribution of the oil in the sand, agrees with this conclusion.

Below the glauconitic sandstone at Lakes Entrance there are 6 feet to 68 feet of sandstone from which large flows of artesian water are recorded. The meagre evidence available suggests that these are estuarine. At other localities along the Victorian coast the basal Tertiary beds are Coal Measures (Eastern View) or sparsely fossiliferous marine sandstones (Pebble Point). Nevertheless, in places source material may have been deposited on the basement rocks, with the encroachment upon them of the Tertiary sea, perhaps down dip in a facies not seen in outcrop. It is highly probable, however, that if this happened most of the oil would have been flushed out of the sands at such places as Lakes Entrance by later incursion of fresh water. It may be profitable to examine the direction of flow of the water and whether the possibility exists for oil to have been held in structural or stratigraphic traps in the direction of that movement.

There are several places along the Victorian coast where the contact of the Tertiary and Jurassic rocks can be seen. At none of these places is there any evidence of significant pre-Tertiary, post-Jurassic folding, so that it seems that fold axes in the Tertiary will be co-planar with those in the Jurassic. This means that wells can be sited so as to test the possibilities of the Tertiary, and of the surface of unconformity between the Tertiary and the Jurassic for oil, and of the Jurassic for dry gas. I do not know enough about the regional geology to venture any opinion as to merits of any test being continued through to the rocks underlying the Jurassic.

SYDNEY BASIN.

" Tests so far made have provided valuable geological information but otherwise cannot be regarded as having done any more than narrow the area of search for oil and gas. Hopes for the discovery of oil and gas now depend upon a suitable structure being found, which can be proved to extend through the Permian, and upon the Permian being in more favourable facies (a reasonable hope) in the deeper parts of the basin." (Raggatt, 1954.)

Certain conclusions may be drawn from an examination of the palæogeography of the Permian (see Figure 5). In the absence of information from deep bores there is an element of conjecture in drawing the boundary of the " Lower Marine " sea and the area of deposition of the Greta Coal Measures ; but the available evidence does not allow a great deal of room for error and the boundaries shown in Figure 5 are probably sufficiently close to the truth to allow the general inference that the northern part of the Basin has far better prospects than the southern part. Taking into consideration the comments made concerning the results of earlier drilling, the area with best prospects would appear to be that bounded approximately by lines drawn between the following places : Muswellbrook, Newcastle, Wollongong and Springwood. Isopachs of the Newcastle Coal Measures and of the " Upper Marine ", based on the results of drilling, suggest that these two units are thickest in the area outlined, so that the prospects of finding oil and gas in the upper part of the Permian are better in this part of the Basin than elsewhere.

An examination should be made of the pre-Permian rocks around the Basin to see whether any useful conclusions can be drawn as to the kind of rocks that may be expected to underlie the Permian in the deeper parts of the Basin. If, for example, the conclusion were reached that the Permian is underlain by Kuttung and Lambian, deep drilling would be a hazardous venture ; but if the Permian is underlain by Burindi and by Devonian and Silurian rocks such as occur in the Yass district, deep drilling would be well worth while.

GREAT ARTESIAN BASIN.

Strictly speaking the Great Artesian Basin includes only the area of Mesozoic rocks in which artesian water is found, but in discussing the oil prospects it is usual to include the surrounding areas, if only for the reason that the opinion is widely held that the oil and gas found in the Mesozoic rocks came from rocks of the same age as those found in outcrop around its margin (Woolnough, 1931).

The search for oil and gas has so far been restricted to two objectives : (*a*) testing the lower Mesozoic in the Artesian Basin area itself for gas and oil ; (*b*) testing domes in the outcropping Triassic and Permian in the Springsure-Rolleston area about 150 miles north of Roma. I have little to add to what I have said about this work in my earlier address. So far as Springsure-Rolleston is concerned, it is suggested that unless regional studies disclose some good reason for drilling one of the other structures, it would appear preferable to test further the Arcadia Dome. The Arcadia bore yielded a large flow of gas. It is true that much of the gas was carbon dioxide, but the presence of this gas in large quantities is not unusual in oilfield regions, e.g. Montana and Mexico.

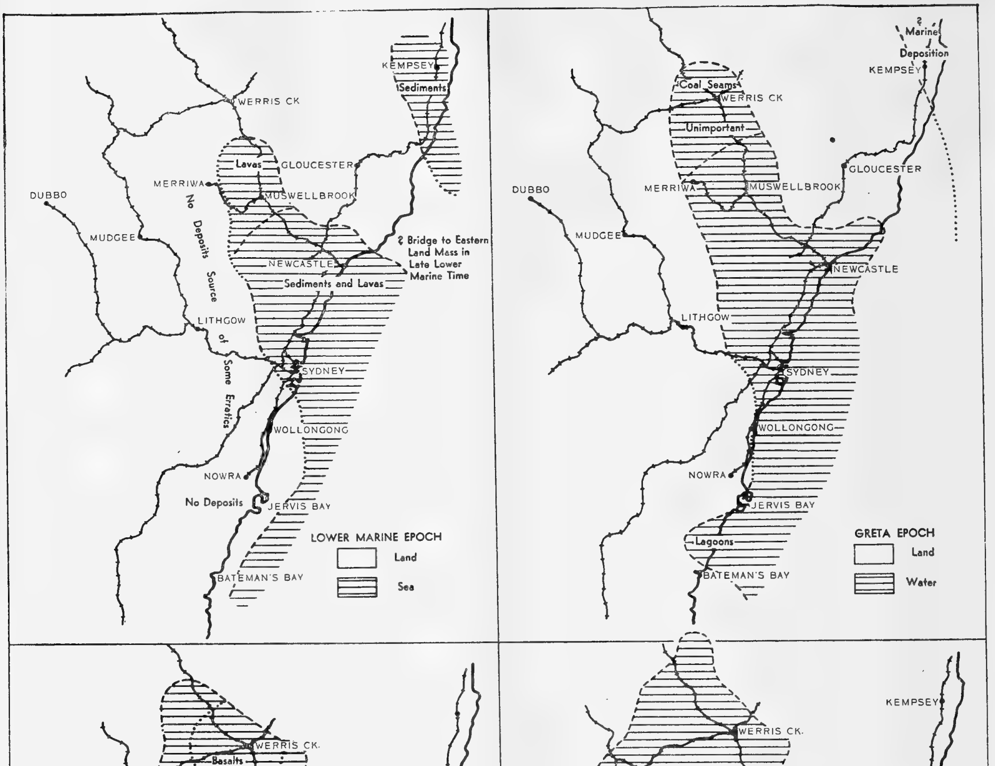


Fig. 5. Sydney Basin-Palaeogeography of Permian.

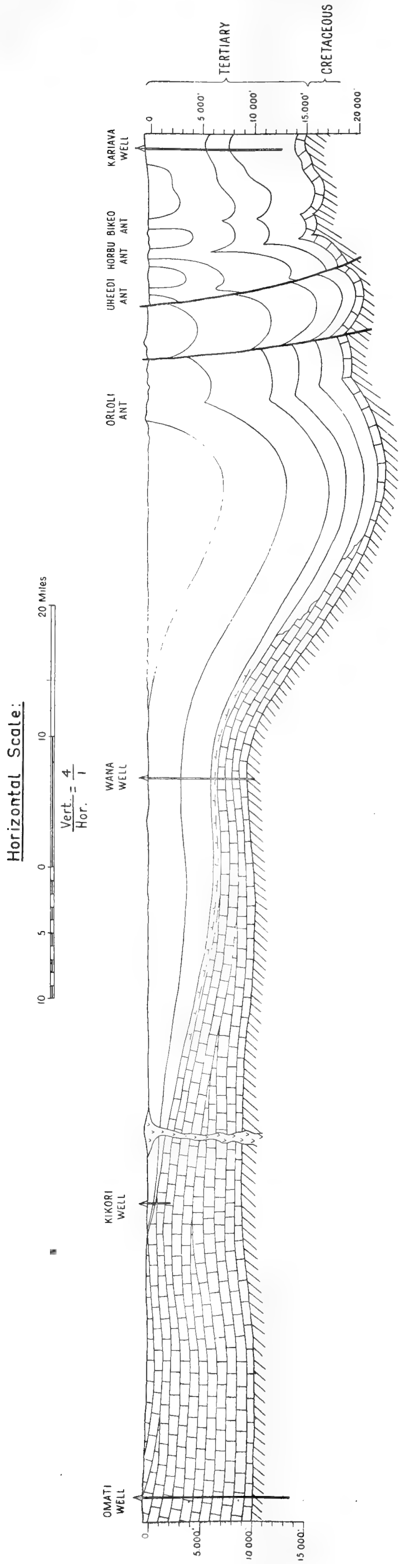


Fig. 6. Schematic Cross Section Omati-Wana-Kariava Papua

The Arcadia Dome has not been geophysically surveyed. This should be done and at least one other test well drilled before it can be said to have been adequately tested.

Nothing has been done so far to investigate the pre-Mesozoic geology of the western and south-western part of the Basin.

The Amadeus trough to the south of Alice Springs is 400 miles long and 150 miles wide. It contains sediments ranging in age from Upper Proterozoic to Ordovician. The Proterozoic rocks include shale, limestone and dolomite. The Cambrian which is upwards of 3,000 feet thick, consists of shale, limestone and sandstone. The Ordovician is predominantly sandy. Its thickness has been estimated at 6,000 feet; this is an overestimate, because allowance has not been made for repetition by faulting.

These rocks may extend eastwards under the Mesozoic rocks of the Artesian Basin. If so, in addition to their own potentialities for oil there may be surfaces of unconformity overlain by marine sediments which should be investigated for their oil possibilities. Obviously, this is a task which could be undertaken only by government or by a company of wide experience and adequate financial resources.

Papua New Guinea.

Principal interest centres upon the test drilling by two companies: Island Exploration Co., Pty., Ltd., and Australasian Petroleum Co. Pty., Ltd. Between them these companies have spent nearly £12,000,000 on the search for oil in Papua-New Guinea.

For some considerable time, and until recently, the activities of Australasian Petroleum Co. Pty., Ltd., have been concentrated in the geological structure known as the Aure trough. This is a deep depression named after the Aure River, a tributary of the Purari. Drilling in the trough has disclosed a thickness of at least 15,000 feet of Tertiary rocks, predominantly argillites of Miocene age. It is highly probable that beneath the Tertiary there are considerable thicknesses of Cretaceous, Jurassic and Permian rocks. Very deep drilling would be required to test these rocks and it is not likely to be undertaken for a long time.

Six holes, ranging in depth from 4,721 feet to 12,621 feet, were put down in the Aure trough by Australasian Petroleum Co. Pty., Ltd. Not only were they "dry holes", but they failed to reveal suitable reservoir conditions. For this reason the centre of interest has now moved to the country west of the trough where the Miocene is in limestone facies.

Island Exploration Co. Pty., Ltd. has always been interested in this tract, so that there are now two large companies drilling to test similar objectives. Figure 6 illustrates what these objectives are: to locate and test structures where the Miocene limestone and/or the Cretaceous are overlain by suitable cover rocks.

Oil seepages are common in outcrops of the Cretaceous rocks on the flanks of the Kubor range and the Miocene limestone has a high porosity. Argillaceous rocks in the Pliocene should provide adequate cover. With the essential conditions so well satisfied, a successful end to the search for oil in Papua is looked for with considerable confidence.

Acknowledgements.

Some of the information used in this paper has been supplied by officers of the Bureau of Mineral Resources in response to personal inquiries. I am most grateful for this assistance. My thanks are due to the Director, Acting Chief Geologist and draftsmen of the Bureau and draftsmen in my own office for their help in preparing illustrations and lantern slides.

I also wish to thank the Australasian Institute of Mining and Metallurgy for making available the block for Figure 4 and Australasian Petroleum Co. and Island Exploration Co. for permission to use information on which Figure 6 is based.

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OIL PRODUCTS AND THEIR UTILISATION.

By Professor Hunter.

The word " lamp " is derived from a Greek word meaning a torch. A torch was the earliest source of artificial light known to primitive man. The next step in development must have been the utilisation of animal oils and fats in some form of crude lamp. Archæological excavations have revealed that the Egyptians and other ancient peoples used wick-fed lamps many thousands of years ago, and until the beginning of the twentieth century, wick-fed lamps remained the main source of artificial light.

By the middle of the nineteenth century the principal illuminant used in lamps was sperm oil, obtained from the sperm whale.

In the late 1840's the sperm whale fisheries of the world were seriously declining. Sperm oil, due to declining production and constantly increasing consumption, was becoming more and more expensive. Substitutes were being sought. In France and Scotland lamp oil was being produced by the heating and distilling of shale. In America the distillation of coal was employed for its production.

On the 29th August, 1859, a Colonel Drake completed the drilling of a well at Oil Creek, Pennsylvania, in the United States of America, and, after months of wearisome effort, at a depth of 69 feet, he obtained petroleum, from which lamp oil or kerosine could be prepared by a distilling process.

This petroleum was no new thing. It had a history of usefulness to man running back into the mists of antiquity and long antedating the establishment of the modern petroleum industry. Asphalt and bitumens were used as a cement in building the walls of Babylon, and were an article of commerce among the ancient Mexicans. Liquid petroleum, collected from springs, was used as a medicine both internally and externally by many primitive peoples. Crude petroleum was used as a lamp oil in Italy and China before the beginning of the Christian era. Flares from burning gas and oil springs were strange and impressive phenomena having a place in the religious rites of the ancient Persians, Egyptians and Greeks, and formed the central mystery around which grew up that strange sect, the fire-worshippers of Baku and Persia. At this time, in the middle of the nineteenth century, the only question with regard to petroleum as a suitable raw material from which to manufacture lamp oil was the all-important one of quantity. This question was answered with an emphatic affirmative by the developments which followed upon the completion of the Drake well.

Within ten years from the bringing in of Drake's well, which flowed at the rate of 1,000 gallons a day, Pennsylvania was producing 80 million gallons of crude oil a year. A few years later kerosine was to be found in the remotest parts of the world.

By the year 1900 the use of coal gas and electricity had displaced much of the demand for kerosine and brought a gloomy note into the young petroleum industry. In 1900 the motor-car was still a curiosity ; the diesel engine was in its infancy, and aeroplanes did not exist. Largely through foreign demand and an increasing export trade the infant petroleum industry managed to survive until the motor-car engine developed. The motor-car with its gargantuan appetite for gasoline and lubricants, proved to be the greatest of all the economic forces which have brought the petroleum industry to the prominent place it occupies in the life of man today. It may well be said that while the petroleum industry owes much of the galvanizing effect on its progress to the growth of the internal combustion engine, the fact that the petroleum industry alone could produce the necessary fuels and lubricants for this engine contributed in no small part to making the motor-car and aeroplane possible.

In ninety-five years the petroleum industry has grown into the world's largest industry. From the first well producing five tons of oil a day, the industry has expanded till it now produces one million tons a day of oil to supply petrol for over 40 million motor vehicles, each of which consumes on an average about 700 gallons of petrol a year. The industry also supplies the fuel for half the ships of the world and all its aircraft. Today nearly half of the energy used throughout the world is provided by petroleum. In America, 187 million horse-power a year is generated from petroleum products for agricultural purposes alone. All the lubricants which are required to keep the moving parts of every machine in the world from seizing up now come from petroleum.

Principal Petroleum Products.

Petroleum always occurs in the earth along with large quantities of hydrocarbon gases, known as natural gas. On reaching the surface the liquid crude petroleum and this natural gas are separated.

The crude petroleum, which is a black sticky oil, must be refined. This is done largely by the process of distillation. In this process the more volatile components present in the crude petroleum are vapourized and condensed into distillates. These distillates are then given a refining treatment with various chemicals and redistilled to produce such things as petrol, kerosine, diesel oil, lubricating oils and paraffin wax.

The residue from such a distillation process, which is not volatile enough to be vapourized without decomposition, consists of black asphaltic matter and coke. These residual products are utilised for such things as heavy fuel oils, asphalt for road making and petroleum coke for making into carbon black, or may be converted by high temperature treatment to more gasoline and petroleum gases.

The principal products of petroleum and some of their uses are shown in Table 1.

Petroleum Products in Australia.

The petroleum products most largely consumed in Australia are motor and aviation spirit, kerosine, gas oil, diesel oil and fuel oil. In the past, these products, prepared and refined overseas, have been imported into Australia at a cost of approximately £87 million per annum. In the last few years new refineries have been built in Australia, and it is expected that these will be in full production by 1956. This means that our imports of refined products will be materially reduced, and that our imports of crude oil will, of course, be correspondingly increased. It is expected that the demand for refined products in 1956 will actually be satisfied in a large part by the greatly expanding Australian refinery facilities. The import pattern will, in consequence, be considerably changed, and, with the new refineries in operation, the cost of petroleum imports in 1956 should be approximately £60 million per annum, resulting in a saving of some £27 million a year. An additional benefit from the erection of these refineries will be that the dollar content of the oil bill will be reduced, as most of the crude oil to be refined in Australia can be imported from sterling sources.

In Table 2 the expected output from Australian oil refineries has been compared with the Australian consumption of petroleum products. It will be seen from this table that some gasoline and kerosine will still have to be imported to satisfy demands. In the case of fuel oil, however, there will be a surplus of some 850,000 tons per year over and above the present consumption. This fuel oil will be residual fuel oil and can be used for industrial purposes.

TABLE 1

Principal Petroleum Products and Their Uses.

Petroleum gases ..	Household and metallurgical fuel. Chemicals. Carbon black. Sulphur and sulphuric acid. Fertilizers.
Gasoline	Motor fuel. Aviation fuel. Special engine fuel.
Naphthas	Industrial solvents. Lacquer solvents. Paints. Tractor fuel.
Kerosine	Domestic fuel. Illuminant. Signal oil.
Distillate fuel and gas oil	Diesel engine fuel. Furnace oil. Gas making.
Lubricating oil	Machinery lubricating. Cosmetics. Medicinal. Electrical oils.
Paraffin wax	Containers and wrappers. Candles. Matches. Polishes.
Asphalt and bitumen	Road making. Paints. Coatings.
Coke	Carbon black. Electrodes. Fuel.

On the basis of 1 ton of black coal or 2·4 tons of brown coal being approximately equivalent to 0·73 tons of oil, the surplus of 850,000 tons of fuel is equivalent to about 1·2 million tons of black coal or 2·8 million tons of brown coal. This surplus could have a considerable effect on the Australian economy, particularly on that of N.S.W., which is the State mainly producing black coal.

TABLE 2.

Expected Output from Australian Oil Refineries.

Product.	Expected Output in Thousand Tons per annum.	Consumption in Thousand Tons per annum.
Gasoline	2,281	2,492
Gas and diesel oil ..	1,188	1,075
Kerosine	220	458
Fuel oil	1,998	1,156

In 1953 the total consumption of N.S.W. black coal was 13·8 million tons. If the surplus fuel oil equivalent to 1·2 million tons of black coal succeeds in replacing N.S.W. black coal from the Australian market, it will mean a loss of nearly 9% of N.S.W. trade in black coal.

In Table 3 an estimate of the energy available to Australia is shown. It will be seen from this that the total yearly energy available to us, calculated in tons of black coal equivalents, is about 29 million tons. Just over 75% of this is produced in Australia as black and brown coal, the remainder comes from imported oil. The proportion of oil to coal used for energy purposes in Australia has steadily risen since 1936, when 15·8% of imported oil was employed, until today, when this proportion is now 24·2% of oil. With the building of new oil refineries in Australia it could be expected that this proportion could increase considerably at the expense of the Australian coal industry.

TABLE 3.

Estimates of Energy Available to Australia.

(Thousand tons of black coal equivalents.)

Year.	Black Coal.	Brown Coal.	Total Coal.	Oil.	Electricity.	Gas.	Total.
1936–37 ..	11,724	1,296	13,020	2,452	37	28	15,537
1937–38 ..	11,880	1,500	13,380	2,616	40	29	16,065
1938–39 ..	12,612	1,332	13,944	2,822	43	30	16,839
1946–47 ..	14,136	2,448	16,584	3,627	70	46	20,327
1947–48 ..	14,772	2,676	17,448	4,553	77	50	22,128
1948–49 ..	14,928	2,928	17,856	5,358	84	51	23,349
1949–50 ..	14,916	3,180	18,096	6,078	88	48	24,310
1950–51 ..	16,428	3,036	19,464	6,956	97	51	26,568
1951–52 ..	19,176	3,372	22,548	7,562	105	56	30,271
1952–53 ..	18,552	3,372	21,924	7,054	114	57	29,149

The four major uses for black coal in Australia are for metallurgical purposes (particularly steel making), for gas making, electricity generation, and as a fuel for railway locomotives. It is interesting to examine the possibility of these uses for coal in the light of their possible replacement by oil.

Coal is an absolute essential for steel making and cannot be replaced by oil in this regard, so that this market should expand with expanding steel making capacity.

The Australian Gas Light Company of Sydney, the largest producer of town gas in Australia, has recently signed an agreement under which half of its 1956 production of gas will be derived from oil, and it is believed that another project is under discussion which will increase this proportion to about two-thirds. In Victoria the Gas and Fuel Corporation is considering taking some 30% of its gas requirements from an oil refinery close to Melbourne. It would therefore appear that in the future coal for gas making purposes is going to be considerably displaced by oil.

In the field of electricity generation, there is no immediate indication that coal will be displaced by oil, but some of the 850,000 tons per annum surplus fuel oil from the new oil refineries could find its way into this field. At the same time, in Australia developmental work on the utilisation of atomic energy for electricity generation is being given serious consideration, and while atomic power stations are not likely to displace existing coal burning power stations, there is a strong, if remote, future possibility that some of the new electricity generating plants may operate on atomic energy.

It is significant to note that the railway systems in the three south-eastern States of Australia have over 230 oil burning steam locomotives in use at present. In addition, the use of a diesel electric locomotive is about 45% cheaper than that of a coal fired steam locomotive, while the first cost of such an engine is only about 25% more than that of a coal fired locomotive. Already 70 diesel electric locomotives are in operation in Australia, and further conversion to this form of traction will undoubtedly occur in the future. The use of oil for railway operations could therefore displace substantial quantities of coal. In this connection, too, should be mentioned some interesting costs which have been calculated in the United States on the operation of an atomic powered locomotive. An approximate estimate suggests that the first cost of an atomic locomotive will be twice that of a diesel and 2½ times that of a coal fired locomotive. The fuel for atomic powered locomotion would be uranium-235 or plutonium. The price of these materials is secret, but the U.S. calculations have shown that an atomic locomotive would be competitive with a diesel electric even if the price of such fuel was £6,000 per pound against diesel fuel at about 1/– per gallon. It is conceivable, therefore, that atomic power could in the future become a competitor with both oil and coal for railway use.

PETROLEUM AS A RAW MATERIAL.

The most significant development in the petroleum industry during the last ten years, however, has come from its use as a raw material for the manufacture of chemicals, plastics, pesticides, surface coatings, fertilizers, explosives, synthetic fibres, synthetic rubber and detergents.

Synthetic Rubber.

For two decades synthetic rubber was an unrealized chemists' dream. With the loss of Indonesia and Malaya by the Allies in World War II, the U.S.A. in just two years increased her synthetic rubber production from 8,000 to 800,000 tons. This latter figure was almost equal to the maximum world consumption of natural rubber in any previous year. During the post-war years, as more natural rubber became available, synthetic production declined to 400,000 tons. Five major types of synthetic rubber are now produced, and consumption has steadily risen to 500,000 tons in 1951, to over one million tons a year in 1952, while today the world is producing 1·5 million tons a year of synthetic rubber from petroleum as a raw material compared to a production of 1·7 million tons a year of natural rubber. So that we can say that nearly 50% of world rubber requirements is now produced from petroleum.

Fertilizers.

Ammonia and its derivatives, particularly ammonium sulphate and nitrate, are important fertilizers. Ammonium nitrate is also used for explosive and munitions manufacture.

Today these materials are largely synthesized from atmospheric nitrogen by its reaction with hydrogen, obtained from steam and coke or from steam and natural gas.

In the U.S.A. nearly 75% of all synthetic nitrogen production is derived from natural gas. In Australia, our most important fertilizer is superphosphate, made from imported sulphur and imported rock phosphate. Natural gas usually contains hydrogen sulphide. This can be converted to sulphuric acid, which in turn could react with rock phosphate to give superphosphate. Hence, natural gas could help supply Australia's fertilizer requirements and free our national economy's complete reliance upon American sulphur, if such gas contained fair quantities of hydrogen sulphide.

Synthetic Fibres.

In the U.S.A. three out of every four pounds of wool consumed are imported, so that a great incentive has always existed in that country to produce a wool substitute from indigenous raw materials. This has resulted in the recent formation and rapid growth of a synthetic fibre industry founded on natural gas and petroleum as the basic raw materials.

U.S. consumption of synthetic fibres is 556 million pounds a year, compared to 495 million pounds a year of wool. As six square yards of cloth are produced from one pound of synthetic fibres, against two and a half square yards from a pound of wool, more synthetic cloth is produced in the U.S.A. than woollen cloth.

Total sales of synthetic fibres in the U.S.A. are in excess of £500 million per year. Capital investments in plant are in the region of £500 million. Raw material purchases are over £200 million per year, with an annual payroll of £100 million.

Plastics and Paints

Synthetic plastics, resins and surface coatings in paints produced from petroleum as a raw material now total over 150 million pounds a year in the U.S.A. alone, which is greater than the present rate of production of all other plastics.

Synthetic Pesticides.

In this modern age the farmer treats his crops with chemicals through all stages from planting to harvesting. In the U.S.A. over 1,000 million pounds a year of chemical pesticides are produced, of which 50% are derived from sulphur and 30% from petroleum.

Synthetic Soaps.

In no chemical field has development been so spectacular and rapid as in that of synthetic detergents—the so-called synthetic soaps or syndets. Such materials of exceptional wetting, and excellent draining and dispersing power have led in turn to the introduction and development of mechanical dish-washing and home laundering machines.

In 1940 the U.S.A. produced 30 million pounds of syndets, which today has increased to 2,000 million pounds, 65% of which is produced from petroleum.

All this is a symbol of things to come. Gigantic plants are already producing rivers of chemicals, fibres, plastics and rubber from petroleum.

This is changing the economy of whole countries and will profoundly influence world affairs in the future.

In these previous remarks I have tried to indicate briefly something of the history and industrial significance of petroleum products. In order to assess the real value of a petroleum industry and its products to Australia, however, let us first compare the industrial potential of this continent with that of a highly industrialized community—the U.S.A.

THE INDUSTRIAL POWER OF THE U.S.A.

The U.S.A., with 6·5% of the world's population, using 61% of the world's petroleum production and 45% of the world's mineral production, produces 50% of the world's industrial output. It is no accident that has raised the U.S. to the position of the world's leading industrial nation. It is due to an abundance of raw materials and resources vigorously developed and exploited.

Seventy-five years ago about 35 metallic and non-metallic minerals satisfied the needs of an industrial community. Today nearly 100 such minerals are required, of which about 40 are of major significance. In 20 of these 40 minerals the U.S.A. is over 50% self supporting, and in addition possesses important deposits in 30 more.

On the agricultural side, abundant rainfall and high soil fertility ensures adequate supplies of grain, dairy products, meat, fruit, vegetables and natural oils. This in turn has led to the development of large industries based on the processing of these commodities. Vast forests, grown as crops, together with a huge production of cotton, gives plentiful supplies of cellulose to support paper, board, cotton and rayon industries.

Enormous deposits of coal, anthracite and shale ensure the U.S.A. sufficient supplies of energy for at least 1,500 years at the present rate of consumption. With 65% of the world's known reserves of petroleum and natural gas, the U.S.A. has until recently been self-supporting in respect of diesel oil, petrol, fuel oil and lubricants. For the first time in nearly 100 years, however, the consumption of petroleum is tending to become greater than the rate of production.

The rapid growth of cities, industry and agriculture in America has required large water resources which are available.

Two of America's most important deficiencies of raw materials are rubber and wool. The lack of these, at one time serious, has now been overcome by the manufacture of synthetic rubber and synthetic fibres from indigenous petroleum.

The overall picture, then, is that of a country with large natural resources, good rail, road, water and air transportation facilities, adequate manpower and large markets all combining to make a highly industrialized community with a high standard of living.

THE INDUSTRIAL POTENTIAL OF AUSTRALIA.

Australian mineral resources are poor. Our only extensive deposits of metallic minerals are lead, zinc, gold, silver and possibly aluminium. Iron ore is high in quality but low in quantity, with estimated reserves of 250 million tons compared to 10,000 million tons in the U.S.A. Partially deficient in copper and tin, we are unfortunately wholly deficient in phosphorus and sulphur, upon which the whole agricultural economy of the country depends. Australia's only extensive non-metallic mineral deposit is coal, with a reserve estimated at 35,000 million tons, sufficient to last us, at our present rate of consumption, for over 1,500 years.

On the agricultural side, inadequate rainfall with a bad seasonal and geographical distribution combined with a low overall soil fertility result in severe limitations on agricultural productivity. Compared with the U.S.A., with the same land area, Australia has only 400,000 square miles capable of producing crops, against 1,600,000 square miles in America. No vast forests, cotton or rubber crops are available to provide raw materials for large cellulose and rubber industries.

Huge land areas with low rainfall and high evaporation rates mean a deficiency of water resources for both industry and agriculture.

An antiquated rail transport system, poor roads with long distances between settled areas, inadequate manpower and small markets complete a picture of a community unlikely to become highly industrialized.

The discovery of extensive petroleum deposits in Australia could considerably improve our industrial potential and further improve our standards of living. Large discoveries of petroleum could wipe out our £60 million a year bill for imported petroleum products and might even give us a new export trade in these commodities. In addition, such discoveries could create new indigenous industries in fertilizers, plastics, surface coatings, fibres, pesticides, explosives, and rubber by providing the necessary raw materials.

Large immediate expansion of such industries and of a parent petroleum industry should not be expected because of our small capital resources and small markets.

PETROLEUM CHEMICALS.

By R. F. Cane, D.Sc., F.A.C.I.

INTRODUCTION.

William Bell, of American Cyanamid, once said that in his opinion the most useful and beautiful piece of research that any scientific organization could possibly undertake would be to work out some formula by which one places in a test tube a bright idea, together with so many units of labour, so much raw material, so many units of selling cost and so much of market price and popular favour, the solution shaken with government interference and taxation acid added, then the whole boiled for five minutes. If the contents turn green, the project should be proceeded with forthwith—if red, immediately abandoned, and if white, deferred until later.

Of all industries, it is felt that this formula would command the greatest price in petrochemicals manufacture, for, although this scion of the petroleum family has grown from birth to lusty adolescence in a brief 35 years, it has suffered its share of growing pains, and from the annoying habit of the test solution showing all three colours at the same time, alternatively mixed to a dull, muddy grey.

PETROCHEMICALS.

It is first necessary to define what is meant by the term petroleum chemical—or " petrochemicals ".

One journal has defined a petrochemical as a " chemical compound or element recovered from petroleum or natural gas, or derived in whole or part from petroleum or natural gas hydrocarbon and intended for chemical markets ". This definition excludes mixed hydrocarbons used for other than chemicals, and excludes a single hydrocarbon such as butane or iso-octane used as fuel. The meaning of the term is by no means crystallized and at least three organizations in the U.S. are studying a suitable definition of the term petrochemical.

Although many people have expressed disapproval of this pseudo-technical word, some refusing to use it altogether, it is here to stay and to save even further confusion among the semanticists I shall use it without apology.

In the beginning, it is well to realize that petrochemical manufacture cannot be segregated from other fields and placed in a distinct category. It merges with and overlaps the rubber, textile, oil and other industries, as well as being more or less dependent upon them for both the raw material and consumption of product. Many of its processes are not new, but have been borrowed from those used for many years in the coal and oil field, although perhaps the scale of operations is often larger in petrochemicals. This large scale of operation and the high capital costs of plant make the petrochemical industry particularly vulnerable to new discoveries and to fluctuations in markets.

This fact, to a more or less extent, is being felt in some quarters now, where too many producers, anxious to take the cream off the market, have caused an over-supply of certain products. New discoveries can also have far-reaching consequences, rendering obsolete more or less overnight a particular process or product. The general impression gained overseas this year was that the petrochemical industry, having passed the teething stage, and finding the road to success no easier or harder than any other industry, was now taking stock of itself whilst settling down to steady growth.

Organic chemicals manufacture has always been closely associated with the production of fuel, aromatic chemistry had its genesis in the by-products of coal, while aliphatics probably largely arose from a study of combustion itself.

The gigantic tonnage of raw materials used in the manufacture of liquid fuel for power and locomotion has, in turn, meant that large quantities of relatively cheap hydrocarbons have become available as by-products of the petroleum industry, and these are replacing vegetation as a source of raw material for chemicals.

This change from the use of vegetation to petroleum for chemical raw material has been brought about by two factors, firstly, the cheap cost of the hydrocarbons ; secondly, the necessity to reserve crop area for the growing of food, itself a source of human energy. Had this change not occurred, serious inroads would have been made into the world's food to supply the present requirements of organic chemicals for industry.

