in the BEIR Committee has delayed publication of the final version. A sizable minority of the committee (perhaps now the majority) believes that the previously adopted linear no-threshold extrapolation from the effects at high-dose rates may overestimate the dangers of low-level radiation [see E. Marshall, *Science* **204**, 1062 (1979)].
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Melanesian Prehistory: Some Recent Advances

J. Peter White and Jim Allen

Summary. Human occupation of New Guinea had begun 50,000 years ago, but islands further east were settled only in Recent times. In part of the New Guinea highlands, wet and dry horticultural systems began by 9000 years ago. Local intensification is evident until the present, but only the most recent major crop (sweet potato, which has been grown in the region for less than 300 years) is documented. On the south coast, exchange systems and economies locally diversify over the last two millennia. In the Melanesian islands, exotic materials were moved 3000 kilometers 3000 years ago, but whether traders or colonists were involved is not yet clear. The prehistory of the area is proving more complex than was believed even a decade ago.

Speculation about the history of the inhabitants of New Guinea and adjacent islands to the east, the whole area generally referred to as Melanesia (Fig. 1), began with its early European discoverers and was continued into the mid-20th century by linguists, physical anthropologists, artifact collectors, and others (*1*). Scientific archeology in Papua New Guinea began in 1959 (*2*), and research during the following decade (*3*) established long-term artifact sequences in the central highlands and on the south Papuan coast. Subsequently, greater attention has been given to economic change and development. A Pleistocene occupation and the local development of intensive horticulture over the last 9000 years has been defined in the highlands, and on the south Papuan coast the growth of maritime-oriented coastal economies and exchange networks has been documented. In the eastern islands, movement of materials over long distances is found in the earliest dated sites, which were occupied by horticulturalists. We review these data here. We do not review data for areas or periods where, in our view, an integrated prehistory cannot yet be written, although research is being done in those areas (*3*, *4*). Almost no archeological research has been undertaken in Irian Jaya (*5*).

Only about 60 professional archeologists, including graduate students, have worked in the area, the majority within the last decade. Thus, an unusually high proportion of data and interpretation remains in unpublished papers, letters, and verbal communications. We have drawn on our knowledge of these, but refer to published reports wherever possible.

Early Inhabitants

The oldest definite archeological evidence for human occupation of the main island of New Guinea is scattered wood charcoal dated to 26,870 ± 590 years (sample ANU-191) associated with some flaked stone artifacts at Kosipe, Papua (*6*). The site lies within a series of mineralogically distinct volcanic ashes from Mt. Lamington, 140 kilometers distant; the Kosipe dates are confirmed by a fuller sequence of ashes nearer the source (*7*). A date of about 30,000 years is claimed (*8*) for burned wood and some impacted stones on the margins of a peat swamp near Mt. Hagen. A human cause is likely, but further details are not available. The Kosipe site is above 1900 meters altitude. Hope and Hope (*9*) have argued that its location is explicable in terms of the 50,000 km^2 of mountain grasslands which crowned the cordillera above 2200 m during the Pleistocene; these grasslands may have supported some now-extinct megafauna that would have been a favored prey of hunters. Some Late Pleistocene megafaunal remains known from the Highlands (*10*) occur in the same layers as artifacts at the Nombe site (*11*), but kill sites have not been discovered, and all occurrences to date are below 2000 m.

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Fig. 1 (facing page). (A) Melanesia, showing main islands. (B) Eastern New Guinea (Papua New Guinea) and the Bismarck Archipelago showing sites. Altitudes are given in meters.

