Ancient Environmental Degradation

PATRICK V. KIRCH, JOHN R. FLENLEY, DAVID W. STEADMAN, FRANCES LAMONT, AND STEWART DAWSON

Prehistoric Human Impacts on an Island Ecosystem: Mangaia, Central Polynesia

An interdisciplinary study of Mangaia Island in Central Polynesia has outlined a sequence of environmental change over the past 7000 years. The arrival of prehistoric Polynesians ~2000 years ago resulted in a series of dramatic changes to this previously isolated island ecosystem. Deforestation of the central volcanic core, increased rates of erosion and sedimentation in the valley bottoms, extinction and extirpation of native land birds and of nesting seabirds, and the introduction of exotic species are among the main environmental changes indicated. The loss of most species of indigenous land birds was accompanied by an increased dependence on domesticated pigs and chickens. The growing human population intensified the stresses on Mangaia's natural resources, resulting in a stratified society that placed high value on intensively cultivated agricultural lands.

THE VOLCANIC AND CORAL ISLANDS of the central Pacific have long held the attention of biogeographers as a theater of evolution and adaptive radiation.[3,9] Prior to human colonization, these isolated islands and archipelagoes were devoid of land mammals or large predators. The highly endemic biotas of these islands are therefore characterized by reduced interspecific competition and vulnerability once isolation was broken down.[8,9] As the botanist Raymond Fosberg put it, "perhaps the thing that most distinguishes... oceanic islands... is their extreme vulnerability, or susceptibility, to disturbance."[7:559]

The human discovery and colonization of the remote central and eastern Pacific (i.e., the region usually labeled Polynesia) commenced with the rapid dispersal of Austronesian-speaking peoples in the mid-second millennium BC. Archaeologically, this dispersal is evidenced by the Lapita Cultural Complex[13] and by the various Polynesian cultures that were derived from Lapita.[15] The Western Polynesian archipelagoes of Samoa and Tonga were first settled by 1200 BC, whereas the colonization of New Zealand did not occur until about AD 800. This Polynesian dispersal marked the first significant breakdown in the biologic isolation of oceanic islands. The colonizing Polynesians were horticulturalists who introduced a variety of tropical root, tuber, and tree crops (e.g., *Colocasia* taro, *Dioscorea* yams, breadfruit, and bananas), as well as domestic pigs, dogs, and fowl. Other plants, such as garden weeds, and animals (including geckos, terrestrial snails, and certain insects) were inadvertently introduced as well. As their populations expanded over the centuries following initial settlement, the Polynesians significantly affected their island ecosystems through both direct and indirect impacts. Forest clearance for agriculture, hunting and gathering of wild foods (especially endemic and indigenous land birds), landscape modifications for irrigation and settlement, and other activities led to the transformation of natural into culturally modified and socially manipulated landscapes. Archaeological, palynological, and paleotological studies on various Polynesian islands have begun to reveal the extent and nature of environmental changes wrought by prehistoric Polynesian occupation.[1,4,6,10,11,16–21,23]

To further explore the nature of human-induced environmental changes on small Polynesian islands—and more importantly, the reciprocal effects of such change on the island societies themselves—in 1989 we commenced an interdisciplinary investigation of Mangaia in the Southern Cook Islands (Figure 1). Our aim has been to apply the varied methods and data of archaeology, geomorphology, palynology, and avian paleontol-

Figure 1.
The Tangatatau rock shelter (site MAN-44) prior to excavation.
P.V. KIRCH

