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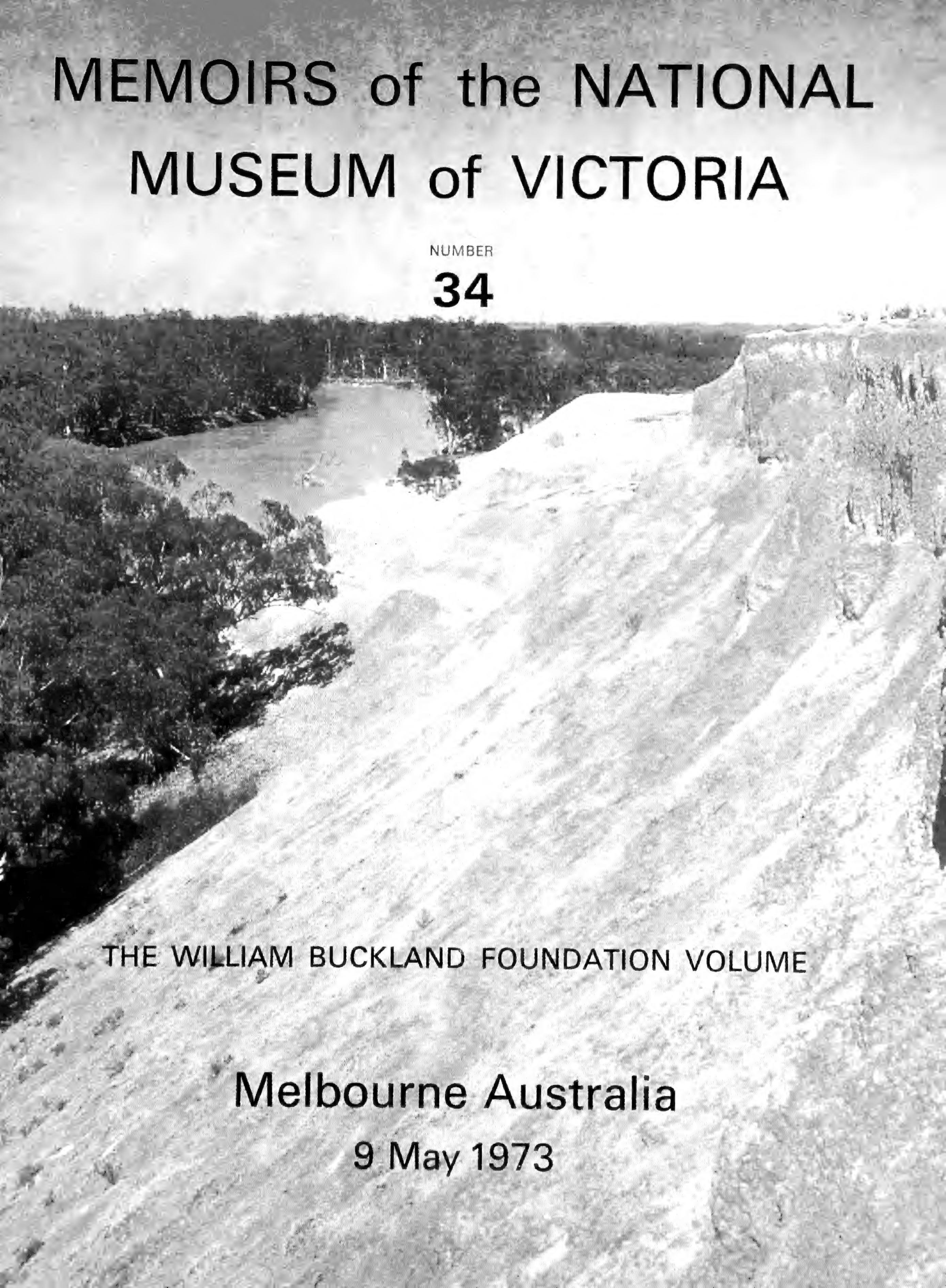

THE WILLIAM BUCKLAND FOUNDATION VOLUME

Melbourne Australia

9 May 1973

MEMOIRS

of the

NATIONAL MUSEUM OF VICTORIA

MELBOURNE AUSTRALIA

No. 34

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J. McNally

Deputy Director and Editor
Edmund D. Gill

PUBLISHED BY ORDER OF THE TRUSTEES
9 MAY 1973

Registered at the G.P.O., Melbourne for transmission by post as a book
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ACKNOWLEDGEMENT

The four year field programme reported in this Memoir would not have been possible without the generous financial assistance of three Foundations. The funds provided were:

The William Buckland Foundation	$14,000
The Sunshine Foundation	3,000
The Nuffield Foundation	2,800
	$19,800

These funds were used to employ a Field Officer, Mr K. N. G. Simpson, and to meet expenses for equipment, travel and field work. In addition, the National Museum of Victoria provided the services of its staff and other field expenses.

In appreciation of the major contributions of the first-named Foundation, this volume is called The William Buckland Foundation Volume.

Thanks are extended to local residents for ready assistance and pleasant hospitality. The many scientists whose co-operation made this volume possible are also thanked for their help.

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Photograph of the cliffs on the W. side of Nampoo Station homestead, above Sharp Point on the N. bank of the River Murray E. of Cal Lal, N.S.W. The top 6 m is a weathered profile topped by the Bakara Pedoderm complex. Greenish gray Blanchetown Clay partly covered with oxidized material from the cliff top forms the slope. In the distance is the Murray River flowing through a floodplain formed by the Coonambidgal Formation on which is *Eucalyptus camaldulensis* lining the streams and *E. largiflorens* on the floodplain beyond. The forested land will be flooded if the Chowilla Dam is built.

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GEOLOGY AND GEOMORPHOLOGY OF THE MURRAY RIVER REGION BETWEEN MILDURA AND RENMARK, AUSTRALIA

By Edmund D. Gill

Deputy Director, National Museum of Victoria, and Director of Chowilla Research Project

Introduction

"To a person uninstructed in natural history, his country or seaside is a walk through a gallery filled with wonderful works of art, nine-tenths of which have their faces turned to the wall". So said T. H. Huxley. Although instructed in natural history, we found the area studied in this *Memoir* so dry in its time of deep drought when we first went there, so flat, and so unvaried compared with other research areas, that we wondered what story it had to yield. However, it was judged that this country, like all others scientists have investigated, would have a useful and fascinating story when it had been deciphered. So it proved to be.

The Research Project

The flattest continent in the world is Australia, and it is also the driest. Put these two facts together, and it can be inferred that the major river system is somewhat unusual. Such the Murray/Darling system certainly is, as the sequel clearly shows. The river tract between Mildura and Renmark is a significant part of this system. Here the Darling River and the Darling Anabranch enter the Murray. Here the valley is 15 to 30 km wide, then suddenly narrows to five kilometers, so making the proposed Chowilla Dam possible. So flat is this area that, if the dam is completed, 1370 km^2 will be inundated. Lake Victoria, a giant billabong (oxbow) system, is on an anabranch formed by the Frenchman's Creek and the Rufus River. It has acted as a massive sand trap, so that a large dune tract lies on its E. bank, emplaced and remodelled over 20,000 years at least by the persistent W. winds of that country. Under natural conditions Lake Victoria is half dry (except in flood time) being an abandoned part of the course of the Murray. At present it is used as a water storage (11,200 hectares).

This Research Project was triggered by the commencement of building operations at the Chowilla Dam site. The Trustees thought that this little-known area where three States meet should be investigated before it was inundated. The undertaking was therefore a salvage one, but on a scale not attempted in Australia before. The area to be flooded plus a necessary marginal area gave a total of 2600 km^2 to be studied. As a result, the study had to be of a reconnaissance nature, with more detailed attention to significant sites. No account of the geomorphology, geology and archaeology of the area has been given before, but there are numerous incidental references in a wide literature; an attempt has been made to provide a bibliography of the more important references. The stated aim of the Project was to collect data and materials that would have been lost as a result of the construction of the dam, but the ultimate aim was to achieve a fundamental understanding of this tract of country—how it came into existence and what the present processes are. A contribution to this aim is set out in this *Memoir*.

The Project was successful beyond expectation. The fundamental geology is of wide application. The palaeontology is making important contributions to knowledge, e.g. Late Pliocene(?) fish remains include *Neoceratodus*, and the skeletons of extinct marsupials make possible the indentification of post-skeletal material previously not referable to any species. Some skeletons were still articulated. The archaeology reveals middens back to 18,000 years ago. The Aborigines of the area were very conservative and kept to their old core/flake culture, eschewing the new blade culture with hafted tools. An Aboriginal skeleton with gypsum widow's cap proves use of this device back to c. 750 years at least. The palaeoclimatology permits recognition of the beginning of the present aridity.

This extensive research operation would not have been possible without supporting funds. The William Buckland Foundation made the chief contributions, and the Sunshine Foundation also contributed. E. D. Gill received a grant from the Nuffield Foundation towards the geological research. Sir Robert Blackwood, Chairman of Trustees (now President of the Council under a new Act), took a special interest in the Project, and joined most of the field expeditions; he has presented in this *Memoir* his work with K. N. G. Simpson on the excavation of Aboriginal skeletons. The funds provided by the Foundations made it possible to employ Mr. K. N. G. Simpson as Field Officer. We are grateful to the scientists who have contributed papers to this *Memoir,* and to those whose assistance is acknowledged in the appropriate places. Mr. G. Douglas of Werrimul gave us a great deal of assistance in the field. We are much indebted to the people on the land. Their hospitality, their assistance when needed, and their fund of local information greatly assisted us. Through their help we were able to achieve much more than would otherwise have been possible.

An account of this investigation was given in ten radio lectures requested by the Australian Broadcasting Commission. These were later published under the title "Rivers of History" (Gill 1970).

Major river system of the flattest continent

Our planet has six continents of which two are islands—Australia and Antarctica. In average elevation above the sea, Antarctica is the highest and Australia the lowest. More than half of Australia is below 300 m, and only about five per cent is above 600 m. Australia is the flattest continent in the world, which fact has a profound effect on its major river-system, the Murray/Darling. The names of the two rivers are commonly linked in this manner because the branch river (Darling) is 160 km longer than the main river (Murray), which is 2570 km long.

Moreover, Australia is the world's driest continent with 75 per cent of its land surface arid or semi-arid. That Australia is so flat and so dry, explains many of the unusual features of the Murray/Darling. Both rivers rise in high rainfall areas of the Great Dividing Range. The Murray rises in the temperate zone on the Kosciusko Plateau. The Darling rises in the subtropical to tropical areas further north.

After only 300 km or so these rivers flow with a very low grade (because the continent is so flat) through 1500-2500 km of river course which contributes little or no water (because the continent is so dry). Along the course of the Darling River from the Queensland border to where it joins the Murray River at Wentworth is about 2170 km over which it falls only 120 m. Thus over a long distance the remarkably low mean declivity of 5·6 cm per km is maintained.

The Murray River at Albury has a fall of 14·2 cm per km which is reduced to the minimum of about 1·6 cm per km for the last 160 km. The water at Albury takes a month to reach the sea. That in the headwaters of the Darling takes two months or more to reach its conjunction with the Murray at Wentworth. Water from the Dartmouth dam being constructed on the Mitta Mitta River will take six to eight weeks to reach S. Australia. The Murray/Darling system has an average annual run-off of only 15,000 m^3 per km^2. The Yangtze-Kiang River in China has a run-off of $1{\cdot}19 \times 10^6$ m^3 per km^2 per annum.

In the area under study between Mildura (Victoria) and Renmark (S. Australia) the valley of the Murray River (Pl. 1) widens to 32 km, including Lake Victoria which is a former meander system, then narrows to 4·8 km at the Chowilla Dam site. Further downstream it narrows to 1·6 km. It is a significant part of the course because here the Darling and its Anabranch join the Murray, the effects of tectonics on the river course can be studied, the cliffs reveal the essential stratigraphy, many fossil localities have been discovered, and Lake

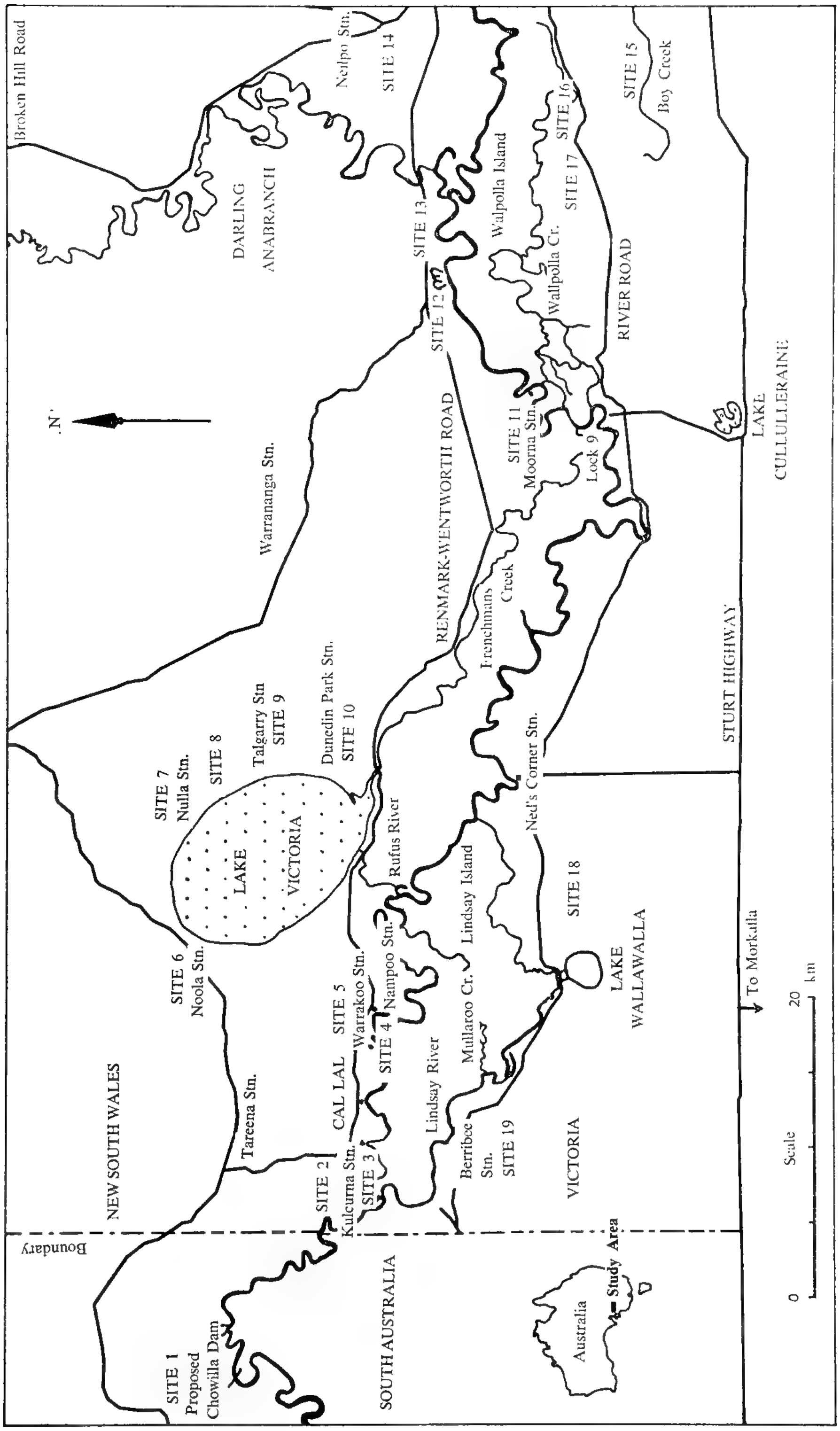


Fig. 1—Locality map of study area.

Victoria with its large lunette on the E. side constitutes a phenomenon of unusual interest.

For much of its course the substrate of the river systems is clay (Browne 1934). If the Darling and the Murray ran into deep sandy country they could well be swallowed up, because the volume of water carried is relatively small, and the evaporation is high ($\sim$1·8 m p.a.). The Darling travels in what is virtually an aqueduct of clay which prevents loss by soakage. Some irrigation channels in sandy areas lose 80-90 per cent by soakage, which gives an idea of what could happen to the river waters if they had a similar substrate. In the area of study the river flows chiefly in clay or clayey sand that acts as an aquiclude. The Chowilla Sand is clean and can act as an aquifer, but it is a channel sand, and so is limited in capacity. I have seen no springs emerging from it. Probably the Blanchetown Clay and other clayey formations prevent water reaching it from the surface, while the complex interdigitation of formations limits the distance water can travel in the channel sands.

Apart from the meanders, the river course directions are curious and call for explanation. To understand this part of river-history, it is necessary to consider the geology of the area. Apart from their courses in the mountains and foothills, the Murray and Darling Rivers run over a deep sedimentary basin—the Murray Basin. This will now be considered, because the geological history is such that what happens at depth influences what happens at the surface.

Drainage basins

In the E. half of Australia there are two large drainage basins—the Lake Eyre and the Murray. The Lake Eyre drainage basin is the largest in Australia, and is large by world standards, being some 1,300,000 km^2 in extent. Although so large a basin, it drains very little water. Because the continent is so flat, the declivities are low, and there are no high mountains round the edge of the basin. Because Australia is so dry, very little rain falls (the isohyets range from 12 to 25 cm only) and having flat sandy terrains to cross with a very high evaporation, the water seldom reaches Lake Eyre. Only once in living memory (Mawson 1950, Bonython 1955) has Lake Eyre been filled. Lake Eyre occupies a very shallow depression a little below sealevel. What would be a small or negligible flexure on most terrains, here created a huge drainage basin because if the flatness of the country.

To the SE. is the smaller Murray Basin (Fenner 1934), which can be defined approximately by the 180 m contour. A wide northern part is occupied by the Darling River and its tributaries. The Darling and Paroo Rivers meet at Wilcannia and pass through a comparatively narrow zone which has been named the Cobar Neck, being W. of that city. The basin then widens again to comprehend the Murray River and its tributaries along with the Darling River from the N. This is often referred to as the Murray/Darling riverine plain. The area discussed in this *Memoir* is more or less in the middle of this plain.

The Murray and Darling begin in the Great Dividing Range with a strongly dendritic stream pattern (Taylor 1914). Because the inland is semi-arid, the tributaries rapidly disappear. In the N. the Darling is the only continually flowing stream. In the S., no tributary of consequence enters the Murray after the Darling joins it at Wentworth. The Murray and Darling Rivers may thus be considered gutters that drain the waters of the W. side of the Dividing Range across the semi-arid inland to reach the sea to the SW.

Sedimentary basins

The surficial drainage areas of the present are directly related to the sedimentary basins of the past. In E. Australia there are two important sedimentary basins—the Great Artesian Basin to the N. and the Murray Basin in the S. There is a narrow connecting area W. of Cobar as there is in the present drainage basins. It is called the Darling Corridor by Devine and Power (1970). While the Murray Basin is a unit, the Great Artesian Basin has a number of sub-basins such as the Carpentaria Basin on the Gulf of that name, and the Surat Basin in E. Queensland which has been a source of oil. The Great Artesian Basin is chiefly of Mesozoic

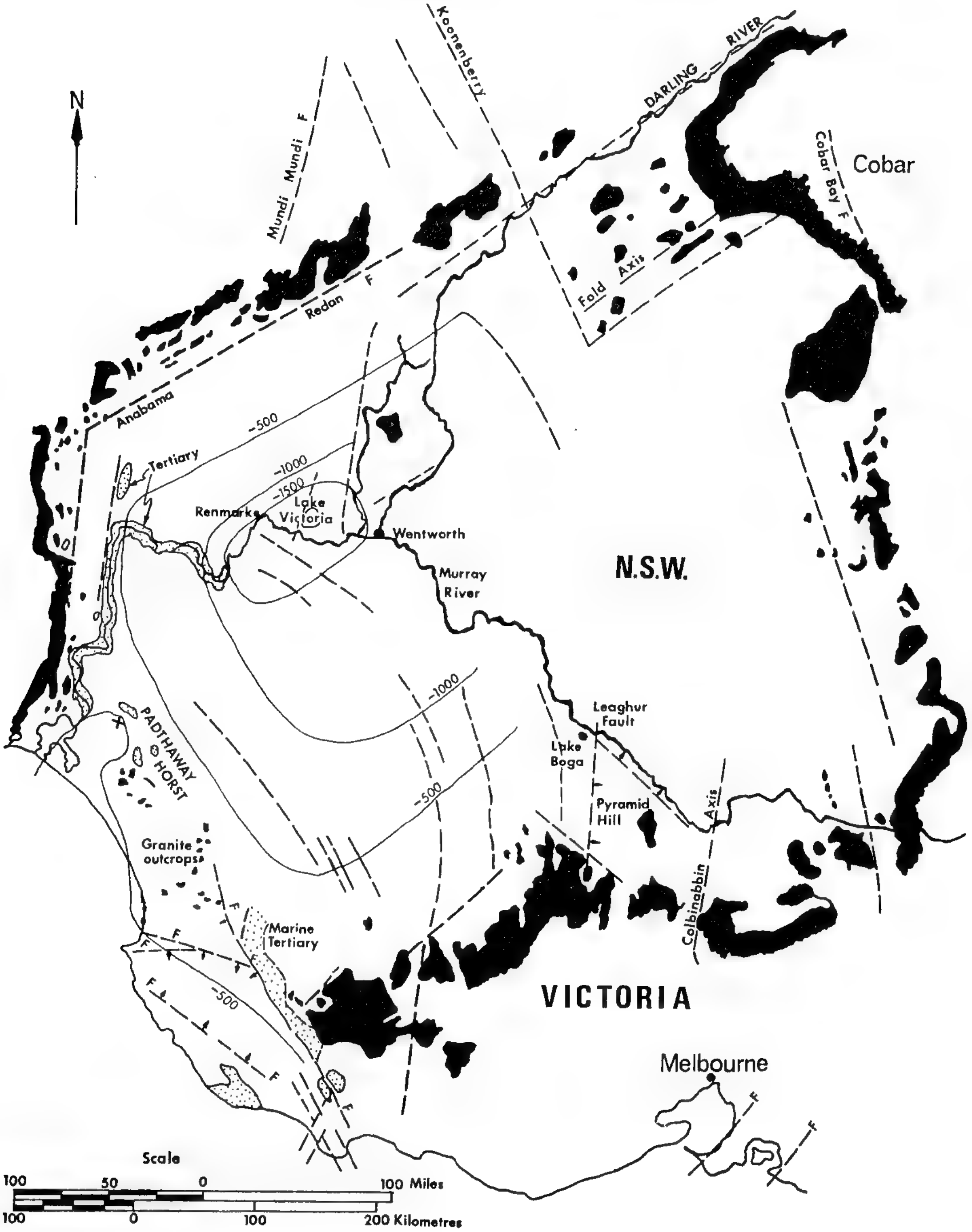


Fig. 2—The structure of the Murray Basin (after Hills) with some additional information.

strata, while the Murray Basin consists of Mesozoic and Cainozoic strata. Although the Murray Basin appears small beside the Great Artesian Basin, it is nevertheless quite extensive, being about twice the area of France.

Murray framed sedimentary basin

In outcrop, the Cainozoic beds of the Murray Basin present a rounded structure, as may be seen in the 1960 Tectonic Map of Australia published by the Bureau of Mineral Resources. However, the fundamental bedrock structure is quadrate, as shown by Hills (1956) whose map is reproduced as Fig. 2 with the addition of some later information.

The Australian Oil and Gas Corporation Limited sank bores at Renmark, Lake Victoria, and Wentworth. With their permission, Fig. 3 is published containing the information obtained therefrom. The palaeontologist who reported for the Corporation was able to identify all strata with some certainty as high as the Bookpurnong Beds. These are probably Cheltenhamian (Uppermost Miocene) and those reported in the Lake Victoria bore are no doubt the same horizon as that in a deep well at Tareena Station (Tate 1899) on the N. side of the Murray River between the S. Australian border and Lake Victoria (now part of Kulcurna Station). Tate was uncertain of the age of the occurrence, but compared the fauna with

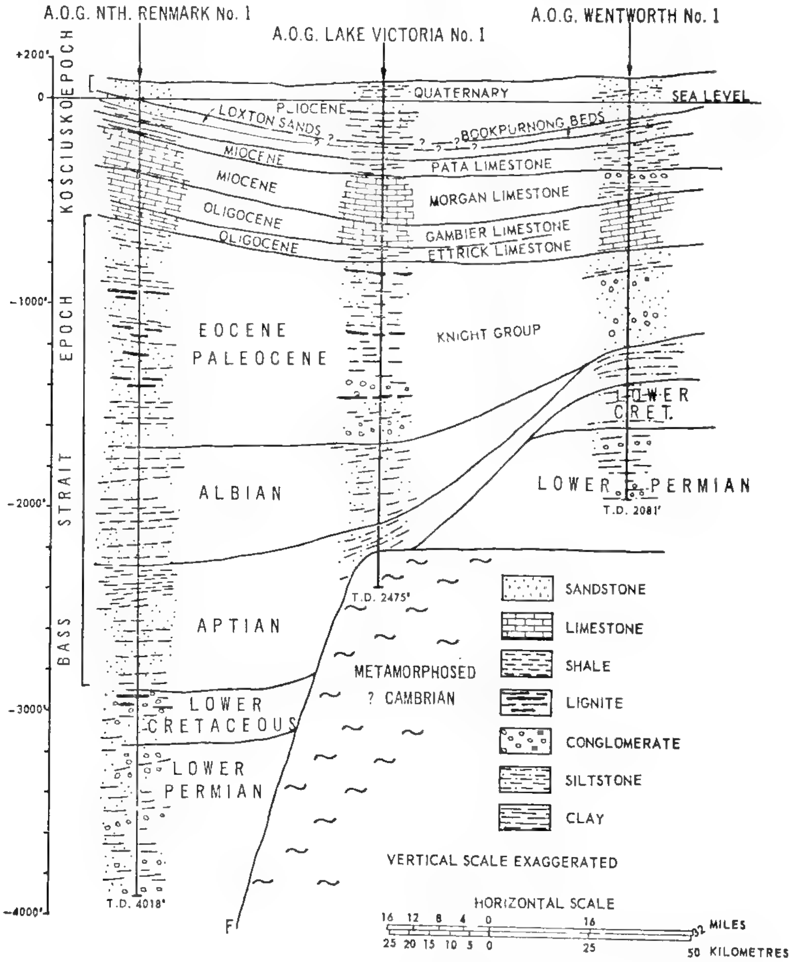


Fig. 3—Geological section between Renmark and Wentworth by courtesy of Australian Oil and Gas, with some adaptations.

that at Beaumaris, Victoria, which is the type locality for the Cheltenhamian Stage. Mr. T. A. Darragh, Curator of Fossils of this Museum, considers that the fauna is probably Cheltenhamian, pointing out that *Pelicaria coronata* is one of the characteristic species obtained from the well. At both Beaumaris and Tareena Station, the sediments are nearshore marine in ecology.

At the Chowilla Dam site, Loxton Sands (Firman 1966) have been proved, and it may be that at Tareena Station and Lake Victoria they lie between the Cheltenhamian marine bed and the Parilla Sand (which outcrops along the Murray River and up Salt Creek), but this has not been established. Presumably, the calcareous marine bed was at the base of the Tareena well, while the Loxton Sands or equivalent provided the aquifer (if any). Certainly the clayey Parilla Sand at or near the surface would act as an aquiclude.

The stratigraphy revealed by the bores of Fig. 3 shows:

1. A succession of alternating marine and non-marine phases.
2. A massive fault in the basement rocks, with a throw of the order of 600 m demonstrated, but the exact amount of dislocation unknown. The A. O. G. geophysicists traced this structure for some 24 km NE. of the Lake Victoria well site. The fault is a major one, and so is here named The Lake Victoria Fault. Its orientation is that of the Bouger anomaly contours (Bureau of Mineral Resources, Geology and Geophysics plans G. 239/1/1 and 2/1).
3. On the interpretation given in Fig. 3, movement began in the Aptian. As the undifferentiated Lower Cretaceous is of the same thickness on both sides of the fault, it is concluded that displacement occurred after its deposition.
4. The earth movements have been slow. Kulp (1961) gives the beginning of the Cretaceous as 135 m.y. and the beginning of the Albian as 120 m.y. It has thus taken in excess of 120 m.y. to build this part of the Murray sedimentary basin.
5. The rate of movement has varied with time. As the relative thicknesses of the formations indicate, movements were more rapid in the Aptian-Eocene and in the post-Miocene. These belong to the Bass Strait (Gill 1964, p. 347) and the Kosciusko Epochs (Andrews 1910) respectively. As registered by the movements in this area, the Bass Strait Epoch lasted for some 70 m.y., while the Kosciusko Epoch has existed for only about 15 m.y. However, the latter epoch may be considered as still in progress. The present may be a lull in a longer period of movements. The gap between the Bass Strait and Kosciusko epochs in the Murray Basin is about 45 m.y.

Basin Frame

The frame of older rocks round the basin consists chiefly of the Adelaide Geosyncline formations on the W. and the Tasman Geosyncline formations on the E. The former consists essentially of Precambrian to Cambrian rocks, while the latter consists chiefly of Lower and Middle Palaeozoic rocks. Their structural relationships are shown on the 1971 Tectonic Map of Australia. These geosynclines provide also the frame rocks to the N. To the SW. is the opening by which the sea reached the Murray Basin, but this is complicated by a horst, the Pinnaroo Block. Along the Padthaway Ridge are highs of granitic rocks that formed an archipelago in the Tertiary sea. In other words, the horst formed a sill over which the sea passed into the basin.

Tectonics

The Cainozoic tectonics of Australia are weak, contrasting with the powerful movements that characterize New Guinea to the N. and New Zealand to the E. The rates of movement contrast strongly. Thus in the middle of the Murray Basin depression (Fig. 3) the average rate of sinking since the beginning of the Cretaceous has been ~1 m per 120,000 y. whereas average rates calculated for various lengths of time back into the Cainozoic are in New Zealand ~1 m per 100 y, and in New

Guinea from 1 m in 5,000 y to 1 m in 88 y (Gill 1972). During the Cainozoic, the tectonic movements were in the form of broad warps that deepened basins and flexed up marginal low-mountain areas such as the Mt. Lofty Mts. on the W. of the Murray Basin, and the Great Dividing Range on the E. and S.

1. *Constancy of Tectonic Pattern*

As a result of the mildness of the movements, no change in the tectonic pattern of the study area has occurred since the commencement of the Cretaceous Period. Moreover, ancient faults of Palaeozoic, or greater age (such as the Lake Victoria Fault) have continued to make their influence felt (cf. Firman 1970), because the small movements on these lineaments are significant on a surface where slopes are so slight. The basin is completely filled with sediments and so the surface is about as flat as it can be. The only steep slopes are the banks of the river tract, which has been incised ~36 m (Pl. 2).

2. *Geomorphic Control by Deep-seated Lineaments*

These palimpsest tectonics, as they might justifiably be named, are critical to the understanding of this area. The description of the formation of Lake Victoria later in this contribution illustrates this well. The River Murray in the area of study flows through a terrain of E-W dunes, but those to the N. appear to be an older system than those to the S., so some tectonic boundary may be involved. N. of the river, the Blanchetown Clay typically outcrops at or near the surface, so that water tanks can be excavated in it. The sand supply is therefore limited. To the S., the country is more sandy, and the irrigation channels in some areas lose most of their water by soakage.

Hills (1956a) states that "tectonic significance must be attached to every stretch of the River Murray, and that from trends alone a clear indication of structure—the nature requiring to be investigated in each case—is provided". Johns and Lawrence (1964) with reference to that part of Murray Basin in NW. Victoria state, "It appears that movement along ancient lines of weakness in two or three directional trends (approximately NW., NE. and N.) within the basement rocks, have been dominant in the formation of the basin". Hills (1956b) has called this "resurgent tectonics".

3. *Strong Influence of Small Faults in Flat Country*

Displacement in the Cadell fault near Echuca on the Murray River (Harris 1939), although with a throw of a maximum of only 12m, caused a major diversion of the river. The fault is across the river (N.-S.) with a tilt downstream to the W. The main flow of the Murray River was diverted S. along the fault line, to join the Goulburn R. above Echuca, thus taking over some 80 km of the course of that river. Some water flows N. along the N. arm of the fault line to Deniliquin, then turns W. as the Edward River to form an anabranch fed through the offtakes in the low-lying forest areas between Tocumwal and Echuca. So this minor fault, because of the flatness of the country, strongly diverted Australia's largest river, and created the Echuca Depression in which a lake was formed, and from the sandy beaches of which the Bama Sandhills were built. The N. and S. divergences of the Murray River join up to the W. again, thus surrounding the triangular Cadell Tilt Block. In the mountainous upper reaches of the Murray, the development of a fault across the river with a final displacement of 12 m. would have a negligible effect, but on the flat surface of the sedimentary basin, it caused a major dislocation (Bowler and Harford 1963, Bowler 1967).

The continuing influence of extremely old lineaments to the present time is illustrated by the Berridale Wrench Fault (Lambert and White 1965), the main movement of which is dated Early to Middle Devonian, with continuing minor dislocation during the Tertiary, while "seismic activity . . . indicates possible recent movement." Hills (1961) has commented that "in Australia the results indicate long-continued activity along ancient lines of weakness and considerable evidence for greater mobility of the cratonic units than is normally attributed to them. Lineaments and blocks are prominent and many of the geo-

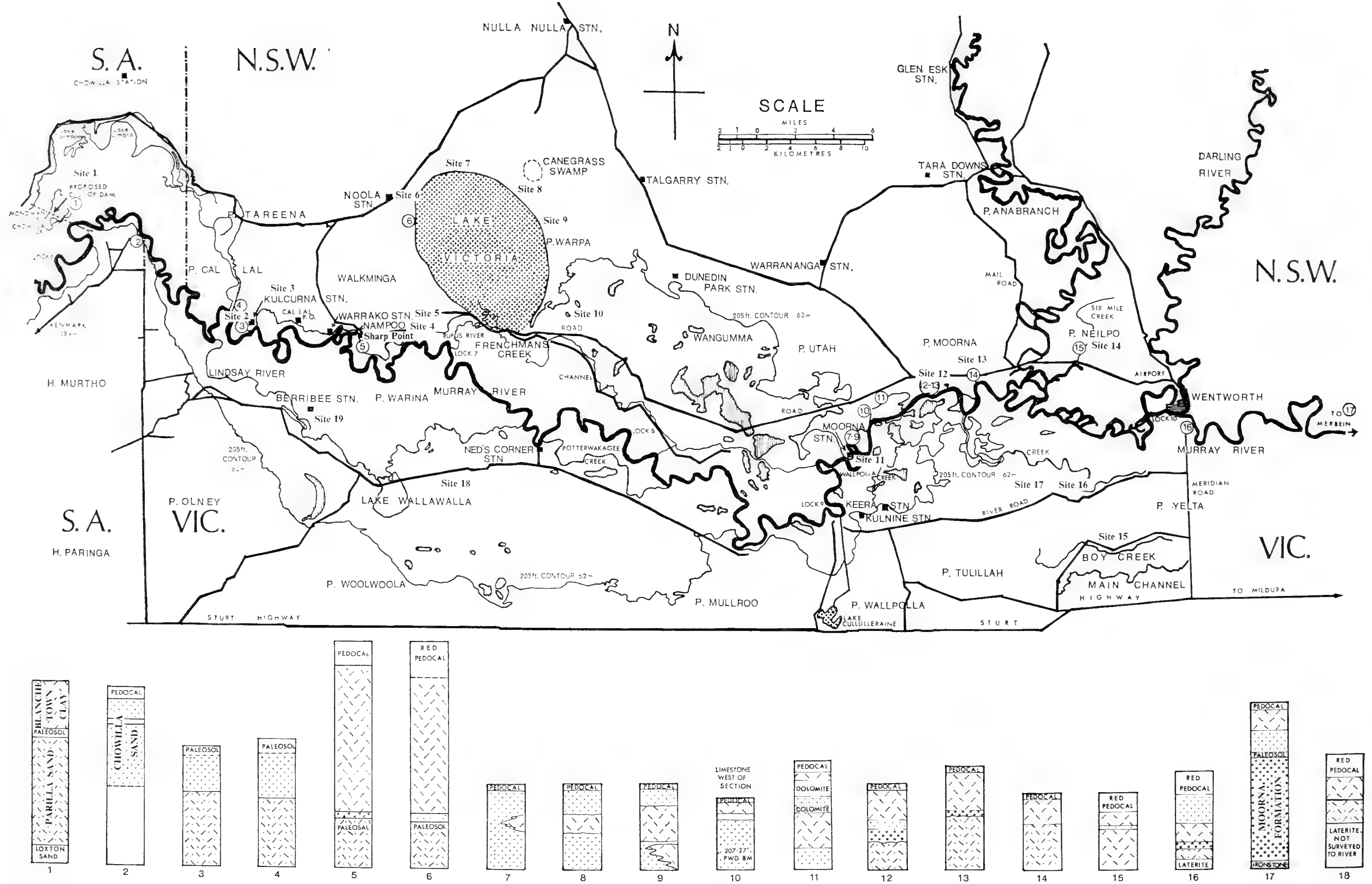


Fig. 4—Map of project study area, with a series of measured stratigraphic sections. The numbers below the sections appear in circles at the sites on the map above. The 205 ft. (62 m) contour is the level to which flooding by the Chowilla Dam was designed. Such contours are on the S.A. datum of M.S.L. Adelaide = 106·88 ft. Lake Wallawalla is dry, and Lake Cullulleraine is an irrigation storage. Only sections 1-2, 5-6 and 17 reach the local plateau level. Behind the other sections, the terrain rises, and in many instances Blanchetown Clay was proved there.

Note that the downwarp in this area from the Pinnaroo Block to the W. causes the Loxton Sand to disappear below river level as one moves E., and then similarly the Parilla Sand. The latter reappears at Paringi far to the E. In the Lake Victoria syncline, the Moorna Formation is intercalated below the Blanchetown Clay/Chowilla Sand complex. The vertically hatched areas on the river floodplain are Rufus Formation. The base of each section is river level, while No. 6 on Lake Victoria is at the level of Lock 9, from which the lake is filled. H (in S.A.) = Hundred; P (in Victoria) = Parish. Section 18 (not on map) is from Paringi, SE. of Mildura.

logical basins are framed by lineaments". As already indicated, this is true of the Murray Basin.

4. *Structure Pattern at Surface*

Firman (1970) has recorded a faint pattern of structural elements which he recognized from low-flying light aircraft and mapped from aerial mosaics. The results were related to geophysical and geologic information. They were used to define the Pinnaroo Block (Firman 1966).

5. *Degree of Tectonic Control of Sedimentation*

Without subscribing to a complete theory of tectonic control of sedimentation (e.g. as discussed by Crook 1967), it can be stated as fact that the tectonic style of the area affects the nature of the sedimentation. On first studying the area, I was impressed with the almost universal occurrence of fine sands—in the Parilla Sand, the sandy phases of the Blanchetown Clay, the Chowilla sand (although a channel deposit), the various Quaternary riverine and dune systems, and much of the Moorna Formation. It was with some surprise therefore that I came upon the ossiferous gravelly sand of a channel deposit in the Moorna Formation at Fishermans Cliff, on Moorna Station. Even the sediments of the present Murray River, rejuvenated by incision of a course round the Pinnaroo Block, are fine clayey sands on the floodplains as seen in the red outliers (relicts of a Pleistocene terrace with giant marsupial remains, here named the Rufus Formation) and the Coonambidgal Formation. Washed sands characterize the channels. This general fineness of sediment is a function of the low dynamics of the streams which in turn is due to their exceptionally low grades, a result of the mild tectonics. See grain size analyses in section on *sedimentation*.

The tectonic uplift of the Pinnaroo Block dammed the Murray River and brought about the formation of the ancient Lake Bungunnia (Firman 1965). Tectonic movement was therefore the initiator of Blanchetown Clay deposition.

Flatland Geomorphology

Sturt (1849) began his account of exploration in Australia with this statement: "The Australian continent is not distinguished . . . by any prominent geographical feature . . . nor do any of its rivers . . ., not even the Murray, bear any proportion to the size of the continent itself". This description is particularly true with reference to the area now described.

Rivers

Meanders apart, the River Murray in the study area has a general direction of a little N. of W. To the W. of the Darling Anabranch this general direction is offset about 20 km by a section of the river that flows SW. The reason is not known, but it is suspected to be associated with tectonic influences that also caused the Darling Anabranch to gain entry to the Murray where it does. The locations of Wallpolla Creek with its anabranches and Boy Creek may be connected with this same pattern. The designers of the Chowilla Dam envisaged (at one stage at least) filling to the 205 ft. contour (62·5 m). This contour is based on the River Murray Survey of 1909-1914 when the South Australian datum was used, which is approximately 105 feet below Mean Sea Level. This unusual datum originates in the fact that part of South Australia (the Lake Eyre region) extends below sea-level. Thus the 205 ft. contour is approximately only 100 ft. (30·5 m) above M.S.L. although so far from the sea (Wentworth is about 820 km by river from the sea). This contour is relatively close to the river at the S.A. border but further E. swings out widely both N. and S. of the river. It nears the river again at the S. end of this SW. flowing sector, and follows it fairly closely to where this sector begins. The position is complex in the Wallpolla Creek area because this stream is actually an anastomosing system of used and abandoned channels, as though tectonically instigated shifts of channel had repeatedly occurred. Perhaps the curiously isolated, but large channel called Boy Creek is a former course of the Murray River. As our project had to cover so large an area in so brief total field work time, our investigation had to be of a reconnaissance nature, but in numerous places in this account interesting problems for future investigation (such as this one) will be indicated. Some are listed in Appendix 2.

The Darling River enters the Murray by twin streams—the Darling itself at Wentworth (Pl. 1) and the Darling Anabranch about 14·5 km further W. *Anabranch* is an Australian word and appears to have been used first by Colonel Jackson (1834, p. 79), who states "Thus such branches of a river as after separation re-unite, I would term anastomosing branches; or, if a word might be coined *anabranches*." Thereafter, it was used by Leichhardt (1847, 2: 35), Sturt (1849, 1: 93), Blandowski (1857, p. 174) and others. The word was spelt without the hyphen by Leichhardt, and I presume was originally used by Jackson only to indicate that he had taken the *ana* from *anastomosing* and joined it to *branch*. Sometimes the first syllable is spelt *anna* (first by Blandowski 1857, p. 128), which is incorrect by derivation, and sometimes as two words (as on the military map) which is not according to original usage.

The Darling and its Anabranch are both wide streams. Twin streams are like sympatric species of animals—one usually has a slight advantage over the other and in time takes over. However, both these streams flow strongly at present and a comparative study would be an interesting project. A string of lakes, filled only in flood time, is associated with the Darling in the Menindee district, while another group that could be regarded as belonging to the same system, is associated with the Anabranch. The origin of these lakes is unknown, but may have a similar genesis to that of Lake Victoria discussed later in this paper. Lake Menindee has yielded a rich deposit of fossil vertebrates (Tedford 1967), and more recently Lake Tandou further to the SW. has yielded a similar fauna, an account of which is provided in this *Memoir* by Dr. D. Merrilees. Further E., a similar system of dry lakes includes Lake Mungo, which has yielded records of both marsupial and human occupation plus evidence of high lake levels (Bowler et al. 1970).

The so-called creeks of the area are generally dry, and their significance is in the past rather than the present. The stratigraphy of the river flats at the Chowilla Dam site show a marked change in river regime. Six Mile Creek between the Darling and its Anabranch is an old river channel, as also probably is Boy Creek. All the creeks, and indeed the rivers themselves, are classifiable as misfit streams (Dury 1960). The amount of water that flows is small compared with distance traversed and the size of the valleys. It is important not to think in terms of the present flow, for the streams (especially the Murray) are controlled by dams and locks. Under natural conditions floods and droughts had severe effects. As recently as 1945 I walked dry shod across the bed of the Murray River near Koondrook. George Everard in an unpublished diary tells of a low river level in 1857 observed by him between Kulkyne and Wentworth. "We could cross quite easily in most places, having to swim the middle about a chain; the rest we could walk, the water being so shallow". Thus, under natural conditions the the river at times was not much of a barrier, whereas at present a high water level is always maintained.

The junction of the Murray and Darling Rivers (where the town of Wentworth stands) is an historic site, the area having been visited in:

1836 by Mitchell (1839, 2: 116)
1844 by Sturt (1849, 1: 103)
1853 by Mueller (Barnard 1904)
1856 by Blandowski (1857).

Rainfall and Floods

The rainfall is only 22-26 cm in this area, contributing little to river flow because it is so low, and because surficial sands soak up much of it. Some rain runs into enclosed areas which may result in salt lakes such as occur E. of the Lake Victoria dunes on Talgarry Station, and Salt Lake E. of the Wentworth-Renmark road on Dunedin Park Station. Heavy local falls may result from thunder storms. During our field work at Lake Victoria, one fall of 9 cm occurred, about 40 per cent of the average annual rainfall. The evaporation is about 1·8 m.

Flood water has two sources—Summer monsoonal water that flows down the Darling (Sturt 1849, 1 : 6), and Spring meltwater from the Kosciusko highlands further S. Normally, the floods do not coincide (as noted by Mitchell 1839, 2 : 116) but from time to time this happens, and king floods result. In the town of Wentworth a monument stands to the men and machines that saved the town during such a flood. The oscillation of flood and drought is a characteristic of this river system which has been present for a very long time, because the whole biotic complex is adapted to it. This characteristic ruined the boat trade, which was unable to depend on access. An extreme instance is that of the boat that went up the Darling to Bourke, but could not return for three years because a prolonged drought so lowered the water level that passage was impossible (Cameron 1966). In 1968 there was a flow in the Murray of 15,000 cusecs (35,000 1. per sec.) but in 1967 only 780 (1,800 1. per sec.) during a drought. However, in the major flood of 1956 the flow was 140,000 cusecs (330,000 1. per sec.). The largest recorded flood is 156,000 cusecs (368,000 1. per sec.). There was a Great Flood and rain in the Darling in 1863-4 (Hardy 1969, p. 134) that brought many hardships, but also green feed to an arid land. Such events could not be depended upon by settlers. For example, Tate (1885) records that floods filled Lake Momba in 1864 then not again until 1885. Cameron (1966) describes the big flood of the Darling River in 1890, and the unsuccessful attempts to save the town of Bourke.

Drought (Heathcote 1969) in Australia "is a permanent feature and not just a misadventure". It has to be planned for as a cyclic event. For some time this was not understood. For example in 1883 the Government was doubtful (Everard, n.d.) whether the N. part of Victoria, called The Mallee (Hardy 1914) "was worth saving". When Sturt reached the Darling River on Feb. 4th, 1829, at New Years Creek, he found the water too saline to be potable, and the Aboriginals had left the area.

River Terraces

Between Wentworth and the Chowilla Dam Site, the floor of the Murray River tract is exceptionally wide (Fig. 4). This is probably due to the river oscillating from side to side during the period of impedence while the stream was incising the Murray Gorge in the Pinnaroo Block. A local tectonic factor is also probably involved, as will be discussed in the section on the origin of Lake Victoria. It is the broadness of the river tract here that will cause so large an area to be inundated (1300 km^2) if a dam is built at Chowilla, and it is the usually steep walls of the valley tract that nevertheless will contain the water.

The river tract is an uneven pattern of dull gray and bright red. The gray alluvium is mostly, but not all, covered by the king floods, so some of it was deposited by still higher waters. However, the surface is relict (except for the lowest areas) and consists of old channels of well-washed sand and floodplains of clayey sand, which have not been masked by any later alluviation. These are comparable with the Coonambidgal Formation described by Butler (1958), Pels (1966), Bowler (1967), Firman (1967) and others. The gray country consists of uncompacted sediments that may be treacherous for the motorist in wet weather. The red country is compacted and passable in wet weather. The gray country is unoxidized, while the red is strongly oxidized. The gray country has little development of soil profiles, while the red has a well-developed soil profile with mobilization of carbonates in earthy patches to small nodules. The gray country is young, while the red country is much older.

Few fossils have been found in the gray country, but radiocarbon dates therefrom are Holocene. The red country has provided the mineralized bones of extinct marsupials, which elsewhere in this region are Pleistocene. The gray country is extremely flat and related to the baselevel of present deposition. Blandowski (1857, p. 127) was impressed with the flatness of this country describing "clay flats of remarkable evenness". In Brown's Paddock on Keera Station on the S. side of the Murray River, a survey from auger holes to a bench mark crossed about 0·3 km of gray floodplain and found only about 7 cm difference in level.

On the other hand, the red country consists of the remnants of a Pleistocene floodplain that stands well above (commonly 7 m) the existing floodplain (Fig. 5), and has suffered erosion, sometimes extensive. In the section on stratigraphy, this formation is described as the Rufus Formation, and some account of its sediments given. The Coonambidgal Formation is characterized by *Eucalyptus largiflorens* with *E. camaldulensis* along the waterways. The Rufus Formation is marked by non-myrtaceous plants such as Oldman Saltbush, *Atriplex nummularia, Callitris* and *Casuarina.* The great variety of the shapes of these outliers catches the eye on the air photos, but those checked proved to owe their morphology to the directions of the Coonambidgal channels. The small area covered by Rufus Formation outliers in Fig. 5 is a measure of the extensive erosion effected by the Coonambidgal streams. The strong contrast between the Coonambidgal Formation and the Rufus Formation in oxidation, compaction, pedology, erosion, secondary mineralisation and in palaeontology, indicates a considerable time break with consequent change of environment. It would be helpful to know how great this period is. No dependable chronology is yet available. There are indications of the order of age in that the lunette on the E. side of Lake Victoria onlaps the Rufus Formation there, which contains *Sarcophilus,* now extinct on the mainland. The oldest date from the Lake Victoria dune system so far is 17,530 yr (ANU-404A) but this is high in the succession so the base of the dune is considerably older. At Lake Mungo (Bowler et al. 1970), in this same river system, the base of the dune system is of the order of 32,000 years.

The deep weathering of the Rufus Formation would take a great deal of time. Norris (1969) says the process of reddening "is promoted by

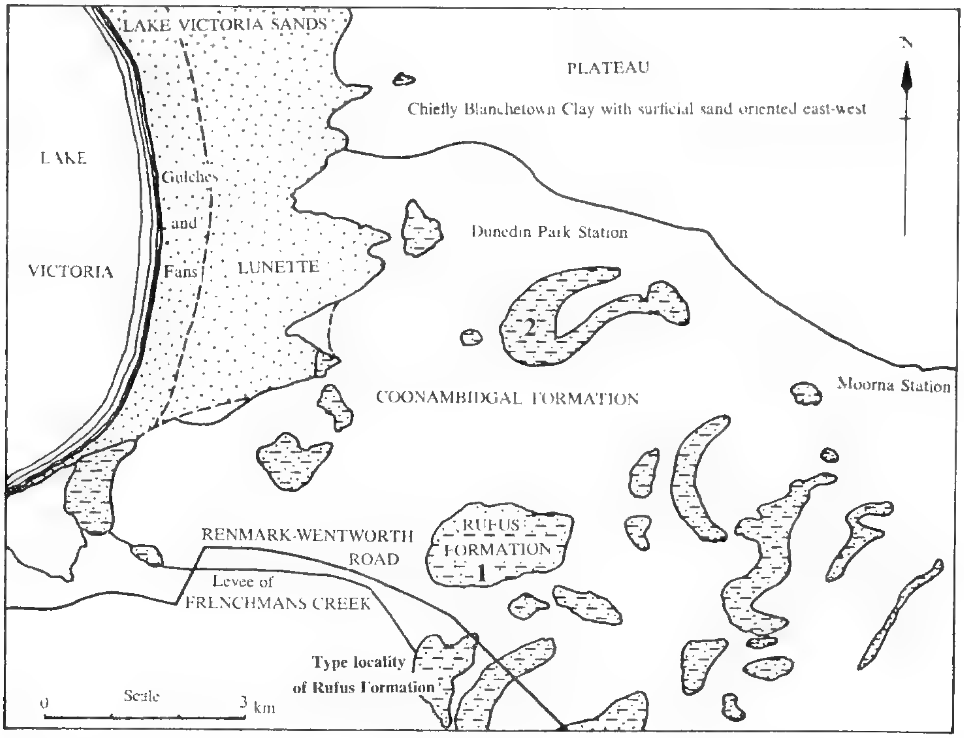


Fig. 5—Trace of air photos to show the distribution in the river valley (N. of the Murray River and E. of Lake Victoria) of the higher red country (Rufus Formation, oxidized remains of a Pleistocene fluviatile terrace) and the lower greenish gray country (Coonabidgal Formation). Sites 9-10.

warm temperatures, oxidizing conditions and the periodic presence of moisture. Reddening is due to the gradual weathering of iron oxide and silicate mineral grains; the weathering tends to cause the coatings to become thicker and affects increasing numbers with the passage of time. In addition, evidence suggests that the haematitic grain coatings are resistant to the abrasion associated with aeolian transport". Palaeoclimatic evidence indicates changes in river regime with time in the Murray valley, and it will probably be possible later to correlate this stratigraphic break between the Coonambidgal Formation and the Rufus Formation with one of those periods of change. The Rufus Formation may be middle Pleistocene in age.

Meanders and Oxbow Lakes

"All the varied forms of the land are dependent upon . . . structure, process and time". W. M. Davis 1954. In the area studied, the Murray River is a mass of meanders, and oxbow lakes (called billabongs in Australia) are very common (Pl. 3). This exceptionally extensive meander belt is worthy of closer study. In the short time available, the oxbow lake between Moorna Homestead and Woolshed close to the Wentworth-Renmark road (upstream from Fishermans Cliff and the paddock called The Selection) was studied briefly. This attractive body of water has a high biomass production. Some 60 species of birds were counted on or around it. On one occasion about 200 black swans alone were counted. Fish, tortoises, atypid prawns (determined by Dr. W. D. Williams) molluscs and ostracods were noted without a survey being made. Such places formed an important source of food for the Aborigines. This high biologic production results in carbonaceous sediments on the lake floor. When a drought was on, the lake level dropped and a spade hole was dug in the peaty floor at the S. end of the W. arm of the oxbow. It revealed only 23 cm of carbonaceous sediment over a highly compacted mottled clayey sand which is apparently the B horizon of a former soil.

The cliffs of the oxbow are very steep and the talus slope reaches only 0·2-0·5 of their height. Where gulches debouch into the billagong, there are small deltas covered with reeds. Thus the thickness of floor sediments and the morphology of the cliffs suggested a youthful age.

Figure 6 provides a surveyed section of the N. side of a gulch cut in the NW. cliff of the oxbow lake. This traverses the delta of sediment washed out of the gulch. The rainfall is only 23 cm p.a. but much of this often falls suddenly in thunderstorms and so erodes with high energy. Examination of other cliffs in the area showed this to be a widespread condition and hinted that there might have been a "1000 y. flood" or such event (or series of events) that cleaned out the river courses and oxbows by flooding of unusual energy. It was therefore decided to bore the floor of the oxbow lake to obtain sediment from the base of the "clay plug" for radiocarbon dating. If successful, this would give the order of age of the present geomorphic unit.

Mr. W. Levy kindly provided a boat. The Museum carpenters constructed a high tripod to stand on the floor of the lake to which a suitable boring apparatus could be attached. However, some 25 cm of very soft gray sediment made it difficult to set the tripod, the legs of which had to be heavily weighted to make them stable. C.S.I.R.O. Division of Applied Geomechanics, through its Chief, Dr. G. D. Aitchison, kindly supplied the boring apparatus and the services of Mr. Gavin Renfrey, without whose expertise we could not have mastered the many problems that arose. Ultimately, the core was taken, the profile being

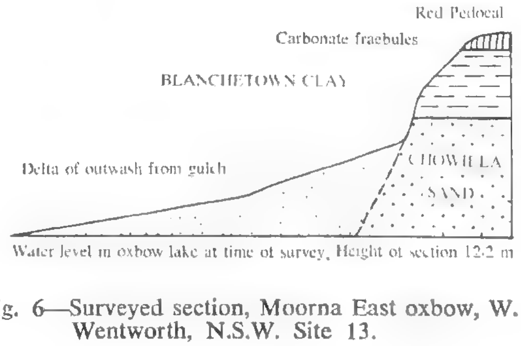


Fig. 6—Surveyed section, Moorna East oxbow, W. of Wentworth, N.S.W. Site 13.

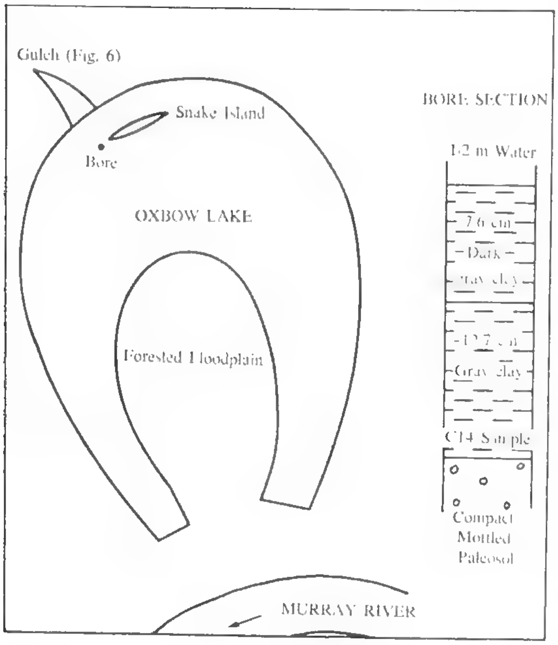


Fig. 7—Moorna East oxbow with the gulch beside which the section (Fig. 6) was surveyed; also site of bore. On right is section of bore. Radiocarbon date 770 ± 150 yr B.P. Site 13.

as in Fig. 7. The sample from the layer immediately above the eroded former land surface was dated by Professor K. Kigoshi as 770 ± 150 y. B. P. (GaK-3217). The carbon content was not as high as anticipated (the percentage fell off at the base) so that the sample was insufficient for a precise dating. However, the order of age was determined, and the juvenility of the oxbow lake established. This was all that could be done under the circumstances, but the further elucidation of this matter would be a worthwhile project.

Plain

The plain in which the river tract is incised is of the order of 36 m above the river (Pl. 2). The plain descends to the river or its floodplain usually by steep slopes or cliffs. From the air the green linear river tract contrasts strongly with the general redness of the terrain. To this natural ecology is now added the green patchwork of the irrigation blocks. A question worthy of investigation is why the Murray River has followed the course it has across this flat plain of lacustrine (Blanchetown Clay) and riverine sediments. As already pointed out, there are tectonic factors involved. There are also lithologic factors. It is noteworthy that a marked difference exists between the country S. of the river and that to the N. The Victorian section of the plain is characterized by the Big Desert and associated semi-arid sandy country, all geomorphically distinct by reason of its E-W. longitudinal dunes with sharply defined crests (air photos). These dunes have earthy carbonate subsoils, and calcrete nodules are only found (in my experience) under these dunes as quarries and borings showed. By contrast, the country N. of the river has relatively only a veneer of sand, and over large areas Blanchetown Clay outcrops at the surface. Thus, conservation of water S. of the river is a problem, while N. of the river large tanks excavated in the green Blanchetown Clay are common. As the air photos readily reveal, the country N. of the river has an E-W. grain with some development of longitudinal dunes, but the usual carbonate soils are those bearing laminated calcite nodules in the subsoil. As these two areas belong to different States, this important difference has not been indicated in studies published so far, and merits further investigation.

Because the Blanchetown Clay is of Upper Pliocene or Lower Pleistocene age, its surface is a relict landform. So also are the land surfaces consisting of Chowilla Sand, and further E. of prior streams (dating >40,000 by radiocarbon). Younger relict surfaces are dunes in the Mallee with uppermost subsoils dating 16,000-18,000 years (the substrate is of course older than the soil on it), and the sediments of the ancestral streams further E. that are not buried by later deposits.

Thus the broad flat plain of the Murray Basin is largely a relict surface of varying ages because

(a) The river system is confined to a tract cut into this plain, and

(b) The dune systems are mostly dead, or just being re-modelled.

The relict nature of the surface is also indicated by the polygenetic soils. The ground is packed with carbonates, which will be discussed (including their chronology) in a later section.

Relict surfaces imply terrain stability, but at the present time the countryside is characterized by instability. Gulches in active erosion characterize river banks and the sides of Lake Victoria. Much of the surface of the dune system on the E. side of Lake Victoria is now mobile with extensive blowouts and sandfalls. The fence between Nulla and Talgarry Stations on the E. side of Lake Victoria overlies three others because of the build-up of sand. Blowouts among the saltbush are common and a great number of such bushes have piles of loose sand under them. During the drought, dust storms were common. The reconciliation of relict terrains with all this instability is that the latter has mostly occurred since European occupation (as will be discussed later).

Finally, this review of planar areas above the floodplains should refer to some bordering flatlands or remnants of them along the river channels. At Cal Lal (Fig. 4) one descends from the general plain to a flat area well above the floodplain (e.g. behind the police station). This flat area (obviously once more extensive) is due to differential erosion, as the area corresponds with the top of a silicified zone that is part of a paleosol. The same kind of surface at the same stratigraphic level occurs on the E. bank of Salt Creek, Kulcurna Station, for some distance.

On the W. side of Lake Victoria there are mesas and promontories that suggest a former surface below the level of the general plain. It may represent a stage in the excavation of the Lake Victoria basin.

Salt Lakes and Swamps

When rain falls on the flat plain of this country, much of it lies about in claypans or penetrates dunes and sandspreads where it constitutes a temporary aquifer, apparently made use of by the Aboriginals. In other places the water runs into hollows with no outlets and salt lakes develop. Such depressions are not uncommon, but their origin has not been investigated.

Salt lakes have been noted in two types of geomorphic situation, viz.:

(a) In depressions, e.g. on Dunedin Park Station E. of the road from Wentworth to Nulla Station; also on Pine Camp Station.

(b) In negative areas where drainage has been cut off, such as behind the dune system at Lake Victoria. A salt lake occurs E. of the dunes on Talgarry Station S. of the track to the pump at Lake Victoria. To bore this lake, follow changes in regime, and by radiocarbon date its time of origin and history was a project that had to be abandoned for lack of time. As the dune system is apparently within the range of radiocarbon, presumably the lake is also, since it was formed by the dune system blocking the drainage.

Fletcher Lake NE. of Wentworth (Mildura military map, 2 cm=5 km) has a high lunette on the E. side. There are many dry lakes such as Lake Wallawalla (Fig. 4). Lake Cullulleraine is a water storage.

Cane grass swamps are common in the floodplain of the river system, a typical example being one on Moorna Station we called Triple Swamp by reason of its trilobed shape as seen in the air photos (Wentworth Run 2, 1363-5231, 9·7·65, NE. of C.P.) Stratigraphic sections from the cliff behind this swamp are described later.

In the NE. part of Lake Victoria basin behind the dune system E. of the lake is a cane grass swamp. An auger hole was sunk about 20 m E. of the track that passes it, and traversed on 24th July, 1969:

0·0 –0·3 m	Reddish brown (Munsell 2·5 YR 5/4) clayey sand gradually merging to
0·3 –0·63m	Light brown (7·5 YR 6/4) sand with hard carbonate
0·63–2·13m	Light yellowish brown (10 YR 6/4) slightly clayey sand without carbonate. Moisture at 2m and so a little darker
2·13–2·59m	Mottles of light gray (5 YR 7/1). Becomes greenish gray (5BG 7/1) at 2·31m. Pyrolusite at 2·53m. Heavy at 2·61m.
2·59–3·07m	Very pale brown (10 YR 7/3) sand. Darker material included 2·74–3·04m.
3·07m +	Light gray mottles again. Salty water at 3·35m.

Claypans (small playas)

This term is widely used in Australia but, although related in meaning to "playa" (Chico 1968), is not its equivalent. The term playa is used in many senses, but in Australia is applied to a large dry lake (Jutson 1934), while "salina" or "salt lake" (e.g. Bettenay 1962) is employed if a salt crust is present. A claypan is a small flat unvegetated area, in an arid or semi-arid environment characterized by sheetflood deposition of fine sediments (usually red to pale brown). In the area studied claypans are commonly 20 to 30 m in diameter and tend to be round in shape. On Nulla Station some large claypans were joined up to form an air strip for light planes in fine weather.

By extension, the term claypan is used also in the study area for places of similar appearance to the above, which are in reality places stripped by wind erosion of the surficial sand to expose a flat hardpan of similar sand bound by clay skins. Such sediments do not effervesce on application of acid, and so the amount of carbonate is negligible. On such stripped zones Aboriginal implements and rock debris form a lag deposit; also lumps of baked clay that were used as cooking stones (to be discussed later). Claypans can form in dunelands by centripetal wash of the fine fraction which has either been blown up into the dunes as aggregates or deposited on them by aerial transport. Fossil claypans of this type occur in the dune system on the E. side of Lake Victoria. They are characterized by fine herringbone rills when exposed.

Two important features of the geomorphology remain for comment, but each is a major topic and so individual sections will be devoted to them, viz.:

(a) Dunes
(b) Lake Victoria.

Dunes

The semi-arid Murray Basin, with its extensive fluviatile sand sources and a wind regime with seasonal persistent westerlies (Fig. 8), is a natural setting for dunefields.

The Murray River at Echuca adopts a NW. trend which it maintains overall as far as S. Australia. This is also the orientation of the broad ridges that constitute the chief geomorphic feature of the Mallee in N. Victoria (Hills 1939, Thomas 1952, Lawrence 1966). Lakes and other surface features (and as a result the railways) are affected by this general trend, but it has no relation to the configuration of the bedrock below the Murray Basin sediments. Across this lineation are the E-W. longitudinal dunes of the surficial Woorinen Formation (Lawrence 1966, Fig. 8). In some places the dunes spill into lakes, proving their longitudinal character and direction of sand movement.

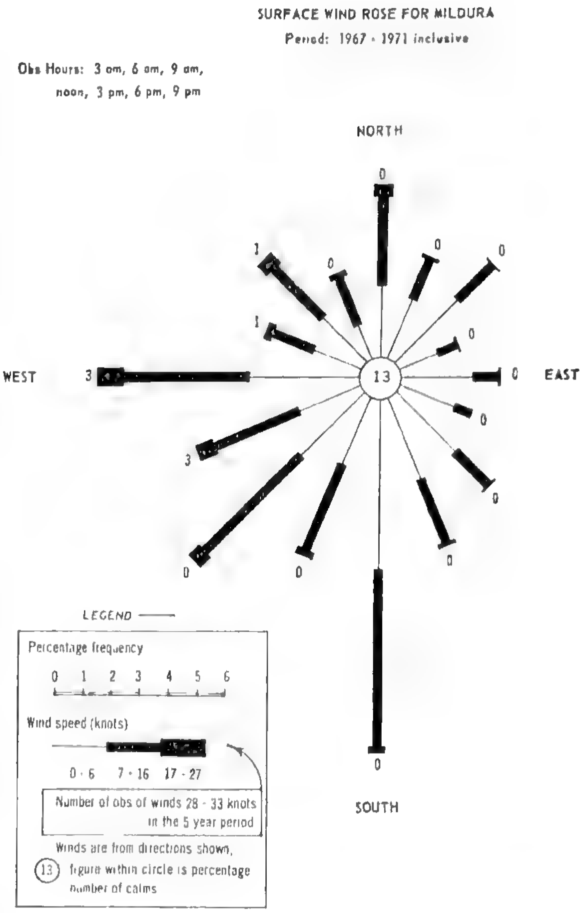


Fig. 8—Wind rose showing the predominant W. winds that determine the direction of the longitudinal dunes. Prepared by The Commonwealth Bureau of Meteorology.

Following the Murray river to the NW. from Echuca is a large very flat floodplain (of both present and past) consisting of very clayey sediments and without ridges. NW. of Benjeroop the flat plain ceases, and areas of red soil with hard carbonate nodules rise like islands above the gray sediments (e.g. near "Winlaton" homestead). It may be that the Leaghur Fault of Macumber (1969) at its north end swings round the N. margin of the Gredgwin Ridge to this area, and is partly responsible for this change in terrain.

The broad NW.-SE. Mallee ridges represent the interfluves of rivers once active, while the E-W. longitudinal dunes represent the drying up of the rivers and establishment of a desert. Thus Mabbutt (1968) remarks about Central Australia deserts—"As in most of the world's deserts, aeolian sand surfaces mark the retraction and disintegration of drainage systems and the abandonment to wind action of coarse-textured alluvia in former depositional environments".

The evidence of former rivers signifies more humid conditions (at least in the areas of origin), while the establishment of the dunes proves drier conditions. That the dune system is now inactive except for some of the more sandy crests, that they are almost completely vegetated, and that they commonly have a fairly deep soil developed on their surfaces, proves that conditions are less desertic than when the dunes were formed, i.e. the climate has been both more humid (rivers) and drier (desert) respectively.

The dunes are parallel, which is "characteristic of large open expanses of dunes where sand movement has been least complicated by relief or drainage" (Mabbutt 1968). The climax of dune building was when this system was active. Mabbutt and Sullivan (1968) discuss whether the dunes of the Simpson Desert are normal dunes or windrifts (swales formed by corrasion). They support the former view but perhaps these ideas should not be set in apposition, as at least some of the dunes in the Simpson Desert have cores of older material, as do some in the Mallee. As subsequent evidence will indicate, the Mallee ridges are polycyclic as observed by Hills (1939). Jennings (1968) notes that desert dunes cover 19 per cent of Australia. His map shows an Australia-wide response in dune trend to the continent's overall wind system. The directions of the dunes in our study fit the continental pattern of wind directions. It is likely that during the Last Glacial at certain times the Mallee with its active dunes was comparable to the present Simpson Desert. For more information on the Simpson Desert see Folk (1969, 1971) and Boyland (1971). Thus there has been a range of regimes from river country to dust bowl.

Like the savanna lands of other parts of the world, those in Australia reflect the climatic variations of past ages. They are marginal areas that more readily register climatic shifts. Thus Thomas (1971) says, "Thick duricrusts beside the River Niger near Niamey were formed under humid conditions in the Tertiary period: sand dunes are about 20,000 years old but are fixed". "Chad Basin in W. Africa provides evidence of former climates. During arid phase over 20,000 years ago, seif dunes trending NE. to SW. were formed. By 10,000 years ago wetter conditions had fed enlarged 'Mega-Chad' . . . . In the last 7,000 years the climate has come drier and Lake Chad has shrunk. Transverse dunes appeared during minor climatic changes".

Mallee Dunefield

Hills *et al.* (1966) state that "Longitudinal dunes are best developed where there is an abundant supply of sand, especially in large alluvial basins". The Mallee Dunefield of E-W. longitudinal dunes is a re-organisation of sand from the Diapur Sand, Chowilla Sand and such, during dry periods. The dunes exist because there was an adequate supply of sand to windward, and the aeolian traction was sufficient to move the sand, but not strong enough to cause only deflation (as on a gibber plain), leaving a lag deposit. The climate of the time was dry enough for the sand to be mobile, and for the vegetation to be depressed enough to prevent immobilization of the dunes. The dunefield is extensive even more so than is shown on the World Aeronautical Chart, or on the map in the Reader's Digest Complete Atlas of

Australia (1968). On the aerial photos, the dunes are very distinct and the crests appear sharp, but on the ground they appear rounded. This is of course a matter of scale. As the field has long been immobile, the crests cannot remain sharp as in an active dune system. The first two years of our observations were a time of drought, and this field was also observed by the writer during the severe 1945 drought. During the latter, the country was denuded of green herbage, and even the domestic geese flew round of an evening (usually they are too heavy). However, the dunefield was not reactivated. The crests in more sandy areas became mobile but the system as such remained inactive. The dunefield is thus definitely relict. However, we should think in terms of the natural conditions that existed in the Mallee before European occupation, because the latter has greatly increased sand movement. The western Mallee is less stable than the eastern part. Some idea of the Mallee in its original state can be obtained from early observers as recorded, for example, by Blandowski (1857), Bride (1898), Everard (n.d.), Hardy (1969), Hawdon (1852), Kenyon (1942), and Morton (1861).

1. *Swan Hill Paleosols*

Churchward (1961, 1963 a-c) studied these dunes and their soils in the Swan Hill area on the Murray River. As a pedologist he was concerned chiefly with the soil mantles, and his findings can be summarised thus:

SOIL MANTLE	LIME	CLAY	PEDALITY	PED FACES	COMPACTION
4. *KYALITE* (15,550 yr)	No mobilisation	No segregation	None	None	Soft granular structure with organic buildup
3. *SPEEWA* (24,000 yr)	At 35cm	Movement A to B	Weak	Low lustre clay skins	Firm
2. *BYAMUE* (29,750 yr)	At 120cm	Strong segregation	High	Thick glossy clay skins	Dense
1. *TOOLYBUCK* (Oldest)	None—becoming acid	Very strong segregation	Very high	Very glossy clay skins	Very dense

The dates provided have been published by the Australian National University in *Radiocarbon* vol. 12, and the laboratory numbers from youngest to oldest are ANU-183, 184, 185 respectively.

It is to be noted that with increasing age the soils are more mature, therefore one would expect each pedogenic phase to be successively longer. The increasing maturity of the soils is shown by the depth of carbonate leaching, the degree of clay segregation, the pedality, the amount of development of lustre on the ped faces and compaction status. Each of these factors involves time. However, the length of time between the dates for the Speewa and Kyalite soils is not less than that between the dates for the Byamue and Speewa soils, but 47 per cent more. No simple damped harmonic curve can therefore express the history on present evidence. The reason is that two unrelated factors are involved, viz. the accumulation of the substrate (dune building), and the modification of the substrate surface by pedogenic processes (soil formation). The former is an unstable phase of the terrain, and the latter a stable phase. Oscillation of these states is indicated by the successive dune deposits and soils. However, the diminishing intensity of soil formation raises the question as to whether widespread palaeoclimatic changes are involved or local variations. This can be checked by examining what has happened in other parts of of the dunefield. During the present Project, such checks were made. Multiple paleosols were found to characterize the dunefield. Two paleosols were the commonest, but three and sometimes four were also found. Sections at three widely spaced localities are given in the following paragraphs with radiocarbon datings of the soil carbonates. The reliability of such dates will be discussed in the section on palaeopedology, and the climatic phases in the section on palaeoclimatology.

2. *Ouyen Paleosols*

In 1939 Hills drew attention to evidence of this kind in the same dunefield N. of Ouyen at and near the 290 mile post. Carbonate layers on the Calder Highway (p. 315, Pl. 24, fig. 2) he interpreted correctly as paleosols and indicators of more humid periods during the time of dune building. On the same highway 1 km S. of the 283 milepost (about 3·2 km N. of Ouyen and 4·8 km S. of Kiamal), there is a site on the W. side of the highway about 90 m S. of a branch road on the E. side where I studied the roadcut shown in Figure 9. The section comprised:

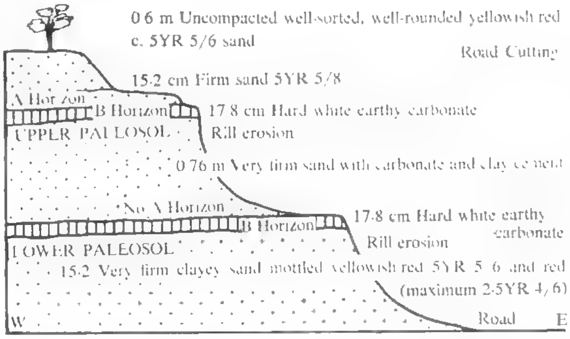


Fig. 9—Roadcut about 3·2 km N. of Ouyen, N. Victoria, on the Calder Highway, showing carbonate paleosols in E-W. dune (Woorinen Formation). Carbonate from the upper paleosol dated c. 16,400 yr B.P.

60cm	Uncompacted well-sorted well-rounded aeolian sand of variable colour but around yellowish-red 5 YR 5/6.
15cm	Yellowish-red 5 YR 5/8 firm sand
c.18cm	Hard white carbonate of earthy type (not solid crystalline) of variable thickness along the outcrop, grading into
69cm	Very firm clayey sand with some carbonate and clay cement, characterized by rill erosion.
c·15cm	White carbonate similar to the horizon above
90cm	Very firm clayey sand, mottled yellowish-red (5 YR 5/6) and red (to maximal 2·5 YR 4/6) with rill erosion.

The two carbonate layers are B horizons. The clay in the dune sands is interpreted as windblown dust washed in by rainwater (cf. Gill 1966, p. 556). Even at the present time much fine red dust is blown over the Dividing Range to S. Victoria (Chapman and Grayson 1903) and E. to the Snowy Mts. and beyond (Walker and Costin 1971).

From the upper carbonate layer a sample was collected, which yielded a radiocarbon date of $16{,}400\,{}^{+450}_{-560}$ yr B. P. (GaK-3218). This is comparable in age with the date of 15,550 yr at Swan Hill for the Kyalite soil. As soils take a good deal of time to develop, and are not perfectly synchronous over their range, such variations in age are to be expected. See also the discussion of carbonate dates in the section on palaeopedology.

3. *Hattah Paleosols*

On the E. side of the Calder Highway (79) between mileposts 309 and 310 (from Melbourne) there are extensive pits for the removal of carbonate soil nodules for road works. On the S. side of the entrance track, a roadcut sections an E-W. dune. As pits with nodules occur to the E. of the cutting on the axis of the dune, and no nodules are found in the dunes, it was surmised that the nodule bed underlies the dunes. To test this an auger hole was put down on the N. slope of the dune near the road and overlooking the access track. The section proved was:

20cm	Reddish yellow 5 YR 6/6 fine sand merging to
18cm	Light red 2·5 YR 6/6 fine sand merging to
63cm	Light red 2·5 YR 6/6 fine sand merging to
43cm	Fine sand with earthy carbonate as small firm lumps up to 0·6cm diameter. Colour lighter because of carbonate, on decrease of which 6/6 then 6/4 (light reddish brown) grading to
51cm	Reddish-yellow 5 YR 7/6 fine sand still with some carbonate. Slightly lighter at 170cm from surface. Carbonate disappeared at 196cm from surface. Merging over 13cm to
53cm	Reddish-yellow 5 YR 7/8 fine sand
13cm	Reddish yellow 7·5 YR 7/6 more clayey fine sand (colour and texture change, merging to
28cm	Pink 7·5 YR 7/4 fine sand with solid carbonate nodules which stopped the auger at 290cm.

This section is interpreted as follows:

Soil 1	0–1·01m	A horizon
	1·01–1·95m	B horizon with carbonate
Substrate	1·95–2·48m	Dune sand
Disconformity		
Soil 2	2·48–2·61 m	Remainder of A horizon of original terrain or top of B horizon.
	$2{\cdot}61$–$2{\cdot}90^{+}$m	B horizon of original terrain.

Nodules from the lowest part of the above auger hole (site approximately 142° 15′E, 34° 46′S) were radiocarbon dated by Dr. T. A.

Rafter, New Zealand Institute of Nuclear Sciences (Lab. no. R 2729/4) with the result of 27,500 ± 70 yr B.P. $\delta^{13}C$ w. r. t. PDB $= -3{\cdot}5\,^0/_{00}$. This is comparable with a dating of 27,800 obtained for similar material from N. of the River Murray (to be discussed later).

If my interpretation of the above section be correct, then this date is the maximal age for commencement of dune building at this site. Indeed, it is probably quite in excess of that time, because the date is an average of the many years required to grow such a nodule. For the purpose of this argument the C14 date is taken at its face value.

4. *Berribee Station Paleosols*

Berribee Station is situated in the far NW. corner of Victoria on the S. side of the Murray River. Two types of dunes occur there, viz. the E-W. longitudinal dunes of the Mallee Dunefield, and channel-bordering dunes of the Coonambidgal complex on anabranches of the Murray River. In the air photo constituting Plate 4, three oblique zones of different types of country can be readily discerned, viz.:

a. *Coonambidgal Country,* consisting of the present Murray River channel to the N., the anastomosing Lindsay River to the S., other anabranches and past channels, all with their respective floodplains.

b. *E-W. Dune Country* occupying the S-W. sector of the photo. Zones 1 and 2 meet in the NW. sector of the photo, where they are separated by a cliff.

c. *Relict Floodplain.* This intermediate zone in the middle and SE. sectors of the photo is above present river floodings but has apparently been subject to inundation in the past. One use is for crops (as can be seen in the photo) and is partly irrigated. From the photo it can be seen that the E-W. dunes penetrate it. This is obvious on the ground, as when the auger was sunk, it was considered to be in the zone of the dunes. It is thus an area of interdigitation of the dune-building and riverine processes. The site is marked on the air photo in Pl. 4, and is approximately 142°4′ E and 34°8′. It is about 2·6 km SSW. of the Berribee homestead (Mildura military map c. 408,785). The site is on the summit of an E-W. dune, and the auger penetrated:

38 cm	Red sand 10 R 4/6 (moist)
190 cm	Light red sand 2·5 YR 6/6 with earthy carbonate fraebules up to 1·3cm diameter but generally smaller. Most can be broken in the fingers. From 203-365cm from the surface there is a greater concentration of carbonates with fraebules up to 2·5cm in diameter. Carbonate zone 1.
36 cm	Red sand 2·5 YR 5/8. No carbonate present, hard lumps being due to cementation by clay, pyrolusite and such.
53 cm	Red sand 2·5 YR 5/6 with earthy carbonate sometimes forming fraebules that can be broken by the fingers. Carbonate zone 2.
132 cm	Red sand 2·5 YR 5/8 without carbonate. Lumpy as 36cm band above.
104 cm	Gray 5 YR 6/1 fine sandy clay with white earthy carbonate and pyrolusite. Carbonate zone 3.
13$^+$cm	Same matrix without carbonate.

This section is shown diagrammatically in Fig. 10 to visually communicate that more than half the profile is full of earthy carbonate. My interpretation of this section is:

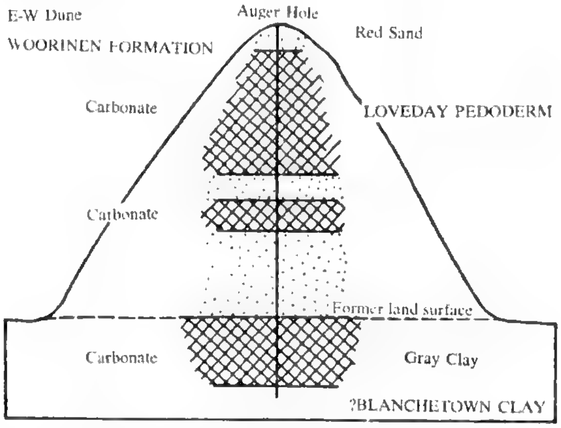


Fig. 10—Section of E-W dune c. 2·6 km SW of Berribee Station homestead, S. of the River Road, NW. Victoria (Pl. 4). Site 19.

Soil 1	0· 0–0·38 m	A horizon of pedocal
	0·38–2·28 m	B horizon
Soil 2	2·28–2·64 m	A horizon
	2·64–3·17 m	B horizon
Dune Sand	3·17–4·49 m	
Disconformity at base of dune		
Soil 3	4·49–5·53 m	B horizon of truncated soil profile on Pleistocene alluvial terrace
Alluvium	5·53–5·66$^+$m	Flood plain sediments.

Other interpretations are possible. The saturation of this section with carbonate requires explanation. There appears to be far too much to be derived from the sediments themselves. Not far away in S. Australia marine limestone and later carbonate rocks are exposed, which could have been a source of windblown carbonate dust that was transported by W. winds to the site. (cf. Chapman and Grayson 1903, Walker and Costin 1971, Glasby 1971).

Dr. T. A. Rafter also assayed these carbonates for radiocarbon content and calculated the following C14 ages:

Carbonate zone 1 14,200 ± 790 yr B.P.
δ^{13}C w.r.t. PDB = $3{\cdot}5\,^{0}/_{00}$
Carbonate zone 2 31,300 ± 1,200 yr. B.P.
δ^{13}C w.r.t. PDB = $-2{\cdot}1\,^{0}/_{00}$
Carbonate zone 3 Beyond C14 range
$1\sigma >$ 34,300 B.P.
$2\sigma >$ 28,800 B.P.
δ^{13}C w.r.t. PDB = $-3{\cdot}5\,^{0}/_{00}$

For logs of two other auger holes in this vicinity see section on sedimentology.

All the datings of the E-W. dunes are on carbonate of the same type, and deposited under the same conditions. Indeed much of it may have the same origin, blown in on the prevailing W. winds that built the dunes. It is reasonable therefore to directly compare these dates. Considering the variables in pedogenesis, the dates match well. They indicate at least three periods of terrain stability when soils formed:

3 ~ 16,000 yr. B.P.
2 ~ 28,000 yr. B.P.
1 > C14

After each phase of dune-building, the morphology was depressed by weathering and erosion, as is indicated by the near horizontal soils.

The dunes of the Mallee Dunefield belong to the Woorinen Formation, which will be discussed in the section on stratigraphy. Some grain size analyses of the sediments will also be reported later in the paper.

5. *Lowan Sands*

It has been mentioned that there is more surficial instability of the terrain in the W. of the Mallee Dunefield than in the E. This is due to the tongues of Lowan Sands (Lawrence 1966, Fig. 8) that cross the area like giant blowouts. The origin of these sands has been discussed by Hills (1939), Crocker (1946) and Lawrence (1966). Because of the low dynamics of the Murray River system the Parilla Sand, Chowilla Sand, Diapur Sandstone and other sand formations are all characterized by unusually fine grades that make them rather similar. It is therefore not easy to specify the formations that have provided the quartz sand for these dunes. These sands are polycyclic. The sand forming the dunes on the E. side of Lake Victoria was carried on site by river action, and bears the general character of the sands of this sedimentary basin. They are thus not typical dune sands, but finer than usual. Because polycyclic, they are well rounded and well sorted, thus contrasting with the dunes of the Simpson Desert (Folk 1971, p. 47) "but briefly removed from their poorly-sorted fluvial source material".

6. *Lindsay Island Dunes*

This island is the area between the Murray River and the anastomosing Lindsay River (an anabranch). It consists of Coonambidgal sediments, and comprises mainly the following types of deposit:

a. Greenish-gray to gray clayey sand flood plain deposit (red gum flats).
b. Well washed light brownish gray channel sands.
c. Channel-border dunes (with Murray pines) developed by aeolian action on the channel sands.

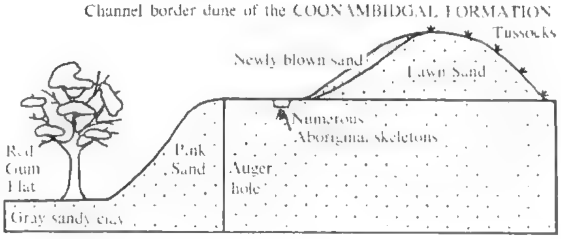


Fig. 11—Surveyed section of channel border dune oriented N-S. on Lindsay Island. Berribee Station, NW. Victoria.

The air photo constituting Plate 4 shows part of this area, and in particular the two-mile long N-S channel bordering dune which is part of site 19. Figure 11 is a section across this dune, and the logs of the auger holes there shown are as follow:

Auger 1	99cm	Light brown 7·5 YR 6/4 to light yellowish brown 10 YR 6/4 silica sand merging to
	38cm	Pale brown 10 YR 6/3 sand merging to
	137cm	Light yellowish brown 10 YR 6/5 sand
	282cm	Pale brown 10 YR 6/3 sand
	15cm	Compact mottled light gray 10 YR 7/1 and reddish-yellow 7·5 YR 6/6 clayey silt.

This profile is interpreted as:

0–5·56 m	Dune sand with little variation (oxidized).
5·56–5·71⁺m	Riverine Coonambidgal sediments (reduced).

Auger 2	10cm	Dusky red sand 2·5 YR 3/2 moist, merging to
	28cm	Reddish brown 5 YR 4/4 sand merging to
	53cm	Reddish yellow 7·5 YR 6/6 sand merging to
	41cm	Yellowish red 5 YR 5/6 sand merging to
	79cm	Light yellowish brown 10 YR 6/4 sand merging to
	107cm	Very pale brown 10 YR 7/3 sand
	58cm	Mottled clayey fine sand—light gray near 5 YR 7/1 and reddish yellow 7·5 YR 6/6. Occasional streaks are a stronger red. At 3·07m carbon present and iron oxide straight narrow markings that appear to be root sites.
	137cm	Similar sediments with changing percentage of fines and changing amount of mottling.

This profile is interpreted as:

0–3·71m	Oxidized aeolian sand with a thin juvenile soil.
3·71–5·36m	Gleyed riverine Coonambidgal sediments

Auger 3	10cm	Pinkish gray 7·5 YR 6/2 well sorted and well-washed sand.
	36cm	Light gray 10 YR 7/1 poorly sorted sand including grades heavier than in dunes
	33cm	Lighter gray N 7 sand, poorly sorted and with clay balls. Auger brought up half of one 3·8cm in diameter plus other pieces. Merging to
	8cm	Light brownish gray 2·5 YR 6/2 sand with a few streaks of light olive brown 2·5 YR 5/4.
	28cm	Offwhite (near N8) sand

The final 36 cm of the hole were difficult to drill as the sand was running so freely. The log is interpreted thus:

0– 10cm	Dune slope wash
10–175cm	Oxidized, mostly well-washed riverine sands less sorted than dune sand derived from them.

Grain size analyses have been carried out on some samples, and are reported later in this paper.

Cal Lal Dunefield

In the study area a distinct difference exists between the country N. of the Murray River and that S. of it, so that the course of the Murray may be a function of this difference, modified by the minor tectonics already described. The Mallee Dunefield to the S. is a complex of E-W. longitudinal dunes with pedocals of earthy carbonate. It is a sandy terrain. The area N. of the river is characterized by a substrate of impermeable green Blanchetown Clay with a complex pedocal containing solid crystalline calcite nodules. At first the terrain appears to be a typical sandy one, but closer examination shows that the sand is largely a veneer. The excavations for water "tanks" show this well, as also did our spade and auger holes. The air photos show that some areas N. of the river have well-developed dunes, and some have none, but overall an E-W. grain is present, developed undoubtedly by the persistent W. winds. Dunes N. of the river are best developed in the study area close to

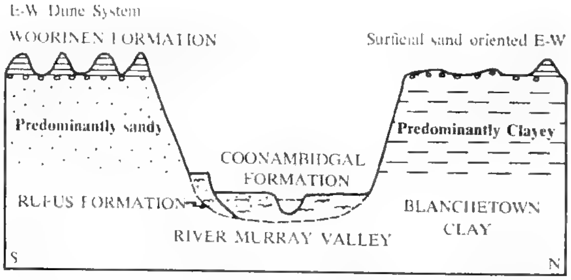


Fig. 12—Notional section of Mallee and Lake Victoria dunefields to show their different character due to different substrates. The river follows the interface. Thus farmers in the Mallee have difficulty retaining irrigation water, while N. of the river water tanks are dug directly into the surface.

Fig. 13—Map of Lake Victoria and environs showing features pertinent to this study. Based on Engineering and Water Supply Chowilla Dam map (S. Australian Government).

sources of sand e.g. E. of Lake Victoria. The difference between the country N. and S. of the river is fundamentally that the S. country has a sandy substrate (Diapur sandstone, Chowilla Sand and such) while the N. country has a clayey substrate.

It is to be expected that the river would find and follow the interface between the two (Fig. 12). In the short time available for this Project the idea could not be developed, but its clarification seems important for understanding the country and for the planning of irrigation, water conservation, groundwater utilization and such like.

Mt. Hancock Dune

Any eminence in a flat terrain appears important. From considerable distances one can see a large dune of mobile sand that has been given the name of Mt. Hancock. It surmounts the high cliffs on the E. side of Salt Creek near its confluence with the Murray River, and is approximately N. of Kulcurna Homestead. The structure is conspicuous because so elevated, isolated, and of light colour due to absence of vegetation. Its origin is a function of lateral differentiation and placement relative to prevailing winds. At this cliff site, the Blanchetown Clay cuts out, and the Chowilla Sand takes over a great part of the cliff section, as can be seen also on the right bank of the Murray River between Kulcurna Homestead and Salt Creek. As the Chowilla Sand is a well-washed sand, it breaks down to loose sand very readily except where it is affected by the paleosol that mobilised silica. The cliff below Mt. Hancock has thus a good supply of free sand, an adequate source of material for dune building. As the cliff is on the E. bank of Salt Creek, the prevailing W. winds supply the necessary traction. As W. of the creek is a very extensive lowland flood plain, the winds are able to exercise their full force.

Lake Victoria

"Beneath me lay a beautiful lake, about 30 or 40 miles in circumference, with a line of gum trees scattered along its edge . . . To this splendid lake of which I had the pleasure of being the first European discoverer I gave the name of Lake Victoria" (Hawdon 1852, pp. 42-3). Hawdon made his journey in 1838 and named the lake after Queen Victoria.

Shortly afterwards Sturt (1849, vol. 1: 94) gave this description—"Lake Victoria is a very pretty sheet of water, 24 miles in diameter, very shallow, and at times nearly dry. It is connected with the Murray by the Rufus, and by this distribution of its waters the floods of the Murray are prevented from being excessive".

It should be noted that there was some early confusion in nomenclature. For example Bonwick (1855) refers to Lake Victoria but his maps show two lakes of this name, viz. (1). What is now called Lake Alexandrina at the seaward terminus of the Murray River, and (2) Lake Victoria, between the River Darling and the S. Australian border.

"Among the unlicensed Murray squatters were Edward Meade Bagot . . . and George Melrose who came up the river in 1847 to occupy the bush frontages of Lake Victoria. The latter's shepherded flocks did so well that he would have liked to legalize his claim but this was impossible. Until the position of the border was fixed, he discovered, neither colony was in a position to grant a lease. The charms of Lake Victoria so attracted Melrose that he chose it to honeymoon with his Scottish bride, Euphemia—as the first white man's lubra to be seen in those parts she caused quite a stir amongst the Aboriginal tribes" (Hardy 1969, p 63). Melrose, tired of waiting for a lease, went elsewhere. The surveys were not completed until 1854. However, we have here a picture of a beautiful lake with vegetated banks when first visited.

The foregoing descriptions will again be relevant when present day erosion patterns are discussed.

Lake Victoria (Figs. 4, 13) is 13 km long and 10 km wide with an axis oriented a little W. of N. Under natural conditions only the S. end was full, a heavy flood being needed to cover the whole present lake bed. In the early days of settlement the Wentworth to Renmark road or track crossed the N. end of the lake bed as also did the telephone line. Lake Victoria

(Pl. 5) is now a reservoir. Waters held in the Menindee Lakes on the Darling River can be released down that stream and by control at Lock 8 diverted through Frenchmans Creek (bordered by artificial levees) into Lake Victoria. They are released through a regulator down the Rufus River and so into the Murray River again. Although 732 km by river from the sea, Lock 8 is only 25 m above sealevel.

Distinct from the existing Lake Victoria is the basin of which the present lake occupies only a part. This basin is sunk into the plateau of Blanchetown Clay and associated formations so that the level of the reservoir is 30-35 m below plateau level. The water is about 16 m maximum depth and an unknown depth of sediments lies below that, but these are shallow judging by the mode of genesis of the lake. The basin thus probably reaches a maximum of the order of 38 m below the general plateau level. (The present lake is pressed against the W. perimeter of the basin, which is scalloped by a series of erosion amphitheatres (Fig. 14) that are separated by promontories somewhat lower than the plateau level. On the E. shore of the lake is a large lunette, about 14 km long and up to 2·4 km wide. To the NE. of the lake is a large area approaching half the size of the lake consisting of lunette backed by swamps, claypans and relics of Rufus Formation. Separated by a promontory from this NE. area is one to the SE. which is of different character again, consisting of ancient Coonambidgal floodplain and channel sediments through which stand outliers of Rufus Formation. This area stretches SE. to Moorna Station and S. to Frenchmans Creek. Thus in the Lake Victoria basin there are four geomorphic elements:

1. The erosion amphitheatres on the W. perimeter.
2. The lake.
3. The NE. area with lunette, swamps, claypans and Rufus Formation outliers.
4. The SE. area composed of greenish grey Coonambidgal Formation sediments with higher red relics of Rufus Formation.

On a map the lake is seen to be a smooth-shored oval stretch of water but the basin in which it lies has no such character. The basin is about twice the area of the lake, but in view of its shape, it is not easy to decide where its S. boundary should be. The perimeter of the basin is irregular on the W. because scalloped, and in the E. has broad rounded sweeps. Any explanation of the genesis of the lake must account for these features.

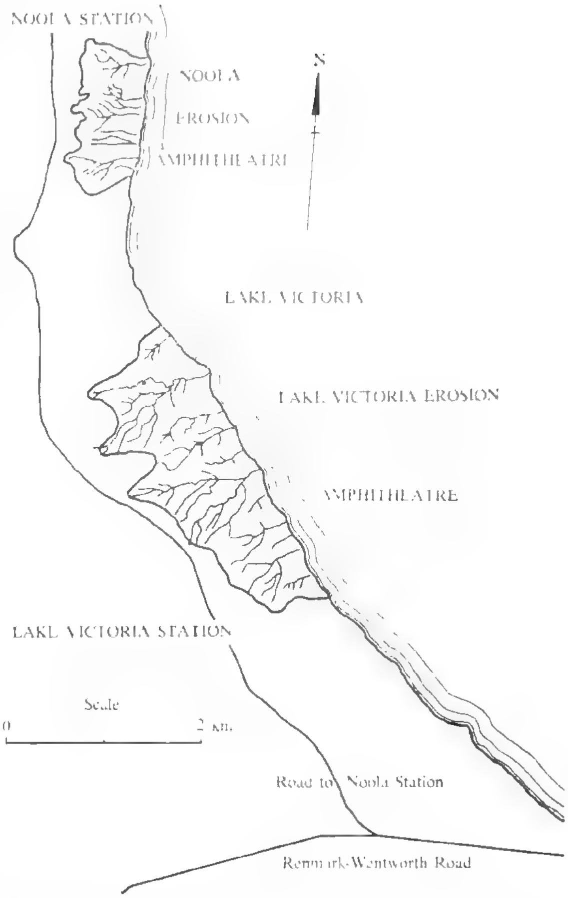


Fig. 14—Erosion amphitheatres on the W. shore of Lake Victoria, N.S.W. Based on air photos. Site 6.

Genesis of Lake Victoria

If the Lake Victoria basin is considered apart from the present lake and lunette, it is seen to be an area wide open to the S. It is not enclosed with a narrow outlet as is the present lake due to the encircling W. perimeter of the basin on one side and the lunette on the other. The axis of the basin is similar to that of the lake, i.e. deflected to the W. As the Blanchetown Clay and associated formations continue round the walls of the basin without appreciable change, the basin does not owe its presence to faulting. It is erosional, scoured by the ancestral Murray (or a large anabranch, or both) deflected NW. from the present course. It would appear that the stream left the present valley tract in the general area of Moorna Station homestead (Parish of Moorna) and ran more or less NW. through the Parishes of Utah and Wangumma to the Lake Victoria region. The Lake Victoria basin is thus regarded as a giant billabong and the scalloped margins are probably remnants of the Pleistocene meanders there. The time of formation was after the deposition of the Blanchetown Clay (Plio-Pleistocene) because, with associated deposits it forms the plateau. On the other hand, the basin was cut before the deposition of the red Rufus Formation because relics of this terrace occur in the main Murray River tract, in the open S. end of the basin (Dunedin Park Station) and in the more restricted NW. area of the basin behind the lunette. After the Rufus Formation was formed, some change in the river regime resulted in cessation of terrace-building, deeper scouring of the river tract, and then deposition of the Monoman and Coonambidgal Formations. This explanation of the Lake Victoria basin accounts for its stratigraphy and geomorphology. It also accounts for its W. trending axis. That the lake is pressed against the W. perimeter is consonant with this theory. Sand carried in by the river was blown up over many thousands of years by the persistent W. winds of the area to form the lunette on the E. side of Lake Victoria. Its position is a balancing of the water pressure against the W. perimeter and against the accumulating sand on the E. side. With the diminution of river flow into the basin, the lunette extended S. and cut off the water supply or forced the inlet channel S. so that water flowed only through the Frenchmans Cr. anabranch. Thus the present lake was established.

The genesis of the lake is far more complicated than this simplified account. The lunette had numerous alternating unstable (dune-building) and stable (soil-forming) phases. These can be divided into two periods represented by the Nulla Nulla and Talgarry Members of the Lake Victoria Sands which constitute the lunette (see section on stratigraphy). Some deep valleys were formed and a general depression of the dune morphology effected between emplacing the two Members. There was a marked change of fauna because large extinct marsupials characterize the Nulla Nulla Member while the modern fauna only occurs in the Talgarry Member.

The Lake Victoria lunette (for term see Hills 1940, discussed Gill 1964, p. 353, Campbell 1968, Macumber 1970) has an unusual morphology. More typical ones occur at Lake Wallawalla, S. of Lindsay Is. (Fig. 15), and Fletcher Lake, N. of Curlwaa.

The unusual character of the lunette lies in its great width and commonly horizontal bedding, which are related factors. Typical dune morphology from sand blowing up windward slopes, and spilling down lee slopes does occur, but more often the bedding is flat or near it. Similar structures occur in modern blowouts where sand is blown horizontally for great distances, then slides down a normal sandfall. It is therefore inferred that the supply of sand was inadequate in relation to the energy of the W. winds that provided the traction. Also as the sand was so fine, it was more easily moved. The periods of dune stabilization could therefore be due to:

1. Cut-off of sand supply (e.g. by change of river course),
2. Change in wind regime (considered unlikely) or
3. Increase in precipitation causing a stronger vegetative cover.

The factor yet to be explained in this theory of the genesis of Lake Victoria is what caused the river to divert to the NW. Attention is drawn to the large fault at depth below the E. side of Lake Victoria described in the section on tectonics. In this terrain of such exceptionally low declivities, a small movement on this fault could cause the river to be diverted. As the diversion occurred immediately after the

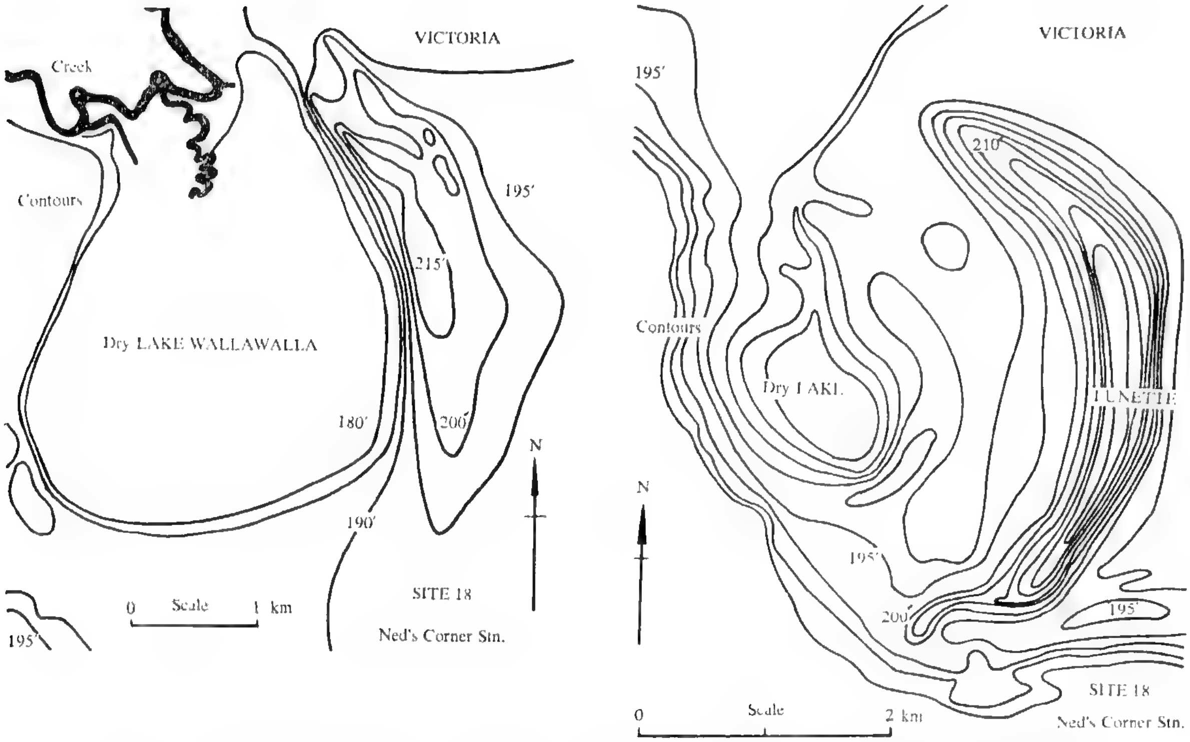


Fig. 15—Lake Wallawalla and an unnamed similar dry lake to the W. of it, both with lunettes. The age of these structures has not yet been determined. Based on Engineering and Water Supply Dept. (S.A.) Chowilla Dam map.

deposition of the Blanchetown Clay (i.e. just after the draining of Lake Bungunnia) a near horizontal lake-floor terrain would be present where the smallest tectonic disturbance would have a positive influence on the direction of river flow.

Lake Victoria Gulches

In this semi-arid country (22-25 cm rainfall) where rain seldom falls but may fall in quantity over a short period, a characteristic landform is the washout or gulch—short, steep and often deep valleys tending to vertical sides. It is comparable with the wadi of the Middle East, the arroyo of certain parts of North America, and such. The term "gully" is often used in Australia, but usually refers to an open, short valley in humid areas, where vertical sides are not usually found. Thus the term *gulch* has been chosen, and is used herein as defined above. Its derivation is from a Middle English word that meant to "swallow or devour greedily". Thus the Shorter Oxford Dictionary states that the word means "a narrow and deep ravine with steep sides marking the course of a torrent". Twice during our field work one third of the year's rainfall fell in one storm. Heavy rain in country of poor vegetative cover causes brief gushing torrents that rapidly corrade. This is particularly so since European settlement, which has often been accompanied by too heavy stocking. The first settlers came from a humid country, and did not understand this dry land.

Lunette Gulches

The most notable system of gulches in the area of study is that along the E. shore of Lake Victoria where the dune front has been severely eroded. These numerous gulches have provided important stratigraphic, pedologic, sedimentologic, archaeologic and palaeontologic data, and merit detailed study. Monash University Department of Zoology under Professor J. W.

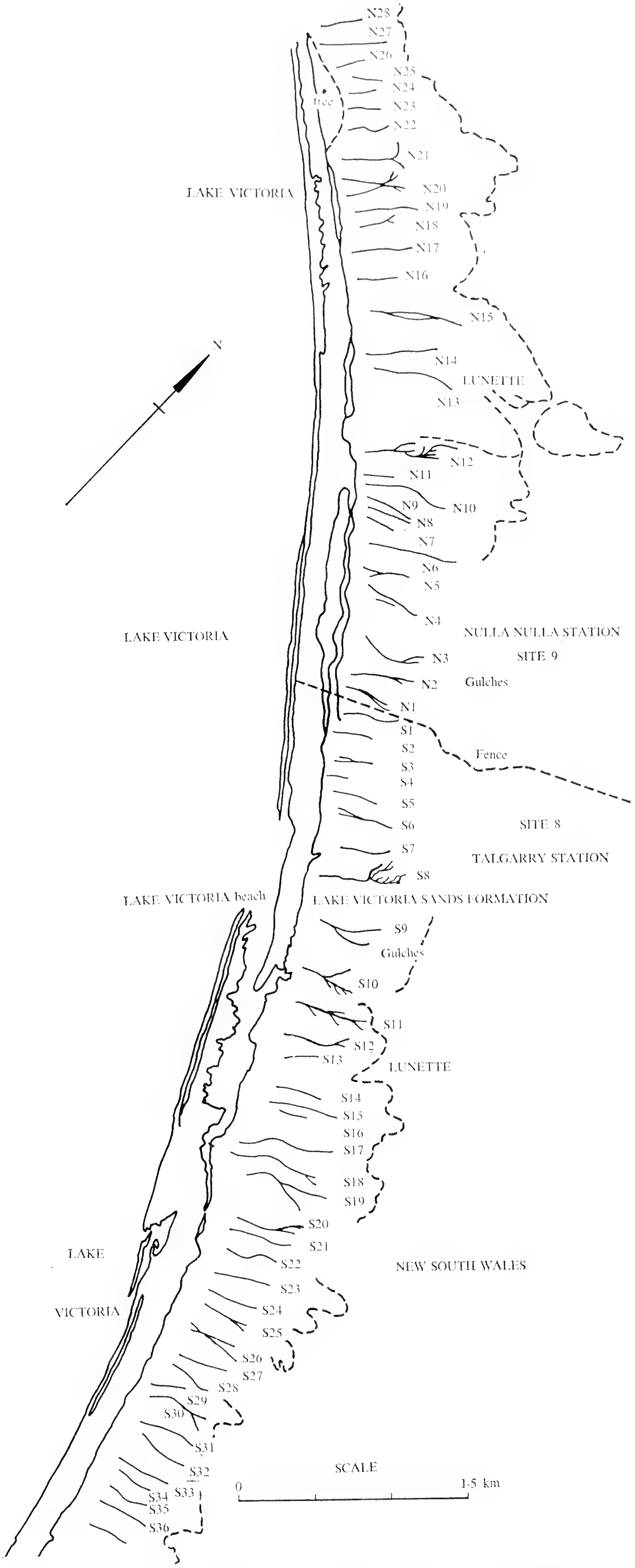


Fig. 16—Map prepared from air photos of the gulch system in the lunette on the E. side of Lake Victoria, N.S.W. Fixing of fossil and other sites was difficult, so the gulches have been numbered N. and S. of the Nulla/Talgarry fence, the only permanent marker. Numbered pegs have been set at the heads of most of the gulches. Four deep concrete bench marks were inserted for fixing levels. As the lunette structures are subhorizontal (on the whole), vertical levels have significance.

Warren is continuing the study of the vertebrate fossils from this and other localities. With recurrent gulches of similar morphology, changing somewhat from year to year, we found it rather difficult to record sites so that they could be located again with speed and accuracy. It was therefore decided to number the gulches. As the only permanent mapped feature is the boundary fence between Nulla and Talgarry Stations, the gulches were numbered N. and S. of this line with appropriate N. or S. prefixes (Fig. 16). Over most of the lunette, square hardwood pegs 1·2 m long and with sides 5 cm wide were inserted at the gulch heads and the relevant number drilled by a series of holes into the leeward side. After two years they show no sign of deterioration. Four concrete benchmarks were also emplaced, and surveyed on to Chowilla Dam Survey pegs so that levels can be related to Murray River and sea level datums.

The morphology of the lake front is a wedge of sand blown up from the lake beach, modified by fans of outwash sand from the gulches. The morphology of the gulches varies. The ephemeral streams corrade steeply, tending to develop vertical walls. Wind erosion cuts deep blowouts with steep sides. This geometry is modified by rainwash, aeolian action and the activities of sheep, goats, rabbits and man. The reduced stability since settlement has made the area rather barren in contrast with the natural condition described by the discoverers. The hamada of outwash fans along the lunette above the beach appears to be recent. The sand slope was measured at 7°. About the middle of the E. shore (air photo CAC 37-5012 Lake Victoria run 5, 1954, 23 mm S. of E-W. line through CP) an auger hole was sunk 10 m from the water's edge on 25th Nov. 1969.

0·3 m Very pale brown 10 YR 7/3 (dry medium loose sand very poorly sorted, grading to
0·45 m Brown 7·5 YR 5/4 (moist) ditto grading to
0·6 m Damp ditto grading to
0·45^{+}m Dark brown 7·5 YR 3/2 (wet) ditto.

The sand was uncompacted and water from the lake penetrated to the bore hole making further boring impossible with an auger. It was hoped to reach a carbonaceous former lake bed deposit that could be dated by radiocarbon.

(b) *West Bank Gulches*

The lunette gulches are mostly single channels (Fig. 16), 65% being so classifiable. Another 24% are simply branched, while the remaining 11% have multiple branches. It is a matter of interpretation which gulches go into which category, but these figures are of the correct order, and indicate a simple pattern of gulch formation. The erosion pattern on the W. bank is quite distinct, and the difference is a function of substrate. The lunette gulches are in fine sand with some clay, while the W. bank ones are eroded mostly in Blanchetown Clay and Chowilla Sand. From plateau level there is a steep slope from 10° to 30° then a lower slope to the lake edge.

Fig. 14 shows a tracing from air photos of these amphitheatres and the dendritic pattern of the gulches. Fig. 13 also shows a similar development on the N. bank of the lake W. of the "Old Hotel" (the site of an hotel belonging to the coaching days when this was a stopping place between Wentworth and Renmark).

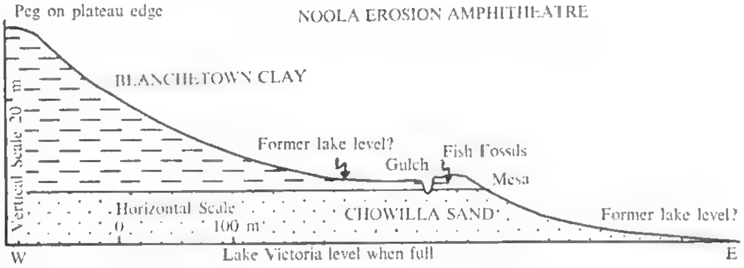


Fig. 17—Surveyed section of the Noola Erosion Amphitheatre, NW. shore of Lake Victoria, N.S.W. Site 6.

(c) *River System Gulches*

Gulches occur along the river banks (Murray, Darling and Anabranch), round some billabongs, and along creeks, such as Salt Creek and Six Mile Creek. Some of the best developed are on the E. side of Salt Creek on Kulcurna Station. One had such bright oxidation colours that we called it Kaleidoscope Gulch. One gulch N. of this was characterized by a cirque-like head. In this area, the silicified Chowilla Sand forms a lower plateau level as at Cal Lal. This zone is resistant to erosion so deeper gulches with steeper sides result. Pieces of the silicified sand block the gulch floor in places. This rock contains rhizomorphs up to 5 cm diameter. The indurated zone forms a shallow syncline, which causes variation in the depth of the gulches.

Gulches round Triple Swamp have yielded dolomite, fossil bones and Aboriginal sites as well as extensive stratigraphic information as recorded later in this paper. Much of the information discovered is due to the development of this feature. As every heavy rain gouges them out a little more, fresh sections are always available.

Stratigraphy

> *Geologists "first tracked mud and heresy into the schools of learning 200 years ago"*. Fuller (1971)

1. *Standard section*

In connection with the proposed Chowilla Dam, bores were sunk across the Murray River valley at a site between Renmark, S.A., and the Victorian border (Figs. 1, 4). J. B. Firman studied the geology and prepared a report which has not been released. However, a summary of the stratigraphy has been published (Firman 1966, 1967). Firman kindly provided a copy of his cross-section (Reproduced in Fig. 18) and this well-attested profile is here used as a standard section. For the present purpose, the following are noted:

(a) *Superposition*

The succession is simple, so the relative ages are clear.

(b) *Tectonism*

After the Parilla Sand was deposited, earth movements belonging to the Kosciusko Epoch caused uplift of the Pinnaroo Block (=Murray Ridge of earlier writers), damming the Tertiary river drainage, and so causing deposition of the Blanchetown Clay. Later, penetration of this natural barrage led to downcutting and excavation of the broad (4·8 km) gorge (so called because of depth and steep to vertical banks) into the Blanchetown Clay, Chowilla Sand, Parilla Sand, and Loxton Sands.

A disconformity thus exists between the Tertiary Loxton Sands and the Late Quaternary Monoman and Coonambidgal Formations.

(c) *Palaeoecology*

The Murray Basin has a succession of Tertiary marine strata (Fig. 3), the latest of which in our study area is the Bookpurnong Formation, which was also encountered in a well excavation (Tate 1899) on Tareena Station (Fig. 4), and in all the oil bores (Fig. 3). The succession of facies with time (i.e. upwards through the section) portrays the retreat of the sea from the Murray Basin, viz:

Parilla Sand (clayey)	Riverine floodplain
Chowilla Sand (well washed)	Riverine channel
Blanchetown Clay	Lacustrine
Loxton Sand	Estuarine
Bookpurnong Formation	Marine (shallow water)
Pata Limestone	Marine (shelf)

With this principle of facial succession established, one would expect to find a similar succession throughout our limited area of study, and this appears to be so. The A.O.G. Wentworth No. 1 Bore (40 km N. of that town) revealed Loxton Sands or equivalent at 52·5-80·5 m and Bookpurnong Formation below that to 109·1 m.

The A. O. G. Lake Victoria No. 1 Bore (at the S. end of the lake) penetrated "typical" Bookpurnong Formation from 93·9-113·4 m "with a rich microfauna". Above this are "pyritic sands with carbonized wood fragments and fish bones", which might be estuarine and the equivalent of the Loxton Sands. They are similar to the sediments in the Wentworth Bore at that stratigraphic level. The A. O. G. North Renmark No. 1 Bore (about 8 km N. of that town, near the corner of the Ral Ral Ave. and the Wentworth Road) encountered Loxton Sands from 18·3-42·7 m. Bookpurnong sediments were reported from 42·7-61 m. Thus in all three bores the Bookpurnong Formation is adequately defined but the Loxton Sands are proven only in the Renmark Bore. Even there, definitive fossils (small foraminifera, echinoid spines and molluscan fragments) occur only in the lowest 3 m. So perhaps the sediments in the other bores are riverine equivalents of the estuarine Loxton Sands.

(d) *Structure*

The strata (including the non-marine) in the standard section are superposed in a regular manner with subparallel surfaces. This regularity does not continue in the non-marine formations of the study area to the east. For example, the Chowilla Sand does not maintain the fixed stratigraphic position it possesses on the Pinnaroo Block. On the contrary, it appears below the Blanchetown Clay, within it, or above it, or any combination of those. Thus E. of the Pinnaroo Block it is a facies indicator, and no longer a stratigraphic marker.

Structure E. of the Chowilla Dam site can be defined by the highest indubitably determined stratigraphic horizon in the A.O.G. section (Fig. 3), viz. the base of the Bookpurnong Formation. Adjusting the levels to the sealevel datum, the results are:

Renmark Bore	37·4 m
Lake Victoria Bore	83·7 m
Wentworth Bore	69·5 m

In compensation for the uplift of the Pinnaroo Block, the strata to the east sagged, and the resultant structure is here called the *Lake Victoria Syncline*. As this syncline was due to upthrust of the crustal block to the W., the mild fold is understandably asymmetric with a lower dip on the E. flank. The openness of this syncline is in keeping with the minitectonics (for term see Gill 1972) of the area. The Lake Victoria syncline explains why:

I. The Parilla Sand, although a well characterised formation disappears below river level east of Kulcurna Station. As far as I have been able to check the stratigraphy, it does not reappear until the Paringi area 29 km SE. of Mildura.

II. The characteristic interdigitation of the formations upstream from the dam site, i.e. within the syncline. The Pinnaroo Block constituted a natural dam, and created a temporary or structural base level (Chorley and Beckinsale 1968). However, the gross interdigitation means that the lake so formed was not one large sheet of water that persisted over the whole area throughout the period of impedence to river flow, but rather a fluctuating series of lakes and swamps across which river channels kept changing. The high evaporation no doubt had much to do with this. Widespread beds of dolomite developed at one time, and in some areas these were eroded before deposition continued, while in others the very fine dolomite was mixed with sand. As would be expected, the most continuous lacustrine conditions prevailed near the damming Pinnaroo Block. Thus the thickest sequence of Blanchetown Clay can be seen along the Murray River at Lake Victoria (Warrakoo) and Nampoo Stations (Fig. 4).

2. *Regional Formations*

The formations consist almost entirely of low dynamics sediments, comprising clays to fine sands. This applies to both the aeolian and riverine formations, because the former are derived from the latter. The coarse fractions of the originating streams are trapped in the E. side of the Murray Basin because the traction was not available in this flat country to bring them further W. Significant in the stratigraphy therefore are:

(a) The presence of any gravels, as they are so rare.

(b) The change from sand to clay, and vice versa.

(c) The change from clayey sand (floodplain) to well-washed sand (channel) deposits.

(d) The presence of dolomite and limestone, because they indicate special sedimentary conditions.

(e) The presence of paleosols because they indicate a cessation of sedimentation, a time-break, and an absence of water or other such cover. They indicate also a period of stability, and the extent to which the subaerial agencies could leach (and otherwise alter) the surface of the terrain. The nature of the minerals removed or mobilised indicates the prevailing geochemical conditions, which have implications with respect to the vegetative cover and fauna.

The paleosols are described in an accompanying paper on palaeopedology.

The formations will now be briefly described from oldest to youngest.

(a) *Bookpurnong Formation* (Figs. 3, 18). This is the youngest of the marine formations; it extends throughout the studied area. It is therefore used as a stratigraphic and chronologic datum. Questions of chronology will be dealt with in the section on that subject. Although it does not outcrop at the surface it was

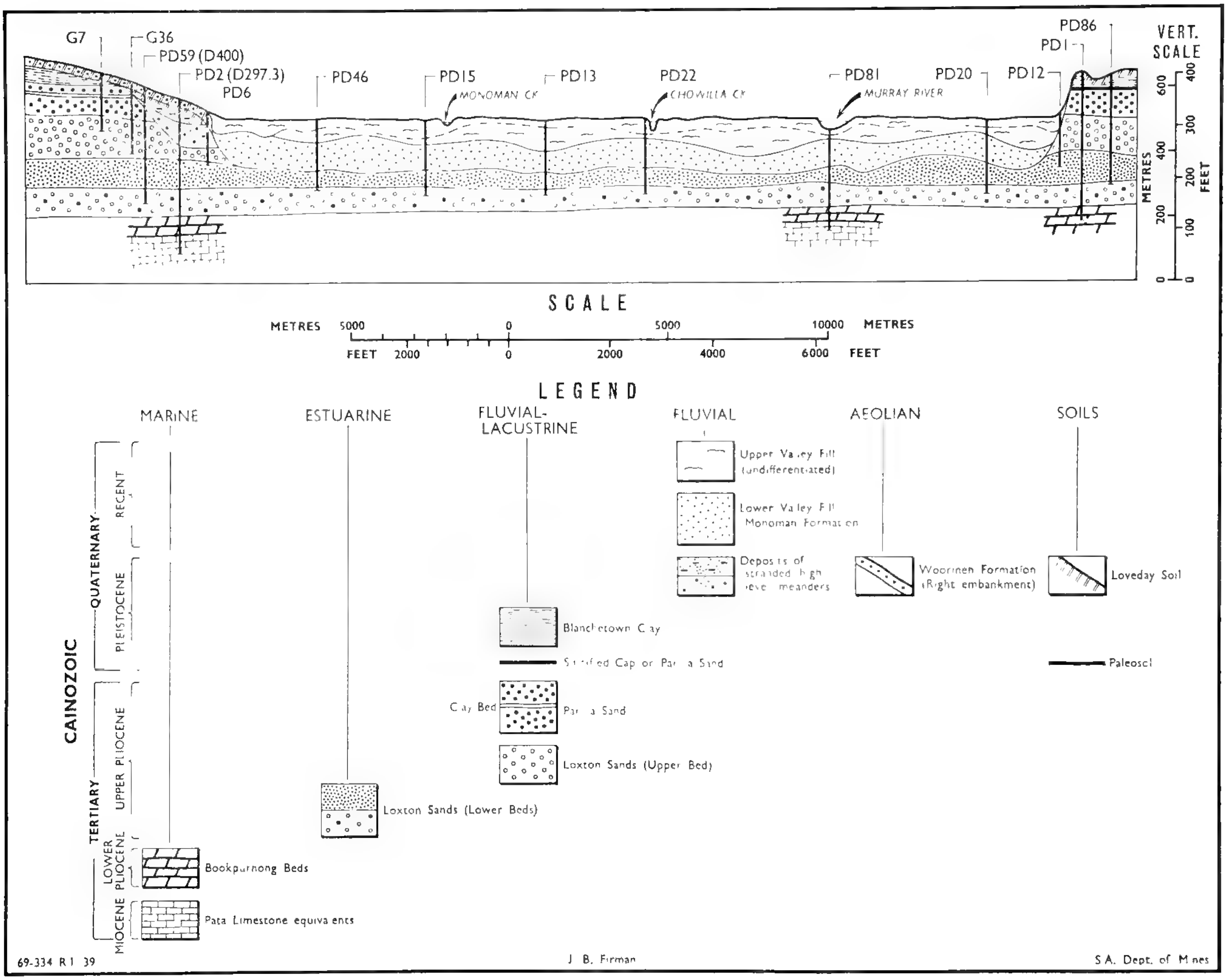


Fig. 18—Standard stratigraphic section at the proposed Chowilla Dam site, by courtesy of the S.A. Dept. Mines. Site 1.

encountered in a well on Tareena Station and can be followed in the three A.O.G. bores. For lithology and palaeontology see Ludbrook et al. 1958, Ludbrook 1961, 1969, Firman 1966, 1967.

(b) *Loxton Sands* (Figs. 3, 18). This formation of fossiliferous estuarine sands forms the cliffs at Loxton, S.A., is present at the base of the Chowilla Dam section (Fig. 18), occurs in the Renmark bore (Fig. 3), but appears to grade into a riverine facies further E.

The succeeding formations occur in the Lake Victoria syncline in river and lake bank outcrops:

(c) *Parilla Sand* (Figs. 4, 18-20). The gray compact clayey sand, with a vertical cleavage is very consistent and easily recognized. Where cliffs are undercut in river or gulch it forms vertical faces, and where not it forms steep rilled slopes. The section on the right bank of the River Murray at Kulcurna Station just downstream from the homestead is unusual in that it consists of only two formations—Parilla Sand surmounted by Chowilla Sand (Fig. 19). A similar thickness occurs on the S. bank of the River Murray at Boundary Point (Victoria/SA. boundary). The cliff was measured nearest the homestead where it is lower but more accessible, viz.:

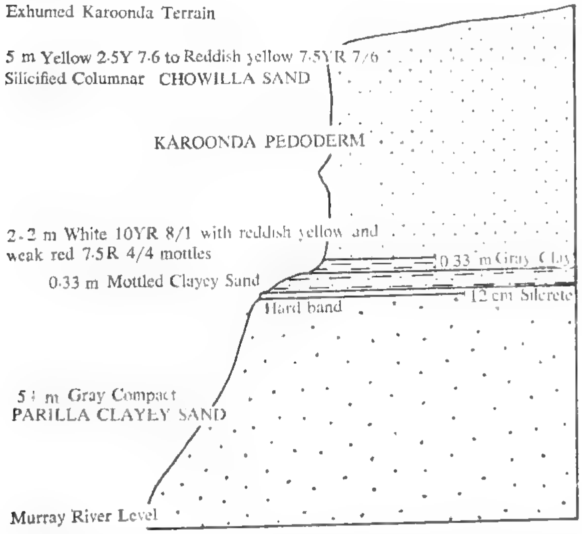


Fig. 19—Measured section of cliffs beside Kulcurna Station homestead, Cal Lal, N.S.W. Right bank of Murray River. Site 3.

5m	Yellow (2·5 YR 7/6, and variants) to reddish yellow (7·5 YR 7/6) lightly silicified columnar sandstone forming vertical cliff Chowilla Sand
2·2m	Mostly white (10 YR 8/1) silicified sandstone with reddish yellow and weak red (7·5 R 4/4) mottles; rhizomorphs, and silicified burrows. The top of this bed is more silicified than elsewhere, and forms the upper hard band seen in the cliffs. Similar horizons occur at Salt Cr. and the Chowilla Dam site—Chowilla Sand.
0·33m	Black to gray clay. Causes change in cliff slope. Recognizable on inaccessible faces of the cliff by course cracking. Minute crystals of gypsum on some joint planes
0·33m	Mottled gray, light brown and red clayey sand with fine cracking.
0·15m	Platey silcrete in one to six layers. Material suitable in places for Aboriginal implements. This forms the lower hard layer seen round the cliffs
5 + m	Compact gray (10 YR 5/1) clayey sand—Parilla Sand.
13·01m	

The thick lightly silicified columnar sand reminded the author of a similar deposit above kaolin in the Home Rule pit near Gulgong, N.S.W. The white sand at the base of the Chowilla Sand varies in thickness. The formation is an aquifer while the underlying Parilla clayey sand is an aquiclude, so the whiteness may be a function of leaching along the base of the aquifer. There is a sharp boundary to the underlying clay, so the ancient river spread sand over a lagoon or swamp. The clayey sands are interpreted as a floodplain deposit and the well-washed sands above as a channel deposit. The clean sands readily admitted air, and so are oxidized.

The degree of silicification varies greatly. It is less near the mouth of Salt Creek so that loose sand has blown up to form the eminence called Mt. Hancock. At the N. end of the Salt Creek cliff is silcrete, that when free to vibrate rings like a bell if struck.

At the outlet of Salt Creek and for a short distance upstream the section is essentially as above. Then the Blanchetown Clay comes in, and a measured section marked by a peg at the S. end of Scrub Paddock is as shown in Fig. 20, viz:

4·1m	Red Bunyip (?) Sand
2·1m	Red and yellow silicified Chowilla Sand
1·2m	White ditto

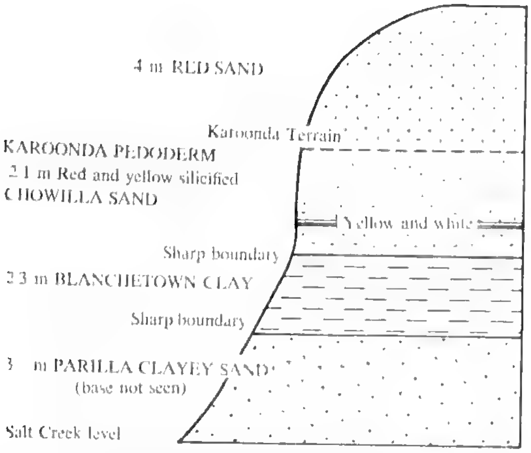


Fig. 20—Measured section on E. bank of Salt Creek, Kulcurna Station, N.S.W., at the S. end of Scrub Paddock. Site 2.

2·3m Green Blanchetown Clay
3·0m + Gray compacted clayey Parilla Sand 8·3m to creek level covered by talus

Firman (1966, 1967a,b, 1971) gives the Parilla Sand as the equivalent, at least in part, of the marine Norwest Bend Formation. The 1972 S.A. Department of Mines map of surficial deposits in the Murray Basin shows a succession of ecologies in the formations as they appear from W. to E. on the Murray River from Morgan to the Victorian border, viz.:
Morgan Limestone (marine shelf)—Loxton Sands (Estuarine)—Parilla Sand (Riverine)—Blanchetown Clay (lacustrine).

The formations are thus younger from W. to E., and pass from marine to terrestrial from W. to E. In the study area the Parilla Sand is overlain (with a sharp break) by either Blanchetown Clay or Chowilla Sand. In some places there is evidence of slight erosion on the top of the Parilla Sand, but in general the top of the formation is remarkably horizontal.

The Murray River cliffs between Paringa and Loxton, S.A., show excellent outcrops of Parilla Sand. For example, where the Sturt Highway meets the cliffs 2·4 km NW. of the Loxton turnoff (12 km from Renmark) near a parking bay, the Parilla Sand constitutes approximately the lower half of the cliff (Pl. 2 fig. 1, Pl. 6, fig. 1). The Parilla Sand can be seen to continue for some kilometres along the cliffs, but it cuts out E. of Salt Cr. (Kulcurna Stn.). Pl. 8, fig. 2 shows the occurrence there with its typical vertical cleavage and rills.

Parilla Sand (Fig. 18) is the main cliff outcrop on both banks of the Murray River at the Chowilla Dam site (Pl. 2, fig. 2). The top of the formation is marked by a bench consisting of the silicified materials of a paleosol (see paper on palaeopedology). The top of this fossil soil is the Karoonda Surface (Firman 1967) or Terrain.

