COMMONWEALTH OF AUSTRALIA
DEPARTMENT OF NATIONAL DEVELOPMENT
BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

BULLETIN 86

Stratigraphy and Vertebrate Fauna of the Otibanda Formation, New Guinea

BY

M. D. PLANE

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MINISTER: THE HON. DAVID FAIRBAIRN, D.F.C., M.P.
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ILLUSTRATIONS

SUMMARY

Late Tertiary intermontane lacustrine and fluviatile deposits in the Morobe District of New Guinea contain vertebrate fossils in association with dated pyroclastic rocks.

Metamorphic rocks ranging in age from probable Palaeozoic to middle or late Cretaceous form a complex basement into which granodiorite plutons were intruded in the late Cretaceous or early Tertiary. From probable Oligocene or Miocene time porphyritic rocks intruded the metamorphics and granodiorite; this activity culminated in explosive vulcanism which produced vast quantities of agglomerate. The agglomerate blocked the drainages, and lacustrine and laterally restricted floodplain deposits formed behind the dams during the Pliocene. A formation, the Otibanda Formation, which includes lacustrine sediments, floodplain deposits, and interbedded tuffs is formally defined. Its thickness cannot be estimated, but a measured section is more than 2500 feet thick.

The type section at 'Sunshine' contains fossiliferous sandstone and mudstone with conglomerate and intercalated pyroclastic rocks which yield Potassium/Argon dates from below the mammal horizons of 6.1 and 7.6 million years. A 5.7 million year date higher in the section is associated with the type faunal locality, which has produced an incisor of the earliest known rodent from the Australian region and new representatives of the marsupial families Macropodidae and Diprotodontidae. The fauna also includes gastropods, crocodilians, snakes, birds, and a dasyurid. Fossil vertebrates have been collected from 21 widely scattered localities.

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INTRODUCTION

Late Tertiary lacustrine and fluvial deposits crop out in intermontane valleys within the Morobe Administrative District of New Guinea, in an area of 440 square miles on approximately 7°S latitude and 146°E longitude. This area falls within portions of the Wau, Nauti, Bulowat, and Mount Missim 1-mile map areas.

The investigation of the area was undertaken so as to learn something of the stratigraphy of the late Tertiary sediments, to relocate vertebrate fossil localities, to find additional vertebrate fossils, and to locate and sample pyroclastic rocks in association with fossils for Potassium-Argon dating.

Wau and Bulolo, the only centres of population and industry in the map area, may be reached by air and road. An unsurfaced all-weather road joins the two towns to Lae, a seaport on the Huon Gulf. Although this road may become impassable during short periods of extremely wet seasons, it is maintained throughout the year. Regular flights connect both towns with the main commercial air services to Australia at Lae and Port Moresby. Two tracks branch from the Lae-Wau road, one leading to Edie Creek and the other to Slate Creek. Both are subject to washouts during the rainy season, and in years of particularly heavy rainfall may be closed for months at a time. At their best they are only suitable for four-wheel drive vehicles.

Field observations, both stratigraphical and palaeontological, were plotted directly on to vertical air-photographs of the Wau, Bulowat, Nauti, Mount Missim, and Bulolo Valley series. The initial base map was prepared from photographs of the Bulolo Valley series plotted on to a base triangulation grid—this work was undertaken by the Forestry Department of the Papua-New Guinea Administration and was replotted on to standard meridians by the Bureau of Mineral Resources. The controlled base map unfortunately does not cover the entire area and uncontrolled photo-mosaics have been used to fill in the gaps. The reliability of the topography on the final map (Pl. 6) is indicated in a small diagram on the map.

Photogeological interpretation is possible on a broad scale in the map area. The granodiorite of the Morobe Batholith produces a particularly distinctive drainage pattern (Pl. 1), and the south-western trace of the Sunshine Fault was initially postulated from air-photo interpretation which subsequent investigation proved correct.

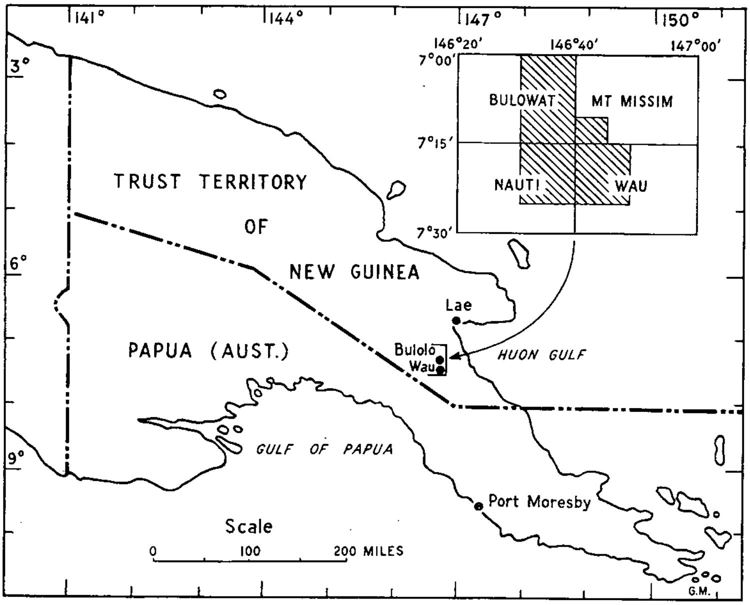

Figure 1. Locality Diagram.

Within the 24 miles from the northern outcrops of late Tertiary rocks at Sunshine to the southernmost outcrops near Wau two distinct climatic zones can be recognized. These zones depend in part upon elevation, which in the map area ranges from 2000 to 8000 feet above sea level. The northern part of the area near Sunshine and the areas at lower elevations in the grasslands of the Watut and Bulolo valleys fall into Köppen's (1931) Tierra caliente zone, while the southern portion of the map area, at higher elevations, in the headwaters of the Watut and in the Wau valley can be grouped in the Tierra templada zone.

The only climatic data are for the centres of Wau and Bulolo, which are fairly representative of the two zones.

Mean Annual Daily Maximum and Minimum Temperatures: Wau 82.5°F. - 61.8°F; records for 5 years. Bulolo 87.3°F - 63.3°F; records for 5 years.

Mean Annual Rainfall: Wau 76.68 inches; records for 12 years. Bulolo 64.20 inches; records for 14 years.

Mean Annual number of days on which rain fell: Wau 208 days; records for 12 years. Bulolo 164 days; records for 14 years.

Rain falls during all months of the year in both regions, with more during the period November to April than the period May to October. In the Tierra caliente zone most days are warm to hot and humid. In the open and shadeless grasslands conditions can be most unpleasant. Temperatures do not drop greatly at night. Winds follow no set pattern and are gentle except for those which precede the not infrequent afternoon thunderstorms. Tierra caliente changes to Tierra templada somewhere between 2500 and 3000 feet in this area. It is a subtle change, the most notable feature being the relief of cool nights. Also, the humidity is considerably less during the day and is only unpleasant during stormy weather. Mists and light rain make up a good deal of the rainfall in this zone, in contrast to the predominantly stormy rain of the Tierra caliente zone.

Two main types of vegetation exists: rainforest and grassland. The rainforest is characterized by dense undergrowth and is difficult to penetrate in areas where tracks are not well defined. The valleys of the Bulolo and Watut have been largely deforested, probably by continual clearing and burning of the vegetation, and are now grassland. Very large stands of Hoop and Klinki 'pine' *(Araucaria cunninghamii* and *A. klinkii)* are found throughout the forested area. Mixed hardwoods, including varieties of oak, beech, and walnut, together with rather poor cedar and rare, but fine, examples of the 'pine' *Agathis alba* complete the dominant arboreous element.

Several species of grass are found in the grasslands, but they are dominated by the 2 to 3-foot-high kunai *(Imperata cylindrica).* The persistence of this species and the lack of second-growth forest is usually attributed to annual burning.

The endemic fauna remains abundant in spite of continual attrition from native hunters. Mammal and bird life abounds in the forests, and snakes inhabit both the forest and grasslands. In the forest pythons are plentiful, and a poisonous variety of adder is widespread in the grasslands. Representatives of the marsupial families Dasyuridae, Peramelidae, Phalangeridae, and Macropodidae are found associated with interesting endemic murids and the ubiquitous rats and mice.

Most of the human population is grouped round Wau and Bulolo. These towns occupy sites in grassland valleys and can be contrasted with the hamlets of the indigenous population, which, at the advent of Europeans, were confined to forest clearings. Both towns were established in the mid-1920s and owe their origin to gold mining. Gold mining remained the principal industry until World War II and was chiefly responsible for the re-establishment of the towns after hostilities ceased. With the subsequent waning of gold production industry has diversified.

Interest in the late Tertiary rocks was, at first, directly connected with gold mining. The gravels which unconformably overlie them were the principal goldbearers, and the Tertiary rocks formed a clear-cut lower limit. Although many of the earlier miners realized that the 'sedimentaries,' as they called these rocks, contained some gold, they worked them only in sections like Koranga, where they found higher values in the upper stratigraphic levels.

Formal investigation of the regional geology was undertaken by N. H. Fisher, Government Geologist, in the 1930s (Fisher, 1944). In 1937 Anderson published a description of the fossils found by Fisher along with notes on the geology by Fisher. Most fossils found by miners during the 1930s were presented to the Australian Museum, but one specimen found its way to the British Museum of Natural History. The only systematic search for fossils was made by Fisher in 1939, when he revisited the locality from which *Nototherium watutense* Anderson had come. Geological work and mining ceased during the war, but since then several Bureau of Mineral Resources geologists, resident at Wau, have investigated various areas and aspects of the late Tertiary rocks. G. D. Woodard, while a student at the University of California, Berkeley, worked in the area in 1955. He collected some fossils including the type of *Protemnodon buloloensis* from the 'Sunshine' localities.

ACKNOWLEDGEMENTS

It is a pleasure to acknowledge the assistance extended to me by many individuals and institutions during the course of this study. I am particularly grateful to the late Dr R. A. Stirton, who first stirred my interest in the fossil mammals of New Guinea; his continued encouragement was largely responsible for the completion of the study. Dr N. H. Fisher's interest in the project springs from his association with the early discoveries of fossil mammals in New Guinea. His continuing interest has been encouraging.

I am grateful for the opportunity I had to study specimens lent to me by Dr J. W. Evans and Mr H. O. Fletcher (Australian Museum, Sydney), Mr J. T. Woods (Queensland Museum), Mr H. M. Van Deusen (American Museum of Natural History), and Dr S. M. Benson (Museum of Vertebrate Zoology, University of California). Dr G. H. Curtis (Geology Department, University of California, Berkeley) has processed five samples of pyroclastic rocks for Potassium/Argon dates. His interest and friendly co-operation are most gratefully acknowledged.

I have profited greatly from discussions with Dr W. Z. Lidicker (Museum of Vertebrate Zoology, University of California) and from the many helpful suggestions and criticisms offered by Dr D. E. Savage and Dr R. H. Tedford. Many people in Wau and Bulolo assisted me with their local knowledge; of these Keith Collins-Rubie of the Bulolo Gold Dredging Company must be singled out. He helped Woodard in 1955, and his continued interest in the fossil vertebrates enabled me to relocate several localities and was instrumental in saving several specimens which otherwise might have been destroyed. Horace Clissold of Wau, Mick Leahy of Zenag, and Mr and Mrs Charlie Lawrence of the Gold and Power Company, Slate Creek, gave assistance and hospitality. I have profited greatly from discussions with many fellow students in the Paleontology Department, University of California, Berkeley. Special thanks are due to Michael Woodburne, whose counsel and knowledge of Australian fossil faunas has always been available to me. The line drawings in this report are the work of Owen Poe, Augusta Lucas, and Pat Lufkin of the Museum of Paleontology art staff.

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TOPOGRAPHY

The main topographic features in the area are the valleys of the Bulolo and Watut Rivers, the ridge which separates them, and two ranges of mountains, the Kuper and Ekuti.

The Bulolo River, from its source to its confluence with the Watut, is about 30 miles long. It rises in the south-east (Fig. 2) and flows north-north-west in a broad deep valley. Over its entire course it encounters only one major constriction, the Bulolo gorge. The gradient of the river is about 1 in 80.

The Watut River rises about 10 miles to the west of the Bulolo and flows north-north-west for 12 miles. It then runs west for 3 miles, after which it resumes its northerly course and gradually curves to the north-east.

The Watut-Bulolo divide, a north-south ridge, falls from over 7000 feet at the headwaters of the two rivers to just below 2000 feet at their confluence. It is a well-marked narrow ridge near the headwaters, but loses its definition as it approaches the confluence.

The Ekuti Range constitutes the main divide in this area, separating the Kapau, Kabu, Kareeba, Indiwi, Eloa, and Korpera Rivers, which flow south to the Papuan Gulf, from the Langimar, Watut, Snake, and Bulolo, which flow north into the Huon Gulf. This range trends north-west and for the most part forms a well-marked divide.

The Kuper Range forms another divide, separating the north-flowing Bulolo and Watut Rivers from the Bitoi and Francisco Rivers, which flow almost due east into the Huon Gulf.

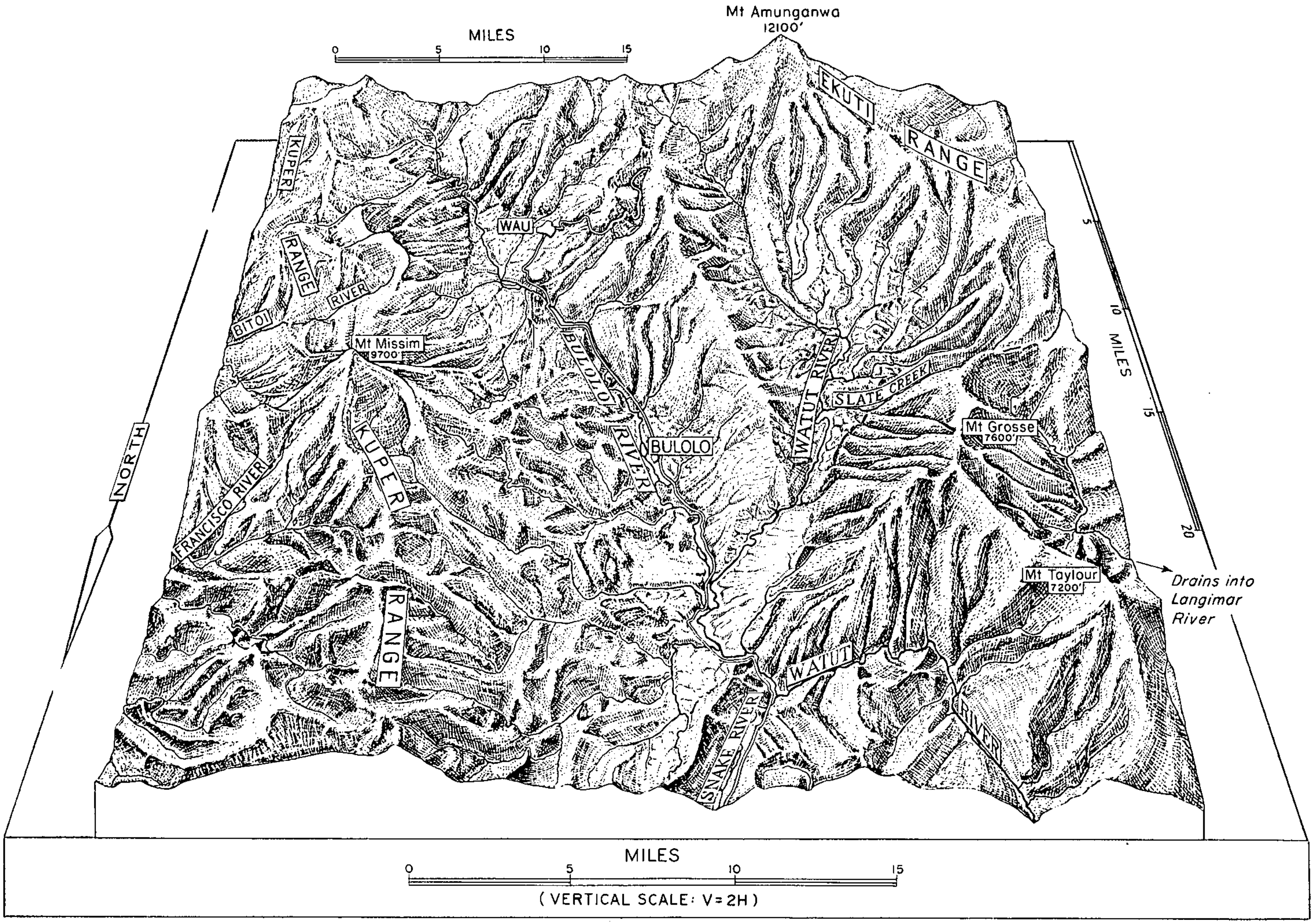


Figure 2. Physiography of Wau, Watut, and Bulolo Valleys.

SUMMARY OF GEOLOGICAL HISTORY

	Activity	*Time*
1.	Deposition of Kaindi Metamorphics in probable near-shore environment.	? Palaeozoic-middle Cretaceous
2.	Kaindi Metamorphics diastrophically deformed and broadly folded.	Mesozoic
3.	Intrusion of large masses of granodiorite.	early Tertiary
4.	Porphyry intrusions throughout Tertiary together with uplift and continual erosion. No evidence of early Tertiary sedimentation.	
5.	Intrusion of late porphyries and commencement of extrusive activity which produced breccia and agglomerate. Valleys dammed up and lakes formed.	? Miocene-Pliocene
6.	Lacustrine and fluviatile sediments deposited while explosive vulcanism continued intermittently.	middle Pliocene
7.	Uplift increased and coarse sediments deposited. Final destruction of lake by increased sediment load and continued uplift.	? late Pliocene
8.	Sediments tilted and piedmont deposits formed in Wau Valley by streams disgorging from Mount Kaindi.	? early-middle Pleistocene
9.	Last vulcanism produced rhyolite flows and breccia which overlie piedmont deposits near Wau.	? late Pleistocene
10.	Coarse sediment deposition continued in Bulolo and Wau Valleys. Up to 300 feet of gravels in Bulolo Valley. Uplift continued.	? late Pleistocene - Sub-Recent
11.	Commencement of present drainage pattern initiated dissection of terraces and flats.	Recent

STRATIGRAPHY

The *Kaindi Metamorphics,* the basement for the Morobe District, were named by Fisher (1944) after Mount Kaindi, the 8000-foot peak to the west of the township of Wau.

Kaindi Metamorphics crop out in the south-eastern and north-western corners of the map area (Pl. 6). Those in the north-western section are part of a large body of basement metamorphics which extend north-east to the coast of the Huon Gulf. The metamorphics in the south-east are not demonstrably connected with those to the north, but are assumed to be part of the same group. They stretch east to the Owen Stanley fault, mapped by Dow & Davies (1964), and are part of the large mass of metamorphics known as the Owen Stanley Metamorphics, which extend south into Papua.

The rocks of the Kaindi Metamorphics, as originally mapped by Fisher, include the Snake River Greywacke and Sericite Schist and Greywacke of Dow (1961) and the Sampa Beds of Dow & Davies (1964). The Sampa Beds and the Snake River Greywacke contain megafossil assemblages regarded by Glaessner (1949) and Skwarko (1967) as Cretaceous. These rocks are the youngest of the Kaindi Metamorphics. Older rocks which underlie the Snake River Greywacke and Sampa Beds are unfossiliferous and on general considerations have always been regarded as Palaeozoic. In summary, the basement complex consists of a large and very thick sequence of metamorphic rocks which range in age from probable Palaeozoic to late Cretaceous.

Before metamorphism these rocks were a sequence of greywacke and limestone with lesser conglomerate and siltstone and some possible tuff. They were regionally metamorphosed and belong in the greenschist facies. Intensive contact metamorphism is imposed on the regional metamorphism near the granodiorite pluton and the porphyry intrusions.

Dow (1961) believes that the Kaindi Metamorphics were probably deposited in a near-shore environment which was being supplied by abundant volcanic debris; and that the limestone represents reefs with all traces of organic material obliterated by metamorphism.

The *Morobe Granodiorite* (Fisher, 1944) was named after the Morobe Goldfield, in which it is the most prominent intrusive rock. Two large areas of outcrop are found in the map area (Pl. 6). Of these the area to the north-west is a portion of a 300-square-mile mass exposed between Bulolo and Salamaua. The area to the south-west is part of a smaller mass which forms the divide between the headwaters of the Kapau, Kabu, Kareeba, and Indiwi Rivers draining to the south, and the Watut and Bulolo Rivers draining to the north.

Both Noakes (1938a) and Fisher (1944) described the granodiorite. Noakes's comprehensive description details the mineralogy and petrology. He believed that the composition of the original magma was probably intermediate between granite and granodiorite, while local differentiates produced granodiorite, quartz monzonite, tonalite, and hornblendite. Fisher notes some minor pegmatite development.

The age of the intrusion can only be stated in the broadest terms. It intrudes both the Snake River Greywacke and the Sampa Beds and thus can be no older than late Cretaceous. Marine rocks, of probable Miocene age, unconformably overlie the intrusives in the Langimar River 20 miles to the west of the map area.

Several generations of porphyritic rocks can be found in the Wau/Bulolo/Edie Creek area. They were discussed in some detail by Fisher, who concluded that they could be divided into two groups. The early porphyries are noted for the intense silicification and pyritization they produce in the Kaindi Metamorphics, notably in the contact areas. This makes difficult the demarcation of boundaries between metamorphics and porphyry. The early porphyry is typically a well-crystallized quartz-biotite porphyry with large phenocrysts of quartz, plagioclase, biotite, and abundant hornblende, set in a crystalline matrix of feldspar, quartz, biotite, hornblende, and magnetite. In many places little secondary alteration is apparent. Fisher observes that this rock is very similar petrologically to both the Morobe Granodiorite and the later porphyries.