To give two examples of this : If the U.S. production of methyl alcohol still depended on the distillation of wood, as it did thirty years ago, and not largely on natural or water gas, then an area equivalent to 4% of their total forest land would have to be reserved permanently for the growing of timber to supply their present demands for methanol.

To supply the present world demand for ethylene by making it, not from natural gas but by the older process of the dehydration of fermentation alcohol from sugar, would immediately deprive one-eighth of the world's population of their sugar, excluding molasses.

DISTRIBUTION.

On a world-wide basis petrochemical production may be divided into two groups with respect to the occurrence of natural gas : (1) the countries which have it, (2) the " have-nots ". As an illustration of the " have " countries, the obvious example is the United States, where the production of natural gas for heating and chemical use in 1952 was eight billion cubic feet. This amount is hard to imagine, but when it is expressed as 53 cubic miles one gets an idea of the enormous volumes which are used. Not only about one and a half million tons of ammonia, one million tons of carbon black and 300,000 tons of sulphur were derived from natural gas last year in the U.S., but today something like a quarter of the entire United States chemical industry is based on petrochemicals, and in another decade it may contribute one-half.

England and Australia, on the other hand, would represent the " have-nots " and in the U.K. ethylene, butadiene, carbon black, glycol, etc., have to be made from gases obtained by cracking imported oils, while ammonia is still largely dependent on water-gas from coke.

Let us now look briefly into how these chemicals are produced and what sort of forward picture can be envisaged for Australia. Natural gas, that great storehouse of raw materials for petrochemicals in the U.S., is somewhat variable in make-up, but consists always predominantly of methane, with smaller amounts of ethane and higher hydrocarbons, together with hydrogen sulphide, nitrogen and sometimes helium. The constituents of natural gas are chemically unreactive and therefore are of little use, as such, in chemicals manufacture, except as raw material for such chemically simple structures as ammonia, for which it produces the hydrogen, methanol and carbon black. Methane is now becoming a possible source of acetylene by the Sachsse partial combustion process.

AMMONIA.

Both ammonia and methanol production depend on the decomposition of natural gas or hydrocarbon mixtures from refineries and is accomplished by one of two methods : either natural gas is burnt in a limited supply of nearly pure oxygen to give hydrogen and carbon monoxide, the monoxide removed or converted and then nitrogen added to give the required three times hydrogen : nitrogen ratio, or the gas and steam are reacted together with air to give the ammonia synthesis gas. In either case practice then follows conventional ammonia production, where the synthesis gas is passed over an iron containing catalyst at temperatures up to 1000° F. and pressures between 3,000–15,000 p.s.i.

If nitrogen is not added, the gas can be used directly for methanol production or as a feed to a Fischer-Tropsch synthesis. Very large ammonia plants are operating overseas, using one or other of the above processes and production is as large as 350 tons a day for a single plant, compared with the 10 tons a day for the average plant in Australia.

Increasing amounts of ammonia are being used for direct injection into the soil rather than present Australian practice of using ammonium sulphate as a source of nitrogen. Cyanides are also made petrochemically by reacting ammonia, natural gas and air over a platinum catalyst.

Because of the high pressures used, ammonia plants are not cheap, a reasonably sized plant, say of 75 tons per day, might cost five million.

CARBON BLACK.

Carbon black is also made in large quantities from natural gas by burning it in a limited air supply so as to produce a sooty flame, or by cracking the hydrocarbon so as to form free carbon of the correct physical properties.

In places where suitable gas is not available, as in England, and would be here, carbon black is made from a high aromatic oil, either natural or obtained from the cycle stock from catalytic cracking.

The minimum sized plant that it pays to operate lies between 20 and 25 million pounds per year, and this is about the same size as the total Australian market.

The only other material which I should like to mention among what might be called non-conversion products, i.e. products not made by converting one hydrocarbon to another, either as an end-product or an intermediate, is sulphur and sulphuric acid.

SULPHUR.

Today approximately half a million tons per year of sulphur in the Western world is produced from hydrogen sulphide, either from natural gas or refinery gases. The sulphur so produced is extremely pure and can demand premium price for certain operations.

In cases where the potential sulphur make is not quite large enough to justify sulphur production, or there is a demand for sulphuric acid for fertilizers, hydrogen sulphide can be converted directly to sulphuric acid.

Before we go on to the more complicated picture of what might be termed conversion products, that is hydrocarbon to hydrocarbon to chemical, consider how petrochemical ammonia, carbon black and sulphur fit into the Australian picture.

With the exception of the war years, Australia has been importing ammonia in the form of sulphate since 1929. Now, with a 55,000 tons per year ammonium sulphate plant due for completion this year at Risdon in Tasmania, and possible future sulphate from Mt. Morgan, there is a possibility that Australia may have an exportable surplus of ammonium sulphate, as she did after the 1914–1918 war, when her product had, of necessity, to sell overseas in severe competition with foreign material.

It is thought possible that ammonia will be made in Australia, using refinery gases as a raw material. If this happens it is felt there will be severe competition for the home market, because the petrochemical product can be made at a very much less cost than ammonia derived from coke and steam. If one of the major oil companies decides to erect a reasonably sized plant it may be then uneconomical to operate one or more of the small plants now making sulphate.

With regard to carbon black, as mentioned earlier, the Australian market is about the same size as the minimum economic plant, and unless the present purchasing agreements of the rubber companies for carbon black are altered, the demand for a fraction of this total would not be sufficient to justify the capital outlay and allow economic operation. In my opinion, one can write " not probable " against carbon black.

On the other hand, it is thought likely that, later on, one or more of the refineries now being constructed will recover the sulphur from their gases. The refinery now being erected at Kwinana in W.A. has a crude design capacity of three million tons a year, and this represents something like 50,000 tons per year of sulphur. Of course, only a small proportion of this eventually ends up as hydrogen sulphide, but plants handling as little as 4,000 tons per year have been found to be economically sound. With the increasing application of catalytic reforming and desulphurizing in which all sulphur is removed as hydrogen sulphide, sulphur recovery is becoming increasingly important. In the U.S. about 5% of their total production of six million tons is coming from petroleum and natural gas.

HYDROCARBONS.

Having now dismissed some billion dollars of industry, we return to what can be and is done today with what might be termed conversion products. Although the paraffins, methane, ethane, propane, butane, etc., are not reactive themselves, they can, by means of high temperature decomposition or cracking be converted into the corresponding or lower olefin, which is a reactive compound, suitable for chemical manipulation. These olefins are also present in refinery gases, some in coke oven gas and in oil-gas.

Obviously methane cannot be changed into its corresponding olefin, but quite spectacular results are being obtained by the partial decomposition of methane in oxygen—the so-called Sachsse method for acetylene. In the Sachsse method, methane and oxygen are preheated separately in a special burner and then injected with a high velocity into a combustion chamber, then the gases are quenched or cooled in the matter of two or three thousandths of a second. The raw gas from such operations contains about 10% of acetylene and this can be removed by selective solvents. The residual gas, consisting of hydrogen and carbon monoxide, is used for ammonia production, the nitrogen being obtained by either of the methods mentioned above.

Three such plants are in operation in the States, and more than this in Europe. The disadvantage of this process is the need for an oxygen plant.

Other methods are available for conversion of paraffins to acetylene but none, apart from the Sachsse method, has become commercially important yet.

ETHYLENE.

Normally ethylene is made from propane or ethane or mixtures of these, and less often today recovered from refinery gases, for unless ethylene is present in very large volumes of gas in sufficiently high concentration and without other complications, it is usually cheaper to make it, at about 20% to 30%

concentration, in a plant designed for this purpose, and then separate it, than to separate it directly from refinery gases containing 5% to 15% ethylene, even though these gases may be considered in some ways as waste products of no commercial value.

Here again we meet the very large scale at which these plants have to operate to make them economically attractive. The smallest ethylene plant that it pays to build and operate overseas is, in round figures, 10,000 tons a year. It is relatively easy to make such ethylene and separate it from heavier gases, but it is a problem of separating ethane and ethylene from the lighter constituents, hydrogen and methane, and purifying the ethylene so produced, that demands very large capital outlay and considerable research into technique.

A plant to produce 10,000 tons annually of ethylene might cost half a million pounds, but the plant to purify it after production might cost four to five million pounds, for here one is dealing with not only high pressure, but with technique of handling gases at quite low temperature and separating constituents boiling fairly closely together. This high capital cost is reflected in the need for high throughput. One set of figures taken out in 1951 for cracking propane at 4 c./lb. to ethylene show that at 10 m. lb./yr. cost of manufacture was 7 c./lb., at 30 m. lb./yr. cost of manufacture was 5 c./lb., and only at 60 m. lb./yr. does the cost of manufacture approach 4 c./lb., the cost of the raw material.

About one million tons of ethylene is made annually in America as a raw material for the manufacture of styrene for alcohol, ethylene oxide, glycol, acrylonitrile and a host of other minor products, while the U.S. demand for ethylene is expected to increase to 4000 m. lb. by 1960.

Before mentioning how some of these products are made, let us first see what sort of future they have here. The position in Australia is quite different from that in America, for there are no known resources of natural gas nor proven oilfields to serve as feed for the ethylene plant, the population and consequently the market for ethylene derivatives is very much smaller ; the climate is much milder and the use of glycol anti-freeze, the oldest and most important petrochemical except alcohols, is negligible. Glycol itself absorbs over 60% of a total annual production of 600 m. lb. of ethylene oxide, 75% of the glycol being used directly as an anti-freeze. Also in Australia there is no large volume use of synthetic rubber, alcohol and benzene are cheap and readily available here, there is no need to make them specially. There is no large urban problem of hard waters necessitating domestic synthetic detergents.

At the moment there seems little chance of synthetic alcohol competing with the fermentation product and even today, some million gallons a year of alcohol are blended into automotive gasoline in Queensland and burnt to carbon dioxide and water ; and, unless there were sudden and drastic changes in the sugar industry it would appear that fermentation alcohol would have to become very much dearer for the synthetic product to compete. At the moment the reverse reaction appears a cheaper source of ethylene, that is the dehydration of alcohol to make ethylene, compared with the hydration of ethylene to make synthetic alcohol.

With regard to styrene, it seems that a case might be made for the production of the monomer, all of which is now being imported for the polymerization plant of Monsanto in Victoria. Styrene demands two raw materials, ethylene and benzene. Benzene is available and cheap compared with overseas prices, and ethylene could be made available either by the dehydration of alcohol or from petroleum sources.

The greatest use of styrene, of course, is in synthetic rubber, and today synthetic rubber is the greatest end-product of all petrochemical operations in the U.S., consuming annually about one and a half million tons of hydrocarbon and, not only does the synthetic rubber industry consume over 20% of all petrochemical production, but it, *per se*, represents the largest manufacturer. So far, Australia has not been a large consumer of synthetic rubber, and unless there are changes in the availability of the natural product, or a new type of rubber is discovered with vastly superior properties, it is thought that synthetic rubber production at our scale of consumption is most unlikely for some time.

This being so, one is left with glycol, polyethylene and styrene, and perhaps polyvinyl chloride, as large ethylene consumers. Because of our mild climate we are not forced to use automotive anti-freeze, and this immediately takes the core out of the reasons for glycol production. This lack of demand for glycol and the high Australian chlorine cost renders prohibitive other products based on ethylene chlorhydrin. At the moment the Australian market for polyethylene has not been fully developed and polyvinyl chloride is based on acetylene.

This leaves some five to six thousand tons of consumptive capacity for ethylene, which is far below the minimum scale mentioned earlier, and unless some rich source or cheaper method is found to purify the product to the purity required by most petrochemicals, that is from 95% to nearly 100% purity, it is seen that the immediate future in Australia for ethylene-derived-from-petroleum is rather dismal. In five or ten years time, perhaps, when the demand for polyethylene has increased and, as seems likely, new and improved methods of generation, purification and manufacture of end-product have come about, then ethylene manufacture does seem likely in this country.

As mentioned earlier, the cost of ethylene is predicated by two facts : (1) the relatively high energy consumption per ton of product, it consuming something like 700 times per unit quantity the amount of energy as does a normal refinery, and (2) the high capital cost of plant to handle such ethylene when produced, and thus the necessity for large throughputs.

In the U.S., with its great refinery capacity and ample natural gas and markets, ethylene is usually made by cracking ethane or propane at low pressures at 700–800° C.

In England and Europe the process has been to crack naphtha or gas oil, and in a few places ethylene is extracted from coke oven gas by low temperature distillation.

Ethane may appear the most attractive raw material because, by simple dehydrogenation, only ethylene and hydrogen are obtained, and by-product formation can be kept low. However, ethane requires much higher cracking temperatures than does propane, and cost of transportation of the raw material is prohibitive ; accordingly ethane cracking is confined to places where ethane is found. Propane is easily liquefied and transported ; it requires less drastic temperatures for cracking, but, as it can decompose in several ways, the yields are not as high as with ethane.

In the case of naphtha and gas oil, yields are even lower and there is appreciable formation of by-products which are highly aromatic in nature and are unsatisfactory for recycling, but they can serve as chemical intermediates or, at worst, as fuel. Which ever way ethylene is made the raw gas is purified by either straight low temperature distillation or a combination of this and oil absorption. Mention should be made of the enormous quantities of ethylene made at Hüls by hydrogenation of acetylene from methane from coal hydrogenation gases.

Ethylene is undoubtedly the main building block of the petrochemical industry and occupies first or second place among all the large volume organic chemical intermediates. Figures could be given showing the phenomenal growth of ethylene derivatives, such as polyethylene, ethylene dichloride, ethyl chloride and polystyrene ; for instance, polystyrene production has increased sevenfold over the last seven years, and its production is now about 400 m. lb. per yr. in the U.S. ; polyethylene has soared to astronomical heights in a matter of a few years, and is expected to be the first plastic to reach 1,000 m. lb. annually. Synthetic alcohol is fast replacing the natural product. And, in all, some 2,300 m. lb. of ethylene were used in chemicals' manufacture in the U.S. last year. But quoting statistics in the chemical industry is always a dangerous game : a compound can be counted twice in cases where one organization sells a semi-refined product to another for final purification, and in the extreme the same atom can be counted many times in various stages of chemical manipulation. Nevertheless, as someone has said, " a statistician is a specialist who draws a straight line from an unwarranted assumption to a foregone conclusion " ; we can rest assured that the conclusion here is that the production of ethylene will increase and it will continue to be the mainstay of the petrochemical industry.

About one-third of the production of ethylene is converted to ethylene oxide, and from the oxide to glycol and other materials. More than a quarter of the ethylene ends up as alcohol and about one-tenth in styrene and ethyl chloride. Other miscellaneous products aggregate about one-quarter.

Propylene is usually obtained direct from refineries, especially those with a catalytic cracker, or from the " heavies " from an ethylene plant. Propylene separation is easy and presents no practical difficulties, for most petrochemical operations can tolerate the propane with which it is mixed. The dominating outlet for propylene is hydration to isopropyl alcohol, thence to acetone, methyl isobutyl ketone and the methacrylates, while a fast-growing demand exists for the tetramer for alkylation with benzene to give Alkane, the base of detergents such as Surf and Tide. The latest use for it is to make cumene as an intermediate for phenol.

Butenes are used predominantly for synthetic rubber, for which they are dehydrogenated to butadiene.

Again reverting to the Australian picture, it seems likely that one or other of the cracking plants now being erected will produce enough propylene to justify the manufacture of isopropyl alcohol and acetone, etc., and perhaps tetramer, but of course the economics of running a series of small diverse plants are not as favourable as one large unit producing a single product, and for this an overseas market would have to be found—the final decision rests with the oil companies.

Catalytic reforming will potentially double our supply of benzene but, as Australia is already disposing of over half the present output as automotive fuel, the picture will be little altered. Toluene and toluene-containing solvents, which have been short for some time, should become readily available, and there will exist a potential supply of xylenes for the production of phthalic anhydride and terephalic acid should the need arise.

As an overall picture, it seems that Australia, for the time being, will not see a rapid growth of petroleum chemicals production such as has happened in the last ten years in the U.S., and this is simply because sufficient market does not exist here and our Pacific neighbours, although many in numbers, have not the *per capita* demand as has the Western world. What I feel will happen is that certain spearheads will be thrust into this absorbing field and then, as our population and demand increases, the flanks will be brought into action.

The petrochemical industry, whether as a whole or some particular facet, by reason of its phenomenal growth, has had a particular allure for the individual, group or company, and this has, to a certain extent, been fostered by the popular technical press. However, there is no doubt that petrochemicals are no easy road to large profits or early retiring age. Many people are included to draw loose comparisons between the petroleum refinery and the petrochemical plant, and although this may be so as regards pretty photographs, to a large extent the resemblance ends there.

The average petrochemical installation is about one-tenth the size of the average refinery, and consequently its investment cost per unit of product is three to four times as great. Figures taken out by the Chase National Bank in New York show the average investment cost in refineries is about 125 dollars per daily gallon, whereas in the petrochemical industry it is greater than 400 dollars. Service requirements are also much greater than in refineries, ranging from 10 to 100 times. There is also the problem of transportation of finished product which is usually more difficult than pumping gasoline or transporting it in rail cars.

Nevertheless, while this field is indeed a fertile area for the properly trained and equipped, entry into it must be made slowly and with caution. The large capital investment, rapid obsolescence of plant and possibly product, high energy and service requirements and the large sums which should be ploughed back into research and development to maintain a competitive position in this rapidly changing picture are a few of the obstacles in the petroleum chemicals race and even though a synthesis may look extremely attractive on paper, the scaling-up of this a millionfold may be quite another story.

THE ECONOMIC EFFECTS OF AN OIL INDUSTRY ON THE AUSTRALIAN ECONOMY.

By Professor C. Renwick.

Any examination of the economic effects of an oil industry on the Australian economy must start with a review of the state of the economy at the moment. In the last year or so Australia has shown considerable stability in its general economic conditions, with retail and wholesale prices remaining fairly stable and with an increase in national income of 5%. This means that there was a real gain in terms of goods and services for consumption in the economy. Total wages and salaries rose by about 7%, business and professional income by about 6%, and overall there was a personal consumption expenditure which was 10% greater than in the financial year of 1952-1953.

These figures show, then, a healthy stability in the economy in which a wide range of industries held production at a high level. Output from the iron and steel, coal, copper and zinc industries approached or passed previous figures, and there was a big increase in the manufacture of many domestic articles. This was reflected in a considerable increase in the volume of retail trade. Markets widened, too, but our exports fell in money value even though they remained at a relatively high figure. I think we can sum up the period in the words of the Federal Treasurer : " 1953–1954 was a period of stable and widespread prosperity ; perhaps never before in our history have we had a year to equal it."

The prospects for the economy depend upon several factors—firstly on the stabilization of this high level of production and consumption ; secondly, on the degree of national and private development ; and thirdly, on economic and business conditions abroad.

Taking up the last of these first, it is an interesting fact that, despite an economic decline in the United States, the prosperity of the rest of the world has been maintained, giving the lie to the remarks that : " When America sneezes, the rest of the world catches pneumonia ". For more than a year America has shown signs of economic malady, in fact has been sneezing vigorously, but so far the rest of the world has failed to give, by and large, so much as a polite cough. Industrial output in the United States is down by 10% on her high level of a year ago, but an industrial boom continues in Western Europe.

One reason for the survival of prosperity in the rest of the world in the face of the American recession is the degree to which America has cut herself off from world trade. The flow of dollars is now drying up in some respects, but continues for armament and development of " backward areas ". Another reason is that big business in America, in such fields as steel and oil, is now determining its own price stability. The American industrial structure is such that giant firms dominate the various heavy industries, and these giant firms restrict output and stabilize prices in order to conserve their position. If we take the case of the production of oil, for example, the surplus that could have developed has been controlled by cuts in the production of crude oil both at the government level, in the case of the Texas Railroad Commission, and by a voluntary cut of refinery output by big companies themselves. In this way they have prevented the appearance of embarrassing surplus stocks. These cuts are cushions against over-production following on over-investment, and are stabilizing in some degree the American economy.

I have said a good deal about the case of America because she is regarded as one of the determining factors in world economic progress, being the most substantial and diversified industrial producer and consumer. So far we have not caught cold from America, but the germs are in the air all the time ; should our resistance be lowered, then the Australian economy will be seriously affected.

At this stage, then, we should look at the health of our economy with a view to discovering what signs of stress are apparent. One thing that springs to the eye immediately is the growth of secondary industry behind tariff walls, which we must examine in a moment, another is unhealthy financial speculation connected particularly with oil and uranium. Consideration of these points brings us back to the first two of the three conditions of stability which I mentioned a few moments ago.

The general feature underlying tariff policy at the moment is the inflation of costs in all fields of activity which this policy has helped to induce. This, in turn, has brought about pressure on resources, pressure which is likely to become still more inflationary if encouraged. Inflationary pressure will threaten the ordinary business firm on which stability depends and also some of the developmental projects, such as the Snowy Mountains Scheme and the oil explorations in Western Australia. Rising costs will be the greatest enemy of any successful development of an oil industry in this economy just as they have become the enemy of long established and successful industries such as steel and wool. Both these industries have been seriously affected by rising costs, which have developed as a result of tariff protection.

These rising costs are like a disease : once they secure a grip on one part of the economy, they spread outwards to all parts and even the healthiest industries will be affected. The problem is to control costs at all points, particularly at those points where they are most likely to increase most rapidly.

Rising costs can be explained quite simply in terms of such things as attractive wage rates, shortages of building materials, inadequate transport and a search for quick profits. Fundamentally, it is a question of a scramble for scarce resources which have many alternative uses. The Australian tariff policy, in recent years, has tended to encourage the growth within this economy, at high cost, of a miniature diversified industrial economy. It is a small scale replica of the United States. This has been achieved without guaranteeing future stability of the economy.

In connection with the development of an oil industry within the Australian economy we can dispose very quickly of certain illusions which have developed with surprising speed in recent months. To quote from a popular Australian magazine : " The discovery of oil in substantial quantities in Australia is hoped to play as great a part in the future development of the country as the discovery of gold did at an earlier stage of our history. Gold brought wealth to the country. It also brought the first big influx of free settlers, and an outstanding population increase in what was then a backward colony. Now Australia is a nation. Oil, together with the other great hope in our future, uranium, could make it a powerful nation."

I would suggest that, for this type of development to take place, the amount of oil discovered and usable would have to be great. At the same time there is to be considered the fact that America, one of the great oil producers and suppliers of capital for oil exploitation, is at this moment limiting oil production to maintain internal stability. This suggests something of a dilemma. If oil is to be a great source of national development, it would at the same time be a source of national embarrassment if we attempted to export it in large quantities to a stable or declining world market. But the problem is deeper still, touching fundamentally on the matter of the formation and use of capital in the economy.

The by-products of an oil industry are of tremendous significance to an industrial economy providing, as they do, a great range of subsidiary commodities, but this range of subsidiary commodities is achieved only under conditions of large-scale and diversified production such as obtains in the United States.

The Australian economy is not really like that of the United States, even though we enjoy a high standard of living. This is not based fundamentally on division of labour in a large population plus growing markets at home and abroad. Rather, we have achieved our prosperity and development by sacrificing the development of national capital in the form of public works of all kinds, and at the cost of losing or failing to develop much of our export market.

High levels of current consumption have replaced what seems to be an old-fashioned but nevertheless basic activity: that of capital accumulation. This has led to a consumption of resources in the short run which must affect future productivity in the Australian economy.

If a large-scale oil industry were to develop in Australia, it would probably be at the cost of still more national development, and would be established in direct competition with alternative private capital investment. Wool still remains our trump card in the field of exports, and the prospects of a great export market in oil seem slight. The internal use of Australian oil would be as a substitute for crude products brought here and refined in our refineries.

A moderate production of oil, then, would conserve our foreign balances and make the defence position better. But it could seriously disrupt the coal industry, which is already in a difficult position, and impinge on all other industries in some degree. The positive gain of oil production in Australia will lie in the extent to which we can substitute our oil for foreign oil without an increase in costs, without retarding other essential national development, and without thoughtlessly disrupting important spheres of production in other sectors of the economy.

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ON THE ASYMPTOTIC BEHAVIOUR OF HANKEL TRANSFORMS.

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School of Mathematics, New South Wales University of Technology.

Manuscript received, July 19, 1954. Read, December 1, 1954.

SUMMARY.

Assuming that

$$\bar{g}(u)=\int_0^\infty xJ_\nu(ux)g(x)dx,$$

it is proved that, with certain restriction on the functions and constants,

$$\lim_{u\to\infty}\{u^{p+2-a}\bar{g}(u)\}=\frac{\Gamma(\frac{1}{2}p+\frac{1}{2}\nu-\frac{1}{2}a+1)}{2^{a-1}\Gamma(\frac{1}{2}p+\frac{1}{2}\nu+\frac{1}{2}a)}\lim_{x\to0+}\left\{(-1)^p x^{p+\nu+a}\left(\frac{d}{xdx}\right)^p\left(\frac{g(x)}{x^\nu}\right)\right\}.$$

This formula is modified to cover the case when $g(x)$ and its derivatives possess a finite number of finite discontinuities.

I. INTRODUCTION.

In my previous paper [G] on the same subject, I obtained the above result for the case $p=0$. This was proved in two theorems which will be referred to as G1 and G2.

The generalizations follow very easily, provided some restrictions are placed on the behaviour of the derivatives.

As in [G], it will be assumed that when $g(x)$ is given, $\bar{g}(u)$ will be defined by

$$\bar{g}(u)=\int_0^\infty xJ_\nu(ux)g(x)dx, \quad \ldots\ldots\ldots\ldots\ldots (1.1)$$

and when $\bar{g}(u)$ is given, $g(x)$ will be defined by

$$g(x)=\int_0^\infty uJ_\nu(xu)\bar{g}(u)du. \quad \ldots\ldots\ldots\ldots\ldots (1.2)$$

The integrals in equations (1.1) and (1.2) are not assumed to converge absolutely at the upper limit. When we are dealing with the Hankel Transforms, we may assume that both equations hold. However, this will not be assumed in this note.

In addition to the restrictions placed on ν in the theorems, it will be assumed that ν is not a negative integer.

The following notation will be used:

$$D\equiv\frac{d}{xdx}, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1.3)$$

$$g(\nu,x)\equiv x^{-\nu}g(x), \quad \ldots\ldots\ldots\ldots\ldots\ldots (1.4)$$

$$\gamma(p,\nu,a)\equiv\frac{\Gamma(\frac{1}{2}p+\frac{1}{2}\nu-\frac{1}{2}a+1)}{2^{a-1}\Gamma(\frac{1}{2}p+\frac{1}{2}\nu+\frac{1}{2}a)}. \quad \ldots\ldots\ldots (1.5)$$

II. THE GENERALIZATION OF THEOREM G1.

Theorem A (i).

If $g(x)$ is a function of x, such that

(i) $\left(\dfrac{d}{dx}\right)^n g(x)$ is absolutely continuous in $0<x_0<x<\infty$, for all $x_0>0$, and $0 \leqq n < p$;

(ii) $x^{2n+2\nu+2}D^n g(\nu, x) \to 0$ as $x \to 0+$, $0 \leqq n < p$;

(iii) $x^{n+\nu+\frac{1}{2}}D^n g(\nu, x) \to 0$ as $x \to \infty$, $0 \leqq n < p$;

(iv) $x^{p+\nu}D^p g(\nu, x) \equiv f(x)$

satisfies the assumptions of G1 ($\nu+p$ replacing ν of that theorem).
Then

$$\lim_{u\to\infty}\{u^{p+2-a}\bar{g}(u)\}=\gamma(p, \nu, a) \lim_{x\to 0+} \{(-1)^p x^{p+\nu+a}D^p g(\nu, x)\}, \qquad (2.1)$$

where $\bar{g}(u)$ is defined by equation (1.1) and where

$$\tfrac{1}{2}<a<p+\nu+2. \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2.2)$$

Proof.

Let

$$\bar{h}(u)=\int_b^c xg(x)J_\nu(ux)dx, \qquad \ldots\ldots\ldots\ldots\ldots \quad (2.3)$$

where $0<b<c<\infty$.
If we write

$$\mathrm{K}(n, x)=x^{\nu+n}J_{\nu+n}(x),$$

we find from [W.B.F.], p. 45, that

$$\frac{d}{dx}\mathrm{K}(n+1, x)=x\mathrm{K}(n, x). \qquad \ldots\ldots\ldots\ldots\ldots \quad (2.4)$$

Now multiplying both sides of equation (2.3) by $u^{1+\nu}$ we obtain

$$u^{1+\nu}\bar{h}(u)=\int_b^c g(\nu, x)\,.\,(ux)\mathrm{K}(0, ux)dx$$

$$=\int_b^c g(\nu, x)\frac{d}{d(ux)}\mathrm{K}(1, ux)dx.$$

After integration by parts

$$u^{2+\nu}\bar{h}(u)=\Big[g(\nu, x)\,.\,\mathrm{K}(1, ux)\Big]_b^c-\int_b^c xDg(\nu, x)\,.\,\mathrm{K}(1, ux)dx.$$

That is

$$u^{3+\nu}\bar{h}(u)=\Big[g(\nu, x)\,.\,u\mathrm{K}(1, ux)\Big]_b^c-\int_b^c Dg(\nu, x)\,.\,(ux)\mathrm{K}(1, ux)dx.$$

After repeating this step p times

$$u^{2p+1+\nu}\bar{h}(u)=\sum_{n=0}^{p-1}\Big[(-1)^n D^n g(\nu, x)\,.\,u^{2p-2n-1}\mathrm{K}(n+1, ux)\Big]_b^c$$

$$+(-1)^p\int_b^c D^p g(\nu, x)\,.\,(ux)\mathrm{K}(p, ux)dx,$$

or

$$u^p\bar{h}(u)=\sum_{n=0}^{\infty}\Big[(-1)^n x^{\nu+n+1}D^n g(\nu, x)\,.\,u^{p-n-1}J_{\nu+n+1}(ux)\Big]_b^c$$

$$+(-1)^p\int_b^c x[x^{\nu+p}D^p g(\nu, x)]J_{\nu+p}(ux)dx. \quad \ldots\ldots \quad (2.5)$$

We now let $b\to 0$ and $c\to\infty$. Since for large values of x

$$|J_\mu(x)|<Ax^{-\frac{1}{2}}$$

for small values of x

$$|J_\mu(x)|<Bx^\mu$$

where A and B are constants, the integrated terms on the right side of equation (2.5) vanish. So

$$u^p\bar{g}(u)=(-1)^p\int_0^\infty x\{x^{\nu+p}D^p g(\nu, x)\}J_{\nu+p}(ux)dx. \quad \ldots\ldots\ldots\ldots \quad (2.6)$$

Then referring back to G1 we obtain

$$\lim_{u\to\infty}\{u^{p+2-a}\bar{g}(u)\}=\gamma(p, \nu, a)\lim_{x\to 0+}\{(-1)^p x^{p+\nu+a}D^p g(\nu, x)\}, \quad \ldots\ldots \quad (2.7)$$

assuming that

$$\tfrac{1}{2}<a<p+\nu+2, \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2.8)$$

which proves the theorem.

We now suppose that at a finite number of points, $x=x_q$, some (or all) of the derivatives $\left(\frac{d}{dx}\right)^n g(x)$, $0\leqq n<p$ possess finite discontinuities. For all other values of x we assume that the assumptions of Theorem A (i) hold.

Define

$$\Big(\lim_{x\to x_q+}-\lim_{x\to x_q-}\Big)\{x^{\nu+n+1}D^n g(\nu, x)\}\equiv G(n, q). \quad \ldots\ldots\ldots\ldots \quad (2.9)$$

Then equation (2.5) shows that the left side of equation (2.6) must be replaced by

$$u^p\bar{g}(u)+\sum_{n=0}^{p-1}\sum_q(-1)^n G(n, q)u^{p-n-1}J_{\nu+n+1}(ux_q). \quad \ldots\ldots \quad (2.10)$$

This modification would be carried through to equation (2.7) and we have proved

Theorem A (ii).

Assuming that

(i) at a finite number of points $x=x_q$, $\left(\frac{d}{dx}\right)^n g(x)$, $(0 \leqq n < p)$, may possess finite discontinuities, and

(ii) otherwise the assumptions of Theorem A (i) hold, then

$$\lim_{u\to\infty} \{u^{p+2-a}\bar{g}(u) + \sum_{n=0}^{p-1} \sum_{q} (-1)^n G(n, q) u^{p-n-1-a} J_{\nu+n+1}(ux_q)\}$$
$$= \gamma(p, \nu, a) \lim_{x\to 0+} \{(-1)^p x^{p+\nu+a} D^p g(\nu, x)\} \quad \ldots\ldots\ldots\ldots \quad (2.11)$$

where $\bar{g}(u)$ is defined by equation (1.1), and $G(n, q)$ by equation (2.9), and where

$$\tfrac{1}{2} < a < p + \nu + 2.$$

III. The Generalization of Theorem G2.

The constants $G(n, q)$ defined in equation (2.10) cannot be so defined in this section; they must be defined in terms of $\bar{g}(u)$.