The formation is named after the town of Parilla in S. Australia (Firman 1971 and references). Firman (1971, p. 62) claimed that the Parilla Sand could be traced "as far upstream as Nyah in Victoria". In this *Memoir* Parilla Sand is retained in its original definition, and the very varied sediments lying immediately below the Blanchetown Clay (except Chowilla Sand) in the Lake Victoria Syncline are described as the Moorna Formation. Parilla Sand probably occurs below this. The uplift of the Pinnaroo Block occurred in post-Parilla time, and earlier than the deposition of the Blanchetown Clay.

(d) *Blanchetown Clay*. Firman (1965, 1971) provides the origin of this stratigraphic name and maps the extent of the formation in S. Australia. The type section is on the left bank of the Murray River 4·8 km below Blanchetown in S. Australia. The formation is distributed "North and east of the Pinnaroo Block" (Firman 1971, p. 54). It may be described as the most characteristic formation of the study area. On present knowledge, the thickest outcrops are in the River Murray cliffs on Warrakoo and Nampoo Stations and on the banks of Lake Victoria, i.e. in the Lake Victoria syncline. The formation thins out to the east (Fig. 36) but continues at least as far as Robinvale, where Blanchetown Clay outcrops in the river cliffs. The lithology is typically a greenish gray claystone to siltstone. A. J. Gaskin, C.S.I.R.O., suggested that the green colour is due to ferrous iron in the lattice. As may be expected, the clays grade in places to sandy phases. See Segnit, this *Memoir*.

Figure 21 is a measured section E. of Nampoo Station homestead on the W. side of a track down the cliff to river level. At this

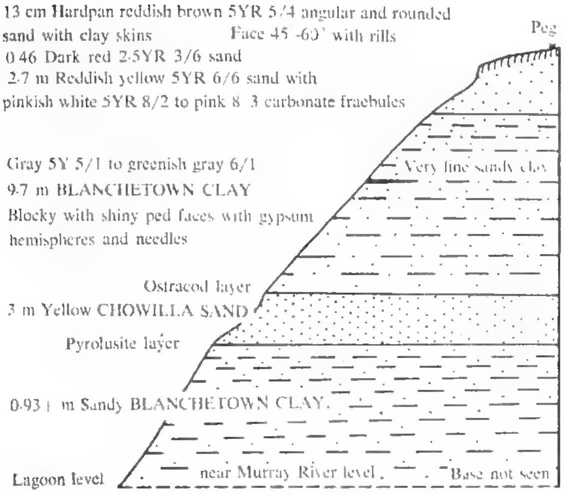


Fig.21—Measured section of cliff on the E. side of Nampoo Station homestead beside track to river level. Site 4.

point the section is about 22 m thick, but W. of the homestead the cliffs are 36·6 m high and the surficial reddish horizon is 6·4 m thick where measured. This consists of reddish brown and greenish mottled clayey sand with thick calcrete-bearing soil at the top. These sediments are interpreted as altered Blanchetown Clay. Whether the Blanchetown Clay continues below the river level is not known. For the present the whole Nampoo section at Sharp Point 36·6 m thick, is referred to the Blanchetown Clay. The dolomite members in it will be discussed later. There are intercalated bands of sand and clayey sand. The lowest bed could be Moorna Formation.

The top of the section near the track was examined in more detail, and the following information obtained:

12·7cm	Reddish-brown (5 YR 5/4) angular and rounded sand with fine clay skins forming a hardpan (Al horizon removed by erosion). The hardpan tends to form verticle edges on the cliff and is columnar. Penetrometer 0·2 kg/sq cm merging rapidly to
46cm	Dark red similar sand (2·5 YR 3/6), blocky and forming a slope of 45°-60° with rills. Penetrometer varied round 1kg/sq cm
2·7m	Reddish yellow (5 YR 6/6 but varying with amount of carbonate and faint mottling) sand. Numerous carbonate nodules, pinkish white (5 YR 8/2) to pink (8/3). Boundary distinct
9·7m	Gray (5 YR 5/1) to greenish gray (5GY 6/1) claystone, blocky with shiny ped faces (secondary clay). Gypsum crystals in form of hemispheres and needles (Blanchetown Clay)

Slip material covers the rest of this section, but W. of it 60 cm of Chowilla Sand (Pl. 7, fig. 2) underlies Blanchetown Clay (Pl. 7, fig. 1) with a thin ostracod layer at the base of the latter. Below the Chowilla Sand is 2·5 m of clayey sand, the top of which has undergone varying degrees of silicification, interpreted as a function of the Karoonda surface pedogenesis. The maximum is a hard band nearly a metre thick that stands out firmly on the cliff profile. E. of the homestead the ground surface slopes down to near river level where a gulch cuts the cliff. Here a thick silicified layer has been quarried. In the gulch a 12 cm band above the sandy layer is crowded with ostracods. Determinations of fossils are given in the section on palaeontology.

Roberts (1968) has provided information on this formation gained by drilling in the Waikerie district, S.A. He suggests that the Blanchetown Clay was once over 24 m thick there, but has since been eroded. The Bungunnia Limestone occurs capping the Clay on two of the three hills of clay buried under aeolian sand, but it also occurs in one of the low areas. Thus either the limestone is not one stratum laid horizontally, or it has been faulted (which seems unlikely).

The Blanchetown Clay is sparsely fossiliferous. At Warrakoo (Lake Victoria) Station (Fig. 4) NE. of the homestead, the high steep cliffs have two harder bands in this formation near the top. They consist of siltstone and where laminated contain in places soft plants with simple branching, which are apparently water plants. Ostracods are the commonest fossils, usually crowding bands 5-15 cm thick. Generally, these layers are at the base of the clay deposit following a sharp boundary from sand, suggesting shallow waters. However, they also occur in lenticles in the mass of the formation. When examining the thick exposure of Blanchetown Clay on the N. bank of the Murray River at Sharp Point W. of the Nampoo Station homestead, I saw what appeared like pieces of tissue paper. Examination under a lens showed that they were a layer of ostracods one shell thick. The layer was then found in place.

Mollusca have been found only in a brown sandy clay at the N. end of the large erosion amphitheatre on Noola Station (Fig. 14). On the N. wall of the N. gulch complex thousands of small *Corbicula* occur with all sizes from young to adult. The bed outcrops in three gulches and the separating interfluves over an area approximately 60 m by 30 m. The valves are rarely together and are poorly oriented. They are reminiscent of the banks of similar shells found now on the floor of Lake Menindee (on the Darling River system, used as a reservoir) when it is dry. A similar lens was seen further S. in the same erosion amphitheatre on Noola Station.

Fish spines, vertebrae and other fragments were found in the same area in the Blanchetown Clay and in sandy bands included therein. Oblique burrows about 0·3 cm diameter were noted in the latter. At Bone Gulch on Moorna Station bones of a large marsupial were discovered in the base of the Blanchetown Clay.

At Triple Swamp (Fig. 22) on Moorna Station is a gulch with beds of dolomite to be described later in this section. On the E. side of Triple Swamp gulch are two beds of dolomite in Blanchetown Clay, as shown in Fig. 23. The cliff is almost vertical and the face between the two dolomite beds slightly concave. A pebble of milky quartz about 18 mm by 8 mm was found in the position indicated in Fig. 23. (See also Pl. 8, fig. 1). It is very well rounded and has a slight polish. Also it is completely out of character with its enclosing matrix which is clay, the sediment of the lowest dynamics of all. The pebble was indubitably in situ. The narrow end was protruding, it was more than half buried, and had to be dug out of the hard clay. A fine layer of secondary minerals lined the cavity from which it was taken. For example, pyrolusite was on the wall of the cavity and in corresponding places on the pebble. As the pebble is sedimentationally out of place, it could only have reached this position by being floated in. Pebbles of this size are almost unknown in this region of low declivities and fine sediments. For this and other reasons it is unlikely to be a drop pebble from a floating stump. The most probable explanation is that the stone is a gastrolith from a large bird or reptile. On the interpretation of the dolomite given in this *Memoir* the water would be shallow, but even if deep the pebble could be from a floating cadaver. Many smooth pebbles found on clay pans at the present time appear to be explicable only as gastroliths, and are probably from emus.

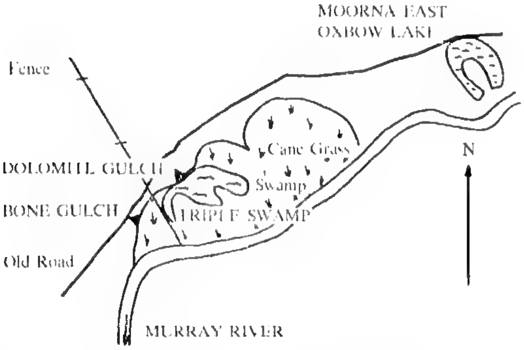


Fig. 22—Map of localities—Moorna E. oxbow, Triple Swamp, and Bone Gulch. Traced from air photo Moorna Station, W. of Wentworth, N.S.W. Site 12.

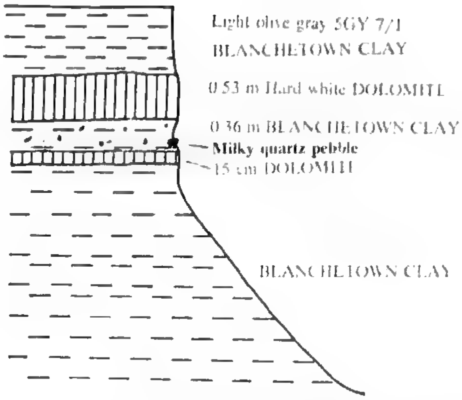


Fig. 23—Occurrence of pebble in clay sediments at Dolomite Gulch, Triple Swamp (Fig. 22), Moorna Station, W. of Wentworth, N.S.W. Site 12.

(e) *Blanchetown Clay, Dolomite and Limestone Members*

Triple Swamp (Pl. 9, fig. 1) is a flat swampland that is covered by Murray River floods. The sediments are greenish gray clayey sands to sandy clays referable to the Coonam-

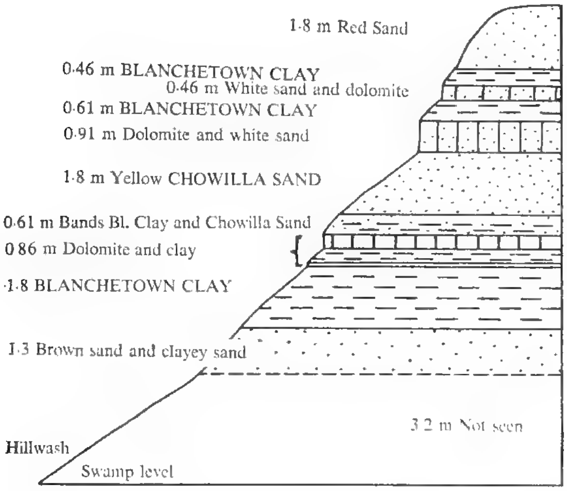


Fig. 24—Measured stratigraphic section at Dolomite Gulch (Fig. 22), Moorna Station, W. of Wentworth, N.S.W. Site 12.

bidgal Formation. This canegrass swamp dries out and cracks deeply in summer. In places there are sand rises with *Eucalyptus largiflorens*. The cliffs behind permit one to view a long section of the stratigraphy which consists of Blanchetown Clay and Chowilla Sand, but with many variations. The cliffs in the vicinity of Triple Swamp Gulch are unusual in that three white layers (Pl. 9, fig. 2) glare in the strong sunlight of this semi-arid region. The white rock is dolomite, pure in some places, and sandy in others. These white layers stand out against the red soil at the top of the section and the greenish gray (5 GY 6/4, 7/1) to gray (5 Y 6/2) Blanchetown Clay. The dolomites are dense and so stand out in the cliffs (Pl. 8, fig. 1). In the gulches they form vertical faces. The rock was too hard for the penetrometer used, but the Blanchetown Clay gave readings of 16-20 kg/sq cm. The red sand at the top of the cliff gave 4-8 kg/sq cm. and the topsoil 2-4 kg/sq cm. The topsoil is a later addition here because an Aboriginal midden was found between the A and B horizons.

A second striking occurrence of dolomite is found at Sharp Point on the N. bank of the River Murray at Nampoo Station. Here again, the beds lens out, but nevertheless reach a maximal thickness of 1·2 m. Here too, there is association in places with sand. The succession and variation is shown diagrammatically in Fig. 25. On the other hand, there is a difference in that opal is associated with the two dolomite layers at Nampoo. The two layers cut out to the E. then a 1·2 m band appears near the Nampoo pump, cuts out then reappears further E. as a sandy dolomite to dolomitic sand. Silcrete is associated with the sand and not opal. There is a slight dip to the E. (1 in 400), and it could be that the second dolomite band is hid from sight to the E. The changes to the W. are shown in Fig. 25.

Messrs. Sharp and Howells Pty. Ltd. obliged with an analysis of dolomite from the lower layer at Sharp Point, with this result:

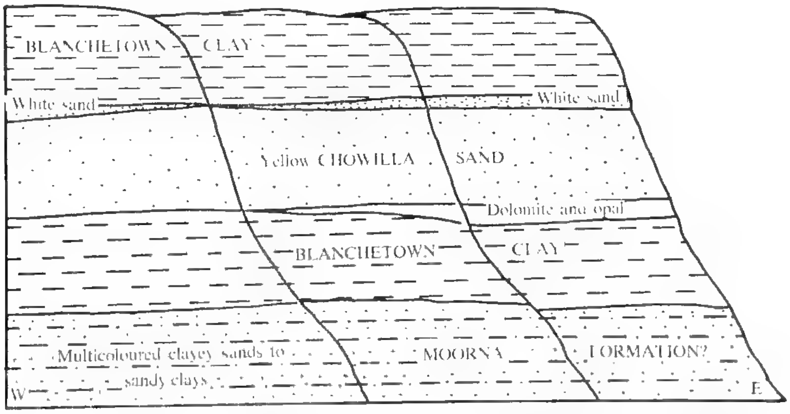


Fig. 25—Sketch of successive headlands in dissected cliff at Sharp Point (Devil's Elbow), Nampoo Station, E. of Cal Lal, N.S.W. (Fig. 4). N. bank of Murray River. Site 4.

$CaCO_3$	54·5 per cent
$MgCO_3$	42·5
Silica etc. by difference	3·0
	100.0%

Dr. E. R. Segnit (as reported in a paper in this *Memoir*) made X-ray and D.T.A. analyses of the dolomites. He determined cristabolite and tridymite. The opal beds have caused a change in slope of the cliffs at Sharp Point and resulted in a small headland jutting into the river. This more resistant rock has resulted in a very sharp turn in the river here, hence the name. Early river pilots called it the Devil's Elbow. A section of the little headland is given in Fig. 26.

While the whitish sand below the Chowilla Sand is shown as horizontal, it is disturbed in places as much as 15°, apparently by the churning of the clays. Slickensides are common in this zone. These relationships are shown in the field sketch made at Sharp Point reproduced in Fig. 27.

The opal occurs both in masses as shown in Fig. 27, and in nodules which are generally bulbous but with some little sharp points at irregular intervals on the surface, which is white. The upper dolomite bed at Sharp Point has massive rock, replaced to varying degrees by opal, brecciated (and recemented) opalized dolomite and nodules. The opal is a highly vitreous translucent (clear, brownish, bluish, pinkish) to opaque (mostly brown). Just above the upper opal bed is a finely laminated band (0·6 cm thick) rich in ostracods. Laterally, this opalized dolomite becomes in places a silicified sandstone.

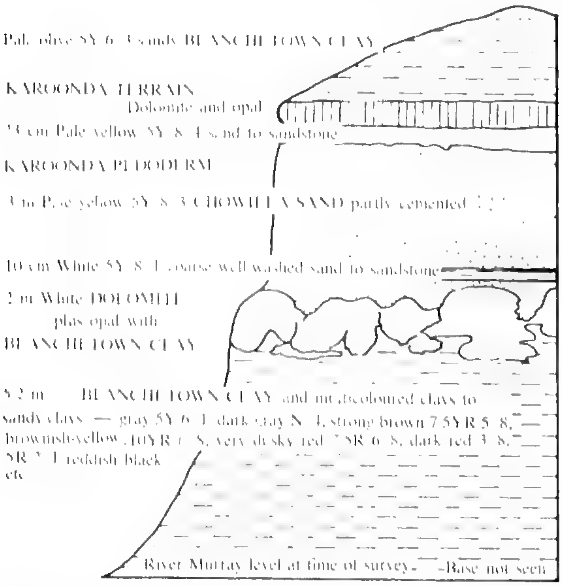


Fig. 26—Measured section at Sharp Point, Nampoo Station, E. of Cal Lal, N.S.W. N. bank of Murray River. Site 4.

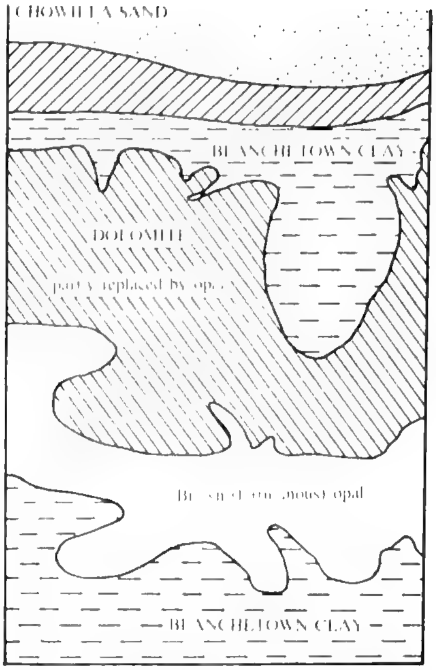


Fig. 27—Interpretation of dolomite and clay at Sharp Point, Nampoo Station, E. of Cal Lal, N.S.W. Much of the dolomite has been replaced by opal. Site 4.

The opal/silica deposits are regarded as pedogenic. The Chowilla Sand below the upper dolomite layer is mottled. The clayey sand below the lower layer is also mottled and contains rhizomorphs of quartz plus opal (E. R. Segnit det.) There is often silicification without opal at the same stratigraphic horizon as at Cal Lal, the Murray River cliffs at Kulcurna Homestead, on Salt Creek and elsewhere. On Salt Creek opal is deposited in Blanchetown Clay but in the same cliff at the same horizon only

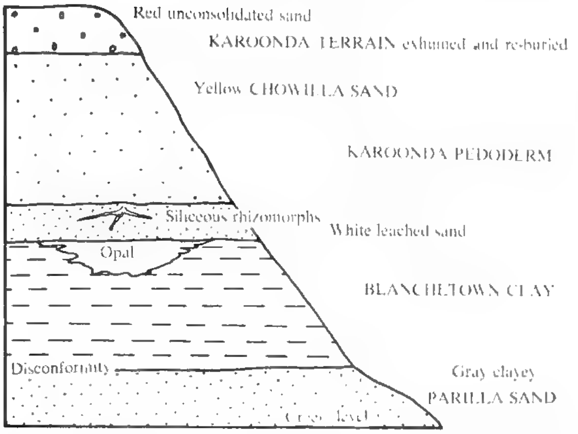


Fig. 28—Section of E. bank of Salt Creek towards the S. end, on Kulcurna Station, Cal Lal, N.S.W. Site 2.

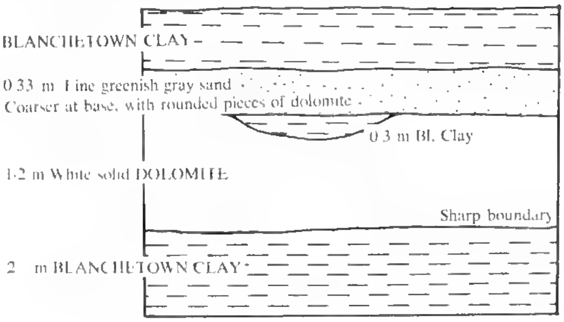


Fig. 29—Section in cliff at Nampoo Station homestead pump, E. of Cal Lal, N.S.W., providing evidence of erosion of dolomite. Site 4.

10 m away where sand has replaced the clay, silcrete is deposited. Also sand just above the opal has rhizomorphs, as shown in Fig. 28. In some of the gulches at the S. end of Salt Creek, masses of silicified sandstone have fallen to the floor of the gulch and these provide an excellent opportunity for studying the branching rhizomorphs. There are also burrows, which are not branched, do not vary in diameter, and have some kind of segmentation of the infill.

Although no dolomite layer was noted in the Salt Creek section, a bore put down E. of the creek in connection with a salinity survey penetrated a dense fine-grained rock. By the time I examined the site, none remained, but Mr. Hans Hansen of Kulcurna Station told me that it appeared the same to him as a lens of dolomitic rock (which he kindly drew to my attention) on the cliff behind Kulcurna Homestead. For relation to Salt Cr. see Fig. 4.

The dolomite has suffered minor erosion in some places, while at others it remains only as fragments in sediments. The former is illustrated by Fig. 29 which shows a section on Nampoo Station E. of Sharp Point. Fragmental remains can be illustrated by the W. end of Fishermans Cliff section (Fig. 30) where pieces of gravel in the Moorna Formation are covered with white coatings. These worn coatings drew attention because they looked like calcium carbonate and so the first appearance of the present semi-arid climate that amasses such carbonate. However, Dr. Segnit identified the mineral by X-ray as dolomite, so a gravelly dolomite must have been formed then eroded to provide this sediment. Carbonates are so abundant in this climate that almost any rock effervesces on application of cold acid (as did the dolomite) so this field test can be misleading. At the E. end of Fishermans Cliff the section is as in Fig. 31. A layer 0·6 cm thick, 0·6 m below the top of the Moorna Formation, has small

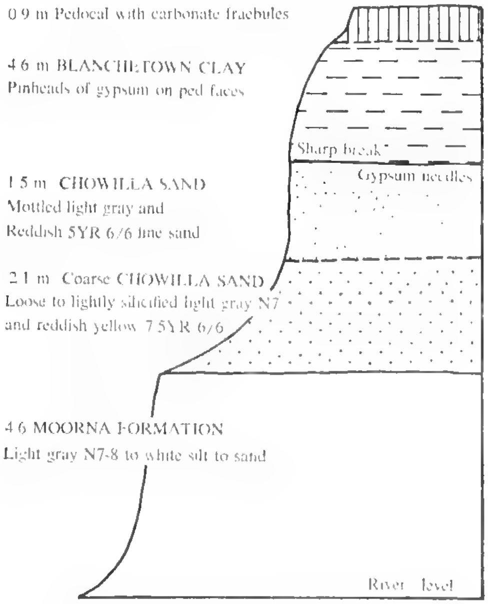


Fig. 30—Surveyed section W. end of Fisherman's Cliff, Moorna Station, W. of Wentworth, N.S.W. N. bank of Murray River. See Fig. 31 for E. end. Site 13.

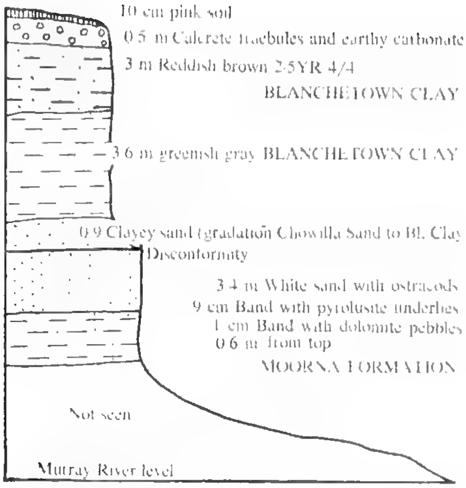


Fig. 31—Measured section at the E. end of Fisherman's Cliff, Moorna Station, W. of Wentworth, N.S.W. Lateral differentiation can be seen by comparing this section with that from the W. end (Fig. 30). Site 13.

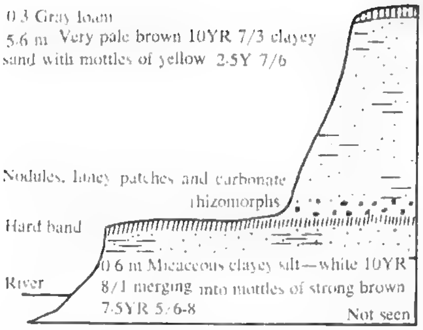


Fig. 32—Measured section on N. bank of the River Murray, Tammit Station, 16 km from Euston, N.S.W., in the Sandhills Paddock. The carbonate is dolomite.

rounded to angular pebbles of dolomite. Just below this band is one rich in pyrolusite about 8 cm thick. The same detrital dolomite band associated with pyrolusite occurs to the NE. in the gulch at the NW. corner of Moorna Oxbow lake. So the dolomite was once more widespread than appears by present outcrops. In a rapid reconnaissance of the Murray River upstream from the study area, dolomite (E. R. Segnit det.) was found on Tammit Station about 14·5 km from Euston. In the Sandhills Paddock about 16 km WSW. of the homestead, Mr. O. Grayson showed me the section given in Fig. 32, where the right bank of the Murray River reveals:

0·3m	Gray loam
5·5m	Very pale brown 10 YR 7/3, with yellow mottles 2·5 YR 7/6 clayey sand. At base, rhizomorphs, carbonate patches, and dolomite nodules forming a berm in river bank
0·6m	Micaceous clayey silt, white 10 YR 8/1 merging into mottles of strong brown 7·5 YR 5/6-8
1 + m	Clayey sand with iron oxide mottles, becoming ironstone in places. Forms reef at Tammit homestead.

Similar sections were seen in other places on the river in this area.

Firman (1966, 1971a) has described the Bungunnia Limestone in S. Australia as a formation succeeding the Blanchetown Clay and occurring E. of the Morgan fault line scarps, also W., N. and NE. of the Pinnaroo Block. It is a "micrite flaggy or banded, oomicrite, oolitic algal biolithite, calcilutite; generally dolomitic and containing ostracodes". This formation does not occur in the study area, but there are lenses of similar lithology in the Blanchetown Clay. They are related to the Nampoo and Triple Swamp dolomite members but are lithologically distinct. The members described above are pure white dolomite, extremely fine in texture (Segnit, *et al.* this *Memoir*)), and no fossils have yet been found in them. By contrast the Bone Gulch dolomite member and the Morkalla dolomitic limestone member are light brown, much harder rocks (the latter is used for paving paths) and highly fossiliferous, being packed with ostracods and other evidence of biologic activity.

On the W. side of Bone Gulch on Moorna Station, N.S.W., erosion has stripped Blanchetown Clay from the top of the dolomite which in turn has protected mottled Blanchetown Clay below it. The rock is pale brown, whitish or pinkish in places, and of low specific gravity, due to the large numbers of ostracods *(Ilyocypris, Candona* and *Diacypris).* The bed is only 1·3 cm to 5·4 cm thick, but extends 140 m along the river, and intermittently for another 60 m. As the deposit has been eroded by the Murray River, its original extent is not known. The deposit indicates shallow lacustrine conditions. It is sandy in places. The ostracods are dolomitized, so secondary dolomitization is involved. The matrix is olive gray 5 Y 6/2 and the mottles reddish-brown 2·5 YR 5/4 and white 7·5 YR N8. The white is due to gypsum crystals and carbonate. Rosettes of gypsum up to 12.5 cm occur but most of this mineral is in small pieces 0·5-2·5 cm diameter. The clay becomes greener with depth. Professor R. H. Tedford described (in litt.) "ostracod coquinas" in the water supply canal cut between Lake Pamamaroo and Lake Menindee to the N., and others are reported elsewhere in this paper.

In the Morkalla district of NW. Victoria are the properties of Messrs. B. Nunn, R. and L. Gray, and F. Heitmann which have on them flaggy dolomitic ostracodal limestone. Where thick enough, and near enough to the surface, it is ripped up with a tractor and sold for making ornamental paths. Dams on the Nunn property show clay which is probably Blanchetown Clay. On the Old Station dam on Grays' property, limestone is reported at 2·5 m with clay above. About 1·5 km WSW. of L. Grays' house (Pl. 8, fig. 3) just E. of a N-S. fence and S. of an E-W. fence, a scour showed ostracodal limestone in situ (Pl. 8, fig. 4). At this site it is horizontal and in three layers over a marly clay. The limestone is a light greenish colour inside and off-white on the outside. A section was measured as follows:

5cm	Red sand and small pieces of calcrete (hill-wash)
2cm	Layer 1 of limestone, crazed on top
1·9cm	Layer 2
1cm	Layer 3
40 + cm	Mottled green, white and reddish brown clay to clayey marl

The limestone was followed round the base of a red sand ridge at the same contour for 1·5-2 km, indicating that the deposit is horizontal and probably extensive.

(e) *Chowilla Sand*

The Blanchetown Clay (Pl. 7) and the Chowilla Sand (Pl. 6, fig. 1) are the two most characteristic formations of the study area, but they contrast strongly. The former is predominantly clay, while the latter is predominantly quartz, usually well-washed. The former is a low dynamics lacustrine sediment, while the latter is a riverine channel deposit. Similar deposits occur in the Holocene Coonambidgal Formation where the loose channel sands provide the source for the structuring of channel border dunes. There are parts of the river at present where the dynamics are such as to wash clay from sand and provide sufficient of the latter to build limited beaches and dunes, e.g. in the Mildura area. The Blanchetown Clay and the Chowilla sand interdigitate to a remarkable degree in this area, and (as is to be expected) sometimes grade into one another. Firman (1971a, p. 57) provides the origin of the name of this formation and its type locality. He gives the distribution as from Merbein in Victoria to Berri in S. Australia. In a rapid reconnaissance of the Murray valley upstream, Chowilla Sand was noted at Monak in N.S.W. in sand quarries on the right bank of the Murray River and at Robinvale on the left bank, where the formation is partly silicified.

The lateral differentiation of the Chowilla Sand is illustrated by Fig. 33. At the windmill

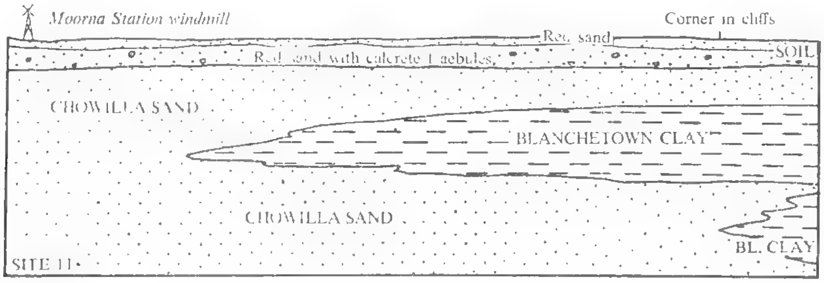


Fig. 33—Section of cliff N. of Moorna Station homestead, W. of Wentworth, N.S.W. Sketched from measured sections and cliff traverse to show lateral differentiation. Site 11. cf. Fig. 34.

end of the section are some bands of silcrete which the Aboriginals could have used for implements. At Moorna Station homestead extensive silcrete outcropped at river level before the building of locks raised the level of the water there, Mr. A. T. Honner informed me. The stone was used in the building of the homestead. At the corner marked on Fig. 33, N. of the homestead, the section was measured as follows:

0·5m	Red sand
1·0m	Same with calcrete nodules, white 5 YR 8/1 to pinkish white 8/2
5·3m	Greenish olive gray 5 Y 5/2 Blanchetown Clay
5·4m	Yellow Chowilla Sand to river level.

The Blanchetown Clay has shiny ped faces with fine selenite crystals, and oxidizes to light gray 5Y 7/1-6/1. In the middle is a narrow band of white 5Y 8/2 sand with some clay laminations. The top 5-10 cm is dark with pyrolusite, which is common as a secondary mineral in the sand formations. In the basal Chowilla Sand more pyrolusite occurs, and a piece of fossil bone was found. The bed should be prospected for vertebrate fossils. This is the same horizon as that in which occur the plentiful fossils at Bone Gulch.

Figure 34 provides a diagram of part of the Triple Swamp cliffs. It relates the important Bone Gulch (with nearby ostracod dolomite) to the Triple Swamp Gulch with its three dolomite bands. It also shows the extensive interpenetration of Chowilla Sand and Blanchetown Clay.

The two illustrations given of interpenetration, and the many sections with Chowilla Sand provided earlier in the paper, prove that this formation cannot be used as a *time indicator* but only as a *facies indicator*. In such conditions of lateral change it is difficult to correlate one section with another because of lack of datum planes. However, these are provided in the study area by pedoderms and fossils. Both of these require further study and refinement, but this will be discussed in the section on chronology. Another factor that can cause difficulty is the presence of disconformities and interformational erosion. The pedoderm is a disconformity in that a significant amount of time was involved in its formation. It represents a period of non-deposition. There are evidences of interformational erosion (e.g. Fig. 29) but these are on a minor scale, being usually small channels. They are therefore not very significant with respect to the stratigraphy. In the Paringi (N.S.W.) section two such channels occur in the top of the laterite. A minor one occurs in the top of the Chowilla Sand at Bone Gulch.

Although the Chowilla Sand dominates the section in some places (e.g. 33) it is absent or very reduced in others. Fig. 35 shows a section in a gulch running N. at the N. extremity of the Salt Creek cliffs in the Scrub Paddock of Kulcurna Station (originally called Hypurna, the Aboriginal name for the creek — J. Higgins).

(f) *Moorna Formation*

This is a new formation hereby proposed for an assortment of mostly unoxidized riverine deposits, gravels to silts, that occur below the Blanchetown Clay in the very broad and shallow Lake Victoria syncline. Because the Parilla Sand in this area is warped below river level, the only other formation occurring below the Blanchetown Clay is Chowilla Sand. This well-washed oxidized well-sorted channel deposit is readily distinguished. Unlike the

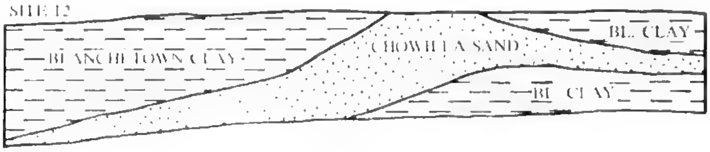


Fig. 34—Sketch of the cliff section between Bone Gulch and Dolomite Gulch (surveyed sections) to show interdigitation of Blanchetown Clay and Chowilla Sand. c. Fig. 33. For localities see Figs. 1, 4, 22 Site. 12.

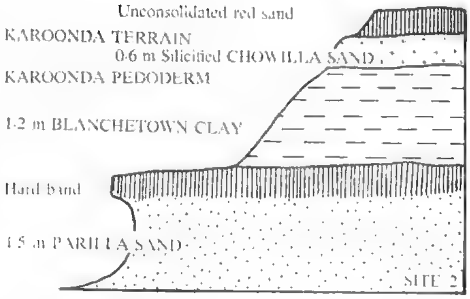


Fig. 35—Measured section of gulch in Scrub Paddock, Kulcurna Station, Cal Lal, N.S.W. Site 2.

Moorna Formation, it rises through the Blanchetown Clay, divides it, and caps it. The Moorna Formation always maintains its stratigraphic position.

The type section (Fig. 30) is on Moorna Station (from which it derives its name) at the W. end of Fishermans Cliff (Fig. 4, Site 13) so called by us because a fisherman has his hut at the E. end of the cliff. The paddock above is called The Selection by the Moorna management.

At the W. end of Fishermans Cliff (Fig. 30) the Moorna Formation consists of poorly-sorted gravel to coarse sand with the fragmentary bones of fish and marsupials, but at the E. end of the cliff (Fig. 31) it has laterally graded into laminated clayey silts and other fine deposits. The former is interpreted as a channel deposit, and the latter as a floodplain deposit. At the W. end the Chowilla Sand (with a fossil tortoise) is interposed between the Moorna Formation and the Blanchetown Clay. The Chowilla Sand is not quite typical because a lateral differentiation is beginning that becomes clear at the E. end of the cliff. For example, besides the usual well-sorted light brown sand there is some light gray (N7) with large reddish yellow (7·5 YR 6/6) mottles, and some is coarser than usual. Below is 4·6 m (and perhaps more) of Moorna Formation consisting of light gray to white (dolomitic) N7 to N8 coarse sand to gravel. It is clayey in some places and clean in others. A bore is desirable to determine the thickness of the deposit, and to discover if Parilla Sand lies below it. An undisturbed core through to the Bookpurnong Formation would be enlightening.

At the E. end of Fishermans Cliff (Fig. 31) the Chowilla Sand thins to 0·9 m, is clayey, and is greenish gray where unoxidized, i.e. it has graded into a sandy phase of the Blanchetown Clay, at least 7 m of which overlies it. A sharp break at the base appears to be a disconformity, and may be the Karoonda Terrain. The underlying Moorna Formation consists of consolidated sediments that form vertical cliffs at the section site. The top is 7·9 m from the top of the cliff.

The succession is:

Top 0·6m	Very pale brown sand 10 YR 7/3-4, some very hard (20 kg/sq cm) and some very soft (2 kg/sq cm)
0·6cm	White sand and pebbles of dolomite
9cm	Quartz sand with black pyrolusite The above two narrow bands have a local dip of 40° for 0·6m, which with the detrital dolomite is evidence of erosion. The eroded band is 28-60cm of white to very pale brown (10 YR 8/1-4) unstratified sand cemented in places with silcrete
3–4m	white sand to clayey sand; 76cm of this layer is finely laminated, 84 laminae being counted in 10 cm. Penetrometer measured 12-20 kg/sq cm
2·7 + m	Intercalated very pale brown sand (10 YR 7/4) and reddish brown (2·5 YR 5/4).

The Moorna Formation here is thus 16·3+ m thick. The thickest outcrop noted was at Merbein, where the left (W.) bank of the River Murray at the scenic lookout between the Winery and the Pumping Station reveals the section shown in Fig. 36. Here below mottled Blanchetown Clay up to 3·6 m thick is 4·3 m of Chowilla Sand. On the section line there is a conglomerate of masses of silcrete, quartz gravel and yellow sand lying on an uneven floor. Further S. towards the Pumping Station, a silcrete layer is in situ, and obviously this layer has provided the conglomerate. It is the Karoonda Terrain, and the silcrete is a pedoderm.

The Moorna Formation consists of over 17·9 m of off-white to light gray, very poorly-sorted, current-bedded sands to gravels with varying clay content, sparsely micaceous, pre-

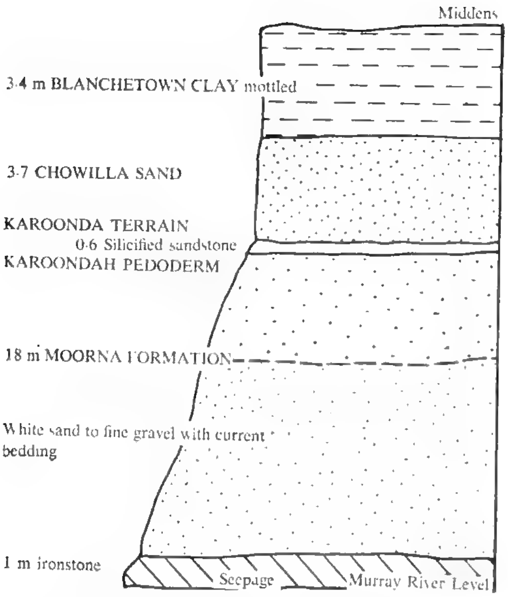


Fig. 36—Surveyed section of the cliff on the left bank (W.) of the Murray River at The Lookout, Merbein, Victoria.

dominantly clear quartz but some milky, with rounded to angular grains, cemented in places, rhizomorphs present in the upper 3 m, unoxidized. By contrast, at the base (at river level) is 0·6-1·8 m of soft ironstone through which water seeps to the river. The ferruginized sand is included in the Moorna Sand. What further thickness lies below is unknown. A bore to determine this and discover what formation lies below would be useful.

Referable to this formation are the strata below the Blanchetown Clay in the E. Moorna oxbow lake section (Fig. 6), of which the detail is as follows:

Top	51cm	Firm (20 kg/sq cm) red-brown (2·5 YR 4/4 and some lighter shades of clayey sand with pyrolusite
	0·6cm	Light brown (7·5 Y 6/4) do. with detrital dolomite
	18cm	As at top but more light brown in colour
	0·6cm	Dolomite
	20cm	As 18cm layer above
	13cm	Stiff clayey sand. Same colour as above but with purplish bands. Gypsum rosettes 1.5-3cm diameter.

Thus the basic regional stratigraphy consists of Bookpurnong Formation (oldest) Loxton Sands, Parilla Sand, Blanchetown Clay, Chowilla Sand and Moorna Formation. For most of the study area only the last three outcrop. At this stage of geologic development, the Lake Bungunnia system became defunct as the Murray River cut down into this succession of strata, and drained them to base level.

The formations listed below as further regional deposits are thin surficial ones overlying the foregoing basal units. This is why the Blanchetown Clay forms the surface of much of the country and is widely used for excavation of tanks (water reservoirs).

(g) *Bakara Pedoderm* (Firman 1963, 1966, 1971a).

This is discussed in the accompanying paper on palaeopedology.

(h) *Woorinen Formation* (Lawrence 1966, Firman 1971a).

This comprises the E-W dune system described earlier (Figs. 9-10).

(i) *Loveday Pedoderm* (Firman 1966, 1967b).

This soil is developed on the Woorinen Formation dunes, and is discussed in the accompanying paper on palaeopedology.

(j) *Bunyip Sand* (Firman 1966, 1967b, 1971a).

This formation occurs as dunes, or as a veneer of red sand on the plateau in which the river tract is cut. About 0·8 km S. of Talgarry Station homestead is an example of a red sand dune belonging to this formation. It was eroded by winds during the 1967-8 drought so that its structure could be examined. The sections examined showed a homogeneous compacted red-brown sand. Aboriginal middens were associated with the dune, both on it and in it. The internal middens could be used to date the dunes.

On the hillslope above the Salt Creek measured section (Fig. 20) Bunyip Sand forms a deposit that is partly hillwash and partly aeolian. A section in a gulch showed:

Top	13cm	Loose red sand
	10cm	Weak red (10 YR 5/4) sand forming a hardpan held by clay skins
	36cm	Deeper red (10 R 4/3) sand

60cm Weak red sand lightened in colour by patches of earthy carbonate and nodules; also burrow fillings and in a few places thin seams down joint planes

60cm Mottled weak red (10 YR 4/6) and red (2·5 YR 5/6) and yellowish red (5 YR 5/6) with off-white patches of carbonate and white specks of gypsum. Latter mostly in lower half of this horizon. Also rough surface non-magnetic ironstone concretions up to 1·3 cm diameter

(k) *Yamba Formation* (Firman 1971a, Lawrence 1966).

Gypsiferous clays and sands in playas and low dunes. The gypsum is commonly of the "seed" and "flour" types. An example in the study area is the Morkalla district. Lawrence (1966) refers to a number of such areas.

3. *River Tract Formations*

The Murray River is incised deeply into the regional formations so that the present floodplain is about 37 m below the general terrain (Fig. 12). In the section on geomorphology, the tract in the area of study has been described as a pattern of higher red country and lower gray country (Fig. 5). These two types of country are surface expressions of two formations which will now be described, along with another formation proved by the Chowilla Dam site investigation, viz.:

Top (c) Coonambidgal Formation (Gray country)
(b) Monoman Formation (underlies c)
(a) Rufus Formation (Red country).

In addition to these riverine formations, there is the aeolian Lake Victoria Sand.

(a) *Rufus Formation*

This is a new formation here proposed and the type locality is the outlier shown on Fig. 5, where vertebrate fossils have been found that prove a Pleistocene age. The site is between the Wentworth-Renmark Road (at a bend in it) E. of Lake Victoria and N. of Frenchmans Creek on Dunedin Park Station, N.S.W. The name is after the nearby Rufus River which runs from Lake Victoria to the River Murray. The lithology is a clayey fine sand, and the facies riverine, as is shown by the nature of the sediments along with the flatness of the tops of the outliers. The latter were obviously once a continuous river terrace that was corraded and dissected. The outliers themselves have suffered some dissection—a mark of antiquity in this low rainfall area. The red terrace residuals stand up to about 7 m above the surrounding gray Coonambidgal sediments, and aprons of hillwash are common. The sandy fraction may be re-worked into local small dunes. The vegetation on this formation is *Eucalyptus largiflorens, Atriplex,* and such shrubs, then an under storey of herbs. The flora is renewed by floods. With it is associated a fauna of birds (including emu), marsupials, reptiles and invertebrates. Aboriginal middens, ovenstones and skeletons are found on the Rufus Formation residuals but none was found in the surrounding Coonambidgal floodplain. Three *Velesunio* middens were noted at the S. end of outlier 1. Middens also occur on the reworked red sands at the borders of some outliers. Small rounded polished pebbles occur, and these are thought to be emu gastroliths. The stratigraphy was tested by a surveyed section with auger holes.

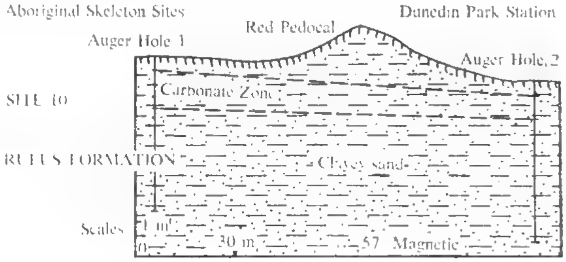


Fig. 37—Section in Rufus Formation residual marked 1 in Fig. 5. The site of Auger hole 2 was covered by the 1956 flood. It is at approximately the same level as Auger hole 1 (extreme left of figure) in Brown's Paddock, Keera Station, on the other side of the river (Fig. 38). Broken lines connect the limits of the carbonate zone proved in the two auger holes, but it is likely that the pedocal follows the present land surface. Site 10.

On the W. side of outlier 1, the section shown in Fig. 37 was determined, and the bore logs were:

Auger 1 72m E. of N-S. fence

0·20 m Red 2·5 YR 4/6 fine micaceous sand with very little clay (about 30cm of red sand has been eroded off this surface) grading to

0·33 m Red 2·5 YR 5/8 do. with masses of hard carbonate, grading to
0.41 m Very pale brown 10 YR 7/3 do. Gradual change to
0·86 m Light yellowish brown 2·5 Y 6/4 almost greenish fine sand. Sudden break to
0·08 m Light gray 5Y 7/2 fine sand. Decreasing amount of carbonate
0·28 m Yellowish brown 10 YR 5/8 fine sand without carbonate. Fairly sharp change to
0·58 m Light gray 5 Y 7/1 do. with yellowish brown mottles at the top
0·33+ m Same but darkened by pyrolusite. More clayey and some mottles. Plentiful mica at bottom.

3·07 m

Auger 2 On top of residual on clay pan where about 0·3m red sand has been stripped.
0·76m Red 2.5 YR 5/6 fine slightly clayey sand. Fine carbonate at surface and hard lumps from 25cm
0·36m Reddish yellow 5 YR 6/6 micaceous fine sand with little clay. Carbonate fraebules up to 4cm diameter, merging to
0·63m Lighter in colour and less carbonate. Very pale brown 10 YR 7/3 fine sand with fraebules to 2cm diameter but usually less. Marked change to
2·08m Brownish-yellow 10 YR 6/6 fine micaceous sand with little clay or carbonate. Lighter and darker bands present.

Auger 3 On slope at R.L. — 7·32m.
0·43m Red 10 R 4/6 moist fine sand merging to yellowish red 5 YR 5/6 merging to
0·18m Reddish yellow 7.5 YR 6/6
0·76m Pale brown 10 YR 6/3 fine sand with white masses of carbonate. At 0·81m from surface small translucent crystals of gypsum (selenite). At 1·22m from surface fraebules up to 1·3cm in diameter. Disappeared by 1·45m. Gradual change to
1·27m Light brownish gray 10 YR 6/2 clayey sand with small hard pieces of carbonate. Reduced to earthy patches at 1·5m and disappears at 1·8m. Merges z
0·79m Same with light gray mottles. Sandier at 2·85m
0·84m Light gray (2·5 Y 7/2 to 10 YR 7/2) slightly clayey sand with faint mottles of light yellowish brown 10 YR 6/4. At — 2·6m light bluish-gray mottles dominate and a layer of pyrolusite occurs. Rest of core to 4·27m light bluish-gray with 10 YR 6/4 and 7·5 YR 5/6 mottles. Water at 4·27m.

Auger 4 On floodplain of Coonambidgal sediments.
0·15m Strong brown 7·5 YR 5/6 slightly clayey fine sand
0·91m Brown to yellowish brown 10 YR 5/3 to 5/4 clayey micaceous fine sand. Gradual change to
0·41m Mottled pale brown 10 YR 6/3, brownish yellow 6/6, and light gray 7/1 micaceous fine sand. Marked change to
0·41m Mottled gray with decrease to disappearance of pale brown and large development of strong brown 7·5 YR 5/6 to dark brown 4/4. Increasing amount fo pyrolusite forming black patches. Sudden change to
0·20m Pale brown 10 YR 6/3 do. Water (salty but not strongly so) at 2·08m from surface
0·36m Clayey medium to coarse sand mottled pale brown and gray colours mostly 5 Y 6/1 and 5 GY 6/1. White carbonate forming hard lenticles. At 2·29m from surface oxidation colours gone
0·28m Pale brown sand for 15cm then layers of greenish gray colours 5 G 5/1 to 4/1. Some strong brown mottles at 2·7m. Water moderately salty.

In summary, the Rufus Formation consists here of fine micaceous sediments fully oxidized (red) at the surface, where by aeolian action sand has been sifted from clay. Only one thin lenticle (Auger 4) of coarser sediments was met. Below the surface brown colours dominate, below which the sediments are in a state of chemical reduction. Pedogenic carbonate follows the land surface so the erosion of this bank anyway took place in the Pleistocene. Perhaps heavier rainfall occurred then, and the geomorphology has remained much the same in succeeding drier times. It has been noted elsewhere, e.g. Brown's Paddock, Keera Station, Victoria (Fig. 38), that the carbonate soil on the Rufus Formation follows the present landform. The soil on the Rufus Formation consists of:

A1 0·30m Red micaceous fine sand
A2 0·20m Hardpan of red sand plus clay but without carbonate
B 1·8 m Brown sand with carbonate and some mottling
C 6+ m Mottled to gray sand.

The Coonambidgal sediments (represented by Bore 4 above) have no developed soil profile or accumulation of carbonate.

One outlier (Fig. 5) is horseshoe shaped, but is not a channel border dune. Its perimeter defines a Holocene meander, and indeed such permit the earlier vagaries of the river course to be worked out. The centre is not at floodplain level, but consists of a gradual slope.

In the NW. corner of Moorna Station, N.S.W. (air photo Lindsay Run 1, No. 5112) is outlier 7 (Fig. 5) which overlaps slightly into Dunedin Park Station. It is very irregular in shape and large, with a flat top. In Brown's Paddock on

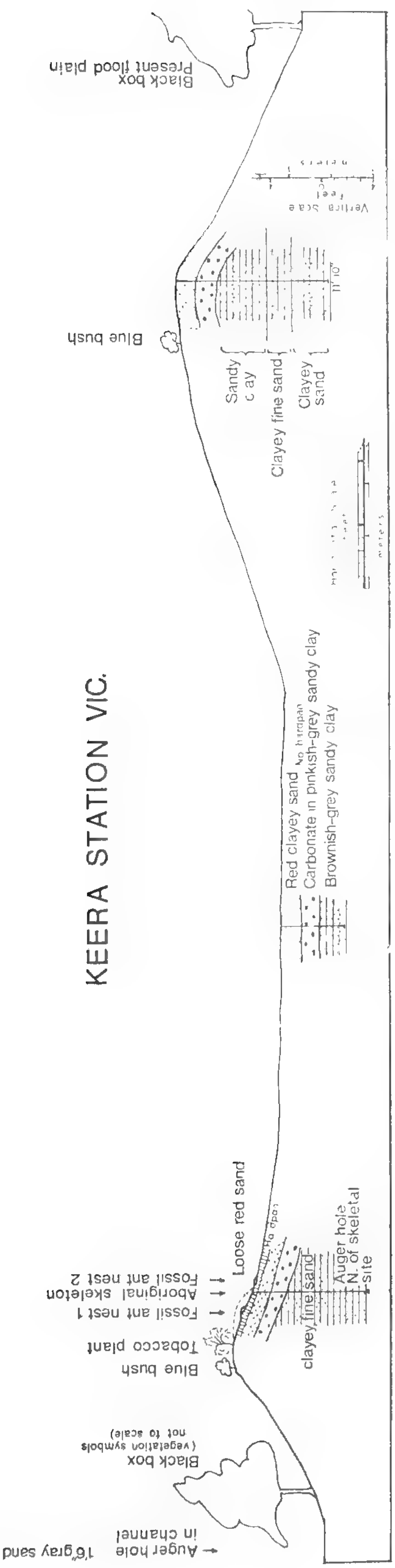


Fig. 38—Surveyed section of eroded Rufus Formation in Brown's Paddock, Keera Station, Victoria. The flat at the extreme left of the figure was covered by the 1956 flood (highest recorded flood).

Keera Station, Victoria, extensions of the Rufus Formation terrace form two dune-like ridges as shown in Fig. 38. The outcrops in this area show that the Pleistocene terrace represented by this formation was very wide, like the present one. On present evidence, the overall geometry of the river tract is not significantly different from what it was in the Middle Pleistocene (this term is purposely vague). The soil has mobilized calcite and selenite during its formation.

An outlier of Rufus Formation also forms an anchor for the S. end of the Lake Victoria lunette (Fig. 5). The sharp rather straight line defined by the S. limit of the lunette is a function of sand being blown past this outlier.

Finally, one of the most significant relics of this terrace is *within* the Lake Victoria basin, and *between* the lunette and the east wall of the basin. This has yielded a ramus of *Sarcophilus,* the Tasmanian Devil. The presence of Rufus Formation within the basin proves that the basin was cut before this formation was emplaced. Its presence so close to the wall of the basin suggests that the basin, like the rest of the river tract, has much the same morphology as it had in the Middle Pleistocene. These matters need more adequate investigation.

(b) *Monoman Formation*

The Murray River in the study area has scoured its tract to some depth, then infilled it again—a mark of changed conditions. At the Dam site (Fig. 4), over 390 river miles from the mouth, the Loxton Sands (Fig. 18) are incised to about 1·5 m below present sealevel, while at Swan Reach the down-cutting reaches about 15 m below sealevel (Firman 1971b, p. 3). The valley fill consists of two formations, the Monoman Formation being the lower and the Coonambidgal Formation the upper. The former was named by Firman (1971a and references) after Monoman Creek in the Dam area, and the D line of bores there is the type section (Fig. 39).

As there was danger of dam underflow through the coarse sediments of the Monoman Formation, a bitumenous grout curtain was designed to cut off water movement. A deep trial trench was dug for experimental purposes on

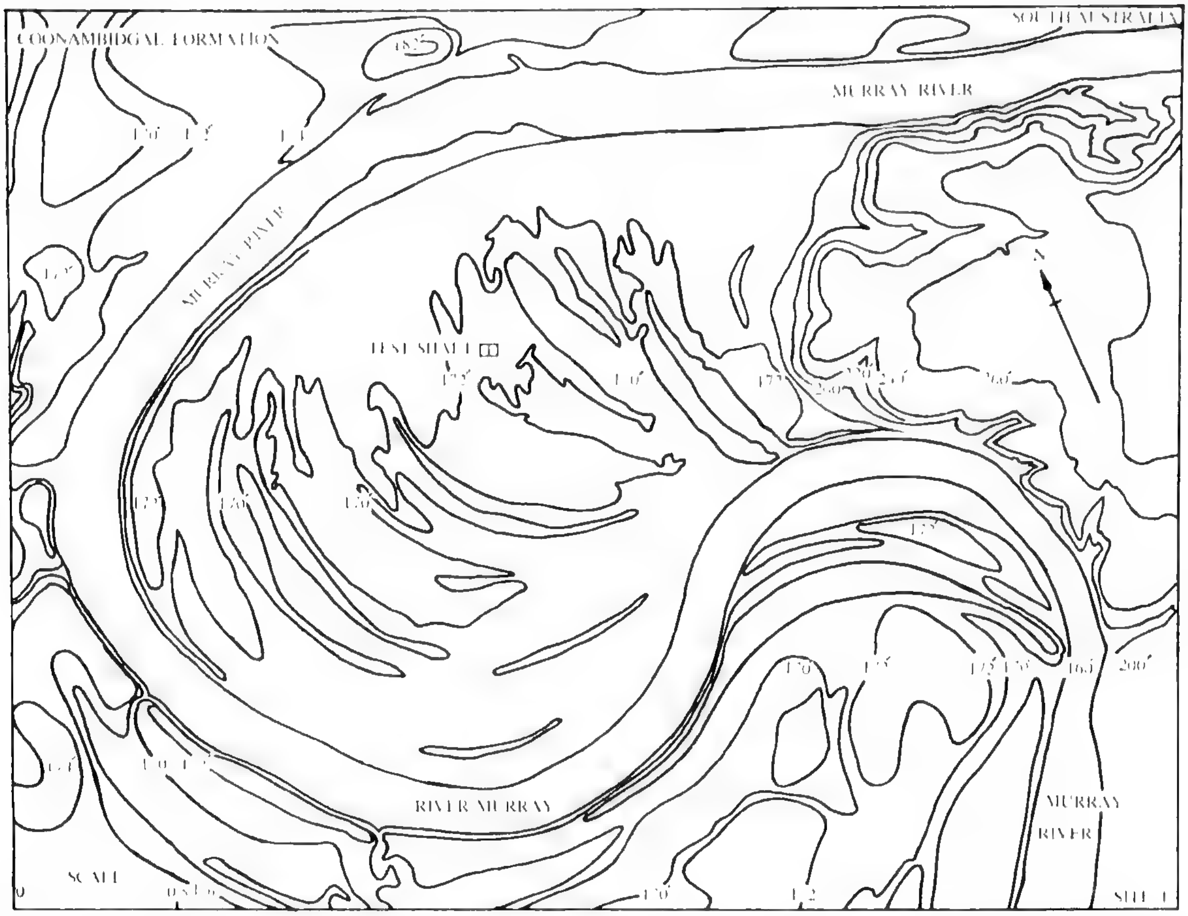


Fig. 39—Map of proposed Chowilla Dam area to show the extreme flatness of the present flood-plain, and the origin of the fossil finds (Fig. 40). Based on S.A. Engineering and Water Supply Chowilla Dam map, whose datum is 106·88 ft. below mean sealevel, Adelaide. The contours are in feet. Thus although the Murray River at the downstream end of this map is c. 390 miles (628 km) from the sea, it is only of the order of 53 ft. (16 m) above sealevel. Site 1.

the floodplain enclosed by the loop of the Murray River proper at Big Bend near the intersection of E.W.S. co-ordinates 99, 200 N and 60,050 E (approximately Lat. 140°25S, Long. 33° 59'S). The contractors placed samples of about 1 m^3 of each of the sedimentary layers in a row, so that those involved with the setting of the grout curtain could devise suitable procedures. I examined these samples, and the depths given are approximations provided by the engineer, Mr. J. Kendricks:

0 –3 m	Gray sandy clay of the present floodplain (unoxidized)
3 –4·5m	Transitional, the percentage of clay reducing with depth, the coarseness of sediments increasing, and the oxidation status increasing
4·5–6 m	Yellow, well washed, poorly sorted coarse sand to gravel (aquifer)
6 –7·5m	Transitional, from oxidized to unoxidized
7·5–15 m	Chemically reduced sediments, pH c.6.5.

Mr. Kendricks also advised that there is an horizon of logs and stumps across the valley at a level between 8·2 and 10·1 m below the surface. From the sample sediments I collected a small log and pieces of wood. Mr. H. D. Ingle of C.S.I.R.O. Wood Structure Section determined these as:

Eucalyptus largiflorens (log)
Eucalyptus camaldulensis?
Casuarina luehmannii?

These species are characteristic of the area at the present time. A piece of the log was dated by radiocarbon 7,200 ± 140 y B.P. (GaK-2513), while another piece of wood from the same fossil tree horizon dated 4,040 ± 100 y (Firman 1967b, 1971b). The latter is reported to come from "25 ft." below the surface, a rounded figure that probably means 7-8 m. However, it is clearly from the upper part of the wood horizon, so its younger age is to be expected. As these samples were wood, and adequate in size, their dates may be expected to be reliable. If so, and neglecting biologic age, a difference exists of 3,160 years, a considerable gap in Holocene chronology, and one associated round the world with a small climatic change. A disconformity is indicated, probably followed by rapid burial of the trees to preserve them. It is significant that in the D line of bores (Fig. 18) and the test trench, fossil wood was found only in this zone, and plentifully. This horizon may thus be taken for the present as the boundary between the Monoman Formation and the Coonambidgal Formation (Fig. 40). However, more precise data are still required.

The small fossil log grew fine, acicular, white to very pale green crystals of melanterite (determined by Dr. A. W. Beasley). They are probably derived from the decomposition of marcasite. The environment was acid, as it to be expected where plant matter is decomposing, so the form of iron sulphide would be marcasite (Edwards and Baker 1951). After the scrapings were taken for identification, further crystals, grew on the same site, indicating continuing oxidation. Melanterite often occurs as an efflorescence on the walls and timbers of mines in the oxidized zone of pyritic ore bodies, especially in arid regions. Jarosite, also a product of the weathering of marcasite, was found infilling cavities, including cell spaces.

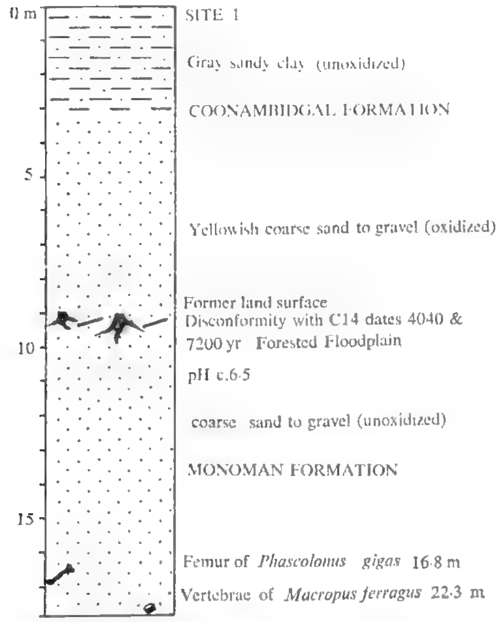


Fig. 40—Coonambidgal and Monoman Formations as revealed by the Test Shaft (Fig. 39) and cutoff trench, Chowilla Dam site, S.A. Site 1.

A black (chemically reduced) femur of *Phascolonus* cf. *gigas* (Marshall, this *Memoir*), the giant wombat, was found in the Monoman Formation at 16·8 m from the surface in the test trench, and a vertebra of *Macropus* cf. *ferragus* at 22·3 m in Bore Hole 20 on line D (Fig. 39). These fossils indicate a Pleistocene age, and thus support the idea of a disconformity at the fossil tree horizon. On the chronology suggested here, the Coonambidgal formation is Upper Holocene and the Monoman Formation Lower Holocene/Uppermost Pleistocene, with a Middle Holocene interval between. The Monoman Formation thus correlates at least in part with the Nulla Nulla Sand Member of the Lake Victoria Sand that constitutes the lunette on the E. side of Lake Victoria. The Monoman Formation is younger than the Rufus Formation, with a time interval between them during which that alluvium was dissected and deep channels corraded. This was no small interval, as a very large area (Fig. 4) was eroded and the incision was deep. As no suitable boring equipment was available, the distribution upstream of the Monoman Formation could not be determined.

The question remains as to why the Murray River corraded its course, then reversed this process and deposited the Monoman Formation. Corrasion is a function of rejuvenation. In spite of the Pinnaroo Block being a zone of tectonic uplift, the river there is cut below sealevel. This prompts a glacioeustatic interpretation, viz. that lowering of sealevel caused the corrasion. If the age given in this section to the Monoman Formation be correct, then the Last Glacial was the time when corrasion took place. However, it is not so easy to explain the infill. Rise of sealevel during the Flandrian Transgression could account for a new base-level but not infill to a considerable height above it. The river bank at the dam site is about 16 m above sealevel. Because S. Australia includes the Lake Eyre basin which is depressed below sealevel a datum of -100 ft from mean sealevel, Adelaide, was accepted, which has now been corrected to 106·88 ft. This figure has to be subtracted from the contours on Fig. 39. The alluvium rises to approximately 200 ft. at the dam site, which is about 28 m above present sealevel. Moreover, the Monoman Formation is a high energy deposit of well-washed sand and gravel, while the present floodplain consists of low energy clayey fine sand. Some factor other than eustasy is involved, and is probably a climatic one.

(c) *Coonambidgal Formation*

Both the Monoman and Coonambidgal Formations are variable riverine deposits best accommodated under the designation "Formation" rather than a rock term. Nevertheless, in the study area the latter has a sediment range offset to the fine side compared with the former. The Coonambidgal Formation overlies the Monoman Formation. The type section is the bank of Coonambidgal Creek, at the NE. corner of lot 75, Parish of Deniliquin North, N.S.W. (Butler 1958, Lawrence 1966, p. 548). This Formation has time equivalents (in part at least) on the general terrain above the river tract in the red Bunyip Sand (or redistributed such), the white Molineaux Sand, and the gypseous Yamba Formation. In the Lake Victoria basin its time equivalents are in the Talgarry Sand, the very recent Dunedin Park Sand, and the colluvial fans on the scarp forming the W. bank. However, all writers do not use this formational name in the same sense. Closer definition and dating is needed.

Before the Coonambidgal Formation was formally defined, Butler (1958) used the term to describe a "system" of riverine sediments. His section was adopted as the type one. There the sediments overlie the Mayrung Surface. At Moorna East Oxbow, Coonambidgal sediments overlie an old land surface (Fig. 7).

While the Coonambidgal sediments are flooded by the present river, they are not completely covered, showing that they are not completely in phase with the present river regime (cf. Dury 1960, 1965). Pels (1964b, p. 115) describes how the Murray follows the Coonambidgal sediments as far as Bullatale Creek off-take (W. of Tocumwal), "from whence it now travels parallel to them and a few miles S." Pels gives other examples of the partially ancestral character of the Coonambidgal Formation. Its age is Holocene. However, in the study area, all post-Blanchetown riverine sediments are confined to the present incised river tract. With the breakdown of the Pinnaroo Block barrage (or Padthaway Ridge) the Murray Gorge was incised. Upstream, in the slightly downflexed Lake Victoria region, the river swept to and fro, cutting the wide river valley that would make a Chowilla Dam inundation area so large (Fig. 4). This time of downcutting corresponds to some of the ancient stream deposition in the E. of the Murray Basin. The period is Post-Blanchetown Clay (Upper Pliocene?) and Pre-Rufus Formation (Middle? Pleistocene). This was a high energy activity, as also was the deposition of the early valley fill—the coarse sand and gravels of the Monoman Formation.

The typical surface expression of the Coonambidgal Formation in the Dam area is shown in Fig. 39. On Berribee Station (Fig. 4) there is a gentle slope to the river tract instead of the usual cliffs. The dunes of the Woorinen Formation are higher on the slope than the Coonambidgal riverine sediments, which occupy the bottom of the valley (Pls. 3-4). No interpenetration was found. The Coonambidgal sediments occupy a younger part of the river tract. This is in keeping with the radiocarbon datings. Carbonate in the surface soil of a Woorinen dune on Berribee Station dated 14,200 ± 790 y. (N.Z.) Fossil woods at the base of the Coonambidgal Formation (as interpreted in this paper) dated 4,040 and 7,200 y. respectively. On Berribee Station the Lindsay River forms an anabranch with the Murray River, and the enclosed land is called Lindsay Is. The collagen of Aboriginal bones from a burial in the top of a Coonambidgal channel border dune on Lindsay Island dated

3,580-± 370 y. (ANU-420D). Bowler (1967) dated Coonambidgal sediments as 5,110 ± 130 y. (N-302). A closer definition of the Coonambidgal Formation and more dates are required to define the period of riverine activity that its sediments represent.

(d) *Stratigraphic Correlation in Murray Basin*

The stratigraphy and geomorphology of the study area described above present a broad terrain consisting of Blanchetown Clay and associated deposits overlying marine beds. On this is a veneer of mostly windblown deposits. Due to the limited supply of suitable sediments, this veneer is relatively thin and in some places absent. Thus it is a common sight to see water reservoirs (tanks) cut in green Blanchetown Clay. Into this terrain the Murray River incised a deep tract, now partly infilled with the Monoman and Coonambidgal deposits. However, this W. side of the Murray Basin contrasts with the E. side. The latter has no marine beds in the stratigraphic succession, but a thick complex of mostly riverine deposits, often coarse, that contrast with the usually fine riverine sediments capped by the extensive lacustrine Blanchetown Clay with lenses of dolomite and dolomitic limestone found on the W. side of the Murray Basin. The terrain is a relict one (Pels 1966) and consists of the channel and floodplain deposits of ancestral and prior streams (Bowler 1967, Bowler and Harford 1963, 1966, Bowler and Macumber 1968, Dury 1963, Butler 1950, 1958, 1960, 1961, Langford-Smith 1960, 1962, Pels 1964a, b, 1966, Stannard 1962). Both tectonics and climatic change were master factors in the process. Earth movements of the Bass Strait Epoch began in the Mesozoic (Fig. 3) and faded in the lower Tertiary. Those of the Kosciusko Epoch began at the end of the Miocene and there are small displacements in Bookpurnong Beds in the Murray Basin, but the main uplift was in Upper Pliocene and Lower Pleistocene times. Tectonic movements caused diversion of streams over a long period (e.g. Pels 1966). The uplift of the Dividing Range resulted in two processes significant for the present study:

1. *The down-warping of the country* inland from the Divide (E. side, Murray Basin) so that riverine sediments 1500 km from the sea extend below sealevel.
2. *The construction of a massive bahada* or apron along the inner side of the range by the formation of numerous extensive coalescing fans.

It has not been evident before what became of these active prior and ancestral streams. The stratigraphy described shows that, following the retreat of the sea, they faded out in the W. into low energy streams, and into the series of lakes that deposited the Blanchetown Clay. With each phase of the downwarp, the rivers graded to a new base level.

On the Darling River NNE. of the study area, in the vicinity of Menindee, is a string of lakes that under natural conditions is dry except in flood time, but are now used for water storage. Connecting these lakes is a gypsiferous greenish gray clay that I think should be referred to the Blanchetown Clay. Thus in this area also there are extensive fine lacustrine sediments forming part of the lake system or systems into which the ancient streams flowed from probably the

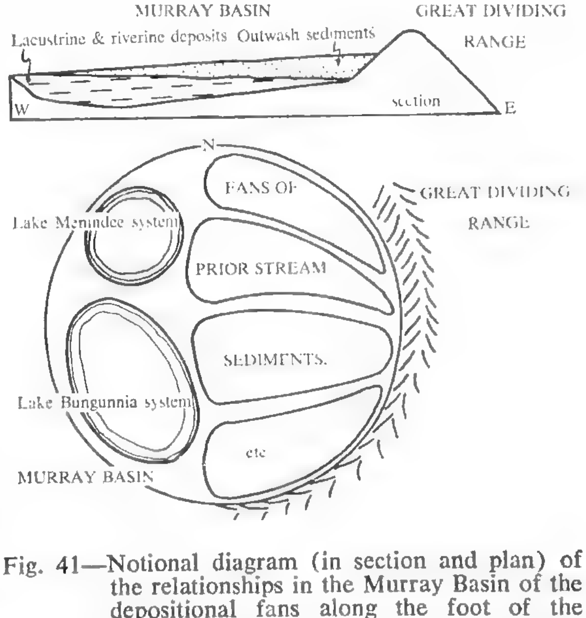


Fig. 41—Notional diagram (in section and plan) of the relationships in the Murray Basin of the depositional fans along the foot of the Dividing Range to the fine lake/river sediments described in this *Memoir*. The Lake Menindee and Lake Bungunnia systems are separated because of their significantly different levels at the present time, but the matter has not been investigated.

Upper Pliocene to the Lower Pleistocene (see section on Chronology). Significantly, this was the period of active tectonic movements when the Pinnaroo Block was uplifted and extensive damming of the Murray occurred. Figure 41 is a schematic representation of the concept outlined above.

(e) *Lake Victoria Sand*

This stratigraphic name is hereby proposed for the large and complex lunette (in the original sense of Hills 1940 for a crescentic dune) on the E. side of Lake Victoria. It is composed of three members:

3. Dunedin Park Sand. Mostly 0-200 yr
2. Talgarry Sand. Upper Holocene
1. Nulla Nulla Sand. Upper Pleistocene to Lower Holocene.

The Lake Victoria Sand is named after the lake it borders, while the three members are named after the three pastoral stations that include areas of the lunette on their properties.

The low dynamics of this flatland river system have already been discussed. A result is that even the dune sands are finer than is normal, as can be seen in the section on grain size analyses. Another unusual feature of the lunette is the comparative rarity of normal dune structures due to sandfalls. The majority of the bedding is subhorizontal (Pl. 10, fig. 1). The inference is that the wind dynamics exceeded the sand supply, so that the dunes during building were in a more or less constant state of blowout. The smaller grain size of the sand meant that it was lighter and could more easily be blown.

The lunette is a large structure 15 km long and up to 2 km wide, though more usually 0·4-0·8 km in width. It thins out at each end, but the two members thin out differentially. The Nulla Nulla Sand thins earlier towards the S. end, while the Talgarry thins out earlier towards the N. This structure could be due to small differences in prevailing winds at the time of construction (considered more likely) and/or differences in the river regime supplying the sand. The S. end of the lunette is tied to an outlier of Rufus Formation. The lake side of the lunette is characterized by a frill of gulches and interfluves (Fig. 16) while the inland side is notable for its numerous sandfalls of Dunedin Park Sand. The crest of the lunette is commonly blown out leaving mesa-shaped residuals of Talgarry Sand, with its characteristic gray columnar soil (Pl. 10, fig. 1). The floor of a blowout is usually a subhorizontal paleosol. The result is a long flat blowout across the lunette with a sandfall at the inland end. Along the lower part of the lake slopes there is a sand apron (14° steepest slope where measured), compounded of sand blown up from the beach by W. winds, and fans of sand washed out of the

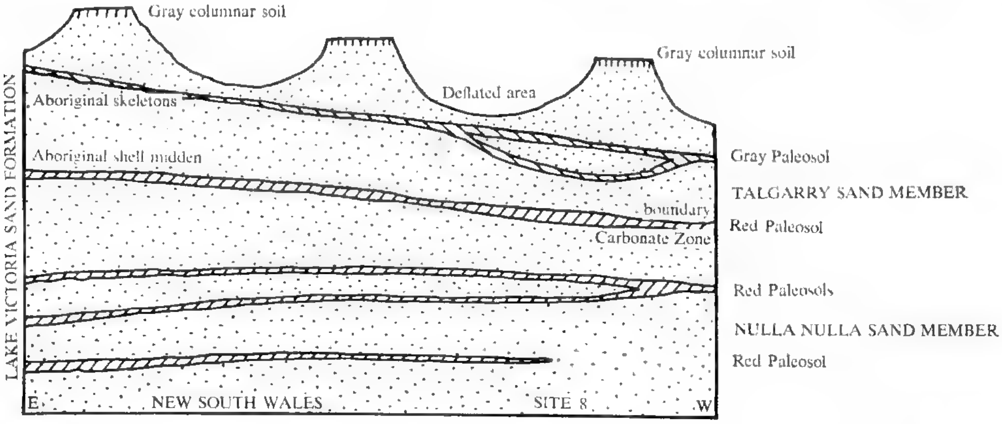


Fig. 42—Sketch of S. wall of Gulch N12 (Fig. 16), in the lunette on the E. side of Lake Victoria, as revealed by drought conditions in 1968. This is the largest number of superposed paleosol units seen in the lunette. The basic occurrence is shown in Fig. 4 of Gill on Palaeopedology, this *Memoir.* Site 8

gulches by the infrequent rains. The apron is included in the Dunedin Park Sand.

In 1967-8 during a drought, the stratigraphy of the lunette was revealed by wind erosion and absence of vegetation. Difficulty was experienced in distinguishing the numerous gulches, so those N. of the Nulla/Talgarry fence have been numbered northwards using the prefix N., while those S. of the fence have been given the prefix S. (Fig. 16). Interfluves are given thus N1/2. All the gulches N. of the fence and many of these S. of it were marked at their heads by long pegs with numbers drilled into the wood, as paint would be sand-blasted away. In addition, four deeply-sunk concrete bench marks were inserted in the area of most intense study. These are linked to the Chowilla Dam survey (and so sealevel at Adelaide), as follows:

BM 1	47 m	above	MSL	Adelaide
BM 2	43 m	"	"	"
BM 3	49 m	"	"	"
BM 4	47 m	"	"	"

The foregoing system makes it possible to locate a site with accuracy, and give its R.L. Because of the subhorizontal structure of the lunette, such an R.L. is more significant than in most dune systems.

Fig. 42 is a sketch of the N. wall of the interfluve N14/15. This section shows clearly the two main Members—Nulla and Talgarry. The distinction is not always so obvious, because in such an environment there is always some sand movement and remodelling complicating the stratigraphy. Overall, the two Members are readily distinguished, and are important in that they represent two periods of dune building. The paleosols represented in Fig. 42 constitute the largest number seen in one section. Such paleosols reflect the general alternation of stable and unstable conditions seen in the in the E-W. dunes. By means of radiocarbon dating it would be possible to make correlations within the range of the method. The few assays it was possible to make are given in the section on chronology, where the possibilities of such an investigation can be glimpsed.

The two Members making up the bulk of the lunette can be distinguished as follows:

	Nulla Nulla Sand	*Talgarry Sand*
1.	More compact (3-5 kg/cm^2)	Less compact (1-3 kg/cm^2)
2.	More leached	Less leached
	Free carbonate rare (unless transferred from above)	Free carbonate common
		Rhizomorphs present
	Selenite needles rare	Selenite needles common
3.	Red non-columnar paleosols	Gray columnar paleosols
4.	Internal structures reduced	Internal structures fresh
5.	Extinct marsupials	Extant marsupials
6.	Human remains only in top	Human remains throughout
7.	Fossil bones mineralized (may be coated with carbonate)	Fossil bones not mineralized (or much less than those in the Nulla Sand)
8.	Clay more organized as skins	Clay mostly free.

There is much variation, the usual difficulties of dune stratigraphy being present. However, the differences are real. A check with a Munsell chart showed that, although occasionally the

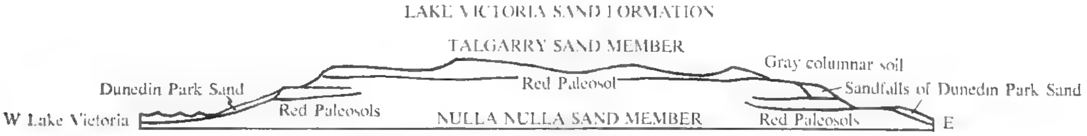


Fig. 43—Diagrammatic E-W. section of the Lake Victoria lunette to show the subhorizontal nature of its essential structures. The summit of the lunette is wind-eroded, resulting in the Dunedin Park sandfalls to the E. The hamada of Dunedin Park sand on the lake frontage is partly blown up from the beach and partly washed down from the gulches. The prevailing wind is W.

lowest Talgarry soil becomes reddish, it does not become as red as the Nulla Nulla paleosols. The fossils are an important difference.

During the depositional break between the two members, blowout structures developed. In places the paleosols of the Nulla Nulla Sand are truncated on the W. face of the lunette (Fig. 43). In NS. section deep gulches are seen in the Nulla Nulla Sand that have been infilled with Talgarry Sand (e.g. N14).

The erosion of the red paleosol in the fossil swale is part of the evidence of this process. No such corrasion has been noted during the emplacement of the Nulla Sand. Thus, in the late Pleistocene, when the giant marsupials were becoming extinct, deposition gradually ceased on the Lake Victoria lunette. The time of maximal world glaciation of c.18,000 yr B.P. is significant for terrace building and regional (E.-W.) dune building, so perhaps it was also for this lunette in the river tract.

Because of the erosion between the two members of the Lake Victoria Sand, the top of the Nulla Sand has different ages in different sites, e.g.:

1. Mussel shells from midden in red paleosol a short distance N. of the Nulla/Talgarry fence where the Nulla Sand is uneroded, 6,360 ± 140 yr B.P.
2. Mussel shells from midden near peg N18 at head of gulch 5·3 m below top of Nulla Sand, 15,900 ± 275 yr B.P.
3. Mussel shells in Nulla Sand at N. end of lunette 1·2 km SE. of Old Hotel site, Nulla Station, 16,720 ± 260 yr B.P. Charcoal from this midden 15,300 ± 500 yr B.P.
4. Mussel shells from midden in red paleosol in second last gulch at S. end of lunette, Talgarry Station (Fig. 44), 17,530 ± 320 yr B.P.

Corrasion tends to stop at a paleosol because such are much more difficult to erode. The foregoing evidence suggests that the erosion interval was mid-Holocene, the same time as the interval between the Monoman and Coonambidgal Formations. However, more work on the stratigraphy and many more dates are required to establish this. On Moorna Station, on the high ground above Triple Swamp at Triple Swamp Gulch (Pl. 9), an Aboriginal midden was found on the B horizon of the soil where the original A had been eroded (apparently by deflation) and then reconstituted. The mussel shells from between the original B and the re-built A horizon dated 7210 ± 160 yr B.P. This stripping could therefore belong to the same period.

Thus, on present evidence, the Nulla Sand was built up mostly in the late Pleistocene. The included paleosols dated by the middens in them (14,000-17,000 yr) appear to tie up with the paleosols of that range of C14 dates in the E-W. dunes on Berribee Station, at Ouyen and at Swan Hill, even with soil formation in S. Victoria (see section in chronology).

A lakeside profile was surveyed (Fig. 45) when the lake level was at its lowest during the drought. A wide beach of white sand was exposed, and such is the source for sand blown up the profile by the prevailing W. winds.

One may well ask what becomes of all the clay transported by the river with this sand. Much clay has accumulated on the floor of Lake Victoria. The Darling River is muddier

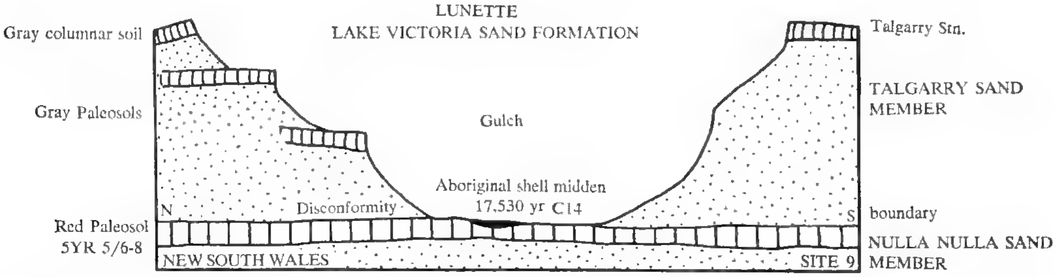


Fig. 44—Section of second last gulch at the S. end of the Lake Victoria lunette (Fig. 16). Site 9.

than the Murray because its waters are fresher. As the percentage of dissolved salts increases (especially sodium), as in the Murray River, the clay flocculates. Much is deposited in the low energy anabranches and billabongs or oxbows (e.g. Fig. 7). Such a stream does not penetrate the ground easily or erode its banks by wetting and weakening. Erosion is by physical processes. Much clay is blown up into the lunette as aggregates or attached to sand grains. In swales and such low areas, strong wetting can re-organize the clay as clay skins that bring about the compaction of the sand. The fineness of the sand and the evenness of grain size makes this process the more effective. Numerous fossil claypans of this type can be seen in the Nulla Sand but they are rare in the Talgarry Sand. They erode with a typical fine herringbone pattern. Sections of such pans can be seen in the walls of gulches.

River and wind action have thus combined to reduce clay content and build a stockpile of fine sand over many millenia. This lunette sandpile has been roughly estimated at 100,000,000 tonnes. It has provided a habitat for marsupials, placentals, reptiles, birds and man. This biologic history has been preserved because of the readiness with which the dead animals were interred in the rather dry sands. However, the river system is no longer adequate to transport sand to this site, but the wind energy is adequate (with the aid of introduced animals) to erode the dunes, revealing their inner structure and fossil content (Marshall, this *Memoir*).

(f) *Lake Victoria Hamada*

No formational name has been created for the colluvial fans that overlie the Blanchetown Clay and associated formations that constitute the scarp along the W. side of Lake Victoria. To a certain extent they are the time equivalents of the Lake Victoria Sand. The youngest member is a series of recent fans that are obviously the latest product of sediment flow on these slopes. The fans are geomorphologically complete except for contemporary gullying. Although so young, the fans have a surface held by carbonate precipitation, usually within the range of 5-15 cm deep. This earthy carbonate has preserved Aboriginal skeletons and middens. In the field we called it the "indurated layer", and it can be traced across all the erosion amphitheatres (Fig. 14) on the W. side of the lake. It continues right up to the edge of the general terrain some 35 m above the lake. The hamada slope is of the order of 10°.

About 400 m N. of a windmill and J. May's camp (shown in Fig. 17) on Noola Station is a typical fan which includes Aboriginal middens. Associated with one of these were carbonized twigs that looked like salt bush. A radiocarbon assay gave a "modern" age (ANU-423), which is less than 200 years. As the midden was immediately below and affected by the indurated layer, this accumulation of carbonate is very recent, and the gullying even more recent, i.e. during European occupation. The widespread occurrence of the indurated layer shows that the hamada had achieved a certain degree of stability. Figure 46 shows a

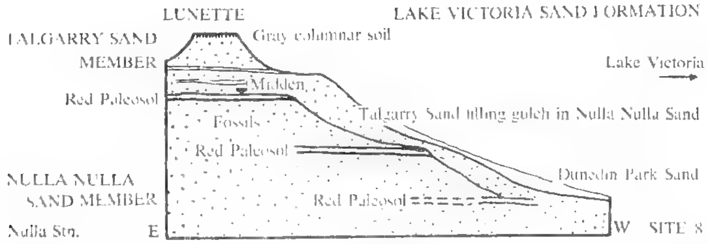


Fig. 45—Sketch of an actual lakeside profile in the Lake Victoria lunette, Nulla Station, N.S.W. Site 8. Boundaries between the Nulla Nulla Sand and Talgarry Sand are subhorizontal normal to the lake, but parallel to the lake are scalloped in places by fossil gulches. The structures reveal successive phases of stability of the terrain.

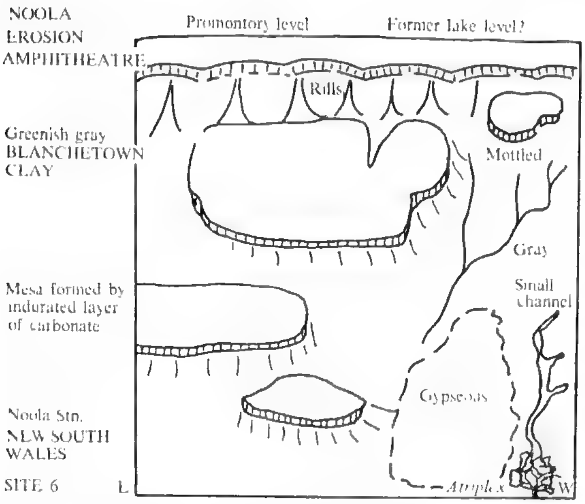


Fig. 46—Sketch of slope in Noola Erosion Amphitheatre showing the latest pedocal, consisting of indurated layer 10-15 cm thick, which covers the low fan slopes (c. 10°) at the foot of the scarp forming the W. shore of Lake Victoria, N.S.W. Carbonized twigs from this layer dated 'modern' by C14, so the soil is less than 200 yr old. The strong dissection has therefore occurred since European occupation. Aboriginal bones and middens are cemented in this layer.

typical dissection of the indurated layer on the N. side of the promontory constituting the S. limit of the Noola erosion amphitheatre (Fig. 14). This layer is part of a 1·5 m oxidized zone on the promontory surface (0°-3°), below which is a similar thickness of mottling in the Blanchetown Clay. On the 10° slope from this promontory is 15-25 cm of indurated layer resting directly on 1·5 m of mottled Blanchetown Clay. In the middle of the Lake Victoria amphitheatre the oxidized zone attains a thickness of 4·5 m.

The development of a hamada that was later dissected is a process that has occurred a number of times on this lake scarp. It is part of the impermanence of semi-arid terrains. Figure 47 shows a fossil gulch which contained bettong bones. The bones were strewn out in a manner such as occurs in hillwash, so the animal was not burrowing, but has the same age as the sediments.

A gulch 1·1 m deep near the N. wall of the Lake Victoria amphitheatre, about 100 m W. of a mesa reveals a Pleistocene gulch fill of light brown (7·5 YR 6/4) clayey sand to brown (5/4) sandy clay with small lenticles of gravel (Fig. 48). A zone of earthy carbonate 25-40 cm deep occupies the surface of the fill.

A small Aboriginal midden and fireplace of oval section was present 45 cm from the surface. It consisted of well compacted (8-10 kg/cm^2) ash, charcoal and mussel shells 20 cm deep and 45 cm wide. The general colour was brown (7·5 YR 4/2 to dark brown (3/2). The bottom of the structure was lined with charcoal suggesting an excavated fireplace. Many of the mussel shells were on edge, standing vertically. Four worm burrows were visible in vertical section and two in horizontal section. None could be found in the surrounding sediments. This is taken to mean that a zone of high organic content attracted the worms. A radiocarbon dating of the charcoal gave 18,200 ± 800 yr B.P. This is the oldest Aboriginal site dated by us in the project area.

Chronology

"The same regions do not remain always sea or always land, but all change their condition in the course of time". —Aristotle (384-322 B.C.)

1. *Methods*

The chronology of the formations described is difficult because no materials suitable for isotopic assay older than the range of radiocarbon have been found. Moreover, the formations exposed in natural sections of the country rock over most of the area are Moorna Forma-

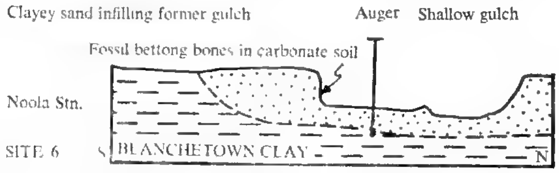


Fig. 47—Measured section of gulch (10·4 m wide, 1·2 m deep) in hamada on W. shore of Lake Victoria, cut in the fill of a still older gulch. The S. bank shows 38 cm of brown 7·5YR 5/4 clayey sand over an earthy carbonate zone (B horizon) 69 cm thick. Nearby this zone was dated 18,200 yr (GaK-2514) on the charcoal of an Aboriginal midden. In the above section bettong bones were taken from the carbonate cement.

tion, Blanchetown Clay and Chowilla Sand. These sediments suffer lateral differentiation and considerable interdigitation, thus complicating correlation. The chronology is therefore based on certain datum planes that traverse the area, as follows:

5. Chronometric dating by radiocarbon.
4. Paleosol that mobilized carbonates (calcrete) and beyond the range of C14 (earliest pedocal).
3. Paleosol that mobilized silica (silcrete, common opal, disperse silica giving silicified sands).
2. Paleosol that mobilized non-magnetic iron oxide (laterite).
1. Bed with Cheltenhamian marine fossils, met in oil bores and in the Tareena water well (Tate 1899).

These stratigraphic planes can be demonstrated to be superposed.

The paleosols provide datum planes that are independent of the lateral differentiation and interdigitation. They also define successive changes of climate and related geochemical conditions. This palaeoclimatic sequence can be paralleled elsewhere, which assists extrapolation. Further, Marshall (this Memoir) has identified in the Moorna Formation vertebrate taxa comparable with those found in Pliocene beds elsewhere. This formation lies below and is older than the Blanchetown Clay and Chowilla Sand. In the valley of the Murray River an oxidized fluviatile terrace (Rufus Formation) contains a vertebrate fauna with taxa such as occur in Pleistocene deposits elsewhere. Vertebrates also assist with the chronology of the lunette on the E. side of Lake Victoria, where the lower part of the formation contains large extinct marsupials, while the higher part contains only extant taxa.

An attempt was made to use palynology, even though it has a restricted application in this dry, oxidized terrain. Two horizons of dark gray to black fine sediments were found, one at the top of the Parilla Sand in the Murray River cliffs beside Kulcurna Homestead, and another nearby at the S. end of Salt Creek in the Blanchetown Clay where it thins out on an old lake shore. The former provided no definitive evidence, but the latter gave a flora more or less identical with that of the present semi-arid terrain (Churchill, this Memoir). There is thus no chronologic value in the results, but they are of profound ecologic interest in that there is an indication of the time of incoming of the present aridity following the subtropical rainforest milieu evidenced by the laterite. This aspect is dealt with in the section on palaeoclimatology. Every method that appeared likely to assist the chronology was attempted, including fission track dating of opal, palaeomagnetism, thermoluminescence, neutron activation, the U/Th assay of pedogenic calcretes, and fluorine/phosphate analyses of bones. Reports on the application of some of these methods are given in accompanying papers. By synthesizing the results of the datum plane study and the above methods with the tectonic and palaeoclimatic patterns, a chronology has been derived which is about as far as one can go under present circumstances.

2. *Tectonic Pattern*

In the S. Australian River Murray region the late Cainozoic stratification is regular, and consistent over a great area. The sequence is:

Youngest Bungunnia Limestone
Blanchetown Clay
Chowilla Sand
Oldest Parilla Sand.

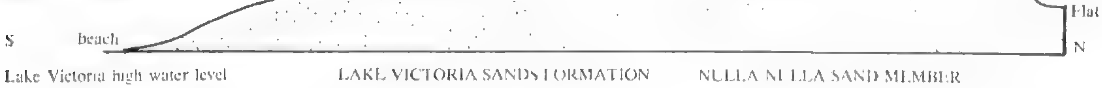


Fig. 48—Surveyed section 292 m long on the N. shore of Lake Victoria E. of the Old Hotel site at end of track from Nulla Station.

As can be seen by Fig. 18, the Parilla Sand outcrops strongly at the dam site in the valley walls. This is true also as far east as Kulcurna Homestead. The formation is then affected by the Lake Victoria Syncline and disappears from sight in the river banks, not to re-appear again till Paringi 29 km SE. of Mildura. About 1·5 km SE. of the Paringi turnoff the Murray River cliffs come close to the Robinvale-Gol Gol road (Sturt Highway). There cliffs about 25 m high show 4·5 m of Parilla Sand which, unlike any other formation present, develops a vertical face. The distance between these two outcrops of Parilla Sand is about 130 km in a direct line. The Parilla Sand is a gray fluviatile clayey sand of constant character, apparently not affected by significant tectonic movements during its emplacement. It has since been flexed downwards in the Lake Victoria Syncline. By contrast, the succeeding formations have been affected by tectonic movements. The Moorna Formation, interposed between the Parilla Sand and overlying formations, is limited (as far as we know) to the Lake Victoria Syncline. Above the Moorna Formation is the Blanchetown Clay/Chowilla Sand complex. In S. Australia (on the uplift block) these formations hold a definite order, but in the depressed Lake Victoria Syncline area, they grossly interdigitate and the Blanchetown Clay reaches a much greater thickness (Pl. 5). The onset of significant Kosciusko Epoch earth movements can thus be recognized in the study area. The Murray Basin is so large a structure, that to fit its earth movements into a tectonic pattern, one needs to view the tectonics of the whole of SE. Australia and not movements on local faults as at Melbourne and Adelaide. This general view shows a mid-Tertiary quiescence with slight movements at the end of the Miocene and in the Lower Pliocene, then strong movements in the Upper Pliocene and Lower Pleistocene. Since the movements in the Lake Victoria Syncline are so subdued (deep movements are buffered by 1·5-3 km of soft sediments—Fig. 3), it is reasonable to conclude that the well-marked changes following the deposition of the Parilla Sand are those of the Upper Pliocene. If this be so, then the Moorna Formation represents the beginning of the damming of the Murray River by the uplift of the Pinnaroo Block, while the lacustrine deposits of the Blanchetown Clay (and associated limestone lenses) mark the establishment of this impedance to drainage. It would seem that this was variable, because after some lacustrine deposits were emplaced, the lake dried up so as to yield dolomite then pedogenic opal (Fig. 26) and silcrete. The oscillation between channel, floodplain and lacustrine facies, as reflected in the interdigitation of the Chowilla Sand/Blanchetown Clay sediments, bears witness to these changing conditions.

This argument from tectonic pattern makes the Moorna Formation Upper Pliocene (a conclusion reached by Marshall in this volume on the evidence of vertebrate fossils) and the Blanchetown Clay/Chowilla Sand complex Upper Pliocene to Lower Pleistocene, if we can define what that means. This will be attempted in the next section which deals with the Plio-Pleistocene boundary. Fig. 3 shows post-Eocene sedimentation to have been regular until post-Bookpurnong times, after which an appreciable thickening of sediments occurred in the Lake Victoria region. The Bookpurnong Beds are uppermost Miocene in the study area as judged by the fauna from the Tareena well, already discussed. However, it should be noted that this formation over its very wide distribution is somewhat diachronous (Lawrence 1966, p. 534), apparently due to the slow retreat of the sea in the Murray Basin from E. to W. The argument from the tectonic pattern is thus consistent with the other methods of dating.

3. *Plio-Pleistocene Boundary*

Discussions about which beds are Pliocene and which Pleistocene have little meaning under present circumstances, unless one states what is accepted as the boundary. Shotton (1967) and others have pointed out that various interpretations of the boundary fall between 1·75 and 3·5 m.y. A review of the Plio-Pleistocene boundary in Australia has recently been made (Gill 1972b).

In 1948, INQUA defined this boundary by unanimous vote, so the procedural position is unequivocal. The chronometric dating and extrapolation of this horizon is the problem. In the writer's opinion, the best approximation on present evidence is the dating of the boundary at about 1·8 m.y. This is used temporarily in order to make objective what is meant in this paper by the terms Pliocene and Pleistocene.

In the section on palaeoclimatology the changes in climate are described. These have general chronologic significance, as also do the changes in flora that accompanied them. Important changes in fauna also occurred, but these have yet to be elucidated before they can be used for definitive dating. Changes in soil type also accompanied changes in climate, and these are described in the accompanying paper on palaeopedology.

4. *Radiocarbon Dating*

The following dates were obtained from assays of materials from the study area:

1. **Modern (ANU-423).** Wood charcoal from small shoots in surficial layer indurated with secondary carbonate. Associated with an Aboriginal midden of mussel shells *(Velesunio ambiguus).* The site is on a fan forming part of the hamada on the NW. side of Lake Victoria, about 0.4 km N. of J. May's camp near the lake windmill on Noola Station, N.S.W., Anabranch Military map ref. 422,800. The result dates Aboriginal occupation of the site, provides a maximal date for the latest lithification by secondary carbonate, and proves the modern age of the widespread gullying that cuts the indurated layer.
2. **180 ± 80 yr B.P. (GaK-2511).** Charcoal from midden of *Velesunio* shells on the N. side of the polythene water pipeline from near the Talgarry Station homestead to Lake Victoria, N.S.W. The site is on high ground (near top of ridge with *Casuarina* copse) overlooking the salt lake behind the lunette (Field sample CHA/253). Dates Aboriginal occupation, and in a general way the uncompacted sandy soil in which it occurred.
3. **770 ± 150 yr B.P. (GaK-3217).** Finely disseminated carbon from core taken in floor of Moorna East oxbow (billabong) below soft loose sediments and overlying a highly compact mottled zone (B horizon of paleosol) of pre-oxbow land surface. Collected 23 May 1969. Recovered carbon only 0·7 gm so the date could contain an unexpected error. However, the date is in keeping with the recent age of the oxbow inferred from sharp banks and low talus slopes. Moorna Station, W. of Wentworth, N.S.W.
4. **1320 ± 80 yr B.P. (GaK-2008).** Charcoal from large Aboriginal midden of *Velesunio* shells beside a prominent track S. of the pipeline on Talgarry Station on a low dune associated with the inland limit of the lunette complex, W. of the salt lake and fenceline. Collected 22 April 1968. Illustrated in Gill 1969, p. 177, fig. 2.
5. **1660 ± 110 yr B.P. (Gak-2512).** Charcoal from Aboriginal midden on the S. side of the pipeline track mentioned under (2) but E. of *Casuarina* copse at top of slope, Talgarry Station, N.S.W. In uncompacted sandy soil, SW. of dam (at gate in fence).
6. **1930 ± 80 yr B.P. (GaK-2007).** Charcoal from Aboriginal oven with calcrete ovenstones in sand on top of hill near Salt Creek SE. of Dickie's Gate beside copse of trees in NE. corner of Scrub Paddock, Kulcurna Station, N.S.W. Collected 28 April 1968.
7. **3580 ± 370 yr B.P. (ANU-420D).** Collagen of Aboriginal bones from burial in top of channel border dune, Lindsay Island, Berribee Station (Fig. 5), Victoria. Sample CHA/174, site 2.
8. **4170 ± 200 yr B.P. (GaK-1432).** Collagen of Aboriginal bones (extended burial) from Site 16, Lybra Paddock, Keera Station, W. of Merbein, Victoria (Mildura Military Map ref. 481,779). In SE. Australia collagen is leached away after 5-6,000 yr so that bone datings are seldom possible on this fraction if beyond that age. The four samples from this site (GaK-1430-3) are intrusive burials, and although reasonably sized samples were provided the yield was sub-standard. As a result GaK-1431 was measured under low gas pressure and 1432-3 were diluted with dead carbon. The dates may therefore not be accurate, but it is noted that where two skeletons occurred one above the other, the ages are in the correct order, viz. 4170 and 4400 yr.
9. **4400 ± 220 yr B.P. (GaK-1433).** Same type of material and same site as foregoing sample. Extended burial.
10. **5350 ± 290 yr B.P. (GaK-1431).** Ditto. Flexed burial.
11. **5840 ± 90 yr B.P. (GaK-1429).** Charcoal closely associated with loosely flexed Aboriginal skeleton, Brown's Paddock (Fig. 38), Keera Station, Victoria. Mildura Military Map ref. 469,777.
12. **5900 ± 550 yr B.P. (GaK-1430).** Collagen of Aboriginal bones from Site 5, Lybra Paddock, Keera Station, Victoria. This was a sitting burial. The samples from Keera Station were selected to cover various types of burial.
13. **6360 ± 140 yr B.P. (GaK-2416).** *Velesunio* shells from Aboriginal midden in red paleosol between the Nulla Nulla Sand and Talgarry Sand (members of the Lake Victoria Sand formation) where no inter-Member erosion has occurred. This is therefore a minimial date for the Nulla Nulla Sand. Site 50, Nulla Station, on lunette on E. side of Lake Victoria, N.S.W.
14. **7200 ± 140 yr B.P. (GaK-2513).** Small log of *Eucalyptus largiflorens* (Black Box) determined by Mr. H. D. Ingle, C.S.I.R.O., on wood structure. The engineer overseeing the test trench for a bituminous groundwater cut-off curtain at the Chowilla Dam

site (S. Aust.) showed me the heaps of sediment samples from various depths that he prepared for contractors. The fossil wood came from the sample covering 7·5-10·5 m from the surface (25-35 ft). The log was about 10 cm in diameter so that there is a small factor of biologic age.

15. **7210 ± 160 yr B.P. (GaK-1726).** *Velesunio* shells from Aboriginal midden between the A and B horizons of surface red (5 YR 6/4) soil on E. side of Triple Swamp Gulch, Moorna Station, N.S.W. The A horizon has therefore suffered stripping, then been replaced. This history is reflected in the lack of compaction in the A horizon, viz. 2-4 kg/cm^2 (B horizon 4-8·8 kg/cm^2 but harder in zones of secondary carbonate deposition). The shells were excavated by Sir Robert Blackwood from 0·5 m^3 of sandy soil during the survey of the gulch (Fig. 24).

16. **9160 ± 340 yr B.P. (GaK-2921).** Bone apatite from bones of extinct marsupial collected 30 Oct. 1968 by H. E. Wilkinson from Nulla Nulla Sand in lunette on Nulla Station, E. side Lake Victoria, N.S.W. The sample of about 700 gm included an imperfect tibia, scapula and metatarsal of *Protemnodon.* Bones had a carbonate encrustation such as is not seen on bones from the Talgarry Sand. Site 50, from blow in interfluve 4-5 N. In view of the current discussions on apatite datings, this result should not be taken too literally. However, it is consistent in that it falls between the limiting dates for the Nulla Nulla Sand of 6,360 and 17,530.

17. **11,250 ± 240 yr B.P. (GaK-1062).** Selected thick pieces of well-preserved *Velesunio* shell from base of large Aboriginal midden on top of high cliff on left bank of Murray River at Redcliffs, Victoria (34° 19'S, 142° 17'E). The cliff sections a high terrace. The antiquity of the midden was originally surmised from the degree of compaction, and that the midden was sectioned by the high cliff.

18. **12,600 ± 1300 yr B.P. (ANU-404B).** Charcoal from Aboriginal mussel shell midden associated with sample 404A (dated 24) which dated 17,530 yr. Sample was only 7% of requirement.

19. **14,200 ± 790 yr B.P. (NZ R2729/1).** Earthy carbonate from 0·6-0·9 m in auger hole (No. 2) sunk through top of an E-W. dune of the Woorinen Formation c.1 km SSW. of Berribee Station homestead (Fig. 10), NW. Victoria. (Sample CHG 88/33). Dr. T. A. Rafter, D.S.I.R. Institute of Nuclear Sciences, advised that the concentration of CO_2=10·5%, and $\delta^{13}C$-2·6‰.

20. **15,300 ± 500 yr B.P. (GaK-2515).** Charcoal from large Aboriginal midden in Nulla Nulla Sand containing also *Velesunio* shells (date 23), bones including *Onchogalea frenata*, a gastrolith and a quartzite scraper. The site is near the end of the track shown on the Ana Branch Military map that finishes at the N. shore of Lake Victoria. The ruins of an hotel stand there. and the midden is c.1 km E. of the old hotel, Nulla Station, N.S.W. The midden was still partially covered by compact Nulla Nulla Sand as seen in Fig. 48. The midden measured 13 x 6 m and was very compact. It was 15 cm thick and stratified with lighter and darker layers. Site 52, sample CHA/248. Some burnt bone was present. Bones are rare in shell middens as the vertebrates were usually cooked in the ovens represented now by small heaps of burnt stones with charcoal. This may be the reason why bones of a small animal only were found in this site. The midden site was surveyed to a Chowilla Dam Survey bench mark, which had a compass bearing of 148° therefrom, was 100 m (328 ft) distant, and 4·1 m lower. This is the N. limit of the lunette, which cuts out at the ridge traversed by the track to the old hotel. W. of that is a large erosion amphitheatre which we called the Old Hotel Amphitheatre.

21. **15,900 ± 275 yr B.P. (ANU-405).** Shells of *Velesunio* from an Aboriginal midden in a stratified context in the lunette on the E. side of Lake Victoria, N.S.W. The midden is at the head of gulch 18 on Nulla Station near the marker peg N18. A small mesa of Nulla Nulla Sand stands over the midden to a depth of 4·55 m. The flat top is due to a paleosol. The sample (CHA/330) was excavated from the midden. Human bones were found at the outcrop of the midden, and it appeared that they could come from nowhere else as they were in among the loose shells, but they were not *in situ.*

450

22. **16,400 ± 560 yr B.P. (GaK-3218).** Earthy but solid carbonate (i.e. sand lithified with carbonate) from section of E-W. dune exposed on the W. roadcut of the Calder Highway (Melbourne to Mildura), 3·2 km N. of Ouyen, Victoria. Sample from B horizon of paleosol 76-94 cm from surface. Another paleosol 0·7 m lower in the dune was not dated (see morphology section re dunes). Collected 15 May 1969.

23. **16,720 ± 260 yr B.P. (ANU-422).** *Velesunio* shells from Aboriginal midden c.1 km E. of old hotel site on N. shore of Lake Victoria. See date 20 above for charcoal from same site, and discussion of chronology. Sample CHA/248.

24. **17,530 ± 320 yr B.P. (ANU-404A).** *Velesunio* shells from second last gulch in lunette on SE. shore of Lake Victoria, Talgarry Station, N.S.W. Sample from red paleosol in Nulla Nulla Sand (Fig. 44) where a blowout occurred later infilled with Talgarry Sand. These blowouts may have taken place during the Postglacial thermal maximum (see date 13 above). Sample CHA/320. δ C^{13}%δ 0·0 ± 2·0. When this date is taken with No. 13, it can be seen that the top of the Nulla Sand varies from 6,500 to 17,500 yr according to how deep erosion has cut into that Member.

25. **18,200 ± 800 yr B.P. (GaK-2514).** Aboriginal midden consisting of compacted fine charcoal with mussel shells in hollow in sand of gulch (Fig. 47) on NW. shore of Lake Victoria (Noola Station), N.S.W., near fossil bettong bones. Sample CHA/289. This is the oldest midden dated in this area. With time the pieces of charcoal of a midden break down and become a compacted mass of fine carbon. After weaken-

ing by bacterial action (surfaces progressively retrograded by oxidation of the carbon to carbon dioxide), the charcoal collapses and compacts as a result of ground pressure.

26. **27,500 ± 700 yr B.P. (N.Z. R2729/4).** Soil carbonate from near carbonate nodule quarry between 309 and 310 mileposts on E. side of Calder Highway S. of Hattah and Mildura, Victoria. The road is cut through an E-W. dune. An auger hole was sunk through the dune to obtain *in situ* samples of sediments and paleosols (see log and comment in section on dunes under Geomorphology). X-ray showed the mineral to be calcite, and that quartz was present.

27. **27,800 ± 1900 yr B.P. (GaK-1727).** Outer 5 mm of large carbonate soil nodule (c.12 cm diam.) consisting of laminated calcite. This zone encloses an older generation of small nodules (date 30). Sample from bank at N. end of Moorna E. oxbow (Site 13), Moorna Station, N.S.W. At this site, carbonate nodules are excavated for roads.

28. **28,000 ± 1800 yr B.P. (GaK-1728a).** Inner part (5-10 mm) of laminated cortex of soil carbonate nodule from Moorna E. oxbow (date 27). The difference in figures between assays 27 and 28 does not necessarily mean that there is an appreciable difference in age. See discussion in paper on palaeopedology. The core of this same nodule was beyond the range of the radiocarbon dating method used (date 30).

29. **31,300 ± 1,200 yr B.P. N.Z. R2729/2.** Soil carbonate from auger hole 2 in E-W. dune on Berribee Station, NW. Victoria (detail under date 19), belonging to the Woorinen Formation. Depth 2·64-3·17 m.

30. **>31,700 yr B.P. (GaK-1728b).** Small nodules formed most of the soil carbonate nodule used for assays 27, 28 and 30 from Moorna Station, N.S.W. This sample from the centre of this compact calcitic nodule was beyond the assay range.

31. **>34,300 yr B.P. N.Z. R2729/3.** This is the third soil met in the auger hole through the E-W. dune on Berribee Station, Victoria, and is that occupying the surface of the terrain before the dune was built. See discussion of dunes in section on Geomorphology.

Comment: This is a small grid of dates for so large an area, but more were not possible. The dates are of course in "radiocarbon years" pending corrections (such as that for the half life of C14). The disparity between dates of over 30,000 yr assayed on marine carbonate, and dates on the samples given by the U/Th method, cause one to critically consider the dates on terrestrial carbonate in this same time range. Some kind of cross check is required. In an attempt to do this, sets of samples from the study area were sent to two laboratories with different approaches to see if they could apply successfully the U/Th methods described by Kislitsina and Cherdyntsev (1967) and by Hansen and Stout (1968). No positive results have been obtained so far. Nevertheless, it must be significant that the many carbonate C14 terrestrial dates known to me, all fall in the correct order where there is stratigraphic superposition. I introduced dating of terrestrial pedologic carbonates in 1964 when working on the geology of the Talgai Cranium (Darling Downs, S. Queensland). At that time, carbonates were not usually believed to be of any use for radiocarbon dating, but as no other materials were then available, it was decided to try them out. The reasoning was that the bedrock had been leached by lateritization, and that the carbonate in the shells and nodules originated in Tertiary basalt in the headwaters of the streams. This was taken into solution, so releasing the original carbon dioxide. The mollusca in the stream incorporated the CaO in their shells, but using modern carbon dioxide. Assay of modern mussels from the same river system collected prior to atom bomb tests proved this to be so (Institute of Nuclear Sciences, N.Z.). Such shells in stream terraces were used for dating. Fossil shells incorporated in riverine sediments are dissolved by soil acids, and the CaO redeposited in the B horizon as nodules, utilizing soil air. Such nodules were the second type of material used for dating.

In addition to the stratigraphic series, centres and outer layers of some nodules were dated. These also gave dates in the correct order of age, and up to 2,000 yr difference was found between outer layer and core. The mineral was calcite, and petrologic examination by C.S.I.R.O. (Dr. G. Baker) showed that no re-crystallization had occurred.

In putting perspective into events in the study area, the radiocarbon dates elucidated certain processes. For example, the dynamics of the region are such that all the Quaternary sands are of similar grade (see section on sedimentation). The radiocarbon dates show that with time there is an increase in compaction for such sands when in similar environments.

5. *Paleosols*

The significance of these pedoderms for

chronology and palaeoecology is discussed in an accompanying paper.

6. *Fluorine Test.*

The Chief Chemist of the Division of Agricultural Chemistry, Mr. J. O'Brien, kindly arranged for the analysis of a series of fossil bones collected during the Chowilla Project, and the results are given in an accompanying paper by Mr P. J. Sinnott. For chronology the Fluorine Indices (for definition see Gill 1954) and the percentage of nitrogen are significant. These figures with stratigraphic detail and some interpretation are set out below. The sample numbers are as in the Sinnott report.

1. Piece of fossil fish from 0·9-1·2 m above Chowilla Sand, in the erosion amphitheatre S. of the homestead on Noola Station, situated on the NW. side of Lake Victoria, N.S.W. Site 6.
2. Fragments from large marsupial pelvis in Moorna Formation (or base of associated Chowilla Sand, which were not distinguished at the time), Fisherman's Cliff, Moorna Station, N.S.W. Site 13.
3. Bone from Chowilla Sand under Blanchetown Clay at Bone Gulch, Moorna Station, N.S.W. Site 12.
4. Fragments of *Procoptodon goliah* from Rufus Formation on the property of Mr. J. Curtis, 'Karawinna', on Boy Creek, Lot 22 Parish of Tulillah, Victoria (Fig. 4).
5. Fragments of large marsupial from Rufus Formation between Frenchmans Creek and the Wentworth-Renmark road, Dunedin Park Station, N.S.W. Site 10.
6. Fragments of marsupial bone from interfluve N14/15, lunette on E. side of Lake Victoria, Nulla Station, N.S.W. in Nulla Nulla Sand. Site 8.
7. Fragment of *Procoptodon goliah* from Nulla Nulla Sand, Talgarry Station, N.S.W. Site 9.
8. Piece of bettong bone from Aboriginal midden in Nulla Nulla Sand, E. of Old Hotel site, Nulla Station, N.S.W. Site 7.
9. Marsupial bone from Talgarry Sand, 0·9-1·2 m above base of formation at interfluve 13/14N, Nulla Station, N.S.W. Site 8.
10. Fragments of human skeleton lightly cemented with carbonate in the surficial 'indurated layer' of a hillwash fan in the erosion amphitheatre SW. of the homestead, Noola Station, NW side of Lake Victoria Site 6. Sample CHA/288.
11. Fragments of human skeleton (field number 6/0) collected 26 Apr. 1967 from Lybra Paddock, Keera Station, N.W. Victoria. CHA/35.
12. Fragments of human skeleton (field number 1/B), Brown's Paddock, Keera Station, N.W. Victoria. CHA/8.
13. Fragment of holotype of *Zygomaturus victoriae* (S. Australian Museum P4986) from Lake Victoria Station at the time it consisted of all the country in the Lake Victoria area. Mr. K. Crozier of 'Warrakoo' and Mr. D. Harvey of 'Nulla' kindly checked the matter, and the well from which the fossil came (depth '45-60 feet') was probably to the north of the lake. The formations of the riverine tract are not involved, so it must have come from the Blanchetown Clay, the Chowilla Sand or the Moorna Formation. It did not come from the first formation, because it is brown in colour and not whitish like the bones found therein; also the bones are undisturbed whereas those from the Blanchetown Clay seen by us are distorted due to movements of the clay (which contains montmorillonite). In the study area the Chowilla Sand interdigitates freely with the Blanchetown Clay. The Fluorine Test and the Nitrogen Test do not distinguish between the Chowilla/Blanchetown and the Moorna formations, so it cannot be said (on this evidence) whether the holotype comes from the Chowilla Sand or the Moorna Formation. However the Chowilla Sand is always oxidized and the Moorna Formation usually not, so the fossil (being brown) is more likely to belong to the Chowilla Sand. So far efforts to locate the exact site have not been suc-

cessful, but if they are, then the depth will give some indication which formation is involved.

14. Fragment of bone from National Museum of Victoria specimen P29500.
15. Fragment of bone from National Museum of Victoria specimen P28882.
16. Fragment of bone from National Museum of Victoria specimen P29502.

Specimens 14-16 are from the Moorna Formation and associated Chowilla Sand, Fishermans Cliff, Moorna Station, N.S.W. Site 13.

The results of the assays according to formations, and the radiocarbon dates where available (for control), are:

	Formation	*C14*	*Fluorine Index*	*% Nitrogen*	*Sample number*
A.	Indurated layer (no formational name)	<200 yr	2.28	0.226	10
B.	Talgarry Sand	<6400 yr	6.86	0.026	9
C.	Nulla Nulla Sand	6400-18,000+ yr	6.62	0.043	6
			9.73	0.020	7
			1.89	—	8
D.	Rufus Formation	? Mid. Pleistocene	5.53	0.045	4
			5.09	0.041	5
E.	Intrusive in Rufus Formation	4000-6000 yr	2.45	0.041	11
			1.81	0.118	12
F.	Blanchetown Clay	Pliocene/Pleistocene	16.94	0.019	1
G.	Moorna Formation	Late Pliocene	16.42	0.013	2
			20.58	0.007	3
			14.09	—	14
			17.15	—	15
			19.06	—	16
	? Moorna Formation		14.80	—	13

The Fluorine Indices as a group are high, but the reason for this is not understood. However, they show an increase with age, and the percentage of nitrogen falls off with age. There is thus a general relative dating, but the chief value of such tests is to discover samples that are out of context. Thus clearly sample 8 is wrong. The bone belongs to a bettong, a burrowing marsupial, so perhaps it is intrusive. The human remains in the Rufus Formation (samples 11 and 12) are also clearly intrusive. The disconformity between the Blanchetown Clay and the formations in the incised river valley is made clear by the jump in fluorine indices and the drop in nitrogen percentages. The Blanchetown Clay and the Moorna Formation are conformable, the former overlying the latter. This is reflected in the very similar figures.

Sedimentation

"To see a world in a grain of sand" William Blake (Auguries of Innocence)

The development of geophysics made possible the discovery of the fundamental structure of the earth's crust. Investigations led to the differentiation of the heavier oceanic crust and the lighter continental crust. So evolved the concept of the continents as rafts of sial floating in a sea of sima.

Later, the demonstration of a far greater horizontal mobility for the crust than previously envisaged, the discovery of mid-oceanic ridges with evidence of spreading, and the need for some other explanation of tectonics and vulcanism than as expressions of a shrinking earth, led to new credence being given to Wegener's hunch of continental drift. Wegener did not prove it, nor is it now proved. However, it is true that the supporting evidence has been very greatly increased. During the past 10 years there has been such a rapid accumulation of data and so fast a flurry of changing ideas that this is clearly no time for dogmatism.

The calving of land masses (e.g. Australia from a southern supercontinent), and the collision of continents are vast traumatic events which must leave major lesions on the skin of the earth. On the other hand, there are many long slow warpings of the crust with associated accumulation of sediments that are of quite a different order of dynamics. Such is the Murray

Basin. Although cheek by jowl with the massive fault system that yields the Mt. Lofty Ranges of Precambrian sediments, the Murray Basin has very slowly subsided over more than 120 m.y. The mean rate through this period in the deepest part of the basin (and so the fastest sinking) is only 1 m per 120,000 yr. At this maximal rate, the land would sink only 8·3 cm in the whole of the Holocene (10,000 yr). It is no wonder that the surface of the Murray Basin is so flat and its dynamics so low. This is the background against which to view the grain size analyses. However, the factor of tectonicity (cf. Krumbein and Sloss 1963) has been qualified by climatic change (see section on palaeoclimatology), for a humid region has become a semi-arid one.

Grain Size Analyses

Unless otherwise stated, the sieving has been carried out by Mr. K. G. Simpson and assistants under the direction of Dr. A. W. Beasley, Curator of Minerals, National Museum of Victoria, whose research lies in this field. The integration and interpretation of these results are the writer's responsibility. I am indebted to Dr. Beasley for his considerable assistance. Mrs. J. Dudley checked the calculations and drew most of the histograms.

Enquiries indicate that communication would best be served for those in the many disciplines interested in this report if the results are given in the form of histograms. These are numbered, and in general follow from the oldest to the youngest sediments. Wentworth's size classification is used.

Parilla Sand

This formation outcrops in the Murray River cliff beside the Kulcurna Station homestead (Fig. 19). The sediments are gray (unoxidized) and without reaction to acid. The formation was sampled at two levels:

1. Clayey sand at base of cliffs. Sample CHG/78.
2. Same 3·6 m from top of formation (6 m exposed). CHG SS 115.

Histograms 1-2 (Fig. 49) show well-sorted sediments with better sorting higher in the formation. Histogram 2 is remarkably like that for the overlying Chowilla Sand (Histogram 9, Fig. 53) which suggests that one was derived from the other, or both came from a common source by a transport system of like dynamics.

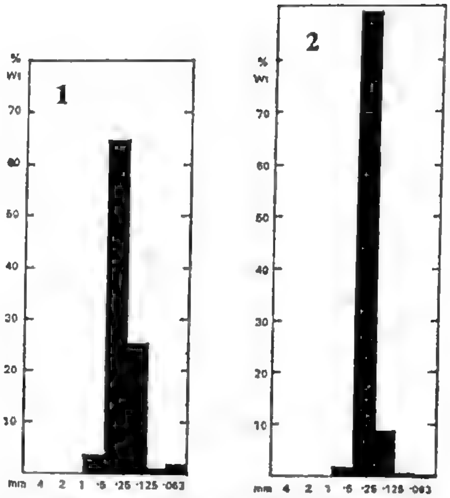


Fig. 49—Grain size analysis histograms of Parilla Sand. 1 = Gray clayey sand at base of Murray R. cliffs, Kulcurna Station homestead, Cal Lal. N.S.W. Sample CHG 78. Site 2 = Same site. 3·7 m below top of formation. Sample CHGSS 115. For section see Fig. 19.

Moorna Formation

Histograms 3-6 (Fig. 50) are of Moorna Formation sediments in the section at the W. end of Fishermans Cliff (fossil bone site). Histograms 4-5 are of the same sample, and their close similarity is taken to mean reliability of analysis. They are unusually coarse for this region, and represent a riverine channel deposit. The deposit cuts out laterally. The base of the Moorna Formation outcrop at this site is finer (Histogram 3) with the medium and fine sand columns dominant as against the dominant coarse sand column for the sediments above.

Histogram 6 represents an unusual sediment because many of the grains are coated with dolomite (see Segnit, this volume). The inference is that these were eroded from a bed of sandy dolomite such as occurs at Triple Swamp Gulch (Fig. 24). The grains are well rounded. Some fines make the histogram slightly bimodal. Figure 51 shows the change in grain

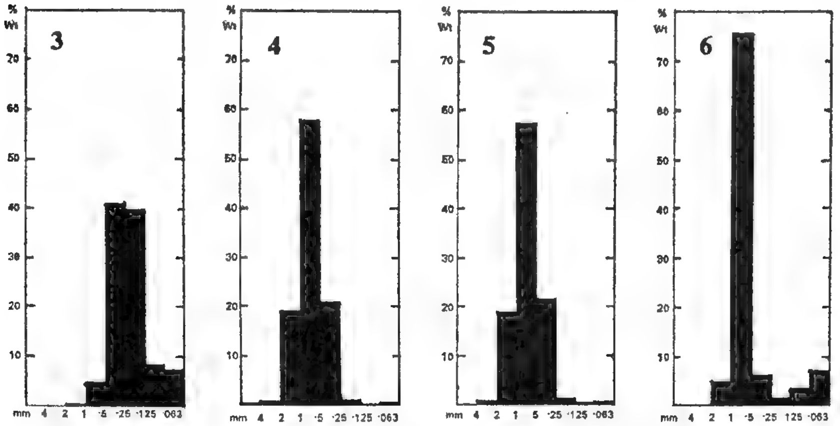


Fig. 50—Grain size analysis histograms of Moorna Formation sediments (see also Figs. 50-51). 3 = W. end of Fisherman's Cliff, N. bank. Murray R., Moorna Stn., W. of Wentworth, N.S.W. Fig. 30. Sample CHGSS 113. Site 13. 4 = Same site, clean sand at top with some grains dolomite-coated. See Fig. 51. The level is between the lower clayey part of the Moorna Formation and the overlying yellow Chowilla Sand with fossil tortoise. The sample is part of the matrix that carried the fossil bones described by Marshall in this *Memoir*; it came from c. 105 cm above the clayey sand (CHGSS 111).

size analysis when the dolomite is stripped by acid treatment.

Histograms 7-8 (Fig. 52) are of Moorna Formation sediments in two places other than Fisherman's Cliff. A brown (7·5 YR 5/6) sand at the base of the exposed section at Triple Swamp Gulch W. of Fisherman's Cliff gave histogram 7. The dominant grade is medium sand. Histogram 8 is of the thick light-gray sands in the Merbein Cliffs (Fig. 36). The grades of sand vary. This sample is from 0·6 m below the siliceous paleosol in the section at The Lookout. The spread of grades is rather similar to that of the Chowilla Sand into which it merges. The coarser sediments with current bedding occur lower in the section.

Chowilla Sand

Histograms 9-16 (Fig. 53) cover this formation, following sites from W. to E. No. 9 is remarkably similar to that of the underlying Parilla Sand (No. 2) and suggests derivation from it, or the same source. No. 10 shows the variation in the top of the formation. The major part of this deposit is homogenous with a slightly columnar structure. The top has sub-

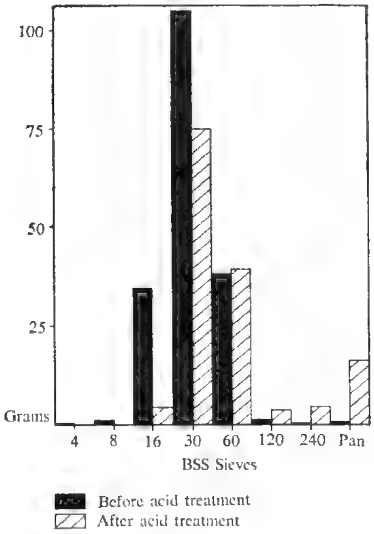


Fig. 51—Grain size analysis histogram of sediments from the Moorna Formation at the W. end of Fisherman's Cliff, Moorna Station, N.S.W. Site 13. Histograms 4-5 show the analysis of natural sand, while this figure shows the effect of stripping off the dolomite coatings.

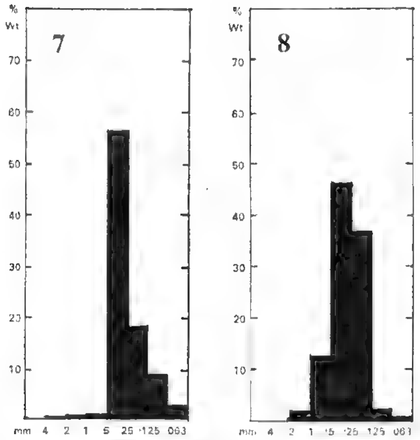


Fig. 52—Histograms 7-8 of grain size analysis of Moorna Formation sediments. 7 = White sand 0·6 m below top of formation (i.e. below the paleosol) in the cliff section at The Lookout, Merbein, V. Fig. 36. Sample CHGSS 108.

parallel bedding. No. 11 is from Nampoo Station in the Murray River cliffs where the Chowilla Sand is a narrow bed in the Blanchetown Clay sequence.

Dr. A. W. Beasley reports on the mineral composition of samples 13 and 14 as follows: "The sand samples are composed essentially of light mineral grains, most of which are quartz. Feldspar grains are generally cloudy from alteration, and some are almost opaque; they are often lath-shaped. White mica occurs in minor amounts; it is more common in the finer size-grades of the samples. The quartz grains in samples 13 and 14 are commonly iron stained in a patchy fashion, and inclusions are very numerous. The larger grains are subrounded to rounded, while the finer size particles are usually subangular. The degree of roundness of most grains indicates that they have had a fairly long detrital history."

Heavy Minerals

Dr. Beasley reports that "the assemblages consist essentially of the same species, but there are differences in their relevant proportions, the significance of which could only be determined by more numerous analyses. The suites indicate granitic and metamorphic source rocks. The opaque minerals are relatively common, while the non-opaque heavy minerals include zircon, tourmaline, hornblende, apatite, rutile, sphene, anatase, staurolite, garnet, epidote, andalusite, cassiterite and biotite. The degree of roundness of the heavy mineral grains varies considerably; most are subrounded or subangular. The weight percentages of heavy minerals in the 0·25 mm to 0·125 mm size grains are as follows:

Sample	13	0·20%
Sample	14	0·25%
Sample	17	0·13%."

Sample 14 has the lowest degree of sorting of all the Chowilla Sand samples tested. This may be due to being so close to the clay facies. At Bone Gulch there is a series of alternating thin beds of clay and sand. The sands have concentrations of fossil bones, and the highest percentage of heavy minerals. Ostracods are common, indicating shallow water. Some of the bones are worn. It is considered likely that these beds were deposited by an oscillating level of the lake, the higher levels washing the sands and concentrating bones and heavy minerals. The partly articulated bones of a large diprotodontid were found in the base of the Blanchetown Clay. The animal may have been mired in shallow water.

Histogram 15 is of a sample from the Yelta cliffs which likewise has a comparatively poor degree of sorting . Histogram 16 is of a sample from the Merbein cliffs, and shows a dominance of medium and fine sand grades seen also in other samplings of this formation.