The later porphyries are believed to have been emplaced considerably later (Fisher, 1944). They produced little contact metamorphism: some silicification and pyritization can be observed, and the contacts with the metamorphics, which are often marked by gouge, can be readily seen except in areas of intense weathering. The composition of both porphyries is similar, but the later ones are not so well crystallized, nor is their groundmass as coarsely crystalline. These rocks have been considerably altered by hydrothermal action and deep tropical weathering. Fisher notes that they were intruded under different circumstances from the early porphyries, and postulates intrusion much closer to the surface.

The porphyries are not differentiated on Plate 6, but they are distinguished from the agglomerates which represent the next episode in the geological history of the area.

The intrusion of the later porphyries was either concurrent with or closely followed by explosive volcanic activity. Centres of vulcanism developed, and the ensuing agglomerate is widespread over the Bulolo and Watut Valleys and the Bulolo-Watut Divide. At Edie Creek, which Fisher (1944) considered a former centre of vulcanism, the agglomerate and its relationships to the Kaindi Metamorphics and volcanic breccia were well demonstrated in underground mine workings. The agglomerate is best exposed in the Bulolo gorge, downstream from Wau; the Bulolo River, to the north and downstream from Bulolo; Anamapi Creek, a tributary of the Bulolo; and road cuts on the Bulolo-Watut Divide. The agglomerate is hard and resistant to erosion: in most of the places mentioned, streams and rivers have cut gorges through the rocks, which stand as steep cliffs.

The agglomerate (here regarded separately from the volcanic breccia) is composed of dacitic material together with representatives of the underlying rocks. Fisher observed that the basement rocks vary from place to place and postulated several different sources of volcanic activity. His conclusions are affirmed by agglomerates which contain prominent granite, porphyry, and schist components, others which contain only schist and porphyry inclusions, and those composed only of older porphyry and dacite. Rare obsidian flows are associated with the agglomerates.

The early agglomerate blocked the drainage systems, and evidence of rounding and sorting of clasts can be seen at exposures in the Bulolo gorge and Anamapi Creek. It appears that a considerable portion of the later deposition of the agglomerate was subaerial. Suggestions of bedding can be found in some outcrops, but these are too few and nebulous to warrant the assignment of orientation to these generally massive agglomerates; nor can the thickness be estimated. Examples of the random orientation of the agglomerate can be seen in the lengthy section exposed in Anamapi Creek, or as it is sometimes called, Coldwater Creek. Here the agglomerate varies from well sorted to poorly sorted, and from massive to bedded. The few interbedded lenses of claystone are never more than five feet thick, and lens out rapidly.

The agglomerate is nonconformable on Kaindi Metamorphics, Morobe Granodiorite, or porphyry. It has not been dated, but from the ages obtained from the overlying beds is possibly older, but not younger, than early Pliocene.

Field relationships in mines at Edie Creek and Golden Ridges suggested to Fisher that the volcanic breccia was a later phase of the volcanic sequence that produced the agglomerate. He observed that in places where the breccia and agglomerate occurred together they graded imperceptibly one into the other. They do not always occur together and the breccia bodies are not numerous. The volcanic breccia has not been mapped as a unit in this report. It is composed almost entirely of angular fragments of schist and porphyry with little volcanic matrix.

Gravel, sand, clay and interbedded tuff were deposited in two shallow-water lakes or restricted floodplains as soon as explosive vulcanism ceased. They form the Otibanda Formation, which is described in detail later. The formation has been deformed and exhibits dips of as much as 45°. Interbedded tuff beds have proved suitable for potassium/argon dating. Fossil vertebrates and freshwater gastropods are found in the formation.

The lakes were drained by tilting, and a large quantity of detritus, eroded from the Kaindi Metamorphics to the south-west of Wau, was later deposited in the Wau Basin. Several alluvial fans merged at the foot of Mount Kaindi to form a piedmont deposit which unconformably overlies the Otibanda Formation.

The dying stages of vulcanism are represented near Wau by rhyolite flows and breccias, which overlie the piedmont deposits in a small area between Koranga and Namie Creeks. The last major depositional event was the deposition of large quantities of boulder and pebble gravel, cross-bedded arkosic sand, and arenaceous clay in the valley of the Bulolo River near Bulolo township and the formation of terraces and flats, of similar material, along the Watut and Bulolo Rivers. The present erosion cycle has dissected the terraces and flats, and good sections of gravels can be seen in the sluicing sites at Sunshine and Widubosh, where this unit is 80-100 feet thick. At both localities a ferruginous cemented conglomerate marks the erosion surface on which the gravels were deposited. It is never more than 6 inches thick and probably represents a fossil gravelly soil. Drilling reports indicate that in some portions of the Bulolo Valley the gravels attain a thickness of 300 feet. These gravels and sands were derived during accelerated erosion from the country rock with some reworking of the Otibanda sediments. The gravels and sands are flatlying. Some evidence of uplift can be observed in the terraces being worked at Niba Gold and Widubosh. There the gravels dip very gently towards the Watut River, away from the Sunshine Fault, on which movement has evidently continued until quite recently. This unit has produced carbonaceous imprints of fossil leaves, fossil wood, and a fossil crocodile, but no fossil mammals. The gravels are probably late Pleistocene.

OTIBANDA FORMATION

The Otibanda 'Series' was named by Fisher (1944). Postwar workers, recognizing the new stratigraphic code, changed the name, in informal publications, to 'Otibanda Lake Beds.' It is here changed again to the formal name Otibanda Formation; the name is derived, as was Fisher's Otibanda Series, from the Otibanda Patrol Post, Upper Watut River, Morobe District, New Guinea. The Patrol Post no longer exists, but its position is known to have been 7°15′40″ South, 146°31′00″ East, in the Nauti 1-Mile Map Area.

A section of almost continuously exposed conglomerate, sandstone, claystone, and tuff beds, which may be seen in landslides and in the alluvial mine workings known as 'Sunshine' in the northern portion of the Watut Basin, has been selected as the type. Rocks are exposed on the northern and southern banks of the river, but the exposures are not continuous. Fossil vertebrates have been found in the sandstone and claystone units of this section and a tuff has provided a potassium/argon date.

The type section is shown on Figure 3. The exact stratigraphic thickness of the formation is not known. The type section is measured from the Sunshine Fault to the southernmost outcrops in the abandoned alluvial workings at Sunshine. It is 1605 feet thick and the top of the sequence was not seen, as it is covered by alluvium and vegetation. Another composite section in Koranga Creek (Fig. 4) contains the lowest Otibanda beds, which were deposited disconformably on massive agglomerate and tuff. There, too, the top of the formation was obscured.

The Otibanda Formation rests disconformably on agglomerate in many localities. When agglomerate is not present, the Otibanda Formation lies nonconformably

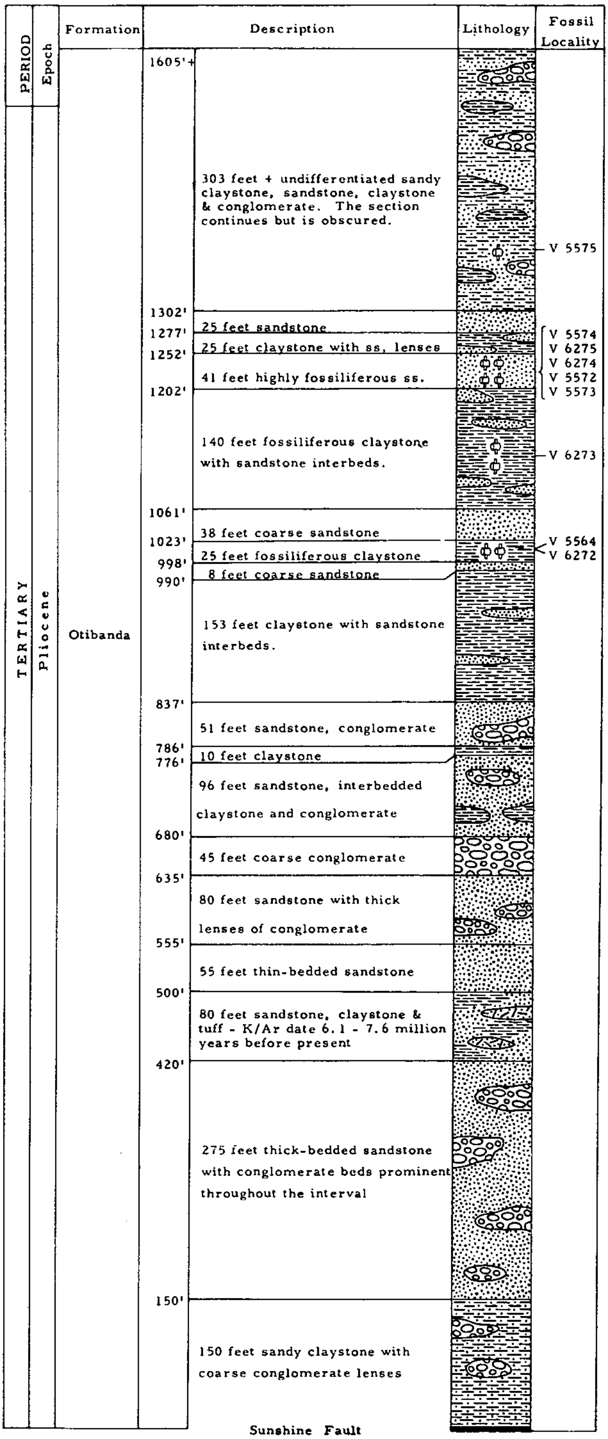


Figure 3. Type Section, Otibanda Formation.

on the Kaindi Metamorphics or Morobe Granodiorite. In many places the formation is overlain, with angular unconformity, by Quaternary gravels.

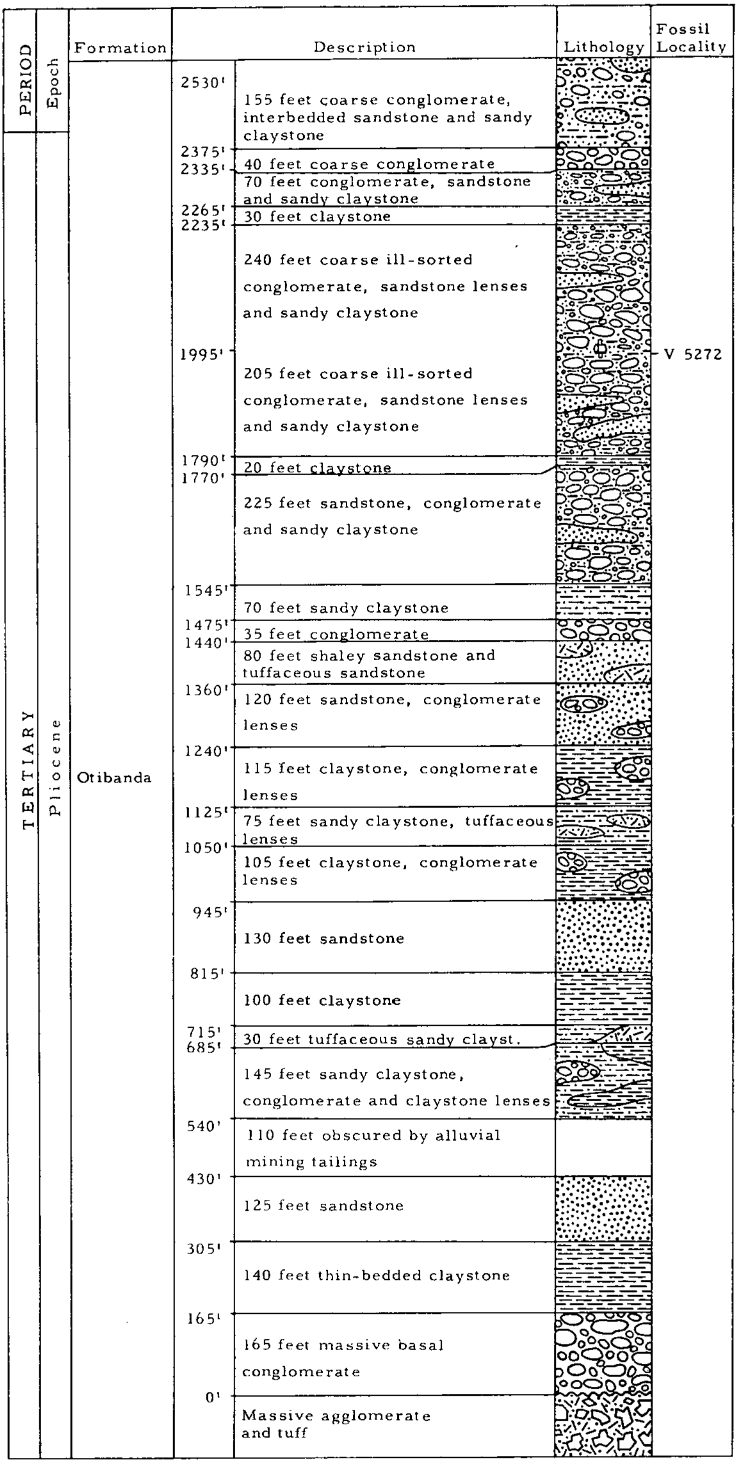
Pyroclastic tuff is interbedded with the sandstone and claystone at several localities, three of which have provided samples suitable for potassium/argon dating. The dates range from 5.7 to 7.6 million years before present, indicating a Pliocene age.

Rocks of the Otibanda Formation crop out in portions of the Wau, Bulowat, and Nauti 1:63,360 planimetric series map areas. The rocks were deposited in two areas. The larger parallels the course of the present Watut River, and is bounded, for the most part, to the west by the Sunshine Fault and to the east by a depositional contact with the Morobe Granodiorite and the late Tertiary agglomerate. The smaller area, of almost elliptical shape, occupies the lower portion of the present Wau Valley. It is bounded by nonconformable contact with Kaindi Metamorphics, Morobe Granodiorite, and Tertiary porphyries, but its contact with the agglomerate is disconformable. In both areas outcrops are confined to river courses, streams, road cuts, landslides, and areas where alluvial gold mining has stripped the overlying Quaternary gravels. The Otibanda Formation sediments are deeply dissected by rivers and streams which form a complex high-density drainage pattern.

The formation is composed of a great variety of lithological types, most of which are semiconsolidated. The beds are competent, as even after considerable uplift (with dips up to 45°), no failure, internal faulting, or secondary deformation was observed. Fisher (1944) described the 'Series' as being composed of shale, mudstone, sandstone, and conglomerate with intercalated tuff and fine agglomerate. Dow (1961) writes of unconsolidated sandstone and mudstone with quartz conglomerate, and angular boulders of siliceous sinter. Woods (1962) differentiates between the smaller area near Wau which contains sandstone, siltstone, and mudstone with interbedded tuff and agglomerate, and the larger depositional area which contains andesitic volcanic material, possibly subaerially deposited. This, in general, is correct, though not all the rocks of the formation are unconsolidated.

The predominant colours seen in the rocks of the formation are blue-grey and buff to brown. These reflect the nature of the source rocks. Kaindi Metamorphics produce predominantly blue debris and Morobe Granodiorite and Tertiary porphyry brown. Thick sections of strata, as seen in exposures in the upper Watut Valley, are predominantly blue or brown, but in many other exposures repetitive colour lamination has been observed. The blue rocks are generally finer-grained, better-sorted, and more compact, and the brown are coarser-grained, poorly sorted, and less consolidated. Red beds are rare; only one was noted in the type section at Sunshine. Rare purple beds have also been observed, and white beds, usually of pyroclastic material, are more numerous.

Conglomerate varies greatly from place to place. Those in the type section at Sunshine can be contrasted with the basal conglomerate in the Koranga section. In the type section, brown coarse poorly sorted loosely consolidated conglomerate



PERIOD	Epoch	Formation		Description	Lithology	Fossil Locality
TERTIARY	Pliocene	Otibanda	2530'	155 feet coarse conglomerate, interbedded sandstone and sandy claystone		
			2375'	40 feet coarse conglomerate		
			2335'	70 feet conglomerate, sandstone and sandy claystone		
			2265'	30 feet claystone		
			2235'	240 feet coarse ill-sorted conglomerate, sandstone lenses and sandy claystone		
			1995'	205 feet coarse ill-sorted conglomerate, sandstone lenses and sandy claystone		V 5272
			1790'	20 feet claystone		
			1770'	225 feet sandstone, conglomerate and sandy claystone		
			1545'	70 feet sandy claystone		
			1475'	35 feet conglomerate		
			1440'	80 feet shaley sandstone and tuffaceous sandstone		
			1360'	120 feet sandstone, conglomerate lenses		
			1240'	115 feet claystone, conglomerate lenses		
			1125'	75 feet sandy claystone, tuffaceous lenses		
			1050'	105 feet claystone, conglomerate lenses		
			945'	130 feet sandstone		
			815'	100 feet claystone		
			715'	30 feet tuffaceous sandy clayst.		
			685'	145 feet sandy claystone, conglomerate and claystone lenses		
			540'	110 feet obscured by alluvial mining tailings		
			430'	125 feet sandstone		
			305'	140 feet thin-bedded claystone		
			165'	165 feet massive basal conglomerate		
			0'	Massive agglomerate and tuff		

Figure 4. Koranga Composite Section.

with rounded clasts up to cobble size predominates. Granodiorite pebbles and cobbles are more numerous and larger than the better-rounded schist pebbles. The matrix is a coarse, poorly sorted arkosic sand. At Koranga the basal conglomerate is blue, thick, poorly sorted, limonite stained, and well compacted. The cobbles and pebbles are a little larger than those found at Sunshine, but the Kaindi Metamorphics were the principal source and granodiorite components are rare. Conglomerate is found throughout the section at Koranga (Fig. 4), but becomes coarser and more prevalent in the upper half of the section. These coarse rocks are brown, poorly sorted, massive, and fairly well consolidated. The predominantly brown colour is not primary, but is a product of oxidation of iron minerals in the blue schist clasts and in the matrix. The matrix varies from coarse sand to a gritty clay. Many of the larger clasts (up to 10 inches in the longest dimension) are angular. These conglomerates, with interbedded cross-laminated sandstone lenses, are the product of rapid deposition. A further example of basal conglomerate from the Wau basin can be seen in Sandy Creek, where it is again a thick, poorly sorted, but well-consolidated rock, with granodiorite and schist components in approximately equal amounts. A conglomerate bed is conspicuous to the north of Slate Creek near the granodiorite boss (Pl. 6). It is 40-50 feet thick, includes large well-rounded boulders up to 18 inches long, and is composed of both granodiorite and schist detritus. This well-indurated and ironstained example includes several small lenses of cross-bedded arkosic sandstone.

The general term sandstone has been applied to all the coarse arenites. Field examination has shown that many are derived directly from the granitic source areas, and are arkoses. Others appear to have been derived from volcanic detritus, while still others are darker and evidently contain much material derived from the Kaindi Metamorphics. In order to understand somewhat better the provenance and environment of deposition of these sediments, samples were collected from sixteen localities for microscopic examination. The technique used to collect and prepare the specimens follows the method set out in Tourtelot (1961). Thin sections were made and one rock from the type section was examined using a whole-rock x-ray diffractograph pattern.

Examination of the thin sections and the diffractogram indicates that most of the sandstones are immature wackes. Lithic wacke predominates, but some of the sandstones contain no lithic fragments. Mineralogically the rocks are composed of lithic fragments, angular to subangular quartz, subangular feldspars of the plagioclase group, biotite, the alteration products chlorite and illite, green and brown pleochroic hornblende, and opaque iron minerals. The minerals and lithic fragments are set in a matrix of fine clay, the mineralogical content of which is not determinable by normal petrographic means. The diffractograph indicates a matrix composed of micas and of clay minerals of the montmorillonite group. The red bed in the type section contains more decomposing biotite mica than any of the other sandstones, and I attribute its unique colour to this decomposition. Many of the sandstones are superficially weathered. However, petrographic examination indicates that if one samples 12 to 15 inches below the surface the rocks are remarkably fresh.

The one lithological feature which is persistent throughout the arkosic wackes is cross-bedding. This can be seen in Plate 3/1, a lens of arkosic wacke in a medium to fine-grained blue lithic wacke.

Various terms have been applied to the argillaceous rocks of the formation. They all fall into the categories mudstone, claystone, or shale, as used by Gilbert (1954). Gilbert describes mudstone as a consolidated argillaceous rock, claystone as a consolidated argillaceous rock of rather uniform fine grain and distinct plasticity, and shale as an argillaceous rock that breaks in a distinctly platy fashion, parallel to the bedding.

Like the other sediments of the formation the argillaceous rocks range in colour from dark blue to brown and buff. Seven samples were collected in the way described above and thin sections were made. These sections did not prove helpful in determining the mineral content and only one whole-rock x-ray diffractogram, made on the claystone from the Awe faunal type locality, proved useful in this respect. This blue-grey thickly bedded claystone of very even grainsize is well compacted, hard and brittle. The blue-grey of fresh exposures weathers to a pale grey and the rock is very hygroscopic. Mineralogically it is composed of quartz, feldspar, kaolinite, montmorillonite, illite, and sericite. Some of the claystones are thickly bedded, but laminated rocks are common and many of these can be classified as shale.

Other rock types found within the formation are limestone, siliceous sinter, and tuff. Two types of limestone occur. The first is the argillaceous limestone known from only one locality in the Watut Valley. It is pale buff, hard, brittle, and full of small gastropods and traces of possible plant material. An x-ray diffractogram of the argillaceous fraction of this rock indicates the presence of quartz, feldspars, and a broad pattern of clay minerals probably belonging to the montmorillonite group. The other limestone, again known from only one locality, in the type section, is an inch-thick white crystalline rock with no traces of organic material. This rock proved, on chemical analysis, to have the following composition:

0.67%	Fe
58.26%	Ca as $CaCO_3$
2.40%	Mg as $MgCO_3$
30.90%	Insolubles
Trace (—0.10%)	P_2O_5

Titration and filtering of the insolubles after they had been digested in 2N HCl gave no SO_4^{--} and Cl^-. This would seem to indicate a particularly pure source of calcium which probably acted as a trap for small amounts of bone phosphate, derived from the mammal bones incorporated in the deposit.

The siliceous sinter is a fossiliferous brown to red hard obsidian-like rock. The fossils are small freshwater gastropods and leaf and plant impressions.

