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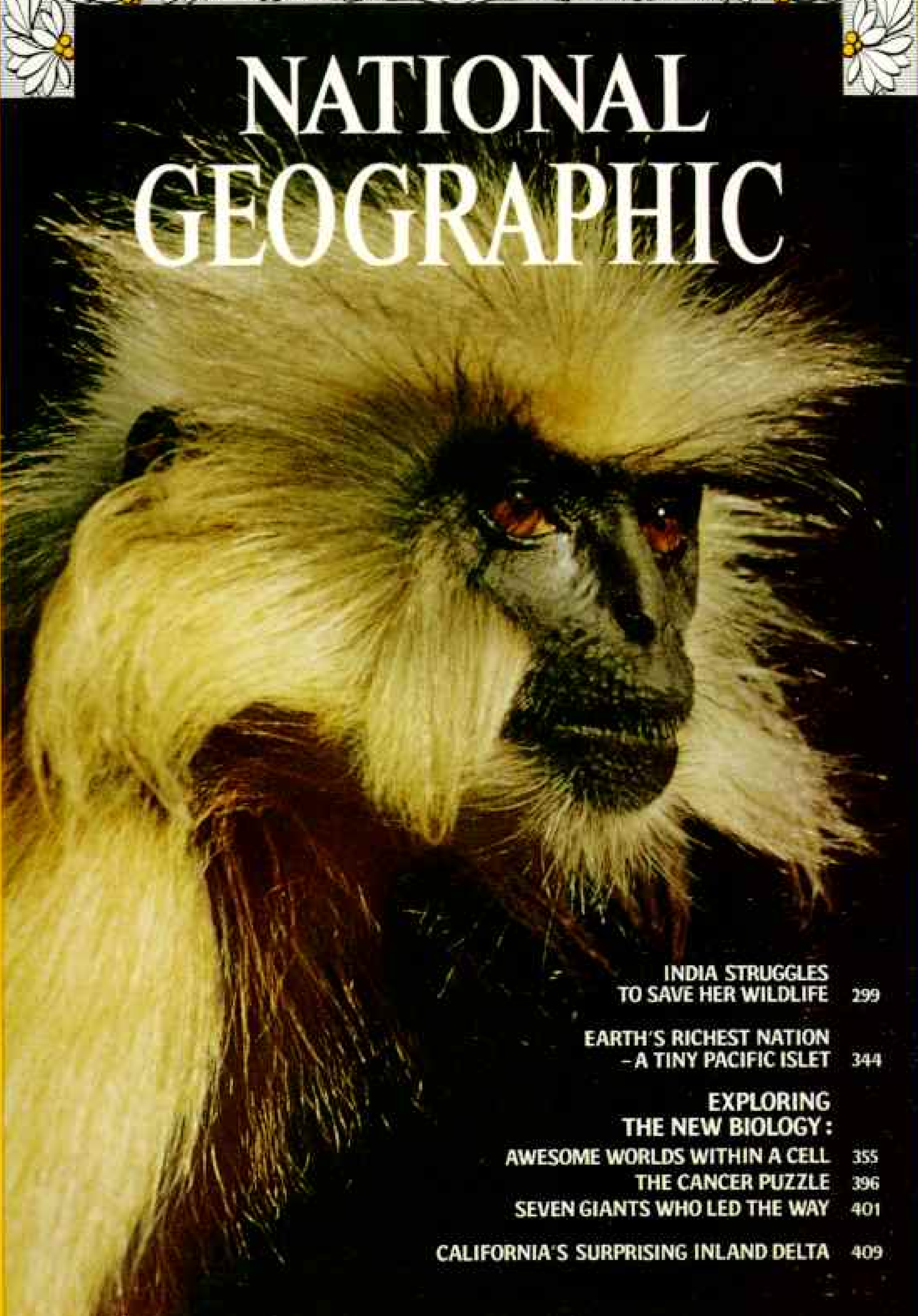


INDIA STRUGGLES TO SAVE HER WILDLIFE 299

EARTH'S RICHEST NATION – A TINY PACIFIC ISLET 344

EXPLORING THE NEW BIOLOGY:

AWESOME WORLDS WITHIN A CELL 355

THE CANCER PUZZLE 396

SEVEN GIANTS WHO LED THE WAY 401

CALIFORNIA'S SURPRISING INLAND DELTA 409

OFFICIAL JOURNAL OF THE NATIONAL GEOGRAPHIC SOCIETY WASHINGTON, D.C.

FIRST CAME the conquest of the atom. Now another great revolution is upon us. Like the atom, the new biology explored in this issue offers incredible promise —and perhaps an equal measure of peril.

It is not a simple subject. In fact, no article we have ever published has been more difficult, either in the amount of effort and skill that went into its preparation, or in the perseverance readers must bring to it if they are to understand this complex new face of science. You will find the effort worthwhile. What could be more important to us as human beings than a glimpse of the inner workings of life itself?

But therein, as Shakespeare observed, lies the rub. For in reporting such mind-shaking scientific theorizing, we must also report the consensus of the world's astronomers and geologists that our universe developed slowly during billions of years, and that of the biologists that life, too, developed in a slow but grand design over the eons.

A significant number of readers will find neither of these explanations acceptable. The majestic words of Genesis continue to provide for many of us a satisfactory answer (which science still cannot give) to those deepest of all mysteries: Who are we? Where are we? How did it all begin? "I cannot believe," wrote Albert Einstein, "that God plays dice with the world." Thus others among us see, behind every revelation of science, the guiding hand of a higher power.

In reporting the headlong pace of biology, geology, and astronomy, we follow the same precepts that led us to cover Kansas City and Siberia, ecology and pollution, remotest Africa and downtown Toronto. Our mission, the increase and diffusion of geographic knowledge, bids us hold up a mirror to the world, so that the magazine's pages will reflect the earth and the universe around us as clearly as we are capable of perceiving it. But all of us, as individuals, must accept or reject other peoples' interpretations as they accord with or disagree with our deeply held political, religious, and cultural values.

I like to think that this cherished combination—access to knowledge, presented factually and fairly, and the freedom to arrive at our own conclusions—is what makes NATIONAL GEOGRAPHIC readers among the best-informed people on the planet.

Gilbert M. Grosvenor

NATIONAL GEOGRAPHIC

THE NATIONAL GEOGRAPHIC MAGAZINE VOL. 150, NO. 3

September 1976

India Struggles to Save Her Wildlife 299

Most of us are familiar with the threat to Africa's wild creatures, but India's stand in even greater peril. A team headed by John J. Putman and Stanley Breeden spent more than a year assembling this disturbing report.

Who Are Earth's Richest People? 344

For the moment, that honor belongs to the citizens of a Pacific islet called Nauru. Mike Holmes finds most Nauruans basking in today's affluence while their officials worry about tomorrow—the day the phosphate runs out.

THE NEW BIOLOGY

I–Awesome Worlds Within a Cell 355

Mysteries fade away only to reveal greater mysteries as scientists strive to solve the riddles of life. Rick Gore and Bruce Dale help us glimpse this still-baffling universe of tiny worlds that all of us carry within ourselves. Paintings by Davis Meltzer.

II–The Cancer Puzzle 396

In his quest for clues to cancer causes, biochemist Robert F. Weaver studies one of life's most primitive forms—the slime mold.

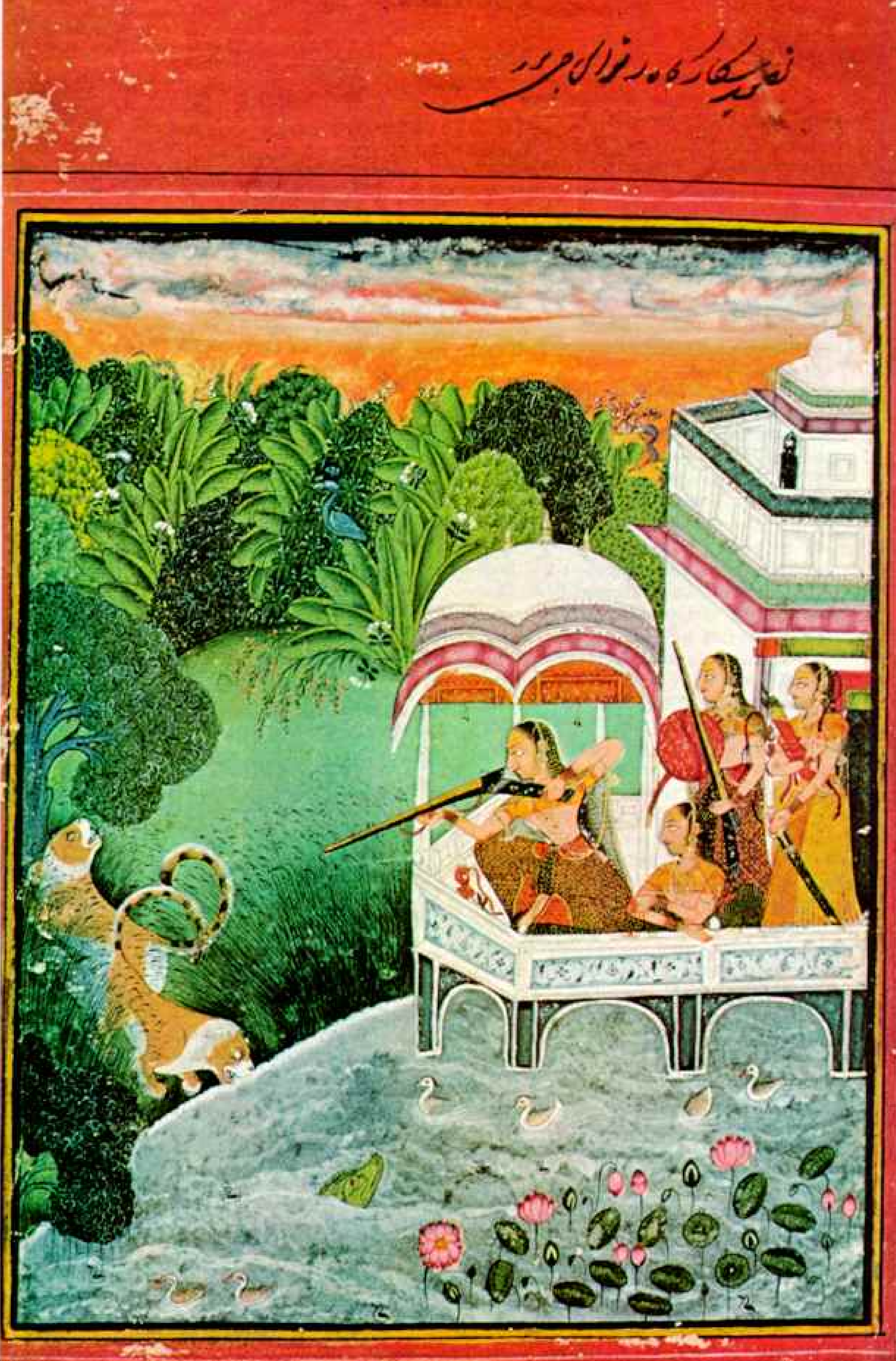
III–Seven Giants Who Led the Way 401

Today's insights are firmly grounded in the work of a handful of pioneering biologists. Paintings by Ned Seidler.

California's Surprising Inland Delta 409

Dikes bespeak the Netherlands, fields of scarlet pomodoros hint of Italy. Add Chinese villagers, soil that burns or blows away, and cargo ships steaming into the heart of California. Judith and Neil Morgan find one surprise after another in this often-overlooked crossroads of the Golden State. Photographs by Charles O'Rear.

COVER: *Unknown to science until 1907, the rare golden langur typifies India's rich but threatened wildlife (foldout, pages 307-309). Photograph by Stanley Breeden.*



India Struggles to Save Her Wildlife

By JOHN J. PUTMAN
SENIOR EDITORIAL STAFF

Photographs by STANLEY BREEDEN, RAJESH BEDI, and BELINDA WRIGHT

"The tigress ... had arrived in Kumaon as a full-fledged man-eater, from Nepal, whence she had been driven out by a body of armed Nepalese after she had killed two hundred human beings, and during the four years she had been operating in Kumaon had added two hundred and thirty-four.... This is how matters stood ... I would start for Champawat immediately on receipt of news of the next human kill."

—COL. JIM CORBETT IN "MAN-EATERS OF KUMAON," 1944

KASHMIR, LATE SEPTEMBER. The nights were cold now, and there had been snow at 13,000 feet. The Gujars, tribal nomads, were coming down from the high pastures. The men walked, driving their sheep; women, children, tents, and cooking pots rode on belled ponies; the aged and dying were carried on litters. At the sound of the pony bells, the hill farmers would pause in their harvest to watch the caravans pass, harbingers of winter.

Very early in the morning in the valley below, you could watch the geese and ducks—greylags, pintails, mallards—come in from China to the north. Dark clouds of birds, they passed low with the whisper of hundreds of beating wings to settle on Dal Lake.

While I was at Dachigam Wild Life Sanctuary, northeast of Srinagar (map, page 309), the last of the Kashmir stags, or *hanguls*, were coming down to the lower slopes. The velvet was off their antlers, and they called and challenged. Now and then came an answering bugle. Soon the stronger males would drive off their rivals, collect their harems, and breed. Not long after, they would go their separate ways. The fawns would be born in May.

The rhythms of nature are sharply perceived in India. Nature is its calendar—the coming of winter, the dry season, the monsoon. The precise year, the century seem less important. Sometimes, camped in the hills, it is possible to imagine that the years have passed India by—that the Hindu gods still ride their favorite mounts, the swan, the kite, the bull; that Mogul emperors still ride forth with hooded hunting cheetahs selected from a stable of hundreds; that forests and hills still teem with such game that a British colonial, jaded with shooting, might turn to hunting with matched bulldogs and a knife; that the redoubtable Jim Corbett still putters

Reaping the royal bounty, a maharani takes aim at a tiger in an 18th-century hunt. Two hundred years later, much of India's wildlife—among the world's most varied—faces extinction. Recently the government has taken steps to protect its endangered species within some 150 sanctuaries. But a bigger problem looms: Six hundred million people demand room for living. Can they and India's wild creatures survive side by side?

RAJASTHANI MINIATURE, BUNDI SCHOOL (18TH CENTURY), COURTESY NATIONAL MUSEUM, NEW DELHI

"Tigers steal beneath the brake ..."

Glare of a big cat in Kanha National Park echoes the words of the *Ramayana,* a 2,000-year-old Indian epic. Today India's tiger population has dwindled to an estimated 2,000. A government program called Project Tiger fights to save them, with nine sanctuaries designed to allow ample habitat and prey.

BELINDA WRIGHT

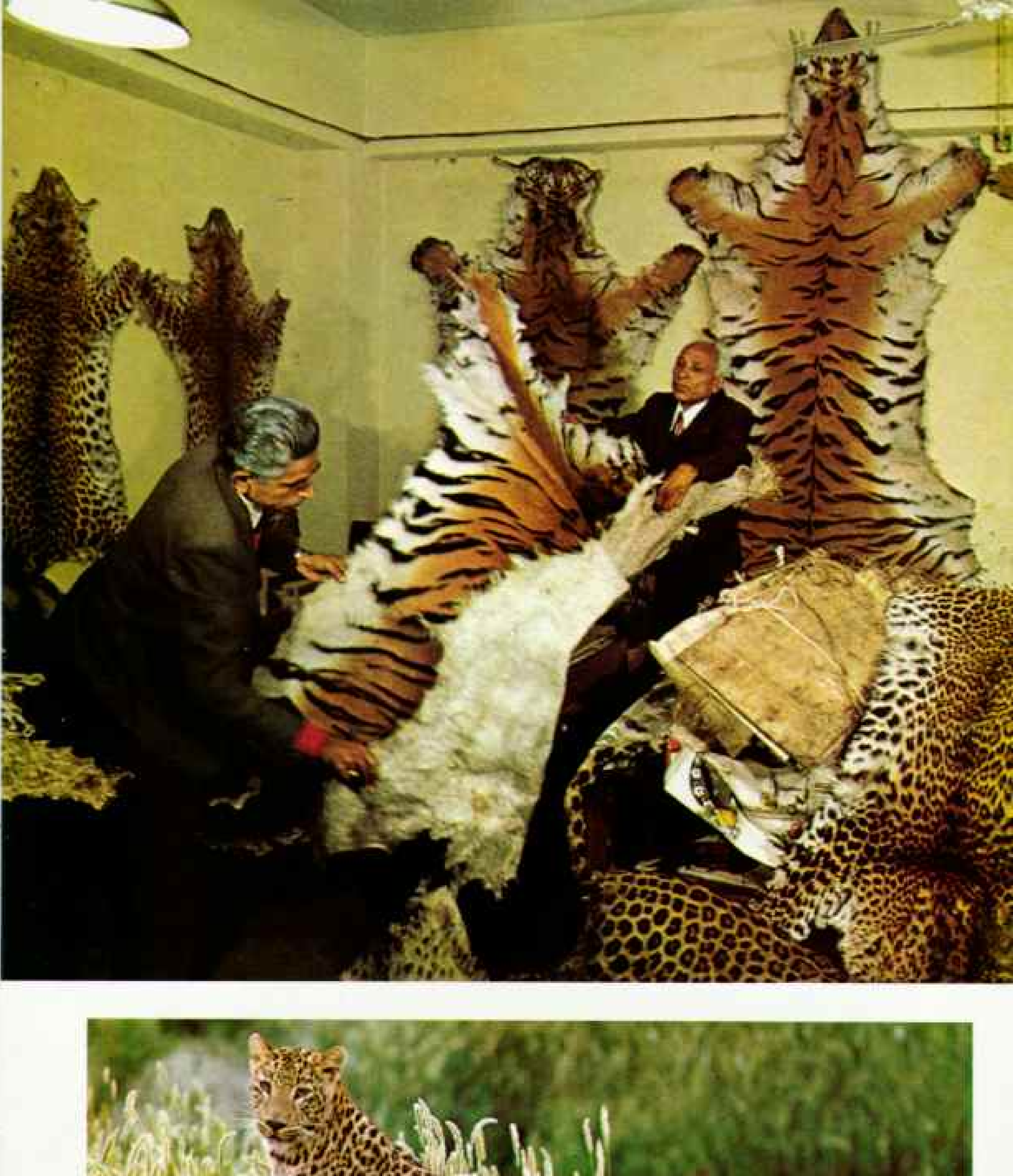
around his cottage at Kaladhungi, awaiting word of the next kill by a man-eating tiger.

But these are imaginings. The years have not passed India by, but ravaged her. The great forests have shrunk under the ax and the plow, and shrunk again; the vast herds, 10,000 strong, and herd after herd, have diminished to small pockets; the predators have become the hunted. The Indian cheetah is now extinct, the tiger gravely endangered; even the birds have dwindled in both numbers and species.

So great has been the slaughter of animals, so entrenched the pattern of destruction of habitat, that many came to believe that India's treasure of wildlife was doomed. Not until the early 1970's did the central and state governments of India join in the first firm steps to rescue her wildlife. It was very late, but the struggle had begun.

During four months in India I visited almost every corner of the subcontinent and talked with scores of persons concerned with its wildlife. I wanted to learn what steps were now being taken to preserve the animals that remain and what the chances were of success.

The cost of failure would be great, for India has a remarkable variety of wildlife: some 500 different mammals, 1,200 species of birds, more than 30,000 species of insects, as well as many kinds of fish, amphibians, and reptiles. Some—such as the blackbuck, the



RAJESH BEDI (ABOVE) AND STANLEY BREEDEN

Crackdown on the poachers

Illegal hoard of 89 skins was seized by officials (**above**) in a raid on a poacher's den in New Delhi. Each tiger or leopard pelt could have brought the lawbreaker $1,000. One cat that got away—a magnificent leopard (**left**)—roams free in the 125 square miles of Tiger Haven (map, page 309).

Nilgiri tahr, the golden langur, the lion-tailed macaque, the pygmy hog—are unique to the subcontinent (pages 307-309).

This unusual assemblage of animals began long ago, when India was a separate landmass drifting northward toward Asia. After the continents met, India's indigenous animals were joined by migrants moving east from Europe and Africa, south from central Asia, and west from China.

It became a land that offered a rich variety of habitats: the great sweep of the Himalayas to the north, mangrove swamps along the eastern coast, desert to the west, deciduous forests in the central plateau, reed jungles in the valleys of the Ganges and Brahmaputra.

AS EARLY AS 2000 B.C. Hindu sages began to classify this bounty of wildlife, noting the "ovum or seed," the habitat, the food preferences of hundreds of species.