Blanchetown Clay

Histograms 17 and 18 (Fig. 54) are of samples from this formation (with the clay removed). Sample CHG SS/42 (No. 17) is from just above the ossiferous Chowilla Sand at Bone Gulch, Moorna Station, N.S.W. The sediments are poorly sorted with three modes—clay (69%), silt and fine sand. Histogram 17 for material greater than clay size is bimodal, with a primary mode in the fine sand grade and a lesser one in the silt. Dr. Beasley reports "The

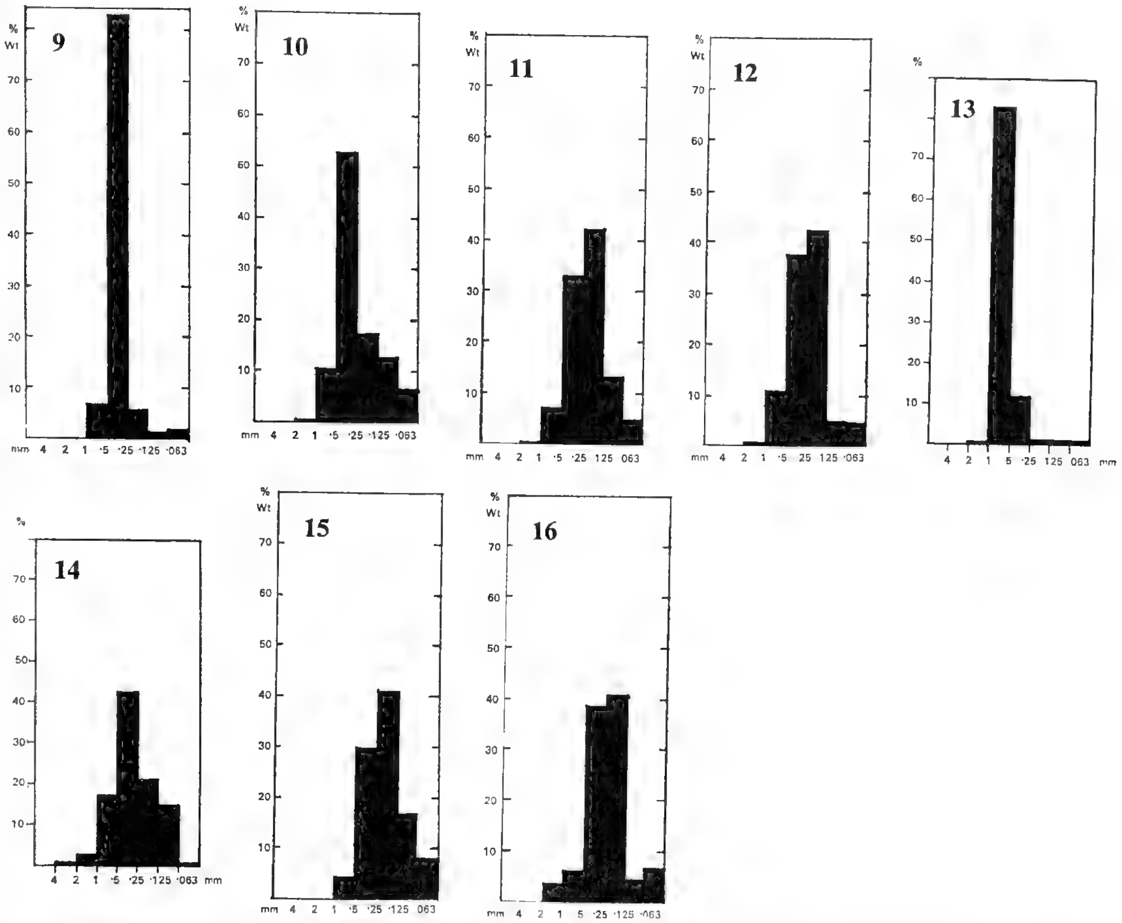


Fig. 53—Histograms 9-16 of grain size analysis of Chowilla Sand. 9 = Upper part of Murray R. cliff at Kulcurna Stn. homestead, Cal Lal. N.S.W. Site 3. Fig. 19. Sample CHG 38. 10 = Same site, but sample from cliff top. CHG 77. 11 = Under Blanchetown Clay at foot of cliffs below Nampoo Stn. homestead. E. of Cal Lal, N.S.W. 12 = Sand below Blanchetown Clay, Middle Gulch. Noola Erosion Amphitheatre, Noola Stn., NW. side of Lake Victoria. Site 6. W. end, Fisherman's Cliff, Moorna Stn., N.S.W. Sample CHGSS 43, 15 = Middle of sand formation at top of cliffs, S. bank Murray R., at Yelta, Vict. See Gill on Palaeopedology, this *Memoir*, Fig. 1. 16 = Chowilla Sand between Blanchetown Clay and Moorna Formation in Merbein Cliffs, Vict., at The Lookout. Fig. 36. Sample CHGGS 114.

material greater than clay size is mainly quartz. Although inclusions are numerous in the quartz, the grains are comparatively free from iron staining. They are cleaner than in the sand samples. Ostracods are fairly common. Felspar grains are cloudy from alteration. Flakes of white mica are present but not common. The suites of heavy minerals indicate granitic and metamorphic source rocks. The weight percentage of heavy minerals in the 0.25 mm to 0·063 mm grade is 0·13. The underlying Chowilla Sand has 0·25%".

A sample of Blanchetown Clay from the Murray River cliffs at Nampoo Station, E. of Cal Lal, N.S.W. had 90% clay, so the range of clay content in this formation is considerable. Within the Blanchetown Clay are bands of sand which vary from white (well-washed) to greenish gray (containing clay).

Histogram 18 (Fig. 54) shows the sample CHG 151a (after washing) from a sandy layer in Noola erosion amphitheatre on the NW. shore of Lake Victoria. The analysis is dominated by the fine sand grade, and so represents

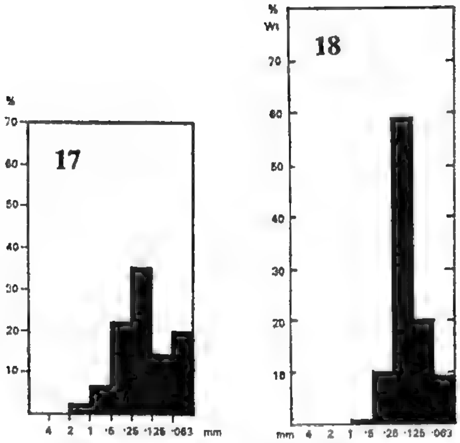


Fig. 54—Histograms 17-18 of grain size analysis of washed samples of Blanchetown Clay. 17 = Clay from Bone Gulch. Moorna Stn. (Fig. 34), W. of Wentworth, N.S.W. 18 = Sandy layer in this formation with *Corbiculina*, Noola Erosion Amphitheatre, Noola Stn.. NW. side Lake Victoria (Fig. 17), N.S.W. Sample CHG 151a.

an environment of low dynamics. The bed had numerous shells of the bivalve *Corbiculina.*

Woorinen Formation

1. *Berribee Station Dunes.* An auger hole put down through an E-W. dune provided the samples which yielded the histograms 19-26 (Fig. 55). They all show good sorting with fine sand being the dominant grade. All the histograms are unimodal except 24 and 26 which are bimodal. It would be interesting to know if the bimodal zones can be traced from dune to dune.

2. *Hattah Dune.* Histogram 27 (Fig. 55) of sediment from the Hattah district, but in the same system of E-W. dunes, gave a similar result.

Histogram 24 (sample 36 from 3·4-4 m) is the best sorted (SO=1·3) yet is bimodal with 21·59% silt. The base of the dune is represented by histogram 25 (sample 37 from 4·6-5·5 m) which is skewed to the fine side. Samples 36 and 37 had 11·9% and 5·70% of clay removed before the grain size analyses were commenced. The clay content is believed to be (1) partly blown in with the original sediments as clay skins on sand grains, and as aggregations, and (2) partly added later from dust storms. The increase in clay content at the base is believed to be due (1) partly to washing down of clay by rain water, and (2) partly to the dune overlying a very clayey substrate which probably contributed a good deal of clay in the initial stage of dune building. Histogram 26 (sample 38 from 5·5-5·7 m) represents part of the old terrain on which the dune was built. It shows the typical dominant fine sand column, but with a silt column almost as high. The histogram is thus bimodal. To gain the sample for grain size analysis 57·92% of clay was removed from the field sample. A floodplain lagoon or a lake is indicated, because 83% of the field sample was fine enough to pass through BSS sieve 240.

Rufus Formation

1. *Dunedin Park Station, N.S.W.* Figure 37 provides a surveyed section across the margin of an outlier (number 1 in Fig. 5) of this formation near Frenchman Creek. This outlier is a remnant of a higher Pleistocene terrace of the Murray River. Its sediments are now oxidized to a red colour, that contrasts with the greenish gray sediments of the present floodplain. No doubt the Rufus Formation was once that colour too. Four auger holes were sunk along the section line. For logs see under Rufus Formation in stratigraphy section. Histograms of the sediment analyses are given in Fig. 56 as follows:

Histogram	28	Outlier 1, Auger 1,	0-20cm
	29		20-46cm
	30		61-69cm
	31		0·94-1·02m
	32		1·22-1·52m
	33		1·80-1·88m
	34		1·88-2·13m
	35		2·21-2·36m
	36		2·67-2·74m
	37		2·74-2·90m
	38		3·00-3·07m
Histogram	39	Outlier 1, Auger 2,	0-15cm
	40		53-61cm
	41		86-94cm
	42		1·22-1·35m
	43		1·75-1·83m
	44		3·76-3·84m

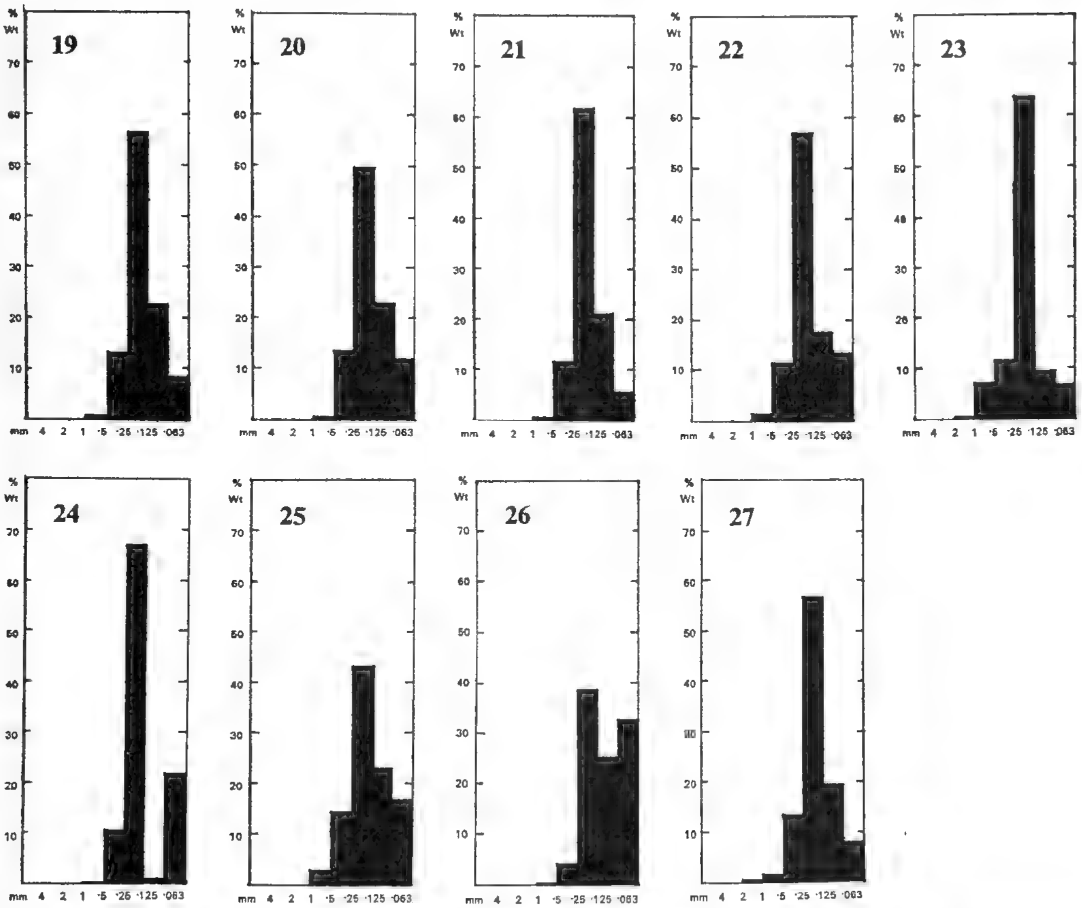


Fig. 55—Histograms 19-27 of grain size analysis of sediments from the Woorinen Formation (Pleistocene E-W. dune system). 19-26 from Auger hole 2 through dune c 3 km SSW. of Berribee Stn. homestead, Vict. CHGSS sample nos. in brackets.
19 = 0 — 0·38 m (32), 20 = 0·6 — 0·9 m (33), 21 = 2·3 — 2·6 m (34), 22 = 2·6 — 3·2 m (35), 23 = Repeat of 22, 24 = 3·4 — 4 m (36), 25 = 4·6 — 5·5 m (37), 26 = 5·5 — 5·7 m (38), 27 = Sediment from 2·6 — 2·9 m (118) in auger hole through E-W. dune, Calder Highway between mileposts 309 and 310, near Hattah, N. Vict.

Histogram	45	Outlier 1, Auger 3,	3·07-3·15m
	46		3·35-3·51m
Histogram	47	Outlier 1, Auger 4,	3·51-3·63m
	48		4·11-4·27m
Histogram	49	Outlier 1, Auger 4,	0-15cm
	50		36-46cm
	51		0·99-1·07m
	52		1·30-1·37m
	53		1·57-1·65m
	54		1·83-1·88m
	55		2·29-2·36m
Histogram	56	Outlier 2, Auger 1,	53-61cm
	57		1·32-1·42m
	58		2·44-2·54m

2. *Keera Station, Victoria.* Figure 38 is a cross-section of Rufus Formation structures at the E. end of Brown's Paddock (Site 17) Keera Station, Victoria, that at first glance look like dunes. They are extensions from a Pleistocene terrace remnant. Three auger holes were sunk as follows:

Auger 1 46^{+}cm of gray well-washed mobile sand (which the auger could not lift) at the N. end of section (Fig. 38), local channel.

Auger 2 For site see Fig. 38.
50cm Red (2·5 YR 4/8) slightly clayey sand forming hardpan (surface sand deflated)
50cm Reddish brown (5 YR 5/4) and such clayey sand with glaebules of earthy carbonate up to 2 cm diameter. Gradually becomes grayer with depth till light gray (10 YR 7/2). Carbonate rich to 80cm then decreasing to 90cm

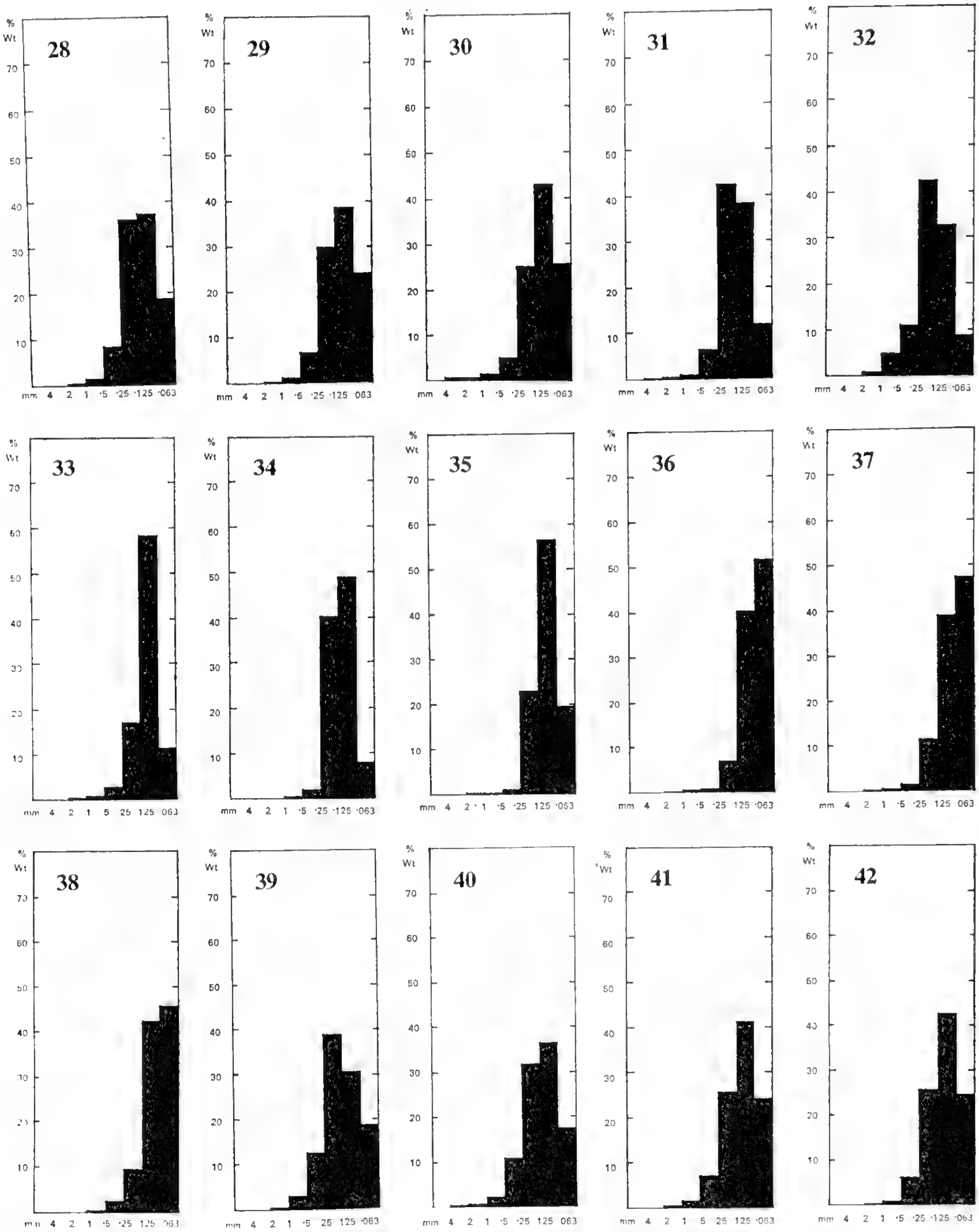
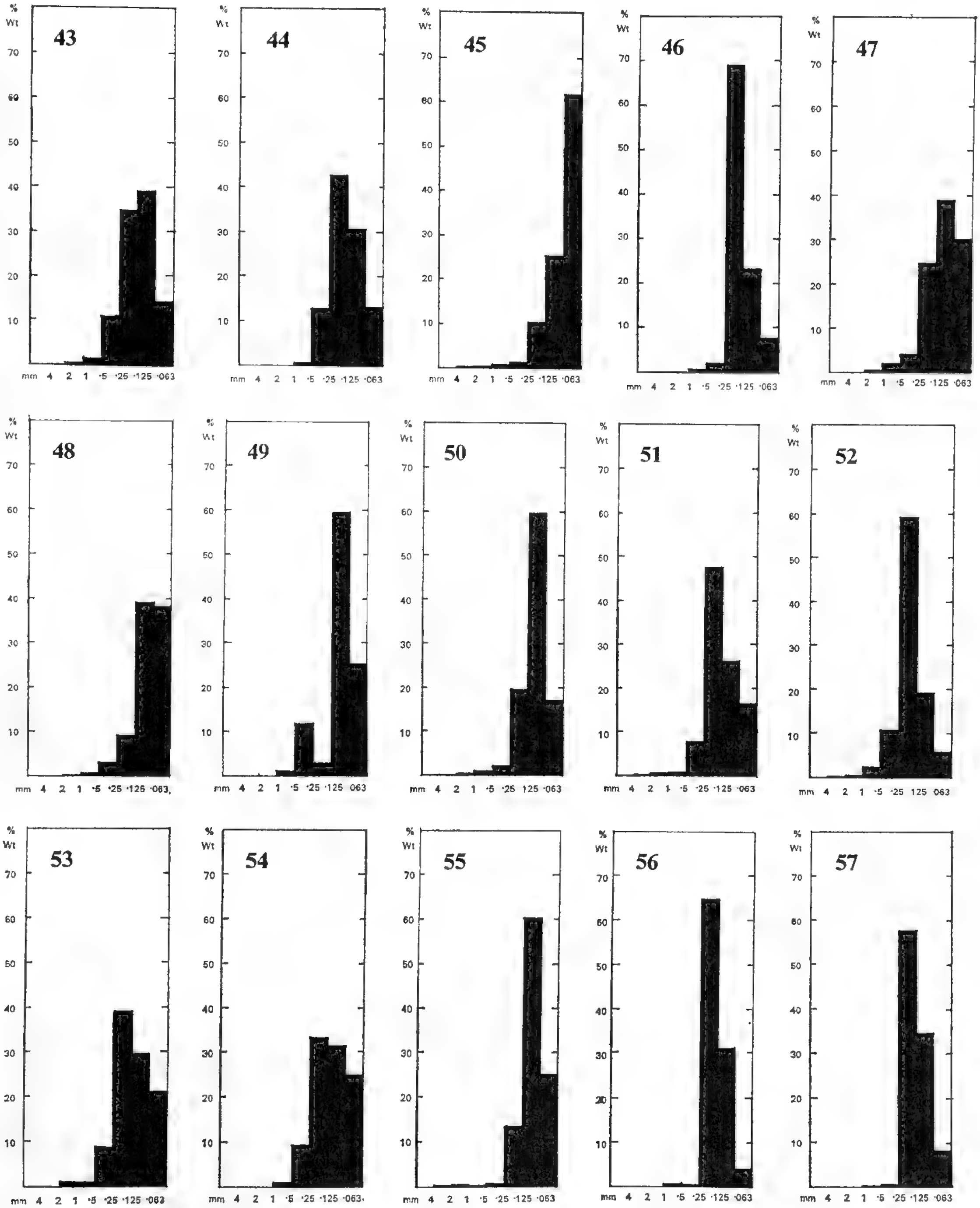
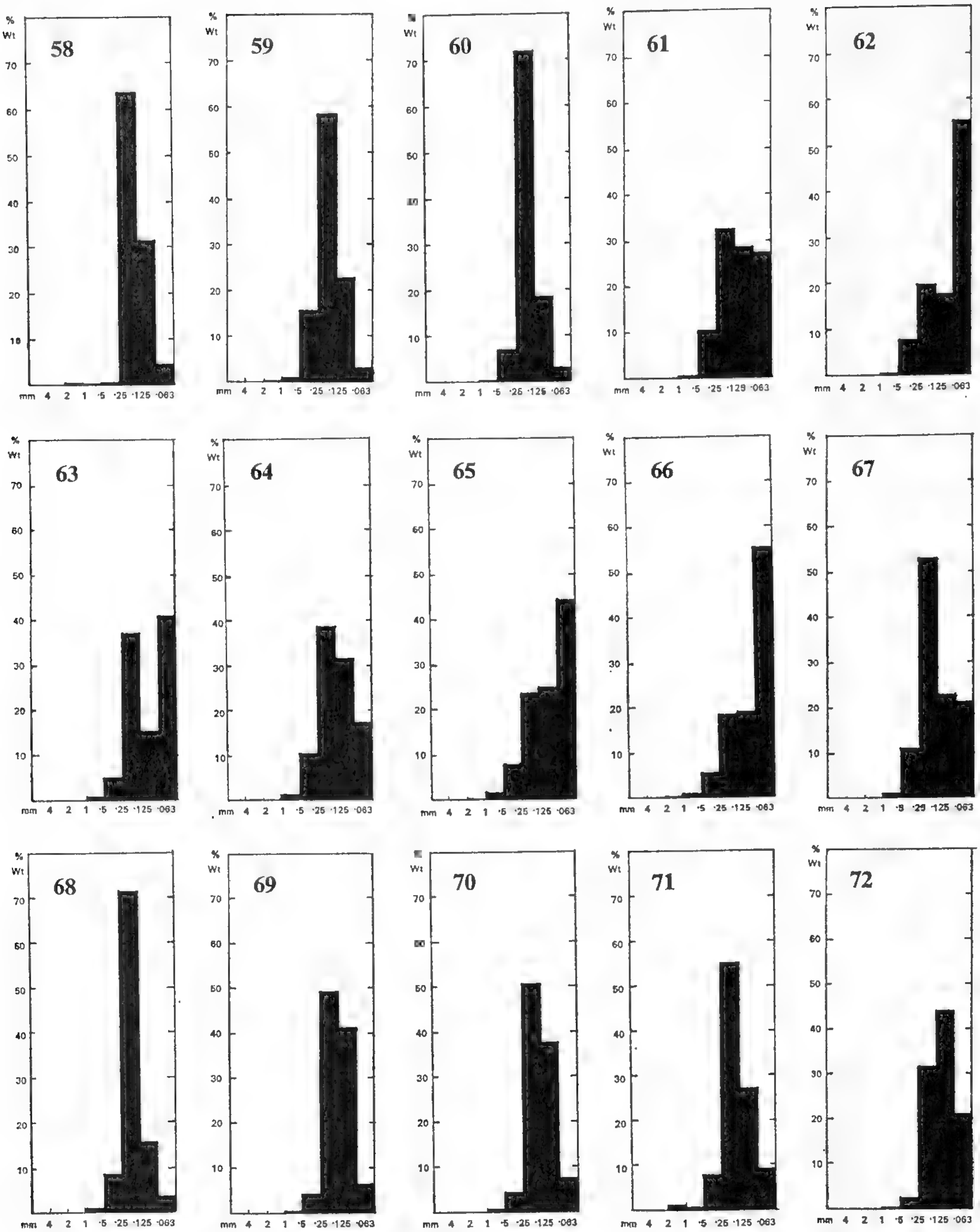


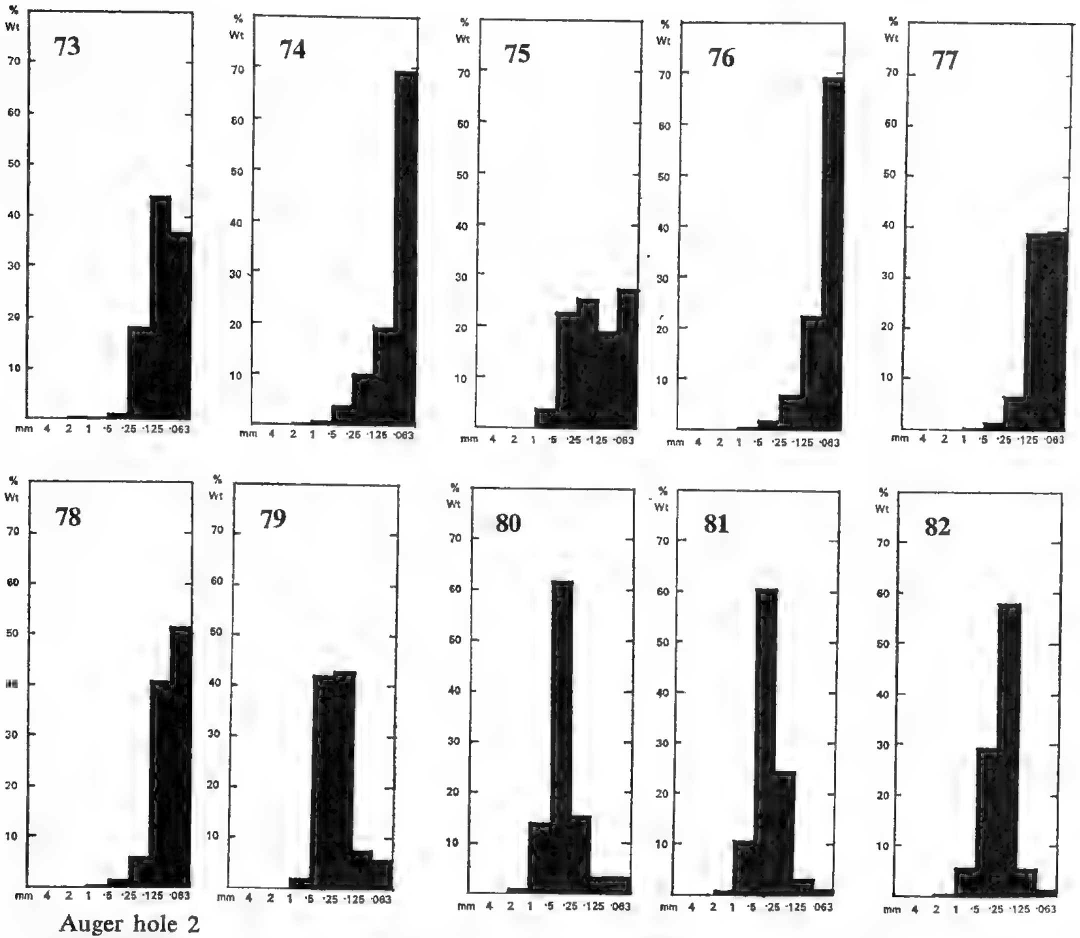
Fig. 56—Histograms 28-82 of sediments from the Pleistocene Rufus Formation (riverine). CHGGS sample numbers in brackets. Samples from auger holes in residual marked 1 on map in Fig. 5, Dunedin Park Station, N.S.W.
28 = 0 — 0·2 m (74), 29 = 0·2 — 0·46 m (75), 30 = 0·6 — 0·68 m (76), 31 = 0·94 — 1·2 m (77), 32 = 1·2 — 1·5 m (78), 33 = 1·8 — 1·9 m (79), 34 = 1·9 — 2·1 m (80), 35 = 2·2 — 2·4 m (81), 36 = 2·67 — 2·74 m (82), 37 = 2·74 — 2·89 (83), 38 = 3 — 3·07 m (84). See histograms 57-58.
Auger hole 2
39 = 0 — 0·15 m (85), 40 = 0·53 — 0·6 (86), 41 = 0·86 — 0·94 m (87), 42 = 1·22 — 1·35 m (88), 43 = 1·75 — 1·83 m (89), 44 = 3·76 — 3·83 m (91).



Auger hole 3A
45 = 3·5 — 3·63 m (100), 46 = 4·1 — 4·3 m (101).
47 = 0 — 0·15 m (92), 48 = 0·36 — 0·46 (93), 49 = 0·99 — 1·07 m (94),
50 = 1·3 — 1·37 m (95), 51 = 1·57 — 1·65 m (96), 52 = 1·83 — 1·88 m (97),
Auger hole 3
53 = 2·29 — 2·36 m (98).
Just W. of residual marked 2 in Fig. 5
54 = 0·53 — 0·6 m (102), 55 = 1·32 — 1·42 m (104), 56 = 2·44 — 2·54 m (105).
Auger 1, residual 1 (see histograms 28-38)
57 = 3·04 — 3·14 m (106), 58 = 3·35 — 3·5 m (107).



Surface soil, residual marked 1 in Fig. 5
59 = Loose red sand at surface, 60 = Sardpan below.
Brown's Paddock (Site 17), Keera Stn., Vict. (Fig. 38), auger hole 1
61 = 0·76 — 0·91 m, 62 = 1·98 — 2·13 m, 63 = 2·28 — 2·44 m.
Auger hole 4
64 = 0 — 0·41 m, 65 = 0·51 — 0·76 m, 66 = 1·02 — 1·32 m, 67 = 1·83 — 2·06 m,
78 = 2·44 — 2·69 m.
Lybra Paddock (Site 16), Keera Stn., Vict. Auger hole 1
69 = 0 — 0·43 m, 70 = 0·43 — 0·91 m, 71 = 0·91 — 1·6 m, 72 = 1·6 — 1·68 m,
73 = 2·74 — 2·92 m.



Auger hole 2
74 = 0·1 — 0·46 m, 75 = 0·46 — 0·66 m, 76 = 0·66 — 1·17 m (samples 74-76 were from the middle of the depth ranges given), 77 = 1·17 — 1·27 m, 78 — 1·27 — 1·55 m, 79 = 2·29 — 2·54 m, 80 — 2·74 — 3·5 m, 81 = 3·5 — 3·66 m, 82 — 4·57 — 4·78 m.

1·12m	Zone of incipient mottles, some areas tending towards grayish green and others towards brown. At 2 m from surface gradual change to less clayey sediment
51cm	Light yellowish brown (2·5 Y 6/4) sand. Probably more oxidized because more permeable
13cm	More clayey and with light gray (10 YR 7/2) mottles.
84^{+}cm	Light yellowish brown (2·5 Y 6/4) sand.

Total depth 3·6m.

Auger 3	33·2m N. of skeletons (C14 site).
30cm	Red (10 YR 5/6) loose sand without carbonate
45cm	Red hardpan of same sand with clay; no carbonate
28cm	Light gray to light brownish (10 YR 6/1) clay with off-white masses of earthy carbonate up to 1·5cm in diameter. Selenite crystals (needles)
94cm	Similar sediment almost without carbonate
46^{+}cm	Same with pyrolusite.
2·43m	Total depth.

Auger 4	On section line (Fig. 38) near samphire flat.
25cm	Reddish brown (5 YR 5/3) slightly clayey sand forming a hardpan, merging to
5cm	Same with carbonate merging to
30cm	Pink (5 YR 7/3) to pinkish gray (7/2) clayey sand with glaebules of earthy carbonate pinkish white (7·5 YR 8/2), merging to
15cm	Light brownish gray (10 YR 6/2) sand with less carbonate merging to
30cm	Clayey sand, some colour, reduced carbonate; pyrolusite and gypsum appearing; merging to
1·07m	Pale red (2·5 Y 6/2 and such) clayey sand
19^{+}cm	Light brownish gray (2·5 Y 6/2) to light 7/2) sand with yellow (2·5 Y 7/3 at 2·8m from surface.

Total depth 2·31m.

Auger 5	On section line (Fig. 38) in middle of samphire flat.
33cm	Red sand blown and/or washed over flat, and some gray sand intermixed

15cm	Yellowish red (5 YR 5/6) clayey sand, some pyrolusite at top.
43cm	Pinkish gray (7·5 YR 3/2) sandy clay with numerous patches of earthy carbonate
56⁺cm	Light brownish gray (10 YR 6/2) sandy clay with a little carbonate and with selenite (rich at 1·07m from surface)
1·47m	Total depth

Auger 6	On crest of south ridge of section line (Fig. 38).
13cm	Light red (2·5 YR 6/6) slightly clayey sand forming hardpan
20cm	Red (2·5 YR 4/6) sand
1·27m	Pink (7·5 YR 7/4) sand with earthy carbonate glaebules up to 4cm diameter. Amount of carbonate reduced from 84 cm from surface merging to
46cm	Reddish yellow (7·5 YR 6/8) sand with finely divided carbonate
18cm	Dark brown (7·5 YR 4/4) sand with selenite and pyrolusite (which makes the sediment darker), merging over 5cm to
8cm	Pink (7·5 YR 8/4) sand with no appreciable amount of carbonate
1·19m	Light brown (7·5 YR 6/4) clayey sand—a marked increase in clay content
25⁺cm	Reddish yellow (7·5 YR 6/6) sand.
3·76m	Total depth.

The sediments from anger holes (2) and (3) were subjected to grain size analysis and the results are given in histograms 59-68 (Fig. 56) as follows:

Histogram	59	Site 1, loose red surface sand	
	60	Site 1, auger 3,	0-38cm
	61		76-91cm
	62		1·98-2·13m
	63		2·29-2·44m
	64	Site 1, auger 2,	0-41cm
	65		51-76cm
	66		1·02-1·32m
	67		1·83-2·06m
	68		2·44-2·69m

The auger holes prove that the profile is a stable one except for the mobile surface sand which was probably stable also before occupation by flocks of sheep. The profile has been stable long enough for the carbonate soil to develop, which (judging by the soil on the E-W. dunes) is at least 16,000 yr old. This soil occurs (with modification) on the flat as well as the ridges (Fig. 38), so no strong erosion can have occurred there during that period. Local information is that floods reach the end of the flat but do not penetrate between the ridges across the section line. The erosion of the former terrace (judging by the soil) must therefore have occurred prior to 16,000 yr ago. The terrace was eroded before the Lake Victoria Sands were deposited because they onlap outliers. However, more than halfway up in these largely subparallel blowout sands is a paleosol with a midden dating 17,530 yr B.P. If that figure is doubled, a chronology like that of the Lake Mungo lunette is obtained. So the erosion of this system may have occurred in the earlier half of the Last Glacial. It would take a long time because hundreds of square kilometres of this terrace have been excavated, as Fig. 4 shows.

The sediments are all fine and very well sorted, but the stratigraphy is very variable as one would expect in a riverine environment. This applies to the Coonambidgal Formation, and to the sediments being laid down at the present time. Figure 61 shows variation in clay content from 0·50% to 68·23%, and in carbonate content from 0 to over 30% by weight. The grain size analyses were done on clay-free and carbonate-free sediments.

On Keera Station, auger holes were sunk also at Site 6 (Lybra Paddock) where many Aboriginal skeletons were excavated, and some dated by C14. They came from burials intrusive in the surface of the eroded Rufus Formation. Figure 57 shows auger 1 at the level where the skeletons were found, and auger 2 at the level

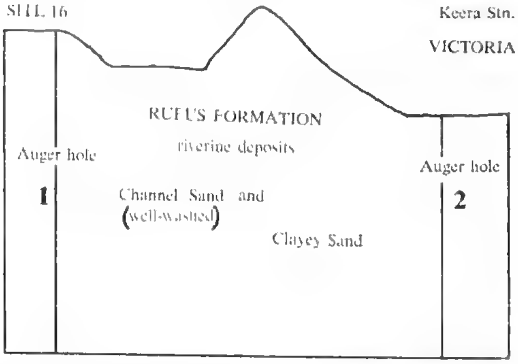


Fig. 57—Eroded Rufus Formation in Lybra Paddock, Keera Station, beside Wallpolla Creek, Vict. The site of Auger hole 2 is the 1956 floodplain of the Murray River. All sediments oxidized except 1·17 m of sediments on the above floodplain. Both auger holes were 4·8 m deep; only Auger hole 1 is shown fully. Line between auger holes = 57° magnetic.

of high floods as in 1956. This level was surveyed to a bench mark on the River Road by Sir Robert Blackwood and Mr. Gerald Douglas This showed it to be about the same height as the site of auger 1 in Brown's Paddock (Fig. 38). The logs of the auger holes are as follows:

Auger 1	On terrace.
43cm	Strong brown (7·5 YR 5/6) micaceous (as all the sands here) grading to
48cm	Reddish yellow (7·5 YR 6/6) sand with patches of earthy carbonate up to 0·5cm diameter, grading to
1·55m	Similar sediments with carbonate concretions (irregular, elongate)
1·47$^+$m	Similar sediments with only traces of carbonate.
4·77m	Total depth.

Auger 2	On floodplain 0·82m lower.
10cm	Light gray (10 YR 7/1) silty sand
36cm	Dark brown (7·5 YR 3/2) to very dark gray (3/1) clayey sand, grading to
20cm	Grayish brown (2·5 Y 5/2) clayey sand with patch of earthy carbonate hard enough to grate an auger at times, grading slowly to
51cm	Yellowish brown (10 YR 5/6) slightly clayey sand, carbonate fading out at 84cm from surface, sharp break to
10cm	Very pale brown (10 YR 8/3) washed sand, probably a channel, sharp break to
28cm	Light gray (2·5 Y 7/3) to pale yellow (7/4) slightly clayey sand, sharp break to
10cm	Very pale brown (10 YR 7/3 washed sand, probably a channel, rapid change to
53cm	Pale yellow (2·5 Y 7/4) slightly clayey sand
10cm	Pale brown (10 YR 7/4) washed sand (channel?)
25cm	Light yellowish brown (10 YR 6/5-6) to brownish yellow sand
20cm	Mottled greenish gray (5 GY 6/1) to yellowish brown sand with clayey accretions, grading to
97cm	Yellowish brown (10 YR 5/4) washed sand
46cm	Darkish reddish brown (5 YR 2/2 and such) washed sand, sharp break to
15cm	Light gray to greenish gray (5 Y 7/1 to 5 GY 7/1) washed sand with yellowish red (5 YR 5/8) mottles, sharp break to
41$^+$cm	Yellowish red (top 3cm) to yellowish brown (10 YR 5/4) washed sand.
4·70m	Total depth.

Grain size analyses (Fig. 56) were carried out on sediments from these two drillings as follows:

Histogram 69	Site 16, auger 1,	0–43 cm
70		43–91 cm
71		0·91–1·60 m
72		1·60–1·68 m
73		2·74–2·92 m
Histogram 74	Site 16, auger 2,	10–46 cm
75		46–66 cm
76		0·66–1·17 m
77		1·17–1·27 m
78		1·27–1·55 m
79		2·29–2·54 m
80		2·74–3·51 m
81		3·51–3·66 m
82		4·57–4·77 m

Monoman Formation

The solitary sample (CHG 55) from this formation consists of the matrix round the fossil log used for radiocarbon dating. It came from the trench sunk for an experiment on a bitumen curtain designed to prevent underflow at the proposed Chowilla Dam (Figs. 39-40). Histogram 28 (Fig. 56) shows a channel deposit with the dominant column being very coarse sand (1-2 mm).

Coonambidgal Formation

This formation includes fine-grained lagoon (or oxbow) and floodplain sediments, channel sands and channel border dunes. Histogram 29 (Fig. 56) is of alluvial on the SW. shore of Lake Wallawalla that formed the matrix of skull 61-A. It is an admixture of all grades from coarse sand to silt inclusive. There is a doubt whether these sediments should be included in the Coonabidgal Formation, but time to investigate the point has not been available.

By contrast, histogram 30 (Fig. 57) is of alluvium at the base of auger hole 1 sunk through a channel border dune. It is essentially a silt, being skewed strongly to the fine side. Histogram 31 is of the matrix of skeleton 53-A at the W. end of Lindsay Island, Berribee Station, NW. Victoria. Once again there is a typical dominance of the fine sand grade, yielding a strongly unimodal histogram.

Figure 12 shows a section of a channel border dune in the Coonambidgal Formation on Lindsay Island, Berribee Station, NW. Victoria. The logs of auger holes 1-3 are given in the geomorphology section where dunes are discussed. Auger hole 4 showed the following:

10cm	Pinkish gray (7·5 YR 6/2) well sorted sand washed from dune (surface).
36cm	Light gray (10 YR 7/1) poorly sorted sand with grain sizes coarser than in dune.
33cm	Lighter gray (N7) sand, very poorly sorted and with clay balls up to 7cm diameter. Gradual change to
8cm	Light brownish gray (2·5 Y 6/2) sand with a few streaks of light olive brown (2·5 Y 5/4).

28cm	Off-white (near N8) well-washed sand, very difficult to bring up.
61$^+$cm	Same but light gray (2·5 Y 7/2).

An analysis of the N8 sand from this riverine sequence was carried out (histogram 87). The usual dominant column appears, but offset one grade to the coarse side because it is from a channel deposit. The mobile sand prevented further boring. Berribee auger hole 5 was sunk E. of the section shown in Fig. 11. The site is a red gum hollow, which is filled by present flood waters situated about 110 m SSE. of the peg at auger 1.

10cm	Dark brown (10 YR 4/3) well sorted sand. Juvenile soil formed by accumulation of humus, merging to
10cm	Grayish brown (10 YR 5/2) similar sand, merging to
10cm	Pale brown (10 YR 6/3) sand, merging to
28cm	Light gray (10 YR 7/2) well washed sand, merging to
63cm	Off-white (2·5 Y 8/2) mobile sand gradually changing to
23cm	Very pale brown (10 YR 7/3) mobile sand, gradually changing to
1·22m	Light yellow brown (10 YR 6/4) mobile sand
15cm	Pale brown (10 YR 6/3) sand, and light-gray (5 Y 7/1 to 5 GY 7/1) clayey fine sand merging to
36cm	Very pale brown (10 YR 7/3) sand
13cm	Same with gray clayey fine sand as above
8cm	Pale brown (10 YR 6/3) sand without gley
8cm	Same with patches of yellow (10 YR 7/6)
13cm	Brown (10 YR 5/3) clayey sand
25cm	Same with gray clayey fine sand as above.
36cm	Brown sand without gley.
33$^+$cm	Brown with mottles of gray and strong brown (7·5 YR 5/6) concentrating in places to dark reddish brown (5 YR 3/2) sand, but the latter disappears 15cm from the bottom, leaving brown and gray sand only.
4.53m	Total depth.

An analysis was carried out of a sample 71-74 cm from the surface (off-white mobile sand), and the result appears in histogram 88 which is bimodal. Dominance moved back to the fine sand grade. Sand is blown from the channels to form the dunes, and sand from the dunes is washed back into the channels. The grade of sediments dominating the channel deposits is limited by its dynamics. The sands are well sorted (So = 1·46) as usual.

Nulla Nulla Sand

This is the lower member of the Lake Victoria Sand (lunette). Fig. 58 presents three histograms characterized by a dominant column of fine sand—the typical grade in this river system of low dynamics. The sediments are finer than are usually found in dunes, but this is what the river transport provided. The light weight of the sand grains, the limited supply brought in by the river, and the persistent seasonal W. winds are no doubt the chief contributory factors to the subhorizontal position of most of these sands. Ample winds moving a light sand of limited quantity kept the dune in a state of almost constant blowout.

Histogram 89 (Fig. 58) is from Talgarry Station just S. of the border fence with Nulla Station, below our bench mark 1 (CHG SS 110). Histogram 90 is from a clayey horizon (CHG 98) with badlands erosion on Nulla Station (N14/15). Histogram 91 (Fig. 58) is for the matrix of a fossil marsupial from Talgarry Station, and is dominated by the very fine sand grade.

Talgarry Sand

This is the upper member of the Lake Victoria Sand (lunette). Histograms 92 and 93 (Fig. 61) show two types of sediment found in the Talgarry Sand that have parallels in the underlying Nulla Nulla Sand.

Sediments in relation to Facies. The sorting coefficients of the sand fractions relative to facies

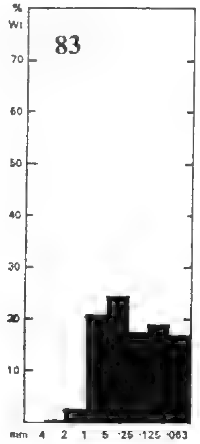


Fig. 58—Histogram of grain size analysis of Monoman Formation sediments from the cut-off trench at the Chowilla Dam location (Site 1). Sample CHG 55.

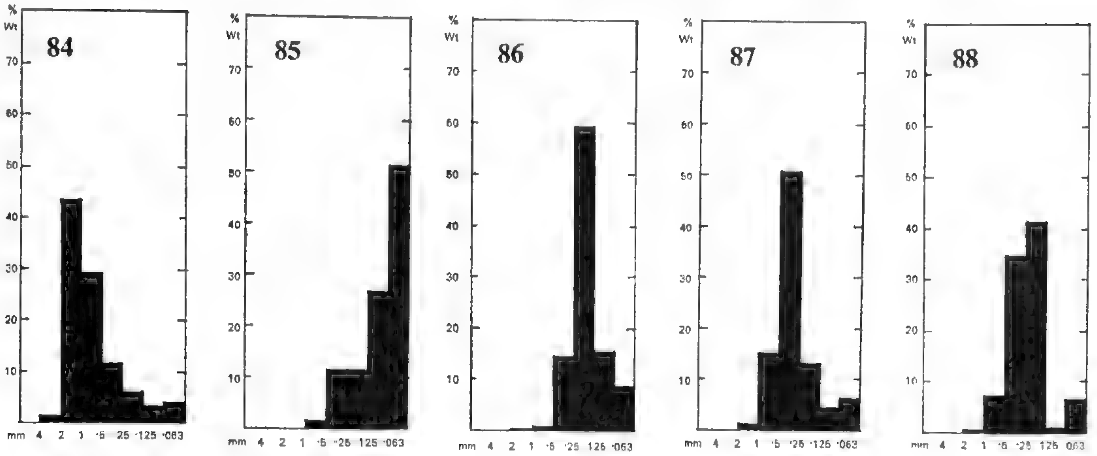


Fig. 59—Histograms 84-88 of grain size analyses of Coonambidgal Formation sediments. 84 = Matrix of Aboriginal skeleton 61A from SW. side of Lake Wallawalla (Figs. 14-15). Sample CHGSS 118. This is doubtfully referred to this Formation. 85 = Mottled clay from bottom of auger hole 1, c. 3 km SSW. of Berribee Stn. homestead under Woorinen Formation dune. This is almost certainly not Coonambidgal but the formation to which it belongs has not yet been determined. Sample CHGSS 31. 86 = Matrix of Skeleton 53A, W. end of Lindsay Island (Site 19). Coonambidgal channel border dune. Sample CHA 95. 87 = Off-white (2·5Y N/8) sand from auger hole 4, Lindsay Is., Berribee Stn., N.S.W. (Fig. 12) 0·86 — 1·14 m. Sample CHGSS 39, 88 = Same site, auger hole 5 sunk on E. side of channel border dune (Fig. 12) 0·66 — 0·74 m. Sample CHGSS 40.

are as follows (the number of So determinations is given in brackets):

1. *Riverine floodplain*	
Parilla Sand (2)	1·3–1·17
Rufus Formation (52) (omitting So 4·3)	1·20–2·55
Coonambidgal Formation (5) (omitting So 2·10 which doubtfully belongs to the formation)	1·22–1·46
2. *Riverine channel*	
Moorna Formation (5)	1·25–1·54
Chowilla Sand (6)	1·14–1·68
Blanchetown Clay, sandy facies (1)	1·27
3. *Lacustrine*	
Blanchetown Clay (1)	
4. *Dune*	
Woorinen Formation (9)	1·29–1·52
Nulla Nulla Sand (3)	1·53–1·60
Talgarry Sand (2)	1·44–1·77

The whole series is remarkably fine which can be attributed to long transport and no fresh sediments brought in during the long flows across dry country. The degree of sorting is remarkable. This can be attributed to the low dynamics cutting out the larger fractions, and the long transport ever improving the sorting. There is an enormous range in the percentages of carbonate and clay. Accumulation of carbonate is largely a pedogenic function. The variations in the clay content of riverine alluvia are such as are to be expected. In this semi-arid country, windblown fine sediments have been added later to waterlaid sediments.

Denudation. The mean denudation rate is remarkably low. Langbein and Schumm (1958) have studied the quantitative relationship between sediment load and annual precipitation, concluding that maximal sediment yield occurs in areas of 25-30 cm rainfall, to which our study region belongs. The authors measured solid load only. Ahnert (1970) points out that seasonal distribution of rainfall is important, and it certainly is in our Project area. Ahnert deals also with the significant factor of relief. 'The mean denudation rate in mid-latitude river basins is directly proportional to mean basin relief'. The very flat Murray Basin has minimal denudation. Many relict features such as the

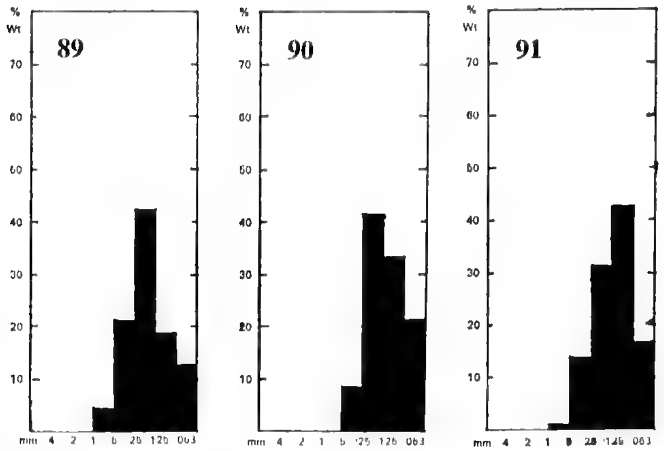


Fig. 60—Histograms 89-91 of grain size analyses of sediments from the Nulla Nulla Sand member of the Lake Victoria Sand Formation (Figs. 42-45). 89 = Nulla Nulla Sand from below bench mark 1 on S. (Talgarry Stn.) side of the boundary fence (Fig. 16). Sample CHGSS 110, 90 = Clayey sand with herringbone erosion, Gulch N14 (Fig. 16) interpreted as a fossil claypan. Sample CHG 98. 91 = Matrix of marsupial fossil from Nulla Nulla Sand, Lake Victoria Lunette, Talgarry Stn. Sample CHGSS 129.

Pleistocene E-W. dune system persist little altered. North of the Murray River and West of the Darling River, the terrain consists of the Pliocene/Pleistocene Blanchetown Clay with discontinuous surficial sand. A 'steady state relief' has been established.

Palaeontology

As most of the outcropping formations were deposited under semi-arid conditions, plant fossils are not common. The highly oxidizing environment (see Maher, this *Memoir* for climatology) is inimical to the preservation of plants. The ?water plants in the Blanchetown Clay at 'Warrakoo' have already been mentioned, and the fossil trees at the Chowilla Dam site. Blackburn (1971) has recorded a podocarp root from Telangatuk East, further S. in Victoria. Gill and Bethune (1967) obtained pieces of wood from a bore at Narrandera that dated 32,000 ± 1,200 yr and > 33,000 yr. Wood was obtained by Mr Bethune in a bore at Raak, Victoria. At Mildura wood from a depth of 10·7 m near the Psyche Bend pumping station dated 5,400 yr (NZ-196). Churchill (this *Memoir*) has recorded pollens and spores. The amount was small but further work in this field is projected because this flora marks the incoming of the semi-aridity. Near where the sample was collected for Dr Churchill, a thicker section was later revealed by removal of slope wash. This outcrop presented 1 m of black sediments, providing scope for serial study. The cliffs of Salt Creek at the S. end consist of Chowilla Sand with slump material forming a talus slope at the base that probably conceals Parilla Sand. The palynological site is where the Blanchetown Clay begins to lens in within the Chowilla Sand. The deposit is that of a lake shore.

The Animalia are better represented among the fossils. Marshall's paper in this *Memoir* describes the vertebrates, which can be compared with those from Lake Tandou in the same region (Merrilees, this *Memoir*).

The formations described have the following fossils:

1. *Bookpurnong Formation,* Cheltenhamian marine fossils of shallow water facies.
2. *Parilla Sand.* Samples of these floodplain sediments yielded no spores or other fossils, but as the beds are unoxidized and carbona-

ceous in some places, further search may find them.

3. *Moorna Formation.* Fish (including *Neoceratodus*), tortoise, ratite bird (egg shell), marsupials and ostracods.
4. *Blanchetown Clay* (and its limestone members). Fish, marsupials, worms (casts), molluscs and ostracods (McKenzie and Gill 1968).
5. *Chowilla Sand.* Fish, tortoise, marsupials, crustaceans (gastroliths) and ostracods. At Bone Gulch on Moorna Station, in the Chowilla Sand below the Blanchetown Clay are structures interpreted as burrows (Pl. 7).
6. *Rufus Formation.* Fish, ratite bird (egg shell), marsupials and rats. In Browns Paddock, Keera Station (Fig. 38), are 'fossil' formicaria. Noting a circular patch of carbonate rising 10 cm above the surface of the carbonate-free red sand hardpan, I sank an auger to investigate the anomaly, and found that a carbonate rich zone continued to a depth of over 50 cm. The structure was then excavated by spade, and recognized by K. N. G. Simpson as the former nest of a large ant such as the Bulldog Ant (*Myrmecobius*). The galleries attained a maximal diameter of 1·3 cm. The carbonate at the surface had been carried up by the ants from the B horizon of the soil, including pieces up to 1·2 cm long. We found a small species of ant no larger than 10 mm in length occupying the galleries in the top 2-5 cm of the abandoned formicarium.
7. *Nulla Nulla Sand.* Molluscs, reptiles, marsupials (including extinct genera and species), rats and man (skeletons and middens).
8. *Talgarry Sand.* Same range of fossils, but all living species.
9. *Monoman Formation.* Fossil wood and marsupials.
10. *Coonambidgal Formation.* Aboriginal burials and middens.

Aboriginal bones and middens along with some marsupial bones were found in the hamada on the W. side of Lake Victoria. As our investigation was only at reconnaissance level, there are probably many more palaeontological sites to be found. Certainly more fossils will come from a systematic treatment of the sites discovered.

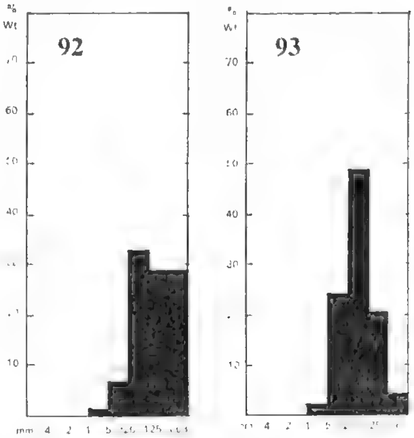


Fig. 61—Histograms 92-93 of grain size analysis of Talgarry Sand member of the Lake Victoria Sand formation.
92 ± Sample CHGGS 112 at BM 1, Talgarry Stn. just S. of boundary fence shown in (Fig. 16. 93 = Matrix of Skeleton A from Gulch S1 (Fig. 16), Talgarry Stn., E. side of Lake Victoria, N.S.W. Sample CHG 309.

Following very heavy rain, bones in the Nulla Nulla Sand can achieve consistency rather like that of cheese, and can be readily cut with a knife. On drying out, they become hard again. While plastic they can be deformed. A few workers in other countries have noted (pers. comm.) the same or a similar phenomenon, but no study of it has been discovered in the literature.

Palaeoclimatology

Je m'en vais chercher un grand peutêtre.

Rabelais

This subject is as difficult as it is important. For the former reason many avoid it. Adequate treatment involves great masses of detail plus unifying ideas. However, if all authors provided such palaeoclimatic data as they have, and passed on any ideas that occurred to them, we would be much further advanced in this large field of learning. The palaeoclimatology of the study area is approached in this way.

Terrestrial palaeoclimatology is more difficult than marine palaeoclimatology, because more variables exist. Local microclimates are pre-

Figure 62

Sedimentology

The Sorting Coefficient (So) is of sediment without carbonate or clay, unless otherwise stated. Perfect sorting = 1, 2.5 = well sorted, 3 = normally sorted, and 4.5 = poorly sorted (Trask.)

PARILLA SAND

Histogram	Sample	% Carbonate	% Clay	So	
1	78	0	2.92	1.30	Floodplain
2	115	0	13.86	1.17	

MOORNA FORMATION

Histogram	Sample	% Carbonate	% Clay	So	
3	113	2.18	27.65	1.54	
4	111^1	17.9	3.42	1.49	Dolomite removed from sand grains
5	111^2	-	-	1.36	Untreated sample; channel facies
6	118	12.26	0.56	1.25	
7	94	0	19.62		
8	108	0	2.88	1.45	

CHOWILLA SAND

Histogram	Sample	% Carbonate	% Clay	So	
9	38a	0	0.85	1.23	Channel facies
10	77	0	1.98	1.14	
11	109	3.66	11.87	1.48	
12	117	3.20	0.51	1.57	
13	41				Early tests; washings not weighed
14	43				
15	116	0	4.39	1.52	
16	114	0	18.16	1.68	

BLANCHETOWN CLAY

Histogram	Sample	% Carbonate	% Clay	So	
17	42	0	68		Normal facies; more clay sometimes
18	151a	21.95	18.35	1.27	Sandy facies with *Corbicula*

WOORINEN FORMATION

Histogram	Sample	% Carbonate	% Clay	So	
19	32	0	5.40	1.34	Dune facies
20	33	7.02	7.72	1.30	
21	34	3.38	13.01	1.34	
22	35^1	10.98	0.88	1.29	
23	35^2			1.29	Repeat
24	36	3.29	11.9	1.30	
25	37	11.87	5.70	1.52	
26	38b	0	57.92	1.31	Floodplain or lake of underlying terrain
27	118	30.14	2.34	1.37	

RUFUS ALLUVIUM

Histogram	Sample	% Carbonate	% Clay	So	
28	74	13.73	8.01	1.59	Floodplain facies Outlier 1, Auger 1
29	75	14.33	8.23	1.58	
30	76	10.71	26.15	1.52	
31	77	7.51	14.51	1.48	
32	78	5.27	10.77	1.37	
33	79	3.33	6.80	1.36	
34	80	5.16	4.40	1.50	
35	81	2.66	15.44	1.37	
36	82	2.07	42.08	1.37	
37	83	1.57	68.23	1.65	
38	84	0	22.97	1.46	
39	85	0	18.61	1.69	Outlier 1, Auger 2
40	86	7.14	20.95	1.60	
41	87	5.30	15.67	1.54	
42	88	4.37	15.86	1.55	
43	89	2.03	8.34	1.57	
44	91	0	8.47	1.57	
45	100	0	22.47	1.40	Outlier 1, Auger 3
46	101	0	4.62	1.20	
47	92	0	2.93	1.57	Outlier 1, Auger 4
48	93	5.93	54.28	1.54	
49	94	8.98	25.16	1.31	
50	95	0	5.59	1.29	
51	96	4.65	19.63	1.56	
52	97	0	8.88	1.33	
53	98	29.57	14.75		
54	102	6.82	59.98	1.72	Outlier 2, Auger 1
55	104	3.40	18.37	1.28	
56	105	0.61	2.38	1.29	
57	106	18.97	0.50	1.37	
58	107	30.09	9.62	1.51	
59	400	4.40	2.26		Site 1, Auger 1
60	401	1.6	12.9		
61	402	12.7	16.0	1.78	
62	403	0	63.9	2.55	
63	404	0	47.5	4.3	
64	405	0	18.6	1.61	Site 1, Auger 4
65	406	16.8	35.7	2.00	
66	407	5.3	39.08	2.04	
67	408	0	42.07	1.57	
68	409	0.93	3.80	1.28	
69	410	0	12.0	1.41	Site 1, Auger 1
70	411	0	6.4	1.41	
71	412	0	4.98	1.43	
72	413	0	4.0	1.45	
73	414	0	16.2	1.46	
74	415	0	69.2	1.41	Site 6, Auger 2
75	416	9.69	12.5	2.22	

Histogram	Sample	% Carbonate	% Clay	So	
76	417	2.11	2.62	1.52	
77	418	0	12.6	1.43	
78	419	0	18.6	1.50	
79	420	0	4.76	1.42	
80	421	0	3.05	1.33	
81	422	0	1.60	1.33	
82	423	0	2.25	1.06	
		MONOMAN FORMATION			
83	55				
		COONAMBIDGAL FORMATION			
84	215	18.80	9.98	2.10	Lake Wallawalla, doubtfully referred this formation
85	31	0	25.80	1.22	
86	95	1.68	15.5	1.34	
87	39	0	11.61	1.43	
88	40	0	3.70	1.46	
		NULLA SAND			
89	110	1.09	4.18	1.53	
90	98	7.42	6.53	1.60	
91	129	2.37	0.12	1.56	
		TALGARRY SAND			
92	309	0	2.30	1.44	
93	112	0	3.48	1.77	

valent. Living organisms have inbuilt adaptive mechanisms so that within limits they change with the changing environment. Climacteric events are sometimes of sufficient magnitude to leave a record of these atypical happenings, diverting attention from the more significant persisting characters of the terrain. The solution to this problem in our investigation was to consider evidence that was consistent over large areas of country. For example, the E-W. longitudinal dune system, once mobile but now immobile as a system, covers some 200,000 km². This extensive regional change in the status of sediments sensitive to effective rainfall and wind regime is a matter of prime palaeoclimatic importance. Another example is that beneath this semi-arid terrain, clogged with surficial carbonates and sulphates (proof of low humidity and little leaching), there lies a fossil lateritic profile (proof of high humidity and very deep leaching). Smaller changes of climate are harder to discern, but they are best deciphered in marginal areas where maximal change has occurred. Many misinterpretations of past climates have been due to lack of an adequate chronology. In the present study, the order of events is unequivocal, and progress has been made with chronometric measurements, but a great deal remains to be done. Thus, while the change from humidity to semi-aridity can be located in the stratigraphic succession, the time cannot be defined with any precision.

In SE. Australia, the palaeoclimatic history prior to the period represented by the rocks exposed in the study area may be generalized as follows:

1. *Cretaceous Frigid Supercontinental Climate*

It is widely held that Australia was attached to the Antarctic continent in the Cretaceous (Smith and Hallam 1970), that the south pole was nearby (Wellman *et al.* 1969), but higher temperature zones existed to the NW. (Gill 1972d and references), and that Australia drifted away from Antarctica in the Upper Cretaceous to Eocene (Veevers *et al.* 1971, Jones 1971). The high percentage of felspar (~ 40%) in the extensive Lower Cretaceous rocks of Victoria has long been a puzzle, but if the climate were frigid, this can be understood. Solitary pebbles of plutonic and metamorphic rocks and patches of gravel unassociated with current bedding, and not streamed out in lenses, may be drop pebbles from floating ice. In 1949 I observed with Mr A. A. Baker and others a cliff in the Cape Patterson area in S. Gippsland, E. Victoria, a large mass of laminated fine arkose about 4·5 m long with sharp broken edges, and fragments 'floating' in the surrounding matrix. This massive piece of rock was certainly not transported by water. It is completely out of character with the surrounding sediments and their dynamics; its edges are uneroded. At the time, the only solution I could conceive was that it fell from a cliff, but this could not be accepted by reason of the stratigraphy shown in the wide shore platforms and high cliffs. To explain this as a rock mass dropped from melting ice into the sediments on the floor of a lake explains all the factors observed. More recently, varves have been found at Koonwarra, with fossils that appear to represent winterkill (Waldman 1971).

2. *Mid-Tertiary Subtropical or Tropical Rainforest Climate*

The marine biota is a warm one, while on land there were large reptiles and thick rainforests that formed extensive brown coals (Gill 1961a-b, Duigan 1966, Dawson and Sneddon 1969, Dawson 1970). At first, the climate appears to have been without seasonal change in humidity, so that deep leaching with kaolinization occurred to 60 m. These conditions created the *Nunawading Terrain* (Gill 1964) and were succeeded by a seasonal monsoonal type climate that yielded laterite. It is significant that at that time (Pliocene, Gill 1971) laterite developed both land- and seaward of the Dividing Range. The type section of Cheltenhamian marine sediments on the coast at Melbourne is lateritized, as also are sediments overlying the Cheltenhamian fossil bed at Tareena Station on the Murray River. In some places, the Nunawading Terrain is overlain by later sediments that are lateritized.

If at this time, SE. Australia was drifting N. from the frigid zone towards its present temperate zone position, the tropical or subtropical climate must have been due to a change in world climate that widened the tropical belt. On what is known of world climates, this could well be.

Axelrod and Bailey (1969) have suggested that climatic change in the Miocene could have been effected simply by transgressive seas reducing extremes, 'and hence biota (both marine and non-marine) would assume a somewhat warmer aspect under the more equable conditions'. However, more than a change in equability is involved in SE. Australia as is proved by gross change in soil types, by the presence of certain stenothermal genera, and such major shifts. The change from the cold climate in early Tertiary to more or less tropical conditions in the mid-Tertiary, followed by a major change in fauna and flora with cooling and drying climate in the upper Tertiary is more than can be explained by an increase in equability. The change took place both N. and S. of the Dividing Range. The sea exercises little control of the climate N. of the Range. It should be noted that Australia is naturally more equable in climate than most continents (e.g. Europe, Asia and N. America) because it is set in a wide expanse of ocean and possesses no land link with the Antarctic. In addition, its mountains are exceptionally low, for Australia is the flattest continent.

The deep kaolinization of the Nunawading Terrain is apparent in the solid rock areas of Victoria, New South Wales and South Australia, but not of course in the rapidly sinking Murray Basin. Moreover, the study area was invaded by the sea during the mid-Tertiary.

Following the above two palaeoclimates, there were three phases that left their impress on the terrain by significantly different types of paleosols, viz.

(a) A lateritic profile that accumulated non-magnetic iron oxide.
(b) A paleosol that accumulated silica in sands and common opal in clays. Such a soil infers a different pH from lateritizing conditions.
(c) A series of pedocals that accumulated earthy carbonates to crystalline nodules, the latter typically with an amorphous centre but concentric laminae on the outside.

3. *Monsoonal type climate*

This develops rainforest, but is characterized by alternating wet and dry seasons. Heavy rainfall drenches the earth with copious warm waters that leach it deeply, causing kaolinization. This is followed by a dry season when the water table falls and the air enters, oxidizing the zone above the table. Mottles of iron oxide form, and if the process continues long enough, the part of the mottled zone always exposed to oxidation becomes fully oxidized, resulting in the ironstone horizon which is 'laterite' in the strictest sense.

The lateritic profile is so deep and the leaching so intense that it reflects a climate which is the converse of the present semi-arid conditions, wherein soluble carbonates remain at the surface. The next climate represents the transition between these extremes.

4. *Monsoon/Arid Transition Climate*

Whether this is an adequate characterization of this climate, there is not enough evidence to say, but it is established that a climate causing deep leaching changed to a desertic one. The present climate is semi-arid but when the EW. dunes were active, the climate would be classifiable as arid. This transition is reflected in the sediments, the fossils and the soils. Tectonic movements about this time appear to have further uplifted the Dividing Range, which event must also have contributed to change of climate in the areas concerned. However, the climatic change extends far beyond the influence of the Dividing Range (e.g. Lowry 1970, Twidale 1972), so factors other than uplift are involved.

When Australian Oil and Gas sank Lake Victoria No. 1 well, they met late Miocene marine Bookpurnong Beds at 308 feet (94 m). Above that was a sequence of gypseous sands (arid/semi-arid) passing into pyritic sands (pluvial) with carbonized wood fragments and fish bones. The passage is from alkaline to acidic sediments.

The lowest formation outcropping along the Murray River in the study area is Parilla Sand which is a gray clayey fine sand. It is riverine, and its carbon content (high in places) contrasts with the low carbon content of the Coonambidgal Formation which was deposited by the same river. It is succeeded by the well washed oxidized Chowilla Sand (channel deposit) which interdigitates freely with the Blanchetown Clay. For the present purpose the latter two formations can be treated as one, and then the successively higher levels will represent successively younger zones. The Blanchetown Clay is thickest in the Nampoo Station cliffs, and it is at the base of the exposure that evidence of the incoming drier climate is first met. By tracing the river cliffs to the NW., the gradual replacement of Blanchetown Clay by Chowilla Sand can be followed through Cal Lal to the Kulcurna Station homestead, where Blanchetown Clay is mising. Nearby at the S. end of Salt Creek the formation lenses in again well up in the Chowilla Sand section, i.e. at what is interpreted to be a later horizon. There the present semi-arid flora has been recognized by Churchill (this *Memoir*).

At Sharp Point on the Nampoo cliffs (Fig. 26), three types of evidence combine to indicate the increasing dryness of the climate:

(a) *Deposition of dolomite* (cf. Zenger 1972). As indicated elsewhere in this paper, it is considered that this rock was a product of warm temperatures, low rainfall and high evaporation resulting in saline waters. Such dolomite is precipitated in the Coorong in S. Australia at the present time. The two dolomite layers show repetition of the sensitive conditions necessary for deposition. Deposits also occur at Triple Swamp (Fig. 24) and elsewhere low in the Blanchetown Clay/Chowilla Sand complex. The top of this complex is at plateau level. No dolomite has been found in the top three quarters of the complex.

(b) *Drying up of Lake.* The Blanchetown Clay is a lacustrine deposit. To spread channel sands (Chowilla Sand) across a lake bed (Blanchetown Clay) is evidence of shallowing, as also is the deposition of the dolomite. The lake dried up eventually as is proved by the formation of a soil and development of rhizomorphs. This soil accumulated silica, which at Sharp Point is in the form of common opal, but at Cal Lal is a cement forming silicified sandstone. In places, e.g. N. Salt Creek, silcrete occurs. I followed opal deposited in clay to where in the sandy facies nearby it became silicified sand to silcrete.

Deposition of opal appears to be controlled by impedance of drainage, and so presumably the formation of a gel. The formation of opal has been attributed to different geological periods, including the time of development of the lateritic profile. Because of basin sinking, the succession is here extended, making it easier to distinguish successive geologic events. In this instance, it can be proved that the opal is younger than the laterite. The upper opal layer at Sharp Point is a cemented breccia in places, suggesting some kind of dessication followed by further deposition.

This paleosol is very widespread. It is the Karoonda Surface or Terrain of Firman (1967). For example, Kosciusko Epoch sediments overlying kaolinized granitic rocks at Home Rule, N.S.W., are silicified, and this may be referable to the same climatic phase. Silicification has been noted near the surface in many places in the Mallee area of N. Victoria. It seems a good thing to give the same name to the fossil terrain and the paleosol that occurred on it. In this case, the latter could be called the Karoonda Pedoderm. No application has been made for the recognition of this as a stratigraphic name.

The paleosol is often eroded, as can be seen (for example) by following the silcrete layer along the Merbein Cliffs (Fig. 36). It is absent in other places, although features such as mottling of the Blanchetown Clay (e.g. in the S. bank of the Murray Cliff at Yelta) may be an expression of it.

In W. Victoria a fossiliferous site has been described which records the changeover period from the humid climate with a conifer/*Nothofagus* flora to the present dry *Eucalyptus*/*Acacia* flora (Gill 1957). A vertebrate fauna has been described from the same horizon (Turnbull and Lundelius 1970). A basalt flow 4·35 m.y. old has sealed off the deposit. Fluviatile sediments under thick basalts at Smeaton are referable to this same changeover period (Gill, in prep.). Dr Ian McDougall kindly undertook to date for me a sample from one of the overlying basalt flows with the result of 2·11 m.y. (Aziz-ur-Rahman and McDougall 1972). The changeover time appears to have been of considerable duration, and so is listed here as a separate palaeoclimatic phase.

5. *Arid/Semi-arid Climate*

All formations later than the Chowilla Sand/Blanchetown Clay complex have carbonate associated with them, except for those forming the present river floodplain. Polygenetic carbonate soils characterize the surface of the Blanchetown Clay forming the flat plateau country. At least three cycles are involved, as represented by:

(a) Crystalline calcite nodules included in a younger generation of such nodules.
(b) The younger generation of these hard nodules which are $\sim$ 28,000 years old.
(c) The still younger accumulation of earthy carbonate $\sim$ 16,000 years old.

In the dunefields, corresponding periods of terrain stability and instability can be traced over extensive areas. In the erosion amphitheatres on the W. side of Lake Victoria there are matching periods of erosion and deposition, judging by the few radiocarbon dates available. There are indications also of Holocene oscillations, finishing with the 'indurated layer' (Fig. 46) currently being deposited.

Mid-Holocene Thermal Maximum. Such is described from many parts of the world, but many Australian workers have claimed it does not occur here. This is too much to claim as so little work has been done on palaeoclimatology. However, one can describe the evidence one finds, and offer an interpretation of it.

Before C14 and U/Th dating, evidence of more than one drier period was telescoped into a single 'Arid Period' believed to be of mid-Holocene age. In 1955 the author wrote a paper placing the term 'Arid Period' (as applied to the mid-Holocene) in inverted commas and stating it was a misnomer. It was pointed out that the basic climatic change is one of mean temperature, that this does not necessarily mean change in humidity in a particular direction, and therefore the term 'Arid Period' should not be used. In spite of this, numerous authors have referred to this paper as indicating my belief in the mid-Holocene 'Arid Period', and it is hoped that this note will encourage the accurate reading of what was written. Nevertheless, I do think that in Australia there was a small but definite mid-Holocene climatic oscillation characterized by a small rise in temperature such as has been described from many parts of the world. In the study area the following evidence has been noted:

1. A disconformity between the Monoman and Coonambidgal formations at the Chowilla Dam site is marked by a layer of fossil stumps and logs that range in age from 4,080 to 7,200 years. The sediments below are oxidized.

2. A disconformity exists in the large lunette on the E. side of Lake Victoria between the Nulla Nulla Sand Member and the Talgarry Sand Member. Aboriginal midden shells in the paleosol marking the disconformity dated 6,360 years. At the end of this period, gulches were excavated by wind erosion then later infilled with Talgarry Sand.
3. On the E. side of Dolomite Gulch at Triple Swamp on Moorna Station an Aboriginal midden was found between the A and B horizons of the soil. The original A horizon must therefore have been eroded away and later reconstituted. The date of the midden (7,210 yr) is within the erosion interval. At Port Campbell in Western Victoria a winnowing of the A horizon of a humus podsol was proved, and the interval as represented by charcoal samples was 4,830 to 5,700 years. Limits on the period of time involved are placed by other samples which dated 7,380 and 3,880 years respectively (Gill 1965). Along the coast of Victoria are emerged marine shell beds with evidence of slight warming that give dates from 3,980 to 7,040 years (Gill and Hopley 1972).
4. In N. Victoria a ridge of granite (Terricks Range) stands up through the sediments of the Murray Basin. At Mitiamo, the excavation of the clayey sand on a pediment revealed an Aboriginal skeleton at the base that dated 5,540 yr. B.P. so this was presumably in a time of deflation when the pediment was swept almost bare (Gill 1967).
5. The most characteristic mammal of this semi-arid country is the Red Kangaroo *Megaleia rufa*. It does not occur now S. of the Dividing Range in Victoria. However, in the mid-Holocene it was in S. Victoria. Mr E. H. Wilkinson and Dr P. Lang found it at the outlet of Lake Gnarpurt in Western Victoria. The skeleton was in fine lacustrine sediments with *Coxiella* shells, which dated 4,550 years (Gill 1971b). These thin-shelled brackish-water gasteropods give a date on the young side where check has been possible, so the Red Kangaroo may be a little older, but still mid-Holocene.

   Early records and surface bones show that *Bettongia leseur* was also characteristic of the semi-arid fauna before the introduction of European cats and dogs. Bones of this species occur at Bushfield in W. Victoria, where they underlie the Tower Hill Tuff dated 7,300 years B.P. (Gill 1963, 1972c, Wakefield 1972).

6. *The Last 30,000 Years*

Radiocarbon dating provides reasonable chronologic control for this period. Insufficient is known to make a proper palaeoclimatic chart, and too few dates have been obtained. The carbonate dates in the upper part of the radiocarbon range need to be treated with reserve until they are better understood. However, the following table is the picture that appears on present evidence, and it is presented as a stimulus to further thought. Some of the contemporary events S. of the Dividing Range are also given.

Order of C14 Age	*Events*
0–4,000 years B.P.	Emplacement of youngest colluvial fans, dunes, and floodplain deposits (Coonambidgal Formation, Dunedin Park Sand Member, etc). Formation of youngest carbonate soils, and youngest Aboriginal middens and ovens. Modern erosion (0-150 yr.) Probably two phases in this period.
4,000–6,500	Terrain instability in study area. In Lake Victoria lunette, soil (with midden dated 6,360 y.) cut by gulches and covered by Talgarry Sand Member. Extant vertebrate fauna with minor changes. No surficial Aboriginal sites of this age found, but burials of this period prove their presence.

	Disconformity between Coonambidgal Formation and Monoman Formation at Chowilla Dam site marked by fossil trees, and oxidation of underlying sediments. Pediment with Aboriginal skeleton buried at Mitiamo, N. Victoria. Deposition in Devon Downs site further down Murray R. Deposition of pedogenic carbonate N. and S. of Dividing Range (not presently so deposited S. of Range). Red Kangaroo migrated S. of Dividing Range. Deflation of topsoil at Port Campbell, S. of Range, where surface presently well stabilized. Higher sea level on coast of Victoria shown by emerged marine platforms, shellbeds, and other shoreline structures.
6,500–9,000	Terrain stability. This period is ill-defined, but before the above sand movements began, a red soil was formed over most if not all of the large Lake Victoria lunette. Below this soil, high in the Nulla Nulla Sand were bones of an extinct kangaroo that dated 9,610 yr.
9,000–15,500	Terrain instability. Deposition of upper part of Nulla Nulla Sand Member in the Lake Victoria lunette. Deposition of the uppermost member of the E-W. dune system. Extinct vertebrates.
15,500–17,500	Terrain stability. Paleosol formed in Lake Victoria lunette, and in E-W. dune system (Woorinen Formation). Paleosol in clay (parna) dune on E. side of Lake Corangamite, S. of Dividing Range.
17,500–27,500	Terrain instability. Penultimate member of E-W. dune system emplaced. Deposition of lower part of Nulla Nulla Sand in Lake Victoria lunette. Extinct marsupials present. In some places a paleosol intervenes at 24,000 yr. (e.g. Nyah, W.).
27,500–30,000	Terrain stability. Paleosols formed in E-W. dune system. Probably Lake Victoria lunette initiated in this period. Pedogenic calcite nodules with laminated cortices below E-W. dune-field and on general terrain of Blanchetown Clay. At least two generations are involved, the second extending back beyond the range of radiocarbon dating. S. of Dividing Range, shells from high level beach of Lake Corangamite dated 28,240 yr (Gill 1971b).

The information available so far indicates alternating periods of terrain stability and instability. These are judged to be a function of significant variations in dryness, and probably also in windiness (Wilson and Hendy 1971). In the more humid country S. of the Dividing Range there is a similar pattern but, as may be expected, the time limits of the periods are not exactly the same.

Ecology

Two ecologic zones characterize this country (1) the flatland of the general terrain, and (2) the flatland of the wide floodplain incised 37 m therein.

1. In the study area, the general terrain is markedly different N. and S. of the Murray River.
    (a) To the S. the country is essentially sandy due to the dunes and sand

spreads of the Woorinen Formation. This is the Millewa Land System of Rowan and Downes (1963). Mallee scrub is the dominant vegetation.

(b) To the N. of the river the country is essentially clayey (due to the Blanchetown Clay substrate) with only a veneer of sand. Saltbush is the dominant vegetation.

The sandy facies to the S. of the Murray R. is an expression of fluviatile activity later modified by wind action. The clayey substrate to the N. of the river is an expression of lacustrine activity. The River Murray has followed the interface between these blocks of different sediments. The sands are much easier to erode than the clays. These generalizations provide a basic understanding of the country, but the actual situation is of course much more complex. The hypothesis put forward here for the course of the Murray requires testing by more detailed investigation. A tectonic factor is also likely.

2. The floodplain has been divided by Rowan and Downes (1963) into two zones:
   (a) Ned's Corner Land System consisting of higher ground (including the Rufus Formation). The dominant vegetation is saltbush.
   (b) Lindsay Island Land System, which is Holocene floodplain (Coonambidgal Formation) with channel border dunes and such. The dominant vegetation is *Eucalyptus camaldulensis* lining the streams, with *E. largiflorens* on the floodplains behind.

Information on the present fauna is given by Simpson (this *Memoir*) and that of the past by Marshall and Merrilees (this *Memoir*) plus the paleontology section of this paper. An investigation of the operation of the ecosystems involved is needed.

During the drought of 1967-8 many sheep died of malnutrition. Although in good seasons there is only minor competition between sheep and kangaroos, it becomes direct in time of drought. Graziers culled the kangaroo population, but the latter were still numerous, as they came from inland to within watering distance of the river. As soon as the rains came, the kangaroos disappeared inland. During the drought some birds that are normally further N. also came S. Thus at such a time there is a temporary population zone shift.

The Aboriginals were oriented to the river in a similar way, and went into the hinterland when the rains formed pools and re-charged small reservoirs in bodies of sand underlain by clay. Their mussel middens, implements, and fireplaces provide the evidence. As mussels occur only in the rivers and lakes, they must have been carried inland. They were noted on Talgarry Station nine miles E. of Lake Victoria, the nearest source.

Evolution of Ecosystem

When the Lower Cretaceous epicontinental seas withdrew, Australia changed from a pattern of islands to its present island continent status. The river systems ancestral to the present ones were then established. At that time SE. Australia had a subantarctic climate which graded to a subtropical one in the N. (Gill 1972d). This gradually changed until in mid-Tertiary a subtropical climate with extensive rainforests (that formed brown coals in grabens, and deep-leached soil profiles on horsts) existed in this area. From then till now there has been an overall drop in temperature and humidity. The incoming of the present aridity to the study area is described elsewhere in this paper. The time was ~ 2 m.y. ago. In that period the fauna in and around the river adjusted to a regime where the river could be anything from a string of salty pools in drought to a flood reaching tens of kilometres wide. Thus great extremes of chemical and physical conditions were involved. When the warm flood waters crept across the extensive floodplains, a whole new pulse of life occurred that resulted in plant renewal and the triggering of a complex faunal cycle. The millions of microzoa fed the small fish that emerged, and on which birds and other animals fed (Lake 1967). The introduction of dams and weirs has interfered with this natural cycle, but some simulation of it by dam control would be possible. Only 19 species of native freshwater fish live in the vast Murray/Darling R. system, but they show some remarkable adaptions to their unusual habitat. These must have evolved since the present semi-arid climate came. Eight species of fish have been introduced. Rainbow and brown trout do well in the colder upper reaches of the rivers, while redfin and tench do well in the dams.

Conservation of the Ecosystem

The present ecosystem took 2 m.y. to develop, and is very finely adjusted to very unusual conditions. In that period of time many new species have appeared and many became extinct in the study area. The lungfish (*Neoceradotus*) and many marsupials have disappeared from it (Marshall and Merrilees, this *Memoir*). On the other hand, a fossil tortoise found in Fisherman's Cliff, Moorna Station, in Chowilla Sand between the Moorna Formation and the Blanchetown Clay could not be distinguished by Professor J. W. Warren from its living counterpart.

The dry terrain is subject to erosion, but was much more stable before the introduction of herds of sheep and other animals. To conserve the ecosystem requires careful management. The first two years of our study (1967-8) were drought years, and wind erosion was very extensive. However, the incidence of erosion varied from station to station. The examination of the air photos shows the unused or little used areas are much more stable. On the other hand, some areas that were badly eroded have been restored by good management.

The extensive occurrence of Aboriginal middens with charcoal in the topsoil extending back to 2,000 yr ago shows that until recently the surface has kept intact over wide areas for two millenia. As charcoal is one of the most easily eroded materials, its presence is good evidence of undisturbed ground. On the W. side of Lake Victoria, the stratigraphy of the gulches and colluvial fans shows that in the past there have been periods of erosion and periods of infilling (Fig. 47). To delineate these and date them would be a useful project. Active gullying is now in progress, and there is difference of opinion as to when this was initiated. The latest cementation by carbonate is the fixing of the top 10-15 cm of the latest colluvial fans. This indurated layer contains middens, Aboriginal bones, and other dateable materials. A midden of this layer on Noola Station contained carbonized twigs (probably saltbush) that gave a modern reading upon radiocarbon assay. This means that the age is 200 yr at most, so the erosion has occurred since the arrival of Europeans, their sheep and rabbits and their machines.

Water erosion following heavy rain is assisted by the nature of the spoor of sheep and other ungulates. Kangaroos and emus have discontinuous spoor, but sheep scuff the ground with their hooves and excavate a rut down which water rushes, so initiating a gulch. Similarly I have seen rain following the tyre marks of a motor car. Thus the terrain is sensitive to wind and water erosion, necessitating careful management, if it is to be conserved. This is desirable both economically and scientifically. The country has a considerable capacity for recovery.

Aboriginal Ecology

'The earth's surface being to them a book they always read.' Major Mitchell

Having been over 30,000 yr in the country (Bowler *et al.* 1970) the Australian Aboriginals had long become an integral part of the ecosystem by the time Europeans arrived. The Aboriginals were one with their country. It was in character for them to prefer the local opal for their implements rather than the more efficient imported flint 'because it was part of them' (so said Aboriginals in the Western Desert). Natives on the Darling River asked Mitchell to return water he had taken from it. They had totemic relationships with animals in the local fauna. During the long period they inhabited this area, there were changes of climate and many of the local species became extinct. They were a conservative people (keeping to the ancient core/flake culture), but managed to accommodate themselves to these changes. When animals that became extinct were totems, deep-seated mental adjustments were necessary. Economic change was enforced by loss of technological raw materials (bone, skin, hair, tendons, fat, etc.) from the animals that went extinct, plus loss of a food source.

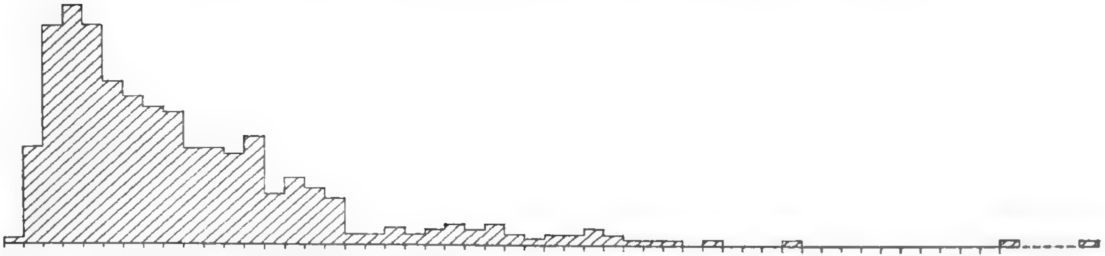


Fig. 63—Histogram of weights of stones from Aboriginal oven in Scrub Paddock at top of hill SW. of Dickie's Gate, and E. of Salt Creek, Kulcurna Station, N.S.W. Site 2. Categories are of 10 grams each, extending from 1-10 to 501-510; then there is a gap, and the final category is 581-590.

Two sources provide information on the way of life of the Aboriginals of this area:

1. *Early explorers and settlers,* Mitchell (1839), for example, described the Darling R. natives, their dress, artefacts (spears, canoes) and something of their daily activities such as hunting marsupials, spearing fish, netting ducks, collecting mussels and roots, using fire, dancing, communicating by calls and fire-signals, and burying the dead. Sturt (1849) described the natives at Lake Victoria and thereabouts. The notes of Beveridge (1865), Hawdon (1852), Morton (1861) and others are likewise helpful. Lawrence (1968) has accumulated valuable background information.
2. *Archaeologic evidence.* In this *Memoir* Casey has described artefacts, Blackwood and Simpson the Aboriginal skeletons, and Sandison their pathology. Many middens have been recorded. From an ecologic point of view, three types of Aboriginal fireplace need to be distinguished:

(a) *The midden.* In this area these consist of mussel shells (*Velesunio*), charcoal, ash and sometimes burnt ground (Gill 1969). The term is derived from a Scandinavian word for a refuse heap, and so is appropriate.

(b) *The oven.* This is a fireplace characterized by cooking stones. These are accompanied by charcoal, ash and sometimes burnt ground. Due to the shortage of rocks in this area, all manner of materials were used. Sandstone, ironstone and pieces of wasps' nests were utilized. Over much of the area, only pedogenic materials were available, such as carbonate nodules and silcrete. Figure 63 shows the size distribution of carbonate nodules in an oven on Kulcurna Station illustrated in Gill 1969, p. 181. The weight analysis is of the oven stones shown in the well-defined round oven area in the foreground of the photograph.

Where no stones were available for ovens, the Aboriginals baked mud lumps for this purpose. It is the nearest they came to making pottery. Impressions that appear to have been made with fingers, or in one instance an arm, have been noted. Barbetti (this volume) has studied the palaeomagnetism of these oven clays. Thermoluminescent tests have also been made on them. See Pl. 10, fig. 3.

In some ovens the stones were a mixture of imported rocks and the baked clay lumps. Mitchell (1839, vol. 2, p. 81) states' 'The common process of natives . . . is to lay the food between layers of heated stones'. Beveridge (1865) described the customs of the Murray R. natives among whom he lived in the Lake Boga area. He said. 'They cook their food by means of red hot clay placed over the bottom and round the sides of a hole prepared for that purpose. Over the hot clay they place a thin layer of damp grass, upon which they lay the joint to be cooked, covering it over also with damp grass, upon which more hot clay is placed, the whole is then carefully covered with sand. It is a very perfect method, and can be made large enough to roast an ox, or small enough to cook an opossum'. Similar methods are still used by some tribes of Aboriginals, e.g. at Yirrkala in N. Australia.

Brough Smyth (1878) stated that the Lower Murray natives 'cook their large game in ovens made in the following manner—a hole is made in the earth and lined with stones; in it they make a fierce fire, until the stones become almost red hot; the kangaroo, or what they intend to cook is then placed in the oven, on the top of which some more hot stones are placed, and the whole covered with earth; the heat of the stones and the confined steam together cook the meat' (Vol. 2, p. 298).

Beveridge's and Brough Smyth's descriptions are important in that they explain that the ovens were used for thick meat. In the lunette on the E. side of Lake Victoria, numerous shell middens are found, and fossil extinct marsupials are also found there, so some have inferred that this proves the Aboriginals did not use these marsupials for food. This in an incorrect inference. It should be noted that the Aboriginals employed two cooking media—the small midden fire for cooking small pieces of meat such as mussels, and the oven, the heat-holding capacity of which permitted the cooking of thick pieces of meat. Only once were bones found in a midden, and that was in the one on the N. shore of Lake Victoria E. of the old hotel site. This contained some bones of the small marsupial *Onchogalea frenata*. Thus, the composition of shell middens is not a guide to what marsupials were used for food.

Unfortunately, no bones have been found in ovens in the study area. It has been noted how the bones of both modern and fossil animals readily decrepitate in this climate when they are exposed at the surface. No bone implements were found by us. Gallus (this *Memoir*) describes two bone fish-hooks associated with a skeleton. Brough Smyth (1878 vol. 1, p. 203) believed them to be absent, so perhaps their use was prehistoric.

Ovens were used by the earliest known Aboriginals, evidence of whose presence has been discovered at Lake Mungo, NE. of our study area (Bowler *et al.* 1970). Burnt clay has been dated there at 30,750 yr B.P. (Anonymous 1972, Barbetti and McElhinny 1972). Dury and Langford-Smith (1970) recorded a fireplace at Lake Yantara in NW. New South Wales that dated 26,200 yr B.P. Judging by the photograph, lumps of burnt sediment were present.

As these pieces of 'brick' could be used again and again, it might be assumed that when rain fell, sediment on site was puddled and burnt. Ecologic analysis shows that in some sites at least this can be proved untrue. Thus ovens on dunes of well-sorted sand have cooking stones made of relatively poorly-sorted sediments from the nearby river.

Finally, it should be kept in mind that clay balls were also used as sinkers (Hardy 1969, p. 12).

c. *The hearth.* This third kind of fireplace has ashes and charcoal only (with burnt ground at times). No shells, bones or cooking stones are present. The localized nature of the deposit and its very close similarity to the middens and ovens shows that it is of Aboriginal origin.

The fireplaces preserved are of course only a fraction of those made. If ten groups of Aboriginals in this area each made one fire a day for 30,000 years, this would amount to about 11,000,000 fireplaces.

(d) *Stone material.* Being over a deep sedimentary basin, the terrain is a stoneless land. Then how did the Stone Age men manage for stoneware? Their light industry (the small tools) was supplied from local pedogenic materials (opal, silcrete, carbonate), while their heavy industry (millstones, mortars and such) were mostly imported from the areas where Palaeozoic and Precambrian rocks from the margin of the basin, viz. the Great Dividing Range to the E., the Barrier and other Ranges to N., and the Mt. Lofty Ranges to the W. A petrological study to define origins (cf. Ambrose and Green 1972, Dixon *et al.* 1968, Glover and Cockbain 1971, Shotton 1968, Sieveking *et al.* 1970) is needed.

Local rocks, even when unsuitable, were tried. Mr and Mrs H. Hansen collected a millstone made of a relatively soft calcareous sandstone, the source of which was probably Pine Camp Station, where it outcrops at the side of a dry lake. The best known local development of pedogenic siliceus sandstone is at Moorna Station homestead where it was used for building. The paleosol that yielded it is now under water, as the river level is controlled in this reach of the river. This rock was utilized by the Aboriginals.

Because all the local rocks are pedogenic materials of a limited range of types, it is easy to recognize the 'stranger rocks' brought in by human agency. It has already been mentioned that the local common opal was used and not the Mt. Gambier flint (Daley 1926), which was traded up to the N. Mallee not far from the Murray R. Only two pieces of flint were found among the many thousands of Aboriginal implements and flakes examined. Tertiary marine fossils were recognizable in them, and Whitehead (this *Memoir*) reports on the application of a new method in an endeavour to prove their origin.

As the Aboriginals brought in by trade silicified sandstone and quartzite for their large implements, it might be expected that they traded out other things such as opal. (On trading see Mulvaney 1967, p. 94 ff., Tindale 1968). However, Sir Robert Blackwood and I as a check collected opal-like material from between Wentworth and Broken Hill; also at Menindee and Mootwingee. Dr E. R. Segnit examined these, but they all proved to be very fine-grained silcrete and not opal. It is known that the Aboriginals traded reed stems from the Murray R. for spear shafts (Gutheridge 1907, Stone 1911).

On the lunette, a yellow Tertiary fossil shark's tooth, *Isurus hastalis*, was found. The nearest formation from which this could come is Miocene limestone that outcrops on the banks of the Murray 150 km to the W.

The range of Aboriginal implements found in the area was a surprise. No pirris (Campbell 1960) or tula adzes (or a few doubtfully) were found although these are the 'two basic prehistoric implement types'. So says Mulvaney (1964) and added that they 'appear inexplicably to observe State boundaries in their occurrence' They were not found in the study area nor in some places examined further N., so in this region the boundary is N. of the State boundary. Mr T. Brown (pers. comm.) of Broken Hill has a good collection but they came chiefly from N. of that town. Rare groundedge axes and cylcons have been reported, but these uncharacteristic occurrences do not reflect the local material culture, but perhaps strange objects accepted as having magical power. The fact is that the plentiful artefacts of the area demonstrate the primitive core/flake culture, such as characterizes the earliest known Aboriginals.

The distribution of artefacts is instructive. They occur in high concentrations beside Lake Victoria and at sites such as (a) The inland limit of the lunette sand encountered on the Talgarry pipeline track from Lake Victoria to the dams near the homestead. (b) On the same track SW. of the second dam from the road (on the fenceline). Both these sites are in geomorphic lows with sand underlain by clay. After heavy rain, pools of water last up to two months, and even when they have disappeared water is available in the sand. Thus we have a picture of the Aboriginals as river people who moved inland as pool-campers after the rains. Some sites are more than 15 km from the river/lake system.

The Aboriginal skeletons collected (Blackwood and Simpson, Sandison, this *Memoir*) and those seen but not collected, indicate a comparatively healthy people, as far as this can be judged from their bones. Broad based on the productive river/lake ecosystem, they were apparently well fed (mussels, fish, crayfish, turtles, water-fowl, emus, marsupials, plants). In addition, they were conservative, adhering to the ancient core/flake industry, and allowing the new cultures of hafted tools and microliths to go by. They imported only what was necessary, relying on local materials. Their outside contacts were minimal, so limiting the likelihood of infection from elsewhere.

The natives ground nardoo (Howitt 1908, Lees 1915) on their millstones, and used hammerstones on mortars for a wide range of jobs (McCarthy 1967). Canoes were used (Mitchell 1839, Beveridge 1865, Curr 1886) on the rivers and lakes (Mitchell 1839), and 'canoe trees' still remain with the scars (now well overgrown at the edges) whence the bark was removed. Scars left by bark removed by early settlers for tables and such are sometimes confused with Aboriginal canoe trees. We therefore experimented by removing squares of bark from the same red gum with a steel tomahawk and an Aboriginal stone axe of similar size. The former cut sharp narrow deep cuts with sides approximately parallel, while the latter cut shallower burred cuts with curved sides. We found that a sharp stick was also effective.

The reed spear-shafts of the river people were too light for stone heads, so the tips were made from mulga (*Acacia*). Mr J. Higgins (the oldest resident) described how the Aboriginals cut a groove round the mulga branch then cut thick slivers towards the groove, thus obtaining pieces of this very hard wood about the size and shape of the quartzite flakes used elsewhere for the same purpose. We did not know that mulga occurred this far south, but Mr Higgins pointed out two relict patches, one of over 10 hectares and the other with only a few trees.

The literature describes pieces of stone used for various types of magic by Aboriginals. Some formless pieces of imported stone found in the study area are presumed to have had some such use. For example, a flat piece of flakey mica schist from Ned's Corner Station was useless as an implement but its bright golden flecks could well have suggested some innate power to an Aboriginal.

McCarthy (1968) has described coastal and inland sequences of cultures with the Dividing Range between as a barrier. Such barriers are as much psychological (accepted boundaries) as they are physical. Similarly, the Murray River was a barrier. These barriers can be regarded as diffusion lines through which diffusion vectors (usually southwards) operated to bring about cultural change. The Murray R. constitutes a strip ecology surrounded by semi-arid country, so it is a natural interface, and tribal boundaries were related to it. Tindale (pers. comm.) states that the Maraura tribe lived to the N. and the Ngintait tribe to the S. The Maraura controlled the opal mines, and this is probably why large lumps are often found N. of the river but only small pieces in smaller quantity S. of it. N. of the Murray R. were quartzitic millstones and mortars, pirris, tulas, flake knives and picks, stone-tipped spears, bull-roarers, cylcons, carved trees, copi grave markers and so on. To the S. were basalt mortars, flint artefacts, wooden spears with hardened tips, and so on. However, in our study area only the large flat millstones appear to have the Murray R. as an actual limit of distribution. They are common N. of the river, but of negligible occurrence S. of it.

In review, one is amazed that in spite of the changing ecology (climate, fauna, etc.) there was a technological stability that lasted in this area for some 30,000 years. In spite of this, the Aboriginals of the area readily took to European meats, tomahawks, knives, blankets, and so on (Mitchell 1839).

Economic Considerations

The soil is this country's greatest wealth, so it needs conservation. Some of the world's finest wools are grown in this semi-arid country. Water is the limiting factor. In the dry summer time, especially in drought, the terrain appears harsh, but when the heavy rains fall, a miracle of regeneration is re-enacted. The perennials spring up with amazing rapidity and in six to eight weeks mature and seed. As the irrigation areas prove, this land is most productive when water is available.

South of the Murray R., the dominance of sandy terrain results in losses of up to 90% of the water passed through the feeder channels. N. of the river the Blanchetown Clay (below the veneer of sand) permits the excavation of earth tanks to preserve run-off water. The Darling R. is the local Nile in that it begins in a humid zone then flows 2,500 km and more through dry country. The clay floor and banks preserve its waters which are not supplemented by tributary streams.

On this semi-arid terrain there is one sheep to 2·5 hectares (6 acres) or more. The large woolshed of the Lake Victoria station has processed up to 98,700 sheep at one shearing (32 stands). Some cattle are raised along the rivers and lake shores. Cattle require fresher water than sheep which will drink water with up to 7,000 ppm (weight), i.e. about one fifth the salinity of the sea.

The water table in this area is very low. Piezometer bores in connection with the Chowilla Dam (data kindly made available by Gutteridge, Haskins and Davey) proved oxidation from the general land surface about 37 m above the river up to 12 m below river level, and up to 8·5 below water level in August 1968. The pH of the groundwater varied from 7·1-8·3. Sodium and chloride constituted 77·1% of total salts. Water from all the bores (traverse lines across the Murray R. from the

S.A. border to Mildura) had much the same ratio of salts.

The salinity of groundwaters and river waters has been a major problem. During the drought of 1967 the River Murray Commission contracted Gutteridge, Haskins and Davey in association with Hunting Technical Services Ltd. to study this matter and in 1970 three volumes were published, viz. 1. The Report, 2. Maps, and 3. A Summary. These volumes define the amount of salt involved, and its effects under the varying conditions obtaining in that area from time to time. The Report indicates the need of further research and the importance of adequate management.

Salt is harvested at Lake Tyrrell. Papers on salinity in the Murray region include Anonymous 1968, Crabb 1968, Hutton 1958, 1969 and references, Livermore 1968, McLaughlin 1966, Penman 1969, Williams 1970. Papers on underground water include Barnes 1951, Gibbons *et al.* 1972, Lawrence 1966, Macumber 1968, O'Driscoll 1966 and references.

Gypsum has been worked commercially in the study area. Timber is gained, chiefly river red gum. Commercial fishermen operate along the Murray R.

Beds of dolomite are reported for the first time in this area, but at present there is no commercial use for it.

Conclusion

This virtually unknown piece of country has proved to have rich geologic, archaeologic and biologic histories. The present reconnaisance, reported here inadquately under pressure of time, is but an indication of what has yet to be discovered. There are so many obvious worthwhile research projects and I am so often asked for suggestions, that I append a list.

APPENDIX 1

List of Maps

Military maps 1″ = 4 mi.	Renmark, Chowilla, Mildura, Anabranch.
Fire maps	Wentworth.
Photo maps	Lindsay, Wentworth, Mildura.
E.W.S.	1–6.
Air photos	Lindsay, Wentworth, Lake Victoria.

APPENDIX 2

Research Projects

1. Relationship of stream direction to tectonics.
2. The system of exceptionally fine-grained fluviatile, lacustrine, beach and dune sediments..
3. Age and evolution of Lake Victoria.
4. The Boy Creek/Wallpolla Creek anabranch system.
5. The remarkably extensive meander belts.
6. The age of the major oxbows as shown by radiocarbon dating of their basal sediments.
7. The origin of mottled profiles below present base level (e.g. Moorna East oxbow lake).
8. Analysis of meander lengths of the present and the past.
9. The differences in lithology and pedology N. and S. of the Murray River in the study area.
10. Origin of depressions (such as hold salt lakes) in the flat plain.
11. Stratigraphy of Salt Lake on Talgarry Station to follow its origin and history, dating by radiocarbon.
12. Relationships of E-W. longitudinal dunes (Woorinen Formation) with other formations (e.g. Rufus Formation), and with the various levels of Murray River incision.
13. Dunefield history, and the nature of the depression of dune forms in each stability phase, marked by near horizontal soils.
14. Differences between Mallee and Lake Victoria Dunefields, and the reasons therefor.
15. The relationship between Lowan Sands and the Mallee E-W. Dunefield.
16. The relationship of the present Lake Victoria to the basin in which it lies.
17. The gulches in the lunette on the E. side of Lake Victoria (which present extensive stratigraphic, pedologic, sedimentologic, archaeologic and palaeontologic data).
18. The facies of the Lake Bungunnia deposits, and their palaeogeography.
19. Survey the Triple Swamp cliffs, Fisherman's Cliff, and the cliffs of Moorna E. oxbow lake (which are nearly continuous) to provide a detailed section many kilometres long that would elucidate the lateral variation and interdigitation of formations in this area.
20. The Rufus Formation, its character and extent. It offers the opportunity of discovering any significant change in the Murray R. tract and the Lake Victoria basin since the ? Middle Pleistocene. Also its relationship to ancestral and prior streams.
21. The Monoman Formation, its distribution upstream, and its relationship with the ancestral and prior streams; also with change of sealevel.
22. Systematic C14 and other dating of paleosols in the Lake Victoria lunette and the E-W. dunes (Woorinen Formation) to define the periods of stability (soil-forming) and instability (dune-building) on this terrain. This would constitute a valuable contribution to palaeoclimatology.
23. Along with 22 or as a separate project to carry out grids of grain size analyses to discover (a) the degree of consistency in the sediments and (b) whether certain types (e.g. bimodal) can be

traced through the system. Study the mineralogy of clays and other minerals of the dunes and associated sediments in an effort to find out which are locally derived and which are additives from afar.

24. Take undisturbed cores from the surface to the Bookpurnong Formation through the type Moorna Formation section to study the sediments and fossils in detail. Check if the Parilla Sand occurs below the surface, and the nature of the changeover from marine to riverine sedimentation.
25. Definition of the incoming of the present semi-aridity by detailed investigation of the stratigraphy, palaeontology (including palynology), mineralogy and palaeoecology of the horizon concerned.
26. Investigate the bones in the Nulla Nulla Sand Member which develop a cheese-like consistency in very wet weather, and may be deformed while in this plastic condition.
27. Describe the ecosystems of the area, and study their evolution.
28. Petrologic examination of the stones used by the Aboriginals to define their origins.

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Explanation of Plates 1-11

PLATE 1

Fig. 1—Murray River at Kulcurna homestead, Cal Lal, N.S.W. Low declivity and extensive floodplain are characteristic of the river tract. *Eucalyptus camaldulensis* lines the river, while behind is *Eucalyptus largiflorens.*

Fig. 2—Darling River below the bridge at Wentworth, N.S.W. Tucker Creek enters on the far side. Telephoto view (which puts the *Eucalyptus camaldulensis* in the foreground a little out of focus). Pelicans swim on the placid waters. To the right of the photo, the river joins the Murray.

PLATE 2

Fig. 1—Bank of Murray River tract at Paringa, S. Australia. Rilled Blanchetown Clay with Parilla Sand below. Between is a band of yellow silcrete (Chowilla Sand) causing the platforms at mid-cliff level. The silcrete is the Karoonda Pedoderm, marking the Karoonda Terrain.

Fig. 2—Standard stratigraphic section at the proposed Chowilla Dam site (Fig. 4). The succession is the same as at Paringa.

PLATE 3

Floodplain of the River Murray, consisting of Coonambidgal Formation sediments. N. is to the top of the photo. The Murray R. appears to the SW. and Salt Creek (Kulcurna Stn.) to the E. with oxbows, anabranches, meander scrolls, and such. On the N. side of the oxbow in the NE. corner is Tareena Homestead, now a part of Kulcurna Stn. Last century, Cheltenhamian (late Miocene) marine fossils were recovered from a well on Tareena Station. Air Photo CAC 37-5004 Lake Victoria Run 5, 21 Feb. 1954. Crown copyright, published by permission of the Director, Division of National Mapping, Dept. National Development, Canberra, A.C.T.

PLATE 4

Air photo of Berribee Station, NW. Victoria, Lindsay Run 2 1363/5245, reproduced by courtesy of the Under Secretary of Lands, New South Wales. N. is to the top of the photo. To the N. is the Murray River, and S. of it is the anabranch called the Lindsay R. Between is Lindsay Island. The prominent N-S. channel border dune at the W. end of the Island is that shown in Fig. 11. The arrow marks the site of the auger hole in the E-W. dune shown in Fig. 10. Lindsay Island consists of Coonambidgal Formation sediments, while the SW. sector of the photo is occupied by E-W. dunes (Woorinen Formation). The auger hole is in an area of penetration of the E-W. dunes by riverine action. For general relationships see Fig. 4.

PLATE 5

Fig. 1—Lake Victoria, now used for water storage. Photo shows lake at lowest level, and the swash mark its top level. The dead trees mark the old water's edge. They now form nesting places for birds. The sediment is fine sand.

Fig. 2—Grayish green Blanchetown Clay outcrops here above Sharp Point, and is surmounted by the rilled red soil profile at plateau level. The white band at the base of this soil is not carbonate, but a layer of white sand belonging to the Blanchetown Clay formation. Due to the semi-arid climate, the outcrop is not overgrown. See cover picture.

PLATE 6

Fig. 1—Murray River cliffs at the Kulcurna Station homestead. The lower part of the cliff is Parilla Sand and the top part Chowilla Sand. The surface is the exhumed Karoonda Terrain. The building at the end of the cliff is the remnants of the wharf whence wool was loaded on to river boats in the early days.

Fig. 2—Bone Gulch, Moorna Station, W. of Wentworth, N.S.W. (Fig. 22). The wall of the gulch is mostly Blanchetown Clay, which includes layers of ostracods and some bones. The main ossiferous deposit is the Chowilla Sand below. The fossils are mostly worn and are concentrated in the top of the formation, suggesting a natural sieving action.

PLATE 7

Fig. 1—Gulch in Murray River cliffs below Nampoo Station Homestead, E. of Cal Lal, W. of Wentworth, N.S.W. The pine tree on the skyline is the position of the homestead. See Fig. 4. The entire section consists of Blanchetown Clay, which is unvegetated in this semi-arid climate.

Fig. 2—Base of the section shown in Fig. 1. Under the clay is a thin bed of Chowilla Sand and below that a formation of clayey sand which should probably be referred to the Moorna Formation. See Fig. 21.

Fig. 3—Soil at plateau level, developed in Blanchetown Clay.

Fig. 4—Large rosettes of gypsum in Blanchetown Clay in gulch in W. bank of Six Mile Cr., Neilpo Stn., W. of Wentworth, N.S.W.

Fig. 5—Two types of fossil ? burrows in Chowilla Sand immediately under the Blanchetown Clay at Bone Gulch (Pl. 6, fig. 2). The burrows are infilled with Blanchetown Clay.

PLATE 8

Fig. 1—Dolomite Gulch, Triple Swamp, Moorna Station (Figs. 4, 22-24) W. of Wentworth, N.S.W.

Fig. 2—Section of E. bank of Salt Creek, Scrub Paddock, Kulcurna Stn. (Fig. 20), Cal Lal, N.S.W.

Fig. 3—Dolomitic limestone at Morkalla, NW. Victoria (Gray Bros. property), proof of lacustrine conditions in what is now a semi-arid land. Ostracod fossils show the water was fresh.

Fig. 4—Close-up of dolomitic limestone of Fig. 3. It is *in situ* and underlain by multi-coloured Blanchetown Clay.

PLATE 9

Fig. 1—Triple Swamp from the mouth of Dolomite Gulch, Moorna Station (Figs. 22-24), W. of Wentworth, N.S.W.

Fig. 2—W. side of Dolomite Gulch, Triple Swamp, Moorna Stn., showing the white bands of dolomite. All the layers of dolomite known in the study area are associated with the base of the Blanchetown Clay.

PLATE 10

Fig. 1—Mesa of Talgarry Sand, Nulla Stn., Lake Victoria lunette, N.S.W. The subhorizontal stratification should be noted. Unlike the underlying Nulla Nulla Sand, the Talgarry Sand has well-defined internal structures, contains only living species, and has a gray columnar soil at the surface.

Fig. 2—Lake Victoria from the lunette on the E. side. The foreground shows Nulla Nulla Sand, and higher (behind the photographer) is the Talgarry Sand. The low slope near the lake (14° where measured) is Dunedin Park Sand, partly washed from the gulches and partly blown up from the beach.

Fig. 3—Remains of an Aboriginal oven, consisting of pieces of baked alluvium (used where there are no stones) and charcoal. On sites of well-sorted windblown sand, the oven stones sometimes consist of relatively unsorted sand, showing that the material was carried up as mud from the river.

PLATE 11

Fig. 1—Site of Aboriginal burials and middens in Lybra Paddock, Keera Station, N. Victoria. The substrate is eroded Rufus Formation (Fig. 57). Site 16. The loose sand from erosion of the terrace is Dunedin Park Sand.

Fig. 2—Section in erosion gulch at Paringi where the Sturt Highway touches the Murray R. tract between Euston and Burnoga. Blanchetown Clay overlies Parilla Sand, below which is the mottled zone of a lateritic profile (Timbeon Pedoderm).

—All photos by the author.

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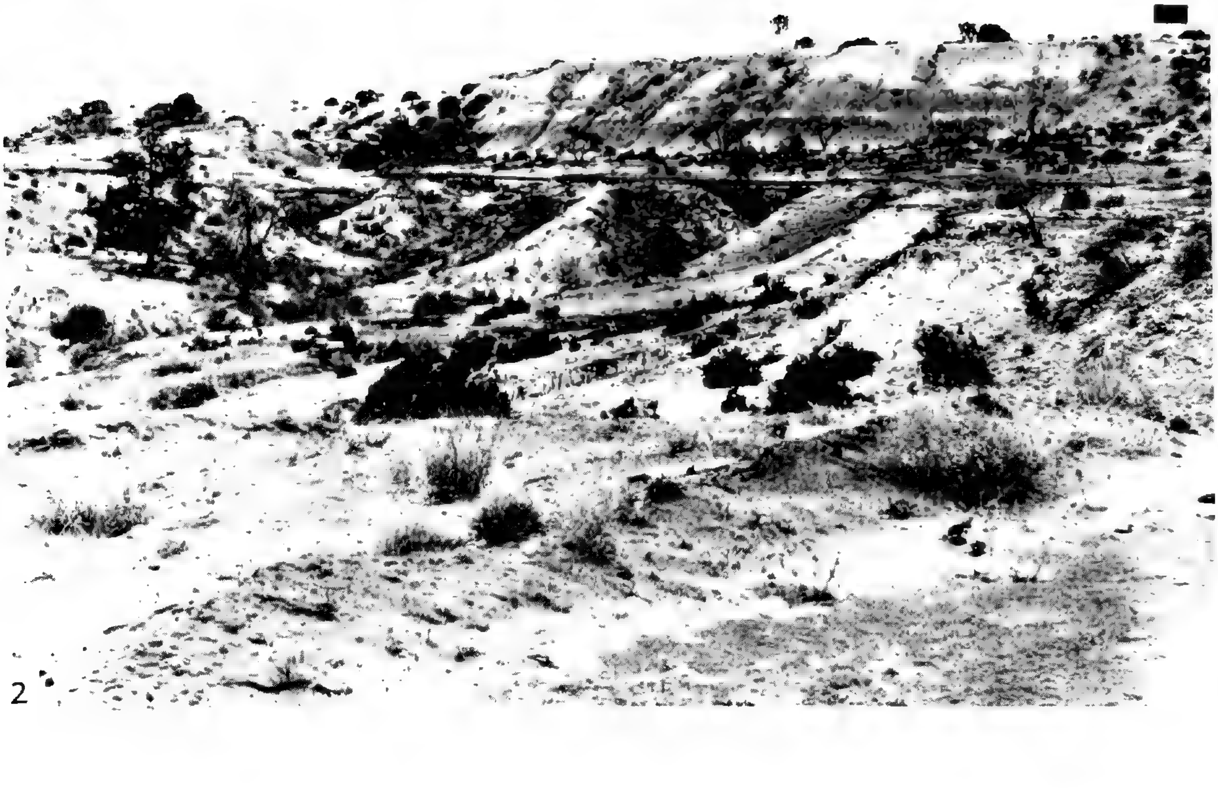

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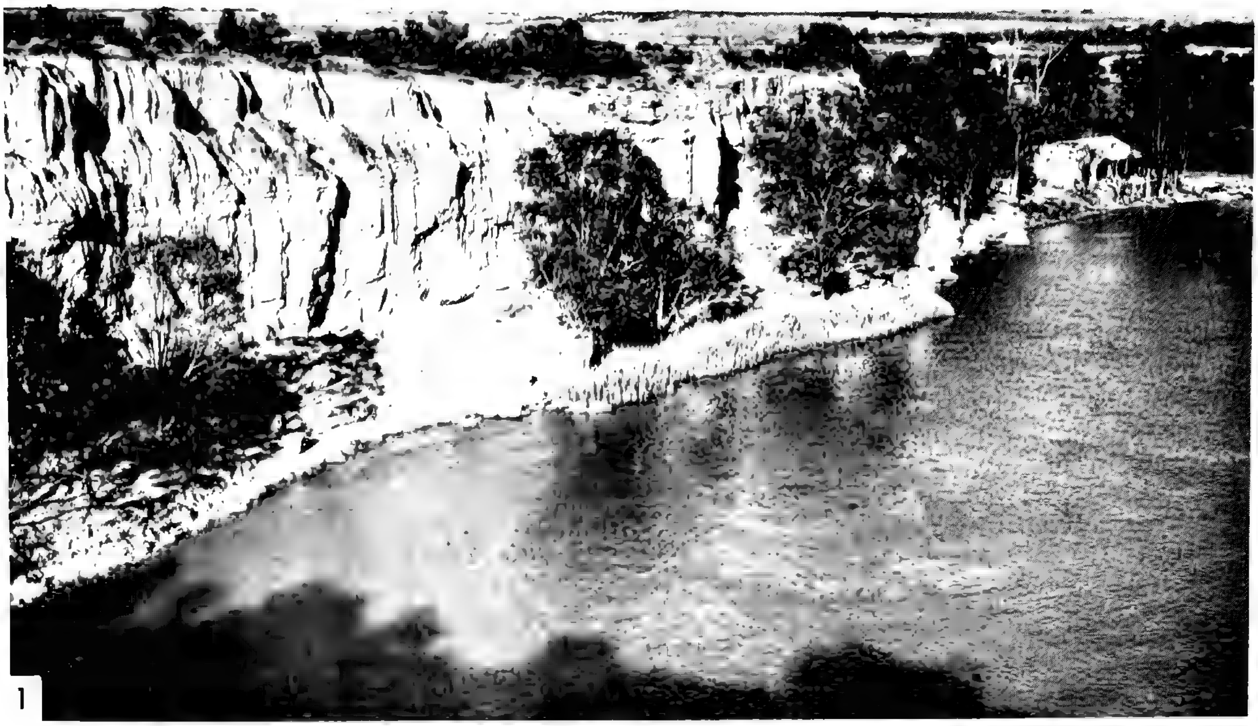

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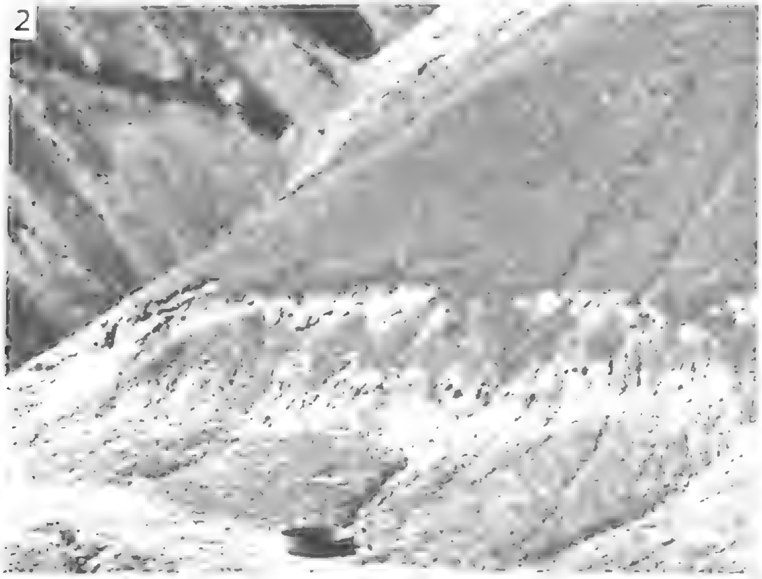

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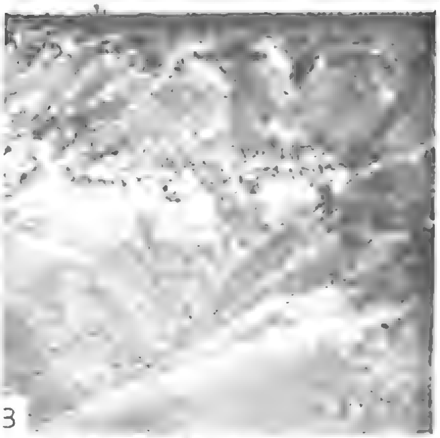

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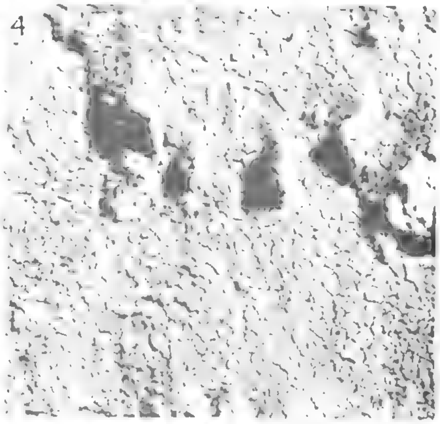

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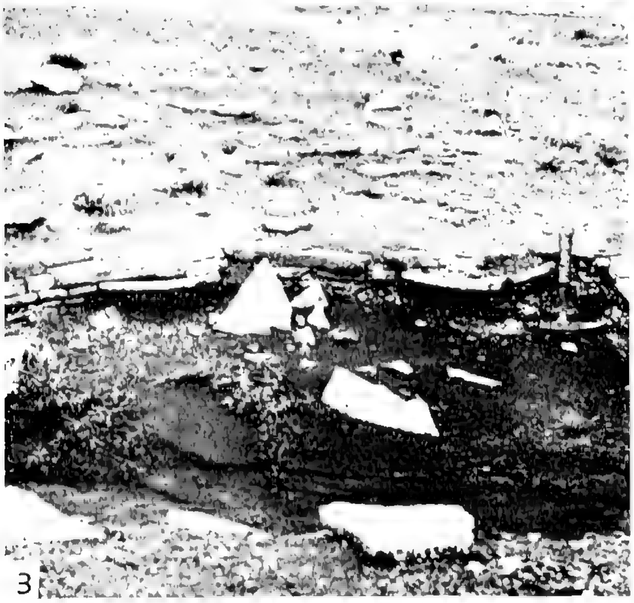
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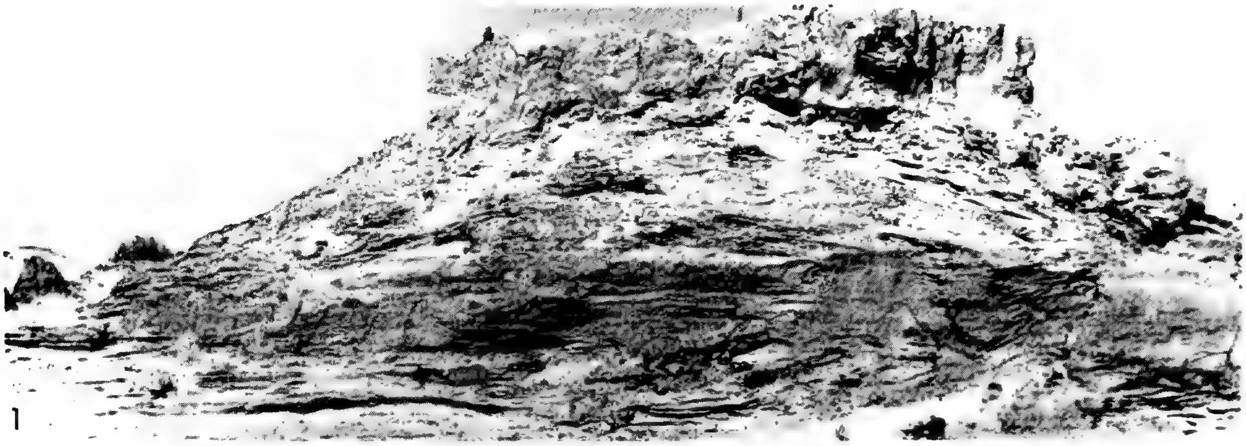

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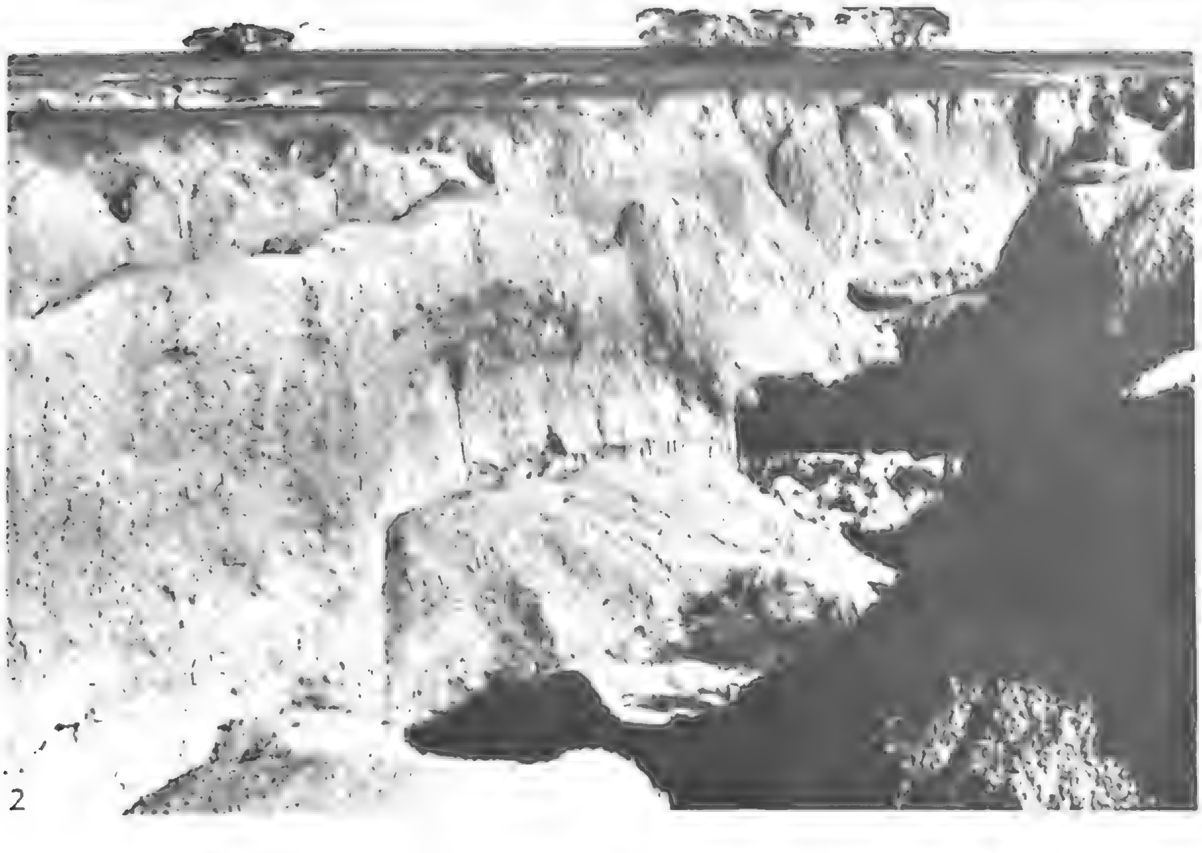

2

ATTITUDES OF ABORIGINAL SKELETONS EXCAVATED IN THE MURRAY VALLEY REGION BETWEEN MILDURA AND RENMARK, AUSTRALIA

By Sir Robert Blackwood and K. N. G. Simpson

Abstract

The attitudes of burial of 72 skeletons excavated at seven sites in the Murray Valley in Victoria between Mildura and the S. Australian border and at one site at Lake Victoria, N.S.W., are described. The antiquity of the burials in Victoria is from 4,000 to 6,000 years B.P. Orientation varied widely, but the head was placed predominantly in a S. direction. Orientation at Lake Victoria was random, and the burials were comparatively recent. Extreme tooth wear to a helicoidal plane of occlusion was frequent. A unique burial with a widow's cap in place on the head is described. Cranial types are illustrated by reference to eight skulls. Methods of removing complete skeletons as they lay *in situ* are described.

Introduction

During 1967-69 the authors excavated Aboriginal skeletons in the general area which would have been inundated upon construction of the Chowilla dam some 30 km upstream from Renmark on the Murray River in S. Australia. Human skeletal remains were found widely distributed between Wentworth, N.S. Wales and the S. Australian border (Fig. 1), but the majority excavated came from eight burial sites. The modes of burial and attitudes of these skeletons together with their antiquity and related matters are the subject of this paper.

Burial Sites

Of the eight burial sites concerned, seven were S. of the Murray River in Victoria and one was on the NE. side of Lake Victoria in N.S. Wales. The locations of the burial sites are shown in Fig. 1 and details of the individual sites are plotted in Figs. 2-3.

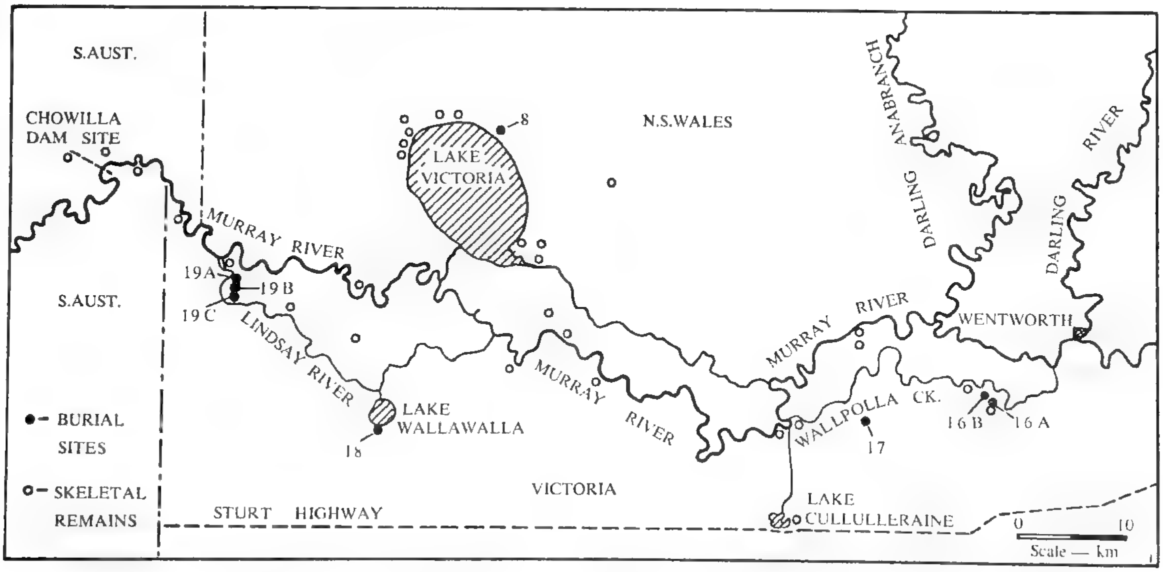

Fig. 1—Location of human skeletal remains in and bordering on the proposed Chowilla inundation area on the River Murray, and locations of the burial sites examined.