Tuff beds are found throughout the formation. Microscopically they are seen to be composed of some angular quartz, abundant subangular plagioclase, much of which is zoned, brown laths of hornblende, biotite, and iron minerals. These minerals are set in a matrix of very fine volcanic material.

The total stratigraphic thickness of the formation is not known. The type section at 'Sunshine' contains 1605 feet of sediments, but neither the bottom nor the top of the section is observable.

At Koranga the bottom of the 2530-foot section is preserved, but the top is again obscured by lack of exposures. Both sections are composite, but continuity was ensured by lateral tracing of beds. In neither section was there any evidence that faulting had caused false thickening by duplication of beds. Local reversals, probably due to faulting, were observed at some localities. The generally southerly dips indicate a considerable thickness of sediments.

The rocks of the Otibanda Formation were derived from the surrounding Kaindi Metamorphics, Morobe Granodiorite, Tertiary porphyries, agglomerate, and volcanic detritus. The environment in which they were deposited has always been assumed to be a lake, initiated by the damming up of the drainage by late Tertiary agglomerate. In part this interpretation is still tenable; but many of the sediments in this formation are fluviatile rather than lacustrine in origin.

Evidence which may be cited in support of the lacustrine origin of some of the rocks is: uniform thick beds with laterally persistent stratification, and laminated claystone. Fossil gastropods, dealt with in more detail in the faunal section, also seem to indicate permanent water. Evidence for the floodplain environment is documented by cut-and-fill stratification, stream channels (Pl. 5/1), lenticular cross-bedding in the coarse sands, poorly sorted conglomerate and sandstone, and directionally oriented pebbles in sandstone. The lamination cited as evidence for lacustrine deposition may alternatively be used as evidence of floodplain slackwater deposition. Weller (1960) points out that river alluvium may grade imperceptibly into lake sediment, and this appears to have happened in different marginal areas and at many times during the deposition of the Otibanda sediments.

Examination of thin sections of sandstones indicates that many easily destructable minerals have survived and the sand grains are not greatly abraded. Deposition evidently took place rapidly in a tectonically active environment, as sorting is poor and clay and sand are often deposited together. It is known that volcanoes were active and, as this was probably an area of non-deposition from late Cretaceous or early Tertiary time, relief was moderate to high. Such an environment would have fostered rapid deposition, and the lack of decomposition in the sandstone components reflects rapid stripping of the debris from the source areas. Transport was swift and the sediments were carried only a short distance to be dumped into a subsiding basin in which they probably accumulated relatively quickly. The combination of diastrophism and rapid sedimentation has caused detrital sedimentation to preponderate over chemical and organic accumulation. The two limestone beds observed are both thin and insignificant when compared to the total thickness of the section. The limestone from the type section bears out the thesis of freshwater deposition, and the lack of sulphates and chlorides may indicate water in which intake exceeded evaporation — though it may also reflect later leaching.

The absence of red-beds, despite the environment, may be explained by the drainage pattern. The pattern was developed, probably, in the early Tertiary; and by the time that drainage was dammed and deposition of the Otibanda Formation began, erosion had cut through the deep soil profile and was attacking fresh bedrock. Therefore no red-beds were deposited; only if a stream were deflected after the drainage was dammed, and once more had to cut down through deep red soils, would red-beds be laid down. Krynine (1936) established the principle on which this explanation is based.

Diastrophism continued after deposition ceased, and uplift probably was centred in the area to the north and west of the formation's present boundaries. The Sunshine Fault described by Dow (1961) possibly represents final fracture along a line of previous diastrophic activity. Dow noted that the Otibanda Formation is downfaulted against Cretaceous rocks near the Sunshine alluvial gold workings. He also observed the small remnant of Otibanda Formation on the upthrown side of the fault and estimated a vertical throw on the Sunshine Fault of 550 to 600 feet.

The earliest age assignment formerly given to the Otibanda Formation was Pleistocene. Fisher is quoted by Anderson (1937) as being of the opinion that the beds are Pleistocene. However, Anderson cautions that *Nototherium watutense* might be slightly older than its Australian Pleistocene congeners. Subsequent workers have all regarded the formation as Pleistocene. In 1962 Stirton located pyroclastic material associated with fossil mammals. The first date, from an incompletely fused sample, gave a minimum date of 4.5 million years (Stirton, 1963). Later two more samples from the type section were processed and gave dates of 7.6 and 6.1 million years (Evernden et al., 1964). At present no explanation can be given for this discrepancy. A sample from another locality yielded an age of 5.7 million years (G. Curtis, pers. comm.). This date, KA 1653, is associated with the Awe Fauna type locality; it was taken from a tuff bed 60 to 70 feet stratigraphically above the main fossil quarry. The age of the formation therefore is middle Pliocene. No lithological correlation is possible with other formations in New Guinea or on the Australian continent. A discussion of the faunal correlation will be deferred to the following section.

FAUNA

Depositories of specimens are abbreviated as:

AMNH : American Museum of Natural History, New York;
AM : Australian Museum, Sydney;
CPC : Commonwealth Palaeontological Collection, Bureau of Mineral Resources, Canberra;
GSQ : Geological Survey of Queensland, Brisbane;
MVZ : University of California, Museum of Vertebrate Zoology, Berkeley;
QM : Queensland Museum, Brisbane;
UCMP : University of California, Museum of Paleontology, Berkeley.

All localities, including those found in the years preceding 1955, have been given University of California Museum of Paleontology locality numbers, such as UCMP V6234 (Fig. 15).

All measurements, unless otherwise stated, are in millimetres, and all illustrations, unless otherwise stated, are natural size.

Faunal terminology. — It has become standard practice for vertebrate palaeontologists, particularly those who work with fossil mammals, to regard their fossil assemblages as biological entities and to refer to them as local faunas or simply as faunas. The use of the term fauna has proved confusing to some zoologists, for they have assumed that the concept of fauna implies a representation of all the animals living in a given area at a given time. No such implication is intended; and it is highly unlikely that all the animals which were living in one place at one time would be preserved, even by a catastrophic event. The fossils which are available to us represent only a sample, and probably a very small sample, of the past inhabitants of an area.

A collection of fossils from one quarry may possibly represent animals living in an area at one time; but they may simply represent an accumulation of bones and teeth brought together by physical forces during the deposition of the sediments in which they are entombed. Assemblages of fossils from several localities are usually considered as representatives of one fauna if they have genera and species in common.

I have recognized one fauna from the valleys of the Watut and Bulolo Rivers and have designated a type locality in accordance with the practice adopted by Stirton et al. (1961) for their sequence of faunas in the Lake Eyre Basin. The vertebrate fauna from the known localities in the Otibanda formation is herein designated the Awe [1] fauna. In order to prevent confusion in the event of the future discovery of animals which inhabited environments hitherto unsampled, a faunal name which differs from that of the formation in which the fossils

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[1] Awe (ah-we) is the name used by most indigenous people for the Watut River. The linguistic origin of the word is not known to me.

occur was chosen. The type locality is on the west bank of the Watut River, Upper Watut Valley, New Guinea (UCMP locality V6234). From this small quarry (Pl. 5/2) came abundant teeth and more limited postcranial elements of marsupials. The quarry also produced the oldest known eutherian fossil from the Australasian Region.

The descriptions and fossil list which follow are a composite from all the known localities. Only *Nototherium watutense* (Anderson), 1937, *Kolopsis rotundus* Plane, 1967, and *Kolopsoides cultridens* Plane, 1967, have previously been described. Information about the Gastropoda, Ophidia, Crocodilia, and Aves has generously been made available to me in the form of personal communications by James R. Firby, Max Hecht, Wann Langston Jr, and the late Alden H. Miller.

Class GASTROPODA
Order Basommatophora
Family Lymnaeidae
Lymnaea sp.

Order Stylomatophora
Family Camaenidae
? Planispira sp.

Order Caenogastropoda
Family Bulimidae
Gabbia sp.

Family Fissoidae
Hemistomia sp.

The gastropoda, all from locality UCMP V6276 and from specimen D-516, are a freshwater assemblage recording abundant vegetation. *Planispira* is a land snail, which lives under leaf mould at the margins of standing water.

Phylum CHORDATA
Class REPTILIA
Order SQUAMATA
Family BOIDAE

AMNH — Locality UCMP V6269

Snake vertebrae from the Awe fauna have been assigned to this family. The family is represented in the living fauna of the area today.

Order CROCODILIA

UCMP 70134, 70135, 70136 — Locality UCMP V6269, V6234

Crocodile teeth are abundant at many of the localities. Limb bones have also been found. Most of them are nondescript and can probably be referred to the genus *Crocodilus,* which lives in New Guinea today. A very distinctive set of fossil teeth from V6269 has laterally compressed crowns with curious regular serrations on the anterior and the posterior cutting edges. These animals can probably be referred to the suborder Sebecosuchia and represent the latest Tertiary fossils known in this suborder. Their occurrence in New Guinea lends support to the idea (Langston, 1956) that the Sebecosuchia may have been cosmopolitan crocodilians.

Class AVES
Order CASUARIIFORMES
Family CASUARIIDAE
CASUARIUS sp.

UCMP 70129, 70130 Locality UCMP V6234

Bird bones are not abundant in the Awe fauna. Some phalanges from the type locality have been assigned to the living genus *Casuarius* Brisson, 1760. The elements represented are the distal end of the left first phalanx of digit II and, articulating with it, all of the second phalanx. Also found was the right second phalanx of digit II from a somewhat larger or more robust individual.

These bones come closest to the living *C. bennetti* Gould, 1857, but the fossils do not correspond precisely enough to warrant their being assigned to that species. The second phalanx of digit II is longer than its equivalent in *C. bennetti,* but is much smaller than those bones in the large Recent species *C. casuarius* (Linnaeus, 1758) or *C. unappendiculatus* Blyth, 1860. Nor does it match the configuration of the phalanx from a young *C. casuarius* which is the same size as the fossils.

The fossil, then, suggests the modern small cassowary type, rather than the large form. The only known fossil cassowary previously reported is the Pleistocene *C. lydekkeri* Rothschild, 1911 (Miller, 1962), also a representative of the small slender group.

Class MAMMALIA
Subclass THERIA
Infraclass METATHERIA
Order MARSUPIALIA
Superfamily DASYUROIDEA
Family DASYURIDAE

Apart from some scraps which are tentatively identified as dasyurid, only one mandible with M_1 can be put in this family with certainty.

The anterior portion of a right mandible UCMP 63640 with the M_1 in place was found at locality V6364. The mandible is broken directly behind M_1. Anterior to M_1 the alveoli of P_3, P_2, and P_1 are preserved. The anterior root of P_1 is in its alveolus and P_3 is single-rooted. The large canine alveolus is prominent.

A large mental foramen lies directly below M_1 on the labial side of the mandible. Anterior to it and below the anterior and posterior alveoli of P_2

are a pair of small mental foramina. On the lingual side of the jaw there is a large foramen in the symphyseal region. The trigonid of M_1 is composed of a high central protoconid, the tip of which is broken; a very reduced paraconid low on the anterior edge of the tooth; and a low, but well-developed, metaconid which protrudes lingually. The talonid is composed of a hypoconid, hypoconulid, and entoconid. The entoconid and hypoconulid have low broad bases and are bluntly cuspate. The hypoconulid lies directly posterior to the entoconid on the extreme lingual side of the tooth. Labial to the hypoconulid is a posterior cingulum which descends ventroposteriorly to form a wide shelf. This shelf forms the posterolabial corner of the tooth.

The fossil has been compared to specimens of *Antechinus flavipes* (Waterhouse, 1838) and *Parantechinus apicalis* (Gray, 1842). A series of 35 *Antechinus* from the University of California Museum of Vertebrate Zoology has also been examined. Species included in the series are *A. flavipes, A. maculatus* Gould, 1851, *A. minimus* (Geoffroy, 1803), *A. swainsoni* (Waterhouse, 1840), and *A. bellus* (Thomas, 1904). In all but one of the specimens examined the third lower premolars had two roots. The exception was the one specimen of *A. maculatus* from the Northern Territory, which had an extremely reduced P_3 with only one root. In *A. minimus* from Tasmania on the other hand the P_3 is extremely reduced but still retains two roots.

Comparison. The paraconid in the fossil is much more reduced than the paraconid in *A. flavipes* but is of the same order as the reduction in *P. apicalis.* The protoconid in the fossil is high and central like that in *P. apicalis.* In contrast the protoconid in *A. flavipes* is more slender and more labial in position. The metaconid in the fossil is relatively larger than in either of the compared species and differs from them in its lingual projection. The hypoconid, hypoconulid, and entoconid in the fossil are much lower and broader based than in *A. flavipes.* The entoconid and hypoconid are better developed and more distinct than they are in *P. apicalis.* Neither *A. flavipes* nor *P. apicalis* has the broad posterior cingulum seen in the fossil.

I would suggest that the fossil belongs in the *Antechinus-Parantechinus* complex: it is closer to *Parantechinus* than it is to *Antechinus.*

Superfamily PHALANGEROIDEA
Family MACROPODIDAE

The remains of macropodids are widely distributed in the Otibanda Formation. Both poorly preserved fragments and complete well-preserved fossils are found. Most of the recognizable specimens are referable to the genus *Protemnodon* [1] Owen (1873), but none of these macropodids have been previously named. Two new species of *Protemnodon* are proposed; one is distinctly larger than the other and also differs in other respects. A third, meagrely represented, macropodid,

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[1] *Protemnodon* Owen (1873) is not congeneric with *Wallabia* Trouessart (1905) as proposed by Raven (1929) and adopted by Tate & Archbold (1937), Simpson (1945), Raven & Gregory (1946), and Tate (1948). See Stirton (1963).

is a small animal with similarities to the living genera *Dorcopsis* and *Dendrolagus*. It may be near to the ancestry of some of the living macropodids in the *Dendrolagus-Dorcopsis* complex.

It is usually difficult to associate teeth and jaws with other parts of the skeleton because of the manner in which the elements become disassociated and scattered before they are buried. Some bones and dentitions, however, are clearly associated as parts of an individual animal.

Any description or reference to middle Pliocene macropodids from New Guinea necessitates knowledge of the Pleistocene genera and species of Australia. Most of these were described by Sir Richard Owen of the British Museum (Natural History) and recently reviewed by Stirton (1963).

The ancestry of the group of macropodids usually referred to as wallabies is very poorly known. The living species, which have been referred to the genus *Wallabia* by various authors, are diverse in the morphology of the premolars and in chromosome number Sharman (1961). Ride (1957), however, grouped them together on the construction of the I^3. The larger and better-known species of *Protemnodon* from the Otibanda Formation shares some characters in the incisors with living wallabies rather than with the known Pleistocene protemnodons. This may be convergent evolution or may possibly reflect primitive heritage characters retained by the Pliocene protemnodons (but not the late Pleistocene forms) and some living wallabies. It is to be hoped that evidence from the late Tertiary fossils will help in the clarification of the ancestry of both the wallabies and the protemnodons.

Stirton's (1955) dental nomenclature, which retains Owen's term link, has been followed and the cusp nomenclature applied to the molar teeth is that usually employed (Stirton, 1955; Woods, 1960; and Ride, 1961). All measurements have been made in accordance with the diagrams in Figure 5. I have followed Stirton's system for serial designation of the cheek teeth for the reasons so clearly set out in Tedford (1966). For more detail the reader is referred to that paper. I have also followed Tedford's (1966) scheme for designating wear on premolar and molar teeth:

'*Tooth wear* — The serial eruption of the molar teeth in the Macropodidae makes a satisfactory statement of the average state of wear of the tooth row in older juvenile and adult animals impossible. Rather than present an entirely subjective evaluation of the total state of wear of the dentition it was found advantageous in this study to categorize successive wear stages of the individual teeth according to the pattern indicated by the specimens at hand. A more complex scheme is theoretically possible, but several of the wear stages apparently follow one another quickly, and for this reason are not demonstrated by the specimens at hand. The following scheme is thus a simplification found adequate and practical to use with the molar dentition (including DP3):

Unworn (U) — Lophs and lophids unworn, tooth unerupted or rising into occlusion

Beginning wear (B) — Protoloph(id) worn, but enamel not breached enough to expose dentine.

Early wear (E) — Protoloph(id) worn, enamel breached; metaloph and hypolophid worn, but enamel not breached.

Medial wear (M) — Protoloph(id), metaloph and hypolophid worn, enamel breached; forelink breached (when present may not be breached if weak), midlink worn (when present), but enamel not breached.

Late wear (L) — Lophs, lophids and links breached, anterior cingulum remaining in toto or in part.

Very late wear (L+) — Anterior cingulum worn away.

Four wear stages could easily be distinguished in the premolars (P2 and P3) of the Sthenurinae. To avoid confusion of the premolar and molar symbols Roman numerals are used for the former.

Unworn (I) — Tooth unerupted or rising into occlusion.

Beginning wear (II) — Enamel worn, but not breached, exposing dentine.

Medial wear (III) — Enamel crown breached, but longitudinal basin persists, and less than half estimated known height worn away.

Late wear (IV) — Longitudinal basin broken up into isolated enamel lakes or completely worn away.' (Tedford, 1966, p. 4-5).

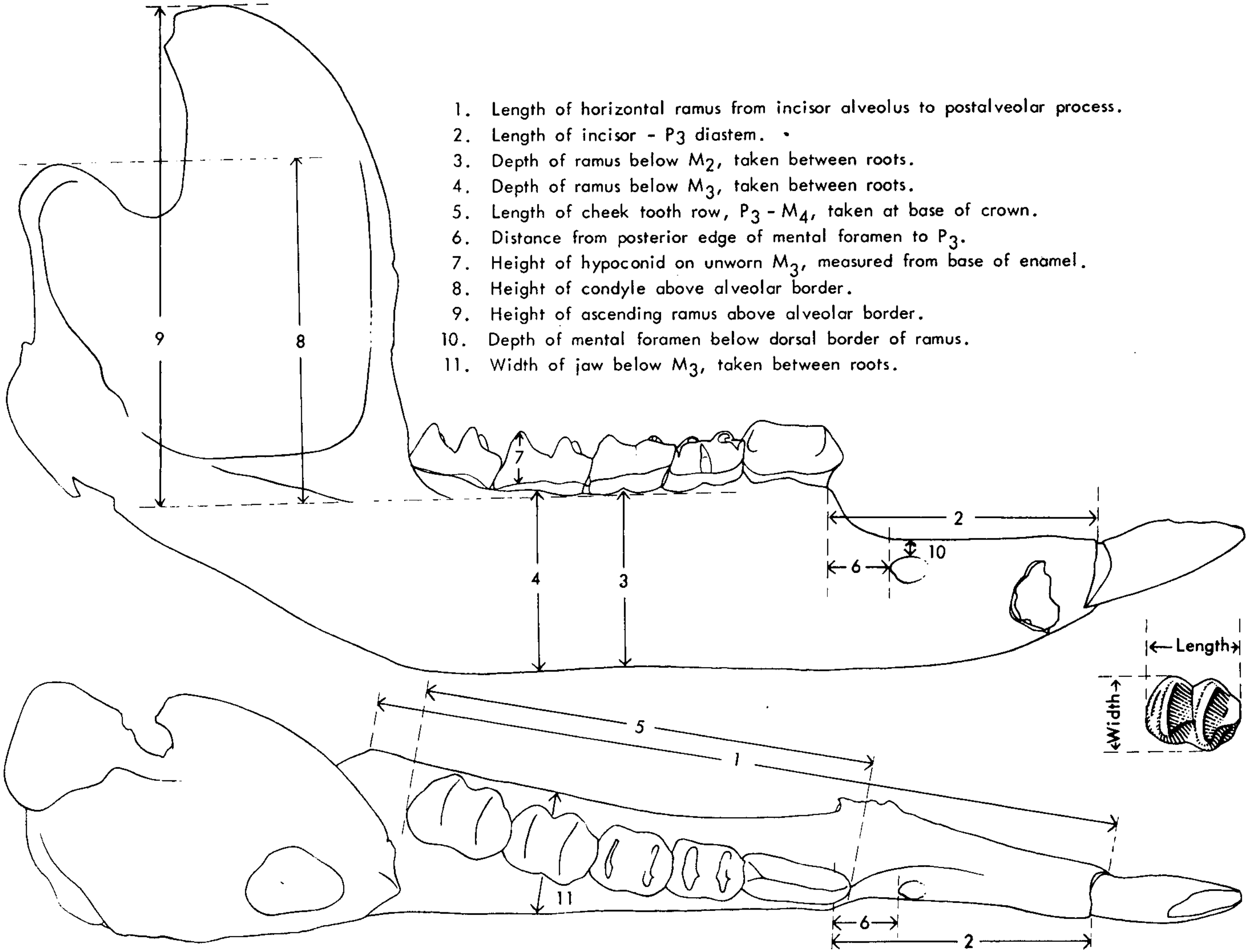
Subfamily MACROPODINAE
PROTEMNODON OTIBANDUS sp. nov.

Holotype. CPC 6771. Right mandible of mature individual complete with I_1, P_3, and M_{1-4}. The ascending ramus is complete but the dorsolingual edge of the inflected angle is broken, as is part of the floor of the pterygoid fossa. The wear formula is II.MMBB.

Paratypes (all UCMP specimens). Premaxilla fragment with I^{1-3} in place: 69832.
I^1: 69790, 69791, 69792, 69793, 69794, 69795, 69796, 69797, 69798, 69799, 69800, 69877, 69859.
I^2: 63631, 69803, 69804, 69806, 69825, 69826.
I^3: 69827, 69828, 69829, 69830, 69831.

Maxilla fragments: 69851, 69852, 69853, 69854, 69857.

P^2: 69833.
P^3: 69834, 69835, 69836, 69837, 69838, 69839, 69863, 69864.
M^1: 69840, 69841, 69842, 69851, 69857.
M^2: 69852, 69851, 69853, 69854, 69857.
M^3: 69851, 69853, 69854, 69857, 69843, 69844.
M^4: 69847, 69848, 69849, 69853, 69854.
I_1: 69860, 69871, 69872, 69873, 69874, 69875, 69876, 69877, 69878.
P_3: 69863, 69864, 69861, 69879, 69895, 69981, 69991.
M_1: 69865, 69895, 69896, 69897, 69899, 69981, 69987, 69991.
M_2: 69895, 69896, 69897, 69900, 69981, 69986, 69987, 69991.