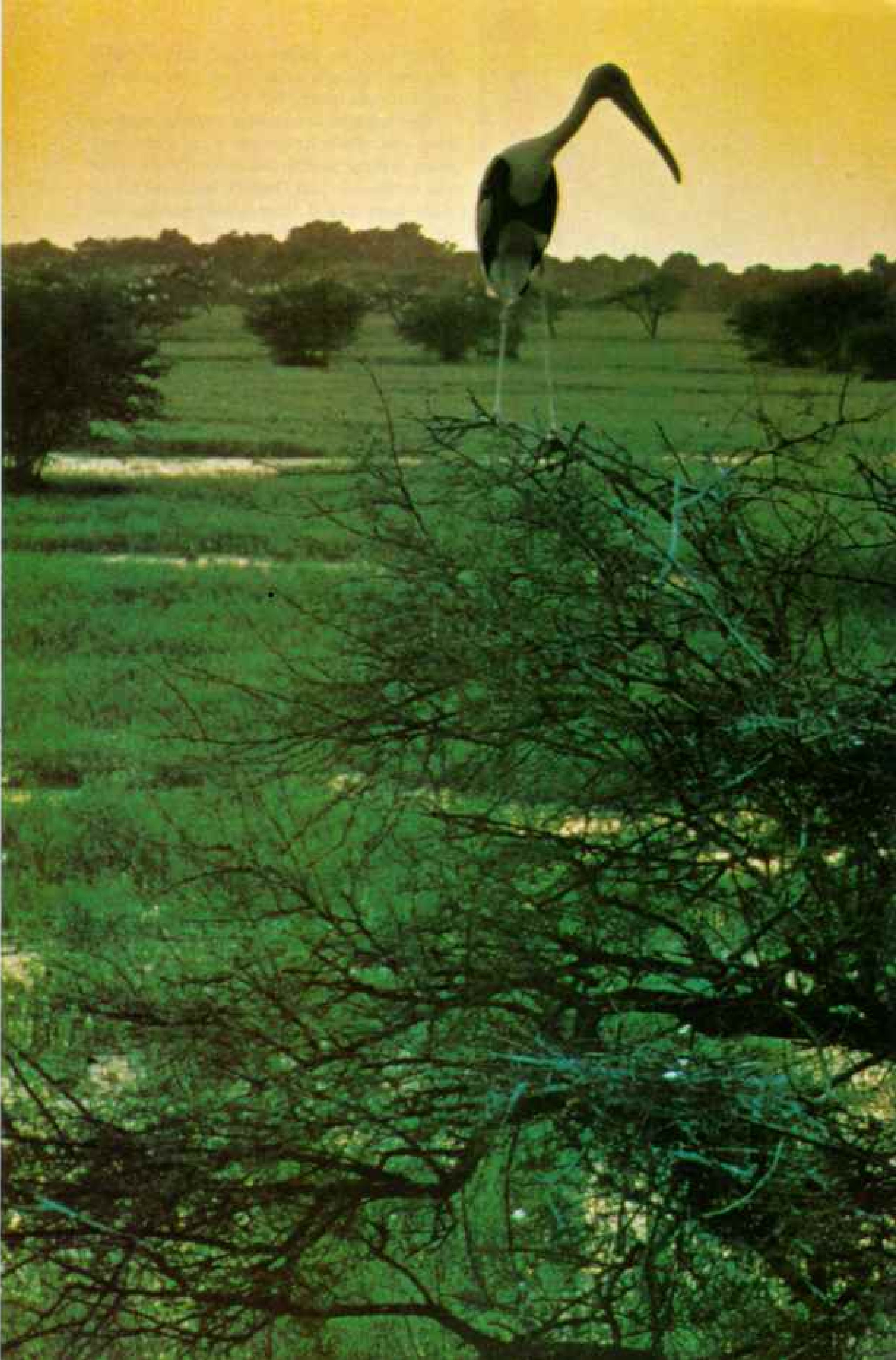
A notion of conservation was introduced in the Hindu precept of *ahimsa,* nonviolence to any living creature. In the fifth century B.C., Buddha, sitting under a pipal tree in what is now the State of Bihar, taught his disciples that a man's mind must embrace all living things "as a mother cares for her son, her only son . . ."

Not long after, the Emperor Ashoka issued his Fifth Pillar Edict, perhaps the first conservation law in history. It decreed that animals such as "bats, monkeys, rhinoceroses, porcupines, and tree squirrels" were to be strictly preserved and that "forests must not be burned, either for mischief or to destroy living creatures."

And while Mogul emperors of the 16th and 17th centuries won renown as hunters (one arranged a month-long hunt with 50,000 beaters), they were also keen naturalists. The Emperor Jehangir filled notebook after notebook with observations: how, unlike the birth of most humans, "young elephants are born with their feet first"; how the clever pied-crested cuckoo deposits its eggs in the nests of babblers, to be cared for by the latter.

These traditions—the Hindu reverence for living things and the Mogul ideal of the sportsman-naturalist—would reemerge to spur India's present conservation effort.

With the coming of the British raj, colonial sportsmen found a Garden of Eden: ". . . wild pig, porcupine, *(Continued on page 310)*



TWILIGHT VIGIL: *Painted storks guard nests in a treetop of Keoladeo Ghana Bird Sanctuary. From July through September, monsoon torrents cover these lowlands with an eleven-square-mile lake, creating a nesting place for 400,000 birds.*

STANLEY BREEDEN

MARKHOR Some 250 of these elusive wild goats hold out in India's Himalayan foothills.

GREAT INDIAN RHINOCEROS Displaced by agriculture and beset by poachers, only 900 remain.

WHITE-WINGED WOOD DUCK These waterfowl have been little studied due to their secluded jungle habitat.

HIMALAYAN TAHR The wild goats are thinly scattered between Kashmir and Bhutan.

SNOW LEOPARD The demand for fur coats has all but wiped out these beautiful cats in India.

LADAKH URIAL They survive in scattered herds along the upper Indus in the Himalayas.

LION-TAILED MACAQUE Ruffed and tufted, the 500 remaining monkeys exist only in tiny dots of territory.

GAVIAL Once inhabited the many rivers of northern India, but have been gravely depleted by hunters.

INDIAN WILD ASS Human disturbance and disease have reduced them to 720, mostly in the Little Rann of Kutch.

GAUR These ungulates have suffered from hunters, farmers, and the diseases of domestic cattle.

BROW-ANTLERED DEER Fewer than 25 remain in marshlands in the State of Manipur.

WESTERN TRAGOPAN A type of pheasant found only in the Western Himalayas.

SWAMP DEER (BARASINGHA) About 3,000 live in isolated marshes and open woodland.

ASIATIC ELEPHANT Once roamed almost all the forested countryside. About 7,000 are now left in the wild.

KASHMIR STAG (HANGUL) Probably fewer than 250 inhabit forests around the Vale of Kashmir.

SIBERIAN WHITE CRANE Once regular winter visitors to much of the Ganges, they are now seen only in Keoladeo Ghana.

GOLDEN LANGUR Unknown to science until 1907, they exist in one small pocket on the Bhutan border.

MUSK DEER Protected since 1973, many are still shot by poachers for the valuable musk gland.

ASIATIC BUFFALO Fewer than 2,000 remain in jungles and riverine marshes.

BLACKBUCK These antelopes are merely sprinkled throughout their original range today.

INDIAN TIGER Grand prize of Indian hunters, the great cat has dwindled to about 2,000.

NILGIRI TAHR Some 1,000 cling to precipitous cliffs in the Western Ghats, their only home.

GREAT INDIAN BUSTARD Scattered through open grassland of western India.

PYGMY HOG They remain only in belts of marshy grassland in Assam and the Himalayan foothills.

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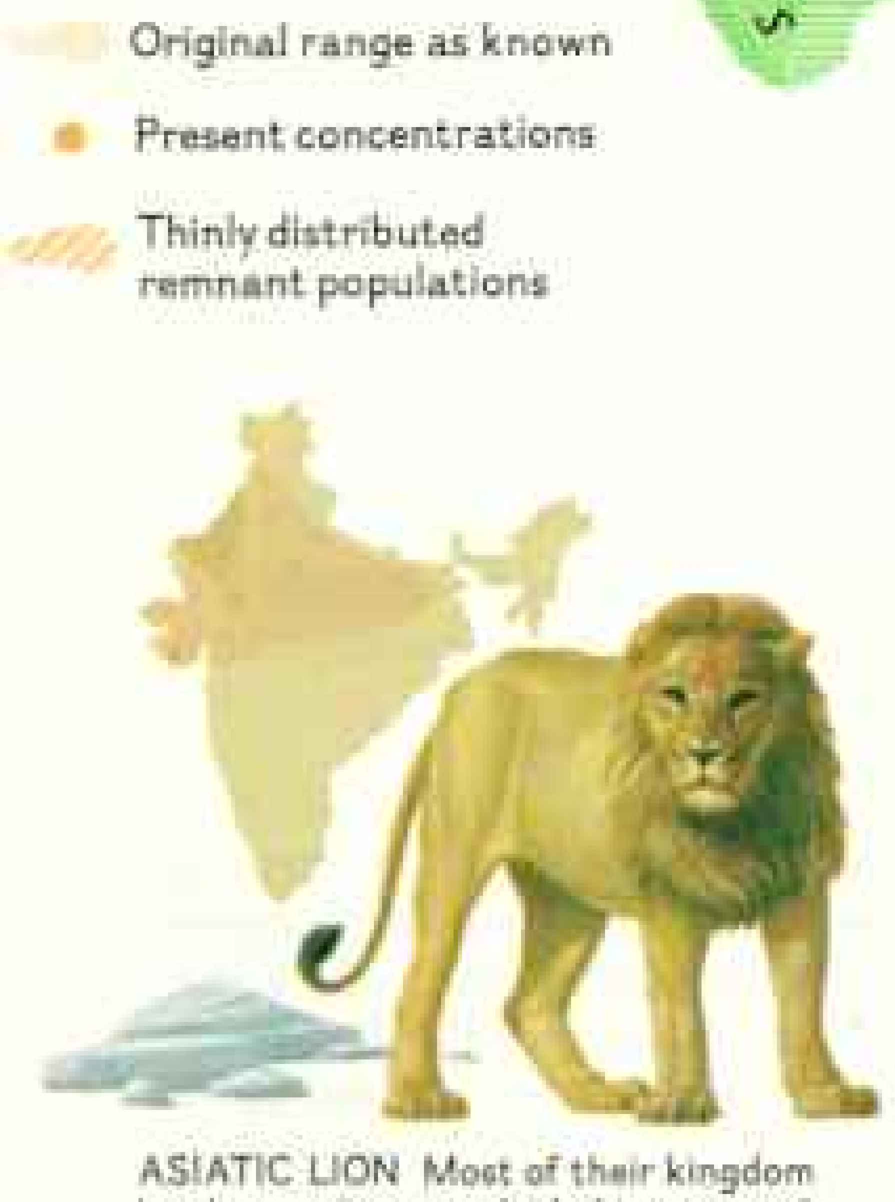


ASIATIC LION Most of their kingdom has been taken over by habitation and crops. They survive only in the Gir Forest.

India's wildlife vanishes as man alters the land

Compassion for all living things has been a tenet of Hinduism for 4,000 years. Even the princely rulers, who collectively shot game by the millions, were often conservationists. But, since independence in 1947, a darker story has been written for India's wildlife. Uncontrolled killing has prevailed in many areas. Ever-increasing pressure for land by an ever-increasing population threatens the living space of the nation's hundreds of species of mammals and 1,200 species of birds.

But the battle lines have been drawn to try to save other animals from the fate of the Indian cheetah. The last of its kind was shot in 1948.

PAINTINGS BY NED SEIDLER

(Continued from page 303) wild fowl, game fowl, and other animals, dear to the sportsman, are to be met with in incredible numbers." Englishman and raja blasted away.

There seemed no end to the game. It was still so within the memory of living men.

Dr. Sálim Ali, 80, a small Gandhi-like figure and India's most renowned ornithologist, remembers: "Forty or fifty years ago, when you traveled by train from Bombay to Ahmadabad, there was hardly a time after you left the settled areas that you didn't see herds of blackbuck. At that time we all shot; in a morning you could easily bag three or four blackbucks.

"And every hunter with any ambition wanted a tiger. Some shot five, ten, thirty. I remember once, about 1953, when I was doing some fieldwork in Madhya Pradesh, I met the Maharaja of Surguja. He was an old man with palsy and braced his rifle on a stick.

" 'I am very happy today,' he told me.

" 'Why?' I asked.

" 'Because today I have shot my 1,100th tiger!'

"He ended up with 1,157."

THE CRACK of the great smoothbores during the days of the raj significantly reduced India's wildlife, but the maharajas protected game in their preserves, while British civil servants prevented wholesale slaughter in the forests.

Disaster came with independence in 1947.

Exultant Indians rejected the old shooting regulations along with colonialism. They began to shoot wildlife everywhere, on private estates, in sanctuaries, in forest and field. The slaughter was increased when the government, facing food shortages, distributed crop-protection guns to farmers, dooming those animals that lived near cultivated fields. The availability of jeeps led to motorized hunting at night, when hunters fired away at any animal eyes reflected in the beam of their searchlights. In time the government made agricultural poisons readily available, and farmers learned they could poison not only insects but also the big cats that raided their farms at night.

Hari Dang, ecologist and educator, recalls: "Postwar exploitation—open season on all resources! Shoot everything, burn what's left, destroy the rest. It was our disaster period. You had the same thing in the American West —in the 1800's everybody started shooting, and the great herds were destroyed."

Dharmakumarsinhji, 59, of the Princely House of Bhaunagar, remembers how "war broke out against the animals. Before the reduction was felt, it was too late. It can never again be like it was in the past."

At the same time, thanks to improved health care, India's population began an extraordinary climb. Whereas it grew by only eighty million from the turn of the century to 1941, the population ballooned by 280 million from that year to today's 600 million.

Each new mouth cried for food, each new body needed a piece of earth to sleep on, each cook pot required firewood. Between 1900 and today, perhaps half of India's forests, home for much of its wildlife, vanished. Most was converted to cropland.

Into the remaining forests poured millions of domestic livestock, searching for grazing. Protected from slaughter by Hindu belief and tradition, India's cattle numbered 200 million, most undernourished, many diseased.

For India's wildlife the struggle for survival became a competition with human beings and their livestock for the very basics of life—food, shelter, space.

It is not surprising that the government of India did not recognize the problem and act to remedy it. Independence had been preceded by half a century of political struggle and by World War II; it had been accompanied by partition, gigantic exchanges of populations, massacres; it was succeeded by severe economic and social problems, four wars, political uncertainty.

But a handful of people did keep alive India's traditional concern for her animals. M. D. Chaturvedi, a *(Continued on page 314)*

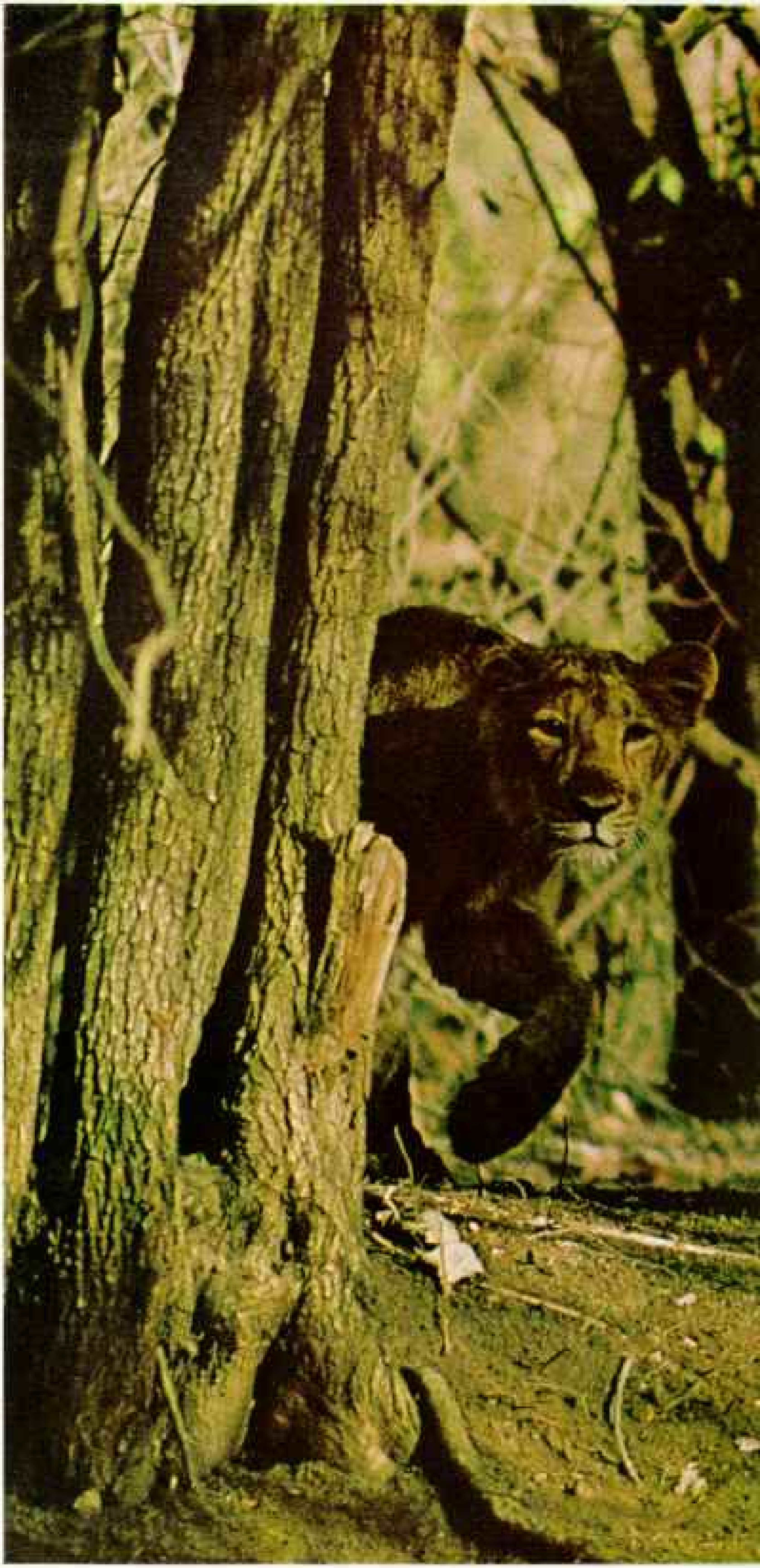
Apothecary of Asia, the great Indian rhinoceros is still desired by Chinese who believe the animal's horn possesses medicinal powers. In times past the creatures roamed the entire Ganges Basin; then they were slaughtered until only a few dozen individuals remained. Today about 700 are safeguarded in Kaziranga National Park. Jungle mynas rid the animals of insects and warn of intruders.

STANLEY BREEDEN

"I have witnessed in this jungle graceful creatures passing fair..."

RAMAYANA

Threatened, not threatening, young lions pad soundlessly through the Gir Forest—their "last stand." About two hundred of these Asiatic lions, the only ones outside zoos, inhabit the forest. They compete for survival with thousands of head of hungry livestock that deplete vegetation and cause streams to dry up. Today the government seeks to halt this competition by relocating villagers and enacting tough controls.