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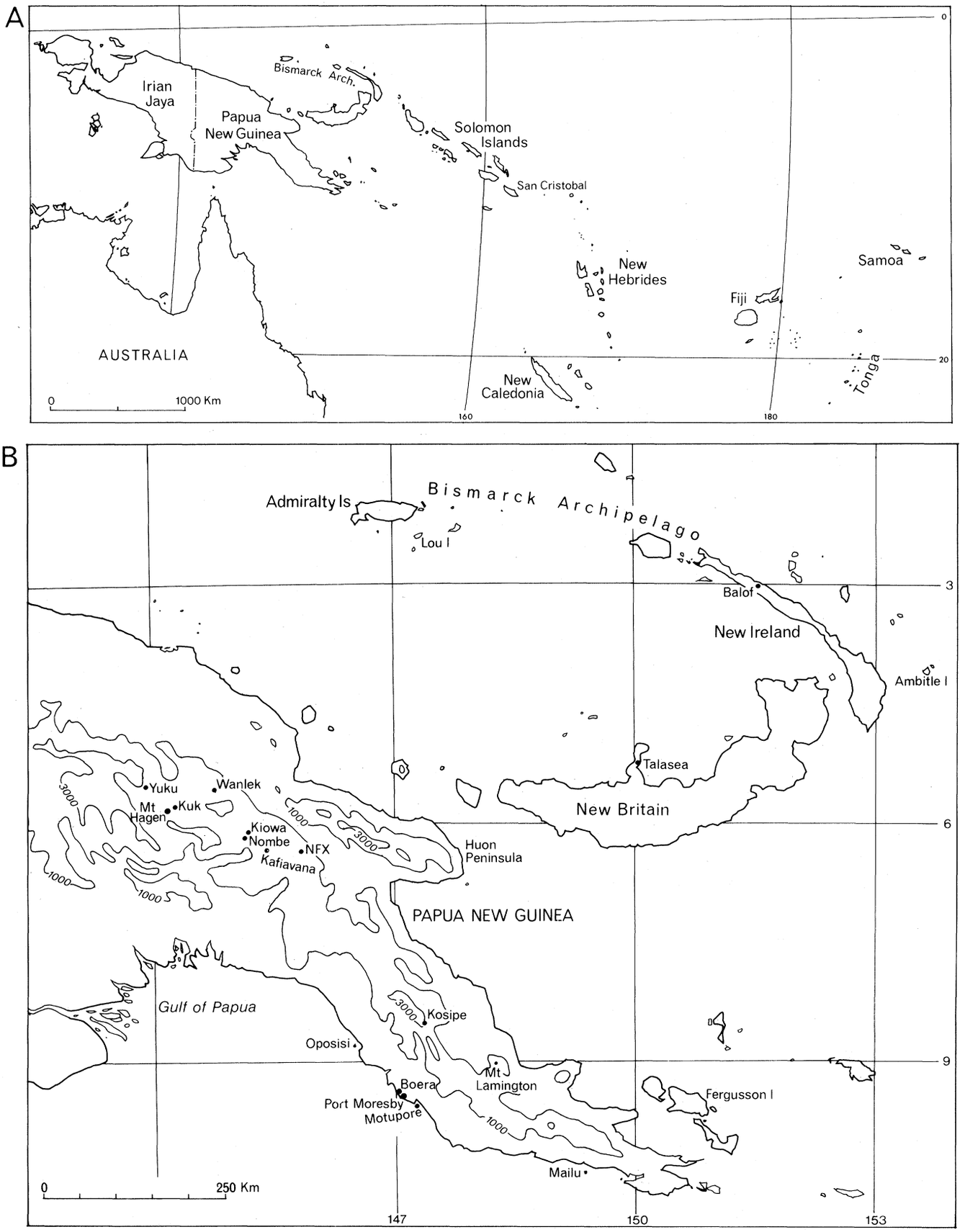
No comparably early, or early Holocene, sites have been found below 1000 m altitude, even in areas of rising or prograding coastline such as the northern side of the Huon Peninsula (*12*). Despite considerable searching, the oldest lowland site so far discovered dates only to 4000 years (*13*). Open sites [Wañlek (*14*), NFX (*15*)] and rock-shelters [Kiowa, Yuku (*16*), Kafiavana (*17*)] demonstrate human use of most of the interior uplands during the terminal Pleistocene.



Earliest occupation of the land mass probably occurred around 50,000 years ago, contemporaneously with Australia (*18*), to which New Guinea was joined until about 8000 years ago (*19*).