Assume that

(*a*) a finite number of positive values of x (denoted by x_q) are given, and

(*b*) to each x_q, a set of finite constants $G(n, q)$ is chosen.

In terms of these constants, we define the set of functions $\bar{g}_n(u)$ by

$$\bar{g}_0(u) = \bar{g}(u) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.1)$$

$$\bar{g}^{n+1}(u) = u\bar{g}_n(u) + (-1)^n G(n, q) J_{\nu+n+1}(ux_q). \quad \ldots\ldots\ldots \quad (3.2)$$

With these definitions in mind we may prove

Theorem B.

If $\bar{g}(u)$ is a function of u such that

(i) $\int_0^\infty u\bar{g}_n(u) \frac{J_{\nu+n}(ux)}{x^{\nu+n-1}} du$ converges uniformly in x for $0 \leqq n < p$;

(ii) $\bar{g}_p(u) \equiv \bar{f}(u)$

satisfies the assumptions of G2 ($\nu + p$ replacing ν of that theorem), then

$$\lim_{x\to 0+} \{(-1)^p x^{p+\nu+a} D^p g(\nu, x)\}$$
$$= [\gamma(p, \nu, a)]^{-1} \lim_{u\to\infty} \{u^{p+2-a}\bar{g}(u) + \sum_{n=0}^{p-1} \sum_{q} (-1)^n G(n, q) u^{p-n-1-a} J^{\nu+n+1}(ux_q)\}$$
$$\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.3)$$

where $g(x)$ is defined by equation (1.2) and where

$$-\nu - p < a < 1\tfrac{1}{2}. \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.4)$$

Proof.

Introducing the unit function $H(t)$ defined by

$$\left.\begin{array}{l} H(t) = 1, \ t > 0 \\ H(t) = 0, \ t < 0 \end{array}\right\}, \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.5)$$

we find that

$$\int_0^\infty J_{s+1}(ux_q)J_s(ux)du=\frac{x^s}{x_q^{s+1}}H(x_q-x),$$

([W.B.F.], p. 406.)

In particular, this formula gives

$$\begin{aligned}\sum_q\int_0^\infty &x^{-\nu-n}G(n,\,q)J_{\nu+n+1}(ux_q)J_{\nu+n}(ux)du\\ &=\sum_q x_q^{-\nu-n-1}G(n,\,q)H(x_q-x)\\ &=Q(n)\ \text{(say)}. \qquad (3.6)\end{aligned}$$

Then

$$g(x)=\int_0^\infty u\bar{g}_0(u)J_\nu(ux)du$$

and

$$g(\nu,\,x)=\int_0^\infty u\bar{g}_0(u)x^{-\nu}J_\nu(ux)du. \qquad (3.7)$$

After using equation (3.6) with $n=0$, we obtain

$$\begin{aligned}g(\nu,\,x)+Q(0)&=\int_0^\infty [u\bar{g}_0(u)+\sum_q G(0,\,q)J_{\nu+1}(ux_q)]x^{-\nu}J_\nu(ux)du\\ &=\int_0^\infty \bar{g}_1(u)x^{-\nu}J_\nu(ux)du.\end{aligned}$$

This equation is now differentiated with regard to x and the result is justified by uniform convergence. Thus

$$\begin{aligned}D[g(\nu,\,x)+Q(0)]&=D\int_0^\infty \bar{g}_1(u)x^{-\nu}J_\nu(ux)du\\ &=x^{-1}\int_0^\infty u^{1+\nu}\bar{g}_1(u)\frac{\partial}{\partial(ux)}[(ux)^{-\nu}J_\nu(ux)]du\\ &=-x^{-1}\int_0^\infty u^{1+\nu}\bar{g}_1(u)(ux)^{-\nu}J_{\nu+1}(ux)du\end{aligned}$$

([W.B.F.], p. 45).

$$\begin{aligned}&=-x^{-1}\int_0^\infty u\bar{g}_1(u)x^{-\nu}J_{\nu+1}(ux)du\\ &=-\int_0^\infty u\bar{g}_1(u)x^{-\nu-1}J_{\nu+1}(ux)du. \qquad (3.8)\end{aligned}$$

After p steps we obtain

$$\begin{aligned}&x^{\nu+p}D[D[\ldots[D[g(\nu,\,x)+Q(0)]+Q(1)]\ldots]+Q(p-1)]\\ &=(-1)^p\int_0^\infty u\bar{g}_p(u)J_{\nu+p}(ux)du \qquad (3.9)\end{aligned}$$

In the neighbourhood of the origin (i.e. to the left of all the x_q), it is clear that the left side of equation (3.9) reduces to

$$x^{\nu+p}D^p g(\nu, x). \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.10)$$

It is also clear that equations (3.1) and (3.2) give

$$\bar{g}_p(u)=u^p\bar{g}(u)+\sum_{n=0}^{p-1}\sum_{q}(-1)^n G(n, q)u^{p-n-1}J_{\nu+n+1}(ux_q). \quad \ldots \quad (3.11)$$

So equation (3.9) and Theorem G2 give the required result (3.3).

We have only to show that the $G(n, q)$ defined by equation (2.9) are the same as the $G(n, q)$ defined at the beginning of this section. This follows easily after an examination of the left sides of equations (3.8), (3.9) and the intermediate equations.

It is also clear that when

$$G(n, q)=0, \text{ for all } n<p, \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.12)$$

equation (3.3) reduces to equation (2.1).

We have shown that provided $g(x)$ and $\bar{g}(u)$ satisfy the assumptions of the theorems, equations (2.1) and (2.11) hold for

$$-\nu-p<a<p+\nu+2 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.13)$$

If $f(x)$ or $\bar{f}(u)$, defined in Theorems A(i) and B respectively, possesses discontinuities, it follows from sections 3 and 4 of [G] that the additional restriction

$$p+\nu>-\tfrac{1}{2} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.14)$$

must be made.

The two most important special cases of equation (2.1) are:

(i) for $a=0$

$$\lim_{u\to\infty}\{(-1)^p u^{p+2}\bar{g}(u)\}=(p+\nu)\lim_{x\to 0+}[x^{p+\nu}D^p g(\nu, x)] \quad \ldots \quad (3.15)$$

for $p+\nu>0$.

(ii) for $\nu=0$

$$\lim_{u\to\infty}\{(-1)^p u^{p+2-a}\bar{g}(u)\}=\gamma(p, 0, a)\lim_{x\to 0+}[x^{p+a}D^p g(x)] \quad \ldots \quad (3.16)$$

for $-p<a<p+2$.

In conclusion, it must be noted that amongst the results obtained by taking particular forms for $g(\nu, x)$ we find the interesting case:

If $g(x)$ and its derivatives are continuous, and if in the neighbourhood of the origin can be expressed in the form

$$g(x)=\sum_{n=0}^{\infty}a_n x^n \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.17)$$

then

$$\lim_{u\to\infty}[u^{2p+3}\bar{g}(u)]=(-1)^{p+1}[(2p+1)(2p-1)\ldots 1]^2 a_{2p+1}$$

where $\bar{g}(u)$ is the zeroth order transform and a_{2p+1} is the first non-zero odd coefficient in equation (3.17).

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GEOLOGY AND SUB-SURFACE WATERS OF THE COONAMBLE BASIN, N.S.W.

By J. RADE*

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INTRODUCTION.

The present paper deals with the geology of the Coonamble Basin, situated in the Dubbo area of the central portion of New South Wales. The Coonamble Basin is taken as a separate unit, since it forms the largest embayment of the New South Wales portion of the Great Artesian Basin and bears several characteristic geological features.

The main part of the Coonamble Basin is located between Gilgandra and Warren in the south and reaches north to the vicinity of Walgett, the northern boundary coinciding with the Barwon and Namoi Rivers. The eastern margin is located to the west of the Warrumbungle Mountains, while the western margin is formed by a peninsular-like structural high in the Palaeozoic basement complex which stretches in a north-easterly direction into the Great Artesian Basin. The area of the basin is approximately 9,000 square miles.

Previous geological publications concerning the artesian bores of the Coonamble Basin include those by Symmonds (1912), Mulholland (1950), and David (1950). The results of the foraminiferal studies of the sediments of the Great Artesian Basin, made by Crespin (1944, 1945, 1946, 1953), are also applicable to the smaller area at present under consideration.

Full use of the data collected by the Water Conservation and Irrigation Commission, Sydney, has been made in the writing of the present paper.

GEOLOGY.

Palæozoic basement rocks underlie the Mesozoic rocks of the Coonamble area. The Palæozoic basement complex consists of sediments of Ordovician, Silurian, and Devonian age. These are intruded by Kanimblan granites, often in the form of felspar porphyries, especially in the eastern part of the area. It is also possible that some of the granites encountered in the western part of the basin belong to the Caledonian orogenic epoch. The Palæozoic sediments are often found to be represented in the bores by slates and micaceous schists. The granites evidently form large batholiths, and occupy the cores of the structural ridges of the basement.

The configuration of the basement complex will be treated later in the paper, but before this is done, a more detailed account of the lithology of the basement complex will be given. At Coonamble the Coonamble No. 3 bore reached the basement at a depth of 2,158 feet. The basement consisted of slate containing a variable amount of quartz. Palæozoic slate was encountered at a depth of 1,995 feet in the Quambone No. 2 bore, situated 20 miles to the west-north-west of Coonamble. It was overlain by the sandstones and coarse gravel of the Pilliga Sandstone of the Walloon " Series ". In the

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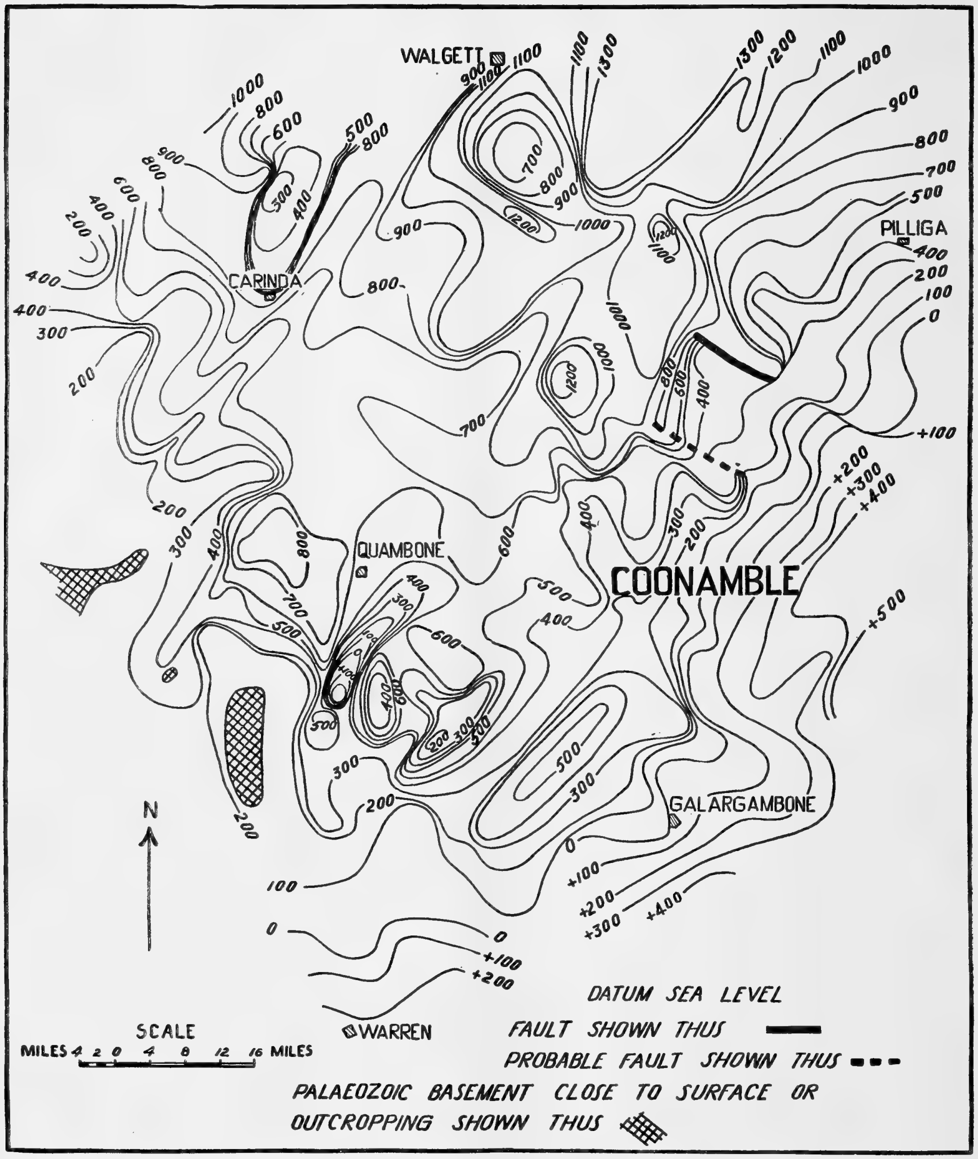
Carinda bore, located near Carinda, Palæozoic slates were encountered at 2,240 feet below the surface, while similar slates were encountered at depth of 2,133 feet in the Wangrewally bore, situated 27 miles south-west of Walgett. The Sunny Vale No. 2 bore, situated 44 miles north-west of Warren, encountered Palæozoic slates at 1,335 feet; the bore reached a depth of 1,577 feet 10 inches and was then reported to be in dense volcanic tuff. Volcanic breccia is recorded at a depth of 2,020 feet below the surface of the Quambone No. 1 bore, situated 32 miles west of Coonamble. In the Wingadee No. 6 bore, located 26 miles north of Coonamble, micaceous schist was encountered at a depth of 2,075 feet.

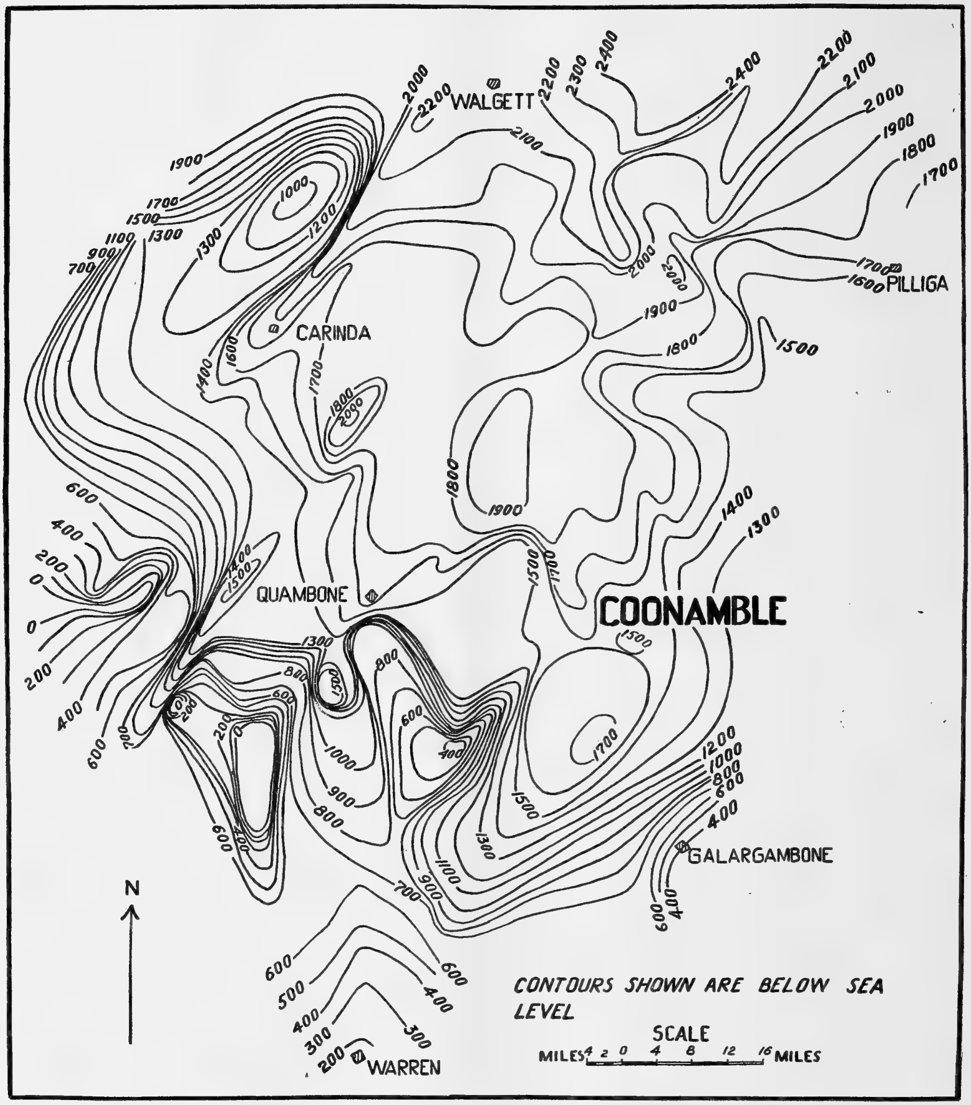


Text-fig. 1.

The Kanimblan granites were encountered by the Tholoo bore, in the north-eastern part of the map area, 30 miles east of Walgett. They were first penetrated at a depth of 2,680 feet, and the drilling continued in the granite for a further 52 feet. Granite was also encountered at Warren in the southern part of the map area, where the Warren bore penetrated it at a depth of 817 feet. The Three Corners bore, situated north-north-east of Warren, struck granite at 941 feet. In both the Warren bore and the Three Corners bore the granite was overlain directly by the Pilliga Sandstone of the Walloon " Series ". The granites form a north-easterly trending basement ridge to the north-north-east of Warren, and are encountered at a depth of 900 feet in the Wildwood bore, situated 37 miles to the north-north-east of Warren. It is suggested that these granites of the Warren district represent a north-westerly continuation of the great granite batholith which is exposed to the south-west of Dubbo. Evidence supporting this conclusion is found in the small outcrops of granite which are found between Dubbo and Warren. Most of the south-western part of the map area is underlain by granite outcropping at Mt. Foster, Mt. Harris, and Mt. Eugolma. To the north-west of these mountains the granite is encountered at a depth of 395 feet in a bore situated in Portion 20 of the parish of Willie, County of Gregory, 60 miles north-west of Warren. The granite was first struck at 717 feet, and drilled for a further 91 feet in the Thornwood bore, situated 63 miles north-west of Warren. The dome in the Palæozoic basement complex which occupies the north-western corner of the map area also consists of granite. On the north-west side of this dome the Brewon No. 4 bore, situated 32 miles west-south-west of Walgett, reached granite at a depth of 2,354 feet. The Bogewong No. 1 bore, situated on the crest of the dome, 27 miles south-west of Walgett, struck the granite at 1,399 feet below the surface. Granite was first reached at a depth of 1,543 feet and penetrated for a further 62 feet in the Borgara bore, situated 21 miles south-west of Walgett. From this bore data it is clear that the granites partially form the margins of the Coonamble Basin, either outcropping or coming to within a shallow depth from the land surface.

The Mesozoic rocks encountered in the area are of Triassic, Jurassic and Cretaceous age. As pointed out by Mulholland (1950, p. 126), the Triassic sediments consist mainly of shales ; they are thickest in the eastern parts of the basin and thin considerably towards the west. As evidence of this, the Jurassic rocks are seen to overly the Triassic sediments in the eastern part of the basin, whereas they directly overly the Palæozoic basement complex in the western portion.

The Jurassic sediments are much more shaly than their equivalents in the Moree district. This is readily related to their environments of deposition, since the sediments of the Coonamble Basin were deposited in an embayment of the main lake. It is found that the Jurassic sediments are particularly shaly in the western part of the basin, but have a more usual character in the eastern part. This is partially due to the configuration of the basement, and partly due to the character of the sediment which was introduced into the basin. The terrigenous material brought into the eastern part of the basin would have been derived from the weathering of the Kanimblan granites and the New England granodiorite batholith. The latter was being subjected to intensive denudation during the Jurassic period, and sandy sediments are thus to be expected. The slates and micaceous schist of the basement complex were freely exposed to the west of the Coonamble Basin during the Jurassic, and thus sediments of a finer texture are to be expected in this area. The nature of the sediments must also be related to the depths in different parts of the basin and the turbulance of the water at the time of deposition. Relatively turbulant water is thought to have been present on the more open eastern part of the basin. However the contours of the basement rocks on the western side of the basin seem to suggest that this area consisted of a number of north-easterly directed embayments. Shales are known to have accumulated in the quieter waters of this part of the basin.



Text-fig. 2.

The high pyrite content of some of the shales seems to indicate that the waters were tranquil and stagnant in at least some parts of the basin. Conditions must have been similar to those in which pyrite is known to have developed in some of the Jurassic sediments of Europe.

The Jurassic Walloon "Series" consists of the Purlawaugh Shale and Pilliga Sandstone. The Purlawaugh Shale is best known from the eastern part of the Coonamble Basin, where it is difficult to distinguish it on lithological grounds from the lower Mesozoic sediments. In the Galga No. 1 bore, situated 25 miles east-south-east of Coonamble, the Purlawaugh Shale is first encountered at a depth of 980 feet. The upper 693 feet of the formation consists of shale, and this is underlain by clays with a thickness of 150 feet. Mulholland (1950, p. 125), has stated that the thickness of the Purlawaugh Shale in the Coonabarabran area is about 200 feet. Recent investigations by the writer have shown that the thickness of this formation in the Warialda intake area, located east of Moree, is in the vicinity of 300 feet. It can be concluded that only the upper part of the shales in the Galga No. 1 bore represent the Purlawaugh Shale, and that the lower shales and clays are of Triassic age. Investigations in the eastern part of the Coonamble Basin show that the Purlawaugh Shale was only deposited between the granitic ridges of the basement complex, the granitic ridges having apparently projected as land ridges during the period of deposition of the shale.

In the eastern portion of the Coonamble Basin, the Purlawaugh Shale is overlain by the Pilliga Sandstone, the latter formation being represented in this area by a pure sandstone without intercalations of shale. This formation has been penetrated in several of the bores drilled in the area under consideration. The Nebea No. 2 bore, situated 12 miles north-east of Coonamble penetrated 1,291 feet of sandstone with gravel intercalations. This formation was overlain by the shales and clays with thin sandstone intercalations, which are thought to be of Cretaceous age, and underlain by the Palæozoic schists of the basement complex. In the Milchomi bore, 37 miles north-east of Coonamble, the shales, clays, and sandstone intercalations of the Cretaceous were penetrated to a depth of 1,151 feet, where they gave place to the sandstones of the Pilliga Sandstone, the latter being penetrated for a further 756 feet.

To the west of the Coonamble Basin, the Pilliga Sandstone directly overlies the slates, tuffaceous and micaceous schists, and granites of the basement complex. Some bores in the eastern part of the basin, such as the Tholoo bore, show that in some places the Pilliga Sandstone directly overlies the Kanimblan granites. The same stratigraphic associations are known in the southern part of the basin, as was shown earlier in the paper with reference to the Warren bores. Further to the west in the deeper portions of the Coonamble Basin, the Pilliga Sandstone is known to include intercalations of shale.

Conglomeratic intercalations are sometimes encountered in the Pilliga Sandstone. It is significant that these conglomerates generally occur in the vicinity of the ridges of the Palæozoic basement complex. In this connection it is interesting to examine the north-westerly trending ridge which is known to the north-west of Coonamble. The Yowie bore is situated 12 miles to the north-west of Coonamble and is situated on this basement ridge. The bore logs record the repeated occurrence of conglomerates, and the sediments are generally coarser than those of corresponding horizons in other parts of the basin. This is to be expected, since the waters overlying this basement ridge would have been shallower and more turbid than in the deeper parts of the basin. Tuffaceous schists of the basement complex were penetrated by the Yowie bore over a distance of 46 feet.

The sediments of the Walloon " Series " encountered in the Yowie bore show clearly marked cycles of sedimentation, five complete cycles having been recognised. They begin with fine grained sediments such as shale and fine sand, and terminate with the deposition of conglomerates. One such cycle was also encountered in the Cretaceous sediments. Here a bed of quartzite pebbles and shale with a thickness of 23 feet is encountered at a depth of 397 feet, and is underlain by 40 feet coal. The whole sequence is enclosed by beds of clay. It is considered by the present author that these cycles of sedimentation reflect the saltatory uplift of the margins of the Coonamble Basin during the Mesozoic.

Conglomerates are also encountered in other parts of the Coonamble Basin. The Woodlands bore, situated 4 miles south-south-west of Coonamble, encountered a conglomerate bed with a thickness of 8 feet at a depth of 1,720 feet. This bore is situated on the south-western margin of the basement ridge mentioned in connection with the Yowie bore. In the previously mentioned Nebea bore, north-east of Coonamble, 23 feet of gravel and sand were encountered at a depth of 1,213 feet.

Conglomerates were encountered north of Warren, in an area in which the granites form a basement ridge which is elongated in a north-easterly to south-westerly direction. They were met with in the Wildwood bore, situated 37 miles north-north-east of Warren. The northern, south-western and southern sides of this basement ridge are known to be encircled by conglomerates. To the south-west of the ridge they are encountered at a depth of 900 feet in the Coburg bore, situated 27 miles north-north-west of Warren. The Stray Leaves bore, situated 28 miles north-north-east of Warren and on the southern side of the basement ridge, encountered 13 feet of conglomerate at a depth of 1,305 feet. To the northern side of the same ridge, 50 feet of relatively unconsolidated sandstone and conglomerate were encountered at a depth of 1,400 feet below the surface in the Ellerslie bore, situated 43 miles north-north-east of Warren. Further to the north-west, 12 feet of gravels and sandy shale were encountered at a depth of 988 feet in the Stanley bore, situated 57 miles north-west of Warren. Conglomeratic intercalations ranging in thickness from 4–9 feet are recorded from the Walloon " Series " where it was penetrated by the Wallamgambone bore, 59 miles north-west of Warren.

In Jurassic times the Coonamble Basin formed a large embayment along the border of Lake Walloon. Sedimentation took place under tranquil conditions in the western portion of the embayment, but the water must have been more turbid in the eastern portion. However in no part of the embayment were conditions as turbid as they appear to have been in the Moree district. These tranquil conditions of deposition account for the fine texture of the sediments in the Coonamble Basin, and for the numerous intercalations of shale in the Pilliga Sandstone.

The average thickness of the Walloon "Series " in the Coonamble Basin is 800 feet. Mulholland (1950, p. 126), estimates the thickness of the Pilliga Sandstone in the Coonabarabran intake area to be of the order of 600 feet.

Difficulty is sometimes encountered in the Coonamble Basin in determining on lithological evidence the transition from the Jurassic sediments to the lacustrine Blythesdale " Series ". However, geological and hydrological investigations in the Moree district have shown that the sediments of Jurassic and Cretaceous age are more readily separated and that the upper artesian aquifers are located in the Lower Cretaceous Blythesdale " Series ". With this information regarding the stratigraphic position of the aquifers in the Moree district, it is possible to interpolate in the Coonamble Basin and determine the stratigraphic horizon by reference to the aquifers. The Blythesdale " Series " as developed in the Coonamble Basin is similar in lithology to the corresponding sediments of the Moree district, consisting of shales and sandy shales, with coal seams and sandstone intercalations. The average thickness of the Blythesdale " Series " in the Coonamble Basin is between 500 feet and 600 feet.

The Blythesdale " Series " is followed by the marine Roma " Series ", consisting almost entirely of blue and grey shales, but with occasional intercalations of sandy shales. The average thickness of the Roma " Series " in the Coonamble Basin is between 700 feet and 900 feet.

Foraminiferal determinations of samples from the Roma " Series " have been made by Miss Irene Crespin, Palæontologist, Bureau of Mineral Resources. In the Lochinwar bore, situated 3·5 miles west-south-west of Carinda, the youngest Foraminifera were found from 254–304 feet in grey carbonaceous shale and sandstone. They were associated with indeterminate plant remains, thin shelled Mollusca, and Ostracoda. From 704–754 feet, the bore samples contained fragments of limestone, and from 754–802 feet, fragments of calcareous sandstone, carbonaceous shale and limestones containing rare Foraminifera were reported. Miss Crespin has kindly given permission for the publication of her foraminiferal determinations of the fauna contained in the Lochinwar bore between depths of 254 feet and 802 feet. They are as follows :

Ammobaculites australe.
Ammodiscus sp.
Anomalina mawsoni.
Eponides sp.
Haplophragmoides cf. chapmani.
Lagena lævis.
Lenticulina cf. gibba.
Marginulina bullata.
Marginulinopsis subcretacea.
Pyrulina fusiformis.
Robulus gunderbookœnsis.
Saracenaria cf. acutiauricularis.
Spiroplectammina cushmani.
Valvulineria parvula.

Ostracoda were also encountered between 254–704 feet, and they have been identified by Miss Crespin as follows :

Bythocypris sp.
Cythereis sp.
Cytheropteron cf. concentricum.

This assemblage of Foraminifera and Ostracoda is characteristic of the Lower Cretaceous sediments of the Great Artesian Basin.

The Roma " Series " in the Coonamble Basin is overlain by the Upper Cretaceous Winton " Series ", representing the lacustrine deposits which developed in Lake Winton. These are of a more sandy character than the marine Roma " Series ", and contain small seams of lignite and coal. Gas was encountered in the coaly intercalations between the shale at 665–675 feet in the Keelendi No. 2 bore, situated 16 miles north-west of Pilliga. The Winton " Series " is best known in the northern part of the Coonamble Basin, especially towards the north-eastern portion. The average thickness of the Winton " Series " in the Coonamble Basin is 500 feet.

A separate paper, by the present author, dealing with the basement structures of the New South Wales portion of the Great Artesian Basin will be published in the near future. Thus, only a brief summary of the basement structures of the Coonamble Basin will be given in the present paper. It may be seen from the accompanying contour plan that the main trend dominating the basement of the Coonamble Basin has a north-easterly direction, being expressed in the alignment of the ridges and valleys in the western part of the Basin. A basement valley, elongated in the same north-easterly direction, occurs in the eastern portion of the Coonamble Basin to the north-west of Galargambone. A dome-like topographic feature of the basement complex, also elongated in the north-easterly direction, is found to the south-west of

Walgett. Most of the basement valleys which exhibit this north-easterly alignment are extremely narrow.

Close observation of the basement contours in the north-eastern portion of the Coonamble Basin indicates the presence of a north-north-westerly trend direction. This trend is expressed by the ridges which protrude from the south-eastern margin of the Coonamble Basin. They are well developed in the vicinity of Coonamble. A basement ridge with a trend direction slightly north of west protrudes from the east-south-east into the Coonamble Basin about 26 miles north of Coonamble. The ridge is thought to be composed of Kanimblan granite. The roughly meridional elongation of the central portion of the Coonamble Basin, to the north-west of Coonamble, is thought to be due to the interrelation of the above-mentioned trends.

Bryan (1925, p. 21), recognised two trends in Queensland, one in a north-easterly direction and the other in a north-north-westerly direction. He regarded the north-easterly trend as being the older of the two. The work in the Coonamble Basin has convinced the present author that the north-easterly trend can be referred to the Caledonian diastrophism, whereas the north-north-westerly trend represents the Variscan diastrophism.

A contour plan of the aquifers of the Coonamble Basin has been drawn to determine to what extent the contours of the basement complex are reflected in the contours of the aquifers. The aquifers of the Lower Cretaceous Blythesdale " Series " were found to be the most easily recognised, and have thus generally been used in the construction of the aquifer contours. Certain structural features are seen to be common when a comparison of the contours of the basement complex and the aquifers is made. The same structural basins and domes occur on both contour plans. Similarities in the two sets of contours may be seen in the domal structure to the south-west of Walgett and the small basin which occurs to the south-south-west of Coonamble. Both of these structures are elongated in a north-easterly direction. It has been seen that this trend direction dominated in the Palæozoic basement complex of the Coonamble Basin, and that it is related to the older Palæozoic period of diastrophism.

Of great interest are the contours of the aquifers which overly a Palæozoic ridge which protrudes into the Coonamble Basin from the east-south-east, and is situated 23 miles south-west of Pilliga. The contours point to the presence of a fault along the northern side of the ridge. The strike of the fault is north 64 degrees west, and the throw is approximately 400 feet. The depression in the aquifer contours to the north of the fault can be traced further to the west-north-west, where it is located again 18 miles south-east of Walgett. The west-north-westerly continuation of this depression cannot be traced in the basement complex, so that it is clear that supplementary structures which are unknown in the basement complex do occur in the overlying Mesozoic rocks.

A probable fault bordering the southern side of the above-mentioned Palæozoic ridge is encountered 33 miles south-west of Pilliga. However, the contours of the Palæozoic basement do not reveal its basement continuation, probably because very little information regarding the basement is available, few bores having reached it in this area. In better known areas, faulting of the basement is known to be a characteristic feature. It is well known from the eastern margins of the Great Artesian Basin, and similar infaulted embayments in the Moree district and the Warialda intake area have recently been detected by the present author.