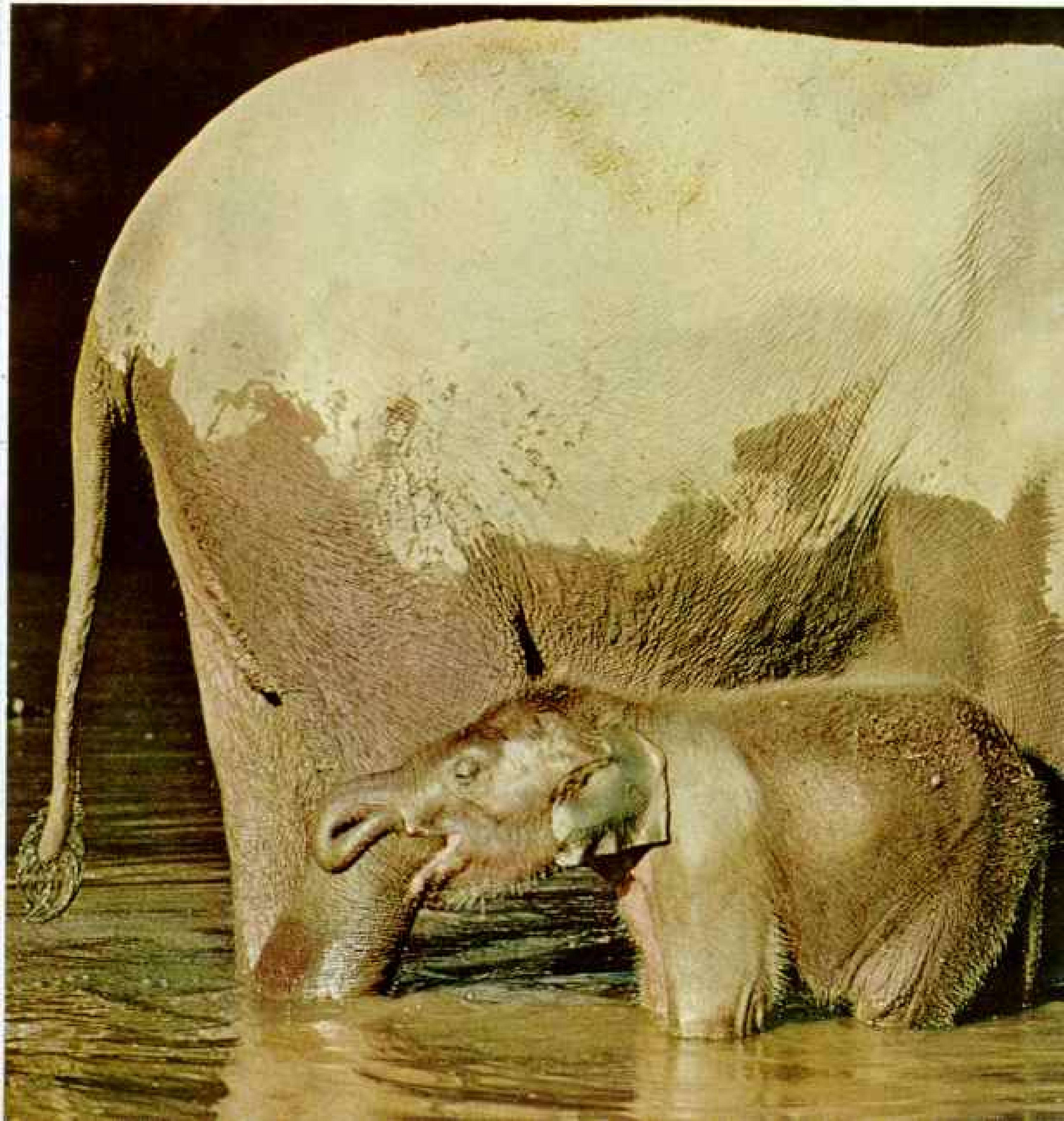
BELINDA WRIGHT

forest officer who shot 86 tigers before turning to saving wildlife; E. P. Gee, an English tea planter who traded his gun for a camera; P. D. Stracey, an English inspector general of forests in Assam; Zafar Futehally, a Bombay industrialist; M. Krishnan, a journalist in Madras; and perhaps a score more. Many were members of the venerable Bombay Natural History Society, founded in 1883 to encourage the study of India's wildlife.

It was through the efforts of such people that the Indian Board for Wild Life was created in 1952 to advise the central and state governments on wildlife conservation problems. But it was not until the end of the 1960's that things began really to come together.

The turning point, according to many, came in 1969 when the International Union for Conservation of Nature held its triennial convocation in New Delhi. The union is a scientific body with a representation of 100 nations and many individuals.

The assemblage of so many natural scientists in the city, their visits to sanctuaries and parks, and the local and international news coverage drew attention to the plight of India's wildlife. Those Indians already working for conservation were encouraged; the subject was brought to the attention of those who had not noticed before.



Prime Minister Indira Gandhi gave the inaugural address, strongly endorsing conservation. Her appearance, many believe, was the vital factor. One Indian participant remembers: "From being a catch phrase, wildlife became a serious commitment of government. The ministers got involved; all those who had hindered now began to help."

Action followed swiftly. In 1970 India outlawed the shooting of tigers and ordered a census of their population. Since 1972 the central and most state governments have adopted the Wild Life Protection Act, which bans the killing of 61 endangered species, provides stiff penalties for offenders, and lays out the legal framework for enforcement.

Money began to move from the center to the states to encourage the development of sanctuaries. In 1973, spurred by a million-dollar pledge from the World Wildlife Fund, India inaugurated Project Tiger. The species had dwindled from an estimated 40,000 at the turn of the century to 2,000.

Nine existing sanctuaries were designated as tiger reserves, and the central government allocated 4.5 million dollars. "The object," Project Director K. S. Sankhala told me in New Delhi, "is to start a nucleus for regenerating the species, a sort of series of nurseries for tigers, where they can rest, breed, spread out."

Trained and tamed...

KAY WILLIAMS (LEFT) AND BELINDA WRIGHT

Escaping the heat, a female elephant and her calf share a quiet moment in a training camp in southwestern India (**left**). Domesticated for centuries, the Indian elephant has hauled everything from timber to battle-bound maharajas, thundering over bloodstained desert. In tribute to its labor, a marble sculpture graces a temple of the Jains (**above**).

...but a lucky few still roam free

Wild elephants graze in Corbett National Park below the Siwalik Range. Though such herds have dwindled, their chances for survival are promising. Working animals must come from wild stock since elephants are seldom bred in captivity, but recent mechanization has reduced the demand for new captives.

"Although there is much in the sport of tiger-hunting that renders it inferior as a mere exercise, or as an effort of skill. . . . yet there is a stirring of the blood in attacking an animal before whom every other beast of the forest quails, and an unarmed man is helpless as the mouse under the paw of the cat—a creature at the same time matchless in beauty of form and colour, and in terrible power of offensive armature—which draws men to its continued pursuit after that of every other animal has ceased to afford sufficient excitement to undergo the toil of hunting in a tropical country."

—CAPT. JAMES FORSYTH, BENGAL STAFF CORPS, IN "THE HIGHLANDS OF CENTRAL INDIA," 1871

TO CHECK on the progress of Project Tiger, I headed toward Kanha National Park, in the center of India. It was late February, when chital fawns were finding their legs, the peacocks coming into full plumage, the wild boar in full rut. The preserve, founded in British days and later expanded, sits on the western edge of one of

India's last great forests. Swamp deer and bisonlike gaur graze unafraid in its meadows. Kanha is, by consensus, among India's best managed parks.

The first morning out on elephant back, I saw a tiger—a handsome female with four cubs. She let us approach fairly close, then vanished into a bamboo lair. Through the canes I glimpsed a bright red flash, the partly eaten haunch of a fresh kill.

Kanha's tiger population has risen from 31 to 48 in the past few years. H. S. Panwar, field director for Project Tiger at the park, explained why: "The basic problems were first to stop the disturbance caused by logging operations and to move out the villagers and cattle. Then to rebuild the habitat—allow the grass to grow back, protect it from fire, build dams and water holes for the animals, and, of course, stop shooting of any kind."

Project Tiger funds help achieve these goals, paying for staff additions, roads and dams, and the cost of moving out villages. The state provides land for resettlement.

Progress, Mr. Panwar said, had been swift. "The environment responds quickly, and once the forestry operations have ceased and the villages have been shifted, the animals lose their fear." When an additional fifty square miles was recently added to the park, the tiger population there rose from five to eight.

Behind Kanha's success lie hidden ingredients: a state government and political leaders attuned to the benefits of conservation, relatively low population pressure, and the vigor and diplomatic abilities of both Mr. Panwar and his predecessor.

Mr. Panwar had been "only a forester" for ten years. Once he had been posted here. As he roamed the park's sal forests and hills, something happened: "Thereafter my interest kept coming back here—to the animals." Now he's content safeguarding them.

One evening as we sat on the veranda of the guesthouse, I asked him about tigers. I had in mind the late Captain Forsyth's ferocious portrayal of the beast.

"I once had occasion," Mr. Panwar said,

"to observe the courtship and mating of the tigress you saw. She and a male lived together, day and night, for a week. There were various displays: The female gave her mating roar and sprayed, the male answered in kind.

"It's quite a rough affair, their mating. One day I came on a kill site and followed the dragline to where the two were. He sniffed her, got excited, gave a mating call, and began to circle her. After some play, they mated. Afterward, they disappeared.

"Then I heard the mating call again and the sound of a big scuffle. When I saw them later, their coats were marked by bites and cuts. They kept together for some time, then went their own ways.

"The gestation period for a tiger is 95 to 110 days. The newborn are just slightly bigger than dog puppies, and usually number four or five, although the average survival rate is only about two. The tigress rears them by herself, first bringing food to the den. In time she will take the cubs out for direct feeding on a kill.

"Within the first few months they begin their understudies at hunting; sometimes they play a hide-and-seek game with their mother. As she conceals herself in the grass, the cubs come searching. She raises her tail, flicks it, then suddenly shifts it, and they learn to pounce and grab. Later the cubs join the mother in the hunt. Sometimes they fail.

"The training goes on for one and a half to two years, until the cubs leave the mother. She then may mate again. The cubs often stay together for a time; they are too inexperienced to establish themselves alone. By three years they are off on their own and start to establish their territories."

Mr. Panwar believes that the survival of the tiger is assured: "There is no question of them being wiped out in preserves like this.

BELINDA WRIGHT

The quick of now, the dead of then

Enduring trophies may be captured on film in Kaziranga National Park, where swamp deer glide past elephant-borne visitors (**above**). In the past, beaters drove wild prey toward the sure kill of hunters such as Britain's Lord Linlithgow (**below,** center) and his party.

JOSHI STUDIO, RAJKOT, 1941

The question concerns those outside the national parks and sanctuaries."

At Kaziranga National Park, wedged between the Brahmaputra River and the Mikir Hills in the eastern State of Assam, I found more indications of progress in conservation. I rode on elephant back with Indian tourists through tall elephant grass to the clearings and water holes where animals meet.

There were hog deer, swamp deer, barking deer; wild pigs; buffalo. Down by the river, wild elephants grazed.

But the centerpiece of Kaziranga is the great Indian one-horned rhinoceros (page 311). Long ago they ranged the length of the Ganges Valley, but the reed jungles they require were converted to cropland. In time most of the remaining rhinos came to dwell in Assam, mainly in Kaziranga. The rhino's horn is believed to contain wondrous properties as an aphrodisiac and as a medicine, and poachers shot them until they had dwindled to only a few dozen.

Tough new enforcement measures—including guard posts linked by radio, jeep and elephant patrols, and armed foresters—stopped the slaughter just in time. Today 700 of the rhinos graze the park, their dainty stride contrasting with their armorplate-like shields of folded skin. Indeed, some observers are concerned that Kaziranga may have become overstocked with these animals.

KANHA AND KAZIRANGA are two of India's success stories, but not every preserve has shared equally in the money and attention or success in resolving long-standing problems.

Periyar Wild Life Sanctuary, situated in the hills of the southern State of Kerala, is one of India's most popular tourist attractions. Perhaps 100,000 visitors a year come to take a

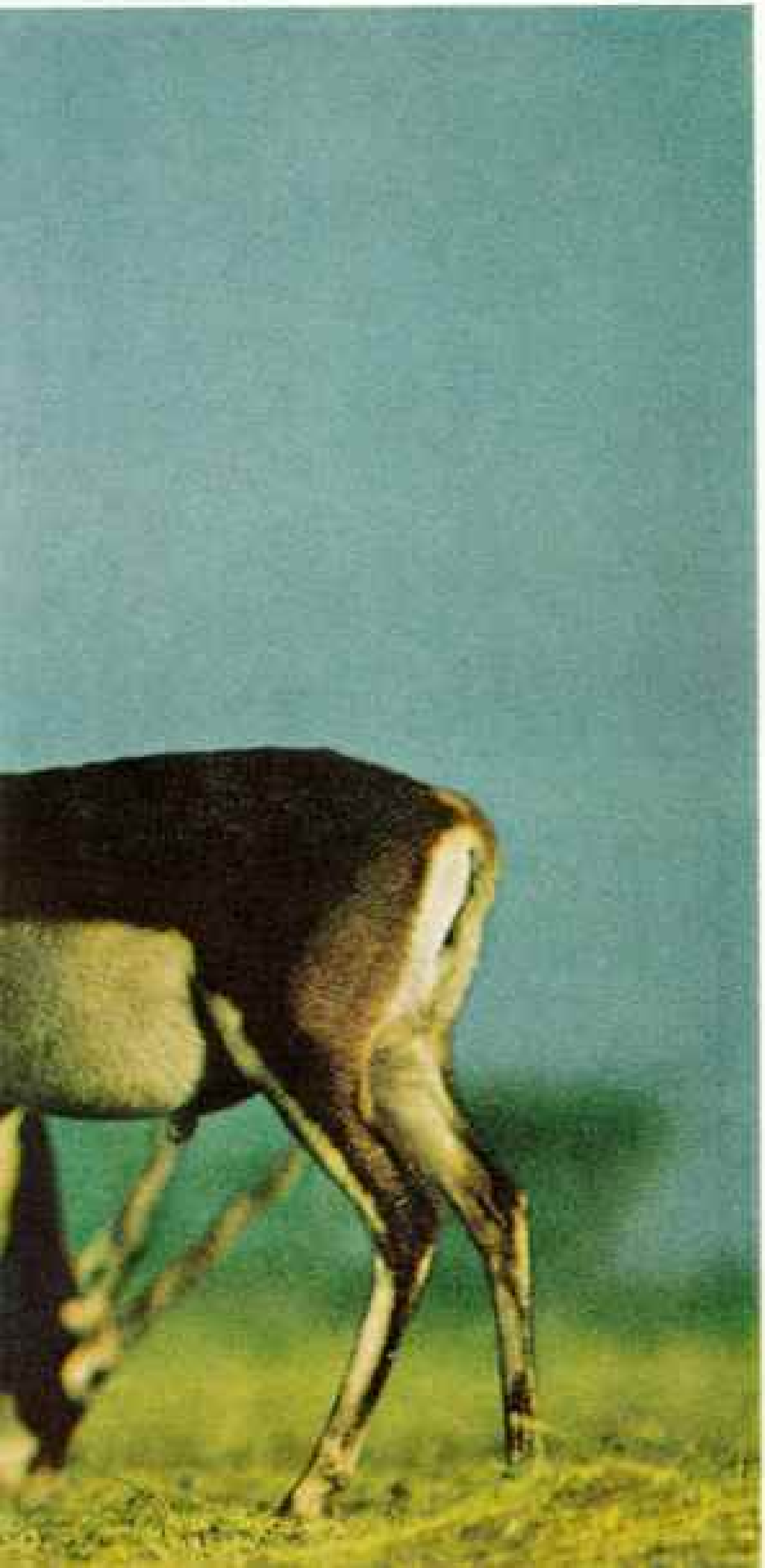
This bullet missed, but the next may not

A blackbuck flees a poacher, jeep-mounted and heavily armed (**right**). The illegal encounter occurred in a desert area of Rajasthan, where law enforcement is difficult. In the State of Bihar, a government sign (**above**) admonishes in Hindi, "Stop Thieves and Hunters." It depicts outlaw hunters jacklighting game animals; immobilized by the blinding beam, they become easy prey.

STANLEY BREEDEN (ABOVE) AND BELINDA WRIGHT

Fleeting freedom

Shadowed on a scarp, elusive Nilgiri tahrs, or wild goats, range the high country of southwestern India. Blackbucks (**below**)—hunted for meat and prized for their spiral horns—are now scarce. These animals, protected in Velavadar Sanctuary, belong to a herd of 2,500—perhaps the largest in India.



boat ride around its man-made lake and view the animals on the shore.

Among them is one gravely endangered species: the lion-tailed macaque (page 343). These unobtrusive monkeys once thrived in the Western Ghats, but catchers snared them for the pet trade and their forest homes yielded to farms and tea and black-pepper plantations. Lion-tails probably number fewer than 500; perhaps twenty live in Periyar.

No detailed census has been attempted. "There is a lack of devoted personnel, a lack of the scientific feeling. We simply cannot take an accurate count," one officer told me.

Last year about 300 gaur (page 308) died in the park of an epidemic of rinderpest, a viral disease probably transmitted by sick cattle passing through. The herd dwindled to about a hundred beasts, although it has now begun to increase.

When the park advertised for a fence to keep out domestic livestock, no one bid. The state government rates were too low. The state is currently digging a trench around Periyar to thwart the cattle.

Poaching and illegal logging continue: Wild pig, sambar deer, and teak bring good money. Men are posted down the lake, but they lack radios and motors for their boats. "Are they to approach a heavily armed party?" one officer said. "It is very dangerous. If they close their eyes or run away, who can blame them?"

FOR THE INDIAN WILD ASS, still another gravely endangered species, major problems include poaching, disease, and the human taste for salt.

The wild ass is a handsome beast—tawny on top, white underneath, with a dark stripe running along its spine. Dharmakumarsinhji, when young, had seen them "in the thousands." Today they number perhaps 720. Most of them live in the salt-rich Little Rann of Kutch, a scrubby wasteland in western India (pages 340-41).

During the monsoon, from June to October, the Little Rann floods into a broad lake and the wild asses take refuge on the *bets*, island-like bits of higher ground. In the dry season, when the Rann becomes a parched desert, they travel to its edges to browse.

In 1973 a sanctuary was established for them. It includes *(Continued on page 328)*

Men and animals compete for food

Finishing off a buffalo, a young lion in the Gir Forest (**above**) must still guard his meal against the Harijans living around the sanctuary. Here a group butchers a calf (**right**) after driving away the lion that felled it. In addition, logging has stripped away the cats' habitat—evidenced by piles of teak logs (**left**).

ALL BY RAJESH BEDI

"Herds of lightsome monkeys..."

RAMAYANA

India teems with monkeys, but some species are both unique and endangered. A bonnet macaque (**left**) sits barely two feet tall on its haunches. Strolling showmen often use the animals in their acts.

Sprinting across open ground, a common langur (**below**) is protected by Hindu custom.

Hoolocks, or white-browed gibbons (**right**)—India's only apes—are trapeze artists of the forest, hurtling along treetop trails with ear-splitting howls.

ALL BY STANLEY BREEDEN

(Continued from page 323) the rim of the Rann and a narrow belt of adjacent land, covering 1,900 square miles.

I came in the dry season. The mornings were cool and clear, and there was sometimes overhead the tracery of migrating demoiselle cranes; by noon the sun was merciless, the air filled with dragonflies, and mirages turned distant parts of the Rann into blue water.

On some mornings the asses, having grazed crop- and scrublands during the night, would be just filing back into the Rann, where they spent their days. On other mornings they would already be far out on the Rann, specks of white caught in the slanting rays of the sun.

It was the mating season. They stood a lot, grazed a bit, rolled on their backs to relieve irritation. The young suckled. And now and then the herd male, as the urge struck him, would come charging in, select a female, steady her with his head, and mount. One day a bachelor male appeared on the horizon. He charged, neighing, toward the herd, trying to cut out a female. The herd male rushed in, they kicked and bit at each other; the bachelor fled, the herd male in pursuit. Returning, he tried to collect a hero's reward, selecting one female. She kicked him several times. He gave up and began to lead the herd back toward the croplands.

The breeding appeared successful during the three days I watched, but the herd often had been disturbed. The Rann abounds in salt; during the dry season workers dig wells, allow the water to evaporate in pans, then remove the salt. The passing of a salt worker,

even a quarter of a mile away, sends the nervous, sensitive herd shifting. Plans are under way to step up production. India needs the salt, the state needs the revenue. So the fate of the wild ass remains problematic.

"Where is Jerdon's Courser? An inquiry.... Jerdon's is so rare that it has not been reliably seen since the year 1900. If this bird is seen by you, kindly report to your nearest forest official."

—FLYER ISSUED BY THE BOMBAY NATURAL HISTORY SOCIETY, 1974

ONE MORNING I went bird-watching with Dr. Sálim Ali in the Borivli National Park outside Bombay. We drove through massive traffic and all the noise of a metropolis of six million, then through teeming bustees, whose inhabitants came out in the streets to bathe and relieve themselves. Then we were in the park and afoot.

There was the rustle of palms in a light breeze. We spotted palm swifts, then a rufous-backed shrike, black-headed orioles, racket-tailed drongos. Then out of the forest came a column of tribesmen, each carrying branches. They filed by, looking at us only briefly.

"What is this! What is happening! An army coming out of the forest!" Dr. Sálim Ali cried. Part of Borivli's habitat was disappearing before our eyes. "What can you do? What should you do?" Dr. Sálim Ali added. "They must eat, and need wood for their cooking fires." He shook his head: "Population—it is at the root of every problem."