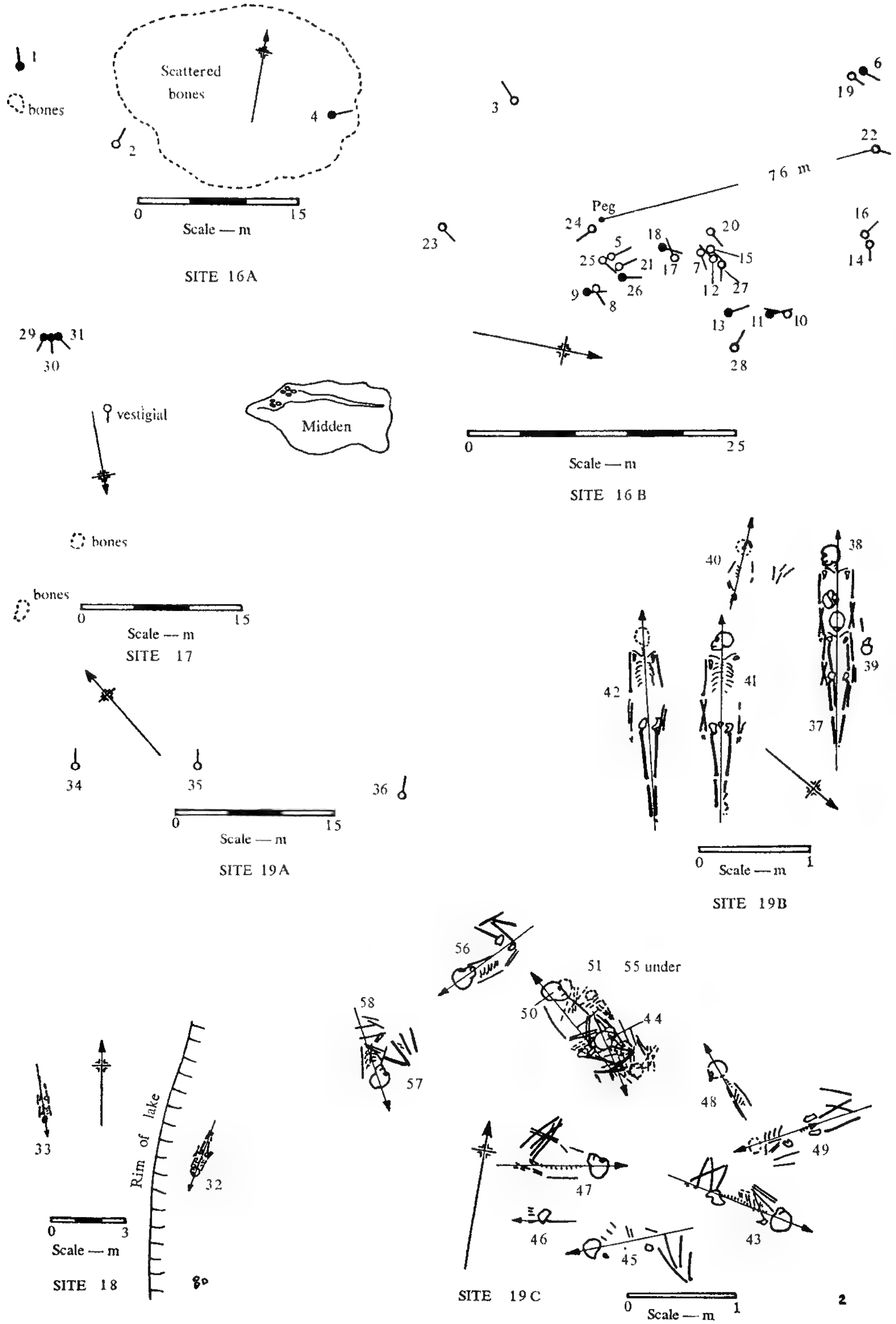

Fig. 2—Plans of burial sites 16A-B, 17, 18, 19A-C.

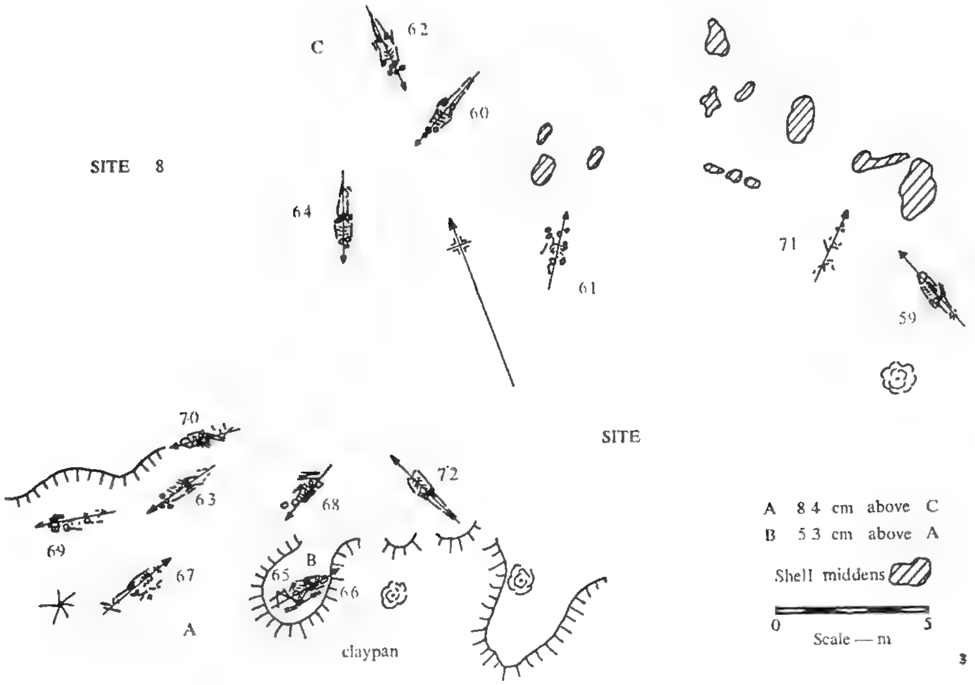

Fig. 3—Plan of burial site 8.

Victorian Sites

The seven Victorian sites are referred to by co-ordinates from the Australian Army Survey (1:250,000) Mildura map SI-54-11, Ed. 1, Ser. R 502.

Site 16A. Grid reference 482,779. The site is in the Lybra Paddock of Keera Station. It is portion of a fluviatile terrace, somewhat eroded, partly in a bend of the Wallpolla Creek, almost surrounded by a belt of Black Box (*Eucalyptus largiflorens*) and Murray Pine (*Callitris preissii*) with *Mesembryanthemum* flats. The sediments are lightly compacted.

The burials were located in the SE. portion of a sand rise. The skeletons recovered were adjacent to an eroded area covered with scattered bone fragments, indicating that a number of other skeletons had previously been exposed by wind action, disintegrated and scattered. Four skeletons (Nos. 1-4) were excavated, and their relative positions are shown in Fig. 2. The orientation of the bodies is indicated by a line and the head by a circle. A solid circle indicates that a cranium was present while an open circle indicates absence.

Site 16B. Grid ref. 481,780. The site is in the NW. portion of the same terrace area. Beneath yellow sand is a firm red sand which forms the surface at the NW. boundary of the area. Here 24 skeletons were excavated (Nos. 5-28) and their positions are shown in Fig. 2. The main group of skeletons was concentrated adjacent to our marker peg and were buried in the yellow sand. Those located well away from the marker peg to the NW. (Nos. 6, 14, 16, 19, 22) were buried in the underlying red sand.

To the SE. of the marker peg, and some 30 m from it, a well-defined midden of mussel shells (*Velesunio ambiguus*) was exposed on the surface. Approximately 6 x 12 m and 2-5 cm thick, the thickest portion formed a NS. ridge along the length of the midden. Near the S. end were pieces cemented by secondary carbonate. No artefacts were found in the midden. There were small scattered areas of shell and burnt clay in the area surrounding the site.

Site 17. Grid ref. 469,777. The site is a residual of a Pleistocene fluviatile terrace (named Rufus Formation by Gill, this *Memoir*) in dune-like form located in Brown's Paddock on Keera

Station. It is bordered on the N. by a thin belt of Black Box and surrounded by Samphire and *Mesembryanthemum* flats. A loose red sand surface is underlain by a red hardpan. The skeletons excavated were buried in this hardpan, a red sand compacted by clay skins. The hardpan above the skeletons was exposed by wind and water erosion.

Three closely-grouped skeletons (Nos. 29-31) were excavated. Scattered bones indicated two burials nearby and the skeleton of a child was still discernible in partial section on the surface of the hardpan. The site plan is shown in Fig. 2.

Site 18. Grid Ref. 419,777. The site is at the extreme S. of Lake Wallawalla on the Lindsay River floodplain. Two skeletons only (Nos. 32-33) were excavated and portions of the cranium of a third were collected loose on the surface nearby. The skeletons were located in a fine grey clayey sand at the lunette rim of this dry lake. The soil was tightly bound and the bone surfaces were hardened by secondary carbonate. The larger scale of Site 18 in Fig. 2 allows the skeletons to be shown in outline.

Site 19A. Grid Ref. 404,792. The site is a small channel border dune associated with the Lindsay River system located at the W. end of Lindsay Island on Berribee Station. This dune, of loose red sand, is considerably wind-eroded. Three skeletons (Nos. 34-36), partly exposed and scattered by wind erosion, were excavated. Their relative positions are shown in Fig. 2.

Site 19B. Grid Ref. 404,791. The site is located on a channel border dune approximately 1,000 m long running N-S on Lindsay Island, Berribee Station. The dune is part of the Lindsay River system in the bend where that river runs N. to rejoin the Murray River near the S. Australian border, and is surrounded by Red Gum (*Eucalyptus camaldulensis*), Black Box and Tea-Tree. A high ridge runs the full length of the dune. The W. side of the ridge is grassed, but the E. side is a sand blow. The excavation site was approximately midway along the ridge immediately under the crest in the sand-blown area. Six closely spaced skeletons (Nos. 37-42) were excavated in loose yellow sand (Fig. 2).

Site 19C. Grid Ref. 404,790. The site is located S. of Site 19B on the S. end of the same dune. Sixteen skeletons (Nos. 43-58) were excavated in loose yellow sand. Two distinct levels of burial were noted and the skeletons were disposed in random fashion (Fig. 2).

New South Wales Site

Australian Army Survey (1:250,000) Anabranch map SI-54-6, Ed. 1, Ser. R 502.

Site 8. Grid Ref. 431,607. The site lies on the E. border of the Lake Victoria lunette (Fig. 1) in the fine red sand of an exhumed paleosol. The paleosol surface itself has been subject to some wind and water erosion. The general level of the burial site was 30 m above the level of Lake Victoria.

Fourteen skeletons (Nos. 59-72) were excavated. Associated with the burials were concentrations of dispersed mussel shells of no significant thickness. A plan of the site is shown in Fig. 3.

Description of Excavated Skeletons

In the following descriptions the terms right and left refer always to the right hand and left hand sides of the skeletons. The terms superior and inferior, proximal and distal, medial and lateral are likewise used in the anatomical sense. The terms over and under, above and below refer to the positions of skeletal elements as they lay in the grave.

The dentition is indicated by the formula:

UR 87654321 12345678 UL
LR 87654321 12345678 LL

where UR means upper right; UL means upper left; LR means lower right and LL means lower left. The upper line refers to the upper teeth reading from the right side of the palate (UR) to the left side of the palate (UL). The lower line refers to the lower teeth from the right side of the mandible (LR) to the left side of the mandible (LL). The numbers refer to the following teeth:

1—medial incisor
2—lateral incisor
3—canine
4—anterior premolar
5—posterior premolar
6—first molar
7—second molar
8—third molar or wisdom tooth

The formula is used simply to indicate the presence of a *complete* tooth (when its corresponding number appears) or the absence of a *complete* tooth (when its corresponding number is replaced by a hyphen). Remarks on evulsion, tooth wear, the degree of eruption of third molars and other particular features of the teeth are additional to the dental formula.

The orientation of the skeleton was determined for each burial and is expressed as the *true* bearing of a line representing the general alignment of the body in the direction of the head. In extended burials this directional line generally coincides closely with a line connecting the feet with the centre of the cranium. In flexed burials it represents the approximate centreline of the trunk disregarding the position of the legs. The orientation line is given in all drawings.

The orientation line was marked over each skeleton by stretching a cord horizontally between pegs clear of all skeletal remains. Coordinates were measured along the cord from a zero reference point on it, horizontally at right angles to it and vertically below it for all points required to locate the skeletal elements. From these measurements, and from photographs of the skeletons, the drawings of Figs. 4-17 were made. The drawings are not intended to show anatomical detail but to show the attitude of the skeleton and the disposition of its bones.

In most cases a plan is adequate to show the attitude of burial. In three cases (Skeletons 4, 26, 44) both a plan and an elevation are necessary. In one case (Skeleton 2) no plan was neccessary, side and front elevations being sufficient.

The skeletal elements of Figs. 4-17 are identified as follows: Sc—scapula; Cl—clavicle; P—pelvis; H—humerus; R—radius; U—ulna; F—femur; T—tibia. Right arm and leg bones have the prefix R. Left arm and leg bones have the prefix L.

All the skeletons excavated have been numbered consecutively in this paper for ease of reference. The skeletal material has been deposited in the National Museum of Victoria and the registered numbers are recorded with the prefix NMV. In addition the number assigned to each skeleton in the Chowilla Project field notes is recorded with the prefix CHA.

SITE 16A, SKELETONS 1-4.

Skeleton 1. NMV X72799, CHA 14. Fig. 4

A supine extended burial, head lying on the right side, body straight, arms extended alongside the body with the hands inferior to the pelvis, feet together. The bones were generally in good condition. When found, the cranium was emerging from the surface and had been crushed on both temporal regions, probably by ambulating sheep. The feet had also been exposed and some of the distal bones had been dispersed. The balance of the skeletal material was covered by 5-15 cm of soil. The skeleton was 178 cm long measured from the estimated position of the underside of the heels to the top of the cranium.

The cranium was reasonably complete and has been largely reconstructed (Fig. 20). The mandible was separated from the maxillae by some 2-3 cm.

Dentition:

UR	87654321	12345678	UL
LR	87654321	12345678	LL

All teeth were fully erupted in both mandible and maxillae. Teeth large, wear moderate and even. Upper medial incisors 0·94 cm wide at the occlusal edge.

Rib cage substantially intact, with manubrium and sternebrae present but somewhat eroded and displaced. Both clavicles complete. Both scapulae substantially complete. Head of left humerus eroded. Hands complete. All vertebrae present except atlas and axis, well preserved.

The pelvis was nearly complete but fragmented, and has been reconstructed. Sacral vertebrae fused except S1 and S2. Sub-pubic angle 55°. Clearly male. Symphysis pubis with dorsal margin clearly defined and surface bevelled ventrally. Probable age 26-30.

Leg bones largely complete but with some erosion at the ends. Feet complete except for some distal bones. Orientation 160°.

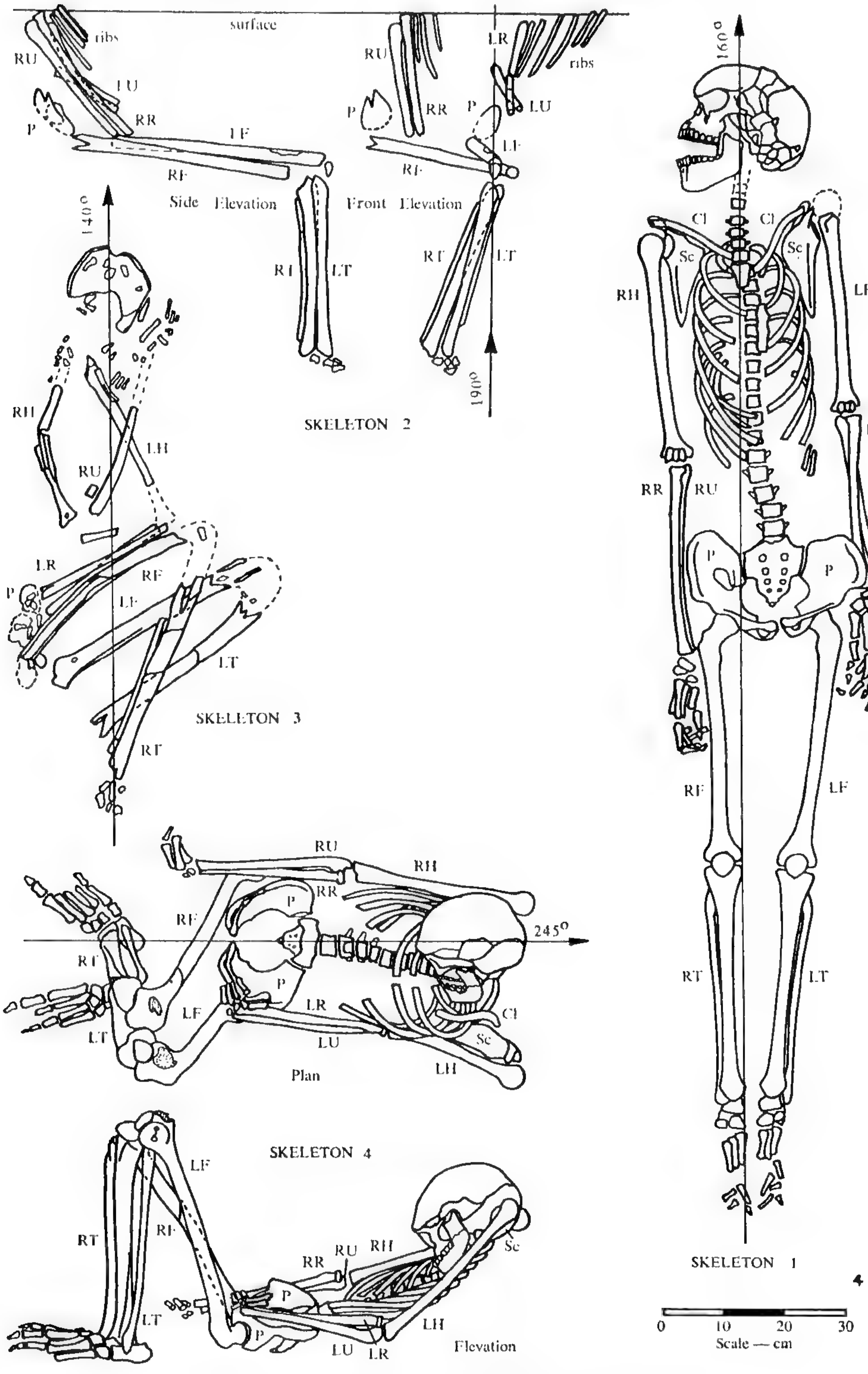

Fig. 4—Burial attitudes of Skeletons 1-4, Site 16A.

Skeleton 2. NMV X72800, CHA 31. Fig. 4.

A sitting burial of a most unusual kind. The body had been buried as if seated on a bench with the femora substantially horizontal, the tibiae and the thorax substantially vertical. Wind erosion had lowered the surface after burial exposing the cranium and shoulder bones, which had been dispersed and destroyed. When excavated, the ground level intersected the thorax some 23 cm above the hip joints at about the level of the elbows. The lower arm bones were in place together with a few pieces of rib and two vestigal iliac bones. The femora were contiguous at the knees, the left femur resting on the right, with the left tibia crossing over in front of the right tibia so that the right and left foot bones were in their correct lateral relationship. The leg bones were considerably eroded at the ends. The feet were buried at a depth of 61 cm below the existing ground surface. Orientation 190°.

The leg bones of this skeleton were used for radiocarbon dating and gave an age of 5,900 ± 550 years B.P. (GaK-1430).

Skeleton 3. NMV X72801, CHA 28. Fig. 4.

A flexed burial lying on the left side. The body was buried immediately below the existing surface. The cranium had emerged and been eroded away, leaving only fragments and a portion of the left temporal and parietal regions. These were sufficient to determine the position of the head at burial. The upper arm bones were incomplete, much eroded and broken, but clearly showing that the arms had been folded across the chest with the hands adjacent to the head. No thoracic bones or vertabrae present. Vestiges only of pelvis present. Leg bones much eroded, particularly at the ends. Knees drawn well up, superior to the pelvis, with the right leg bones resting on the left leg bones. Orientation 140°.

Skeleton 4. NMV X72802, CHA 103. Fig. 4.

A reclining supine burial with knees together and drawn up so that the femora and tibiae were almost vertical, inclining slightly to the left side. Feet extended and flat, as if placed on a horizontal surface at the same level as the pelvis. The depth of burial from knees to heels was 43 cm. Right arm extended alongside the thorax with the hand inferior to the pelvis. Left arm extended alongside the thorax but flexed in the vertical plane with the hand resting on the pelvis. The bones were generally well-preserved.

Cranium slumped forward and inclined to the right with the mandible resting on the thorax. Maxillae crushed a little and the mandible broken on the right side due to lateral pressure.

Dentition:

UR 8765432–	–2345678 UL
LR 87654321	12345678 LL

The upper medial incisors have been evulsed. The teeth were moderately and evenly worn.

Rib cage largely complete but collapsed ventro-dorsally. Vertebral column complete. Pelvis and sacrum intact. Sub-pubic angle 55°. Definitely male. Feet and leg bones complete. Orientation 245°.

After excavation this skeleton was treated with 'Aquadhere' *in situ* by the method discussed below and was brought intact to the National Museum in Melbourne where it has been preserved complete for display.

SITE 16B, SKELETONS 5-28.

Skeleton 5. NMV X72803, CHA 74. Fig. 5.

A fully extended burial with the body in a straight line lying on the right side. The left tibia and a section of the roof of the skull were exposed on the surface before excavation. Surface erosion and scattering of exposed bones had removed the bulk of the left side of the cranium, the teeth, the left humerus and the left side of the rib cage. The right arm bones were eroded but fairly complete with some right hand bones inferior to the pelvis. Pelvis vestigial. The proximal half of the left femur was absent but the leg bones were otherwise fairly complete. The right knee was ventral to the left knee, but the right tibia crossed under the left tibia so that the right foot was dorsal to the left foot and was lying sole upwards. The estimated height was 170 cm. Bone con-

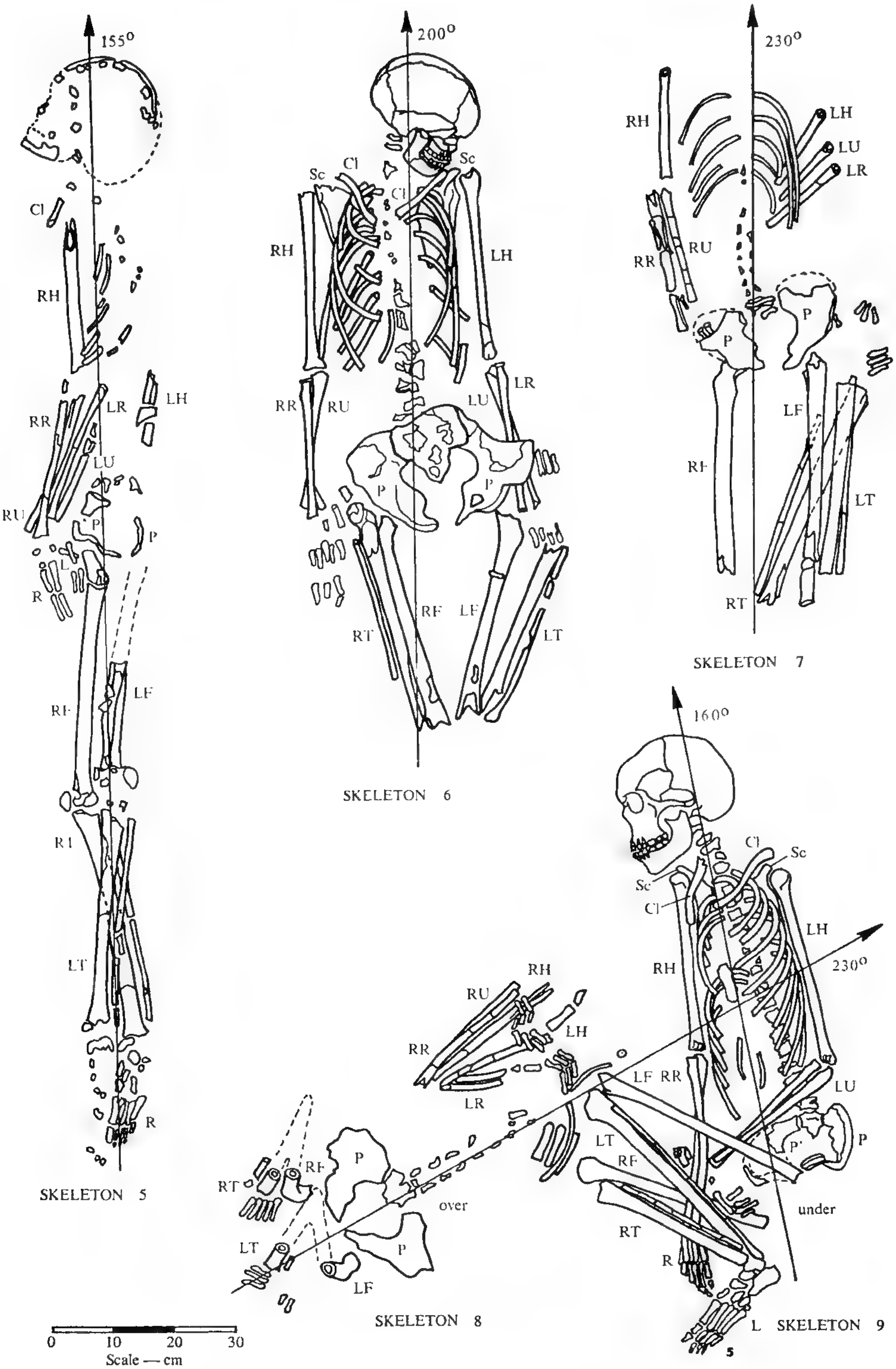

Fig. 5—Burial attitudes of Skeletons 5-9, Site 16B.

dition good. Skull bones up to 1·2 cm thick. Orientation 155°.

Skeleton 6. NMV X72804, CHA 69. Fig. 5.

A supine flexed burial with the head inclined to the left. Femora extended in the plane of the body wtih the knees contiguous. Tibiae flexed sharply back almost parallel with the femora, the feet being adjacent to the pelvis.

The cranium was substantially complete and lay on the left side with the chin resting on the left shoulder.

Dentition:

UR 87654321 12345678 UL
LR 8—54321 12345678 LL

The clavicles and scapulae were almost complete. Rib cage and vertebral column fragmentary. Arms extended alongside the body, the lower left arm passing beneath the pelvis, the hands inferior to the pelvis. The pelvis was eroded but nevertheless well-delineated.

Femora and tibiae considerably eroded at the ends. A few foot bones were located in the pelvic region. Orientation 200°.

This skeleton was buried in sand with sufficient clay content to make it set very hard around the bones. Excavation for removal of the bones would have been very difficult. A reinforced concrete slab was therefore cast in sections underneath the burial as described below. The undisturbed skeleton was removed complete and taken to the National Museum in Melbourne where it is on display.

It is difficult to conceive how the lower legs could be flexed back in such close contact with the thighs without some severance at the knee joints and without tying together. However, the movement of the bones during decomposition of the body and settling of the infill may have accentuated the closeness of the bones.

Skeleton 7. NMV X72805, CHA 79. Fig. 5.

A supine flexed burial with the femora extended in the plane of the body and the tibiae flexed back sharply under the femora towards the left side of the body with the feet adjacent to the pelvis.

The cranium and shoulder region had been exposed, eroded away and were not present. A few rib portions *in situ* with fragmentary vertebrae and sufficient of the eroded iliac bones to define the position of the thorax. Right arm extended alongside the thorax with the hand under the pelvis. Left arm bone portions indicated that the lower left arm was flexed back towards the shoulder with the elbow under the thorax. Leg bones eroded at the ends. A few foot bones were present. Orientation 230°.

Skeleton 8. NMV X72806, CHA 70. Fig. 5.

A supine burial with the legs flexed so that the knees were raised above the plane of the body with femora and tibiae almost vertical. Feet on the same level as the pelvis.

This was a somewhat vestigial skeleton just below the existing surface of the ground. Clearly the original surface at the time of burial was at least 45 cm above that when excavated in order to cover the knees. Erosion appeared to have scattered and removed the cranial and thoracic bones and the major part of the femora and tibiae. The position of the body was defined by the position of the feet, the pelvis and the line of fragmentary vertebrae present. The proximal ends of the femora and the distal ends of the tibiae, although much eroded, clearly defined the vertically flexed position of the legs. Sufficient of the arm bones was present to show that the arms were folded over the chest and that the upper trunk inclined a little to the right. Orientation 230°.

Associated with Skeleton 8 were a single upward projecting right tibia and a fibula, both eroded at the distal end and with no foot. Further excavation revealed Skeleton 9 buried at a lower level than Skeleton 8 and the right tibia and fibula belonged to it. Skeleton 9 was buried subsequent to Skeleton 8 and perhaps the absence of a cranium and upper thorax of Skeleton 8 was due to disturbance of those bones while digging the grave for Skeleton 9. The excavation of the grave for Skeleton 9 must have cut through part of the region occupied by the upper trunk of Skeleton 8. A portion of the right side of a mandible with three teeth in place (lower right canine and premolars, well worn) was found buried with Skeleton 9 but not belonging to it. This was presumed to be a part of Skeleton 8.

Skeleton 9. NMV X72807, CHA 71. Fig. 5.

A flexed burial, the body inclining to the right with the cranium resting on the right side. Right arm extended along the right side of the thorax and passing between the legs. Left arm flexed across the pelvic region with the hand over the pubic area. Left leg flexed superior to the right leg, knees at a higher level than the pelvis and feet. The right foot and the distal end of the right tibia has been exposed at the surface and eroded away. The left foot was complete.

The cranium was almost complete and well-preserved. It was slightly compressed laterally resulting in some fracturing in both temporal regions and some peaking along the sagittal suture for some 5 cm immediately anterior to bregma. This distortion had undoubtedly occurred post mortem as disclosed by displacement along the coronal suture. This distortion tends to accentuate the unusually long and narrow facial aspect. Brows prominent. Wormian bone at lambda. (Fig. 21.)

Dentition:

UR 87654321 12345678 UL
LR 87654321 12345678 LL

The upper medial incisors were very wide, being 1·06 cm wide at the occlusal edge with loss of alveolar bone between their roots. Tooth wear was severe and of typical helicoidal character (Murphy 1964). A portion of the mandible was crushed and disintegrated on the right side. Lower jaw slightly prognathous, mandible deep in front (symphysial height 4·20 cm).

Clavicles and scapulae well-preserved and almost complete. The majority of the rib cage was present but collapsed ventro-dorsally to a thickness of 5 cm with consequent inferior movement of the ventral surface. Vertebral column fragmentary. Pelvis severely eroded, the vestiges being insufficient to determine the sex although the cranial characteristics were clearly male (Table 4). The right arm bones complete, the right arm being extended along the right side of the thorax and passing between the flexed legs with the right hand complete *in situ* inferior to the legs. The left upper arm extended alongside the thorax with the lower left arm bones flexed to the right over the pubic region. Only a few bones of the left hand remained. Leg bones eroded slightly at the ends. Right foot eroded away at the surface and scattered. Left foot complete and *in situ*. Orientation 160°.

This skeleton was well-preserved and it extended to a depth of 38 cm below the existing surface. The right hand and left foot were treated with 'Aquadhere' in accordance with the technique described below and were preserved intact as units.

Skeleton 10. NMV X72808, CHA 39. Fig. 6.

A fully extended supine burial. The cranium (except for a few fragments) together with the cervical vertebrae, scapulae and the proximal ends of the humeri had been exposed by erosion of the soil and scattered. A few vestiges of thoracic and lumbar vertebrae and some rib fragments were present. The arms were extended alongside the body with the hands resting over the pubic region. Pelvis fragmentary. Leg bones eroded at the ends. The distal ends of the tibiae were close together. The feet were completely scattered by exposure. There were a few small particles of charcoal associated with the skeleton. Orientation 0°.

Radiocarbon dating of the bones gave the age as 4,170 ± 200 years B.P. (GaK-1432).

Skeleton 11, immediately below Skeleton 10 and in contact with it, was revealed during excavation. The head lay beneath the distal portion of the left femur of Skeleton 10 with the body oriented 170°.

Skeleton 11. NMV X72809, CHA 45. Fig. 6.

A supine burial. No leg bones were present and it was not possible to determine whether the burial was extended or flexed.

The cranium was substantially complete, the supraorbital ridges smooth, the mandible complete. (Fig. 21).

Dentition:

UR –765432– –2345–7– UL
LR 8—54321 12345—8 LL

Tooth wear was extreme. Lower right and left first and second molars were evidently lost at an early age since bone regrowth had almost

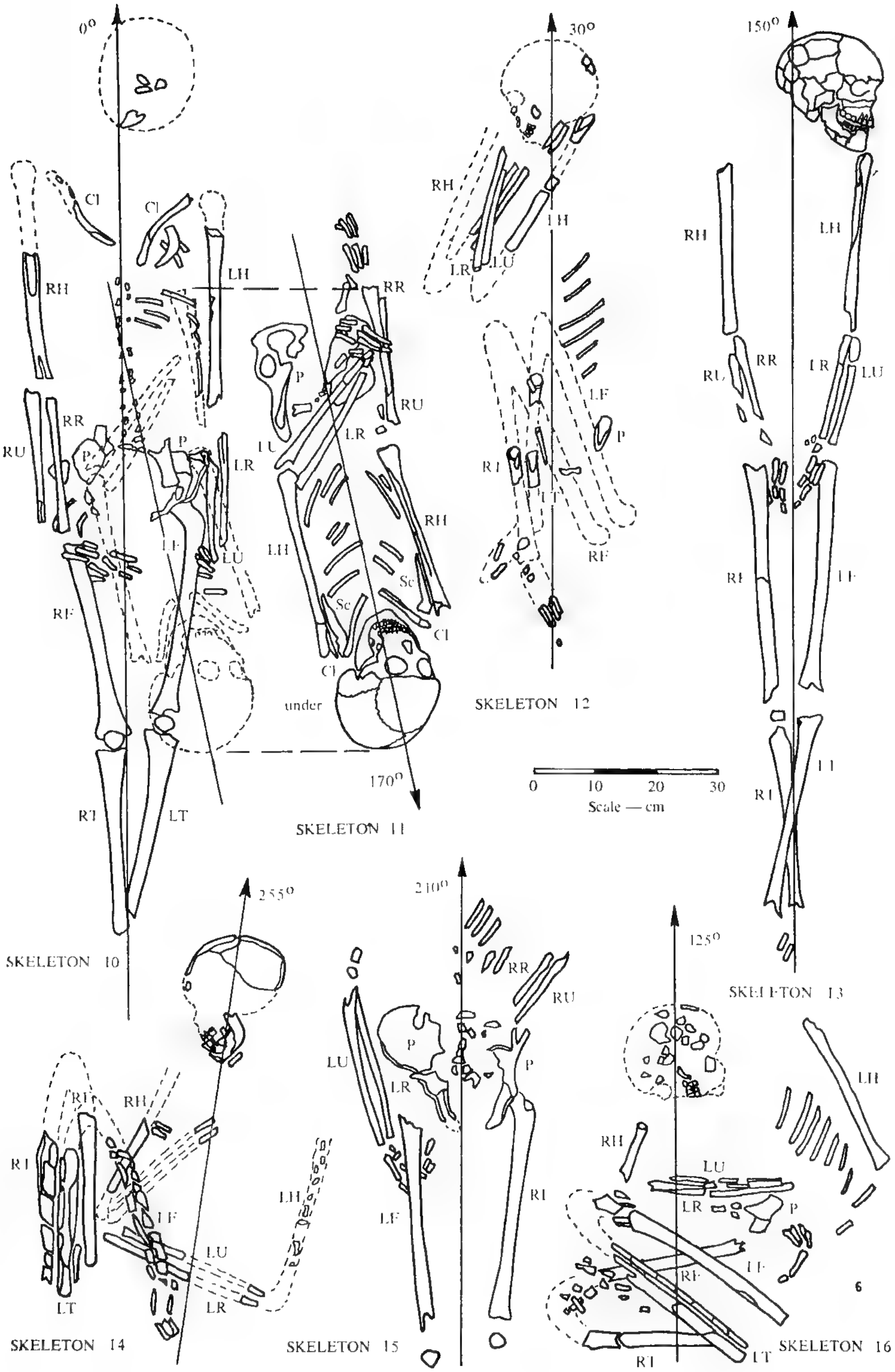

Fig. 6—Burial attitudes of Skeletons 10-16, Site 16B.

completely covered the corresponding root sockets. The remaining lower teeth showed marked helicoidal wear, which again suggests early loss of the molars coupled with fairly advanced age. There was marked cuspate wear on the lower right third molar. The upper medial incisors had been evulsed.

Remnants of the scapulae, clavicles and rib cage were present. The right arm was extended alongside the thorax with some hand bones present inferior to the pelvis. The left humerus was extended alongside the thorax with the lower arm bones flexed across the pelvis with some left hand bones resting on the iliac bone. The pelvis was fragmentary but reasonably well-defined. There were no lower limb bones. Orientation 170°.

Radiocarbon dating of bones gave the age as 4,400 ± 220 years B.P. (GaK-1433).

The orientation of Skeleton 11 is so unrelated to that of Skeleton 10 that it appears unlikely that these two bodies were buried contemporaneously in the same grave. The complete absence of leg bones attached to Skeleton 11 suggests that they were removed during excavation of a grave for Skeleton 10. Close contact of the bones supports that view. The edges of the acetabular fossae of Skeleton 11 were sharply defined, implying mechanical removal and not chemical weathering. This skeleton may have been buried in an attitude approximating that of Skeleton 8, i.e. supine but with the knees raised and turned to the left. Finally the evidence of the radiocarbon dates suggests that Skeleton 10 was buried independent of and subsequent to Skeleton 11, although statistically the radiocarbon dates are not significantly different.

Skeleton 12. NMV X72810, CHA 78. Fig. 6.

A very fragmentary skeleton representative of an extreme flexed burial lying on the right side. Only a few fragments of the cranium remained in place, but those, together with three loose teeth in the sand matrix, were sufficient to indicate that the head lay on the right side and was compressed onto the thorax. The arms were folded back against the thorax with the hands adjacent to the head. A few pieces of rib, vestiges of pelvis and fragments of leg bones and feet were just sufficient to indicate extreme flexure of the legs with the knees drawn up towards the head and brought close to the body. Orientation 30°.

Skeleton 13. NMV X72811, CHA 32. Fig. 6.

A fully extended supine burial with the head resting on the left side. The skeleton consisted of a cranium with moderately prominent brows, laterally compressed and somewhat broken in the temporal regions, together with arms and leg bones only. Upper and lower jaws compressed laterally, broken medially and shattered, but with teeth substantially in place.

Dentition:

UR 87654321 –2345678 UL
LR –7654321 12345678 LL

Very severe helicoidal wear to the pulp and almost to the roots on lower molars on the buccal side.

Arms extended alongside the thorax with both hands over the pubic area. The left tibia crossed over the right tibia at their midpoints. Two small foot bones were present. Estimated height 152 cm. Orientation 150°.

Skeleton 14. NMV X72812, CHA 65. Fig. 6.

A very fragmentary skeleton lying on the right side. Most of the cranium and the superior portion of the thorax had been exposed by soil erosion and dispersed. A few pieces of thin cranium bones (2·3 to 3·0 mm thick) were present and these, together with portions of the mandible with the lower left canine, incisors and third molar in place, and the upper left premolars and first molar embedded in the sand matrix, were sufficient only to delineate the position of the head. Fragmented traces of arm bones showed the right arm flexed back towards the head and the left arm flexed across the pubic region. Fragmented pieces of leg bone showed both legs drawn up sharply in front of the thorax with the left leg resting on the right leg. Clearly an adult with molars fully erupted. Orientation 255°

Skeleton 15. NMV X72813, CHA 52. Fig. 6.

A fragmentary prone burial. No cranium or upper thoracic bones were present except a few rib fragments. The lower arm bones suggest that the left arm was extended alongside the thorax with the hand beneath the left femur, with the right arm flexed towards the pelvic region. The pelvis was defined broadly by several pieces, and fragments of lumbar vertebrae were present. The femora were extended and eroded at the ends. Both patellae were present. No tibiae or other lower leg or foot bones were present, these having been exposed by surface erosion and dispersed. Orientation 210°

Skeleton 16. NMV X72814, CHA 51. Fig. 6.

A fragmentary flexed burial lying on the right side. Fragments of bone and loose teeth in the sand matrix defined the position of the cranium. A few pieces of rib were present, but no other thoracic bones remained. Left arm flexed over the thorax. Small fragments of pelvis were present. Both legs sharply flexed with the knees drawn well up in front of the thorax. The left leg was above the right leg and the left knee was superior to the right knee. Orientation 125°.

Skeleton 17. NMV X72815, CHA 67. Fig. 7.

An extended burial lying slightly on the right side, with the cranium lying on its right side, the arms folded over the pelvis and the legs slightly flexed toward the right.

Cranium well-preserved, substantially complete, slightly compressed laterally. Supraorbital ridges smooth, mastoid processes small. Mandible complete (Fig. 21).

Dentition:

UR –765432– –234567– UL
LR –7654321 1234567– LL

The upper third molars were just erupting. The lower third molars were unerupted. Wear slight. Lower incisors crowded (see Sandison, this *Memoir*). Upper medial incisors evulsed. Probable age 20-23 years.

Thorax substantially complete and vertebrae well-preserved. Collapse during decomposition had resulted in the ventral surface moving dorsally and to the right, giving a thickness of rib cage as excavated of 5 cm and a maximum width of 14 cm. Humeri alongside thorax with arms folded across the pelvic regions, hands on iliac bones. Pelvis incomplete and insufficient to determine sex, but cranial characters are female. (Table 4).

Legs flexed a little to the right, with the left knee resting on the right knee. Feet approximately on the centreline of the thorax. Orientation 185°.

The thorax was treated with 'Aquadhere' using the technique described below and was removed as a unit. Along the line of the body and 5-7 cm above it was a seam of charcoal mixed with sand. The appearance suggested that a series of small branches or wooden stems had burned to charcoal in a narrow trench above the body extending over its full length. There was no evidence of burnt bone in the skeleton. The fire must have been lit subsequent to burial. The skeleton was buried between 22 and 35 cm below the existing surface.

Alongside Skeleton 17 at a level between the existing surface and 10 cm below it was Skeleton 18. The feet of Skeleton 17 lay close to the left lower arm bones of Skeleton 18 in plan, but at a lower level. Skeleton 17 was far better preserved and its position suggested that it was buried subsequent to Skeleton 18 without disturbing it, but there is no firm evidence to support this conjecture.

Skeleton 18. NMV X72816, CHA 66. Fig. 7.

An extended supine burial with the left femur resting on the right femur, the left leg being slightly flexed to the right. A skeleton preserved as traces only.

No cranium, vertebrae or pelvis present. A few pieces of rib only. Arm and leg bones severely eroded at the ends, with only a few foot bones present. Arms alongside thorax. The feet of Skeleton 17 were 8 cm below the left lower arm bones. Left knee flexed slightly and resting on the right knee. Orientation 50°.

Although closely adjacent to Skeleton 17, there did not appear to be any association between the two.

Skeleton 19. NMV X72817, CHA 68. Fig. 7.

A supine burial with legs flexed sharply back to the right.

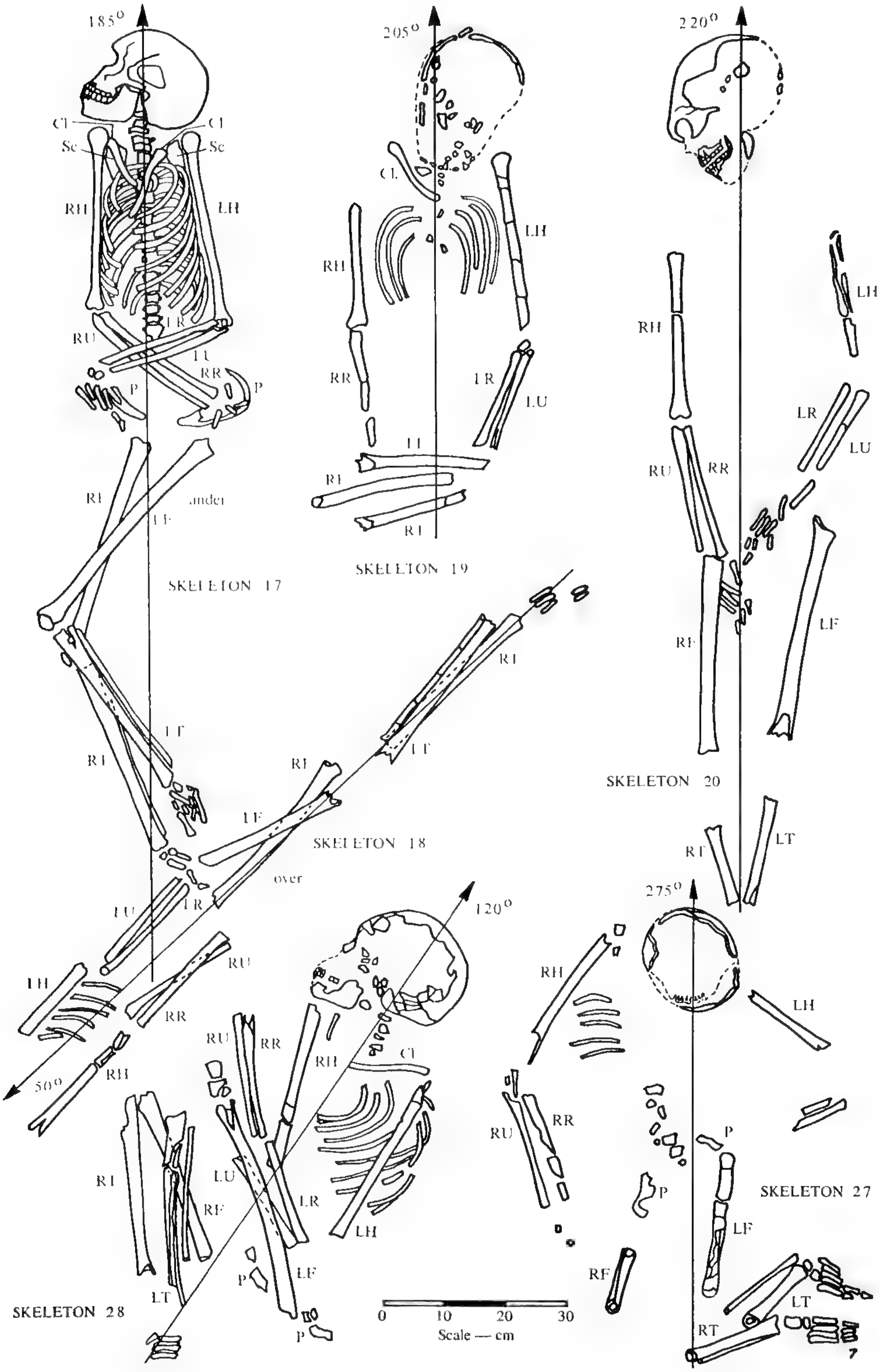

Fig. 7—Burial attitudes of Skeletons 17-20, 27-28, Site 16B.

This skeleton, which consisted of traces only, was located in hard clayey sand. The cranium was substantially eroded due to exposure, but there were sufficient fragments of the cranium to define the position of the head which was slightly on the right side. One clavicle and a few pieces of rib were present. No vertebrae were preserved and there was no pelvis. Both arms alongside the thorax. Femore flexed to the right and at right angles to the body. Only the right tibia was present, flexed sharply back inferior to the femur. No foot bones present. Orientation 205°.

Skeleton 20. NMV X72818, CHA 102. Fig. 7.

A fragmentary extended supine burial.

The cranium was present as fragments and sections only, including the frontal bone showing prominent brows. The mandible was fragmentary. The upper and lower left teeth were held in place by bone fragments and the sand matrix.

Dentition:

UR ——— 12345678 UL
LR ——— 12345678 LL

Two upper right molars and one lower right molar were present as loose teeth. All teeth were very severely worn to the pulp. The lower left premolars were worn at an angle of 15° and the lower left molars were worn to an angle of 30° from the plane of occlusion sloping downwards labially and leaving only 1 mm of enamel skirt on the molars.

There were no thoracic bones present and no pelvic bones. The arm and leg bones were severely eroded at the ends. The lower arm bones were flexed across the pelvic region with the hands over the pubic area. The tibiae were in contact at the distal ends as if bound together at burial. Orientation 220°.

Skeleton 21. NMV X72819, CHA 80. Fig. 8.

A very fragmentary flexed skeleton. There were no cranial or upper thoracic bones present, these having been dispersed by exposure. The thorax appears supine but the position of the arm bones suggests that the shoulders had been twisted to the left with the right shoulder much superior to the left, and the left arm passing below the legs. The legs were flexed to the left. The left tibia had been folded back close to the left femur and superior to it, with the left foot over the remnants of the pelvis. The right tibia was not present and the position of the few right foot bones suggests that it had been displaced. Orientation 150°.

Subsequent excavation from Skeleton 21 towards Skeleton 26 indicated that a former rabbit burrow entrance had been situated at the probable position of the cranium of Skeleton 21. This may have been responsible for the disturbance of the head bones. The burrow crossed the lap of Skeleton 26. An asymmetric basal portion of a large fish spine was found in the undisturbed sand immediately adjacent to the right femur of Skeleton 21.

Skeleton 22. NMV X72820, CHA 61. Fig. 8.

A fragmentary flexed skeleton. The body apparently lay on its right side with the lower arms folded back towards the shoulders. The legs were flexed substantially at right angles to the body, the tibiae being folded back in close proximity to the femora with the left leg bones resting on the right leg bones. All bones fragmentary and eroded. Orientation 180°.

Skeleton 23. NMV X72821, CHA 29. Fig. 8.

A very incomplete skeleton extending from the surface down to 15 cm below it. No trace of a cranium was found nor of any pelvic bones and lower limbs. It did not appear as if these elements had been exposed and scattered. It was therefore concluded that the burial represented the trunk only, laid supine with the left arm flexed back towards the shoulder and the right arm flexed across the lower thoracic region. A few small pieces of charcoal lay under the centre of the thorax. In this case the orientation of 22° probably has no real significance.

Skeleton 24. NMV X72822, CHA 73. Fig. 8.

A fragmentary skeleton, apparently buried supine with the legs flexed upwards. Only fragments of cranium were present. There were no thoracic bones. Fragments of the pelvic bones lay adjacent to the proximal end pieces of both femora, the position of which suggested that

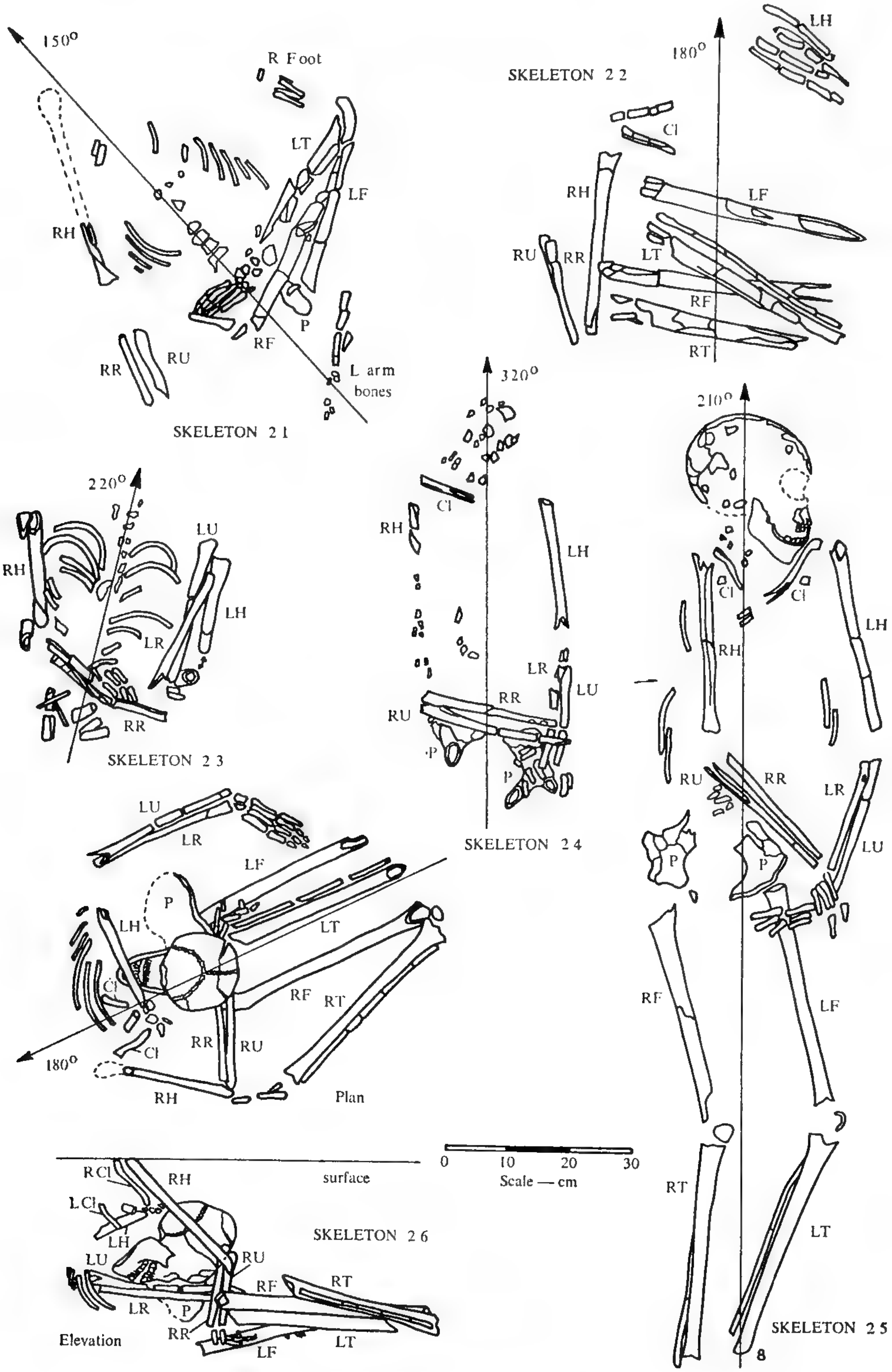

Fig. 8—Burial attitudes of Skeletons 21-26, Site 16B.

the legs were flexed upwards. The remainder of the leg bones had been exposed and scattered. Right arm alongside the thorax with the lower arm flexed across the pelvic area. Left arm alongside the thorax. All bones severely eroded and very fragmentary. Orientation 320°.

Skeleton 25. NMV X72823, CHA 75. Fig. 8.

A fully extended supine burial, head on the left side, legs flexed slightly to the left, hands to the left side of the body. Erosion had exposed the right side of the cranium, which had disintegrated and scattered. The remaining pieces, including substantial portions of the mandible, clearly indicated the position of the head. Four upper incisors were in place as were three lower incisors and one canine. A total of eight molars and eight premolars were found loose. The wear of the teeth was severe. Pieces of clavicle and a few rib fragments defined the position of the rib cage. Left arm alongside the thorax with the left hand resting on the proximal end of the left femur. Right arm slightly over the thorax with the lower arm bones flexed across the body superior to the pelvis, the right hand resting on the left wrist. Pieces of the iliac bones defined the pelvis position. Femora flexed slightly to the left side with the distal ends of the tibiae remaining on the centreline of the body. Feet exposed and scattered. Arm and leg bones fragmented and severly eroded at the ends. Orientation 210°.

The left tibia had a small bone growth 1·5 cm long standing 2·5 mm proud on the anterior border midway between the ends, apparently a periostitic growth consequent upon a blow.

Skeleton 26. NMV X72824, CHA 76. Fig. 8.

A squatting burial with legs flexed, compressed from above.

The body had apparently been buried in a sitting position, as defined by pieces of rib, the clavicles and the position of the proximal ends of the humeri. The arms had been placed more or less alongside the thorax, with the left lower arm and hand alongside the pelvis and left femur, and the right lower arm flexed across the pelvis with the right hand lying over the proximal end of the left femur. Pelvis fragmentary. Leg bones much eroded at the ends, encrusted with a substantial calcareous layer, but otherwise in good condition. Both femora were placed in a horizontal position extending forward from the trunk, with the tibiae flexed back sharply, so that the feet were in the pelvic region. The leg bones were very closely in one horizontal plane as seen in the elevation drawing (Fig. 8) and this was no doubt due to settlement during decomposition. Evidence of the remarkable degree of vertical compression was the fact that the lowest element of the skeleton was within 32 cm of the surface.

An interesting feature was the position of the cranium. Whatever its original position at burial, it is clear that as the thorax decomposed the cranium sank downwards onto the chest. With continuing decomposition and settlement the chin penetrated the chest cavity and swung downwards and backwards, so that the head finally came to equilibrium with the face in a horizontal plane facing downwards, with the chin to the posterior side of the body and the parietal bones in the anterior position. The cranium was substantially complete except for the supramaxillary region. The elements of the cranium had parted at the sutures and distortion due to their relative movement was considerable, the cranium having been compressed somewhat antero-posteriorly. There was considerable evidence of permanent distortion of some of the cranial elements.

Dentition:

UR 8765432– –2345678 UL
LR 8765432– –2345678 LL

The upper medial incisors had been evulsed. The lower medial incisors, although missing from the mandible as teeth, had been broken off post mortem, leaving the roots in the bone. Wear generally moderate, but there was no apparent wear on the two upper third molars. The occlusal surface of the upper left third molar was 3 mm superior to the occlusal surface of the second molar, whose occlusal surface was in turn 3 mm superior to that of the first molar, giving a stepped appearance. The occlusal surfaces of the second and third upper right molars were at the same level, but were 4 mm superior to the occlusal surface of the upper right first molar. Both the lower third molars stood proud of the first and second molars by 1·5 mm. With this unusual variation in the height of the occlusal surfaces, it is apparent that occlusion between the second and third molars could not occur. The rear molars had fully erupted, but apparently so recently as not to be subject to perceptible wear. Probably age 25 years. Orientation 180°.

Excavation revealed an unoccupied rabbit burrow extending from an entrance at the head position of Skeleton 21 and passing across the lap of Skeleton 26. The burrow passed just beneath the skull. Of interest is the fact that all bones below the burrow position were encrusted with a calcareous layer approximately 1 mm thick. This is apparently of recent origin, possibly derived from the reaction of uric acid and/or other fluids introduced while rabbits were in occupation.

Skeleton 27. NMV X72825, CHA 77. Fig. 7.

A supine flexed burial with the head forced forwards onto the thorax.

In its final equilibrium position the cranium was clearly vertical. The erosion of the ground caused the superior half of the cranium to be worn away and scattered, so that when located, a horizontal section of the skull just above the brow level appeared at the surface. The cranium had been crushed a little vertically. The mandible, located underneath it, was substantially complete, although the inferior part of the cranium had largely been eroded away.

Dentition:

UR –765432– –2345678 UL
LR –7654321 1—45678 LL

The upper medial incisors had been evulsed. The lower left teeth had been displaced upwards and medial to the upper left teeth as a result of vertical compression. Wear moderate.

A few rib portions with fragmentary vertebrae and pelvic bones were present, just sufficient to delineate the trunk. Arm bones very eroded and fragmented, but clearly alongside the thorax. Femora extended more or less in line with the body but slightly to the right. Tibiae flexed sharply back to the left with the feet on the left hand side and lying superior to the position of the knees. Leg bones fragmentary, broken and eroded. Orientation 275°.

Although classed as a supine flexed burial, it is possible that the body was placed in the grave in a slightly reclining position which resulted in the forward collapse of the cranium during decomposition.

Skeleton 28. NMV X72826, CHA 35. Fig. 7.

A flexed burial lying on the right side.

Erosion had exposed the left side of the cranium and worn it away so that fragments present were merely sufficient to delineate its position—on the right side and facing right. Small pieces of the right mandible were present with the lower right second and third molars in place in the bone. These two teeth were considerably worn into the pulp, with the roots exposed for 6 mm above the bone. Slight lateral calculus present on the lower edge of the crowns both lingually and labially.

Traces of cervical vertebrae were present, and a few pieces of rib delineated the thorax. Upper arms alongside the thorax with the lower arms folded upwards in front of the thorax. Pelvis extremely fragmented. Femora flexed well up in front of the thorax with the tibiae flexed sharply back against the femora. A few foot bones present. All bones fragmented and severely eroded. Orientation 120°.

Radiocarbon dating of the bones gave an age of 5,350 ± 290 years B.P. (GaK-1431).

Site 17, Skeletons 29-31.

Skeleton 29. NMV X72827, CHA 17. Fig. 9.

A flexed burial lying on the right side.

A very much eroded and comminuted skeleton buried in hard red clayey sand. The cranium lay on its right side and had been severely compressed laterally to a thickness of 8 cm, with an overlap at the sagittal suture of 2·5 cm. It had been severely comminuted. The right side of the cranium had been flattened by soil pressure. Mandible substantially complete, but broken at the front and laterally compressed against the right humerus lying immediately

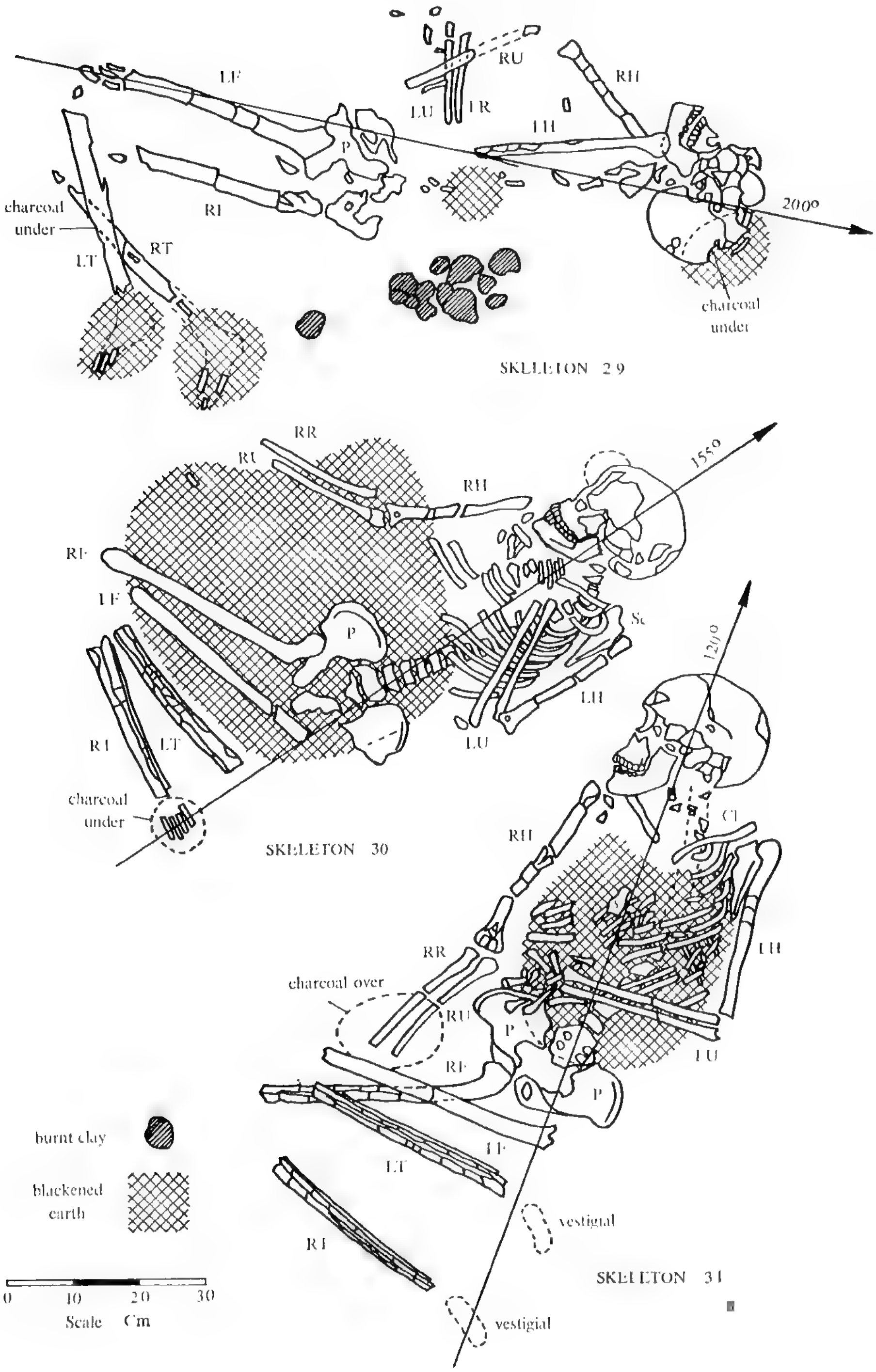

Fig. 9—Burial attitudes of Skeletons 29-31, Site 17. The three skeletons are shown in their correct relative positions as they lay in the grave.

below it, so that the right lower teeth were forced medial to the right upper teeth. The cervical vertebrae had been forced upwards under the mandible.

Dentition:

UR –76543—	——45678 UL
LR invisible	1234–678 LL

The teeth showed little wear and were preserved *in situ* with the cranium. The soil held the fragments of the cranium together when treated with 'Aquadhere'.

The arms were folded across the thorax anteriorly, the degree of lateral compression during decomposition being such that the upper ends of the humeri were only 5 cm apart. No thoracic bones were present.

Only remnants of the pelvis and sacrum were present. The femora extended in line with the trunk and the tibiae were flexed backwards with the feet superior to the knees. A few isolated foot bones were present. All limb bones were much comminuted and eroded. Orientation 200°.

Dark areas of soil were present around both feet, in the lumbar region, and under the cranium. Charcoal was present in quantity under the cranium and under the tibiae. A small concentration of 13 calcined clay hearthstones was located adjacent to the lumbar region but these were not associated with charcoal.

A sample of the dark soil was found to consist of 93·8 per cent of coarse silica sand, 5·0 per cent of silt-size iron-stained quartz particles with some humic organic matter, and 1·2 per cent of organic volatiles. The organic volatiles were responsible for the dark colouration of the soil.

The charcoal associated with the skeleton was radiocarbon dated at 5,840 ± 90 years B.P. (GaK-1409).

Skeleton 30. NMV X72828, CHA 333. Fig. 9.

A flexed burial with the body lying on the right side.

Cranium somewhat fractured and with the left temporal region flattened. Mandible broken at the symphysis due to lateral compression, the right and left portions overlapping. Sutures normal, brows not prominent, mastoid processes large.

Dentition:

UR 8765432–	–234567– UL
LR 87654321	12345678 LL

Upper medial incisors evulsed.

Substantial elements of the rib cage were present together with a largely complete but much eroded vertebral column. Thorax on the right side. Right arm extended and somewhat anterior to the thorax. The left humerus alongside the thorax, with the left lower arm bones flexed upwards across the thorax towards the shoulder region. Pelvis partially present with eroded sacrum. The sacrum and pelvic girdle appeared male. Femora flexed to the right and the tibiae flexed back inferior to the femora. A few foot bones present, located on the centreline of the trunk. Some charcoal was found lying under the foot bones. Orientation 155°.

A large area of dark soil underlay the right arm and extended under the pelvic area and the femora. Analysis showed the dark colouration to be due to the presence of humic organic material and not to charcoal.

Skeleton 31. NMV X72829, CHA 334. Fig. 9.

A flexed burial lying on the right side.

Cranium lying on the right side, fairly complete, comminuted in the temporal regions and with the right side flattened by lateral pressure. Brows not prominent. Mandible much comminuted on the right side which was crushed in under the palate, although the teeth remained substantially *in situ*.

Dentition:

UR 87654321	12345678 UL
LR invisible	1234567– LL

Upper medial incisors wide, 1·14 cm at the occlusal edge. Both upper third molars were just emerged from the bone with the occlusal surfaces still some 8 mm superior to those of the upper second molars. Probable age 20-23 years.

The clavicles, left scapula, rib pieces and traces of vertebrae defined the position of the thorax lying partially on the right side. Right arm fully extended, anterior to the thorax, with the hand under the left knee. Left humerus alongside the thorax, with the lower left arm bones flexed across the lower thoracic region, the hand resting on the right iliac bone. The pelvis was well-defined in position but was insufficient to determine the sex. Leg bones very much eroded, flattened by soil pressure and fragmented. Femora drawn up approximately at right angles to the body and to the right, left knee superior to right knee. Left tibia flexed backwards close alongside the left femur. Right tibia flexed backwards to a lesser degree. Both feet present as faint traces only. Orientation 120°.

A small calcined clay hearthstone was lodged underneath the left scapula. Some charcoal was present over the lower right arm bones.

In Fig. 9 the three skeletons (Nos. 29-31) excavated at Site 17 are shown correctly oriented and spaced relative to one another. It is tempting to think of them as a group burial surrounding a small fire, since all were buried at the same level, all have areas of soil associated with them which have been discoloured by organic matter, and they are associated with a number of calcined clay hearthstones mainly concentrated between Skeletons 29 and 30. Skeleton 29 was dated 5,840 ± 90 years B.P. from charcoal associated with it, but funds did not permit of dating Skeletons 30 and 31. Although buried in the same soil horizon, Skeletons 30 and 31 were so much better preserved than Skeleton 29 that they were probably interred at a much later date. Only dating of these bones can provide a firm answer.

SITE 18, SKELETONS 32-33.

Skeleton 32. NMV X72830, CHA 215. Fig. 10.

A prone extended burial with the head lying on its left side and facing to the left. Bones hard and somewhat mineralized on the surface due to carbonate deposition.

Cranium fairly complete but crushed laterally, flattened and broken on the left temporal region in particular. Coronal suture no longer visible. Sagittal suture just visible. Mandible complete. A mussel shell was wedged between the mandible and the zygomatic arch on the right side. Another mussel shell lay medially within the mandible.

Dentition:

UR	8765432–	–2345678	UL
LR	87654321	12345678	LL

Wear moderate and helicoidal. Incisors worn flat and to the pulp. Upper medial incisors evulsed.

Scapulae, clavicles, rib pieces and eroded but clearly defined vertebrae delineate the thorax. There were fragments of mussel shell among the bones near the centre of the spinal column. The pelvis was much broken and eroded and was insufficient to determine the sex. Arms extended alongside the thorax, left hand bones missing, right hand bones inferior to the pelvis. Deltoid tuberosity strongly developed on each humerus. Leg bones somewhat fragmented and eroded at the ends. Femora extended in the line of the thorax with the left tibia crossing over the right tibia just superior to the distal ends. No foot bones present, these having been exposed and scattered. Orientation 200°.

Numerous pieces of yellow ochre were in place around the leg bones, with one piece of red ochre below the right knee and several more embedded in the soil above the level of the skeleton 60 cm away from the body at the level of the right hand.

The placing of mussel shells on various parts of the body at burial appears to have been done deliberately as a part of burial ceremonials in some cases (e.g. in burials examined by Graeme Pretty at Roonka Station, Lower Murray Valley, S. Australia—personal communication). The shell lodged in the right mandible of Skeleton 32 could have been placed there deliberately, but the shell found lodged medially within the mandible could not have migrated there from a similar position in the left mandible and could hardly have been placed in position post mortem. Likewise the shell found in the central thorax area could not have been placed there post mortem. It seems probable in this case that the shell has been lodged fortuitously and has been derived from the grave infill.

Skeleton 33. NMV X72831, CHA 214. Fig. 10.

An extended supine burial.

Bones hard and mineralized on the surface by carbonate deposition. Skeleton disturbed, fractured and scattered by a combination of surface erosion and the penetration of a shallow root from a nearby tree. This had passed through the cranium and along the centreline of the body to the pelvic and upper leg regions. Its position is indicated in the drawing (Fig. 10). As a result, only portions of the left side and occipital regions of the cranium were present, together with fragments of the mandible. Two loose molars were found, both well-worn. The bones were exceedingly fragmentary but showed the arms to have been fully extended alongside the thorax and below the pelvis. Pelvis very fragmentary and scattered. The left femur was absent. The right femur, broken and eroded, was extended in the line of the body. Pieces of both tibiae were present, but somewhat displaced. No foot bones were present. Orientation 170°.

SITE 19A, SKELETONS 34-36.

Skeleton 34. NMV X72832, CHA 95. Fig. 10.

A supine flexed burial with the legs flexed to the left and the arms folded back on the chest with the hands towards the head. The bones had become somewhat scattered by exposure. A few fragments only of the cranium were present with shattered remnants of four teeth, well worn down. A skull fragment shows the suture to be of an intricate interlocking character.

Ribs displaced, but the arm bones clearly show the humeri parallel to the thorax with the lower arm bones flexed back parallel to the thorax with the hand positions adjacent to the cranium. Pelvic bones fragmentary, but the sub-pubic angle which approximates 100° suggests a female. Femora flexed to the left side at right angles to the centreline of the thorax, right over left, with the tibiae flexed back sharply inferior to and closely associated with the femora. Remnants only of vertebrae, hand and foot bones present. Orientation 220°

Skeleton 35. NMV X72833, CHA 96. Fig. 10.

An extended supine burial with the arms alongside the thorax and the legs inclined slightly to the left.

Because of soil erosion the cranium was present only as scattered pieces of bleached bone. Mastoid processes small, supraorbital ridges not prominent. A piece of the left maxilla was present with the upper left premolars in place. Right half of the mandible present with the premolars and the third molar in place, and the sockets of the remaining teeth present. Four upper molars, three lower molars and four premolars found loose in the sand. Wear on all teeth severe, helicoidal and angular to as much as 40° from the occlusal plane. Wear on the lower right third molar was severe and concave with the anterior edge upstanding.

Rib cage substantial with ten fragmentary vertebrae present including the axis. Pelvic bones substantial. Sub-pubic angle of 100° indicates a female. Arms extended alongside the thorax, hands inferior to the pelvis, with the lower arm posterior to the pelvis. Legs fully extended but inclined towards the left relative to the body axis. A few finger bones lay between the tibiae. Foot bones substantial, with the right foot almost complete. Orientation 220°.

Skeleton 36. NMV X72834, CHA 97. Fig. 10.

An extended supine burial.

Cranium fully exposed by soil erosion and scattered, leaving a few small remnants only. Thorax partially exposed and scattered, but well defined by rib portions and pieces of scapulae. Right arm flexed slightly to the right with the hand over the pelvis. Ten fragmentary vertebrae present. Iliac bones well-preserved. The sub-pubic angle of 65° indicates a male. Leg bones fully extended in line with the thorax with the feet well apart. A majority of the feet bones were present. Orientation 230°.

SITE 19B, SKELETONS 37-42.

Skeleton 37. NMV X72835, CHA 98. Fig. 11.

An extended supine burial in association with Skeletons 38 and 39.

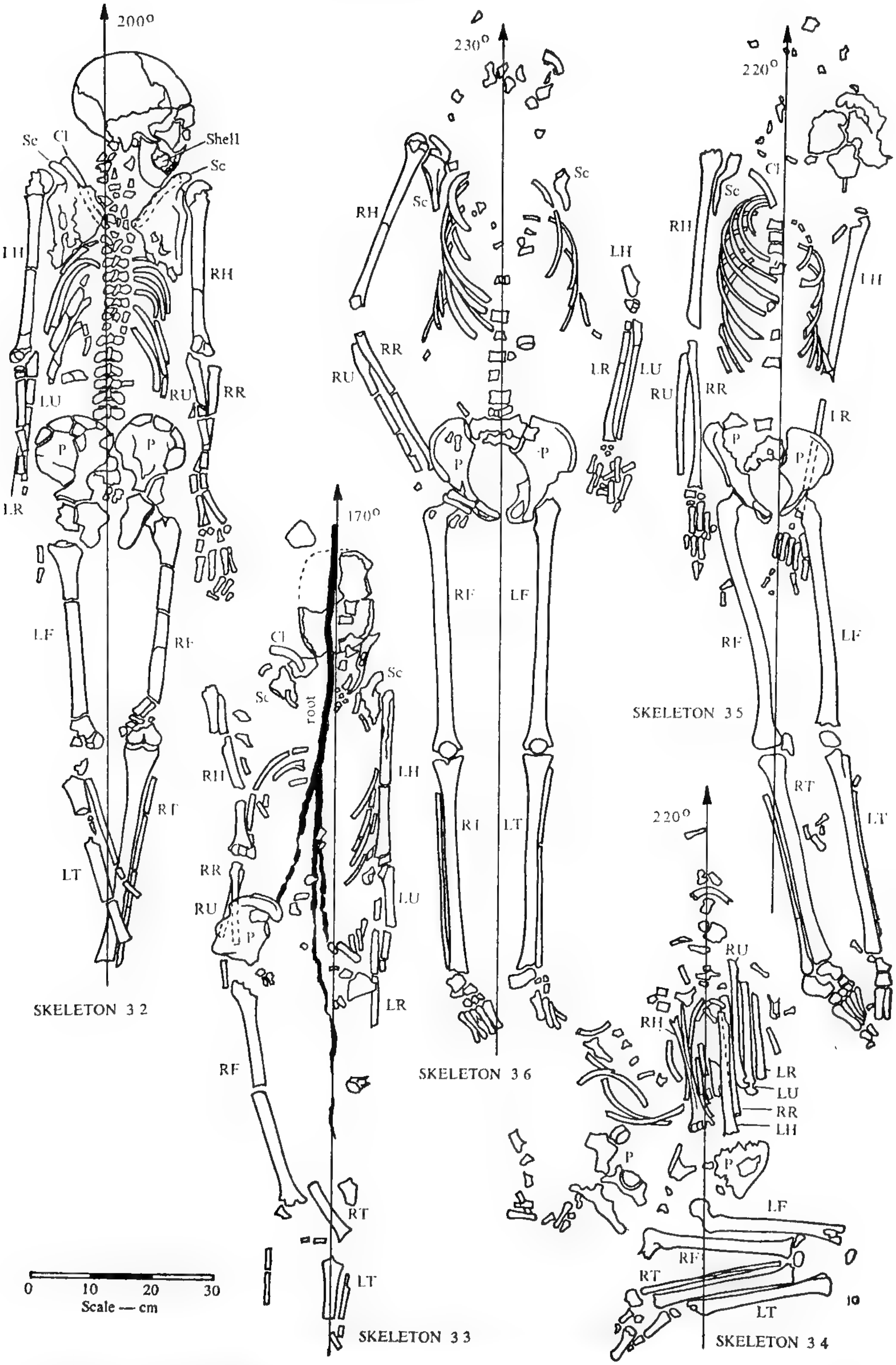

Fig. 10—Burial attitudes of Skeletons 32-33, Site 18, and Skeletons 34-36, Site 19A.

Cranium fairly complete with the face fallen forward onto the thorax so that the mandible had been forced upward under the palate. Some vertical compression had caused the atlas and axis to be forced into the foramen magnum and to be become comminuted. (Fig. 20).

Dentition:

UR 8765432– –2345678 UL
LR ——5432– 12345—— LL

Wear helicoidal and severe, up to 30° from the occlusal plane. Upper third molars fully erupted and well worn. Upper molars worn close to the roots. Medial upper incisors evulsed. Lower right medial incisor broken off post mortem due to movement of the mandible. Bone regrowth had been complete over the sockets of all lower molars indicating their early loss. Probable age over 35 years.

Clavicles and portions of the scapulae present, but no other thoracic bones remained Pelvic bones fragmentary. Arms alongside the thorax with the hands inferior to the pelvis. Leg bones eroded at the ends but otherwise substantial. A few foot bones were present. Orientation 230°.

Below the right elbow, portions of a mandible (3, Fig. 11) were found and above the level of Skeleton 37 and to the left of its pelvis, the frontal bone and attached maxillae of Skeleton 39 (3, Fig. 11) were located.

Skeleton 38. NMV X72836, CHA 99. Fig. 11.

A fully extended supine burial in association with Skeletons 37 and 39.

Cranium lying on the right side, fairly complete but with the right temporal region somewhat crushed, and the right ramus of the mandible broken due to soil pressure.

Dentition:

UR 8765432– —345678 UL
LR ——4321 1234—— LL

Teeth well-worn, helicoidal, with wear up to 30° from the horizontal occlusal plane. The bone was broken away at the position of the upper medial incisors and it was impossible to determine whether or not these teeth had been grown over the sockets of the lower left second premolar and molars, and the lower right second and third molars indicating early loss. This was substantiated by the presence of a helicoidal wear pattern on the remaining lower teeth. Age probably in excess of 35 years.

Cervical vertebrae present, together with the clavicles, the greater part of the scapulae and a few rib portions. Arms extended alongside the thorax. No lumbar or thoracic vetrebrae or pelvis present. The legs extended below the thorax and femora of Skeleton 37. Orientation 220°.

The parietal and occipital bones of another cranium (Skeleton 39) were found located over the thorax of Skeleton 38 lying between its cranium and that of Skeleton 37 (3, in Fig. 11).

Skeleton 39. NMV X72837, CHA 100 and 101. Fig. 11.

The skeleton consisted of cranial portions only, associated with Skeletons 37 and 38. The locations of these portions have been described above.

The frontal bone, together with its associated maxillae and upper teeth, which were found located to the left hand side of Skeleton 37, fitted together with the parietal and occipital bones located between the crania of Skeletons 37 and 38, and were clearly elements of one cranium (Skeleton 39). The portions of mandible recovered below Skeleton 37 were reassembled into a substantially complete mandible, the teeth of which occluded well with the upper teeth of this cranium and clearly formed a part of it.

Dentition:

UR –765432– –2——67– UL
LR 87654321 12345678 LL

The teeth showed very little wear. Both lower third molars had just erupted through the bone and their occlusal surfaces were 6 mm below those of the lower second molars. The upper third molars were unerupted. Medial upper incisors evulsed. A young person, probable age about 20 years.

Skeletons 37-39 are shown in the drawing (Fig. 11) in their correct positions relative to one another. The elements of Skeleton 37 bear the suffix 2, the elements of Skeleton 38 bear

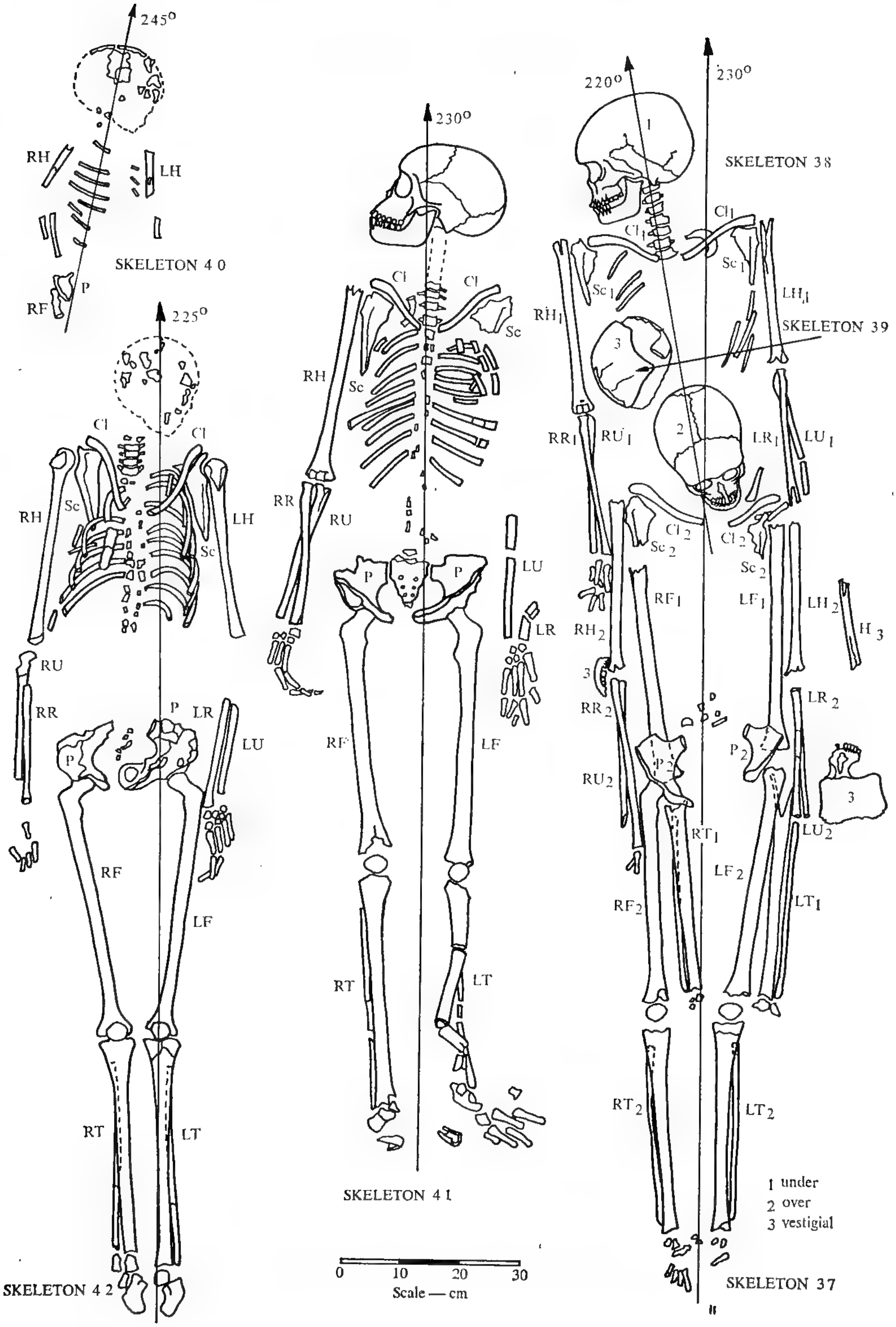

Fig. 11—Burial attitudes of Skeletons 37-42, Site 19B.

the suffix 1, and the elements of Skeleton 39 bear the number 3. It seems from the position of the three skeletons that 39 was buried subsequent to 38 and above it, and that 39 was then disturbed and scattered when the grave was dug to bury 37, the only evidence of 39 being the cranial elements recovered. It seems probable also that the lower thoracic and pelvic regions of 38 were removed and lost during the burial of 37.

Skeleton 40. NMV X72838, CHA 357. Fig. 11.

A supine burial, apparently extended, with the head turned to the left. Remains extremely fragmentary but sufficient to indicate the position of the cranium, the thorax (with the arms extended alongside it) and the pelvis. A small portion of the right femur suggested the extended position. Clearly a young child. Orientation 245°.

Skeleton 41. NMV X72839, CHA 162. Fig. 11.

A fully extended supine burial with the head turned to the right.

Cranium almost complete, supraorbital ridges not prominent, all sutures well-defined. Palate small. (Fig. 21).

Dentition:

UR	87654321	12345678	UL
LR	87654–21	12345678	LL

Teeth with very slight helicoidal wear. The rear molars were fully occluded but unworn. The medial incisors were 1·14 cm wide at the occlusal edge. Age probably about 25 years.

The atlas and axis were present under the cranium, separated by 7 cm from the lower four cervical vertebrae, indicating some post mortem displacement. Balance of the vertebral column fragmentary. The clavicles, portions of the scapulae and pieces of rib cage defined the thorax well. Arms extended alongside the thorax, hands inferior to the pelvis and well clear of it on each side (Pl. 12, fig. 3). The left humerus was completely absent, again suggesting some post mortem disturbance. The pelvis and sacrum were fairly complete. Leg bones eroded at the ends. Left tibia and fibula broken in several places. Some foot bones were present and the feet were well separated. Orientation 230°.

A small burnt clay hearthstone was found alongside the neck.

Skeleton 42. NMV X72840, CHA 163. Fig. 11.

A fully extended supine burial.

A few fragments only of the cranium were present and were not sufficient to define the attitude. Four cervical vertebrae and vestiges of thoracic vertebrae were present which, together with the clavicles, scapulae and portions of the rib cage, clearly defined the thorax. Arms extended alongside the thorax with the hands inferior to the pelvis. Pelvis somewhat fragmented. Legs fully extended with the knees and feet close together. The calcaneum and talus of each foot were present, but there were no other foot bones. Orientation 225°.

SITE 19C, SKELETONS 43-58.

Skeleton 43. NMV X72841, CHA 166. Fig. 12.

A flexed burial lying on the right side with the legs flexed to the right.

The cranium was lying on its right side. The left side and the occipital region were fairly complete. The supramaxillary region was somewhat comminuted. The right side comminuted and largely absent. The saggital and lamboidal sutures were fused and invisible. The maxillae and the mandible were present but had been laterally compressed and broken medially.

Dentition:

UR	876543—	12345678	UL
LR	87654321	12345678	LL

Moderate helicoidal wear to 15° from the horizontal occlusal plane. Probable age 35-40 years.

The thorax was well defined by rib portions, the scapulae and remnants of vertebrae. The skeleton lies on the right side with the left shoulder anterior to the right shoulder. Left arm folded back close to the chest with the hand bones immediately anterior to the face. The right humerus lay below the rib cage with the right lower arm bones flexed upwards towards the face and lying directly below the left lower arm bones in the grave. The pelvic bones were fragmentary and insufficient to define the sex, Femora flexed at right angles to the centreline of the trunk, with the lower leg bones closely inferior to them and the feet immediately inferior to the pelvis. The right leg lay underneath the left leg. Orientation 100°.

Skeleton 44. NMV X72842, CHA 167. Fig. 12.

A flexed squatting burial, vertically and severely compressed.

Cranium largely complete, lying partly on the right side with the right temporal region severely crushed inwards. Maxillae substantially intact with the upper teeth in place. Mandible dislodged to the left and separated from the cranium. Brows not prominent. Wormian bone present at lambda.

Dentition:

UR 8765432– –2345678 UL
LR ———21 12345678 LL

Upper medial incisors evulsed. Wear moderately severe, helicoidal. Upper premolars and canines worn to the pulp. Upper molars moderately worn with the occlusal surface of the second molars 2·5 mm superior to that of the first molars and the occlusal surface of the third molars 2·5 mm superior to that of the second molars, giving a stepped appearance.

The left shoulder region had been superior to the cranium but had been exposed at the surface and abraded away. The left scapula and clavicle had been displaced. The right shoulder was 10 cm inferior to the top of the cranium. Both lower arms were folded forward and rested on the legs. Femora approximately horizontal with the tibiae folded back immediately below them with the feet under the pelvis. Pelvis fragmentary. There was heavy termite damage to the surfaces of the left arm bones. Orientation 150°.

The drawing (Fig. 12) is presented both in plan and elevation in order to show the attitude of this skeleton and to illustrate the extraordinary degree of vertical compression which it had undergone. The whole skeleton occupied a vertical space of only 33 cm. This skeleton lay immediately over the mass of skeletons comprising Nos. 51-55 inclusive and was in close contact with skeleton 50 on its dorsal side. The juxtaposition of these skeletons is discussed below.

Skeleton 45. NMV X72843, CHA 168. Fig. 12.

A flexed burial lying on the right side.

A few fragments only of cranium were present with three molars, one premolar and one canine of the upper left teeth *in situ* in the sand matrix. This was sufficient only to delineate the position of the head on the right side. No thoracic bones were present. Small fragments of the left lower arm bones and pelvis were evident. Femora flexed to the right with the tibiae flexed back inferior to them. The foot position was inferior to the pelvic region, but no foot bones were actually present. Right femur extensively channeled on the surface by termite attack. Orientation 245°.

Skeleton 46. NMV X72844, CHA 169. Fig. 12.

A small portion of a skeleton consisting of pieces of pelvis only, with broken pieces of the shaft of the left femur and a few fragments of hand bones. The position of the femur and the location of the hand bones suggest an extended burial with an orientation of 260°.

Skeleton 47. NMV X72845, CHA 170. Fig. 12.

A flexed burial lying on the right side.

Cranium fragmentary, but clearly showing the position of the head on the right side. The left maxilla and the left side of the mandible were *in situ* and substantially complete.

Dentition:

UR –7654—— –2345678 UL
LR 876——— –2345678 LL

Wear moderately severe, helicoidal. Third molars fully erupted and well-worn. Slight calculus on the lower buccal margin of the crowns of the upper left second molar and the lower left first molar. Probable age at least 30 years.

Vestiges of vertebrae delineated the position of the thorax. There were a few fragments only of pelvic bones. Both arms extended alongside the thorax with the lower right arm passing beneath the leg bones and the lower left arm posterior to the pelvis. Both hands lay inferior

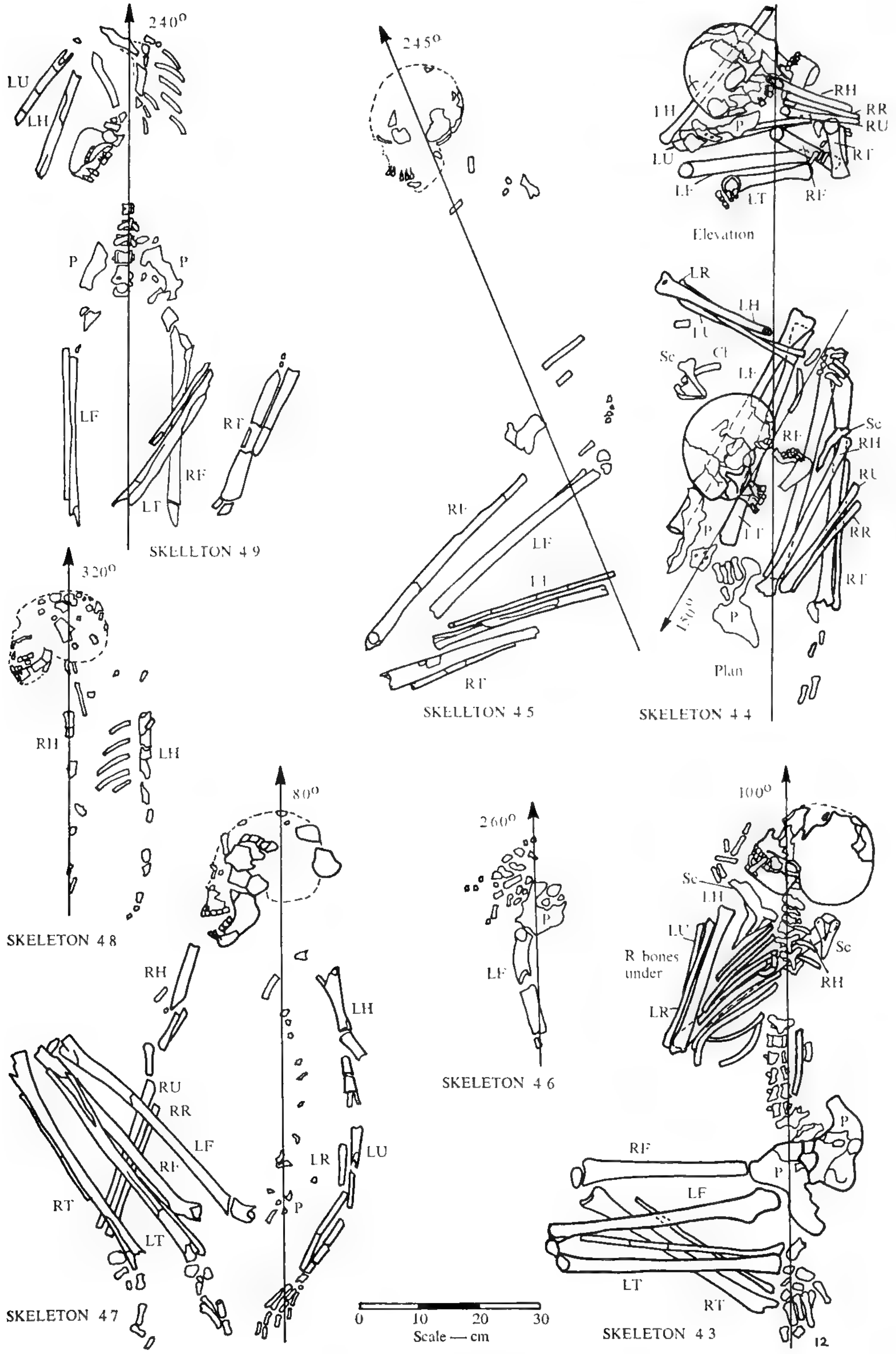

Fig. 12—Burial attitudes of Skeletons 43-49, Site 19C.

to the pelvis. Femora drawn well up towards the thorax with the tibiae flexed back immediately inferior to them, the right leg bones lying beneath the left leg bones. A few foot bones lay immediately inferior to the pelvis. Orientation 80°.

The position of this skeleton suggested that it might possibly have originally been buried nearly supine with the head to the right and the knees drawn up vertically, and that the legs moved to the right and subsided over the right arm during decomposition and settlement.

Skeleton 48. NMV X72846, CHA 171. Fig. 12.

A fragmentary burial of a small adult, apparently on the right side.

Fragments of cranium and teeth *in situ* in the sand matrix delineate the size of the head and its position as lying on the right side. The head was small, but eleven loose molar crowns were present in the sand and therefore it was that of an adult. A few rib fragments and pieces of the right and left arm bones outlined the thorax with the arm extended alongside it. No other bones were present. Orientation 320°.

Skeleton 49. NMV X72847, CHA 172. Fig. 12.

A flexed prone burial.

No cranial bones were present, but a mandible, the left side of which was fairly complete, was located in the centre of the thorax area and had been displaced post mortem. Five lower molars, two lower premolars and two incisors were present showing moderately severe wear.

Left humerus alongside the thorax with the lower arm flexed back towards the head. The left clavicle, sternum and rib portions delineated the upper thorax. Four lower lumbar vertebrae were present and confirmed the prone position. Only vestiges of the pelvis remained. Femora in line with the thorax. Tibiae flexed back and directed to the right side of the body. The position of the feet was superior to that of the knees but no foot bones were present. Orientation 240°.

Skeleton 50. NMV X72848, CHA 173. Fig. 13.

A flexed burial lying on the left side.

Cranium substantially complete but comminuted in the left temporal region and flattened on the left side by soil pressure. Brows prominent. Mandible displaced to the left and crushed by lateral pressure. Teeth held in place by portions of bone and the sand matrix.

Dentition:

UR 8765432– ——5678 UL
LR 8765432– ——5678 LL

The ten teeth not in place were recovered loose in the sand, showing that all teeth were present at death. The molars were fully erupted and wear was slight. Age probably about 30 years.

The cervical vertebrae were reasonably preserved, but the balance of the vertebral column was largely eroded away or otherwise absent. The thorax was well-defined by rib portions, the right clavicle and the sternum. Upper arms alongside the thorax with the lower arms folded across the pelvic region with the hand bones above the pelvis. Pelvis substantial. The subpubic angle of 55° indicates a male. Femora flexed to the left with the tibiae flexed back inferior to the femora. Both feet substantially complete. The left leg lay beneath the right leg. The leg and arm bones were eroded at the ends but were otherwise well-preserved. Orientation 320°.

The juxtaposition of this skeleton with Skeletons 44 and 51-52 is discussed below.

Skeletons 51-55. NMV X72849-X72853, CHA 174-178. Fig. 13.

These skeletons were all flexed squatting burials subject to considerable vertical compression and subsidence after burial and during decomposition. They must be treated as a group because, as reference to Fig. 13 will show, they have been buried in such a manner as to become inextricably mixed by overlapping and interpenetration. This clearly required simultaneous burial and decomposition. Further, the skeletons were all buried at approximately the same level, and extended from 33 cm to 51 cm below the existing surface level. This extremely restricted vertical dimension confirms the very considerable vertical settlement during decomposition. The essentially

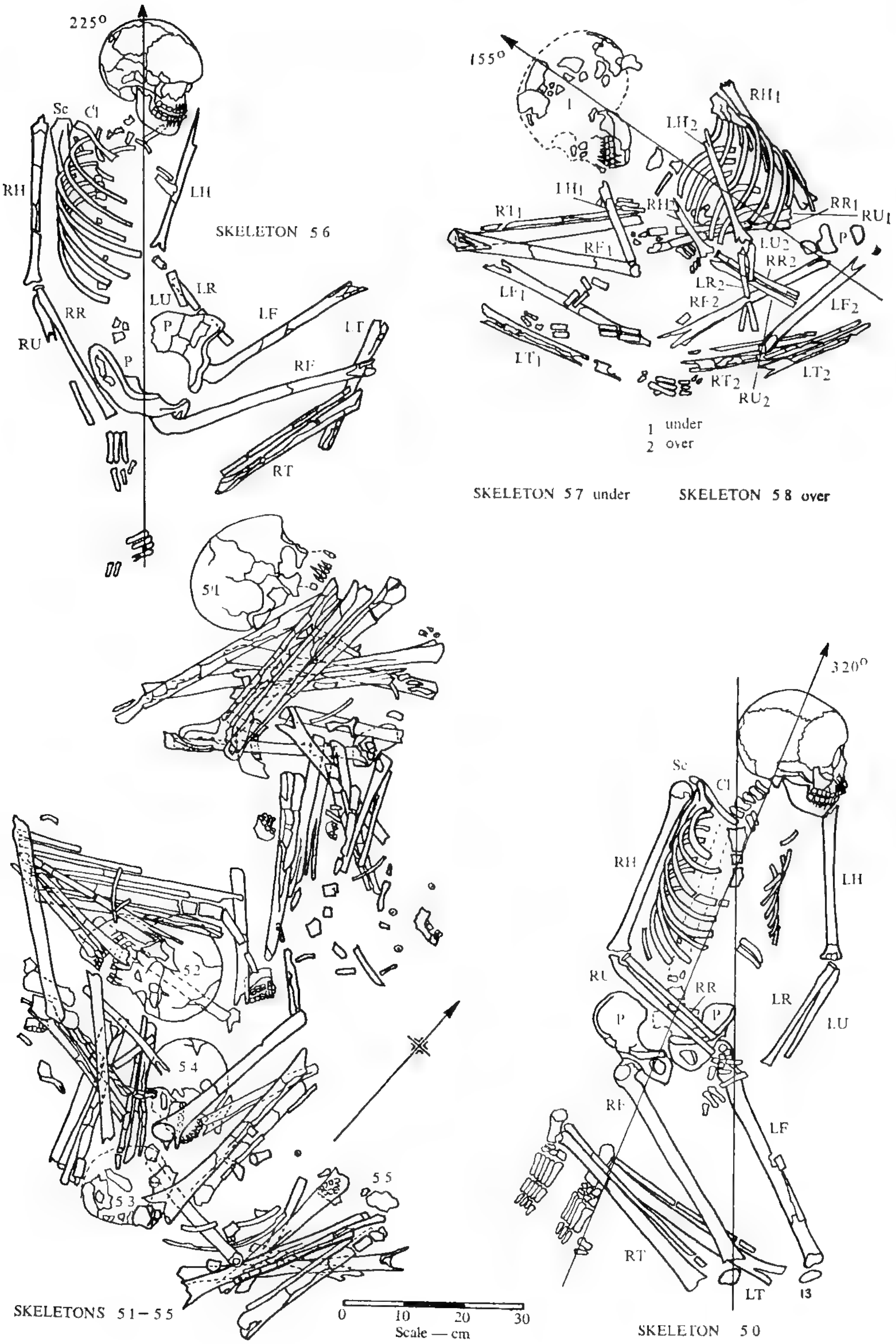

Fig. 13—Burial attitudes of Skeletons 50-58, Site 19C.

horizontal position of the leg bones also confirms this, and indicates a very severe degree of flexure at the time of burial as well.

The bones generally were very considerably eroded and fragmented. Many of them were extremely friable and some remained only as traces. Many of them had been subject to severe attack by termites. Their condition suggested a much greater age than those of Skeletons 44 and 50, which had been buried subsequently and immediately on top of the mass of skeletons 51-55.

Skeleton 44, also a flexed squatting burial, was buried with the skull 5 cm from the skull of Skeleton 52 and to the N.W. of it. Skeleton 50 was buried immediately over the skulls of Skeletons 52, 53 and 54 with its head above the skull of Skeleton 51. The relationship may be seen in Fig. 2 which illustrates the location of skeletons at Site 19C. The relative positions of Skeletons 44 and 50 showed that 44 was buried subsequently to 50.

Skeleton 44 was excavated first, since the upper portion of its left humerus appeared at the ground surface. This resulted in the exposure of Skeleton 50. Excavation of Skeleton 50 and its removal together with Skeleton 44 revealed the mass of skeletal material below. Preliminary excavation of this mass of material seemed to indicate that there were five cranial remnants and these were designated Skeletons 51-55. Complete excavation, however, made it clear that there were six skeletons involved, there being 12 femora and 11 tibiae identifiable. It was not possible to assign skull fragments, although many were present, to a sixth cranium. On complete excavation also, the cranium initially assigned to Skeleton 55 was found to consist only of extremely decomposed pieces.

As excavation proceeded it became clear that it was not possible to assign particular post-cranial remains to particular crania with any certainty. For this reason, while the cranial remains initially designated as Skeletons 51-55 have been preserved individually, the post-cranial bones have been preserved *en masse*.

Reference to the drawing of these skeletons *in situ* (Fig. 13) will also make it clear that there were six skeletons present as judged by the groupings of the severely-flexed leg bones. The general relationship of groups of bones is such that the bodies must have been buried prior to decomposition and are not re-buried skeletal remains (Pl. 13, fig 4).

The following additional notes are relevant:

Skeleton 51. Cranium somewhat eroded but defines the position of the head on the left side. Maxillae not present, but three upper molars, four upper premolars and two upper incisors were present in the sand matrix. There was no mandible.

Skeleton 52. Cranium lying on the left side with the left temporal region severely crushed and broken. Left humerus underneath the cranium. Supraorbital ridges not prominent. Maxillae attached and the mandible in position but both crushed laterally.

Dentition:

UR 8765432– –234567– UL
LR 8765432– –234567– LL

Teeth well worn helicoidally. Upper right third molar not fully occluded. An adult, probably about 24 years of age.

Skeleton 53. Pieces of cranium only, very severely eroded. The left maxilla was in place with the upper left molars and premolars and lateral incisor well-worn, but flat on the occusal surfaces. Loose crowns of the upper right second and third molars were present. The third molars appeared to be fully occluded. Age probably about 30 years.

Skeleton 54. Cranium severely crushed laterally to a width of 7·5 cm, the comminuted bone being held in place by the sand matrix. The left maxilla attached, the right maxilla loose. Small fragments only of the mandible were present.

Dentition:

UR 8765432– –2345678 UL

Medial upper incisors evulsed. Wear severe but flat. Upper third molars fully erupted but very little worn. Occlusal surface of both upper canines superior to the occlusal surface of the upper premolars and a little worn on the anterior edge of the occlusal surface only.

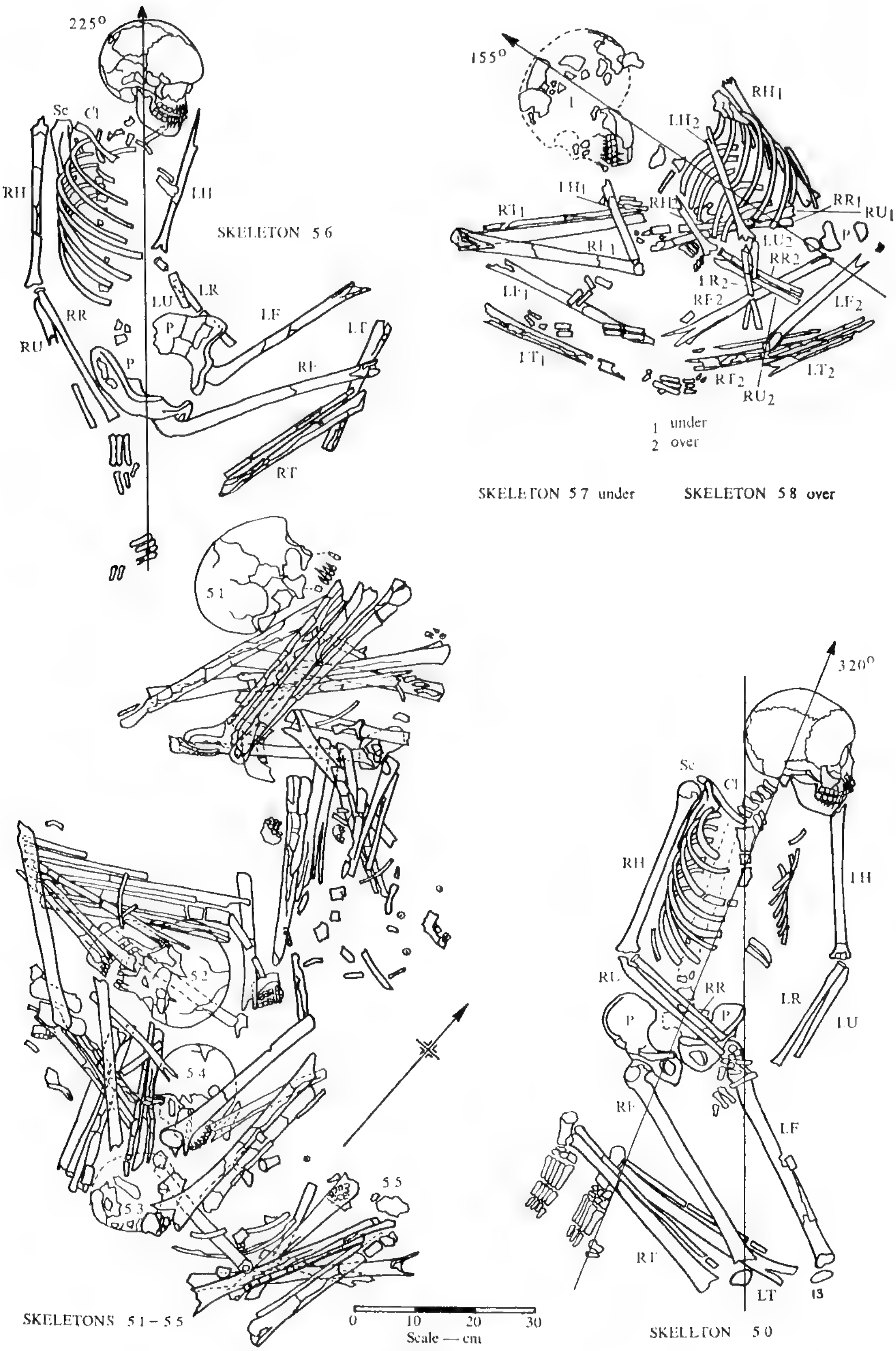

Fig. 13—Burial attitudes of Skeletons 50-58, Site 19C.

horizontal position of the leg bones also confirms this, and indicates a very severe degree of flexure at the time of burial as well.

The bones generally were very considerably eroded and fragmented. Many of them were extremely friable and some remained only as traces. Many of them had been subject to severe attack by termites. Their condition suggested a much greater age than those of Skeletons 44 and 50, which had been buried subsequently and immediately on top of the mass of skeletons 51-55.

Skeleton 44, also a flexed squatting burial, was buried with the skull 5 cm from the skull of Skeleton 52 and to the N.W. of it. Skeleton 50 was buried immediately over the skulls of Skeletons 52, 53 and 54 with its head above the skull of Skeleton 51. The relationship may be seen in Fig. 2 which illustrates the location of skeletons at Site 19C. The relative positions of Skeletons 44 and 50 showed that 44 was buried subsequently to 50.

Skeleton 44 was excavated first, since the upper portion of its left humerus appeared at the ground surface. This resulted in the exposure of Skeleton 50. Excavation of Skeleton 50 and its removal together with Skeleton 44 revealed the mass of skeletal material below. Preliminary excavation of this mass of material seemed to indicate that there were five cranial remnants and these were designated Skeletons 51-55. Complete excavation, however, made it clear that there were six skeletons involved, there being 12 femora and 11 tibiae identifiable. It was not possible to assign skull fragments, although many were present, to a sixth cranium. On complete excavation also, the cranium initially assigned to Skeleton 55 was found to consist only of extremely decomposed pieces.

As excavation proceeded it became clear that it was not possible to assign particular post-cranial remains to particular crania with any certainty. For this reason, while the cranial remains initially designated as Skeletons 51-55 have been preserved individually, the post-cranial bones have been preserved *en masse*.

Reference to the drawing of these skeletons *in situ* (Fig. 13) will also make it clear that there were six skeletons present as judged by the groupings of the severely-flexed leg bones. The general relationship of groups of bones is such that the bodies must have been buried prior to decomposition and are not re-buried skeletal remains (Pl. 13, fig 4).

The following additional notes are relevant:

Skeleton 51. Cranium somewhat eroded but defines the position of the head on the left side. Maxillae not present, but three upper molars, four upper premolars and two upper incisors were present in the sand matrix. There was no mandible.

Skeleton 52. Cranium lying on the left side with the left temporal region severely crushed and broken. Left humerus underneath the cranium. Supraorbital ridges not prominent. Maxillae attached and the mandible in position but both crushed laterally.

Dentition:

UR 8765432– –234567– UL
LR 8765432– –234567– LL

Teeth well worn helicoidally. Upper right third molar not fully occluded. An adult, probably about 24 years of age.

Skeleton 53. Pieces of cranium only, very severely eroded. The left maxilla was in place with the upper left molars and premolars and lateral incisor well-worn, but flat on the occusal surfaces. Loose crowns of the upper right second and third molars were present. The third molars appeared to be fully occluded. Age probably about 30 years.

Skeleton 54. Cranium severely crushed laterally to a width of 7·5 cm, the comminuted bone being held in place by the sand matrix. The left maxilla attached, the right maxilla loose. Small fragments only of the mandible were present.

Dentition:

UR 8765432– –2345678 UL

Medial upper incisors evulsed. Wear severe but flat. Upper third molars fully erupted but very little worn. Occlusal surface of both upper canines superior to the occlusal surface of the upper premolars and a little worn on the anterior edge of the occlusal surface only.

Occlusal surface of the upper lateral incisors superior to that of the upper canines with no apparent wear on the occlusal edge, suggesting that the upper incisors did not occlude with the lower incisors. Age probably about 25 years.

Skeleton 55. Small cranial fragments only, with a separated portion of the maxilla. Five upper molars, four upper premolars, one canine and two incisors were present in the sand matrix. There was no possibility of determining the attitude or orientation of the cranium.

The dentition of these skeletons suggests that all five were adult. No evidence was present to suggest a possible cause of death. A selected mass of bone representative of the group of burials was radiocarbon dated at 3,580 ± 370 years B.P. (ANU-420D).

Skeleton 56. NMV X72854, CHA 345. Fig. 13.

A flexed burial lying on the left side.

The cranium was largely complete but considerably broken and lay on its left side. It was comminuted and crushed on the left temporal region due to soil pressure and the left side was pressed inwards and was concave. Supraorbital ridges not prominent. Left maxilla crushed. Mandible displaced slightly to the right, the left side crushed and broken.

Dentition:

UR 8765432– ————8 UL
LR 87654321 –2345—— LL

The teeth not in place were present loose and as crowns. Teeth worn slightly and helicoidally. Very little wear on the rear molars. Age probably 25-28 years.

The thorax, delineated by portions of the right ribs and vestigial vertebrae, appeared to lie slightly on the left side. The lumbar region was flexed slightly to the left with the arms alongside the thorax, the lower arms being flexed slightly to the left. Right hand bones inferior to the pelvis. Pelvic bones somewhat fragmented and eroded. Femora flexed to the left approximately at right angles to the body with the tibiae flexed back inferior to them. A few foot bones lay inferior to the pelvic region. Orientation 225°.

Skeleton 57. NMV X72855, CHA 346A. Fig. 13.

A severely flexed burial lying on the right side, semi-prone.

The cranium, compressed laterally, was very fragmentary, the bone being very thin and consisting mainly of the outer cortex. The maximum thickness of the occipital bone was only 3·8 mm. The upper teeth were in place in portions of the maxillae and in the sand matrix. Mandible, broken at the symphysis, present in position.

Dentition:

UR 8765432– ——45678 UL
LR 87654321 –2345—— LL

The rear molars were fully occluded but unworn. Age about 25 years.

The rib cage, well defined by rib portions, lay on the right side but with the left arm anterior to the right arm, indicating a semi-prone position of the thorax. The right upper arm lay alongside the rib cage with the lower right arm flexed upwards and passing below the rib cage as the skeleton lay in the grave. The left upper arm lay approximately parallel to the rib cage, the left lower arm being flexed over the left leg bones and broken into numerous short sections of paired bones during decomposition and settlement. No pelvic bones were present. Femora flexed strongly upwards to the right with the tibiae flexed sharply back, the right tibia lying superior to the right femur, the left tibia lying inferior to the left femur. A few foot bones were present. Orientation 155°.

Skeleton 57 was buried in association with Skeleton 58 (see discussion below).

Skeleton 58. NMV X72856, CHA 346B. Fig. 13.

A severely flexed burial lying on the right side.

Only two very small fragments of cranium were present. The cranium of this skeleton apparently lay slightly inferior to the cranium of Skeleton 57 and on top of the upper thorax of Skeleton 57 as buried in the grave. The remains of an unoccupied rabbit burrow were found in the apparent position of the cranium of Skeleton 58 and rabbit activity was evidently responsible for its fragmentation and removal. No rib cage was present, but the arm bones located in the grave above the rib cage of Skeleton 57 indicated the position of the thorax. The left lower arm bones crossed over the right lower arm bones, both lying in the grave above the leg bones. Small vestiges of the pelvis were present. Femora flexed sharply upwards to the right with the tibiae flexed sharply back inferior to them. The left leg lay above the right leg. No foot bones were present. Orientation 155°.

Skeleton 58 was clearly the skeleton of a young child as judged by the length and diameter of the limb bones. It had been buried above Skeleton 57 in the grave. The intimate contact of the bones of Skeleton 58 with those of Skeleton 57 indicated that they were buried together and that decomposition and settlement were contemporaneous. There is no factual evidence, but conjecture suggests the burial of a mother and young child together.

In the drawing of these skeletons in Fig. 13, they are shown in their correct relationship one to the other. The elements of Skeleton 57 bear the suffix 1 and the elements of Skeleton 58 bear the suffix 2.

SITE 8. SKELETONS 59-72

Skeleton 59. NMV X72857, CHA 274. Fig. 14.

An extended supine burial.

The cranium, substantially complete, lay on its left side, facing left. The right temporal region was comminuted. The mandible was forced to the right approximately 2 cm and was broken at the symphysis. Skull base asymmetric (see Sandison, this *Memoir*). The atlas, axis and three cervical vertebrae were forced up under the mandible. (Fig. 20).

Dentition:

UR 87654321 12345678 UL
LR 876543— —345678 LL

Teeth worn moderately, helicoidally.

The rib cage was clearly defined by rib portions, two clavicles and two scapulae. The left shoulder had been forced up under the head. The vertical column and sacrum were largely complete. Pelvis complete. The sub-pubic angle of 45° indicates a male. Femora extended in line with the thorax. This skeleton was buried with the head 20 cm below the present surface and the feet above it. As a result, the tibiae were broken and the distal ends had been exposed and scattered. Orientation 340°.

Skeleton 60. NMV X72858, CHA 271. Fig. 14.

An extended supine burial.

The cranium had been exposed by surface erosion and consisted of scattered pieces only. The mandible was broken at the symphysis and the ascending rami were absent.

Dentition:

LR 87——— ———678 LL

The teeth present showed extreme helicoidal wear to 40° from the horizontal occlusal plane, being worn down to the roots on the buccal side.

Rib cage well defined by rib portions and parts of the clavicles and scapulae. Vertebral column substantially complete. The two lowest thoracic vertebrae were fused together. Upper arms extended alongside the thorax with the lower arms flexed medially, the right hand being over the pubic area and the left hand under the pelvis. The sacrum and pelvis were eroded and incomplete. Leg bones eroded and extended in line with the thorax with the feet together. No foot bones were present. The right fibula was broken and displaced. Orientation 240°.

A fragment of a maxilla was found lodged between the femora.

Skeleton 61. NMV X72859, CHA 273. Fig. 15.

Apparently an extended supine burial, but very much broken up and scattered by erosion. Scattered and bleached pieces of cranium included the frontal bone, the parietal bones, the occipital bone and the right mastoid process. Supraorbital ridges prominent. The mandible was broken into three pieces. Portions of both maxillae were present but unattached.

Dentition:

LR 8765432– ——56–8 LL

In the mandible, all sockets without teeth contained root stumps. The portion of the left maxilla present contained the roots of the lateral incisor, the canine and both premolars. The portion of the right maxilla present contained the roots of the posterior premolar and the first and second molars. There was a supernumerary incisor fully embedded in the bone of the right palate adjacent to the palatine torus (see Sandison, this *Memoir*).

The right elements of the thorax were much scattered, particularly the scapula and humerus. An almost complete vertebral column was present, which with the left half of the rib cage, the left clavicle, scapula and arm bones, defined the position of the thorax and showed it to rest supine. Left arm alongside the thorax. A somewhat eroded sacrum and right pelvic bones together with the head and broken proximal portion of the right femur in place, confirmed an extended burial. The proximal half of the left femur was present but had clearly been displaced and reversed in aspect. No lower leg

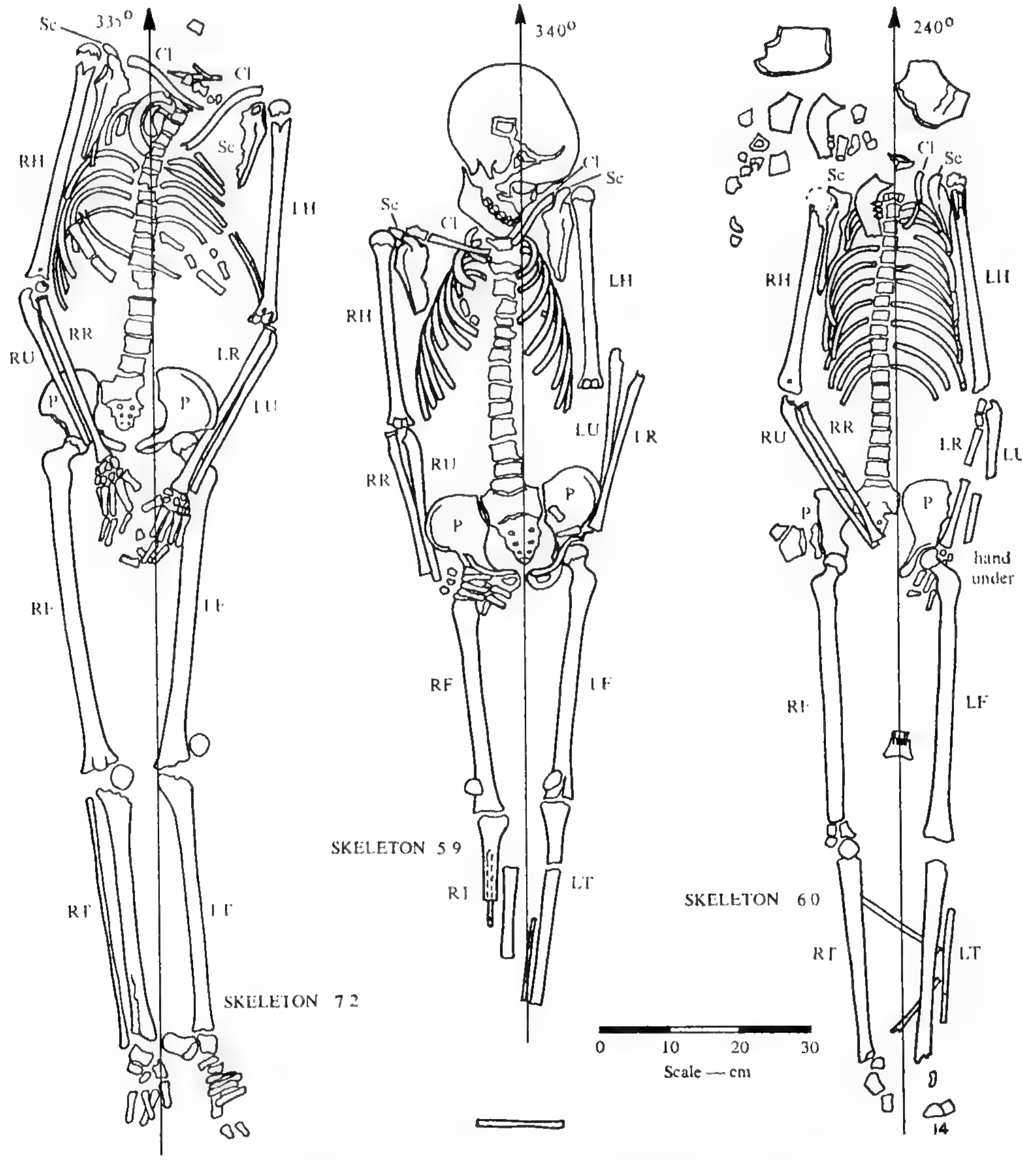

Fig. 14—Burial attitudes of Skeletons 59-60, 72, Site 8.

bones or foot bones were present. Some hand bones in the pelvic region suggested the position of the hands was over the pubic area. Orientation 35°.

Skeleton 62. NMV X72860, CHA 270. Fig. 15.

An extended supine burial with the head and feet exposed and scattered by surface erosion.

Many scattered pieces of cranium were present, including two occipital bones, one of which did not belong to this skeleton. The main portion of the cranium was reconstructed. It showed prominent parietal lobes and slight lateral compression with a raised sagittal suture. Supraorbital ridges not prominent. The smooth occipital crest area and small mastoid processes suggested a female. No maxillae, mandible or teeth were present.

Thorax area somewhat displaced generally, but well-defined by rib portions and remnants of the scapulae and vertebrae. The attitude of the lower lumbar vertebrae confirmed the supine position. Sacrum and pelvic bones much eroded. Arms somewhat displaced but clearly extended alongside the thorax. The femora, eroded and split by exposure, extended in line with the thorax. Only the proximal portion of the right tibia was present and there were no foot bones. Orientation 175°

Skeleton 63. NMV X72861, CHA 264. Fig. 16.

An extended supine burial with the lower

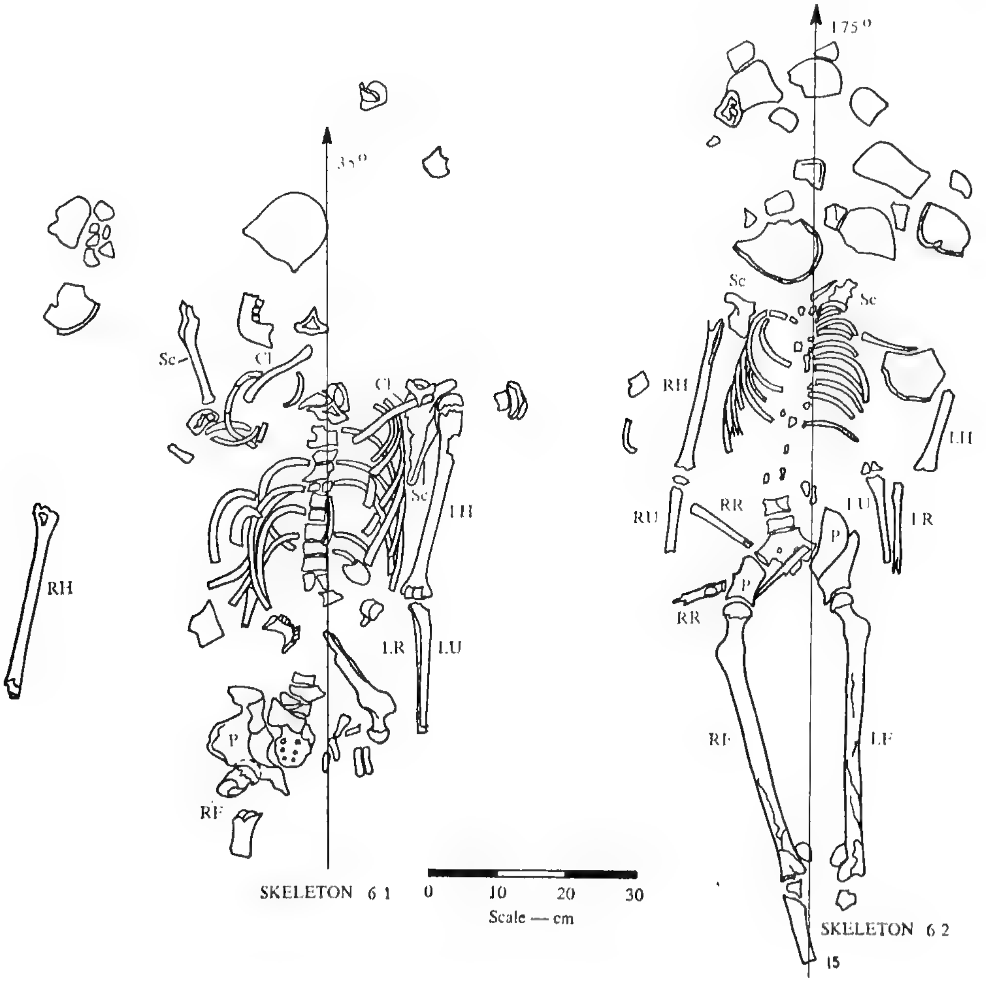

Fig. 15—Burial attitudes of Skeletons 61-62, Site 8.

legs, left arm and cranium exposed and scattered by erosion.

Only greatly displaced portions of cranium bone were present. Supraorbital ridges not prominent. Occipital crest area smooth. Maxillae and the right side only of the mandible were present.

Dentition:

UR —65432–   –23456— UL
LR 87654——   LL

The teeth were worn very severely and helicoidally, well into the pulp. Upper medial incisors evulsed, with a gap of 8 mm between their sockets.

The thorax was slightly sinuous as defined by rib portions, clavicles, scapulae and a complete but eroded vertebral column. The left scapula was exposed and sun-bleached. The left upper arm had been exposed and scattered. The left lower arm was flexed across the pelvic region. Right arm extended alongside the thorax with the hand over the pubic region. The sacrum complete with all sections fused, was typically female. The pelvis was largely present and was much eroded, but the sub-pubic angle approximated 90°, confirming a female. Femora inclined slightly to the right. The right femur was deeply channelled by termite attack. The lower leg bones were much fragmented and scattered, but confirmed the extended position. No foot bones present. Age probably over 35 years. Orientation 255°.

Skeleton 64. NMV X72862, CHA 269. Fig. 16.

An extended supine burial with the feet and cranium exposed, broken up and scattered by surface erosion.

The cranium was present only as substantial bleached and scattered portions lying loose on the surface. Supraorbital ridges not prominent. The maxillae and broken portions of the mandible were present.

Dentition:

UR 87654——   ——45678 UL
LR 876543—   —345678 LL

Teeth worn severely and helicoidally. The rear molars were well-worn, indicating an age of at least 30 years. All roots of the upper third molars extended into the maxillary sinus.

Thorax well defined by the clavicles, scapulae, rib portions and substantially complete vertebral column. The two lowest thoracic vetrebrae were fused together. The sacrum was complete and typically male, with all joints fused together, confirming the age of at least 30 years. Pelvis substantially complete with a sub-pubic angle of 40°, indicating a male. Arms extended alongside the thorax with the lower left arm flexed over the pelvis and both hands lying over the pubic area. Left radius distinctly bowed (see Sandison, this *Memoir*). Femora complete and extended. The right tibia was broken and displaced, but the left tibia was extended and confirmed the burial position. Orientation 200°.

Skeleton 65. NMV X72863, CHA 275. Fig. 16.

A flexed supine burial in association with Skeleton 66.