NATIONAL GEOGRAPHIC RESEARCH & EXPLORATION 8(2):166–179; 1992

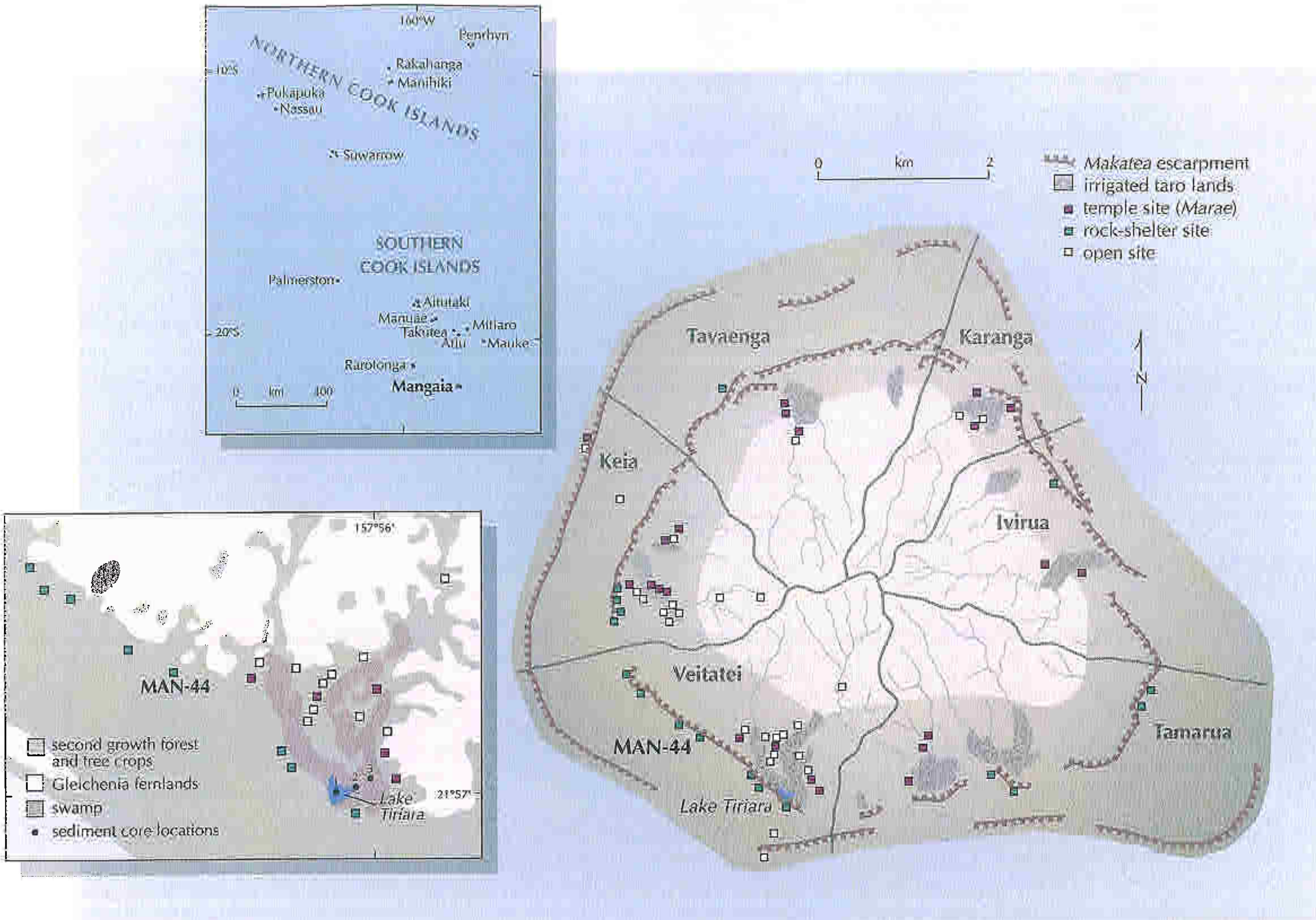


Figure 2.
Mangaia Island, showing the Veitatei study area and locations of key sites. Top inset shows locations of archaeological sites, the Tangatatau rock shelter (MAN-44), and the pollen cores (TIR-1, -2, and -3). Lower inset shows location of Mangaia within the Cook Islands.

ogy to the reconstruction of the prehistoric environment during the middle to late Holocene (ca. 7000 BP to present), thus spanning the period prior to and following Polynesian occupation of the island. This report briefly summarizes our key findings and discusses their wider implications.

Mangaia: Environment and Culture

We selected Mangaia as our field site because the island exhibited several geologic and geomorphic features conducive to the preservation of a Holocene stratigraphic record and because David Steadman's[19,20] previous paleontological survey had revealed bones of extinct birds, in limestone caves. Mangaia (157° 55' E, 21° 55' S) is the most southerly of the Cook Islands (Figure 2), with a total land area of 52 km^2. Geologically, the island consists of two main formations: a central volcanic cone, rising to 169 m, of highly weathered basalts dated to 17 million to 19 million years ago, surrounded by a ring of elevated limestone called the *makatea* (of reefal origin), dated to ~110 000 years ago.[24] The volcanic cone has a radial drainage pattern, and alluvial sediments have accumulated in the valley bottoms against the inner makatea escarpment. In the Veitatei Valley, the stream feeds a permanent lake (Lake Tiriara) ponded against the makatea, which partially drains out to sea through a cavern system in the limestone. Lake Tiriara was a promising site for sediment coring.

At the time of early European mission contact (in 1822) the Polynesian population of Mangaia was estimated at ~3000 persons, although some

PATRICK KIRCH, professor, Department of Anthropology, University of California, Berkeley, CA 94720.

JOHN R. FLENLEY, professor and chair, Department of Geography, Massey University, Palmerston North, New Zealand.

DAVID W. STEADMAN, senior scientist, Biological Survey, New York State Museum, Albany, NY 12230.

FRANCES LAMONT and STEWART DAWSON, School of Geography and Earth Resources, University of Hull, Hull HU6 7RX, United Kingdom.

depopulation as a result of epidemic disease may already have occurred.[25] This suggests a late prehistoric population density of at least 58 persons/km^2; the actual density per area of arable land was doubtless higher because much of the karstic makatea is devoid of soil. The Mangaian subsistence economy focused on intensive cultivation of taro (*Colocasia esculenta*) in irrigated pond-field systems constructed on the alluvial sediments of the narrow valleys. Until the islanders were converted to Christianity by the London Missionary Society (about 1835), warfare was endemic, marked by campaigns of territorial conquest in which the principal goal was control of the rich taro fields (Figure 3).[2] Various aspects of the contact-period sociopolitical structure and religious ideology also indicate intense pressures on limited land and food resources. For example, the religious system was dominated by a war cult in which the war god Rongo was a transformation of the ancient East Polynesian god of agriculture and fertility. Human sacrifice to Rongo was required on the installation of a new conquering paramount chief,[2] although the god also received daily offerings of cooked taro root at the "national godhouse."

Figure 3.
View of Tamarua Valley from the makatea escarpment. Note the reticulate grid of irrigated taro fields in the valley bottom, and the volcanic hills with degraded fernland vegetation in the distance.
P.V. KIRCH

Although virtually nothing was known of the island's archaeology or prehistory prior to our 1989 fieldwork, various aspects of the island's environment and culture strongly suggested that humans had effected major changes in the Mangaian ecosystem since initial human colonization. Much of the inner volcanic cone consists of a degraded laterite supporting only a fire-resistant scrub vegetation dominated by *Gleichenia linearis* ferns, ironwood (*Casuarina equisetifolia*), and screwpines (*Pandanus tecto-*

Figure 4.
Lake Tiriara with the inner makatea escarpment at the right. The raft used to obtain sediment core TIR-1 is visible on the lake.
P.V. KIRCH

rius). This degraded landscape, described as early as AD 1777 by the British explorer Captain James Cook, was unlikely to have been a natural ecological climax. Furthermore, the intensive irrigation systems, which were the focus of contact-era Mangaian subsistence, had been constructed on alluvial sediments derived from the eroded volcanic uplands. Our working hypothesis was therefore that prehistoric Polynesian activities (most likely forest clearance associated with shifting cultivation) had resulted in the deforestation and erosion of the hilly volcanic interior and in accelerated rates of sedimentation in the valley bottoms.