I saw this conflict also at Keoladeo Ghana, a spectacular bird sanctuary located a hundred miles south of New Delhi. Each summer and fall the monsoon covers 11 square miles of wet meadowland with a shallow lake. With the rains, some 400,000 resident birds arrive to breed; perhaps 200,000 migrant birds come later, for winter feeding.

The birds load tree limbs until they droop; feed on the lake's fish, frogs, snakes, and insects; and fill the air with an incredible din of cries, cackles, and croaks. But their voices are joined each day by the whoops and songs of herdsmen who lead some 7,000 buffalo to feed in the same limited area.

The buffalo disturb the birds in their nesting and may destroy food sources. If buffalo were banned, the birds, which have no other such nesting area within hundreds of miles, would benefit. But as the former Maharaja of Bharatpur, who lives nearby, said: "Where could the herdsmen go? They have plowed up their own grazing land."

Such pressures, along with hunting and

Street fighters

Eyes aflame, a mongoose crushes the head of a *ghorapachar* snake after dodging the reptile's bite. Fights between these natural enemies are often staged on city streets as a tourist attraction. BELINDA WRIGHT the catching of birds for their feathers or the pet trade, have substantially reduced India's flocks. The pink-headed duck exists only in the memory of men; the forest-dwelling white-winged wood duck is now rarely seen, its numbers unknown. Only a hunch by Dr. Sálim Ali led the Bombay Natural History Society to circularize for information on Jerdon's courser, a small ground-living bird, not sighted in 76 years. There was no response.

But even when a species is known to be slipping into extinction, help is often slow to come. The great Indian bustard, three feet tall and weighing as much as forty pounds, is such a creature (page 337).

I found the rare bird some distance from Bikaner, in the desert area of west Rajasthan. Villagers described its habits: "In the morning it looks for food; at noon it goes and sits in the shade. It never sits on a tree. At night it simply folds its neck back over its back.

"The females give one or two three-inch eggs, generally one. The birds remain here throughout the year. The meat is good, especially in summer."

The bustard eats dung beetles and lizards, but principally the leaves and flowers of the *kerad* bush. During the days I observed them, solitary males strolled the meadow—sometimes only a head and neck moving above the grass like a periscope. They moved heavily, seemingly pompously, like Colonel Blimps strolling with some distaste down Piccadilly.

So slow are the birds that they can easily be shot with muzzle-loaders, or even killed at takeoff by hurling a large stick at them. Poachers often approach on camels or in jeeps; nothing seems to frighten the bustard.

Protection is marginal. The local forest guard's first responsibility is to protect a fenced-off area so that some grass can remain when the drought comes and all other grass dies or has been eaten.

One local man said he had in previous years seen as many as thirty bustards, this year only six or so. I had been fortunate, he said, to see nine.

That night as the Bikaner Express rumbled toward New Delhi, I pondered what I had seen. Clearly, there had been gains, but losses continued in many areas. What were the chances of the government holding its forests, providing more and better-trained staff, above all checking the population growth?

"What of thee I dig out, let that quickly grow ever,
Let me not hit thy vitals, or thy heart."

—VEDIC HYMN TO EARTH, 1000 B.C.

INDIA'S FORESTS, 95 percent in state hands, are still dwindling. The most recent survey shows an annual loss of .2 percent, 382,000 acres. This diminishment is expected to continue for some time.

"The loss now," explained Inspector General of Forests S. K. Seth, "is to the construction of dams and industrial complexes. These must be located in forests, because that is where the streams are."

Thus 18 square miles of the best grazing land in Corbett National Park was submerged by the waters of the Ramganga Dam, causing an artificial concentration of animals that could be harmful.

Mr. Seth believes, as power requirements are met and the consciousness of the wildlife problem grows, such projects will taper off.

But India's conservationists see another threat: While forests continue to shrink, demand for wood products soars.

Last year India produced 13 million cubic yards of industrial wood; by the year 2000, demand is expected to reach 65 million cubic yards. As forests cannot be expanded, Mr. Seth said, the only method of meeting demand is to turn to intensive forest practices—cutting millions of acres of old mixed forests and replacing them with plantations of quick-growing species.

Conservationists protest that wildlife requires the old mixed forests with their variety of shelter and food, and that the new forests—teak, eucalyptus, and pine—provide poor habitat. "Eucalyptus is the worst," one told me. "Even the birds will not come to those trees; they hold no berries."

Mr. Seth disagrees. Time will tell.

To inquire about India's progress in slowing its birthrate, I called on Dr. Karan Singh, Minister of Health and Family Planning. A handsome, bustling man, he is the former Prince of Jammu and Kashmir, a poet and Sanskrit scholar, and has served in varied state and central government posts.

"Our population," he said while ringing for tea, "is just over 600 million. Our increase is 13 million a year, which is nearly the population of Australia. We are determined to

Musk magic lures hunters

Drooping canine teeth mark males of the small, imperiled musk deer (**right**), prized for the walnut-size gland beneath its abdomen. *Kasturiwale*, or "musk men," of New Delhi buy them from poachers and sell the glands to local pharmacies. Here, one musk man checks his old-fashioned shotgun (**below**).

STANLEY BREEDEN (TOP) AND RAJESH BEDI

Two hundred dollars for a musk gland? This enormous specimen will probably fetch that much for these merchants. The musk men sell them as a panacea for impotence.

overcome this problem, and have already made progress. The birthrate has dropped some 11 percent since 1956. Of course mathematics will show that, despite the drop in the rate of increase, our population will continue to grow for many years."

ONE INDIAN SCIENTIST, projecting the rate of decline, foresees that India will achieve zero population growth by the year 2081. But her population will then be 1.6 billion, almost triple that of today.

An awareness of these numbers has shaped the policy of the Indian Board for Wild Life. Its chairman? The same Dr. Karan Singh. He paused to pour the tea.

"Our strategy," he said, "is to concentrate our efforts on national parks and sanctuaries, to try to keep secure certain islands of forest that harbor wildlife." Little hope is held for animals outside these islands.

Dr. Singh was proud of the board's achievements: the 1972 Wild Life Protection Act, the increase in the number of sanctuaries to some 150, the efforts to spread wildlife education in schools, the export controls. "Perhaps our greatest failure is in our inability to have our administrative decisions and rules carried out on the ground. We are an advisory body, without executive powers. We know exactly what is to be done," he said. "The problem is, the doing of it!"

"The doing of it!"—India's antipoaching and export laws, enforced in some areas, have slowed the sales of tiger, leopard, and crocodile skins. But the killing of certain animals is so widespread, and the tradition so deep, that much continues. What is one to do about certain tribesmen in the Punjab, so short of food they have begun to kill not only wild boars but even jackals? Or the Baverias, who roam the scrublands and forests of Rajasthan with sleek hunting dogs leashed with strips of cloth? By tradition they have lived on the small game their dogs catch, and by snaring reptiles and performing as snake charmers. Or the *kasturiwale*—the musk men?

I met the kasturiwale in a vacant lot in a New Delhi suburb, only a few miles from where I had talked with Karan Singh. Their tents were neatly aligned and immaculate. The men, with gold earrings and necklaces, were packing their bags for a day's selling.

They collect medicines in the Himalayan foothills. Most prized is musk, a secretion from a walnut-size gland found under the belly of the adult male musk deer. It is believed the male uses the secretions to attract the female, for the gland functions only during the month-long rutting season. The poacher must strike then (page 331).

He kills the animal, cuts off the gland, dries it on a warm stone, and sells it to the kasturiwale, who carry it to the city. They sell most to ayurvedic (traditional) pharmacies as an ingredient for perfumes and medicines. But they also offer the furry, fragrant pods to individual buyers, and mix the musk in their own potions. Their tonic for male sex troubles, for instance, includes bitumen, amber, a boiled whole lizard, orchid tubers called "ice of a stone," and *kasturi*—musk.

They said business was increasing. "Modern medicine is too strong, hard on the system. Chronic patients—those with gout, general disability, nervous-system diseases—prefer our medicine especially." Each carried a thick book of endorsements, complete with photographs.

I met them again that evening. "It was a good day. In the north of the city we sold to a policeman some general tonic and some saffron." They would remain in New Delhi perhaps a month, depending on business, and planned to return next year. The trade is illegal, the musk deer endangered.

"You ride the elephant, and the elephant lumbers
Near the banks of the Champa River;
Tell me the truth, O my darling mahout,
Where do you stay and where is your shelter?"

—A MAHOUT SONG, ASSAM, 1976

KIPLING WROTE of the elephant catchers in *The Jungle Book:* "What Little Toomai liked was to scramble up bridle-paths that only an elephant could take... the glimpses of the wild elephants browsing miles away... the blinding warm rains, when all the hills and valleys smoked; the beautiful misty mornings when nobody knew where they would camp that night."

The elephant catchers of Assam still pursue the wild herds, capturing some three hundred each year. Most are sold to traders from the State of Bihar who sell them in turn at the great animal fairs, the Sonepur, Singheswar, and Khagaria *melas*. As elephants seldom are permitted to breed in captivity, the wild herds are almost the only source.

I joined the catchers in the hills of Assam, at Dabaka depot, a cluster of tents. Half a dozen recently captured elephants were staked fore and aft with ropes to huge pegs. The catchers were feeding them sugarcane, rubbing them with grass and leaves, and singing them lullabies. "Come on, *hati*, see how nice it will be if you become tame, the rubbings, the daily bath, the nice food; quit fighting, hati!" When an elephant struck at a man with its trunk, the man struck back with a stick, then resumed the rubbing and singing.

As the elephants became more docile, the men began to teach them a score or more of commands: *Ageth!* (Forward), *Pichu!* (Backward), *Chai!* (Circle), *Tere!* (Sleep), *Utha!* (Lift one leg), *Biri!* (Lift with the trunk), *Dhar!* (Catch with the trunk).

Then one morning my party of catchers left for the Mikir Hills. They rode two to a *koonkie*—a trained elephant. When the

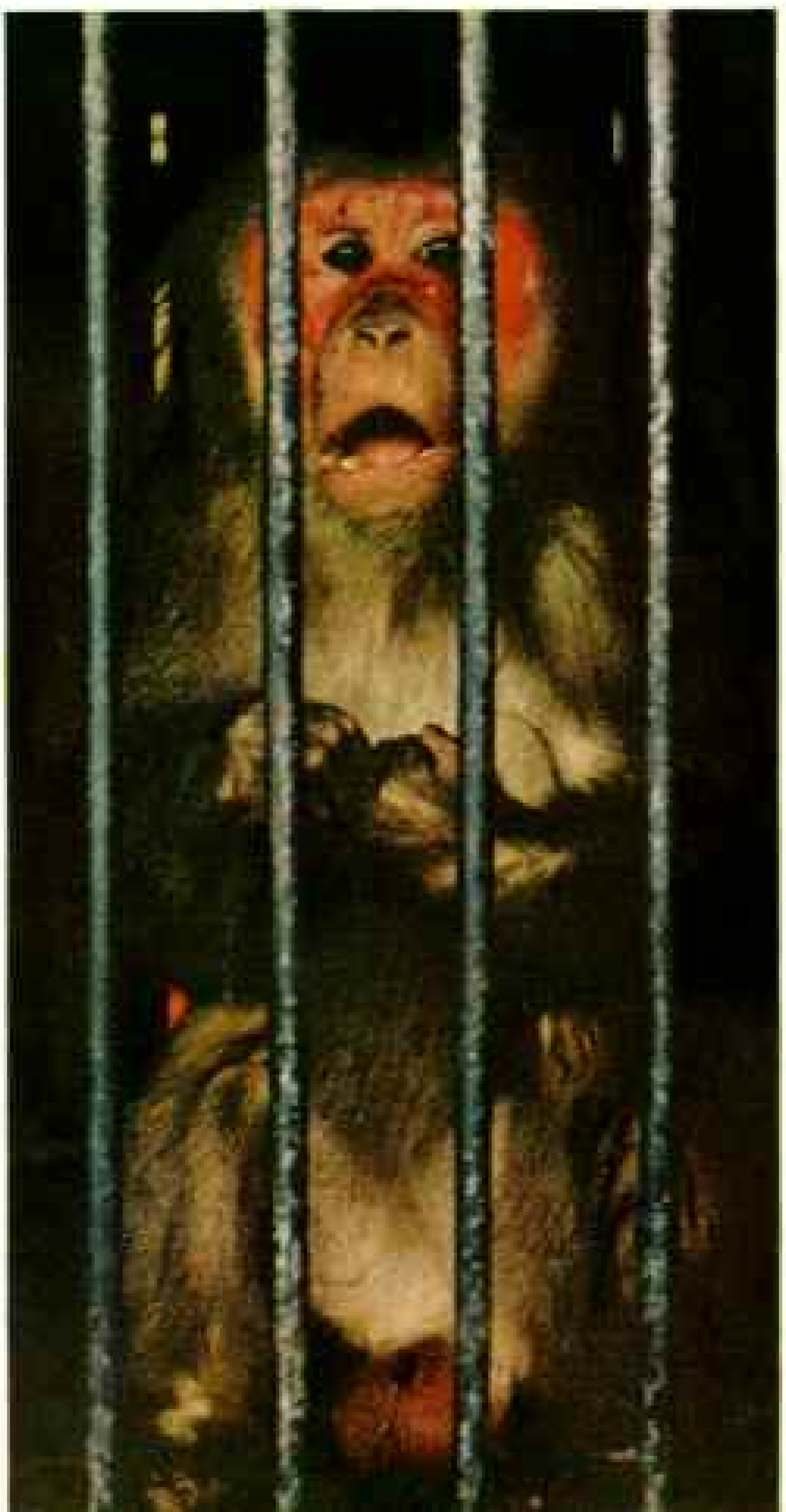
RAJESH BEDI

Sacred but not safe, the mugger crocodile, shown here at the Delhi Zoological Park, faces extinction in its marsh and river habitats. Hindus worship muggers kept in temple pools, but the state-protected reptile wins no such grace from hunters seeking the valuable skins.

STANLEY BREEDEN (ABOVE) AND BELINDA WRIGHT

Some see only caged horizons

"Improving" nature, dealers in a Calcutta market spray thousands of munia birds (**below**) with vegetable dyes for buyers in Asia and Europe—and until recently, the U. S. as well. Packaged in cages (**left**), about a third of the birds succumb to the ordeal. At a traveling animal market in the State of Bihar, Himalayan black bears —scarce in India—are kept in tiny pens (**above**), and a stump-tailed macaque languishes behind bars (**right**).



quarry was found, the master would sit on the koonkie's neck, give the commands, hurl the great lasso. His assistant, clutching a rope, would stand on the koonkie's rump, jabbing it with a long metal-tipped spear to urge it on. Within a few days we were deep into the hills, feeling both the hard raised spine and soothing gait of our mounts.

We slept under canvas, with leaves for mattresses and fires at each end of the tents to keep away wild animals. Each day we drank tea and were on our koonkies by dawn.

Sometimes there were green clouds of parakeets in the mornings, and at dusk swarms of bats. Now and then we heard the jabber of monkeys, perhaps warning of tigers.

Three times we came on wild elephants; three times we failed to catch. Our only hope was to find young or female elephants somewhat apart. Instead, each time a great tusker saw us and challenged. We stood no chance against such wild males; they would have killed the strongest of our male koonkies.

We pushed on and on. Often the mahouts sang. In one song a girl protests that the love between a boy and a girl can provide as much satisfaction as the feeling that comes from controlling a great elephant. In another song a poet cautions that life is full of troubles like the dark night sky, and that happiness comes only like lightning, briefly, for half a second. And that amount of happiness, the poet says, is sufficient.

On the eighth morning we found more signs: mashed grass, dung, a wallow where the elephants had played. On and on. But we never caught up. "The elephant keeps moving," one mahout said. "He goes and he goes."

On the tenth day we came down out of the hills into tea plantations; it was warm and sunny, and the workers paused to watch us pass. The hunters began to sing; the younger men called to girls at a respectful distance.

The days in the hills, the up and down, the sliding on mud had punished the elephants. We camped in a fallow field where the hunters would refit and rest their animals. In a few days they would resume the hunt. It might be a month before they succeeded; they might not succeed at all. Life, the poet said, is like the dark night sky.

The days in the hills had been special, something apart, yet even there I could not escape the struggle between India's wildlife and its people. Now and then, from a hilltop, I could see the smoke that signaled another settlement in what was jungle. We had camped one night in the ruins of a village attacked by angry elephants, and each day were eagerly assisted by tribesmen who wanted crop-raiding elephants caught; the very scarcity of our prey indicated their decline.

UNTIL THE END of World War II Assam was thinly populated, remote, a fit place for a Kipling tale. But thereafter came industrialization. The state is now India's largest producer of oil and tea, and forest industries have been accelerated. People from Bihar moved in for the jobs.

To man's changes were added nature's. In 1950 a catastrophic earthquake struck the state, shifting the terrain, changing the course of the Brahmaputra River. This, along with loss of forest cover, has led to heavier flooding than normal, and to the inundation of villages. The people are invading the forested hill slopes, seeking new homes.

Chief Conservator P. Barua told me that thousands of acres of forestland had been lost to such settlement. Only recently has the state government agreed to the strong measures necessary to stop it.

"When we notice encroachment, we first give notice to vacate. Then we take police and elephants to the site. The police drive out the encroachers; the elephants demolish their houses.

"Where do the people go? That's the problem. I can only say: They came from somewhere, let them go back."

Conservationists believe that a key to preserving wildlife lies in the education of the young. The old cannot be changed. Many state governments are planning to introduce the subject into school curriculums. And private organizations such as World Wildlife Fund–India are making parallel efforts.

In 1966 the World Wildlife Fund asked Fatesinghrao Gaekwad, former Maharaja of Baroda, to set up a fund appeal in India. Some were surprised. True, he loved the outdoors and was a successful industrialist, but he was also a noted hunter.

Indeed, the year before, Fatesinghrao had gone on a two-month safari to Africa with his father, the late maharaja, and a cousin. They shot 33 species.

Drafted to help save his species, a male great Indian bustard is captured in Rajasthan to mate with a zoo-confined female. The enormous birds, weighing as much as forty pounds, have been severely depleted by poachers.

But Fatesinghrao came back from Africa with more than trophies. He also had 4,000 feet of motion-picture film. He spent day after day at the editing table, and something happened during that sustained viewing: "The futility of shooting, of destroying wildlife, came to me," he told me during a visit to his bungalow in New Delhi.

Thus he was delighted to take on the World Wildlife Fund job. He began to solicit fellow industrialists; with 21 other Indians, he joined the World Wildlife Fund's exclusive 1001 Club, founded by H.R.H. Prince Bernhard, The Prince of the Netherlands. Members pledge $10,000 each.

"Today we have now passed the hand-to-mouth level of existence," Fatesinghrao told me. The organization has a capital fund of 123,750 dollars, which is set aside to earn income. Annual membership in World Wildlife Fund–India has climbed to 2,000. Yet the fund's effort—like that of India's other conservation groups—is described by one official as "a pebble tossed into a pond. Our only hope is the ripple effect."

An example of the ripple approach is the fund's plan to introduce nature clubs, starting with pilot programs in Gujarat and Maharashtra. "We hope to have a hundred clubs active within a year," one official said. "And 500 within 18 months." The budget for all of India: $33,000. The staff: two headquarters officers and one for each state.

It was to the Gir Forest in Gujarat that I journeyed last. It seemed to combine all the ingredients of India's wildlife struggle. The forest, which has dwindled from 1,000 to 500 square miles since the turn of the century, is one of the few left in the state.

Signs of xerification, or drying up, were apparent. Good grasses have been grazed away and, in many places, have yielded to unpalatable ones. Some streams have dried and the water table has dropped.

For years the forest has sheltered some 200 Asiatic lions, the last of a subspecies that once ranged from Greece to eastern India; some 6,000 Maldhari herdsmen and their 25,000 cattle and buffalo; and, during periods of drought, up to 80,000 domestic animals brought in from the surrounding countryside.

The struggle for survival in Gir was desperate. The lions killed the Maldharis' cattle for food; the Maldharis in turn drove the lions from their kills, and sometimes poisoned them. The cattle, meanwhile, overgrazed the forest and trampled the very earth, speeding up the process of xerification, ruinous to all.

The state government is now acting to save the forest and its wildlife from the impending destruction. The Maldharis and their cattle are slowly being moved out, and a low rubble-and-hedge wall, 103 miles long, has been built to mark clearly the sanctuary boundaries, and to keep out cattle from surrounding villages.