One tool form found in most sites older than 4000 years on the main island is the waisted blade (*11, 20, 21*) (Fig. 2), sometimes edge-ground. The occurrence of morphologically similar implements in sites of comparable age in Asia (*20*) and Australia (*22*), as well as in Recent contexts in the Solomon Islands (*23*), has led to considerable speculation concerning origins of the form; chopping or hoeing have been the assumed functions (*21, 24*). New Guinean continuations of the form have been seen in broad-bladed, tanged (stemmed) tools dating probably from mid-Recent contexts in the Highlands, although these latter have also been derived directly from Indonesian bronze prototypes (*25*). Most studies of waisted blades have included any tools with waisting (side notching) or tanging, despite differences in manufacturing techniques, raw materials, and size (*26*). In the Highlands, these tools coexist with unwaisted, ground stone ax-adzes for at least 5000 years (*16, 17*). Their early occurrence suggests that tool hafting is at least 30,000 years old in the region, but further work is required before their economic significance can be assessed.

Earliest occupation of the Bismarck Archipelago consists of food bone remains dated to 6800 ± 410 years (sample NSW-95) from the lowest level of Balof shelter, New Ireland (*27*). Claims (*23, 28*) for similar or greater antiquity are made for a surface collection of flaked stone artifacts from New Britain (*29*), but this is not independently confirmed. In New Caledonia, dates ranging from 7,000 to 13,000 years come from the shell cores of earthen mounds on the southern end of the island (*30, 31*), but no associated cultural material has been recorded, while the exact status of the material being dated is unclear. Pleistocene occupation of any island east of New Guinea remains to be demonstrated.

On the basis of the diversity and current distribution of Papuan (formerly Non-Austronesian) languages throughout the interior, linguists (*32*) suggest that the earliest inhabitants of New Guinea spoke languages of this stock. Languages of Austronesian stock, spoken by many coastal people in New Guinea and almost all islanders to the east, are considered to have been present in the area for at least 6000 years (*31, 33*). Although the majority view (*4, 33*) inclines toward an origin for the ancestors of this stock in southeast Asia and sees the spread in terms of migrations of people, we believe that the dynamics of their spread in Melanesia are unclear.

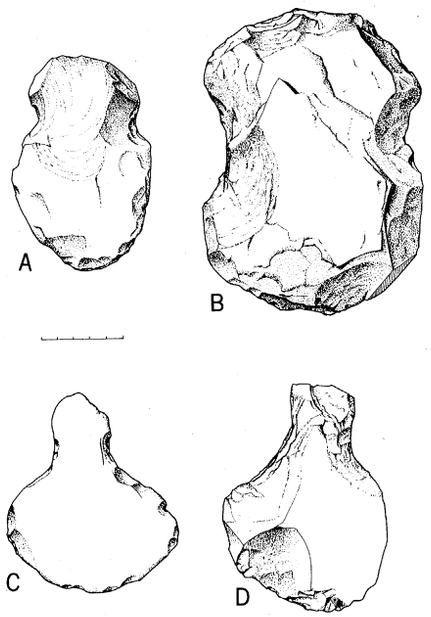


Fig. 2 Waisted (A, B) and tanged (C, D) blades from Kosipe (A, C), Nombe (D), and Kangaroo Island, Australia (B). The scale is in centimeters.

Physical anthropologists (*34*) derive the Melanesian populations from southeast Asia, but the exact sources and the relative importance of diversification since arrival as against original variability are still vigorously debated. Historical reconstructions on the basis of synchronic data have been strongly criticized recently (*35*), and no Pleistocene or early Holocene human skeletal material has been recovered to date.

The high degree of integration between archeological, linguistic, and, to a lesser extent, physical anthropological data observed by researchers (*34, 36*) immediately to the east in Polynesia has encouraged a search (*20, 31, 33, 37*) for similar correspondence in the area under review. With some limited exceptions, such attempts have failed. We believe this is because of longer time depths, a higher incidence of contact between peoples throughout the area, and greater sociological diversity. We suggest that a better archeological picture is required before any success can be anticipated.