Methods

To reconstruct the environmental history of Mangaia during the period before and after prehistoric Polynesian colonization, we devised an interdisciplinary strategy involving collaborative field studies in archaeology, geomorphology, palynology, and paleontology. We chose the Veitatei drainage basin in the southwestern part of the island (Figure 2) as the locus for our fieldwork, primarily because of the presence of Lake Tiriara with its potential for obtaining long pollen cores. Our 1989 field season was conceived as a reconnaissance or pilot project, and complete archaeological survey was not attempted. Rapid survey revealed various kinds of prehistoric sites within the Veitatei basin, including small temples (*marae*), open habitation sites around the margins of the irrigation systems, burial and refuge caves in the makatea, and rock shelters in the inland makatea escarpment. Of these, one rock shelter in particular, named Tangatatau and designated site MAN-44, promised to yield a deeply stratified cultural sequence containing well-preserved faunal and floral remains (Figure 1). We therefore concentrated our 1989 archaeological and paleontological efforts on the test excavation of this site. We excavated a 1- × 5-m trench, following natural stratigraphy, through the central part of the site, and an additional 1-m^2 unit. Fine sieving (through 1/16- and 1/8-inch mesh) resulted in the recovery of a large faunal assemblage, including the bones of various species of extinct or extirpated birds.

At the same time that the rock-shelter excavations were conducted, the geomorphology–palynology team (Flenley, Lamont, and Dawson) obtained three cores from Lake Tiriara and the surrounding alluvial sediments (Figure 4). The lake core was taken using a modified Livingston piston sampler operated from a raft, whereas the swamp cores were taken with a D-section sampler. Palynological preparation of core TIR-1 followed the techniques of K. Faegri and J. Iversen.[5] Sedimentological techniques employed on the cores included x-ray photography, loss on ignition, organic carbon determination, flame photometry (for sodium and potassium), and x-ray fluorescence (for other elements).

Chronological control for both the MAN-44 excavation and the pollen cores are provided by a series of 23 radiocarbon dates, which are reported in full elsewhere.[14] The pollen cores span the period from ca. 7000 BP to present; samples from the MAN-44 rock shelter cover the period ca. AD 1000 to European contact.

The beauty of the present work is that it brings together these specializations [anthropology, archaeology, ecology, botany, paleontology, etc.] and presents the results in a format accessible to those with more general interests.

A REVIEWER

Results

Two major data sets pertaining to the mid- to late-Holocene environmental history of the island were obtained: one from the stratified Tangatatau rock shelter and one from the Lake Tiriara cores.

TANGATATAU ROCK SHELTER

Tangatatau, the first stratified site to be archaeologically excavated on Mangaia, yielded a wealth of data—artifactual, faunal, floral, and sedimentary—that permits a tentative outline of Mangaian prehistory from about AD 1000 to initial European contact.

The rock shelter is large (area under the dripline, ~225 m^2), with complex cultural stratigraphy extending to depths of 1.5 m below surface (Figures 5&6). Our main excavation bisected the rock-shelter floor, providing a central stratigraphic section. Fifteen ^{14}C determinations on charcoal indicate a consistent age–depth depositional sequence spanning the period ca. AD 1000 to 1600.[14]

The complex stratigraphy of the main trench (36 discrete strata) was subdivided into 10 chronostratigraphic analytic zones (J to A) (Figures 6&7). Zones J to G form an early phase of occupation in which the sediments are mostly ashy with many large charcoal particles. Zones F to A represent a significant change in the depositional regime, with clay influxes alternating with discrete phases of midden dumping and hearth or oven activity.

Analysis of the excavated material from Tangatatau indicate a number of significant trends:

- Most significant, in terms of environmental change, is a dramatic reduction in the frequencies of indigenous and endemic land birds represented from

Figure 5. *Excavations in progress in the main trench at Tangatatau rock shelter (site MAN-44).* P.V. KIRCH