A close study of the eastern portion of the accompanying contour plan of the aquifers will reveal the presence of the later Palæozoic north-westerly trend. This trend is clearly expressed by the anticlinal structures which trend in from the eastern margin of the Coonamble Basin. The interrelation of this latter trend with the dominant trend produces, towards the centre of the Coonamble Basin, small basin structures in both the basement and the overlying sediments. Several granites of Palæozoic age outcrop in the southern part of the area covered by the contour plan. The contours of the aquifers in this area are complex, and it is probable that the accompanying contour plan does not represent them accurately.

HYDROLOGY.

Some shallow but salty aquifers are known from the Coonamble Basin. The depth range of these salty aquifers is 80–200 feet, the average depth being about 100 feet.

Subartesian aquifers are encountered in the Upper Cretaceous Winton " Series " ; they are of economic value in those areas where the artesian aquifers are found only at great depth. The water is generally brackish, although suitable for sheep, but the yields are small. Such aquifers are known to the north-west and west of Pilliga, and range in depth from 470–640 feet. In this same area the first true artesian aquifers are encountered 700–800 feet deeper than the aquifers of the Winton " Series ", and the main artesian aquifers occur 1,100 feet below the Winton " Series " aquifers. The following table contains information regarding the aquifers of the Winton " Series " in the north-eastern portion of the Coonamble Basin.

Name of Bore	Location	Year completed	Depth of aquifer in feet	Water rose	Yield of aquifer
Gorian ..	24 miles NNW of Pilliga	1905	518	within few feet of surface	very small supply
Keelendi No. 2 ..	16 miles NW of Pilliga	1941	470	110 feet	4800 g.p.d.
Kiewa	28 miles WSW of Pilliga	1936	590	—	200 g.p.h.
Wingadee No. 7 ..	31 miles W of Pilliga	1920	640	40 feet	small supply

The aquifers of the Winton " Series " are also encountered in the partly infaulted embayments of the eastern portion of the Coonamble Basin. This was the case with the Nyleve bore, situated 30 miles north-east of Coonamble in an embayment which is known to be terminated to the south by a fault. The aquifer was penetrated at 512 feet below the surface ; the static water level was found to be 90 feet below the surface, and the water proved to be brackish. Apart from the areas mentioned above, the aquifers of the Winton " Series " are also known from the north-western portion of the map area.

The upper artesian aquifers are located in sandstone intercalations of the Lower Cretaceous Blythesdale " Series ". These intercalations have an average thickness of 30 feet. Some typical from the Coonamble Basin will be mentioned below. In the Ottendorf bore, situated 16 miles north-west of Coonamble, the sandstone intercalation which forms the aquifer of the Blythesdale " Series " has a thickness of 40 feet. The Milchomi bore, situated 36 miles north-east of Coonamble, encountered the Blythesdale aquifer at a depth of 849 feet below the surface. It occurred in a sandy intercalation into shales which extended from 785–890 feet. In the Thornydyke No. 2 bore, situated 25 miles north-west of Coonamble, the upper artesian aquifer of the Blythesdale " Series " consisted of a sandstone intercalation into the shales and extended from 1,335–1,367 feet. The same aquifer was encountered in the Thornydyke bore, situated 24 miles north-west of Coonamble. Water was first struck at 1,310 feet, and occurred in a sandstone intercalation into the shales, which extended from 1,272–1,342 feet.

The main artesian aquifers are located in the sandstones of the Jurassic Walloon " Series ". These sandstone beds are often sealed by intercalations of shale, especially in the deeper western portions of the Coonamble Basin. The main aquifers commonly follow the contours of the surface of the basement complex, so that contour maps of the Palæozoic basement are of considerable value. The main aquifers commonly lie a short distance above the surface of the Palæozoic basement, but in the Hollywood No. 1 bore they lie immediately above the surface of the basement.

A contour map of the upper artesian aquifers of the Coonamble Basin has been prepared by the present author. The aquifers of the Lower Cretaceous Blythesdale " Series " have generally been considered in this compilation. However, the Blythesdale aquifers are not well known around the margins of the basin, and since the map was prepared essentially for practical purposes, the upper aquifers of the Walloon " Series " have been included in the map where bore information regarding the aquifers of the Blythesdale " Series " is not available. This substitution of the aquifer used in mapping is particularly common in those marginal areas where the Blythesdale aquifers are not developed. Such is the case in the southern and south-western parts of the map area, where the Kanimblan granites outcrop at Mt. Foster and Mt. Harris. However, it is probable that this practice does not introduce any relatively great inaccuracy, since the maps are only of a general nature.

This contour plan has considerable practical value, since if the depths of the Blythesdale aquifers are known, then the depths of the aquifers of the Walloon " Series " may be readily calculated. As a rule, the contours represent the horizon of artesian flow, although in a limited number of cases the flow has been subartesian. This was the case with the Noonbah bore, situated 38 miles south-west of Coonamble, which encountered a subartesian aquifer at a depth of 293 feet. However, in this bore the water rose to a shallow depth, fresh water appearing at a static water level of 50 feet below the surface. In this case the water came from a 4-feet coal seam intercalated into clay and shale. This coal seam may be used as a datum level, since in the Thurn bore, situated 24 miles west-north-west of Coonamble, the same coal seam was penetrated at 1,115 feet below the surface and was found to have a thickness of 2 feet. The coal seam in the Thurn bore was underlain by 38 feet of sandstone, the latter being in turn underlain by sandy shale. The sandstone bed provided a subartesian aquifer which brought water to a static water level 20 feet below the surface and yielded 600 gallons per hour. The aquifers in both of the bores mentioned above may be correlated with the upper aquifer of the Blythesdale "Series ". This aquifer does not persist to the south-south-west. Thus in the Buttabone No. 1 bore, situated 52 miles south-west of Coonamble, only the aquifers of the Walloon " Series " were encountered appearing at 750 feet and 850 feet below the surface. The first true artesian aquifers in the Thurn bore did not appear until a depth of 1,717 feet had been reached.

In the eastern portion of the Coonamble Basin the water of the main aquifers contains less than 40 grains per gallon of total solids, but towards the west the amount of total solids increases. This is clearly shown by the series of chemical analysis of the waters from bores along the line connecting the Tunderbrine No. 3 bore, situated 30 miles south-east of Coonamble, with the Brewon No. 4 bore, situated 32 miles west-south-west of Walgett. The water encountered in the Tunderbrine No. 3 bore is of excellent quality, containing only 13 grains per gallon of total solids. The highest content of total solids of the bores along this line is found in the waters of the Ottendorf bore, which contained 76 grains per gallon. Here only the aquifers of the Blythesdale " Series " were penetrated, and the deeper aquifers of the Walloon " Series " were not encountered. The waters from the bores in the south-western portion of the Coonamble Basin bear approximately 50 grains per gallon of total solids, this being a higher total solid content than is found in the bores in the south-eastern portion of the Basin. The chemical content of the water can be related to the change in the type of sedimentary deposit, since shales predominate in the south-western part of the Coonamble Basin. Sodium sulphate occurs in the waters of the bores to the south-east of the section under examination, but in the north-west of the section, commencing with the Wingadee No. 3 bore, situated 35 miles north-west of Coonamble, no further sulphates have been recorded. The results of the chemical analysis of the water obtained from the bores mentioned above can be found in Report of Interstate Conference on Artesian Water (1912, p. 93, 99–100, 106–108), Report of the Second Interstate Conference on Artesian Water (1914, p. 246, 248) and Report of the Fourth Interstate Conference on Artesian Water (1924, p. 33).

The Tunderbrine No. 1 bore, situated 38 miles south-east of Coonamble, contains 155 grains of total solids per gallon, while the Tubba bore, situated 82 miles west-north-west of Coonamble, contains 84 grains per gallon of total solids. Both of these bores are located near the margin of the Coonamble Basin.

The increase in the content of total solids contained in the artesian water towards the west of the Coonamble Basin bears a relation to the prevailing flow direction of the water. It is considered by the present author that the artesian water moves from the south-eastern intake area towards the west and north-west, where it is mixed with the waters coming from the north-east. This water from the north-east is considered to originate from the intake areas of part of Queensland, and to traverse the Moree district in its journey to the Coonamble Basin. The main " salting " of the artesian water probably takes place in the western portion of the Coonamble Basin due to contact of the water with the shales which dominate the lithology of the Mesozoic rocks in this area. There is no further intake of water in the western part of the Coonamble Basin, due to the lack of intake beds. On the contrary, there is a natural outlet for artesian water, evidenced by the mound springs. These mound springs are known to occur between the Tubba and Coolabah bores near the western margin of the Coonamble Basin, and are also represented by Guddie Spring, which is situated near the Gilgoin No. 1 bore, 22 miles west-north-west of Carinda. The present author thinks it probable that these springs are located along the eastern margin of the peninsular-like basement prominence which forms the western margin of the Coonamble Basin.

SUMMARY.

Rocks of both Palæozoic and Mesozoic age are represented in the Coonamble Basin. The trends which dominate the structure of the Palæozoic basement complex are thought to be of Palæozoic age. The Mesozoic sediments of the Coonamble Basin were deposited in a large embayment, and this mode of deposition is responsible for the fact that these sediments are more shaly than corresponding sediments in other parts of the New South Wales portion of the Great Artesian Basin. The stagnant conditions under which sedimentation occurred in the Coonamble Basin during Mesozoic times is responsible for the wide-spread occurrence of pyrite in the sediments. The total solid content of the artesian waters in the Coonamble Basin increases from east to west. This can be correlated with the type of sediment through which the artesian waters pass, shales being more abundant towards the western margin of the Basin.

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QUARTZITE XENOLITHS IN THE TERTIARY MAGMAS OF THE SOUTHERN HIGHLANDS, N.S.W.

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With Plate IV.

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I. Introduction.

In the course of a preliminary survey of the Tertiary volcanics in that part of the Southern Highlands centring around Mittagong, Bowral and Moss Vale, about 70 miles south-west from Sydney, the author collected specimens of basalt and dolerite containing the quartzitic xenoliths which constitute the subject of this paper. Such xenoliths have so far been found only in the more basic rocks from High Range and Mt. Flora, ten miles north-west and six miles north from Mittagong respectively.

II. General Geology.

The stratigraphy of the area is very simple in outline, the region being part of the elevated margin of the Sydney Basin, consisting of Permian and Triassic sediments resting more or less horizontally and with violent unconformity on an older Palæozoic basement-complex of Ordovician, Silurian and Devonian (?) meta-sediments and acid plutonic rocks of a granitic nature. The Triassic Hawkesbury Sandstone, a 600 ft. thick orthoquartzite, is particularly important since it was from this unit that the xenolithic fragments are thought to have been derived.

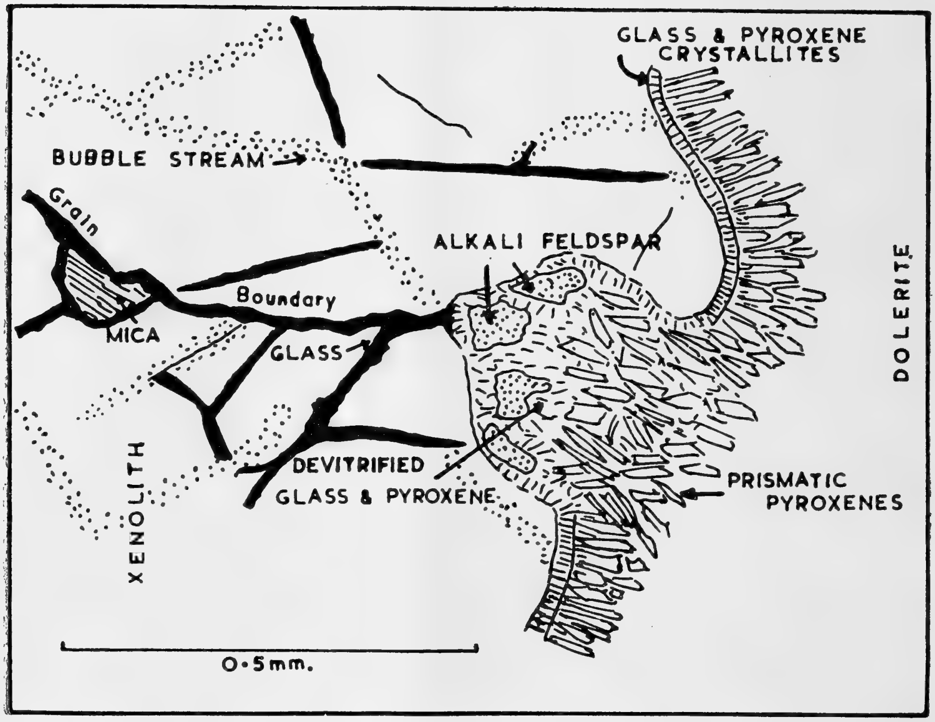
III. The Xenolithic Rocks.

(*a*) *The High Range Basalt.*

The basaltic rocks on High Range are the thin remnants of an originally more extensive sheet which has suffered continuous erosion since the Kosciusko uplift (late Pliocene). The rock is a rather coarse-grained olivine-titanaugite-basalt carrying small amounts of analcite. The principal felspar is an intermediate labradorite (Ab40) in laths averaging 1 mm. in length. Olivine occurs as phenocrysts 1 to 3 mm. across, and is generally detectable in hand-specimen. It is a highly magnesian variety (2V nearly 90°), considerably fractured, and sometimes marginally serpentinized. The pyroxene is a pinkish-brown titaniferous augite intergranular to the feldspar laths. Individual grains proved to be too small to undertake an optical investigation, but they do not appear to be pigeonitic. Interstitial feldspar is a basic oligoclase in anhedra up to 1 mm. across. Analcite, magnetite and apatite are the main accessory minerals.

The xenoliths are difficult to distinguish from the olivine phenocrysts in hand-specimen and they certainly were not recognized as foreign inclusions in the field. In thin-section, however, they are very striking by virtue of the spectacular reaction rims which have formed around them. These reaction rims (Plate IV, Fig. 1) have the characteristic structure so often described in the literature, consisting of an outer zone of closely packed small prismatic clinopyroxenes arranged radially to the periphery of the xenolith, followed inwardly by a narrower zone of brownish, turbid glass (largely in a devitrified state) and extremely minute, needle-like pyroxene crystallites. The outer zone is about 0·25 mm. wide and the inner zone about 0·1 mm. This occurrence departs from the usual in that there is little evidence of the production of alkali-feldspathic material in the inner zone.

The xenoliths consist of two or more grains of quartz in very close contact and, in nearly all cases, the formation of a glassy reaction product has extended along the full length of the intergranular boundaries. It is where these grain junctions intersect the periphery of the xenolith that reaction has been most intense, and it is only in such places that we find alkali feldspar in the reaction rim (see Fig. 1). There is also some development of a fibrous, brown micaceous mineral along some of the fracture planes through the quartz grains, though these fractures are commonly occupied by glass. Another characteristic of the xenoliths in the High Range basalt is the presence of bubble streams traversing the quartz grains (see D. L. Reynolds, 1936, p. 379). These have the appearance of narrow channels crowded with minute globular inclusions extending from the reaction rim into the substance of the quartzite.



Text-fig. 1.

Part of the margin of a quartzite xenolith in the High Range basalt showing the mode of occurrence of alkali feldspar in embayments at grain boundaries.

No instances were found of the xenoliths having completely reacted with the magma, but it is thought feldspathic patches and veins in a similar basalt from Mt. Wanganderry (about five miles to the west of High Range) may represent the final product of such a process.

(*b*) *The Mt. Flora Dolerite.*

The Mt. Flora dolerite occurs in the form of a sill domed upwards by the intrusion of a laccolithic body of solvsbergitic rock beneath it. It is only where the dolerite is in contact with the Hawkesbury Sandstone that it contains quartzitic xenoliths, often in great numbers. It is not difficult to find specimens in which the proportion of xenolithic material is greater than that of the host rock.

Normally, the non-xenolithic phase is essentially a teschenitic rock having a fairly coarse grain-size and consisting of intermediate labradorite, pyroxene, serpentine representing original olivine, and such accessories as titaniferous magnetite, apatite, biotite and abundant analcite. The xenolithic phase, however, has a rather different character in that there is no analcite, and the pyroxene and feldspar are generally deeply altered to carbonate and chlorite. The quartzite xenoliths range in size from 1 mm. to 1 cm., and are commonly highly irregular in outline, with large embayments clearly visible even in hand-specimen. In thin-section the xenoliths are again surrounded by striking reaction rims up to 2 mm. wide and consisting of an inner zone of turbid alkali-feldspathic material, now largely replaced by calcite, and an outer zone of prismatic clino-pyroxenes altering to carbonate and chlorite. One of the smaller xenoliths from the Mt. Flora dolerite is illustrated in Plate IV, Fig. 2. In places the pyroxenic mantles have been disrupted and it is apparent that in such regions the feldspathic material of the inner zone was migrating into the surrounding dolerite.

The quartz grains of the xenoliths have frequently developed a remarkably good rectilinear cleavage, generally confined to the area of the bubble streams present in these xenoliths as in those of the High Range basalt. Thin veins of epidote cutting across the xenoliths are common, and veins and lenses of calcite are even more abundant, in fact the xenolithic quartzite is quite often almost completely replaced by masses of crystalline carbonate. This process of replacement seems to have operated at a late stage in the cooling history of the rock.

TABLE 1.

Values of the Optic Axial Angles of Pyroxenes from the Xenolithic and Non-xenolithic Phases of the Mt. Flora Dolerite, illustrating the Relatively Subcalcic Nature of those from the Xenolithic Phase.

Optic Angle (2V)	
Pyroxenes of Non-xenolithic Phase.	Pyroxenes of Xenolithic Phase.
51°	48°
49°	46°
56°	47°
54°	42°

Bowen (1922*a*) holds that the addition of siliceous xenoliths to a basic magma tends to decrease the amount of olivine and to increase the magnesia content of the pyroxene and the anorthite content of the plagioclase. The character of the Mt. Flora dolerite supports this theory, in that the serpentine pseudomorphs after olivine, so common in the non-xenolithic phase, are completely absent from the xenolithic phase. Also, the pyroxenes of the xenolithic phase are slightly subcalcic relative to those of the normal rock type (see Table 1).

The fact that there is no significant difference in the composition of the plagioclases from each type indicates that the xenoliths were taken up at a time too late to influence the course of crystallization of the feldspar.

IV. Discussion.

(a) The Process of Reaction.

The reactions of quartzite xenoliths with the enclosing magma have received considerable attention in the abundant literature since about 1890 (see Daly, 1933, table 37, p. 299). In most cases it has been shown that the xenolithic material has in some way been incorporated in the magma, but the processes through which this has been achieved have been the subject of considerable speculation.

The simplest theory postulates direct fusion of the xenolith by magmatic superheat with subsequent incorporation in the liquid magma. Daly (1933, p. 307) suggests that " hundreds of cubic kilometers of Sialic rock " may be incorporated in a single basaltic injection by this means. However, the role of direct fusion in assimilative processes is now generally discounted (Bowen, 1922*a*). A point arising from consideration of the Reaction Series (Bowen, 1922*b*) would indicate that direct fusion is at least theoretically possible in those cases where the added minerals are lower in the Reaction Series than the minerals crystallizing from the magma at the time of addition. As a development of this theory, Bowen (1928) suggests that a low-melting fraction of granitic composition (alkali feldspar and quartz) is withdrawn from the xenolith into the liquid phase of the magma, leaving behind a recrystallized residue of the excess silica, alumina and lime originally present in the xenolith. The heat required for these " stewing " processes can only be provided by an increased precipitation of those minerals with which the magma is saturated. In view of the fact that the quartzite xenoliths contain no substances capable of recombining to form a granitic fraction, it follows that no such reaction could have taken place in the present instance.

Bowen (1922*b*) has shown, however, that minerals higher in the Reaction Series can be made over into those phases with which the magma is saturated by a process of ionic reaction with the magma itself. It is by means of chemical rather than physical reaction that the assimilation of the quartzitic xenoliths has been accomplished. Also, it is necessary to postulate the addition of certain substances to the xenoliths, for only by such a process of metasomatic reaction can they have been converted into magmatic phases.

(b) Origin of the Reaction Rims.

As indicated above, the xenoliths are surrounded by an inner reaction rim of glass and/or alkali feldspar, and an outer rim of closely packed, small prismatic clinopyroxenes. The outer pyroxene zone, though more striking in appearance, is more readily explained than is the inner reaction rim. The author does not consider the pyroxene zone to constitute a reaction rim *sensu stricto* since, in his opinion, no chemical reaction between the magma and the xenolith was involved in its formation. It is due, rather, to the operation of purely physical (or, if the reader prefers to consider them as such, physico-chemical) processes as will be explained below.

The absence of marked contact alteration, apart from a moderate degree of induration at the immediate contact, in the sediments through and into which these magmas were injected, together with faulting contemporaneous with intrusion, attest to rapid emplacement and cooling. The character of the consolidated igneous rocks indicates, too, that they were intruded in an essentially fluid condition. One may assume, therefore, that under these conditions accidental inclusions of country rock would be quite cool in contrast to the high temperature of the magma. The temperature of these fragments must be raised to that of the enclosing magma if they remain in contact with it for any length of time and, in so doing they will absorb a certain amount of heat from their surroundings. As we have seen, heat can only be supplied from the magma by an increased precipitation of those minerals with which it is saturated. It is suggested that in this and similar cases the xenoliths were taken into the magma at a time when it was saturated with respect to pyroxene, that is, very early in its crystallization history, and that the heat required to raise the temperature of the fragments and to ensure the continuation of true reaction was supplied by the crystallization of pyroxene in their immediate vicinity as a peripheral corona.

It now remains to account for the origin of the zone of feldspathic and glassy reaction material so characteristically present between the pyroxene corona and the quartz. This zone constitutes a true reaction rim, and as indicated above, reaction in such cases as these can only take place by way of metasomatic addition of magmatic substances to the xenoliths. Such a process was invoked quite early in the century by Lacroix (1903) to explain the feldspathization of quartz-granulite xenoliths in a nephelinite from Drevain. In 1907 Campbell and Stenhouse (p. 133) indicated that reaction has involved the addition of alkalis to the xenoliths, while in more recent times D. L. Reynolds (1936, 1940, 1946), Holmes (1936) and Muir (1953) have ably demonstrated the importance of metasomatic reaction in the transfusion of quartzitic xenoliths.

Holmes' investigations in the basic and ultrabasic lavas of south-west Uganda (1936, p. 416) show that the production of a reaction glass by metasomatic replacement of the quartz has resulted from the introduction of K_2O, Al_2O_3 and H_2O in proportions very different from those in which they could have been present in the magma. He has shown that the reaction corresponds chemically to the feldspathization of the quartzite. Holmes (p. 417) also draws attention to the fact " that the composition of the lavas is no more than a rough guide to the composition the magmatic material from which the migrating emanations were actually given off ". The volatiles, for instance, which must have had considerable influence on the course of chemical reactions within the magma, have been largely lost during the later stages in the cooling history of these rocks. Moreover, Reynolds (1936, p. 397) considers that it is unlikely that the migrating units were oxides. It is more probable that they were free ions, or those ions in some way combined with the fluxing volatiles.

The initial formation of a reaction glass of feldspathic composition at the interface between the xenolith and the magma is no doubt a reaction governed by the laws of surface chemistry, the reactants being supplied by migration of Al_2O_3, K_2O and H_2O (or the appropriate ions) from their source environment to the interface. Having migrated into this position they are adsorbed on the quartz surface and are then ready to participate in reactions of chemical combination or replacement. The nature and degree of activity of the minor magmatic constituents in a catalytic capacity in these reactions is an unknown factor, but Ramberg (1952, p. 206) tells us that they consist mainly of H_2O, CO_2, F, Cl, S, B and other substances which " tend to be concentrated in the intergranular adsorbed phase . . . " He goes on to state that " these substances generally have relatively high vapour pressure and are weakly bonded in or on the silicate lattices ".

It has been demonstrated (Muir, 1953) that the pyroxenic corona has developed around the quartz prior to the formation of the reaction rim. Such a zone of radiating prismatic pyroxenes cannot hinder the diffusion of ions to the quartz surface since, no matter how tighlty packed they may be, there are always inter-crystal boundaries to provide channels for migrating fluids or particles. After the formation of the first layer of reaction products, even though only a few molecules in thickness, we are faced with the problem of transporting the reactants through this outer insulating mantle so that transfusion may proceed inwards from the margins to the centre of the xenoliths, as it assuredly does.

The writer considers that this process is governed by the concept of chemical potentials. The quartz of the xenolith contains very little or no Al_2O_3 or K_2O, while the surrounding magma has a *relatively* high concentration of these substances. Such material will, therefore, migrate towards the quartz under the influence of the resulting potential gradient. Once a feldspathic reaction rim has formed there is an even more marked concentration gradient across the interface between the inner surface of the feldspathic rim and the quartz, so that the tendency for Al_2O_3 and K_2O to leave the reaction rim and cross the interface to the quartz is increased. This, in turn, creates a deficiency in these substances at the outer margin of the reaction rim. In consequence of this, the concentration gradient between the reaction rim and the magma is maintained despite the higher total concentration of Al_2O_3 and K_2O in the reaction rim. There is, therefore, a continued migration of material from the magma to the rim to replace that lost to the quartz on the inner side of the reaction zone. In this manner transfusion can proceed towards the centre of the xenolith until falling temperature puts a stop to further reaction and/or migration. A particularly interesting case has been described by Fromm (1891) of the formation of nepheline rims around quartz xenocrysts in the Herzstein basanitoid. Such a phenomenon records the migration in over-abundance, and at a rate faster than the quartz→feldspar reaction can use them up, of alkalis and alumina from an originally highly alkaline magma.

Why is it that the product of transfusion is almost invariably a potash-rich glass, feldspar or feldspathoid (rarely), even when the magma is a dominantly sodic one? Ramberg (1952), discussing the relative diffusibility of different particles, has shown that at temperatures above 500° C. potassium is more mobile than sodium, while at lower temperatures sodium is the more mobile ion. This may in some way be bound up with the effects of solvation on the sizes of the different ions. Ramberg suggests that the process may be akin to the diffusion of small particles through a semi-permeable membrane which holds back some while allowing others to pass freely. In lavas, at any rate, these reactions take place at temperatures probably higher than 500° C, thus accounting for the predominance of K_2O over Na_2O in the reaction products.

The fact that an elevation of temperature may and, in the case of quartz, does change the dimensions of the crystal lattice has been clearly demonstrated (see, for example, Wykoff, 1926). X-ray investigations have shown that the dimensions of the unit cell of beta-quartz (above 572° C.) are greater than those of alpha-quartz and it is possible that such expansions of crystal lattices may well reduce resistance to diffusion of ions through them and will increase the reactivity of the crystalline substances by a general weakening of the bonds. The glassy nature of the reaction rim in its present state would indicate that it may have been at least semi-fluid at the time of its formation. This fluidity may well have been due to the fluxing properties of the " fugitive constituents " (Shand, 1927) which tend to be concentrated in the reaction zone. Whatever the origin of this condition, however, a zone of fluid reaction material would offer little resistance to the diffusion of ions to the quartz/magma interface.

Apart from the differing diffusion rates of sodium and potassium, there is another factor which may be at least partly responsible for the preferential early development of a potash-rich reaction product. This is a simple reversal of the Reaction Series (Bowen, 1922*b*), in which the normal sequence with decreasing temperature is from calcic plagioclase, through alkali feldspar, to quartz.

If reaction commences at the quartz end of this series by the addition of potash, alumina, etc., together with an elevation of temperature, quartz will be replaced by potash feldspar and the potash feldspar by sodic feldspar if the reaction progresses beyond the first stage. Observations supporting this hypothesis are not difficult to find. Reynolds (1936, p. 381) notes that albite sometimes replaces potash feldspar in the reaction rims after the formation of the latter mineral. Muir (1953, p. 419) records a similar phenomenon associated with the xenoliths in the Ballachulish granodiorite. These examples demonstrate that that part of the reaction rim longest in contact with the magma is made over into phases higher in the Reaction Series, while on the inner side of the rim those reactions forming the lowest possible member of the Reaction Series continue the transfusion of the xenolith.

V. PETROGENETIC SIGNIFICANCE.

Most authors agree that the material generated by the transfusion of quartzite can become mobile, the final result depending upon whether or not the transfused material is assimilated by the magma. If the transfusion product is assimilated and becomes part of the magma, there is little or no effect upon the immediate course of differentiation. The main effect is to increase considerably the quantity of " granitic " residual material formed in the later stages of differentiation (Turner and Verhoogen, 1951). This will find expression in one or other of two possible ways : (1) by the development of a micropegmatitic or otherwise quartz-rich interstitial differentiate, or (2) in the formation of especially siliceous late differentiates as separate rock types. Daly has compiled a list of reported cases of assimilation of highly siliceous sediments up to 1933. His table (Table 37, p. 299) illustrates the above statements when the examples are rearranged according to the nature of the differentiation products.

In those cases where the transfusion products are not assimilated the final result is similar, though the path by which it is reached is a very different one. The transfused material remains as a separate phase within the enclosing magma and, being largely fluid, constitutes a syntectic magma. Reynolds (1936) has described this process in considerable detail in her account of the transfusion of quartzite xenoliths in the hornblendite of Kiloran Bay, Colonsay. Here the development of syntectic magma has gone so far as to result in the formation of a network of feldspathic veins through the hornblendite and " without the evidence of complete exposure, this small portion would hardly fail to be interpreted as resulting from the invasion of solid hornblendite by a feldspathic magma ". She also observes that the appearance of this occurrence is very similar to rock bodies which have generally been interpreted as being due to magmatic differentiation or multiple intrusion. In Colonsay, at all events, the vein material was in fact a syntectic magma, and the appinite and syenite resulting from transfusion are chemically, mineralogically and texturally normal igneous rocks (Reynolds, 1936, p. 395).

The draining off of this syntectic magma, with subsequent concentration in some one part of the igneous mass, will result in the formation of a body of apparently igneous rock having a seemingly younger age than the main intrusion. In such a way at least some of those cases of " magmatic differentiation " may be explained where the later acid differentiate exhibits sharp, even intrusive contacts with the basic parent magma.

VI. SUMMARY.

Quartzite xenoliths from the High Range basalt and the Mt. Flora dolerite have been described. Reaction rims consisting of an outer zone of prismatic clinopyroxenes and an inner zone of glass and/or alkali feldspar have been developed around the xenoliths. It has been shown that only the inner zone is a true reaction rim and that it has resulted from metasomatic transfusion of the quartzite. The mechanism of this reaction has been explained in terms of ionic diffusion, concentration gradients and a possible reversal of Bowen's Reaction Series. The effects of assimilation of quartzite xenoliths on the differentiation trends in the host rock have been discussed and it has been shown that failure to assimilate the transfusion products may result in the formation of a syntectic magma.

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Explanation of Plate IV.

Fig. 1.—Quartz xenolith from High Range basalt showing outer prismatic pyroxene corona and a thin inner zone of turbid glass between the corona and the quartz. Fractures and bubble streams traverse the xenolith in sub-radial arrangement. Ordinary light, X35.

Fig. 2.—Partly transfused quartzite xenolith from the Mt. Flora dolerite. Zone (P) consists essentially of small prismatic pyroxenes ; zone (F) of alkali feldspar and glass ; zone (Q) of quartz. Cleavages have developed in the central bubble-charged region of the xenolith. Ordinary light, X35.

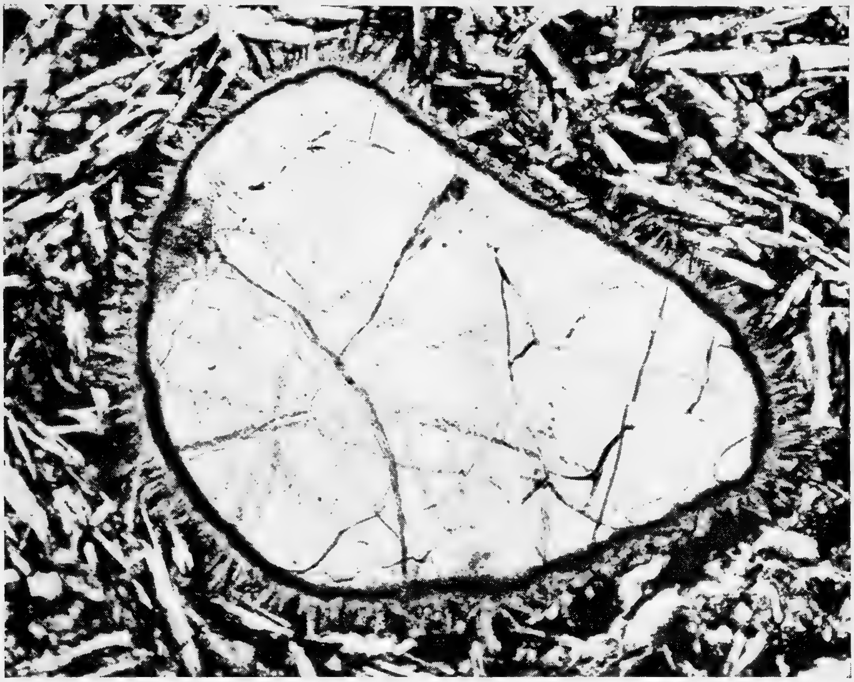


Fig. 1.