1. Length of horizontal ramus from incisor alveolus to postalveolar process.
2. Length of incisor - P$_3$ diastem.
3. Depth of ramus below M$_2$, taken between roots.
4. Depth of ramus below M$_3$, taken between roots.
5. Length of cheek tooth row, P$_3$ - M$_4$, taken at base of crown.
6. Distance from posterior edge of mental foramen to P$_3$.
7. Height of hypoconid on unworn M$_3$, measured from base of enamel.
8. Height of condyle above alveolar border.
9. Height of ascending ramus above alveolar border.
10. Depth of mental foramen below dorsal border of ramus.
11. Width of jaw below M$_3$, taken between roots.

Figure 5. Standard measurements on macropod mandibles.

M_3: 69870, 69895, 69896, 69897, 69899, 69900, 69981, 69986, 69987, 69991.

M_4: 69895, 69896, 69897, 69898, 69900, 69987.

Referred Specimens. AM F36557: left mandible with M_3 moderately worn. AM F37681: right P^3 well worn. UCMP 45246: immature individual with parts of cranium including both maxillae with P^2, P^3, DP^3, and M^1; upper incisors I^{1-3} of both sides (only part of the enamel surface preserved in third incisors); both mandibles with incisors and P_2, P_3, DP_3, M_1 and M_2 (DP_3 and M_1 missing in right mandible), part of coronoid, temporal crest, and condyle of right mandible missing. UCMP 45244: old individual with teeth nearly worn away. Part of crushed cranium with roots and bases of crowns of right I^1 and I^3 parts of alveoli of left incisors; premaxilla palate anterior to incisive foramina and between incisor alveolar borders; cranium from anterior and of P^3 to posterior border of orbit severely crushed and distorted; right P^3 well worn but complete; right M^{1-3} heavily worn showing some enamel outline; left tooth row essentially destroyed and useless for description and comparisons; distal end of right tibia, proximal end of left fibula, distal end of left fibula with epiphysis missing.

Type locality. UCMP V6234, west bank of Upper Watut River.

Age. Middle Pliocene (5.7 m.y. before present).

Specific diagnosis. Upper incisors less U-shaped in outline than in known Pleistocene species, occlusal surface not horizontal; I^1 has marked ventromedian point on occlusal surface in worn teeth; occlusal pattern on I^2 unlike Pleistocene species, more like wallabies having posterolabial groove opening on to posterior rim of tooth; labial notch on I^3 in middle of crown. Upper premolars P^2 and P^3 have sharp vertical crests on anterior ridge; posterior basin on P^3 ovate (3 x 3). Deciduous premolar DP^3 with anterior cingulum not protruding anteriorly in shelflike manner; forelink well developed; protocone and paracone separated by deep, wide cleft across protoloph; deep narrow anteromedian basin behind anterior cingulum; spurs ascending from paracone and metacone nearly close labial mouth of transverse valley.

Upper molars with anterior cingulum less protuberant than specimens referred to *P. anak;* midlink lower than in any known species; crowns lower than in any known species.

Mandible shorter, not as deep and narrower than in *P. anak,* the smallest known Pleistocene species; tooth row also shorter. Lower incisor smaller than in known species. Lower molars wider, in proportion to length, than in known species; anterior cingulum relatively wider transversely; crowns lower; labial side of transverse valley more steeply declined than in other species. Distinct cuspid at labial end of transverse valley on M_1.

Description and Comparison

P. otibandus is smaller than the smallest species of *Protemnodon, P. anak,* described by Owen from the Darling Downs and Wellington Caves of Australia, but it is larger than the other species from the Otibanda Formation.

Cranium. In the old individual, UCMP 45244, the palatal parts of the palatine bones have been partly crushed, but the transverse palatine ridge below the posterior narial opening appears to have been opposite M_2. The bone fragments in that area appear to be other parts of the cranium that have been crushed down. The dorsoventrally rounded inner surface of the maxillary opposite M^3, and in part M^2, is well preserved and in place. There the palatal surface is approximately 7.0 wide. If this is the contact surface of the squamous maxillopalatine suture, as it appears to be, the palatine extended anteriorly at least to a point opposite the posterior half of M^2. Enough of the palate is preserved anteriorly to show that palatine vacuities did not extend across the suture into the maxillary part of the palate. Palatine vacuities may, or may not, have been present in the palatines behind the suture.

An infralacrimal foramen is located on the facial surface in front of the crushed orbital rim, and the surface above is too badly broken and displaced to locate and determine the nature of the lacrimal tuberosities or the supralacrimal foramen. The lower orbital rim is rounded and 4.6 wide, and the facial crest across the jugal is 4.3 below the lowest point of the orbital rim. The width of the premaxillary palate between the alveoli of I^3 appears to be not more than 23.0 and the anterior end of the incisive foramen is, at least, 12.5 posterior to I^3. There is a groove, on both 45244 and 69832, where a little more bone is preserved; it runs forward from near the anterior end of the incisive foramen on the labial side of the premaxillary. In 45244 the posterior edge of the base of the maxillar process is opposite the posterior part of M^3 and the anterior part of M^4. The position is slightly anterior to this in 69851 but is in the same position as 45244 in all the other known maxillae.

Upper Incisors. Although the outline of the incisors, I^{1-3}, from one side of the premaxilla to the other is not clearly displayed in 45244 or 69832, they do seem to show that the outline was less U-shaped than in the late Pleistocene forms. The New Guinea specimens are numerous enough and well-enough preserved to show that the incisors did not wear off in the same horizontal plane as in the other known protemnodonts. The first incisor, as seen in the unworn examples of UCMP 45246, has an unworn occlusal length of 7.2. The height of the enamel crown in these relatively unworn examples is 18.0. The tooth is strongly downcurved and occlusion on the posterior surface soon produces a broad wear surface with a marked ventromedian point.

The second incisor in 45246 is unworn and has an occlusal length of 6.6. This tooth is curved dorsoventrally and has a crown height of 9.0. It is only slightly higher at the anterior edge than at the posterior edge. The tooth has a shallow occlusal basin opening into a short groove that emerges at the posterior rim of the tooth, which is not visible from the labial side. The lingual and labial crests are equal in length. The lower labial surface is straight except for a bulbous ridge at the posterolabial corner of the tooth. This ridge extends about a third of the way up the crown towards the enamel base.

Several well-preserved examples of I^3 were found in the Awe quarry. Measurements were made on the unworn left and right teeth UCMP 69831 and 69827. Their unworn occlusal length is 9.0 and 9.2. The tooth has a strong labial notch which is 4.8 posterior to the anteroventral corner of the tooth, and slightly posterior to the middle of the labial surface. It is directed anteriorly on the occlusal surface in unworn teeth, and terminates 0.05 posterior to the anterolabial corner of the tooth. The notch is not completely unobstructed but rather consists of an anterior basin which is isolated from the posterior notch by a slight obstruction. This is particularly well developed in 69831. The notch can be seen on the labial surface of the tooth. It is most strongly developed near the occlusal surface and fades gradually to the base of the enamel. The crown is approximately 7.5 high. The root is slender and has no emargination on its labial surface.

Upper Premolars. P^2 is represented by both teeth from UCMP 45246 and by 69833. It is approximately one-third smaller, or a little less, than P^3. There are four cusps on the sectorial crest. The posterior and anterior cusps are equal in height and higher than the two intermediate cusps. In front of and behind the higher cusps are anterolabial and posterolabial vertical ridges. Between these ridges are two sharply defined, vertical, intermediate ridgelets that are separated by three intermediate grooves. In contrast to the ridges, the ridgelets fade out before they reach the base of the enamel. The anterolabial ridge is rather flattened and its surface therefore extends around on to the anterior end of the tooth. There is another sharp ridgelet on the posterior edge of the anterolabial ridge. Like the intermediate ridgelets, it fades out before it reaches the base of the crown. The posterolabial ridge is narrower and more rounded than the anterior one. The labial surface is straight anteroposteriorly and slightly convex dorsoventrally. A spur ascends from the posterior cusp and is in line with the main crest on the left P^2 of 45246, but is slightly diverted posterolabially in the right P^2.

The posterior lingual cusp is three-quarters as high as the posterior cusp on the sectorial crest, and is connected to it by a small sharp crest. A pocket is formed behind this little crest by a spur that ascends from the posterolingual cusp and curves out to join a spur that ascends from the posterior cusp of the ectoloph. A second small pocket, anterior to the main pocket, is seen in UCMP 69833. Another spur ascends from the anterior edge of the posterolingual cusp to a commissure that separates it from the lingual basal cingulum. The cingulum, which forms the inner margin of the longitudinal basin, is 4.3 long. The basin is crossed by two laminae that connect with two intermediate lingual ridgelets which ascend from the anterior intermediate cusp on the sectorial crest. A third and fourth lamina are found in 69833. One is anterior and the other posterior to the commissure. They join and are connected to the posterior intermediate cusp on the sectorial crest. The basin opens to the lingual side through the commissure at the anterior base of the posterior lingual cusp and from the top of the median lingual groove. The lateral wall of the longitudinal basin is nearly vertical on the lingual side of the crest. The anterior end of the basin is closed by a sharp lingual crest that ascends from the anterior cusp to the sectorial crest and connects to the anterior end of the lingual cingulum. Anterior to this

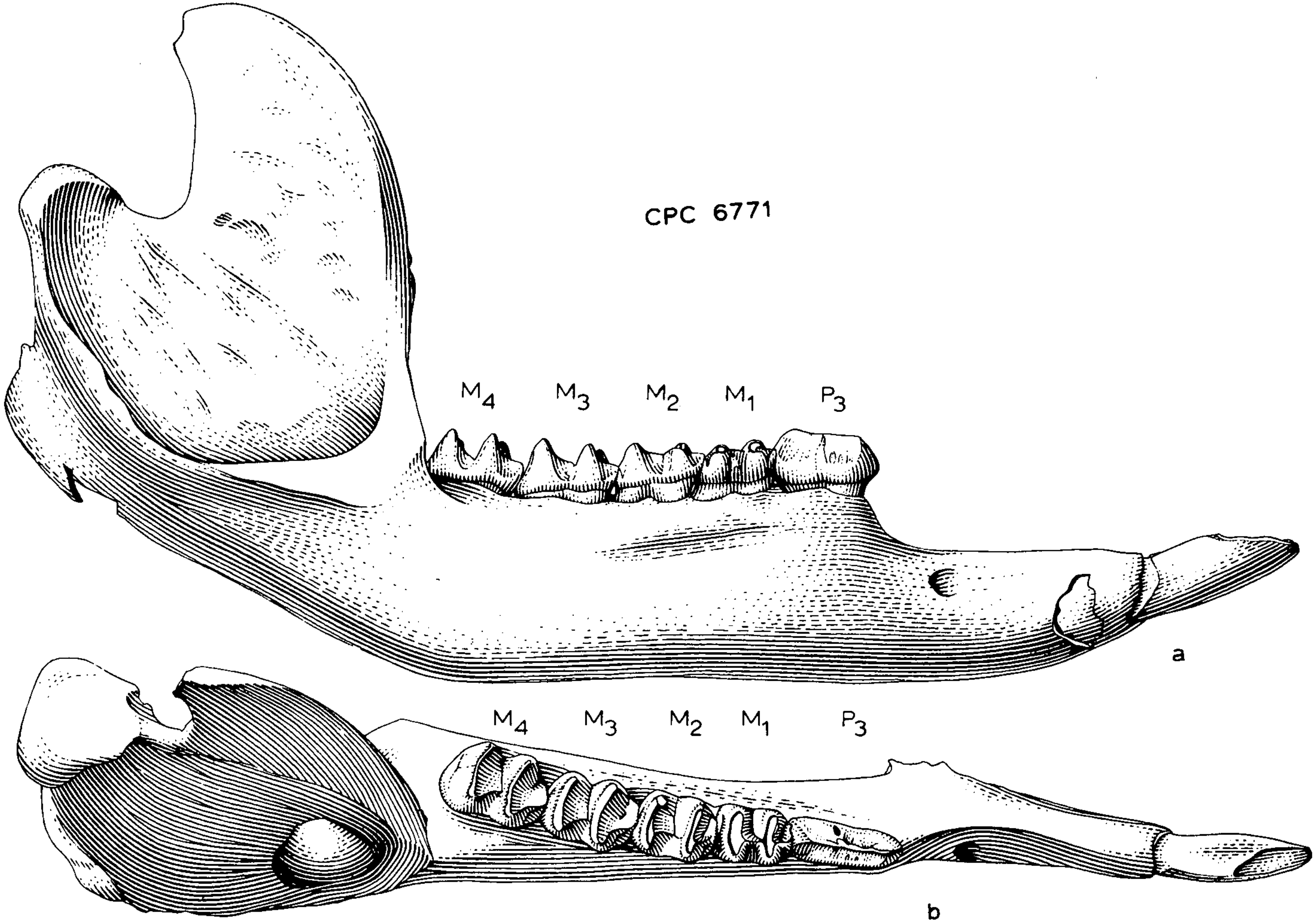


Figure 6. *Protemnodon otibandus* **sp. nov.,** *type* **a, mandible, labial view; b, mandible, occlusal view. CPC 6771.**

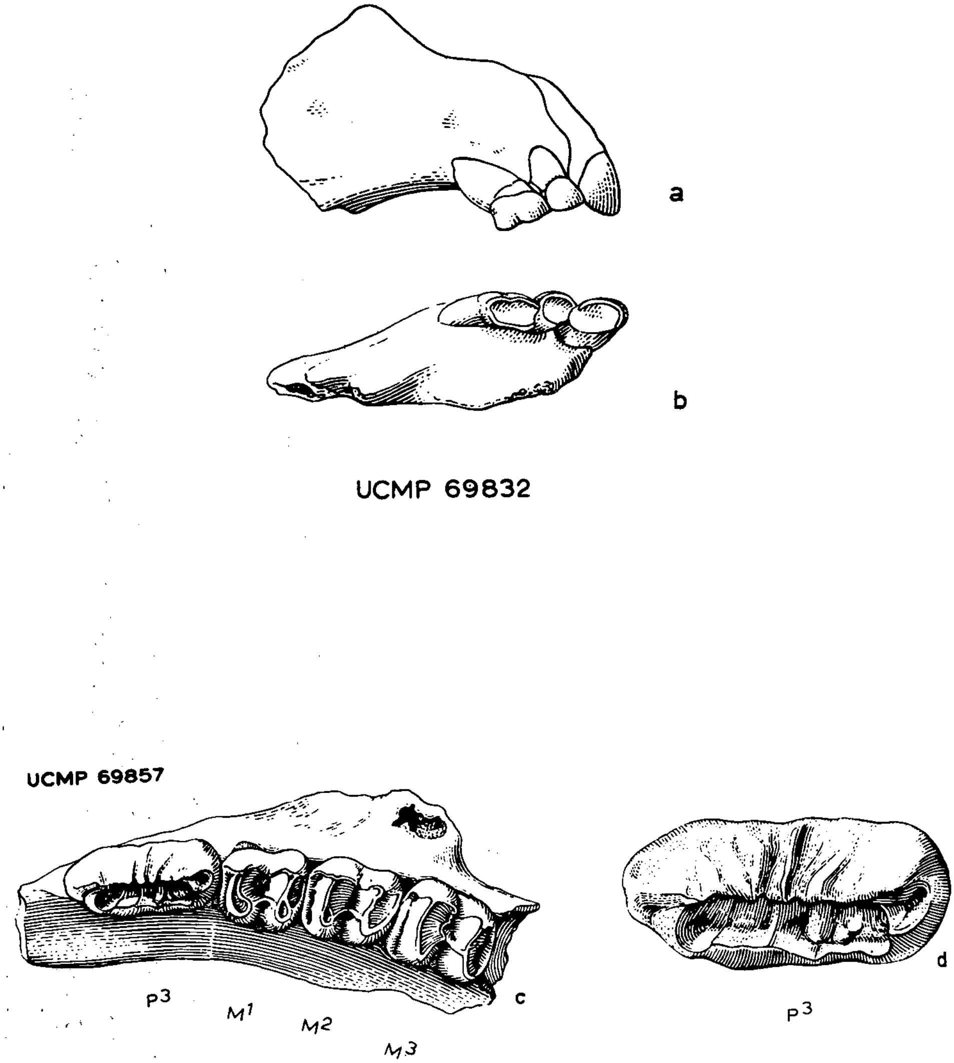


Figure 7. ***Protemnodon otibandus*** **sp. nov., a, premaxillary, I$^{1-3}$, I^{1} restored from UCMP 69794, labial view; b, occlusal view; UCMP 69832. c, paratype. Upper cheek teeth P^{3}, M$^{1-3}$, occlusal view; d, upper premolar, occlusal view x 2. UCMP 69857.**

structure is a depressed area on the side of the sectorial crest. Its anterior border is formed by a spur that ascends inward and then backward but does not reach the anterior end of the lingual cingulum; consequently this is the narrowest part of the tooth.

Measurements

P^2	1	2	3	4	5
UCMP 45246 (right)	13.1	7.4	6.2	7.2	6.8
UCMP 45246 (left)	12.4	7.5	6.5	7.1	7.0
UCMP 69833 (right)	12.1	7.4	7.2	—	—

1. Length; 2. Width opposite posterior main cusp; 3. Width opposite anterior main cusp; 4. Greatest height of enamel on posterolabial side; 5. Greatest height of enamel on anterolabial side.

P^3 is well represented. The description is based primarily on the unworn teeth UCMP 45246, 69857, and 69864. The tooth has six cusps on the sectorial crest. For convenience I have numbered them anteroposteriorly 1 to 6. 5 is only faintly discernible. The anterior cusp, 1, is the highest, and 6 is higher than 2, 3, 4, or 5. Sharp labial and lingual crests, resembling the intermediate ridgelets, ascend from the anterior cusp to the base of the tooth. The crest on the lingual side closes the longitudinal basin anteriorly. The following intermediate ridgelets, numbers 2 and 3, are also prominent, but number 4 is somewhat less so. The three anterior ridgelets, numbers 2, 3, and 4, extend to the base of the enamel on the labial side of the sectorial crest, while on the lingual side they reach, and may in some specimens cross, the longitudinal basin as laminae. Number 5 is only faintly indicated, and on the lingual side of the crest does not cross the longitudinal basin as a lamina. In contrast to the anterior cusp, the posterior cusp has no vertical crest. The posterolingual cusp is connected to the lingual side of the posterior ridge of the sectorial crest by a sharp transverse crest. A spur ascends from the posterolingual cusp posteriorly then labially to the base of the sectorial crest. This forms a nearly square posterior basin which in the specimens on hand is 2.5 - 3.0 square. The sectorial crest is nearly straight but curves labially at its posterior end. The lingual basal cingulum terminates anteriorly at the base of the vertical crest of the anterior ridge. Near the base of enamel at the most anterior part of the tooth is a pair of rounded stylar expansions. The lingual expansion is always larger than the labial. The emargination between them is very shallow and is approximately in line with the anterior crest from cusp 1 on the sectorial crest. The length of the shortest P^3 is 3.5 longer than the longest molar (14.0). The width of P^3 decreases anteriorly in all the specimens examined. On the other hand the height of the enamel-covered crown is higher anteriorly than posteriorly.

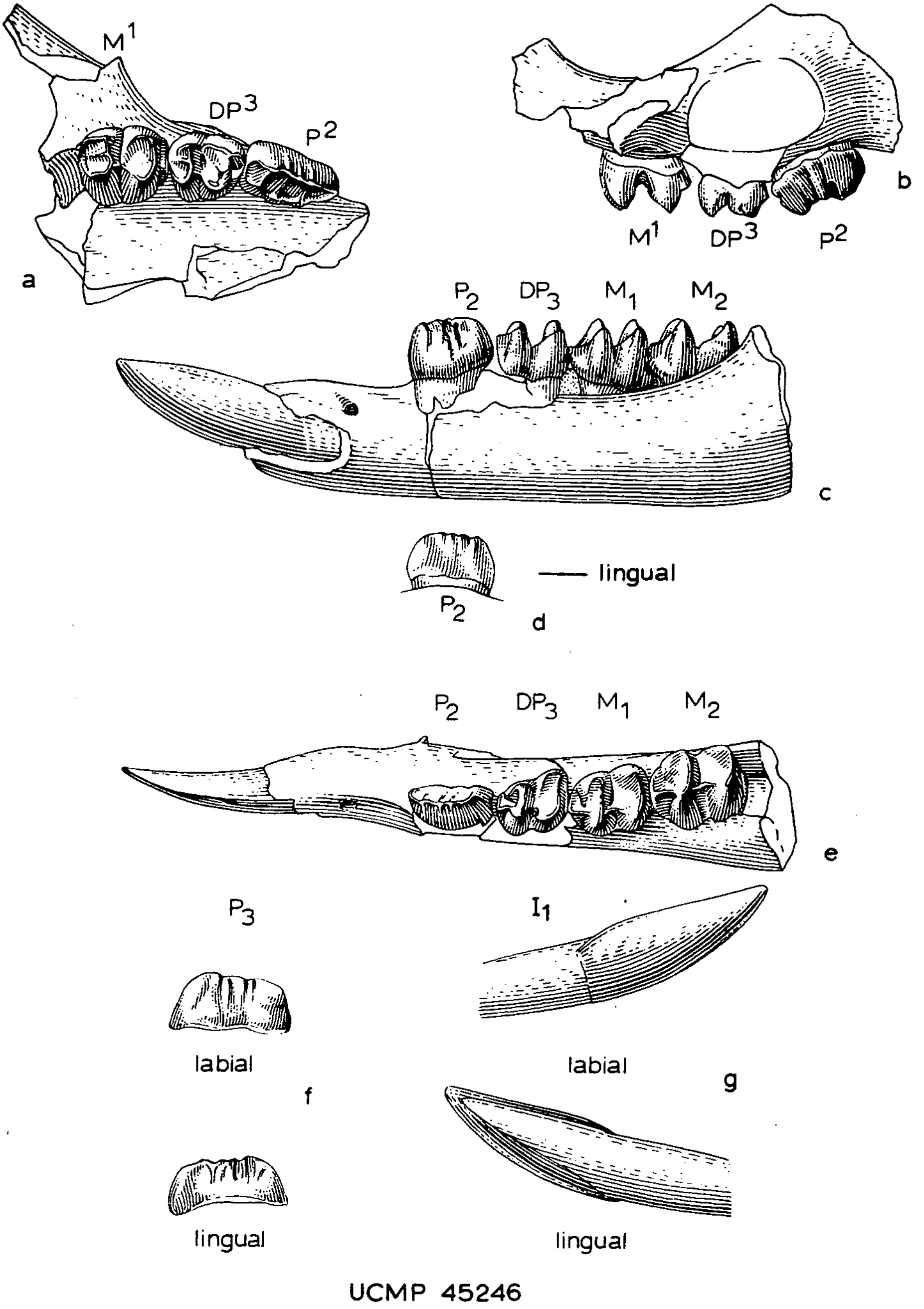


Figure 8. *Protemnodon otibandus* sp. nov., a, upper cheek teeth, P^2, DP^3, M^1, occlusal view; b, labial view; c, mandible with I_1, P_2, DP_3, M_{1-2}, labial view; d, P_2 lingual view; e, mandible with I_1, P_2; DP_3, M_{1-2}, occlusal view; f, P_3 excavated from crypt, labial and lingual views; g, I_1, lingual and labial views; UCMP 45246.