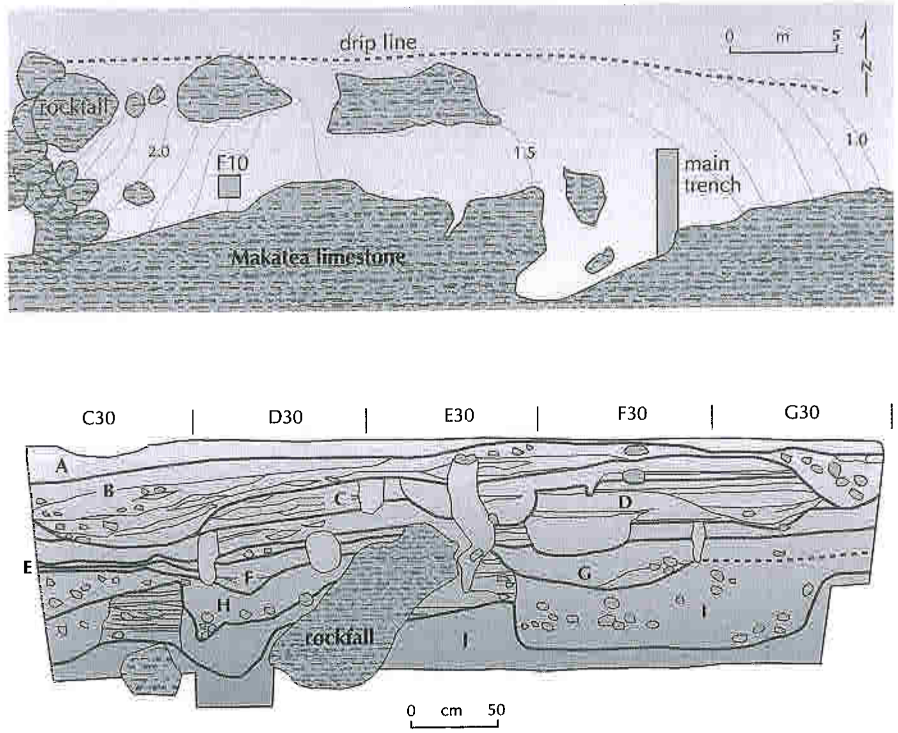


Figure 6.
Top, *plan map of the Tangatatau rock shelter (site MAN-44) (contour interval, 10 cm).* Bottom, *stratigraphic section through the main trench, west face.*

Demonstrating the degree to which humans have significantly impacted their environments in the past has important implications for modern policy making and environmental activism. We need to dispel the notion of the noble savage and tropical eden so that we can work to create an environmental future rather than simply reacting to the environmental consequences we unknowingly produce.

A REVIEWER

the earlier to later strata. The lower deposits yielded bones of eight species of land birds that are either extinct or were extirpated on the island during the later prehistoric period.[22] These include rails (*Gallirallus ripleyi, Porzana rua*), pigeons (*Ducula galeata*), doves (*Gallicolumba erythroptera, Gallicolumba nui, Ptilinopus rarotongensis*), and parrots (*Vini vidivici, Vini kuhlii*). Bones of an extirpated seabird (*Gygis microrhyncha*) are also confined to lower strata. The upper deposits also exhibit a phase of concentrated predation on nesting populations of seabirds, and the assemblages from these strata include two extirpated species (*Pterodroma nigripennis, Nesofregetta fuliginosa*). In addition to the pattern of bird extinction and extirpation, the faunal record indicates a major reduction in the frequency of the native fruit bat (*Pteropus tonganus*). These changes in the island's avifauna and bat population most likely resulted from a combination of direct predation by humans and of extensive habitat destruction or modification.

• In contrast to the situation with native land birds is an increase over time in the frequencies of domestic pig and chicken, indicating development of the animal husbandry component of agricultural production. The introduction of the Polynesian rat (*Rattus exulans*) is also evidenced in the faunal record from the beginning of the Tangatatau sequence.

• Increasing stress on marine subsistence exploitation is indicated by dramatic size reductions in certain molluscs, such as *Turbo setosus*, and in the diminutive size of the fish remains. About 10 000 fishbones were recovered, predominantly of such inshore taxa as Labridae, Scaridae, and Acanthuridae. The fringing reef of Mangaia is very narrow and lacks a lagoon. Thus the large human population of Mangaia in the late prehistoric era was likely to have put heavy pressures on this narrow zone of reef habitat.

• The site also yielded abundant carbonized plant material, primarily wood charcoal, *Aleurites moluccana* (candlenut) endocarp, and charred *Pandanus tectorius* drupes. In most Pacific islands, *Pandanus* kernels are famine food, but in Mangaia these reputedly contributed to the regular diet in late prehistory,[2] a further indicator of food stress. Also included among the carbonized materials are several specimens of parenchymatous tuber material, identified as sweet potato (*Ipomoea batatas*). This material, identified by Jon Hather (Institute of Archaeology, London), is the first archaeological evidence of sweet potato introduction to central Polynesia from South America. The Mangaia sweet potato remains are the oldest archaeological specimens of this crop yet excavated in Polynesia, and unquestionably indicate the prehistoric transfer of the plant from South America to Central Polynesia.

- The sedimentary regime indicates a shift in depositional processes, with the upper strata containing clay lenses resulting from erosion and fluvial deposition of volcanic sediments from the inland slopes. This is indirect evidence for forest clearance and erosion of the interior volcanic cone, which we believe correlates with the palynological sequence described below.

- The Tangatatau site provides indirect evidence for expansion of nearby irrigated wetlands in the later phases of occupation, in the form of hydrophilic snails of the genus *Tryonia* (Hydrobiidae) which appear in increasing numbers in zones F to A. These snails are too minute to be edible and were presumably transported to the site on *Colocasia* corms and stalks, to which they readily adhere.

- The site also yielded an extensive collection of prehistoric artifacts, including basalt adzes and other formal and informal basalt tools, fishhooks (finished and in various stages of manufacture), abrading tools, tattooing needles, and other types (Figure 8). Of particular note is the high frequency of fishhooks manufactured from pearl shell (*Pinctada* sp.) in the lower deposits. These are replaced by hooks of *Turbo setosus* shell in the upper layers. Because pearl shell does not occur on the Mangaia reef, this material was presumably imported from one of the other islands in the southern Cooks group (probably Aitutaki or Rarotonga). The shift to *Turbo* shell in the later half of the sequence may indicate a cessation of external trade or exchange relationships and increasing social isolation. This would fit with Mangaian oral traditions that refer to warlike inter-island relationships at the time of initial European contact.[2]