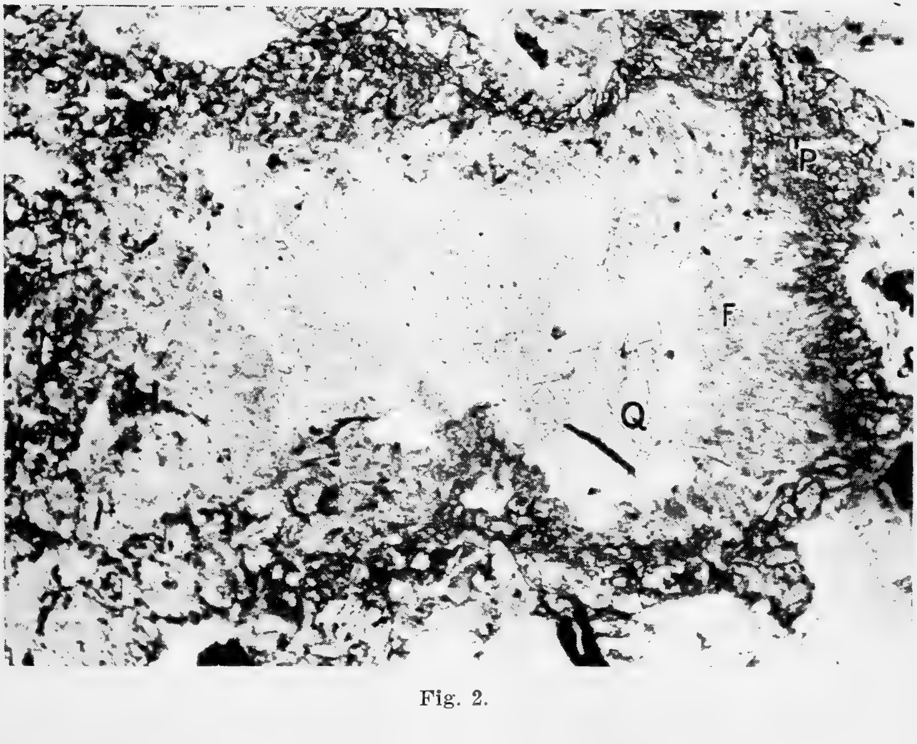


Fig. 2.

PETROLOGY OF GRAYWACKE SUITE SEDIMENTS FROM THE TURON RIVER–COOLAMIGAL CREEK DISTRICT, N.S.W.

By KEITH A. W. CROOK, B.Sc.,
(Deas-Thomson Scholar, University of Sydney.)

Manuscript received, November 8, 1954. Read, December 1, 1954.

INTRODUCTION.

Initial work in the Turon River-Coolamigal Creek district was incorporated in an honours thesis at the University of Sydney (Crook, 1953). The author wishes to acknowledge the interest and assistance rendered by Messrs. G. H. Packham and D. K. Tompkins and the late Dr. H. Rutledge.

The area dealt with (see Text-fig. 1) is situated immediately to the west of the Ben Bullen Complex described by Joplin (1936), and incorporates portions of the parishes of Ben Bullen, Coolamigal, Turon and Cullen Bullen, the major part lying in Portions 15 and 54 of the Parish of Coolamigal, County of Roxburgh.

Wilkinson (1887, p. 57) appears to have been the first to mention the sediments in this district. He referred to them as Devonian, in which he was followed by Carne (1908, p. 61). Joplin (1935) referred to the limestones in the Ben Bullen Complex as Middle or Upper Devonian. She included a brief description of the associated "areno-argillaceous series" (1935, p. 368), but came to no conclusions concerning their age. She did, however, consider the rocks to be possibly tuffaceous.

SUMMARY OF STRATIGRAPHY AND STRUCTURE.

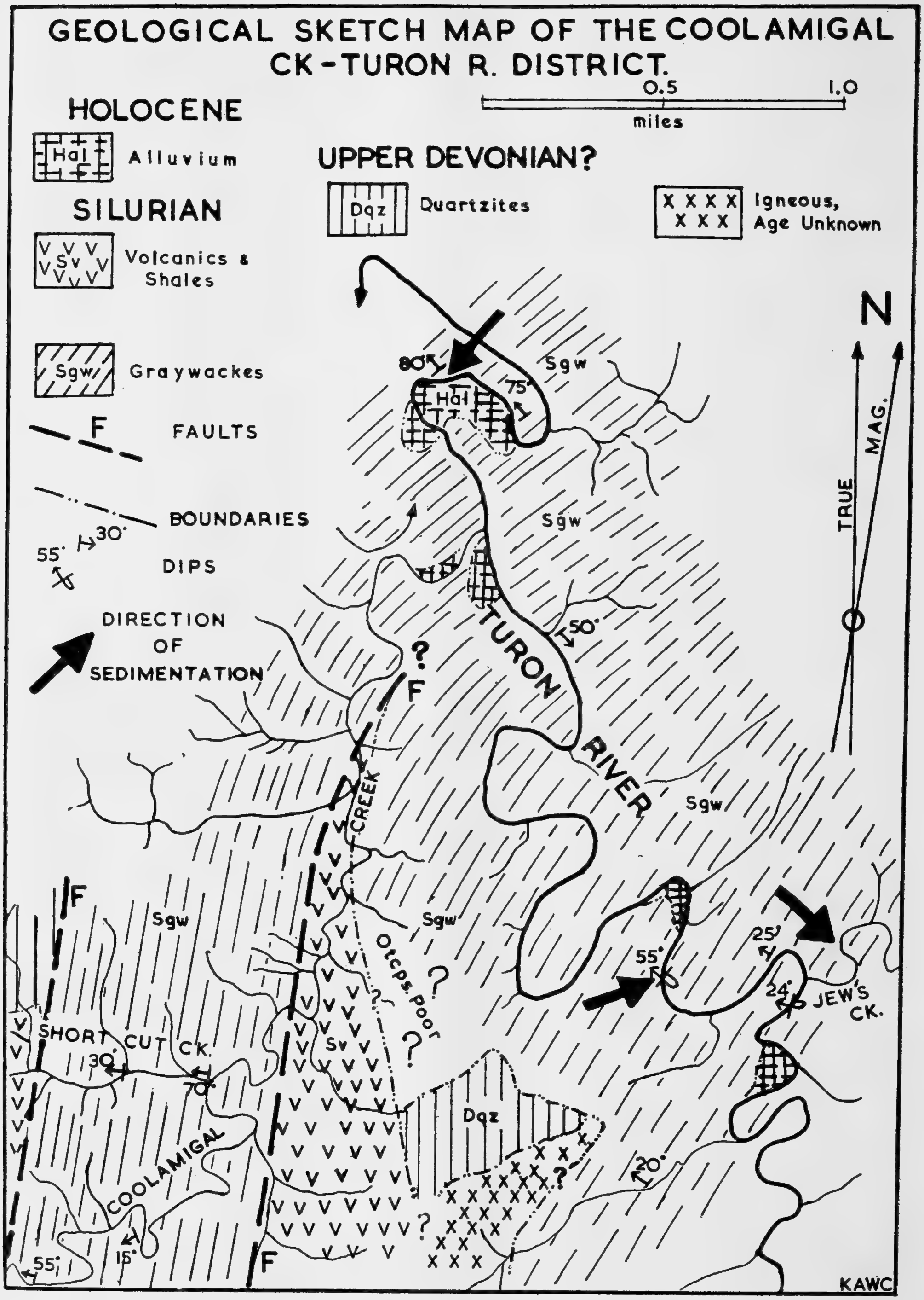
The oldest rocks in the area are andesitic volcanics and shales outcropping for some distance along Coolamigal Creek. These rocks occur again on the western edge of the area, where the shales contain fossils of Lower or Lower Middle Silurian age. The assemblage contains some new forms, the genera represented being *Tryplasma*, *Syringopora*, *Heliolites*, *Rhizophyllum*, *Cystiphyllum* and *Encrinurus ? bowningensis*. Shales containing a similar assemblage, including *Tryplasma lonsdalei*, *Halysites* and *E. bowningensis*, occur associated with the volcanics further to the west in the valley of Palmer's Oaky Creek. The age of the volcanics is thus probably near the top of the Lower Silurian.

The volcanics consist of pyroxene-andesites of the type common in central western N.S.W., with interbedded tuffs and agglomerates. In the vicinity of the fault on Coolamigal Creek, an agglomerate has suffered shearing and replacement, the contained blocks being silicified.

The volcanics are overlain, apparently conformably, by a sequence of Graywacke Suite sediments, chiefly arenites but with minor amounts of coarser and finer types. These are dealt with more fully below.

Overlying these, with apparent unconformity, are unfossiliferous orthoquartzites, which are provisionally assigned to the Upper Devonian. They are pale grey, fine grained rocks which outcrop only on a high hill top in the southern portion of the area.

No Permian rocks occur in the area, although they are well developed a mile or so to the east. To the south and west isolated hill tops are capped with


GEOLOGICAL SKETCH MAP OF THE COOLAMIGAL
CK-TURON R. DISTRICT.
0.5
1.0
miles
HOLOCENE
Hal
Alluvium
SILURIAN
Sv
Volcanics & Shales
Sgw
Graywackes
UPPER DEVONIAN?
Dqz
Quartzites
Igneous, Age Unknown
F
FAULTS
BOUNDARIES
55°
30°
DIPS
DIRECTION OF SEDIMENTATION
N
TRUE
MAG.
80°
75°
50°
TURON RIVER
CREEK
Otcps. Poor
SHORT CUT CK.
COOLAMIGAL
JEW'S CK.
30°
70°
55°
15°
25°
24°
20°
KAWC

Text-fig. 1.

Permian conglomerates and shales at levels topographically lower than the Upper Devonian.

Holocene gravels, sands and muds occur along the course of the Turon River and its tributaries. Some of these deposits are fossil, whilst others are still being formed.

Igneous rocks are widespread, generally as dykes and sills. Lamprophyres, frequently more or less altered, are of common occurrence. In the south there occurs a large area of very much altered igneous rock, apparently intrusive.

It is probable that there is a major thrust fault striking slightly west of south down the valley of Coolamigal Creek. The outcrop of the fault plane has not been observed, but the shearing of the andesites and the abrupt changes in lithology, coupled with the appearance of wedges of graywacke surrounded by sheared andesite, indicates the presence of a fault of some magnitude.

On the western side of the fault, dips have a fairly constant direction to the west or north-west, except in the lower portions of Coolamigal Creek, where much minor folding has occurred. Here the axes of the folds dip towards 325° at about 50°, indicating that the major pressure came from the north-west.

On the eastern side of the fault some beds are overturned, at up to 55°, whilst others are quite normal. This may be due to a series of tight overturned folds with axes dipping to the north-west at about 30°.

The strike of the graywackes, relative to the distribution of the volcanics, suggests that there may be a fault separating them in the south. In the south-west, on Short Cut Creek, a fault brings the volcanics and graywackes in contact. The associated shearing is on a much smaller scale than that observed near the Coolamigal Creek fault.

SEDIMENTS.

The sediments overlying the volcanics are of the Graywacke Suite, as defined by Packham (1954), whose classification is followed herein. Graded bedding is common in the more labile members, whilst the more quartzose frequently contain shale pebbles. Slump structures, micro-current-bedding (confined to the coarser layers) and load casts are associated with the graded bedding.

In hand specimen these sediments—lutites excepted—are very dark green or black, although some of the more quartzose types may be varying shades of grey or yellow-brown.

In dealing with these rocks 27 thin sections have been cut from specimens collected from widely spaced localities. Micrometric analyses of 16 of these are tabulated in Table 1 and plotted on Text-figure 2. On thin section examination the sediments can be divided into two major groups without much difficulty. These were called " graywacke " and " subgraywacke ", and each group can be further subdivided on texture. These names, given on thin section study, which are shown by the key symbols on Text-figure 2, show a high degree of correlation with the names decided from plotting the results of the micrometric analyses. All specimens and slides are housed in the museum of the Department of Geology and Geophysics, University of Sydney.

(a) *The Labile Graywackes.*

The coarsest of these are rudites, or polymictic breccias (Pettijohn, 1949, p. 196), which are poorly sorted, grain diameter ranging from 0·1 mm. to 4 cm., most of the material being between 3 and 6 mm. The paste or matrix is generally subordinate, although in W19 it forms almost half the rock due to an abundance of silt sized feldspar, and also possibly to shearing.

The arenites show a greater development of paste than the rudites. A thin section mechanical analysis, following Packham's method (in press), was carried

TABLE 1.

Micrometric Analyses of Graywacke Suite Sediments from the Turon River-Coolamigal Creek Area

Spec. No.	Rock Type.	Felds.	Pyroxene and Amphib.	Rock Fragments.	Pyroxene+ R.F.+ Felds.	Qtz.	Heavies.	Qtz.+ Heavies.	Paste.
Q23	Graywacke rudite.	—	—	88·5	*88·5*	0·5	—	*0·5*	*11·0*
W8	,, ,,	—	—	92·6	*92·6*	1·9	—	*1·9*	*5·5*
W19	,, ,,	5·8	—	44·2	*50·0*	4·3	—	*4·3*	*45·7*
N20	Graywacke.	10·0	—	53·1	*63·1*	2·5	—	*2·5*	*34·4*
O6	,,	9·5	—	60·7	*70·2*	3·4	—	*3·4*	*26·6*
Q26	,,	9·3	3·6	38·7	*50·7*	4·3	—	*4·3*	*45·0*
C19b	,,	7·6	8·8	58·3	*75·8*	3·2	—	*3·2*	*21·0*
W4	,,	12·7	—	44·3	*57·0*	10·3	—	*10·3*	*32·7*
O12	Graywacke siltstone.	5·5	—	32·5	*38·0*	4·5	—	*4·5*	*57·5*
C7b	,, ,,	8·3	—	27·8	*36·1*	7·2	—	*7·2*	*56·7*
O1	,, ,,	2·5	—	29·6	*32·1*	6·4	—	*6·4*	*61·5*
Q19	Subgraywacke.	1·8	—	3·3	*5·1*	64·2	1·0	*65·2*	*29·7*
C6	,,	3·2	—	5·3	*8·5*	60·6	1·5	*62·1*	*29·4*
Q28	,,	2·3	—	2·5	*4·8*	61·1	0·9	*62·0*	*33·2*
N5	,,	1·2	—	2·7	*3·9*	57·3	1·3	*58·6*	*37·5*
O10	Subgraywacke, siltstone.	0·4	—	2·5	*2·9*	49·4	1·3	*50·7*	*46·4*

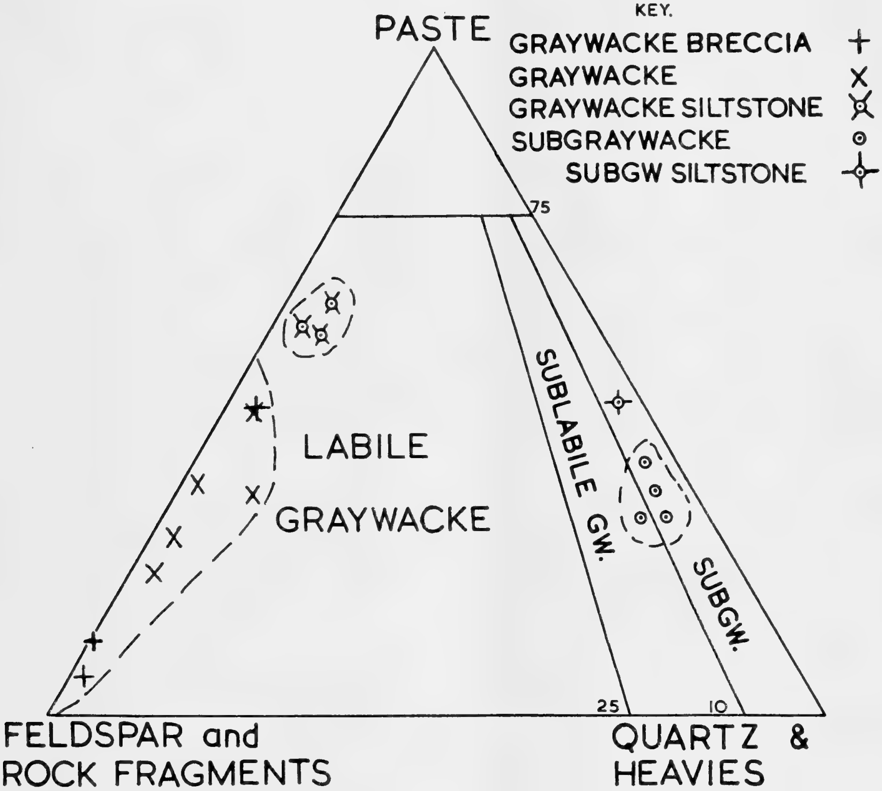
Figures in italics are those plotted in Text-figure 2.

out, but, due to a tendency of many of the fragments to merge imperceptibly into the chloritic paste, the results are not of great accuracy. Values of the geometric measures of the specimen examined are:

Sorting coefficient, 1·99. Skewness, 0·79.

The siltites are difficult to deal with, due to their high percentage of paste. In texture they vary greatly, some passing into chloritic silty shales.

Quartz is generally the best rounded constituent of the labile rudites and arenites (see Table 2). This also applies to the siltites. Rock fragments and feldspar are usually quite angular.



Text-fig. 2.

Rock fragments are a major constituent of these rocks, many varieties being represented. Of these the most characteristic and abundant is an altered ophitic dolerite. Its feldspar is untwinned albite, containing acicular inclusions, and the ferromagnesian mineral, probably augite originally, is replaced by isotropic green chlorite. Minor amounts of iron ore are present. The widespread occurrence of this dolerite, coupled with its distinctive appearance, suggests that it may be of value in correlation problems.

This dolerite, together with radiolarite and fine aphyric volcanics, is present in more than 80% of the rudites and arenites. Some arenites (W4) and most siltites contain only fine grained volcanics and silty shale fragments.

Also present in the rudites are fine black feldspathic "tuff" with radiolaria, porphyritic volcanics, recrystallised limestone and siltstone. The pyroxene bearing arenites contain an unusual assemblage, which includes intergranular basalt, porphyritic andesite—generally with hornblende and feldspar phenocrysts, devitrified spherulitic pitchstone and minor amounts of recrystallised limestone.

Feldspar is widespread, although uncommon in all rudites save W19. It is generally clear albite with acicular inclusions, and has probably been derived from the ophitic dolerite. Smaller amounts of more altered twinned feldspar, an acid plagioclase, are also present. This is developed to the exclusion of the clear albite in W4.

TABLE 2.
Roundness Values of Grains.
(Using Visual Chart, Krumbein and Sloss, 1951, p. 81.)

Nature of Grains.	Roundness Values.	
	Majority of Grains.	Large Grains.
Rock fragments in Graywacke Breccia	0·1–0·4	0·8
Quartz, in Graywacke Breccia	0·5–0·9 (W19 0·1–0·5)	— —
Rock fragments, Labile Graywacke	0·1–0·3	0·5
Feldspar, in Labile Graywacke	0·2–0·4	—
Amphibole and Pyroxene Graywacke	0·2–0·4	—
Quartz, in Labile Graywacke	0·5–0·9	—
Quartz, in Subgraywacke	0·1–0·5	—

The quartz, which is not common, appears to be entirely of igneous or vein origin. Strings of bubbles are frequent, and composite grains are met with. Extinction is generally undulose. No signs of secondary enlargement have been observed. The quartz in W4 contains occasional inclusions of muscovite.

TABLE 3.
Results of Mechanical Analyses.

O6, Labile Graywacke.			Q28, Subgraywacke.		
Class Limits. (mm.)	Cumulative Percentage.		Class Limits. (mm.)	Cumulative Percentage.	
	Observed.	Corrected.		Observed.	Corrected.
0·0835	100·0	100·0	0·0105	100·0	100·0
0·0835–0·167	72·3	78·4	0·0105–0·0385	61·8	62·9
0·167 –0·334	57·6	65·5	0·0385–0·0665	41·7	49·5
0·334 –0·501	31·2	39·6	0·0665–0·0945	19·7	24·9
0·501 –0·668	13·5	18·3	0·0945–0·119	10·9	16·9
0·668	4·5	7·2	0·119	4·6	8·0

Certain of the arenites (C19b and Q26) contain appreciable amounts of pale green clinopyroxene and a little amphibole. In C19b limited amounts of detrital bright green chlorite are present. The amphibole is pleochroic: X, brown; Y and Z, deep brownish green; 2V (—) about 30°, and is very distinctive. Occasional small grains of amphibole, associated with bright green chlorite, have been met with in the siltites.

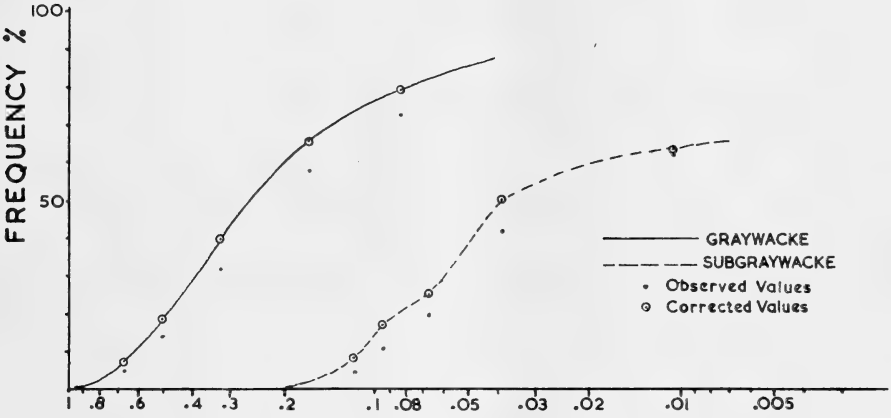
The paste, or matrix, is chloritic, but may be converted to biotite by metamorphism, as in W4. In passing it may be noted that W4, which is anomalous in many respects, comes from a well-defined bed, devoid of internal bedding, associated with the overturned fold and slump structure referred to below.

(*b*) *The Sublabile Graywackes and Subgraywackes.*

No rudaceous representatives of these have been found, and the arenites are appreciably finer than their labile graywacke counterparts, and contain much silt (Text-fig. 3). Mechanical analysis (Table 3, Text-fig. 3) shows a polymodal distribution of the grains, which is probably characteristic of these arenites.

The siltites are not so common as their labile graywacke equivalents, and show an increase in paste and detritial muscovite over the arenites.

The roundness values of the quartz in these sediments (Table 2) is lower than that of the quartz in the labile graywackes. There is little difference in roundness between the arenites and siltites.



Text-fig. 3.

The most important constituent of these rocks is quartz. The apparent sphericity of all grains is high, and trails of bubbles and undulose extinctions are frequent.

Rock fragments and feldspar are only minor constituents, the former being mainly fragments of shale and siltstone, and, very occasionally, igneous rocks. Microcline, twinned plagioclase and an untwinned feldspar, probably orthoclase, are present.

A characteristic feature of these rocks is the heavy mineral assemblage. Micrometric analyses show the rocks may contain up to 1·5% of heavies.

In thin section the following stand out: (1) abundant apatite; (2) blue and yellow tourmaline abundant; (3) zircon subordinate; (4) rutile present in only minor amounts. The abundance of apatite is quite striking, and may prove diagnostic for rocks of this age.

The matrix, or paste, is partly chloritic and partly sericitic, and may contain considerable amounts of comminuted muscovite. Occasional large fragments of muscovite are present.

Alteration.

Alteration is restricted to low temperature diagenetic effects. Authigenic pyrite is widely developed, generally euhedral, and is not restricted to any particular rock type. Quartz-chlorite and quartz-carbonate veins occur frequently, the chlorite being generally vermicular penninite. The carbonate may be either ankerite or siderite.

SEDIMENTATION.

In dealing with the sedimentation, two sets of features are important: sedimentary structures and composition of the sediments.

Following Kuenen (1953), use has been made of certain sedimentary structures to determine the direction of provenance. Three determinations are shown on Text-figure 1. That shown on Jew's Creek was determined by calculating the direction of dip of a layer of micro-current-bedded material, allowing for folding. This gives the direction of current flow, in this case 130°. This value, subject to the qualifications below, may be taken as the direction of provenance.

Two other determinations have been made, both using slump structures. In these cases the direction of provenance is the same as the direction of slumping. The northern occurrence gives a value of 225°. The southern occurrence is on the overturned limb of a tight minor fold, and the direction in this case is 60°.

Because of the small number of determinations it would be inadvisable to draw any firm conclusions regarding direction of provenance. The variations in direction observed may be due to:

(1) Variations in the direction of provenance during the deposition of the sequence, such that some members were derived from one direction and some from another.

(2) Variations in the topography of the sea floor causing currents and slumps to have directions other than normal to the shore line.

Bearing these possibilities in mind, there is evidence that the sediments in the north were derived from the north-east, whilst those in the south came from the west.

The composition of the sediments gives some idea of the lithology of the terrain from which they were derived. Several of the rock types represented have their equivalents in the Lower Silurian of the Palmer's Oaky district. They may not have been derived from this region, for similar rocks may well be present beneath the younger sediments to the east. The radiolarite, feldspathic "tuff" and several of the volcanics, particularly the andesites, are similar to those to the west, but some types, notably the dolerite and intergranular basalt, have not been found in that region.

Erosion and deposition of the material was swift, as is shown by low roundness values, and the presence of unweathered pyroxene, amphibole and rock fragments. The presence of unweathered euhedral pyrite in radiolarite fragments in Q23 also indicates this.

The nature of the quartz and the presence of quartzose members raises some problems. Many of the quartz fragments in the labile members are well rounded, indicating an appreciable distance of transport. The absence of secondary enlargement renders derivation from a pre-existing sediment unlikely.

The quartz seems to be of plutonic igneous or vein origin, and the presence of minor amounts of microcline in the subgraywackes suggests that part came from a granitic terrain. It should also be noticed that veins of milky quartz are of frequent occurrence throughout the Ordovician and Silurian of central western N.S.W.

The quartzose members are not shoe-string sands (Pettijohn, 1949, p. 257), and their composition differs radically from the labile members ; they probably represent definite influxes of material from a quartz-rich terrain. They do not appear to be of cyclic occurrence.

CONCLUSIONS.

(1) The sediments developed in the Turon River-Coolamigal Creek district include a sequence of graywackes of probable Middle Silurian age.

(2) Rock fragments present in the labile members are of types similar to rocks outcropping in the Lower Silurian to the west.

(3) The detrital quartz is of plutonic igneous and vein origin, and that in the quartzose members has probably been derived from a granitic terrain.

(4) Fragments of a distinctive type of altered ophitic dolerite are common in the labile members. This may be valuable for correlation purposes.

(5) Apatite is abundant in the subgraywackes, and this may be of value in correlation problems.

(6) Use of sedimentary structures as indices of provenance shows that the sediments in the north may have come from the north-east, and those in the south may have come from the west.

More detailed examination of this area would provide a much fuller picture of the sedimentation and sediments than that presented here. Circumstances, however, do not permit the author to continue this investigation, and he feels it best to publish the results obtained to date for the reference of future workers.

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THE PERMIAN COAL MEASURES OF THE STROUD–GLOUCESTER TROUGH.

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N.S.W. University of Technology.

With Plate V.

Manuscript received, November 8, 1954. Read, December 1, 1954.

INTRODUCTION.

Since the discovery of coal in 1855 by Odenheimer some seven miles or so to the north of Stroud Road, little in the way of systematic work has been attempted in the development of this coal basin.

David visited the basin in 1889 and reported on coal seams in the Johnson's and Stoney Creek areas, but these examinations were too cursory to have effected any correlation of the strata. Sussmilch, in 1921, described the Devonian and Carboniferous stratigraphy in addition to making important contributions towards a better understanding of the structures at the northern end of the Trough, and later in the same year Morrison inspected coal outcrops along the Gloucester River, within the town itself, and reported on shafts near the Avon River, to the east of the town.

Since 1922, Osborne, in his efforts to elucidate the complicated structural history of the Hunter-Myall-Manning Province, has been brought into contact with the coal measures on many occasions, but, as these deposits lay beyond the scope of his research, little attention was paid to them.

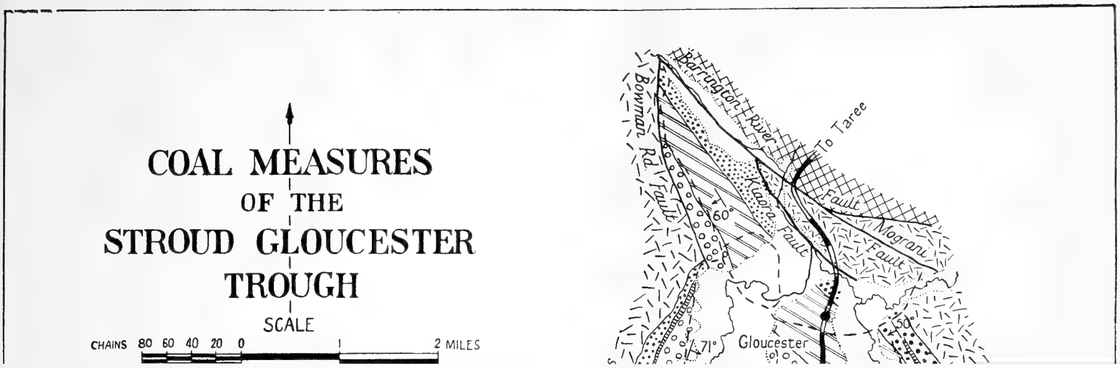
The present paper is principally concerned with the stratigraphy, economic potentialities and related aspects of the coal measures.

PHYSIOGRAPHY.

As a section is devoted to structures, at this point it will suffice merely to mention the general synclinal nature of the strata which strike meridionally, dipping toward the axis at angles ranging up to the vertical. The coal measures extend for 25 miles in the direction of the strike whilst the width of the syncline as it now stands is variable from a matter of a few hundred yards in the southern extremity near Dewrang, to seven or eight miles in the vicinity of Stratford and the Upper Avon. Further north a general narrowing takes place as the town of Gloucester is approached and one and a half miles beyond this town the syncline terminates abruptly in a complicated fault system.

Both Permian and Carboniferous strata have been caught up in the folding movement, and as the upper beds of the latter system are principally volcanic a marked contrast is made with the comparatively weak Permian strata. The product of erosion consists of two sub-parallel lines of hills, often with precipitous faces, exposing bare rock in places, whilst the coal measures occupy the valley floor between. The foothills generally, but not invariably, mark the boundary of the two systems.