Forest officials report that the lion and other wildlife populations seem more stable, that grass is coming back in some areas, and that prospects are generally good. The Maldharis, they reported, are finding a better life in their new homes.

BOTH BY STANLEY BREEDEN

Rare beauty, the satyr tragopan, or crimson-horned pheasant (**above**), lives in the lofty Himalayas, which offer the protection it needs to survive. Stately sarus cranes (**right**) strut and trumpet through a mating ritual at Keoladeo Ghana Sanctuary.

I WONDERED ABOUT THEM—the human equation in the struggle to save wildlife. I visited one of the *nesses*, villages, still in the forest. It was early morning, when the mist lifts slowly from the valleys and there is the smell of cooking fires. The men take their staves and axes and lead their herds from thornbush stockades. Young women follow, collecting the droppings, which they mix with topsoil and sell to village farmers. This, along with ghee, a cooking oil made from the milk of their buffalo, provides their income. Hand churns were already busy when the last herds vanished into the forest, leaving plumes of dust.

Then I went to the settlement of Chotili, some 30 miles away. There were 90 families. Each had received a concrete-block house, 20 *bighas* of land, seed, instructions in farming, and an iron rod around which a plow could be built. Their community seemed set in a vast, flat sea of cropland.

Most found their new life in some ways better. There was a school for their children, they grew wheat and peanuts on their 8 acres, there was a town with stores nearby.

But water and food for their cattle were in short supply. "There is only one well, and there is no wasteland to graze—all around are farms." Since arriving three years ago, half of their 1,800 cattle have died.

The men still wore their traditional costumes: golden earrings, sometimes three to an ear; white tunics, embroidered and pleated; jodhpur trousers, loose to the knees, then tight. Yet something was missing. Not until later did I remember: the long staves and

handmade axes of the forest herdsmen. Their lives are changing, their future uncertain.

So too is that of the Gir and its lions. A Canadian researcher concluded that the lions prey so heavily on buffalo that once the livestock is moved out, the lions will lack adequate food. Park officials disagree.

And there is the weather, which man cannot control. The last monsoon had been heavy, and so there had been relatively good grazing in the surrounding countryside. The Gir Forest guards, reinforced by police, have been able to check the annual invasion of starving cattle and desperate herders.

But the memory of 1973, when the monsoon failed, remains: "With drought came a flood of men and animals—a thousand head of cattle arriving every day for a month, continually coming. It was July. There was nothing we could do."

WHEREVER I WENT in India, people concerned with wildlife gave major credit for progress to the "P.M."—Prime Minister Indira Gandhi. In time it became clear that much that happened could be traced to the open door she keeps for friends of wildlife. Despite even the current political tensions, she hears pleas and, if they are worthy, writes a letter, places a phone call, makes a visit.

I called on her at her office in Parliament

Easily spooked, Indian wild asses streak across the Little Rann of Kutch (**above**). The presence of salt workers often disturbs the rare, high-strung beasts. To give them hideouts, wildlife personnel plant trees (**left**). Eager to display the creatures, Indian zoos offer as much as $3,000 for a colt such as the one here roped by horsemen (**right**).

House. She had, I knew, grown up as an only child, and her childhood had been invaded by the turbulence of India's struggle for independence. She recalled those days: "My parents and relatives, most of the family, were often being imprisoned. Our house was raided by the police and things confiscated."

She found companionship and a sense of peace with nature. She developed a "love for stones no less than trees, and for animals of all kinds." There were pets: horses, a bear, dogs, a handsome blackbuck kept "for a very long time," until it jabbed one too many guests with its spiraled horns.

There were camping trips in Kashmir, and at home the warm nights when everyone slept outdoors. She remembered how her father, the late Jawaharlal Nehru, who was to become India's first Prime Minister, would point out the constellations and name each. She learned that "when you know a thing by name, you feel much closer to it; even with a bird, if you know it is a robin, there is a different relationship."

In time she developed a certain philosophy: "If a person is not at home with nature, then I think he is not at home with himself either."

Of her own efforts, she said: "It isn't at all easy to get any of this done; you have to pursue it all the time. Even when we make a sanctuary, there are sometimes problems. At

RAJESH BEDI (FACING PAGE AND BELOW) AND STANLEY BREEDEN

Keoladeo Ghana we have a problem because there's no proper wall around it. Dachigam has been injured by a sheep farm. I'm told most of the stags have gone away.

"But I don't think I have a choice. If you don't do it now, there won't be any wildlife left. And when you are head of government, you have to deal with all the problems more or less simultaneously."

The personal intervention of the Prime Minister is a fortunate thing for India's wildlife, yet her individual importance may also indicate a weakness in the governmental institutions set up to preserve wildlife. "If she goes," one conservationist said, "then I think we will have no chance of success. It may all fall apart."

The Delhi Zoological Park is spacious and pleasant, in part because of Mrs. Gandhi's personal intervention. There is a cheetah, but African; male peacocks that dance with tails fanned; Manipur brow-antlered deer, whose wild kin number fewer than 25. But its most popular inhabitant is Jimmy the tiger. He stalks a large enclosure, often concealing himself behind grass. Now and then, when people stop before the enclosure, the keeper obligingly calls "JIM-M-M-Y!" The large and beautiful cat comes charging out of the bamboo and, with a heart-stopping roar, plunges into the surrounding moat. He looks at the viewers, paddles back, and retreats into his mini-jungle. The audience is delighted.

IT IS POSSIBLE that someday all of India's larger wildlife will, like Jimmy, be confined to zoos or extended zoological parks such as the Gir Forest. I thought of all those people who had struggled so long to prevent that: Sálim Ali, Dharmakumarsinhji, Krishnan, and all the others. What were their chances of success?

One United States scientist with much experience in India told me tersely, "Too little, too late." Another foresaw: "They'll keep what's in their preserves, nothing more." Dr. Karan Singh had answered the question in words befitting a poet: "If there is any wildlife left in India in the year 2000, it will be because of what we are doing now."

The truth is that the future is uncertain. One can only look for signs.

A FEW DAYS before I was to leave India, I happened to meet Mr. V. B. Singh, chief wildlife warden for the State of Uttar Pradesh. His is the most populated state in India, with 88 million people. So intense is the pressure for land that the state plans to compel the settlement of its 3,000 nomads and their 10,000 animals. There is simply no spare grazing land for migrants. To accommodate the reluctant settlers, the state will carve 1,200 acres from a state forest.

But Mr. Singh was quite optimistic: "Things are moving in the right direction." He cited increasing funds, a greater consciousness of the problem, the expansion of sanctuaries, and the establishment of 116 square miles of Corbett National Park as a sanctum sanctorum, free from all disturbance, even logging.

"The number of tigers in Corbett has reached the saturation point," he said, "about 55. And they are spilling out." Some, because of lack of food, loss of habitat, or because of injury or old age, have turned to cattle lifting, even man-eating.

"We have three man-eaters in Uttar Pradesh. One has taken five lives and has been officially declared a man-eater and condemned. The other two have taken only one person each.

"Twenty days ago we began to gather information about the man-eater, and a senior forest officer has been delegated to destroy it. He is our chief conservator, an old *shikari* [hunter] and a fine shot. He is now staying close to his office in Lucknow, awaiting word of the next human kill."

In India, time is still measured by the endless turn of the seasons, and for both its wildlife and its people, the struggle often remains one for survival. □

Swinging free in captivity, a lion-tailed macaque—a species gravely endangered—is protected in a zoo. In the wild the reclusive monkeys exist only in small patches of dense forest. India has declared her resolve to preserve her wildlife heritage. If she fails, humanity is the loser. Wrote Kipling in *The Jungle Book* of Mowgli's bond with his animal friends: "We be of one blood, ye and I." RAGHU RAI

This Is the World's Richest Nation—All of It!

ARTICLE AND PHOTOGRAPHS BY
MIKE HOLMES

"TOMORROW will take care of itself," goes a familiar saying on tiny Nauru (**above**). That sunny outlook is understandable, for the handful of islanders who own this miniature Pacific realm—earth's smallest independent republic—enjoy greater per capita wealth than do the citizens of any other nation.

But without careful planning, their rosy tomorrow could end in less than twenty years, when the last scoop of rich calcium phosphate—the base for superphosphate fertilizer—will have been gouged from the eight-square-mile island's low crown.

Against that day, President Hammer DeRoburt (**right**)—here inspecting phosphate diggings—busily directs an aggressive program of investments. He provides for the present as well, assuring the good life for the 3,700 Nauruans. The government offers free or low-cost everything for everybody, from owners of relatively unproductive "coconut land" to "phosphate land" millionaires.

And nobody pays any taxes on Nauru.

Until recently, the little republic had been Treasure Island only for outsiders. Exploitation began in 1907, mainly by Australia, New Zealand, and the United Kingdom, which eventually held Nauru as a joint trust. Islanders won control of their riches in 1967 and independence the next year.

Now each year Nauru sells as much as 2.2 million tons of phosphate at about $60 a ton to green the fields of Australia, New Zealand, and Japan. Phosphate landowners immediately get $3.40 a ton. The rest is divided between the national government, the Local Government Council, and long-term investment funds—a nest egg that could be worth three billion dollars when the last phosphate ship churns away. Meanwhile, the place once called Pleasant Island is being literally torn asunder, and its people are catapulted into dependence on a world far beyond their horizons.

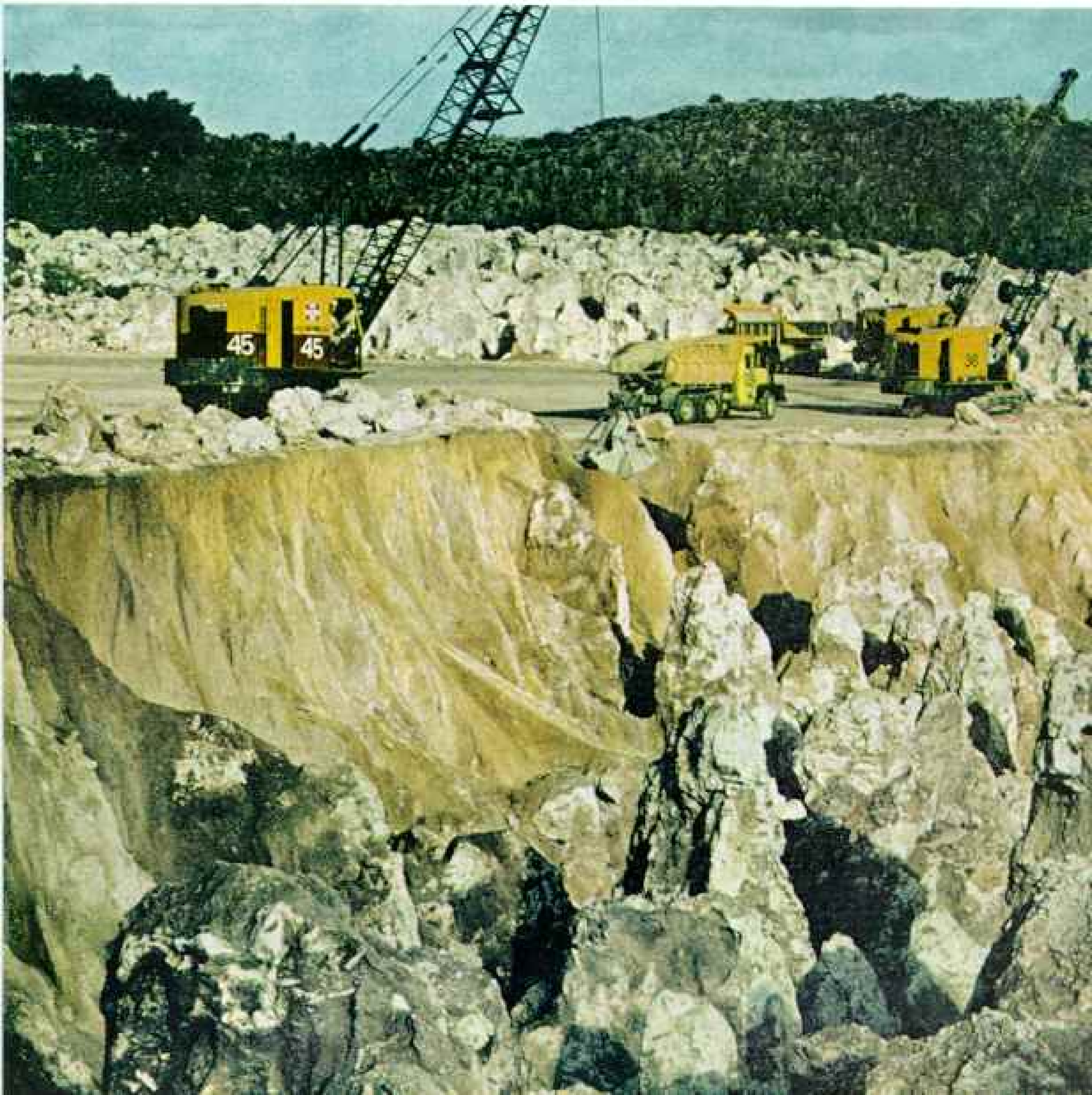
RENÉ BURRI, MAGNUM (BELOW)

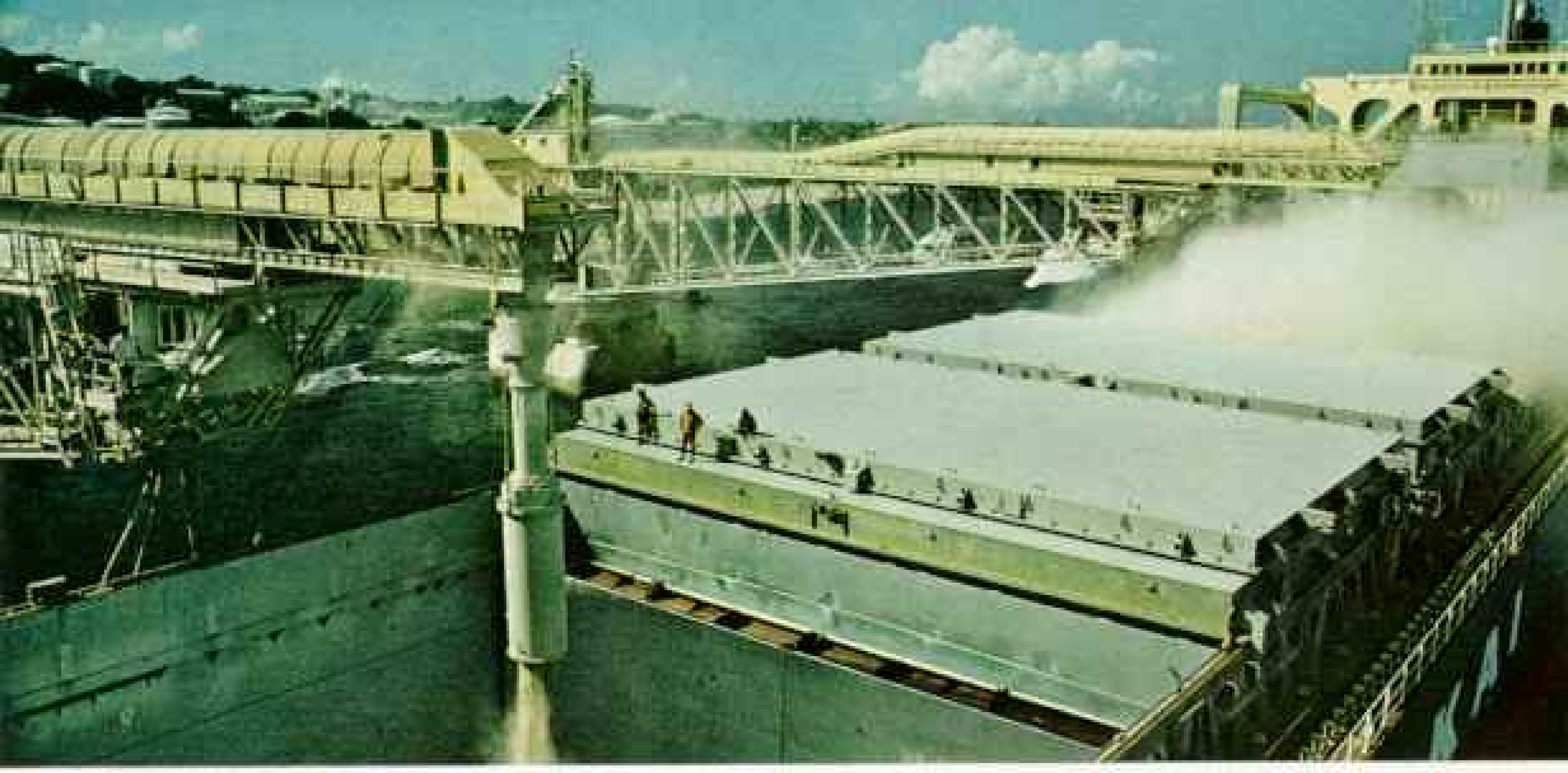
MILLIONAIRE in the making, Baugie Dediya (**left,** in yellow shirt) can easily afford the videotape TV he and his family watch in their home, rented from the local government for $5.35 a month. With a cousin, he owns 30 acres packed with phosphate. The family also owns an expensive stereo, three washing machines, two jeeps, a sedan, a motorcycle, and a motorboat. A sobering side effect of Nauru's vehicle boom has been a rash of tragic traffic accidents. Baugie's son-in-law, David Harris (in the wheelchair), has lost both legs—in two separate mishaps.

At play, islanders often take to the links. Juanita Menke (**below**) retrieves her ball on a "green" of crushed coral.

In Melbourne, Australia, 3,000 miles away, the 52-story Nauru House (**right**) nears completion. Nauru has invested 45 million dollars in the skyscraper, the city's tallest, in return for rent from offices that will house 4,000.

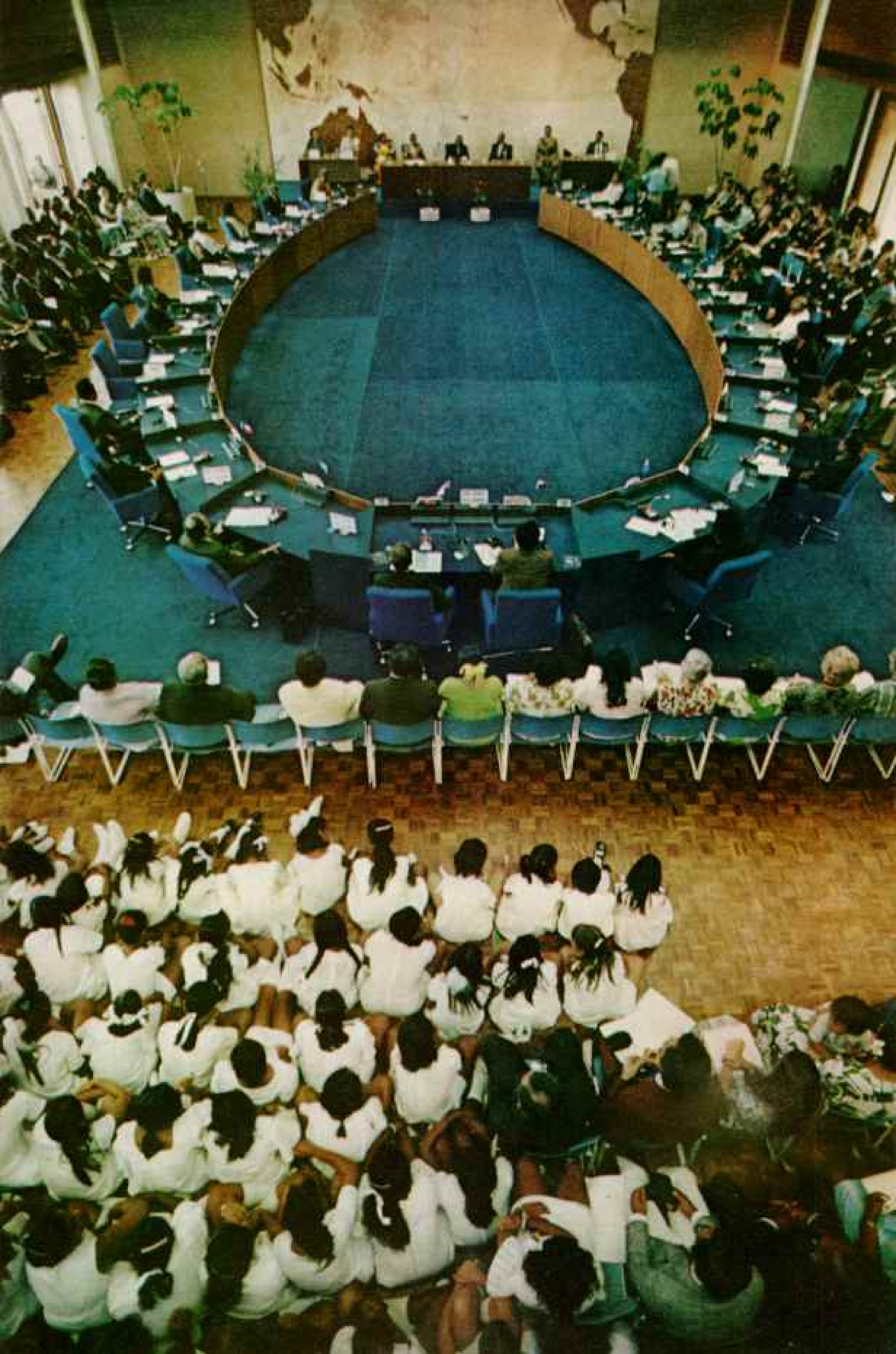
LONELY LODE midway between Australia and Hawaii (**left**), Nauru inherited its fortune from eons-old deposits of either decayed marine organisms or bird guano. In 1900, Albert Ellis discovered in Sydney that a "fossilized rock" from Nauru—used as a doorstop—was actually fantastically rich phosphate. Today, power grabs (**below**) gnaw the mineral from the coral-cloaked flanks of limestone pinnacles. After processing, the phosphate flows on cantilever conveyor belts into a Japanese bulk carrier (**right**) moored beyond the island's fringing reef.