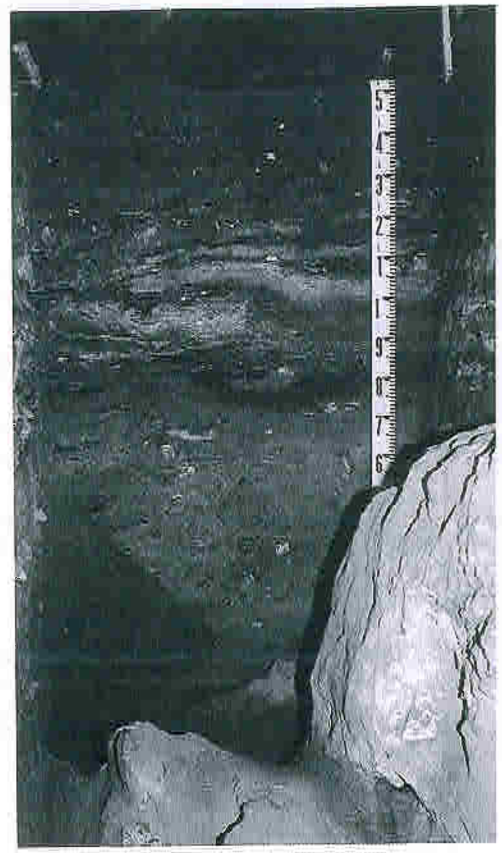
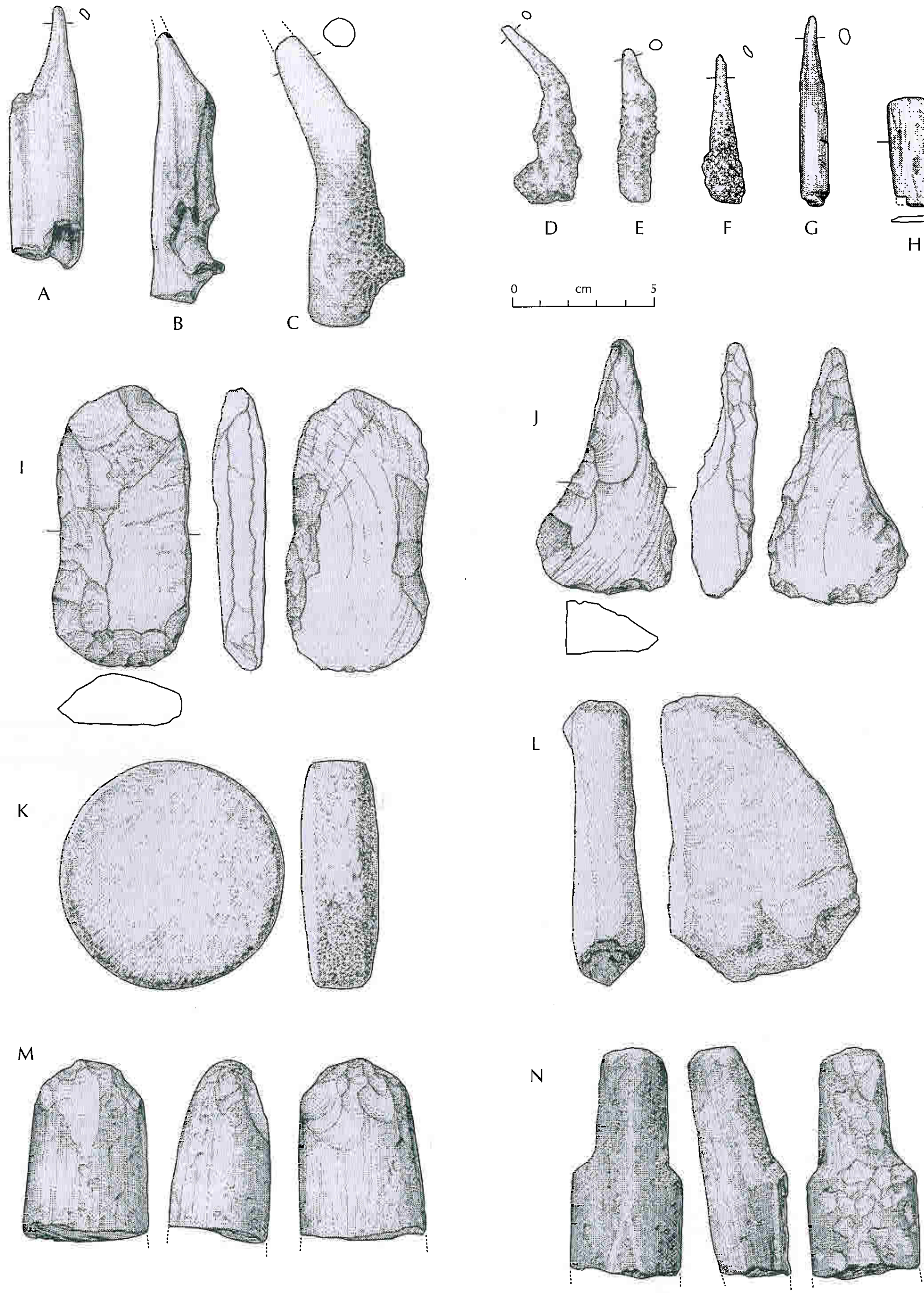


Figure 7.
Detail of the stratigraphy exposed by the main trench excavation at Tangatatau rock shelter (site MAN-44). Note the thick gray, lower cultural deposit overlying the pre-contact reddish zone J. The upper strata consist of finely lensed midden and ashy hearth deposits.
P.V. KIRCH

PALYNOLOGICAL AND SEDIMENTOLOGICAL RESULTS

The three cores obtained from Lake Tiriara and the adjacent swamp exhibit remarkable consistency, giving confidence that the results are representative of the entire lake catchment. The sediments consisted mainly of organic detrital muds, fine in the lake and coarse in the swamp. All the cores contained numerous horizons of gray clay, presumed to be inwashed from the highly eroded and weathered basaltic uplands. The longest core (TIR-1) consisted of 15 m of deposits, but none of the cores reached bedrock. Core TIR-1 was selected for pollen analysis, and six radiocarbon dates indicate that this core spans the period from 7000 BP to the present.