Highlands Horticulture

Twentieth-century European explorers (*38*) of New Guinea's highland interior found large populations living in intermontane valleys at altitudes of 1600 to 2000 m. As many as 200 persons per square kilometer were supported by intensive horticulture of sweet potatoes and large herds of pigs (*39*). Earlier theories (*2, 40*) saw the history of the region in terms of migrations of peoples with their agricultural techniques and plants causing rapid changes in economy and population at various times over the last 5000 years. Recent investigations (*41*) in open swamp sites near Mt. Hagen show that present horticultural methods of drainage, mound building, and tillage were probably developed locally over the last 9000 years or more, although the proximate causes of this development have not been discussed in print. At Kuk, scene of research on the largest scale, Golson has reported three clear stages in the development of agricultural systems (*41*):

1) Irregular patterns of gutters, hollows, and mounds are dated to about 9000 and 5500 years. Designed to provide both wet and dry areas for cultivation (*42*), these features are associated with drains, 2 by 1 m in section and up to 2 km in length, which removed excess water from the swamp and its catchments to nearby streams.

2) Between 4000 and 2500 years ago, a dendritic pattern of hierarchically scaled drains removed more water from larger areas. The introduction of this system suggests locally increased swampiness.

3) Dating from about 2500 years ago, a grid pattern of small ditches articulating with larger drains was constructed. Over time the small ditches were dug shallower and they were spaced more closely, again suggesting increased swampiness of the area. Golson's account links this to forest clearance, with concomitant increased soil erosion of the surrounding slopes, an interpretation supported by pollen analytical data (*43*).

No direct evidence for the crops grown has yet been obtained, with the exception of one *Lagenaria* exocarp and pollen from indigenous herbaceous domesticates recovered from a ditch at Minjigina site in the same area and dated to about 2300 years (*43*). Present subsistence horticulture relies heavily on sweet potato (*Ipomoea batatas*), a plant of South American origin (*44*) brought by Europeans to the Philippines only in the late 16th century A.D.; it probably arrived in the New Guinea Highlands no more than 300 years ago. Charred remains less than 250 years old occur at Kuk (*41*). Prior to that time, crops presumably included plants originating both locally [for example, Australimusa bananas, sugarcane, and *Pueraria lobata* (*45*)] and in southeast Asia (for example, taro and yams), but none of these has the

hard seeds or skins that are normally preserved archeologically. A pollen record will be difficult to obtain, for some plants produce little or no pollen at this altitude and human harvesting of others (such as taro) usually occurs before the flowering. The suggestion that taro was a major root crop for at least the last 6000 years (*41*) is, then, inferred from the horticultural systems' evidence of wet cultivation.

Some plant food remains are reported (*46*) from rock-shelters on hillslopes 8 km south of Kuk. Preliminary studies suggest that the fruit of one local tree, *Pandanus julianetti*, evolved from a thick-walled (?wild) to a thin-walled (?domesticated) variety during the last 9000 years.

Artifacts occur in direct association with other swamp agricultural systems dating back to 2500 years (*24*). Paddle-shaped wooden spades as long as 2.5 m and bipointed digging sticks as well as ground stone ax-adzes, all similar to those recorded by the first Europeans in the area (*24*), have been found in the ditches. Similar ax-adzes occur in rock-shelter sites in the Highlands back to 10,000 years (*17*).

Although largely an autochthonous development, Highlands' economies were in contact with the coasts. The earliest evidence for this is the presence of *Cypraea moneta* L. shells in a level dated at or greater than 9500 years (sample ANU-20) at Kafiavana shelter (*17*); sea shells occur in later levels of this and other sites. Obsidian from both Talasea and Fergusson Island has been traded into the area during the last 3000 years, with ceramics entering the eastern area only during the last 1000 years (*15, 17*). Distribution mechanisms within the Highlands have been described by Hughes (*47*) and others (*48*), but the antiquity of these has not been determined, although we believe that similar styles of exchange systems have existed in the area throughout the period of human settlement.

Domestic Animals

Throughout the Highlands today, protein and prestige derive largely from pigs (*Sus scrofa*) of southeast Asian origin. Prehistoric remains come primarily from rock-shelter sites (*16*) and most date to within the last 2000 years. At Yuku and Kiowa sites a small handful of cranial specimens are claimed (*49*) for levels as old as 10,000 years. Elsewhere (*17*), five fully identified specimens date to more than 4690 ± 170 years (sample ANU-42) but considerably less than 9500 years (sample ANU-20). The presence of pig wallows in 9000-year-old levels at the Kuk site has been tentatively proposed (*50*). One argument against the earliest dates is the absence of feral pigs from northern Australia in prehistoric times. Given their highly successful colonization of that area during the last 100 years (*51*), if they were in the Highlands 10,000 years ago we would also expect them in Australia, since the present water barriers did not exist then.