A remarkable change in the topography of the valley floor takes place just to the south of Craven. The undulating hilly country of the south gives way to


COAL MEASURES
OF THE
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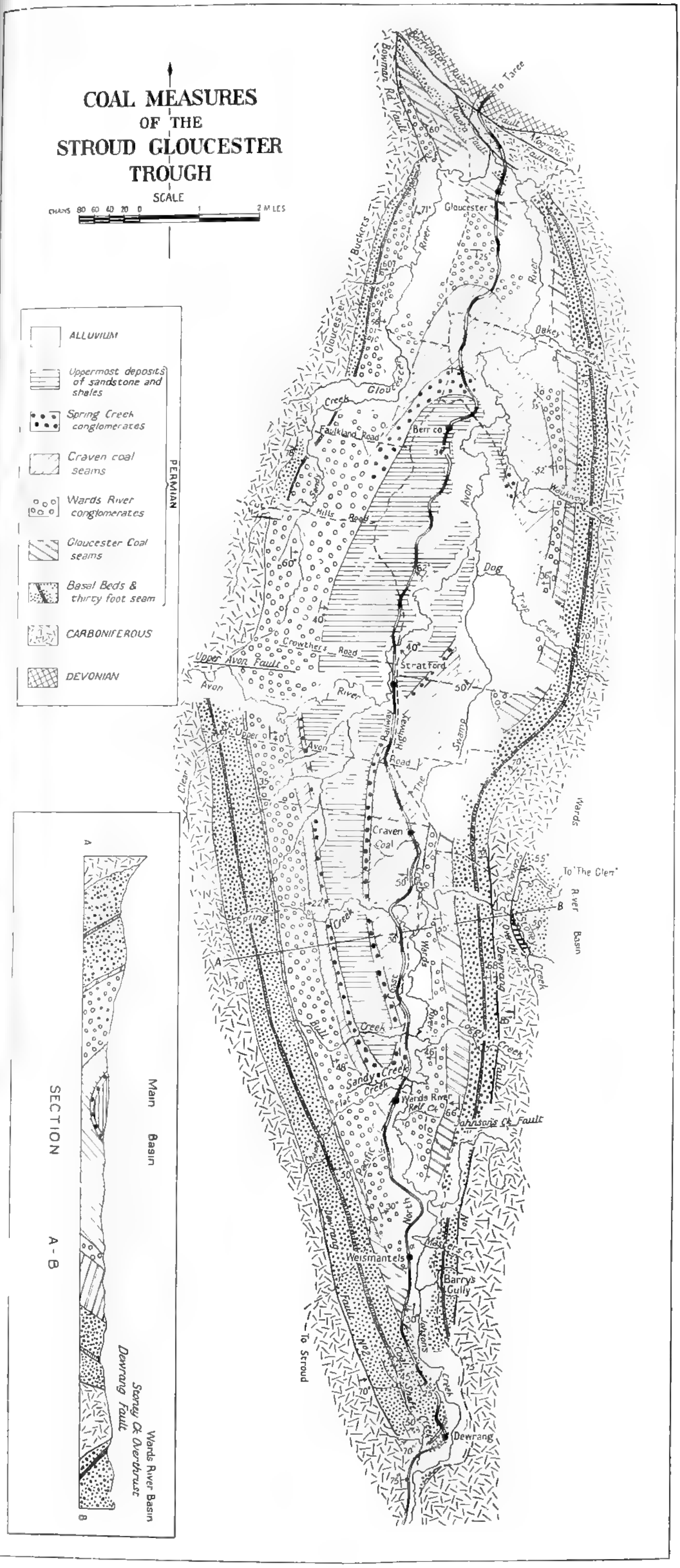
TROUGH
SCALE
CHAINS 80 60 40 20 0
1
2 MILES
Barrington River
To Taree
Bowman Rd. Fault
Kiaora Fault
Fault
Mograni Fault
60°
71°
50°
Gloucester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CHAINS 80 60 40 20 0 1 2 MILES
ALLUVIUM
Uppermost deposits of sandstone and shales
Spring Creek conglomerates
Craven coal seams
Wards River conglomerates
Gloucester Coal seams
Basal Beds & thirty foot seam
PERMIAN
CARBONIFEROUS
DEVONIAN
SECTION A - B
A
B
Main Basin
Wards River Basin
Stoney Ck Overthrust
Dewrang Fault
Bowman Rd Fault
Barrington River
To Taree
Kiaora Fault
Bucketts
Gloucester
Gloucester River
Oakey Creek
Faulkland Road
Berrico
Sandy
Cut Hills Road
Avon
Waukivory Creek
Dog Trap Creek
Crowthers Road
Upper Avon Fault
Avon River
Stratford
Railway
Highway
Road
The Swamp
Upper Avon
Clear
Craven
Coal
Wards
To 'The Glen'
River Basin
Spring Creek
Cast Creek
Wards River
Dewrang
Stoney Creek
Bulli Creek
Sandy Creek
Flat Creek
Wards River Relf Ck
Johnsons Ck Fault
Loggy Creek Fault
Pacific
North
Dewrang Fault No 2
To Stroud
Weismantels
Masters Ck
Barrys Gully
Johnsons Creek
Coal Shaft Creek
Dewrang

flat, alluvial and swampy country on the north, some hundred or so feet higher in elevation. The change marks the divide between the Ward's River-Johnson's Creek drainage system flowing southward to the Karuah, and eventually Port Stephens; and the Avon-Gloucester Rivers, which trend northward to meet the Manning and hence to the coast. Coal Creek, a tributary of Ward's River, actually has its headward reaches on the northern side of the divide, but manages to reach the parent stream by way of a deeply entrenched course.

The ubiquity of river gravels at every possible level of the present topography is indicative of the numerous cycles of erosion to which this area has been subjected, and as shown above the valley has embarked upon a further cycle of base levelling, undoubtedly brought about by a tributary of the Karuah extending its headward reaches to capture the ancestors of the Ward's River-Johnson's Creek system, which, prior to this capture, flowed northward.

STRATIGRAPHY.

Rocks of Devonian, Carboniferous and Permian age outcrop in the area, in addition to superficial river deposits referable to a late geological period. A description of the first two systems may be found elsewhere in the literature, and it is intended to give only a brief historical account of the area to the close of the Carboniferous.

Summary of the History to the Close of the Permian.

The rhythmically bedded Carboniferous tuffs, mudstones and lava flows contrast markedly with the deeper marine deposits of the Devonian, and Sussmilch, who discussed the relationship of these two systems at some length, was of the opinion that an angular unconformity exists. Such an unconformity would be referable to the Tabberabberan Orogeny.

On the other hand, the conformable nature of the lower and upper Burindi contact suggests that in this area at least the effects of the Kanimbla Diastrophism were not felt, but rather from the commencement to the close of Burindi times a general silting-up of a shallow basin took place, accompanied by small, intermittent epeirogenic movements and, during the Upper Kuttung, the area was dry land suffering periodic and extensive inundations of lava flows, accompanied by contemporaneous erosion. Evidence for this is shown by the disconformable nature of the Kuttung-Permian contact and, in one or two localities, notably along the Faulkland Road, rhyolitic conglomerates of the Kuttung Series form the basement beds for the Permian.

Permian.

Lying between the volcanic hills of the Upper Kuttung Series is a thick terrestrial group of conglomerates, sandstones, mudstones, arkoses and carbonaceous shales with numerous coal seams ranging up to 30 feet in thickness. That these deposits are of Permian age is placed beyond doubt by the frequent occurrence of such plant remains as *Glossopteris*, *Gangamopteris*, *Noeggerathiopsis* and *vertebraria*.

In the southern part of the area between Craven and Dewrang, the fold trends N.20 W. with a plunge to the north. Faulting in this vicinity has produced a more southerly extension of the outcrop.

North of Craven, where the influence of remarkable E.-W. tear faults is most intense, the axis swings to the N.N.E., but between Berrico Siding and Gloucester a gentle plunge southwards is present, though this tendency is rendered less apparent by the presence of many minor structures. Beyond Gloucester a complicated fault system has assumed control and only the eastern limb of the syncline is preserved, the strike being N.N.W.

Throughout the entire length of the synclinal basin the axis is displaced to the western side of the Permian outcrops, suggestive of asymmetrical folding. However, that this is not so may be seen by the regular and complementary increase in dips as the measurements are made away from the axis ; and, in fact, the apparent asymmetry is due to a divergence of the strata from west to east. Further evidence is given by the greater predominance of conglomerates in the west, together with the overlapping of several of the formations.

The following is a generalised section of the Permian stratigraphy in descending order :

		Approx. Thickness
6.	Broad Gully Formation of sandstones, carbonaceous shales, conglomerate and a little coal	770 ft.
5.	Spring Creek Conglomerate	50 ,,
4.	The Craven Coal Measures	2,300 ,,
3.	Ward's River Conglomerate	220 ,,
2.	The Avon Coal Measures	1,900 ,,
1.	Dewrang Formation of sandstones, conglomerate, arkosic sandstones including the "30 Foot Seam"	1,100 ,,
		6,340 ,,

1. *The Dewrang Formation.* The presence of a considerable amount of strike faulting between the Upper Kuttung Series and the basal beds of the Permian, coupled with the prevalence of thick talus slopes along the contact, requires specialised conditions in the physiography for the observation of the basal deposits.

However, on the eastern bank of Johnson's Creek, to the extreme south of the Permian outcrop, the contact is clearly exposed. Fifty feet of sandstones, carbonaceous shales rich in flora, conglomerates and two eighteen-inch coal seams overlie the lavas.

The same sequence may be observed a mile further north, on the Johnson's Creek Road, and along the eastern margin between Loggy Creek and The Glen Road, where 600 ft. of strata consisting principally of sandstones, outcrop.

On the western side of the syncline the sandstones may be seen where they intersect the Pacific Highway, but beyond the latitude of the Upper Avon, conglomeratic sandstones predominate.

The conglomeratic pebbles, like those of the Ward's River and Spring Creek Conglomerates, consist almost exclusively of acid lavas, often with the fluidal fabric well preserved, though tuffaceous material comprises a small proportion. A variation in the degree of sphericity is observed between the pebbles of the western and eastern sides, the former being more angular than the equidimensional material of the east. The matrix is predominantly arkosic, consisting of 40% silica grains with a variable amount of plagioclase, often displaying a remarkably fresh state of preservation, and chloritised biotite, whilst a considerable proportion of the rock consists of unresolved clay material.

Approximately 600 feet stratigraphically from the base of the Permian occurs a thick coal seam, to which Odenheimer in 1855 gave the name "The 30 Foot Seam". The seam may be traced for most of the distance round the synclinal basin with good exposures located on the north bank of the Avon River close to the Upper Avon Fault, near Chainey Flat Creek, along Coal Shaft Creek, in a railway cutting a few hundred yards north of Dewrang Siding, at Barry's Gully and Masters Creek, and further north near Oakey Creek.

Several prospecting shafts are located along Coal Shaft and Masters Creeks and at Barry's Gully, whilst a small colliery has operated in the first-named locality. Records of these shafts are to be found in the reports of Odenheimer and David. (It is interesting to note that Odenheimer reports 28 feet of excellent coal close to the surface in one of these shafts.) The seam dips steeply toward the axis, the lowest recorded angle being 35°.

Overlying the "30 Foot Seam" and the associated carbonaceous shales are approximately 500 feet of medium to coarse grained sandstones, which are pebbly in places and locally grade into conglomerates. Bedding is fairly well defined and the rocks contain a high percentage of plagioclase, generally in a much decomposed state, in addition to minor amounts of chlorite, biotite, zeolite, hematite and calcite.

2. *The Avon Coal Measures.* Approximately 1,100 feet above the base of the Permian is a thick succession of intercalated sandstones and coal-bearing strata totalling 1,900 feet in thickness. Good outcrops occur within the town of Gloucester along the southern bank of the river and opposite the railway station. Fifteen coal seams were counted, ranging in thickness from two to eight feet, with a general dip south-west at 55°. Minor faulting and buckling of the strata is prevalent, and an attempt to mine the coal by the Gloucester Main Colliery experienced difficulty in this respect.

On the eastern bank of the Avon River, 600 yards south of the Krambach Road, several infilled prospecting shafts are situated on the lowermost beds of the formation. A description of one of these shafts is given by Sussmilch.

Southwards from this latter area, the formation may be traced by isolated outcrops to within two miles of Dewrang, with good exposures occurring on the southern bank of Ward's River and in tributary streams of Johnson's Creek.

On the western limb the coal-bearing strata can be followed from the intersection with the Pacific Highway, three miles south of Ward's River village to the Avon River, but between the latter point and the Gloucester River evidence is lacking, suggesting an overlap.

3. *Ward's River Conglomerate.* Exposed along the eastern bank of Ward's River, to the south of Craven, where the stream flows parallel with the Pacific Highway, is a massive cliff-forming conglomerate containing two horizons of interbedded shales and coaly bands. The formation measures 220 feet in thickness.

The conglomerate pebbles have been derived, almost exclusively, from the Upper Kuttung Series, and are usually elongated in one or two directions, varying in size to some extent but generally large and tightly packed, though here and there the sandstone matrix forms small lenses and thin beds devoid of rudaceous material. In composition the matrix resembles the basal sandstones.

Further south along the Johnson's Creek Road, near Relf's Creek, the same strata may be seen striking N. 8° E. with a dip of 45° to the west. On the western side of the axis the equivalent deposits across the Pacific Highway within a mile south of Ward's River village, striking N. 20° W. and dipping to the east at 47°. The southerly extension of these beds is difficult to trace, but the proximity of the same strata on both sides of the syncline and the steepness of the dips involved renders a difficulty in visualising the beds as merely folded and not faulted additionally.

To the north-west the massive conglomerate may be traced almost to Gloucester, forming cliffs along the banks of the intersecting streams, notably those of Spring and Sandy Creeks.

South of Craven the conglomerate is quarried for road metal, but further north swamp and alluvium conceal the outcrop for the most part. However, within the town of Gloucester and along the Barrington Road excellent exposures may be seen in the various road cuttings and creek beds.

4. *The Craven Coal Measures.* Outcropping in a series of road and railway cuttings less than a mile to the south-east of Craven Post Office is a thick formation containing numerous coal seams up to nine feet in thickness. The beds have suffered considerable distortion and several classical examples of structures in miniature may be seen. To what extent these folds and thrusts have displaced the strata is difficult to estimate, since many more must remain concealed beneath the thick soil cover. The succession has a thickness of approximately 2,300 feet and contains at least 30 coal seams.

North of Craven all trace of the strata is lost under the alluvium of " The Swamp ", but at the junction of the Upper Avon Road and the Pacific Highway the uppermost beds with several coal seams may be seen cutting across the road with a strike N. 10° E. The swing in the strike becomes more pronounced along the East Stratford Road, where the coal-bearing strata run N. 32° E. with a dip of 55° N.E. Undoubtedly the Upper Avon Fault has been influential in this respect.

Further north the strata strike more or less meridionally, but only isolated outcrops occur, notably along Waukivory and Dog Trap Creeks ; and, just to the south of Gloucester on the Pacific Highway thick deposits of carbonaceous shale and sandstone, with a shallow southward dip, mark the northern extent of the Craven Coal Measures.

South of Craven exposures of carbonaceous shales, coal and arkosic sandstones in road and railway cuttings extend as far as Ward's River village, where the dip is to the north.

Along the western margin of the syncline the strata may be traced northwards to the Avon River, where a considerable thinning of the formation takes place, and beyond this point the deposits fail to outcrop.

5. *Spring Creek Conglomerate.* Overlying the Craven Coal Seams is a heavy unstratified conglomerate approximately 50 feet thick, resembling the Ward's River Conglomerate in composition. Good outcrops are to be found along Spring Creek and south towards Ward's River School, but northwards from Spring Creek the conglomerates are difficult to trace, which is surprising in view of their competent nature. However, occasional outcrops of conglomerate on the expected horizon suggests that this rock occurs right round the synclinal basin.

6. *Broad Gully Formation.* In the Spring Creek sector, lying along the axis between the two outcrops of the conglomerate described above, is a succession of carbonaceous shales, arkosic sandstones, conglomerates and mudstones with several thin coaly beds. The strata on the whole deviates but a little from the horizontal, though minor puckering coupled with the lack of good exposures makes measurements difficult. However, from an economic viewpoint the beds are of little interest.

WARD'S RIVER BASIN.

A mile east of Craven, along The Glen Road, the eastern boundary of the coal basin is reached, and for a further 600 yards the road traverses the Upper Kuttung Series, which dip steeply to the west. Beyond the lavas coal measures are encountered once more, with a steep easterly dip. A thick arthracitic coal seam, which outcrops along Stoney Creek, forms the basal beds with a strike N. 20° W., dipping to the east at 50°.

The relation of the basal seam to the Carboniferous lavas is difficult to ascertain in such rugged country, since thick talus slopes obscure the contact at every occasion. However, the juxtaposition of coal measures and basement lavas dipping steeply in opposite directions is suggestive of either an unconformity or faulting.

A thick succession of mudstones, carbonaceous shales and sandstones, which locally grade into conglomerate, overlie the coal seam, but the geology of this subsidiary basin was not fully investigated and the extent is unknown.

ECONOMIC ASPECTS.

In describing the Permian stratigraphy, attention was drawn to the occurrence of coal seams in commercial thicknesses at several horizons and, though two attempts have been made to mine the coal (at Gloucester and near Dewrang Siding) and many prospecting shafts have been sunk, chemical analyses are few.

On the present survey, opportunities for satisfactory sampling of the coal were restricted to one locality, viz. a small cross-cut driven into the bank of Coal Creek, one-half mile south-east of Craven. This drive intersected three seams, the upper two of which were sampled. The following proximate analysis is representative of both seams, excluding bands : hyg. moist, 10% ; vol. mat., 25% ; fixed carbon, 45% ; ash, 20%. The coal was in a partly weathered state, and much soil material had been added along the cleats; the nature of the coal in thin section indicates that a somewhat lower ash content could be expected from a fresher sample.

In attempting to ascertain the effect of faulting on the rank of the Stoney Creek seam, a random sample was taken from the creek bed and a proximate analysis was carried out, yielding the following results : vol. material, 33% ; fixed carbon, 37·3% ; ash, 9·7%. Recalculating on an A.F.D. basis : vol. material, 36·5% ; fixed carbon, 63·5%. These figures indicate a low rank bituminous coal, which is surprising in view of the high physical rank the coal appears to have in hand specimen. However, it must be remembered that only one determination was made, and that on a random sample, hence the results obtained cannot be regarded as representative.

STRUCTURAL GEOLOGY.

Perhaps no other area within the State presents such a unique opportunity for studying the rapid succession of differing tectonic environments as the Stroud-Gloucester Trough. However, it is not intended to duplicate the work of Osborne, Sussmilch *et al.* in this respect but rather to add and possibly modify some of their work.

Undoubtedly the most remarkable feature of the area is that due to a late E.-W. compressional stress of some magnitude which superimposed new structures on pre-existing ones causing the development of tear fractures and the displacement of whole blocks of country. The displacements were differential in part, and where the blocks became " anchored " at one extremity but yielded at the other a certain amount of rotation took place, whilst minor fractures and folds developed about the anchored regions. Mograni, Barrington River and Upper Avon faults are examples of major displacements, whilst the minor structures developed to the south of Craven (see Osborne and Andrews) and within the town of Gloucester are located about the " hinge " regions.

A modification found necessary concerned the position of the Kiaora Fault. This fault, which obliquely transects the coal measures to the north-west of Gloucester, was first recorded by Sussmilch and later named by Osborne and Andrews (1949). Alluvium covers much of the critical area, but nowhere in the region could evidence be found to support the existence of such a fault. However, on the north side of the Gloucester River along the contact of the coal measures and the Kuttung lavas between the railway line and Kiaora crossing slickensides are numerous and the strata has been greatly disturbed, suggesting faulting. It is proposed to retain " Kiaora " for this fault.

A further area in which a possible fault exists lies to the south of the " Buckets ", where the Gloucester River cuts through the volcanic hills. A considerable wavering of the strike occurs and the unusual courses taken by both the Gloucester River and Sandy Creek are suggestive of faulting, though no displacement could be measured.

Reference has been made previously to the discordant nature of the Ward's River Coal Measures and Kuttung lavas contact, a marked discordance which is not observed between coal measures and Carboniferous elsewhere ; and, in view of the prevalence of slickensides in the basal coal seam of the Ward's River measures it would appear that a fault separated the two systems. Moreover, the Ward's River Basin is associated with that block of country which has suffered the greatest lateral movement, a stress condition more compatible with overthrusting than normal faulting. Hence it is proposed to term this fracture the Stoney Creek overthrust.

Age of the Coal Measures.

Since the earliest discovery of the Gloucester Coal Basin attempts at a correlation between these deposits and the type Permian of the Lower Hunter area have proven unsuccessful, perhaps the reasons being the absence of recognisable marine deposits and the specialised nature of the sedimentation environment. On the present survey several attempts were made at microspore correlation, but with unsatisfactory results. Perhaps the best method of effecting a correlation of the respective deposits would be by a correlation of the tectonic disturbances which affected both areas.

Owing to the conformable nature of the Carboniferous-Permian boundary and the limited extent of the measures, it would appear that the Permian was laid down during a mild compressional period which initiated the syncline. This period of intermittent subsidence was followed by a stress relief period during which the tensional boundary and intragraben faults developed. At a later period a compression of some magnitude tended to squeeze the sediments into a tightly pinched syncline, and finally, though possibly as a culmination of this compression, a rotational disturbance brought about the tear fractures.

In view of the magnitude of the disturbances and the close proximity of the areas, it would be expected that disturbances in one area would be recorded in the other and *vice versa*. In short, it is postulated that the Gloucester Syncline was initiated early in the tectonic history of the Permian of the Hunter Valley along with that of the Lochinvar Dome (epi Muree Osborne, 1950) or the Cranky Corner Basin (pre-Greta in age). In which case the Gloucester coal measures were developed not later than Muree times.

Conclusions.

Coal, in commercial thickness, occurs at numerous horizons throughout the thick Permian terrestrial sediments of the Stroud-Gloucester Trough. The quality of the coal has not been fully investigated, but the steep dip of the seams, the presence of numerous minor structures and the high level of the water-table wound render mining hazardous.

The associated sediments, which have been derived *in toto* from the underlying Carboniferous rocks, are predominantly coarse in grade size and there is a gradation towards finer material from west to east, suggesting that the western margin of the coal measures was not far removed from the source areas, whereas the original eastern boundary extended some distance beyond its present confines, the coal measures have since been removed by erosion. This is with the exception of the infaulted Ward's River Basin.

The coal measures are probably not younger than Muree.

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LIVERSIDGE RESEARCH LECTURE*

CHEMICAL STRUCTURE AND BIOLOGICAL FUNCTION OF THE PYRROLE PIGMENTS AND ENZYMES.

By R. Lemberg.

Mr. President, Members of the Royal Society, Ladies and Gentlemen,

It is a testimony to the far-sightedness of Liversidge, to whom we owe these lectures, that the aim of the bequest is today as essential and its terms as well-conceived, as they were at the time of his life and death. It is, indeed, difficult for me to imagine that sixty-three years separate the short time which Liversidge spent with Michael Foster at the Cambridge Physiology School from the time of my collaboration with Sir Joseph Barcroft at the same school, and with Sir Frederic Gowland Hopkins at its daughter school of Biochemistry ; the same number of years separate our arrivals in Australia.

It was during the years Liversidge was still at Cambridge, in 1871, that Hoppe-Seyler laid the foundations of the field of knowledge which I am going to discuss, by his conversion of hæmoglobin to a porphyrin, followed a few years later by his discovery that the same type of compound could be obtained from chlorophyll.

When the Royal Society entrusted me with this lecture, I felt somewhat diffident, knowing that I had chosen a general survey of the pyrrole field as my subject for the Presidential Address of Section N of A.N.Z.A.A.S. at the Canberra January meeting, and that I should be in danger of repeating what I had said there. Permit me, therefore, to put before you the story of some of my own adventures in this field. If such a procedure is perhaps ill-suited for a ceremonial lecture such as this—there is a good excuse to be found in Liversidge's terms, i.e. that these lectures should be designed to encourage research. Nothing is more needed for the encouragement of research than the demonstration that a research career is a great intellectual adventure compared with which " mere physical adventure is a pale and colourless experience ". This phrase is taken from a lecture of Frederic Wood-Jones, F.R.S., entitled " The Spirit of Adventure ", and found in his book " Life and Living ", a lecture which every student, research worker and university teacher should read. As in all adventures, hardships and uncertainties are part of the game and heighten its enjoyment.

It is the story of a long research adventure which I intend to put before you. Everyone of us, however, explores only a few corners of a continent, and a rough map of what is known today must precede the story. The field is that of the tetrapyrrole pigments and enzymes, full of intrinsic chemical interest, but still more fundamentally important for the physiologist and biologist. Structure, metabolism, function and their correlation will therefore receive attention.

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* Delivered to the Royal Society of New South Wales, July 15, 1954.

BIOLOGICAL IMPORTANCE.

There are three fundamental biological processes—two of them closely linked up—for which tetrapyrroles are essential (Text-fig. 1).

Firstly *photosynthesis*. The elucidation of this process by which sunlight energy is converted into the potential energy of foodstuffs may one day bring humanity more benefits than atomic energy, and certainly less danger and misery. Several chlorophylls, e.g. *a* and *b* in higher plants, or bacterio-chlorophyll in purple bacteria, and the bile pigment-chromoproteins of red and blue algæ, phycoerythrin and phycocyanin, are involved in photosynthesis. In addition, we know that iron-porphyrin (hæm) complexes bound to protein are also required, such as cytochrome *f* in the chloroplasts of green plants, cytochrome c_2 in purple bacteria.

Photosynthesis	Chlorophylls. Phycochromoproteins. Hæm enzymes.
Cellular respiration ..	Cytochrome oxidase. Cytochromes. Peroxidases. Catalases.
Oxygen storage and transport.	Myoglobins and hæmoglobins. Chlorocruorin.

Text-fig. 1.—Biological role of tetrapyrroles.

Secondly, *cellular respiration.* We may define life as a complex organisation by which a steady state of a free energy content far above that of the equilibrium is maintained by a constant influx of energy needed for the maintenance of the steady state and of the complex organisation itself. This energy is provided in most cells by the stepwise oxidation of food materials, and in the chain of events which require the movement of electrons from the substrates to atmospheric oxygen, hæmo-proteins such as cytochrome oxidase and several cytochromes are involved. The peroxidases and catalases serve as auxiliaries in this process. An overwhelming part of life on earth depends on the systole and diastole of these two processes photosynthesis and cellular respiration. Only a few autotrophic and a few strictly anaerobic bacteria form an exception ; some of the autotrophs at least, e.g. the nitrate reducing bacteria, probably also use cytochromes, and some obligatory anaerobes contain a little catalase.

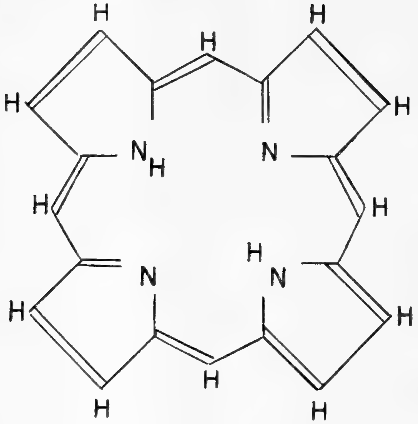
Thirdly, when an organism grows in bulk and complexity, diffusion is no longer sufficient to bring the oxygen for cellular respiration from outside. Special *oxygen carriers* in the blood are required. Hæmoglobins are found in moulds, e.g. in yeasts, and in leguminous root nodules, but their essential function appears to begin sporadically in Invertebrates, to become regular in Vertebrates, with the recently discovered exception of a few fishes. Finally, the red muscle which is able to store oxygen combined with myoglobin, is a far more efficient organ than the white muscle which lacks it.

CHEMICAL STRUCTURE.

If we now turn to chemical structure, we find that the structural basis of all these compounds is the porphin ring (Text-fig. 2), directly for hæm compounds and chlorophylls, more indirectly for the bile pigments.

Porphyrins are porphin substituted with various side chains at the eight β-positions of the four pyrrole rings ; hæms are their internal tetracoordinate iron complexes, chlorophylls magnesium complexes, usually of dihydro- or tetrahydroporphyrins. Finally, bile pigments are essentially porphyrins whose ring has been opened by oxidative scission.

Of the porphyrins (Table 1), protoporphyrin, with four methyl, two vinyl and two propionic acid side chains, is the most important. It forms the prosthetic groups of hæmoglobins and myoglobins, of a number of cytochromes, such as *b* and *f* (and in somewhat modified form of cytochromes *c*), of catalases and of some peroxidases.



Text-fig. 2.—Porphin.

Porphyrins with a formyl side chain are found as the prosthetic groups of cytochrome oxidase (the Atmungsferment), of cytochrome *a* and of the oxygen carrier in the blood of Sabellid worms, chlorocruorin.

TABLE 1.

Porphyrins and Their Occurrence as Metal Complexes and Prosthetic Groups.

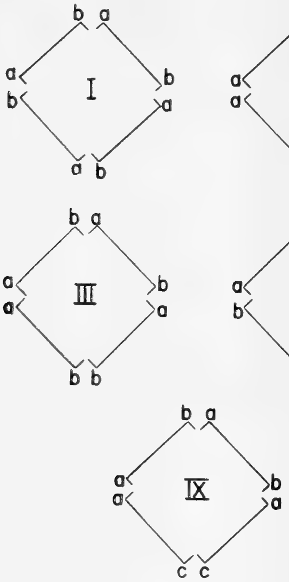
Porphyrin.	Side Chains.	Occurrence as Prosthetic Group or Metal Complex.
Ætio-III	4M, 4E.	0.
Meso-IX	4M, 2E, 2P.	0.
Proto-IX	4M, 2V, 2P.	Fe : hæmoglobins, myoglobins. cytochromes *b*. catalases, horse radish peroxidase. (Mg : Chlorella mutant.)
Hæmato-IX.. ..	4M, 2HE, 2P.	Fe : (modified) cytochrome *c*.
Acetyldeutero- ..	4M, 2P, 1Ac.	Fe : lactoperoxidase.
Chlorocruoro- ..	4M, 1V, 1F, 2P.	Fe : chlorocruorin.
Cyto-(*a*)- ..	1F, 1 long alkyl.	Fe : cytochrome oxidase, cytochrome *a*, a_1.
Copro-I and III ..	4M, 4P.	(Cu, Zn : urine.)
Uro-I and III ..	4AC, 4P.	(Cu : turacin.) (Zn : urine.)

Abbreviations :

M=methyl, $.CH_3$.
E=ethyl, $.C_2H_5$.
V=vinyl, $.CH{=}CH_3$.
HE=hydroxylethyl, $.CHOHCH_3$.
F=formyl, .CHO.
AC=acetic acid radical, $.CH_2CO_2H$.
P=propionic acid radical, $.CH_2.CH_2.CO_2H$.

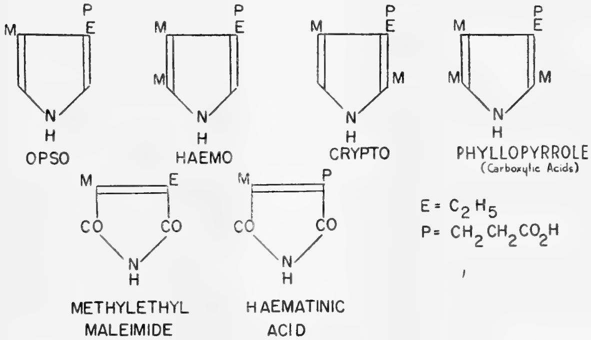
Acetyl groups are found in bacteriochlorophyll and in the peroxidase in milk (Morell, 1953).

Coproporphyrins with four, and uroporphyrins with eight carboxyl groups in their side chains, are found, usually in small amounts as free porphyrins, occasionally as copper or zinc complexes. They will mainly interest us in connection with the biosynthesis of hæm.



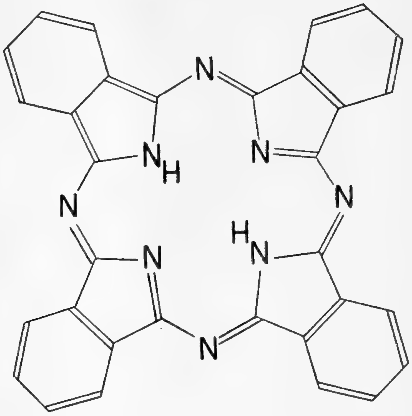
Text-fig. 3.—Porphyrin isomers.

Porphyrins with two types of side chains (e.g. copro- or uroporphyrin) can form four isomerides (Text-fig. 3), but only two, types III and I, have so far been found in nature. All functionally important compounds, chlorophylls as well as hæm compounds, are derived from type III. Porphyrins with three types of side chains, such as protoporphyrin, can form 15 isomers ; the natural protoporphyrin IX is derived from type III.



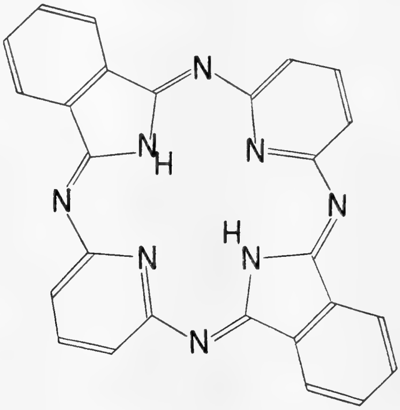
Text-fig. 4.—Products of reductive and oxidative scission.

The correct formula for the porphin ring was given by Wilhelm Küster (Küster and Deihle, 1913) based on his studies on the products of oxidative scission, substituted maleimides, and on the studies of other workers on the products of reductive scission with hydroiodic acid, substituted pyrroles (Text-fig. 4). This evidence culminated in the synthesis of protoporphyrin and hæmin by H. Fischer in 1929 (cf. Fischer, 1937, p. 372). Monopyrroles are first condensed to two dipyrrolic pyrromethenes and then two of these to the unsymmetrically substituted type III porphyrin.



Text-fig. 5.—Phthalocyanine.