The cranium lay face upwards and was substantially complete, the supraorbital ridges and the glabella both being prominent. Maxillae present. Mandible present, but broken and forced outwards on each side by pressure from the atlas, axis and four cervical vertebrae which were forced into it by settlement of the cranium.

Dentition:

UR 87654321   12345678 UL
LR 87654321   12345678 LL

Teeth worn very severely and helicoidally, to 40° from the original occlusal plane. All incisors were worn well into the pulp. An abscess had erupted through the bone on the left side of the mandible on the lateral surface at the position of the root of the lower left first molar (Pl. 12, fig. 5).

Thorax position defined by the right clavicle and scapula together with rib portions and a complete vertebral column. The superior section of the thorax had been displaced to the left post mortem. The left humerus and the left ulna were absent and had probably been disturbed during the burial of Skeleton 66. The left radius was present with the left hand over the pubic area. Right arm alongside the thorax

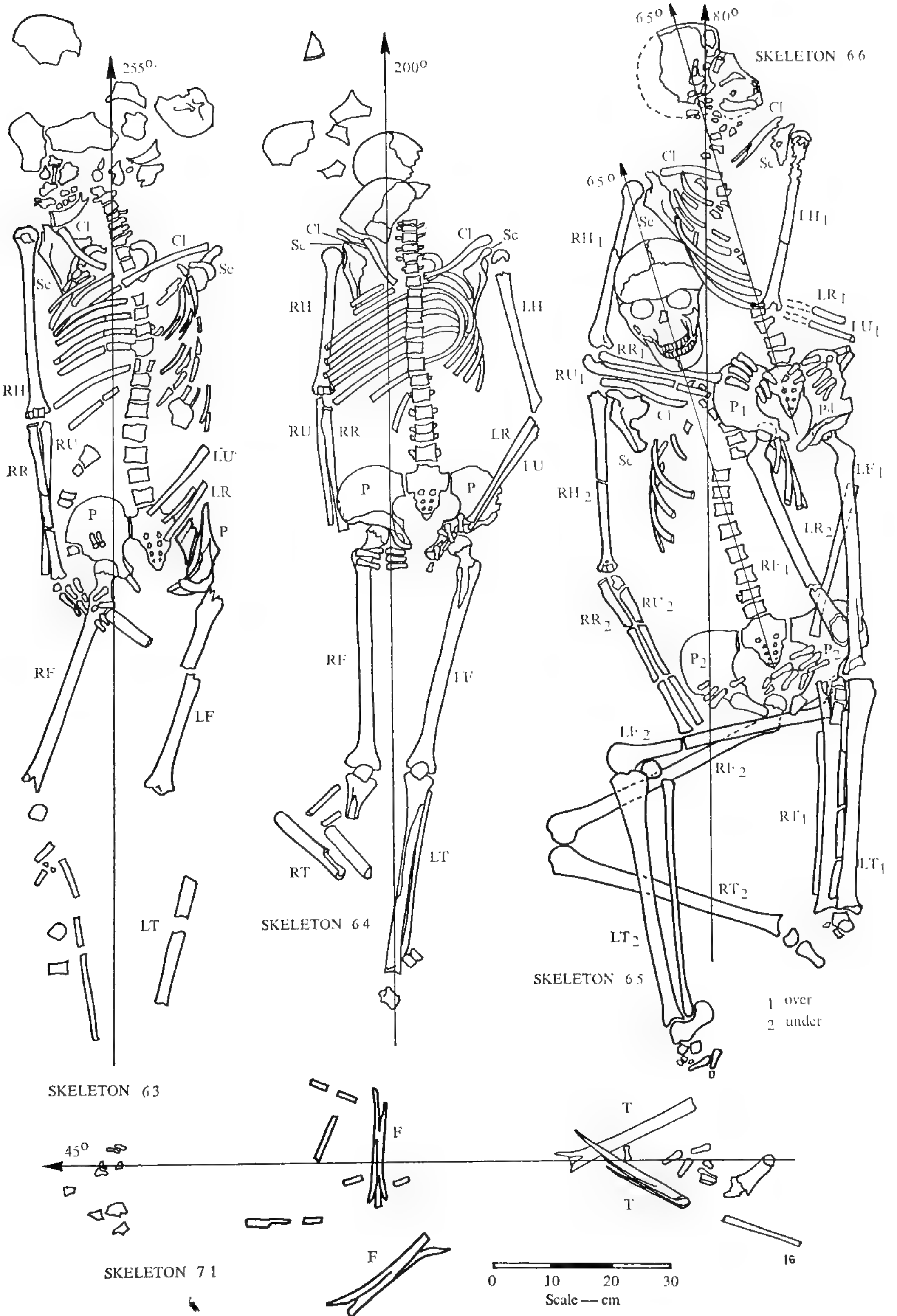

Fig. 16—Burial attitudes of Skeletons 63-65, 71, Site 8.

with the right hand over the pubic area. The sacrum was characteristically male with all joints fused, indicating a probable age of 35 years or more. The sub-pubic angle of the pelvis of 60° indicated a male. Femora flexed to the right at right angles to the body. Right tibia flexed back inferior to the right femur with some foot bones lying inferior to the pelvis. Left tibia flexed back approximately parallel with the centreline of the thorax. Some left foot bones were present. The left leg lay on the right leg in the grave. Orientation 65°.

Skeleton 66. NMV X72864, CHA 263. Fig. 16.

An extended supine burial in association with Skeleton 65.

The cranium was exposed and scattered by surface erosion and was very fragmentary, mainly consisting of the left parietal and temporal regions with some portions of the maxillae and mandible. It lay on the left side.

Dentition:

UR —3456–8 UL
LR ——432– –2345—8 LL

Teeth worn severely and helicoidally, to 30° from the original occlusal plane. Bone regrowth had completely covered the sockets of the lower right posterior premolar and the first and second molars and had almost covered that of the lower right third molar. Bone regrowth had also covered the sockets of the lower left first and second molars, the third molar being present as a tooth. The evidence suggested that these teeth were lost at an early age. Anodontia seems unlikely. Age probably over 30 years.

The thorax was defined by the clavicles, substantial portions of the scapulae, the right side of the rib cage and a few remnants of vertebrae. Both elbows were flexed to the right hand side, the lower arms being flexed back to the left with the hands over the pelvic area. Skeleton 66 lay above Skeleton 65 in the grave and its right arm embraced the cranium of Skeleton 65. The sacrum and pelvis were somewhat eroded, but clearly lay above the thorax of Skeleton 65 in the grave. The femora, eroded at the ends, extended in line with the thorax, knees together. The tibiae were close together, somewhat eroded, but clearly lay above the thorax of Skeleton 65 in the grave. The femora, eroded at the ends, extended in line with the thorax, knees together. The tibiae were close together, somewhat eroded and flexed slightly to the right. The foot bones were present as remnants only. The legs clearly lay above the pelvis and legs of Skeleton 65 in the grave. Orientation 65°.

Skeleton 66 had been buried subsequently to Skeleton 65. Its right arm hooked around the cranium of Skeleton 65 suggests a contemporaneous burial, but the absence of the left upper arm bone and shoulder of Skeleton 65 indicates that they had been disturbed and removed in digging the grave for Skeleton 66. The right hand side of the rib cage of Skeleton 66 lies partly over the cranium of Skeleton 65. The difference in attitude of the two skeletons seems inconsistent with simultaneous burial. In the absence of radiocarbon dating of these skeletons, it is in our opinion that Skeleton 66 was buried some time after Skeleton 65, certainly subsequent to the decomposition and consolidation of the latter skeleton.

In the drawing of Fig. 16 Skeletons 65 and 66 are shown in their correct position relative to one another. The elements of Skeleton 65 bear the suffix 2 and the elements of Skeleton 66 bear the suffix 1.

Skeleton 67. NMV X72865, CHA 261. Fig. 17.

An extended supine burial with the head and legs exposed, broken and scattered by erosion.

Only fragmentary pieces of cranium were present, including the left maxilla with all teeth in place except the third molar and the medial incisor. Teeth worn severely to the pulp, helicoidally, to as much as 30° from the original occlusal plane. The roots of all teeth were completely exposed externally by resorption of alveolar bone.

The rib cage was well-defined. Vertebral column fairly complete, but eroded. A substantial portion of the sternum was present. The right clavicle and scapula were present. Right arm alongside the thorax with the hand over the pubic area. Left scapula and arm bones

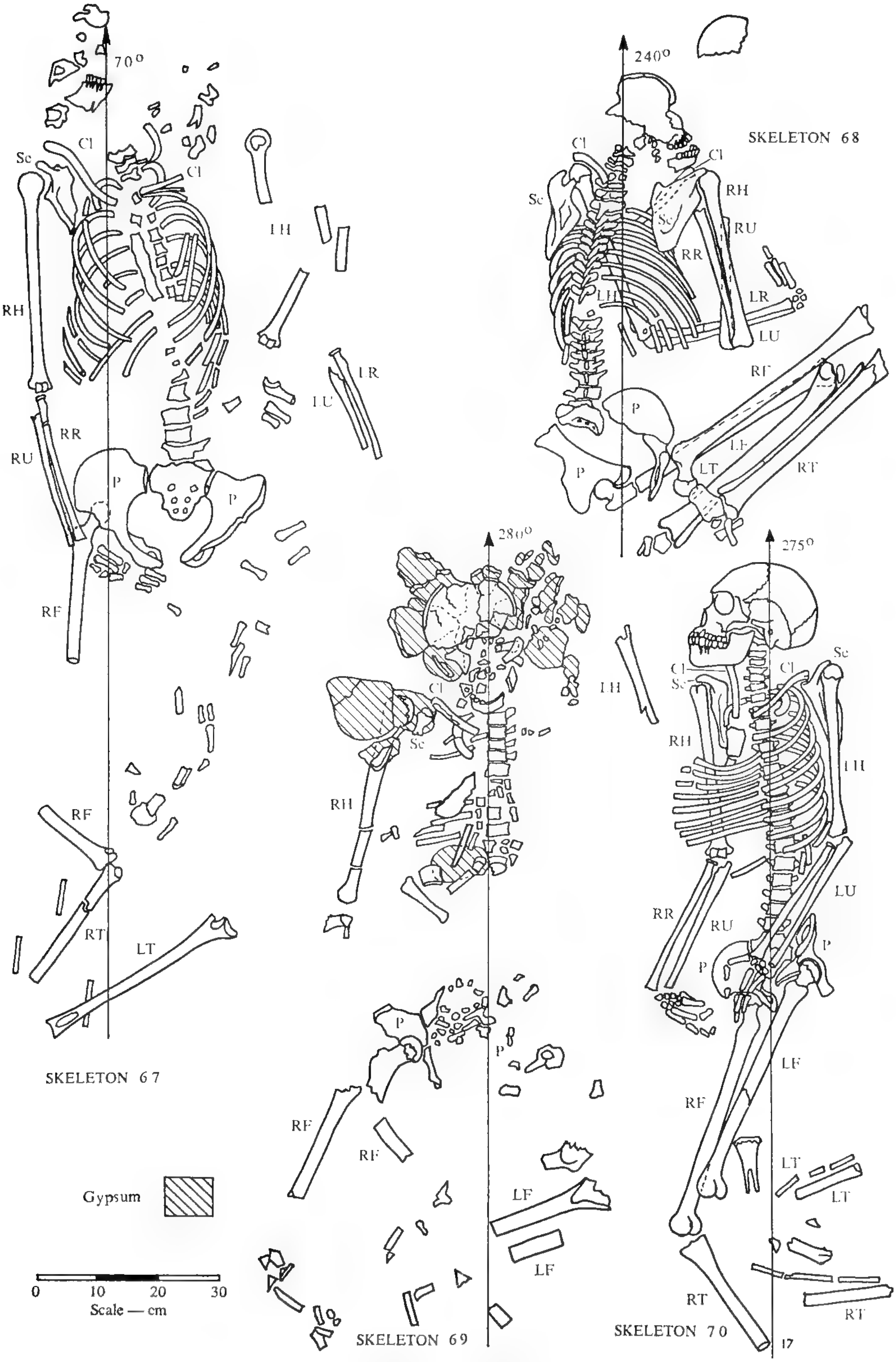

Fig. 17—Burial attitudes of Skeletons 67-70, Site 8.

broken and scattered by surface exposure. The sacrum was largely complete with all joints fused, indicating an age of about 30 years. Pelvis largely complete. The sub-pubic angle of 80° suggests a female. The right femur with the head in place in the pelvis confirms the extended burial even though its distal half, together with both the tibiae have been displaced and disturbed. No left femur was present and the left hand bones had been disturbed and scattered inferior to the pelvis. Orientation 70°.

Skeleton 68. NMV X72866, CHA 265. Fig. 17.

A severely flexed burial lying on the left side with the thorax semi-prone.

A well-preserved skeleton except for the cranium which lay on its left side, but which had been exposed, broken on the right side and occipital region and scattered by surface erosion. However, the frontal bone and both temporal regions were present in place together with the maxillae. The mandible was present except for the frontal section and ascending rami. Supraorbital ridges not prominent.

Dentition:

UR	—654321	1234567–	UL
LR	8–65432–	——45678	LL

Both the lower third molars were fully erupted but were substantially unworn. Remainder of the teeth well worn to the pulp, helicoidally. Age probably about 25 years.

Both scapulae were complete and both clavicles were present. The scapulae situated above the clavicles, as well as the attitude of the vertebrae, clearly confirmed the prone position at the shoulders, and its gradual development from the pelvic area. The pelvis lay on the left side but tended towards the prone position. Rib cage fairly complete. Sternum complete. The vertebral column was complete and very well-preserved. Left humerus under the thorax with the left lower arm bones flexed to the right and with some left hand bones present. Right humerus extended alongside the thorax with the right lower arm bones flexed immediately back towards the shoulder, contiguous with the humerus, and with the hand position underneath the right scapula. The right hand bones, however, had been exposed and scattered. Femora flexed sharply upwards and to the right. Tibiae flexed back immediately inferior to the femora with a few foot bones inferior to the pelvis. The right leg bones lay on the left leg bones. Orientation 240°.

Skeleton 69. NMV X72867, CHA 268. Fig. 17.

An extended supine burial with a widow's cap in place on the cranium.

The drawing shows the scattered nature of this skeleton which had become almost completely exposed by erosion. The cranial remains clearly showed that the head had been buried face upwards. The front portion of the mandible was *in situ* but without teeth. Although the supramaxillary region and frontal bone of the cranium had been comminuted and scattered, the rear portion of the cranium was essentially in place although fractured into several pieces. The cranium was surrounded by scattered pieces of a widow's cap, but that portion which had covered the temporal and occipital regions, although fractured into a number of pieces, was essentially in place. Since it extended beneath the cranium as buried in the grave, it was clearly in place on the head at the time of burial (Pl. 13, fig. 1). Reconstruction of the cranial elements confirmed that the remains of the widow's cap matched the spherical curvature of the cranium when separated from the cranial surface by some 6 mm.

The supine position of the thorax was shown by the attitude of the five thoracic vertebrae still in place. These, together with several fragmentary vertebrae inferior to them, plus the remains of the sternum and a few rib portions, defined the thorax itself. The right humerus was extended alongside the thorax although a little displaced. Portions of the widow's cap were found below the right shoulder bones. This can only be explained as being due to the displacement of the right humerus and scapula during decomposition and settlement following collapse and displacement of the widow's cap. Portion of the left humerus had clearly been displaced by exposure, all the left side of the thorax being completely absent. Pieces of pelvis remaining in place with many hand bones scattered over the pelvic area suggest that the hands were placed over the pelvic region at burial, as is common among the skeletons of Site 8. The head of the right femur still in position in the pelvis, together with a proximal portion of the shaft, indicates an original extended burial even though the remainder of the right femur and portions of the left femur were considerably displaced. Portions of both femora present were reassembled to confirm their connection with the other skeletal remains and were then used for radiocarbon dating. An age of 750 ± 170 yr B.P. was obtained (ANU-421). Orientation 280°.

The widow's cap itself varied in thickness from 1·2 cm to 2·5 cm. It was composed of gypsum with some flakes of mussel shell incorporated in the matrix on the concave surface. The pieces of the cap clearly showed the impression on the concave surface of the net on which it was formed. Plastic casts were made of these net impressions so that the form of the woven netting was reproduced (Pl. 12, fig. 7). In the absence of fibre remains it was not possible to determine the nature of the fibres used to produce the yarn.

Skeleton 70. NMV X75432, CHA 267. Fig. 17.

An extended burial lying on the right side, but semi-supine.

Cranium substantially complete. Supraorbital ridges moderately prominent. Mandible broken at the mental symphysis, but complete. (Fig. 20).

Dentition:

UR	8765432–	12345678	UL
LR	8765432–	12345678	LL

Wear was even and moderate. Upper canine roots extensively exposed by recession of the alveolar bone. All third molars were little worn. Age probably about 28 years.

Both clavicles and scapulae were present. The thorax was well defined by a complete vertebral column and rib cage. Right ribs displaced over the right humerus during settling and decomposition, no doubt due to the semi-supine position of the body combined with vertical earth pressure (Pl. 13, fig. 5). Both arms extended alongside the thorax with the hands over the pubic region. Sacrum typically male with all joints fused. The pelvis was complete and sub-pubic angle of 55° indicated a male. Femora slightly flexed to the right. Tibiae broken and somewhat scattered by surface exposure, but clearly flexed slightly to the left. Orientation 275°.

Skeleton 71. NMV X75435, CHA 272. Fig. 16.

An extremely fragmentary skeleton, all the bones being fully exposed on the surface.

A few small fragments of the cranium were present including a fragment of the right mandible with the lower right third molar and the sockets of the lower right first and second molars present. Therefore it was the skeleton of an adult, aged about 25 years.

There were only a few fragments of arm bones. Pieces of the shafts of both femora lay on the surface, sun-bleached, distorted and split by exposure. Similar portions of both tibiae were present with the remnants of some foot bones. The general distribution of the bones suggested an extended burial. Orientation 45°.

Skeleton 72. NMV X75434, CHA 266. Fig. 14.

An extended supine burial.

The cranium had been almost completely dispersed by erosion. Only small fragments, including the right and left mastoid processes, were present together with a small fragment of mandible showing bone regrowth over the sockets of the lower left molars.

Shoulders well defined by the clavicles and a scapula. These, together with rib portions and an almost complete vertebral column, defined the thorax. Both arms extended alongside the thorax with the lower arms flexed towards the centreline with the hands over the pubic region (Pl. 12, fig. 1). Sacrum characteristically male, with all joints fused. Age probably at least 35 years. Pelvis in good condition with the left iliac bone complete. The sub-pubic angle of 60° indicated a male. Femora and tibiae extended in line with the thorax. Most bones of both feet present. Orientation 335°.

TABLE 1

NUMBER OF BURIALS AT ALL SITES RELATED TO THE ATTITUDE OF BURIAL

Attitude of Burial	Burial Site 16A	16B	17	18	19A	19B	19C	8	Total Number
Extended supine	1	7		1	2	5		11	27
Extended prone				1					1
Extended on side		1						1	2
Flexed supine	1	7			1			1	10
Flexed prone							1		1
Flexed on right		6	3				5		14
Flexed on left	1						2	1	4
Squatting	1	1					6		8
Total	4	22	3	2	3	5	14	14	67

Attitude of Burial

An analysis of the attitude of burial of the 67 burials examined in which the attitude of the skeleton could be firmly established is presented in Table 1. This table shows the attitudes represented at each burial site in addition to those of the whole sample.

Of the 67 burials examined, 45% were extended, 43% were flexed and 12% were squatting. Of the eight squatting skeletons only one (Skeleton 2) had been buried with care. The remainder (Skeletons 26, 51-55) had apparently been interred with scant circumspection in the smallest possible space. It would appear, therefore, that in some 90% of burials as represented by the subjects of this paper, some care was taken in laying the body in the grave. However, in only half of these instances was burial undertaken with apparent formality, the body being laid out extended and almost exclusively supine.

While the above statement is applicable to the burials examined as a whole, it is clear that practice varied as between burial sites. A broad comparison of the relative frequencies of extended, flexed and squatting burials at each burial site with those in the overall sample is shown in Table 2. Here the attitudes of burial are expressed as percentages of the sample at each site, and of the total sample.

At only three sites were the numbers excavated sufficient to draw conclusions of any significance, but at each of these sites (16B, 19C and 8) the pattern of the attitude of burial differed markedly. At Site 16B where 22 attitudes were clearly defined, 36% were extended, 59% flexed and 5% squatting. At Site 19C where 14 attitudes were clearly defined, none were extended, 57% were flexed and 43% were squatting. At Site 8 where 14 attitudes were defined, 86% were extended, 14% were flexed and none were squatting. At Site 19B only five attitudes of burial were defined, but it is interesting to note that all were extended supine burials, closely spaced and similarly oriented. The contrast between the attitudes at this site and the attitudes at Site 19C, clearly seen in the site plans in Fig. 2, is most marked.

As an overall average it can be said that apparently formal burial practice is evenly divided as between flexed and extended atti-

TABLE 2

ATTITUDES OF BURIAL AT EACH SITE—PERCENT

Site	Attitude of Burial—Percent Extended	Flexed	Squatting
16A	25	50	25
16B	36	59	5
17	0	100	0
18	100	0	0
19A	67	33	0
19B	100	0	0
19C	0	57	43
8	86	14	0
Total Sample	45	43	12

tudes. However, the departures from the overall average at Sites 16B, 19C, and 8 are very significant, indicating a wide variation in practice in different localized areas.

In the extended supine burials examined, the arms are generally extended alongside the thorax with the hands either inferior to the pelvis and placed lateral to the legs (Pl. 12, fig. 3), or the lower arms are flexed medially with the hands placed over the pubic area (Pl. 12, fig. 1). Skeleton 1 (Fig. 4) is a typical example of the former and Skeleton 72 (Fig. 14) of the latter. Skeletons with the hands located over the pubic area were found only at Sites 16B and 8. This mode of laying out the body was found in 21% of the total burials, in 18% of the burials at Site 16B and in 71% of the burials at Site 8. Examination of the drawings of the skeletons excavated at Site 8 (Skeletons 59-72, Figs. 14-17) shows that 10 of the 14 skeletons were placed in the grave with the hands resting over the pubic area. This proportion is very significantly different from the proportion in the total sample and shows that placement of the hands in this position was evidently a customary attitude of burial practised by the Aboriginals using Site 8.

In only 13 cases could the sex of the skeleton be determined with certainty. Nine of these cases (or 70%) were males and four (or 30%) were females. Six males were buried extended and three were buried flexed. All four females were buried extended. Nothing significant can be deduced from these figures as regards any relationship between attitude of burial and sex.

Orientation in Burial

The orientation of the skeleton expressed as a true bearing was determined for each burial. In order to determine whether any definite pattern of orientation existed either within individual burial sites or among the skeletons sampled as a whole, the frequency of occurrence was recorded for orientations falling within 30° intervals. Thus the number of skeletons with orientations lying between bearings of 0° to 30°, 30° to 60°, 60° to 90° and so on were recorded for each burial site examined, and for the sampling as a whole. Table 3 sets out the results for 64 skeletons for which orientations were determinable.

As has been noted in the discussion on attitudes of burial it is clear that only at Sites 16B, 19C and 8 were the skeletons excavated sufficient in number to give any significant indication of general orientation. The frequencies of occurrence for the intervals of orientation selected are plotted graphically in Fig. 18 for burials at Sites 16B, 19C and 8 and for the total

TABLE 3

FREQUENCY OF ORIENTATION OF SKELETONS

Interval of Orientation	Number of Burials at Site									Extended Supine Burials Only
	16A	16B	17	18	19A	19B	19C	8	Total	
0° to 30°		1							1	1
30° to 60°		2						2	4	3
60° to 90°							1	3	4	2
90° to 120°							1		1	
120° to 150°	1	2	1						4	
150° to 180°	1	5	1	1			3	1	12	5
180° to 210°	1	5	1	1				1	9	3
210° to 240°		5			3	4	1		13	9
240° to 270°	1	1				1	2	3	8	3
270° to 300°		1						2	3	2
300° to 330°		1					2		3	
330° to 360°								2	2	2
Total	4	23	3	2	3	5	10	14	64	30

sampling. No predominant direction or orientation exists among burials at Sites 8 and 19C. At Site 16B there is a tendency to orient the body with the head towards the south, although it is not habitual. A similar tendency is evident in the orientation of the skeletons representing the total sample, but again it is by no means universal.

The overall pattern of orientation is considerably influenced by the pattern of Site 16B burials and the few skeletons excavated at Sites 16A, 17 and 18, all of which happened to have a general southerly orientation.

An examination was also made of the frequency of orientation, using the same intervals of bearing, of the 30 extended supine burials for which orientations could be determined, to see whether a more definite pattern of orientation existed when considering only those so buried. The results are recorded in Table 3 under the column for extended burials only, and are plotted in Fig. 18. The same trend towards a southerly orientation exists as for the sampling as a whole and is not significantly different.

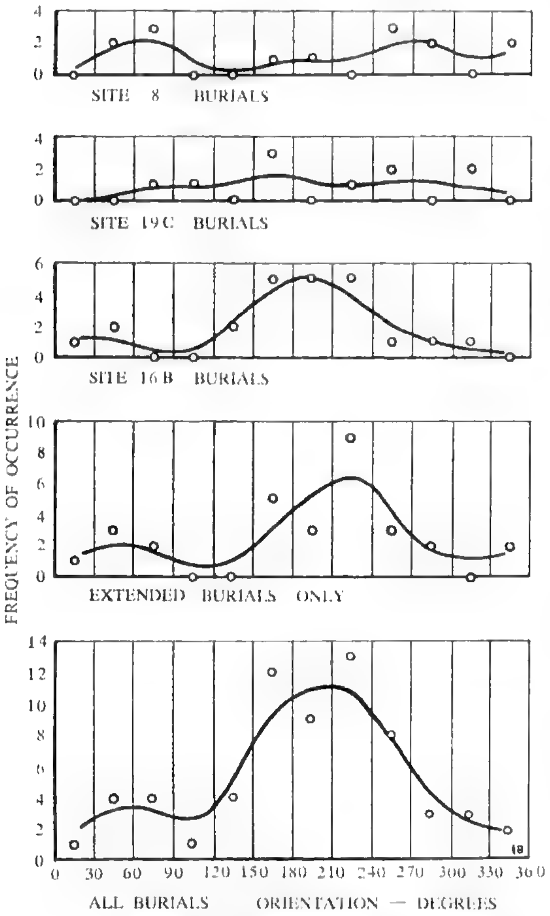

Fig. 18—Frequency of orientation of skeletons in the graves.

The general orientation differs from the orientations reported by Sunderland and Ray (1959) for the Chowilla and Lake Victoria areas. They reported the majority of skeletons lying N-S. but with the heads to the N. In the present series only one third lay within 30° either way of N-S. irrespective of the direction of the head and the general trend was for the head to be directed S.

In considering the attitude and orientation of burial it has not been possible in the absence of dating all skeletons, to consider any changes in practice with time.

Tooth Evulsion

The practice of tooth evulsion was evident at all burial sites. It was confined to the two upper medial incisors. There was evidence of evulsion by impact and fracture, but in the majority of cases the roots were absent. Whether this indicates evulsion by loosening and complete extraction or loss of the roots subsequent to impact evulsion cannot be determined.

There were 26 skulls in which evulsion was clearly either present or absent. In 11 of these (42%) evulsion was present. In 15 of these (58%) evulsion was absent. Of these 26 skulls, 24 could be correlated with the attitude of burial with certainty. Nine of these (38%) showed evulsion and 15 (62%) lacked evulsion. Extended burials were represented by 11 skeletons within this group and in four cases (36%) evulsion was present and in seven cases (64%) evulsion was absent. Flexed burials were represented by 13 skeletons within the group and in five cases (38%) evulsion was present and in eight cases (62%) it was absent. Thus evulsion is not associated in any way with attitude when the burials are considered as a whole. The number of samples at each site was too small to reveal any significant differences.

Only seven skulls showing clear evidence of the presence or absence of evulsion could be associated with skeletons whose sex could be determined with certainty. One male and one female showed evulsion, but in five males evulsion was absent. These figures cannot be regarded as significant except to suggest that evulsion in males was infrequently practised amongst the Aboriginals represented by the present series of burials.

Artefacts and Abnormalities

No artefacts or personal possessions were found buried with the skeletons. No burnt bone was found. Small amounts of charcoal were found associated with some remains, notably Skeletons 17, 23, 29-31.

Calcined clay hearthstones were associated with Skeletons 29 and 30 lying between them and at the same level. That these stones were a closely-packed group suggested that they lay *in situ* as originally assembled to form a cooking hearth, although if this was so it is difficult to imagine how they came to be buried at the level of two bodies lying in an excavated grave. No charcoal was associated with these stones and their association as a group was probably fortuitous.

Skeleton 69 was buried with a widow's cap on the head and this unique occurrence is discussed below.

Mussel shell was lodged in the cranium of Skeleton 32 but had probably become intimately associated with it subsequent to decomposition and settlement of the grave infill. Particles of both red and yellow ochre were also found associated with Skeleton 32.

In several cases (Skeletons 44, 45, 63) severe termite damage was present on some of the bones. This takes the form of heavy surface channelling and is illustrated in P. 12, fig. 2. No bones were found which had been fractured during life and only three bone abnormalities were seen. Skeleton 25 had a periostitic growth on the anterior border of the left tibia, evidently caused by a blow. Skeletons 60 and 64 each had two thoracic vertebrae fused together.

Skeleton 59 showed asymmetry of the base of the skull, and the left radius of Skeleton 64 was distinctly bowed. These pathological symptoms are discussed by Sandison, this *Memoir.*

Removal of Skeletons *in Situ*

On excavation, Skeleton 6 was exposed in a firm matrix from which it would have been difficult to remove the fragile bones intact. It was decided to remove it as a complete burial and to transport it intact to the National Museum in Melbourne.

A rectangular trench some 30 cm deep was excavated around the skeleton and three tunnels (A, Fig. 19) approximately 10 cm high and

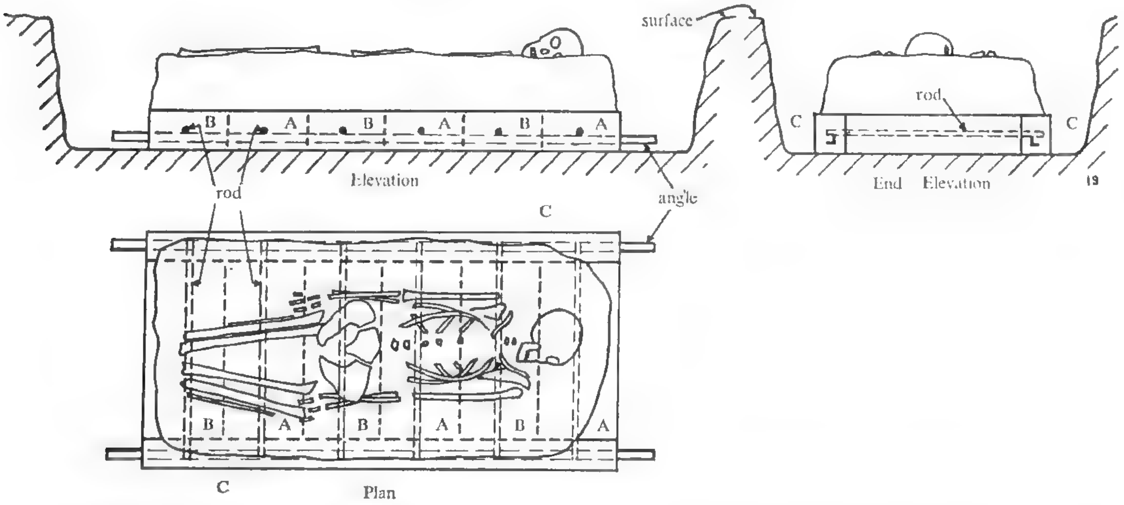

Fig. 19—System of construction of a concrete slab underneath Skeleton 6 to permit removal of the burial intact. Concrete sections, A, B and C were placed in that order.

30 cm wide were excavated transversely below it. These tunnels were filled with cement mortar with a steel rod inserted centrally in each so as to protrude some 10 cm at each end. After hardening, intermediate tunnels (B, Fig. 19) were excavated. These were grouted and reinforced similarly and allowed to harden. Light angle iron reinforcement was placed longitudinally on each side of the skeletal platform, passing beneath the protruding ends of the lateral reinforcing bars and tied to them. Formwork allowed pouring of longitudinal members (C, Fig. 19) to complete the concrete slab under the skeleton (Pl. 13, fig. 3), which was allowed to harden for some two months. The slab, supporting the undisturbed skeleton, was then lifted by the protruding ends of the longitudinal reinforcement. It was placed on an airbed on the floor of a truck and transported to the National Museum where it is on display.

While this method was quite successful, the technique was slow and laborious. A quicker and better method of preserving an intact burial was desirable.

During the excavation work many fragile and friable bones were strengthened before removal by the application of 'Aquadhere' (PVA glue) diluted with twice its volume of water. This almost invisible coating soaks into the surface layer and when dry hardens sufficiently to allow delicate bones to be handled safely. Combined with the sand between adjacent bones, this solution forms a membrane some 3-4 mm thick which holds them firmly together in their correct relative positions.

First experiments were made on a hand of Skeleton 9, which was so treated (Pl. 12, fig. 8). After hardening, the loose sand underneath was brushed away leaving the bones united by a thin web. A complete foot was also removed from Skeleton 9 and preserved in the same way. The technique was then applied to a larger section when a complete rib cage and thorax were removed from Skeleton 17. Finally, a complete skeleton (Skeleton 4) was removed and brought to the National Museum in Melbourne as an entity and is now on display. Skeleton 4 (Fig. 4) was a supine reclining body with the knees raised, the femora and tibiae being substantially vertical, with the feet close to the pelvic region. The cranium was slumped forwards on to the thorax. The area occupied by this skeleton in plan was therefore quite small and it was well suited to the experiment. After treatment with diluted 'Aquadhere' a baseboard was inserted underneath the skeleton by following a wooden cutting blade (Pl. 13, fig. 2).

Where the matrix is friable this technique provides a very satisfactory method of removing an excavated skeleton in its *in situ* condition. Many marsupial skeletons were also removed by this method during the course of the palaeontological work associated with the Chowilla Project.

Tooth Abnormalities and Wear

Those skeletons with teeth present showed a complete absence of dental caries. In only two cases (Skeletons 27, 47) was there slight evidence of calculus on the lingual and buccal margins of molar crowns. Exposure of the roots on the surface by thinning and resorption of the alveolar bone was frequently present to some degree, and was occasionally severe (Skeletons 28, 67, 70). An abscess below the root of the lower left first molar of Skeleton 65 had erupted through the lateral surface of the mandible (see Pl. 12, fig 5). The lower right first molar of the same skeleton showed loss of bone around the roots on the buccal side caused by pyorrhoea. Two examples of stepped occlusal surfaces of the molars were seen (Skeletons 26, 44) and Skeleton 54 showed a similar stepped condition on the upper canines and incisors. Skeleton 61 had a supernumerary incisor fully embedded in the right palate adjacent to the palatine torus. All roots of the upper molars of Skeleton 64 extended through to the maxillary sinus. Skeleton 17 showed crowding of the lower incisors.

Where wear was slight the teeth appeared flat and uniformly abraded. Teeth with moderate wear uncovering the dentine generally showed the development of the usual helicoidal occlusal plane (Murphy, 1964). In those skeletons showing severe wear well into the pulp, the helicoidal occlusal plane was developed to the extreme. In such cases the worn occlusal surfaces of the first and second molars were at angles of as much as 40° from the plane of the original unworn occlusal surface, the worn surface on both upper and lower molars sloping downwards laterally so that the lingual margin is superior to the buccal margin. In some cases wear was so severe that the lower molars were worn down into the roots on the buccal side (Skeletons 60, 65). Pl. 12, fig. 5 shows the mandibular teeth of Skeleton 65 which have been subject to extreme helicoidal wear.

In several cases (Skeletons 11, 37, 38, 66, 72) lower molars had apparently been lost premortem at an early age, the sockets having closed and healed by bone regrowth and loss of the supporting alveolar bone. Subsequent wear in Skeletons 11 and 38 had resulted in the development of a helicoidal pattern of wear on the remaining canines and premolars.

Isolated lower third molars in Skeletons 11 and 35 were very severely worn to the pulp, the resulting occlusal surfaces being concave. In Skeleton 35 the lower right third molar was worn by incomplete coverage of its surface by the corresponding upper third molar, leaving a sharp point of hard enamel on the linguomesial margin rising some 2 mm above the general level of the worn occlusal surface (Pl. 12, fig. 6).

It seems probable that helicoidal wear develops because the lateral distance between both lingual and labial surfaces of the upper molars is greater than the distance between the corresponding surfaces of the lower molars. Thus wear is more concentrated on the labial side of the lower molars and the lingual side of the upper molars, and where wear is rapid due to the mastication of abrasive food, the helicoidal pattern is soon developed. In Skeleton 65, for instance, the overhang of the upper molars over the lower molars approximates 1 mm. It can be clearly seen in Pl. 12, fig. 4, which shows the occluded teeth on the left side. This figure also shows the severe thinning and resorption of the alveolar bone exposing the roots of the upper left canines, premolars and first molar in particular.

Extreme helicoidal wear, particularly when combined with premortem loss of lower molars with subsequent healing of the sockets, is in itself a sign of advanced age at the time of death. The descriptive notes on individual burials provide confirmatory evidence of this in many cases by reference to other skeletal features. Skeletons exhibiting extreme helicoidal tooth wear were found at Sites 16B, 19A, 19B, 19C and 8, but the number of skeletons excavated whose teeth were sufficiently preserved to determine the degree and pattern of wear was significant only at Sites 16B and 8. Severe helicoidal wear was present in 40 per cent of such skeletons at Site 16B, and in 70 per cent of such skeletons at Site 8.

At and in the vicinity of the burial sites examined there was no real evidence of the dietary habits of the populations concerned, except that at Sites 16B and 8 small middens of mussel were present. No mammal bones were found, and only one small fishbone was associated with Skeleton 20 at Site 16B. There was no evidence, therefore, that the higher incidence of severe tooth wear at Site 8 could be attributed to diet. The greater age at death was the predominant factor, wear in general being rapid due to the abrasive nature of all food consumed in a dry, sandy environment.

Antiquity of Skeletons

Radiocarbon dates were determined for six skeletons individually (Nos. 2, 10, 11, 28, 29, 69) and for the mass of skeletal material representing Skeletons 51-55. In all cases except Skeleton 29 the determinations were made on the organic content of the bone. Skeleton 29 was dated using charcoal intimately associated with it in the grave. For the first time, some idea of the range of age of burials in the area between Mildura and the S. Australian border has been obtained.

Skeleton 29 at Site 17 on Keera Station, dated by charcoal, gave an age of 5,840 ± 90 years B.P. A comparable age of 5,900 ± 550 years B.P. was obtained for Skeleton 2 at Site 16A, also on Keera Station. Skeletons 10, 11 and 28, all at Site 16B, very close to Site 16A, gave ages of 4,170 ± 200, 4,400 ± 200 and 5,350 ± 290 years B.P. respectively. It can therefore be said that the skeletons in the area examined on Keera Station were buried from some 4,000 to 6,000 years ago.

The alkaline soils of this low rainfall area favour the preservation of skeletal material. It is now clear that the very large number of burials known in the region is not the short-term result of a high population density, but is the result of burial over a long period by a relatively small population. In the restricted area of Site 16B alone, interment must have been practised over a period of more than 1,000 years, yet only 24 skeletons were recovered there.

Radiocarbon dates were determined for Skeletons 10 and 11 because they were buried in close proximity, Skeleton 10 lying above Skeleton 11. As has been discussed above, the archaeological evidence in the grave was that Skeleton 10 had been buried subsequently to Skeleton 11. Dating confirms this and suggests a possible difference between the burials of some 200 years, although statistically the radiocarbon date determinations considered in isolation reveal no significant difference.

The skeletons of Site 8 at Lake Victoria were buried in a red paleosol thought to be some 16,000 years old as dated elsewhere in the lunette (Gill, this *Memoir*). Most skeletons here had been exposed to some extent and the bones had become bleached and scattered. The condition of the unexposed bones, however, did not suggest great antiquity. This was confirmed by a radiocarbon date based on the organic content of bones of Skeleton 69. The age was 750 ± 170 years B.P. It seems reasonable to assume that this would be representative of all burials at this site, which were intrusive into the paleosol.

Unique Widow's Cap Burial

The Aboriginal custom of wearing funerary skull caps as a sign of mourning for a near relative is well known. Worn predominantly by widows, and made of gypsum in the shape of a helmet formed over a net base placed on the head, these widows' caps were commonly placed on the grave after removal at the conclusion of the mourning period. Dummy caps of gypsum are also known to have been used as grave markers. There are many references in the literature to widows' caps found placed on graves, and Davidson (1948), in what is the best summary of the subject to date, notes the occurrence of this custom in the lower Darling area of N.S.W.

The evidence in the grave after excavation of Skeleton 69 at Site 8 in the E. border of the Lake Victoria lunette, as set out in the detailed description of Skeleton 69 above, shows that it was buried with a widow's cap actually in place on the head (Pl. 13, fig. 1). The authors are unaware of any reference in the literature to a body having been buried with a widow's cap in place on the head, and believe Skeleton 69 is unique in this regard.

The skeletal remains were insufficient to determine the sex, but in view of the preponderance of reference in the literature to the wearing of mourning caps by widows, it seems likely that the burial represents the body of a widow who died during the mourning period. There is, however, no direct evidence in support.

The cap itself was composed of gypsum with some flakes of mussel shell incorporated in the matrix on the concave surface. The flakes were oriented parallel to that surface, confirming construction in successive layers. The thickness varied from 1·2 cm to 2·5 cm. It had been constructed over a net base. The concave surface of the cap showed impressions of the net. Plastic casts were made of these impressions to reproduce the form of the net (Pl. 12, fig. 7). The mesh varied from 6 x 10 mm to 10 x 13 mm. The cord from which it was formed was from 2·0 to 2·3 mm in diameter, two ply, right hand twist. The net was apparently made by knotting and cutting off at almost every mesh intersection (Pl. 12, fig. 7). No fibre remains were present.

The pieces of leg bones associated with Skeleton 69 were radiocarbon dated. Dating was based on the organic content of the bone. The burial occurred 750 ± 170 years B.P. The assay was on "collagen" obtained by acid hydrolysis (Longin method) (ANU-421). It is clear that the burial is comparatively recent. In the absence of further supporting evidence the burial cannot be regarded as representing ancestral burial practice, and it must be regarded for the present as a fortuitous occurrence of death and burial of an individual during the period of mourning.

Cranial Types

The skulls of only eight skeletons (Nos. 1, 9, 11, 37, 41, 59, 70) were sufficiently complete to permit of cranial measurement. These skulls were all to some slight extent distorted and had undergone some degree of reconstruction. Nevertheless, it is believed that they give a reasonably good impression of the general cranial features, and it is for this purpose that they are reproduced here in Figs. 20-21 in norma lateralis, norma frontalis and norma verticalis. The skulls have been drawn from the right or left according to which side was the more complete. With the three projections of the cranium placed in their correct relationship in each case, a clear impression of the shape and form of the head becomes apparent.

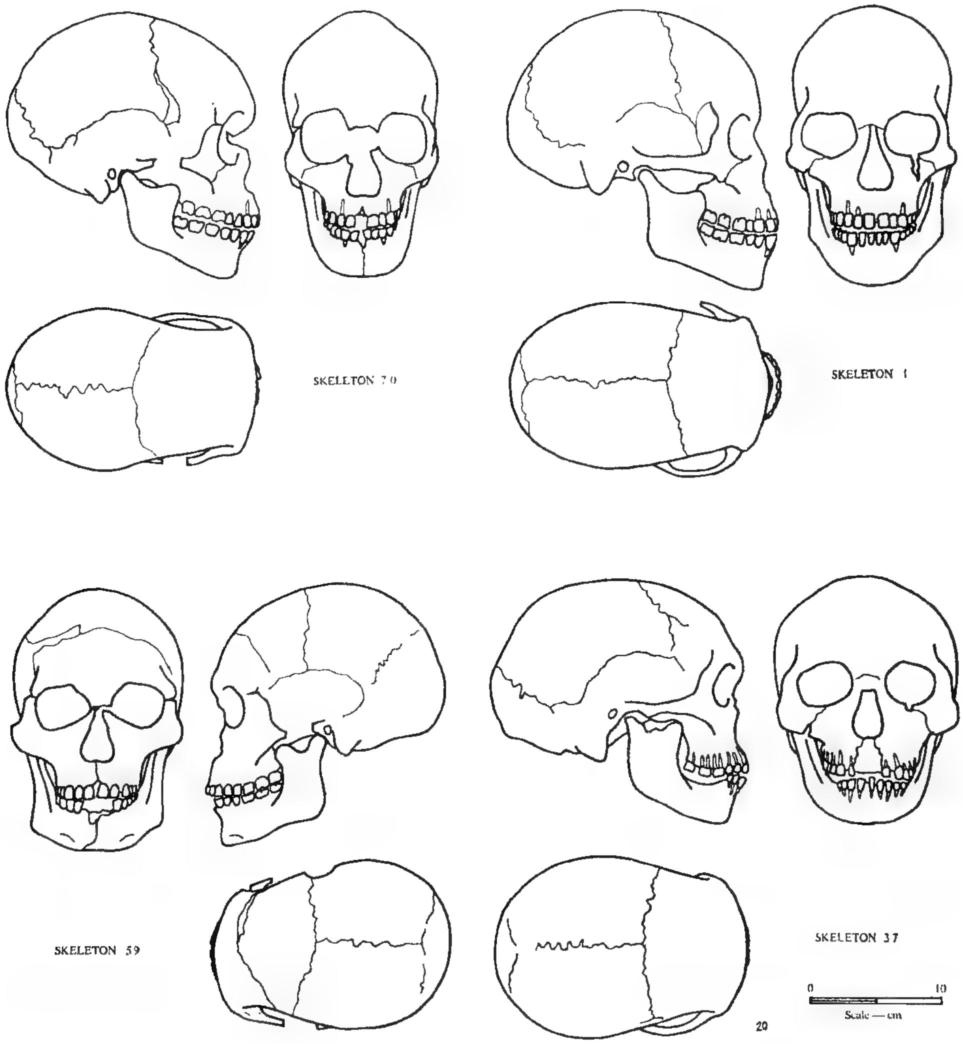

Fig. 20—Skulls of Skeletons 1, 37, 59, 70 as seen in norma lateralis, norma frontalis and norma verticalis.

The cranial measurements of these skulls insofar as they could reasonably be made are set out in Table 4. Measurements are given to the nearest millimetre, greater accuracy being unwarranted. The measurements recorded are those described by Brothwell (1965).

Sex determinations were made on these skulls using the method of Larnach and Freedman (1964). Determination by pelvic characteristics confirmed the sex of Skeletons 1, 59 and 70. There were six males and two females.

The cephalic index has been calculated for each skull. The skull of Skeleton 11 with an index of 76 would be classed as mesocephalic, but taken as a whole the group is typically dolichocephalic.

The cranial form in norma verticalis is predominantly birsoid, although that of Skeleton 9 is ovoid and that of Skeleton 17 is ellipsoid. The cranial form has been determined according to the classification of Sergi (Martin and Saller, 1957).

In spite of the considerable variety of form exhibited by the skulls individually, which can

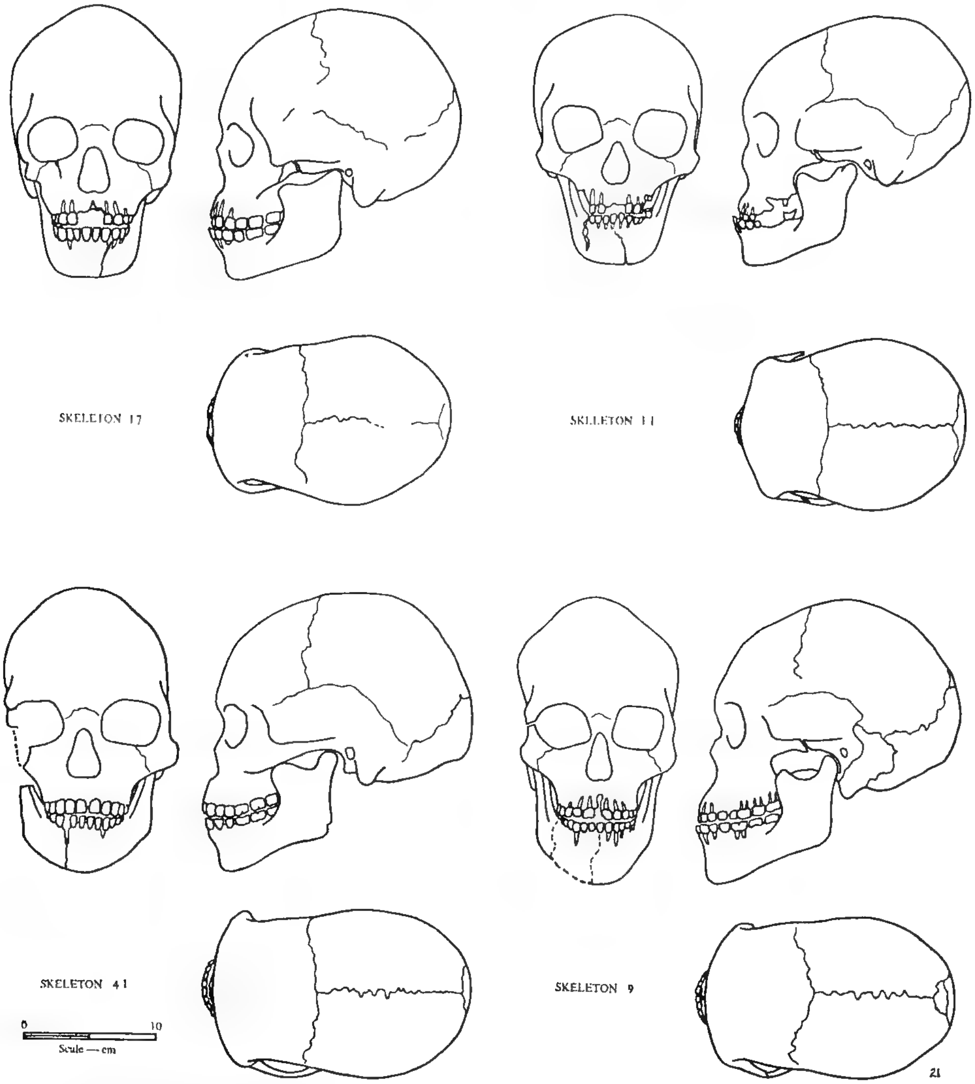

Fig. 21—Skulls of Skeletons 9, 11, 17, 41 as seen in norma lateralis, norma frontalis and norma verticalis.

TABLE 4

CRANIAL MEASUREMENTS OF SELECTED SKULLS—cm

Skeleton No.	1	9	11	17	37	41	59	70
Maximum cranial length	19·8	18·6	17·1	18·0	19·5	19·2	18·9	18·8
Maximum breadth	12·3	12·0	13·0	12·5	14·0	12·4	12·8	12·0
Basi-bregmatic height	—	—	—	—	—	13·4	12·6	13·2
Basi-nasal length	—	—	—	—	—	10·2	10·0	11·4
Basi-alveolar length	—	—	—	—	—	10·8	10·0	10·3
Upper facial height	7·3	7·2	6·5	6·2	6·9	7·1	7·1	7·2
Bi-maxillary breadth	9·4	9·4	8·7	—	9·5	—	9·4	8·9
Bizygomatic breadth	—	11·9	12·0	—	13·4	—	—	—
Nasal height	5·1	5·2	—	4·8	4·8	5·1	5·2	5·6
Nasal breadth	3·0	2·3	2·5	2·6	2·6	2·8	3·0	2·8
Orbital breadth—Right	4·0	4·2	3·9	3·8	3·9	—	4·0	—
—Left	4·0	4·0	3·9	3·5	4·0	4·0	3·8	—
Orbital height —Right	3·3	3·3	3·3	3·0	3·4	3·2	3·0	3·9
—Left	3·2	3·5	3·5	3·4	3·2	3·1	3·0	3·9
Palatal breadth	4·1	3·9	—	3·1	3·6	3·4	4·1	3·7
Mid frontal breadth	9·4	9·6	9·8	9·4	10·0	10·2	8·9	9·0
Frontal arc	14·0	12·9	11·1	12·0	13·0	13·0	12·4	12·5
Parietal arc	13·0	11·1	10·7	12·0	13·2	14·5	10·1	12·0
Occipital arc	10·6	12·4	11·0	—	—	11·5	13·0	10·1
Bimastoideal diameter	12·6	—	12·9	11·4	12·1	—	12·4	11·9
Symphysial height	4·1	4·2	3·4	3·2	3·3	3·9	3·5	3·1
Maximum projective mandibular length	11·4	12·1	10·4	10·2	—	11·4	9·9	—
Coronoid height—Right	5·6	5·5	4·9	5·9	—	—	5·7	—
—Left	5·6	5·5	—	5·9	—	5·5	6·1	—
Mandibular angle	130°	123°	128°	109°	—	119°	105°	119°
Minimum ramus breadth								
—Right	3·7	3·6	3·2	3·8	3·3	—	3·1	3·2
—Left	3·5	3·7	3·1	3·7	—	3·9	2·9	3·1
Bigonial breadth	10·4	9·1	7·2	7·0	—	—	10·4	7·3
Foramen mentalia breadth	4·9	4·8	4·2	4·6	4·7	4·8	4·6	4·3
Cranial form in norma verticalis	birsoid	ovoid	birsoid	ellipsoid	birsoid	birsoid	birsoid	birsoid
Sex determination	M	M	F	F	M	M	M	M
Cephalic index	62	64	76	70	72	65	68	64

be clearly seen in Figs. 20-21, there are two characters common to all, which are typical of the Australian Aboriginal.

All skulls seen in norma frontalis show the presence to some extent at least, and sometimes markedly so, of a paramedian flattening or even concavity, on either side of an elevated, rounded sagittal ridge of the parietal. In Skeletons 9, 17 and 70 this is combined with prominent parietal eminences, more typical of the Tasmanian Aboriginal skull. In Skeletons 9 and 17 the elevation of the sagittal ridge was slightly emphasized by lateral compression in the grave, but was nevertheless pronounced.

The cranial outline of all skulls as seen in norma lateralis is extraordinarily uniform in character. Fenner (1963) has described the typical outlines for Aboriginal skulls from the N. Territory, N. Queensland and SE. Australia. The cranial outlines in norma lateralis of the skulls figured here are compared in Fig. 22 with the typical outline of Fenner for Aboriginal skulls of SE. Australia, which has been drawn in each case with the same maximum cranial length as the individual skull with which it is compared. The correspondence is remarkably close.

Acknowledgement

The authors acknowledge the assistance given them by Mr E. D. Gill (who was in charge of the Chowilla Project of the National Musuem of Victoria) both in the field and in the preparation of this paper. Their thanks are also extended to the Director and to many members of the staff of the National Museum for their advice and help.

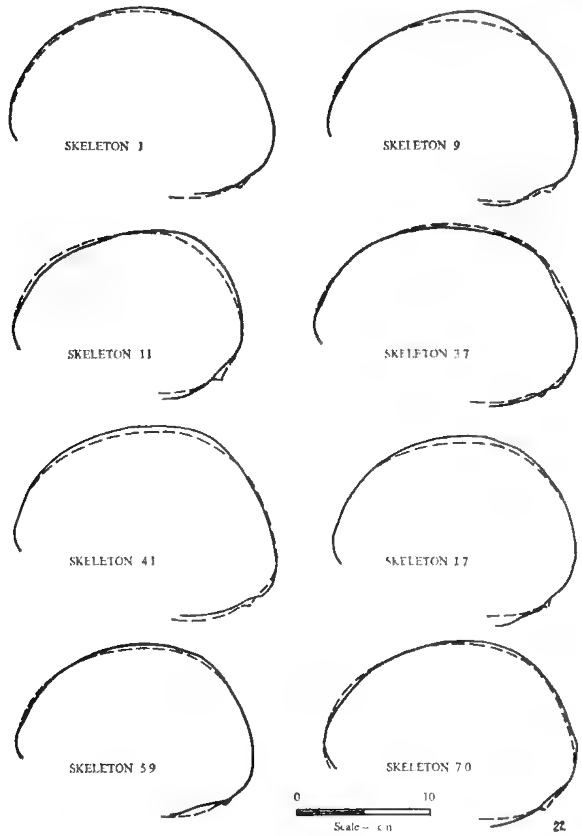

Fig. 22—Profiles in norma lateralis of the crania of Skeletons 1, 9, 11, 17, 37, 41, 59, 70 (full line), compared with the outline (broken line) of the typical Aboriginal cranium of SE. Australia as described by Fenner (1939).

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Explanation of Plates

Plate 12

Fig. 1—Typical position of hands over the pubic area in extended burials—Skeleton 72.

Fig. 2—Examples of bones subject to termite attack post mortem.

Fig. 3—Typical position of hands alongside the body in extended burials—Skeleton 41.

Fig. 4—Occluded teeth of Skeleton 65 showing overhang of the upper molars over the lower molars and exposure of roots of the upper teeth by resorption of the alveolar bone.

Fig. 5—Mandible of Skeleton 65 showing eruption of an abscess through the lateral surface below the first molar and extreme helicoidal wear to the roots of the first and second molars.

Fig. 6—Lower right third molar of Skeleton 35 showing severe concave wear of the occlusal surface leaving a sharp, upstanding point on the linguo-mesial margin.

Fig. 7—Plastic cast taken from the concave surface of the mourning cap of Skeleton 69 which reproduces the detail of the net on which the cap was formed.

Fig. 8—Complete hand of Skeleton 9 removed as a unit by treating the bones and sand matrix with diluted 'Aquadhere'.

Plate 13

Fig. 1—Remains of the cranium of Skeleton 69 with the remnants of a mourning cap still in place. The photograph was taken from a position superior to the head.

Fig. 2—Skeleton 4 completely excavated and prepared with diluted 'Aquadhere' for removal as a unit. The wooden 'saw' was used to cut through the base while inserting a board support on which the skeleton was transported to the National Museum of Victoria for display.

Fig. 3—Skeleton 6 as it lay *in situ* after construction of a concrete platform beneath it. The skeleton was removed on this platform for display in the National Museum of Victoria.

Fig. 4—Mass of Skeletons 51-55 during excavation after removal of Skeletons 44 and 50.

Fig. 5—Skeleton 70 fully excavated showing collapse and distortion of the rib cage during settlement in the grave.

Fig. 6—Cache of mussel shells as exposed by wind erosion at the summit of the lunette on the E. side of Lake Victoria, N.S. Wales.

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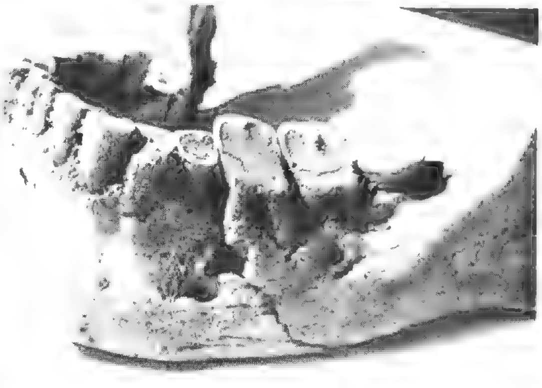

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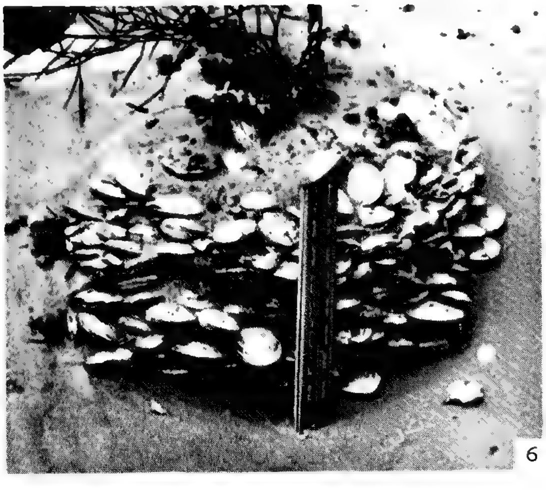
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FOSSIL VERTEBRATE FAUNAS FROM THE LAKE VICTORIA REGION, S.W. NEW SOUTH WALES, AUSTRALIA

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Abstract

Fossil vertebrate localities and faunas in the Lake Victoria region of S.W. New South Wales, Australia, are described. The oldest fossil bearing deposit, the late Pliocene or early Pleistocene Moorna Formation and associated Chowilla Sand have yielded specimens of *Neoceratodus* sp., *Emydura macquarrii,* several species of small dasyurid, specimens of *Glaucodon* cf. *G. ballaratensis,* a species of *Protemnodon* which compares closely with *P.* cf. *P. otibandus* from the late Pliocene or early Pleistocene Chinchilla Sand in SE. Queensland, specimens of *Lagostrophus* cf *L. fasciatus,* species of *Petrogale, Macropus, Osphranter, Sthenurus, Bettongia, Diprotodon, Lasiorhinus,* a peramelid, at least two species of pseudomyine rodents and a species of *Rattus* cf. *R. lutreolus.* It is shown that the holotype of *Zygomaturus victoriae* (Owen) 1872 may have been collected from these sediments. The late Pliocene or early Pleistocene Blanchetown Clay has yielded species of *Neoceratodus, Thylacoleo, Phascolonus, Bettongia, Sthenurus,* a diprotodontid, and a rodent. The late Pleistocene Rufus Formation has yielded species of *Dasycercus, Sarcophilus, Thylacinus, Phascolonus, Lasiorhinus, Bettongia, Procoptodon, Onychogalea, Macropus,* and *Leporillus.* A large species of macropod and a species of *Phascolonus* were collected from the late Pleistocene Monoman Formation. The lunette on the E. side of Lake Victoria has yielded a large, diverse fauna of late Pleistocene —Holocene age, that includes such extinct species as *Protemnodon anak, P. brehus, Procoptodon goliah, Sthenurus andersoni, S. atlas, S. tindalei, Thylacoleo carnifex, Phascolonus gigas, Macropus ferragus, and Diprotodon optatum.* The oldest C14 date obtained for an occupation site of Aboriginal man at Lake Victoria is 18,800±800 yr B.P. (GaK-2514). No evidence was found of a direct association of man with late Pleistocene megafaunal species at Lake Victoria.

Introduction

The first reported discovery of fossil vertebrates at Lake Victoria, N.S.W. was made in September 1967 by Mr. Max Tulloch of Mildura and Mr. Hal Loftus of Cheltenham. During a camping trip to the area they discovered, and partially excavated, the skeleton of a large macropod from the lunette on the NE. side of Lake Victoria. Mr. Hal Loftus subsequently sent the specimen to Mr. Colin Macrae of Beaumaris who recognized the material as fossil, and conveyed this information to Mr. Thomas Darragh, Curator of Fossils at the National Museum of Victoria. This specimen was later identified as *Procoptodon goliah* (P28277). Loftus provided Darragh with a map of the collection site, and on 17-26 October 1967, Darragh, accompanied by Mr. Ken Simpson (Field Officer) and Mr. Donald Shanks, went to Lake Victoria and relocated the specimen. The remaining portion of the skeleton had since weathered out of the matrix and was greatly damaged; however, other specimens of *Procoptodon, Bettongia, Diprotodon, Thylacoleo,* and *Lasiorhinus* were collected. The site was then recognized as having great potential warranting further investigation.

At this time, the National Museum of Victoria was already involved in a large reconnaissance program (the Chowilla Project) to systematically study the region which was to be flooded behind the proposed Chowilla Dam. Lake Victoria was part of the holding basin (Gill, This Memoir). Mr. E. D. Gill, Deputy Director of the National Museum of Victoria supervised the salvage projects. During a series of field trips a large collection of fossils was made from the Lake Victoria lunette. Stratigraphic studies of surrounding areas and older sediments subsequently led to the discovery of additional deposits containing fossil vertebrate

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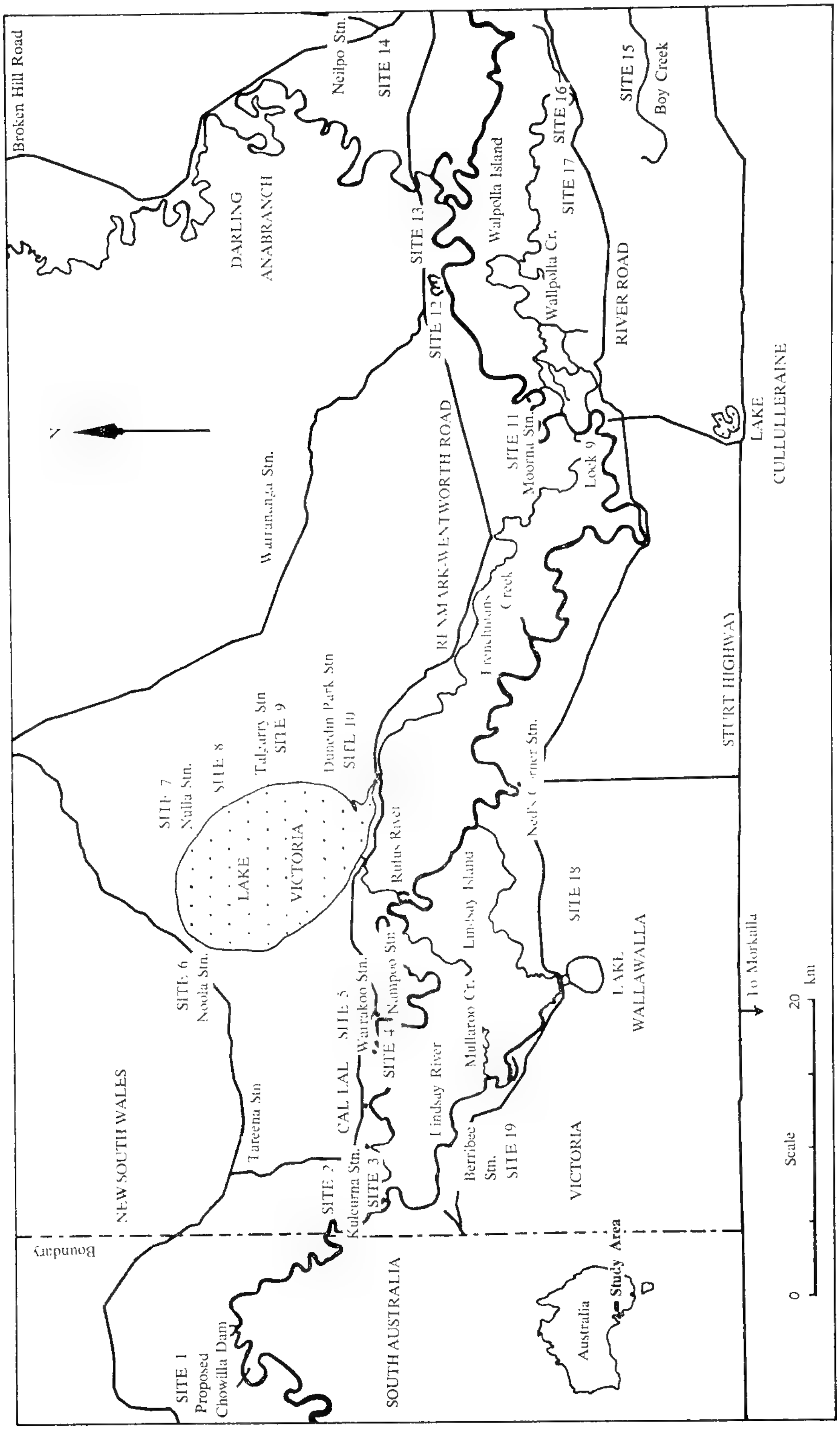

Fig. 1—Map of the Lake Victoria area showing the fossil vertebrate localities discussed in the text.

material. A total of nine localities has yielded an abundance of fossil vertebrates (Fig. 1; see appendix on Sites). The fossil bearing deposits are of late Pliocene to Holocene age (Fig. 2).

The fossil vertebrate collections were subsequently made available for systematic study to Professor J. W. Warren, Department of Zoology, Monash University. In November 1970 these materials were turned over to me to form the basis for a Post Graduate degree under the direction of Professor Warren. My thesis includes a systematic and phylogenetic study of the late Pleistocene fauna from the Lake Victoria lunette. During 1971, Warren, Simpson and myself returned to this area on several occasions and made additional collections.

This paper presents a preliminary report of the fossil vertebrate localities and faunas discovered in conjunction with the Chowilla Project, but includes mention of other fossil mammal occurrences from the Murray River Basin. These localities occur in the vicinity of Lake Victoria, New South Wales, delimited to the E. by Mildura, Victoria, and to the W. by Renmark, South Australia.

Format

Although it is preferable to defer publication pending completion of an in depth systematic study, the interest expressed in these localities and faunas warrants a preliminary report. The species list given for Sites 7-10 is extracted directly from my dissertation. A systematic diagnosis of these species is complete for most of the taxa, and will appear at a later date. The extinct species from Site 13 have been compared with the type speciments (e.g. *Protemnodon otibandus,* and *Glaucodon ballaratensis)* and many of the smaller forms (e.g. *Dasyurus, Lagostrophus* and *Rattus*) compare well with living species. Several of the smaller forms probably represent new taxa (e.g. small dasyurid cf. *Dasyuroides* or *Dasycercus)* for which phylogenetic relationships are here proposed. A complete analysis of the fauna from Site 13 will not be made available for four or five years and I have given preliminary descriptions of some of the more important taxa at this time. For this reason a disparity exists between the amount of attention received by the fauna from Site 13 and those from Sites 7-10 and 12.

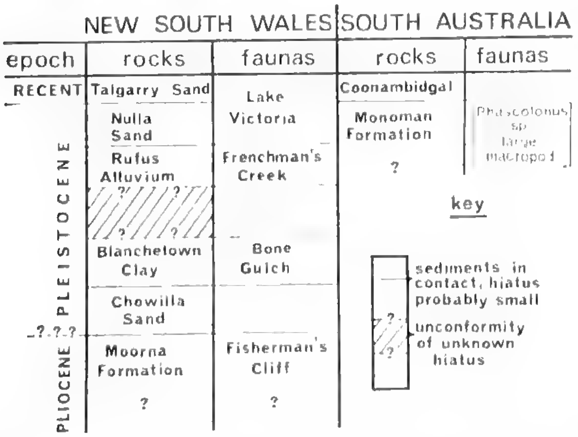

Fig. 2—Chart showing the stratigraphic relationship of the rock units and faunas discussed in the text. The proposed ages are based on both rock-stratigraphic and biostratigraphic information. Compare this figure with Fig. 2 of Stirton *et al.*, 1968.

Higher mammalian taxonomic categories follow those adopted by Butler *et al.* (1967) and taxonomy below the family level largely follows Ride (1970). All specimens are registered and housed in the National Museum of Victoria (NMV). All measurements in the text are in millimetres and the scales appearing on the Plates and Figures are all in centimetre gradations. I have followed Stirton *et al.* (1968, pp. 1-2) in separating rock stratigraphic and biostratigraphic names. Grid references are given for each locality based on the Australian Army Survey (1:250,000) Mildura map SI-54-11, Anabranch SI-54-7, and Renmark SI-54-10, Edition 1, Series R 502.

Methods

At Sites 7-10, 13 collecting techniques initially involved walking over the area and picking up float material (Pl. 14, fig. 3). Minor excavations were made to uncover partially exposed specimens (Pl. 14, figs. 1-2, 4). During 13-21 August 1971, we employed the wet sieve technique (Hibbard 1949) at Site 13 in an attempt to recover smaller elements. Samples of the upper coarser fraction of the Moorna Formation were first washed in fine meshed screens to remove clay particles and break down any consolidated masses, dried, and taken back to the laboratory where detailed examination and sorting was accompanied by use of a binocular microscope. This method proved to be successful as only then were teeth of rodent, small dasyurid, and small macropod found. Sorting in the laboratory revealed that some samples yielded far greater numbers of specimens than others, suggesting the occurrence of local concentrations. No wet sieved samples of the lower portion of the Moorna Formation, Chowilla Sand or Blanchetown Clay were taken at Site 13. At Site 12 all fossil material was obtained by quarrying operations, and not by wet sieving.

At Sites 7-9 along the Lake Victoria lunette, numbered stakes were placed by Gill and Simpson at the E. end of each erosion gully. Collection localities were marked in reference to these points. More important finds (larger, more complete skeletons) were surveyed to one of the four N.M.V. bench marks (Gill, This *Memoir*).

Float specimens were sorted into age groups based on degree of leaching and presence or absence of adhering carbonate and sand, following the deductions employed by Tedford (1955, 1967). Specimens collected at Site 10 were labelled as float or in situ, and the precise localities of the more complete specimens were surveyed to an N.M.V. bench mark.

The geology of the region is treated by Gill (This *Memoir*). The faunas are considered in ascending order of age in the following pages.

Site 13, Moorna Formation (late Pliocene or early Pleistocene)

Grid reference 469,788

Stratigraphy

The Moorna Formation consists of coarse stream channel sediments at this site. Many of the fossil specimens, both bones and teeth, have been worn by stream action, and the finer dental patterns have often been lost. Articulations have been largely dissociated, and most material consists of isolated tooth and bone fragments. The bone is a rich brown to yellow with dendritic manganese staining. The bone surfaces are usually smooth and the smaller cancellous vacuities are not filled with sediments. Most of the specimens are mineralized. For details of stratigraphy and grain size analysis see Gill (This *Memoir*). At this site the coarse gray Moorna sediments grade up into yellow finer better sorted Chowilla Sand, but for the present purpose both are referred to as the Moorna Formation.

Age

Absence of volcanic rocks in the study area prevents chronometric dating by isotopic methods. Stratigraphic and geomorphic methods have been used by Gill (This *Memoir*) in proposing a late Pliocene age for the Moorna Formation.

The stage of evolution of the diverse mammalian fauna from these sediments offers an independent assessment of their age. The age of the deposit from which the holotype of *Glaucodon ballaratensis* was collected is interpreted by Gill (1957, p. 191) as late Pliocene or early Pleistocene. Stirton (1957, p. 133) argued that if *Glaucodon* was in the direct line of ancestry of *Sarcophilus* then the age of the beds from which *Glaucodon* was collected may be as old as "late Miocene or slightly older". At the time Stirton believed that species of *Sarcophilus* were represented in Pliocene deposits. Marshall and Bartholomai (1973) have shown that there are no specimens of this genus *(Sarcophilus)* which may be definitely assigned to Pliocene or even earlier than late Pleistocene age. *Glaucodon* may therefore be regarded as in the direct line of ancestry to *Sarcophilus* and still come from deposits of a Pliocene-Pleistocene age. As the Moorna specimen of *Glaucodon* (P28268) is probably conspecific with that of the holotype (P16136) (see below) the deposits are deemed to be of comparable age.

Aziz-ur-Rahman and McDougall (1972) recently obtained a K-Ar date of 2·1 m.y. on a sample of basalt from the West Berry Consols Mine No. 1 Bore in Victoria. The Smeaton locality, containing *Glaucodon ballaratensis* is located 4·2 km to the north. The sediments from which *Glaucodon* was taken are younger than the basalts, making *Glaucodon* "latest Pliocene or younger in age" (ibid.).

Species of *Protemnodon* have been found to be widely distributed in deposits of Pliocene and Pleistocene age, and are proving to be useful index fossils (Plane 1972). The Moorna specimen of *Protemnodon* (P28266) agrees best with specimens of *P.* cf. *P. otibandus* from the Chinchilla Sand of SE. Queensland (see below) which are considered to be late Pliocene or early Pleistocene in age (Stirton *et al.* 1968, pp. 17-18, Woods 1962).

Most of the other species from the Moorna Formation are too poorly known at present to be of use as index fossils. Many of the smaller macropodids appear to be conspecific with living species, while others are probably the direct ancestors of living species. The age based on biostratigraphic and rock-stratigraphic grounds suggests a late Pliocene or early Pleistocene age. It is reasonable to postulate that we are dealing with a fauna whose age may be roughly equated with the Villafranchian of Europe or the Blancan of North America.

The fauna from this locality is here designated the Fisherman's Cliff Local Fauna.

Fisherman's Cliff Local Fauna

(late Pliocene or early Pleistocene)

Class Gastropoda
  Order Basommatophora
    Family Lymnaeidae

The species *Lymnaea* cf. *L. tomentosa* is represented by a single specimen (P29444) determined by Mr. T. A. Darragh.

Class Osteichthyes
  Superorder Teleostei

Numerous vertebrae, neural spines, otoliths and skull fragments apparently representing several species of bony fish.

Order Dipnoi
  Family Ceratodontidae

A species of *Neoceratodus* is represented by a single tooth plate (P28879).

Class Reptilia
  Order Chelonia
    Family Chelyidae

A relatively complete, associated carapace and plastron (P30775) agrees well with the living species *Emydura macquarrii* (identified by Professor J. W. Warren). This species presently occurs only in the Murray River and its tributaries (Rawlinson 1971, p. 21) but a specimen from the mid-Tertiary of Tasmania showing affinities to this species (Warren 1969) suggests a wider distribution in the past.

Class Aves
  Order Casuariiformes

Several egg shell fragments (P28881) indicate the presence of a large ratite. The convex surface is granulated and the concave surface is smooth, a character of the shells of living species of both *Dromaeus* and *Casuarinus*.

Class Mammalia
  Superorder Marsupialia
    Order Marsupicarnivora

Dasyurus cf. *D. hallucatus* is represented by a single M^3 (P28889). The M^3 of *D. hallucatus* (C684) is easily separated from the slightly larger species of *Dasyurus* (e.g. *D. viverrinus* C6062, *D. geoffroii* C6084, and *D. maculatus* C2165) by the proportionately smaller metastylar ridge (terminology after Clemens 1966, p. 3). A fragment of a left M^2 or M^3 (P28890), has a long metastylar ridge, and compares closely in size with *D. geoffroii* (C6084) and *D. viverrinus* (C6062). A right M_3 (P29428) agrees closely in size and morphology with *D. geoffroii* (C6084). The tooth is narrow relative to its length, the talonid is narrower than the trigonid, and the protoconid is set slightly anteriad of the metaconid. In *D. viverrinus* (C6062) the tooth is broad relative to its length, the talonid is as wide as the trigonid and the protoconid usually lies directly linguad to the metaconid. Judging from the stage of evolution of the fauna as a whole this specimen may prove to bear closer affinities to *D. dunmalli* from the late Pliocene or early Pleistocene Chinchilla Sand of SE. Queensland (Bartholomai 1971) although an entire dentary is needed from Site 13 to support this speculation.

A species of the genus *Glaucodon* is represented by a left ramus with M_{1-4}, and alveoli

TABLE 1

Comparison of holotype of *Glaucodon ballaratensis* (P16136) with P28268 from Site 13

Specimen	M_1		M_2		M_3		M_4			Width of Mandible Below M_4	Depth of Mandible Below M_4
	L	MW	L	MW	L	MW	L	MW	M_{1-4}		
P16136	7·5	4·2	—	—	—	—	9·9	5·7	34·0	7·0	17·0
P28268	7·7	—	8·6	5·7	9·7	6·0	10·4	5·9	36·5	8·0	19·3

Abbreviation: L=length, MW=maximum width

of the incisor, canine, and premolars (P28268) (Pl. 15, figs. 3-4) and an isolated M^2 (P28684) (Pl. 15, figs. 1-2). The former specimen compares closely with the holotype of *G. ballaratensis* (Stirton 1957). These specimens are compared in Table 1.

P28268 is more robust in the mandible and the teeth show greater apical cusp wear than P16136. The holotype (P16136) is a young animal in which the M_4 shows little evidence of wear, while the large amount of occlusal wear in P28268 indicates that it represents an older individual. In P28268, the talonids are well developed in M_{2-3}, proportionately larger than in *Sarcophilus harrisii* (C6239) and smaller than in *Dasyurus maculatus* (C2165). These specimens (P16136, P28268) are compared following the procedures set forth by Simpson *et al.* (1960, p. 210) for comparing two isolated specimens possibly of a single species. The results, using the raw data presented in Table 1, are given in Table 2.

TABLE 2

Comparison of holotype of *Glaucodon ballaratensis* (P16136) with a specimen of *Glaucodon* (P28268) from Site 13

Dimension	M_1	M_4		M_{1-4}	Width of Mandible Below M_4	Depth of Mandible Below M_4
	L	L	MW			
log difference	·0114	·0214	·0150	·0308	·0580	·0552
minimum value of V[a]	1	2	1	2	3	3

[a] values of V and D were taken from Simpson *et al.* 1960, p. 209.

Abbreviations: L=length, MW=maximum width

Linear dimensions with values of V greater than 5-6 usually warrant specific distinction, although values of V between 3-4 are commonly used (ibid). Keeping in mind the ontogenetic differences of these specimens and absence of notable morphological differences, it appears probable that they are conspecific.

A small species of dasyurid compares closely in size and molar morphology with *Dasyuroides byrnei* (C458) and *Dasycercus cristicauda* (C655). It is represented by a right edentulous ramus fragment with alveolus of C-M_1 (P28886) and a right ramus fragment with M_{2-4} and alveolus of M_1 (P28888) (Pl. 15, figs. 5-6). A comparison of the two rami fragments shows that in P28886 there is a single alveolus (rudimentary P_3?) between those for M_1 and P_2. This species is regarded as a possible ancestral form of *Dasyuroides* or *Dasycercus* (or both). An isolated right M_3 (P28857) shows the hypoconid portion of the talonid set further posteriad than the entoconid and there is no trace of a hypoconulid. This specimen may be either a variant of the same species as P28888, or may represent a second species or genus of small dasyurid.

Order Peramelina

Family Peramelidae

The bandicoots are represented by a single right M^2? (P28686) (Pl. 15, figs. 8-9). The striking feature of this specimen is the presence of five prominent stylar cusps, with cusp $B > D > C > A \simeq E$ (see Clemens 1966, p. 3 for stylar cusp terminology).

Order Diprotodonta

Family Vombatidae

Several molar fragments (P29447, P29448) indicate the presence of a species similar in size and morphology to the living species of *Lasiorhinus*. The labial edge of the molar lobes are well rounded, not sharp as in species of *Vombatus* (Merrilees 1967, p. 407).

Family Macropodidae

Subfamily Potorinae

A right M_1 (P29416) and fragment of a P^3 (P29417) are tentatively referred to a species of *Bettongia*.

Subfamily Sthenurinae

Two molar fragments (P29422, P29423) are readily assigned to a species of the genus *Sthenurus* by the complex ornamentation on the enamel surface (Tedford 1966). A large right mesectocuneiform (P29424) indicates the presence of a species of this subfamily, and shows that the monodactylous condition which is characteristic of the late Pleistocene members of this subfamily (Tedford 1967, p. 73) was well developed by late Pliocene or early Pleistocene times.

Subfamily Macropodinae

Members of this subfamily are abundant in both numbers and species, representing the most diverse group in the fauna. *Lagostrophus* cf. *L. fasciatus* is represented by two upper molars (P28891, P28892) that are easily identified as such by the medial vertical ridge on the posterior face of the metaloph. A species of *Petrogale* is represented by an upper (P29418) and lower (P29419) P3. Numerous small molars record the presence of species of the size of *Onychogalea, Lagorchestes,* and possibly some of the smaller species of *Macropus.* It is, however, difficult to assign these elements to specific or even generic rank without associated premolars.

The protoloph fragment of an upper molar (P29420) is large, has an incipiently developed (although well defined) forelink, and the labial side of the anterior basal cingular valley is enclosed labially by a connection between the base of the paracone and anterior cingulum. These features are characteristic of species of *Osphranter*.

A species of *Protemnodon* is represented by an isolated fragment of a P_3 (P29421) and a left ramus with the greater part of M_{3-4} preserved (P28266) Pl. 15, fig. 7). The molars are broad for their length, resembling *P. brehus, P. raechus,* and *P. otibandus* in contrast to the

TABLE 3

Comparison of *Protemnodon* sp. (P28266) from Site 13 with a sample of *P.* cf. *P. otibandus* from the Chinchilla Sand, Queensland, a sample of *P. otibandus* from the Otibanda Formation, New Guinea, and a specimen of *P. brehus* from Lake Victoria (Site 8 (P28660).

	M_2		M^3			M^4	
	L	L	AW	PW	L	AW	PW
Specimen P28266	15·2[a]	17·0	12·4	11·0[a]	16·5	11·5[a]	10·1
Chinchilla Sand[d]	11·8-15·5	14·8-16·9	10·3-12·0	—	15·5-17·9	10·5-12·0	—
Otibanda Formation[b]	10·9-13·2	11·8-14·0	10·1-10·5	9·8-10·4	13·3-14·4	10·0-10·5	9·8-10·0
P28660 Lake Victoria[c]	15·2	17·1	13·4[a]	13·2[a]	18·7	—	12·7

[a] approximate
[b] data from Plane 1967
[c] *Protemnodon brehus*
[d] courtesy of Mr. A. Bartholomai
Abbreviations: L=length, AW=anterior width, PW=posterior width.

smaller and proportionately elongated molars of *P. anak* and *P. buloloensis.* P28266 is compared with specimens of *P. otibandus* from the Awe Fauna of New Guinea, material referable to *P.* cf. *P. otibandus* (Mr. Alan Bartholomai pers. comm., Plane 1972) from the late Pliocene or early Pleistocene Chinchilla Sand, SE. Queensland, and a specimen of *P. brehus* from Site 8 at Lake Victoria (Table 3). In stage of evolution P28266 agrees best with the Chinchilla sample of *P.* cf. *P. otibandus.* It is smaller than the late Pleistocene *P. brehus* and larger than the medial Pliocene population of *P. otibandus* from New Guinea.

Family Diprotodontidae

A fragment of the posterior face of the metaloph of an upper molar (P28883) is probably referable to a species of *Diprotodon.* As in *Diprotodon,* a well defined posterior basal cingulum is present and the crown shows the extreme hypsodont development. The enamel shows the "reticulo-punctate" pitting (Huxley 1862) although abrasion due to stream action has reduced the expression of this character.

Remains of *Diprotodon* sp. are also recorded from the late Pliocene or early Pleistocene Chinchilla Sand, Queensland (Woods 1962, p. 46).

The holotype of *Zygomaturus victoriae* (Owen) 1872 was collected from a well "45-60 feet" below the ground surface, in the SW. corner of N.S.W. near the borders of Victoria and S. Australia (Mr. J. A. Mahoney and Dr. W. D. L. Ride, pers. comm.). Owen (1877, p. 271) records that the holotype (South Australian Museum P4986) is a "rich brownish-yellow" and "the minute cancelli are vacant, not filled up with mineralised matter". The type of preservation suggests derivation from the Moorna Formation. If this proves to be true, the phylogenetic position of this species will need re-evaluation as it was previously recognized as a Pleistocene species (Simpson 1930, p. 69). It should thus be compared with Pliocene zygomaturine species such as *Z. keani* (Stirton 1967) from the Mampuwordu Sands at Lake Palankarinna, S. Australia.

Infraclass Eutheria

Order Rodentia

Family Muridae

Next to macropods, rodents constitute the largest number of individuals in the fauna. This group is represented by 27 molars, 33 incisor fragments, one calcaneum, one astragalus, one caudal vertebra, and two podial elements. Two species (possibly genera) of pseudomyine rodents are indicated by differences in loph arrangement of M_1. A single M_1 (P28893) is referable to a species of the genus *Rattus.* The cheek teeth of *Rattus* are easily separated from other Australian murids by the characteristic root pattern, noted by Jones (1922), and Ride (1960). The M_1 of species of *Rattus* has a large root below the posterior loph, one slightly smaller below the anterior loph and two smaller (one labial and one lingual) roots under the medial loph, in contrast to the double rooted arrangement in other Australian murids. P28893 has the characteristic *Rattus* root pattern. This tooth lacks a "talonid" (=posterolophid of Schram and Turnbull 1970), and in this respect agrees with the mainland *R. lutreolus,* while *R. assimilus, R. villosissimus, R. tunneyi,* and *R. fuscipes* have this feature well developed unless secondarily lost through wear (Mr. J. A. Mahoney, pers. comm.). Although P28893 shows a striking resemblance to *R. lutreolus,* it is here referred to the genus *Rattus* with specific allocation deferred pending discovery of additional material.

Rodents of pre-late Pleistocene age are recorded from the medial Pliocene Awe Fauna, New Guinea (Plane 1967, p. 56), and early Pleistocene Kanunka Fauna, South Australia (Stirton *et al.* 1961, p. 43). The abundance of rodents in the Fisherman's Cliff Local Fauna shows this group to be well established by late Pliocene or early Pleistocene times, and the diversity indicates an earlier radiation. Turnbull and Lundelius (1970, pp. 75-76) report rodents as absent from the medial Pliocene Hamilton Fauna of Western Victoria. Considering the abundance of small sized marsupials in that fauna this absence may be real. If this is true, then the time of entry of rodents onto the Australian continent possibly occurred in the interval between post-Hamilton and pre-Moorna times.

Site 12, Blanchetown Clay (late Pliocene or early Pleistocene)

Grid reference 463,785

Stratigraphy

Outcrops of greenish grey mudstones are widespread along the Murray and Darling Rivers and are referred to as the Blanchetown Clay (Firman 1965). They are known from a number of localities in NW. Victoria, SW. New South Wales, and E. South Australia. At this locality they are interrupted by lenses of channel sands and ostracod coquina bands.

The Blanchetown Clay overlies the Chowilla Sand at Site 13. The former is of lacustrine origin, the latter is a channel and floodplain deposit. The two are shown to interdigitate at other localities (Gill, This *Memoir*). The relationship shown in Fig. 2 represents the relationship of these deposits at Site 12 and Site 13 only, and is not intended to express their relationship elsewhere.

The skeleton of a small diprotodontid was found *in situ* in the clay layer at Site 12. Clay penetrated into the cancellous regions of the bone, and compaction has deformed the original shape of these elements. Fish and mammal remains are abundant in interdigitated sand lenses. The material is fragmentary and the finds to date consist of isolated fish vertebrae, spines, and mammal teeth.

Age

Stratigraphically the Blanchetown Clay is regarded as early medial Pleistocene (Firman 1965, 1966), early Pleistocene (Lawrence 1966), or late Pliocene/early Pleistocene (Gill, This *Memoir*). These differences may be partially due to lack of agreed definition of the Pliocene-Pleistocene boundary. The sparse mammal fauna is of little use at the present time in determining the age.

Firman (1967) records remains of species of *Diprotodon* and *Macropus* in this formation in South Australia.

The fossil fauna from this locality is here designated as the Bone Gulch Local Fauna.

Bone Gulch Local Fauna (late Pliocene or early Pleistocene)

Class Crustacea
  Order Decapoda

Crayfish are represented by two gastroliths (P29413, P29414).

Class Osteichthyes
  Superorder Teleostei

Bony fish are the most abundant element in the fauna and are represented by numerous vertebrae of varying sizes, neural spines, and skull fragments.

Order Dipnoi
  Family Ceratodontidae

Several dozen lungfish tooth plates compare closely with the living Australian species *Neoceratodus forsteri.*

Class Reptilia
  Order Chelonia
    Family Chelyidae

Turtles are represented by numerous plastron and carapace fragments.

Class Mammalia
  Superorder Marsupialia
    Order Diprotodonta
      Family Thylacoleonidae

A species of *Thylacoleo* is represented by the anterior face of a left M^1 (P28885).

Family Vombatidae

A large fragment of a lower molar (P26880) indicates the presence of a large wombat. The enamel has the prominent pitted and vertical ridging of species of *Phascolonus*. The size and morphology suggest affinities with *P. magnus* (Mr. H. E. Wilkinson pers. comm.).

Family Macropodidae

Subfamily Potorinae

The rat kangaroos are represented by a single fragment of a right M_2 or M_3 (P26875). The tooth compares best with species of *Bettongia.* The hypoconid is a large cusp while the entoconid is small and confluent with a spur extending lingually from the former. This disparity in size between the labial and lingual cusps distinguishes this tooth from the subequal cusp arrangement seen in species of *Potorus.*

The posterior basal cingulum is deep and situated linguad of centre. A small spur occurs medially on the anterior face of the hypolophid and extends slightly linguad into the interloph valley.

Subfamily Sthenurinae

The anterior labial edge of an upper molar (P26882) has the ornamented ridges of the anterior protoloph face and anterior cingular valley which is characteristic of species of *Sthenurus*.

Subfamily Macropodinae

This subfamily is represented by numerous tooth fragments, although all are undeterminable as to the species represented.

Family Diprotodontidae

A single molar fragment (P26877) is referable to this family. The enamel has the "reticulo-punctate or worm eaten" look which is characteristic of the teeth of *Diprotodon* (Huxley 1862, p. 425) but is not as distinctly developed as in the late Pleistocene forms of this genus. A reasonably complete articulated skeleton of a small diprotodontid (P29487) was found *in situ* but lack of associated dentition and poor preservation of the skeletal material deters even tentative generic identification at the present time.

Infraclass Eutheria
  Order Rodentia
    Family Muridae

Rodents are represented by a single incisor fragment (P29415).

Sites 8, 10, 15, Rufus Formation (late Pleistocene)

Grid reference (Site 8) 434,803
Grid reference (Site 10) 436,794
Grid reference (Site 15) 485,774

Stratigraphy and Age

Overlying the Blanchetown Clay in the incised river tract of the Murray River W. of Mildura are red argillaceous sands of fluviatile origin, termed the Rufus Formation (Gill, This Memoir).

Vertebrate fossils have been found at three localities, Sites 8, 10, and 15. The bones are encrusted with a thin layer of carbonate, which is red like the matrix. The bone tends to remain white although it may have a pink tint. Many of the specimens have minute cracks which are filled with calcite.

Although a great deal of the fossil material was collected as isolated specimens, the percentage of articulated elements was high. Of particular interest are the partial skeletons of *Phascolonus gigas* (P28845, Site 10), *Procoptodon goliah* (P30776, Site 15,) and a nearly 80% complete skeleton of a large species of *Macropus* cf. *M. titan* (Site 10). The presence of this relatively large number of partial skeletons (compare with the total minimum number of individuals, see below) may be explained by their accumulation during a period of flooding, with the deposition of bloated carcases in back water areas and consequently in an environment which was congenial for immediate preservation. Kurten (1953, pp. 69-73) reported similar occurrences for local accumulations of European fossil assemblages.

On biostratigraphic grounds the age of the Rufus Formation is placed as late Pleistocene.

The presence of *Macropus siva* in the fauna from Site 10 is of special interest. This species is recorded only from its type locality in the late Pleistocene deposits of the Eastern Darling Downs, Queensland (De Vis 1895, pp. 113-114) and two specimens from late Pleistocene deposits in Mt. Hamilton Cave SW. Victoria are referred by Wakefield (1963, p. 326) to *M.* cf. *M. siva.* This species is abundant in the fossil collections from Wellington Caves in the Australian Museum (AMF47092) and it is the most abundant medium sized macropodid (P29579) in the fossil collection from the late Pleistocene dark chocolate clay beds at the Keilor Terrace archaeological site (Gallus excavation) in S. Victoria. A specimen from Lake Colongulac, Victoria (P30215) is assignable to this species.

The numbers following the generic and specific names given below represent the minimum number of individuals of each taxon from Site 10. The fauna from the three localities in the Rufus Formation is designated here as the Frenchman's Creek Fauna, the name being derived from Frenchman's Creek, which lies just S. of Site 10.

Frenchman's Creek Fauna (late Pleistocene)

Site 10

- Class Gastropoda
  - Order Stylomatophora
    - Family Camaenidae
      - *Chloritis* sp. (P30211) determined by Dr. Brian Smith.
- Class Aves
  - Order Casuariiformes
    - Fragments of large egg shells (P30210).
- Class Mammalia
  - Infraclass Metatheria
    - Superorder Marsupialia
      - Order Marsupicarnivora
        - Family Dasyuridae
          - *Dasycercus cristicauda* (1) (P29427)
          - *Sarcophilus laniarius* (1) (P28408)
  - Family Thylacinidae
    - *Thylacinus cynocephalus* (1) (P28403)
  - Order Diprotodonta
    - Family Vombatidae
      - *Phascolonus gigas* (1) (P28876)
      - *Lasiorhinus krefftii* (3) (P30212)
    - Family Macropodidae
      - Subfamily Potorinae
        - *Bettongia lesueur* (3) (P28641)
      - Subfamily Sthenurinae
        - *Procoptodon goliah* (1) (P28286)
      - Subfamily Macropodinae
        - *Onychogalea fraenata* (3) (P28651)
        - *Macropus* sp. (2) (P28640)
        - *Macropus siva* (2) (P28385)
        - *Macropus titan* (2) (P28384)
  - Infraclass Eutheria
    - Order Rodentia
      - Family Muridae
        - Subfamily Conilurinae
          - *Leporillus conditor* (1) (P30213)

Site 8

A single specimen, comprising the left ramus of *Sarcophilus laniarius* (P28404) was collected from this site.

Site 15

The partial skeleton comprising a metatarsal IV, distal end of humerus and numerous associated bone fragments (P30776) is referable to *Procoptodon goliah*. This specimen was collected by Mr. Hal Thomas at Boy Creek, Lot 22, Parish of Tulillah, Country of Millewa, on the property of Mr. J. Curtis, Karawinna, Victoria.

Site 1, Monoman Formation (late Pleistocene)

Grid reference 387,804

Stratigraphy

Grey argillaceous sands occur as superficial deposits at the site of the proposed Chowilla Dam. These belong to the Coonambidgial Formation. During excavation of Bore Hole 20, Line D and the Grout Curtain Excavation (Gill, This Memoir), a number of tree trunks were encountered at a depth of 9-11 m. One has been C14 dated at 7,200 ± 140 yr B.P. (GaK-2513). Wood from a depth of 8·3 m gave a C14 date of 4,040 ± 100 yr. B.P. (Firman 1971). At about the 9m level there is probably a disconformity (Gill, pers. comm.), below which occur well washed coarse sands to gravels extending down to a depth of greater than 24 m. These sands have been named the Monoman Formation by Firman (1967).

A portion of a right femur of *Phascolonus* cf. *P. gigas* missing the greater trochanter and distal condyles was obtained from a depth of 18·3 m in the Trial Trench for the Grout Curtain. This specimen is registered as V50 in the collection of the Geological Survey of South Australia. The same specimen had been previously identified as *Nototherium* (Firman 1971, p. 3). The greater portion of a vertebral centrum was collected from a depth of 22·3 m in the Bore Hole 20, Line D excavation. It agrees closely in morphology with the first lumbar vertebra of *Macropus ferragus* (P28568) from Lake Victoria, although the former is slightly superior in size.

On biostratigraphic grounds these sediments are tentatively placed as late Pleistocene.

Sites 7-9, Lake Victoria Sands (late Pleistocene-Holocene)

Grid reference (Site 7) 426,808-427,808
Grid reference (Site 8) 428,808-433,803
Grid reference (Site 9) 433,803-433,799

Stratigraphy

Fossil vertebrates of late Pleistocene age have been found in lunette sediments in New South Wales at Lake Victoria, Lake Tandou (Merrilees, This *Memoir*) and Lake Menindee (Tedford 1967).

Large erosion gullies transect the Lake Victoria lunette in an EW. or SW.-NE. direction. Some attain a depth of 11-12 m. They normally open only on the lakeward side and terminate in large cul de sacs toward the back or E. end.

Fossil mammals are most abundant along the NE. and N. edges of the lunette. No megafaunal species have been found along the SE. side, S. of Site 9. Fossil mammals are found in both members of the Lake Victoria Sands (for definition see Gill, This *Memoir*). In the upper member (Talgarry Sand) only living species (e.g. *Lasiorhinus krefftii, Bettongia lesueur, Onychogalea fraenata, Lagorchestes leporides, Leporillus conditor*) have been found, while both living and extinct species *(Procoptodon goliah, Protemnodon anak, P. brehus, Thylacoleo carnifex, Diprotodon optatum, Sthenurus atlas, S. andersoni, S. tindalei, Phascolonus gigas, Macropus ferragus)* are found in the lower member (Nulla Nulla Sand). The Talgarry Sand is Holocene in age while the Nulla Nulla Sand is late Pleistocene—early Holocene (Gill, This *Memoir*).

Two basic types of preservation were recognized. In the less consolidated crossbedded quartz sands most of the bone material is leached, chalky and delicate to handle. The bone is typically white, and speckled with small manganese dendrites. The more complete and articulated skeletal remains found were in this condition. Secondly, material found in the grey calcareous argillaceous layers, and as float on these layers, are typically encrusted with carbonate and sand. These specimens are usually impregnated with calcite and generally are more poorly preserved than specimens from the crossbedded quartz sands and consist largely of broken dental and podial elements.

Age

The Lake Victoria Local Fauna (see below) is composed of species which are generally recognized as representing a late Pleistocene age (Tedford 1967). A number of C14 dates were obtained on charcoal and shell samples from occupation sites of early man (see Gill, This *Memoir* for complete listing). One charcoal sample (GaK-2515) (15,300 ± 500 yr B.P.) was collected from a midden with which marsupial remains were associated. The bone material represents two dentary fragments of *Onycholgalea fraenata* (P28577, P29499). Apart from this single find, there is no evidence of a direct association of Aboriginal man with other mammal species. Several conclusions may be *inferred* from this evidence.

1. Megafaunal species and man occurred together at Lake Victoria but man did not prey on the larger forms.
2. Man did prey on the megafaunal species although no trace of this association has yet been found.
3. Megafaunal species were not contemporaneous with early man at Lake Victoria and the 18,200 ± 800 yr B.P. date (GaK-2514) (the oldest C14 date obtained on an occupation site of early man at Lake Victoria) sets a maximum date of disappearance and a minimum age for occurrance of the megafauna.

In the fossil collection from Lake Victoria 177 jaw and maxillary fragments are assignable to megafaunal species and represent a minimum number of 87 individuals. From the surrounding Lake district Blackwood and Simpson (This *Memoir*) have examined 67 Aboriginal skeletons, and numerous middens and ovens have been studied. There is no evidence of a direct association of man with the megafauna in any of these studies.

The number of individuals of both megafauna and Aboriginals examined is notably large and it would appear that had an association occurred some evidence would have been recognized. On this admittedly negative evidence the megafaunal species *appear* to have predated that of the earliest known Aboriginals at Lake Victoria, placing the age of the large Pleistocene fauna as pre-18,000 yr B.P.

There is, however, evidence that early man and the megafauna were contemporaneous in late Pleistocene time in other areas of the Murray Basin, indicating that the second inference may in fact be the most likely.

At Lake Mungo, N.S.W. (200 km E. of Lake Victoria) a human cremation was found in a level dated between 25,000 and 32,000 yr B.P. (Bowler et al. 1970). Tedford (1967) reports charred remains of the extinct macropod species *Macropus ferragus* in an Aboriginal oven C14 dated at 26,300 ± 1,500 yr B.P. at Lake Menindee, N.S.W. (240 km N. Lake Victoria) establishing association of early man with the late Pleistocene megafauna.

At the present time I am not convinced that it is possible to completely separate those specimens in the fauna which are of species represented by living forms which occcurred in direct association with the megafaunal species and those which have been added at a later date, and are thus younger in age. The type of preservation of the bone material has been relied upon heavily in sorting of the fossil material, and specimens of the living species which have carbonate encrustation and adhering sand are assumed to have occurred with the megafauna. Some of the species are definitely younger in age than the megafauna as all of the specimens referable to them lack all traces of carbonate encrustation (e.g. *Perameles bougainville, Isoodon auratus, Macrotis lagotis, Pseudomys gouldii*). The presence or absence of carbonate encrustation for each species is marked accordingly in the faunal list given below.

To add further chaos, most specimens were collected as float and because of this it was not possible to establish the exact provenance of the majority of the elements. In view of these problems I have thought it best to treat the entire fossil assemblage from the lunette deposit as representing a single fauna, including specimens from the Nulla Nulla and Talgarry Members of the Lake Victoria Sands. The age of this fauna is thus recognized as late Pleistocene-Holocene in age. I will discuss the spectrum of preservation of the specimens of each species separately at a later date.

The fossil fauna collected from the lunette sediments at Lake Victoria is here designated as the Lake Victoria Local Fauna.

Lake Victoria Local Fauna (late Pleistocene-Holocene)

The mammal species in the Lake Victoria Local Fauna are divisible into four major groups:

1. Megafauna species which are now extinct, e.g. *Thylacoleo carnifex, Phascolonus gigas, Sthenurus andersoni, S. atlas, S. tindalei, Protemnodon anak, P. brehus, Procoptodon goliah, Macropus ferragus,* and *Diprotodon optatum.*

2. Species occurring in the older late Pleistocene sediments apparently in direct association with the megafaunal species and still inhabiting the region today, or within historic times, e.g. *Bettongia lesueur, B. penicillata, Onychogalea fraenata, Lagorchestes leporides, Leporillus conditor.*

3. Species occurring in the older late Pleistocene sediments in direct association with the megafaunal species and represented by living forms not occurring in the area today, e.g. *Thylacinus cynocephalus, Lasiorhinus krefftii, Onychogalea lunata, Phascolarctos cinereus.*

4. Species present in the late Pleistocene sediments which represent larger, ancestral, Pleistocene forms of living species, e.g. *Sarcophilus laniarius, Macropus titan, Osphranter cooperi, Wallabia vishnu* representing larger Pleistocene forms of *S. harrisii, M. giganteus, O. robustus,* and *W. bicolor* respectively. A study of the relationships of the latter four lineages is in preparation. It should be noted that similar findings of "Post Pleistocene Dwarfing" have been reported for European species (Kurten 1959) and the concept of post Pleistocene dimunition in body size is regarded as representing "a general evolutionary trend" (Hooijer 1950).

The large number of browser and browser-graser species in the fauna *(Sthenurus andersoni, S. atlas, S. tindalei, Procoptodon goliah,* *Protemnodon anak, P. brehus)* suggests that the habitat in this area during at least part of lunette formation was more equable than occurs there today. It is most likely that a savanna-open woodland occurred in this area during these more equable periods.

The minimum number of individuals which would account for all of the identifiable tooth elements of each mammal species listed below was computed and is presented in Fig. 3 in the form of a Pie Diagram. This diagram expresses the relative abundance of each species represented in the collection studied from Lake Victoria *only,* and *should not be* interpreted as approximating the population structure during late Pleistocene time.

Class Pelecypoda
  Family Hyriidae
    Velesunio ambiguus

Class Crustacea
  Order Decapoda

Crayfish gastroliths. A series of 12 specimens (P30198) have a mean diameter of 12.0 mm and an overall range of 7.8-21·4 mm.

Class Osteichthyes
  Superorder Teleostei

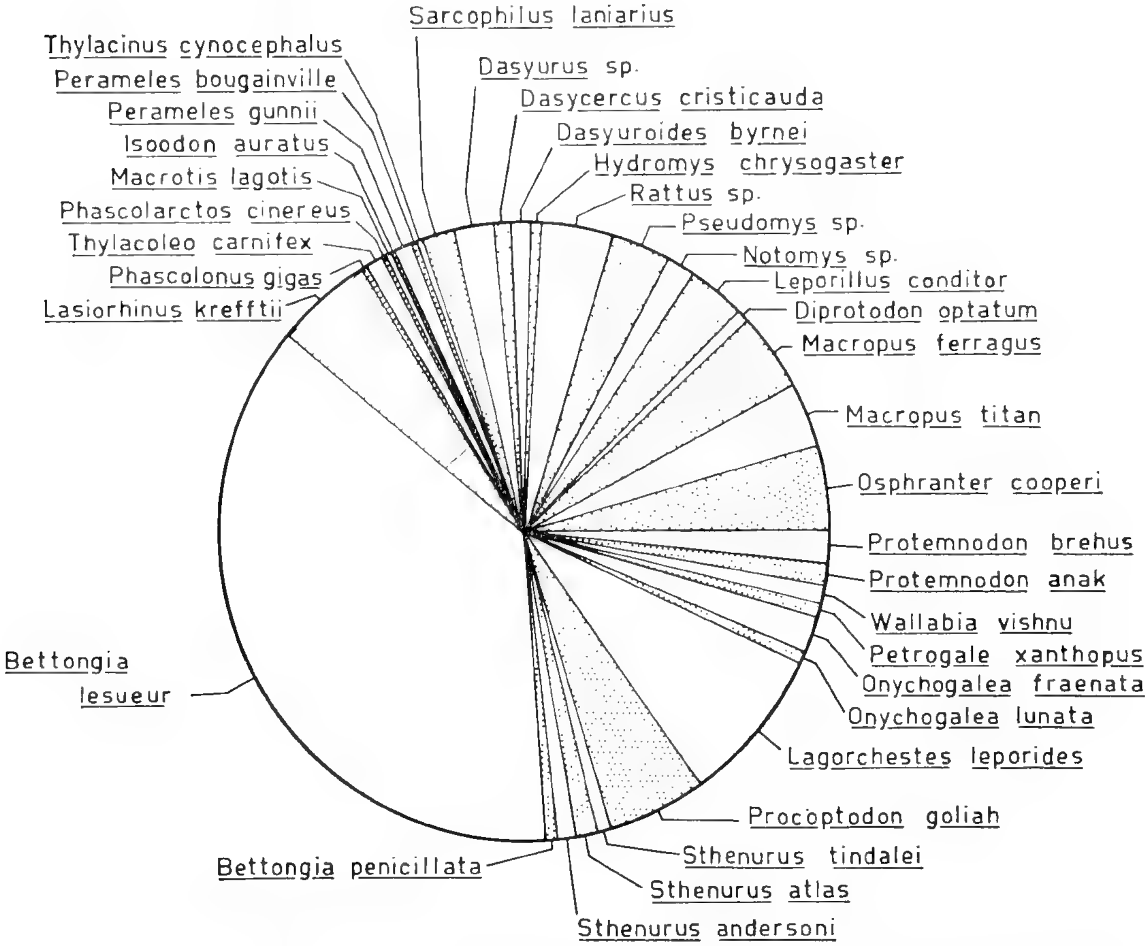

Fig. 3—Pie diagram showing the relative abundance of the mammal species collected from Site 7-9 (Lake Victoria Local Fauna) based on the minimum number of individuals that would account for all of the elements in the collection.

Numerous vertebral elements and spines of fish are represented. A series of five centra (P30200) measure: Breadth = 27·0-30·7 ($\bar{X}$ = 28·6), Depth = 22.4-24·6 ($\bar{X}$ = 23·4) these represent some of the larger centra in the collection.

Class Aves
  Order Casuariiformes

Represented by large egg shell fragments, the curvature of which suggests a size comparable to a species of *Dromaeus*.

Unidentified small humerus (P30201)

Class Reptilia
  Order Chelonia
    Family Chelyidae
      Plastron and carapace fragments.

Order Squamata
  Suborder Lacertilia
    Family Varanidae
      Varanus cf. V. varius (P30206)
    Family Scincidae
      Tiliqua rugosa (P30202)
      Very small species, genus indet. (P30205)
    Family Agamidae
      Amphibolurus cf. *A. barbatus* (P30203)
      Amphibolurus cf. *A. muricatus* (P30204)
  Suborder Ophidia

Large segment of articulated vertebrae. The head region was missing, but nearly 2 m of body was present.

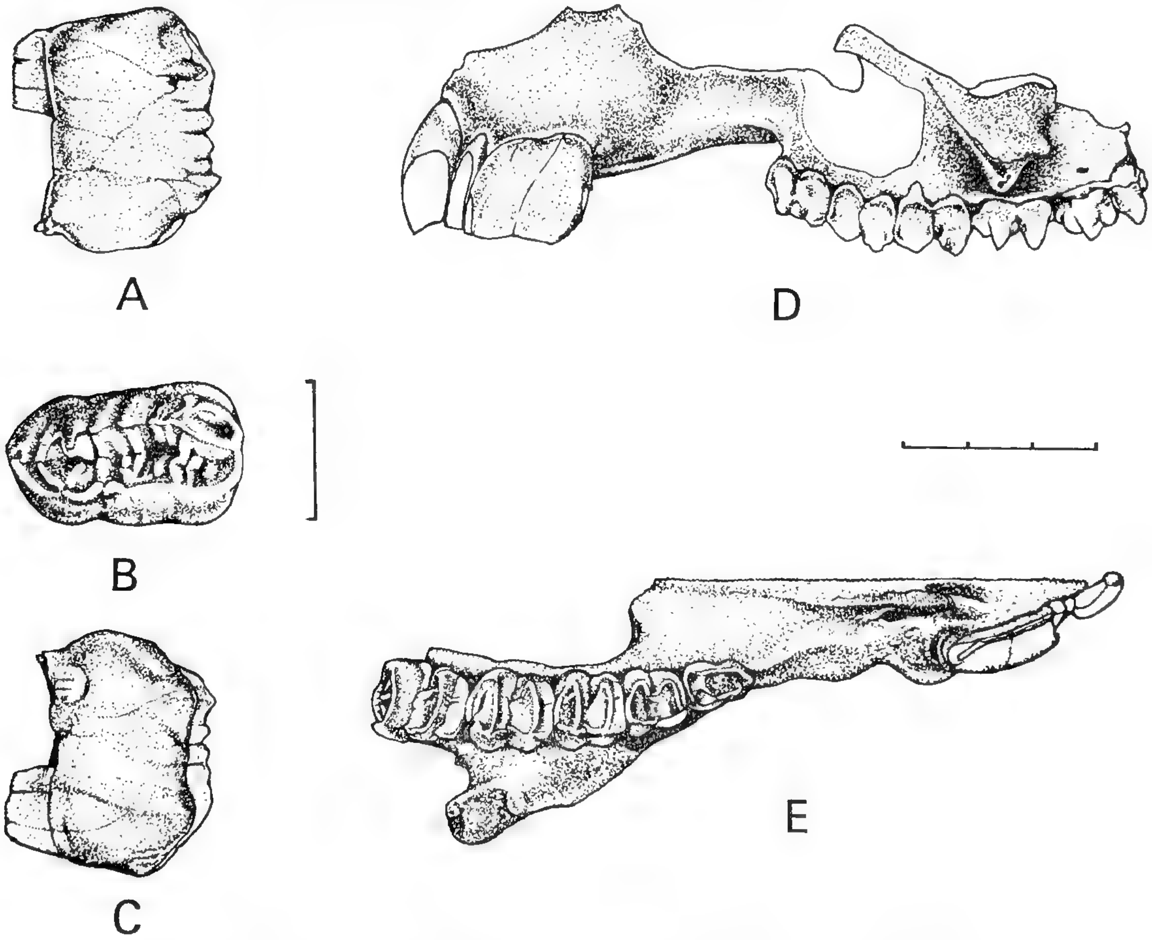

Fig. 5—*Sthenurus atlas* (P28267, Site 8). Left maxillary region with I^{1-3}, P^2, Dp^3, M^{1-3} (D-E) and extracted P^3 (A-C). A = labial, B = occlusal, C = lingual, D = labial, and E = occlusal views.

- Class Mammalia
  - Infraclass Metatheria
    - Superorder Marsupialia
      - Order Marsupicarnivora
        - Family Dasyuridae
          - § *Dasyuroides byrnei* (P28263)
          - § *Dasycercus cristicauda* (P28427)
          - § *Dasyurus* sp. (P28265)
          - ¶‡ *Sarcophilus laniarius* (P26544)
        - Family Thylacinidae
          - ‡ *Thylacinus cynocephalus* (P26573) Pl. 1, fig. 1
      - Order Peramelina
        - Family Peramelidae
          - † *Perameles bougainville* (P28851)
          - § *Perameles gunnii* (P28853)
          - † *Isoodon auratus* (P28850)
          - † *Macrotis lagotis* (P28849)
      - Order Diprotodonta
        - Family Phascolarctidae
          - * *Phascolarctos cinereus* (P28570)
        - Family Thylacoleonidae
          - ‡ *Thylacoleo carnifex* (P29485)
        - Family Vombatidae
          - ‡ *Phascolonus gigas* (P28844)
          - § *Lasiorhinus krefftii* (P30179) Pl. 1, fig. 3
        - Family Macropodidae
        - Subfamily Potorinae
          - § *Bettongia lesueur* (P28634-1) Pl. 1, fig 4
          - § *Bettongia penicillata* (P29425)
        - Subfamily Sthenurinae
          - ‡ *Sthenurus andersoni* (P28650)
          - ‡ *Sthenurus atlas* (P28267) Fig. 4
          - ‡ *Sthenurus tindalei* (P26547)
          - ‡ *Procoptodon goliah* (P28279) Pl. 3, figs. 1-4
        - Subfamily Macropodinae
          - § *Lagorchestes leporides* (P29453)
          - § *Onychogalea lunata* (P28830)
          - § *Onychogalea fraenata* (P28688)
          - * *Petrogale xanthopus* (P28768)
          - ¶ *Wallabia vishnu* (P28666)
          - ‡ *Protemnodon anak* (P28273)
          - ‡ *Protemnodon brehus* (P28660) Fig. 5
          - ¶ *Osphranter cooperi* (P28269) Fig. 6
          - ¶ *Macropus titan* (P28632)
          - ‡ *Macropus ferragus* (P28413) Pl. 1, fig. 2, Fig. 7
        - Family Diprotodontidae
          - ‡ *Diprotodon optatum* (P26542)
  - Infraclass Eutheria
    - Order Rodentia
      - Family Muridae
        - Subfamily Murinae
          - § *Leporillus conditor* (P29503-24)
          - § *Notomys* cf. *N. mitchellii* (P29506-3)
          - § *Pseudomys desertor* (P29505-6)
          - † *Pseudomys* cf. *P. gouldii* (P29501)
          - § *Pseudomys australis* (P29504-5)
        - Subfamily Conilurinae
          - § *Rattus lutreolus* (P29507-2)
          - * *Rattus* cf. *R. tunneyi* (P29508)
          - § *Rattus* cf. *R. villosissimus* (P29509-18)
        - Subfamily Hydrominae
          - * *Hydromys chrysogaster* (P28566)

* All specimens referable to these species have carbonate encrustation.

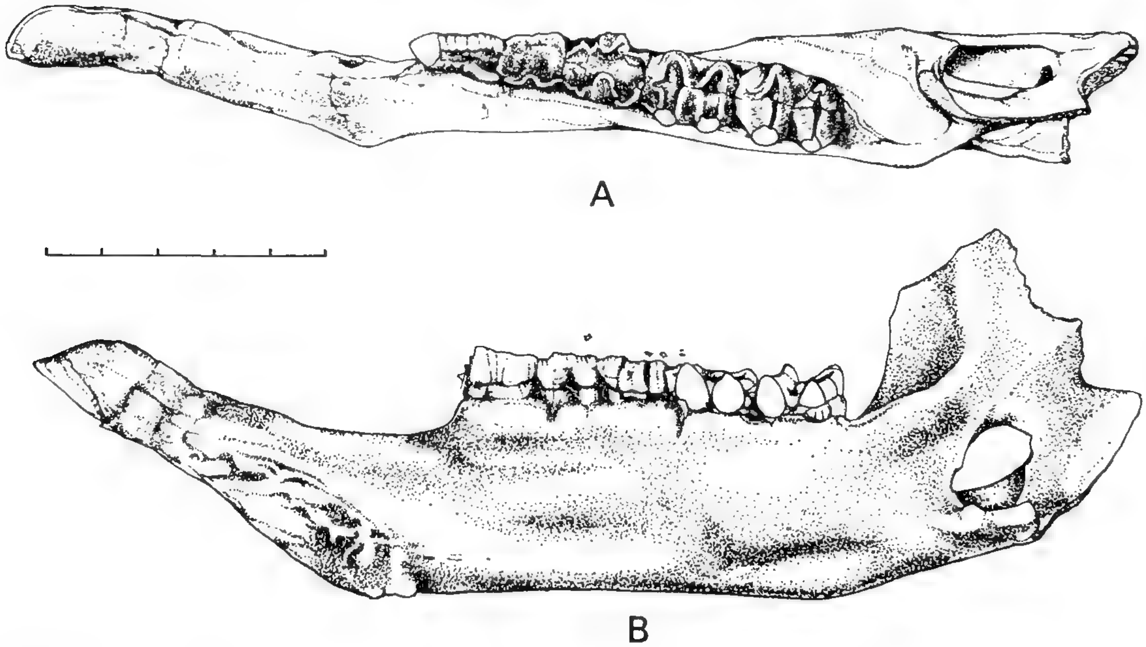

Fig. 5—*Protemnodon brehus* (P28660, Site 8). Right ramus with lower incisor, P_3 missing anterior edge, M_{1-4}. A = occlusal, B = lingual views.

† All specimens referable to these species lack carbonate encrustation.

‡ Extinct on the Australian mainland. All specimens have carbonate encrustation.

§ Some of the specimens assignable to these species lack carbonate encrustation and were probably not directly associated with the extinct megafaunal species.
They are probably no older than Holocene.

¶ Larger late Pleistocene ancestral form of living species.

Summary

Placing an absolute age on the vertebrate bearing deposits in the Lake Victoria region and correlating them directly with previously known deposits from Australia and New Guinea presents a major problem which is beyond the range of this study. It is deemed best to place these deposits and their faunas in a tentative time sequence only. The age of the faunas as based on both biostratigraphic and rock-stratigraphic grounds as determined by Gill (This *Memoir*) are in close agreement and for this reason the latter study serves as a check on the chronologies set forth here.

As presently recognized the Nulla Nulla Sand and Monoman Formation are of late Pleistocene age. The first is aeolian, the latter fluviatile. The Rufus Formation is shown by Gill (this *Memoir*) to be older than the Nulla Nulla Sand. An unconformity separates the Rufus Formation from the underlying Blanchetown Clay. The length of the hiatus is unknown although it is judged to be of considerable

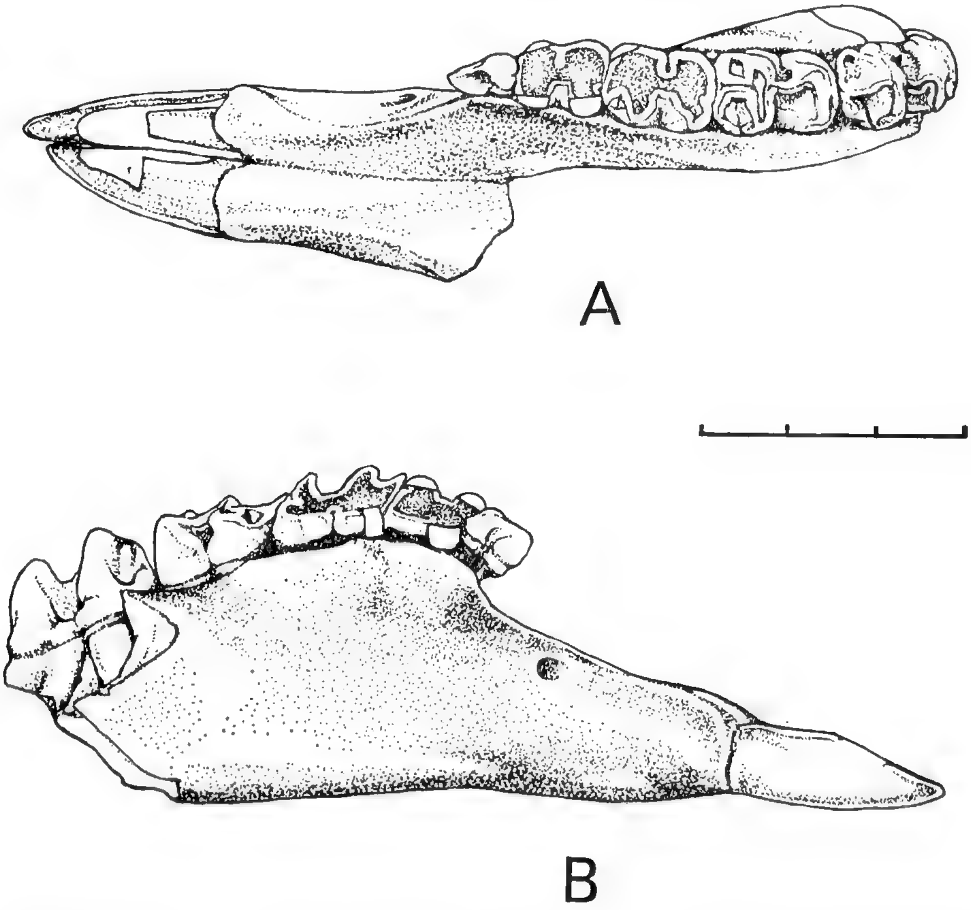

Fig. 6—*Osphranter cooperi* (P28269, Site 8). Right ramus and diastemic portion of left ramus with lower incisors, right P_3, M_{1-3}, M_4 erupting. A = occlusal view, B = labial view.

duration in the study area. The Fisherman's Cliff Local Fauna is comparable in age with the fauna from the late Pliocene or early Pleistocene Chinchilla Sand in SE. Queensland.

The Lake Victoria lunette at Sites 8-9 contains up to four paleosols separated by layers of fine to medium grained quartz sands. A basically similar stratigraphy is reported for the Lake Mungo lunette (Walls of China) (Bowler 1971). The presence of multiple paleosols indicates that a substantial period of time was involved in lunette formation. Bowler (1971) has shown that lunette formation at Lake Mungo has occurred intermittently over the past 40,000 years.

The climate during at least a portion of lunette formation at Lake Victoria was probably more equable than occurs in the area today. This is based on the presence of such woodland species as *Phascolarctos cinereus* and *Wallabia vishnu* (10% larger ancestral late Pleistocene form of *W. bicolor*) which to obtain a congenial environment in this region of the Murray River Basin today "would need the rainfall to double and the appropriate woodland vegetation to migrate westward perhaps 500 km" (Calaby 1971, p. 87). In addition, the presence of a large number of browser and browser-grazer species such as *Procoptodon goliah, Sthenurus andersoni, S. atlas, S. tindalei, Protemnodon anak,* and *P. brehus* suggests that a savanna-open woodland habitat once existed in the Lake Victoria area.

The localities and faunas described here are important because of the clear superpositional relationship of the different fossil bearing units and of the abundance and diversity of the faunas contained in them.

Comparison of Fig. 2 (this paper) with Fig. 2 in Stirton et al. (1968) will place the faunas

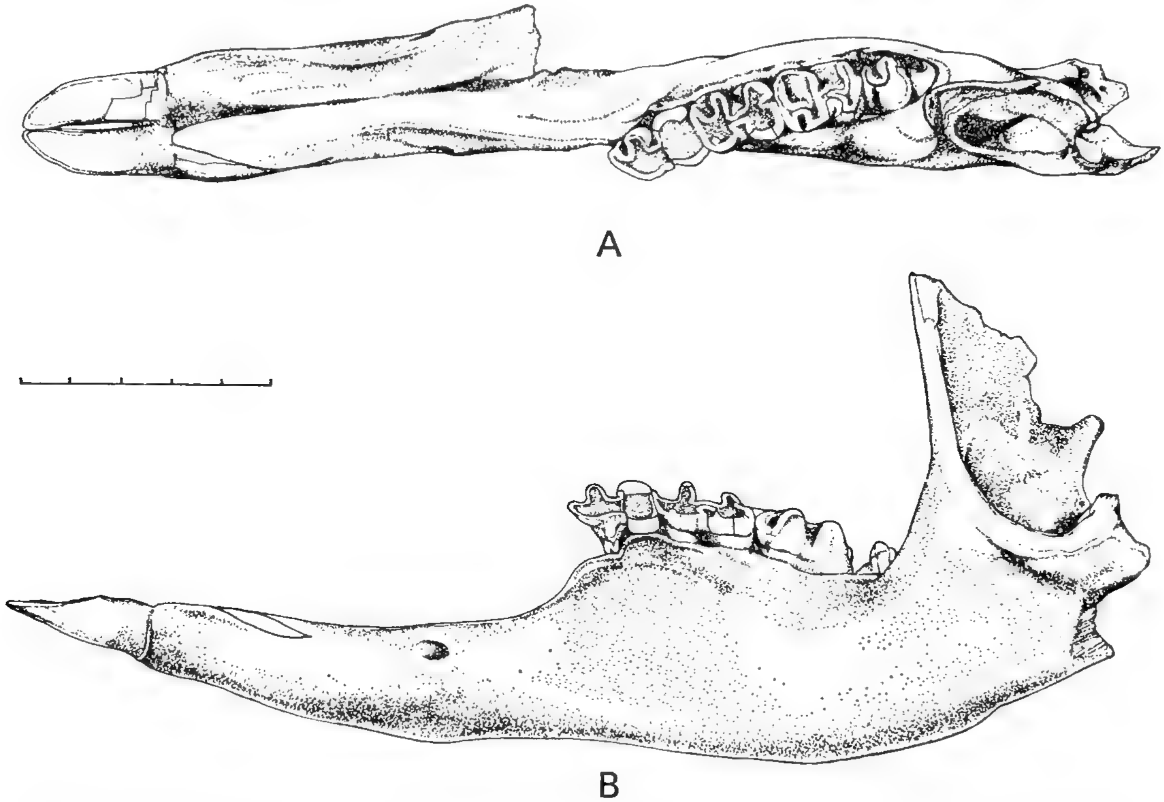

Fig.7—*Macropus ferragus* (P26537, Site 8). Left ramus and diastemic portion of right with lower incisors, left M_{1-3}, M_4 erupting. A = occlusalview, B = labial view.

discussed here in perspective with those from other Australian and New Guinea localities (also see Stirton et al. 1961).

Comments on Early Man and the late Pleistocene Megafauna

The term megafauna is *generally* applied to those large species of terrestrial vertebrates which became extinct at the end of the Pleistocene. The mammal species include *Procoptodon goliah, Sthenurus atlas, Protemnodon brehus, Phascolonus gigas, Diprotodon optatum* and *Macropus ferragus* to name just a few. There are also species in late Pleistocene deposits which represent larger forms of smaller sized living species. These were previously recognized as representing extinct species and hence included, by definition, with those species already listed. The best understood (unpublished data) of these species is *Macropus titan* which represents a 30% larger late Pleistocene form of the living species *M. giganteus,* and *Osphranter cooperi* (including as synonomies *M. birdselli* and *M. altus*) representing a 25% larger late Pleistocene form of the living species *O. robustus.*

The late Pleistocene species megafauna is thus divisible into two major components (1) extinct species and (2) species which experienced a post-Pleistocene dimunition in body size. In the latter the late Pleistocene forms seemingly become extinct, and the living forms (which are not found in direct association with the extinct megafaunal species) appear in deposits less than 20,000 yr in age, in which extinct megafaunal species are absent.

Tedford (1967) reports the charred fourth metatarsal of *M. ferragus* from an Aboriginal oven at Lake Menindee, N.S.W., establishing a direct association with early man with the megafauna. Both *M. ferragus* and *M. titan* are present at Lake Menindee (unpublished data). I have found (unpublished data) that the fourth metatarsals assigned by Tedford (1967) to *M. ferragus* and the fourth metatarsals of a *M. titan* sample from the late Pleistocene chocolate clays at the Keilor Terrace archaeological site (Gallus excavation), Victoria, are inseparable morphologically and metrically. How then does this bear upon the reported association at Lake Menindee, and for that matter associations elsewhere as well?

To base an association on forms which undergo post-Pleistocene dimunition in body size does not necessarily prove contemporaneity with the extinct members of the megafauna, as the dwarfing forms certainly outlived the extinct forms. It is apparent that an association with extinct megafaunal species must be based on one of these species and not on species like *M. titan* or *O. cooperi* which gave rise to smaller living forms. Based on this evidence, which of the species does the Lake Menindee metatarsal belong to, the extinct *M. ferragus* or the dwarfed *M. titan*? The former would establish an association of Aboriginal man with the extinct megafaunal species, the latter would not. Recognition of this problem is of primary importance in defining associations of Aboriginal man with the late Pleistocene megafauna.