The domesticity of all prehistoric animals is difficult to assess. Today, pigs in most areas are tame rather than domestic and are expected to breed with feral or "wild" boars. Consequently, even where samples are large, no morphological changes consequent on domestication may be expected. Current pig herd numbers often equal or exceed those of humans, and the adoption of sweet potato, which provides greater returns for labor and matures more quickly in the Highlands (*52*), would allow considerable expansion of herds (*39, 53, 54*). More broadly, Morren (*54*) has argued that agricultural intensification in the area may be motivated in part by a desire to increase pig herds, a view that implies continuing growth of the pig:human ratio over the last 4000 years or more. This view is more consistent with the archeological evidence than is Watson's (*53*) suggestion of very rapid, recent growth in this ratio, but further data are required to test these models.

Somewhat surprisingly, dogs (*Canis familiaris*) have not been found in Highlands sites older than 1000 years. Specimens from the south coast of Papua are no more than 2000 years old (*16, 55*). The oldest dogs in Australia are about 4000 years old (*56*).

Papuan Coastal Economic Diversification

Well-defined settlement in south Papua began when marine-oriented horticulturalists settled some 650 km of coastal environments about 2000 years ago (*13, 57, 58*). Initial occupations are contemporaneous and are marked by a suite of artifacts that includes elaborately decorated pottery (Fig. 3A), adze forms similar to particular Polynesian