RENÉ BURRI, MAGNUM (RIGHT)

BEATING a path to Nauru's door, the South Pacific Commission of 23 states and territories held its annual conference in the island's new five-million-dollar civic center (**facing page**). Further evidence of the nation's affluence, the Nauru Pacific Line ship *Tryphena* (**above**), one of Nauru's five oceangoing vessels, lies offshore. Beyond the sports field, a barrackslike compound, called Location, houses the government-owned Nauru Phosphate Corporation's 2,600 workers and dependents, mostly Tuvalu (formerly Ellice) and Gilbert islanders and Chinese. Earnings average only about $80 a month, but housing, meals, health care, and schooling are free. Many of the foreigners boost their wages by fishing, which the Nauruans now do only for fun. Islander Ricardo Solomon (**right**) surfaces with a 26-fish grin. He and a friend speared the feast in half an hour.



RACING THE RAINDROPS, "footie" (Australian-rules football) players pad past phosphate workers' quarters. Nauruans competed with 12 national teams in the Olympic-type South Pacific Games held on Guam last year.

A policeman halts traffic (**below**) on a road at the end of a runway as one of Air Nauru's three jets takes off. The airline—yet another investment—flies to Australia, Hong Kong, Japan, and several other Pacific points. Unfortunately, the big birds may have frightened away most of the wild frigate birds, once religious symbols to islanders. Black noddies, terns hunted as delicacies, have also been disrupted; mining has decimated the birds' indigenous *tamano* trees.

A patient gets an X ray, free for a smile, from Nauruan dentist Ludwig Keke. The fruits of this welfare state are rivaled by an old island tradition, *bubuji*, or giving a possession to whoever openly admires it. The president even parted with a Mercedes-Benz.

An envious Australian administrator—one of some 3,500 foreigners on the phosphate-rich Pacific island—succinctly sums up the Nauruans' carefree life-style: "We die worrying; they die laughing." □


10

The essential process by which the likeness of the parent is transmitted to the offspring. . . . is as utterly mysterious to us as a flash of lightning is to a savage.

—BIOLOGIST WILLIAM BATESON, 1902

The Awesome Worlds Within a Cell

By RICK GORE

Photographs by BRUCE DALE

BOTH NATIONAL GEOGRAPHIC STAFF

Paintings by DAVIS MELTZER

Keeper of the keys to life, the double helix, or twin spiral, of the DNA molecule stores the code that every cell uses to sustain and duplicate itself. It is shown here in a painting based on a stylized atomic model. Man and bee, wild flower and microbe, share a kinship of DNA. And along its elegant structure lie genetic messages that make eyes blue, feathers iridescent, and lilacs fragrant.

I PLUNGED A GLASS ROD into the flask of jellylike soup.

"Twirl and lift," directed Maggie Chamberlin, a lab technician at the California Institute of Technology. As I wound, a growing globule of clear organic glue spooled out of the flask and around the rod.

"Just think," said Maggie with a grin. "You are raveling the secret of life."

What I was winding looked no more impressive than egg white. Could it really be DNA, the most celebrated chemical of our time? DNA, the master choreographer of the living cell and carrier of the genetic code?

I had seen DNA (even scientists seldom call it deoxyribonucleic acid) take a much more convincing form earlier that day. Embryologists Barbara Hough and Mike Smith were showing me an aquarium containing dozens of purple sea urchins.

Mike plucked out a male and injected several squirts of salt solution through its prickly hide. Slowly, a white fluid oozed from pores in its back.

He put a few drops of the fluid on a slide. Through a microscope I saw millions of tiny sperm wriggling frantically, their tail-like flagella whipping back and forth with awesome urgency (pages 376-7).

Sperm, I learned, is essentially a bundle of DNA with a tail. It was this substance that Maggie had distilled into the pure DNA in the flask. How different these thrashing missiles of DNA seemed from the inert goo I had spun around a stirring rod!

Yet this contrast struck at the heart of my mission. I was a journalistic traveler in the "new biology," taking notes on the explosion of knowledge that in recent years has utterly transformed the life sciences.

If anything illustrates what has happened in biology, it is this profound new ability to take the very stuff of life out of the cell, to isolate it in a test tube, to dissect it, and to probe the deep mysteries borne in its fragments.

Little more than a generation ago the cell, the living capsule from which all plants and animals are built, was largely uncharted territory. Nor was science sure what a gene, the basic unit of heredity, was made of. Today the cell has been mapped, and biologists know that our genes are made up of that marvelous chemical, DNA.

BIOLOGY has now worked out a logic of life that revolves around the gene. A gene is basically a biochemical bit of information, written in the recently decoded language of DNA. A human cell has perhaps 100,000 different genes linked into strands. They are what tells the cell how to make essential products called proteins.

We commonly think of protein as a muscle-building substance in milk and meat. Actually, protein is the name given to a versatile class of chemical compounds. Protein-rich foods, when broken down, give our cells the fodder for making their own proteins.

There are countless varieties of protein. Hormones—insulin, for example—are messenger proteins that cells use to order other cells to respond to such conditions as too much sugar in the bloodstream.

Proteins called enzymes trigger most of the life events of a cell. A cell uses dozens of different enzymes, for instance, just to digest one important cell food, glucose.

There are also many, many structural proteins—the "bricks" from which cells are built. The fact that you are a man or a mouse, tall or short, brown-eyed or blue, reflects your complement of proteins. When cells divide, or when sperm and egg unite to make a new organism, they pass on through the DNA in their genes instructions for making proteins exactly like their own.

Enormously long strands of DNA intertwine within the core of living cells. So narrow and tightly coiled is this DNA that all the genes in all the cells in a human body would fit into a

HARRY BENSON (ABOVE)

Born defenseless against infection, "Baby David" (**above**) can be held but never touched by his mother. He must live isolated in a sterile environment while science seeks a way to help him. His problem stems from defects in some of his estimated 100,000 different genes, which are encoded segments of DNA that carry life-shaping instructions. A NASA experimental suit (**right**) may give mobility to such children, but as yet they must live as aliens on their own planet.

box the size of an ice cube. Yet if all this DNA were unwound and joined together, the string could stretch from the earth to the sun and back more than 400 times.

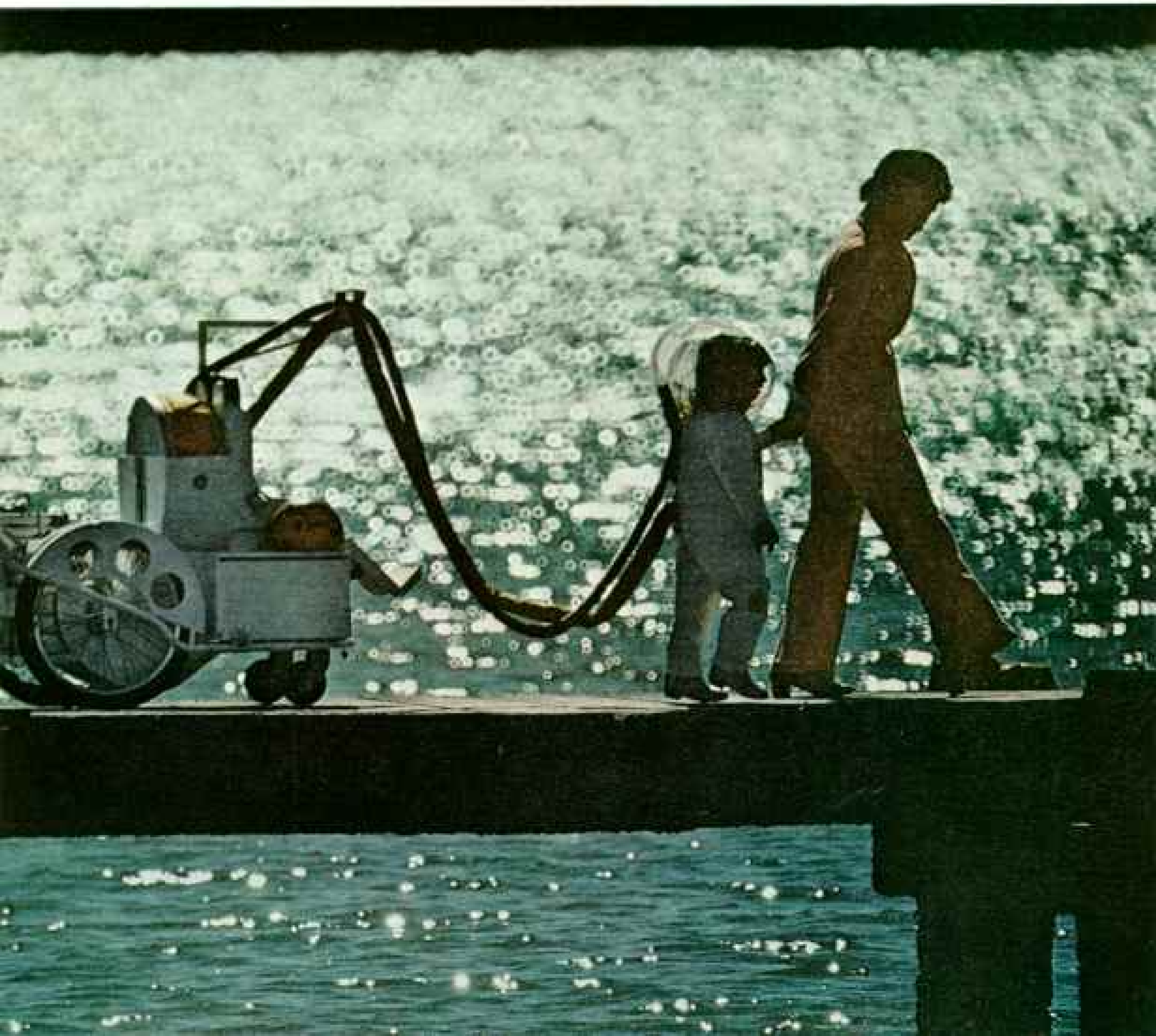
Moreover, biologists have found that virtually every cell contains the entire repertoire of genes for that plant or animal. One cell in my toe, say, has all the data in its DNA for making another man physically identical to me. That many instructions, if written out, would fill a thousand 600-page books. The unique experiences of our lives, of course, make us more than a product of our genes. Yet it is our DNA that sets the basic physical limits of what we can or cannot become.

Since they realized that DNA holds such a trove of secrets, biologists have taken revolutionary strides. They have built genes artificially and transplanted genes from frogs, mice, and fruit flies into bacteria. They have even put human genetic material into frog eggs and coaxed them—though they could never develop as anything but frogs—into manufacturing human protein.

Some scientists now prophesy that, in the future, gene manipulation may be used to cure ancient genetic diseases, and perhaps even cancer; to prolong life; to create new types of agricultural plants and animals; and someday possibly to make significant changes in man himself.

The new biology thus promises much that is good and much that is provocative. A remarkable genetic technique called cloning has been demonstrated by the English scientist J. B. Gurdon. He destroyed the nuclei (the cell parts that contain the genes) of frog eggs and then replaced them with others taken from a tadpole's intestinal tissue. Amazingly, the eggs developed into tadpoles identical to the one that donated its intestinal nuclei.

Eventually it should be technically possible



to do the same with humans, to make limitless copies, or clones, of people considered to be desirable by transplanting their DNA into human eggs. Science-fiction writers already fantasize about armies cloned from a hybrid Goliath, or a world filled with clones of famous and powerful people.

Such conformity, however, would require much more than biological identity. Disturbing psychological conditioning, for example, would be needed. Moreover, biologists strongly disavow any interest in human cloning. Nor would our society today tolerate the attempt.

More imminent, however, is the risk that well-meaning genetic manipulators, working on, say, the cancer problem, might inadvertently turn a common bacterium into a lethal germ and thereby unleash a great new plague.

Such hazards resulted in a self-imposed moratorium on experimentation by many of the world's leading biologists while they spent the past two years developing what they regard as ultrasafe guidelines for their work. Critics, meanwhile, contend that some of these experiments cannot be made fail-safe, and that, despite their potential for good, they are too dangerous for society to permit.

The DNA age is clearly and urgently upon us, and while I seldom found biology's new laws as easy as twirling DNA on the end of a rod, I did find that, behind their abstruse terminology, biologists have discovered a surprising, elegant simplicity to the game plan of life.

Any one cell, embodying as it does the record of a billion years of evolution, represents more an historical than a physical event. You cannot expect to explain such a wise old bird in a few simple words.

—MAX DELBRUCK
CALIFORNIA INSTITUTE OF TECHNOLOGY

THE MAIN ARENA of current biology, the stage upon which DNA acts, is the living cell. Cells are the basic units of life; all plants and animals are built from these tiny chemical factories.

We are whatever we are because of our cells. Our every breath is the work of lung cells and red blood cells. Each step we take, each word we speak is the collaboration of thousands of nerve and muscle cells.

Bacteria and other microscopic organisms consist of only a single cell. It takes a hundred trillion cells or more, however, to make a human being. We have about a million cells in every square inch of our skin, and about thirty billion in our brains. Our blood holds twenty trillion red blood cells; thirty thousand would fit in this one 0.

Some cells are spheres, some are spirals, many are rectangular. Some have tails. Others, certain nerve cells, are star-shaped, with microscopic bodies, each with a wispy "arm" several feet long.

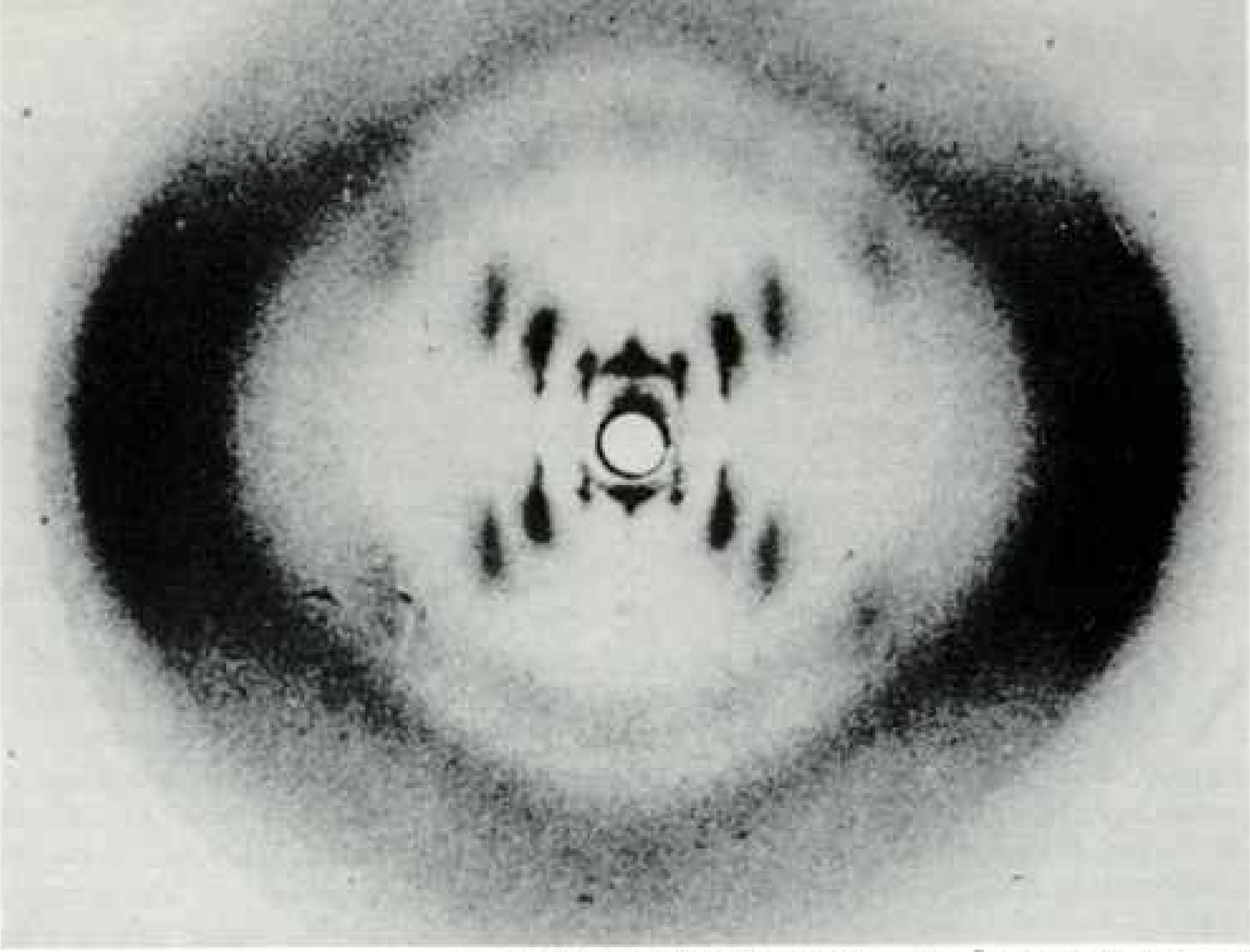
The English microscopist Robert Hooke named cells in 1665 after he detected their dead remnants in a shaving of cork. Dutchman Anton van Leeuwenhoek in 1673 was first to describe a living cell (page 401). But not until 1838 did two German scientists, Matthias Schleiden and Theodor Schwann, deduce that all plants and animals are made of cells. Biologists subsequently found that cells divide to make more cells, that each cell manufactures a series of chemicals. But as late as the early 1950's, scientists knew few details about the life of a cell.

Now, using high-powered electron microscopes and ingenious techniques borrowed from physics and chemistry, biologists have broken through the cell's barrier of invisibility and have charted its interior. They have found a forbiddingly small yet enormously complex world; its magnitudes, like those of the cosmos, astonish and confound.