The pollen record of core TIR-1 (Figure 9) is dominated by tree pollen and fern spores. Particularly abundant among the former are Urticaceae/Moraceae, *Ficus*, Pandanaceae, and *Weinmannia*. Palmae and *Cocos* comp. are present throughout. The ferns include *Acrostichum*, *Cyathea*, *Gleichenia*, and *Pteris*. Gramineae pollen is present in most samples. The pollen record may be considered in three zones. The earliest, zone 1 (before ca. 6000 BP), is dominated by fern spores, especially of *Acrostichum*. In the middle, zone II (ca. 6000 to 1600 BP), tree pollen dominates. In the upper part, zone III (1600 BP to present), tree pollen markedly declines and ferns rise, especially *Acrostichum*, *Gleichenia*, and *Cyathea*. This zone begins at 3.5-m depth, bracketed by two radiocarbon dates to ca. 1600 BP. The sediment chemistry record of core TIR-1 coincides with


A
B
C
D
E
F
G
H
0
cm
5
I
J
K
L
M
N

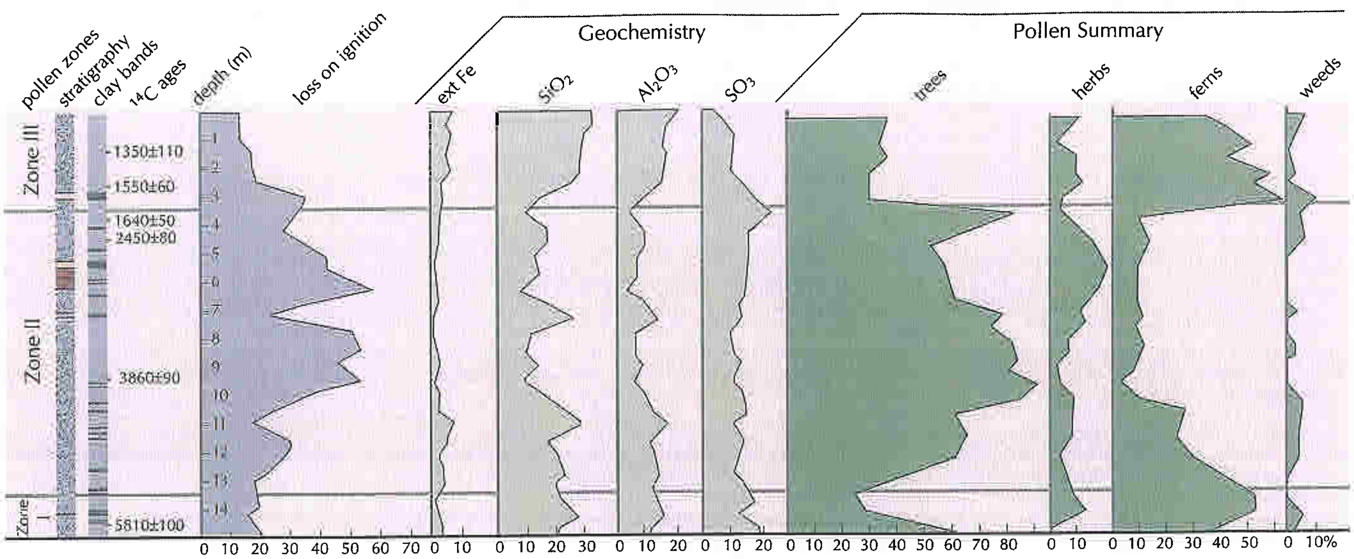


Figure 9.
Summary stratigraphic, geochemical, and pollen diagram for core TIR-1, Lake Tiriara.

the pollen record (Figure 9). In zone I organic matter has low values, and SiO_2, TiO_2, Al_2O_3, and Fe_2O_3 have high values. In the middle zone the sediment is more organic, and the values for the above-mentioned oxides decrease. They all increase, however, in zone III, when organic matter again declines. A thick clay band at 3.00 to 3.12 m indicates a major erosive event in the Veitatei catchment.

We interpret the TIR-1 pollen record as follows: The earliest phase (zone I), ca. 7000 to 6000 BP, appears to have been a time when the catchment was poorly forested. Charcoal was present, suggesting that fires may have occurred. At this date these are likely to have been natural, and this, combined with the lack of forest, suggests a climate drier than the present one. There is similar evidence for a dry climate on the nearby island of Atiu at this time (correspondence with A. Parkes, University of Hull, United Kingdom, 1991). The middle phase (zone II), ca. 6000 to 1600 BP, appears to have been a period when rain forest dominated the catchment. The climate was probably similar to that of the present, and the vegetation was generally undisturbed. There is some stratigraphic evidence for erosive events (clay bands) from ca. 3000 BP, but the forest seems to have recovered quickly. Whether this disturbance resulted from human activity or from natural causes (e.g., tropical cyclones, El Niño events) is unknown. The final phase (zone III), ca. 1600 BP to present, apparently indicates sustained disturbance of the forest, leading to continual erosion and permanent deforestation. Given that the present environment of the island seems eminently suited to forest growth, it is difficult to explain the forest decline by any means other than human activity.