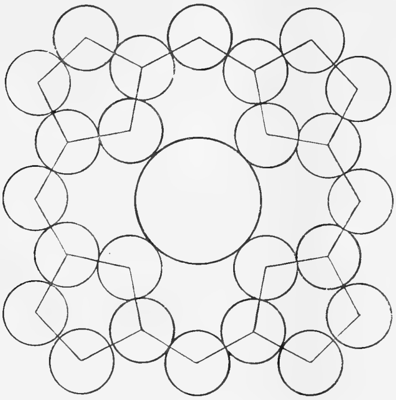
Finally the structure has been confirmed by purely physical methods. Phthalocyanine (Text-fig. 5), a tetrabenzenotetrazaporphin, synthesised by Linstead (1934) was the first organic compound to give a complete Patterson X-ray diagram in the hands of Robertson (1935). The molecule is flat and there is no real difference between the four isoindole rings, although the symmetry only approaches the tetragonal one. Linstead has bridged the structural gap



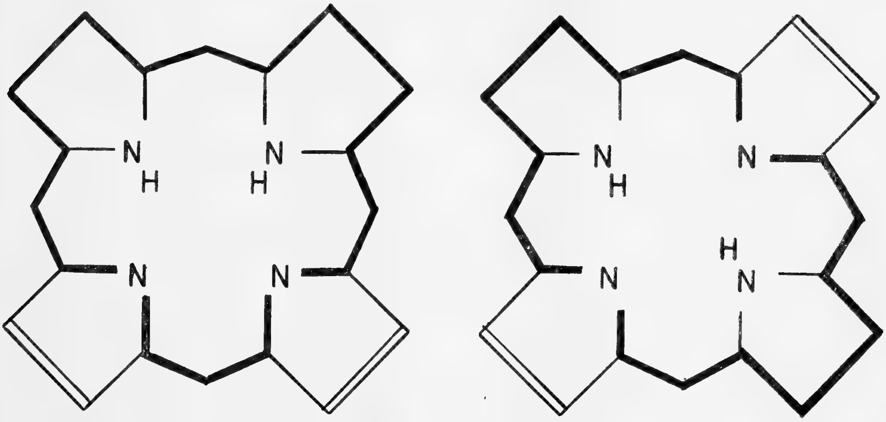
Text-fig. 6.—Dipyridine-diisoindole macrocyclic ring system of Linstead.

between phthalocyanin and porphin by synthesising tetrabenzo- and tetraazoporphyrins. The central 16-membered ring (Text-fig. 7) leaves a hole in the centre with a diameter of 2·65 A, just large enough to be filled by atoms such as iron (atomic diameter, 2·54 A.), but the ring is also adjustable by small alterations of the length of, and angle between, its many bonds, to take larger atoms such as Mg, and to bind even atoms like Be, otherwise never found in planar tetracoordination.

Recently Linstead (1953) has synthesised similar macrocycles with two of the four isoindoles replaced by either pyridine or benzene. The dibenzene-diisoindole compound no longer forms metal complexes ; it lacks the possibility of tetracoordination. The dipyridine-diisoindole compound (Text-fig. 6) forms such complexes. It is of interest that the free compound has a spectrum quite different from that of porphins, whereas those of the metal complexes resemble porphin complexes. In the free compound the hydrogen atoms are evidently strictly bound to the two isoindoles, thus severely restricting resonance which is still possible in the metal complex.



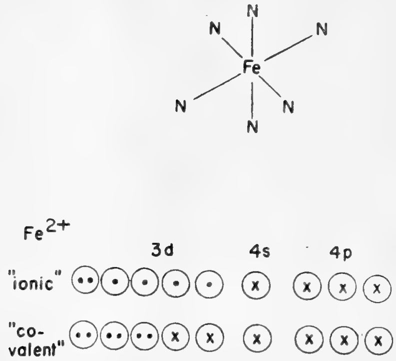
Text-fig. 7.—Stereochemistry of porphin. The central circle represents the central hole filled by two hydrogen atoms in porphyrins and by the metal atom in the metal complexes. The four adjoining circles are those of the four pyrrole nitrogen atoms, the remaining circles represent carbon atoms.



Text-fig. 8.—Porphyrin tautomerism.

The type of linkage of the central hydrogens in the free porphyrins is not yet fully established. It appears that free porphyrins consist of mixtures of two tautomeric forms (Text-fig. 8), each in turn stabilised by resonance of several canonical forms.

Iron in the *hæm compounds* can be bound in two different ways. In addition to the four valancies going to the four nitrogens of the porphin ring, there are two additional sites of coordination above and below the porphin plane (Text-fig. 9). Ferrous hæm binds, e.g. two molecules of pyridine to a hexacoordinate complex, called hæmochromogen, or more concisely hæmochrome. In this instance the linkage, called " covalent ", is of d_2sp_3 type, using the 3d, 4s and 4p orbitals of iron, and the molecule is diamagnetic. In other compounds, however, the paramagnetism of ionic iron is preserved. The linkages, not quite fortunately called " ionic ", are also covalent, but involve only the 4s, 4p and perhaps 4d orbitals of iron.



Text-fig. 9.—Iron porphyrin (hæm) compounds.

TABLE 2.

Chlorophylls and Related Compounds.

	State of Ring.	Side Chains.	Isocyclic Ring C_6-$C\gamma$.	X in $-CH_2-CH_2CO_2X$.
Chlorophyll *a* ..	Mg dihydro-porphin.	4M; 1E, 1V, 1P	$-CO\cdot CH(CO_2M)-$	phytol
Protochlorophyll ..	Mg porphin.	,,	,,	phytol.
Vinylphæoporphyrin a_5	Mg ,,	,,	,,	H.
Chlorophyll *b* ..	Mg dihydro-porphin.	3M, 1F; 1E, 1V, 1P.	$-CO\cdot CH(CO_2M)-$	phytol.
Bacteriochlorophyll ..	Mg tetra-hydroporphin.	4M; 1E, 1Ac, 1P.	$-CO\cdot CH(CO_2M)-$	phytol.

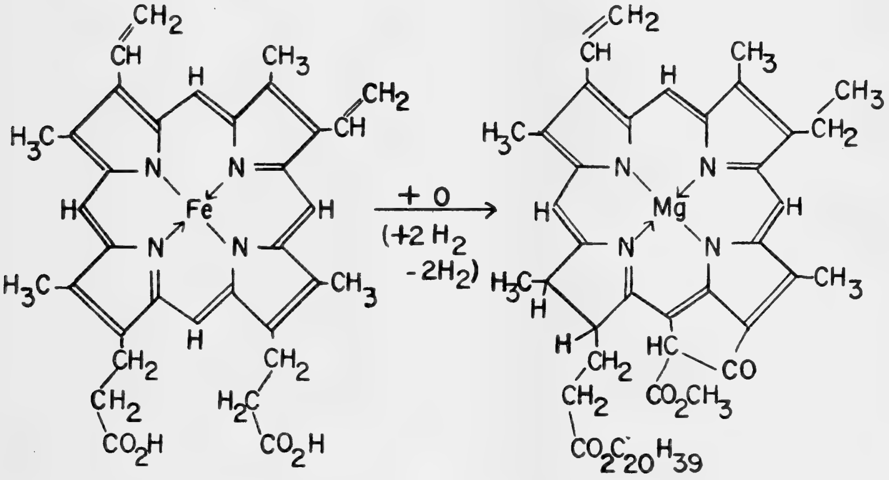
Phycochromoproteins.

Phycocyanin	biladiene- (*a*, *b*).	4M, 2E, 2P.	protein, no metal.
Phycoerythrin ..	,, +1H.	,,	,,

Chlorophyll (Table 2) contains Mg instead of the iron of hæm. Text-figure 10 shows the relationship between hæm and chlorophyll *a*. We may imagine that one of the propionic acid groups of hæm is curled up and oxidatively condensed to a fifth isocyclic ring. This oxidation is partly counterbalanced by hydrogenation of the nucleus (transforming porphin to dihydroporphin or chlorin) and reduction of one vinyl to ethyl. Finally the carboxyl groups are esterified, one with methyl thus protecting the β-keto acid carboxyl, and one with the long chain aliphatic alcohol phytol. We shall see below that this picture is not merely imaginary.

Protochlorophyll from which chlorophyll *a* arises on irradiation in the plant is still a porphin, not a chlorin derivative. Chlorophyll *b* carries a formyl instead of a methyl side chain of chlorophyll *a*. Bacteriochlorophyll is a tetrahydroporphin with an acetyl side chain.

In contrast to the porphin derivatives, the *bile pigments* are compounds with an open tetrapyrrolic chain, although in many instances they are probably more correctly formulated as rings closed by a hydrogen bond ; this holds at least for their metal complexes. In the porphin series there is only one stable hydrogenation state of the central ring system, which remains essentially intact if hydrogen is introduced into one or two crossed double bonds to form dihydro- and tetrahydroporphins. Porphyrinogens with four —CH_2— bridges are rather unstable substances, probably for stereochemical reasons. No compounds are known which contain —CH_2— and —CH= bridges. This is different in the bile pigments (Text-fig. 11) where several classes exist, varying in colour from white to yellow, red, violet and blue-green, which differ in number of conjugated double bonds. Wherever a —CH_2— group replaces a —CH= bridge, the conjugation becomes interrupted. The fully conjugated bilatrienes or verdins correspond to the porphyrins, the leuco-compounds or bilanes to the porphyrinogens. But between them we find systems with only two (urobilins), twice two (rubins), or three pyrrole rings (violins), belonging to conjugated systems. It is this field to the development of which my first studies contributed.

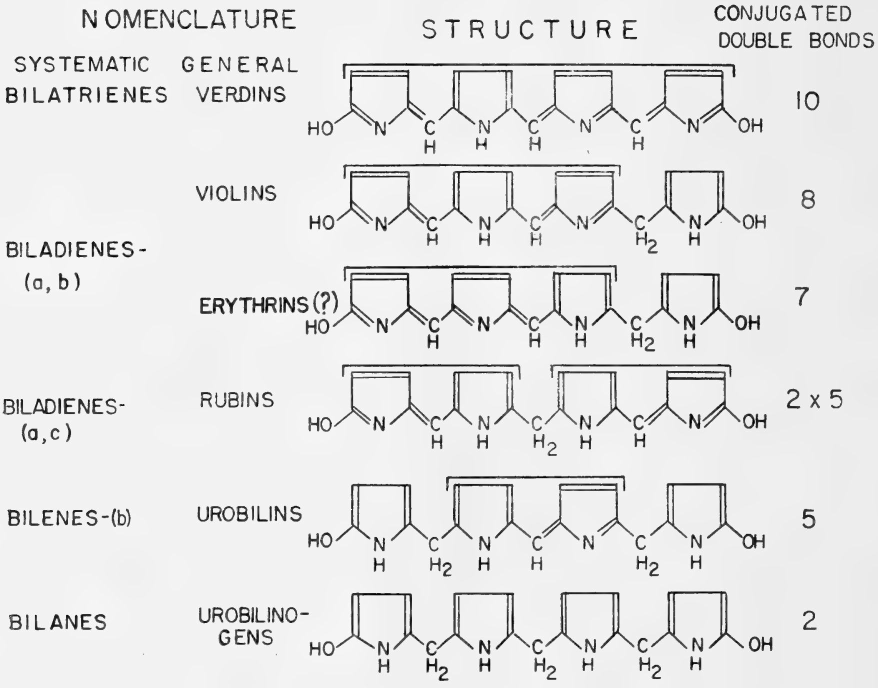


Hæm. Chlorophyll *a*

Text-fig. 10.—Relationship between hæm and chlorophyll *a*.

Chromoproteins of Red and Blue Algæ. My starting point was a sentence in Kostytschev's well-known text of plant physiology. Speaking of the chromoproteins of red and blue algæ, he concluded : " Their chemistry has not been sufficiently investigated." These beautifully crystalline, strongly fluorescent proteins, phycoerythrin and phycocyanin had attracted the attention of many botanists (Engelmann, Gaidukov, Molisch, Boresch, Kylin). It had been shown that they acted as photosensitisers of the photosynthesis of red algæ, allowing them to penetrate into deeper layers of the sea than green or brown seaweeds. The absorption of phycoerythrin and phycocyanin is maximal in the orange to green part of the spectrum, where that of chlorophyll is small. This is of particular importance in deeper layers, where red light no longer penetrates. Some Cyanophyceæ also show the interesting phenomenon of " complementary chromatic adaptation ". Irradiated with coloured light, they change their colour to one roughly complementary to that of the incident light.

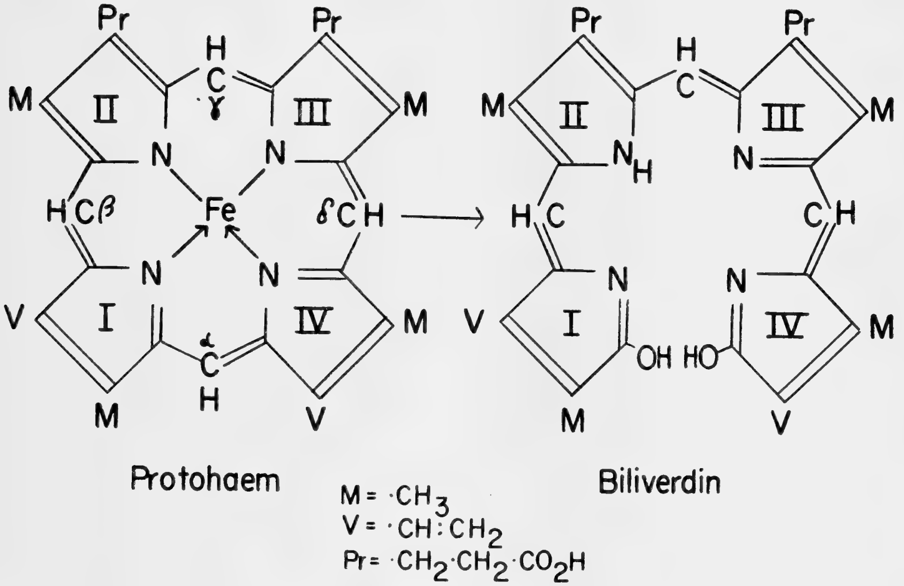
The interest of the botanists in these compounds has recently been revived by the findings of Haxo and Blinks (1950) that light energy absorbed by phycoerythrin or phycocyanin is used more efficiently for photosynthesis of some algæ than is light absorbed by the chlorophylls. While it appears that chlorophyll *a* is necessary for the energy transfer in these algæ, the explanation of the phenomenon is not yet clear (cf. French and Young, 1952 ; Duysens, 1951).



Text-fig. 11.—Bile pigments.
The brackets over the pyrrole rings indicate those which form a system of conjugated double bonds.

Kitasato (1925) had failed to find any evidence for the pyrrolic nature of the prosthetic group, but I suspected that his experiments were inconclusive. I used the very suitable starting material which Kitasato had described, a Japanese delicacy called " nori " prepared from *Porphyra*, a red alga. At the outset I struck the great difficulty that the prosthetic groups of both the red phycoerythrin and the blue phycocyanin was far more firmly bound to the protein than in hæmoglobin, and new methods had to be devised to obtain them free from attached peptide. Once this was done, it was easy to demonstrate the pyrrolic nature, and the strong fluorescence of the zinc complexes placed them into close relationship to urobilins (bilenes). The prosthetic groups of phycoerythrin and phycocyanin were identified with two new compounds, mesobiliviolin and mesobilierythrin (see Text-fig. 11) which could be obtained by ferric chloride oxidation of mesobilirubinogen (mesobilane), the leuco compound of bilirubin (Lemberg, 1930). Thus two new types of bile pigments were obtained which were later converted into the crystalline mesobilirubin and mesobiliverdin by alcoholic potash (Lemberg and Bader, 1933).

There is still much work to be done in this field for a chemist who is not afraid to start with a few hundred litres of extract to end up with a few milligrammes of substance. The structure of the prosthetic group of phycoerythrin and its relationship to that of phycocyanin is not yet safely established, and this is of particular interest for the problem of complementary chromatic adaptation, which is based on the relative increase of the substance, phycoerythrin or phycocyanin, absorbing most of the light.

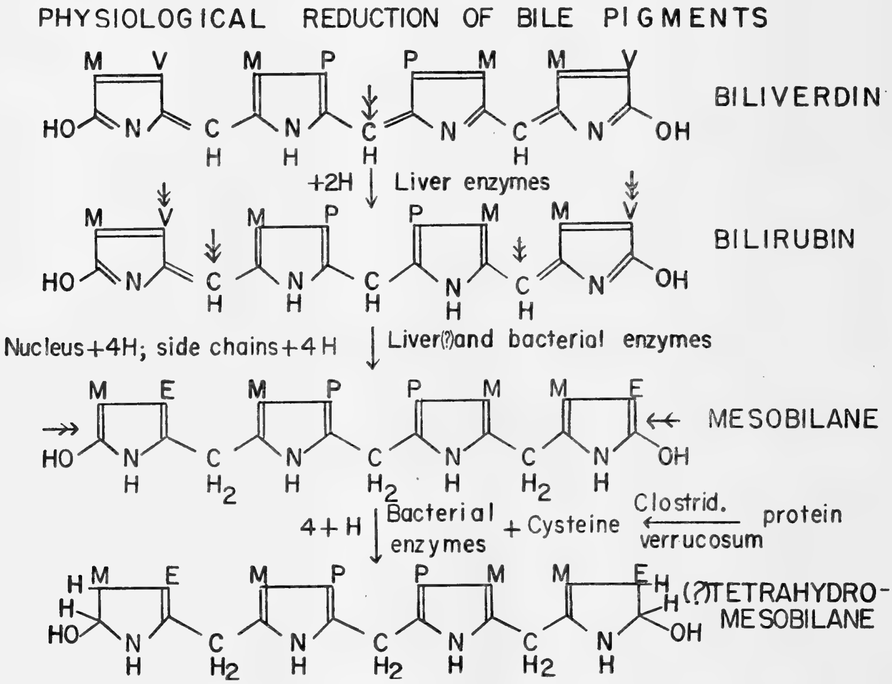


Text-fig. 12.—Relation of biliverdin to protohæm.

The type of linkage between prosthetic group and protein required further study. Apart from the firm peptide linkage, there is a second weak linkage easily broken by dilute acid. It is this linkage which is necessary for the strong fluorescence of the native chromoproteins and for their extraordinarily strong absorption of light.

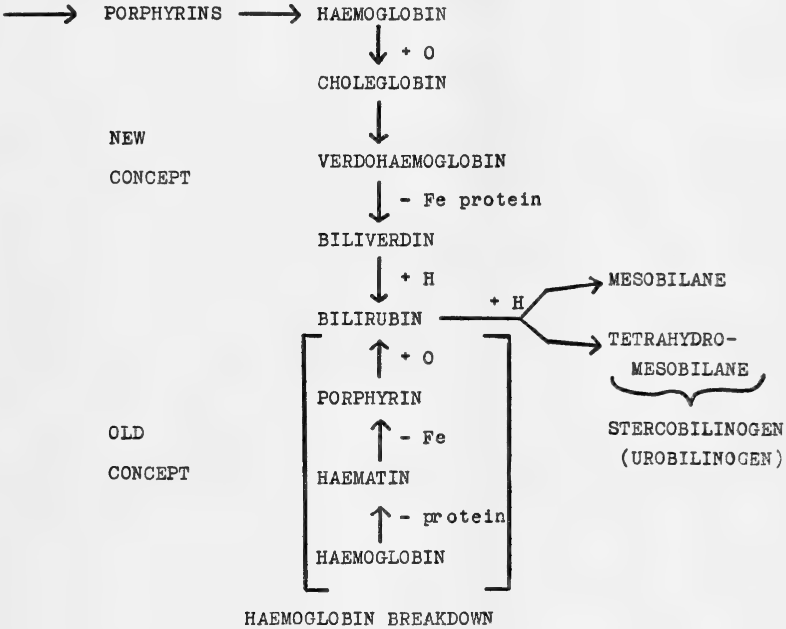
The biogenesis of these and other invertebrate bile pigments, such as that found in the hæmolymph of insects (Hackman, 1952), e.g. our common cicada, appears to be different from that in Vertebrates, and the nature of the side chains indicates neither formation by oxidation from hæm compounds, as in the Vertebrates, nor photooxidation of chlorophyll.

Bile Pigments. The next step was an attack on another class of bile pigments. Oocyan, the blue-green pigment of many birds' egg shells, e.g. of the duck and the emu, was the first pigment of the bilatriene class to be isolated in pure form (Lemberg, 1931). It is this compound which causes the blue-green colour in the well-known Gmelin or Fouchet reaction for bile pigment. At that time I worked in Hopkins' laboratory as a Fellow of the Rockefeller Foundation. There was an atmosphere of adventure in which the Institutes of Hopkins, Barcroft and Keilin were closely linked. One of those days Keilin brought Barcroft to me to discuss a green pigment in the dog's placenta which disturbed Barcroft's attempts at hæmoglobin estimation. In a short time I had identified this substance, uteroverdin, with oocyan and established its structure as that of dehydrobilirubin or bilatriene (see Text-fig. 11) (Lemberg and Barcroft, 1932). Later it was prepared from bilirubin by dehydrogenation (Lemberg, 1932). Uteroverdin had been intensively studied by early biologists and embryologists of the German and French schools. It was the careful study of this old literature in the peaceful atmosphere of the Old Cambridge Library which made me first doubt the primogeniture of bilirubin. Its correct structure showed biliverdin to be more closely related to hæmin than is bilirubin (Text-fig. 12). In one of my first studies in Australia I described the reduction of biliverdin to bilirubin in liver slices, and the enzyme systems which can use biliverdin as hydrogen acceptor (Lemberg and Wyndham, 1936). This reduction (Text-fig. 13) is continued in the mammalian organism by bacterial enzymes in the intestine ending in a mixture of mesobilane and tetrahydromesobilane, known as urobilinogen or stercobilinogen ; in the literature you find these names urobilinogen and stercobilinogen confusingly applied to mesobilane and tetrahydromesobilane respectively (cf. Lemberg and Legge, 1949, p. 134). The structures of tetrahydromesobilane suggested by Fischer is open to doubt and requires reinvestigation.



Text-fig. 13.—Physiological reductions of bile pigments. The double arrows indicate the part of the molecule at which reduction takes place.

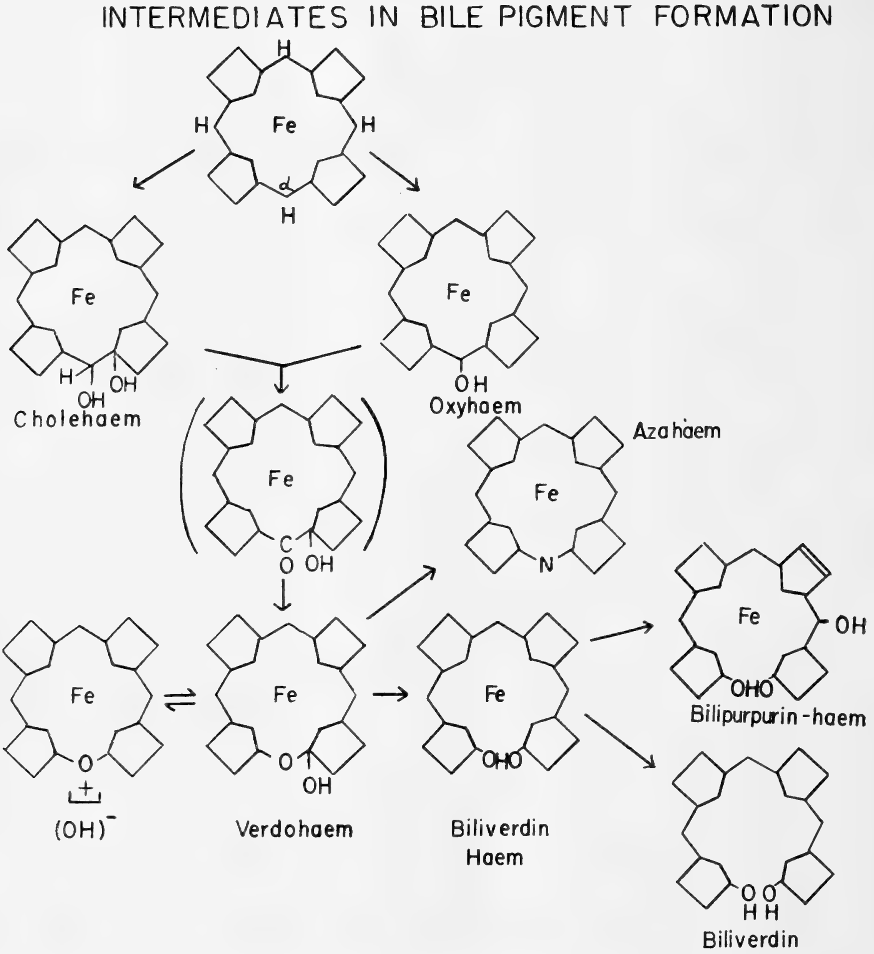
Bile Pigment Formation. The knowledge of the properties of biliverdin led directly to the next step, the explanation of the transformation of the hæm compounds to bile pigments. It was one of the rare instances in which a reinterpretation of data of other workers allowed one to predict the outcome of a study with some degree of certainty. At that time, Warburg (1932) classified the hæmins into three classes according to their colour, red hæmins derived from protoporphyrin, green hæmins derived from chlorophylls, and dichroic green-red hæmins such as the prosthetic group of the Atmungsferment, derived from what we now know to be formylporphyrins. Warburg and Negelein (1930) had formed such a " green hæmin " by coupled oxidation of hæmin in pyridine solution with hydrazine. Its supposed methyl ester, obtained by the action of methanol hydrochloric acid, had been obtained crystalline. This ester contained four chlorine atoms. Now hæmins contain only one, there was little chance of chlorination under the experimental conditions, and I knew that biliverdin readily forms a ferrichloride $[B]^+[FeCl_4]^-$. I could show that the " green hæmin ester " was, in fact, biliverdin ester ferrichloride, and the transformation of hæmin to biliverdin had thus been carried out inadvertently (Lemberg, 1935).



Text-fig. 14 —Hæmoglobin breakdown.

The green hæmin in itself, however, was still an internal iron complex, but with an increased lability of its iron ; in fact a pyridine hæmochrome, which I called verdohæmochrome. It had been formed by the removal of one carbon atom from the ring and by its replacement by oxygen. With ammonia, the oxygen could in turn be replaced by nitrogen, yielding a monoazahæmin with restored firm iron linkage (Lemberg, 1943). Oxidation of the ring thus precedes iron removal, and no porphyrin is formed as intermediate of hæmoglobin breakdown. It took more than ten years of intensive work before this new concept (Text-fig. 14) became generally accepted.

The first model was still far removed from physiological conditions, but step by step it was brought nearer to them. Hydrazine was replaced by ascorbic acid, hæmin in pyridine by hæmoglobin at physiological pH and 37° C. Intermediates were observed and a clearer picture of the reaction mechanism obtained (cf. Lemberg and Legge, 1949, Chapter X). The work was not lacking unexpected surprises. Thus hæmoglobin gave finally biliverdin, but as intermediate choleglobin with a hæm different from verdohæm. The greening of hæmoglobin by certain streptococci is due to choleglobin formation, and a cholehæm prosthetic group was later found in the peroxidase of leucocytes (Foulkes, Lemberg and Purdom, 1951).

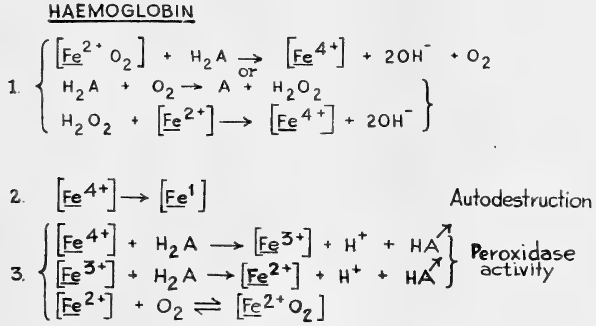


Text-fig. 15.—Intermediates in bile pigment formation.

Text-figure 15 shows the picture as it finally emerged. The ring is at first oxidised but remains still carbon-closed. (The structure of cholehæm is here depicted in the same way as Linstead formulates his first oxidation products of phthalocyanine, but hydroperoxidic structures are not excluded.) Later the carbon is replaced by oxygen and Sjöstrand has recently demonstrated that it emerges as carbon monoxide. This poison is thus not quite unphysiological. Other hæm compounds, myoglobin, catalase, methæmalbumin and even free hæmatin are similarly oxidised. The mechanism is essentially a peroxidative autoxidation of the ring catalysed by the hæm iron, in which a $[Fe^{2+}.H_2O_2]$ or $[Fe^{4+}]$ or $[FeO^{2+}]$ complex is involved (Text-fig. 16).*

Catalase and Peroxidase. This brings the problem in close proximity to the mechanism of the enzymes, catalase and peroxidase. Liver catalase contains a verdohæm group which yields biliverdin by the action of acids (Lemberg, Norrie and Legge, 1939). During its action on hydrogen peroxide, some of the enzyme is destroyed by oxidation of protohæm to verdohæm, but the rate of destruction is greatly increased by ascorbic acid. The inhibition of catalase by ascorbic acid or azide is of a type quite different from that produced by cyanide (Lemberg and Foulkes, 1948).

Foulkes and Lemberg (1948) had obtained apparent spectroscopic evidence for a compound between catalase and ascorbic acid, overlooking that our ascorbic acid solutions contained traces of hydrogen peroxide formed by autoxidation. Chance (1948) found that ascorbic acid accelerated the conversion of a primary complex of catalase with hydrogen peroxide into a secondary one, which was our supposed ascorbic acid compound and which he formulated as " catalase-H_2O_2 complex II ". Such a complex played a normal role in the activity of peroxidases. Finally George (1952, 1953) has shown that the " complex II " of peroxidases and of catalase can be obtained by the action of a great variety of oxidants and cannot be formulated as hydrogen peroxide complex. It is best formulated as $[Fe^{4+}]$ or $[FeO^{2+}]$ complex, and ascorbic acid, or even impurities, cause a monovalent reduction of the primary complex having " effectively pentavalent " iron. It is still too early to say what is the real valency of iron in these compounds, and whether radicals in the porphin ring or protein are formed. One therefore speaks of " effective valency ". Neglecting this we may thus write the action of catalase as in Text-figure 17. Formulæ 1–2 represent the normal catalatic activity of catalase, formulæ 3–5 its comparatively weak peroxidative activity in the presence of hydrogen donors, when the $[Fe^{4+}]$ complex is formed and undergoes partial autodestruction.



Text-fig. 16.—Coupled oxidation of hæmoglobin and ascorbic acid $[\underline{Fe}]$ hæm-iron. H_2A ascorbic acid.

1. Formation of $[\underline{Fe}^{4+}]$ directly (first line), or from action of hydrogen peroxide formed by autoxidation of ascorbic acid.
2. Oxidation of porphin nucleus to form choleglobin.
3. Back reduction of $[\underline{Fe}^{4+}]$ to $[\underline{Fe}^{2+}]$.

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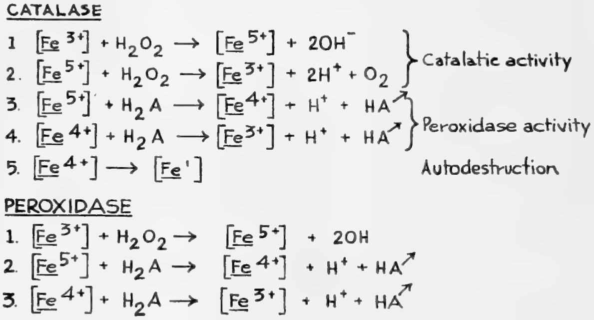
* The fact that ferric hæmatin is not reduced to ferrous by ascorbic acid, but can be transformed into bile pigment by ascorbic acid plus hydrogen peroxide (Kench, 1954) is no evidence against this. Ascorbic acid is required for the process and may well reduce an initial $[Fe^{3+}.H_2O_2]$ or $[Fe^{5+}]$ complex to $[Fe^{4+}]$.

$[Fe]$=hæm.

A [*Fe*$^{4+}$] complex plays a normal role in the mechanism of peroxidase. Under certain conditions, catalase can thus act as peroxidase, but differs from peroxidase apparently in the properties of the [*Fe*$^{5+}$] and [*Fe*$^{4+}$] complexes. Only in catalase the [*Fe*$^{5+}$] complex reacts (directly or indirectly) with a second molecule of hydrogen peroxide. The [*Fe*$^{4+}$] complex of peroxidase is comparatively stable although some bile pigment is also formed (Kench, 1954). The [*Fe*$^{4+}$] complex of catalase undergoes partial oxidation of its porphyrin ring. The verdohæm groups in liver catalase, and the rapid turnover of liver catalase iron, as compared with erythrocyte catalase iron (Theorell *et al.*, 1951), are evidence for the peroxidative activity of liver catalase. No such evidence is available for erythrocyte catalase whose function is that of a safeguard against irreversible oxidation of hæmoglobin to choleglobin by hydrogen peroxide (Foulkes and Lemberg, 1949).

Somewhat similar reactions of catalase occur in the presence of hydroxylamine or azide. Both are oxidised to a mixture of nitrous and nitric oxide (Foulkes and Lemberg, 1949*b*; Keilin and Hartree, 1954). The latter stabilises catalase in the ferrous form as [*Fe*$^{2+}$NO] complex. Keilin concludes from this and other experiments that the [*Fe*$^{2+}$] state is also passed during the normal action of catalase on hydrogen peroxide, but the matter is not yet clear.