Acknowledgements

As my part in this project was initiated just over a year ago, many individuals deserve credit for their generous help and guidance during preparation of this paper. Special thanks to Mr. Edmund D. Gill, Deputy Director of the National Museum of Victoria, Professor James W. Warren, and Mr. Ken Simpson of Monash University, Dr. Richard H. Tedford of the American Museum of Natural History, and Mr. Mike Archer, Western Australian Museum, for their constructive criticisms of the manuscript. For help with collections, my thanks to Sir Robert Blackwood, Mr. Tom Darragh, Curator of Fossils of the National Museum of Victoria, and Mr. Ken Bell, Assistant Curator of Fossils. Appreciation is due Dr. Richard H. Tedford, Mr. Alan Bartholomai, Director of the Queensland Museum, Mr. J. A. Mahoney, Geological Department of Sydney University, Mr. H. E. Wilkinson, Geological Survey of Victoria, Mr. Mike Archer, Dr. Jeanette Hope, Department of Prehistory, A.N.U., and Mr. M. Plane, Bureau of Mineral Resources, Canberra, for advise regarding taxonomic and biostratigraphic problems.

For their courtesy in allowing access to the study areas, my sincere thanks to Mr. T.

Honner (Moorna Station), Mr. Stephen and Trevor Hadlow (Talgarry Station), Mr. D. Harvey (Nulla Station) and Mr. R. Duncan (Dunedin Park Station). I am indebted to Miss D. Harrison for her help with the illustrations and in preparation of the photographs for publication. The line drawings were done by Miss Marion Kaighin. To the many who accompanied us on one or more of the many trips, my deepest thanks.

Addendum

The vertebrate fauna from Site 13 is presently being studied by Mr. Peter Crabb of the Zoology Department, Monash University, who began work on this fauna in May of this year (1972). In addition to the material listed in this paper may now be added 58 rodent molars, another species of dasyurid, smaller than any of the specimens discussed here, and a second species of peramelid cf. *Chaeropus.*

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Explanation of Plates 14-16

Plate 14

Fig. 1—*Thylacinus cynocephalus* (P26573). Partially excavated skeleton, in situ, Site 9.

Fig. 2—*Macropus ferragus* (P28290). Partially excavated hindlimb region, in situ, Site 8.

Fig. 3—*Lasiorhinus krefftii* (P30187). Scattered but associated dental and cranial elements, float, Site 8.

Fig. 4—*Bettongia lesueur.* Skull, in situ.

Plate 15

Figs. 1-2—*Glaucodon* cf. *G. ballaratensis* (P28684). Isolated left M^2, stereopair, Site 13.

Figs. 3-4—*Glaucodon* cf. *G. ballaratensis* (P28268). Left ramus with M_{1-4}, stereopair, Site 13.

Figs. 5-6—*Dasyuroides* sp. or *Dasycercus* sp.? (P28888). Right ramus with M_{2-4}, stereopair, Site 13.

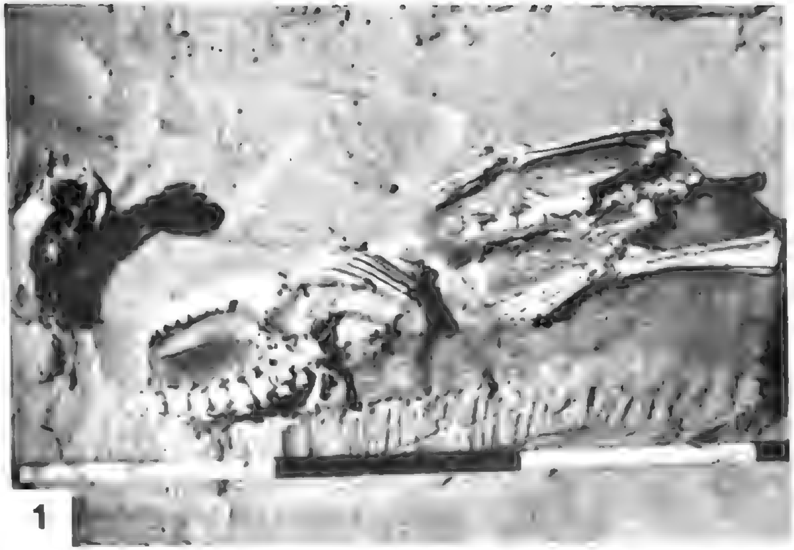
Fig. 7—*Protemnodon* cf. *P. otibandus* (P28266). Left ramus with broken P_3, M_{1-4}, labial view, Site 13.

Figs. 8-9—Peramelid (P28686). Right M^2? 8, lingual view; 9, labial view, Site 13. Note the five well developed stylar cusps.

Plate 16

Figs. 1—*Procoptodon goliah* (P28279, Site 9). Occlusal view of mandible with left and right lower incisors, P_3, M_{1-4}.

Figs. 2-4—*Procoptodon goliah* (P28861, Site 9). 2, dorsal view of left pes with metatarsal IV, metatarsal V (y), mesectocuneiform (x), cuboid, navicular, astragalus, and calcaneum; 3, medial view of same. 4, lateral view of right pes with proximal end of metatarsal IV, cuboid and metatarsal V (y). Note the reduction in metatarsal V (y) and fusion of ectocuneiform, mesocuneiform, and entocuneiform into mesectocuneiform (x). These changes result in a functionally monodactylous pes.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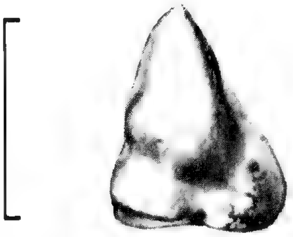
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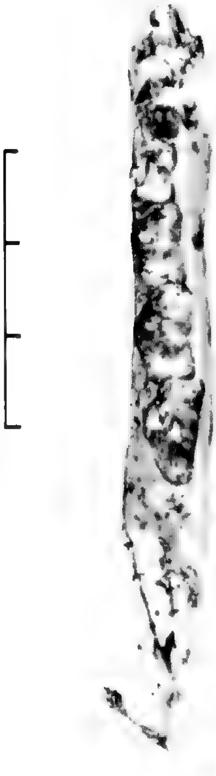
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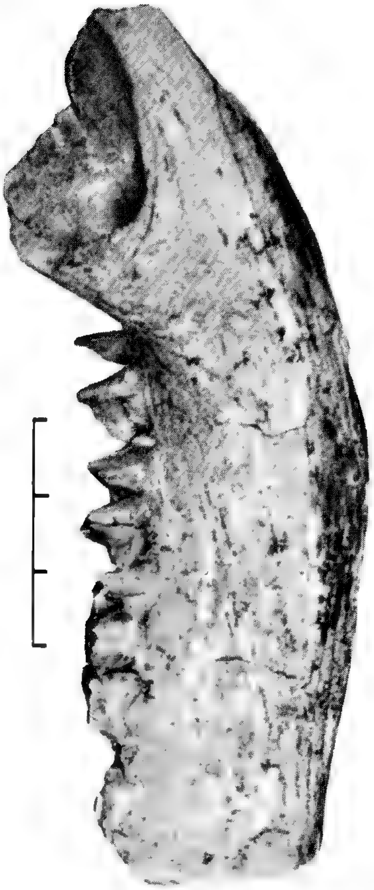
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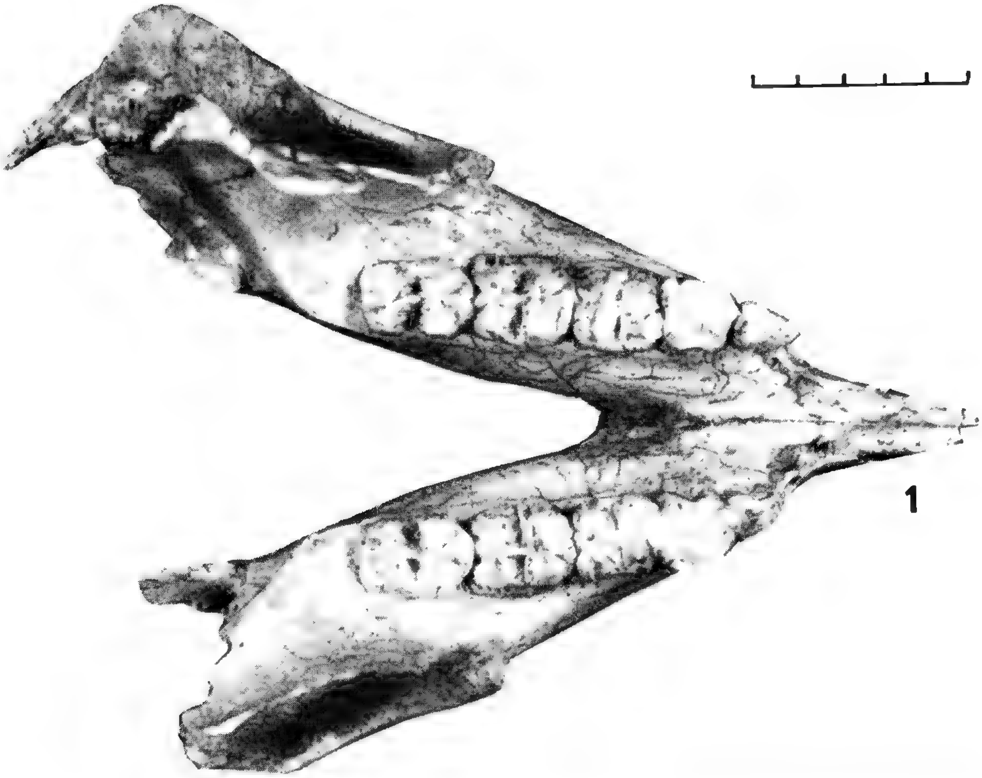

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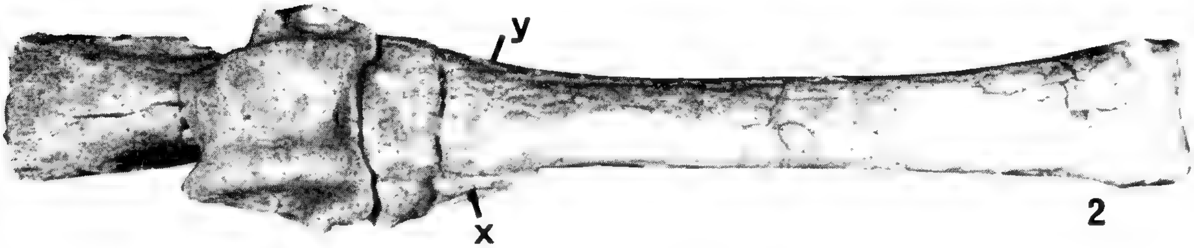

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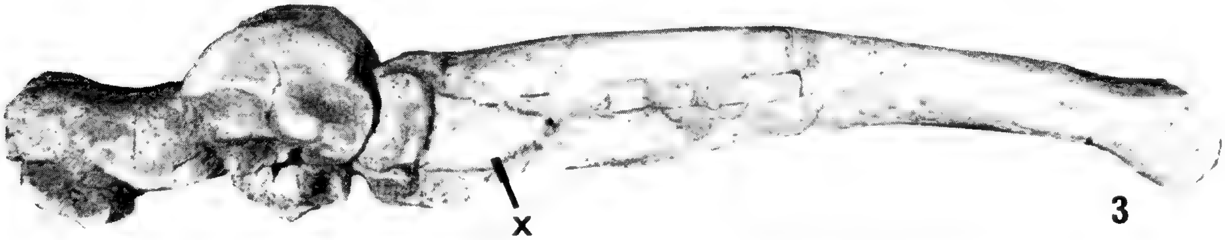

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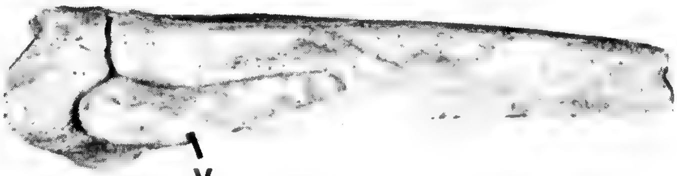

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PALAEOPATHOLOGY OF HUMAN BONES FROM MURRAY RIVER REGION BETWEEN MILDURA AND RENMARK, AUSTRALIA

By A. T. SANDISON
Senior Lecturer in Pathology, Western Infirmary, Glasgow

The skeletal material has been meticulously described (Blackwood and Simpson, this *Memoir*) and little remains to be added. Unfortunately many of the skeletons are more or less fragmented and incomplete. This makes palaeopathological study more difficult. Nevertheless, some observations may be made comparing these Aboriginal bones with those held in the Murray Black Collection of the Anatomy Department, University of Melbourne (Professor L. J. Ray), and in the National Museum of Victoria (Mr John McNally).

As in the reference collections, none of the skulls in the present series shows evidence of cribra orbitalia, parietal hyperostosis, biparietal thinning or other congenital anomaly. The skull base of skeleton 59 is markedly asymmetric, but this is probably exaggerated by postmortem distortion (Pl. 17, fig. 2). Similar asymmetry has been noted in the Murray Black Collection. Indeed, the only important congenital anomaly noted in the skeletons is fusion of thoracic vertebrae in skeletons 60 and 64 (Pl. 18, fig. 3-4). There is no evidence whatsoever that this fusion is of the acquired type due to degenerative spinal arthropathy.

There is no trace of mastoiditis, sinusitis, nor of any other recognizable inflammatory disease process. In particular, neither crania nor postcranial bones show any changes attributable to treponemal disease (trepanarid) which is a conspicuous feature of Aboriginal bones studied by me in Melbourne, Canberra, Sydney and Adelaide, although not in Queensland Aboriginal skeletons studied in Brisbane. Further there is no evidence of degenerative joint disease of the osteo-arthritic type nor of pyogenic infection of bones or joints. The tibial periosteal reaction seen in skeleton 25 is almost certainly of traumatic origin (Pl. 18, fig. 1). This is a not uncommon finding in skeletal collections from cultures of all degrees of antiquity. In contrast with the other reference collections in Melbourne there is little evidence in the present series of other trauma except for a probable healed fracture of the left clavicle of skeleton 60 sustained in early life (Pl. 18, fig. 2).

Skeleton 64 shows marked bowing of the radii (Pl. 18, figs. 5-6). This bowing of long bones has also been noted in the Murray Black Collection, The condition appears to be related to or analogous to 'boomerang tibia'. There is at present no evidence that the condition is related to trepanarid nor to malnutrition. It may well be of genetic origin.

As in the skulls held in the Murray Black Collection, and in the National Museum Collection, severe tooth wear is often evident. This is probably related to the nature of the diet, the admixture of sand or grit and possibly also to the oral manipulation of wooden artifacts. Mushrooming of the condyles of the mandibles, which is fairly frequent in the reference collections, has not been seen in the present series. Where wear has been severe it may be followed by root exposure, opening of the tooth pulps and apical infection. Some skulls show loss of teeth as in skeleton 37 where the mandible is largely edentulous (Pl. 17, fig. 3). Dental caries is *not* seen; it would appear to be very rare in undoubted pre-contact specimens of Aboriginal teeth.

Crowding of incisors as noted in the young adult skeleton 17 is not uncommon in Aboriginal skulls (Pl. 17, fig. 4). Occasionally, adventitious or impacted teeth are also noted as exemplified by that seen in the palate of skeleton 61 (Pl. 17, fig. 1). Similar observations have been made in the Murray Black

Collection and in the National Museum of Victoria.

It is probably unwise to generalize on these observations in view of the smallness of the sample and the damage and loss of bones in many of the skeletons. The dental appearances are similar to those seen in the Melbourne collections in skulls from around the Murray River with regard to degree of wear, absence of caries and minor anomalies. However, in contrast is the absence of evidence of major trauma, degenerative joint disease, pyogenic infection and trepanarid. Whether this is due to sampling or whether the group described here is in some way different will only be resolved by further skeletal collection from the area surveyed in this report.

It is intended to publish the study of palaeopathological changes in Aboriginal bones held in Melbourne and the other cities as a memoir.

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Explanation of Plates

PLATE 17

Fig. 1—Impacted tooth in palate. Skeleton 61.

Fig. 2—Congenital asymmetry of skull base, probably exaggerated by post-mortem distortion. Skeleton 59.

Fig. 3—Partially edentulous mandible, Skeleton 37

Fig. 4—Crowding of incisor teeth. Skeleton 17.

PLATE 18

Fig. 1—Tibial periosteal reaction due to trauma. Skeleton 25.

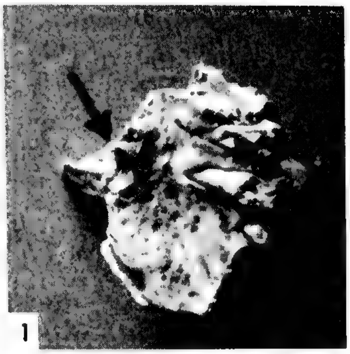
Fig. 2—Healed fracture of clavicle sustained in early life. Skeleton 60.

Figs. 3-4—Congenital fusion of two thoracic vertebrae. No evidence of acquired disease. Skeleton 64.

Figs. 5-6—Bowing of radii, probably of genetic origin. Skeleton 64.

Photographs:

Plate 18, fig. 4. Sir Robert Blackwood
Remainder, Edmund D. Gill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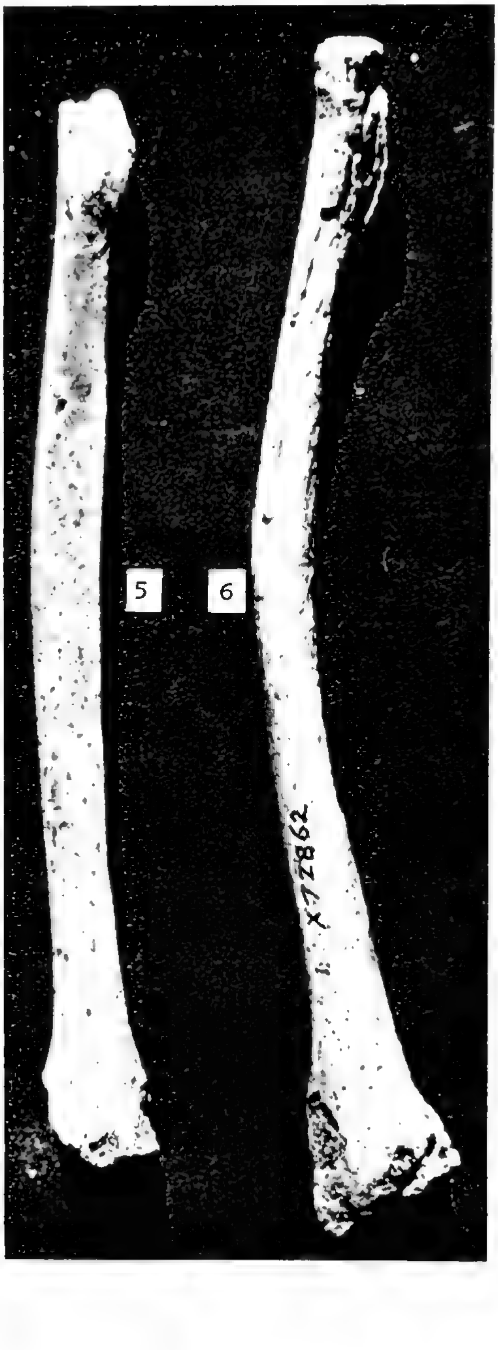
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CHEMICAL METHODS USED FOR DETERMINATION OF FLUORINE, PHOSPHORUS AND NITROGEN IN FOSSIL BONES FROM WEST OF MILDURA, AUSTRALIA

By P. J. Sinnott

Sixteen fossil bone specimens submitted in connection with the Chowilla Project were analysed for fluorine, phosphorus and in some cases nitrogen. The wet chemical methods used for the analyses are established ones which have proved successful in the chemical laboratories of the Division of Agricultural Chemistry, Department of Agriculture, Victoria, Australia.

A brief outline of the analytical methods used and their salient features are given below.

Fluorine

Fluorine was isolated from interfering elements by the Willard and Winter (1933) steam distillation technique using perchloric acid as the acid medium. The separated fluoride was subsequently determined titrimetrically with thorium nitrate using sodium alizarin sulphonate as indicator. In this laboratory, the Lange colorimeter with 100 ml cuvettes proved most satisfactory in obtaining a consistent end-point.

Phosphorus

Phosphorus was determined colorimetrically on a separate portion of sample. The sample was digested with a mixture of nitric and perchloric acids, diluted quantitatively to 250 ml in a volumetric flask and a 10 ml aliquot reacted with ammonium vanadate and ammonium molybdate reagents. The optical density of the resultant yellow solution was measured at a wavelength of 460 nm using a Beckman DU spectrophotometer. The phosphorus concentration was calculated using a standard graph. This method is a slight modification of the methods used by Kitson and Mellon (1944), and Quinlan and DeSesa (1955).

As a matter of convenience, the phosphorus content of sample Nos. 13-16 was determined by the A.O.A.C. (1970) fertilizer method, which is similar to the method already described except that the optical density is measured at a wavelength of 400 nm using the differential spectrophotometric technique (Brabson et al. 1958).

Nitrogen

Nitrogen was determined using the A.O.A.C. (1970) Kjeldahl technique, the only deviation being the use of copper sulphate as a catalyst in place of mercury or mercuric oxide.

Results of Analysis

Sample No.	Fluorine (F) %	Phosphorus (P) %	Nitrogen (N) %
1	2·27	13·4	0·019
2	1·57	9·56	0·013
3	2·53	12·3	0·007
4	0·42	7·59	0·045
5	0·30	5·89	0·041
6	0·96	14·5	0·043
7	1·07	11·0	0·020
8	0·20	10·6	insufficient sample for test
9	0·41	5·98	0·026
10	0·33	14·5	0·226
11	0·22	8·99	0·041
12	0·28	15·4	0·118
13	2·28	13·8	not determined
14	1·35	9·01	not determined
15	2·35	13·7	not determined
16	2·42	12·7	not determined

Fossil Specimens

Lab. No.	Sample No.	
11025/70	1	Bone from Blanchetown Clay, Lake Victoria, N.S.W.
11026/70	2	Bone from Moorna Station, N.S.W.
11027/70	3	Bone from Chowilla Sand, Moorna Station, N.S.W.
11028/70	4	Bone from Boy Creek, Parish of Tulillah, Vict.
11029/70	5	Bone from Rufus Formation Terrace, Dunedin Park Station, N.S.W.
11030/70	6	Bone from Nulla Nulla Sand, Nulla Nulla Station, N.S.W.

11031/70	7	Fragment of *Procoptodon goliah*, Talgarry Station, N.S.W.
11032/70	8	Bone from Nulla Nulla Sand, Nulla Nulla Station, N.S.W.
11033/70	9	Bone from Talgarry Sand, Nulla Nulla Station, N.S.W.
11034/70	10	Bone from indurated layer, Noola Station, N.S.W.
11035/70	11	Bone from Lybra Paddock, Keera Station, N.W. Victoria.
11036/70	12	Bone from Brown's Paddock, Keera Station, N.W. Victoria.
10113/72	13	*Zygomaturus victoriae*, "Lake Victoria", N.S.W., S. Australian Museum P4986.
10114/72	14	National Museum of Victoria, Reg. No. P29500. Moorna Formation, Moorna Station, N.S.W.
10115/72	15	National Museum of Victoria, Reg. No. P28882, Moorna Formation, Moorna Station, N.S.W.
10116/72	16	National Museum of Victoria, Reg. No. P29502 Moorna Formation, Moorna Station, N.S.W.

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FOSSILIFEROUS DEPOSITS AT LAKE TANDOU, NEW SOUTH WALES, AUSTRALIA

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Abstract

Fossil specimens (mainly marsupial) from Lake Tandou, lower Darling River region, N.S.W., now in the S. Australian and W.A. Museum collections, are listed. Some extinct taxa are included. They probably represent the remains of Aboriginal meals during two or more climatic episodes in late Quaternary time, mixed by deflation of a sandy matrix in which they were originally buried, by burrowing animals and by intrusive human burials. Similarly mixed stone artefacts and human skeletal remains are noted.

Introduction

Lake Tandou is one of a series of lakes, normally dry, associated with the Anabranch W. of the lower reaches of the Darling River. It is about 40 km SW. of the township of Menindee, and about 150 km N. of Wentworth, N.S.W.

The presence of fossil mammals at Lake Tandou has been known locally for many years, and was brought to the attention of the S. and W.A. Museums in 1966. P. F. Lawson (S.A. Museum) with H. Marchant and A. Warwick (who made the initial reports) visited Lake Tandou early in May 1967 for reconnaissance, and D. Merrilees (W.A. Museum) and P. F. Lawson (with the assistance of A. Warwick for part of the time) spent 11 days there also in May 1967. A short note on this visit was published by Merrilees (1968, p. 9).

Lake Tandou contains water only intermittently, and its appearance in 1967 was that of a flat grassy plain (Pl. 19, fig. 2) abruptly bounded on the E. by a sandy ridge forming, in plan, a continuous smooth curve with a N. to S. diameter of about 16 km. The W. boundary of the lake floor is less sharply defined, and is indented, so that the floor is nowhere more than about 10 km wide E. to W. The 1967 collecting party confined its attention to the E. shore of the lake.

The 1967 collection was divided between the S. and W.A. Museums. Catalogue numbers such as P 13587 and A 57340 refer to specimens in the S.A. Museum. Catalogue numbers such as 68.9.97 refer to fossil vertebrates, 68.1419 to fossil invertebrates and A 16576 to archaeological specimens in the W.A. Museum. Label data distinguish specimens from the N. (Leonora Downs Station), central (Boothingie Station) and S. (Bindara Station) sections of the area sampled.

Other collections have been made from Lake Tandou. One such is under study in the American Museum of Natural History (R. H. Tedford, pers. comm.) and another, stressing human skeletal material, in the Australian National University (H. Allen, pers. comm.). This report deals only with the S.A. and W.A. Museums collection of 1967.

Nature and Age of Deposit

The sandy ridge on E. side of L. Tandou appeared to consist of a central core of weakly lithified, pale grey to buff, fine sand overlain by and sharply demarcated from barely coherent, bright red, fine sand. Plate 19, fig. 1 shows the contact between these two deposits, and undisturbed residuals left by deflation. Between the residuals is a pale mobile fine sand, generally rippled (Pl. 19, fig. 2). The residuals may be smaller with vertical walls, or much larger than that shown in Pl. 19, fig. 1.

Tedford (1967) describes similar deposits at Lake Menindee, about 40 km NE. of Lake Tandou. Tedford suggests that the ridge bordering the N. and E. shores of Lake Menindee is a lunette (Hills 1940), that the central pale core and the overlying red sand, despite their difference in field appearance, are essentially continuous, but that the red colour of the constituent sand grains in the lower part is masked by a white carbonate cement. Tedford suggests that deposition of this cement is part of a process of soil development. Mobile sand overlying the profile is ascribed to deflation and it is recognized that several episodes may be represented by this uppermost sand.

The ridge bordering Lake Tandou presumably also is a lunette, but parts of it appear to be more complex, so that differentiation of red non-calcareous from pale calcareous sand seems to have been a recurrent process.

Bowler, Jones, Allen and Thorne (1970) describe Lake Mungo, one of a series of lakes, each bordered on the east by a lunette, and all associated with a distributary of a major river, reminiscent of Lake Tandou and Lake Menindee. At Lake Mungo three 'soil-sedimentary' units are described, the sequence capped by mobile sand. Bowler (1970) describes two 'major stratigraphic units' in the lunette bordering Lake Nitchie, S. of Lake Tandou. More detailed stratigraphic studies may reinforce the superficial similarities of the Tandou, Menindee, Nitchie and Mungo lake sites, and reveal recurrent soil formation both at Lake Menindee and Lake Tandou.

Nearly all the fossils recovered from Lake Tandou in 1967 were found lying on eroded surfaces in the middle of the lunette. A few (e.g. 68.9.99) were found *in situ* in lithified grey to buff sand and one or two (e.g. P 13980) in red sand. Most of the specimens had a partial coating of matrix of the order of 1 mm thick. Often this matrix preserved the original articulation of one bone with its contiguous bones in a limb or vertebral column e.g. P 13531. The cement was calcareous. Thus it appeared that nearly all the specimens from the lunette had been embedded in fine sand before lithification, and that many of them had been buried in an articulated condition.

Despite search along the flanks of the lunette, including many water cut channels in the lakeward flank, very little fossil or artefactual material was recovered. Some search was made also on the vegetated seif dunes E. of the lunette, but very little material was found (71.9.44 is an example). However, artefacts (including one made from a large australite) have been found in Redbank Creek, the outlet from Lake Tandou (H. Marchant, pers. comm.).

By contrast, it was rare to walk more than a few metres over eroded lunette surfaces without seeing some scrap of bone or other fossil material, but there appeared to be local concentrations. One such local concentration of mussel shells is shown in Pl. 19, fig. 2. Within each local concentration, the material was usually very heterogeneous, with bettong and wombat bones generally predominant, together with bones of macropodine and other marsupials, reptiles, murids (not in abundance), and fish, egg-shell fragments, shells of fresh water mussels, gastroliths of crustaceans, artefacts (including balls of baked clay), coprolites (e.g. P 14090, 71.9.50) and fragments of human skull and teeth. Charred bettong, fish and other bone fragments not readily identifiable were found occasionally, e.g. P 14092-3, 67.7.3, 71.9.39.

Charring of some bone specimens, the presence of balls of baked clay (probably the linings of cooking pits, cf. Mitchell 1949), the heterogeneity of most of the local concentrations, with remains of aquatic and terrestrial animals ranging from very small to very large size, and direct evidence of human presence in the area suggest that man was the major agent accumulating the animal remains at Lake Tandou.

An occurrence of bone and other remains on bare eroded sand surfaces at Bremer Bay, W. Australia, is described by Butler and Merrilees (1971) but here the major accumulating agent appears to have been owls (possibly only one owl) because the bones were small, predominantly of murids, generally unbroken, and aquatic animals were very sparsely represented although a river and the sea lay within a few hundred metres. None of the bones was charred, and no artefacts or human skeletal remains were found.

Both at Bremer Bay and Lake Tandou the main mode of accumulation appears to have been supplemented. At Bremer Bay, natural deaths on the site, bone débris left by scavenging animals such as foxes or ravens, and bony fragments from the disintegration of carnivores' faeces, appear to have been added. At Lake Tandou, all three agencies appear to have operated, and other factors also appear to have complicated the accumulation.

Deflation seems to have reduced the original level of the lunette up to 20 m at Lake Tandou but by less than 1 m at Bremer Bay. Thus a square metre at Lake Tandou would have received the fossil content of a much larger volume of matrix than at Bremer Bay, and the fossils on the Lake Tandou surface might represent more than one depositional episode. Burrowing by wombats, bettongs and perhaps other animals, and intrusive burials by man, may well have mixed further the fossils from different stratigraphic units at Lake Tandou.

Thus the fossils (listed below) collected at Lake Tandou in 1967 probably represent in the main refuse from Aboriginal meals, mixed with contributions from natural deaths and scavengers, and all further mixed by burrowing and human burials, and by differential deflation. Apart from the remains of rabbits, cats, sheep and such exotic fauna, the geological age of the fossils remains unknown, but by analogy with Lake Menindee (Tedford 1967) and Lake Mungo (Bowler et al. 1970) falls late in the Quaternary.

Because the material collected in 1967 may include remains deposited at different times and under different climatic conditions, neither taxonomic nor climatic inferences from it are made. However, with detailed stratigraphic study of the lunette, and study of the matrix encrusting many of the specimens, decisions on their provenance and age might be feasible in many cases, so permitting such inferences. Bone from exotic animals such as cat often has a different appearance from that of extinct animals, and a few specimens of such modern bone (71.9.68-70) have been kept for reference.

Fauna

The following indigenous taxa have been recognized:

EUTHERIANS

Hydromys sp.—P 13659, 68.11.92-93

Leporillus conditor—P 13570-77, 68.11.94, 68.11.95x, 68.11.96, 68.11.98-101

Other pseudomyines—P 13587-91, P 13593-95, 68.11.113-116

Rattus lutreolus—P 13567, P 13584, 68.11.95y, 68.11.102, 68.11.104

Rattus sp. (*lutreolus*?)—P 13568, P 13578-80, P 13582-83, P 13585-86, P 13592, 68.11.97, 68.11.103, 68.11.105-109, 68.11.112

Rattus sp. (not *lutreolus*)—P 13581, 68.11.95, 68.11.110-111

MARSUPIALS

Dasyurus (*geoffroii* or *viverrinus*)—P 13258-30, 68.9.81

Dasycercus cristicauda—P 13538-42, 68.9.91-96

Sarcophilus harrisii—P 13532-36, P 13910, 68.9.84-85

Sarcophilus laniarius—P 13537, 68.9.86

Thylacinus (probably *cynocephalus*)—71.9.5

Macrotis lagotis—P 13531, 68.9.82-83

Isoodon (*obesulus*?)—P 13527, 68.9.80

Trichosurus (*vulpecula*?)—P 13526, 68.9.86a-88a

Lasiorhinus krefftii—P 13445-13525, P 1309-10, 67.11.1, 68.6.130-279, 71.9.72, 71.9.86-88

Large wombat (*Phascolonus gigas*?)—P 13977-78, 71.9.32

Bettongia penicillata—P 13980, 71.9.36

Bettongia lesueur—P 13907, P 13981-14013, P 14015-23, P 14025-59, P 14061-67, P 14069-73, P 14075-80, P 14082-89, 68.10.2-19, 68.10.22-25, 68.10.34, 68.11.133-161, 68.11.171, 68.11.182, 68.11.184, 68.11.189-190, 68.11.196-201, 68.11.203-210, 71.9.34-35, 71.9.37-39

Onychogalea lunata—P 13556, 68.9.106-110

Onychogalea fraenata—P 13555, P 13559-61, 68.9.112-116

Onychogalea (*lunata* or *fraenata* or both)—P 13553-55, P 13557-58, P 13562-65, 68.9.111, 68.9.117-121

Lagorchestes (*hirsutus* or *leporides* or both)—P 13543-52, 68.9.97-105, 71.9.49

Large wallaby (*Macropus agilis* or *Wallabia bicolor*)—P 13566, 71.9.30

Protemnodon A (*anak*?)—(P 13972?), 71.9.31
Protemnodon B (*brehus*?)—P 13911, P 13971, P 14109, 71.9.18-19
Megaleia rufa—P 13974
Macropus A (*fuliginosus*?)—71.9.25
Macropus B (*birdselli*?)—P 13973, 71.9.23
Macropus C (*titan*?)— P 13909a
Macropus D (*ferragus*?)—P 13970, 71.9.24
Procoptodon goliah—P 13908, P 13912a and b, P 13975-76 (71.9.6-16? 71.9.21?)
Diprotodon optatum—(P 13979?), 68.9.90

MONOTREMES

Tachyglossus aculeatus—P 14094-5, 71.9.71

LOWER VERTEBRATES

Birds—P 14096-7, 71.9.73-75
Lizards—P 14098-9, 71.9.80-81
Snake—P 14100, 71.9.76-79
Fish—P 14101-5, 71.9.82-85

INVERTEBRATES

Freshwater mussels—68.1412-15
Crustacean—P 14106-8, 71.1429-32
(Insect pupal case?)—71.1434

By far the most abundant remains were those of bettongs (at least 90 individuals) and wombats (at least 30 individuals). *Bettongia lesueur* contributed the overwhelming majority of the bettong remains, and the specimens listed above are those with the diagnostic premolar teeth. In addition many specimens showing only molar teeth, and some post-cranial remains, probably are attributable to *B. lesueur*. Remains of only two individuals of *B. penicillata* were found, but one of these specimens (P 13980) was among the most complete of any of the associated skeletal remains collected, obviously representing a carcase which had escaped dismemberment. In most other cases in which associated portions of skeletons were found, it appeared that the carcase concerned had been partially dismembered before burial.

Protemnodon specimen 71.9.18 comprises a rostrum, most of the mandible, most of the pelvis and the shaft of a tibia found in such close proximity as to be reasonably interpretable as parts of the same individual. Like the specimen described by Tedford (1967 p. 104) the pelvic portion of 71.9.18 is 'badly checked and broken' and only the central part of the right innominate bone could be pieced together to form a useful comparative specimen.

However, unlike Tedford's specimen, this includes a complete acetabulum, showing that the acetabulum in *Protemnodon* is slightly more elongated than that of *Macropus fuliginosus*. In 71.9.18 the ratio of greatest diameter of acetabulum to 'least diameter' (measured at right angles to the greatest diameter and crossing the acetabular fossa) is 1·28 as compared with 1·25 for this ratio in a large modern *Macropus fuliginosus* (W.A. Museum M 3328). In *Macropus eugenii* specimen M 6860 this ratio is 1·43.

The tibia of 71.9.18 is badly cracked and lacks both proximal and distal epiphyses. Nevertheless it shows that *Protemnodon* like modern *Macropus eugenii* had a relatively shorter tibia than modern *Macropus fuliginosus*. In the specimens mentioned in the previous paragraph, the ratios of length of the last three lower molars to greatest diameter of acetabulum are comparable (0·89 for *Protemnodon*, 0·90 for *M. eugenii*, 0·86 for *M. fuliginosus*) suggesting that head and body proportions were similar, but the ratios of length of tibia to greatest diameter of acetabulum (120 for *M. fuliginosus*, 95 for *M. eugenii* and an estimated 100 for *Protemnodon*) show that *M. fuliginosus* had relatively longer legs than the other two species.

A second species of *Protemnodon* appears to be represented at Lake Tandou, some 12% smaller than 71.9.18 in tooth dimensions. There has been no recent review of the species of *Protemnodon*, and the Lake Tandou specimens are referred only provisionally to *P. brehus* (the larger species) and *P. anak*.

All the small wombat specimens collected in 1967 are listed above under *Lasiorhinus krefftii* because there is no reason to suspect that any other wombat species of comparable size was present, but many of these specimens are fragmentary and strictly speaking not identifiable to species.

Mr H. E. Wilkinson has kindly supplied the following comments on the more complete specimens from the 1967 collection and other material currently under study by him:

'*Lasiorhinus* specimens collected from Lake Tandou are very similar to those from other localities in the Murray-Darling Basin, including Lake Menindee, and Lake Victoria, and it is clear that they are part of a wide Late Pleistocene to Early Recent distribution, which extended from S.E. Queensland through inland N.S.W. into N. Victoria. The species involved is *Lasiorhinus krefftii* Owen 1872, of which *Lasiorhinus gillespiei* De Vis 1900 is a junior synonym. The species is known to have been living in parts of the N.S.W. Riverina Plains at the time of European settlement, as well as on the Moonie River in Queensland, type locality for *gillespiei*. The type locality for *L. krefftii* is Wellington Caves, and a study of casts of Owen's types and *Lasiorhinus* specimens from the caves, has convinced me that Owen was mistaken in recording *latifrons* from there, and that he confused some of the *krefftii* and *mitchelli* mandibles.

'The confusion is understandable, as *krefftii* has some features which are normally thought of as being *Vombatus* characters, the one which led Owen astray being the presence on many *krefftii* mandibles of a very, to moderately, deep masseteric fossa. In addition, many have a well-developed groove on the upper premolar, and the nasals have a length greater than their combined width. The antero-buccal inflection characteristic of *latifrons* molars is poorly developed in this species, and is confined to M2 and M3 if present. The differences shown by dentition and cranial morphology are amply supported by studies of the post-cranial skeleton, and these also reveal affinities with *Vombatus*. A full description of this species is being prepared, based principally on the material collected at Lake Menindee by the University of California.'

Artefacts and Human Skeletal Remains

Stone artefacts lay scattered in abundance on bare eroded surfaces in the Lake Tandou lunette, and like the faunal remains, probably consisted of a mixture of items let down by deflation from higher parts of the deposit, and items left lying on occupied surfaces and revealed by erosion.

Surface collections of stone implements were made largely from Lake Tandou, but also from Lake Menindee, to which a brief visit was made. The collection was returned to Adelaide, sorted, and divided between the S. and W.A. Museums by the late H. M. Cooper. The S.A. material was registered under A 57339 and A 57340, and the W.A. material under A 17066-88 and A 17094-98. The S.A. Museum share has been examined by G. L. Pretty and the W.A. Museum share by C. E. Dortch, and their comments follow. In each case, material from both Lake Tandou and Lake Menindee is treated as a single sample.

S.A. Museum Collection

This consists largely of scrapers made from cores and flakes with both steep and shallow retouch. The general form of the edge can be divided into discoidal (probably for wood working—planing and shaping of wood), grossly dentated (probably for gouging and graving), or having a relatively straight edge (probably for use as knives when even and saws when dentated). Horse-hoofs (Bowler et al. pp. 49, 51) are represented by a single, small, broken specimen. Hammerstones and points are also represented. Finally, there is a small group of campsite débris—burnt mud hearthstones and freshwater molluscs. The stone from which the implements are made is mostly silcrete, with some chert and milky quartz.

The general characteristics of the assemblage conform to the description given by Tindale (1955) for Lake Menindee. The same range of industries as Tindale describes would seem to be present. The industry discovered at Lake Mungo (Bowler et al. 1970) would appear to be an early phase of this same industrial succession and certain items of this present assemblage parallel those described for Mungo. Radiocarbon dates for both localities would seem to support this correlation (Bowler et al. 1970, p. 57).—G. L. Pretty (pers. comm.).

W.A. Museum Collection

This consists of flake scrapers of varying proportions (flat, thick, and core-like) and edge contours (nosed, notched, irregular and rounded). There are also some crude adzes and a typical horse-hoof core. Other implements include unifacially retouched points of the pirri type, a backed blade, several millstones and hammerstones, and a number of retouched flakes. There are no geometric microliths, and the single backed blade is atypical (C. E. Dortch, pers. comm.).

Skeletal material consisted mainly of small fragments of skull and isolated teeth (e.g. W.A. Museum A 16573-76), suggesting that the site had been used extensively as a burial ground, and that deflation had released, and allowed to become scattered the component bones of buried human bodies. In one case in which some detail could be observed, it appeared that the body had been buried in a kneeling position.

Despite the apparent profusion of animal remains at Lake Tandou, they do not imply very long occupation by or very large groups of human beings. As a first approximation, one might accept 1 bettong as equivalent to 1 meal for a human being, and the 1967 collection listed above as representing about 300 'bettong-equivalents' or meals. This represents only about two months' occupation (if continuous) by a family group of five persons assuming they also ate much plant material. Not all the fossil specimens seen were collected, and probably not all represented remains of human meals, so it is not feasible to decide whether shorter occupation by a larger group of persons fits the evidence better than the rough estimate above.

Relatively little material was found in situ at any level in the Lake Tandou lunette, but among it was mussel shell at the lowest stratigraphic level observed. Presumably this shell was transported from the lake nearby in the same way as shell found at higher stratigraphic levels. Thus it appears that man was present during the whole of the time of accumulation of that portion of the lunette stratigraphically observable in 1967, i.e. nearly all of it.

Acknowledgements

I am grateful to those named in the text as having supplied information, to Messrs M. Archer and A. Baynes for identification of small dasyurid and murid specimens respectively, to Mr P. F. Lawson for companionship in the field, to Mr A. Warwick for his hospitality and help in the field, and to Messrs Heuzenroeder, Farrar and Packer for permission to collect from their properties.

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Explanation of Plate 19

Fig. 1—Contact between upper red weakly lithified and lower pale buff more lithified sands at Lake Tandou, N.S.W., indicated by figure. The two sands are probably the A and B horizons of a single soil profile. The grassed surface may represent an intermediate phase in the degradation of the lunette.

Fig. 2—Concentration of freshwater mussel shells on wind-rippled surface of mobile sand, Lake Tandou. Scale from hammer. Dry bed of lake in background.

FOSSIL POLLEN FROM KULCURNA STATION, CAL LAL, SOUTHWEST N.S.W., AUSTRALIA

By D. M. Churchill
Monash University

Three samples were submitted for pollen analysis by Mr. E. D. Gill in 1969, and were processed in the "clean-air" Palynological Laboratory at Monash University. The slides with the pollen residues are housed in the slide collection of the Botany Department, Monash University, Melbourne, Victoria.

The provenance of each sample is as follows:

Sample 1. CHG-78. Gray clayey sand from base of "Homestead Cliff", Kulcurna Station, N.S.W., Site 3. Coll. 26 April 1968. Parilla Sand.

Sample 2. CHG-80A. Clay from thin band on E. bank of Salt Creek at S. end where Blanchetown Clay lenses out into Chowilla Sand, Kulcurna Station, N.S.W., Site 2. Coll. 26 April 1968.

Sample 3. CHG-80B. Black clayey sand from thin band in middle of "Homestead Cliff", Kulcurna Station, N.S.W. Site 3. Coll. 26 April 1968 from near homestead windmill. Top of Parilla Sand below Chowilla Sand.

The amount of pollen in Sample 2 was very low, and no pollen was found in samples 1 and 3.

The quantitative analysis of pollen when it is present in small amounts is tedious, and very expensive reckoned in man-hours. Further counting seemed unlikely to yield any significant change in frequency. The frequency of occurrence of pollen grains in sample 2 is listed below.

	No. of grains counted
Eucalyptus	58
Callitris sp.	13
Chenopodiaceae	13
Poaceae	1
Cyperaceae	1
Asteraceae	11
Plantago sp.	1
Rumex sp.	1
Acaena sp.	1
	100

Sporomorphs present in sample in frequencies less than 1% but seen on scanning through the slides, include:

Casuarina sp.
Grevillea sp.

Some of the eucalyptus pollen is similar to *E. camaldulensis* and some is similar to *E. largiflorens.*

The high chenopod to grass ratio indicates a saline marsh flat rather than chenopod shrub steppe. The presence of *Plantago, Rumex* and *Acaena* with high compositae is compatible with this interpretation.

No *Leptospermum* or shrub Myrtaceae pollen grains were found. This indicates an open understory with little myrtaceous scrub.

In conclusion, the pollen evidence indicates vegetation, comprising mixed *Eucalyptus-Callitris* woodland flanking a samphire marsh.

FINE SEDIMENTS FROM THE MURRAY RIVER REGION BETWEEN MILDURA AND RENMARK, AUSTRALIA—POSSIBLE TECHNIQUES FOR IDENTIFICATION

By G. D. Aitchison

Chief, Division of Applied Geomechanics, C.S.I.R.O.

In this study of fine textured sediments which may be characteristic of alluvial or lacustrine deposits (as encountered widely in the proposed Chowilla Dam inundation area) it is not an easy matter to identify and/or to differentiate between some of the strata. The normal visual and tactile observations available to the geologist or pedologist are relatively insensitive to changes of clay content or of type of clay mineral within groups of materials dominated by the clay fraction.

During a brief excursion to the region in company with Mr E. D. Gill, it was noted that a great deal of observational and deductive effort was required to define the clayey members of the stratigraphic sequence at various exposure sites. No simple techniques appeared to be available to characterize such strata. It was suggested, therefore, that there could be some possible value in the adaptation for this purpose of some of the simple identification tests used by engineers in the characterization of clays, particularly expansive clays.

Two separate samples were provided by Mr Gill for comparative study, viz. 1: Mottled Blanchetown clay from Murray R. cliff at Yelta, Victoria; 2: Olive gray Blanchetown clay from section at turn in Murray R. c. 800 m. N. of Moorna Station homestead, W. of Wentworth, N.S.W. Both samples were subjected to a limited range of tests defining firstly composition in terms of particle size and nature of clay mineral; and secondly 'index' properties as expressed by plasticity and sorptivity tests. The test data are recorded in Table 1 and 2 below.

TABLE 1—Compositional Data

Sample	Yelta Cliff (Vic.)	Moorna Station (N.S.W.)
Description	Red Sandy Clay	Gray Sandy Clay
Size Fractions	%	%
Sand (> 20μ)	35	5
Silt (2μ to 20μ)	8	4
Clay (< 2μ)	57	91
Clay Minerals in < 2μ fractions		
Dominant Mineral	Montmorillonite	Montmorillonite
Sub-dominant	Kaolinite	Kaolinite
Trace	Illite	Illite

TABLE 2—Index Tests

Sample	Yelta Cliff	Moorna Station
Description	Red Sandy Clay	Gray Sandy Clay
Atterberg Limits		
Liquid Limit	45	91
Plastic Limit	20	35
Plasticity Index	25	56
Sorption Limit (Water content at 20% relative humidity)	2·70	4·61

Although the size fractions in Table 1 indicate a significant difference between the two samples, it is not suggested that a particle size analysis would provide a sensitive basis for differentiation. Such an analysis, in any material dominated by the montmorillonite clay mineral, is highly susceptible to errors arising from slight variations of technique. Furthermore, any such type of analysis in such materials tends to be unduly sophisticated if regarded merely as a means of sample identification.

The Atterberg Limits given in Table 2 involve simpler techniques and are somewhat less susceptible to serious errors. Such index test values, when plotted as in Figure 1, do provide a moderately sensitive means of characterization of a material. Highly active clays tend to

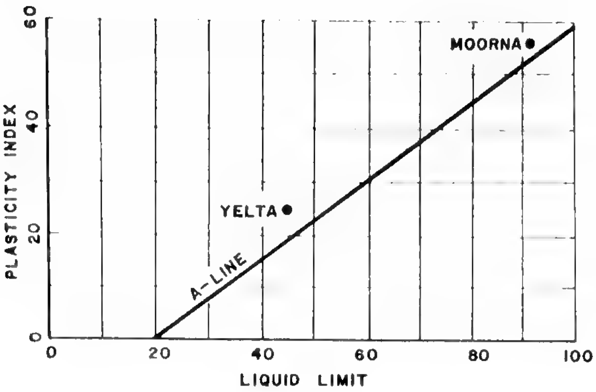

Figure 1

SORPTION LIMIT	<I	I-2	2-3	3-4	4-5	75
TYPE OF CLAY SOIL	RELATIVELY UNREACTIVE	LOW-MODERATE REACTIVITY		HIGH-VERY HIGH REACTIVITY		EXTREMELY REACTIVE
TEST VALUES			2·70 ● YELTA		4·61 ● MOORNA	

* The Sorption Limit is the Water Content (expressed as a percentage of the oven dry weight of the soil) retained in equilibrium with an atmospheric relative humidity of 20 per cent.

Figure 2

plot above the A-line in Figure 1 while less reactive clays fall on or below the A-line. The data of Figure 1 suggest that both clays are of a similar highly reactive type. The Moorna sample has a much greater overall reactivity due presumably to a higher clay content.

The Sorption Limits also given in Table 2 tend to provide a remarkably sensitive and extraordinarily simple means of characterization of clays. Figure 2 reflects the normal spectrum of values of the Sorption Limit. Within this spectrum the Moorna Station clay is shown to have a value approaching the upper limit of the range of activity while the Yelta cliff clay appears as a much less active material.

It is suggested, therefore, that the Sorption Limit test may be of value in the identification of fine textured materials. Although the test cannot be performed in the field, the simplicity of both apparatus and procedure should permit its adoption in any geologic or pedologic laboratory.

OPALINE SILICAS FROM THE MURRAY RIVER REGION WEST OF WENTWORTH, N.S.W., AUSTRALIA

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A variety of opals and opaline silicas were encountered in the area (Gill, this *Memoir*). They ranged from fine-grained earthy materials to typical glassy opals. There was considerable variation in their manner of occurrence, which reflected differences in the genesis of the various types of opal. The characteristics of the following samples are described in some detail.

1. *Grey-green translucent opal* occurring in the upper layers of the dolomite bed at Devil's Elbow, Nampoo Station. This is a typical, often glassy, opal, uniform in colour. It occurs as concretions and nodules with a white outer skin. In places it passes into the white opal.

2. *White opaque opal* occurring closely associated with the grey-green opal in the upper layers of the dolomite.

3. (a) *White opal breccia* occurs as a band up to 1 m thick above the dolomite at Devil's Elbow, Nampoo Station. This material consists of angular fragments of white opaque opal from 2 cm down to sand size recemented to a massive breccia.

(b) *Brown opal breccia* forms a band up to 0·5 m thick at the base of the dolomite at Devil's Elbow. It consists of closely packed fragments of iron-rich opal cemented to a solid mass.

4. *Brown translucent opal* with dendritic growths. This material occurs in large masses in the clay beds about 0·5 km downstream from the above occurrences. It is a chocolate brown opal, almost transparent in thin chips, and contains small black dendritic growths of what is probably manganese oxide.

5. *Siliceous concretions* from the clayey sand below the Blanchetown Clay at the same locality as 4. These are sandy, very irregular in shape, commonly less than 3 cm in length.

6. *Opal claystone* from a thin band at Kulcurna Station on a former cliff behind the homestead. This is a cohesive, soft but brittle earthy material.

Description of the Opaline Silicas

1. *Grey-green opal*

Microstructure. In thin section this opal is uniform in texture, but between crossed polarizers is seen to be very finely fibrous and birefringent. This structure is typical of a lussatite (opal-CT, Jones and Segnit 1971). A few shadowy structures appear to be relics of original replaced materials, and small cavities are lined with colourless isotropic opal. There are occasional grains of detrital quartz.

Scanning electron micrographs were obtained of freshly broken surfaces, lightly etched with hydrofluoric acid, and coated with gold. A general view of such a surface is shown in Pl. 20, fig. 1, and the central portion of this area is shown in Pl. 20, fig. 2. Despite the glassy nature of this opal, there is an extensive system of very fine pores. The etching has also revealed a very fine substructure of grains or fibres of diameter approximately 1,000 Å; these are the

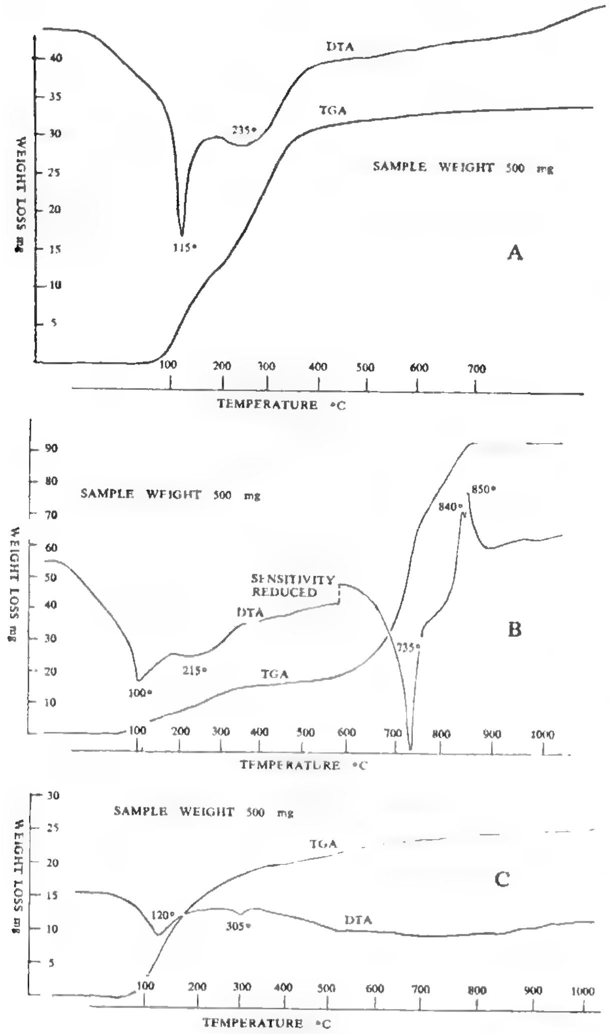

Fig. 1—Differential thermal and thermogravimetric analysis curves of the opaline silicas. A, Grey-green opal. B, Dolomitic opal. C, White opal breccia.

individual crystallites of the disordered cristobalite-tridymite which give rise to the birefringence seen under the optical microscope.

Thermal analysis. Differential thermal analysis and thermogravimetric analysis curves are shown in Fig. 1A. Two low temperature endotherms are recorded, representing two stages of water loss which is also reflected in the weight loss curve. The total weight loss from this sample was 8·45%. The water which was held in capillaries open to the atmosphere boiled off sharply, giving rise to the peak at 115°C. The second, broader peak at 235°C probably represents water which was held in closed micropores; diffusion from these pores would have been more gradual, the diffusion rate reaching a maximum at the temperature indicated.

X-ray diffraction. The X-ray diffraction pattern of this opal (Fig. 2A) shows that it is an opal-CT with a rather high degree of disorder.

2. *White opaque opal*

Microstructure. Microscopic examination showed it to be a very fine-grained, intimate mixture of a carbonate mineral and opaline silica. The particle size of the carbonate mineral was of the order of one micron.

Scanning electron micrographs were made of fracture surfaces lightly etched with hydrochloric acid. Pl. 20, fig. 3 shows a general view of the structure; Pl. 20, fig. 4 shows the central part at a higher magnification. The structure appears to be that of a honeycomb-like network of opaline silica surrounding the grains of the carbonate mineral. Etching with acid has partly dissolved many of the carbonate grains, leaving fragments occupying the cavities.

Thermal analysis. The DTA and TGA curves of this sample are shown in Fig. 1B. These are a combination of the curves for opaline silica and dolomite up to 800°C. The double endotherm at low temperature shows that the opaline silica is of the same type as the grey-green opal. The strong sharp endotherm at 735°C is characteristic of the breakdown and loss of carbon dioxide from the magnesium carbonate component of dolomite. This is followed by two sharp exotherms caused by the reaction of the opaline silica with lime and magnesia to form diopside. The remaining carbon dioxide is lost during this reaction, as is indicated in the TGA curve.

X-ray diffraction. The diffraction pattern in Fig. 2B shows that the white opal is a mixture of opaline silica similar to that of the grey-green opal, and dolomite.

3a. *White opal breccia*

Microstructure. In thin section the white opal particles are rather opaque and show evidence of extensive microcracking. In between the large fragments there is a mixture of small opal grains and quartz grains, with fragments of a micaceous clay mineral. These are cemented together by transparent colourless opal which shows marked birefringence, and is thus probably opal-CT.

The morphology shown by the scanning electron microscope seems to be that of distorted hollow sub-spherical particles about two microns in diameter packed together in an irregular manner (Pl. 21, fig. 1). The fracture surfaces of these particles show very smooth relief, suggesting that the discrete particles of the former gel were very small, probably less than 200-300 Å. The inner and outer surfaces of the hollow particles show evidence of spheres of the order of 0·2-0·5 microns diameter. These are also occasionally seen on the surfaces of larger cavities (Pl. 21, fig. 2).

Thermal analysis. On drying at 110°C, the loss in weight was 2·43%; on ignition, the additional loss was 3·19%. After evaporation and ignition with hydrofluoric and sulphuric acids the residue was 2·92%, giving a silica content of 91·46%.

The DTA and TGA curves are recorded in Fig. 1C. There is a steady weight loss on heating due to the loss of water from the opal; the DTA curve shows a corresponding weak endotherm, which is common for opal-A. A peak occurs at 125° corresponding to the loss of the physically adsorbed water, followed by a weaker broad endotherm centred on 180°C. A double endotherm of this shape is characteristic of most of the opals, whether opal-A or opal-CT, collected from this area.

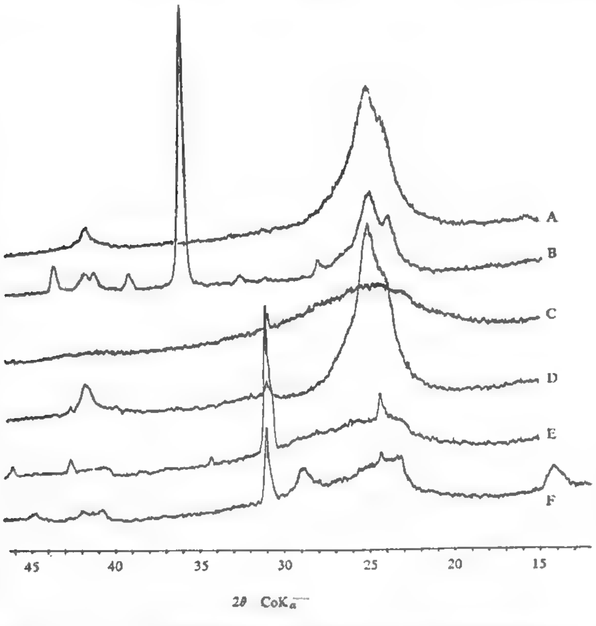

Fig. 2—X-ray diffraction patterns of opaline silicas. A, Grey-green opal. B, Dolomitic opal. C, White opal breccia. D, Brown translucent opal. E, Siliceous concretions. F, Opal claystone.

X-ray diffraction. The X-ray pattern of this material shows no sharp peaks apart from a small peak at 3·34 Å caused by the presence of quartz. The broad hump centred on 4 A (Fig. 2C) is characteristic of the highly disordered form opal-A.

3b. *Brown opal breccia*

The brown opal breccia differs from the white in that it is opal-CT, though poorly ordered in structure. One of its more interesting features is the presence of frequent vugs, the surfaces of which can be seen under the binocular microscope to be coated with minute botryoidal growths. Scanning electron micrographs of the surfaces of the growths show that they are of two types. Some are composed of small crystals of quartz (Pl. 21, fig. 3), whilst others are composed of aggregates of minute crystallites of opal-CT (Pl. 21, fig. 4).

4. *Brown translucent opal*

Microstructure. In thin section this opal is very weakly birefringent, apart from occasional bands and patches. The structure appears to be that of a very finely crystalline opal-CT. Detrital quartz grains are commonly included, and dendritic growths of black to brown oxide, probably manganese, are characteristic (Pl. 23, fig. 1). The latter material has entered and been deposited along fine cracks; in places, the oxide has diffused through the opal near the dendrite, staining it brown. The quartz grains are fairly uniform in size, of the order of 0·5 mm diameter. Shadowy structures seem to be related to a pre-existing grain structure, and very small vugs are concentrically filled with colourless opal.

Scanning electron microscopy of a lightly etched sample shows a smooth surface texture with very small irregular pores (Pl. 22, g. 1).

The surface is even smoother around the borders of vugs (Pl. 22, fig. 2), which themselves appear to represent the growth fronts of the opal-CT. The vug surfaces are comprised of spherulitic masses, the surfaces of which are composed of minute platy crystallites of opal-CT (Pl. 22, fig. 3). These vugs probably correspond to those surrounded by transparent opal as seen in the optical microscope.

Thermal analysis. The DTA and TGA curves of this opal bear a family resmblance to those of the grey-green and white opals (Fig. 3A). A broad double endotherm is caused by loss of water, although the second is much less pronounced. The total weight loss is somewhat higher; loss at 110°C was 5·48%, and loss above this temperature 5·10%.

X-ray diffraction. The X-ray pattern of this opal is almost identical to that of the grey-green material (Fig. 2D). It is an opal-CT with a rather low degree of order. The presence of quartz is also indicated.

5. *Siliceous concretions*

Microstructure. The main feature of the concretions is a fine-grained clay mineral which tends to form pellets, which themselves are cemented together by further clay, and ultimately a colourles opaline silica (Pl. 23, fig. 2). The latter occurs as thin veinlets between masses of clay, or in discrete areas. Quartz grains are frequent adventitious inclusions which are cemented into the mass by both the clay and the opal.

Scanning electron micrographs of opal areas showe a highly porous structure (Pl. 24, figs. 1-2), with some pores containing botryoidal growth surfaces. A group of such spherical growths is shown in more detail in Pl. 24, fig. 3. The surface of these growths is not perfectly smooth, but is composed of much smaller grokth units (Pl. 24, fig. 4). It is not clear as to whether these are aggregates of spherical particles of silica of the order of 0·1 μm diameter, or whether they are the exposed ends of crystallites growing radially from the centre of the large growths.

Thermal analysis. The composition of random samples is variable owing to the concretionary nature of this material. The DTA and TGA curves (Fig. 3B) are representative of the material, and show the characteristic water-loss endotherm centred on 125°C, followed by the dehydroxylation endotherm of the mica-like clay mineral at 550°C. Superimposed on the side of the latter endotherm is a tiny exothermic peak caused by the α → β inversion of the quartz in the sample. The TGA curve shows the two stage weight loss from the silica and the clay mineral; the total loss was 6·5% by weight of the original sample.

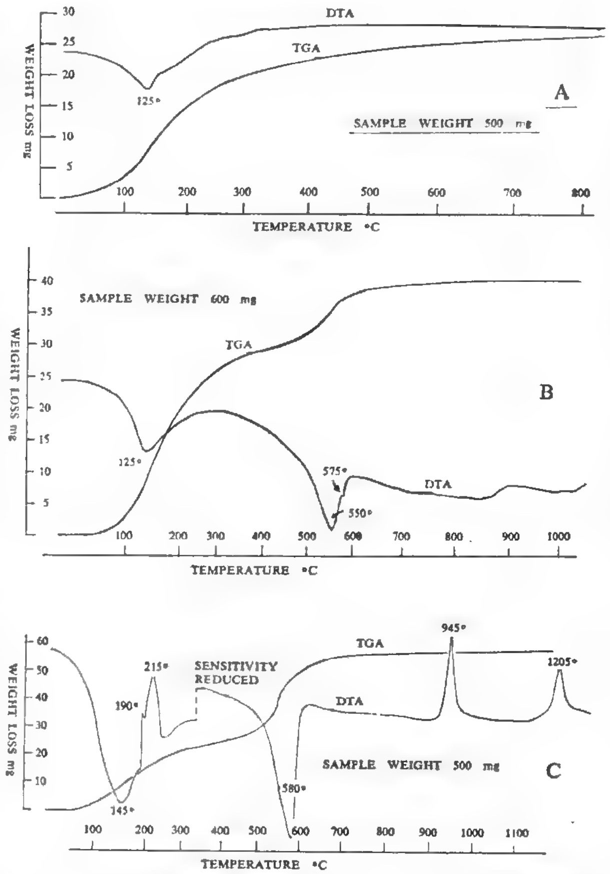

Fig. 3—Differential thermal and thermogravimetric analysis curves of the opaline silicas. A, Brown translucent opal. B, Siliceous concretions. C, Opal claystone.

X-ray diffraction. Fig. 2E shows that the concretions are composed of near amorphous silica, a small amount of quartz, and a poorly ordered illitic clay mineral.

6. *Opal claystone*

Microstructure. This material is very porous, and consists of a very fine-grained, apparently isotropic clay mineral intimately mixed with an abundance of opaline silica of organic origin. The relics mostly have a spicular habit, sometimes tapering, and frequently with an axial hole (Pl. 25, fig. 1).

The scanning electron micrographs chiefly show an irregular powdery aggregate of clay and silica particles which tend to coat and obscure the organic remains. An example of the spicules which occasionally protrude from the broken surface is in shown in Pl. 25, figs. 2-3.

Thermal analysis. Loss of water at 110°C was 2·86%, and the additional loss on ignition was 8·95%. After evaporation with hydrofluoric and sulphuric acids and ignition, the residue was found to be 18·38%, giving a silica content of 69·81%. Assuming the clay mineral to have the composition $Al_2Si_2O_5(OH)_4$, the mineral composition of the opal claystone is approximately 46% metahalloysite, 54% opal, and the composition of the opal itself is approximately 90% SiO_2, 10% H_2O.

The DTA curve of this material shows some unusual features (Fig. 3C). The broad peak at 145°C represents loss of physically adsorbed water from both the silica and the clay mineral components. Superimposed on, or closely following this, are two exotherms. These occur at approximately 190° and 215°C. These can be assigned to the low temperature oxidation of organic material in the sample. Mr J. D. Saxby and Dr D. J. Swaine of the CSIRO Division of Mineralogy were able to extract and analyse the organic material, which they found to be composed of approximately one-third n-alkanes similar to a light petroleum fraction, with the remainder being a complex mixture of polar compounds. It is not at present known whether this organic material is indigenous, or whether it is contamination from nearby habitation.

At higher temperatures there occur the dehydroxylation endotherm at 580°C of the metahalloysite, and the exotherm caused by the collapse of the layer structure at 945°C. The final broad exotherm at 1,205°C is caused by the recrystallization of the residue of the metahalloysite to cristobalite.

X-ray diffraction. The X-ray pattern of the opal claystone (Fig. 2F) indicates that it is composed of a disordered kaolinitic mineral, probably metahalloysite. The presence of the opaline silica is not clearly shown, owing to its essentially amorphous nature; the broad hump in the region of 4 Å tends to be obscured by the prism reflection of the clay mineral. The silica is present in the form of opal-A. A small amount of quartz is also present. On firing to 1,200°C, the diffraction pattern of the sample becomes that of a well ordered cristobalite.

Discussion

The amount and varieties of opaline silicas occurring in this area reflects the magnitude of movement of silica in solution and as a colloid, and its subsequent deposition. All types except that in the opal claystone were almost certainly deposited during interlacustrine conditions and show evidence of variation in the environments of deposition which in part resulted in differences in the morphologies of the opals.

The opal claystone represents the concomitant accumulation of clay and biogenic silica under quiescent lacustrine conditions. The highly disordered nature of the structure of the clay mineral suggests that it may have been formed in situ from the flocculation of colloidal silica and alumina, rather than being brought in as a fine-grained sediment. This accords with the biogenic silica content, as rates of accumulation of both phases must have been quite slow. This type of material could be a source of supply of relatively soluble silica for subsequent solution, transportation and deposition. Such silica, if widely dispersed even in small amounts in the lake sediments, could be one of the primary sources of the silica of the opaline formations.

The main secondary accumulations of silica are those forming massive and nodular opal. These appear to have been formed probably during drier interlacustrine conditions after the deposition of the sediments in which they are contained. Direct evidence of opalization during the lacustrine era is given by the opal breccias. The white opal-A for example was originally deposited as a near-amorphous silica gel. The structure shown in Pl. ??, fig. 1 suggests very rapid flocculation of a sol on mixing with electrolyte particles, either solid or in solution. Later drying and hardening was accompanied by extensive cracking, allowing the broken material to be redistributed and recemented with detrital quartz as a local facies of the sediments.

The massive and nodular opals occur both in the dolomite and in the clay beds. The nodular opal in the dolomite was formed mainly near the top of the bed, with subsidiary layers near the base. The silica was probably introduced as a sol moving downwards from the surface drainage during an interlacustrine period. Such a sol would tend to be close to neutral or slightly acid in nature (pH 6-7). Contact with the finely crystalline porous dolomite could raise the concentration of electrolytes quite rapidly and cause flocculation of the silica, which could then accumulate by a filtration process in the intergranular pores around the dolomite crystallites (Pl. 20, figs. 3-4). Further solution of dolomite would allow more silica to accumulate until finally complete replacement occurred. The silica of the sol may already have been crystalline (disordered cristobalite-tridymite), but in any case conditions in the gel were such that crystallite growth of opal-CT occurred (Jones and Segnit 1972) resulting in an opal composed of minute crystallites as seen in Pl. 20, fig. 2.

The major opal-CT formations are nodular to massive in the clay beds. Drying of clay during interlacustrine periods could create cavities in which opal and other materials could accumulate under the appropriate conditions. Sols or solutions of silica could thus percolate through the clay. Gypsum and other salts are common in these clay beds, suggesting that an increase in electrolyte concentration may have caused the flocculation of the silica sol. The formation of crystallites such as those of Pl. 21, fig. 3 represent the final stage in the depositional process in a nodule. These discrete crystallites probably grew more slowly from residual silica solutions derived from the gel, the silica being deposited on crystalline nuclei on the surfaces of vugs as the material slowly dried.

Massive or nodular opal is not found in the sandy beds. The rapid passage of water through these beds with the leaching of electrolytes would result in a less favourable environment for the deposition of opal from descending sols or solutions. The opal represented by sample 5 appears to have a different type of origin. Small amounts of opal-A have in this case been deposited in the sandy beds, together with poorly crystallized clay mineral, around fine plant roots. The clay and the opal may have formed together from the precipitation of colloidal silica and alumina; the formation of an illitic rather than a kaolinitic mineral would have been favoured by the high silica:alumina ratio. The silica may have been derived in part from the remains of overlaying plant material, the root system acting as a pathway for water slowly percolating through the clayey sand.

Since the formation of the opal, weathering processes have etched the surfaces of nodules, sometimes to a depth of several mm. In some cases nodules have been later broken, and a thinner layer of etching can be seen on the younger surface so formed.

References

JONES, J. B. and SEGNIT, E. R., 1971. The nature of opal 1. Nomenclature and constituent phases. *J. geol. Soc. Aust.* 18: 57-68.

————, 1972. Genesis of cristobalite and tridymite at low temperatures. *J. geol. Soc. Aust.* 18: 419-422.

Explanation of Plates

PLATE 20

Figs. 1-2—Scanning electron micrographs of the grey-green opal (lightly etched with HF) from top of dolomite bed, Nampoo Station.
1. General morphology.
2. Crystallite structure of the opal-CT.

Figs. 3-4—Scanning electron micographs of dolomitic opal (lightly etched with HCl) from dolomite bed, Nampoo Station.
3. Honeycomb-like structure with many holes still containing dolomite particles.
4. Detail of central part of 3.

PLATE 21

Figs. 1-2—Scanning electron micrographs of the white opal breccia (opal-A) from above dolomite, Nampoo Station.
1. Floc-like structures of the body of the opal.
2. Surface cavity showing aggregates of small silica particles.

Figs. 3-4—Scanning electron micrographs of the crystalline structures in vugs of the brown opal

breccia from the base of the dolomite, Nampoo Station.
3. Crystals of quartz coating surface of vug.
4. Aggregate of crystals of opal-CT forming walls of another vug.

PLATE 22

Figs. 1-3—Scanning electron micrographs of brown translucent opal from Nampoo Station.
1. Lightly etched fracture surface.
2. Final growth surfaces in a vug.
3. Detail of opal-CT crystallites in vug.

PLATE 23

Fig. 1—Photomicrograph of the brown translucent opal from Nampoo Station, showing clear quartz grains and dendritic growths of manganese oxide.

Fig. 2—Photomicrograph of siliceous concretion showing quartz grains, clay pellet structure, and interstitial patches of opaline silica.

PLATE 24

Figs. 1-4—Scanning electron micrographs of a siliceous concretion.
1. General view of an opaline area.
2. Detail of structure of an opaline area.
3. Group of spherical growths in cavity.
4. Detail of surface of spherical growths.

PLATE 25

Fig. 1—Photomicrograph of opal claystone from Kulcurna Station showing the presence of abundant biogenic silica.

Figs. 2-3—Scanning electron micrographs of the opal claystone.
1. Fracture surface showing a protruding sponge spicule.
2. Detail of fracture surface of spicule.

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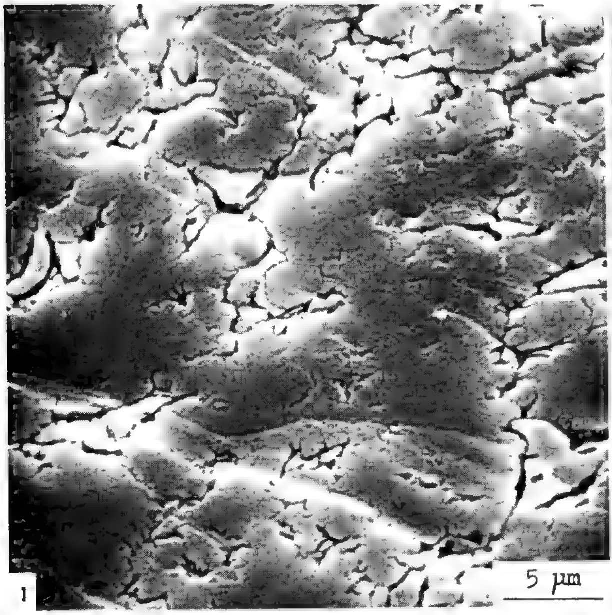

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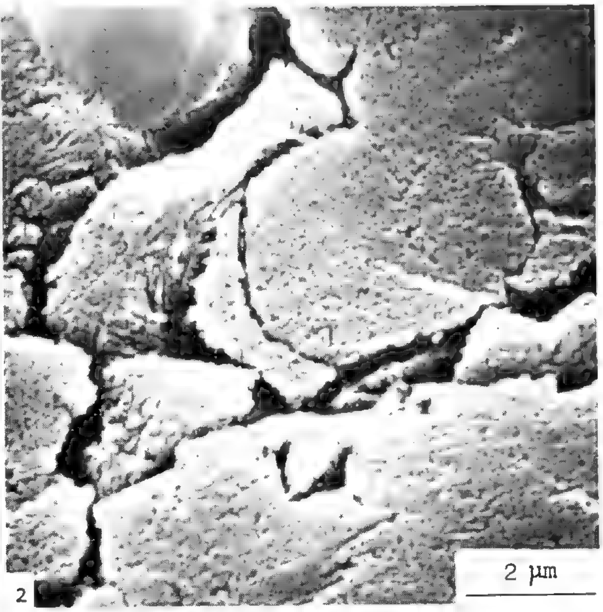

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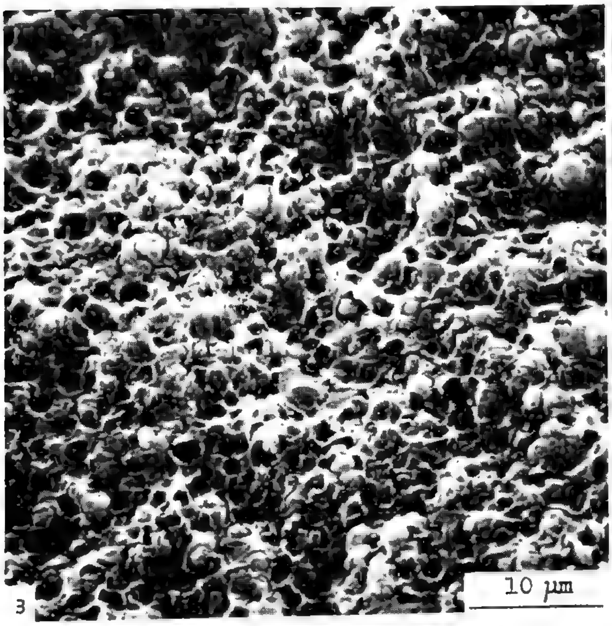

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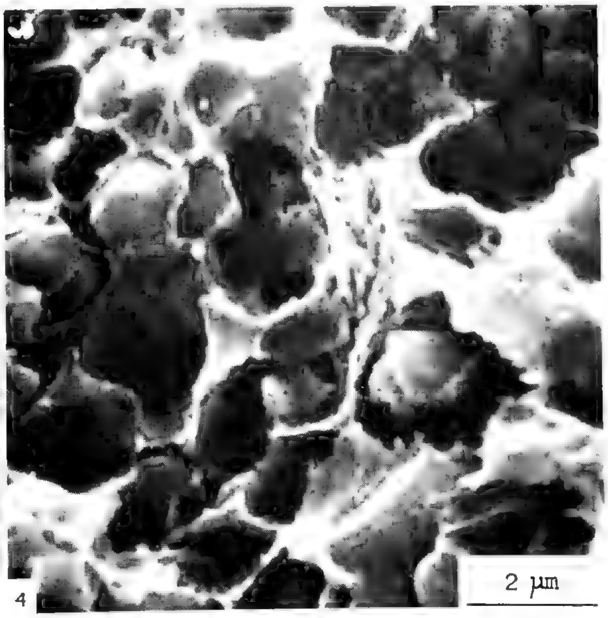

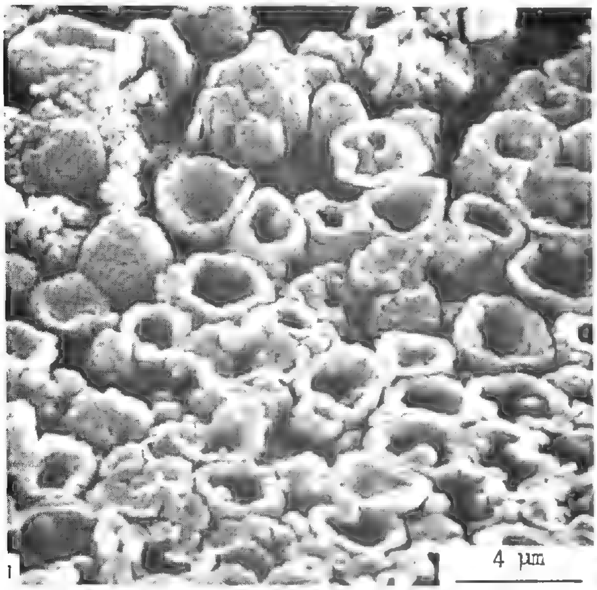
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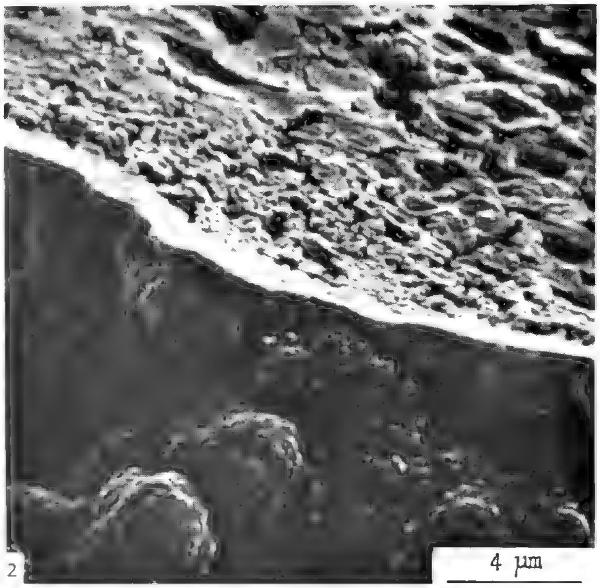
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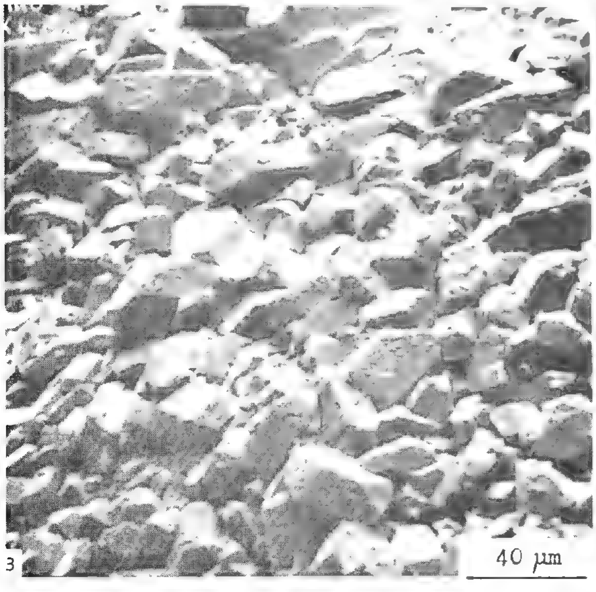
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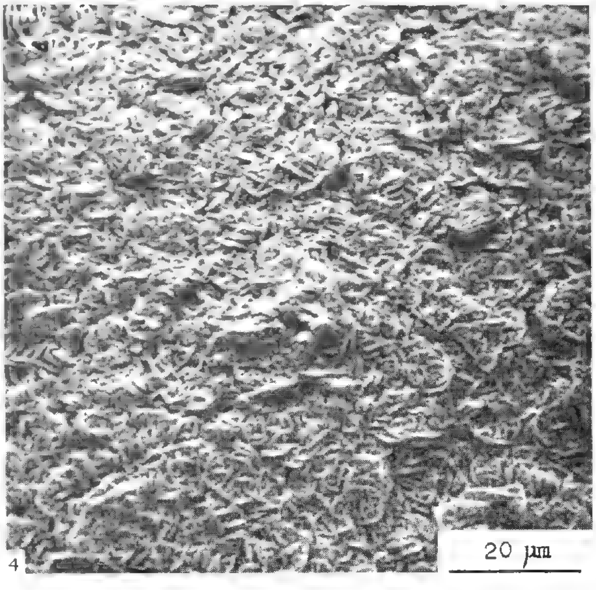
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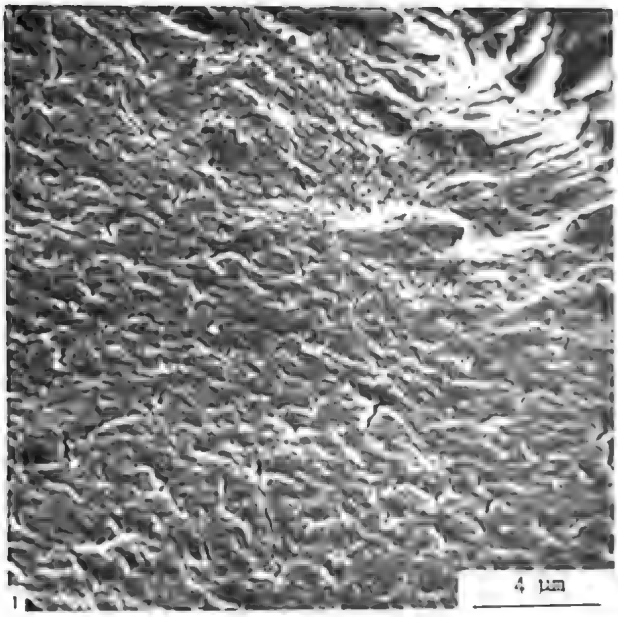
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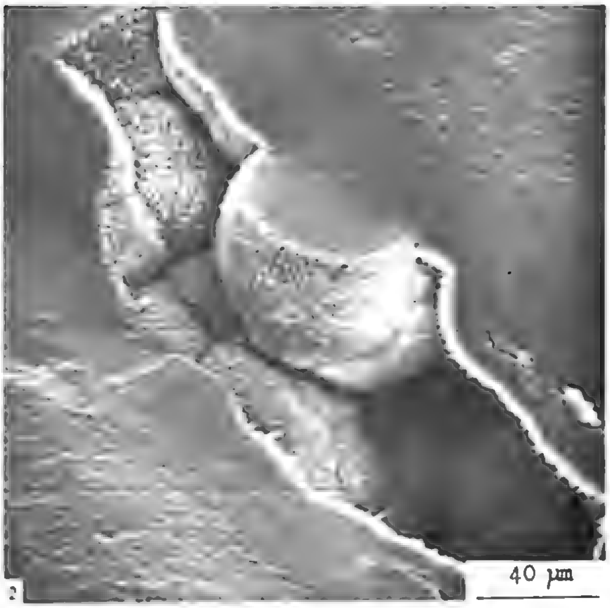
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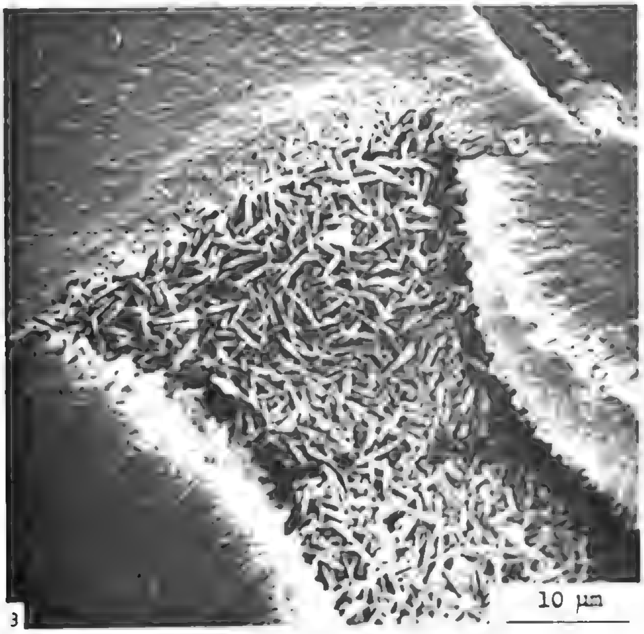
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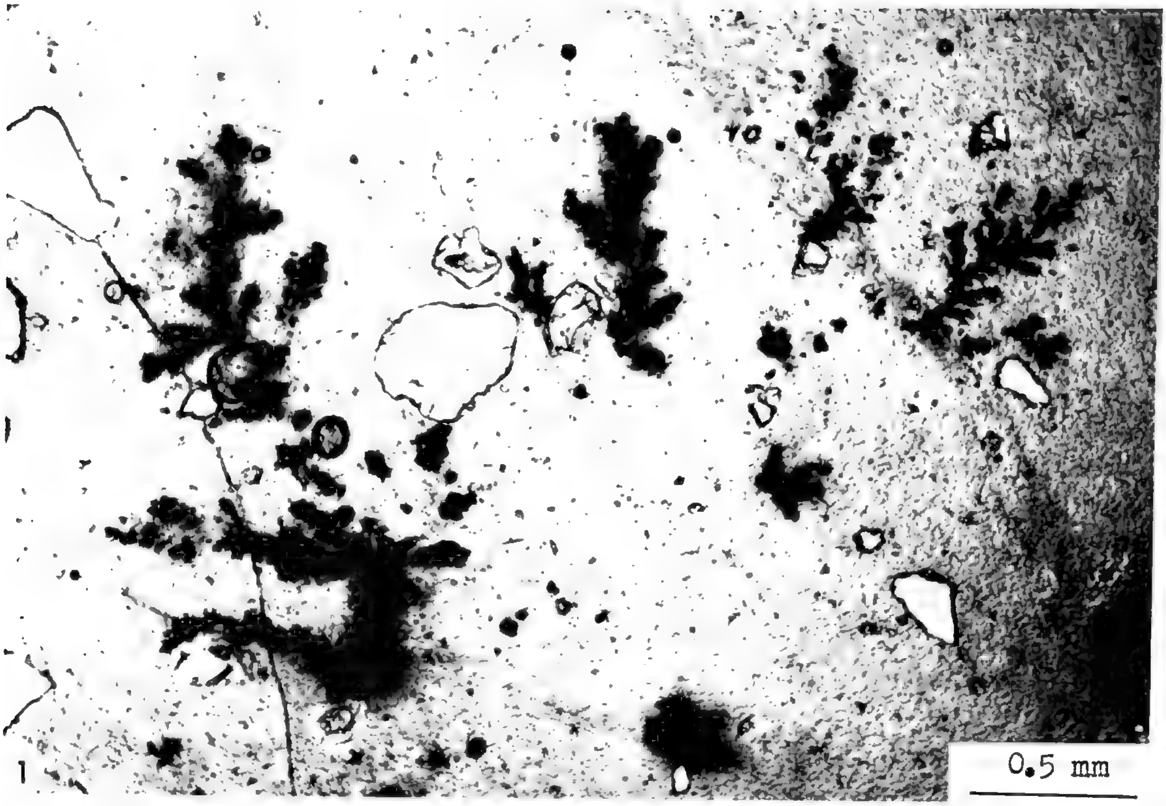

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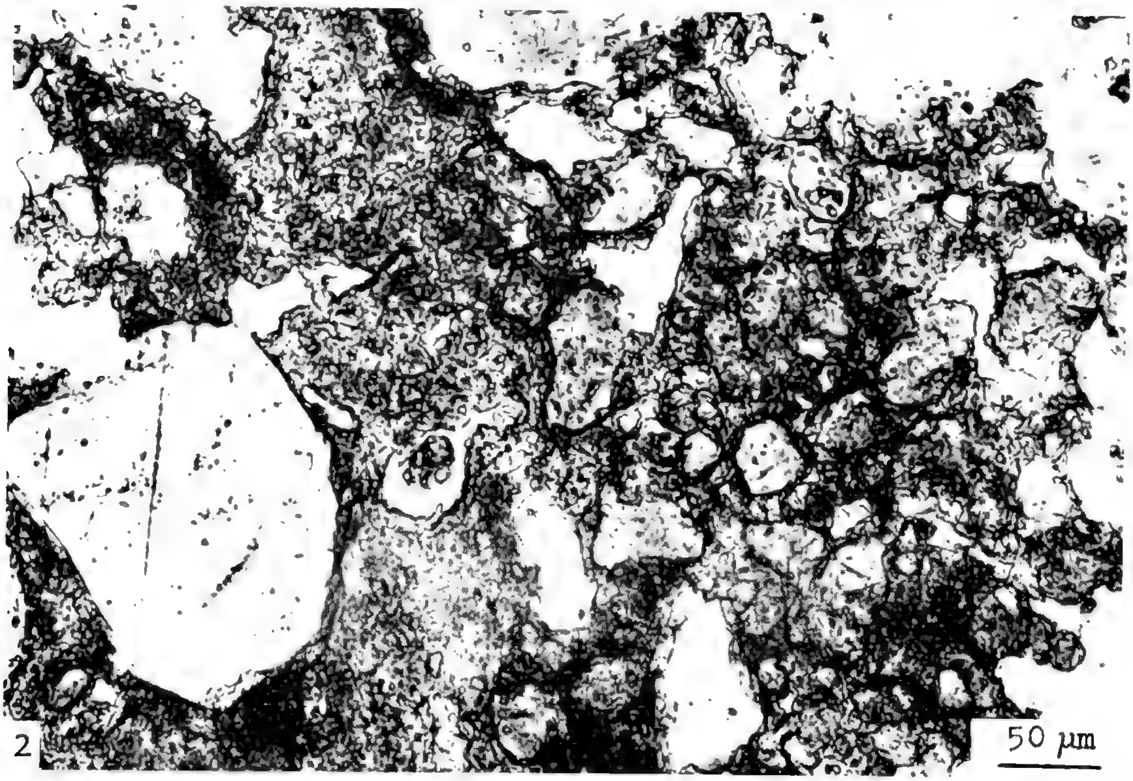

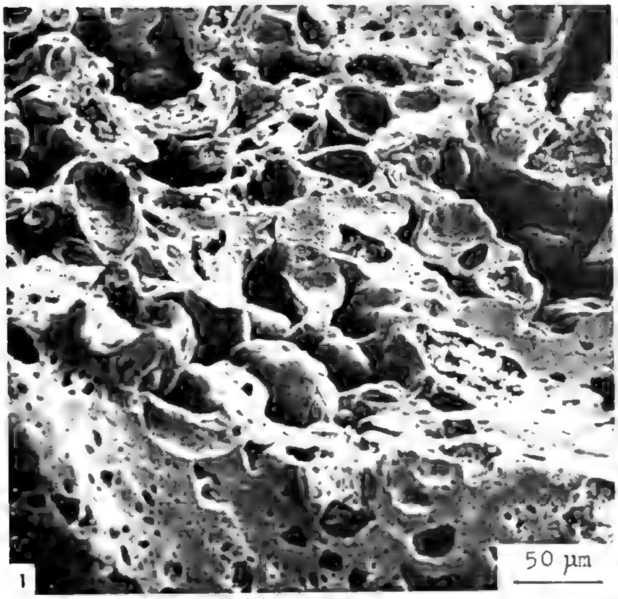
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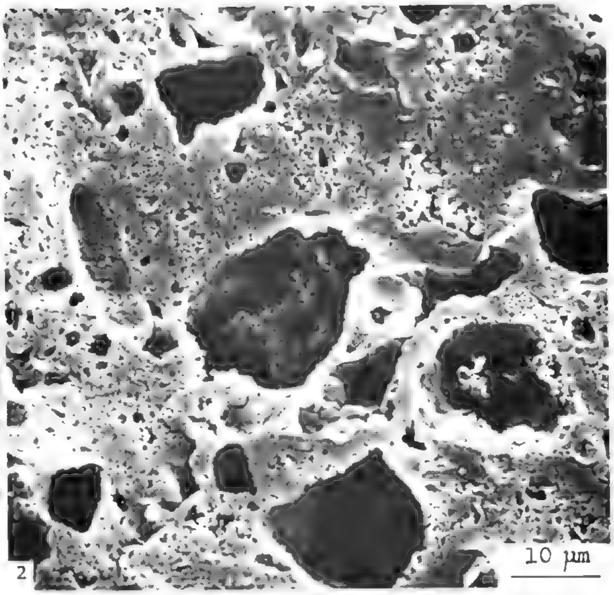
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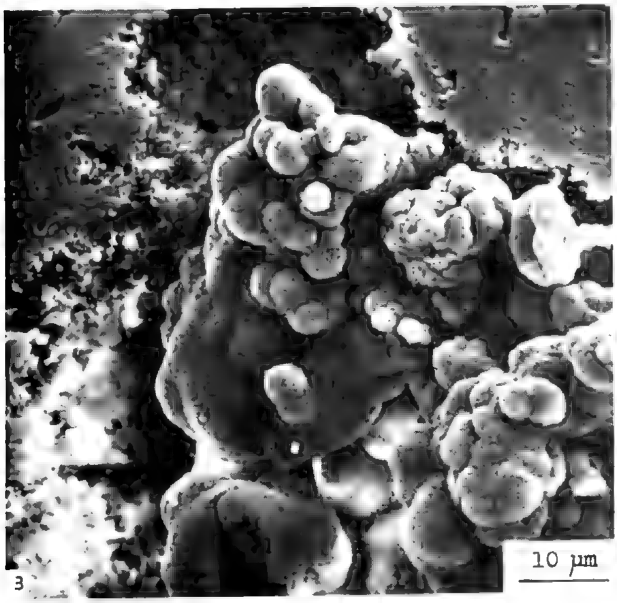
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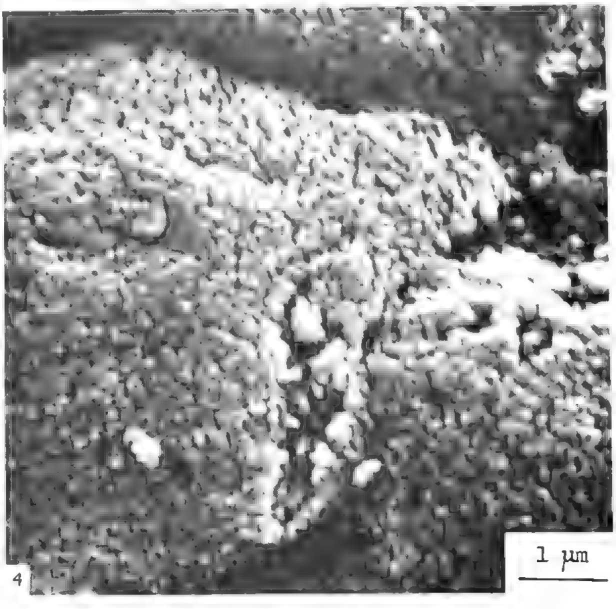
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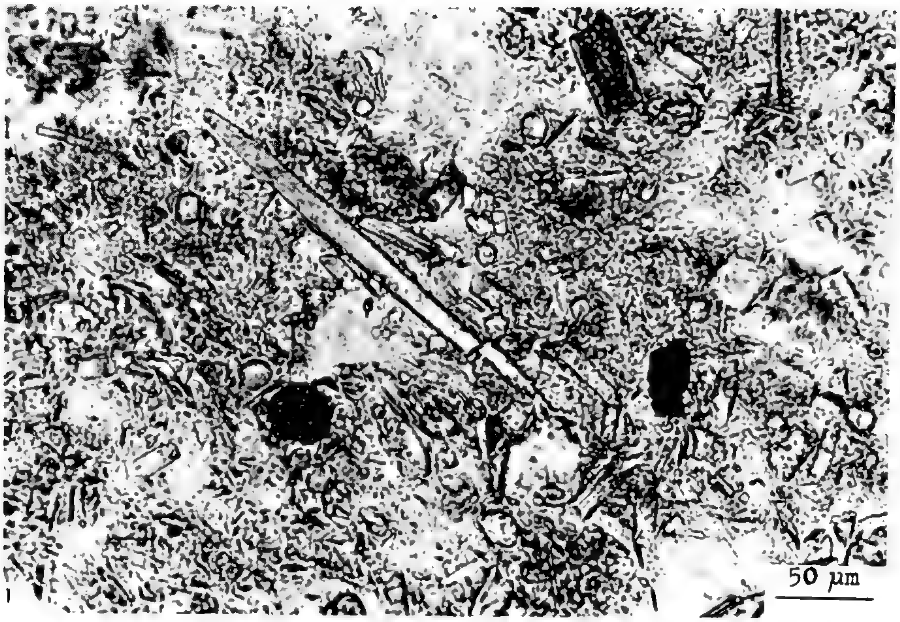
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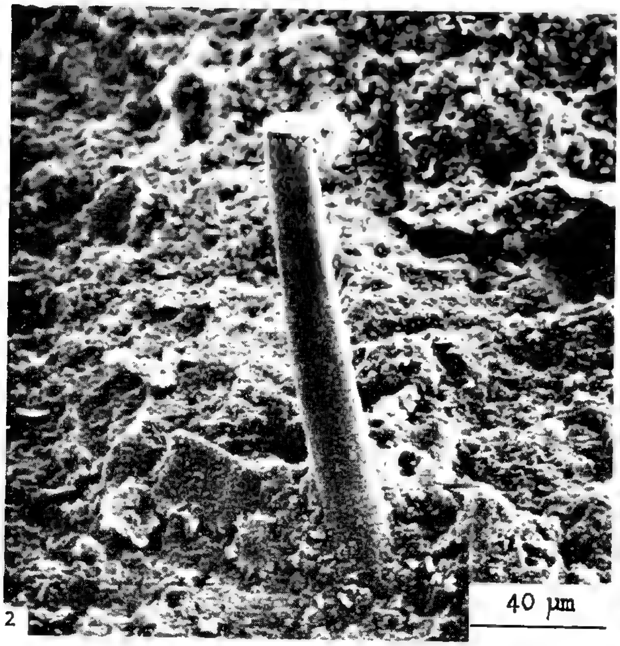
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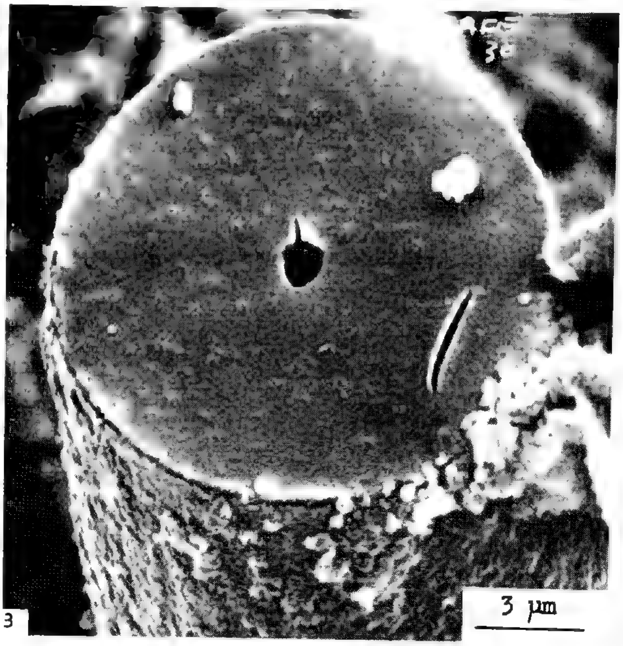
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MINERALS FROM THE MURRAY RIVER REGION WEST OF WENTWORTH, N.S.W., AUSTRALIA

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The geological nature of this region (Gill, this *Memoir*) is such that only a limited number of mineral species are found. The following have been identified:

Calcite is widespread in the form of calcrete, and has also been found as accretions in sandy clay beds. It is also the main constituent of lenses of ostracodal limestone.

Dolomite occurs as a soft bedded sedimentary rock, and some ostracod bands are composed of this mineral.

Gypsum is common, mainly as masses of selenite and smaller accretions in clay beds.

Manganese and iron oxides are ubiquitous, the former as stains and dendritic growths, particularly in the carbonates.

Clay minerals are represented chiefly by kaolinite and montmorillonite.

Quartz is ubiquitous, forming the main constituent of various sandy beds, and occurring as inclusions in the calcretes, and as a constituent of the clay sediments.

Opaline silica is widespread, and is described elsewhere (Segnit, Jones and Anderson, this *Memoir*).

Halite commonly occurs as efflorescences on the surfaces of soil components.

The following is a brief description of the more interesting occurrences of some of these minerals.

1. CALCITE

Calcite is very widespread, particularly in the form of calcrete or kunkar, but is also found as agglomeratic or concretion-aggregates in some of the sediments.

(a) *Calcrete nodules*

These occur in the soil in very large quantities over most of the terrain (Gill, this *Memoir*), either separate, or cemented into hard bands. They consist mainly of calcite, enclosing appreciable amounts of detrital quartz.

The internal structure consists of a central core which is commonly about half the diameter of the nodule (Pl. 25, figs. 1-2), but may be greater. This is coated with successive thin layers of calcite, usually stained brown by small amounts of iron oxides. The core is also usually light brown in colour, although it may contain dark brown to black spots of iron or manganese oxides. It is generally compact (Pl. 25, fig. 1), but in some cases numerous pores are present (Pl. 25, fig. 2). Quartz grains of fine sand size show evidence of rounding; these are plentiful in the cores. The calcite of the cores has a crystallite size of the order of 2 μm but particularly around the quartz grains it is much coarser, of the order of 40-50 μm.

Around the core, deposition of calcite has built up a series of irregular concentric spheres, often enclosing small quartz particles in the process of growth. The crystallite size of the calcite in the rings is usually very small (1-2 μm), although some rings may be coarser (10-20 μm). Iron and manganese oxides are irregularly distributed through these parts of the nodules.

Rarely, weathered micaceous relics, heavy mineral particles such as apatite, and opal particles (possibly plant silica) can be identified.

(b) *Calcite accretions*

Irregular white accretions of calcite were found weathering out of the lower levels of the mottled sand intercalated low in the Blanchetown Clay about 0·5 km downstream from Devil's Elbow, Nampoo Station. Typical examples of these are shown in Pl. 25.

They are composed of white, finely crystallized calcite which forms aggregates of radiating

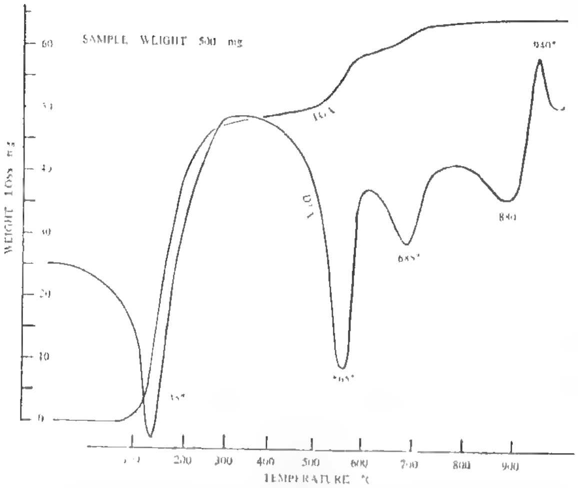

Fig. 1—Differential thermal analysis curve of Blanchetown Clay from cliffs W. of Nampoo Station homestead.

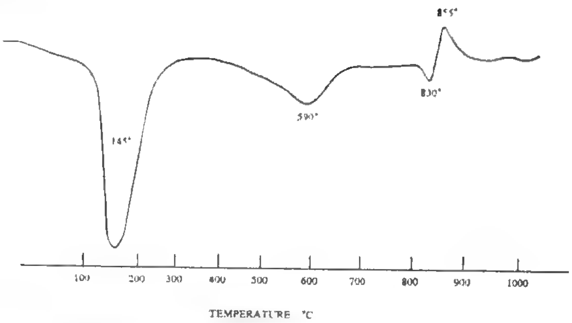

Fig. 2—Diffferential thermal and thermogravimetric analysis curves of sodium montmorillonite from Sharp Point (Devil's Elobw), Nampoo Station.

sheaves of crystallites. They enclose abundant quartz particles in the sand size range of 0·3-0·4 mm. The sheaves of calcite are also quite small, being of the order of 0·5-1 mm in length. The calcite appears to have nucleated on the quartz grains, which generally have a corona of coarser carbonate about 0·05-0·1 mm wide. The quartz grains are frequently cracked; the cracks are filled with calcite, the growth of which has often separated the broken parts of the quartz grains.

2. Dolomite

(a) *Sedimentary (precipitated) dolomite*

The bedded dolomite such as that found at Triple Swamp, Moorna Station, is a very fine-grained, white porous material. It has a very uniform microstructure of dolomite crystallites of the order of 1 μm in size. Black dendritic patches of oxide mineral (see below) a few mm in size are present in much of the dolomite rock, as well as occasional quartz grains.

This appears to be a chemically precipitated dolomite similar to material which is being deposited along the Coorong in S. Australia today (Alderman 1959, 1965, von der Borch 1965).

(b) *Metasomatic dolomite*

Some samples of ostracodal rock, either hard or relatively unconsolidated, are composed of dolomite with no detectable calcite or aragonite. The band containing ostracods from the base of the Blanchetown Clay, west of Bone Gulch, Moorna Station, N.S.W., appears rather similar to the precipitated dolomite; it is unlikely, however, that the ostracod tests were originally dolomite, as when they are found associated with sand or clay they are composed of calcite. It seems probable that the original calcite tests of the ostracods underwent metasomatic replacement by magnesium, either from magnesium solutions at the time of precipitation of the dolomite, or by later replacement in contact with the dolomite after deposition.

3. Gypsum

Gypsum occurs commonly in the Blanchetown Clay. It may be found as large nodules or accretions 25 cm or more in diameter, often with a central core of selenite. Small aggregations, several cm in diameter, are frequently found on exposed erosion surfaces of the clay beds.

4. Manganese Oxides

Manganese oxides occur mainly as dendritic growths in other rocks and minerals. Patches several mm in diameter commonly spot the dolomite at Triple Swamp. Sands from cliffs on Moorna Station north of the homestead contain many grains with black coatings. Chemical tests on these materials confirm the presence of manganese. Black dendritic growths of what is probably manganese oxide are also found at times in the calcrete nodules.

X-ray diffraction examination of the manganese oxide from the dolomite showed only the presence of dolomite itself, and traces of kaolinite and halite, indicating that the manganese oxide is in an amorphous form.

5. CLAY MINERALS

(a) *Montmorillonite*

The clay forming the massive Blanchetown Clay at Nampoo Station shrinks strongly and cracks to a crumbly aggregate of fragments an 2-3 cm or so in diameter on exposure to the atmosphere and drying. It is of a greenish-grey colour.

X-ray diffraction analysis of the original clay and the glycerol saturated material indicate that it is essentially a poorly organized montmorillonitic type of material containing a considerable amount of quartz. The differential thermal analysis curve is given in Fig. 1. It is characteristic of a montmorillonite-type mineral, although the higher temperature endotherms and exotherm occur at somewhat lower temperatures than usual.

(b) *Sodium montmorillonite*

A layer about 10-15 mm thick of a soft but brittle white material with the appearance of an opaque gel occurred at the base of the lower dolomite bed at Sharp Point (Devil's Elbow) on Nampoo Station. X-ray diffraction examination indicated that the material was a rather poorly crystallized montmorillonite-type material.

The sample had a loss of 19·0% water at 110°C, and an additional loss after firing of 11·0%. After evaporation with hydrofluoric and sulphuric acids, the silica content was found to be 74·9%. X-ray diffraction analysis of the residue from this evaporation showed the presence of corundum and spinel, showing that the original mineral contained alumina and magnesia. Transparent tabular crystals which formed on the upper part of the crucible used for the evaporation were identified as beta-alumina ($Na_2O.11Al_2O_3$), proving the presence of sodium.

Differential thermal and thermogravimetric curves of this mineral are given in Fig. 2. The strong endotherms at 140°C and in the 500°-700°C region, together with the exotherm at 940°C are consistent with the identification of the mineral as a sodium montmorillonite.

(c) *Kaolinite*

The white band above the clay between the Parilla and Chowilla Sands on Kulcurna was a fairly pure kaolinite containing about 10% quartz. Its X-ray diffraction pattern indicated that it was poorly crystallized material.

Kaolinite was also encountered mixed with other minerals. It was, for example, a minor constituent of some of the precipitated dolomite sediments, and in the form of methalloysite it formed part of the opal claystone from Kulcurna Station, on the hill behind the homestead.

Addendum

Further Minerals from the Murray River Region

KAOLINITE

A rather pure, white kaolinite with a compact brittle character was formed as layers and lenses one to two cm thick in a friable sandstone in the cliffs at the S. end of the Euston Weir, Robinvale. X-ray examination showed that the material was a structurally well-ordered kaolinite; the crystallite size, as determined by microscopic examination, was of the order of 0·5-1 μm.

SEPIOLITE

An irregular fragment (approximately 15 cm diameter) of a very low density material associated with a little opal-A was found in the detritus at the foot of the cliff at Devil's Elbow, Nampoo Station. Fragments floated in water until they became saturated, and did not disintegrate.

X-ray diffraction and DTA (Fig. 3) showed the material to be sepiolite. The ignited residue after evaporation with hydrofluoric and sulphuric acids consisted of spinel and magnesium oxide, confirming the presence of much magnesium, and indicating the presence of aluminimum. Its composition may be similar to an aluminous sepiolite from South Australia (Rogers, Quirk and Norrish 1956).

It seems probable that the sepiolite formed as a gel-like material at the same time as the opal, and was possibly contemporaneous with the dolomite.

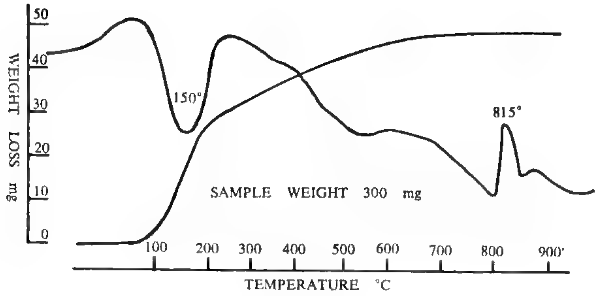

Figure 3

BARITE

Irregular nodular concretions up to 10 cm long of a very finely crystalline barite were sparsely distributed in one section of the Blanchetown Clay between the upper (dolomitic) and lower (ferruginous) parts of the basal horizon. The barite had been precipitated as a very fine-grained mud-like material; the outer surfaces of the nodules frequently showed networks of drying or shrinkage cracks. Internally, the concretions consisted of small nodules, several mm in diameter, of very fine grained barite (particle size 1-2 μm), cemented by more coarsely crystalline barite (5-10 μm).

CELESTITE

A nodule or 'bun' of celestite was found some 100 m downstream from Devil's Elbow. It appeared to have weathered out of Blanchetown Clay along with more abundant gypsum. The celestite crystals were up to 2-3 mm in length, arranged across bands, giving the impression of having (at least in part) crystallized across cracks in the clay.

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Explanation of Plates

PLATE 26

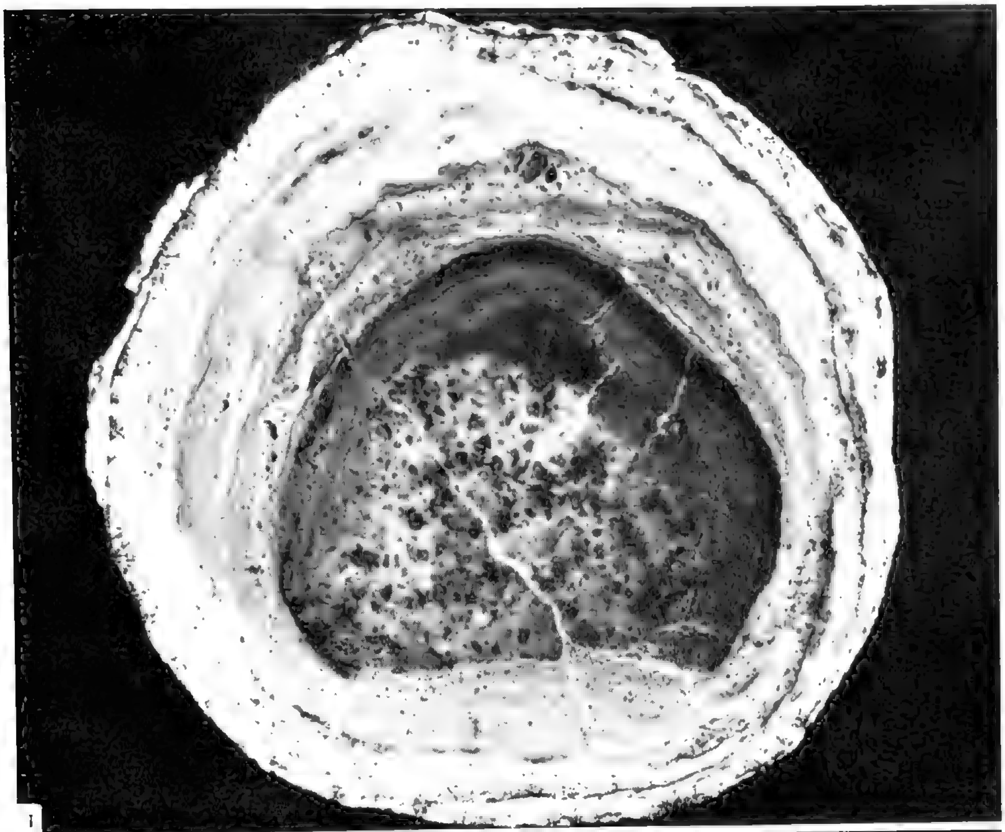
Figs. 1-2—Sections through centres of calcrete nodules from top of Fisherman's Cliff, Moorna Station. Diameter of nodules approximately 1·5 cm.

1. Nodule with dense core containing spots of iron and manganese oxides.
2. Nodules showing pores in core.

Photos: A. L. Lee

PLATE 27

Calcite accretions from clayey sand, near Sharp Point (Devil's Elbow), Nampoo Station. Photo: A. L. Lee.



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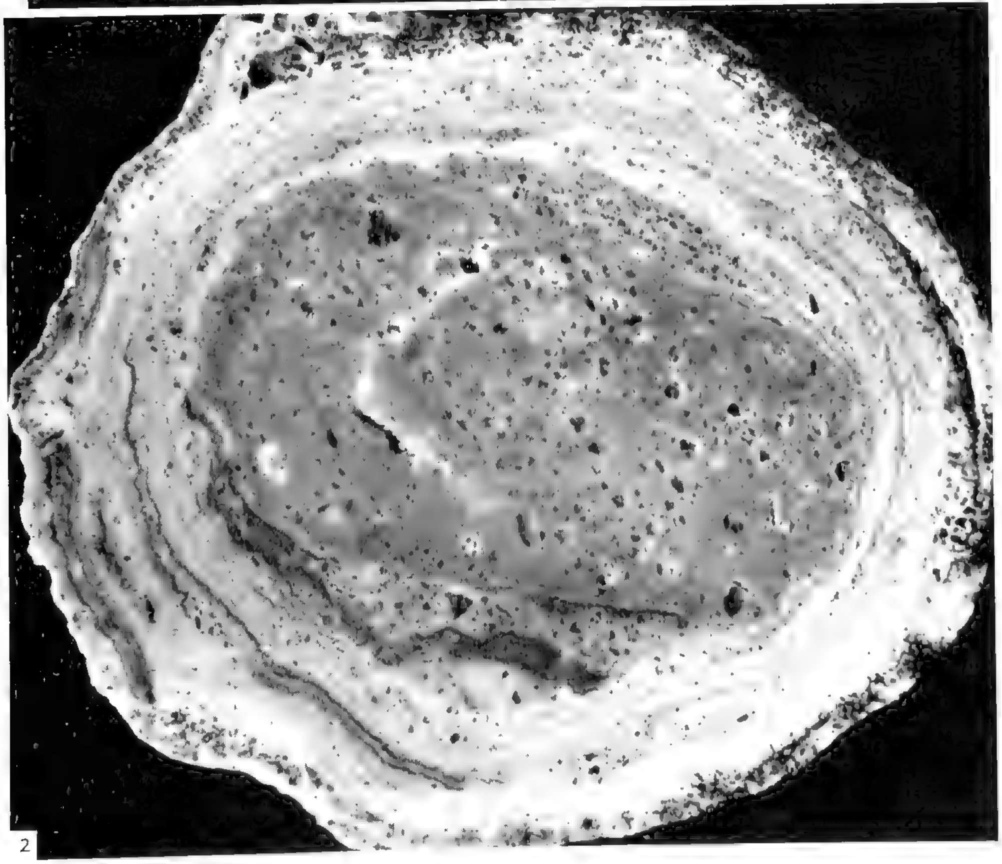

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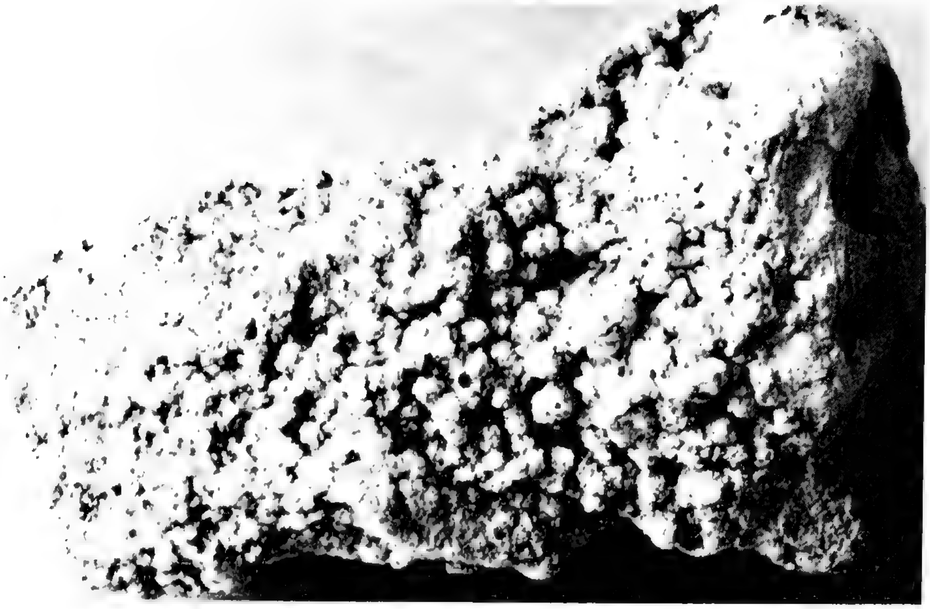

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AUSTRALITES FROM THE MURRAY—DARLING CONFLUENCE REGION, AUSTRALIA

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Abstract

Sixteen naturally etched and subsequently moderately abraded australites from the region between the confluence of the Murray-Darling rivers and the South Australian border have been lodged in the collection of the National Museum of Victoria at irregular intervals over the past 72 years. Since only three others are recorded from this area, a distribution of only one per 1,250 km² is indicated. Found on the surface of fluviatile, lacustrine and aeolian sediments, these australites are regarded as having fallen there rather than being river-transported from elsewhere. The largest specimen, a round core weighing 56·67 g is 28 times as heavy as the smallest specimen, a dumbbell weighing 2·01 g. The low dynamics of the river system preclude fluviatile transport, but it is possible that Aboriginals carried them.

Introduction

The australites were found over 23,600 km² of the plains of the Murray-Darling river system. Thirteen of the specimens are from New South Wales and three from Victoria. The region includes the discovery site of the first australite brought to scientific notice (Fig. 1)—an oval flanged australite button picked up by Major Thomas L. Mitchell in N.S.W. in 1835 on the alluvial plain between the Murray and Darling Rivers. It was described by Charles R. Darwin (1844) as half of a volcanic bomb.

A noteworthy feature of this assemblage is that elongated forms dominate round forms in the proportion of 4:1. Apart from the 16 specimens referred to herein, two from Travellers Lake, 96 km N. of Wentworth, N.S.W., presented by Mr. Gil Black on 16 Oct. 1939, have passed out of the Museum collection, and one is known from Avoca Station, 22 km NE. of Wentworth (Baker 1959, p. 26). The nearest other recorded australites are:

1. A few worn specimens from Oakvale Station in S. Australia, nearly 160 km NW. of Wentworth, and 112 km S. of No. 13, Table 1.
2. A fractured, round, flanged button from Pink Lakes in NW. Victoria (Baker 1959, p. 25), 109 km S. of Wentworth, and 57 km SW. of No. 3 in Table 1.

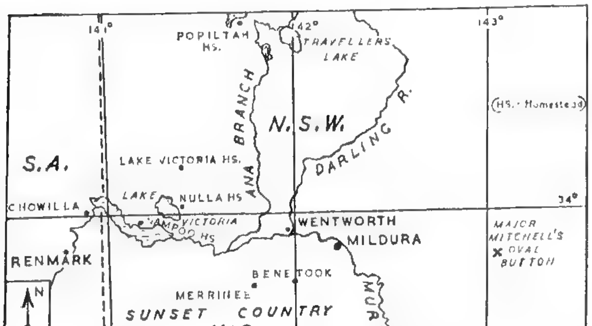

Fig. 1 — Sketch map showing localities.

Field Distribution and History of Discoveries

Australites from an area approximately 120 km from E. to W. and 197 km from N. to S. are listed from 12 general localities (Fig. 1) in Table 1. They were discovered at irregular intervals since 1900. Even though this region has become better known over the past 72 years, there has been no marked increase in the number of specimens brought to the National Museum. It is concluded that the number of specimens received is fairly representative of their spread. The first australite brought to scientific notice was found by Major (later Sir) Thomas Livingstone Mitchell who became surveyor general for N.S.W. in 1828. He led an expedition in 1835 to survey the Darling R., but

Type	Locality	Remarks	Source	Reg. No.
1. Round Core	E. of Nampoo Station 80 km. W. of Wentworth, N.S.W.	Found near old house	Loan Mr. J. Taylor 7 Feb. 1972.	
2. Oval Core	Benetook, 27 km S.W. of Mildura, V.	Earlier and later phases of spallation	Coll. Mr. R. Wilkinson, July 1950	M16879
3. Round Core	16 km NNW. of Hattah Railway Station, V.	On red loam surface of rabbit warren	Donated Mr. R. B. Eggleton 1968	E4873
4. Dumbbell	Popiltah Station 104 km NNW. of Wentworth, N.S.W.	Flow lines trend parallel with long axis	Donated Mr. M. R. Cudmore, 10 Jan. 1900	M5176
5. Boat Core	Near Wentworth, N.S.W.	Asymmetrical in elevation, one end 3 mm deeper. Pronounced rim	Acquired 3 Mar. 1967	E4210
6. Boat Core	NE. side of Lake Victoria, N.S.W.	Map ref. Ana Branch 428607	Donated Mrs. H. Hansen, 9 Apr. 1968	E4306
7. Oval Core	1 km E. of old hotel, Nulla Stn., N.S.W.	In loose sand 2·5 cm depth on dune. Three remnants of exfoliated shell	Coll. Mr. K. N. G. Simpson 15 Apr. 1971	E4834
8. Fractured Oval Core	Lake Victoria Stn. 64 km NW. of Wentworth, N.S.W.	Most of anterior surface lost by fracturing	Donated Mr. Armstrong, 17 Apr. 1917	E4874
9. Oval Core	Travellers Lake, 96 km N. of Wentworth, N.S.W.	Asymmetrical in plan from uneven spallation	Donated Mr. G. Black, 16 Oct. 1939	M11911
10. Dumbbell	Travellers Lake, 96 km N. of Wentworth, N.S.W.	Marked rim separates anterior/posterior surfaces	Donated Mr. G. Black, 16 Oct. 1939	M11913
11. Oval Core	Travellers Lake, 96 km N. of Wentworth, N.S.W.	Posterior surface virtually flat	Donated Mr. G. Black, 16 Oct. 1939	M11908
12. Incomplete Flanged Button	1·6 km S. of Nulla/Talgarry Stn. boundary E. side Lake Victoria, N.S.W.	Between kitchen middens, top of dune	Donated Mr. M. Barbetti 29 Dec. 1971	E4875
13. Half Dumbbell with flange remnants.	144 km N. of Wentworth, N.S.W.	Fractured across middle of waist	Donated Mr. M. R. Cudmore, 4 Nov. 1905	M11380
14. Button core	Lake Victoria Stn. 64 km NW. of Wentworth, N.S.W.	Two minute stumps of worn down flange	Donated Mr. Armstrong, 17 Apr. 1917	M11397
15. Teardrop	Travellers Lake, 96 km N. of Wentworth, N.S.W.	Flow lines trend parallel with long axis	Donated Mr. G. Black, 16 Oct. 1939	M11912
16. Dumbbell	Merrinee, 48 km SW. of Mildura, V.	Rim sharply marked separating posterior/anterior surfaces. Flow lines trend parallel with long axis.	Donated Mr. N. Favaloro, 23 Mar. 1948	E335

was forced to turn back in the face of hostile natives without reaching its junction with the Murray R. (Mitchell 1838). During this expedition he found a strange object which greatly aroused his curiosity at the approximate locality shown on Fig. 1. On return to Sydney, Mitchell presented this specimen to Charles Robert Darwin (1809-1882) who had filled the post of naturalist on Captain Robert Fitzroy's second voyage (1831-1836) of exploration in H.M.S. Beagle, which was in Australian waters 1835-1836. Darwin evidently received the specimen from Mitchell towards the end of 1835 or early in 1836. It was described as an obsidian-like object that represented half a burst volcanic bomb, which had changed its direction after bursting (Darwin 1844).

This specimen was unique until Rev. W. B. Clarke (1855) described specimens of "obsidian bombs" from the cradle of a gold-washer on the Turon R., N.S.W., and from the Uralla (= Rocky) R. in the New England district of that State.

The button-shaped australite found by Mitchell was referred to by Walcott (1898) under "obsidianites", as having been found on a great sandy plain between the rivers Darling and Murray, several hundred miles from any known volcanic origin. Walcott quoted Darwin: "The specimen seems to have been embedded in some reddish tuffaceous matter, and may have been transported either by the aborigines or by natural means". "The external saucer consists of compact obsidian, of a bottle-green colour, and is filled with finely cellular black lava, much less transparent and glassy than the obsidian". Fenner (1935, p. 136) remarked that Darwin suggested (with some doubt) a volcanic origin, since his mind at the time was largely engrossed by problems of volcanic phenomena encountered during the historic voyages of H.M.S. Beagle.

It is now 137 years since the first tektite was found in Australia, in which time only 19 specimens have been brought to scientific notice from the extensive area embraced by this paper. This is in sharp contrast with the total of 45,000-50,000 specimens known from the Australian strewnfield of some 3,200,000 km^2.

o

The concentration density for the Murray-Darling confluence region is only 1 per 1,250 km^2. This contrasts with the Port Campbell area on the S. coast of W. Victoria, where the density is 1 per 0.007 km^2, or about 136 per km^2.

Referring to the specimen described by Darwin, Clarke (1855) suggested it would seem to have drifted a very long distance. From the known habits of the Aboriginals, he thought it more likely to have been dropped by one of them, who probably found it in the trap hills of the Lachlan, to the NE. Clarke was evidently influenced by Darwin's conclusions that the material attached to the surface of the specimen was tuffaceous and that the object was obsidian-like. Fenner (1935, p. 136) classified the specimen as "an oval, with beautiful marked flange, pits, and flow ridges." Compared with the more recently recovered, well-preserved complete buttons from the Port Campbell area (Baker 1961, 1962, 1963a, 1967a, 1968a), the button from the Murray-Darling confluence is much more weathered and much duller in lustre.

In 1968, the author examined the original, which is lodged with specimens of obsidian in the petrological collection of the Geological Survey Museum, S. Kensington, London, with six other australites. It has been significantly corroded by soil etchants, its lustre has been much dulled by some degree of mechanical abrasion (evidently attrition by wind-blown sands), and a number of small facets around the outer edge have been caused by small-scale chipping.

The material attached to the specimen, said by Darwin (1844) to be tuffaceous, is still present. It is jammed into and partially cemented in the gap region (cf. Baker 1959) at the boundary of the flange and core (Baker 1968b). In the opinion of the author, this material is more consistent with a silty to clayey soil.

It varies in colour from greyish to grey-brown and red-brown, and is comparable with the materials constituting the soils of the river plain whence the specimen was recovered, like (for example) the loam on which the core from Hattah, (No. 3, Table 1) was found.