Measurements

P3	1	2	3	4	5
UCMP 45244	19.1	9.0	7.4	—	8.9
UCMP 45246	18.5	8.9	7.3	7.0	7.4
UCMP 69857	19.7	9.0	8.2	7.7	7.4(a)
UCMP 69837	19.0	8.9	8.0	7.3	8.1
UCMP 69864	19.6	8.9	7.9	7.3	8.3
UCMP 69863	19.4	9.0	8.2	—	—
AM F. 37681	17.5	8.1	7.6	—	—

1. Length; 2. Width opposite posterior cusp; 3. Width opposite anterior cusp; 4. Height of enamel on posterolabial side; 5. Height of enamel on anterolabial side. (a) is approximate.

Deciduous Premolar, DP^3, is not well represented, the only examples being the left and right teeth from the specimen UCMP 45246. The anterior cingulum is not widely separated from the base of the protoloph as a shelflike structure. A paraconal crest descends from it to the tip of the paracone and a protoconal crest (forelink) to the apex of the protocone. A slight commissure, however, separates the protoconal crest from the cingulum. These crests are more pronounced, especially the protoconal crest, and the cingulum does not protrude. The transverse anterior valley, behind the cingulum in *P. otibandus,* is interrupted not only by the forelink but by the paraconal crest also, and this forms a relatively short anterior basin. This basin is wide transversely. The forelink is slight, and, although it crosses the anterior valley, it does not descend to the tip of the protocone.

This species has the paracone and metacone separated by a deep and wide anteroposterior cleft across the protoloph. Spurs ascending from the paracone and metacone nearly close the labial mouth of the transverse median valley. Consequently a shallow basin is formed in the valley between these spurs and the midlink. The midlink in *P. otibandus* is nearly equally formed by the upper end of the posterior protoconal spur, and the median metaloph spur, but these two spurs are separated by a commissure. The crescentic metaloph is not divided by a deep median cleft, as is the protoloph, but the median part is arched well above the cusps at each end of the loph.

The depressed posterior surface is outlined by a spur that ascends posterolingually from the metacone and another that curves upward and outward from the inner end of the loph. These spurs join at the anteroposterior midline of the tooth. A short spur from the cutting edge of the metaloph and slightly labial of the anteroposterior midline of the tooth extends halfway up into the depression.

Measurements

DP3	1	2	3	4	5
UCMP 45246 (right)	10.0	9.1	8.7	11.5(a)	11.4(a)

1. Median length; 2. Width of metaloph; 3. Width of protoloph; 4. Height of enamel at metacone; 5. Height of enamel at paracone. (a) is approximate.

Upper Molars. A low anterior cingulum extends nearly across the tooth. From the lingual side, the crest ascends to, or near, the anteroposterior midline, then nearly levels off to a position anterior to the paracone. A spur ascending from the paracone connects with the cingulum at the anterolabial corner of the tooth. The forelink is poorly developed and the anterior transverse valley between the anterior cingulum and the protoloph is shallow. The midlink is relatively low and is formed as in DP^3. A spur runs posteriorly from the paracone nearly up to the highest point of the transverse median valley, where it turns inward abruptly for a short distance then crosses the valley to join a similar structure ascending from the metacone. This results in the labial mouth of the valley being wider than in DP^3. This structure, particularly of the spur which ascends posteriorly from the metacone, is not as well developed in M^{2-4} as in M^1. In the M^3 of UCMP 69857 the spur is reduced to a hair-thin line and in all the fourth upper molars the spur is only faintly discernible. With the fading of the premetaconal spur the postparaconal spur increases in size. In UCMP 69853 this spur almost crosses the median valley, and greatly restricts the labial opening of the valley basally. A posterior spur from the metacone ascends nearly to the base of the enamel. There it is separated by a tiny commissure from the end of another spur that ascends in a wide arc from the hypocone and almost crosses the posterior end of the tooth. Much as in DP^3, a small posterior median spur ascends vertically from the metaloph, but fades out before it reaches the arclike crest from the lingual end of the metaloph. The crests of the metaloph and protoloph are crescentic, and are like the lophs in DP^3. The labial surface of the lophs tend to curve anteriorly.

Measurements on upper molars

M^1	1	2	3	4	5
UCMP 45246 (right)	11.5	—	9.5	—	—
UCMP 45246 (left)	11.4	10.6	10.0	6.2	5.7
UCMP 69857 (left)	10.0	11.0	10.6	—	—
UCMP 69851 (right)	10.5	10.8	10.2	—	—
M^2					
UCMP 45248 (right)	12.8	12.4(a)	12.4	—	—
UCMP 69851 (right)	11.9	10.3	10.3	6.5	5.3(a)
UCMP 69852 (left)	12.1	11.5	11.5	6.3	5.4
UCMP 69853 (left)	11.7	11.9	11.0	6.2(a)	—
UCMP 69854 (left)	11.9	12.3(a)	—	—	—
UCMP 69857 (left)	12.3	11.2	11.6	6.8	—

M^3					
UCMP 45248 (right)	13.9	11.8	12.4	7.2	—
UCMP 69851 (right)	12.9	10.7	11.3	7.0	5.4
UCMP 69853 (left)	13.2	11.7	12.7	—	5.5
UCMP 69854 (left)	13.7	12.5	—	—	—
UCMP 69857 (left)	13.5	11.6	11.9	6.2	6.7
M^4					
UCMP 45248 (right)	14.0	10.5	13.1	—	—
UCMP 69853 (left)	13.1	10.0	12.4	5.0(a)	5.0(a)
UCMP 69854 (left)	13.3	10.9	—	—	6.1

1. Median length; 2. Width of metaloph; 3. Width of protoloph; 4. Height of enamel at metacone; 5. Height of enamel at paracone. (a) is approximate.

Mandible. Eighteen mandibles come from the Awe type locality but not all of them are complete. Measurements on mandibles were made in accordance with Figure 5.

Lower Incisor. The lower incisor is a lanceolate blade with a root which is considerably shorter than the enamel-covered crown (Fig. 6). The greatest vertical depth of the blade, measured on unworn specimens, is 10.2 on UCMP 45246. The tooth is not strongly curved except for its extreme anterior tip, which in unworn specimens hooks medially.

Lower Premolars. P$_2$ is a little more than one-third smaller than P$_3$. There is no median cleft in the central crest, which is slightly serrate. Three anterior cuspids have sharp lingual and labial ribs, which extend half-way to the base of the enamel on the lingual side and more than half-way on the labial surface The anterior and posterior cuspids are not higher than the intermediate cuspids The lingual surface is slightly concave posteriorly, but the basal outline is nearly straight, and the labial surface and basal outline are markedly convex anteriorly The central crest curves lingually both at the anterior and posterior ends. The tooth is pointed anteriorly but not posteriorly and is more than twice as long as it is wide.

Measurements

P_2	1	2	3	4	5
UCMP 45246 (right)	10.8	5.2	5.5	6.9	7.7
UCMP 45246 (left)	11.4	5.0	4.8	6.5	7.3
CPC 6772 (right)	9.7	5.1	4.9	—	—

1. Median length; 2. Width opposite posterior cusp; 3. Width opposite anterior cusp; 4. Height of enamel on posterolabial side; 5. Height of enamel on anterolabial side.

The central crest of P_3 is slightly serrate, and the posterior cusp is slightly elevated above the others. The anterior cusp and the three intermediate cusps that follow have labial ribs which extend more than half-way to the base of the enamel. The labial surface opposite the anterior and posterior cusps is ridge-like or gently rounded; the lingual surface opposite the posterior cusp is nearly flat. The anteroposterior crest is slightly posterolingually curved. There are faint suggestions of labial and lingual basal cingula. The labial surface is concave dorsoventrally and the edge of the crest rolls to the labial side at its dorsal edge. The tooth is markedly wider opposite the posterior cusp than opposite the anterior cusp, and is slightly emarginated on both the labial and lingual sides just anterior to the midpoint. The tooth is sharply pointed anteriorly and is rounded posteriorly. A faint sharp crest descends from the posterior cusp to the posterolingual base of the enamel.

Measurements

P_3	1	2	3	4	5
UCMP 45246 (right)	15.3	5.5	4.7	7.1	—
UCMP 45244 (left)	—	6.6	5.4	—	—
UCMP 69864 (right)	16.5	6.1	5.4	8.7	8.0
CPC 6772 (right)	16.0	6.0	5.3	8.4	7.7

1. Median length; 2. Width opposite posterior cusp; 3. Width opposite anterior cusp; 4. Height of enamel on posterolabial side; 5. Height of enamel on anterolabial side.

The *deciduous premolar* DP_3 has a low and short anterior cingulum which is not high enough to form a pit at the base of the groove, at the anterolabial corner of the tooth. A high anterocentral stylid is completely coalesced with the forelink. From the anterocentral stylid the forelink runs almost straight toward the protolophid where it curves sharply labially to the protoconid. In teeth with only a little wear this feature may sometimes be unobservable. A short but prominent spur extends anterolabially from the metaconid but fades out before it contacts the forelink or the anterior cingulum. It thus forms an L-shaped valley that enters from the anterolingual corner of the tooth and terminates at the protolophid. In little-worn teeth the protolophid is much narrower than the hypolophid. Both lophids are crescentic. The midlink is formed by the continuous connexion of spurs from the hypoconid and protoconid that curve inward then cross the transverse valley labial to the anteroposterior midline. Similar but feeble spurs extend anterolabially and posterolabially from the metaconid and the entoconid but fade out before crossing the transverse valley. There is a small posterior basal cingulum.

Measurements

DP_3	1	2	3	4	5
UCMP 45246 (left)	9.6	6.7	6.1	6.0	6.4
CPC 6772 (right)	8.8	6.8	6.0	—	—

1. Median length; 2. Width opposite hypoconid-entoconid; 3. Width opposite protoconid-metaconid; 4. Height of enamel at hypoconid; 5. Height of enamel at protoconid.

Lower molars. Lower molars are wider, in proportion to their length, than in other species of *Protemnodon.* This is particularly notable in M_1 and M_2. They have a low short anterior cingulum which is transversely wide. The lingual side of the anterior cingulum has a pronounced declination and curves posteriorly towards the base of the metaconid. The transverse portion of the L-shaped valley between the anterior cingulum and the protolophid is deep and declines lingually. The forelink runs from the midpoint of the anterior cingulum, or slightly labial of the midpoint in M_1 and M_2, to the protolophid where it curves sharply labially to the protoconid. A short anterior spur from the metaconid is confined to the upper part of the protolophid. The protolophid is nearly as wide as the hypolophid on M_1 and M_2, but is slightly wider on M_3 and M_4. The protolophids and hypolophids are crescentic. The labial sides of the protolophids and hypolophids are conspicuously wider at the bases than near the apices; this may be due in part to the height of the crown. The lophs tend not to curve anteriorly. The midlink is formed by a long anterolingual spur from the hypoconid, slightly labial to the midline, and a slight spur which descends from the protoconid. Only faint indications of spurs extend anterolabially and posterolabially from the metaconid and entoconid. There is a posterior basal cingulum.

Measurements on lower molars

M_1	1	2	3	4	5
UCMP 45246 (left)	11.1	8.2	7.7	8.2	7.7
UCMP 45244 (left)	10.0	8.8	—	—	—
UCMP 69895 (left)	8.9	8.0	7.9	—	—
CPC 6771 (right)	9.6	7.9	7.8	—	—
M_2					
UCMP 45246 (right)	13.2	—	9.1	—	—
UCMP 45244 (left)	11.2	—	—	—	—
UCMP 69895 (right)	11.0	9.2	9.3	—	—
CPC 6771 (left)	10.9	9.1	9.0	—	—
UCMP 45246 (left)	12.1	9.4	9.4	9.8	9.0
M_3					
UCMP 45244 (left)	11.8	—	—	—	—
AM F.36577 (left)	14.0	10.4	10.5	—	—
UCMP 69895 (left)	12.2	10.0	10.2	—	—
CPC 6771 (left)	13.3(a)	9.8	10.1	7.3(a)	7.1(a)

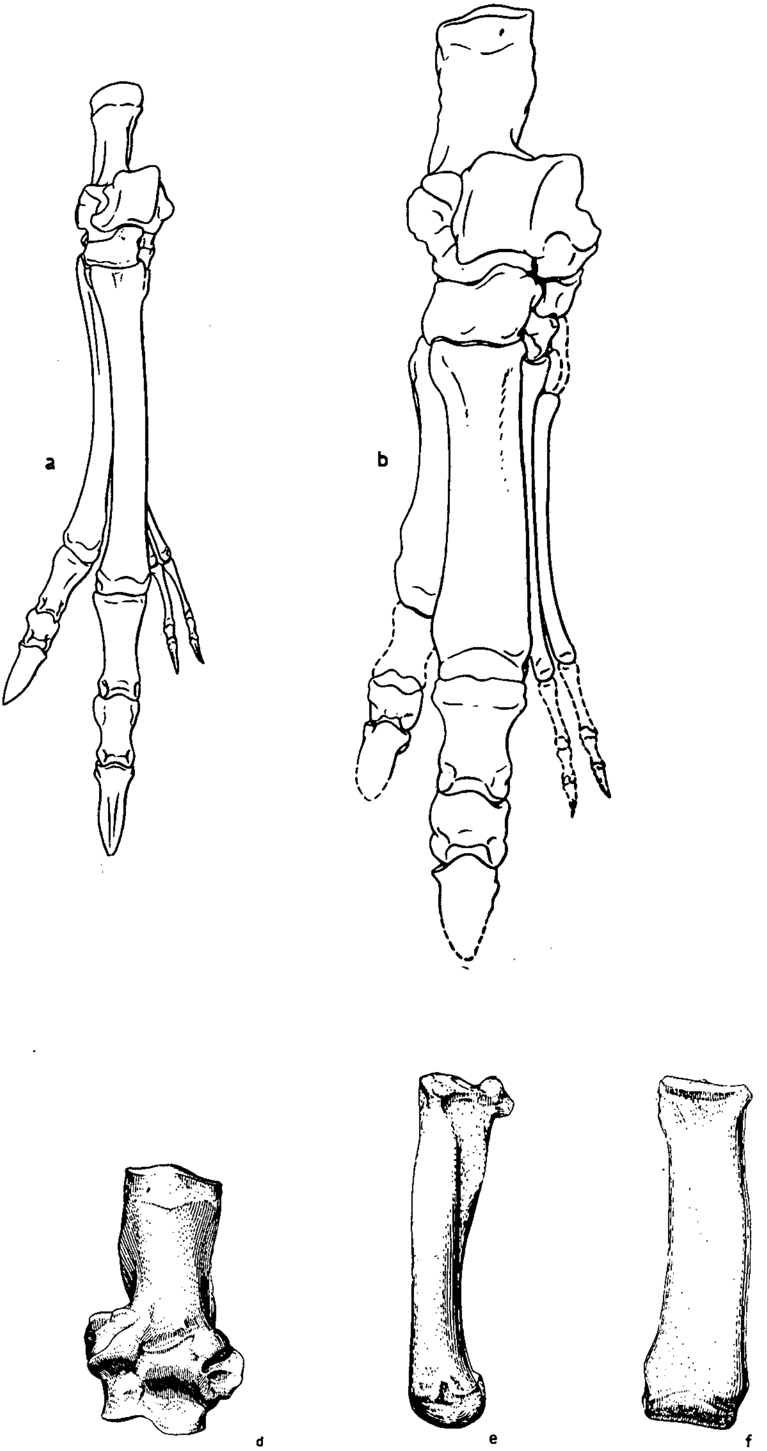


Figure 9. **a,** *Wallabia rufogrisea,* **MVZ, right pes x ⅓, Recent. b,** *Protemnodon otibandus* **sp. nov., right pes with left calcaneum drawn in reverse and restored parts indicated with broken lines, x ½, c, left calcaneum ventral view x ½; d, left calcaneum, dorsal view x ½; f, metatarsal IV, dorsal view x ½; UCMP 45247.**

M_4					
UCMP 45244 (left)	14.4	—	—	—	—
UCMP 69895 (left)	13.3	10.0	10.0	6.9	—
CPC 6771 (right)	13.7	9.8	10.5	7.8	7.4

1. Median length; 2. Width opposite hypoconid-entoconid; 3. Width opposite protoconid-entoconid; 4. Height of enamel at hypoconid; 5. Height of enamel at protoconid.

Postcranial skeleton. In the Awe locality postcranial and cranial elements were found together. All macropodid skeletal parts from this quarry have been assigned to the genus *Protemnodon.*

The elements represented are: portion of an axis, clavicles, thoracic vertebrae, caudal vertebrae, ribs, the distal portion of a humerus, radii, ulnae, carpals and associated phalanges, portions of pelves, parts of femora, tibiae, fibula fragments, and metacarpals with associated phalanges.

Pes. The pes has been discussed by Stirton (1963, pp. 132-133, fig. 126). Additional material has confirmed the view that *Protemnodon* is quite distinct in the proportions of the pes. The foot figured by Stirton can now be referred to the species *Protemnodon otibandus.* The ratio of the total length of the M^t IV to its median width averages 518 for the left and right metatarsals of CPC 6773. This is greater than the figures obtained by Stirton for UCMP 45247 (445) but less than he obtained for *Dendrolagus ursinus* (567), *Prionotemnus* (893), *Wallabia bicolor* (910), or *W. rufogrisea* (956). The proximal, median, and distal phalanges associated with CPC 6773 are very like those figured by Stirton. They are short and broad and do not represent a strict allometric size increase over a pes with proportions like those found in the living genus *Wallabia.* The proximal phalanx on digit IV is 32.0 long and has a maximum width of 22.0. The median phalanx on this digit is 22.0 long with a maximum width of 19.0. The distal phalanx is approximately 22.0 long (terminal 1-2mm are broken) and 15.0 at its widest point.

Manus. A manus, with associated radius, ulna, and the distal end of a humerus, has been assembled (Fig. 10) from a specimen found in the Awe quarry. Comparisons have been made with a young male *Macropus canguru,* MVZ 119716, from Tapanappa, South Australia. The distal end of the humerus has a maximum width of 44.0 in *Macropus* and 73.0 in *Protemnodon.* The length of the radius is 201.1 in *Macropus* and 220.0 in *Protemnodon,* but morphologically they are very similar. The ulna is not complete but is considerably larger than its equivalent in *Macropus,* and morphologically there seems to be a considerable difference between these genera. Our specimen is somewhat crushed but relatively undistorted. It is actually and relatively larger and is more anteroposteriorly flattened. The carpals and phalanges are morphologically similar to those in *Macropus* but are actually and relatively larger.

Comparison. *Protemnodon otibandus* has been compared, in part, with *Wallabia bicolor* Desmarest, 1804, *Wallabia agilis papuanus* (Peters & Doria,

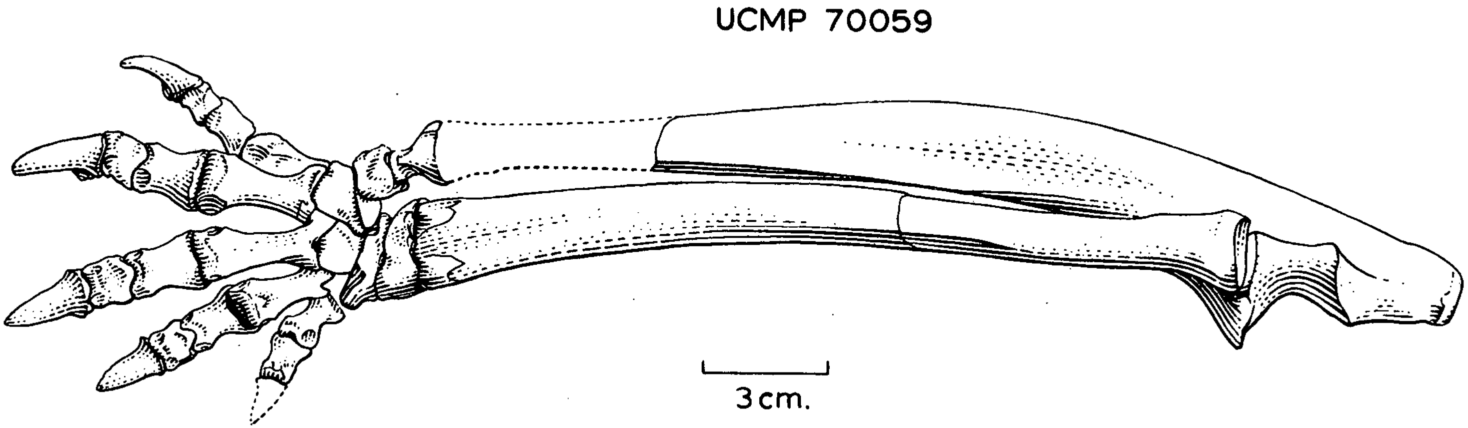


Figure 10. *Protemnodon otibandus* sp. nov., radius, ulna and manus x ½; UCMP 70059.