Figure 8 (opposite page).
Selected artifacts from the Tangatatau rock shelter:
A, B, *bone awls;*
C–F, Acropora *branch coral abraders;*
G, *echinoid spine abrader;*
H, *bone plaque;*
I, *basalt biface, possibly a coconut grater;*
J, *basalt biface, possibly an awl;*
K, *coral gaming disc;*
L, *block coral abrader;*
M, N, *basalt adz butts.*
DRAWINGS BY J. OGDEN

Discussion and Conclusions

While our 1989 pilot season results are not yet sufficient to produce a complete sequence of Mangaian prehistory, they do permit us to construct a model of the impacts of a prehistoric Polynesian population on this central Pacific island ecosystem. We as yet have no direct archaeological evidence for the initial human settlement of Mangaia, but the TIR-1 pollen sequence demonstrates anthropogenic disturbance by ca. 1600 BP. This date accords well with projections of initial colonization into central

Mangaia is an interesting island geographically, first visited by the Europeans in the early 19th century at a time when there had been a major civil war and a whole new political system was just emerging. It is obviously an area of emerging political evolution, one in which we need to have a background in terms of colonization, demographic growth, and agricultural intensification.

MINUTES OF THE 9 JANUARY 1989 MEETING OF THE COMMITTEE FOR RESEARCH AND EXPLORATION

Eastern Polynesia out of Western Polynesia.[12] The island's colonizing population was presumably small, and therefore even if the intrinsic growth rate was high, the island's total population would probably not have reached the 2000+ level until well into the first millennium AD. During this first phase, agricultural activity was likely to have concentrated on the forested volcanic interior, with shifting cultivation of yams, aroids, and bananas in a typical Oceanic swidden pattern. Given that this volcanic zone had only a thin organic soil, developed over deeply weathered, laterized basalts, even low-density (long-fallow) shifting cultivation could have resulted in deforestation and erosion of the interior within a few centuries, as suggested by the pollen and sedimentary sequences in Lake Tiriara.

Thus, by 1000 BP (when the cultural sequence begins to be well documented by the Tangatatau rock shelter) the volcanic interior probably was substantially deforested, with agricultural activities shifting to the valley bottoms and lower volcanic slopes (zones II and III). Between about 1000 and 700 BP, the rock-shelter sequence demonstrates rapid impacts on the native bird and fruit-bat populations, which until this time had survived in refugia provided by the makatea forest. With human population levels increasing and volcanic uplands degrading, the makatea now became a focus of agricultural activity, with increasing habitat disturbance. Further signs of environmental stress are indicated in the reduced size of shellfish and fish, and in the increased use of *Pandanus* kernels.

By ca. 700 BP Mangaia also became disengaged from a former long-distance exchange network that linked the island to other communities in the southern Cooks, if not more widely to the Australs or the Society archipelagoes. This is evidenced by the sudden cessation of imported pearlshell in the lower deposits of the rock-shelter sequence and in the technological shift to the use of local *Turbo* shell for fishhooks.

The final 300 years of the rock-shelter sequence display increasing environmental change and stress on resources. This was also the main phase of intensification of irrigation in the valley bottoms, now enhanced as agricultural environments by the increased influx of sediment eroded from the volcanic interior. It is presumably this last period of increasing emphasis on irrigation, with intense conflict over control of the irrigated lands, that is so richly encoded in the Mangaian oral traditions.[2] We believe that the settlement pattern of dispersed habitations and *marae* temple sites surrounding the margins of the irrigated swamps will also prove to date to this final period.

In sum, our interdisciplinary research has documented a sequence of dramatic human impacts on the physical and biotic environment of Mangaia Island during the past two millennia. The Mangaian case demonstrates that the remote ecosystems of the central Pacific were—as Fosberg originally suggested—highly susceptible to disturbance once the barrier of isolation was broken by human colonizers. In our current world where much emphasis is being given to rapid "global change," the prehistoric record from Mangaia reminds us that even pre-industrial human populations had the capacity to effect substantial and irreversible changes to their world.

REFERENCES

1. **Anderson, A.**: The extinction of moas in southern New Zealand. Martin, P. S. & Klein, R. G., editors: *Quaternary Extinctions*. University of Arizona Press, Tuscon; 1984.

2. **Buck, P. H.**: *Mangaian Society. Bishop Museum Bulletin* 122; 1934.

3. **Carlquist, S.**: *Island Biology*. Columbia University Press, New York; 1974.

4. **Christensen, C. C.; & Kirch, P. V.**: Nonmarine mollusks and ecological change at Barbers Point, Oahu, Hawaii. *Bishop Museum Occasional Papers* 26:52–80; 1986.

5. **Faegri, K.; & Iversen, J.**: *Textbook of Pollen Analysis* (2nd ed.). Munksgaard, Copenhagen; 1984.

6. **Flenley, J. R.; & King, S. M.**: Late Quaternary pollen records from Easter Island. *Nature* 307:47–50; 1984.

7. **Fosberg, F. R.**: Disturbance in island ecosystems. Gressitt, J. L., editor: *Pacific Basin Biogeography*, 557–561. Bishop Museum Press, Honolulu, HI; 1963.

8. **Fosberg, F. R., editor**: *Man's Place in the Island Ecosystem*. Bishop Museum Press, Honolulu, HI; 1963.

9. **Gressitt, J. L., editor**: *Pacific Basin Biogeography*. Bishop Museum Press, Honolulu, HI; 1963.

10. **Hughes, P. G.; Hope, G.; Latham, M.; & Brookfield, M.**: Prehistoric man-induced degradation of the Lakeba landscape: Evidence from two inland swamps. Brookfield, H. C., editor: *Lakeba: Environmental Change, Population Dynamics, and Resource Use*, 93–110. UNESCO, Paris; 1979.

11. **Kirch, P. V.**: The impact of the prehistoric Polynesians on the Hawaiian ecosystem. *Pacific Science* 36:1–14; 1982.