TABLE 2

Data on Australites from the Murray - Darling Confluence Region

	Shape Type	Wt. (g)	S.G.	Diam. or Length	Width mm	Depth mm	Depth Equatorial Zone (mm)	Max. size Etch Pits (mm)
1[a]	Round core	56.67	2.406	D40.5	-	26.9	15.7	2
2	Oval core	52.24	2.416	L42.8	37.2	26.2	-	4
3[ab]	Round core	46.29	2.410	D38	-	25.1	9.5	1.5 x 0.75
4	Dumbbell	32.52	2.407	L73.9	20.8) gibbosities 20.5) 16.9 waist	16) gibbosities 15.8) 13 waist	-	1.8 x 0.75
5[b]	Boat core	26.35	2.422	L48.4	22.6	14 - 17	6.5 - 9	3 x 1.5
6[a]	Boat core	19.50	2.403	L50.5	18.2	15.1	To 9.5	1.5 x 1
7	Oval core	8.73[d]	2.432	L23.7	20	13.7	6.5 - 8.5	1
8	Fractured oval core	7.04	2.401	L25.2	20.6	12	-	1
9	Oval core	5.93	2.419	L21.5	18.7	11.9	-	1 x 0.75
10[f]	Dumbbell	5.25	2.421	L36.9	12.5) gibbosities 11.1) 10.4 waist	9.3) gibbosities 8.2) 7.8 waist	-	0.75
11	Oval core	4.37	2.417	L18	16.3	11.9	8	1.25 x 0.75
12[c]	Incomplete flanged button	4.06[d]	2.384	D21.4	-	9.6	-	0.5
13[c]	Half dumbbell with flange remnants	3.88[e]	2.417	L25.2	16 gibbosity 8.8 waist	9.7 gibbosity 3.7 waist	-	1 x 0.75
14[f]	Button core	3.27	2.390	D19	-	9.5	-	0.5
15	Teardrop	3.14	2.429	L27.1	11.5 gibbosity 5.5 tail	10.5 gibbosity 3 tail	To 6.5 on gibbosity	1
16	Dumbbell	2.01	2.400	L30.3	9.7 gibbosity 7.4 waist	5.9 gibbosity 4 waist	-	1.25 x 0.75

a. Posterior flow swirls 40 x 39 (No. 1), 30 (No. 3), 13 x 6, 36 x 14.5 (No. 6) mm.

b. Etch grooves. To 8 long, 1 wide, 1 deep (No. 3); to 12.5 long, 1.5 wide, 0.75 deep (No. 5) mm.

c. Flange widths 2.5 (No. 12) and 1.5 (No. 13) mm.

d. Total weights including pieces separated off during ultrasonic cleaning. S.G. determined on main pieces weighing 8.42 g (No. 7) and 3.99 g (No. 12).

e. Approximately 7.8 - 8.0 g before fracturing.

f. Anterior surface flow ridges. No. 10 worn down to faintly recognizable structures. No. 12 concentric, becoming wavy by interference towards perimeter. No. 13 worn down, concentric on gibbosity, transverse on waist. No. 14 faint possibly anticlockwise spiral.

Weights and S.G. values determined by Mineralogy Department, National Museum of Victoria.

Weights, Specific Gravity, Dimensions

Only seven shape types are represented from 20 recognized among australites generally (cf. Baker 1959). A noteworthy feature of the assemblage from the Murray-Darling confluence is that elongated exceed round forms in the ratio 4:1.

From Table 2 it is noted that the weight range is 2·01-56·67 g, a round core from Nampoo Station being 28 times heavier than a dumbbell from Merrinee. The total weight of tektite glass is 281·25 g, and the arithmetic average approximately 17·5 g.

The range in specific gravity values is from

2·384 for an incomplete button (Talgarry Station) to 2·432 for an oval core (Nulla Station). The average S. G. is 2·411. No value is sufficiently low to suspect a significant content of internal cavities.

The longest specimen is a dumbbell from Popiltah Station measuring about 74 mm, and the shortest a core from Travellers Lake, measuring 18 mm. The widest specimen is a core from Benetook measuring just over 37 mm, and the narrowest a dumbbell from Merrinee, the widest portions of which are the bulbous ends of up to 9·7 mm. The greatest diameter (40·5 mm) is that of a core from Nampoo Station which also reveals the greatest depth value (nearly 30 mm).

For the unbroken dumbbell-shaped forms (Nos. 4, 10, 16), width and depth measurements are given for both gibbosities (swollen ends). These are significantly greater than width and depth measurements for the constricted waist regions. Minor differences in widths and depths of each pair of gibbosities for a given specimen, are largely a reflection of the effects of erosion (e.g. No. 4). Differences of over 1 mm (e.g. No. 10) more likely point to original small size differences in a pair of gibbosities. The same values for both width and depth for a pair of gibbosities (e.g. No. 16) indicate a high degree of primary dumbbell symmetry and comparable amounts of aerodynamic ablation during the secondary phase of tektite sculpture whilst travelling through the earth's atmosphere at hypersonic speeds (Baker 1958).

The length given in Table 2 for specimen No. 13, is only approximately half that of the unbroken form, since fracturing has occurred virtually across the narrowest part of the waist region.

A feature of the only teardrop-shaped specimen (No. 15) is that width and depth values are not of any great difference for the gibbose portion while the width of the attenuated tail portion is significantly greater than its depth.

There is a distinct rarity of forms with attached flanges or their remnants (Nos. 12, 13), and a complete absence of detached flange fragments. This is a reflection of the significant amounts of erosion to which the smaller specimens have been subjected. Larger forms such as Nos. 1-6, by virtue of their greater size, evidently did not generate circumferential flanges. These specimens have also been subjected to considerable amounts of terrestrial erosion.

Where more clearly defined, measurements could be made of the depths of the flaked equatorial zones on some of the forms, and these are shown in the eighth column in Table 2. The depth of the zone, where present, is measured parallel with the trend of the polar axis (i.e. parallel with AB in Fig. 2) and it extends from the rim at the edge of the posterior surface (Pl. 28, fig. C) towards the front polar regions. The range in zone depth developed on the boat core from near Wentworth (No. 5) from 6·5 mm to 9 mm is due to asymmetry in side elevation (one end is 3 mm deeper than the other). The primary form was evidently also asymmetrical.

Table 2 lists the maximum diameter of etch pits produced by natural solution etching during burial in moist soil. The range is 0·5-4 mm. Few are smaller than 0·5 mm, and all are relatively shallow. They occur on posterior and anterior surfaces and on some flaked equatorial zones, but are never especially common. Some were originally small "chatter marks" of lunate to circular shape, now slightly overdeepened by etching (e.g. No. 2). Sometimes they are a little more common on posterior than other surfaces (e.g. No. 5).

Flow swirls occur on only three of the 16 speciments (Nos. 1, 3, 6). The most interesting is on No. 1, where one large flow swirl showing more or less concentric schlieren occupies nearly the whole of the posterior surface. Only a limited, narrow region of the posterior surface is pitted, and this lies outside the limits of the smoother flow-lined central region of the posterior surface.

Sculpture Features

Most specimens reveal occasional etch pits and flow lines that have been made evident by natural solution etching during an earlier period in their history of terrestrial erosion.

This process commenced after the australites landed and evidently became embedded in moist soils. At a later stage, during periods of soil deflation, they were abraded by wind-borne sand to varying degrees. In this manner, many etch patterns were significantly modified and others obliterated, resulting in a generally worn and dulled character. There is no particular evidence to show that any were eroded in river beds, and no river-worn pebbles were associated with them.

An outstanding etch pattern is revealed by a core from near Hattah in NW. Victoria (Pl. 28). The specimen was cleaned by ultrasonic techniques prior to examination, hence the nature of the soil matrix was not observed. However, it occurred on the red loam surface of a rabbit warren. The etch pattern consists fundamentally of an intricate series of sharply marked etch grooves that have been developed on the posterior surface only.

The grooves are up to 8 mm long and nearly 1 mm deep and 1 mm wide. They are V-shaped in cross section and thus contrast markedly with the general etch grooves on australites, most of which are U-shaped in cross section and straight to sinuous in plan (Baker 1967b, figs. 2-5). As observed in plan (Pl. 28, fig. D), the grooves have acute-angled, bifurcating and trifurcating lateral terminations, except where interference occurs in the polar region. The grooves on other australites most frequently possess rounded terminations (Baker 1967b, figs. 2-5) and occur on anterior surfaces or equatorial zones, seldom on posterior surfaces.

The darker appearance of the grooves in the photographs (Pl. 28, figs. A, C, D) arises from their floors and walls being infinitely fresher in appearance than the surrounding, more eroded posterior surface. The glass of the groove floors and walls has a high degree of vitreous lustre.

Where the grooves are more concentrated towards the central portion of the surface (Pl. 28, fig. A), they link to form a crude interlacing network, but towards the periphery they are independent structures. The floors of some gutters are slightly deeper than others, due to differential etching. The partially radial arrangement of the grooves is not a function of the trends of the internal schlieren, but of the hemispherical nature of the posterior surface (Pl. 28, fig. C).

All the grooves are significantly deeper than earlier-formed (and subsequently partially abraded) micro-etch pits and etched out flow lines (schlieren) which can be readily detected in the enlargement shown in Pl. 28, fig. D. Since these grooves definitely cut across several of the earlier-formed micro-etch pits and distinctly transect the trends of the concentric schlieren (Pl. 28, figs. A, and D), it is evident that they are of much later development. They are, in fact, the last features to have been developed, and are of a nature not commonly present on australites. The only other described specimen with comparable grooves is from W. Australia figured by Simpson (1902, Pl. 38, fig. 1) and showing similar bifurcations and trifurcations.

The two stages of etching reflect climatic change, or transportation by Aboriginals from one climatic zone to another. The earlier developed micro-etch pits and the differential etching of schlieren shown in Pl. 28, fig. D, are regarded as arising from the action of soil etchants with associated soil biota. On the other hand, the etch grooves on the core from Hattah were apparently produced when the posterior surface was exposed at a later period, and could be the result of the solvent action of the hyphal filaments of such organisms as mosses or encrusting lichens. The latter are remarkable for their production of acids (there are over 200 so-called lichen acids).

The only lichen-encrusted australite known (hitherto unrecorded) is a round core from Mt. William in the Grampians, Victoria. The author examined and described this specimen (Baker 1968b), along with other australites in the British Museum (Natural History), London (reg. no. 1926, 394) during tenure of a Nuffield Special Study Grant. Weighing 22 g, this specimen has a specific gravity of 2·395-2·400 (det. Dr. D. R. Chapman), a diameter of 28·7 mm for the spalled core (31·7 mm including the still attached remnant of non-spalled glass), and a depth of 21·2 mm. The label refers to it as being "Lichen-covered". Dried-out lichen could still be observed in 1968; it occupied solution etch grooves and etch pits, especially on the equatorial zone in the vicinity of the still-attached "indicator" remnant, and was firmly attached.

Like the core from Hattah, the round core from Mt. William was generally eroded and in places revealed internal flow line patterns because of light natural etching. The sculpture pattern on the Hattah core (Pl. 28) proves that the etch grooves are of late origin, and not an outcome of high-speed aerodynamic gouging during its atmospheric transit phase.

Fractured Specimens

Four of the australites (Nos. 2, 8, 12-13) have lost significant proportions of their bulk by fracturing. Varying degress of weathering of the fracture surfaces indicate that such fracturing occurred at different stages. On the oval core from Benetook (No. 2) two sets of fracturing at various stages have resulted in the loss of considerable proportions of the tektite glass from one side of the specimen. Age differences for these events are evident from one fracture surface, up to 24 x 14 mm in area, being much dulled through weathering compared with smaller fracture surfaces (up to 17 x 14 mm across) that reveal vitreous lustre and a rippled fracture superposed on the conchoidal to subconchcoidal fracture surfaces.

The dulled fracture surface is of some antiquity, but not quite as weathered as the surrounding non-fractured surface. The high lustre of the smaller fracture surfaces points to much more recent development. The end of the specimen diametrically opposite the more highly lustrous fracture surface reveals a characteristic, almost saccharoidal appearance of chattered and partially shattered glass generated at a pressure point where it was evidently in contact with a hard surface such as a stone, or possibly an anvil. This fracture seems to have been produced by human agency, and the fact that it has been lightly solution-etched points to the probability of fracturing by an Aboriginal rather than a European.

Prior to fracturing, but subsequent to ablation and spallation of the aerothermal strained zone (Baker 1963b), this specimen is estimated to have been some 20 to 30 g heavier, so that its weight would have been in the region of 80 g. The primary biaxial ellipsoid, prior to initial atmospheric entry, would have weighed in the region of 250 g.

The oval core (No. 8) lost the bulk of its anterior surface region through fracturing relatively early in its erosional history. A large conchoidal fracture occurred on the anterior surface, suggesting the possibility of fracturing on impact with the earth's surface on landing. That this may be so, is indicated also by its dull lustre and degree of erosion. If not an effect of impact on landing, then this fracture surface may be a consequence of diurnal temperature changes at a very early stage in the terrestrial history of the specimen. There is insufficient evidence to conclude that it was caused by Aboriginal man.

Of considerably less antiquity is the fracturing of the incomplete flange button (No. 12). This resulted in removal of some of the circumferential flange and a portion of the equatorial regions of the body core. That fracturing occurred relatively recently is indicated by the fairly high degree of vitreous lustre of the fracture surface and by the fact that internal schlieren have only been faintly brought up by light amounts of etching.

Considerable interest attaches to the fracturing of the half-dumbbell with still attached flange remnants (No. 13). Originally a little over 50 mm long (ex-flange), the dumbbell was fractured neatly across the central portion of the waist. The vitreous lustre of the surface has been slightly dulled by weathering, so evidently the fracture is of no great antiquity.

It could have been produced by an Aboriginal, because the broken portion of the constricted waist is bevelled and possibly secondarily retouched by pressure flaking to give a chisel-like edge. The gibbosity of the half-dumbbell is certainly a handy shape for gripping.

Developmental Phases of Etched Core from Hattah

Phases in the diminution of the primary glass

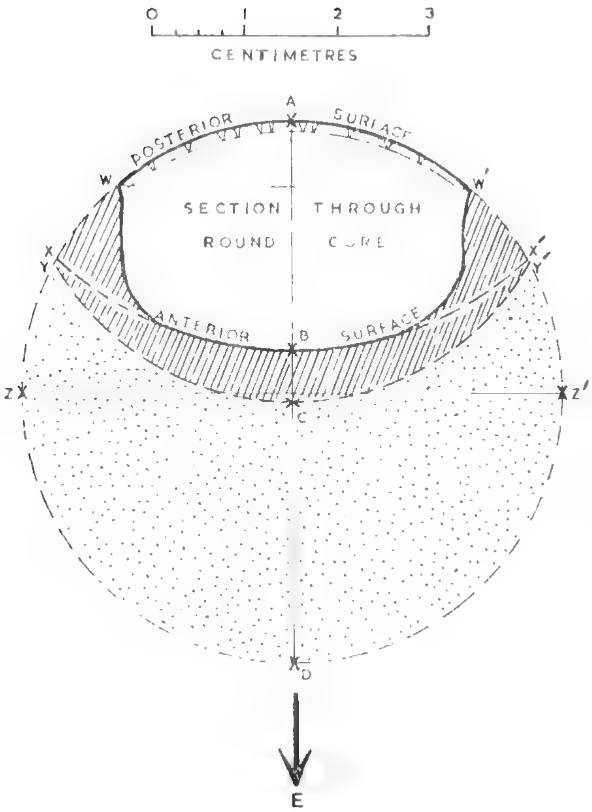

Fig. 2 — Diagram of development of round core from primary sphere of australite glass, based on specimen E4873 from Hattah, Victoria, illustrated in Pl. 28.

sphere from which the remnant round core (E4873) was developed by the secondary process of aerodynamic ablation followed by a tertiary process involving exfoliation and terrestrial weathering, are diagrammatically illustrated in Fig. 2.

The radii of curvature of the posterior and anterior surfaces have been determined graphically from silhouette traces as $R_B = 29\cdot3$, and $R_F = 37\cdot5$ mm. Inasmuch as R_B represents the curvature of the rear part as aligned in stable aerodynamic equilibrium (Fig. 2), and has not been affected by aerodynamic ablation nor severely modified by subsequent terrestrial weathering, the diameter (ZZ′, Fig. 2) of the original parent sphere from which the round core was developed, was approximately 58·6 mm.

Phases in sphere reduction represented in Fig. 2 are:

1. Removal of over 50% of the tektite glass by aerodynamic ablation (cf. Baker 1958), which resulted in the backward migration of the front pole of the specimen from D to C (Fig. 2) and migration of the equatorial regions from ZZ′ to YY′. This represents a loss of 2·9 to 3 cm depth of glass in the stagnation point region (i.e. front polar region) as a consequence of successive thin-film melting, evaporation, and possibly some fusion stripping; as a consequence, the diameter was reduced by approximately 8 mm.

2. Probably during the final stages of subsonic flight through the atmosphere and certainly after earth landing, spallation of the aerothermal strained zone (cf. Baker 1963b) resulted in the loss of a further 10 to 20% of tektite glass. The front pole migrated an additional 0·5-0·6 cm, from C to B (Fig. 2), and the equatorial regions from YY′ to WW′. This left the anterior surface of the round core with the arc of curvature XBX′, whilst also producing a flaked equatorial zone with a relatively sharply marked rim (Pl. 28, fig. C) separating the posterior from the anterior surface, and also producing a slightly recurved silhouette in side aspect, as shown below WW′ in Fig. 2. There was a further reduction of 13 mm in the diameter.

3. Natural solution etching, and some mechanical erosion by wind-borne abrasive particles, gave rise to further but much less significant losses of glass. In this way, the micro-etch pitted and flow-lined portions of the posterior surface (Pl. 28, fig. A) and the micro-etch pitted anterior surface (Pl. 28, fig. B) were produced. Subsequently, much more recent etching, evidently brought about more directly by plant action than by soil etchants, produced the remarkable pattern of etch grooves shown in Pl. 28, (figs. A, C-D), a sculptural pattern confined entirely to the posterior surface. These etch grooves penetrate about 1 mm below the surface as indicated by the Vs and the broken line (below WAW′) in Fig. 2.

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Explanation of Plate 28

Round australite core (E4873) from 16 km NNW. of Hattah Railway Station, NW. Victoria, showing natural solution etch pattern.

Fig. A—Posterior surface (x 2·27) showing intricate, sharply delineated natural solution etch grooves of biochemical origin, superposed upon an earlier-developed etch pattern of micro-pits and concentric schlieren, which had become modified and sometimes obliterated by wind-blown sand abrasion during a period of deflation.

Fig. B—Anterior surface (x 2·13) showing little surface sculpture apart from some micro-pits largely modified by subsequent mechanical abrasion.

Fig. C—Oblique view (x 1·4) showing fairly sharply delineated rim separating the posterior surface (uppermost) from the flaked equatorial zone.

Fig. D—Enlargement (x 4·5) of the later etch pattern of natural solution grooves on the posterior surface, showing sharp, bifurcating and trifurcating terminations. Darker appearance of grooves due to fresher glass than surrounding posterior surface. Etch grooves transect earlier micro-etch pits and concentric schlieren.

(Photographs R.M.I.T.)

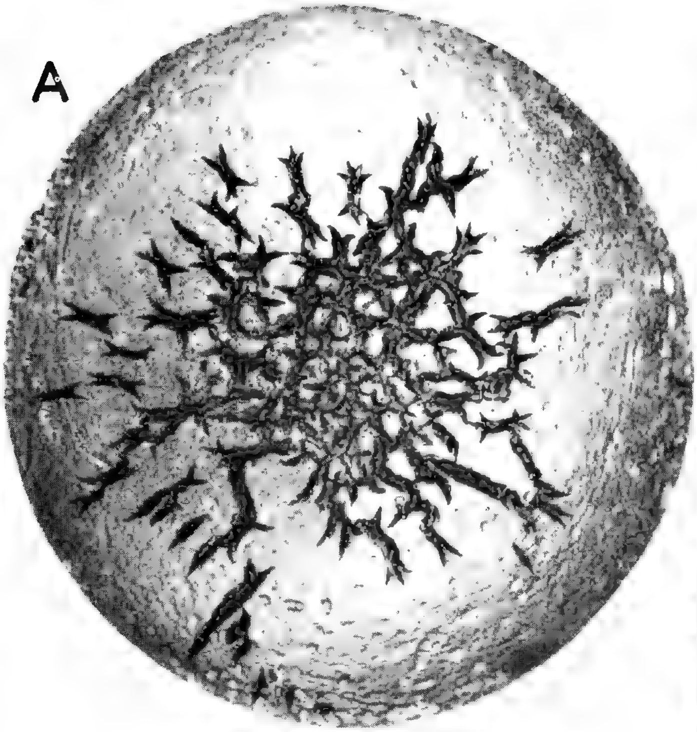
E = direction of movement for sphere in aerodynamic equilibrium moving down the flight path earthwards.
D = front pole of sphere (primary form)
C = front pole of ablated form (secondary form)
B = front pole of remnant core (tertiary form)
A = rear pole common to primary, secondary, and tertiary forms
AD = polar axis of primary sphere (= 58·6 mm)
AC = polar axis of secondary lenticular form (= 30 m)
AB = polar axis of tertiary remnant core (= 25·1 mm)
ZZ′ = diameter of primary sphere (= 58·6 mm)
YY′ = diameter of secondary lenticular form (= 51·5 mm)
WW′ = diameter of tertiary remnant core (= 38 mm)
YCY′ = arc of curvature of anterior surface of secondary ablated form
XBX′ = arc of curvature of anterior surface of tertiary remnant form
WAW′ = arc of curvature of posterior surface of tertiary remnant core

Stippled portion removed by aerodynamic ablation.

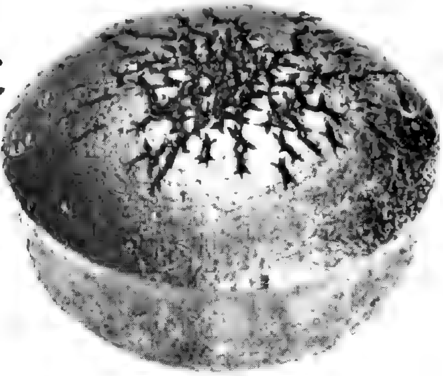
Hachured portion removed by exfoliation of aerothermal strained zone.

Broken line below and parallel with posterior surface represents greatest depth of penetration of etch grooves.

A



C



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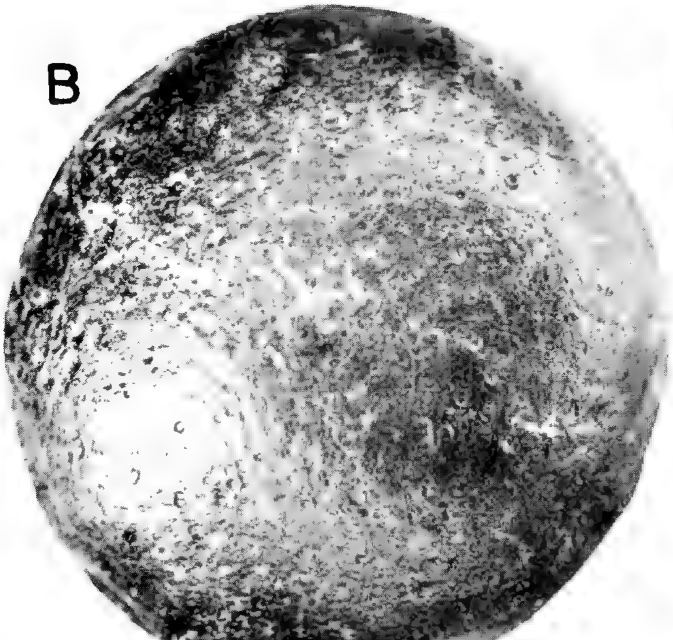
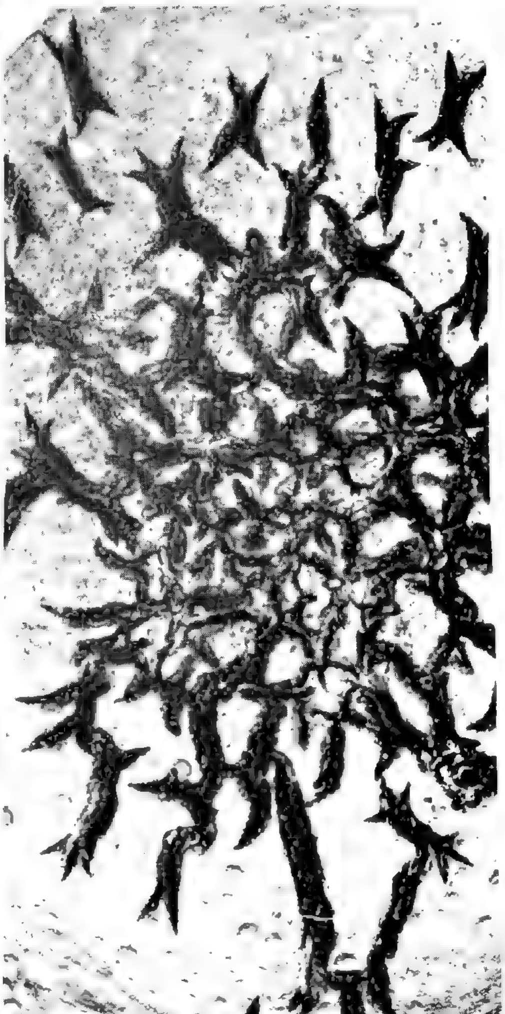


D



ABORIGINAL STONE ARTIFACTS FROM THE MURRAY RIVER REGION BETWEEN MILDURA AND RENMARK, AUSTRALIA

By D. A. CASEY

Honorary Associate, National Museum of Victoria

A large number of Aboriginal stone artifacts from the planned water storage area of the Chowilla Dam and the adjacent country in Victoria and New South Wales was collected during field investigations carried out by the National Museum of Victoria.

This assemblage of artifacts includes flake and core implements unifacially chipped and trimmed, core stones, hammerstones, millstones, mortars and pounding stones. It includes also elliptical artifacts and large ovoid artifacts, both of hitherto unrecorded types and of unknown use.

Classified Artifacts

Amongst these the recognizable types and categories are:

1. *Adze stones* (39 examples). Most are made from irregular pieces of stone and only a few from recognizable flakes. Only two show any similarity to the distinctive *tula* adze flake, and this similarity may well be fortuitous. Many are worn down to the 'slug' shape with pointed ends and step flaking on both margins. They range in width from about 20 to 40 mm. Their average width is 32 mm. Several are highly patinated.

2. *Side scrapers* (2). Discoidal and other types of scrapers are absent.

3. *Flakes and fragments with some secondary trimming* (15). Some may possibly have been intended to be scrapers.

4. *Utilized flakes* (4). Untrimmed flakes with slight chipping of the edge, which may have been the result of use for cutting or scraping.

5. *Highbacked elongate uniface implements* (5). Fig. 1. One is a broken fragment only, and one has an end broken off. Four are of quartzite and one is of sandstone, a material not usually used for flaked implements. They range in length from 9 to 13 cm, and all are about 5 cm wide.

All are similar morphologically, but there are not sufficient examples to claim that they constitute a definite type.

6. *Uniface choppers* (4). Crudely flaked core implements.

7. *Cores.* (a) Horse-hoof cores, of the typical more or less conical shape (7). These examples do not appear to have been used as choppers. (b) Other cores, with one striking platform only (8). (c) Irregular cores, with several striking platforms (12).

8. *Cores or choppers* (11). Crude artifacts that cannot be ascribed definitely to either of these categories.

9. *Hammerstones* (6). As in most assemblages of Australian stone artifacts recognizable hammerstones are few in number.

10. *Millstones.* (a) Lower millstones or fragments of them (9), (b) Upper millstones or fragments of them (16). See also item 14.

11. *Mortars,* with saucer-shaped hollows (15). Four have hollows on both sides. Four have pits or 'anvil' holes, formed by percussion, on the side opposite to the saucer-shaped hollow.

12. *Pestles or pounding stones* (11). All are of the elongate sort, with a pounding surface at one end. This surface is curved, in one direction, presumably as a result of use with a rocking motion. Three of them may have been used also as hammerstones. No examples of the round drum-shaped *kulki* percussion stones were found.

13. *Elliptical artifacts* (3). Artifacts of this type have not hitherto been described. They are approximately elliptical in outline (Pl. 29, fig.

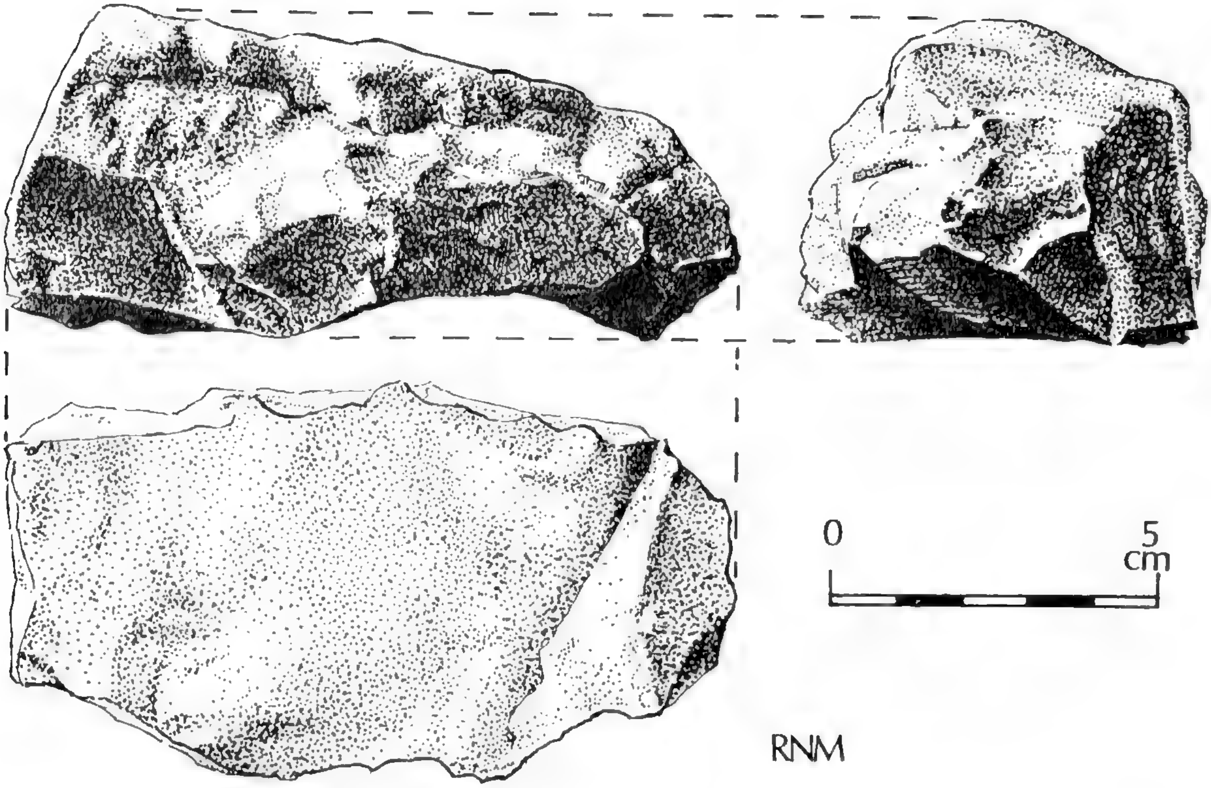


Fig. 1—Highbacked elongate flaked implement, Talgarry Station, Lake Victoria, N.S.W. X76033, reg. no. N.M.V.

1, fig. 2c). Their thickness is small compared to their length or breadth. One or both sides are convex. These examples are 33, 24, and 16·5 cm long. There is one other example only in the National Museum of Victoria, from Langawirra, near Mootwingee, N.S.W. It is 16·5 cm long. In one of them the degree of convexity is approximately the same on both sides. In two it is greater on one side than the other, and in the other, one side is approximately flat. They are not axe-like and have no cutting edge. On all of them the periphery is slightly rounded. All are made from coarse grained ferruginous sandstone. Their surface is markedly rough, and it is not clear whether they have been shaped by hammer dressing or by grinding. The smooth curves of their convex surfaces, however, seem to indicate that they were ground to shape.

Their function is not known. From their form it might be supposed that they are some sort of upper millstone, one or both sides of which have been worn down by use. But there is no real evidence to confirm this, and the coarse grained material from which they are made is not known to have been used for millstones.

It is proposed that this type of artifact be known by the designation here used.

14. *Emu-egg stones* (3). Large ovoid quartzite pebbles about the size and shape of emu eggs (Pl. 29, figs. 2, 3. Fig. 2a, b). In the National Museum of Victoria there are 57 other examples, all from along the Darling River from about Wilcannia to about Pooncarrie and up to about 50 miles E. of the river in the vicinity of Menindee. (Of the 57 examples, 45 are from the Lindsay Black collection of Aboriginal artifacts). These artifacts range in length from about 12 to 18 cm. Many have been hammer dressed over some or the greater part of their surface, presumably to improve their symmetry. Many are beautifully symmetrical. Virtually all have a flat surface, in the middle

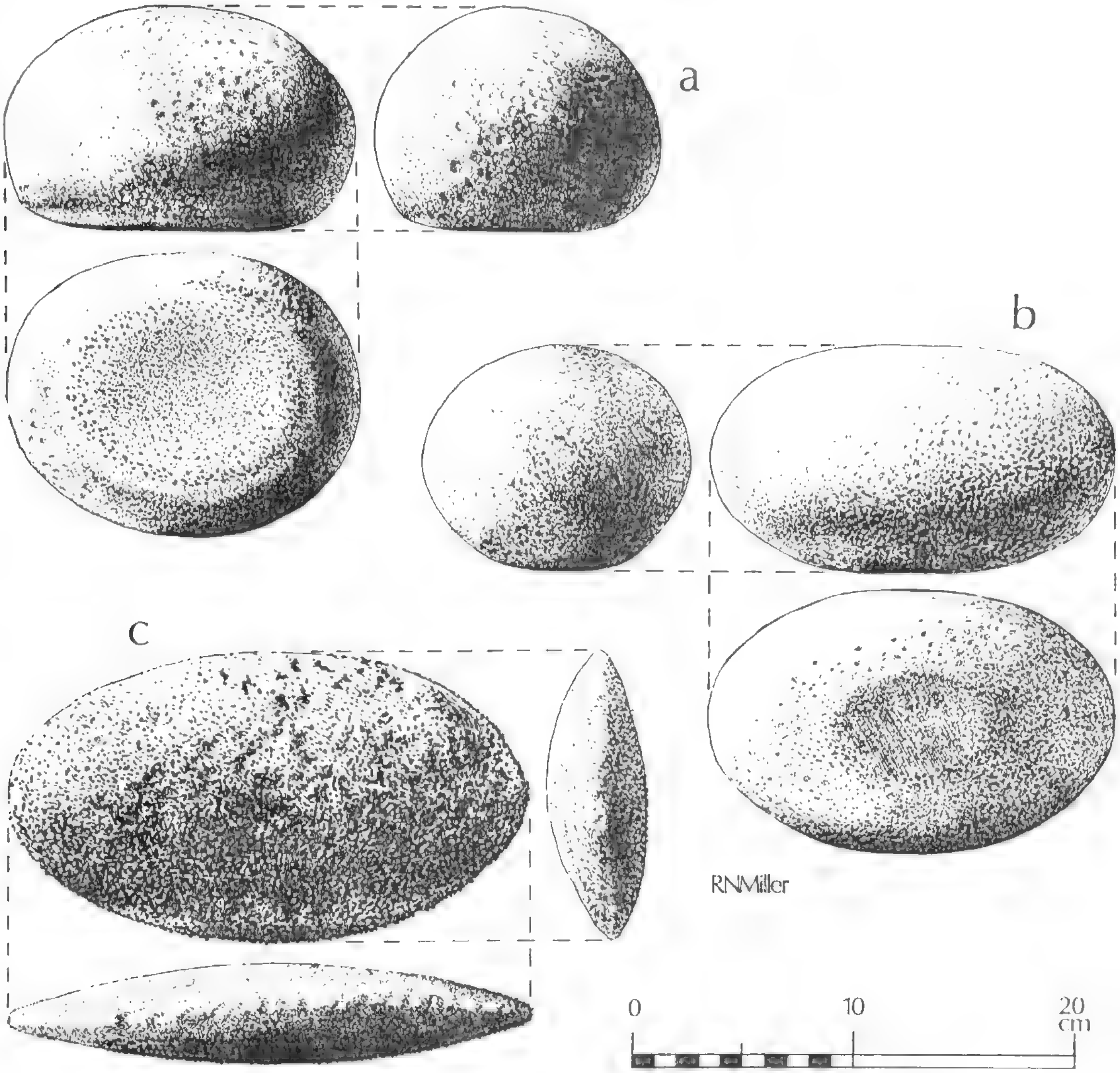


Fig. 2a—Emu-egg stone, Talgarry Station, Lake Victoria, N.S.W. X76033.
Fig. 2b—Emu-egg stone, Albermarle Station, E. of Menindee, N.S.W. X73995.
Fig. 2c—Elliptical artifact, Talgarry Station, Lake Victoria, N.S.W. X76034.

of their longest dimension, on which they could lie without rolling. On most, if not all, of them this is a naturally flat portion of the pebble. On a few examples the flat seems to have been formed or made more regular by grinding, but at least part of the flat surface on many is the natural cortex of the pebble unmodified by hammer dressing or grinding. The flats range in size from about an eighth of the length of the pebble or less, to about three quarters of it. Two or three of the examples from the Lindsay Black collection have no flat at all.

Their function is not known. They do not appear to be implements, and they are perhaps ritual or ceremonial objects. At first sight those with large flat surfaces look as if they were some sort of upper millstone, but none are at all considerably worn down by grinding, and their use for this purpose is thus very improbable.

A few artifacts of approximately the same size as the emu-egg stones, and with similar flat surfaces, but not ovoid in shape, were collected on Talgarry and Nulla Stations, near Lake Victoria. Several of these are of sandstone. They are presumably a massive variety of upper millstone and have been here included in that category.

These artifacts have not been previously described. They are referred to as Emu-egg like stones by Lindsay Black in a manuscript catalogue of his collection. It is proposed that they should be known as Emu-egg stones.

On Flinders Island in Bass Strait, ovoid waterworn granite pebbles have been found in some numbers on Aboriginal camp sites, and elsewhere in the interior of the N. part of the island. Associated with them are mortars with saucer-shaped hollows, pestles and pounding stones, anvil stones, horse-hoof cores, and crude flake artifacts without secondary trimming (Mackay 1946).

The granite pebbles occur naturally only on the sea beaches, and all those found inland must have been taken there by Aboriginals. These range in length from about 12-30 cm. They are notably regular in their ovoid elliptical shape, and they seem to have been selected for this reason. The mortars are made from granite pebbles, but except for these, none of the pebbles has been ground or modified in shape in any way by man. Their function is not known, but they have been found in sufficient numbers to indicate that they served some particular purpose other than that of providing material for the making of mortars.

Flinders Island was, very probably, not occupied by Aboriginals when it first became known to Europeans. The period of Aboriginal occupation is not known. The assemblage of artifacts is typologically not very different from that of the Chowilla area, and although the granite pebbles do not have a flat area anywhere on their surface, they may perhaps be considered as being equivalent to the Emu-egg stones, but this is of course in no way certain.

Unclassified Specimens

As well as the recognizable types and categories of artifacts, a large number of flakes and fragments of stone were collected from many sites within the area. These are of little significance except as evidence of the presence of Aborigines, and as an indication of the various sorts of stone that were used by them. No hard rocks outcrop in the area and therefore all of the material for their stone artifacts must have been brought by the Aborigines from elsewhere. The various sorts of stone used and their probable places of origin are discussed by E. D. Gill in this Memoir.

At two sites, Lindsay Island and E. of the homestead on Berribee Station, fairly large numbers of notably small stone flakes were collected. These are not small blade flakes such as those used in the making of microliths. Accumulations of small flakes are often taken to indicate a scarcity of good stone material and to be the result of every piece having been utilized to the fullest possible extent. However, in this case, it is difficult to understand why large numbers of small flakes should have been found in two localities only.

Nearly all the artifacts collected were found on or near the surface of the ground, so it cannot be assumed that the various types of artifacts were contemporaneous or even that individual examples of them are all of the same age.

Antiquity

It is known from the C14 dates obtained from human bones, and from charcoal associated with middens, that Aboriginals were present in this area up to at least 18,000 years ago (E. D. Gill, this Memoir). It is not possible to say, however, whether any of the artifacts collected do in fact date from this time. Simple uniface flake and core implements existed at a very early period, but they persisted also until recent times. Horse-hoof cores were a very early type but their latest date has not been established. Adze stones were in use at Tartanga on the Murray River in South Australia 6,000 years ago, but they were also in use in central Australia in European times. Nothing is known of the possible age of the Elliptical artifacts. The only artifacts of this assemblage that can be said, with some certainty, to be not quite recent are the Emu-egg stones. These are hammer dressed, and this technique, although it is probably not very ancient, was nowhere in use in Australia in European times. It was associated almost entirely with ground edge implements and it is generally considered that these, with the exception of some found near Oenpelli in Arnhem Land, were a fairly late introduction into the material culture of the Aboriginals.

Although the area was very thoroughly searched, no examples were found of two leading categories of stone artifacts, viz. ground edge axes and microliths. However, one axe was found by a local collector. The area is just beyond the western limit of distribution of ground edge implements in this part of Australia, but it is well within the general area of distribution of microliths and there is no apparent reason for their absence.

Reference

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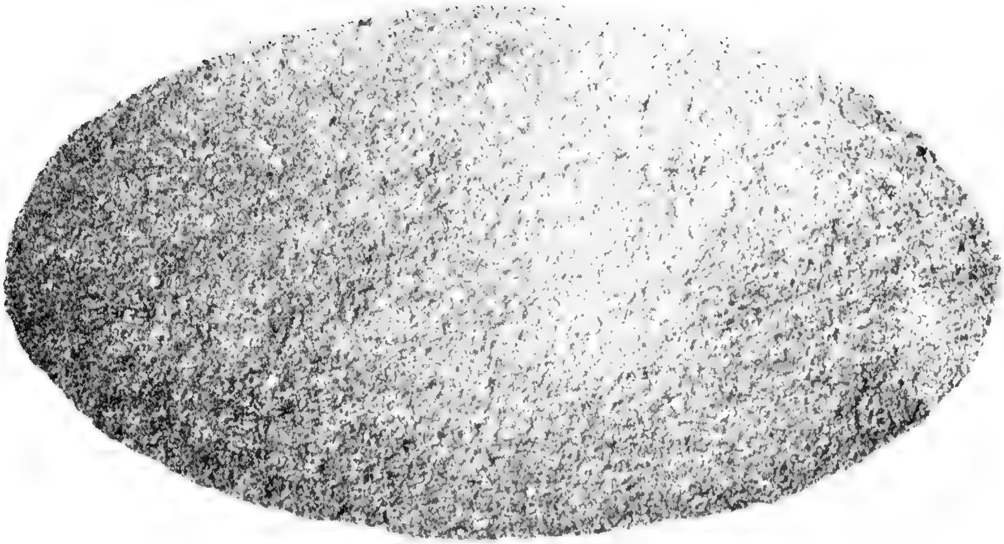
Explanation of Plate 29

All × 1/2.

Fig. 1—Elliptical artifact, Talgarry Station, Lake Victoria, N.S.W.

Fig. 2—Emu-egg stone, Nulla Station, Lake Victoria, N.S.W.

Fig. 3—Emu-egg stone, Albermarle Station, 60 m. E. of Menindee, N.S.W.



1

2

3

ABORIGINAL BONE FISH-HOOKS WITH SKELETONS AT WALLPOLLA CREEK, WEST OF MILDURA, VICTORIA, AUSTRALIA

By Alexander Gallus and Edmund D. Gill

Abstract

Two bone fish-hooks were found associated with an Aboriginal skeleton in a grave on Keera Station on the S. side of the Murray River, NW. Victoria. They are the only fish-hooks known from this region.

Introduction and Acknowledgement

Aboriginal bone fish-hooks have been found in many places in Australia, but in spite of the very large number of Aboriginal sites along the Murray River, and the alkaline conditions for the good preservation of bone in this semi-arid climate, no other fish-hooks have been found in this region.

A trial excavation was carried out at the site in August 1964 on the initiative of Mr J. Pollitt.

Thanks are due to those braving the heat and giving their time to this archaeological work, viz. Messrs. Pollitt, Lawrence, Naughton, Stubbs, Ritchie, Featherstone Sr., Featherstone Jr., Douglas, Williamson, Smith and Fulchare.

The site is shown in Fig. 1. It is near Wallpolla Creek and the River Road, in the SW. corner of Lybra Paddock on Keera Station in the Parish of Tulillah, Victoria. The military map grid reference is Mildura Sheet 483,778, while the latitude is 34° 11′S. and the longitude 141° 45′ E. The site is shown on air photo 5018, Run 3, Wentworth 1364, N.S.W. It is on the W. side of an entry track from the River Road.

Stratification

The site is in the red sediments of a Pleistocene alluvial terrace (named the Rufus Formation by Gill, this *Memoir*) that stands above the greenish gray sediments (Coonambidgal Formation) of the present floodplain of Wallpolla Creek and the Murray River. At the surface of the Rufus Formation is a pedocalcic soil, but at the site this has been stripped to the B horizon. When the site was first visited, fragments of human bones, pieces of freshwater mussel shell (*Velesunio*) and the Aboriginal artefacts were seen protruding from this surface and resting on it. Three layers were distinguished:

Layer 1. Uncompacted windblown red sand, with implements and bones.

Layer 2. Compacted slightly darker red sand, which becomes lighter with depth due to the presence of pedogenic carbonate. This layer contained charcoal, shell and humus.

Layer 3. Compact mottled red sand with carbonate concretions.

Burials

The human burials (part of a multiple grave site) are intrusive into the Rufus Formation. The bones, shells and artefacts collected have been placed in the National Museum of Victoria. Four graves forming a closely spaced group are described.

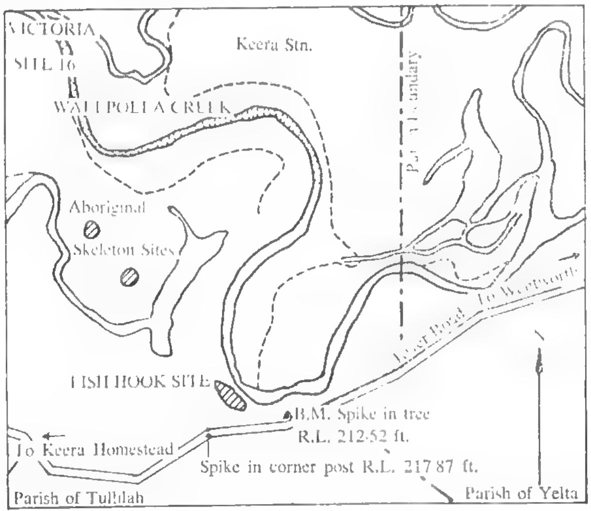


Fig. 1—Locality map.

Grave 1. This contained a flexed burial, with knees drawn up to neck level, but 7·5 cm away. It was disturbed by grave 2. A small pocket of shell occurred outside one elbow, and a large quantity immediately below the skeleton. The shells were more or less complete, but not articulated. Masses of shell under the skeleton were observed at this site associated with flexed burials. The grave was in Layer 3.

Grave 2. This was a pit grave, partly dug into grave 1, and therefore is younger. The skeleton was in a tight bundle placed in a sitting position with knees under the chin. Some of the bones were considerably disintegrated, and no trace of the pelvis could be found. Some shells from grave 1 fell down the vertical walls of this pit.

Grave 3. A partly extended burial with the skeleton on its back, and the head on a shallow ledge. The trunk lay horizontally in the upper part of the pit, but the pelvis and limbs appear to have been pressed into it, the pelvis being turned sidewise. Close to the skull, and underneath it, probably originally on the neck, were the two bone fish-hooks. The hands were on the pelvis. In the lowest part of the grave, near the feet, was a large amount of ash, and some charcoal. This grave also is in Layer 3.

Grave 4. An extended skeleton lying on its back with ankles pressed closely together; skeleton length 1·45 m, width of skeleton across arms 25 cm, and width across pelvis 23 cm. This grave was in Layer 2, and almost at the surface. It is thought that the grave was dug from the surface of Layer 2.

Fish-hooks

Description

The hooks are cut from bone and smoothed in the form of U with uneven sides. The ends of both sides are pointed. The bend of the bone is thicker than the sides. See Plate 30.

Measurements

	No. 1	No. 2
Overall length	43 mm	37 mm
Centre-line of U	12 mm	27 mm
Longer side	31 mm	10 mm
Shorter side	5 mm*	10 mm
Width of hook through concave surface of U	15 mm	14 mm

*(tip missing)

Morphologically, the fish-hooks are of the samolov type, and the nearest prehistoric parallels belong to the Mesolithic (Kjökkenmöddingen, Maglemose Period, Norway, and Natufian, Palestine. Rohan-Csermak pp. 68-91 and Pl. XVII, Nos. 1-3, 1963, and Clark 1967, p. 113, Illus. 788).

Massola (1956) describes recent Aboriginal fish-hooks from the coastal regions of Australia, but they are different from those found in grave 3. On the other hand, the recent use of the samolov type is known from New Guinea (Rohan-Csermak 1963, Pl. XVII, No. 4).

One of the hooks from the Wallpolla Creek shows roughened sulcate area lengthwise across the surface of the bend (Plate 30), which is probably caused by weathering, but may be compared with a structure in this part of the Eurasian sturgeon hooks, which were floated in the water without bait (Rohan-Csermak 1963, Figs. 54, 60 and 78), an attachment (to a weight or the bottom) being responsible for the wear at this point.

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Explanation of Plate 30

Fig. 1—General view of the excavation at the fish-hook site on Wallpolla Creek, N. Victoria.

Fig. 2—Close-up of skeleton on right side of Fig. 1. The fish-hooks were associated with these remains.

Fig. 3—The bone fish-hooks.


1


3


2

AN ABORIGINAL CACHE OF FRESHWATER MUSSELS AT LAKE VICTORIA, NEW SOUTH WALES

By K. N. G. Simpson and Sir Robert Blackwood

On 20 September, 1968, Simpson discovered an unusual accumulation of freshwater mussel (*Velesunio ambiguus*) shells, newly exposed by erosion in the sands of the lunette on the E. side of Lake Victoria, Talgarry Station, New South Wales.

Unlike the many other mussel shell concentrations found in the district during the course of the Chowilla Project, this group was well organized, did not comprise single valves and was obviously not a midden deposit. All the valves were in pairs, not gaping, and had been alive when buried. A number of shells had fallen away from the group since it was exposed, but those that remained were neatly stacked, horizontally oriented, in a close-packed and generally rounded group which measured c. 33 x 51 x 20 cm (Pl. 13, fig. 6).

Within the mass, the shells were stacked in 12 to 13 layers, each layer containing 25 to 30 shells. Assuming 28 shells in 13 layers, the total number present, not counting those fallen away, is in excess of 360.

The mussel shells were of the rounded, symmetrical lacustrine form, clearly separable from the longer-valved asymmetrical riverine form (McMichael and Hiscock 1958, p. 382). External surfaces of many valves were flaking, and were pitted, due to weathering.

The group of shells was buried at a depth of c. 80 cm below the modern sand surface at the side of a deflation hollow (7/8 S. of the pegged sequence of gulches) and intrusive into the Talgarry Sand (Gill, this *Memoir*) on Talgarry Station, New South Wales. The depth from the original dune surface was almost certainly greater than 80 cm.

We interpret the buried mussels as an Aboriginal food store or cache. It indicates that mussels were not always eaten as soon as collected, but sometimes stored for future use. Just how widespread this custom was, remains to be discovered. Dr I. D. Hiscock (Zoology Department, Monash University) has had mussels out of water (in a cardboard box in a laboratory) for 6 years with a high percentage of survival. Certainly the species could easily live without submersion for weeks to months, especially if buried deeply in damp sand.

To collect 360+ mussels probably would not take very long, given a normal abundance. As illustration, Hiscock and two other persons collected 600 mussels in one hour, from a shallow stretch of the Little Murray River near Swan Hill, Victoria, April 1972. Hiscock has an advantage in that he studies freshwater mussels professionally, and is skilled in their location and collection. In his experience mussels tend to be less abundant in lakes and lagoons than in the rivers. He concedes that Aboriginals should be even speedier in collecting mussels under natural conditions in their own territory.

We suggest that other anthropological workers look for the difference (ecophenotypic variation) between the lacustrine and riverine forms of *Velesunio ambiguus* shells. The general source of the mussels can thus be determined, and there may be occasions when this information would be useful.

The cache was excavated and coated externally with 'Aquadhere' prior to its removal as a display specimen for the National Museum. Unfortunately, before it was sufficiently dry for removal, torrential rain caused its collapse; the shells were then simply brought back loose.

We thank Dr I. D. Hiscock for checking a draft of this paper.

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MAGNETIC DATING OF SOME ABORIGINAL FIREPLACES FROM THE LAKE VICTORIA REGION, N.S.W.

By MICHAEL BARBETTI

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When oven stones and the soil underneath are heated in an Aboriginal fireplace, any weak magnetization they may already possess is destroyed. As they cool again after the fire has been extinguished, a new magnetization is frozen in; this remanent magnetization is exactly in the direction of the Earth's magnetic field and its intensity is directly proportional to the strength of the Earth's field. Careful measurement of the intensity or the direction of remanent magnetization makes it possible to estimate the age of an ancient Aboriginal fireplace by comparing the results with known changes of the ancient geomagnetic field in that region.

During the past few thousand years there have been significant changes in both the direction and intensity of the geomagnetic field. In general, variations in the *direction* are quite different for places a few thousand kilometers apart (Aitken and Weaver 1965), so it is not possible to use data from one place to estimate the variation in another part of the world. On the other hand, variations in the *intensity* of the geomagnetic field are essentially the same, and previous measurements from other parts of the world can be applied elsewhere.

Data on ancient changes in the geomagnetic *direction* is not available from SE. Australia, so it is not yet possible to use this method of dating. However, sufficient data has been collected from other parts of the world to define global changes in geomagnetic intensity, and this paper describes how estimates of the ages of some Aboriginal ovens were obtained using this data. The locations of the ovens and types of material are given in Table 1.

A method of determining the ancient geomagnetic field intensity from baked clay was first described by Thellier and Thellier (1959), and the theory is straight-forward. Thermoremanent magnetization is acquired by baked clay containing a small percentage of magnetic minerals as it cools from the Curie temperature (675°C for haematite) in a magnetic field. The partial thermoremanent magnetization acquired in any given temperature interval (for example, between 450°C and 400°C) is independent of

TABLE 1

DETAILS OF OVENS

Oven	Location†	Material analysed	Comment
CHA 10	site 2, Keera Station, V.	baked clay ovenstone	Aboriginal oven on surface
CHA 27	site 5, Keera Station, V.	baked clay ovenstone	Aboriginal oven on surface
CHA 203	Near Dickies gate, Scrub paddock, Kulcurna Station, N.S.W.	two pieces of baked sandstone	Aboriginal oven on surface (nearby oven has radiocarbon age 1930 ± 80 B.P., Gak-2007, Gill 1973).
CHA 332	outlier 3, Dunedin Park Station, N.S.W.	baked clay ovenstone	Aboriginal oven set in hardpan

† For description of location see Gill (1973).

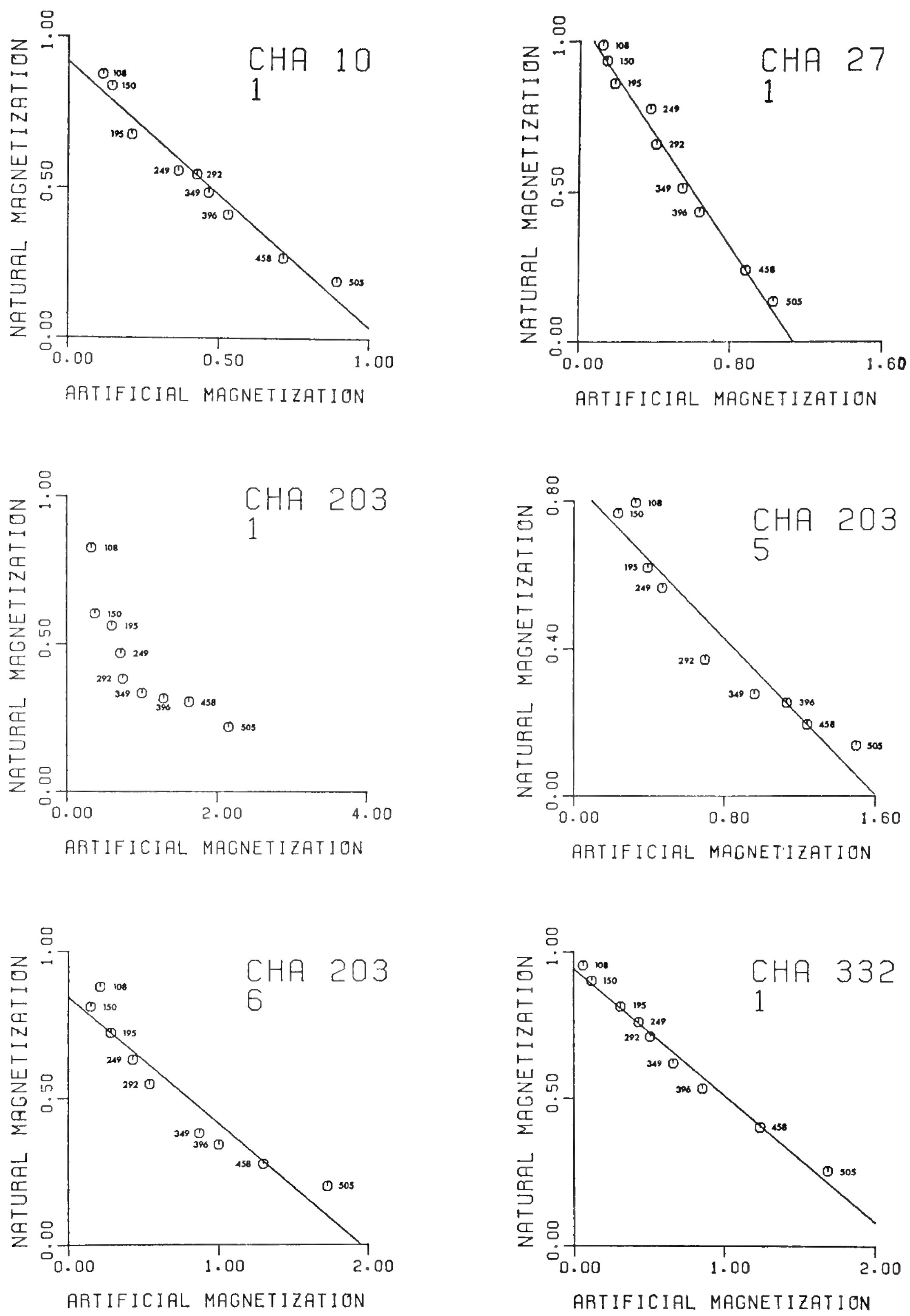

Fig. 1—Partial natural vs. partial artificial magnetization after each double heating. All values are normalized with initial total natural magnetization taken as unity. Numbers near points refer to heating temperatures (°C).

magnetization acquired outside that interval. In weak magnetic fields, such as the Earth's, the intensity of magnetization is linearly dependent on the field intensity.

In the laboratory, the natural magnetization is gradually removed by controlled heating and cooling cycles, repeated twice for each temperature, at successively higher temperatures. After the first heating, the specimen is cooled in the absence of a magnetic field, and the remaining natural partial magnetization is measured. The specimen is reheated to exactly the same temperature and cooled in a known weak magnetic field to give it an artificial partial thermoremanent magnetization in addition to the remaining natural partial magnetization. The double heatings are performed at progressively higher temperatures until the natural magnetization has been reduced to about a tenth of its original value (typically at about 550°C). For each temperature interval the ratio of the intensities of the ancient geomagnetic and laboratory magnetic fields is equal to the ratio of the intensities of the natural and artificial magnetizations.

One method of analysing the results thus obtained is to construct a graph of the partial natural magnetization remaining after the first cooling plotted against the partial artificial magnetization acquired during the second cooling, for each pair of heating and cooling cycles, and to calculate the best-fitting straight line by the method of least squares. The absolute value of the slope of this line is the ratio of the ancient geomagnetic and laboratory magnetic field intensities (Coe 1967).

Figure 1 shows the results from representative specimens and Table 2 summarizes the data obtained in this study. Most of the specimens (2·2 cm x 2·2 cm cylinders) exhibited linearity in the relationship between natural and artificial magnetization. However, three specimens of baked sandstone gave highly non-linear results (for example, CHA 203/1) because of magnetic instability, and no meaningful straight line could be fitted. Three other specimens of sandstone which seemed to exhibit linearity (for example, CHA 203/5 and 6) give significantly different values for the ratio of the ancient field intensity to the laboratory field, and the results were therefore rejected. Results from all specimens of baked clay showed good linearity, and five specimens from one oven stone (CHA 332) gave very consistent ratios from which a mean has been calculated. Ancient field intensities were obtained for three of the four Aboriginal ovens sampled (Table 2).

Since the intensity of the geomagnetic field varies slowly with latitude (the intensity at the

TABLE 2

SUMMARY OF ANCIENT FIELD MEASUREMENTS (WITH STANDARD ERRORS)

Oven	Specimen	Least squares ratio $F_{\text{ancient}}/F_{\text{lab.}}$	Mean ratio $F_{\text{ancient}}/F_{\text{lab.}}$	Ancient field intensity (oersted)
CHA 10	1	0·881 ± 0·078	0·881 ± 0·078	0·522 ± 0·046
CHA 27	1	0·936 ± 0·050	0·936 ± 0·050	0·555 ± 0·030
CHA 203	1	magnetically unstable	results from different specimens do not agree	—
	2	magnetically unstable		
	3	0·616 ± 0·057		
	4	magnetically unstable		
	5	0·529 ± 0·070		
	6	0·432 ± 0·062		
CHA 332	1	0·431 ± 0·024	0·438 ± 0·010	0·260 ± 0·006
	2	0·446 ± 0·027		
	3	0·445 ± 0·020		
	4	0·437 ± 0·027		
	5	0·432 ± 0·020		

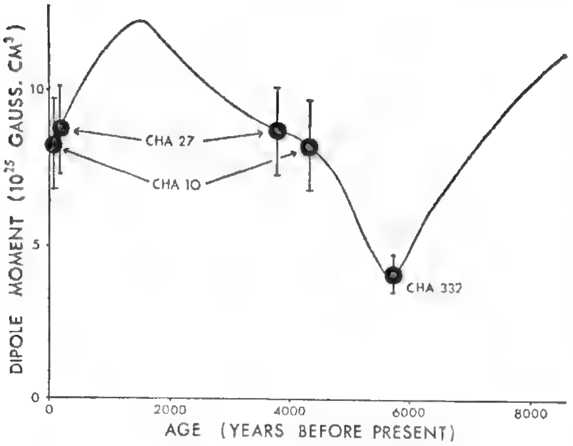

Fig. 2—Variation of geomagnetic dipole moment with time (solid line) after Cox (1968). Points for each oven show where their estimated GDM may be placed on the curve.

magnetic poles is approximately twice that at the magnetic equator), it is necessary to have some way of directly comparing ancient field intensities from different magnetic latitudes. A suitable method is to calculate the moment of a dipole at the centre of the Earth which would have produced the measured ancient field intensity at the site. In order to do this it is necessary to know the ancient magnetic latitude of the site. When the magnetic palaeolatitude is not known (as in this study) it is best to assume that it is the same as the present magnetic latitude because, although it has been suggested that the best-fitting dipole to the Earth's magnetic field has moved in the past few thousand years (Kawai and Hirooka 1967), there is not sufficient data to allow a correction to be made. The equivalent dipole calculated by this method is termed the *Reduced Dipole Moment* (RDM) (Smith 1967). However, although the Earth's magnetic field may be closely approximated by that of an inclined geocentric dipole, small irregularities (usually termed the non-dipole field components) may have contributed appreciably to the observed field at a particular time and place. Consequently, several RDM values from different parts of the world must be averaged to find the value of the *Geomagnetic Dipole Moment* (GDM) at any given time in the past. Smith (1967) compiled all available measurements of RDM and these were averaged in 500-year class intervals by Cox (1968) to obtain GDM values for the last 8,500 years. An examination by the author of the scatter of RDM values from the appropriate GDM value suggests their standard deviation is about 15 per cent. Figure 2 shows the variation of GDM for the last 8,500 years (after Cox 1968).

Table 3 gives the RDM values calculated from the measured ancient field intensity, assuming a palaeolatitude equal to the present *magnetic* latitude of the Lake Victoria region (48°S). In addition to the experimental error, a further 15 per cent variation has been allowed in the RDM value to obtain an estimated GDM for each of the Aboriginal ovens.

Provided only that there is no possibility that CHA 332 is older than 8,500 B.P., then a comparison of the estimated GDM with the curve (Fig. 2) indicates an age of 5,700 ± 300 B.P. The oven was set in a hardpan which is interpreted as the A2 horizon of a soil, and the indicated age is in good agreement with a

TABLE 3
AGES OF OVENS

Oven	Reduced Dipole Moment (10^{25} gauss. cm^3)	Estimated Geomagnetic Dipole Moment (10^{25} gauss. cm^3)	Age limits at 68% confidence level (yrs. B.P.)	Age limits at 95% confidence level (yrs. B.P.)
CHA 10	8·24 ± 0·73	8·24 ± 1·44	0–400 *OR* 2950–4800	0–800 *OR* 2150–5200
CHA 27	8·76 ± 0·47	8·76 ± 1·40	0–500 *OR* 2700–4750	0–1000 *OR* 1950–5100
CHA 332	4·10 ± 0·09	4·10 ± 0·62	5400–5950	5250–6200

radio-carbon age of 5,840 ± 90 B.P. (Gak-1429) from charcoal among Aboriginal skeletal remains excavated from a similar depth at Keera Station (Gill, pers. comm.). The other two ovens (CHA 10 and CHA 27) were situated on the present surface above the hardpan, but even assuming that they are younger than CHA 332 there are two possible ages for each (Fig. 2). Table 3 gives their possible age limits at the 68 per cent (one standard error) and 95 per cent (two standard errors) confidence levels; however, these limits should be regarded with caution, since in each case an RDM has been obtained using only one specimen. Perhaps the best conclusion is that neither oven is likely to have an age between 1,000 and 2,000 B.P.

Acknowledgements

The results presented here were obtained in the initial stages of a research project in archaeomagnetism. The author would like to thank Dr M. W. McElhinny for guidance and encouragement, Mr E. D. Gill for discussion and collection of samples and Dr A. J. Barbetti for writing the computer program used for data reduction and presentation of results.

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EXAMINATION OF FLINTS BY INELASTIC SCATTERING OF PROTONS

By N. E. Whitehead

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Inelastic scattering of protons is a recent technique which uses a proton beam from an accelerator to measure the amounts of various light elements, being mainly useful as far as silicon (Sippel and Glover 1960).

This study is an attempt to compare flints from the proposed Chowilla dam area with those found in various areas associated with Mt. Gambier.

Principle

When a proton strikes a nucleus and is re-emitted with low energy, the nucleus remains in an excited state for less than 10^{-12}s, and on its return to the ground state emits gamma rays, the energy of which is only a function of the isotope involved. Thus two isotopes of the same element will emit different gamma rays. These gamma rays can be detected with suitable instrumentation and used to give information about the chemistry of the sample.

The different isotopes have different energy levels, and some, which are low, are well suited for analytical work, since it requires little energy to excite a nucleus sufficiently for them to be occupied. Another factor requiring consideration is the means of excitation. Gamma rays, atomic particles, and in some cases even energetic X-rays can be used for excitation, but only atomic particles, like protons, deuterons and alpha particles give a radiation background sufficiently low to be analytically useful if trace analysis is being considered. Protons are best for this work, because other particles tend to react with the nucleus in different ways, giving other gamma ray peaks which confuse the analysis.

Protons have a charge of +1, and considerable energy is required to make them strike the nucleus, which is also charged. This problem becomes greater the heavier the nucleus, and it will be seen that this type of analysis, for a fixed proton energy, will be largely limited to the light elements.

Other features of the analysis include its relatively non-destructive nature (since the nuclei all fall back to the ground state they originated from) and the fact that the technique is essentially limited to surfaces. This arises because the protons are very easily stopped by a thin layer of atoms. In the case of the 3 MeV beam of protons used in this work, they have a range of approximately 40 microns in the average siliceous material. This places stringent demands on homogeneity of specimens or demands a number of replicate analyses on different parts of the sample.

Procedure

Specimens were mounted on aluminium backing plates and subjected to a beam of about 0·5 microamp of protons for eight minutes. The energy of the beam was 2·95 MeV and its diameter (controlled by magnetic lenses) was kept large (0·5 cm) to cut down the influence of sample variability. The samples were irradiated in a vacuum of 10^{-4} torr.

Gamma rays from the specimen emerged from the sample chamber through a mylar window and were detected by a lithium-drifted germanium detector of volume 5cc. An Ortec preamplifier and 410 amplifer were used to shape the pulse that resulted and the gamma ray spectrum was stored in a 4096 channel analyser, divided into eight 512-channel segments. All elements were hence recorded simultaneously. A pulser was set to produce pulses which were fed into the detector system and back into the spectrum. The peak that resulted was used for electronic stabilisation of the system, and simultaneously afforded a method of allowing for deadtime in the electronics.

The current of protons reaching the electrically isolated target chamber was converted to pulses (at the rate of 10^{-8} coulombs per pulse) by an Ortec current digitiser and the number of pulses recorded in a scaler. The output from this, the time taken, and the number of pulses fed into the detector system from the pulser were automatically punched out onto paper tape at the end of each run.

The derived spectra were dumped electronically from the memory of the multichannel analyser to a PDP-8 computer and the areas under the observed peaks calculated via programmes written for the purpose. The paper tape was also fed in, and the spectra were all normalised to constant current reaching the target. This procedure has better than 0·1% accuracy.

U.S. Geological Survey Standard rocks were used as standards for the irradiation. The supplied powders were compressed under 25 tons to a self-supporting slab, and from the known analyses it was possible to derive, by the plotting of calibration curves, absolute analysis figures for the flints. The individual points on the graphs were shown reproducible to a few percent.

Silicon did not yield a meaningful calibration curve, showing a vastly increased yield of gamma rays with content of silicon. It is in any case a major element and would presumably not show very great changes from one sample to another.

Samples Analysed

The Mount Gambier Limestone in SE. South Australia has a large quantity of good quality flint. This was utilized by the Aboriginals, who traded it over hundreds of miles. It is not uncommon in N. Victoria, but its distribution suddenly ceases at the Murray River valley tract. The tribes associated with this valley between Mildura in Victoria and Renmark in S. Australia did not use this flint, but preferred the local common opal. Thus, during the Chowilla Project of the National Museum of Victoria (Melbourne), only one flint artefact was found among the thousands that were examined. The present test was applied to see if it could be proved that the flint of this artefact came from Mt. Gambier area. Marine fossils in the flint showed that this could be so.

Reg. No. M14458A Location: Port Macdonnell, 26 km S. of Mt. Gambier, S. Australia.
Reg. No. M14458B Location: Port Macdonnell, 26 km S. of Mt. Gambier, S. Australia.
Reg. No. M14458C Location: Port Macdonnell, 26 km S. of Mt. Gambier, S. Australia.
Reg. No. M25360 Location: Port Macdonnell, 26 km S. of Mt. Gambier, S. Australia.

These flints samples were from the mineralogical collection of the National Museum of Victoria, and were kindly supplied by Dr. A. W. Beasley.

Reg. No. X34381 Portland (collected 1927).
Reg. No. X76430 Lake Bonney, S.A. (Collected 1969).
Reg. No. X76431 Blackfellows Caves, S.A. (Collected 1969).
Reg. No. X76433 Cape Banks, S. A. (Collected 1969).
Reg. No. X76434 L. Bonney, S.A. (Collected 1969).

Sample No.	F(ppm)	Na(ppm)	Li(ppm)	Al (as % Al_2O_3)
Chowilla	210 ± 100	630 ± 40	less than 1	0·23 ± 7
M14458A	16·3 ± 2·5	542 ± 29	less than 1	0·239 ± 0·058
M14458B	413 ± 16	4800 ± 80	0·2 ± 0·6	0·89 ± 0·11
M14458C	23·0 ± 4·1	270 ± 9	less than 0·2	0·084 ± 0·016
X34381	59·1 ± 2·6	341 ± 14	1·0 ± 0·12	0·135 ± 0·023
X76430(i)	17·75 ± 0·05	710 ± 40	0·2 ± 0·3	0·066 ± 0·027
X76430(ii)	less than 7	1270 ± 40	0·19 ± 0·33	0·187 ± 0·06
X76434	less than 7	3090 ± 100	less than 0·9	0·38 ± 0·17
X76431	14·4 ± 2·6	376 ± 14	0·001 ± 1·10	0·059 ± 0·023
X76433	18·6 ± 1·6	0·049 ± 0·003	less than 0·1	0·081 ± 0·008

These flint samples were from Aboriginal implements in the National Museum of Victoria, and were kindly supplied by Mr. A. L. West.

Results

The results are reported in general as the mean of a number of determinations on the sample. The error quoted is the standard deviation of the mean ($\sigma/\sqrt{v}$) where sigma is the standard deviation of distribution and v is the number of determinations. Only the presented elements gave measurable analysis figures.

For sample X76430(i) and (ii) the two results are from areas 1 cm apart and show, for the fluorine figures especially, the extreme variations that may be encountered. It is of interest that the next tabulated figures for X76434 are from the same area (Lake Bonney). The material is quite heterogeneous even on a macroscopic scale. To demonstrate this more fully, the results below are those obtained 0·5 cm apart on a traverse across specimen M14458C.

This is why a large number of results must be averaged to obtain a reliable figure.

Conclusions

It is clear that if the Chowilla flint is compared with a selected flint from Mt. Gambier it could be considered as significantly different, but when the overall range is considered, the hypothesis that the Chowilla flint originated in that area is perfectly consistent with the data, although its fluorine content is on the high side of the distribution.

It is not possible from the above data to state definitely where the Chowilla flint originated, assuming it is indeed from the area represented by the other specimens, but it would seem that the Blackfellows cave area is most unlikely in view of the fact that that specimen alone (X34381) has a significant amount of lithium in it.

The severe heterogeneity of the flint material submitted is in marked contrast to obsidian material from various places in New Zealand (Coote et al.). Inthe latter case obsidian may remain homogeneous for a distance of several kilometres. This is probably because a volcanic melt is significantly more likely to be mixed than a sedimentary material.

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Position	F(ppm)	Na(ppm)	Li(ppm)	Al (as % Al_2O_3)
1	41·6 ± 7·3	275 ± 23	less than 0·2	0·096 ± 0·039
2	19·8 ± 7·9	260 ± 30	less than 0·23	0·119 ± 0·043
3	19·3 ± 7·9	270 ± 30	0·1 ± 0·2	0·011 ± 0·043
4	11·2 ± 7·8	250 ± 30	0·1 ± 0·2	0·063 ± 0·042
5	21·2 ± 7·0	250 ± 20	0·17 ± 0·20	0·102 ± 0·039
6	25·3 ± 8·4	310 ± 30	0·15 ± 0·28	0·111 ± 0·055

FISSION TRACKS AND URANIUM IN AUSTRALIAN OPALS

By Robert McCorkell

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Abstract

An attempt to determine the geological age of four opal specimens by the fission track method has failed, although features believed to be fission tracks were seen in one etched, irradiated specimen. Uranium concentrations of 0·1-11 ppm were measured in the specimens. This uranium was never found to be associated with inclusions. Such concentrations and manner of distribution of uranium in these opals considerably increases the possibility that other hydrous-silica mineraloids may be datable by the fission-track method.

Introduction

In an effort to throw light on the chronology of strata in the Murray Basin of Australia, the National Museum of Victoria forwarded samples of common opal from a paleosol estimated to be of the order of 2,000,000 years old with the request that fission track dating be attempted. This was not successful, but the data obtained are provided. In this *Memoir* the geology of the area is described by Gill, and the mineralogy of the opal by Segnit, Jones and Anderson, thus providing a background for the notes here presented.

Samples

In the Murray Valley region between Mildura and Renmark in Australia an extensive paleosol associated with the Karronda surface has been described. It usually appears in the stratigraphy as a zone of silcrete or silicified sandstone, but where it is formed on clays the silica is in the form of common opal. This was used for implements by the Australian Aboriginals, who scattered it widely through the area. The opal deposits are particularly well developed on the N. bank of the Murray River at Sharp Point on Nampoo Station, between the S. Australian border and Wentworth, where the Darling River joins the Murray. The cliff is about 37 m high, and the palaeosol is near the base. A lacustrine formation, the Blanchetown Clay, forms most of the cliff. The palaeosol is unusual here in that it consists of two horizons associated with thin lenticles of dolomite less than 1 m thick. A sample was provided from each of these lenticles, and to them were added two samples provided by Professor H. B. S. Cooke of Dalhousie University from precious opal sites, as follows:

No. 1. Common opal from upper bed with dolomite in Blanchetown Clay, Nampoo Station, N.S.W.
No. 2. Common opal from the lower bed at the same site.
No. 3. Opal from Coober Pedy, S.A.
No. 4. Opal from Quilpie, Queensland.

Method

Pieces of opal from the above four samples were irradiated for 10 mins. and 2 hours in a flux of $1 \cdot 2 \times 10^{13}$ n/cm²—sec., and then mounted in epoxy and polished. Unirradiated samples were similarly mounted and polished. In addition, mounts consisting of discs of Lexan pressed against polished surfaces of the opals were irradiated for two hours in order to measure the uranium contents of the opal by the Lexan-overlay method. The mounts containing the opals in these cases contained pieces of glass of known uranium content.

Results

The polished irradiated opals were etched in various ways, but fission tracks were seen in only one case. This was in No. 4, when it was etched 10 seconds with 22 wt. % HF at room temperature. The tracks in this are not uniformly distributed but occur in rounded patches which are found rather infrequently in the clearer parts of the specimens. These patches are usually a few hundred microns across and contain a few hundred tracks. Although I believe the features are fission tracks they appear rather short and broken and would be difficult to recognize if they occurred singly. They do, however, have a tubular shape and a 3rd dimension and are not found in the unirradiated opal. Within the patches they are randomly oriented and do not radiate. The patches are quite sharply terminated but are not distinguished from their immediate surroundings in any way except in possessing fission tracks. One of these areas of tracks is shown in the plate.

No fission track-like features were found in any of the unirradiated opals.

The Lexan overlays were etched 8 minutes in 6M NaOH at 70°C. The ratio of the track density in the Lexan facing the mineral in the epoxy mount to that in the Lexan facing the standard glass gives the uranium concentration in the mineral:

$$\frac{\rho \text{ in Lexan facing mineral}}{\rho \text{ in Lexan facing glass}} = \frac{[\mathrm{U}] \text{ mineral}}{[\mathrm{U}] \text{ glass}}$$

Where ρ = track density or number of tracks per unit area. The 'background' track density due to uranium in the Lexan itself proved to be negligibly small. In this particular Lexan the tracks proved to be, in general, rather misshapen, perhaps because of strains introduced into it during manufacture. However, because only a ratio of track densities is needed for the uranium measurement, one is free to restrict himself to counting only certain types of track-like features, i.e., those which are well formed and are clearly fission tracks, provided he uses the same criteria in evaluating ρ (sample) and ρ (standard). In this case I counted only those tracks which showed a clear 'head' and 'tail' and were clearly 3-dimensional, i.e., were not surface features.

The following data on uranium concentrations and distributions were obtained:

No. 1. In a mount composed of many grains 1-3 mm in diameter the uranium concentration is uniform within a grain but variably by factors of 2-4 between grains. Some concentrations in ppm measured on randomly selected grains are

0·15	0·11	0·07
0·32	0·08	

No. 2. Concentration high, so that tracks in Lexan overlay overlap somewhat and are difficult to count. The uranium concentration is estimated to be 11 ppm, and appears to be very uniform.

No. 3. Concentration uniform over a distance of 5 mm or more: 0·11 ppm.

No. 4. Overlay shows many serpentining, ribbon-like, uranium-rich bands, usually ~ 100 microns wide but variable. Within these bands the uranium concentration is fairly uniform. The edges of the bands are sharp. The uranium concentration between these bands is unmeasurably low, and hence, probably < 0·03 ppm. Uranium concentrations measured at randomly chosen points in the uranium-rich bands are, in ppm:

0·57	0·49	0·09
1·59	0·60	0·52

The uncertainties in the measured uranium concentrations vary somewhat, but are never more than ± 15% except, perhaps, for No. 2.

The second illustration in the plate shows a portion of the overlay from Opal No. 4.

Interpretation

Probably fossil tracks in the more uranium-rich opals were not seen because the texture, grain boundaries, obscure them. In addition, the specimens from the Murray River cliffs generally develop a thick encrustation during etching, and become dark during irradiation. Samples 3 and 4 do not darken in the reactor.

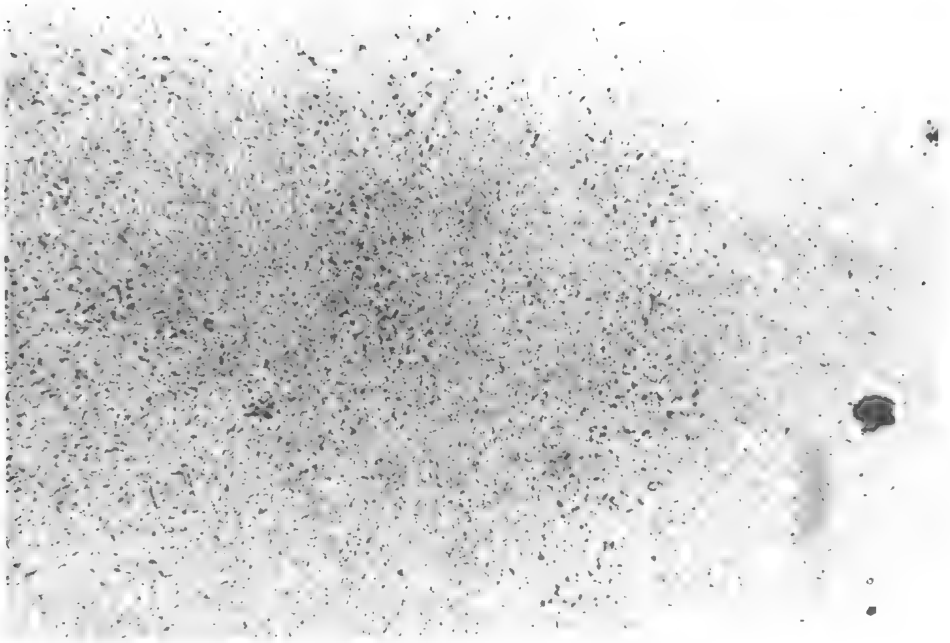
It is interesting that, in the Lexan overlay, no group of radiating fission tracks has been seen. All of these opals must me free of uranium-rich inclusions, although rarely a small enrichment of uranium along grain boundaries was seen in opal No. 1. The uranium in them must have precipitated from solution with the major consitituents; it was not incorporated into the opal as detrital grains, or precipitated with inclusions of minor constituents such as oxides. This is a fact that must be related in some manner to the way in which opal forms. Uranium-rich inclusions are common in other minerals, micas for example. In those micas which have been affected by groundwater, these seem to have formed when uranium from the groundwater precipitated on, or with, grains of opaque minerals, oxides or organic material in the mica. Micas from the interior of unaltered rocks also frequently contain uranium-rich inclusions around which the well-known pleochroic haloes are sometime seen. These may be the usual accessory minerals which form with the major minerals. However, I have noticed that they seem to be more common in micas from meta-sediments than in micas from igneous rocks. I suspect that this may be because, in the original sediments, the uranium was already in the form of detrital grains and any that precipitated from the sea water may have done so on grains of $Fe(HO)_3$, MnO_2, or clays. Apparently, in this respect at least, there is a great difference between the environment in which marine sediments form and that in which opal forms.

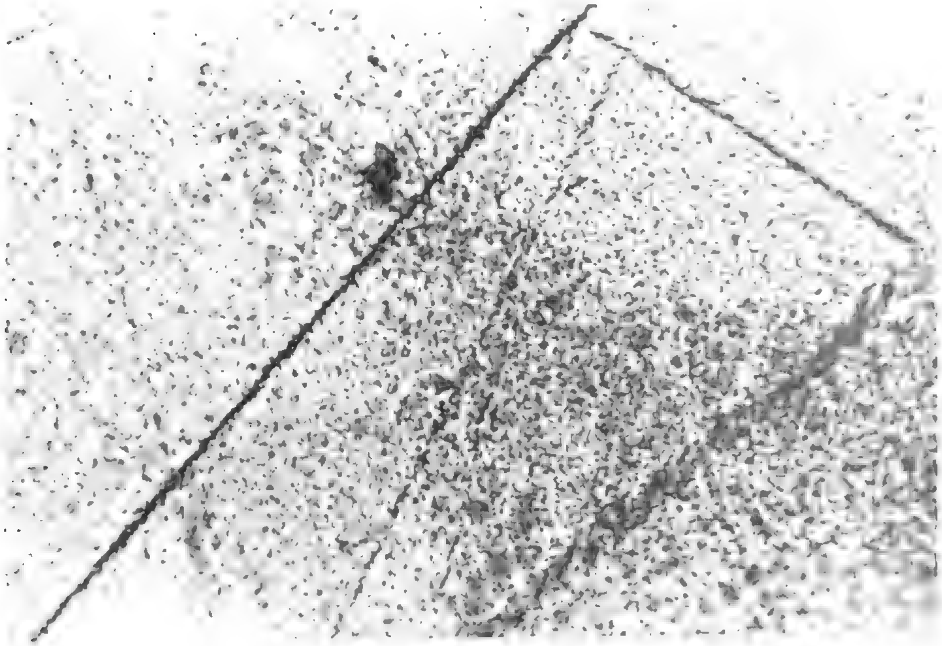
Although I have not succeeded in dating this opal, the results have not been as negative as might have been anticipated. It has been shown that opal contains concentrations of uranium which would make fission track dating possible, and even simple, if other factors were favourable, and this uranium is not associated with inclusions. Since this is so for these opals, it is probably so for opals in general, and for other hydrous-silica mineraloids. (Quartz, on the other hand, has uranium concentrations so low that it could not be dated by the fission track method even if its age were similar to that of the earth.) This considerably raises the chances that, among the great variety of these mineraloids, some will prove to be datable. One should look for types in which the grain boundaries are not prominent under the microscope at powers of $\sim$ 400X, and do not become so on etching with hydrofluoric acid.

Explanation of Plate 31

Upper—Features which are believed to be fission tracks in neutron-irradiated, etched Opal No. 4.

Lower—Etched fission tracks in the Lexan overlay of Opal No. 4, showing uranium-rich bands in uranium-free matrix.





CLIMATE OF THE MURRAY VALLEY REGION BETWEEN MILDURA AND RENMARK, AUSTRALIA

By J. V. Maher

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General Climatic Influences

The climate of the region may be classified in general terms as continental. This is a direct result of its geographical position on the Australian continent, about 250 km from the nearest point of the coastline, which places it far from the modifying influence and moisture of the Southern Ocean, the fairly constant temperature of which tends to temper the daily variations in air temperature of areas closer to the coast.

In the interior, the land surface is heated strongly by solar radiation by day and chills rapidly by night as it radiates heat, often assisted by clear skies and a dry atmosphere.

The latitude of the site and indeed of the whole continent plays a considerable role in the composition of the resulting climate. At latitude 34°S, at the Dam Site, a strong seasonal variation in temperatures is brought about by the relative positions of earth and sun from winter to summer with long days and intense radiation from the sun almost overhead at midday in mid-summer and the shorter days with lower sun angle and less intense radiation in winter.

The position of the continent in the middle latitudes, lying under the quasi-permanent belt of anticyclones (which is such a feature of the southern hemisphere mid-latitudes) is also important. The anticyclonic belt moves N. and S. with the sun, with easterly winds at low levels (the SE. trades) on its N. side, and westerlies on its S. side. In the mid-summer the Dam Site is frequently on the N. side of the belt and in mid-winter is normally on the S. side, but there are many interruptions to this situation, and this is illustrated by the observed distribution of winds (Table 1). The anticyclonic belt is an integral part of the hemispheric circulation of the atmosphere, and strongly affects the climate of the continent, particularly away from the coast, because of the downward circulation of dry air from high levels above it. This tends to maintain clear skies and low rainfall, which are progessively stronger features of the climate as the dry centre is approached.

The region, lying as it does on the fringe of the dry centre has a lower rainfall, higher temperatures and more sunshine and evaporation than any other district in the State of Victoria.

The topography of the district is generally of low relief, most of the area being less than 100 m in elevation and thus has little effect on rainbearing streams. Rainfall at the site comes mainly from lifting and cooling of moist air by the dynamic processes of special weather situations, including thunder-storms, and is therefore variable and somewhat unreliable. Such it is also in many other areas of Australia.

Wind streams are of fundamental importance in the make-up of the climate. With the occurrence of low pressure breaks in the anticyclonic belt, winds occur which may bring air from any direction. Most outstanding are air streams from the N. or NW. which, in summer, bring extremely hot, dry, dusty air from the interior of the continent and result in heat waves with air temperatures well in excess of 40°C (Table 4). These are relieved by cooler winds from the SW., S. or SE. Persistent winds from the NE., particularly in summer, are warm to hot and moist bringing unpleasant, humid, thundery weather. The effect of wind direction in winter is much less important.

Climatic Details

Rainfall

The following comments are based mainly on rainfall statistics for Ned's Corner, but some

TABLE 1

FREQUENCY ANALYSIS OF WIND DIRECTION AGAINST SPEED, MILDURA 1964-68

SPEED RANGES (knots) JANUARY
0900 HOURS

DIR.	CALM	01–03	04–06	07–10	11–16	17–21	22–27	TOTAL
CALM	2	0	0	0	0	0	0	2
NNE.	0	0	2	4	3	1	0	10
NE.	0	3	6	5	1	0	0	15
ENE.	0	1	0	2	0	0	0	3
E.	0	1	3	2	1	0	0	7
ESE.	0	1	3	5	1	0	0	10
SE.	0	0	6	13	1	0	0	20
SSE.	0	0	4	11	5	0	0	20
S.	0	1	3	12	13	0	1	30
SSW.	0	0	1	0	4	1	0	6
SW.	0	1	0	4	5	1	0	11
WSW.	0	0	1	1	0	0	0	2
W.	0	1	0	1	1	0	0	3
WNW.	0	0	0	1	0	0	0	1
NW.	0	1	0	2	0	0	0	3
NNW.	0	0	2	1	2	0	0	5
N.	0	0	1	1	4	1	0	7
SUMS	2	10	32	65	41	4	1	155

SPEED RANGES (knots) JANUARY
1500 HOURS

DIR.	CALM	01–03	04–06	07–10	11–16	17–21	22–27	TOTAL
CALM	1	0	0	0	0	0	0	1
NNE.	0	0	5	1	1	0	0	7
NE.	0	0	1	3	0	0	0	4
ENE.	0	0	0	1	1	0	0	2
E.	0	2	3	0	1	0	0	6
ESE.	0	0	1	2	0	0	0	3
SE.	0	0	2	6	4	0	0	12
SSE.	0	0	2	4	2	0	0	8
S.	0	0	3	7	11	1	1	23
SSW.	0	0	2	2	10	2	0	16
SW.	0	0	2	6	13	2	0	23
WSW.	0	0	1	3	4	2	0	10
W.	0	1	2	5	6	2	1	17
WNW.	0	0	0	0	2	2	1	5
NW.	0	0	0	3	2	0	0	5
NNW.	0	0	0	2	3	0	0	5
N.	0	1	2	2	3	0	0	8
SUMS	1	4	26	47	63	11	3	155

FREQUENCY ANALYSIS OF WIND DIRECTION AGAINST SPEED, MILDURA 1964-68

SPEED RANGES (knots) JULY
0900 HOURS

DIR.	CALM	01–03	04–06	07–10	11–16	17–21	TOTAL
CALM	18	0	0	0	0	0	18
NNE.	0	0	4	4	0	0	8
NE.	0	6	7	3	1	0	17
ENE.	0	0	2	0	0	0	2
E.	0	3	1	0	1	0	5
ESE.	0	0	1	0	0	0	1
SE.	0	0	0	0	0	0	0
SSE.	0	1	2	1	0	0	4
S.	0	2	3	0	0	0	5
SSW.	0	2	1	4	0	0	7
SW.	0	1	4	4	1	1	11
WSW.	0	0	4	2	1	0	7
W.	0	0	6	4	4	0	14
WNW.	0	2	1	7	2	0	12
NW.	0	2	5	6	5	0	18
NNW.	0	0	1	3	1	1	6
N.	0	5	3	8	2	2	20
SUMS	18	24	45	46	18	4	155

SPEED RANGES (knots) JULY
1500 HOURS

DIR.	CALM	01–03	04–06	07–10	11–16	17–21	22–27	28–33	34–40	TOTAL
CALM	2	0	0	0	0	0	0	0	0	2
NNE.	0	0	1	4	0	0	0	0	0	5
NE.	0	0	2	2	1	0	0	0	0	5
ENE.	0	0	0	0	0	0	0	0	0	0
E.	0	1	0	0	0	0	0	0	0	1
ESE.	0	1	0	0	0	0	0	0	0	1
SE.	0	0	1	2	0	0	0	0	0	3
SSE.	0	1	2	0	0	0	0	0	0	3
S.	0	2	1	4	4	1	0	0	0	12
SSW.	0	1	2	1	6	0	0	0	0	10
SW.	0	0	1	2	7	1	0	0	0	11
WSW.	0	0	2	6	2	3	1	0	0	14
W.	0	1	4	6	6	1	2	0	1	21
WNW.	0	0	5	2	2	0	1	0	0	10
NW.	0	1	3	6	11	2	1	0	0	24
NNW.	0	0	1	5	5	1	0	0	0	12
N.	0	2	5	3	8	2	1	0	0	21
SUMS	2	10	30	43	52	11	6	0	1	155

Table 2

RAINFALL STATISTICS

Ned's Corner— Lat. 34°12′ S. Long. 141°30′ E.

Mildura Aerodrome—Lat. 34° 14′ S. Long. 142°05′ E. Elevation 165 ft. (50 m)

	Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
			AVERAGE RAINFALL (100 points = 1 inch)											
Ned's Corner	1927–1972	63	82	67	75	83	83	95	85	75	96	96	72	972
Mildura	1946–1972	70	86	94	72	113	88	98	105	104	108	102	80	1120
			AVERAGE NUMBER OF RAIN DAYS (One point or more)											
Ned's Corner		2	2	2	3	4	4	5	5	3	4	3	2	39
Mildura		3	3	4	5	6	7	9	8	6	7	6	3	67
			HIGHEST 24-HOUR RAINFALL (Points)											
Ned's Corner		158	406	252	88	130	122	105	107	155	189	303	217	
Mildura		198	327	257	153	133	175	94	116	142	180	155	185	
Ned's Corner			MONTHLY AND ANNUAL RAINFALL DECILES (Points)											
Lowest		0	0	0	0	0	0	0	11	0	0	0	0	
Decile 1		0	0	0	0	7	9	35	23	17	21	0	2	
„ 2		1	0	0	11	19	19	56	41	21	29	12	14	
„ 3		12	5	3	22	36	26	62	52	27	35	32	20	
„ 4		16	20	14	37	45	33	71	60	44	49	42	35	
„ 5		26	39	31	44	65	53	83	80	58	62	61	52	
„ 6		62	52	45	50	81	100	104	100	77	104	77	70	
„ 7		93	83	66	113	104	120	113	117	99	136	120	91	
„ 8		127	143	87	133	135	153	129	143	126	165	166	133	
„ 9		196	221	174	191	198	235	180	172	168	236	274	162	
Highest		362	574	551	323	251	387	222	190	344	279	435	361	

rainfall data for Mildura have also been used.

In considering rainfall it is important to look further than the simple averages which are given in Table 2. These show that more rain and rain days are experienced from about April to November than in the remaining months.

The monthly and annual figures for rainfall at Ned's Corner for individual months and years (Table 3) from 1927 to 1972 illustrate this point very clearly. The January average of 63 points calculated over 43 years provides a good example. Only in five years (1935, 1944, 1958, 1959 and 1970) does the January rainfall come within 10 points of the average. There are nine years when the January rainfall was zero and 12 years when it exceeded 100 points. There is a similar pattern in the other months, and these considerations lead to the decile approach to rainfall reliability as illustrated by the figures in Table 2.

The deciles 1-9 are derived by arranging the rainfalls in order of magnitude and determining by interpolation the values of rainfall, the nine decile values, which divide the distribution into 10 parts, each of equal frequency. For example, from Table 2 we have that the lowest 10 per cent of January rainfalls do not exceed zero, 20 per cent do not exceed one point and so on. The median or 50 percentile is 26 points whilst decile nine, in this case 196 points indicates that 90 per cent of the values may be expected in the long run, based on the figures available not to exceed 196 points.

Some idea of the incidence of heavy rainfall

MONTHLY AND ANNUAL RAINFALL TOTALS, NED'S CORNER, VICTORIA ($34^{\circ}12'$S. $141^{\circ}30'$E.)

	Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
	1927	27	4	36	0	30	27	127	63	61	64	65	17	521
	1928	0	359	77	45	34	189	109	11	58	75	0	65	1022
	1929	10	139	18	11	6	19	29	25	75	0	45	361	738
	1930	0	19	65	38	60	10	109	181	52	187	67	186	974
	1931	17	0	93	183	136	271	56	50	165	62	136	26	1195
	1932	14	128	142	121	129	135	83	190	43	25	42	60	1112
	1933	97	12	0	44	103	24	77	122	138	54	333	163	1167
	1934	42	39	45	102	0	23	61	55	69	265	182	15	898
	1935	62	0	85	128	18	38	61	59	99	137	0	70	757
	1936	362	83	87	47	153	73	187	40	17	72	12	99	1232
	1937	201	0	35	44	65	126	68	182	22	146	25	133	1047
	1938	112	55	0	50	22	12	214	50	0	34	0	0	549
	1939	0	421	14	22	77	86	104	129	47	24	269	0	1193
	1940	14	0	0	161	21	10	56	40	54	41	57	35	489
	1941	306	5	71	13	10	242	145	106	41	250	95	20	1304
	1942	13	66	0	178	177	147	85	147	25	279	28	12	1157
	1943	22	30	0	23	8	10	13	66	94	35	22	50	373
	1944	61	10	0	12	85	0	57	19	7	61	70	61	443
	1945	0	24	8	0	36	187	112	91	33	124	94	96	805
	1946	130	144	121	49	45	102	129	47	13	24	227	105	1136
	1947	12	155	314	24	0	100	119	77	114	131	120	79	1245
	1948	0	8	0	126	42	99	83	47	21	174	56	41	697
	1949	26	47	31	5	234	27	39	18	108	152	70	14	771
	1950	0	574	551	24	126	30	96	104	27	30	120	50	1732
	1951	-	-	-	75	77	387	62	150	78	-	-	-	-
	1952	137	45	27	39	251	47	25	55	45	232	200	11	1114
	1953	162	27	0	0	0	113	79	175	299	-	51	25	-
	1954	27	0	0	220	40	26	85	170	21	163	166	158	1076
	1955	15	149	8	39	199	231	63	116	153	35	85	0	1093
	1956	5	0	222	144	210	154	222	90	130	159	38	0	1374
	1957	0	97	27	37	45	165	109	40	20	50	0	187	777
	1958	63	39	4	37	110	5	137	161	93	238	311	.15	1213
	1959	73	83	54	0	48	4	49	11	81	190	0	49	642
	1960	192	79	15	116	198	53	175	88	129	30	130	4	1209
	1961	5	65	65	134	12	20	122	60	110	32	435	78	1138
	1962	207	4	44	0	129	27	64	97	19	43	4	161	799
	1963	113	3	41	112	83	280	121	.125	21	131	40	85	1155
	1964	92	0	0	203	73	48	47	125	344	125	41	142	1240
	1965	0	0	0	21	71	118	201	152	173	56	131	85	1008
	1966	23	198	87	17	44	103	70	53	21	91	77	136	920
	1967	23	157	0	0	59	8	54	80	17	24	0	3	425
	1968	108	1	56	86	93	151	104	109	61	48	33	109	959
	1969	7	256	357	3	186	19	155	40	100	7	10	22	1162
	1970	70	0	10	249	18	53	0	102	255	19	279	20	1075
	1971	0	21	91	323	87	89	72	60	30	0	31	53	857
	1972	182	45	0	-	-	-	-	-	-	-	-	-	-
SUMS	43	2688	3519	2901	3230	3573	3588	4094	3653	3206	4119	4146	3076	41793
MEANS		63	82	67	75	83	83	95	85	75	96	96	72	972

N.B. 100 points = 1 inch

may be obtained from figures showing the greatest 24 hour rainfalls measured. For Ned's Corner and Mildura these are given in Table 2 and show that from two to four inches of rain have occurred in 24 hours from October to March and from one to two inches in the remaining months.

Temperature

Temperatures at Mildura are generally representative of the site area and for this reason statistics for Mildura are included in Table 4.

It is noteworthy that as well as the obvious seasonal variations there are considerable variations in temperature from year to year. The average daily maximum temperature for January, for example, in 1939 was 38·2°C and in 1906, 39·1°C but in 1899 was 29·1°C and in 1924, 29·3°C. This illustrates the differences which can occur between a very hot and dry January and a cooler, cloudy January in which temperatures are consistently lower than normal. In winter, the range in similar circumstances was about 5°C.

Overnight minimum temperatures also show considerable variation from year to year. The mean minimum temperature in January 1904 was 11·9°C and in January 1939 it was 21·3°C. In winter the same effect occurs but the range is again about 5°C between typical cold and warm winters.

Humidity

The climate is normally dry, particularly in summer afternoons when the relative humidity at 3 p.m. averages about 25 to 30 per cent (Table 4). In winter the air is cooler, and relative humidities are higher, although the water content of the air is not great. There are, of course, periods throughout the year when moist streams reach the area. In the warmer months, as mentioned earlier, the heat and humidity

TABLE 4

Mildura—Lat. 34°14′ S. Long. 142°05′ E. Elevation 165 ft. (50 m)

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
AVERAGE MAXIMUM TEMPERATURE °C											
32·9	32·6	29·3	24·1	19·7	16·1	15·4	17·8	21·2	25·0	29·0	31·6
EXTREME MAXIMUM TEMPERATURE °C											
50·8	47·8	46·4	37·2	32·2	26·7	25·6	30·5	35·6	40·0	45·0	49·7
AVERAGE MINIMUM TEMPERATURE °C											
16·5	16·4	13·7	9·9	7·4	5·3	4·6	5·7	7·7	10·2	13·1	15·1
EXTREME MINIMUM TEMPERATURE °C											
4·4	6·1	2·8	1·1	—2·8	—3·3	—4·4	—1·7	—1·7	1·1	1·7	4·4
9 a.m. TEMPERATURE (DRY BULB) °C											
23·2	22·7	19·9	15·4	11·6	8·2	7·6	10·1	13·6	17·4	20·5	22·7
9 a.m. TEMPERATURE (WET BULB) °C											
16·8	17·2	15·4	12·2	9·6	9·9	6·4	7·9	10·3	12·8	14·7	16·3
9 a.m. RELATIVE HUMIDITY—PER CENT											
50	55	60	67	75	82	83	73	63	57	50	48
3 p.m. TEMPERATURE (DRY BULB) °C											
31·1	30·4	27·4	22·7	18·7	15·6	14·9	17·0	20·2	23·0	26·3	29·3
3 p.m. TEMPERATURE (WET BULB) °C											
18·9	19·8	17·9	15·1	13·1	11·2	10·3	11·1	12·7	14·7	16·5	17·8
3 p.m. RELATIVE HUMIDITY—PER CENT											
26	32	35	39	51	55	52	43	36	35	31	27

associated with occasional moist streams from the NE. or E. make conditions most uncomfortable.

Wind

This element is important because under certain conditions, considerable wind erosion may occur. Table 1 gives the frequencies of occurrence of wind from each of 16 points of the compass in relation to various wind speed ranges over a period of five years with one observation per day or 155 in all for five Januaries or five Julys.

Gales are comparatively rare, and tend to blow mainly from the NW, W. and SW, with an occasional northerly gale in summer. In winter and spring in particular, sudden wind changes may bring fairly short periods of gale from the W. or SW. Over a period of 25 years at Mildura Aerodrome there were 19 days of gale (mean wind over 38 knots) and 653 strong wind days (mean wind over 22 knots at some time during the day).

Table 5 shows the distribution of these occurrences in the various months of the year. The gales and strong winds are clearly most prevalent in January, August, September, October and November.

Duststorms

The area is subject to duststorms which occur chiefly in dry years and in summer months because of their physical nature, which requires strong surface heating with its associated unstable turbulent air in the lower layers of the atmosphere. Table 6 shows the numbers of duststorms which have occurred at Mildura from 1946-71 inclusive.

Thunderstorms

These are mainly a summer phenomenon but may occur at any period of the year (Table 6).

Frost

The average number of frosts each month is given in Table 6. There is considerable variation in the frost season from year to year. The average dates of the first and last frosts are 31st May and 1st September, but frost has occurred as early at 19th April and as late as 1st October.

Evaporation

Evaporation rates are high at the Dam Site because of the temperature, wind and humidity conditions. See Table 6 for monthly averages for Mildura based on observations with a Class A Pan from 1967-1972. Lake evaporation is approximately 70 per cent of the Class A Pan figures, or about 55 inches per annum.

Sunshine

The average sunshine hours at Mildura range from 5·8 hours per day in June to 11·3 hours per day in January (Table 6). These figures agree well with the story of the climate as presented above, and are indicative of the large percentage of warm, almost cloud-free days experienced.

TABLE 5

GALES AND STRONG WINDS, MILDURA

Lat. 34°14′ S. Long. 142°05′ E. Elevation 165 ft. (50 m)

FREQUENCY OF OCCURRENCE OF GALES (Mean wind > 38 knots) AND STRONG WINDS (Mean wind > 22 knots) 1946–1971

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
GALES	1	0	1	0	0	0	1	3	8	2	2	2	20
STRONG WINDS	75	27	38	25	31	28	49	75	116	97	82	55	698

(The above are the total numbers observed in 27 years)

TABLE 6

MILDURA—Lat. 34°14′S. Long. 142°05′ E. Elevation 165 ft. (50 m)

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Septt.	Oct.	Nov.	Dec.	Annual
FREQUENCY OF OCCURRENCE OF DUSTSTORMS TOTAL OCCURRENCES 1946–1971												
27	22	27	9	5	4	4	9	14	17	20	25	183
(Greatest annual total 1960 (29), least 1949, 1957, 1958, 1979 (Nil))												
FREQUENCY OF OCCURRENCE OF THUNDERSTORMS TOTAL OCCURRENCES 1947–1971												
35	30	23	13	4	2	4	5	13	20	35	28	212
(Greatest annual total 1971 (18), least 1948, 1949, 1958 (Nil))												
AVERAGE EVAPORATION AT MILDURA (Inches) (1967–1972)												
12·29	11·09	8·70	5·37	2·95	1·94	2·02	2·81	4·96	8·14	8·05	12·00	80·32
AVERAGE DAILY SUNSHINE (Hours)												
11·3	10·6	8·9	8·3	7·1	5·8	6·4	7·3	8·3	8·9	10·0	10·8	
FREQUENCY OF OCCURRENCE OF FROSTS TOTAL OCCURRENCES 1947–1971												
29	28	24	24	40	175	203	122	40	6	4	0	695
FREQUENCY OF OCCURRENCE OF HAIL TOTAL OCCURRENCES 1947–1971												
0	0	2	0	1	0	1	3	0	1	3	1	12
FREQUENCY OF OCCURRENCE OF FOG TOTAL OCCURRENCES 1947–1971												
0	1	2	7	54	92	72	44	13	11	1	2	299

PALAEOPEDOLOGY OF THE MURRAY RIVER REGION BETWEEN MILDURA AND RENMARK, AUSTRALIA

By Edmund D. Gill
Deputy Director, National Museum of Victoria

Introduction

> *'In dry climates, where water seldom or intermittently leaches rocks, saprolitization does not occur, although fossil saprolites, indicating earlier more humid conditions, may be present'.* Dorothy Carroll (1970)

This describes well the study area with which this *Memoir* is concerned. The sediments of the region (and so the substrate for the soils) consist chiefly of silica (fine sand) and clay. They have originated in the humid zone of the Great Dividing Range. Silica is a stable primary mineral, and clay a stable secondary mineral. Silica results from the weathering and erosion of igneous and sedimentary rocks, while clay is a common product of that process. The long traction of the sediments and the low dynamics of the river system in the Murray River have resulted in only the finer fraction reaching the study area. Coarser sediments are common on the E. side of the Murray Basin, but finer sediments characterize the W. side.

Water, the solvent par excellence, is active both in the provision of these sediments and their transport to the sedimentary plain. But water is scarce in the region W. of the Dividing Range, so carbonates (calcite, dolomite), sulphates (gypsum) and chlorides (halite) accumulate at the surface of the terrain. For the minerals involved, see Segnit, this *Memoir.*

In the accompanying paper on the geology and geomorphology of the region, tectonic movements are described that have led to the sinking of the area and the preservation of paleosols by burial. On the other hand, the surface of the plain (disregarding discontinuous superficial deposits) is of Pliocene/Pleistocene lacustrine clay and sand N. of the Murray River, and Pleistocene dune sand S. of the river. The surfaces are relict. In the incised river valley tract, a significant area is occupied by Pleistocene terrace sediments (Rufus Formation). This antiquity of surfaces leads to many polygenetic profiles. On the other hand, the dunefields and the lunette on the E. side of Lake Victoria have preserved series of paleosols.

The dryness of the country, combined with the general fineness of the sediments, leads to

1. Considerable wind traction of sediments, with dunes as a common landform. As the E-W. dune system and the lunettes are relict, this process was more active in the past.
2. Wind-winnowing with airborne fine sediments as a result. The increase of this process during droughts indicates that it must have been a major factor during still drier periods in the past. Thus
    - (a) More clay and silt are found in sand dunes (geomorphic highs) than would be otherwise expected.
    - (b) Because of the accumulations of mineral salts on the terrain, these likewise become airborne, resulting in more accumulation in the dunes and elsewhere than would be otherwise expected (e.g. Gill, this *Memoir*, Fig. 10).

Thus the geologic and geochemical characteristics of this dry land make their unmistakable impress on the soils. In the humid areas seaward of the Dividing Range, these strongly alkaline conditions are replaced by neutral to acid ones. Iron is there accumulated in podzolic hardpans and as pedalferric nodules. The murray River country is marked by the bright reds and yellows of a highly oxidized terrain, but the carbonates prevent the accumulation of iron. On the other hand, pyrolusite is ubiquitous. In the study area it occurs in sediments, on ped and crystal faces, on opal, on carbonate nodules, on silcrete, on fossil bones, and so on. It occurs, often as dendrites, on Aboriginal skeletons, including Upper Holocene ones.

An interesting project would be to quantify and date the accumulation of pyrolusite, so that it could be used for relative dating. This would be possible in the humid areas also. In Western Victoria (a given climate), the accumulation of maghemite on a given substrate (basaltic ash) on a given slope (volcanic ash cone) is a function of time; the same applies to the associated pyrolusite. Also with time the profile deepens and becomes more complex (uniform/duplex). The maghemite nodules increase in size with time, beginning as dust and passing through sizes only a few millimetres in diameter to pea-size, and sometimes larger. Under the conditions defined, maghemite dust has formed in the Holocene, while the minute nodules are latest Pleistocene to earliest Holocene. The youngest profile with pea-size buckshot gravel is 20,000-25,000 years old (Camperdown). Manganese dioxide was used as an age indicator in the dry Tule Springs country in U.S.A. (Shutler 1968).

Pyrolusite accumulates in the acid humid areas and in the alkaline dry areas as well because its solubility is not affected by pH. 'Under highly oxidizing conditions MnO_2 is the stable phase over the whole range of pH' (Mason 1966, p. 171). The dry country thus acts as a huge fractionating column separating the manganese from the iron. Manganese so accumulated on a terrain over a long period could later be washed into shallow seas and form the manganese-rich sediments of this type known from various parts of the world. It may well be that such deposits could assist palaeoclimatic interpretations. Tindale (pers. comm.) says manganese dioxide was used by Aboriginals as a paint.

As no pedologist could be found to prepare an account of the palaeopedology to include in this volume, the present writer (a geologist) has written this paper because the paleosols are a key to a number of aspects of the geologic history. They provide time datum planes through strongly interdigitating sediments, they trace the palaeoclimatic change from humidity to aridity, they mark out the evolution of diverging climatic patterns landward and seaward of the Dividing Range, and they measure the pulse of the stable/unstable phases in the extensive E-W. dune system. See Gill, this *Memoir*.

Three Soil Types

In the stratigraphic succession, three grossly different soil types register in the rocks major changes in the environment between the Pliocene and the present:

3	Soils accumulating carbonates	Quaternary
2	Soil accumulating silica	Plio/Pleistocene
1	Soil accumulating iron (lateritic)	Pliocene

Chronology is discussed in the accompanying paper. Each of the above soil types registers a different climate, and each records a steady state condition of the terrain which allowed the pedogenic processes to continue for a long time. Each of the soil types was developed over a large area (at least 250,000 km^2), and the general geomorphology has been that of a flatland. Each buried soil represents a stratigraphic disconformity. In the dry country, a paleosol represents a depression of the dune morphology. Most paleosols were eroded before being buried under a new formation.

The present carbonate soils are not well understood. The early settlers came from humid land and did not understand them at all. The methods imported from their homelands caused havoc to the topsoils, leading to extensive erosion and widespread dust storms. This has now been brought under considerable control, but it can still be questioned whether there is not too much disturbance of the surface leading to erosion and loss of fine fractions plus humus. Soil is 'one of the most important natural resources'. The ash and charcoal of Aboriginal middens are probably the most sensitive materials to erosion on the landscape, yet such materials up to 2,000 yr old are found in the surface soil showing that the land surface presently in a state of erosion had been stable for a couple of millenia. The youngest soil of all is a thin carbonate crust on fans developed on the slopes of the W. shore of Lake Victoria. This crust is now being rapidly removed, but its age by radiocarbon dating of carbonized twigs is 'modern' (therefore less than 200 yr) so this erosion has occurred since European occupation.

Lateritic Profile

1. *Yelta, Victoria*

The oldest buried soil found in the study area is a massive mottled zone of a lateritic profile. I am indebted to Mr G. Blackburn of C.S.I.R.O. Division of Soils for examining the occurrence for me and confirming that it is lateritic. Figure 1 provides a section of the Murray River cliff on the S. (Victorian) side at Yelta, W. of Merbein and E. of the bridge to Curlwaa. Underneath the Blanchetown Clay, and therefore older than it, is the Moorna Formation, characterized by its varied sediments including coarse-grained ones (both exceptional features in this country). This formation is Upper Pliocene (Marshall, Gill, this *Memoir*) and the paleosol is within it at Yelta. The sediments lateritized are poorly sorted sands that include grains 2 mm in diameter, which is exceptional in this region where the normal range is clay to fine sand, but not unusual for the Moorna Formation.

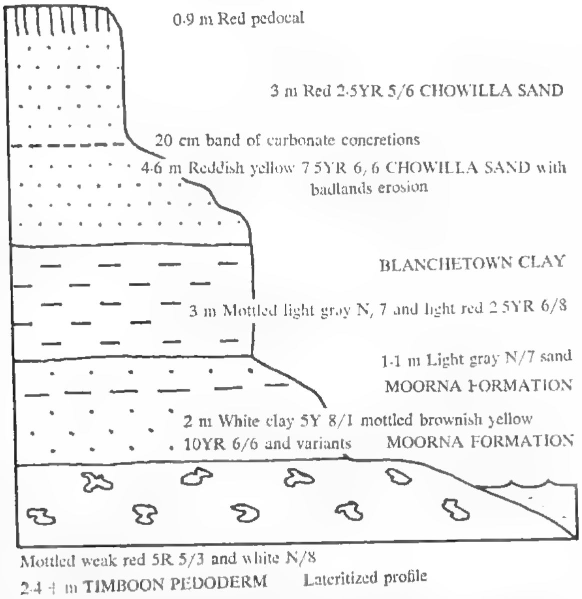

Fig. 1—Surveyed section of Murray River cliff on S. bank at Yelta, Victoria. For map see Gill on Geology of area, this *Memoir.*

The part of the lateritic profile preserved is the mottled zone, which consists here of white N/8 sand with mottles of weak red 5R 5/3 grading to red 7·5YR 4/6 with some minor reddish yellow 7·5YR 6/6. A rhizomorph about 6 mm in diameter was noted and a burrow about 3 mm in diameter set obliquely. This horizon is strongly compacted, and forms a ledge at the foot of the cliff, although this is mostly covered with wash from the cliff. High river levels sweep parts of it clean for a while, but at the W. end where the river impinges on the cliff, the outcrop can always be clearly seen. The mottles are usually 15-25 cm in diameter. On the day of the survey 2·51 m of the mottled zone was exposed, but it could be seen continuing down some distance under the water of the river. It is difficult to be sure of the underwater extension, but it was judged to be at least as deep as the section exposed.

The sediments lateritized are of riverine facies, and apparently were part of a fluvatile plain or terrace, sufficiently high to be drained in the dry season. The terrain almost certainly supported a subtropical rainforest (Gill 1961 a, b). The climate was of the monsoon type, with leaching warm copious waters in the wet season, followed by a dry season when the water table fell and air entered to oxidize the rocks. No greater contrast is possible than this rainforest palaeo-environment with abundant deep-leaching acid waters, and the present semi-arid sparsely-vegetated terrain with shallow strongly alkaline soil.

2. *Paringi, N.S.W.*

On the Sturt Highway between Euston and Mildura, 29 km from the latter on the N. side of the Murray River where it meets the highway, badlands erosion has exposed the section shown in Fig. 2. This section was surveyed from a lone tree on the W. side of the de-

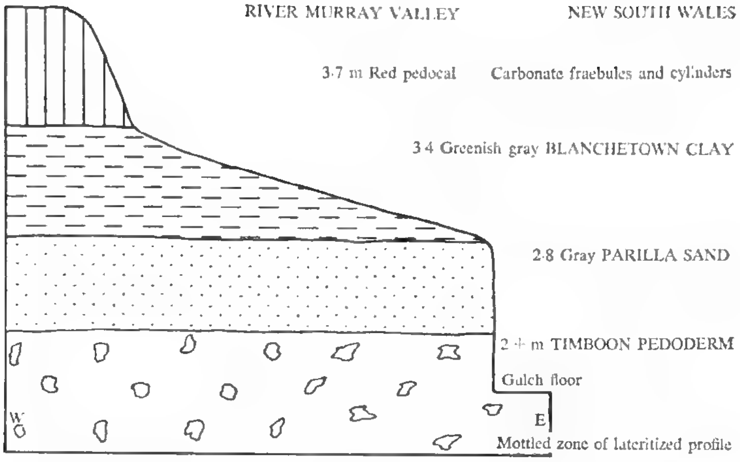

Fig. 2—Surveyed section of Murray River cliff on N. bank at Paringi (not Paringa), N.S.W.

bouchement of the gulch to its floor. Beneath the Blanchetown Clay is a gray clayey fine sand presenting vertical walls along the gulch, all of which characters belong to the Parilla Sand, so the sediments are referred to that formation. Below this a very compact mottled zone occurs with nearly 2 m outcropping, but continuing to a greater depth as was proved by a spade hole. The background varies from white N8 to light gray 5Y 8/1 with mottles up to 18 cm diameter, although these may coalesce into larger sizes. The mottles are red 2·5YR 4/8.

If the formation with the paleosol is Parilla Sand or older, then the fossil soil is developed in an older substrate here than at Yelta. This need cause no surprise. Evidence of intraformational erosion is widespread. The paleosol occurs only as remnants, and the A horizon is nowhere preserved. At Paringi, a channel 4·5 m wide is cut in the top of the mottled zone, and is c. 1 m deep. Above the mottled zone is a hard layer c. 18 cm thick, but it is not present over the channel. The hard layer consists of coarse sand to laminated silt. In the channel is a variety of sediments with current-bedding.

A lateritic profile infers tectonic stability for a considerable time, while widespread erosion infers terrain instability. The latter was probably caused by the Kosciusko uplift.

3. *Distribution*

Rowan and Downes (1963, p. 17) record lateritic profiles in NW. Victoria. One locality is Robinvale lock, where Segnit (this *Memoir*) has proved kaolinite. The writer (Gill 1966) has recorded a lateritic profile at Ultima in N. Victoria. At Tammit Station c. 14 km from Euston, N.S.W., I noted below the homestead a platform of ferricrete 1-1·5 m thick extending c. 80% of the distance across the river. The material was tested with a penetrometer and found to vary from 6 kg/cm^2 to hard solid ferricrete. Colour varied from yellowish red 5YR 5/6 to very dusky red 7·5R 2/2, and the substrate from silty to sandy gravel. Disconformably over the ferricrete there was mottled clayey fine sand to sandy clay, which was light gray 5Y 7/2 to white 5Y 8/2 with reddish yellow 7·5YR 6/6 mottles 1-20 cm diameter. The top metre of this formation was somewhat concretionary, forming a shelf on the shore; it varied from 12 kg/cm^2 to solid. The clay just above the ferricrete had some rhizomorphs. A bore is needed to prove whether or not this is a true lateritic profile.

A very extensive literature exists on lateritic profiles in Australia, but some dealing with adjacent areas are Blackburn and Leslie (1958), Dury (1971), Faniran (1970), Firman (1967), Grubb (1971), Jessup (1960 a, b) and Twidale (1972).

4. *Age and Nomenclature*

The A.O.G. oil bores show that this paleosol overlies marine Cheltenhamian (uppermost Miocene) sediments. At Yelta the paleosol is in the Moorna Formation which is Upper Pliocene. This dating fits the evidence available in S. Victoria (Gill 1971). Fisher (1958) has pointed out the importance of lateritization as a concentrator of minerals. I think that the large concentrations of alluvial gold found in Victoria were a function of deep kaolinization of the bedrock, followed by fluviatile sifting to remove the saprolite.

The laterite constitutes an important time datum plane through very variable rocks. It is the only paleosol that can be traced with confidence landward and seaward of the Great Dividing Range, and indeed over the whole of SE. Australia. Fig. 3 shows diagrammatically the contrasting series of main pedologic types N. and S. of the Dividing Range in a section from the study area to the Western District of Victoria (Gibbons and Gill 1964).

The laterite profile is the only common denominator

With respect to nomenclature, the writer thinks that the close association of a paleosol with an ancient terrain can best be expressed by using the same name. In SE. Australia laterite is associated with the Timboon Terrain (Gill 1964), so applying the term of Brewer et al. (1970), the nomenclature would be the *Timboon Pedoderm.*

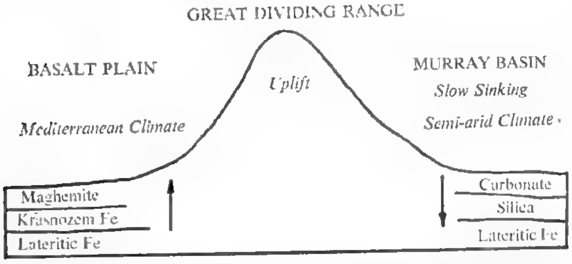

Fig. 3—Diagram to show the different existing ecologies N. and S. of the Great Dividing Range along a section from the study area to W. Victoria. The succession of soil types from the Pliocene to the present is shown for each region, indicating that in the Pliocene the two had similar ecologies, viz. monsoonal rainforest producing lateritic soil profiles.

Soil Accumulating Silica

1. *Stratigraphic Occurrence*

The lateritic profile accumulated non-magnetic alpha iron oxide. Higher in the sequence is a paleosol that accumulated silica. It formed common opal in clay and dolomite, while in sand it formed a range of rocks from lightly bonded silicified sandstone to ringing silcrete. The Timboon Pedoderm occurs in the Parilla Sand and the Moorna Formation, while the silica-amassing pedoderm occurs in the younger Blanchetown Clay and Chowilla Sand. This statement applies to the study area, which is on the down-warped side of the Pinnaroo Block, involving the Lake Victoria Syncline. On the geomorphic highs other relationships are possible. At the Chowilla dam site, the silicified zone occurs on but not in the Parilla Sand. Firman (1967, p. 170) says the siliceous cap is on the *eroded* surface of the Parilla Sand. This is the Karoonda Surface or Terrain (Firman 1966), and so applying the nomenclatorial principle defined above, the paleosol would be called the *Karoonda Pedoderm.*

2. *Distribution*

This pedoderm is very widely distributed, and in many places influences the cliff profiles. Both the opal and silcrete were widely used by the Aboriginals for implements. The Karoonda Pedoderm is present in the Chowilla dam area, along Salt Creek (Pl. 32, fig. 1), at Cal Lal, on Nampoo, Warrakoo, Moorna and other stations along the river, at Merbein, and along the river further to the SE., including Robinvale. Indeed it is almost ubiquitous. Pedogenic silcrete is common in the dry interior of Australia. A vast literature is involved, but it suffices for the present purpose to mention the work of a geomorphologist (Mabbutt 1965), a pedologist (Stephens 1971), and a geologist (Wopfner, H., and Twidale, C. R. 1967). In Central Australia it is common for silica to be found in various parts of the lateritic profile. Much difference of opinion has been evident as to the cause of such occurrences. It is pointed out that in the Lake Victoria syncline there is an extended (and not telescoped) sequence. The siliceous horizon is later than the lateritic profile, so the possibility should be considered that in non-depressed areas these two horizons could be telescoped, i.e. the profile is polygenetic.

3. *Age*

The Parilla Sand and the Moorna Formation are Pliocene in age (Gill, this *Memoir*). As the age of the succeeding Blanchetown Clay is not known with accuracy, it is called Plio-Pleistocene. The Karoonda Pedoderm has not been found in the stratigraphic sequence higher than the base of the Blanchetown Clay. It is commonly in Chowilla Sand under the clay. These two formations interdigitate strongly, and the paleosol is a time datum plane through them. On Salt Creek, Kulcurna Station, the paleosol can be traced from Chowilla Sand into Blanchetown Clay and then into Chowilla Sand again. In the latter, the horizon consists of silicified sand, while in the Clay it consists of common opal. Segnit et al. (this *Memoir*) have described the nature of the opal in the Karoonda Pedoderm at Sharp Point (N. bank of Murray River) on Nampoo Station, E. of Cal Lal (Pl. 32, fig. 2). There two opal horizons occur in this the thickest known section of Blanchetown Clay. A gell-like material under the lower opal proved to be highly disordered sodium montmorillonite. Celestite occurred between the two opal beds; barytes and sepiolite were found but not *in situ* (Segnit, this *Memoir*).

4. *Climatic Association*

The lateritic profile (Timboon Pedoderm) is associated with tropical or subtropical monsoonal conditions, but the Karoonda Pedoderm is associated with the incoming of the present semi-arid conditions. On the E. wall of Salt Creek on Kulcurna Station, where the Blanchetown Clay lenses out to nothing (an old lake shore) towards the south, a black clay yielded palynologic evidence of a flora directly comparable with the present semi-arid one (Churchill, this *Memoir*). A short distance above these fossils in the same section is the silicified sandstone of the Karoonda Pedoderm. This paleosol is therefore a little younger than the changeover from the previously humid climate to the present dry conditions. The Sharp Point section on Nampoo Station c. 10 km to the E. shows that a lake dried up and the soil was formed on its floor. The dolomite is interpreted as a function of a drying up of saline waters. Rhizomorphs show that trees or shrubs grew on the old lake floor. After the paleosol was developed, lacustrine conditions returned, and the water was fresh as is shown by the ostracod fauna.

In the cliffs near Kulcurna Station, and on Salt Creek, there are widespread siliceous rhizomorphs that bear witness to the existence of a land surface, a soil, and vegetation.

In many places (e.g. in cliffs on the W. side of Six Mile Creek on Neilpo Station, and in the Bone Gulch area on Moorna Station further W.) deposits of gypsum characterize the lowest part of the Blanchetown Clay. At Six Mile Creek rosettes and other crystalline masses of gypsum have been seen up to 0·5 m in diameter. The site was worked commercially at one time. This horizon of gypsum could be due to a period of drying up that followed the freshwater phase indicated by the ostracod bands. (For stratigraphy and palaeontology, see Gill this *Memoir*).

Pedocals

Three minerals characterize the terrain in the study area at the present time—a carbonate (calcite), a sulphate (gypsum) and a chloride (common salt). All are present in both earthy and crystalline forms. The carbonate is particularly abundant. In the soil profiles it occurs in earthy form, as fraebules, and as a solid hardpan. It has been estimated that on the average there are in this country $\sim$ 800,000 metric tonnes (or tons) per km^2. Commonly the profile at the surface is polygenetic, as successive deposits of carbonate and radiocarbon dates establish. The persistence of all this carbonate at the surface bears witness to the persistence of semi-arid conditions over a long time preventing its solution and removal. These successive carbonates record the pulse of palaeoclimatic change.

No greater pedogenic contrast could be provided than the calcite fraebules of the highly alkaline terrain of the study area, and the maghemite nodules (gamma iron oxide) requiring an acid water-logged soil for their normal formation. Neverthess, buckshot gravel is found in this region. It was noted c. 50 km W. of Cobar, N.S.W., and in Cobar itself. W. of the railway station at Diapur, Victoria (422 km from Melbourne, elevation c. 198 m) a cutting reveals at the top some 2 m of calcareous clayey fine sand with derived buckshot gravel (maghemite fraebules). The fraebules are quite out of character with the calcareous terrain, and belong to some previous period of more humid conditions.

N. of the Murray River in the study area, the general terrain is one of Blanchetown Clay with surficial sand. Here the carbonate fraebules are at or near the surface. S. of the Murray River, the terrain is dominated by a system of E-W. dunes with two or more paleosols marked by aggregations of earthy carbonate. Beneath the dunes are hard calcitic fraebules as are found at or near the surface N. of the river. The geomorphology and stratigraphy of these paleosols is given in an accompanying paper (Gill, this *Memoir*). In that paper the evidence for climatic oscillation is given. Alternate phases of terrain stability and instability existed. The paleosols are associated with the stable phases, when the climate was more humid, because the carbonates were carried down to the B horizon instead of accumulating at the surface. Southward of the Dividing Range, during the drier phases, carbonates developed in the B horizons in areas where no carbonates accumulate at present (Gill 1973). Where carbonate deposition is well developed, the amount of mineral present is far more than could possibly be derived from the rocks present, so must have been transported in. On the geomorphic highs at least, the transport must have been aeolian—further evidence of terrain instability. Firman (1969) has referred to this pedocalcic complex as the Bakara Soil, which, following the nomenclature of Brewer et al. (1970), would become the Bakara Pedoderm.