1875), *Wallabia billardierii* (Desmarest, 1822), *Prionotemnus palankarinnicus* Stirton, 1955, *Protemnodon anak* (Owen, 1859), *Protemnodon og* Owen, 1873, and other Pleistocene protemnodons. It is smaller than *P. anak,* the smallest Pleistocene species, from the Darling Downs and Wellington Caves, Australia, but larger than the second species of *Protemnodon* from the Awe fauna. Skull material is poor, but on the palate of UCMP 45244 it is evident that the palatine vacuities, if they were present, did not extend across the suture into the maxillary part of the palate, as they do in *Wallabia.* The position of the incisive foramen in the premaxilla is more like that seen in *P. anak* than that in *Wallabia.* The groove which runs forward from the incisive foramen is developed in *P. otibandus* but is only faintly indicated in wallabies. The outline of the incisors in the premaxilla is less U-shaped in *P. otibandus* than in the late Pleistocene forms, and the incisors do not wear off in the same horizontal plane, as in the known Pleistocene forms.

The unworn occlusal length of the median incisor is slightly less than one-third shorter (7.2) than that of the *Protemnodon* specimens AM F17599 (10.0) from the Wellington Caves and AMNH 19256 (10.0) from the Darling Downs; but less than half as long as in the Pleistocene protemnodons AM F37806 (14.8) from the Wellington Caves, AM F38785 (14.7) from seven miles south-west of Willow Tree, near Warrah Creek, N.S.W., or less than half the length of BMNH 44121 (16.4) and BMNH 47832 (16.0) from the Darling Downs. This measurement on I^1 of a large *Wallabia agilis papuanus* MVZ 100061 (5.3) is one-third less than in *P. otibandus.* The length of the occlusal surface on I^1 in *Protemnodon otibandus* falls within the range of those in *Prionotemnus.* The height of the enamel crown (18.0) is similar to that in *Prionotemnus,* and in so far as can be determined, is approximately the same length as those in the late Pleistocene protemnodons and wallabies.

The unworn occlusal length (6.6) of the second incisor is slightly more than one-third shorter than in the large late Pleistocene *Protemnodon,* AM F37806 (10.7) from the Wellington Caves. No unworn teeth from smaller late Pleistocene protemnodons are available for comparison. The pattern of the crown in I^2 is similar in the species of *Wallabia* examined and in *Protemnodon otibandus.* This pattern can be contrasted with that in *Prionotemnus* and the Pleistocene forms, in that, whereas the shallow occlusal basin opens into a short posterolabial groove on the labial surface in *Prionotemnus* and the late Pleistocene forms, it opens at the posterior rim of the tooth and is not seen from the labial side in *P. otibandus* nor in the wallabies. Consequently the labial crest of the basin in *Prionotemnus* and the late Pleistocene protemnodons is shorter than the lingual crest. In the wallabies examined and in *P. otibandus* they are equal in length. The height of the crown in I^2 of *P. otibandus* is closer to the wallabies than to *Protemnodon* AM F37806, or *Prionotemnus.* The anterior edge of the crown in the large Wellington Cave *Protemnodon* is 13.7, whereas the posterior edge of the labial crest is 7.0 and the posterior edge of the lingual crest is only 3.7. The anterior edge in *Prionotemnus* is 8.5 and the posterior edge on the labial crest is 7.5 and the corresponding edge of the lingual crest is 3.5.

The I^3 differs from *Prionotemnus, Wallabia,* and the later Pleistocene protemnodons in the position of the labial notch. It is slightly farther forward in

Prionotemnus and much farther forward in *Wallabia* and the late Pleistocene *Protemnodon* AM F37806. The tooth is about the same size as its equivalent in *Prionotemnus.*

Labial spurs nearly close the labial mouth of the transverse median valley in the DP^3 of *P. otibandus* and a basin is formed in the valley between them and the midlink. In the late Pleistocene *Protemnodon* AM F37806, these labial spurs show a greater inward curvature, especially the spur from the paracone. This leaves the mouth of the valley open and thus no shallow basin is formed. In some of these features *P. otibandus* is very like *Wallabia billardierii* already mentioned, which some authors place in the genus *Thylogale* Grey, 1837. In that wallaby, however, the anterolabial paraconal spur is relatively longer and consequently the anterior cingulum is oblique, not transverse. Furthermore, the protoloph is not divided by an anteroposterior valley. On the whole the DP^3 of *P. otibandus* is more bulbous than it is in *Protemnodon* F37806 from the Wellington Caves.

In the upper molars the protrusion of the low anterior cingulum is smaller than that in the small late Pleistocene specimens referred to *Protemnodon anak.* The midlink is relatively lower than in any of the known genera of large kangaroo except *Sthenurus.* The labial surfaces of the lophs tend to curve anteriorly in *P. otibandus,* but they do so less than in the late Pleistocene specimens. The molars in *P. otibandus* are relatively shorter and narrower than in most of the late Pleistocene protemnodons, and the height of the crowns is consistently lower (for comparison see measurements in Stirton, 1963).

The mandible is smaller than in the type of *Protemnodon og* Owen, 1873, and a little smaller than a new form in the Kanunka fauna. The lower incisors are about as large as those in *Prionotemnus,* but the lanceolate blade is much narrower than in the late Pleistocene protemnodons.

The lower molars are wider, in proportion to their length, than in the other known species of *Protemnodon.* The low, short anterior cingulum does not protrude as far forward as in the Pleistocene species. This cingulum is also relatively wider transversely than in those species, and the farthest anterior point tends to be nearer the midline, as in *P. og.* The declination and posterior curvature towards the base of the metaconid on the lingual side of the anterior cingulum is more pronounced than it is in *Prionotemnus.* The transverse part of the anterior L-shaped valley is consequently deeper and more declined lingually than in *Prionotemnus.* The labial side of the transverse valley is also more steeply declined than in *Prionotemnus* or in the other species of *Protemnodon.*

PROTEMNODON BULOLOENSIS sp. nov.

Holotype. CPC 6774 (UCMP 45243). Fragmentary mandible of adult individual with the teeth well worn; parts of the left mandible from M_1 nearly to the middle of the incisor-premolar diastemal region; left incisor, P_3, M_1 and

M_2 in place; entoconid and inner half of hypolophid of M_3, posterior half of M_4. Tip and root of right incisor with middle part missing, hypoconid of right M_2 and M_3 with entoconid border missing; fragments of coronoid, condyle, and other parts of the mandible. The wear formula is II.MM.

Referred specimen. UCMP 45345; an adult from UCMP locality V5573, in the type Otibanda Formation, referred to this species because of its small size. Root of the upper incisor with the crown worn away; thoracic vertebrae 8, 9, 10, 11, 12 and lumbar vertebra 1; parts of eleven ribs; numerous elements of the right hind foot; calcaneum with olecranon tuberosity partly destroyed; lateral side of astragalus; ectocuneiform; most of distal half of metatarsal II; metatarsal III; proximal and distal ends of metatarsal IV; palmar sesamoid; metatarsal IV — proximal phalanx sesamoids; ungual phalanx of digit 4; metatarsal V; proximal and median phalanges of digit 5.

Type locality. UCMP V5564 at the Sunshine alluvial gold sluicing workings in the type section of the Otibanda Formation.

Age. Middle Pliocene (7.6-6.1 million years before present).

Specific diagnosis. Mandible smaller than in *P. otibandus,* about as large as in *Prionotemnus palankarinnicus;* P_3 - I_1 diastema very short (19.3 approx.); mental foramen only 0.5 anterior to P_3 alveolus. Premolar long, approximately equal to M_1 plus anterior moiety of M_2; high sectorial ridge with pronounced anterior cuspid high and pointed. Lower molars smaller than in any known species of *Protemnodon;* relatively narrow, elongate; low and short anterior cingulum not protruding as far forward as in Pleistocene species and relatively narrower transversely than in *P. otibandus;* lingual side of anterior cingulum with no pronounced declination as in *P. otibandus,* consequently anterolingual valley shallow, does not open lingually to form L-shaped valley; labial side of anterior cingulum less sharply declined than in *P. otibandus;* lophids apparently nearly straight transversely; posterior cingulum absent or faintly developed. Plantar surface of calcaneum rough; curved outline with convexity on medial side, tends to become narrow at lower end; medial sulcus of olecranon shaft deep, especially at lower end, where it is partly roofed by the expanded and anteriorly curved plantar border. Metatarsals all much smaller than in any other known species of *Protemnodon.*

Description and Comparison

Mandible. The mandible is smaller than in any other known species of *Protemnodon.* The incisor-premolar diastema is 19.3 long, and the depth of the ramus below M_2, taken between the roots, is 22.9; the posterior edge of the mental foramen is approximately 0.5 anterior to the P_3 alveolus.

Lower incisor. The ventral length, including the root, of the left incisor is 45.8 and the tooth has a greatest depth of 9.4. The crown is lanceolate and curves inward. From its widest posterior point the tooth declines gently backwards to the surface of the root.

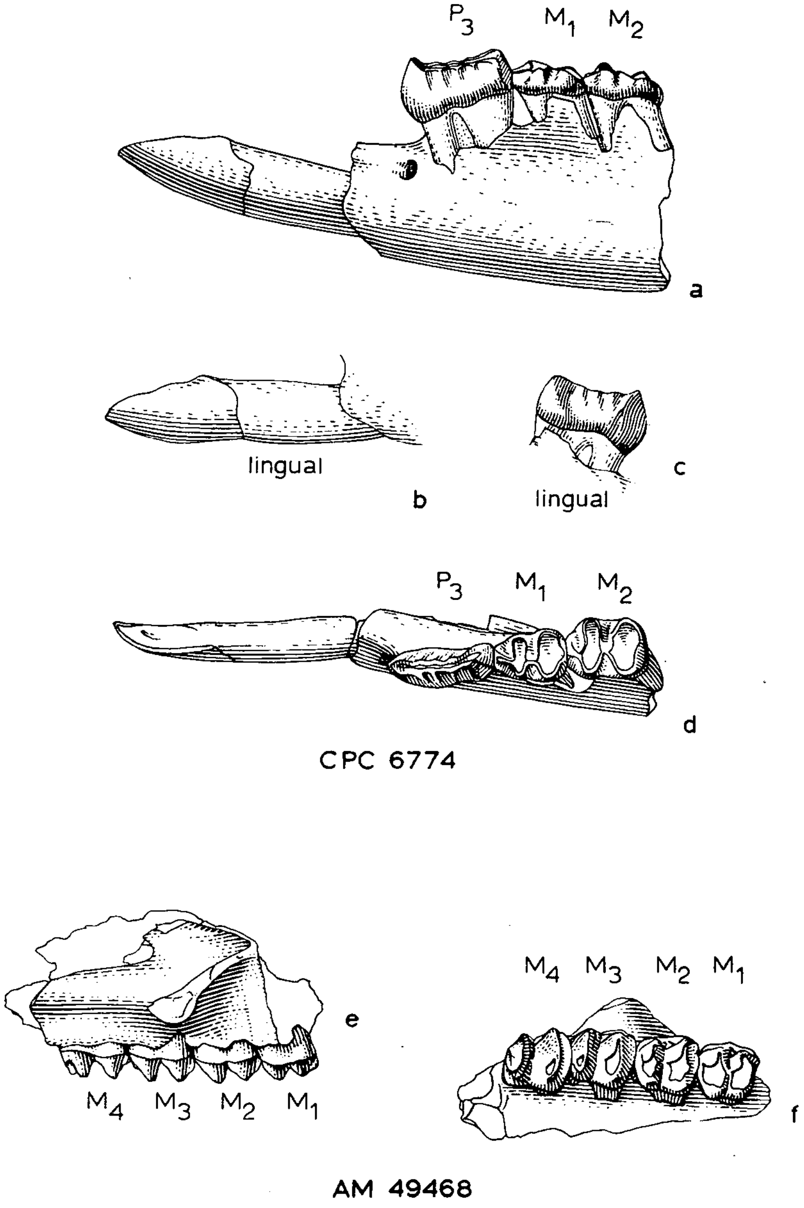


Figure 11. *Protemnodon buloloensis* **sp. nov., type. a, mandible with I_1, P_3, M_{1-2}, labial view; b, I^1, lingual view; c, P_3, lingual view; d, mandible with I_1, P_3, M_{1-2}, occlusal view. CPC 6774 cf.** *Dorcopsis* **large form, e, maxilla with M^{1-4}, labial view; f, occlusal view. AM F.49468.**

Lower premolar. The lower premolar has a sectorial crest which was apparently serrate before wear started. The crest terminates anteriorly and posteriorly in a cuspid. Between these cuspids are three intermediate cuspids. The anterior and three intermediate cuspids have ribs which descend ventrally from them more than half-way to the base of the tooth. Below the intermediate cuspids are lingual ridgelets, which extend half-way to the base of the tooth. The lingual and labial surfaces of the posterior cuspid are ridgelike or gently rounded. The sectorial crest is gently curved and the tooth has faint suggestions of labial and lingual cingula. The lingual surface of the tooth is somewhat concave and the labial surface is slightly convex. The tooth is approximately the same width opposite the anterior and posterior cuspids, but is constricted behind the midpoint. The anterior edge of the tooth is sharply pointed, but the posterior edge is straight transversely, even though this tooth is well worn.

Measurements

P_3	1	2	3	4	5
CPC 6774	14.9	5.1	5.2	—	8.2

1. Median length; 2. Width opposite posterior cuspid; 3. Width opposite anterior cuspid; 4. Tooth too worn to give accurate height of posterior cuspid; 5. Height of enamel on anterior labial side.

Lower molars. The lower molars are very small. They are relatively narrow, elongate, and low-crowned. A low and short anterior cingulum does not protrude very far forward and is relatively narrow transversely. The farthest anterior point on the cingulum is at the lingual corner. The lingual side of the cingulum has no pronounced declination; the anterolingual valley is consequently shallow and does not open lingually to form an L-shaped valley. The labial side of the anterior cingulum does not decline particularly steeply. The forelink is slightly labial of the midpoint. On M_1 the protolophid is narrower than the hypolophid, but on M_2 it is wider. From what remains of M_3 it seems that the protolophid was also wider on this tooth. The lophids in this stage of wear were nearly straight transversely. The midlink is formed by a continuous connexion of spurs from the protoconid and hypoconid. Slight spurs extend anterolabially and posterolabially from the metaconid and the entoconid. A posterior cingulum is absent or faintly developed.

Measurements on lower molars

	1	2	3	4	5
CPC 6774 M_1	9.3	6.9	6.6	—	—
CPC 6774 M_2	10.4	7.5	7.9	6.0(a)	—
CPC 6774 M_3	10.9	—	7.7	4.5(a)	—
CPC 6774 M_4	—	7.2	—	—	4.3

1. Median length; 2. Width opposite hypoconid-entoconid; 3. Width opposite protoconid-metaconid; 4. Height of enamel at entoconid; 5. Height of enamel at metaconid. (a) is approximate.

Postcranial Skeleton

Vertebrae. The centra have no foramina nor are there interneural foramina. On the first lumbar vertebra the transverse process is elongate, thick, and convex dorsoventrally.

Ribs. The longest approximate length is 232.0, the greatest anteroposterior diameter is 12.8, and the greatest transverse diameter 6.4. The proximal surface is strongly grooved and the ribs are widely ovate throughout most of the shaft but usually narrower and thicker proximally.

Calcaneum. The calcaneum is short and wide, with the olecranon process not greatly expanded transversely. The anterior outline of the olecranon shaft is straight or nearly so, from the lateral view. The anterior edge is rather broad. The plantar surface is rough and has convexly curved outline on the medial side, which tends to become narrow at the lower end.

The lateral sulcus of the olecranon shaft is shallow but has a prominent plantar border. The medial sulcus of the olecranon shaft is deep, especially at the lower end, where a deep flexor tendon originated or was inserted. At this position the sulcus is partly roofed by the expanded and anteriorly curved plantar border. The astragalar and sustentacular facets are jointed into a continuous articulation surface. The upper cuboid facet is nearly flat and is not transversely elongate. The lower and posterior cuboid facets are broken off. The sustentacular tuberosity is ovate in outline, extends much farther laterally than the fibula tuberosity, and is separated from the fibular facet and fibular tuberosity by a shallow sulcus. The fibular facet is strongly convex and extends widely down on the anterior face but is without a shelf-like lateral projection. The medial tuberosity is wide and flaring. Below the conjoined surface of the astragalar and sustentacular facets is the deep calcanear facet. The astragalar-capitulum facet is small.

Astragalus. The lateral side of the astragalus is destroyed but the tibial facet can be observed to be deep between the trochleae. The medial surface of the medial trochlear crest is not vertical and the crest is somewhat rounded transversely. The neck has an anterior notch. The proximal tubercle is obtuse but has a dorsal crest, while the medial tubercle is smooth with an ovate surface, and the lower median tubercle is only faintly indicated. The medial fossa is round and prominent. The sustentacular and calcanear facets are conjoined, and the calcanear facet is concave throughout with a small median upper process. The navicular facet is wider anteriorly than posteriorly and its borders are constricted in front of the posterior end. This produces an outline like the sole of a shoe.

Ectocuneiform. The small ectocuneiform is elongate, relatively narrow, and tapers to a point anteroventrally. The navicular facet is 14.9 long and 4.6 wide. The posterior tuberosity is large, wide and convex posteriorly. A lateral oblique median crest apparently had a large entocuneiform facet (it is broken off in this specimen). A small mesocuneiform facet is situated on the ventral surface at the lower end of the oblique median crest. A large facet for M^{t} III is 8.4 long, concave anteroposteriorly and transversely, wide anteriorly (3.2), and pointed posteriorly.

Metatarsal II. Only the distal 38.7 of the shaft is represented. It has a cross section 3.4 x 2.3 and a phalangeal condyle 5.2 wide.

Metatarsal III. This slender bone is 64.0 long but measures 65.5 around its curvature. Its cross-section, 20.0 below the proximal end, is 5.2 x 3.2 and the cross-section, 5.0 above the distal end, is 3.2 x 2.5. The ectocuneiform facet is convex anteroposteriorly, 3.2 wide anteriorly, and pointed posteriorly. There is a small sharp posterior tuberosity. The upper half of the shaft is gently convex on the lateral surface and has a sharp crest on the medial surface. The medial groove behind the crest on the medial surface widens and terminates slightly below the middle of the shaft. The phalangeal condyle is approximately 4.1 wide.

Metatarsal IV. This metatarsal is 76.7 from the posterior cuboid facet to the lower end of the distal facet and 16.0 wide at a point 13.0 below the cuboid facet. It is 20.0 wide across the distal trochleae (though part of the shaft is missing, the intervening space was cast in the field with the proximal and distal ends of the bone in place). The anterior surface is gently convex transversely. Only the anteromedial corner of the anterior cuboid facet remains. The posterior cuboid facet is tilted anteromedially on the posterior process. The plantar facet is somewhat triangular in outline, slightly convex dorsally, and faces posterolaterally. There is a distinct plantar sulcus between the posterior cuboid facet and the plantar facet. The sulcus curves dorsally on the proximolateral surface of the posterior process.

The proximal plantar ridge of the shaft is wide. The lateral and medial epicondylar tuberosities are broken off. The medial fossa is larger than the lateral fossa. The distal heel is sharply crested but extends 4.0 over the distal end of the shaft. The lateral and medial trochleae are only slightly elevated.

Metatarsal V. The M^{t}V is complete and is 69.9 long with a cross-section 20.0 below the proximal end of 14.4 x 10.2. The cross-section 25.0 above the distal end is 9.1 x 10.8. There is a prominent proximomedial tubercle. The shaft is slightly curved medially. The cuboid facet is concave transversely and extends on to the side of the proximomedial tubercule, and also curves over the anterior edge. There is a deep groove on the proximomedial side. The distal medial tuberosity is prominent as is the lateral epicondylar sulcus. The medial epicondylar sulcus is shallow. The distal keel is sharply crested and 5.5 wide at its base. It extends 3.5 over the distal end of the shaft. The lateral and medial trochleae are prominent at the proximal ends. The medial fossa is small but deep. The anterior surface of the convex distal end of the shaft has moved to the medial side.

Plantar sesamoid of M^t IV. This element is somewhat v-shaped with the point of the v at the ventrolateral corner. It has a large wide medial tuberosity proximally, and a wide intermediate sulcus. A small narrow lateral tuberosity has its proximal end opposite the distal end of the medial tuberosity. A distinct notch is apparent on the upper border medial to the proximal end of the lateral tuberosity.

Comparison. The medial curve at the tip of the incisor, the long sectorial crest on P_3, and the size and proportions of the postcranial elements, immediately suggest that *P. buloloensis* can best be compared with *P. otibandus* from the same formation, with small Pleistocene protemnodons, and with *Prionotemnus palankarinnicus* from the Palankarinna fauna of South Australia. The mandibles of *P. buloloensis* and *Prionotemnus* are about the same size, and much smaller than *P. otibandus* or any of the Pleistocene forms. The close proximity of the mental foramen to the alveolus of P_3 is in contrast to other known protemnodons and to *Prionotemnus.* The lower molars are smaller than in any other known species of *Protemnodon.* The anterior cingulum does not protrude as far forward as in the Pleistocene species and it is also relatively narrower transversely than in *P. otibandus.* The labial side of the anterior cingulum is less sharply declined than in *P. otibandus.* The absence of a posterior cingulum is also in contrast to that species.