12. **Kirch, P. V.**: Rethinking East Polynesian prehistory. *Journal of the Polynesian Society* 95:9–40; 1986.

13. **Kirch, P. V.**: The Talepakemalai Lapita site and Oceanic prehistory. *National Geographic Research* 4:328–342; 1988.

14. **Kirch, P. V.; Flenley, J. R.; & Steadman, D. W.**: A radiocarbon chronology for human-induced environmental change on Mangaia, Southern Cook Islands, Polynesia. *Radiocarbon;* in press.

15. **Kirch, P. V.; & Green, R. C.**: History, phylogeny, and evolution in Polynesia. *Current Anthropology* 28:431–456; 1987.

16. **McGlone, M.**: The Polynesian deforestation of New Zealand: A preliminary synthesis. *Archaeology in Oceania* 18:11–25; 1983.

17. **Olson, S. L.; & James, H. F.**: The role of the Polynesians in the extinction of the avifauna of the Hawaiian Islands. Martin, P. S. & Klein, R. G., editors: *Quaternary Extinctions*, 768–780. University of Arizona Press, Tuscon; 1984.

18. **Spriggs, M.**: Landscape, land use and political transformation in southern Melanesia. Kirch, P. V., editor: *Island Societies: Archaeological Approaches to Evolution and Transformation*, 6–19. Cambridge University Press, Cambridge; 1986.

19. **Steadman, D. W.**: Fossil birds from Mangaia, Southern Cook Islands. *Bulletin of the British Ornithologists' Club* 105:58–66; 1985.

20. **Steadman, D. W.**: Two new species of rails (Aves: Rallidae) from Mangaia, Southern Cook Islands. *Pacific Science* 40:27–43; 1987.

21. **Steadman, D. W.**: Extinction of birds in Eastern Polynesia: A review of the record, and comparisons with other island groups. *Journal of Archaeological Science* 16:177–205; 1989.

22. **Steadman, D. W.; & Kirch, P. V.**: Prehistoric extinction of birds on Mangaia, Cook Islands, Polynesia. *Proceedings of the National Academy of Sciences, U. S. A.* 87:9605–9609; 1990.

23. **Steadman, D. W.; Pahlavan, D. S.; & Kirch, P. V.**: Extinction, biogeography, and human exploitation of birds on Tikopia and Anuta, Polynesian outliers in the Solomon Islands. *Bishop Museum Occasional Papers* 30:118–153; 1990.

24. **Stoddart, D. R.; Spencer, T.; & Scoffin, T. P.**: Reef growth and karst erosion on Mangaia, Cook Islands: A reinterpretation. *Zeitschrift für Geomorphologie* 57:121–140; 1985.

25. **Williams, J.**: *A Narrative of Missionary Enterprises in the South Sea Islands*. John Snow, London; 1838.

ACKNOWLEDGMENTS

The research reported here was supported by a grant (4001-89) from the National Geographic Society. Faunal analyses were also supported under National Science Foundation grant BSR-8607535. Additional support and assistance has been provided by the Archaeological Research Facility, University of California, Berkeley. The authors gratefully acknowledge permission from the government of the Cook Islands, and from the chiefs and Island Council of Mangaia, to carry out this work. We especially thank Tony Utanga, Makiuti Tongia, Ma'ara Ngu, Papamama Pokino, Nga Ruatoe, Peter Ngatokorua, Paiti Kareroa, George Tuara, Melinda Allen, and Virginia Steadman for their assistance. This is contribution number 703 of the New York State Museum and Science Service.

A Scholarly Publication of the National Geographic Society

SPRING 1992

Volume 8, Number 2

Research & Exploration

Published quarterly by the National Geographic Society, Washington, D.C.

Abstracting and Indexing of RESEARCH & EXPLORATION:

On-line data bases: BIOSIS, DIALOG, GEOREF, SCISEARCH

Printed abstracts/indexes: Abstracts in Anthropology; Animal Behavior Abstracts; Aquatic Sciences & Fisheries Abstracts; Bibliography and Index of Geology; Biological Abstracts; Cambridge Scientific; Current Bibliography on African Affairs; Current Contents: Agriculture, Biology, & Environmental Sciences; Current Primate References; Ecology Abstracts; Entomology Abstracts; Genetics Abstracts; Geo Abstracts; Oceanic Abstracts; Science Citation Index.

RESEARCH & EXPLORATION (ISSN 8755-724X) is published quarterly by the National Geographic Society, Washington, D.C. 20036. Second class postage paid at Washington, D.C., and at additional mailing offices. POSTMASTER: changes of address to *Research & Exploration*, P.O. Box 2174, Washington, D.C. 20013.

Communications concerning editorial matters, including status of manuscripts, requests to copy or reprint, and requests to translate, should be addressed to:

Anthony R. de Souza, Editor
RESEARCH & EXPLORATION
1600 M Street, N.W., Washington, D.C. 20036
(202)-857-7766.

Annual subscription rates (four issues). Individual: US, $40; Canada Can$55.20 (US$46); elsewhere, US$46 surface, US$66 air. Institutional: US, $50; Canada Can$67.20 (US$56); elsewhere, US$56 surface, US$76 air. Single copies: US, $10; elsewhere, US$11.50 surface, US$15 air.

Communications concerning subscription matters—new subscriptions, renewals, undelivered issues, changes of address—should be addressed to:

RESEARCH & EXPLORATION Subscriptions
National Geographic Society
Department 1675, Washington, D.C. 20036

Communications concerning National Geographic Society research grants should be addressed to:

Steven S. Stettes, Secretary
COMMITTEE FOR RESEARCH AND EXPLORATION
National Geographic Society
17th and M Streets, N.W., Washington, D.C. 20036