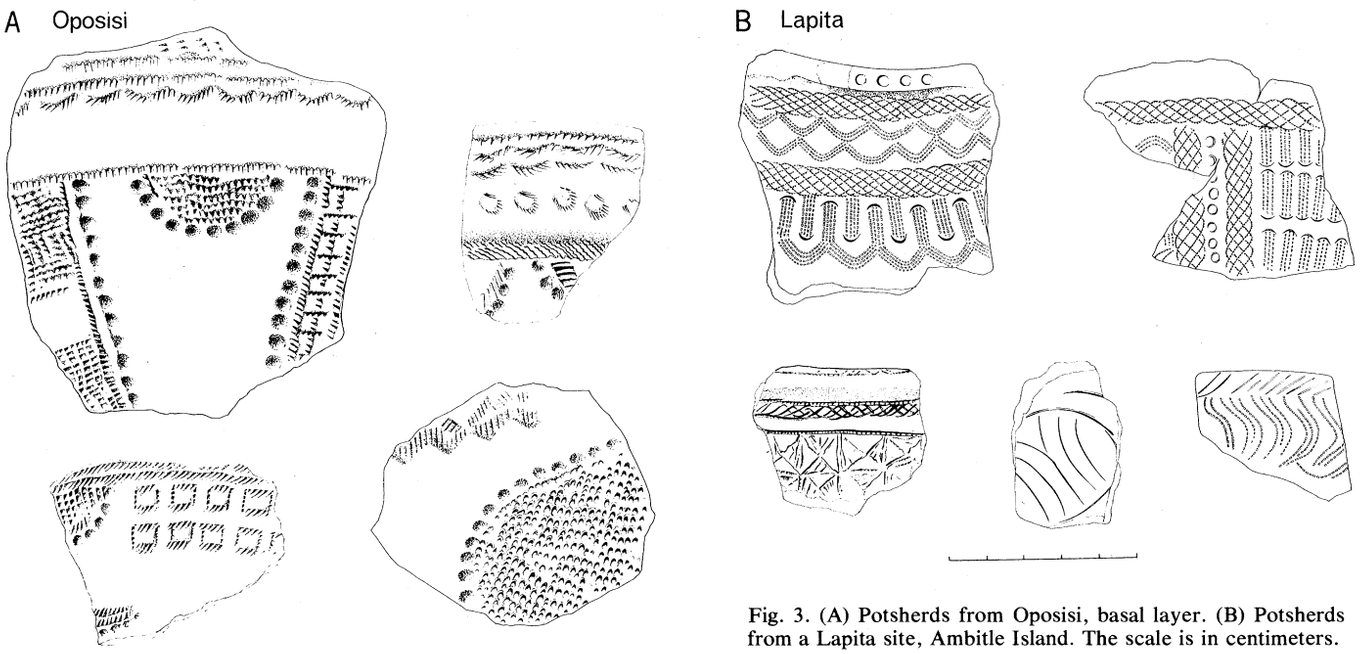


Fig. 3. (A) Potsherds from Oposisi, basal layer. (B) Potsherds from a Lapita site, Ambitle Island. The scale is in centimeters.

adzes, and obsidian transported from Fergusson Island (*59*). At Oposisi (*57*), the site that has yielded the best reflection of this initial settlement, the earliest levels contain a wide range of bone tools and ornaments, including lime spatulas, beads, human cranial tablets, and gravers. A number of researchers have noted the similarities between this repertoire and the Lapita assemblages (*16, 57, 60*), particularly with respect to the ceramics, but the exact derivation remains obscure. The suggestion that these groups spoke an Austronesian language or languages (*55, 57*) finds support in recent linguistic research (*61*) in the area, which places the separation of local Austronesian languages along the coast at 3000 years.

At Oposisi, a cultural distinction has been drawn (*57*) between the earliest and subsequent levels, but in other sites this division is not clearly visible; changes in the material remains at these sites have been interpreted as gradual development, including adaptation to local coastal environments and assimilation with preexisting populations. At sites located between Port Moresby and the Gulf of Papua, ceramic sequences show the same evolution between about 2000 and 1200 years ago and attest close interaction between groups. Site locations vary from offshore islands and coastal beaches to inland plains and hilltops and from dry savannah areas to deltaic swamps with heavy rainfall. Intercommunity exchange is evident, but the degree to which this can be called trade cannot be assessed without finer-grained excavations and analyses.

Discontinuities in this archeological record of gradual evolution appear along the south coast about 1200 to 1000 years ago (*55, 57, 58*), and from this time the cultural homogeneity of the first millennium A.D. is replaced by increasing local diversity. In the Mailu area (*58*), the major discontinuity is visible in the ceramics, while other elements indicate continuity. All data indicate no subsequent radical changes until the late 19th century. Further west, pottery styles change and the trickle of obsidian found in the first millennium sites appears to cease, although a few flakes of this material have been recently reported near Port Moresby in two inland sites which date to this later period (*62*). On the coast itself, site locations alter, and the evidence from one newly settled site, on the islet of Motupore (*60, 63*), indicates a subsistence pattern heavily dependent on a restricted selection of local fauna. In the Port Moresby area, a previous hiatus in the archeological record around the beginning of the second millennium A.D. may now be covered by recent excavations at Taurama and Boera but details are not yet available. Whatever the cause of the discontinuity, coastal occupations around 800 years ago display many features indicating direct ancestry of the subsistence pattern of the late 19th century.

One aspect of the local diversification of the last millennium is the development of the two elaborate maritime trading systems recorded at the time of European contact. These have been investigated by both archeological and historical techniques.

The Mailu system was described early in the 20th century by Malinowski (*64*) and Saville (*65*). Detailed archeological work has so far been restricted to the technological evolution of this system. In this, Irwin (*58, 66*) has shown that in the period of initial occupation Mailu was only one of a number of centers producing pottery in the area, with clay being taken from at least five different locations. By the beginning of the historic period, Mailu was a much larger village than any in the region, it was the central place, it was the only pottery-manufacturing village, the only one possessing large ocean-going canoes, and hence the only village engaged in long-distance trading voyages in both directions along the coast. Its pottery had become extremely standardized in terms of production techniques, size, shape, and decoration. The archeological evidence suggests internal evolution of the system, but nonetheless Irwin (*58*) points to about 300 years ago as the approximate period when the specialized trading aspects become dominant.