1. *Carbonate Glaebules*

Blandowski and many other early explorers comment on the 'numerous nodules of limestone' in the dry country. As they came from a humid country, these would be strange to them, but they are certainly characteristic. X-ray analysis shows the mineral to be calcite. All the nodules have amorphous centres. Some are completely amorphous and various sizes of this type up to 15 cm diameter have been sectioned. Such are crystalline and compact throughout. Others have the exterior covered with fine laminations of calcite, but the laminated part is a smaller proportion of the diameter than the amorphous part. A third type consists of nodules that have been incorporated in a larger nodule. The principle of super-position applies here, and the nodules incorporated in the middle of the large one must be older. The smaller nodules are commonly 2-3 cm in diameter, while the compound ones occur up to 20 cm in diameter. Plate 33, fig. 1 shows a section through such a nodule. A comparatively rare type is the septarian nodule, and is characterized by cracks over its surface that have been infilled since formation. The cracks are pronounced on the upper surface but fade away on the lower surface. They appear to be a function of long exposure. One of these was black, but the colour disappeared on firing in a crucible so the black material was apparently organic. Other black nodules owe their colour to being used by the Aboriginals as oven stones.

2. *Ages of Carbonates*

The oldest soil at the present surface is represented by the top 6 m of the terrain on the N. side of the Murray River, where it is developed mostly in Blanchetown Clay. It is illustrated by the cover picture of this *Memoir*. Superimposed on this is the complex of calcrete-bearing soils, which extend down over eroded surfaces to within about 6 m of the river level, e.g. at Moorna E. oxbow lake. Smaller, less regular fraebules occur on the Rufus Formation, a ?Mid-Pleistocene terrace in the present valley tract. The E-W. dune system, best developed in the study area S. of the Murray R., is characterized by a series of pedocals that have amassed earthy carbonate, which also is calcite. The large lunette on the E. side of Lake Victoria has red paleosols, and the amount of carbonate amassed is small. The lunette onlaps relict 'islands' of Rufus Formation, and so is younger than that formation.

As the paleosols are of considerable importance for stratigraphy, they are discussed under that section in the accompanying paper, as also is the chronology. The youngest soil dated gave a modern age on charcoal, and this shows that the process of carbonate deposition is continuing at present. Paleosols of the order of 16,000 yr and 28,000 yr B.P. are recorded from the E-W. dune system, these dates according well with those of other workers. Under the dune at Berribee Station was a paleosol exceeding the range of C14 (> 34,300 yr, N.Z. R2729/3).

A complex calcite fraebule, such as that illustrated in Pl. 32, fig. 1, gave a radiocarbon age of 27,800 ± 1,900 yr B.P. (GaK-1727) for the outermost 5 mm of the laminated cortex, 28,000 ± 1,800 yr (GaK-1728a) for 5-10 mm from the surface, and > 31,700 yr (GaK-1728b) for the small included fraebules forming the centre of the nodule. The specimen came from the inland end of the Moorna E. oxbow lake on Moorna Station, W. of Wentworth, N.S.W., where the nodules are grubbed from the ground for road-making. Solid pans of calcrete appear in places. Dr T. A. Rafter of the New Zealand Institute of Nuclear Sciences expressed interest in these nodules so some were forwarded to him. He analysed one with the following results:

R2182/2A Outer layer	$\delta\ ^{13}C$ wrt PDB — 5·2‰	18,800 ± 380 yr B.P.
R2182/2B Intermediate layer	$\delta\ ^{13}C$ — 3·3‰	34,400 ± 100 yr B.P.
R2182/2C Inner layer	$\delta\ ^{13}C$ — 3·1‰	33,500 ± 900 yr B.P.

There is not necessarily any contradiction in the results from Japan and New Zealand. Different nodules were assayed, although from the same site. Both obtained younger dates on the outside and older ones in the middle, which super-position demands. The soil is polygenetic, and so evidences of soil formation at various periods are to be expected. In this region, soil formation occurred at roughly 16,000 yr, 28,000 yr and 34,000 yr. Each assay picked up two of these three phases. The matter requires further investigation. In view of the long time gap prior to the 34,000 yr paleosol, the comparatively small fraebules on the Rufus Formation with extinct marsupials that is probably mid-Pleistocene, the lack of understanding of the carbonate cycle, and the surprises that have come from U/Th check on the C14 ages of marine carbonate, I have some doubts about the older calcrete datings.

There is quite an amount of variation in the chemistry of these large nodules because they have incorporated different portions of the substrate, quite apart from any variation in the secondary carbonate. Professor K. Kigoshi has kindly permitted me to quote the following analyses by H. Ito and himself of the nodule he assayed. The first three parts numbered in the table below, are the three portions used for dating, while the fourth is from the very centre of the nodule. The figures are percentages:

	Fe_2O_3	Al_2O_3	CaO	MgO	SiO2	Na_2O	CO_2	H_2O	Total
1.	1·03	2·60	43·0	2·10	12·05	0·257	32·0	3·10	96·17
2.	0·322	0·933	48·5	1·81	6·21	0·214	32·9	3·51	94·40
3.	0·682	1·24	43·6	1·28	15·48	0·328	31·36	1·80	95·82
4.	0·951	1·98	39·1	1·41	22·3	0·338	27·40	2·25	95·74

The three nodule fractions assayed by Rafter, 2A-C respectively, had 35·8, 35·5 and 34·2% of CO_2.

The Moorna Formation (Gill, this *Memoir*) is Pliocene in age, and over it is the Blanchetown Clay-Chowilla Sand complex. Low in this stratigraphic horizon is the Karoonda Pedoderm, but below it (and therefore earlier) were found the sediments which yielded palynologic evidence of the incoming of arid conditions similar to the present. That time is 1·5—2m.y. ago, on present understanding, and more carbonate paleosols than exist would be expected for that period. It is possible that they have been formed and then leached or eroded away, during humid intervals.

For discussion of the dating of these pedogenic carbonates, see Rightmire (1967), Williams and Polach (1969), Bowler and Polach (1971), and Williams and Polach (1971).

3. *Vectors of Carbonate Deposition*

Difference of opinion exists on how carbonate is deposited in the soil profiles of dry lands:

(a) That the carbonate is carried down gravitationally by rain water, i.e. vector normal to ground surface and sense downward.

(b) That the carbonate is carried upwards in solutions rising by capillary attraction. 'Caliches seem to form *per ascendum* by capillarity' (Termier and Termier 1963, p. 402), i.e. same vector but sense upward.

The above two views have been placed in apposition, but this may be a false antithesis. Special conditions are required for capillary action, but when they are present, the rise of solutions may indeed occur. On the other hand, calcrete has been deposited in coarse gravels, where capillary action probably could not occur.

The author's observations suggest that deposition can take place in any vector and in either sense, but that the downward transport of carbonate in solution is the commonest process. That it was in solution is shown by radiocarbon dating. Calcite dust from Tertiary limestones, older paleosols, and such, all combine to form a soil that gives consistent radiocarbon dates over thousands of square kilometres.

Deposition from all directions is shown by the millions of spherical calcrete nodules with a cortex of regular laminations (Pl. 33). Downward movement is shown by Pl. 33, fig. 3, where the large nodules are aggregations of smaller ones united by enveloping laminate calcite, as shown in the section Pl. 33, fig. 1. The small nodules protrude through the bottom, but are thickly covered on top (Pl. 33, fig. 1). The nodules in Pl. 33, fig. 3 are in place, having been exposed by deflation at the edge of the Moorna E. oxbow lake. An excavation was carried out on the flat ground at the NW. end of the lake, and this encountered such nodules in place:

0·15 m	Loose red sand
0·25	Closely packed carbonate nodules with complex ones as in Pl. 33, fig. 1 at the top, merging into
0·76	Scattered nodules in red sandy Blanchetown Clay, merging into
1·5+	Light gray weathered Blanchetown Clay with five layers of softer rather irregular (but generally platey) carbonate nodules, plus some rhizomorphs.

Nearby are areas where a solid harpan covers the calcite spherical nodules (Pl. 33, fig. 2). This locality is at the end of long low slope, and it has been noted that other areas of maximal development of calcrete are so placed. It would seem that the heavy rain that occasionally falls soaks through the loose surficial sand, then accumulates at the foot of the slope where its load of carbonate is deposited on drying out. This also appears to be the process by which the 'indurated layer' on the alluvial fans on the W. side of Lake Victoria (C14 date 'modern') are formed. Nevertheless, the small spherical nodules occur over the whole terrain. These nodules are quarried for the roads, and some of these quarries are on geomorphic highs, e.g. the road up the E. side of Lake Victoria. They are a normal pedogenic product and not evaporites as some have suggested.

Hawley et al. (1968), working in the Rio Grande valley, noted that 'There is a direct correlation between geomorphic surface age and thickness and morphological complexity of associated caliche'. 'Ground water and capillary-fringe processes did not play a significant role in caliche genesis. The C14 analyses indicate that the age of the caliche generally increases with depth. There is strong evidence for aeolian origin of much of the carbonate in the caliche.' These comments apply well to our study area.

In Western Victoria, a thick hardpan of calcrete is covered in some areas by a comparatively thin layer of laminated mammillary calcite (Gill 1973). The hardpan is Last Glacial (~ 20,000 yr B.P.) while the laminated calcite is Postglacial (~ 8,700 yr). As the hardpan is more or less impenetrable, the younger layer must have been deposited from above and not *per ascendum*. Moreover, the hardpan has developed in aeolianite as the B horizon of a terra rossa. The highly calcareous matrix has been leached almost free of carbonate which has been deposited downwards into the hardpan.

In both Western Victoria and the study area there are some well developed rhizomorphs. As these root casts thin downwards, it is difficult to see how the root cavity (and no more) could be filled with secondary carbonate if it were ascending by capillary attraction. In the study area (and many other sites in the semi-arid country) cylinders of carbonate have been collected loose on the surface, and *in situ*. Some of these are thought to be rhizomorphs that have broken into sections, while others almost certainly are infilled burrows. Such were studied at the N. end of Lake Wetherell in the Menindee district. Some were about 2·5 cm in diameter with irregular sides, and a tendency to a spiral arrangement (cf. Gill, this *Memoir*, Pl. 7, fig. 5). Some carbonate cylinders from apparent burrows were tested for phosphate, but the results were negative.

4. *Lunette Paleosols*

On the E. side of Lake Victoria is a large lunette some 14 km long. It is remarkable for two features:

(a) The sand is a grade finer than is usual for dunes (see grain size analyses, Gill this *Memoir*) due to the general fineness of the sediments in this river regime of unusually low dynamics.

(b) The stratification is mostly subhorizontal. The strong W. winds apparently kept this fine sand in a state of constant blowout.

As a result the paleosols are mostly subhorizontal. Figure 4 shows diagrammatically the basic pattern of paleosol occurrence. However, the red soils frequently bifurcate. The largest number seen was when in drought conditions, the S. wall of a gulch showed five red paleosols plus the columnar gray soil at the present surface (Gill, his *Memoir*, Fig. 42). Aboriginal middens are associated with the paleosols, making possible the radiocarbon dates shown in Fig. 4. This series of paleosols needs study by a pedologist. They reflect more humid conditions in that they are not full of carbonates as is the present terrain.

A comparable suite of fossil soils occurs in the E-W. dune system (Woorinen Formation) of this region. The lowest soil shown in Fig. 4 is of the same age as the youngest found in the E-W. system in the study area. Firman (1969 and references) has applied the name Loveday Soil to the paleosols of the Woorinen Formation.

Paleosol Succession

The sequence of fossil soils described in this paper is thus:

Holocene Unnamed

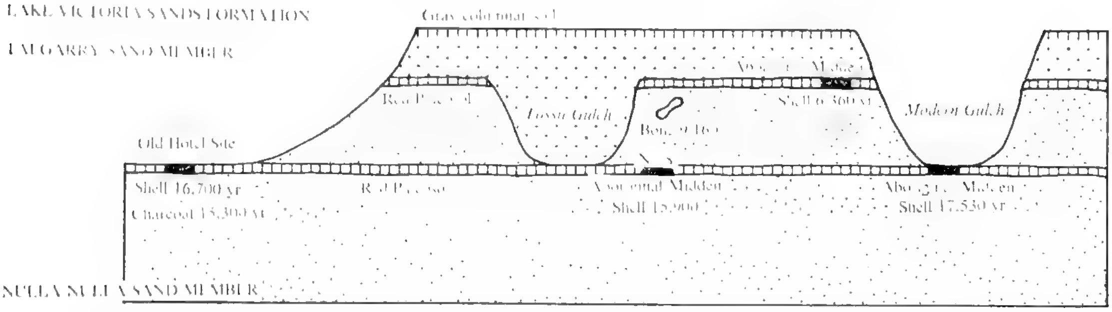

Fig. 4—Diagram of the basic paleosol occurrence in the Lake Victoria Sand (lunette, E. side Lake Victoria, N.S.W.) with chronology. The paleosols are of the order of 6,000 and 17,000 yr old. The latter is the date of the youngest paleosol in the E-W. dune system (Woorinen Formation). In places in the lunette the paleosols divide to give a complex sequence.

Pleistocene	Loveday Pedoderm (pedocal series) Bakara Pedoderm (pedocal complex)
Plio-Pleistocene	Karoonda Pedoderm (silcrete/opal)
Pliocene	Timboon Pedoderm (lateritic).

Comment

These notes have been prepared in the hope that they will encourage a full study of the soils and paleosols of this area. Geologically and palaeoclimatologically they have proved to be very significant, and no doubt they will prove to be as rewarding pedologically.

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Explanation of Plates 32-33

Plate 32

Fig. 1—N. bank of Murray R. at Sharp Point. Nampoo Stn., E. of Cal Lal and W. of Wentworth, N.S.W. (Site 4) showing at base white dolomite (partly replaced by opal) in Blanchetown Clay. Chowilla Sand overlies this, and the sand in turn by another layer of dolomite and opal. When Lake Bungunnia dried up, it ceased depositing Blanchetown Clay and deposited dolomite. Pedogenic processes on the dry lake bed resulted in deposition of silica and formation of rhizomorphs. The Chowilla Sand is a channel deposit. During the re-establishment of Lake Bungunnia, another

dolomite layer was deposited, and the process of silica deposition repeated.

Fig. 2—Exhumed Karoonda Terrain forms a platform on the E. bank of Salt Creek (as it does at Cal Lal and elsewhere), Kulcurna Stn., N.S.W. Opal was deposited in clay or dolomite, while sands were silicified to various degrees. This horizon is the Karoonda Pedoderm.

Fig. 3—Mottled zone of a lateritic profile at the base of the cliff forming the S. bank of the Murray R. at Yelta, N. Victoria. This is the Timboon Pedoderm.

Plate 33

Fig. 1—Polished section through one of the compound nodules at the NW. corner of the E. Moorna Stn. oxbow W. of the Darling Anabranch. Note the older generation of carbonate fraebules enclosed in the laminated calcite envelope. The coin is 1·7 cm diameter. Site 13.

Fig. 2—Same site. Carbonate fraebules as they occur on the ground surface where it has been eroded by wind and rain at the edge of the oxbow cliff. The coin is 1·9 cm in diameter.

Fig. 3—Same site. Large nodules as in Fig. 1 *in situ,* but exposed by erosion. The upper surface has always a thick layer of secondary carbonate. but the enclosed fraebules project out of the thin bottom layer, proving a predominantly downward movement of the carbonate, but the enclosed fraebules project out of the thin bottom layer, proving a predominantly downward movement of the carbonate. The coin is 2·8 cm in diameter.

—All photos by the author.


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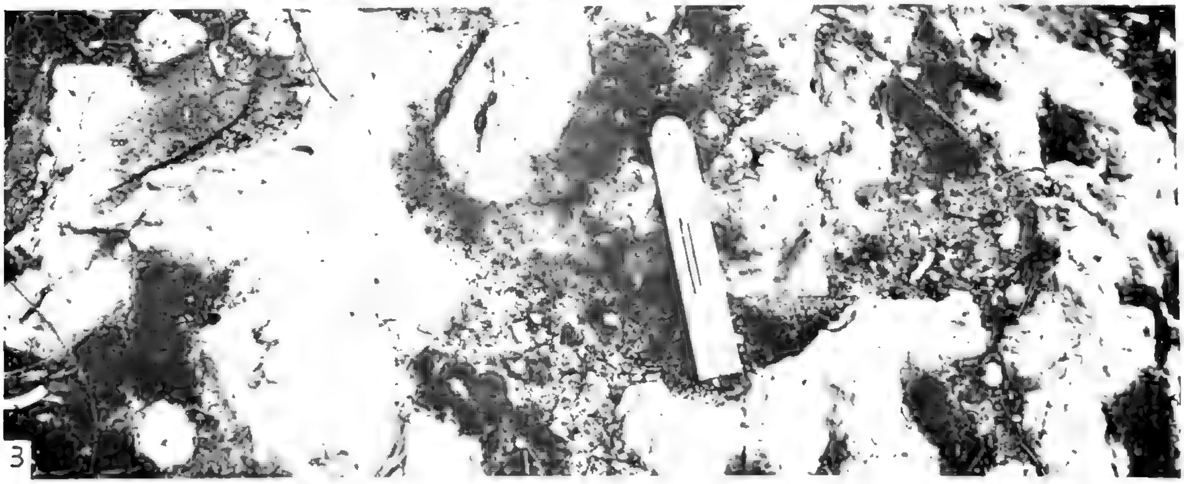
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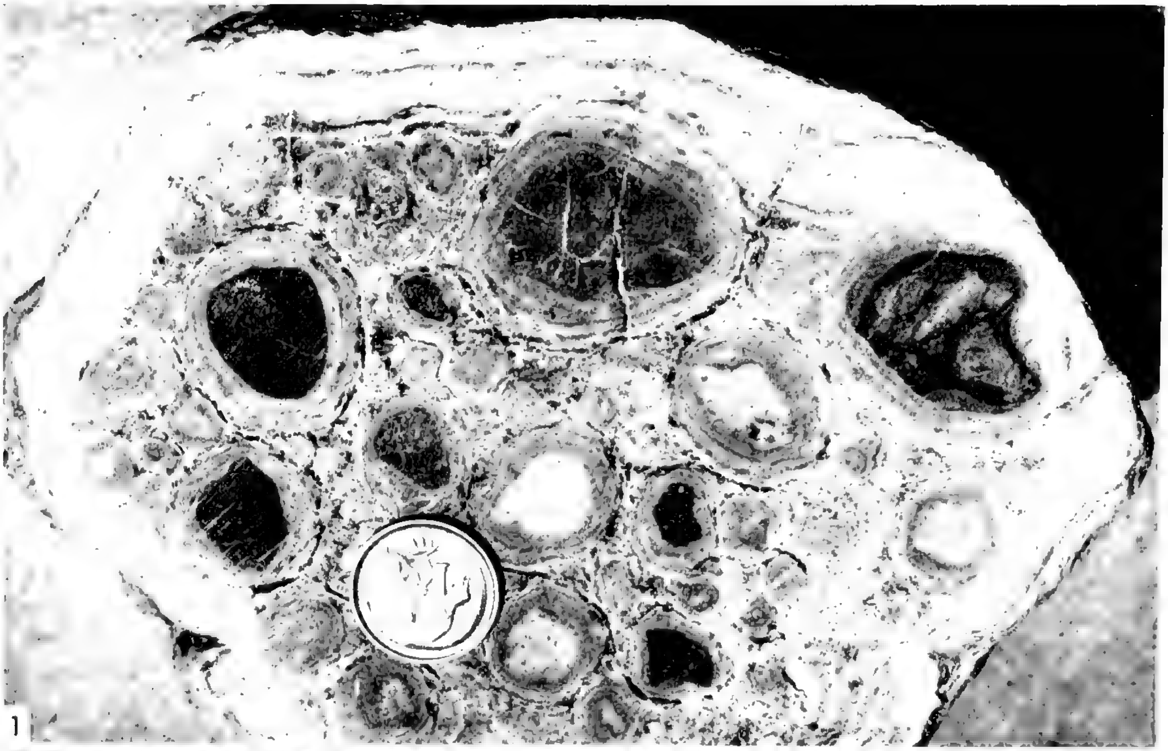
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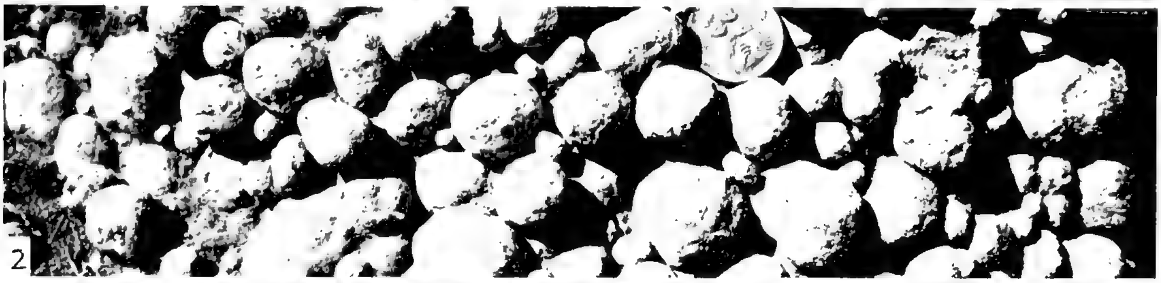
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BIRDS OF THE MURRAY RIVER REGION BETWEEN MILDURA AND RENMARK, AUSTRALIA—BREEDING, BEHAVIOURAL AND FEEDING RECORDS

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Abstract

Breeding, migration and nomadic movements, general behavioural and feeding records are provided for some 126 bird species inhabiting or visiting the Murray River region between Mildura and Renmark, Australia, during the course of 19 field trips from 1967–70.

Introduction

This paper reports part of a systematic recording of information about the bird species inhabiting or visiting the Murray River region between Mildura and Renmark during 19 field trips from 1967-1970. The recording was an adjunct to geologic and anthropologic investigations of the proposed Chowilla Dam inundation area and its environs. In an endeavour to gather all possible information in case of inundation, the recording of the birds of the region was detailed, giving a picture of their lives (including movements). Some 126 species are listed, but many more were recorded.

The sequence of presentation of families and species follows the order and nomenclature of Condon (1969). Where considered necessary, trinomials are introduced. Each species is discussed in chronologic order of record, beginning with breeding records (*Br.*), then those dealing with movement and migrations (*M*), general descriptions of behaviour (*BH*), and finally foods and feeding (*F*). Three of the habitats in which bird recording most commonly occurred are shown in Pl. 34, figs. 1-3.

Plants named in the text were identified from Leigh and Mulham (1965), and by courtesy of the National Herbarium, Melbourne. The insects were named by Miss E. Mathieson, Assistant in Entomology, National Museum of Victoria. Surface wind speeds are according to the Beaufort Scale.

Order Casuariiformes

Family Dromaiidae

Dromaius novaehollandiae

Br: 23 June 1967, male with 4 newly-hatched chicks, Lybra Paddock, Keera Station, Vict. 3 Oct. 1967, male with 3 chicks, post-striped stage, Nampoo Station, N.S.W. 28 Aug. 1968, bird incubating 6 eggs, Berribee Station, Vict., Geoff Bowden (pers. comm.). 23 Sept. 1968, male with several small chicks charged and threatened Bowden when he approached group closely on motor-cycle, Berribee Station, Vict. 20 Nov. 1968, male with 4 tiny striped chicks, Talgarry/Nulla Stations boundary fence, N.S.W. 29 July 1969, male with 8 stripey chicks, 2·8 km N. of Butchers Tank, Dunedin Park Station, N.S.W. 4 Oct. 1969, male with 2 small chicks, Talgarry Station dams, N.S.W.

Order Podicipediformes

Family Podicipedidae

Podiceps novaehollandiae

Br: 22 Oct. 1968, pair at new nest, outer edge of dense cumbungi, Moorna E. oxbow, N.S.W.

P. poliocephalus

M: 22 Oct. 1968, 100+ on Moorna E. oxbow, N.S.W. Normally an uncommon species in the district. 23 May 1969, 200+ at same locality 31 May 1969, 400+ same locality.

F: 31 May 1969, group of 10 diving repeatedly beneath large patch of floating *Azolla,* Murray River, opposite Moorna Station woolshed, N.S.W.

P. cristatus

M: 25 Apr. 1968, 160-200 in well-spaced groups of 20-30 on Lake Victoria, opposite Old Hotel site, Nulla Station, N.S.W. No feeding; birds apparently resting on surface, 1330 hr.

Order PELECANIFORMES

Family PELECANIDAE

Pelecanus conspicillatus

BH: 18 Mar. 1969 (see *P. carbo* 18 Mar. 1969). 22 Mar. 1969, 1908 hr. 4 alighted on 4 separate vertical broken-off stumps protruding from water just offshore at Lake Victoria, Nulla Station, N.S.W., preened briefly, then roosted with bills beneath wings and legs contracted, appearing as huge mushrooms in the lake. 18 July 1969, 2 displaying at each other, standing on log in water, with wings extended, tips drooping, necks extended toward each other, deep grating calls. Butcher's Tank, Dunedin Park Station, N.S.W.

M: 19 Nov. 1968, 5 passed over at estimated 1·5 km, NE. 1410 hr., Bone Gulch, Moorna Station, N.S.W.

F: 29 Jan. 1968, many fish in Lake Victoria dying in warm shallow water (temperatures throughout week ranging from 43 to 47 C. in shade); 47 pelicans seen actively feeding on these fish, NE. Lake Victoria, Nulla Station, N.S.W. 31 Oct. 1968, 60+ feeding in rough water emerging from outlet regulator, Rufus River, N.S.W. Many *P. carbo* also present. 24 Nov. 1968, 25 feeding at outlet of Rufus River regulator, N.S.W. One large injured fish drifting downstream was repeatedly being picked up by pelicans but none could swallow it. One bird got the fish into bill, but the weight caused the bird to tilt forward, dropping the fish. Several other pelicans that had been resting on the bank charged into the water and joined in, but none could swallow it. Fish and fighting pelicans drifted around bend out of sight.

Family PHALACROCORACIDAE

Phalacrocorax carbo novaehollandiae

17 Mar. 1969, a large breeding colony present in dead red gums, NW. Lake Victoria, Noola Station, N.S.W. Nests of sticks placed on forks, horizontal branches or tops of stumps; most nests with downy chicks, 1-3; many eggshells washed up on beach nearby. Adults disperse chiefly to W., NE., SE. for food, departing entirely from the lake. Some birds do feed in lake, e.g. large feeding flocks present (records below). Birds returning to colony from elsewhere travel high, 220-700 m, in line or in shallow V-formation; when over lake flock disperses, birds plummet down individually at high speed. Those coming from W. fly immediately to nests; those from NE. or SE. drop down to near lake level as soon as they cross the shoreline, then reform in lines and fly low over water to the colony before dispersing to nests. Colony has been established in the area for several years, G. H. Lamb, J. May (pers. comm.), Noola Station, N.S.W. 28 May 1969, several occupied nests located in dead red gums, 1-2 km N. of Rufus River Public Hall, SW. of Lake Victoria, N.S.W.

BH: 22-25 Apr. 1968, 1000+ estimated, in several dense feeding flocks, each of 200-400 birds, on Lake Victoria, N.S.W. 24 Apr. 1968, estimated 2000 cormorants spread 5-deep in a long line along beach of Lake Victoria, mostly with wings spread to dry, and preening. Other dense groups out fishing in lake, 1120 hr. Estimated 2000 Silver Gulls also present along shoreline amongst cormorants, and many others, in flocks of up to 300, hovering over groups of fishing cormorants. 18 Mar. 1969, estimated 4000 in huge group on beach, adjacent trees, and in water nearby; 70 pelicans, 400 plus black swans also present. Pump shed area, Lake Victoria, Talgarry Station, N.S.W. 26 Mar. 1969, 60+ in long straggling skein flying NNE. and slowly gaining height to estimated 180 m as leave Lake Victoria, probably to another feeding site. Nulla Station, N.S.W.

F: 31 Oct. 1968 (see *P. conspicillatus* 31 Oct. 1968). 25 Jul. 1969, several large feeding flocks, totalling many thousands of birds, on Lake Victoria, N.S.W.

P. varius

M: 25 July 1969, 11 in dead gums, Lake Victoria, Talgarry Station, N.S.W.

Order Ardeiformes

Family Ardeidae

Ardea novaehollandiae

Br: 18 Nov. 1968, pair courting at nest site high in red gums over Murray River bank. Nest appeared half-built, of sticks, opposite Merbein cliff in N.S.W.

F: 26 Mar. 1969, 1 wading in deep rainwater pool amid *Nitraria* bushes, sand hills at Lake Victoria, Oak Hills paddock, Nulla Station, N.S.W.

A. pacifica

F: 26 Sept. 1968, 1 immature bird feeding in large roadside puddles, open country, c. 3·5 km S. of nearest stream course, Keera Station, Vict.

Family Plataleidae

Threskiornis spinicollis

F: 29 Jan. 1968, 45 plus 23 *P. flavipes* feeding over flooded flat following 127 points rain 3 days earlier. Tareena Homestead, Salt Creek, N.S.W. 27 Nov. 1968, 4 feeding between trees in flooded citrus orchard. Overhead sprinklers in full operation, birds apparently quite unconcerned, Renmark, S.A.

Plegadis falcinellus

M: 25 Mar. 1969, 1 on beach at pump shed, Lake Victoria, Talgarry Station, N.S.W.

F: 25 Oct. 1967, 9 feeding in freshly flooded irrigated lucerne paddock, with other waterfowl and bird species (see notes on Feeding Associations), near homestead Berribee Station, Vict. 27 Mar. 1969, 14 feeding in shallow water at margin of canegrass *Eragrostis australis* swamp, SW. paddock, Nulla Station, N.S.W.

Platalea flavipes

F: 29 Jan. 1968 (see *T. spinicollis*, 29 Jan. 1968).

Order Anseriformes

Family Anatidae

Cereopsis novaehollandiae

M: Dec. 1967-Feb. 1968, 3 birds spent 2 months on irrigated pasture at Moorna Station, N.S.W. See Simpson 1972, p. 97. Pers. comm. from R. Honner and E. Ablett, Moorna Pastoral Co.

Cygnus atratus

Br: 25 Sept. 1967, 2 pairs with 6 and 3 cygnets respectively, all recently hatched, Moorna E. oxbow, N.S.W. 1 Oct. 1967, adult on nest of reeds on small island same oxbow lake, pair with 5 well grown cygnets; pair with 2 newly hatched cygnets. 22 Oct. 1968, 5 or 6 pairs of adults, each with cygnets, varying ages from new-hatched to almost fully fledged, same oxbow.

BH: 18 Mar. 1969 (see *P. carbo* 18 Mar. 1969).

M: 18 Apr. 1968, 300+ at Moorna E. oxbow, N.S.W.

Tadorna tadornoides

Br: 1 Oct. 1967, pair with 3 small ducklings, Moorna E. oxbow, N.S.W. 1 Aug. 1968, pair with eggs, hollow in red gum on banks Monoman Cr. (Kelvin Kempster, pers comm.) S.A. 22 Sept. 1968, pair with 11 chicks on water, Oscars Lagoon, Berribee Station, Vict.

M: 20 July 1969, flock of 44 on water at small salt lake 4-6 km E. of road to Nulla Station, on Dunedin Park Station, N.S.W.

Anas castanea

Br: 21 Sept. 1968, bird flew from hollow in dead spout of living red gum, 10 m over water, Mullaroo Cr., Berribee Station, Vict. 19 Nov. 1968, pair with 3 large downy chicks on Murray River, Moorna Station wool shed, N.S.W.

M: Mar. 1968, banded bird recovered by Richard Harvey of Nulla Station, N.S.W., at NW. Tank, No. 09-15668, Fisheries and Wildlife Dept. banded Lara Lake, Vict. (38° 01′S, 144° 25′E) on 16 Jan. 1967 (c. 530 km direct).

A. rhynchotis

M: 21 Mar. 1969, 10 at Moorna E. oxbow, N.S.W.

Malacorhynchus membranaceus

M: 20 July 1969, 62 at Butcher's Tank, Dunedin Park Station, N.S.W.

F: 27 Nov. 1968, single bird on Murray River feeding among *Azolla* and exposed weeds near bank, Nampoo Station, N.S.W.

Aythya australis

M: 26 Jun. 1967, flock of 200, Moorna E. oxbow, N.S.W. 25 Sept. 1967, 150 at same locality. 15 Mar. 1969, 550+ on water close to shore among dead red gums, N. Lake Victoria, Nulla Station, N.S.W. 31 May 1969, flock estimated 160 flew downriver, Fisherman's Cliff, Moorna Station, N.S.W.

Chenonetta jubata

BH: 23 June 1968, 14 in group, in swampy red gum forest. One male displayed briefly to another male. Berribee Island, Murray R., Vict.

M: 17 June 1968, pair at roadside puddle, Merbein-Renmark road, Ned's Corner Station, Vict. (76 pt. rain overnight).

Oxyura australis

M: 21 Mar. 1969, 32 at Moorna. E. oxbow, N.S.W.

Biziura lobata

BH: 26 Sept. 1967, male displaying to female, Moorna E. oxbow, N.S.W.

Order ACCIPITRIFORMES

Family ACCIPITRIDAE

Milvus migrans

F: 29 July 1969, 1 attempting to pick up a large dead fish floating in Darling River, Wentworth, N.S.W. Direct lift not achieved, but fish eventually grounded in shallow water, where kite commenced feeding.

Haliastur sphenurus

Br: 29 Sept. 1967, nest with 3 small young, 24·4 m in red gum, banks Murray R. on Berribee Station, Vict., opposite Nampoo Station, N.S.W. 21 Oct. 1967, nest in dead tree at Lake Victoria, N.S.W., situated 12 m above water and 92 m out from shoreline. Adults making frequent trips with food for 3 small young. (Pl. 35, fig. 1) 23 Oct. 1968, 1 well fledged young, in same nest as above, Talgarry Station, Lake Victoria, N.S.W. Continuous occupation of the same nest was recorded each year from 1967-72.

BH: (see *H. leucogaster* 1 Oct. 1967).

F: 6 May 1967, pair at freshly killed rabbit, main road, Keera Station, Vict. 27 June 1967, 1 carried a 23 cm skink to tree and ate it, Winjellie Station, N.S.W. 26 Oct. 1967, 1 at dead rabbit, roadside near Walpolla Cr., Keera Station, Vict. 21 Sept. 1968, 1 attempting to catch fish surfacing in the late evening, flying low over the Lindsay R. and clutching into the water with one foot, Berribee Station, Vict. 31 May 1969, 1 at road-killed rabbit, near Moorna E. oxbow, N.S.W.

Accipiter cirrhocephalus

BH: 18 Mar. 1969 (see E. tricolor 18 Mar. 1969).

Hieraaetus morphnoides

BH: 27 Sept. 1967, 1 bird flew from a *Callitris* pine carrying a long-tailed creature, possibly a lizard. It was immediately attacked by a Wedge-tailed Eagle. Both rapidly attained an estimated 300 m in a whirling 'dogfight', where a second Wedge-tail joined the attack. Little Eagle finally dropped prey animal. The second Wedge-tail dived very steeply and caught it, and flew off. Little Eagle attacked first Wedge-tail, which it had previously been avoiding. The two birds passed from sight to SW. 0·8 m W. of Moorna wool shed, Moorna Station, N.S.W.

M: 21 Apr. 1968, 1 flying at 450-600 m, gliding fast, directly away from approaching rainstorm. Moorna wool shed, N.S.W.

F: 31 May 1969, 1 a road-killed Stumpy-tailed Lizard *Trachysaurus rugosa*, Ana Branch bridge, Moorna Station, N.S.W. 5 Oct. 1969, 1 feeding on dead emu chick, near Butcher's Tank, Dunedin Park Station, N.S.W.

Aquila audax

Br: 27 Nov. 1968, recently used nest in broken red gum. Mummified bodies of 2 well-fledged young found nearby, shot by rifle. Salt Creek, Kulcurna Station, N.S.W. (see *H. morphnoides* 27 Sept. 1967).

BH: 29 Apr. 1968, pair flying over Morkalla, Vict., one low, one very high at estimated 850 m. This bird suddenly plummeted almost to ground level to join first bird, and both flew to NE. Within 5 minutes, a torrential rain storm began moving from W. and reducing visibility at ground level to a few metres. 19

May 1968 (see *F. peregrinus* 19 May 1968).

M: 9 May 1967, c. 27 mummified skeletons strung on H. B. Bailey's homestead fence, c. 7 km N. of Werrimul, Vict. 18 skulls, 5 whole skeletons collected. Bailey reported that these had been shot in roughly two batches in late February, and in mid-April, 1967, and that he shot eagles whenever possible. The April period was during his lambing time. Most had been shot with a rifle at a fair range, whilst on the ground at sheep carcases. Most were immature birds (buff plumage), suggesting a massive culling of the previous season's fledglings. It also suggests a period of high mobility of fledglings—a dispersal from nest sites and a gathering at potential feeding sites.

F: 19 Oct. 1967, 2 adults plus 1 immature feeding on remains of a red kangaroo shot for dog meat the previous night. Dunedin Park Station, N.S.W. 2 *C. coronoides* also present, waiting for eagles to finish eating. 29 Apr. 1968 (see *C. mellori* 29 Apr. 1968). 24 Nov. 1968, 1 at road-killed rabbit, Lock 8 turnoff, Dunedin Park Station, N.S.W.

Haliaeetus leucogaster

Br: 31 Oct. 1968, recently occupied nest located, 12 m in red gum, backwater off Frenchman Creek, Winjellie Station/Lock 8 area, N.S.W.

BH: 1 Oct. 1967, adult attacked in flight by a pair of Whistling Kites. Sea Eagle rolled on back, extending legs and talons as each kite passed close by. Attack lasted 2 minutes before Kites desisted; a pair of Australian Ravens then chased Sea Eagle briefly. 3·2 km W. of woolshed, Moorna Station, N.S.W.

F: Apr. 1971, immature Sea Eagle attacked cockatoos feeding on the ground, Nulla Station, Lake Victoria, N.S.W. (Simpson 1972, p. 100).

Circus approximans

BH: 23 Oct. 1968 (see *S. vulgaris* 23 Oct. 1968). 22 Mar. 1969 at 1102 hr. prior to torrential rainstorm, one flew due N., low over sand dunes, directly toward approaching rain. Nulla Station, Lake Victoria, N.S.W. (see also *A. p. pacificus, C. leucosterna, H. nigricans E. tricolor* 22 Mar. 1969).

Family FALCONIDAE

Falco subniger

F: 28 June 1967, 1 pursuing House Sparrows through farmyard and house environs, Scadding's homestead, near Lock 8, N.S.W.

F. longipennis

BH: (see *F. cenchroides* 1 Oct. 1967).

F. peregrinus

23 Feb. 1967, an adult flying very high, estimated 600 m, at very high speed and with very frequent twists or rolls; course fairly direct, SW. Brown's Paddock, Keera Station, Vict. 19 May 1968, pair chasing pair of Wedge-tailed Eagles, diving very close, then climbing steeply and repeating dives several times. Chowilla Dam Construction site, Bunyip Reach, S.A.

F. cenchroides

Br: 18 Nov. 1968, 2 flying young being fed by 2 adults, Merbein Cliff, Vict. Food brought appeared to be large insects.

BH: 1 Oct. 1967, pair chasing and apparently playing with a Little Falcon. A Kestrel and the falcon flew parallel, wing tip to wing tip briefly, then both Kestrels began series of rapid stoops at the falcon, without attempting contact. Moorna E. oxbow, N.S.W. 23 Oct. 1968 (see *G. tibicen* 23 Oct. 1968). 25 Mar. 1969 (see *A. p. pacificus* 25 Mar. 1969).

Order GALLIFORMES

Family PHASIANIDAE

Coturnix pectoralis

F: 30 Oct. 1968, 1 flushed from beneath large *Nitraria* bush in erosion gully, Talgarry Station, Lake Victoria, N.S.W. The ground was strewn with seeds from wild turnip *Brassica tournefortii*. Feeding inferred, but not witnessed.

Order GRUIFORMES

Family PEDIONOMIDAE

Pedionomus torquatus

M: 4 Oct. 1969, 1 bird among young *Brassica tournefortii*, running along vehicle wheel track, alongside S. fence, Oak Hills paddock, Nulla Station, N.S.W. Several clear views obtained by T. A. Darragh and author. Status of the species in the district quite unknown, but probably rare (distribution summary in Frith

1969, p. 149, comments in Wheeler 1967, p. 11, and in Condon 1969, p. 41).

Family RALLIDAE

Tribonyx ventralis

BH: 26 Nov. 1968, 36 feeding in tight group on dry flats at Lake Merretti, S.A. All went across 80 m of open ground to drink at lake edge, then returned together and resumed feeding in same area, 1440 hr.

M: 26 Sept. 1968, 1 at roadside puddles fringed with dense *Eragrostis australasica* Keera Station, Vict. 28 Oct. 1968, 13 skulking beneath large *Nitraria* bushes, Lake Victoria pump shed, Talgarry Station, N.S.W. (see also *P. nigricans* 28 Oct. 1968). 25 Nov. 1968, 7 in dense *Muehlenbeckia* beneath red gums, Nampoo Station, N.S.W. 27 Nov. 1968, 7 still present, same locality.

Gallinula tenebrosa

BH: 23 May 1969, several gave alarm calls as an Eastern Water Rat *Hydromys melanogaster* approached a dense reed bed after swimming from the island, NW. corner of Moorna E. oxbow, N.S.W.

Porphyrio porphyrio

Br: 31 May 1969, adult on and adding to a nest-shaped structure, water edge at margin of dense reeds, small island in Moorna E. oxbow, N.S.W. Not determined whether real nest, or a temporary platform.

Fulica atra

M: 21 Mar. 1969, estimated 3000 at Moorna E. oxbow, N.S.W. 31 May 1969, 300+ same locality.

Order CHARADRIIFORMES

Family CHARADRIIDAE

Vanellus miles novaehollandiae

Br: 26 Sept. 1967, nest with 2 eggs, sandy, lightly grassed patch on W. bank, Moorna E. oxbow, N.S.W. Second nest with 2 eggs on level ground 140 m from water, above Moorna E. oxbow. Nest in light cover of bluebush and grasses, 0·25 km SW. of first nest.

F: 17 June 1968, pair wading in roadside puddle, possibly catching insects off the water surface. Ned's Corner Station, Vict.

V. tricolor

Br: 25 Sept. 1968, adult with 1 well-grown chick on ridge with stand of *Callitris*, W. of Ned's Corner homestead, Vict. 26 Sept. 1968, adult with 2 young, just flying, dam in Lybra Back Paddock, Keera Station, Vict. 23 Oct. 1968, pair adults with 4 large downy young near salt lake, Talgarry Station, N.S.W.

Charadrius alexandrinus ruficapillus

BH: 23 Oct. 1967, a male on top of broad sand dune area, 30 m above Lake Victoria, and 0·4 km inland. A most exposed position—no nest found. Site 7, Nulla Station, N.S.W.

M: 24 Apr. 1968, some 100+ actively feeding amongst patches of slimy green algae on wet sand immediately beside water edge, NE. beach of Lake Victoria, Nulla Station, N.S.W. 16 Mar. 1969, 8 on dry red claypan among *Kochia* and *Atriplex vesicaria* bushes, at dam c. 3 km W. of Nulla Station woolshed, N.S.W.

C. melanops

BH: 28 Apr. 1968, 1 walking between small *Kochia* and *Atriplex* bushes on cliff edge, 18 m above Lindsay R., Berribee Station, Vict., 1640 hr. Unusual situation for this species.

F: 29 June 1968, 1 feeding at edge of large roadside puddle, 1·5 km S. of Lindsay R., Ned's Corner Station, Vict.

C. cinctus

F: 23 May 1969, 1 feeding along margins of extensive rainwater puddles, on clay pans amid *Kochia* bushes, 1 km W. of Moorna Station woolshed, N.S.W. The margins of the puddles were littered with bodies of small beetles and termites, but not known whether dotterel feeding on these.

Peltohyas australis

M: 28 Oct. 1968, flock of 40-50+ on series of small claypans between large bare sand hummocks, and *Nitraria* bushes, 3·2 km inland from NE. area of Lake Victoria, Nulla Station, N.S.W. Birds spread out widely, extremely wary and flew about as vehicle approached. Some appeared to be feeding among tiny *Kochia* bushes at margins of claypans. 30 Oct. 1968, 15 recorded same locality as above.

Family LARIDAE

Larus novaehollandiae

BH: 24 Apr. 1968 (see *P. carbo* 24 Apr. 1968).

F: 25 Apr. 1968, 500 with feeding group of *P. carbo*, Talgarry Station, Lake Victoria, N.S.W.

Chlidonias hybrida

M: 20 Sept. 1968, 1 flying over billabong, near causeway on Sturt Highway leading to Paringa Bridge, via Renmark, S.A.

Hydroprogne tschegrava

BH: 23 Oct. 1968, 7 at salt lake 1·6 km E. of Lake Victoria, N.S.W., on Talgarry Station 1800 hr. Birds apparently intending to roost on small islets of salt-encrusted mud in centre of lake. 28 Oct. 1968, 58 at salt lake for night, 1910 hr. Talgarry Station, N.S.W. 29 Oct. 1968, 50 present same locality, 1925 hr. 18 Mar. 1969, 21 present same locality, 1740 hr. 26 May 1969, 20 gathered at roost site at salt lake, 1645 hr. c. 1·5 hr. prior to sunset, same locality. 4 Oct. 1969, 25 at roost site, salt lake, Talgarry Station, N.S.W. 1740 hr.

Order COLUMBIFORMES

Family COLUMBIDAE

Geopelia striata

F: 28 Sept. 1967, several pairs feeding along remains of old fodder trail laid during hand-feeding of sheep, Murray River bank, near Bone Gulch, Moorna Station, N.S.W.

G. cuneata

F: 28 Oct. 1968, 1 on ground, feeding beneath dense clump of *Nicotiana* bushes, foreshore Lake Victoria, Talgarry Station, N.S.W.

Phaps chalcoptera

BH: 24 June 1968, 8 birds in loose association drinking at rainwater puddle on roadside, margin of *Callitris* pine ridge, 1700 hr., W. end of Berribee Island, Vict.

F: 28 Oct. 1968, 2 feeding beneath huge peppercorn tree, foreshore N.E. Lake Victoria, Nulla Station, N.S.W. Only large tree for 1 km in any direction.

Ocyphaps lophotes

F: 24 June 1967, 8 feeding on ground beneath *Muehlenbeckia cunninghamii* bushes, windmill, Keera Station, Vict. 5 Oct. 1967, pair feeding, apparently on seeds of dried and split melons *Cucumis myriocarpus*, Keera Station homestead, Vict. 25 Apr. 1968, pair feeding, apparently on seeds of *Chenopodium* sp., Tareena Station homestead, N.S.W. 24 Oct. 1968, 2 feeding on loose seeds of *Brassica tournefortii*, erosion gulches of lunette, Lake Victoria, Talgarry Station, N.S.W. 25 Nov. 1968, 17 in group feeding beneath dense *M. cunninghamii* bushes, Kulcurna Station, N.S.W.

Columbia livia

Br: 18 Nov. 1968, several nests with incubating birds beneath Murray River bridge from Yelta, Vict., to Curlwaa, N.S.W.

Order PSITTACIFORMES

Family PSITTACIDAE

Cacatua galerita

F: 27 Sept. 1967, 4 plus 6 galahs feeding on heads of *Helipterum floribundum*, growing in oatfield, 180 m N. of Fisherman's Cliff, Moorna Station, N.S.W. 18 May 1968, 40+ feeding in wheatfield, Paringa, S.A. 20 Sept. 1968, 32 plus 2 *C. roseicapilla* feeding on fruits of *Atriplex visicaria*, Bone Gulch, Moorna Station, N.S.W. 26 Sept. 1968, 8 feeding on fruits of *A. vesicaria* along Lock 9, Lake Cullulleraine channel, Kulnine Station, Vict. 23 July 1969, 15 plus 10 *C. sanguinea* and 3 *C. roseicapilla* feeding in close group on seeds of dried melons *Citrullus lanatus*, Dunedin Park Station, N.S.W.

C. leadbeateri

F: 1 Sept. 1968, 30+ in wheatfield, pulling up germinated plants and presumably nipping off the remains of seed, Paringa, S.A. 22 Oct. 1968, 3 feeding on *Helipterum floribundum*, teasing seeds from floret bases, 1·5 km W. of Moorna Station woolshed, N.S.W. 28 Oct. 1968, 22 feeding on *H. floribundum* florets, 6 *C. roseicapilla* also, foreshore Lake Victoria, Nulla Station, N.S.W. 30 Oct. 1968, 35 plus 10 *C. roseicapilla* feeding on same flower species, same locality. 29 May 1969, 27 feeding on seeds of dried small melons *Cucumis myriocarpus*, Tareena Station, N.S.W.

C. sanguinea

F: 1 Oct. 1967, 10 disturbed feeding on floret bases of *Helipterum floribundum* and seeds of melons, *Cucumis myriocarpus*, 0·5 km W. of Moorna Station woolshed, N.S.W. 26 Oct. 1968, 32 plus 12 *C. roseicapilla* feeding on florets of *Helipterum floribundum*, Lake Victoria frontage, Nulla Station, N.S.W. 19 Nov. 1968, 60+ feeding over oatfield, 1700 hr., and slowly moving under red gums along Murray R. bank. Flock later roosted immediately opposite in trees on Keera Station, Vict. Oatfield under stubble, Moorna Station, N.S.W. 23 July (see *C. galerita* 23 July 1969).

C. roseicapilla

BH: 28 Apr. 1968, 2-300 birds noted flying at estimated 300-600 m, calling loudly and in loose flock, comprising mostly pairs, circling and flying in all directions. General trend to NE. Many pairs began swooping dives and roll-overs, maintaining station in relation to each other. Then whole flock suddenly dropped down, in a mass of twisting, near vertical dives, right to tree-top level before pulling out of dives and alighting in crown foliage of red gums; then flying in a flock down river to W. Total time 2-3 minutes. Near Berribee Station homestead, Vict.

M: 23 June 1968, flock of 400 flying S. toward open country from Berribee Station homestead area, Vict. First light, probably to feed for day.

F: 27 Sept. 1967 (see *C. galerita* 27 Sept. 1967). 5 Oct. 300+ feeding in wheatfield, Sturt Highway, 4·8 km E. of Lake Cullulleraine, Vict. 22 Apr. 1968, 50 feeding on sprouting wheat, Dunedin Park Station homestead, N.S.W. 1 Aug. 1968, 21 feeding, apparently on fruiting bodies of *Atriplex vesicaria*, at roadside S. of Lake Merretti, S.A. 20 Sept. 1968 (see *C. galerita* 20 Sept. 1968). 26 Oct. 1968 (see *C. sanguinea* 26 Oct. 1968). 28 Oct. 1968 (see *C. leadbeateri* 28 Oct. 1968). 30 Oct. 1968 (see *C. leadbeateri* 30 Oct. 1968). 21 Mar. 1969, 400+ in oatfield, feeding amid stubble, Fisherman's Cliff, Moorna Station, N.S.W. 23 July 1969 (see *C. galerita* 23 July 1969).

Nymphicus hollandicus

Br: 27 Oct. 1968, pair with 1 large young in hollow of mallee *Eucalyptus*; axe marks about hollow indicate may have been opened by nest-robbers in a previous season, 6·4 km NW. of Nulla Station homestead, N.S.W.

M: 20 Mar. 1969, 17 in tight flock, NE. at 60 m, calling loudly, 1215 hr., near salt lake, Talgarry Station, N.S.W.

F: 31 Oct. 1968, 7 feeding on seeds in bases of a white fluffy-topped grass growing amid *Kochia* bushes, woolshed area, Nulla Station, N.S.W. 20 Nov. 1968, 60+ in *Casuarina* trees, Dunedin Park Station, N.S.W., and feeding among *Kochia* bushes beneath the trees. Food not determined. 27 July 1969, flock of 50 feeding on ground amid *Kochia* bushes, SE. area of Dunedin Park Station, N.S.W.

Polytelis anthopeplus

M: 23 Apr. 1967, several small groups flying high, S. from red gum forest above shrub steppe toward Millewa country, presumably to feed, 4 km W. of Lake Walla Walla, Ned's Corner Station, Vict.

F: 1 Sept. 1968, two groups, 10 and 18, feeding on roadside weeds (not identified) in shallow drains and culverts under the Vict./S.A. border fence, Paringa road.

Platycercus elegans flaveolus

Br: 21 Sept. 1968, 1 adult repeatedly entering hollow spout of red gum, 21 m over Lindsay River, Berribee Station, Vict.

M: 23 June 1968, flock of 18 in red gums, near punt on Lindsay R., Berribee Station, Vict.

F: 26 June 1967, pair feeding on red gum seeds, opening gum nuts and dropping a steady rain of fragments, Fisherman's Cliff, Moorna Station, N.S.W. 19 Nov. 1967, 2 feeding on ground in centre of irrigated lucerne (alfalfa) paddock, Berribee Station, Vict. 20 June 1968 (see *B. barnardi* 20 June 1968).

Barnardius barnardi

M: 23 June 1968, 10 in loose group, red gums and black box area, near Berribee Station homestead, Vict. This species moderately rare within the river marginal forest of the two eucalypt species, but common on river banks where Millewa Land System immediately abuts Lindsay Island Formation (Rowan and Downes, 1962), and where marginal forest is both narrow and mixed with e.g. *Casuarina*, *Acacia* trees.

F: 30 Apr. 1968, pair plus 4 *P. haematonotus* feeding on an unidentified daisy bush at roadside, Berribee Station, Vict. 20 June 1968, 4 plus pair *P. e. flaveolus* feeding in close group on red gum flowers which were almost dead, Berribee Station, Vict. 29 June 1968, pair feeding on ground beneath dense *Muehlenbeckia* bushes. One bird was scratching small holes and appearing to eat from them. Swampy area adjacent to ephemeral water channel, Berribee Station 'Big Island', Vict. 19 Nov. 1968, 12 feeding on spilt chaff, paddock corner near Fisherman's Cliff, Moorna Station, N.S.W., where sheep sometimes hand fed. 20 Nov. 1968, 8 plus 6 *N. haematogaster*, feeding in close association on ground beneath *Casuarina* trees, Talgarry Station second dam, N.S.W.

Psephotus haematonotus

BH: 24 Oct. 1968 (see *P. nigricans* 24 Oct. 1968).

M: 31 May 1969, flock of 150+ ESE. toward Frenchman Creek red gum forest from inland open country, 0930 hr. Site 10, Dunedin Park Station, N.S.W.

F: 16 June 1967, 5 feeding on *Nitraria* fruits, Lybra paddock, Keera Station, Vict. 30 Apr. 1968 (see *B. barnardi* 30 Apr. 1968).

Northiella haematogaster

F: 27 Sept. 1968, 4 feeding on and beneath Bluebush (*Kochia pyramidata*?), *beneath* Black Box trees, Walpolla Cr., Keera Station, Vict. 20 Nov. 1968 (see *B. barnardi*, 20 Nov. 1968).

Melopsittacus undulatus

M: 28 Sept. 1968, many small flocks 35, 10, 7, 11, 3, 1, 15, 6, 4, 6, 18, 12 all moving SE., low to ground downwind from blustery NW. wind, f3-5. Humid, hot. Most birds calling loudly. Observer static. Brown's Paddock, Keera Station, Vict. This movement of birds was recorded as continuing for two days on a very broad scale in NW. Victoria. General trend to E. Many similar small flocks, and a few numbering 100+ were seen flying E. on 29 Sept. 1968, over mallee country S. of Mildura on Calder Highway, at Merbein, Yatpool, Hattah, Ouyen, Sea Lake. No other species were recorded moving in this period. 24 Oct. 1968, 60+ flying E., low, downwind, 0820 hr. Talgarry Station homestead, N.S.W. 15 Mar. 1969, 50 in tight flock, NW., 1915 hr., Nulla Station woolshed, N.S.W. 18 Mar. 1969, 14 in flock, travelling high, coming in from over Lake Victoria, and alighting in *Nicotiana* bushes on sand dunes. Presumably had crossed lake.

F: 4 Oct. 1969, 200+ feeding on ground beneath small *Kochia* bushes, Nulla Station woolshed, N.S.W.

Order CUCULIFORMES

Family CUCULIDAE

Cuculus pallidus

BH: 23 May 1969, 3, flying in very agitated manner in tight pursuit of each other, much changing of position and loud calls. All birds in same plumage. Moorna E. oxbow, N.S.W. 27 May 1969, 1 bird perched silently 50 cm from a continuously calling Narrow-billed Bronze Cuckoo on same branch of *Casuarina* tree, near Cass's Camp, Talgarry Station, N.S.W. Two birds remained for 8 minutes before Bronze Cuckoo flew off. 27 May 1969, same locality, a single bird flying fast, low, in a tumbling flight with tail spread, then complete roll-over executed in level flight.

Chrysococcyx osculans

BH: 25 July 1969 (see *M. virescens* 25 Juy 1969).

F: 22 Oct. 1967, 1 calling intermittently from tall red gum. Twice flew down to seize furry caterpillars from foliage of *Muehlenbeckia* bushes about base of tree, returning to bare protruding branch to eat them. Site of former hotel, N. end of Lake Victoria, Nulla Station, N.S.W. 18 Mar. 1969, 1 perched on topmost bare branch of large *Casuarina*, repeatedly flying up and hawking small flying insects, possibly winged ants, in a honeyeater-like manner. Nulla Station woolshed, N.S.W.

C. basalis

BH: 27 May 1969 (see *C. pallidus* 27 May 1969).

M: 27 July 1969, 3 together in small *Atriplex* bush 3-4 km NE. of inlet regulator, Frenchman Cr., Dunedin Park Station, N.S.W., on salty flats.

F: 24 Oct. 1968, 2 feeding on ground amid dense *Helipterum floribundum* and *Brassica tournefortii*, but each bird perched on a bare *Nicotiana* branch above the lower herbage level to eat small, smooth, grey caterpillars. Lake Victoria frontage, Talgarry Station, N.S.W.

Order CAPRIMULGIFORMES

Family PODARGIDAE

Podargus strigoides

Br: 27-29 Aug. 1968, nest with 2 eggs, fork of mallee gum, 2·5 m off ground, 8·5 km NW. of Nulla Station homestead, N.S.W. (Graeme Withers, pers. comm.). Adult brooding 2 young, 22·0 cm long, 3·5 m above ground in fork of black box. Nest of lignum and black box twigs, plus some green speargrass tips. (Pl. 35, fig. 2). Clump of trees in shallow ephemeral drainage basin, c. 3·2 km SE. of Nulla Station homestead, N.S.W.

Family AEGOTHELIDAE

Aegotheles cristatus

F: 17 Apr. 1968, 1 catching moths on bitumen road surface, possibly insects damaged by traffic, Tucker Cr. bridge, Wentworth, N.S.W., 2000 hr. 27 Oct. 1968, 2 on grassy patches on ground at roadside, about 4·8 km apart. 1910 and 1935 hr. Each bird leapt into the air and away as vehicle slowly approached. Search of second locality gave no clue to behaviour. S. of Nulla Station, N.S.W. 3 Oct. 1969, 1 with large moth, near *Casuarina* trees, 0·5 km No. of Talgarry homestead, N.S.W., 2030 hr.

Order APODIFORMES

Family APODIDAE

Apus pacificus pacificus

BH: 22 Mar. 1969, 100+ flew fast and low, in direct line to SW. in fairly tight group, across sand dunes and out over Lake Victoria, Nulla Station, N.S.W. 1104 hr. Torrential rain approaching from NNW. (see also *C. approximans, C. leucosterna, H. nigricans, E. tricolor* 22 Mar. 1969) 1206 hr. Heavy rain again approaching from N. and local intense rainfall commenced nearby; 4 swifts plus 10 Tree Martins flew very fast NE., speeding through the fast-closing gap between the two rainstorms, 1558 hr.; 6 swifts plus 18 Tree Martins in close association flying at 50m NW. to pass on W. side of rainstorm rapidly approaching from N. and NE. Main road between Talgarry Station and Nulla Station homesteads, N.S.W. One swift flying lower, clocked at approx. 64 km per hr. on Land Rover speedometer. 23 Mar. 1969, 1700 hr., after clear, warm, calm day, light wind f-2-3, W.-SW., many small groups of swifts assembled over dunes and shoreline of Lake Victoria, Nulla Station, N.S.W. A total of some 400 was estimated. These fed and drifted about from 10 m to 600 m, some aerial chases of pairs and trios observed. By 1845 hr., about 200 in sight in same area, but feeding activity ceased, while calling and chasing activity increased. A few Tree Martins feeding low over lake, and several evening flights of White-backed Swallows (cf. *C. leucosterna* 26 Jan. 1968) in groups of up to 10 birds were observed over erosion gulches known to contain burrows, 1904 hr. All White-backed Swallows disappeared into gulches and did not re-emerge; 300+ swifts in sight, as additional small groups came in from E. and NE. Main flock by now slowly rising in air, drifting birds in loose groups continuously dissociating from flock, moving E. then returning at higher level. Most birds gliding slowly, much shrill calling—a sound comparable to a simultaneous whistling and buzzing with slight downward inflection. Brief flaps and steep glides, then gliding with wings extended and tails slightly fanned. Some birds in tight pairs, one above the other and a little behind, 1908 hr. Many hundreds of swifts in sight, mostly at estimated 300 m, and spread along the line of sand dunes as far to N. as could be seen with 16 x 50 mag. binoculars in the failing light. Birds now tending to drift N., 1912 hr. Light breeze developing at observer's position, force 1 N. Birds still rising, those overhead now seen only with binoculars, but calls plainly heard, 1915 hr. All visual contact lost but calls still plainly heard overhead. These continued to after 1940 hr. Calm clear night, cool, bright moonlight.

The above notes are interpreted as an example of Fork-tailed Swifts rising at dusk to roost overnight in the air. An extensive literature exists in Europe for the Swift *Apus apus*, and a comparison of the above, and other Australian observations will be presented in another paper, now in preparation for the Swift Survey, Victorian Ornithological Research Group. 25 Mar. 1969, 1420 hr. 300+ came from N., circled for several minutes over sand dunes at Lake Victoria, Nulla Station, N.S.W., and many drank from series of broad, shallow rainwater puddles in hollows between massive *Nitraria* bushes, on E. side of sand dunes. Birds skimmed low over water surface, just dipping beaks, then lifting off for others to follow through on the same course. Estimated 100+ Tree Martins travelling with them, but although these alighted some distance off on sand dune, none drank. One martin picked up a small, dead *Nicotiana* leaf, flew into the air a few metres with it, then dropped it. Both species departed together, moving SSE. A Nankeen Kestrel that passed by at this time was mobbed by birds of both species and to escape attention, alighted in a *Nicotiana* tree.

Order CORACIIFORMES

Family ALCEDINIDAE

Dacelo novaeguinae

Br: 30 Sept. 1967, nest in high spout of red gum, Triple Swamp, Moorna Station, N.S.W.

BH: 25 Nov. 1968 (see *H. sanctus* 25 Nov. 1968).

Halcyon pyrrhopygius

F: 20 Nov. 1968, 1 caught small lizard in erosion deflation hollow, E. of main sand ridge of Lake Victoria lunette, Talgarry Station, N.S.W. Bird perched dead *Nicotiana* bush, struck lizard many times against small branch, and finally swallowed it.

H. sanctus

BH: 20 Nov. 1967, adult pursued a Brown Tree-creeper that alighted in same black box tree—nest hole competition? Berribee Station, Vict. 25 Nov. 1968, 1 pursuing Kookaburra, Nampoo Station, N.S.W.

F: 21 Mar. 1969, 1 with large dragonfly, Moorna E. oxbow, N.S.W.

Family MEROPIDAE

Merops ornatus

Br: 28 Oct. 1968, adult feeding a flying young, Cass's Camp, Nulla, N.S.W. (see feeding note below).

M: 23 Feb. 1967. 200+ circling S. 120 m over Murray River at Springcart Gully, 9·6 km S. of Renmark, S.A.; 28 Oct. 1968, two groups of 6 and 8, in fast flight over sand dunes of Lake Victoria, N.S.W. Groups 30 seconds apart, N. and NE., 1020 hr., 80 m-100 m; SW. to S. wind, f2-4; cool morning. Birds in very tight flocks, very rapid minor changes of direction, also of altitude, and of relative position of each bird within the flock. Much loud calling. Heavy rain, cold winds in SW. and Central Vict., 25-28 Oct. 1968. 25 Nov. 1968, 4 flying SW., 60 m, 1440 hr., calm, sunny, 21°C., Nampoo Station, N.S.W.

F: 28 Oct. 1968, an adult feeding one flying young. Adult caught small dragonfly, commenced 'mandibulating' it in its beak, and dropped it still alive. A Willie Wagtail dived at the injured insect, but the Rainbow-bird was quicker and retrieved it. The beak movements were commenced again, and eventually the dead and de-winged insect was fed to the young bird. Cass's Camp, Nulla Station, N.S.W.

Order PASSERIFORMES

Family ALAUDIDAE

Mirafra javanica

BH: 18 Mar. 1969, 1 bird (identity of species not certain) in aerial display over sand hills, 1 km inland from Lake Victoria, Talgarry Station, N.S.W. Bird flying up, then dropping vertically, wings extended, tail elevated, to near ground level, repeating the manoeuvre twice more. Considered to be Bushlark, but viewed from considerable distance with binoculars; may have been Skylark, or (?) Rufous Songlark.

M: 7 Oct. 1969, 2 + 6 together, in tall plumed grasses amid scattered mallee eucalypts on flat country, Dunedin Park/Moorna Station boundary fence, N.S.W.

Family HIRUNDINIDAE

Hirundo tahitica neoxena

Br: 21 Apr. 1967, nest with 2 eggs on lampshade in outhouse, Keera Station, Vict. 29 Jan. 1968, 2 nests, each with 2 eggs, in prison cell of deserted Cal Lal Courthouse, N.S.W. 20 Sept. 1968, nest with 5 eggs, barn at Kulcurna Station homestead, N.S.W. 21 Sept. 1968, nest with 3 small young beneath Forestry Dept. punt, Lindsay R., Berribee Station, Vict. Adults flying with food to young as punt moved to and fro. 20 Nov. 1968, nest with 1 small young on shade of recently installed fluorescent light, Moorna Station woolshed, N.S.W. 23 May 1969, nest with 2 well-fledged young in outhouse, Moorna Station homestead, N.S.W.

BH: 30 Apr. 1968, 18 flying low, repeatedly hovering over, then alighting and immediately taking off again, on a broad claypan, bare except for a few small black stones and scattered sheep faeces. This swirling series of alightings and take-offs continued for 3 minutes. Very light rain falling. Behaviour rather similar to that recorded for Tree Martins (Mollison and Green 1962, Simpson 1964). River Road, Berribee Station, Vict., 0195 hr. 24 Oct. 1968 (see *P. nigricans* 24 Oct. 1968).

M: 18 Apr. 1968, 300+ feeding low over water surface, Moorna E. oxbow, N.S.W. 24 Apr. 1968, several hundred flying NE. over Kulcurna Station homestead, N.S.W., low to ground, much calling, 1830 hr.

F: 25 June 1967 (see *P. nigricans* 25 June 1967). 1 Aug. 1968 (see *C. leucosternum* 1 Aug. 1968).

Cheramoeca leucosternum

Br: 19 Oct. 1967, 5 apparently occupied nest burrows in deep erosion gulch (9/10N. of pegged sequence), Lake Victoria, on Nulla Station, N.S.W. Adults bringing food to two of the burrows. Tracks and scratches of small goanna (probably *Varanus gouldii*) observed to enter one burrow (Simpson this *Memoir*).

BH: 26 Jan. 1968, 30-40 flying about in dense flock over W. end of Kulcurna Station cliffs, N.S.W., late dusk, 1945-2000 hr. Flock viewed from 0·5 km, initially mistaken for bats. Flock rising and diving continuously, suddenly disappeared. 30 Jan. 1968, evening flight before roosting again observed, with observer at roosting site. Birds preparing to roost in group of burrows at W. end of Kulcurna Station cliff, N.S.W. Breeding may have been occurring in burrows but not evidence noted, 1950 hr. Birds flying in pairs and groups of 5-7 in a wide circling flight; travelling up to 0·5 km from colony in a loose flock, continuously merging to dense flock, and immediately dividing into small groups of 3-7 and pairs again. Arriving back near the colony, the loose group repeatedly flew up to the burrow entrances, rose into the air steeply above the cliff edge, and dived down again to the colony. A count of 47 birds was made. Finally, at final dusk and within a few seconds of each other, all the birds went to roost, sweeping in from over the river at tree top level and entering burrows in groups of 4-8, timed at 2014 hr. After a few minutes, the author fired a shot at the cliff to deliberately disturb the birds. They flew out immediately, made a couple of tight turns close to the cliff top in a dense flock, and quickly and quietly re-entered the burrows, in small groups of 4-8 as before. During the earlier flights much shrill calling was heard.

22 Mar. 1969 (see *A. p. pacificus* 22 Mar. 1969). 24 May 1969, two burrows in banks of erosion gulch where large block of sand had fallen away from the bank. One burrow complete; 8 swallows entered it in late evening. Other burrow apparently newly commenced, enabling possible working technique to be deduced. A small centrally placed area on the lower portion of the new excavation is apparently a working area. The bird probably stands on this, and with bill or feet, probably the latter, scratches at sand each side with a downward and outward motion. Deep grooves are plainly visible. The burrow is therefore con-

tinuously developed from the top and upper sides, the lower sides and central portion following the upper inclined working face. White-backed Swallow burrows always tend to have a vertical rectangular shape, at least in the sandy substrates inspected in this district. The birds were not observed working at the excavation. The description is a deduction awaiting confirmation. Erosion gulch 0·75 km NNW. of J. May's camp at windmill, Noola Station, N.S.W. 25 May 1969, 0730 hr. 2 birds, both in adult plumage, meeting beak to beak in mid-air, then gliding parallel for a 20 second period, calling very excitedly. Near shore of Lake Victoria, Noola Station, N.S.W.

F: 1 Aug. 1968, 25-30 hawking low over slightly wind-ruffled surface of Lake Merretti, S.A., together with some 200+ *H. t. neoxena.*

Petrochelidon nigricans

Br: 1 Oct. 1967, 2 pairs with nests in hollow spouts of adjacent red gums beside Murray R., Fisherman's Cliff, Moorna Station, N.S.W. A group of 6 *Struthidea cinerea* arrived in these trees to roost at 1800 hr. The Tree Martins appeared most upset by this invasion, and repeatedly dived at individual Apostle-Birds as they moved about and finally settled in one of the trees (see *S. cinerea* 1 Oct. 1967).

BH: 24 Oct. 1968, following a 2 hr. period of heavy rain, some 60 Tree Martins and flock of 24 Red-backed Parrots became suddenly very vocal as rain eased. Birds spent a few minutes in active preening, before departing from red gum saplings where they had been sheltering during rain and high winds (see section on Feeding Associations). Shortly after cessation of rain, several groups (11, 8, 9, plus one Welcome Swallow) were seen landing on different sandy patches and extensively preening wings and breasts. Some shuffled low over the wet sand as though 'dust bathing' without dust. Lake Victoria at Talgarry Station pump shed, N.S.W. 28 Oct. 1968, a Black-tailed Native Hen was attacked by 5 martins as it ran and flew low across ground to dense cover at Talgarry pump shed, Lake Victoria, N.S.W. (see *T. ventralis* 28 Oct. 1968). 22 Mar. 1969, 60+ and 20+ White-backed Swallows flying together in loose association, and calling very agitatedly as torrential rainstorm approached from NNW., 1106 hr. At 1110 hr. as rain commenced, White-backed Swallows all entered burrows in erosion gulch and martins huddled in groups on branches of *Nicotiana* trees by lake shore. Rain lasted 10 min. or so; both species took flight again. Lake Victoria, Nulla Station, N.S.W. (see *C. approximans, A. p. pacificus, E. tricolor* 22 Mar. 1969). 22 Mar. 1969 (see *A. p. pacificus* 22 Mar. 1969). 25 Mar. 1969 (see *A. p. pacificus* 25 Mar. 1969). 26 Mar. 1969, 100+ in flock on sand dunes, many preening, others shuffling over surface apparently picking up small objects. It could not be determined what these were, or what was happening to them. Inspection revealed no small objects present other than sand grains of very fine size. Considered that the pick-up activity might be a display movement of some kind (cf. *H. neoxena*, 30 Apr. 1968 and references) without actual physical movement of objects.

M: 23 Nov. 1967, numerous groups, mostly travelling below 60 m, moving slowly E. 1845-1945 hr. Feeding across paddocks as travelled. Humid, warm, calm, Keera Station homestead, Vict. 19 Nov. 1968 (see *A. personatus* 19 Nov. 1968). 19 Nov. 1968, 1820 hr. 150+ on telephone lines, N. side Moorna E. oxbow, N.S.W. None present at locality in morning. 18 Mar. 1969, 1052 hr. 70-100 in widely-spread flock flew E., direct flight, calling loudly. Heavy rain from W. began 1103 hr. At 1215 hr. 50 birds flew W., calling loudly, after rain had ceased. Sand dunes, Lake Victoria, Nulla Station, N.S.W.

F: 25 June 1967, several, with several Welcome Swallows, tightly circling and hawking small insects very close to foliage of red gums, on lee side out of strong wind, levee bank, Frenchman Cr., Winjellie Station, N.S.W.

P. ariel

Br: 26 June 1967, many old nests high on Fisherman's Cliff, Moorna Station, N.S.W. Linings of some composed of oat stems from adjacent oatfield, of water couch grass from river bank, and of feather and wool scraps. 28 June 1967, a single empty nest, together with one nest of *Hirundo neoxena*, on underside of leaning and partly hollow red gum, Wangumma Station, N.S.W. 25 Sept. 1967, 19 nests under construction near top of erosion gulch at Fisherman's Cliff, Moorna Station, N.S.W. 29 Jan. 1968, old martin nests occupied by House Sparrows (see *Passer domesticus* 29 Jan. 1968). 23 Nov. 1968, 4 nests, apparently containing young, 3-4 m down from top of Yelta cliff, Murray R., Vict. (see *P. domesticus* 23 Nov. 1968). 25 Nov. 1968, adults building, and bringing food to, group of nests on Kulcurna Station cliff, N.S.W. (Pl. 35, fig. 5).

BH: 27 Sept. 1967, birds flying over cliff above nests at Fisherman's Cliff, Moorna Station, N.S.W. Very disturbed by observer's presence (see 25 Sept. 1967 above). Always remain high whilst any person within 80 m before returning to nest areas.

Family MOTACILLIDAE

Anthus novaeseelandiae

F: 22 Feb. 1967, 1 moving about beneath a very dense overhead cover of dead *Callitris* and *Casuarina* trees—a most unusual situation. Lybra Back Paddock, Keera Station, Vict.

Family. CAMPEPHAGIDAE

Coracina novaehollandiae

M: 24 Apr. 1967, 5 + 8 + 5 small groups flying NW. through tree tops, calling at times. Keera Station homestead, Vict. 23 Mar. 1969, flock of 11, SW. at tree-top level, through red gum forest along Murray R., Moorna Station woolshed, N.S.W.

C. robusta

M: 18 Nov. 1968, 1 in river red gums, Lock 10, Wentworth, N.S.W. Rare in district; assumed straggler or bird moving through.

Lalage sueurii

BH: 26 Sept. 1968, pair, plus pair Willie Wagtails, plus 11 White-winged Choughs, all flying at and scolding a Gould's Goanna, *Varanus gouldii* which was moving through litter beneath red gums, Walpolla Creek, Keera Station, Vict. 19 Nov. 1968, male repeatedly swooping at and vigorously pursuing 2 White-plumed Honeyeaters that entered the same red gum. Between each of several chases, Triller returned to topmost bare branch of the tree and called loudly; call answered similarly from long way off. Bone Gulch, Moorna Station, N.S.W.

Family TIMALIIDAE

Pomatostomus superciliosus

Br: 30 Oct. 1968, adult at nest with 3 young; nest situated 2 m in *Acacia* tree, and composed of *Casuarina* twigs, entrance to SE., lined with wool, feather and fine grasses. Cass's Camp area, Talgarry Station, N.S.W.

F: 23 Sept. 1968, 6 feeding intently on ground beneath dense *Muehlenbeckia* bushes, margin of Lake Walla Walla, Ned's Corner Station, Vict.

P. ruficeps

BH: 21 Oct. 1967, flock of 6 packed themselves into one of several stick 'nests' in *Casuarina* clump (Pl. 35, fig. 3) late at dusk. Communal roosting apparently a feature of this species. Cass's Camp, Talgarry Station, N.S.W.

F: 30 Sept. 1967, small group feeding beneath and through dense *Muehlenbeckia cunninghamii* bushes. Rarely recorded in such a habitat. Identity checked to make sure not *P. superciliosus*, more commonly met in similar situation. W. end of Triple Swamp, Moorna Station, N.S.W. 29 Jan. 1968, 4 feeding on berries of *Nitraria*, site of former hotel, N. end of Lake Victoria, Nulla Station, N.S.W.

Family SYLVIIDAE

Acrocephalus stentoreus

BH: 18 Nov. 1968, continuous calling of several birds from river-edge reed beds at 2000 hr.; dark but calm night, Moorna Station woolshed, N.S.W.

Cincloramphus cruralis

M: 31 May 1969, 1 in oatfield near Fisherman's Cliff, Moorna Station, N.S.W. Extremely vocal, ? new arrival from elsewhere.

Family EPHTHIANURIDAE

Ephthianura albifrons

24 June 1968, 15 flew W. over red gum and black box forest, 1020 hr. Apparently

heading for open *Kochia* areas several km W. and SW., 8/8 cloud, thin rain commenced shortly. Berribee Island, Vict. 22 Oct. 1968, very many sightings made during next few days of mixed parties, numbering commonly to 300+ individuals, of all three chat species in varying proportions, throughout the *Kochia, Eragrostis australasica* and *Nitraria* area on the flats E. of Lake Victoria, on all three stations. Many birds in eclipse plumage; many juvenile plumage. Other parties were noted closer to Wentworth, in smaller numbers, and in a variety of Millewa and Ned's Corner Land System habitats. 30 Oct. 1968, flock of 200+, containing White-fronted and Crimson Chats, flying N.E. low over *Kochia* bushes, aeroplane landing strip, Nulla Station, N.S.W.

F: 5 Oct. 1967 (see *E. aurifrons* 5 Oct. 1967). 20 Nov. 1968, flock of 70 feeding amid new-sprouting *Brassica tournefortii*, sand hills, Talgarry Station, N.S.W. A few *E. aurifrons* also present.

E. tricolor

BH: 18 Mar. 1969, 60-80 plus about 12 Black-faced Wood Swallows flew up in a dense flock, then all plummeted earthward again as a Collared Sparrow-hawk flew direct and low over *Kochia* bushes through open dead *Casuarina* trees 1·5 km S. of Nulla Station homestead, N.S.W. 22 Mar. 1969, at 1045 and 1056 hr., prior to torrential rainstorm, 70+ and 22 flew N. low over crest of and along line of sand dunes calling very agitatedly. Lake Victoria, Nulla Station, N.S.W. (see *C. approximans, A. p. pacificus, C. leucosterna, H. nigricans*).

M: 22 Oct. 1968 (see *E. albifrons* 22 Oct. 1968). 27 Oct. 1968, 150+ in close group, feeding on ground but very steadily moving N. through *Kochia* and *Casuarina* areas. Birds continuously flying up, and dropping down again, to be immediately overtaken by others. Flock flew due N. when disturbed by observer. Nulla Station woolshed, N.S.W. 30 Oct. 1968 (see *E. albifrons* 30 Oct. 1968).

E. aurifrons

BH: 29 May 1969, female performing broken-wing trick as observer moved through *Nitraria* and *Kochia* bushes, NW. Lake Victoria, Noola Station, N.S.W.

M: 22 Oct. 1968 (see *E. albifrons* 22 Oct. 1968).

F: 5 Oct. 1967, 12 feeding on ground around bases of *Nitraria* bushes, together with 8 *E. albifrons*. Lybra Back Paddock, Keera Station, Vict. 20 Nov. 1968 (see *E. albifrons* 20 Nov. 1968). 22 Mar. 1969, 50+ feeding amid *Kochia* bushes at *Casuarina* scrub margin, Nulla Station woolshed, N.S.W.

Family ACANTHIZIDAE

Aphelocephala leucopsis

F: 10 June 1967 (see *A. chrysorrhoa* 10 June 1967). 24 June 1967 (see same species). 18 July 1969, 35-40 in close flock, feeding along margin of large rainwater pool on claypan, SE. area of Dunedin Park Station, N.S.W. 28 May 1969 (see *A. chrysorrhoa* 28 May 1969).

Acanthiza chrysorrhoa addenda

F: 10 June 1967, 14 plus 8 Eastern Whitefaces feeding together beneath black box trees. Both species hopping swiftly over ground, exploring for food and actively feeding. Continual calling. Keera Station homestead, Vict. 24 June 1967, 30 Yellow-tailed Thornbills plus 6 Eastern Whitefaces feeding in same locality. 28 May 1969, 12 plus 18 *A. leucopsis* and one immature *P. goodenovii* feeding in close group under *Casuarina* trees and beneath *Kochia* bushes, Noola Station homestead area, N.S.W.

Family MALURIDAE

Malurus leucopterus

Br: 25 Nov. 1968, 2 males fighting, and alternately chasing a brown bird, and attempting copulation. A new fight each time chasing ceased. *Casuarina/Kochia* association area, 2 km E. of Nampoo Station homestead, N.S.W. 29 May 1969, 2 males, one in partial breeding plumage, fighting each other; 5 brown birds in attendance. *Kochia* area, NW. Lake Victoria, Noola Station, N.S.W.

Family RHIPIDURIDAE

Rhipidura leucophrys

Br: 21 Oct. 1967, newly completed nest, situated on a 25 cm stump of branch, 1·7 m up on lee side of trunk of enormous, solitary peppercorn tree at water edge, Lake Victoria, Nulla Station, N.S.W. Nest composed of wool (dead sheep 1·8 m away under tree canopy), of emu feathers (dead emu 3·8 m ditto), of cobwebs (much of trunk deeply recessed and hung with spider web) and of rootlets (grass roots 4·2 m away by water edge). Adults in attendance. 30 Oct. 1968, nest with 4 eggs, 1·8 m up in *Casuarina*, Cass's Camp, Nulla Station, N.S.W. Nest composed of cobweb, grass fibres (mostly spear grass) and lined with wool. 23 Nov. 1968, nest 2 m over Murray R. on leaning branch of red gum, Yelta cliff, Vict. Adults making many trips with small insects for 3 new-hatched young. Nest interior shaded by dense clump of low-hanging leaves.

BH: 28 Sept. 1967, an adult attacked a small Gould's Goanna *Varanus gouldii*, disturbed by the observer. Near Fisherman's Cliff, Moorna Station, N.S.W. 26 Sept. 1968 (see *L. sueurii* 26 Sept. 1968).

M: 21 Mar. 1969, 5 flying low in tight flock, E. through open mallee gums, 0185 hr., Dunedin Park Station, N.S.W.

F: 25 June 1967, 1 out on floating *Azolla* in mid-river, feeding on insects on surface of the fern, Murray R., Nampoo Station, N.S.W. 1 Oct. 1967 (see *S. vulgaris* 1 Oct. 1967). 31 July 1968, 1720-1810 hr. Many wagtails noted in pairs feeding on small insects on road surface. Counting of birds commenced from near Karawinna, and 88 individuals, mostly in pairs but including seven groups of 4 were counted in c. 65 km. External air temperature cold, estimated 7·8° C., and the sun set during the period of the observation. A sample of insects was collected from the car's radiator and bonnet. All were fresh and were quite obviously the first insects encountered between Melbourne and Karawinna—about 688 km. One mosquito present, not identified. The remainder of the sample of c. 20 insects were *Chironomus tepperi* Skuse (Fam. Chironimidae). Apparently numerous chironomids were flying low over the highway surface because it was warmest there, the black bitumen having absorbed heat during the day, and were being killed or injured by the fairly heavy road traffic. The birds were fairly evenly spaced over the entire distance of the observation. Sturt Highway, between Karawinna and about 4·5 km E. of the S.A. border, Vict. 28 Oct. 1968 (see *M. ornatus* 28 Oct. 1968).

Family MUSCICAPIDAE

Petroica goodenovii

Br: 27 Sept. 1968, adult female with 1 flying young, Walpolla Creek, Keera Station, Vict.

F: 28 May 1969 (see *A. chrysorrhoa* 28 May 1969).

P. culcullata

19 Nov. 1968, pair of adults with 2 flying young in heavily striated plumage. Young feeding themselves, but adults bringing food also. Adult male in partial moult. Murray R. at Bone Gulch, Moorna Station, N.S.W. 23 Nov. 1968, juveniles in same area still; adults not seen.

Family PACHYCEPHALIDAE

Pachycephala rufiventris

Br: 28 June 1967, male in full breeding plumage, Scadding's property, Frenchman Cr. levee bank, N.S.W.

Family NEOSITTIDAE

Neositta chrysoptera

28 Oct. 1968, pair adults feeding 1 flying young, which was begging food with much excited wing fluttering and soft calls. Clump of *Casuarina*, Cass's Camp, Nulla Station, N.S.W.

Family CLIMACTERIDAE

Climacteris picumnus

Br: 26 Sept. 1968, pair feeding 1 flying young, black box trees, Lake Walla Walla, Ned's Corner Station, Vict. 28 Oct. 1968, pair with nest in hollow *Casuarina* trunk, beside track to Nulla Station woolshed. Entrance from knot-hole. Nest of wool and plant fibres. 2 eggs (Pl. 35, fig. 4). Nulla Station, N.S.W. 20 Nov. 1968, 2 well-fledged young in nest (above). Adults not in immediate attendance.

BH: (see *H. sanctus* 20 Nov. 1967). 19 June 1968, group of 6 in fairly close association feeding on black box trunks. Winter flock?, Berribee Station homestead, Vict. 21 June 1968, groups of 6 and 8 in widely separated areas of back box on Berribee Island, Vict. Winter flocks (?) or family groups (?). 29 June 1968, 2 groups of 4 and of 7-8 birds in similar situations, Berribee Island, Vict.

Family DICAEDIDAE

Dicaeum hirundiaceum

F: 29 Sept. 1967, pair in full plumage feeding actively over willow flowers. Not determined whether insects or botanical food being taken. Murray R. bank, Moorna Station woolshed, N.S.W.

Pardalotus substriatus

29 Sept. 1967, nest burrow with adults frequently entering Murray R. cliff at Sharp Point (Devil's Elbow), Nampoo Station, N.S.W.

Family MELIPHAGIDAE

Meliphaga virescens

BH: 25 July 1969, 1 attacked a Black-eared Cuckoo which had been perched on top of a large *Nitaraia* bush, calling softly, Lake Victoria frontage, Nulla Station, N.S.W.

F: 26 Apr. 1968, several feeding on mistletoe flowers on *Casuarina* trees; 1 pursued a Chestnut-tailed Thornbill attempting to land in the same mistletoe clump. Near Lake Merretti, S.A. 24 Oct. 1968, 1 feeding on small orange berries growing on low, multi-leafed succulent. Bird picked a berry, rapidly pressed it many times in beak, whilst holding head tilted up. The berry was held at the extreme tip of the beak. The tongue was occasionally protruded beyond the berry. Finally, the berry was swallowed whole. Several were picked and eaten, several others were picked, pressed, then discarded. Examination of these showed bruising, but presumably these were unripe, although not detectably so. I ate some and found them quite palatable, sweet, but with slight oxalic taste. Lake Victoria frontage, Talgarry Station, N.S.W. 18 Mar. 1969, 4 + 2 feeding on flowers of *Nicotiana* shrubs different areas of Lake Victoria sand hills, Talgarry Station, N.S.W.

M. penicillata

Br: 24 Oct. 1967, nest 20 m in leafy clump of red gum, 180 m E. of punt on bank of Lindsay R., 3 young close to fledging sitting alongside nest, adults bringing food. Nest appeared built of cobweb, fine grass, cocoons and spider egg-sacs. Berribee Station, Vict. 19 Nov. 1968 (see *L. sueurii* 19 Nov. 1968).

M: 22 Apr. 1968, 1 in *Casuarina* clump, road turnoff to Dunedin Park homestead, N.S.W. Nearest red gum forest 2·5 km to SE. approx.

F: 29 Jan. 1968, 5 foraging in almond tree, Kulcurna homestead garden, N.S.W.

Melithreptus brevirostris

F: 21 Sept. 1968, 5 feeding on flowers of black box, Berribee Island, Vict. 22 Sept. 1968, 8 birds feeding in same tree.

Myzantha melanocephala

BH: 5 Oct. 1967, 5 chasing 1 Little Friar Bird, black box trees, Keera homestead, Vict.

Entomyzon cyanotis

Br: 24 Oct. 1967. Bird entering broken-off spout of red gum, c. 10 m up. Same tree as a pair of *Corvus coronoides* (see 24 Oct. 1967), near punt, Lindsay R., Berribee Station Vict.

BH: 27 Sept. 1967, 10 birds in tight flock swept at high speed through and between tops of red gums along Murray R., calling loudly. In sight for 0·8 km plus as flew downstream, Fisherman's Cliff, Moorna Station, N.S.W.

Philemon citreogularis

BH: (see *M. melanocephala* 5 Oct. 1967).

M: 23 Apr. 1967, 2 in red gums, Mullaroo Ck. bridge, Berribee Station, Vict. 'Early arrival for this year', H. F. Thomas, pers. comm.

F: 26 Sept. 1967, 2 feeding on red gum blossom, Big Island, Keera Station, Vict.

Acanthagenys rufogularis

F: 26 June 1967, 4 feeding in orange trees, Moorna homestead, N.S.W. 20 Nov. 1967, 2 feeding on flowers of Silky Oak (*Grevillea*), Berribee homestead garden, Vict. 28 Apr. 1968, 4 feeding on foliage of *Nitraria* bushes, Moorna Station woolshed, N.S.W. 27 Oct. 1968, 1 appeared to be feeding on peppercorn berries. This is not a positive record, as it may have been eating small spiders or insects from dense webs spun over some larger berry bunches, Nulla Station woolshed, N.S.W. 31 May 1969, 2 feeding on flowers of mistletoe on *Acacia* tree, Fisherman's Cliff, Moorna Station, N.S.W.

Family FRINGILLIDAE

Carduelis carduelis

F: 25 June 1967 (see *P. domesticus* 25 June 1967).

Family ESTRILDIDAE

Poephila guttata

BH: 22 Mar. 1969, 4 dust-bathing in vehicle wheel-ruts beside *Nitraria* bushes, near salt lake, on Talgarry Station, N.S.W.

F: 28 Oct. 1968, 9 feeding on open sandy beach, near large peppercorn tree, NE. Lake Victoria, N.S.W., possibly on windblown grass seed.

Family PLOCEIDAE

Passer domesticus

Br: 19 Oct. 1967, pair apparently breeding in broken red gum stump at water edge, Lake Victoria, Talgarry Station, N.S.W., 29 Jan. 1968, several pairs breeding in abandoned Fairy Martin nests, on Kulcurna Station cliffs, N.S.W. 20 Sept. 1968, nest with 1 egg, peppercorn tree, Kulcurna homestead, N.S.W. 18 Nov. 1968, 2 pairs with nests in old burrows of either White-backed Swallow or Rainbow-Bird, bringing food for young, Merbein cliff, Vict. 23 Nov. 1968, pair nesting in old, partly broken Fairy Martin nest, Yelta cliff, Vict.

F: 25 June 1967, many together with numerous Goldfinches, among living and dead stems of cumbungi *Typha augustifolia* or *T. muelleri*. Birds considered to be feeding but not confirmed. Levee bank, Frenchman's Creek, N.S.W.

Family STURNIDAE

Sturnus vulgaris

Br: 27 Sept., 1968, 2 nests with young in outhouse ceiling, Keera Station, Vict. 23 Oct. 1968, pair with nest in old Chestnut-crowned Babbler nest, *Casuarina* clump, Cass's Camp, Nulla Station, N.S.W.

BH: 10 June 1967, adult softly mimicking the ascending call of a Whistling Kite, Keera homestead, Vict. 23 Oct. 1968, flock of 150 mobbed a low-flying Swamp Harrier, Lake Victoria sand hills, Talgarry Station, N.S.W. 5 Oct. 1969, 1 in red gums imitating ascending call of Pallid Cuckoo, Lake Victoria, Talgarry Station, N.S.W.

F: 1 Oct. 1967, 2 accompanying feeding sheep and catching insects from right beside their noses. A Willie Wagtail also in close attendance. Near Moorna E. oxbow, N.S.W. 20 June 1968, 350-400 in dense flock feeding on newly irrigated pasture, late evening. Berribee homestead, Vict. 21 Sept. 1968, 3 feeding closely around the feet of a slowly walking plover *V. m. novaehollandiae* in irrigated pasture, Berribee Station, Vict.

Family GRALLINIDAE

Grallina cyanoleuca

Br: 28 Oct. 1968, nest with eggs 4·6 m in *Casuarina* clump, 0·8 km N. from Talgarry dams, Cass's Camp, Nulla Station, N.S.W. Second nest with 2 young only 11 m away in adjacent *Casuarina* tree, same locality; other old nests were seen at times, but none recorded in detail. The birds breed particularly in the red gum forest.

F: 25 June 1968, 1 seen in middle of Lindsay R. walking on a dense mat of floating *Azolla* fern, catching insects c. 1 cm long. Berribee Station, Vict.

Struthidea cinerea

BH: (see *P. nigricans* 1 Oct. 1967).

F: 2 Oct. 1967, 12 feeding with 8 *C. melanoramphus* on chaff spilled in sheep yards, Dunedin Park Station, N.S.W. 29 Jan. 1968, 10 feeding on area where sheep recently hand-fed on oats and lucerne hay, Tareena homestead, N.S.W. 22 Apr. 1968, 30+ feeding on spilled fodder, sheepyards at Dunedin Park Station, N.S.W.

Corcorax melanoramphus

Br: Nests were seen on several occasions, all abandoned, and details were not recorded. Birds breed widely, particularly in red gum and black box forests.

BH: 27 Sept. 1967, 22 birds flew out some 180 m from black box and red gum forest at

W. end of Fisherman's Cliff, Moorna Station, N.S.W., to feed amid small *Kochia* bushes and *H. floribundum* in the open. Two groups of 3 Black-backed Magpies also present. All remained for more than an hour before returning to tree cover. This species (Chough) rarely seen to leave at least light overhead cover for long at a time; frequents scrub margins much of the time. 26 Sept. 1968 (see *L. sueurii* 26 Sept. 1968).

M: 22 Feb. 1967, 50+ flock 1·3 km N. of Sturt H'way, Karrawinna Rd., Vict. 27 June 1968, 2 groups, 15 and 32, moved rapidly through red gum/black box forest, 30 minutes apart, 1015 and 1045 hr., Berribee Is., Vict. Observer static. 27 Nov. 1968, 25 in flock rapidly moving NW. through marginal vegetation at Lake Coombool, S.A.

F: 21 Apr. 1967, 20+ feeding along partly dry bore drain from windmill, Keera Station, Vict. 2 Oct. 1967 (see *S. cinerea* 2 Oct. 1967).

Family ARTAMIDAE

Artamus leucorhynchus

F: 20 Nov. 1968, 40 in feeding flock along margin of extensive stand of *Casuarina* trees, Dunedin Park Station, N.S.W. Birds repeatedly flying up for insects, alighting between each flight.

A. personatus

M: 28 Oct. 1968 (see *A. superciliosis* 28 Oct. 1968). 19 Nov. 1968, mixed flock, mainly of Masked, some White-browed Wood Swallows, total 400+, travelling high, 600-900 m, trending SW., 1315 hr. Loose flock, strung out in long line, almost at limit of unaided vision, readily identifiable 16 x 50 binoculars, much calling. Birds constantly making minor directional changes. Most of flight gliding, but some birds appeared to be darting at insects, while a few appeared to be travelling in close pairs. Light SW. breeze, 32° C., 1600 hr. Another group of 40+ Masked Wood Swallows, plus a few Tree Martins, travelling high and to SW. as earlier group. Wind now f 2-4 from SW., Bone Gulch, Moorna Station, N.S.W. 25 Nov. 1968, 30-40 plus 1 identified as White-browed Wood Swallow, SW. at 150 m, 0700 hr., calm, sunny, Nampoo Station, N.S.W. 5 Oct. 1969 (see *A. superciliosis* 5 Oct. 1969).

F: 27 Nov. 1968, 30+ feeding over *Casuarina* trees, Cass's Camp, Nulla Station, N.S.W.

A. superciliosus

Br: 23 Oct. 1968, pair with 2 flying young, *Casuarina* clump, Cass's Camp, Nulla Station, N.S.W.

M: 28 Oct. 1968, mixed flock of White-browed and Masked Wood Swallows 150+, 1115 hr., flying NE. over sand dunes, Lake Victoria, N.S.W. Birds high, much calling. Weather details similar to record *M. ornatus* 28 Oct. 1968. 17 Nov. 1968, 100+ in loose flock flying N., 1515 hr., 44·4° C., very dusty, dry. Karadoc, E. of Mildura, Vict. 19 Nov. 1968 (see *A. personatus* 19 Nov. 1968). 25 Nov. 1968 (see *A. personatus* 25 Nov. 1968). 25 Nov. 1968, 9 flying SW., 600 m, 1420 hr., calm, 21·2° C., Nampoo Station, N.S.W. 5 Oct. 1969, 500+ in mixed flock with some Masked Wood Swallows, estimated elevation 1500-2100 m, slowly flying N. against obvious strong wind (f 3-4 on ground). Birds clearly visible with 16 x 50 binoculars. Much calling. Fine, sunny, 1020 hr.; 1115 hr., second group, appeared to be only White-browed Wood Swallows, same direction, lower altitude; 1140 hr., third group, c. 70 birds, estimated 10% White-browed Wood Swallows, remainder Masked. These in much tighter flock, which was repeatedly dispersing, then bunching again as birds flew N.-NE., direction altering slightly as flew. Much excited calling. Several pairs left main group to pursue each other, then rejoin flock. Birds flying at estimated 1200 m and climbing. Moorna Station woolshed, N.S.W.

A. cinereus

Br: 21 Oct. 1967, nest under construction, 4 m up in fork of *Casuarina*. Thin sticks and *Casuarina* cladodes being brought continually by both birds. Just S. of Cass's Camp on Talgarry Station, N.S.W.

BH: 18 Mar. 1969 (see *E. tricolor* 18 Mar. 1969).

M: 25 Apr. 1968, 30-40 in small groups in *Casuarina* trees just S. of Cass's Camp on Talgarry Station, N.S.W.

A. minor

26 Sept. 1968, 90-120 passed over, estimated 300 m, trending W. and calling loudly. Flock loosely spread out in long line, in groups of 6-12. Birds chiefly gliding, occasional brief spells of flapping. Light W. wind, f. 2-3, sunny, 3/8 cumulus cloud, ceiling 2-3000 m, warm, humid after several rainy days. Keera Station, Vict.

Family CRACTICIDAE

Cracticus nigrogularis

F: 10 June 1967, immature birds feeding on worms and small insects, sheepyard, Keera Station, Vict. 14 June 1967, 1 adult bird calling, and repeatedly flying out of and landing back in the crown foliage of a black box tree. On each flight bird brushed foliage with wings, hawked insects flying out, then re-alighted. Lybra paddock, Keera Station, Vict.

C. torquatus

F: 20 June 1968, 1 bird caught lizard *Sphenomorphus q. quoyii*, in black box trees, Berribee Station, Vict.

Gymnorhina tibicen

Br: 20 Sept. 1968, adult on eggs, stick nest 8·5 m in *Casuarina*, 0·4 km NW. of Moorna E. oxbow, Moorna Station, N.S.W. 5 Oct. 1969, adult on eggs, stick nest in *Acacia*, 5 m up, woolshed, Nulla Station, N.S.W. 7 Oct. 1969, nest with 3 well fledged young, 6·5 m in red gum, nest of sticks, Wentworth Aerodrome, N.S.W. 7 Oct. 1969, adult on nest, 12 m in red gum, Lock 10, Wentworth, N.S.W.

BH: 23 Oct. 1968, male attacked a Kestrel. Birds locked claws momentarily, tumbled several metres through air before separating, Talgarry homestead, N.S.W. 20 Nov. 1968, 28 in flock in *Casuarina*/*Kochia* association area, Moorna homestead mailbox (Wentworth-Renmark road), N.S.W. Flock appears late for a winter flock, and may constitute an 'open group' (Carrick 1963) of non-territorial birds. 18 Mar. 1969, 18 in loose flock gathered about large rain puddle, near Talgarry Station second dam, N.S.W. Two drinking.

M: 24 June 1968, 15 in wintering flock flew E. over red gum/black box forest, to open ground, Berribee Island, Vict., travelling in loose group at 30 m.

Family CORVIDAE

Corvus coronoides

Br: 22 Feb. 1967, pair at possible nest on top of old hawk's nest, *Callitris* tree, Lybra Back Paddock, Keera Station, Vict. 26 Sept. 1967, adult on nest, 4·8 km W. of woolshed, Moorna Station, N.S.W. 24 Oct. 1967, 2 fledged young, 36 m in red gum, begging food from adults. Same tree as Blue-faced Honeyeater nest (see 24 Oct. 1967), banks of Lindsay R. near punt, Berribee Station, Vict. 20 Sept. 1968, adult on eggs, stick nest 7·5 m in *Casuarina* tree, 0·8 km NW. of Moorna E. oxbow, Moorna Station, N.S.W.

BH: (see *H. leucogaster* 1 Oct. 1967).

F: 19 Oct. 1967 (see *A. audax* 19 Oct. 1967). 30 Apr. 1968, 1 feeding on road-killed Ringneck Parrot *B. barnardi*, Merbein-Renmark road, Berribee Station, Vict.

C. mellori (as in Rowley 1967)

Br: (see Hobbs 1969).

BH: 22 July 1969, flock area, c. 1 km E. of Six Mile Cr. (Wentworth-Renmark road), N.S.W., 60-80 present.

M: 19 May 1969, 17 in roadside flock 0·8 km E. Ana Branch River bridge, Neilpo Station, N.S.W. 23 May 1969, 39 in flock, same locality.

F: 29 Apr. 1968, 40-60 on and about a dead sheep, Sturt Highway near Morkalla turn-off, Vict. 15-20 on another dead sheep, Gray's property, Morkalla, Vict. One *A. audax* arrived to feed, scattering ravens. 26 May 1969, 14 at dead sheep, Noola Station, N.S.W.

Feeding Associations

This section records areas where a considerable number of species were feeding in close intraspecific association. They are described in chronological order of observation:

25 Oct. 1967, on freshly irrigated pasture, Berribee Station, Vict., 9 Glossy Ibis, 84 Straw-necked Ibis, 4 White-faced Herons, 6 Spur-winged Plover, Starlings, Magpie Larks, Black-backed Magpies and Red-backed Parrots were all feeding in close company.

27 Apr. 1968, late afternoon and early evening, very humid, warm, 8/8 stratus cloud; torrential rain later at night. Chowilla Dam site to Renmark and on via Paringa to Berribee Station, Vict., by car. Enormous numbers of flying ants and termites observed throughout journey, and these were being actively hawked and eaten by the following species: Australian Raven, Little Raven, Black-backed Magpie, Starling, Silver Gull, Magpie Lark, Silvereye, Yellow-throated Miner, Apostle Bird, White-plumed Honeyeater, Black-faced Wood Swallow, White-breasted Wood Swallow.

24 Oct. 1968, Talgarry Station pump shed, Lake Victoria frontage, N.S.W., 60 Tree Martins, 10 Welcome Swallows, 8 Black-faced Wood Swallows and 8 White-breasted Swallows hawking insects immediately in lee of dense clump of red gums, during period of high winds. Only rarely did birds venture to windward, above tree top level, or beyond horizontal extension of trees. Any that did quickly returned to lee side.

20 Mar. 1969, at large rainwater puddle in sand dunes among *Nitraria* bushes, Lake Victoria, on Talgarry Station, N.S.W., 8 White-fronted Chats, 30-40 Orange Chats, 22 Crimson Chats, 3 Crested Pigeons and 25 Starlings were all drinking together in a large mixed flock. Chats of all three species were continuously arriving and departing. Starlings were split into four small flocks, which arrived separately over an 11 minute period from inland, but all left together and crossed sand dunes W. toward dead trees in the lake. Observation period 1620-1712 hr.

21 Mar. 1969, in flowering mistletoe growing on large *Acacia* close to Murray R. bank at Bone Gulch, Moorna Station, N.S.W., 3 White-plumed Honeyeaters, 1 Striped Honeyeater, 2 Little Friar Birds, 3 Yellow Rosellas, 1 Mallee Ringneck and 3 Chestnut-tailed Thornbills, were all feeding together in apparent harmony for a few minutes. Mistletoe clump had a circumference of no more than 1·2 m.

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Explanation of Plates

PLATE 34

Fig. 1—View of Moorna Station, N.S.W. Road margined by Lignum *M. cunninghammi*, extensive shrub steppe with Bluebush *Kochia* spp. etc., and Black Box-River Red Gum in background.

Fig. 2—View south along lunette of Lake Victoria, Talgarry, N.S.W. Slopes with Poached Egg Daisy *Helichrysum floribundum*, scattered clumps of Dillon Bush *Nitraria schoberi* on hill, Native Tobacco *Nicotiana* sp. and River Red Gums along shore, at pump site (N.M.V. camp), and dead Red Gums along former lake shore.

Fig. 3—Lindsay R. and portion of small oxbow on Berribee Station, Victoria. Bluebush *Kochia* spp. in foreground, mature and sapling River Red Gums *Eucalyptus camaldulensis*, Black Box *E. largiflorens*, Lignum *Muehlenbechia cunninghamii* and reeds *Juncus ingens* on far bank.

PLATE 35

Fig. 1—Unusual site for an occupied nest of Whistling Kite *Haliastur sphenurus*, Lake Victoria, N.S.W., Photo Oct. 1967. Same nest occupied annually to 1972.

Fig. 2—Nests of *Pomatostomus ruficeps.* In centre occupied nest, with disused nests left and right, Nulla Station, N.S.W., May 1969.

Fig. 3—*Podargus strigoides* incubating. Nest in Black Box *Eucalyptus largiflorens*, small swamp SE. of Nulla homestead, N.S.W.

Fig. 4—Adult Brown Tree-creeper *Climacterus picumnus* emerging from nest hollow in dead *Casuarina* tree, Nulla Station, N.S.W., 28 Oct. 1968.

Fig. 5—Recently completed nests of Fairy Martins *Petrochelidon ariel*, on Murray R. cliffs at Kulcurna Station, N.S.W., Nov. 1968.

Fig. 6—Dead *Casuarina* trees with recent and old communal roosting and (?) breeding nests of Chestnut-crowned Babbler *Pomatostomus ruficeps*, Nulla Station, N.S.W., May 1969.

Photos by K. N. G. Simpson


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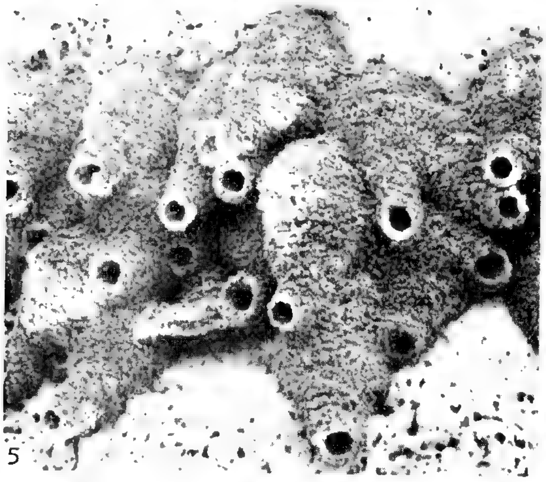
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6

AMPHIBIANS, REPTILES AND MAMMALS OF THE MURRAY RIVER REGION BETWEEN MILDURA AND RENMARK, AUSTRALIA

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Introduction

This paper reports some observations made and specimens collected of amphibians, reptiles and mammals inhabiting the Murray River region between Mildura and Renmark, Australia, during 19 field trips from 1967-70. The picture obtained of the indigenous mammal population was bleak. Compared with the considerable number of species discovered as fossils in the sand lunette of Lake Victoria, N.S.W. (Marshall, this *Memoir*), and the accounts of species, to the order of 34, described for the Murray-Darling confluence and adjacent areas by Blandowski in 1856-7 (Wakefield 1966a), and by Kreft (1866), the mammal population today is severely impoverished in both species and numbers of individuals.

Some results of a field trip organized by the Fisheries and Wildife Department, Victoria, to the Ned's Corner Station area, NW. Victoria, are included by courtesy of Mr J. K. Dempster. I thank Messrs J. Seebeck (Fisheries and Wildlife Dept.), Police Sgt J. Hobbs of Buronga, N.S.W., H. F. Thomas of Irymple, H. Hansen of Kulcurna Station, N.S.W., and H. E. Wilkinson (Mines Dept., Victoria), for information and field assistance. Mr A. J. Coventry identified and revised the taxonomy of the amphibians and reptiles, and Miss Joan Dixon confirmed the identification of mammals collected. Both are from the National Museum of Victoria.

Systematic List

Class AMPHIBIA

Order SALIENTIA
Family HYLIDAE

Litoria peroni 28 June 1967. One specimen (CHR/10) from beneath bark of *Eucalyptus camaldulensis* root buttress, 4 m from nearest water, oxbow on Scadding's property, Winjellie Station, near Lock 8, N.S.W.

Family LEPTODACTYLIDAE

Limnodynastes dumerili 7 May 1971. One specimen (CHR/2) from a dog's water dish, McPhee's Camp, SE. Lake Victoria, Dunedin Park Station, N.S.W.

L. fletcheri 10 May 1967. In drain beside freshly flooded lucerne, Keera Station, Victoria. One specimen (CHR/5).

Crinea signifera complex 25 Mar. 1969. One specimen (CHR/29) from cavity beneath skull of an aboriginal skeleton, partly exposed on lunette, Lake Victoria, Nulla Nulla Station, N.S.W.

Class REPTILIA

Order TESTUDINES
Sub-Order PLEURODIRA
Family CHELIDAE

Chelodina longicollis Nov. 1968. One specimen (CHR/27). Carapace only, not retained. Oxbow lake on Nampoo Station, N.S.W. The species is widespread and common within the riverine tract of the study area.

Emydura. None collected but living specimens and several carapaces recorded from time to time. Widespread and common within riverine tract of the study area.

Order SQUAMATA
Sub-Order SAURIA
Family GEKKONIDAE

Phyllurus milii Early July 1968. One immature specimen (CHR/26), collected by Mr K. Webster, Curator, Chowilla Dame Construction Site, from dead tree on hill W. of Monomon Creek, near dam site, and donated 1 Aug. 1968.

Heteronotia binoei 21 Mar. 1969. One specimen (CHR/31) from burrow in sand, collected by Sir Robert Blackwood, lunette E. side of Lake Victoria, Nulla Nulla Station, N.S.W.

Phyllodactylus marmoratus 26 Sept. 1967. Two specimens (CHR/14-15) one from beneath bark of *E. camaldulensis,* Moorna oxbow, N.S.W., and one from beneath bark of fence post, Moorna woolshed, N.S.W. Common in district; frequently seen on walls of outbuildings at night.

Gehyra variegata 10 May 1967. One specimen (CHR/6) from beneath bark of *E. largiflorens,* Wallpolla Creek, Keera Station, Vic. 20 Mar. 1969. One specimen (CHR/30) from Nulla Nulla woolshed, N.S.W.

Family AGAMIDAE

Amphibolurus pictus 24 Mar. 1969. One specimen (CHR/30) from burrow in sand of lunette, Lake Victoria, Nulla Nulla Station, N.S.W. This species was quite commonly seen in sandy localities during hot weather.

A. barbatus 28 Sept. 1967. One specimen (CHR/16), immature, from edge of dry oxbow, Moorna Station, N.S.W. A widely distributed and frequently observed species.

Family SCINCIDAE

Egernia striolata 23 June 1968. Two specimens (CHR/20-21) found under bark of *E. camaldulensis,* Lindsay Island, Berribee Station, Vic. One specimen trapped F & W (17 Apr. 1967 to 2 May 1967) in Red Gum forest Potterwakagee Creek, Ned's Corner Station, Vic.

Tiliqua rugosa 6 May 1967. One specimen (CHR/1) from Lybra Paddock, Keera Station, Vic. Very common and widespread species. One recorded eating small yellow flowers and another eating road-killed *A. barbatus.* Two others seen feeding at road-killed rabbits. Following a few points or more of rain, these lizards are recorded in increased numbers, and frequently drinking from puddles.

Sphenomorphus quoyii 20 June 1968. One specimen (CHR/19) taken from Grey Butcher Bird (CHV/72), Lindsay River, Berribee Station, Vic. Four specimens trapped by F & W party in break-back traps along banks of Potterwakagee Creek, Ned's Corner Station, Vic., during period 17 Apr. to 2 May 1967.

S. fasciolata 26 Mar. 1969. One specimen (CHR/32) in Nulla Nulla woolshed, N.S.W.

Lerista punctovittatum Early July 1968. One specimen (CHR/25) collected by K. Kempster from dead tree on hill W. of Monoman Creek, near dam site, S. Aust., and donated 1 Aug. 1968; 2 Aug. 1970. One specimen (JS 819) collected by Mr J. Seebeck from garden rubbish, Meringur, Vic.

Morethia boulengeri. Twelve specimens (NMV D 15148-59 inclusive) collected by J. Seebeck, April 1967, in Ned's Corner-Lindsay Point area.

Varanus varius. No specimens. Widely distributed and common, more particularly within or near the riverine tract. Recorded by day and night. One seen carrying small dead rabbit, possibly a road-kill. One at Keera, Vic., semi-tame and regularly visits a caravan site, banks of Little Ranker Creek, for food scraps.

V. gouldii. No specimens. Widely distributed and common, more particularly in open areas away from the riverine tract. On two occasions, pairs were disturbed while they were engaged in possible courtship. Appear to be strongly territorial, and to have permanent homesites. Recorded by day and night. One seen feeding on road-killed Galah, Ned's Corner Station, Vic. Plate 36 insert shows one of a pair of Gould's Sand Goannas photographed at Lake Tyrrell, near Sea Lake, Vic., during 1971. Plate 36 provides circumstantial evidence that a goanna of this species attempted or succeeded in entering a nest burrow of the White-backed Swallow *Cheramoeca leucosterna* in an erosion gulch of the lunette, Lake Victoria, Talgarry Station, N.S.W.

Sub-Order SERPENTES
Family ELAPIDAE

Pseudechis australis 23 Apr. 1968. One specimen (CHR/17) collected by Mr G. Withers, 3 km NW. of Nulla Nulla Homestead, N.S.W. Several other individuals recorded during the study period. Widely distributed, chiefly in drier areas outside the riverine tract.

P. porphyriacus. No specimens. One individual, believed to be this species, seen on Murray River banks, 2 km downstream from Lock 9, on Ned's Corner Station, Vic., 9 May 1967.

Pseudojata textilis 27 Apr. 1968. One specimen (CHR/18) (not retained), killed by Mr K. Ellborough in haystack, Berribee Station, Vic. The species is widespread and quite common in drier areas of the district.

Notechis scutatus. No specimens. Widespread and common within the riverine tract. Recorded by day and night.

Vermicella annulata. One specimen (CHR/4) collected by Miss Heather Fox among sticks on partly cleared country at Meringur, Vic., May 1967 and donated 10 May 1967.

Class MAMMALIA

Order MONOTREMATA

Tachyglossus aculeatus. No specimens. Jan. 1968. One adult female captured by fishermen and brought to Kulcurna Station Homestead from the Murray River banks nearby. Later released locally. Typical feeding excavations of this species are widespread through every habitat in the district. Animals common and widespread, if evidence of typical excavations accepted as such.

Order MARSUPIALIA

Sminthopsis crassicaudata. No specimens. Rabbit trappers J. May (on Noola Station, N.S.W., 1970) and K. Cass (on Nulla Nulla Station, N.S.W., 1967) were able to describe small jumping mice with plump tails that they had seen one or twice in open sandy areas during late dusk. An F & W Environmental Studies Section field trip to Ned's Corner Station and surrounds succeeded in obtaining one specimen (70-163) SW. of Lake Walla Walla, Vic. The specimen was taken during September 1970.

S. murina. No specimens or records. However, a healthy captive was in possession of Sgt J. Hobbs at the Police Station, Buronga, N.S.W., on 23 Feb. 1967. It was captured at Lake Gol Gol (Hobbs 1968).

Acrobates pygmaeus. No specimens. However, reports by local inhabitants indicate that the species is probably moderately common through the *E. camaldulensis-E. largiflorens* association along the riverine tract. Similar findings were made by the F & W party during 1970. A specimen taken on or near Ned's Corner Station years previously had been handed to a naturalist in Mildura.

Trichosurus vulpecula 23 Feb. 1967. The Lock master, Mr G. Thomas, of Lock 9, N.S.W., informed us that Brush-tailed Possums were plentiful in the immediate vicinity, especially in the weeping willows along the river. Tourists and overnight campers fed some semi-tame individuals at the Lock. Numerous fresh and old droppings were seen 24 Feb. 1967. A badly decomposed body of an adult seen near the fowl pen of Nelwood Station, S. Aust., on the Murray R. banks. Fresh dropping present 24 Sept. 1968. Left ramus found on banks of Murray R., Top Island, Berribee Station, Vic. (C10794) 26 Sept. 1968. Rami found SW. corner of Lake Walla Walla, Ned's Corner Station, Vic. (C 10795) 22 Nov. 1968; complete skull with rami, Murray R. bank at Fisherman's Cliff, Moorna Station, N.S.W. (C 10796).

Macropus robustus (erubescens?) First indications of the possible presence of Euros in the district were obtained from J. Hobbs of Buronga, N.S.W. Subsequent questioning of local residents proved that many knew of their presence. A few denied their existence. Examples were later seen by NMV members, and were reliably reported by other interested persons. A specimen was finally obtained.

The F & W party (December 1967) reported that Mr Peter Probert of Rufus River, N.S.W., had seen mobs of up to 20 in an area known locally as 'The Basin'.

The NMV observations and collected information indicate a small and apparently discontinuous population linked, it is considered, with the extensive range of the Euro through S. Aust., central W. New South Wales and W. Queensland. Previous mammal studies in the region (Blandowski 1856-7, reported by Wakefield 1966a, Krefft 1866, Marlow 1958, Wakefield 1966a, b), have not mentioned the presence of *M. robustus.* All the records gained during 1967-70 are from the New South Wales sector of the proposed Chowilla Dam inundation area.

Euros were seen along the river cliffs of

Moorna, Lake Victoria, Nampoo, Warrakoo, Kulcurna and Tareena Stations, and at Lake Victoria in dense marginal vegetation and erosion gulches on Nulla Nulla, Talgarry and Noola Stations. Most of the sightings were of single animals. At both Talgarry and Noola, Euros were disturbed from dense patches of cumbungi and reeds, beneath red gums along the shore of the lake. They made their escape via the long erosion gulches to scrub patches more than a kilometre back from the lake. During 1970 a specimen (CMH/28) was collected by Mr Hans Hansen at Kulcurna Station. The body was frozen at Mildura, and forwarded to the NMV some months later. Hansen had shot at least one other example some months earlier, during late 1969.

M. fuliginosus melanops. The Black-faced Grey (Mallee) Kangaroo is extremely common and widespread within the study area. Scores of sightings, of mobs up to 40, were made during 1967-70. They tend to be more numerous in or close to forested and scrubby areas. Frequently mixed mobs of this species plus *Megaleia rufa* were seen. The species is commonly shot for dog food, sometimes because of alleged competition with sheep, by property owners and staffs of many stations on both banks of the Murray. In drought years the numbers of individuals increases markedly, probably due to food and water shortages further from the river. Shooting pressure, including the engagement of professional shooters, increases at such times. The 1967/8 summer was such a season. Skeletons of more than 200 kangaroos, mostly *melanops* were found on a dump on the banks of the Anabranch, Neilpo Station, N.S.W., early in 1970.

Specimens obtained: limbs, considerably eroded (CHM/2), from Brown's Paddock, Keera Station, Vic., 21 Apr. 1967. Whole carcase and a head (CHM/5-6), 2 May 1967, Keera Station, Vic., deep frozen for display skinning at NMV. Skull, tibia, and fibula, 15 Mar. 1969, coll. E. D. Gill, lunette E. side of Lake Victoria, Talgarry Station, N.S.W.

Megaleia rufa. The Red Kangaroo is extremely common and widespread on both sides Plate 36 insert shows oneof a pair of Gould's sightings, of mobs up to 15, were made during 1967-70. Most of the remarks made for *M. fuliginosus melanops* apply also to this species, except that the species is commonly seen out in the open, away from dense scrub. However, Red Kangaroos were also met within dense red gum-black box forest at times. The F & W party recorded more than 54 sightings of this species in their log book during their observation period from 17 Apr. to 2 May 1967. All these sightings were in NW. Victoria, and it was noted (Dempster 1967) that the animals were mainly associated with the Ned's Corner Land System (Rowan and Downes 1963).

Specimen obtained: fragmented skull, from erosion gulch, cliff at Nampoo Station, N.S.W., 25 Nov. 1968 (CHM/23 = C10797).

Order CHIROPTERA

Bats were frequently seen, but rarely identified.

Taphozous australis. One specimen obtained from abandoned nest of a Fairy Martin, *Petrochelidon aerial*, by H. Hansen on the cliffs at Kulcurna Station, N.S.W., during the winter months of 1968. Preserved as a spirit specimen (CHM/26).

Nyctophilus geoffroyi. Very common within the study area, occupying both trees and buildings. Specimens collected: 3 males, 1 female collected by H. Hansen in out-building of Kulcurna Station, N.S.W., 18 Feb. 1968 (CHM/9-12). CHM/12 donated C.S.I.R.O. Division of Wildlife Research collection (CM 2343). 1 male found dead in shearers' quarters, Nulla Nulla Station, N.S.W., 23 Oct. 1968, collected by H. E. Wilkinson (CHM/21). 1 male found dead, same locality, 6 Oct. 1969 (CHM/27).

Order RODENTIA

Hydromys chrysogaster. No specimens; widespread and common along the Murray R. and associated waterways within the study area. Once seen in broad daylight, but usually at dusk or at night with spotlights. 23 May 1969. A water rat swam from an island in Moorna East oxbow lake, Moorna Station, N.S.W., to a dense reed bed by the bank. Alarm calls were given by several Dusky Moorhens *Gallinula tenbrosa* as it approached.

The F & W party trapped 3 and shot 1 on the Victorian side of the Murray (Pottawackagee Creek) (Dempster 1967).

Mus musculus. Widespread, common, occasionally to plague proportions. Numerous in some reed and cumbingi beds, particularly along the Frenchman Creek and associated waterways. Reached plague proportions in 1969/70, following drought of 1967/68 summer, and a very favourable summer in 1968/69.

Order LAGOMORPHA (introduced)

Oryctolagus cuniculus. Widespread, common in localized concentrations. Subject of commercial trapping, recreational shooting and trapping, mass and local eradication programmes by poison, virus, fumigation and ripping of burrows. A competitor of all herbivores in the district, as elsewhere. Can cause erosion, frequently severe, especially if sheep are also present. Burrows sometimes afford shelter for native mammals (e.g. echidna) and reptiles.

Lepus europaeus. The hare is widespread, but not particularly numerous in the district. A few seen by NMV members, usually at night crossing roads, or in open country or near irrigated pasture.

Order CARNIVORA (introduced)

Vulpes vulpes. The Red Fox is widespread and common in the study area. Seen by day and night. Numerous dead animals seen. Approaches station buildings by night to feed. Specimens collected: 5 skulls (C 10789-93) from various localities within the study area.

Canis familiaris. Domestic dogs were owned on practically every station and property visited. Many are employed to work stock, to hunt kangaroos and rabbits or as guards. Occasionally, dogs were seen alone far out in the bush.

Felis catus. Cats also were found on most properties visited, and out in the bush or paddocks well away from dwellings.

Order ARTIODACTYLA (introduced)

Capra hircus. Several mobs of wild goats are known in the study area, the largest, of more than 40, being on Nulla Nulla and Talgarry Stations, N.S.W. Here they have caused or increased erosion of the sand lunette on the E. side of Lake Victoria. Their observed habit of climbing every prominence in their path has assisted the rapid increase of both sheet and headward erosion. An unfortunate by-product was that many newly exposed fossil mammal and Aboriginal skeletons were destroyed before they could be excavated.

Sus scrofa. Feral pigs are widespread and common, particularly in the red gum and black box forests of the watercourses. They inhabit dense lignum clumps, and make noctural forays onto surrounding paddocks and irrigated pastures to feed. They also commonly eat carrion, and dig for roots and freshwater mussels *Velesunio ambiguus* along dried oxbows and creeks. Many escaped from captivity during floods in 1951 and 1956 to boost the existing population.

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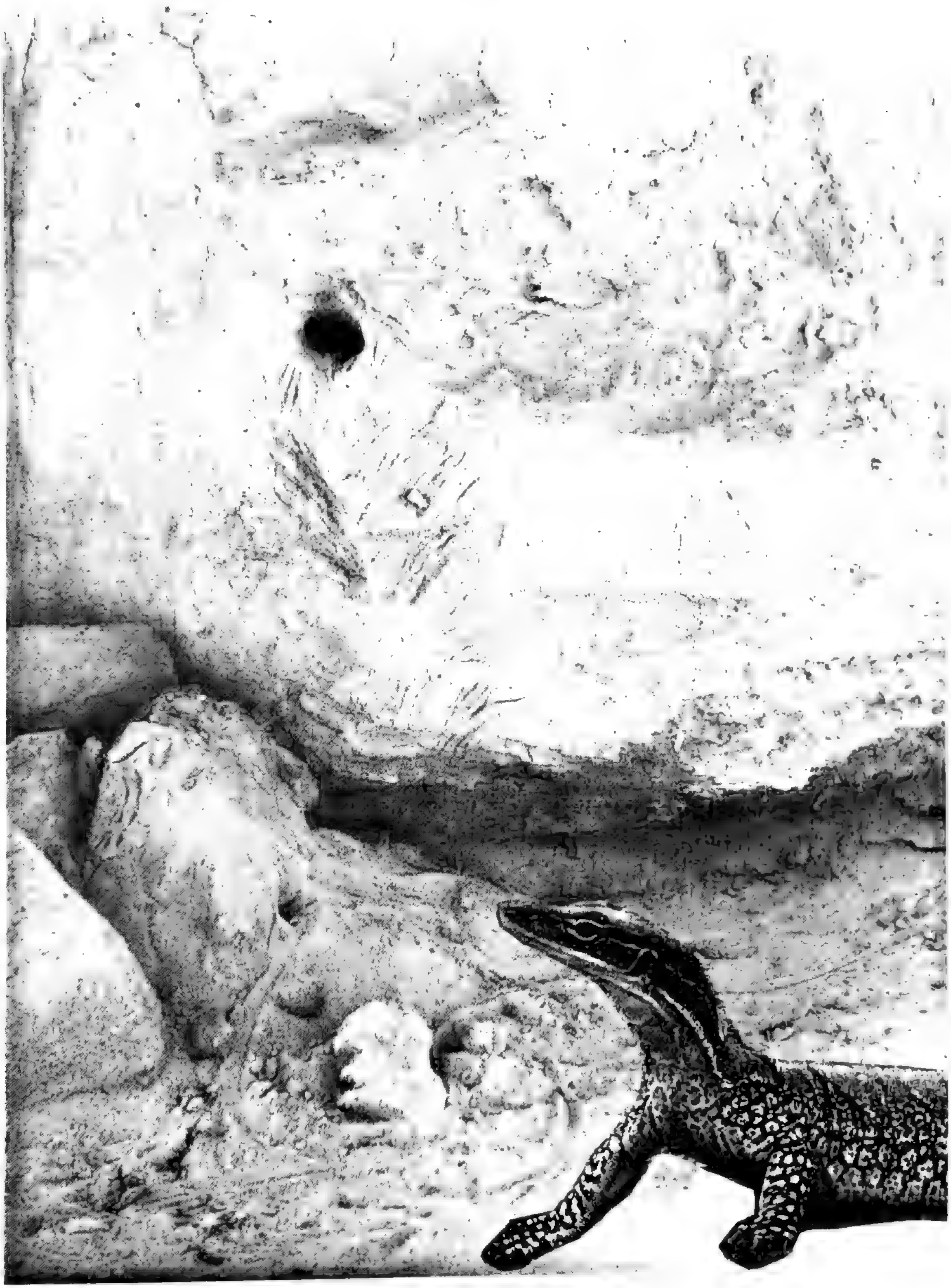
Explanation of Plate 36

Photograph of scratchings by a Gould's Sand Goanna at the burrow entrance of a White-backed Swallow, interpreted as a predatory attack. Superimposed is the head and forelimbs of a goanna of this species.

Photo—author.



NATIONAL MUSEUM OF VICTORIA SITES IN THE MURRAY RIVER REGION BETWEEN MILDURA AND RENMARK, AUSTRALIA

The allocation of site numbers for so vast an area, and to suit the requirements of authors in a number of disciplines, has proved to be extremely difficult. The solution is essentially pragmatic. Where a name already available (such as Merbein Cliffs) can be satisfactorily used, no site number has been allocated. The site numbers refer to complicated areas where there are many localities close together. For example, at Salt Creek on Kulcurna Station, there are section lines, gulches, and fossil localities, with additional archaeological and geological sites on the higher ground beyond the cliffs.

The original site numbers (in brackets below) were allocated in the field in no specific geographic order, or for a standard area, and so had to be rationalised. Either a number has to be given to every little locality, or to general areas wherein specific loci can be indicated as suits the purposes of each author. The latter procedure is judged to communicate better. A hundred locality numbers cannot be carried in the mind, but the 19 listed are practicable.

Copies of this page of site numbers will be attached to all reprints, and placed with the specimen collections in the Museum, so that cross-reference between previously allocated field numbers and the new *Memoir* numbers is simple. The utilization of existing names where possible has greatly reduced the list of site numbers. The latter pass from W. to E. on the N. side of the Murray River, and then from E. to W. on the S. side.

SOUTH AUSTRALIA

1. Proposed Chowilla Dam area (original field numbers 48-49).

NEW SOUTH WALES

2. Kulcurna Station: Salt Creek and Scrub Paddock area (56).
3. Kulcurna Homestead, Murray River cliffs alongside, Cal Lal (55).
4. Nampoo Station, E. of Cal Lal (33).
5. Warrakoo Station, Murray River cliffs E. of Cal Lal, and SW. to W. side of Lake Victoria (72).
6. Noola Station W. to NW. side of Lake Victoria (37, 68-71).
7. Nulla Station from boundary with Noola Stn. through Old Hotel site to Lone Gum (52).
8. Nulla Station on E. side of Lake Victoria from Lone Gum to Talgarry fence, including Oak Hill Paddock (50,65-66).
9. Talgarry Station, E. side of Lake Victoria (28, 51, 57, 63, 67).
10. Dunedin Park Station, SE. side Lake Victoria, extending to Frenchman's Creek (30, 73).
11. Moorna Station area including homestead, windmill, and cliffs to N. and NE. (38, 43).
12. Moorna Station: area including Triple Swamp, Bone Gulch, and Triple Swamp Gulch (45-46).
13. Moorna Station: area including Fisherman's Cliff and Moorna E. oxbow (39-40).
14. Neilpo Station, including Six Mile Creek cliffs (47).

VICTORIA

15. Boy Creek area.
16. Keera Station: Lybra Paddock (formerly Lybra Station) (5-12, 27, 34).
17. Keera Station: Brown's Paddock (1-4, 12, 35).
18. Ned's Corner Station, including Lake Wallawalla.
19. Berribee Station, near S.A. border (15, 19-20, 53-54).

—E. D. Gill