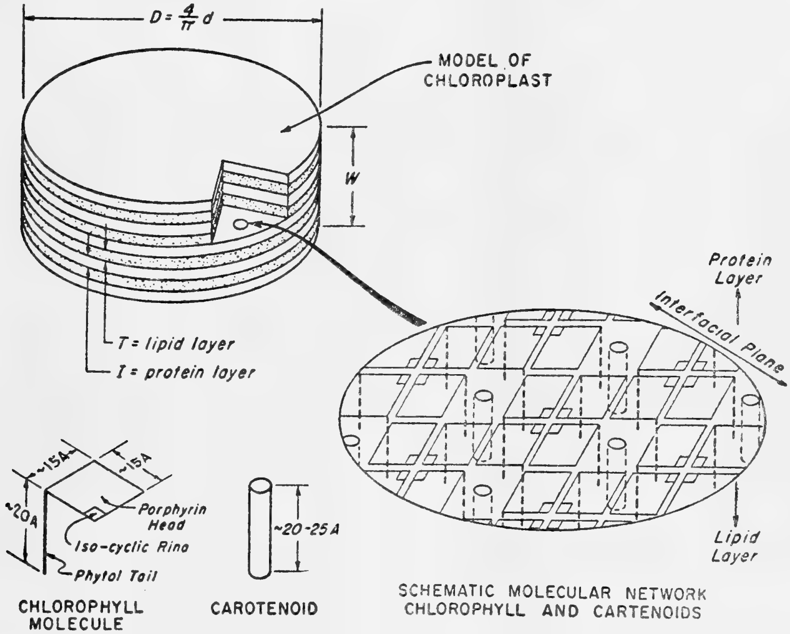


Text-fig. 17.—Mechanism of catalatic and peroxidative actions. [*Fe*] hæm iron, H_2A ascorbic acid.

Cytochromes. Lately our work has been mostly concerned with the cytochromes. The chain of electron passages from hydrogen donor to oxygen ends in a series of cytochromes, e.g. $b \to ? \to c \to a \to a_3$, where a_3 is almost certainly Keilin's cytochrome oxidase and Warburg's Atmungsferment. Whereas cytochrome *b* is derived from protohæm, and cytochrome *c* closely related to it (it may be considered an adduct of protein—cysteine to the vinyl groups of protohæm), cytochromes a_3, *a* and the bacterial cytochrome a_1 are derived from formylporphyrin. Cytochrome a_2 found in bacteria such as *Aerobacter, Azotobacter* or *Escherichia coli* is perhaps the terminal oxidase in these organisms; Barrett and Lemberg (1954) have recently isolated its hæmin and shown that it is an iron complex of a chlorin, not a porphyrin. Porphyrin *a* or " cytoporphyrin " (Warburg) has been obtained spectroscopically pure and in almost quantitative yield from heart muscle (Lemberg, 1953). This preparation largely excludes the formation of the cryptoporphyrins, which are artefacts, some derived from hæm *a*, others from protohæm. The prosthetic groups of cytochrome oxidase (cytochrome a_3) and cytochrome *a* are generally assumed to be identical. Recently we have obtained two fractions of porphyrin *a* having exactly the same absorption spectrum, but differing in their extractability from ether by hydrochloric acid or phosphate buffer, as well as in their behaviour on cellulose or silica gel chromatographic columns. We have shown that these are mutually intraconvertible forms of porphyrin *a* and while it is not excluded that one is the prosthetic group of cytochrome a_3, the other of cytochrome *a*, our evidence so far does not support this assumption (Lemberg, 1955).

The structure of porphyrin *a* is not yet finally established. It has a formyl side chain and a side chain with a double bond conjugated with the porphin ring, probably on a pyrrole ring opposite to the one bearing the formyl. This, or another side chain, is a long alkyl group which increases the molecular weight without contributing to the colour. It appears difficult, however, to account for the two forms of porphyrin *a* on the basis of the present formulæ.

The evidence for a long paraffinic side chain in porphyrin *a* is of particular interest. Both chlorophyll and cytochrome oxidase are contained in intracellular particles, the chloroplasts and mitochondria which possess a complicated internal structure of lipides and proteins. In the chloroplast the chlorophyll molecules form monolayers between protein and lipide layers (Text-fig. 18), with the long phytol tails sticking into the lipid layer which also contains the carotenoids (Wolken and Schwertz, 1953). In porphyrin *a* a similar structure is achieved by different means, not by esterification but by a long aliphatic side chain. Here is a whole new field opening for the biochemist, all that which lies between molecular and microscopic structure.



Text-fig. 18.—Chlorophyll monolayers in chloroplast (according to Wolken and Schwertz, 1953.)

Whereas usually flavoproteins (with isoalloxazine prosthetic groups) carry electrons from pyridine nucleotides to the cytochromes, Appleby and Morton (1954) have recently shown that cytochrome b_2, the lactic dehydrogenase of yeast, contains both hæm and isoalloxazine groups on the same protein.

Biosynthesis of Porphyrins.

The most important progresses in our field have been made during the last eight years in the exploration of the biogenesis of the hæm compounds and of chlorophyll. H. Fischer had considered the uro- and coproporphyrins breakdown products of protohæm and products of carboxylation of protoporphyrin. As has been shown above, however, porphyrins are not in the normal way of hæm breakdown, and there was accumulative physiological and pathological evidence (cf. Lemberg and Legge, 1949, pp. 593 ff., 628 ff.) that these free porphyrins in the body were formed in hæmoglobin synthesis.

Uroporphyrin was the one found in the smallest amounts, so small that only recently Lockwood (1953, 1954) has been able to isolate pure uroporphyrin III from normal urine and to demonstrate that we excrete normally 10–30 μg. per day, one-fifth as much as coproporphyrin. Only in certain diseases (porphyrias), and in the fox squirrel (*Sciurus niger*) normally, is uroporphyrin excreted in milligramme amounts. The quantitatively insignificant or rare, in this instance uroporphyrin, in the instance of bile pigment formation biliverdin, had been considered of minor significance and the suggestion of Turner (1940) that uroporphyrin may be the primary porphyrin had found no acceptance. When in 1946 Rittenberg, Shemin and Bloch found in isotope experiments that N^{15} from glycine (Shemin and Rittenberg, 1946) and deuterium from acetate (Ponticorvo, Rittenberg and Bloch, 1949) were incorporated in the hæm of hæmoglobin by the nucleated erythrocytes of birds, I suggested a new hypothesis of porphyrin biogenesis in my lecture before the Adelaide Congress of A.N.Z.A.A.S., which was published three years later (Lemberg and Legge, 1949, p. 637). At that time it was a rather daring hypothesis, but it has meantime been proved almost entirely by American and English workers. I have contributed nothing experimental to this development, but I believe that my 1949 discussions with Rimington and Neuberger, Rittenberg, Shemin, London, Bloch, Watson and Granick have hastened this development, and I am glad that one of my earlier pupils, John Falk, now Royal Society Foulerton Research Fellow at London University College, has been able to put what one may describe as the coping stone on this edifice.

PORPHYRIN SYNTHESIS

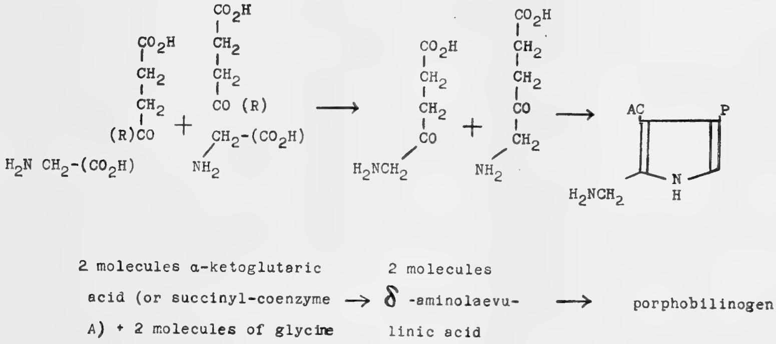
Relation between porphyrins

Proto		Copro		Uro
2 $\cdot CH{=}CH_2$	←	2 $\cdot CH_2\cdot CH_2\cdot CO_2H$		2 $\cdot CH_2\cdot CH_2\cdot CO_2H$
2 $\cdot CH_2\cdot CH_2CO_2H$		2 $\cdot CH_2\cdot CH_2\cdot CO_2H$		2 $\cdot CH_2\cdot CH_2\cdot CO_2H$
4 $\cdot CH_3$		4 $\cdot CH_3$	←	4 $\cdot CH_2\cdot CO_2H$

Text-fig. 19.—Porphyrin biosynthesis. Relation between porphyrins.
The arrows indicate the two reactions which do not necessarily involve the side chains of the porphyrins themselves, but probably those of monopyrrolic or dipyrrolic precursors.

My hypothesis was based on the following facts : The relationship between the side chains of the various porphyrins is such that the conversion of uro- to coproporphyrin ($4CH_2CO_2H \rightarrow 4CH_3$) by decarboxylation and that of copro- to protoporphyrin ($2\text{-}CH_2.CH_2.CO_2H \rightarrow 2\text{-}CH{=}CH_2$) by oxidative decarboxylation are far more likely processes than the hitherto assumed inverse reactions (Text-fig. 19). The primary pyrrolic precursor thus should have the side chains of uroporphyrin, acetic and propionic side chains. Acetate enters the tricarboxylic acid cycle and in it becomes converted into α-ketoglutarate. Two molecules of α-ketoglutarate and two molecules of glycine can be expected to be condensed to such a precursor.

Now here is the story as it stands today (Text-fig. 20). α-ketoglutarate or succinyl coenzyme A formed in the citric acid cycle is condensed with one molecule of glycine to form α-amino-β-ketoadipic acid which is decarboxylated to δ-aminolævulinic acid (Shemin and Russell, 1953). Two molecules of this are condensed to the pyrrolic precursor, porphobilinogen (Dresel and Falk, 1953). This substance was discovered by Waldenström in 1935 as a colourless precursor of porphyrin in the urine of patients with acute porphyria and assumed to be a dipyrrylmethane. Recently it has been isolated (Westall, 1952) and its structure as a monopyrrole established by Cookson and Rimington (1953). Finally Falk, Dresel and Rimington (1953) have shown that porphobilinogen is converted to uroporphyrin, coproporphyrin and the protoporphyrin of hæm in the hæmolysates of bird erythrocytes. The picture of these reactions as given in my 1946 lecture (Lemberg and Legge, 1949, p. 672) still remains essentially unaltered except that the assumed primary monopyrrolic precursor, and not the dipyrrylmethane is identical with porphobilinogen. In the role of porphobilinogen we have one more evidence, how a substance considered as the oddity of a specialist, can assume central importance, and how the study of pathological products can be fundamental for the explanation of normal physiological events. Inversely, there is now hope that our new insight will help us to find means to cure acute porphyria, a distressing and usually fatal disease not as rare as was previously believed.

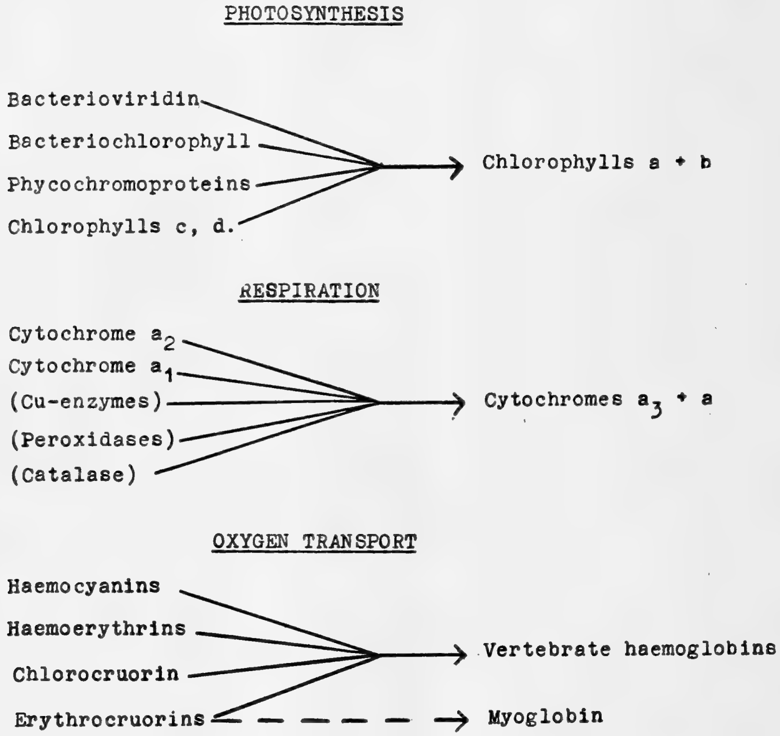


Text-fig. 20.—Porphyrin biosynthesis. Formation of monopyrrolic precursor. R represents -CO_2H group in α-ketoglutaric acid, -SR′ group in coenzyme A. Groups eliminated during the reaction in parentheses.

The synthesis of chlorophyll proceeds along similar lines. The isotope experiments of Della Rosa, Altman and Salomon (1953) show that glycine and acetate are the primary precursors. Granick has discovered mutants of the green alga Chlorella which, instead of chlorophyll, contain the magnesium complex of protoporphyrin (Granick, 1948), that of vinylphæoporphyrin a_5 (see Table 2) (Granick, 1950), or free highly carboxylated porphyrins (Bogorad and Granick, 1953).

We now begin to understand why the synthesis of porphyrins, so difficult for the organic chemist, is so easy a task for nature. A human adult forms no less than 80 g. of porphyrin annually and the amount of hæmoglobin-porphyrin, alone, produced by mankind alone annually is about 160,000 tons. The production of chlorophyll is immeasurably greater and though the hæmatin enzymes are found in small concentrations, they are so widespread that the amounts of their prosthetic groups must also be very large.

These discoveries raise new problems with regard to biochemical evolution. The synthesis of the tetrapyrroles evidently presupposes the existence of a large part of the intermediary metabolism with its numerous enzymes so that it does no longer appear likely that their appearance on earth can have been so primeval as had been frequently assumed. If this is so, then almost all the metabolism as we know it today, with photosynthesis and respiration, chlorophyll and hæm enzymes, is far from primitive in terms of biochemical evolution, although we know from findings of porphyrins and chlorophyll derivatives in Silurian coals that it is at least 300 million years old. Moreover, we have the apparent contradiction that an oxidative cycle is necessary for the synthesis of the very catalysts which catalyse the oxidation. This vast complexity of the basis of life is often insufficiently appreciated by physicists as well as by people who speculate on the origin of life on earth.



Text-fig. 21.—Convergent development.

There is a tendency of convergent development which is displayed by the tetrapyrroles in nature. Nature appears to experiment with a variety of devices before it finally accepts one, which is then no longer modified (Text-fig. 21). Thus we find in the more primitive organism a variety of chlorophylls, and also phycochromoproteins, as catalysts in photosynthesis which in higher plants are replaced by the chlorophyll *a*, *b* system. In cellular respiration, a variety of cytochromes (a_1, a_2) and non-hæm catalysts such as the copper enzymes, are finally replaced by the cytochrome a_3–a system. In a way, also, peroxidases and catalases become of minor significance with the development of this system. In oxygen transport, non-hæm oxygen carriers, the Cu containing hæmocyanin, the iron containing hæmerythrins and the hæmovanadins, as well as more primitive hæmoglobins and chlorocruorin, are finally replaced by the vertebrate type of hæmoglobin with four hæm groups per molecule, while the perhaps more primitive monohæm protein answers a particular function as myoglobin in the red muscle cell. It appears that such compounds as hæmoglobin have not been developed once but several times by Nature, in the same way in which organs, e.g. the placenta, have been constructed in different ways repeatedly.

RELATION BETWEEN STRUCTURE AND BIOLOGICAL FITNESS.

We may now try to sum up the chemical features which we find to be the basis of biological fitness of the tetrapyrroles.

At first glance, it would appear difficult to reconcile the needs for a substance required for photosynthesis with those required for one functioning in cellular respiration, and again those for an oxygen carrier. The former requires a substance able to absorb sunlight and being able to hand on the energy of its activated molecule to the complicated mechanism by which the endergonic reaction $CO_2+H_2O \rightarrow [CH_2O]+O_2$ is carried out. Absorption of light energy has no role in cellular respiration or oxygen transport. Again, the ability to act as electron carrier between the substrates and oxygen in the respiratory chain appears to contradict the properties demanded for an oxygen carrier. In the first instance activation of oxygen and valency changes of the iron atom, in the latter lack of activation of oxygen and no valency change of iron.

Nevertheless, there are physicochemical features which make the porphyrin derivatives suitable for all these tasks. The first is the resonance structure, which at the same time is the basis of the absorption of visible light, helps the formation of stable metal complexes, and results in a most complicated interaction between the π-electrons of the porphin ring and the electrons of the metal.

The role of iron in cytochrome oxidase, the cytochromes, hæmoglobin, peroxidases and catalase has been discussed. That of magnesium in chlorophyll is less certain. The original assumption of Willstätter that its role is the binding of carbon dioxide has been disproved. It now appears much more likely that it is water that is bound on the magnesium atom of chlorophyll, and that the first reaction of photosynthesis, written schematically $H_2O+hv \rightarrow OH+H$, takes place with water thus bound. Chlorophylls form hydrates, as has been demonstrated by the change of absorption and fluorescence which they undergo if water is added to their solutions in water-free hydrocarbons (Livingston and Well, 1952).

The importance of the resonance structure is, however, still larger. If a monovalent electron change is to be connected with the usual divalent hydrogen changes of organic substrates, or with the monovalent changes between oxygen and water, or hydrogen peroxide and water, without the formation of indiscriminately reactive monovalent radicals, such radicals must be resonance-stabilised. Radicals such as OH, O_2H and H have been freely postulated by physicochemists but I doubt whether such almost indiscriminately reactive and freely diffusible radicals could be subjected to the fine control (homeostasis) characteristic of every living cell and could find a place in normal biological reactions. In fact such radicals cause the destruction by γ radiation. Nature uses the device of letting such reactions take place on large resonance stabilised molecules, whose monovalent radicals are less reactive and less or non-diffusible, and which, moreover, are held in position by their linkage to proteins in a well organised chain in special cell organs, such as the mitochondria or chloroplasts. It is thus not accidental that so many of the catalytically important molecules of the cell are coloured, even where colour *per se* is no requisite. Evidence for such resonance-stabilised radicals in the tetrapyrrole field is still largely circumstantial. There is no reliable evidence for the role of a mono-dehydrochlorophyll in photosynthesis or for reversible alteration of the porphyrin ring in hæmatin enzymes. We must go one step further and consider the whole porphyrin-iron-protein complex. Hæmin is a 1000 times better catalatic catalyst than iron, but catalase is 1000 million times more effective. No simple hæm compound has the ability of reversibly combining with oxygen, which is the functional characteristic of hæmoglobin. This requires a specific type of protein, globin. The iron of protohæm behaves quite differently when it is combined with the respective proteins in hæmoglobin, cytochrome *b*, catalase or horse radish peroxidase. We have no less than five different ways of behaviour of hæm iron which depend mainly on the protein and, with the possible exception of cytochrome oxidase, not on the side chains of the porphin ring. In hæmoglobins and myoglobins: $[Fe^{2+}] + O_2 \rightleftharpoons [Fe^{2+}O_2]$; in cytochrome oxidase: $[Fe^{2+}]+O_2 \rightarrow [Fe^{3+}]$, ; in non-autoxidisable cytochromes: $[Fe^{2+}] \rightleftharpoons [Fe^{3+}]+e$. About the reactions of catalases and peroxidases, see Text-figure 17.

It will require a far greater knowledge than we possess today of protein structure, of the type of linkage between prosthetic group and protein, and of quantum mechanics, to understand the complex interactions between π-electrons of the porphyrin, electrons of the iron and the influence of the protein bound to the metal. It is the protein which determines the finest adaptations and variations, e.g. those between hæmoglobins and myoglobins, and still finer ones between the different hæmoglobin of various species, and even in one and the same species, between several hæmoglobins, such as fœtal and adult, or normal adult and a variety of pathological hæmoglobins. This, however, leads us out of the field which I have proposed to discuss into the different one of protein specificity, and I must restrict myself to having pointed out the connection.

We still know far too little, both of biological function and of chemical structure, and particularly about the relations between these two, to see more than a faint glimmer. But this glimmer is enough to let us stand in awe of the incredible complexity and the degree of fitness in this complexity. Perhaps Voltaire's sneer about this " best of all possible worlds " was hardly less one-sided than the all too complacent idea of an order of absolute infallibility in Nature. Surely the truth lies somewhere in between " what a scene of gratification and pleasure " and " Nature red in tooth and claw ", between Henderson's " co-ordinated fitness of animate and inanimate world " and " struggle for life in a hostile environment ".

I cannot close without remembering in gratitude some of my teachers: Heinrich Biltz, to whom I owe most of the little skill I possess as an experimentalist, and an education to patience and perseverance; Karl Freudenberg, who showed me the wide possibilities for the organic chemist in the exploration of natural products; Sir Frederic Gowland Hopkins, David Keilin and other Cambridge friends, who turned my attention from structural to metabolic and functional problems and thus began the conversion of an organic chemist to a biochemist.

My collaborators, many unnamed here, have borne more than their share of troubles in our adventures but have, I hope, also participated in the joys of exploration. Without the support of the hospital authorities, and in particular of the National Health and Medical Research Council, my researches could not have been carried out.

I thank the Royal Society of N.S.W. for the honour they have conferred upon me by entrusting me with this lecture, and I hope that I have shown some lines from my work which may lead into the future.

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ABSTRACT OF PROCEEDINGS

April 7th, 1954.

The seven hundred and first Annual and General Monthly Meeting of the Royal Society of New South Wales was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Dr. Ida A. Browne, was in the chair. Seventy members and visitors were present. The minutes of the previous meeting were read and confirmed.

The certificates of two candidates for admission as ordinary members of the Society were read for the first time.

Edgeworth David Medal.—It was announced that no award was made during 1953 for the Edgeworth David Medal.

Liversidge Research Lecture for 1954.—It was announced that the award of the Liversidge Research Lectureship had been made to Dr. M. R. Lemberg.

Election of Auditors.—Messrs. Horley & Horley were re-elected as Auditors to the Society for 1954–55.

The following papers were read by title only :

" Note on a Paper by J. L. Griffith ", by G. Bosson, M.Sc.
" The Essential Oil of *Eucalyptus maculata* Hooker. Part I ", by H. H. G. McKern, A.R.A.C.I., (Mrs.) M. C. Spies, A.R.A.C.I., and J. L. Willis, M.Sc.
" Occultations Observed at Sydney Observatory during 1953 ", by K. P. Sims, B.Sc.
" Geology and Subsurface Waters of the Area North of the Darling River between Longitudes 145° and 149°, N.S.W.", by J. Rade.

The retiring President, Dr. Ida A. Browne, delivered her Presidential Address, entitled " A Study of the Tasman Geosyncline in the Region of Yass, New South Wales ".

At the conclusion of the address, Dr. Browne welcomed Professor R. S. Nyholm to the Presidential Chair. The new President expressed his thanks to members for his election to the Chair.

The meeting accepted a vote of thanks to Dr. Browne for her services as President and for her Presidential Address.

May 5th, 1954.

The seven hundred and second General Monthly Meeting of the Royal Society of New South Wales was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Professor R. S. Nyholm, was in the chair. Thirty-three members and visitors were present. The minutes of the previous meeting were read and confirmed.

The certificates of three candidates for admission as ordinary members of the Society were read for the first time.

The certificates of two candidates for admission as ordinary members of the Society were read for the second time. David Hiley Stapledon and Clive Charles Wood were duly elected ordinary members of the Society.

Commemoration Ceremony of the Landing of Captain Cook at Kurnell.—The Chairman announced that he had attended this ceremony on May 1st, 1954, and reported that, for the first time, the Society placed a wreath on the Banks Memorial in commemoration of the landing of the first scientist on these shores.

Discussion.—It was announced that, in place of a popular science lecture, a discussion on " Would Space Travel be Worthwhile ? " would be held on Thursday, May 20th, at 7.30 p.m., and the following speakers would lead the discussion : Prof. F. S. Cotton, Dr. D. F. Martyn and Prof. A. H. Willis.

Library.—The following donations were received : 144 parts of periodicals and nine purchased parts.

Address.—An address on " Education in India " was given by Mr. Muni Lal, First Secretary of Information to the High Commissioner of India.

June 2nd, 1954.

The seven hundred and third General Monthly Meeting of the Royal Society of New South Wales was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Prof. R. S. Nyholm, was in the chair. Twenty members and visitors were present. The minutes of the previous meeting were read and confirmed.

Deaths.—The President announced the deaths of the following : George Wright, a member since 1916, and James J. Hill, an honorary member since 1914.

The certificate of one candidate for admission as an ordinary member of the Society was read for the first time.

Library.—The following donations were received : 332 parts of periodicals, 23 purchased parts.

The following papers were read by title only :

" Organ Transformation Induced by Œstrogen in an Adolescent Marsupial (*Trichosurus vulpecula*) ", by A. Bolliger.

" Warialda Artesian Intake Beds ", by J. Rade.

Address.—Dr. N. F. Stanley, Acting Director, Institute of Epidemiology and Preventive Medicine at the Prince Henry Hospital, delivered an address on " Virus Vaccines—with Special Reference to Poliomyelitis ".

July 7th, 1954.

The seven hundred and fourth General Monthly Meeting of the Royal Society of New South Wales was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

A Vice-President, Dr. Ida A. Browne, was in the chair. Thirteen members and visitors were present. The minutes of the previous meeting were read and confirmed.

The Chairman announced the names of those members of the Society who had been elected to the Australian Academy of Science : on the Council, Prof. R. J. W. Le Fevre ; Fellows, Prof. J. P. Baxter, Prof. A. J. Birch, Dr. W. R. Browne, Prof. K. E. Bullen, F.R.S., Prof. J. C. Jaeger, Dr. M. R. Lemberg, F.R.S., Prof. P. D. F. Murray, Dr. H. G. Raggatt, Dr. R. N. Robertson, Prof. W. L. Waterhouse.

Liversidge Research Lecture.—It was announced that the Liversidge Research Lecture would be delivered by Dr. M. R. Lemberg, F.R.S., on Thursday, July 15th, 1954, at 8 p.m., in the No. 3 Lecture Theatre, Chemistry Department, University of Sydney, and would be entitled " Chemical Structure and Biological Function of the Pyrrole Pigments and Enzymes ".

Library.—The following donations were received : 342 parts of periodicals, 14 purchased parts.

Dr. A. Bolliger presented a paper (previously read by title only) on " Organ Transformation Induced by Œstrogen in an Adolescent Marsupial (*Trichosurus vulpecula*) ", expanded under the title " Organ Transformation Induced by Œstrogen in an Adolescent Marsupial (*Trichosurus vulpecula*) with Additional Remarks on ' Change of Sex ' ". Rev. T. N. Burke-Gaffney, S.J., presented a paper on " The T-Phase from the New Zealand Region ", expanded under title " The T-Phase, a Seismological Problem ".

August 4th, 1954.

The seven hundred and fifth General Monthly Meeting of the Royal Society of New South Wales was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Prof. R. S. Nyholm, was in the chair. Thirty-eight members and visitors were present. The minutes of the previous meeting were read and confirmed.

The certificates of three candidates for admission as ordinary members of the Society were read for the first time.

The certificates of four candidates for admission as ordinary members of the Society were read for the second time, and Keith Alan Waterhouse Crook, Syed Manzurul Hasan, Veeraghanta Bhaskara Rao and Denis Keith Tompkins were duly elected ordinary members of the Society.

Presentation of the James Cook Medal for 1953.—The President had pleasure in presenting the James Cook Medal for 1953 to Sir David Rivett, K.C.M.G., F.R.S.

It was announced that August 5th would be the centenary of the birth of William Aitcheson Haswell, who was Professor of Zoology and Comparative Anatomy at the University of Sydney from 1890 to 1918.

Naper Shaw Memorial Prize.—Members were informed that the Royal Meteorological Society had announced the first competition for the Napier Shaw Prize and that further particulars could be obtained from the office of the Society.

Library.—The following donations were received: 209 parts of periodicals, 16 purchased parts.

The following paper was read by title only: "The Palæozoic Stratigraphy of Spring and Quarry Creeks, West of Orange, N.S.W.", by G. H. Packham and N. C. Stevens.

Addresses.—Addresses were given on the subject of "Evolution" as follows: "Man's Place in Evolution", by Dr. N. W. G. Macintosh; "The Implications of Genetics for Darwinism", by Dr. J. M. Rendel.

September 1st, 1954.

The seven hundred and sixth General Monthly Meeting of the Royal Society of New South Wales was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Prof. R. S. Nyholm, was in the chair. Twenty-one members and visitors were present. The minutes of the previous meeting were read and confirmed.

The certificate of one candidate for admission as an ordinary member of the Society was read for the first time.

The certificates of three candidates for admission as ordinary members of the Society were read for the second time. Brian Douglas Booth, Edric Keith Chaffer and Griffith Taylor were duly elected ordinary members of the Society.

It was announced that a symposium on "Oil, Australia and the Future", to be held on Wednesday, October 6th, would take the place of the General Monthly Meeting.

It was also announced that the second in the series of discussions arranged by the Society would be held on Thursday, September 16th, and would be entitled "Was Myxomatosis Wise?" The leaders in the discussion would be Dr. Phyllis M. Rountree and Mr. Grahame Edgar.

Members were informed that the Nuffield Foundation was offering a series of Travelling Fellowships to Australian graduates. Further information could be obtained from the Society's office.

Library.—The following donations were received: 198 parts of periodicals, nine purchased parts, four back numbers.

The following papers were read by title only:

"A Theorem Concerning the Asymptotic Behaviour of Hankel Transforms", by J. L. Griffith, B.A., M.Sc.
"Minor Planets Observed at Sydney Observatory during 1953", by W. H. Robertson.

Commemoration of Great Scientists.—The meeting was devoted to the commemoration of great scientists, the following addresses being given:

"Sir Lazarus Fletcher" (Mineralogist), by Dr. G. D. Osborne.
"Georg Simon Ohm, 1787–1854" (Physicist), by Dr. R. C. L. Bosworth.
"Paul Ehrlich" (Organic Chemist and Immunologist), by Dr. Phyllis M. Rountree.

October 6th, 1954.

The seven hundred and seventh General Monthly Meeting of the Royal Society of New South Wales was held in the Hall of Science House, Gloucester Street, Sydney, at 5 p.m.

The President, Prof. R. S. Nyholm, was in the chair. One hundred and forty members and visitors were present. His Excellency the Governor of New South Wales, Lieut.-General Sir John Northcott, K.C.M.G., K.C.V.O., C.B., had honoured the Society with his presence at the first address of the evening.

Symposium.—In place of the usual General Monthly Meeting a symposium on "Oil, Australia and the Future" was held, and the following addresses were given:

"The Search for Oil in Australia", by Dr. H. G. Raggatt.
"Oil Products and Their Utilisation", by Prof. T. G. Hunter.
"Petroleum Chemicals", by Dr. R. F. Cane.
"The Economic Effects of an Oil Industry on the Australian Economy", by Prof. C. Renwick.

A buffet meal was available to members and visitors from 6.30 p.m. to 7.30 p.m.

The certificate of one candidate for admission as an ordinary member was read for the second time, and Norman William West was duly elected an ordinary member of the Society.

November 3rd, 1954.

The seven hundred and eighth General Monthly Meeting of the Royal Society of New South Wales was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Prof. R. S. Nyholm, was in the chair. Seventy-two members and visitors were present. The minutes of the previous meeting were read and confirmed.

The death was announced of Richmond D. Toppin, a member since 1923.

It was announced that Professor K. E. Bullen had recently been elected to the presidency of the International Seismological Union.

Library.—The following accessions were received: 265 parts of periodicals, 18 purchased parts.

The meeting was devoted to the screening of the following: " Ninety Degrees South ". This film, made by H. G. Ponting, F.R.P.S., and described by him as " an account of experiences with Captain Scott's South Pole Expedition and of the nature life of the Antarctic ", had been made available to the Society through the courtesy of the New South Wales Film Council.

December 1*st*, 1954.

The seven hundred and ninth General Monthly Meeting of the Royal Society of New South Wales was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

Dr. Ida A. Browne, Vice-President, was in the chair. Seventy-six members were present. The minutes of the previous meeting were read and confirmed.

The following deaths were announced: Horatio Scott Carslaw, a member since 1903; Sir Frederick McMaster, a member since 1927; Frederic Wood-Jones, an honorary member since 1946.

The certificates of two candidates for admission as ordinary members of the Society were read for the first time.

Library.—The following accessions were received: 175 parts of periodicals, 11 purchased parts.

The following papers were read by title only:

" On the Asymptotic Behaviour of Hankel Transforms ", by J. L. Griffith, B.A., M.Sc.
" Geology and Sub-surface Waters of the Coonamble Basin, N.S.W.", by J. Rade.
" Quartzite Xenoliths in the Tertiary Magmas of the Southern Highlands, N.S.W.", by R. D. Stevens.
" Petrology of the Greywacke Suite Sediments from the Turon River-Coolamigal Creek District, N.S.W.", by K. A. W. Crook.
" The Permian Coal Measures of the Stroud Gloucester Trough ", by F. C. Loughnan.

Discussion.—The meeting was devoted to a discussion on " Fuel and Power in New South Wales ", and the following addresses were given:

" The Potentialities for Utilization of Solar Energy ", by Mr. Charles M. Sapsford.
" Solar Energy and Photosynthesis ", by Dr. R. N. Robertson.
" The Future of Water Power in New South Wales ", by Mr. H. E. Dann.
" Power Resources in Coal—The Future Outlook for New South Wales Supplies ", by Mr. H. R. Brown.

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