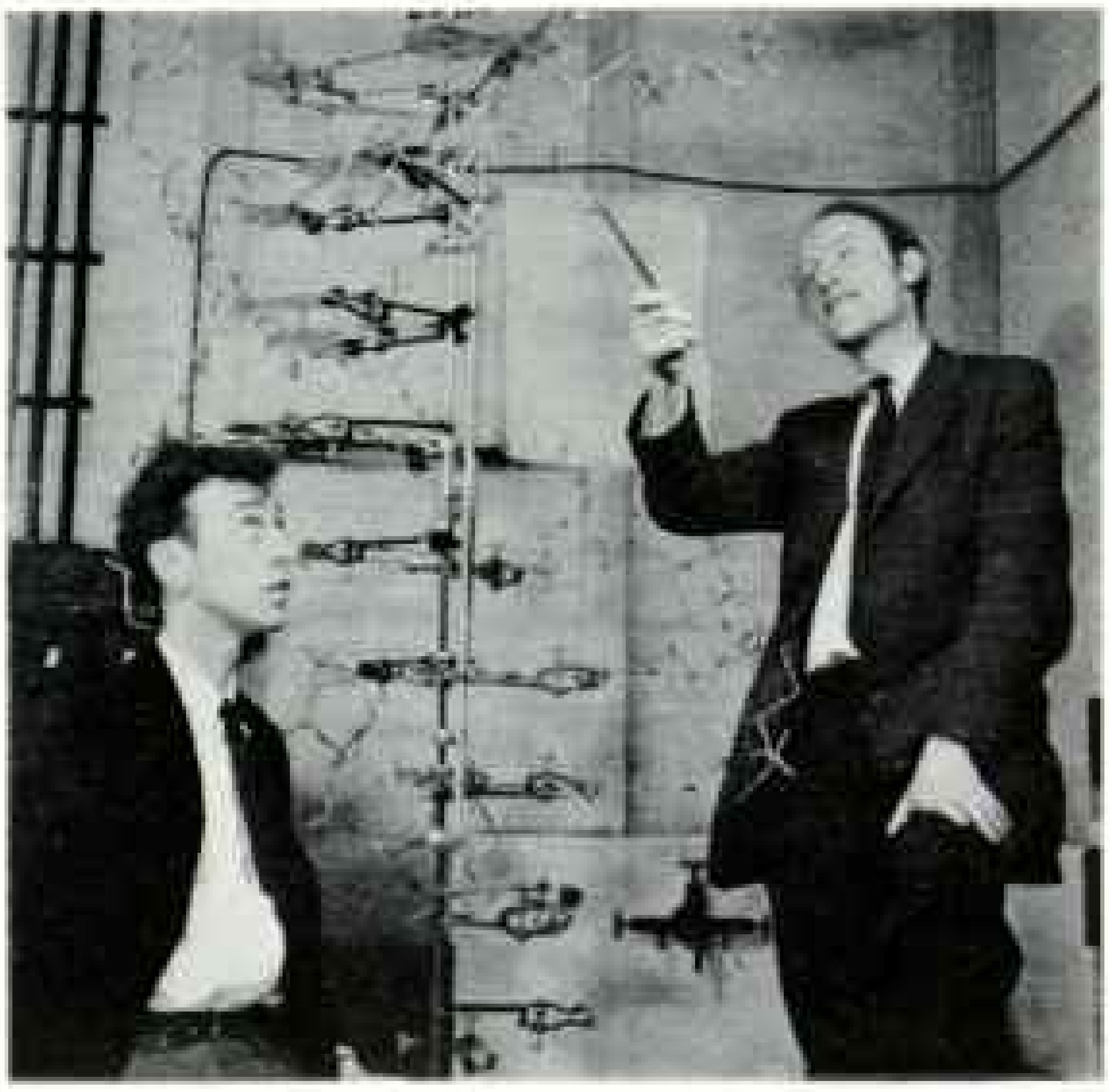
Each cell is a world brimming with as many as two hundred trillion tiny groups of atoms called molecules. Even the largest molecules, like DNA, are measured in units called angstroms—1/250,000,000 of an inch.

"It would be mind-boggling for the early cell biologists to see this," Peter Hepler, a young Stanford University biologist, told me as he flipped through a recently published electron-microscope atlas of the cell. "They had no idea the cell was so chock-full of things. The electron microscope has let us divide the cell into many compartments."

The cell has turned out to be a micro-universe, science now tells us, abounding with discrete pieces of life, each performing with exquisite precision, and often in thousandths of a second, a biochemical dance its ancestors began to perfect countless generations ago in the primordial ocean.



FROM J. D. WATSON, "THE DOUBLE HELIX," ATHENEUM, NEW YORK © J. D. WATSON (ABOVE AND MIDDLE)



The age of DNA

It almost seems that the science of molecular biology sprang full-blown from the brows of James D. Watson and Francis Crick (**left**, from left and page 407). In a one-page scientific paper published in 1953, they first described the structure of DNA, a molecule with "novel features which are of considerable biological interest."

Yet in fact their triumph was built on the work of O. T. Avery, Erwin Chargaff, and others. In London, Maurice Wilkins and Rosalind Franklin had been studying the DNA structure. Franklin's X-ray photograph of crystalline DNA (**above**) had encouraged Watson and Crick in their thesis and helped confirm it.

Suddenly the walls between biology, chemistry, and physics—long crumbling—were leveled, and discovery followed discovery. Among the most important of these, the genetic code by which DNA directs the manufacture of proteins was deciphered by several scientists, including Marshall W. Nirenberg (**left**) of the National Institutes of Health in Bethesda, Maryland.

Moreover, biologists now have concluded that all cells share a grand unity of life. It was at Stanford, while I was looking through a microscope at a common alga, watching its vital juices stream busily through the chlorophyll-colored corridors of its single cell, that I perceived this kinship. What a humbling recognition it was: that my cells, those of the most advanced species on earth, operate with many of the same pieces of machinery, the same chemical reactions, and under the same genetic code as this lowly green scum plucked from a roadside mud puddle.

NATURE HAS SCULPTED a remarkable geography into the cell. It has been my privilege to examine that geography with some of the world's most respected biologists as my guides. Touring the cell means crossing a language barrier. I encountered words I had never heard and names I still stutter over. Exploring the basic topography of the cell is a challenge. But there is no other way to comprehend what wondrously complex creations we are, nor to understand what the new biology has wrought.

Surrounding the cell, enveloping it into a world of its own, is a membrane only one-half-millionth of an inch thick. Within this outer membrane the most obvious feature of every cell I looked at was the nucleus. Sometimes tiny and dark, sometimes seeming to almost fill the cell, the nucleus evoked a special excitement in me. There was the thrilling feeling, when I focused the microscope to bring the nucleus into sharp relief, that I was drawing a bead on the center of the universe.

The nucleus is, indeed, a special place. It is dominated by bodies called chromosomes. Each plant and animal has a characteristic number of chromosomes. Humans have 46; mice, 40; garden peas, 14.

Each chromosome is a package of DNA divided into hundreds of different genes. It is from the chromosomes that the genes send messages to other parts of the cell on how to make the enzymes and other proteins in which that cell specializes.

The genes responsible for blue eyes or any other physical trait are always located at specific spots on specific chromosomes. Our 46 chromosome "threads" linked together would measure more than six feet. Yet the nucleus that contains them is less than four ten-thousandths of an inch in diameter.

The nucleus is most dynamic when a cell divides. Before division, the DNA in each chromosome duplicates. The result is two identical sets of chromosomes. These condense tightly into snakelike shapes and pull apart.

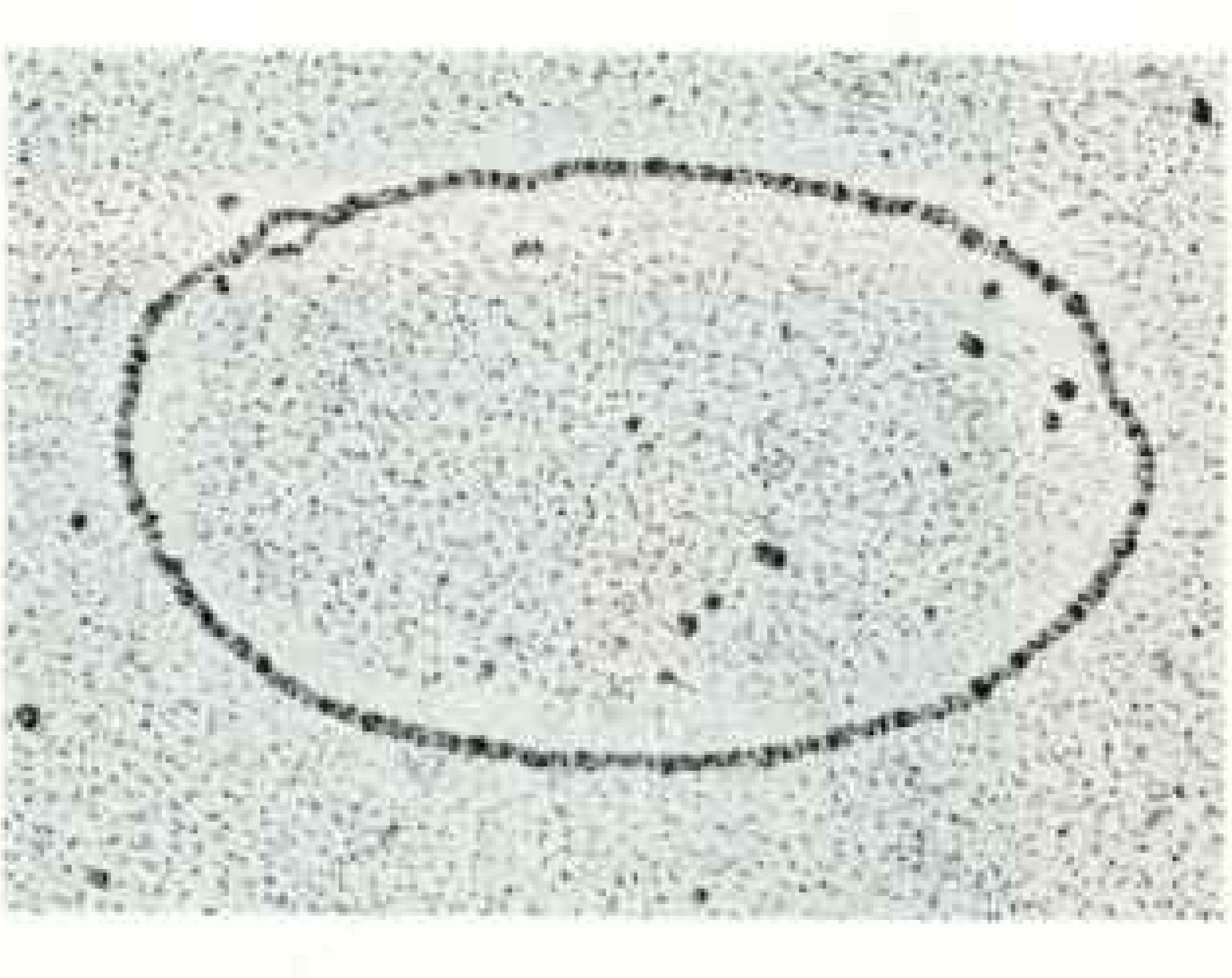
Each set then migrates to opposite ends of the dividing cell. New membranes form to separate the two sets, and each set takes reign over its own new domain.

BUT THERE IS MUCH MORE to the geography of a cell than the nucleus. If we could shrink down, slip through the outer membrane of a human cell, and stand on the nucleus, we would see fantastic sights. We would be in the cytoplasm, a watery world seething with chemical activity.

As we look outward from the nucleus, we might find ourselves entangled in gelatinous meshwork, which pervades the cytoplasmic sea like kelp in a shallow cove. This is the

DNA in action

Human DNA is known to make exact copies of itself, but its complexity defies direct observation. Certain bacteria, however, have small rings of DNA called plasmids, which allow us to see a sequence of replication from one into two genetically identical entities. First, a tiny "bubble," or point of separation, becomes visible (**near right**). This grows into a second looping strand (**center**). Finally, replication is nearly complete (**far right**), with the two rings now connected only at a small point at lower right.



endoplasmic reticulum, or more comfortably, the ER. This scaffold of inner membrane is a great interlocking system of channels through which the cell moves molecules it is making.

Studding much of this membrane and floating in the cytoplasm are millions of small dark particles called ribosomes. The ribosomes are, in a sense, the cell's anvils, where its many different proteins are fashioned.

We watch this process: A ribbonlike molecule, called RNA or ribonucleic acid, arrives from the nucleus at a ribosome. The RNA bears a message from a gene: how to assemble one specific protein. This "messenger RNA" ribbon feeds into the ribosome to be transcribed.

Immediately other smaller bits of RNA—called "transfer RNA"—begin to bring components of proteins, molecules called amino acids, through the cytoplasm. At the ribosome these amino acids are linked, in a particular sequence, into a chain that, once completed, will be the designated protein.

Proteins being assembled at ribosomes along the ER then slip into one of its channels. These are proteins that the cell secretes, such as hormones or digestive enzymes. Some need additional grooming, which they receive as they are shuttled through the channels of the ER. Then they are packaged in a membrane bag called a secretion granule, taken to the cell's surface, and expelled. Other proteins, those made by the unattached ribosomes, remain within the cell to do the housekeeping chores that keep it alive.

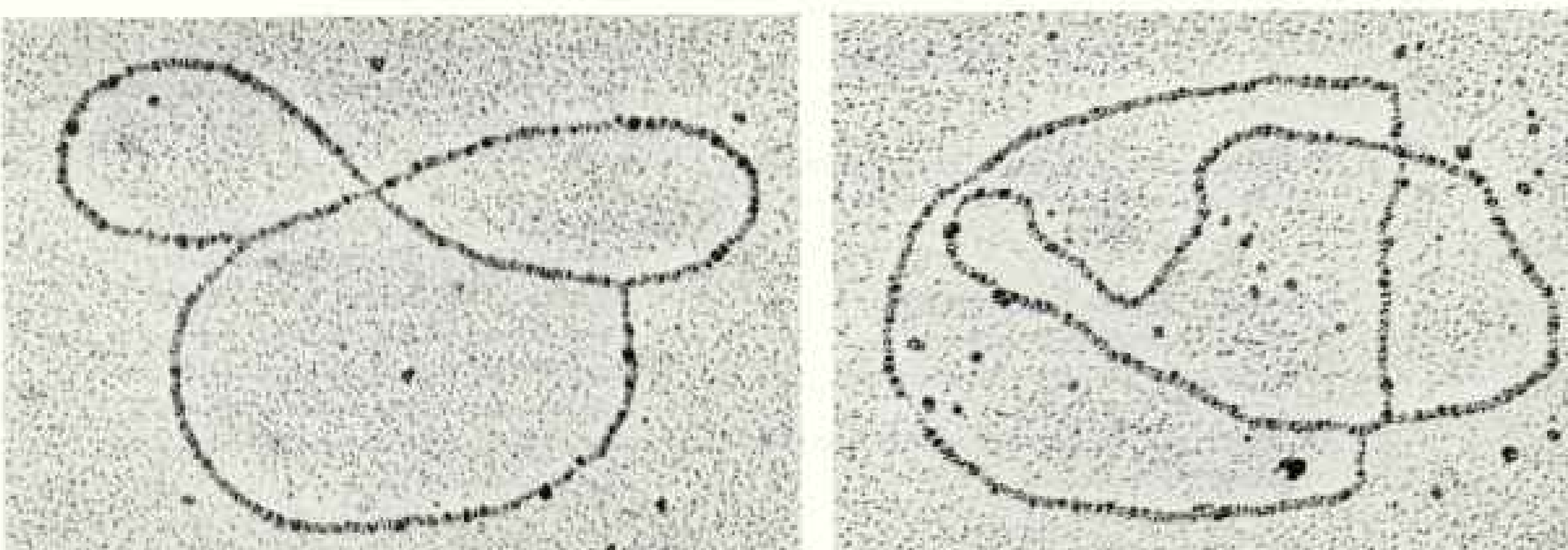
Throughout the sea of cytoplasm are bundles and strands of tubules and fibers. Some appear and quickly disappear; others are more permanent. These microtubules and microfilaments have many jobs. They help pull a dividing cell apart. Also, like the hoop of a barrel, they give structure to the cell. They are the cell's muscles, pushing and tugging its parts around, changing its shape.

The rim of the nucleus can be a dangerous spot for an intruder. We must watch out for globules called lysosomes that cruise the cytoplasm. Lysosomes are sacs of corrosive enzymes that can digest almost anything. White blood cells use lysosomes to attack bacteria and other invaders. Protozoa need lysosomes to digest food.

Lysosomes also serve as cell janitors, breaking down worn-out cell parts and spent enzymes. On rare occasion, they even attack their own cells, earning themselves the nickname "suicide bags." Normally, however, they merely aid in the removal of old or defective cells, an essential to healthy growth. For instance, when a tadpole turns into a frog, the lysosomes in its tail eat the tail up. Without such cell death we would all be born with the webbed hands that the human fetus has at one stage.

THROUGHOUT THE CYTOPLASM also drift bean-shaped dynamos called mitochondria. Many scientists now suspect they were once free-floating one-celled creatures that eons ago found a cozy niche inside an ancestor of the modern cell. Mitochondria actually look like puny, pedestrian pieces of punctuation. Yet without the wizardry they evolved ages ago, we would never have made it out of the primordial soup.

Mitochondria are the powerhouses of the cell. They *(Continued on page 368)*



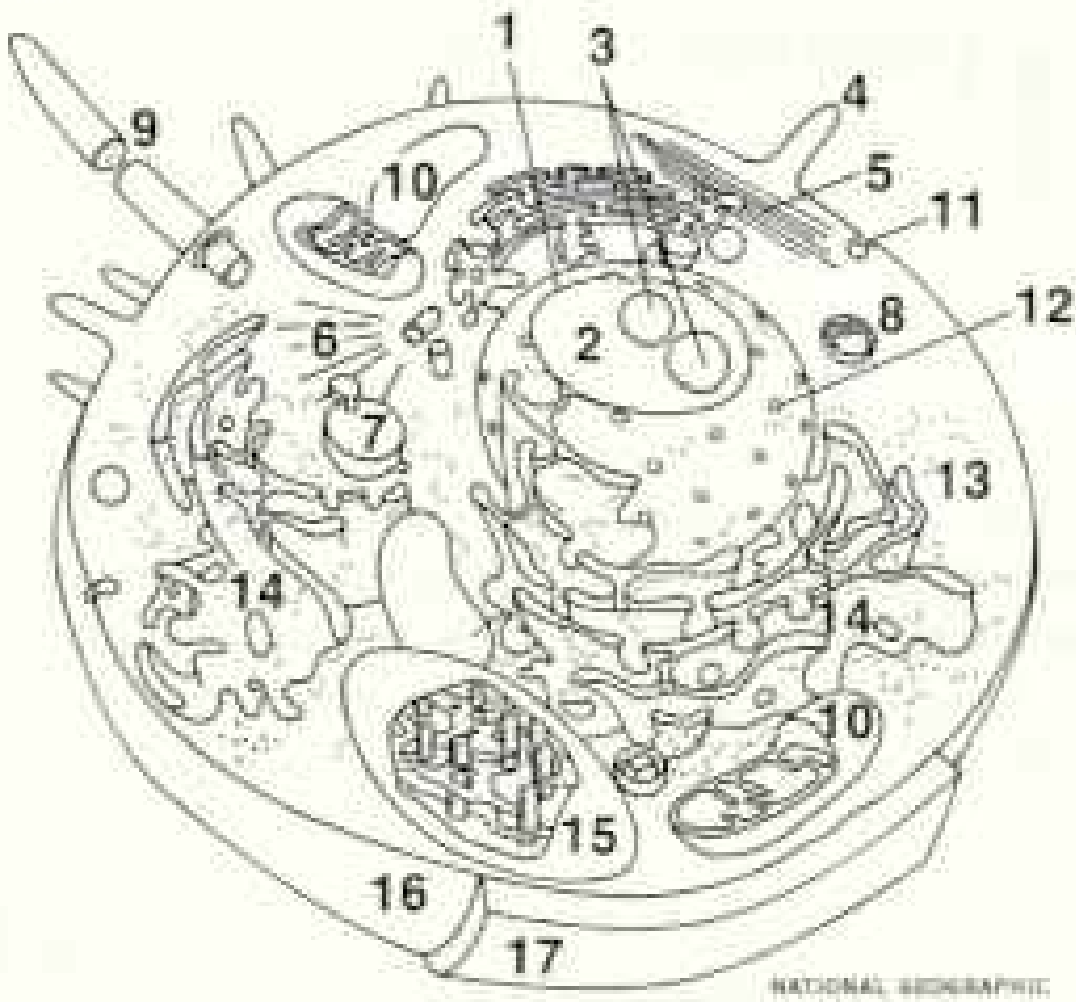
MAGNIFIED 83,000 TIMES; TSUTOSHI KAKEFUDA, NATIONAL INSTITUTES OF HEALTH

The geography of the cell

IF HE WERE SHRUNK to a billionth of normal size, a human would be small enough to explore a living cell. But on its surface, he would be quickly overwhelmed by chemical troops, digested, and done with. Only scientists armed with electron microscopes and other specialized tools have become observers of this bustling world.

Whether specialized to function in the brain of a flea or the claw of a bird, a single cell is built from internal structures called organelles that mirror the complexity of the organs, tissues, nervous system, skeleton, and skin of the whole body.

Much remains unknown, but the composite cell illustrated here (**foldout, facing page,** and **key, below**) shows major internal features of both plant and animal cells.



NATIONAL GEOGRAPHIC ART DIVISION

1 Nucleus, the cell's heredity-bearing core, functions within a thin membrane called the nuclear envelope.

2 Fibers of protein-laced DNA within the nucleus comprise chromosomes, or packages of heredity-carrying genes.

3 An important component of ribosomes (13) is made in the nucleoli.

4 Protrusions that greatly enlarge the cell surface—microvilli—promote increased absorption.

5-6 Giving the cell some muscle, fine fibers called microfilaments (5) and microtubules (6) help maintain the cell's shape and have a role in its motion.