The vertebrae are equal in size to those in the largest individuals of *Macropus* and *Megaleia,* but their capitulum facet is larger, as are the ribs. The calcaneum is shorter but wider than that in the three genera of large living kangaroos. The anterior edge of the olecranon shaft is not as sharp as that found in *Macropus, Megaleia,* or *Osphranter* and is more flattened than that in most wallabies. The tibial facet is deeper between the trochleae in *Macropus, Megaleia, Osphranter,* or what has been called *Protemnodon raechus.* All the metacarpals are considerably smaller than those in *P. otibandus.*

cf. DORCOPSIS, large form

The third species of macropodid in the Awe fauna is clearly not a protemnodon. This animal is poorly represented and the lack of the definitive premolar teeth makes it impossible, at this time, to assign the specimens to a known genus. Two maxilla fragments are assigned to this macropodid and hind limb elements from another individual are regarded as probably belonging to this form. Specimens are:

AM F49468: Right maxilla fragment of a mature individual with M^{1-4} in place. Maxillary process of zygomatic arch and maxillary foramen present. The wear formula is LMME. Locality — Gold and Power Company's Wiganda Creek workings, Upper Watut Valley, New Guinea, UCMP V6172.

UCMP 70132: Right maxilla with portion of the maxillary process preserved and M^3 in place. It is in an early stage of wear. Locality — Awe fauna type locality, UCMP V6234.

UCMP 70128: Right femur, distal half of right tibia, distal 30.0 of right fibula, astragalus, and calcaneum. Locality — Downstream from the Awe fauna type locality on eastern bank of Watut River, UCMP V6356.

Description and Comparison

Maxilla. The posterior edge of the base of the maxillary process is opposite the posterior moiety of M^3 on both AM F49468 and UCMP 70132. The process does not end abruptly, but tapers and fades posteromedially, and terminates below to M^4. The anterior edge of the process slopes rather gently anteromedially and possibly terminates dorsal to M^1. The anterolateral wall of the maxillary foramen is directly above the posterior base of the maxillary process in F49468.

Upper molars. The teeth, when the median anteroposterior length is measured, grade from large to small, in the order M^3, M^2, M^4, and M^1. Molars M^2, M^3, and M^4 are almost equally long. Although M^2 is almost rectangular in outline both M^3 and M^4 taper posteriorly: thus the metaloph, particularly in M^4, is narrower than the protoloph in each tooth.

M^1 is quadrate in outline and evidently had an anterior cingulum which extended across the labial half of the tooth. Much of the medial part of this cingulum is broken, but its labial end is preserved. The anterior cingulum terminates in a faint parastyle anteromedial to the paracone. The stylar nature of this structure is not apparent in occlusal view, but can be seen from the labial side (Fig. 11). A spur ascending from the paracone connects with the cingulum at the parastyle. The anterior cingulum is weak on the lingual side of the tooth and terminates just anterior to the protocone.

The midlink is weakly developed and is formed from both the protoloph and metaloph. It is straight anteroposteriorly. A spur runs posteriorly from the paracone to a point in the median transverse valley, half-way from the midlink to the labial end of the valley. It is joined in the median valley by a similar spur which ascends anteriorly from the metacone. The two spurs are not strongly developed, but are quite distinct. Another spur ascends posteriorly from the paracone to the labial termination of the median valley. At this point it is joined by a spur which ascends anteriorly from the metacone. At the junction of these two spurs a slight style is formed on the upper border of the enamel on M^1. Neither the small spurs nor the style block the labial mouth of the transverse valley. A posterior spur from the metacone ascends to connect to the very small posterior cingulum. This posterior cingulum is better demonstrated, as are most of the features, on the less-worn posterior teeth.

M^2 is essentially like M^1, but in M^3, in both AM F49468 and UCMP 70132, it becomes clear that the midlink is developed from both the protoloph and metaloph. The posterior molars demonstrate that the posterior cingulum is formed by a spur that ascends in a wide arc from the back of the hypocone. This spur almost crosses the posterior end of the tooth and joins the postmetaconal spur. The anterior cingulum on M^4 encloses a small valley. There is no evidence of a posterior median spur ascending from the metaloph. The crests on the protolophs and metalophs in all of the teeth are crescentic.

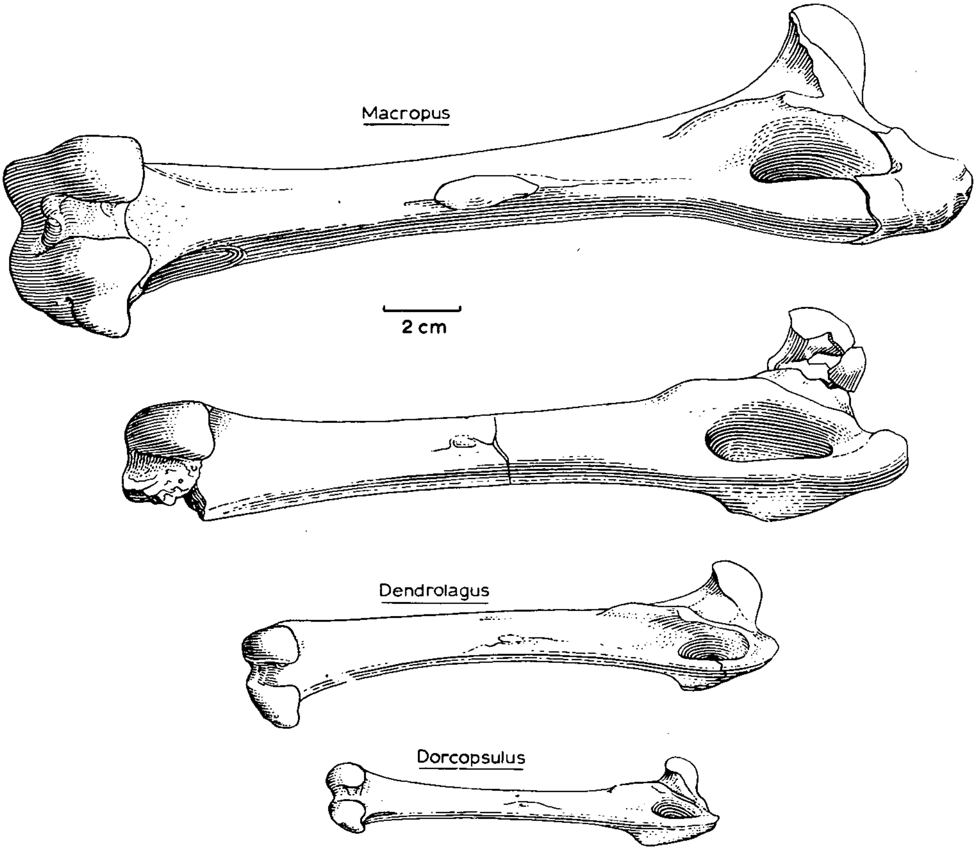


Figure 12. Right femura of *Macropus*, cf. *Dorcopsis* large form (UCMP 70128), *Dendrolagus*, and *Dorcopsulus*, posterior view x ½.

Measurements on upper molars

		1	2	3	4	5
AM F49468	M^1	7.3	7.0	7.0	1.8	2.0
	M^2	8.3	7.5	7.0	2.8	2.8
	M^3	8.4	7.7	6.9	3.0	2.9
	M^4	8.2	7.3	5.8	3.3	3.0
UCMP 70132	M^3	8.3	7.0	6.0	3.7	3.8

1. Median length; 2. Width of protoloph; 3. Width of metaloph; 4. Height of enamel at paracone; 5. Height of enamel at metacone.

Postcranial skeleton. The right femur referred to this form is of a mature animal with all epiphyses fused. It is complete except for the lateral condyle and epicondyle. The length from the greater tuberosity to the most distal point on the median condyle is 206.0. The cross-section of the shaft at a point 120.0 below to the greater tuberosity, is 18.6 x 16.7. A strong lateral crest is developed on the femur ventral to the greater tuberosity. This crest curves anteriorly and terminates in a rounded process opposite the ventral border of the trochanter fossa (Figs 12 and 13). From the process the crest gradually merges ventrally into the shaft.

Tibia. The distal 148.0 of the tibia, including the articulation facet, is preserved. The cross-section of the shaft is 16.0 x 13.4 sixty millimetres from the distal end of the bone. At this point the shaft is rather rectangular in cross-section. The median malleolus is short anteroposteriorly and although it is broken it was evidently higher anteriorly than posteriorly.

Fibula. The distal 30.0 of the fibula, including the articulation facet, is preserved. The lateral malleolus is bluntly rounded anteriorly and declines posteriorly. There is a well-marked tuberosity on the anterolateral side of the fibula just proximal to the lateral malleolus.

Calcaneum. The calcaneum is very short (40.8) and broad (27.5). The olecranon process is expanded transversely and the anterior outline of the shaft is slightly concave, from the lateral view. The anterior edge is smoothly rounded. The plantar surface of the olecranon process is smooth. The median sulcus on the olecranon shaft is deep, especially at the lower end, where it is partly roofed by an expanded and anteriorly curved plantar border. The sustentacular and astragalar facets are joined into a continuous articulation surface. The upper cuboid facet is flat and is separated from the lower cuboid facet by a nearly vertical anteroposterior wall. On the lateral side of the base of the olecranon process is a pair of unnamed tubercles.

Astragalus. The astragalus is complete. The tibial facet is very shallow between the trochleae. The median surface of the median trochlear crest is almost vertical as is the lateral surface of the lateral trochlear crest. The tibial fossa is ovate and prominent. The sustentacular and calcanear facets are conjoined. The calcanear facet is concave throughout and has no process. The

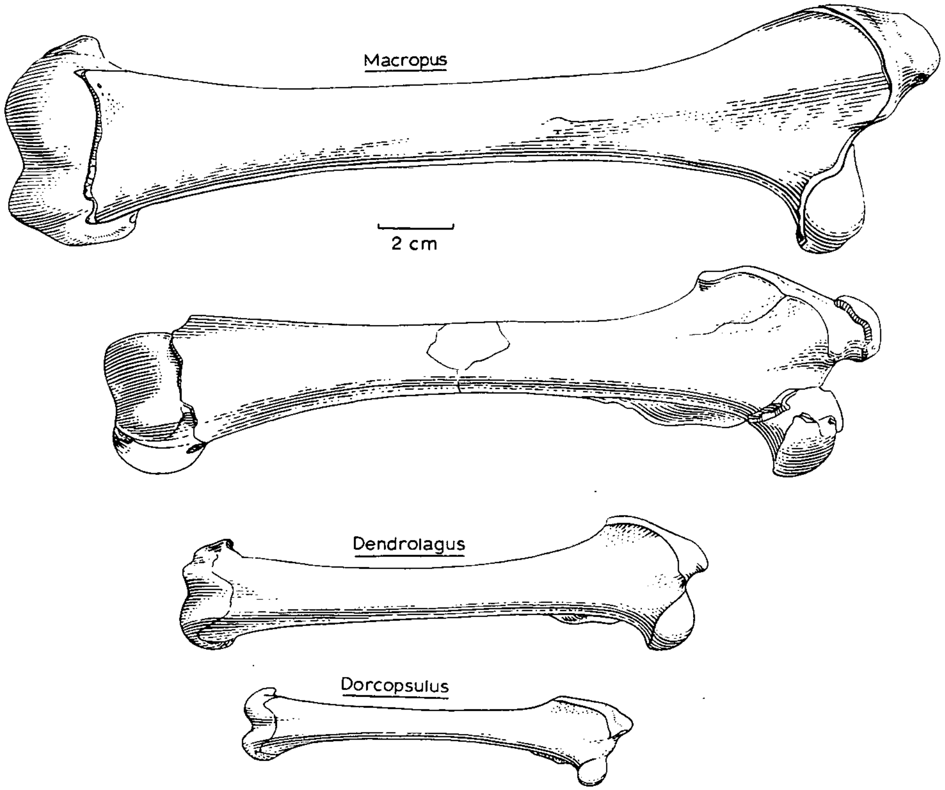


Figure 13. Right femura of ***Macropus,*** **cf.** ***Dorcopsis*** **large form (UCMP 70128),** ***Dendrolagus,*** **and** ***Dorcopsulus,*** **anterior view x ½.**

navicular facet is wider anteriorly than posteriorly and its lateral and median borders are constricted posteriorly.

Comparison. The elements, both cranial and postcranial, which are assigned to this macropodid bear resemblance to animals in the *Dendrolagus-Dorcopsis* complex of Tedford (1966). Comparisons have been made with *Dendrolagus goodfellowi* Thomas, 1908, *Dendrolagus dorianus* Ramsey, 1883, *Dorcopsis hageni* Heller, 1897, *Dorcopsulus vanheurni* (Thomas, 1922), *Petrogale xanthopus* Grey, 1855, and *Macropus giganteus* Shaw, 1790. The general morphology and proportions of the teeth are very like those seen and measured in *Dorcopsis hageni* (AMNH 109392). In detail the fossil is seen to differ in that neither *Dorcopsis hageni* nor any of the species of *Dendrolagus* examined have the second set of spurs ascending from the paracone and metacone to join at the labial edge of the transverse median valley. *Dorcopsis, Dorcopsulus,* and *Dendrolagus* also have relatively narrow anterior cingula and no development of parastyles.

The femur resembles both *Dendrolagus* and *Dorcopsulus* in that it has a prominent lateral crest below the greater trochanter. The intercondyloid fossa is shallower than in any of the Recent genera examined. The distal ends of both the tibia and fibula resemble the *Dorcopsis-Dendrolagus* animals in the shape of the lateral and medial malleoli.

The calcaneum is most like *Dorcopsulus* in general morphology but differs from it in some details, the most notable of which are: the strongly developed medial ridge on the olecranon process, and the development of the unnamed lateral tuberosities on the plantar surface.

The astragalus again more closely resembles *Dorcopsulus* but differs in detail. It is flatter and the median trochlear crest is much lower. Consequently the tibial fossa is shallower. The navicular facet is less restricted posteriorly in *Dorcopsulus.*

The above comparisons are by no means exhaustive, but it seems likely that this macropodid is closer to the *Dendrolagus-Dorcopsis* group than to the other macropodids. It is also probable that within that complex it is more closely related to the *Dorcopsis*-like animals than to the dendrolagines.

Family DIPROTODONTIDAE

Three diprotodontids are found in the Otibanda Formation. All have been named and described (Anderson, 1937; Plane, 1967). *Nototherium watutense* Anderson, 1937, is the largest and, as far as can be told from the present collections, the least numerous. It was initially described by Anderson in 1937; additional material has been described and figured by Plane (1967). It is known only from the lower posterior molars and a possible upper molar fragment. The lower molars are distinctive enough for some comparisons to be made with Nototherinae from the Australian Alcoota and Palankarinna faunas. The second largest animal is *Kolopsis rotundus* Plane, 1967. It is not well represented, but its upper dentition, particularly the premolar, strongly resembles *Kolopsis torus* Woodburne, 1967, from the Alcoota fauna, and shows similarities to *Zygomaturus keanei* Stirton, 1967, from the Palankarinna fauna and *Zygomaturus gilli* Stirton, 1967, from the Beaumaris fauna. The smallest and by far the best represented species is the most distinct and specialized *Kolopsoides cultridens* Plane, 1967. This animal represents a side branch of the subfamily Zygomaturinae. It is unique among the diprotodontids in having a three-rooted upper premolar. It may be related to the genus *Kolopsis* and could have evolved from a diprotodontid like *Neohelos tirariensis* Stirton, 1967, of the Kutjamarpu fauna.

Infraclass EUTHERIA

Order RODENTIA

Superfamily MUROIDEA

Family MURIDAE

A single upper incisor represents the entire infraclass Eutheria in the fauna, but very little can be told about this most interesting fossil from the Awe fauna type locality. That it is a murid is not certain, but I have assumed that it is, because the Muridae are the only family represented in the later records of the Region. Simpson (1961) has commented that the murid group which he refers to as 'Old Papuans' must have been in New Guinea since the Pliocene. This specimen confirms his view, and it is to be hoped that with careful collecting more diagnostic parts of these interesting endemic rodents will be found.

CORRELATION

Although there are potassium-argon dates of 5.7 and 7.6 m.y. for different levels in the Otibanda Formation, it is still not possible to correlate the Awe fauna precisely with the Pliocene faunas of Australia in which diprotodontids and macropodids have been found. The use of stage of evolution for correlation may be misleading in reference to the Awe diprotodontids and macropodids. In the Northern Hemisphere there are examples of mammalian groups which survived in lower latitudes after having become extinct in the middle latitudes where they were formerly distributed. The somewhat anomalous geochronological position of *Kolopsis rotundus,* which maintains certain primitive features in relation to nearly contemporary members of the subfamily occurring in Australian faunas, may indicate that a similar phenomenon has occurred in the Australasian region.

The advanced condition of the Awe species *K. rotundus* compared to the Alcoota species *K. torus* can be demonstrated in the following features of the P^3 of the New Guinea form: the greater height of crown, the more widely separated paracone and metacone, the more robust nature of the five major cusps, the shorter and steeper postmetaconal crest, the steeper labial surfaces, and the more labial position of the apices of the paracone and metacone.

On the other hand, a comparison of *K. rotundus* from the mid-Pliocene with *Z. gilli,* which most probably comes from the early Pliocene, reveals that although it occurs later in time, the New Guinea species is more primitive than *Z. gilli* from the Cheltenhamian Sandringham Sands. Characters in the upper third premolars which reveal this relationship include: posterolingual base of the protocone in *K. rotundus* not expanded to contact the anterolabial base of the metacone as in *Z. gilli,* small depression between the protocone and paracone in *K. rotundus;* shallower labial vertical groove between the paracone and metacone than in *Z. gilli,* size of the hypocone in *K. rotundus* larger relative to that of the protocone than in *Z. gilli.*

Kolopsis torus differs from *Z. gilli* not only in the characters which separate it from *K. rotundus,* but also in those by which *Z. gilli* differs from *K. rotundus.* In other characters, however, such as the absence of a well-developed cingulum labial to the molar parastyles and the lack of a premetaconal crest on the metaloph of the upper molars, *K. torus* is more directly aligned with *Z. gilli* than is *K. rotundus.* Nevertheless, *K. torus* is more primitive than either *K. rotundus* or *Z. gilli.* If the age of *Z. gilli* is early Pliocene, then that of *K. torus* must be no later than early Pliocene and may actually be late Miocene.

Kolopsoides represents another side branch of the Zygomaturinae. It appears to be more closely related to *Kolopsis* than to *Plaisiodon.* This is demonstrated in the separation of the paracone and metacone on P^3, the nearly square outline of M^1, and in the shape of P^3, which is relatively short and wide. It could have evolved from a diprotodontid like *Neohelos tirariensis* of the Kutjamarpu fauna. Some of the most conspicuous characters of *Kolopsoides* which distinguish it from *Kolopsis* are its elongate, three-rooted P^3, which has a widely emarginated

TEMPORAL RELATIONSHIPS OF VARIOUS MIDDLE AND LATE CAINOZOIC AUSTRALASIAN FAUNAS

TASMANIA	VICTORIA	SOUTH AUSTRALIA	N.TERRITORY	QUEENSLAND	NEW GUINEA	EPOCH
		MALKUNI KANUNKA				PLEISTOCENE
	FORSYTH'S BANK GRANGE BURN BEAUMARIS	PALANKARINNA		CHINCHILLA	AWE	PLIOCENE
		KUTJAMARPU	ALCOOTA			MIOCENE
FOSSIL BLUFF		NGAPAKALDI				OLIGOCENE

Figure 14. Correlation Chart

labial outline; a large parastyle that is aligned with, and connected to, the paraconal-metaconal crest and a hypocone which is larger than the protocone; P_3 with the two major cuspids aligned anteroposteriorly; and metalophid-like structures retained in the lower molars. No other species of *Kolopsoides* are known.

Nototherium watutense is not sufficiently known to offer the evidence we should like. It has been assigned to the genus *Nototherium* because it appears to be more closely related to the late Pleistocene species of *Nototherium* than to *Pyramios alcootense* of the Alcoota fauna. The short rather massive horizontal ramus, the posterior end of the symphysis below M_2, the steep inclination of the posterior symphyseal surface, and the reduced midlink-like structures relate it to *Nototherium* rather than *Meniscolophus*. Discovery of the premolars and incisors will help clarify its relationships.

The two species of macropodid assigned to the genus *Protemnodon* are demonstrably less advanced than the species known from the early Pleistocene of Australia. Although these animals are protemnodons, as evidenced by their size, the long sectorial premolar, the shape of the ventral outline of the mandible, and the proportions of the feet, we know no species of this genus from deposits of comparable or older age on the Australian continent. We are faced then with the same difficulties which beset us when attempting faunal correlation with the diprotodontids from this fauna.

Caution in faunal correlation with the Awe species of diprotodontids and macropodids is urged, as it may well be that they represent primitive, slowly evolving forms which survived in the lower latitudes after having become extinct in the middle latitudes where they were formerly distributed. The present state of our knowledge allows us to make the tentative correlations indicated on Figure 14 (see Stirton, Woodburne, & Plane, 1967).