Archeological evidence for the western Motu system, centered on Port Moresby and described by Barton (*67*), indicates an evolutionary course rather different from that seen at Mailu, though with a similar end result. Linked by oral tradition and linguistic evidence to the late 19th century Motu, the site of Motupore has produced archeological evidence interpreted as a reflection of the ethnographic picture (*63*). Economically, that picture shows an intensive local trade in pottery, and presumably other marine nondurables such as salt and fish traveling inland against a large-scale return of stone, wallaby flesh, and presumably vegetables. Since changes throughout the Motupore sequence are minor and evolutionary, this economic picture can be traced back to almost the beginning of occupation. Over that same period, simplification of pottery decoration and intensified production echo events in Mailu.

Some contemporary sites in the area are interpreted as having more generalized economies than Motupore (*62*). This local contrast, along with the technological evidence, suggests that, like Mailu, Motupore became a specialized trading center, developing the complexity seen in the 19th century during the last 800 years. The growth of the main long-distance annual trading voyage (*hiri*) of the Motu has not been investigated archeologically, but oral traditions suggest it is not more than 300 years old (*60*).

The evidence supports, in our view, an interpretation of rapidly developing specialized trading centers and increasing cultural diversity during the last 1000 years [see (*57*) for a gradualist evolutionary model]. Our interpretation fits well with data from research projects in other areas suggesting similar increases in cultural diversity during the last millennium (*60, 68, 69*) and also with suggestions that other maritime trading systems recorded in the 19th century in New Guinea and the Bismarck Archipelago are probably of no great antiquity (*60, 68*). However, a general explanation of these changes still eludes us.

Long Voyages and Lapita Pottery

Data from the Bismarck Archipelago show not only that this area was settled well before the advent of pottery but that stone from various sources was moved to sites more than 500 km away at least 6000 years ago (*27*). Green (*70*) believes that by about 4000 years ago two cultural innovations, the outrigger canoe and a horticultural base of root and tree crops together with some domestic animals, enabled populations from this area to occupy all major islands as far southeast as New Caledonia. A similar model has been proposed on linguistic grounds (*33*). The only archeological support for such a settlement comes from the dubious New Caledonian mound evidence (*30*), as Green's (*71*) recent review of the evidence makes clear. We think that early settlements as far south as San Cristobal Island are to be expected, given short (less than 75 km) water crossings and interisland visibility, but that the early dating of much longer sea voyages to islands beyond this point requires fuller documentation. Evidence of the ability to undertake such voyages will be provided if indications (*72*) of a pre-

ceramic occupation in the Admiralty Islands are confirmed, since an open sea crossing of 175 km is required to reach them.

The earliest firm archeological evidence from islands east of the Bismarcks comes from a number of sites dated between 3500 and 2500 years ago, though clustering in the lower half of that range. These sites are particularly characterized by Lapita pottery (*4, 71*), most recognizable by the bands of very fine geometric decoration impressed with toothed stamps (Fig. 3B) on some of the decorated sherds. Other intersite similarities include their location in coastal or offshore locations; the presence of villages rather than dispersed settlements; an economy that included horticulture, domestic pigs, and heavy exploitation of reef and lagoon (rather than open sea) fish, shellfish, and turtles; and a range of similarly formed shell and stone tools. The near contemporary appearance of Lapita sites throughout island Melanesia has led to some acceptance (*37, 73, 74*) of Green's (*75, 76*) original interpretation of Lapita potters as specialized, long-distance traders who undertook two-way voyages of as far as 600 km. Exchange certainly occurred, since many of these sites contain artifacts of exotic origin, the most spectacular being obsidian flakes in sites in the southeast Solomons, the New Hebrides, and New Caledonia, which have been sourced to New Britain and the Admiralty Islands (*59, 76*)—straight-line distances of nearly 3000 km. However, the long-distance movement of raw materials and artifacts is documented archeologically on so small a scale at present that in our opinion it neither proves that people making Lapita pottery specialized in long-distance trade, nor even demonstrates the mechanisms of movement (*58, 77*). The trader model depends on prior colonization of southeastern Melanesia (*78*) (otherwise, with whom were these people trading?) for which archeological data do not exist. An added complication arises from a recent survey (*72*) in one of the source areas of raw materials, the Admiralty Islands. Obsidian from Lou Island in this group was entering a geographically dispersed range of Lapita sites more than 3000 years ago, yet surveys have failed to reveal any Lapita pottery in the 80 sites now located in a wide range of likely environments. A trader model of the Lapita phenomenon would seem to require such sites.