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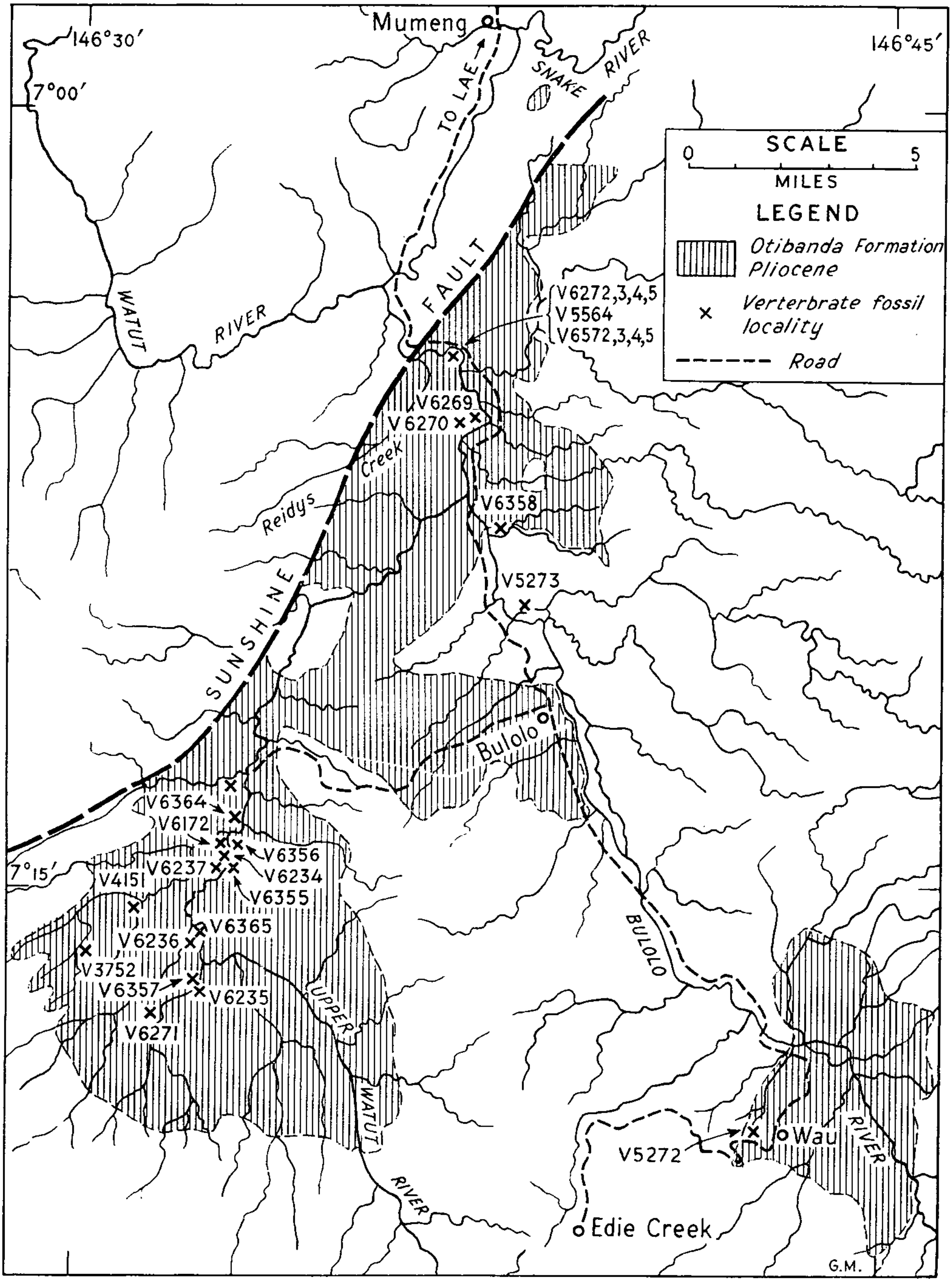


Figure 15. Fossil Localities

FOSSIL LOCALITIES

V 3752, *Fisher locality.* The lithology of this type locality for *Nototherium watutense* is not known. 4.5 miles south-west of the Gold and Power Company's residence at Slate Creek, on a water race which formerly drew water from Wiganda Creek, downstream from the present site of Kaumunga village. Nauti 1-mile Sheet.

V 4151, *Otto Bieri's workings.* The lithology is not known. At the junction of Christmas and Wiganda Creeks, 3.5 miles south-west of the Gold and Power Company's residence at Slate Creek. Nauti 1-mile Sheet.

V 5272, *Koranga locality.* Coarse ill-sorted conglomerate in the western wall of the Koranga Gold Mining Company's upper tail-race. 1 mile 178 yards north-north-west of the Wau District Post Office. Wau 1-mile Sheet.

V 5273, *Zoffman locality.* Stream channel deposits 20 to 30 feet above the present course of Anamapi or Coldwater Creek. 2.75 miles north of the Bulolo township Post Office. Bulowat 1-mile Sheet.

V 5564 *Sunshine locality, Woodard number 1.* Nine localities with greatly varied lithology are all referred to the general Sunshine locality. For details of their stratigraphic positions and lithology reference should be made to Figure 3. This former alluvial gold mining area is on the western bank of the Watut River approximately nine miles north of Bulolo township. The specific locality V 5564 refers to a claystone which is stratigraphically the second lowest fossil locality in the Otibanda Formation type section. Bulowat 1-mile Sheet.

V 5572, *Sunshine locality, Woodard number 4.* Buff sandstone 200 feet higher in the section than V 5564. Bulowat 1-mile Sheet.

V 5573, *Sunshine locality, Woodard number 2.* In the same buff sandstone unit as V 5572 but about 10 feet lower in the section. Bulowat 1-mile Sheet.

V 5574, *Sunshine locality, Woodard number 3.* In the same buff sandstone unit as V 5572 but 30 feet higher in the section than V 5572. Bulowat 1-mile Sheet.

V 6172, *Charlie Lawrence locality.* The lithology is not known. On the lower stretch of Wiganda Creek where the Gold and Power Company were working alluvial gold in 1961. The locality is now submerged beneath a pond. 1.4 miles south-south-west of the Gold and Power Company's residence at Slate Creek. Nauti 1-mile Sheet.

V 6234, *Awe fauna type locality.* Blue to grey claystone on a cliff about 20 feet above the western bank of the Watut River. This platform was formed by the removal of Quaternary gravels during alluvial gold-mining operations. 1.8 miles south of the Gold and Power Company's residence at Slate Creek. Nauti 1-mile Sheet.

V 6235. Blue-grey claystone on the south-east bank of Iroa Creek, 10 feet above water level in material which had slipped from the cliffs above. 4.2 miles south of the Gold and Power Company's residence at Slate Creek. Nauti 1-mile Sheet.

V 6236. Grey to light brown claystone in an erosional gully four to five yards off the track out of Surprise Creek going south. 3.1 miles south of the Gold and Power Company's residence at Slate Creek. Nauti 1-mile Sheet.

V 6237. Blue-green claystone on the west bank of the Watut River, five feet above river level. 2.2 miles south of the Gold and Power Company's residence at Slate Creek. Nauti 1-mile Sheet.

V 6269, *Widubash locality.* Brown ferruginous sandstone and blue-green sandy claystone have produced fossils at this alluvial gold mine which is the property of the Bulolo Gold Dredging Company. On the western bank of the Watut River 7.4 miles north-north-west of Bulolo township. Bulowat 1-mile Sheet.

V 6270, *Niba Gold locality.* Bleached white sandstone and tuff in a worked-out portion of an alluvial gold mine which belongs to Nichterlein and Branigan. To the west of the Watut River, 0.7 miles south-west of the Widubash locality (V 6269) and 7.2 miles north-north-west of Bulolo township. Bulowat 1-mile Sheet.

V 6271, *Blue tooth locality*. Brown arkosic sandstone on a disused water race 0.3 miles east-north-east of the Otibanda rest house (Haus kiap) and 4.2 miles south of the Gold and Power Company's residence at Slate Creek. Nauti 1-mile Sheet.

V 6272, *Sunshine locality, Stirton number 1*. In the same claystone unit as V 5564 but about 10 feet stratigraphically below it. This is the stratigraphically lowest locality in the Otibanda Formation type section. Bulowat 1-mile Sheet.

V 6273, *Sunshine locality, Stirton number 2*. Blue-grey claystone with interbedded brown sandstone about 120 feet stratigraphically above V 6272 in the Otibanda Formation type section. Bulowat 1-mile Sheet.

V 6274, *Sunshine locality, Stirton number 3*. In the same stratigraphic unit as V 5572, V 5573, and V 5574. It is about 10 feet stratigraphically above V 5572. Bulowat 1-mile Sheet.

V 6275, *Sunshine locality, Stirton number 4*. In the same stratigraphic unit as V 5572, V 5573, V 5574, and V 6274. It is about five feet stratigraphically below V 5574. Bulowat 1-mile Sheet.

V 6276, *Clissold locality*. Buff limestone and grey sandstone in the Gold and Power Company's workings on the eastern bank of the Watut River. 0.5 miles south of the (Gold and Power) Company's residence at Slate Creek. Nauti 1-mile Sheet.

V 6355. Blue-grey claystone on the western bank of the Watut River. Stratigraphically 15 to 20 feet above the Awe fauna type locality (V 6234). 1.8 miles south of the Gold and Power Company's residence at Slate Creek. Nauti 1-mile Sheet.

V 6356. Blue-grey claystone on the eastern bank of the Watut River downstream from, and stratigraphically lower than, the Awe fauna type locality (V 6234). 1.4 miles south of the Gold and Power Company's residence at Slate Creek. Nauti 1-mile Sheet.

V 6357. Dark grey-blue gritty sandstone on the western bank of Iroa Creek 30 to 40 yards back from the bank and 60 to 70 feet above creek level. 4.1 miles south of the Gold and Power Company's residence at Slate Creek. Nauti 1-mile Sheet.

V 6358. Coarse-grained brown arkosic sandstone forms an elevated terrace above an unnamed stream which flows into the Bulolo River from the east just upstream from the Bulolo-Watut junction. 4.6 miles north of the Bulolo township Post Office. Bulowat 1-mile Sheet.

V 6362. Lithology unknown. About three miles south of the Watut River-Slate Creek junction. This locality and the following one were supplied by the Geological Survey of Queensland. On the map supplied this locality is shown on the west bank of the Watut River between Suprise and Iroa Creeks. I have been unable to verify it by personal communication. Nauti 1-mile Sheet.

V 6363. Lithology unknown. A little over four miles south-south-east of the Slate Creek-Watut River junction. It is shown on the map on the eastern bank of the Watut River. Nauti 1-mile Sheet.

V 6364. *Dasyurid locality*. Grey-blue sandstone, mudstone, and interbedded tuff on a worked-out alluvial terrace. Western bank of the Watut River 0.96 miles south of the Gold and Power Company's residence at Slate Creek. Nauti 1-mile Sheet.

V 6365. *Foot bone locality*. Light grey gritty sandstone and tuff on a worked-out terrace about 80-100 feet above the western bank of the Watut River. 3.3 miles south of the Gold and Power Company's residence at Slate Creek. Nauti 1-mile Sheet.

Plate 1. Looking north down Watut River. P-Mzk: Kaindi Metamorphics, Tmg: Morobe Granodiorite, Tpo: Otibanda Formation. The 'Sunshine' fossil localities are off the picture to the left.

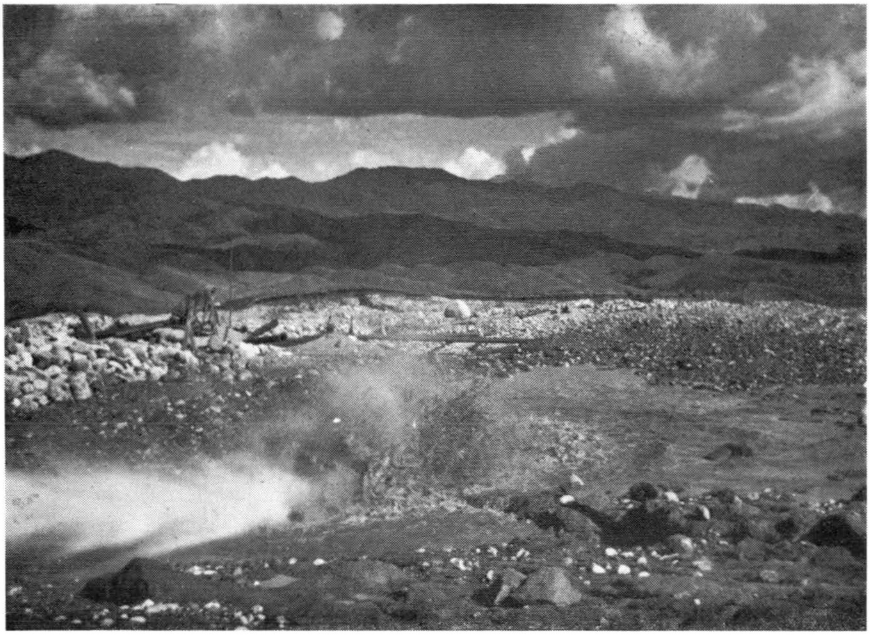


Plate 2/1. Alluvial gold sluicing, Sunshine workings. Kuper range, composed of Morobe Granodiorite, in background.

Plate 2/2. Typical exposures in Upper Watut Valley, looking west. High ridge in background is Ekuti Range.

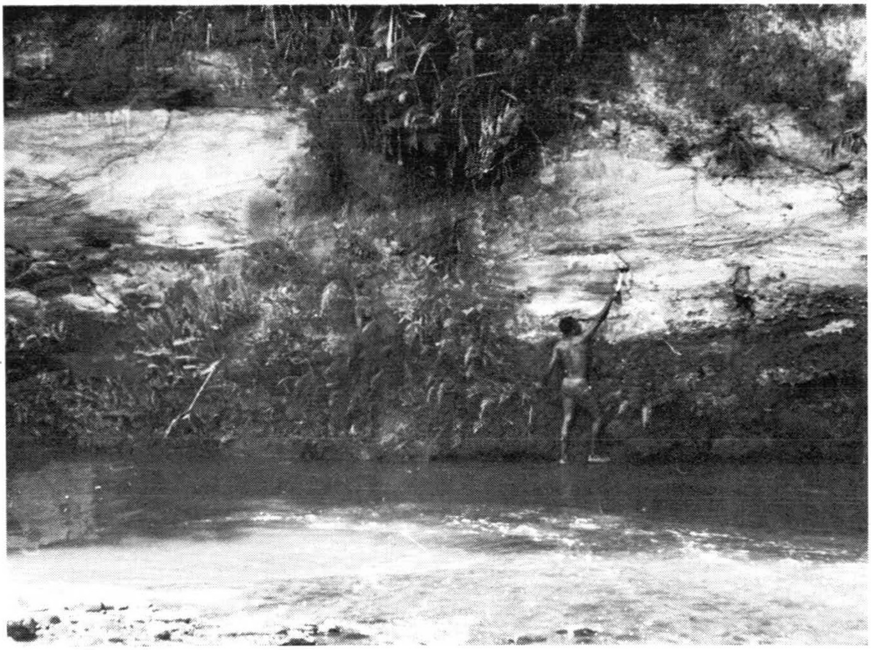


Plate 3/1. Cross bedded arkosic sandstone and pebble lenses, Iroa Creek, Upper Watut Valley.

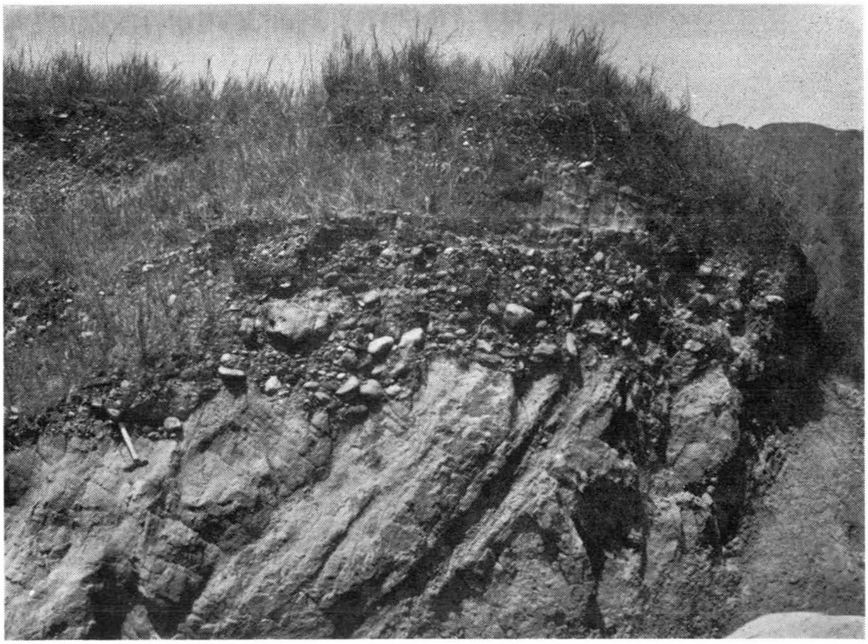


Plate 3/2. Pleistocene gravels unconformably overlying type Otibanda Formation.

Plate 4/1. Cliff of Pleistocene gravels, unconformably overlying Otibanda Formation rocks in foreground. 'Sunshine' locality.

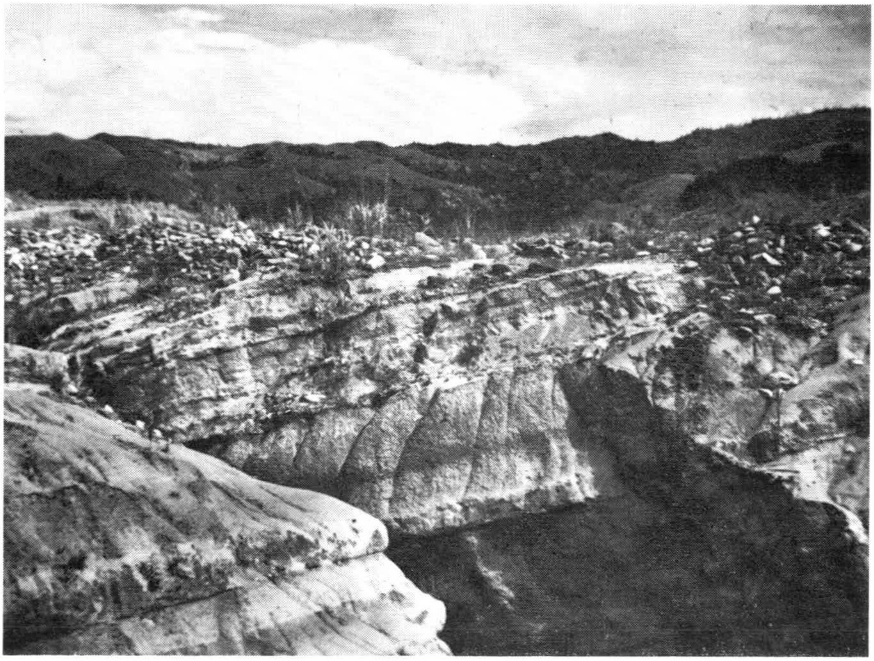


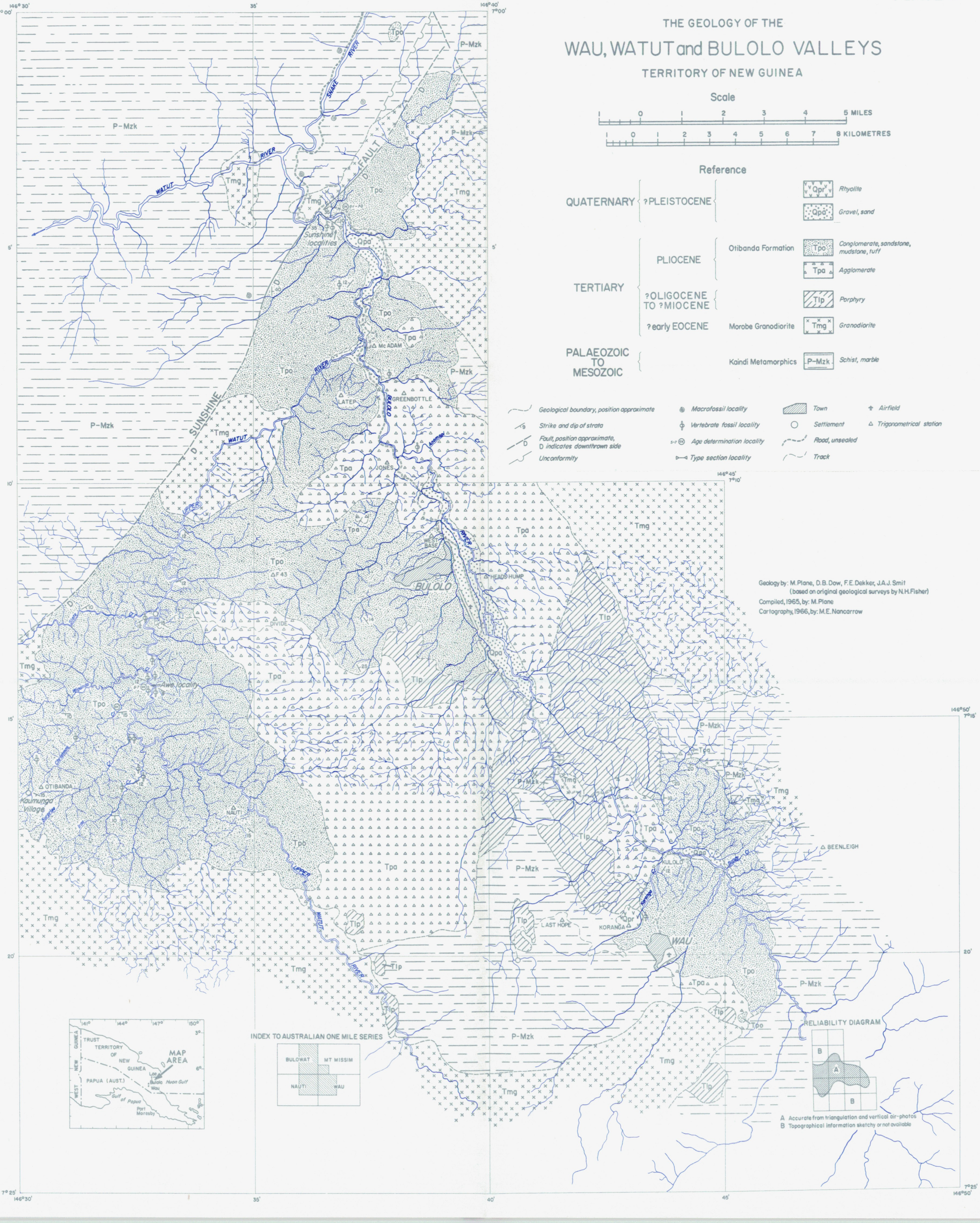
Plate 4/2. Southerly dipping Otibanda Formation, type section.

Plate 5/1. Stream channel in the Otibanda Formation. Koranga Creek measured section.

Plate 5/2. Awe fauna type locality on top of cliff near umbrella.
Looking south, Ekuti Range in background beneath clouds.

PLATE 6

THE GEOLOGY OF THE
WAU, WATUT and BULOLO VALLEYS
TERRITORY OF NEW GUINEA



Geology by: M.Plane, D.B.Dow, F.E.Dekker, J.A.J.Smit
(based on original geological surveys by N.H.Fisher)
Compiled, 1965, by: M.Plane
Cartography, 1966, by: M.E.Nancarrow