An alternative model of the Lapita cultural complex is a colonization one. Our view, which is similar in many respects to Green's (*70, 71*) more recent interpretations and to Irwin's (*79*), is that present archeological evidence is still not at variance with the hypothesis that all Lapita sites east of the Solomon Islands are those of highly mobile colonists who maintained communications and supply lines back to hearth areas and between colonies. This model is most strongly supported by evidence from Lapita sites in Fiji (*80*), Tonga (*74, 81*), and Samoa (*82*). These are probably reflections of initial colonization; while lacking the exotic raw materials of more westerly sites, they display no other gross differences in site inventories or economic behavior.

The colonization model is less certainly applied to Lapita sites within the Bismarcks. Green's (*71*) view is that this area saw the development of the Lapita cultural complex, apparently by settlers from island southeast Asia. Since the region was populated well before this development, and since there is no archeological evidence of southeast Asian presence in the area so early, we question the need to elaborate the simpler hypothesis of local cultural development. We agree that some contact between the Bismarcks and islands to the west is likely around 4000 or more years ago [compare (*83*)] and that such contact may have resulted in the acquisition of certain items and technological knowledge, but we think that most of the technological and economic aspects of the complex could have developed within a local context.

In conclusion, we reiterate that evidence of preceramic settlement and resource movements in the Bismarck Archipelago and of the apparently later settlement of the remoter eastern islands by colonists making Lapita pottery is not compatible with the traditional view (*4, 33*) that the islands of Melanesia were first settled by a migration of peoples bringing Austronesian languages, pottery-making, horticulture, and the art of ocean voyaging from mainland or island southeast Asia. The first two skills may have their origins in that area but probably were considerably modified in Melanesia, whereas the latter two were largely local developments.

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Injuries from the Wichita Falls Tornado: Implications for Prevention

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Tornadoes rank among the top natural disaster killers in the United States (*1*). During the past 50 years, more than 9000 people have died from tornado-related injuries and another 9500 have died in severe windstorms. Improved severe storm forecasting with radar and satellites, tornado warning systems, mass public awareness programs, and improved house construction may have helped decrease this toll of tornado deaths over the years (*2*). Nonetheless, in areas such as Wichita Falls, tornadoes devastate approximately one out of every 2500 square miles of land per year and periodically strike populated communities. New approaches to preventing these tornado-related deaths and injuries are needed (*3*).

Current guidelines for public safety in severe storms are prepared by the National Oceanic and Atmospheric Administration's (NOAA) disaster preparedness staff (*4*). Observations and anecdotal information collected by architects, engineers, and meteorologists after major disasters are translated into safety recommendations (*5*). Currently, people at home are advised to seek shelter in a basement, hallway, closet, or interior room, and to cover themselves with pillows, blankets, or mattresses; people in cars in open areas are advised to drive in a direction perpendicular to the path of the tornado, but if this is not possible, to leave the vehicle and lie flat in the nearest ditch or ravine. People in cars in urban areas are advised to seek shelter indoors. Despite widespread dissemination of these recommendations, their effectiveness in reducing the toll of deaths and injuries has never been tested.

The tornado that struck Wichita Falls, Texas, at 6:15 p.m. on 10 April 1979 provided an opportunity to apply epidemiologic methods to examine the causes of death in these severe storms and to assess the effectiveness of current safety recommendations. The Wichita Falls tornado was ranked at four on the Fujita scale of tornado strength, placing it among the severest 3 percent of all tornadoes in the United States (*6*). The tornado, which had wind speeds estimated to be in excess of 200 miles per hour, devastated an 11-square-mile area (Fig. 1) of residential community and caused damage in excess of $300 million (*7*). Forty-seven people died and hundreds were injured and required emergency care. More than 3000 of the approximately 4800 homes in this area were either completely destroyed or rendered uninhabitable and in need of major repair.

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