7-8 Scavenger organelles, lysosomes such as the digestive vacuole (7) and residual body (8), not only consume foreign matter and dead parts of the cell but, in the normal growth process, eventually recycle the worn-out cell itself.

9 Found in large numbers on certain cells, cilia act as oars in a liquid medium.

10 Dynamos of the cell, mitochondria convert sugar and fat derivatives into energy for the cell's use.

11 Porters for the cell, pinocytosis vesicles convey material from the surface to the interior.

12 Pores allow substances to pass to and from the cell's nucleus.

13 Anvils of the cell, ribosomes are where the many needed proteins are fashioned from amino acids (page 367), following a genetic code carried by a courier known as "messenger RNA" (ribonucleic acid).

14 A maze of channels, the endoplasmic reticulum, or ER, transports hormones, enzymes, and other compounds produced by the cell.

15 Unique to plant cells, the chloroplast carries out photosynthesis, which provides the cell with food and our atmosphere with oxygen.

16-17 Cell membrane (16) and, in plants, the much thicker cell wall (17) provide form and protection. Membranes, which control what enters and leaves the cell, have complex functions, including a role in the immune system's responses to infection and cancer—a puzzle now under intensive study (pages 378-9).

COMPOSITE CELL ENLARGED 10,000 TIMES


Meltzer

The language of life

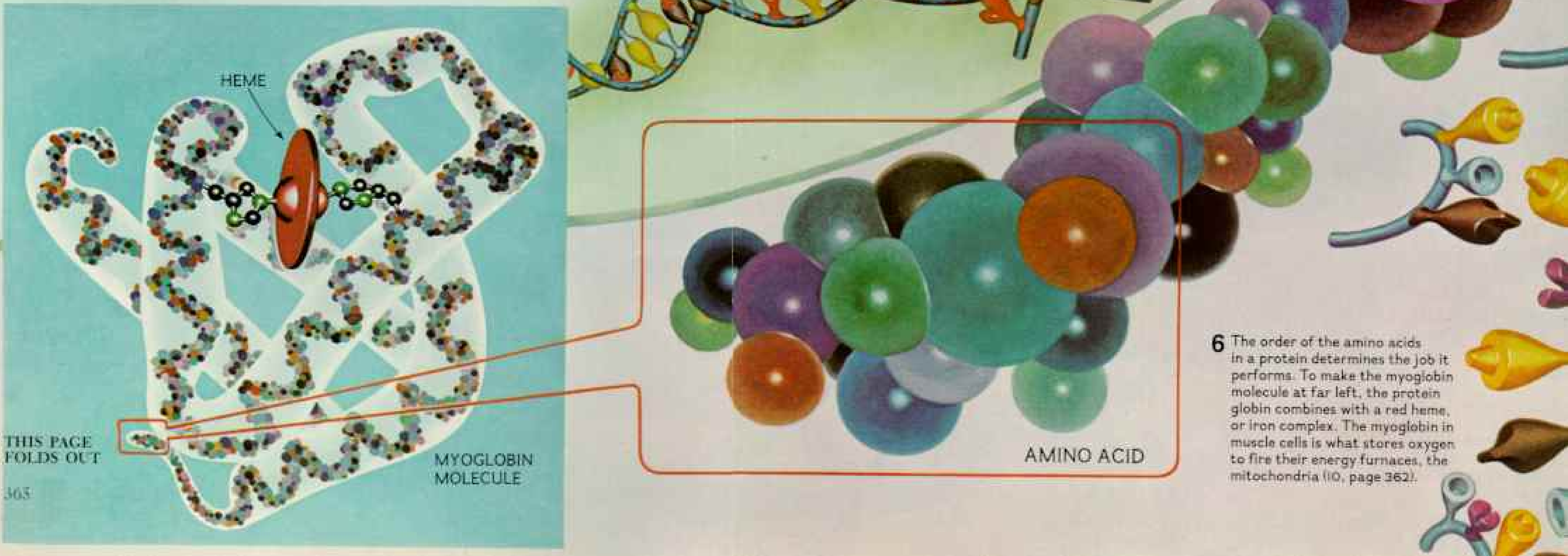
AN INTRICATE molecular code spells out the genetic instructions DNA carries within its double helix. Shown here are two mechanisms DNA uses. One enables DNA to make a copy of itself before a cell divides. Through the other it directs the manufacture of a cell's proteins—the vital molecules such as enzymes and hormones that carry out the business of being alive. Actually components of DNA are joined chemically; they are here depicted as interlocking color-coded units similar to a child's construction set.

1 DNA units called nucleotides, left, each carry one of four different bases anchored to a sugar-phosphate backbone. These bases—adenine, cytosine, guanine, and thymine, or A, C, G, and T—bond the nucleotides in the spiral DNA molecule, a section of which is shown below. The shapes of the bases demonstrate that A can pair up only with T, and C only with G.

2 The sequence of A's, T's, C's, and G's along the lengthy DNA ribbon contains in code the specific information that a cell needs to manufacture its particular set of proteins. By varying the sequence, nature varies the instructions.

3 Before a cell divides, DNA is replicated, or made into identical copies, one for each resulting cell. A section of the DNA strand (left) unwinds and separates along its base joints. The A's, T's, C's, and G's, now single, quickly acquire new partners from the many nucleotides floating free within the cell. Eventually, two new complete and identical DNA molecules form.

4 When a cell prepares to manufacture a protein, a segment of its DNA—a gene—begins to open. Free-floating nucleotides attach to one strand of the gene. These nucleotides resemble those of DNA, but they have a slightly different backbone, and uracil, or base U, replaces base T. As the nucleotides are joined in a single chain called RNA, they unzip from the gene. RNA synthesis moves wavelike down the gene to complete the process. The long ribbon of messenger RNA, having been coded by the sequence of DNA bases along the gene, thus relays instructions for protein building.



6 The order of the amino acids in a protein determines the job it performs. To make the myoglobin molecule at far left, the protein globin combines with a red heme, or iron complex. The myoglobin in muscle cells is what stores oxygen to fire their energy furnaces, the mitochondria (10, page 362).

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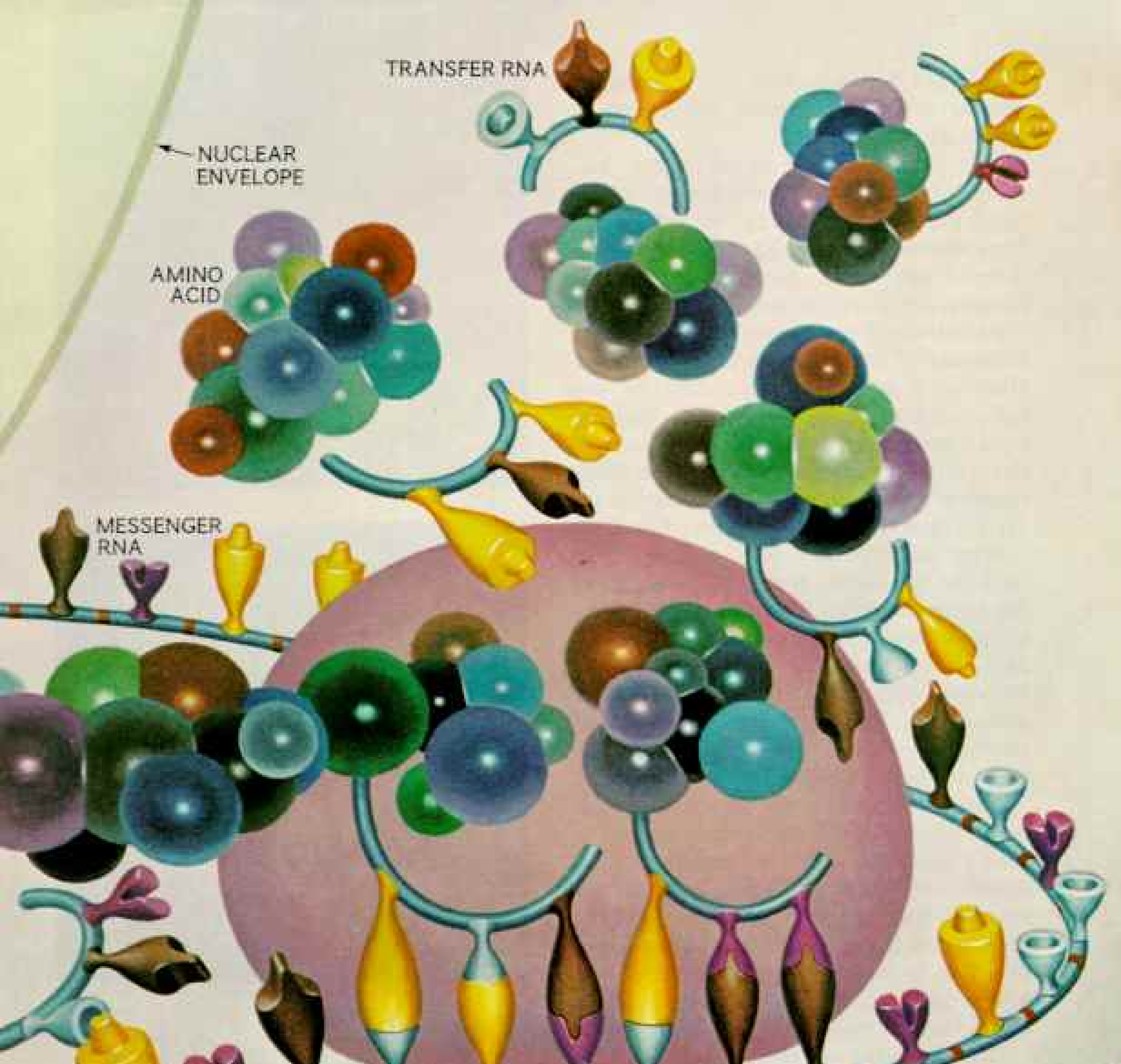


5 The messenger RNA moves out of the nucleus and finds a ribosome (13, page 362) for the assembly of the designated protein. The sequence of A's, U's, C's, and G's on the RNA forms in groups of three-letter "words" —such as ACU, CGG, and CCU. Each word specifies one of the different amino acids, the building blocks of protein. Another type of RNA, called transfer RNA, reads the words and brings the specified amino acid in from the cell's sea of chemicals to the ribosome. There the particular nucleotide word of the transfer RNA matches up with the counterpart section of messenger RNA. In turn, the amino acid links on to a growing chain that will become a protein. Its work done, the transfer RNA separates and returns to a free state within the cell medium.

PAINTING BY DAVIS MELTZER

(Continued from page 361) produce a powder keg of a chemical called ATP, or adenosine triphosphate.

"ATP is the electricity of the system," biochemist Philip Handler, president of the National Academy of Sciences, told me. "It is a form of energy that the cell can use to do anything—make other compounds, contract muscles, permit you to see, to think."

An active cell needs more than two million molecules of ATP a second to drive its biochemical machinery. There may be one mitochondrion or thousands. Cells that use great quantities of energy, as in the wing muscles of birds, have tremendous numbers. Mitochondria often cluster where energy is required, as at the base of a sperm's flagellum.

What mitochondria do, essentially, is to burn the breakdown products of sugars and fats to make energy. Rather than give off the energy as heat, they store it in the ATP molecule. Animal cells obtain the sugars that their mitochondria burn directly from the food the animal eats. Plant cells rely for sugars on photosynthesis, which is carried out by another of the cell's workers, the chloroplast.

Photosynthesis is to me the cell's ultimate magic (page 387). What alchemy it seems to take a sunbeam and turn common carbon dioxide and water into food! What an advantage that primeval organism attained when it first managed this feat, letting others scavenge in a lean sea. And without the oxygen photosynthesis produces, animal life as we know it could never have developed.

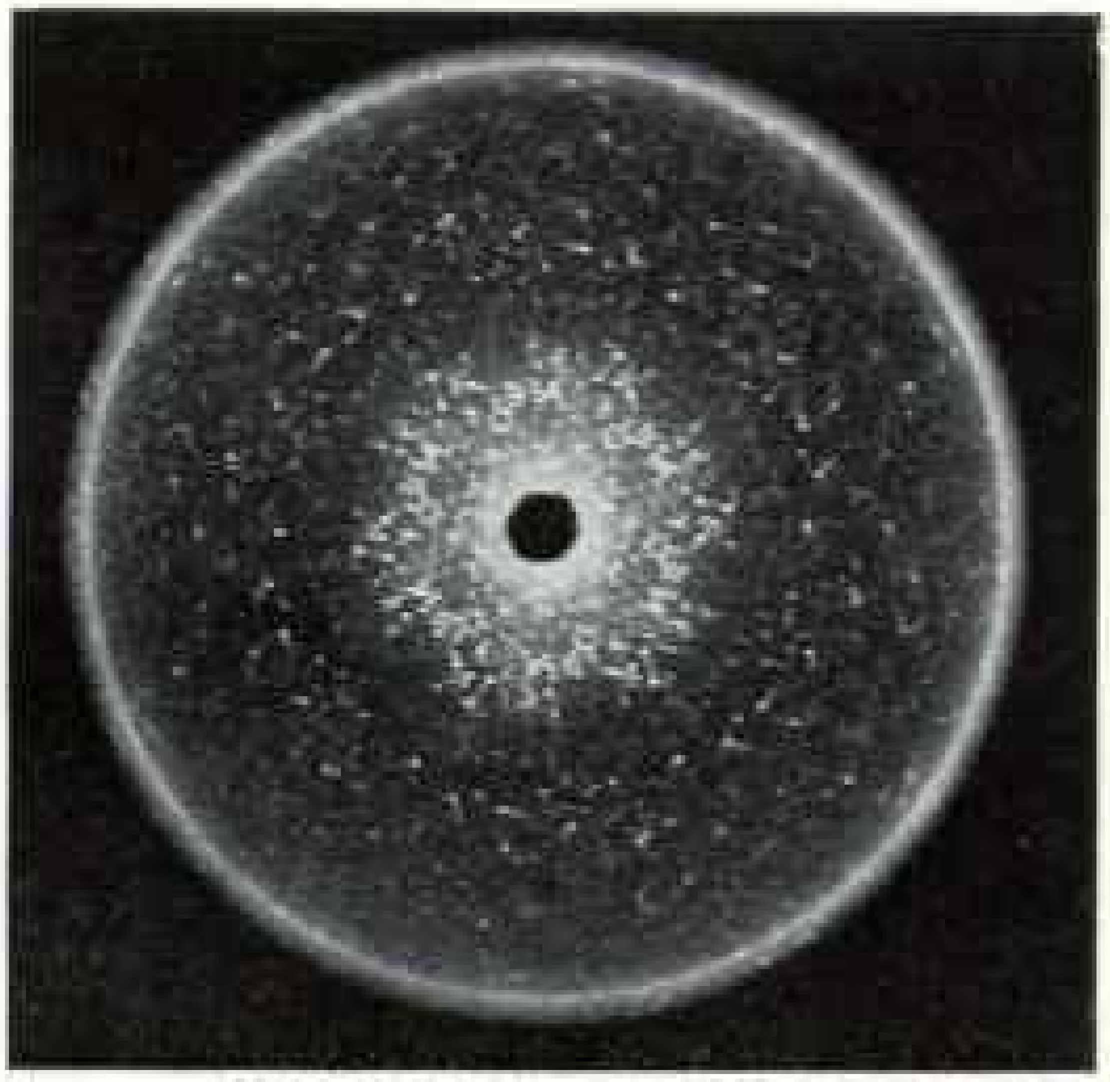
Biologists have not yet determined all the jobs performed by the many inhabitants of the cell. It is clear, however, that the cell is a society unto itself, and that the intricacies of its sociology will puzzle us long after we finish charting its terrain.

One really begins to understand now how the living cell does what it does. The gap between life and nonlife has disappeared.

—ROBERT SINSHEIMER
CALIFORNIA INSTITUTE OF TECHNOLOGY

IN APRIL 1953 a 25-year-old American postgraduate student named James Dewey Watson and a British physicist, Francis Crick, dropped a biological bombshell, one that left newspaper editors around

MAGNIFIED 50 TIMES

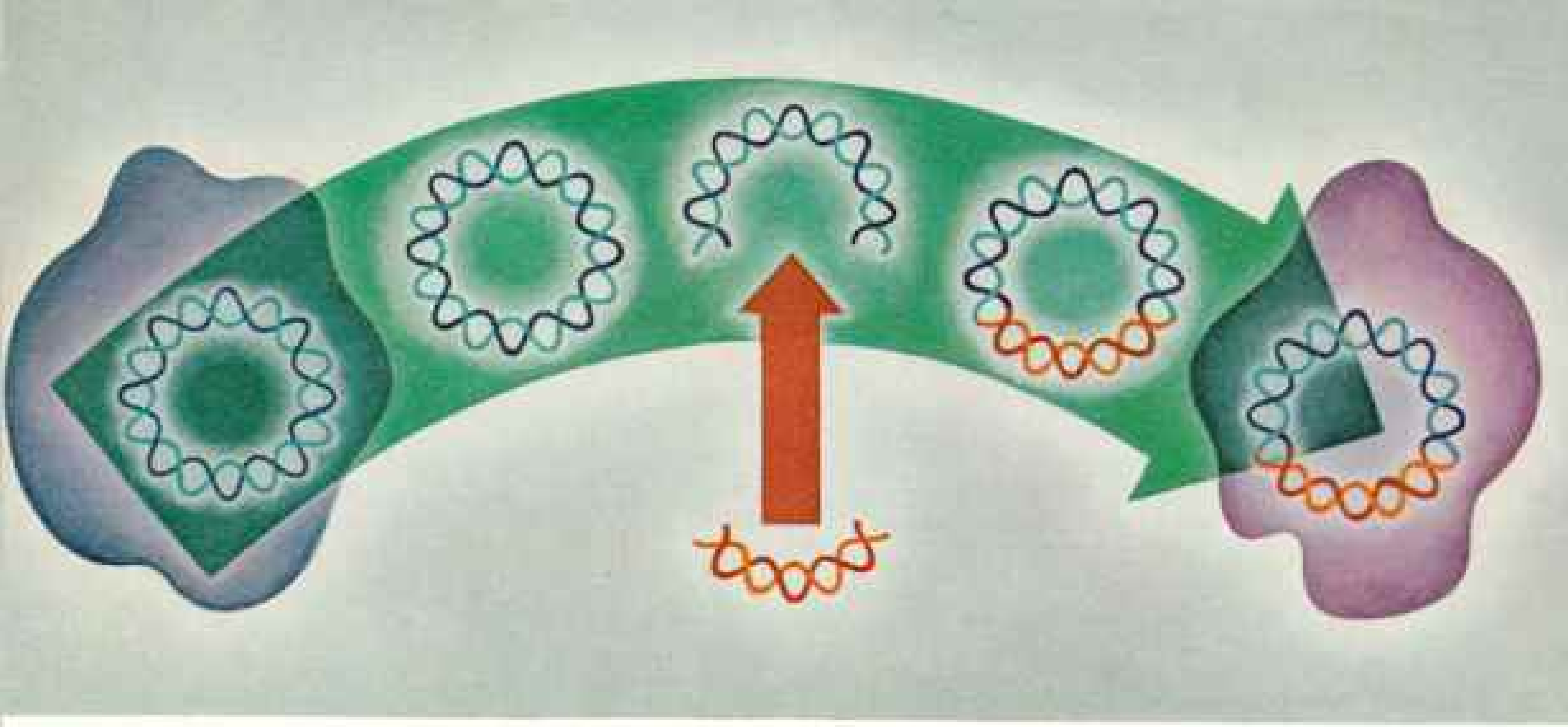


DAVID R. DAVIES, NATIONAL INSTITUTES OF HEALTH (ABOVE AND TOP)

Molecular modeling

Biologists pursue anatomy past the limits visible with even the most powerful electron microscope. The discovery of DNA's structure owed much to model building. One crucial insight came as James Watson arranged and rearranged cardboard cutouts representing DNA's bases.

Modeling also helps scientists studying the architecture of molecules used by immune systems. At the National Institutes of Health, investigators have crystallized part of an antibody (**top**) that attacks bacteria in mice. X-ray photographs of these crystals (**above**) are interpreted into three-dimensional electron density maps (**right**, foreground). The maps reveal molecular structure, the basis for constructing a model of the guardian molecule (background) to better understand immune system operation (pages 378-9).



Genetic engineering: bane or blessing?

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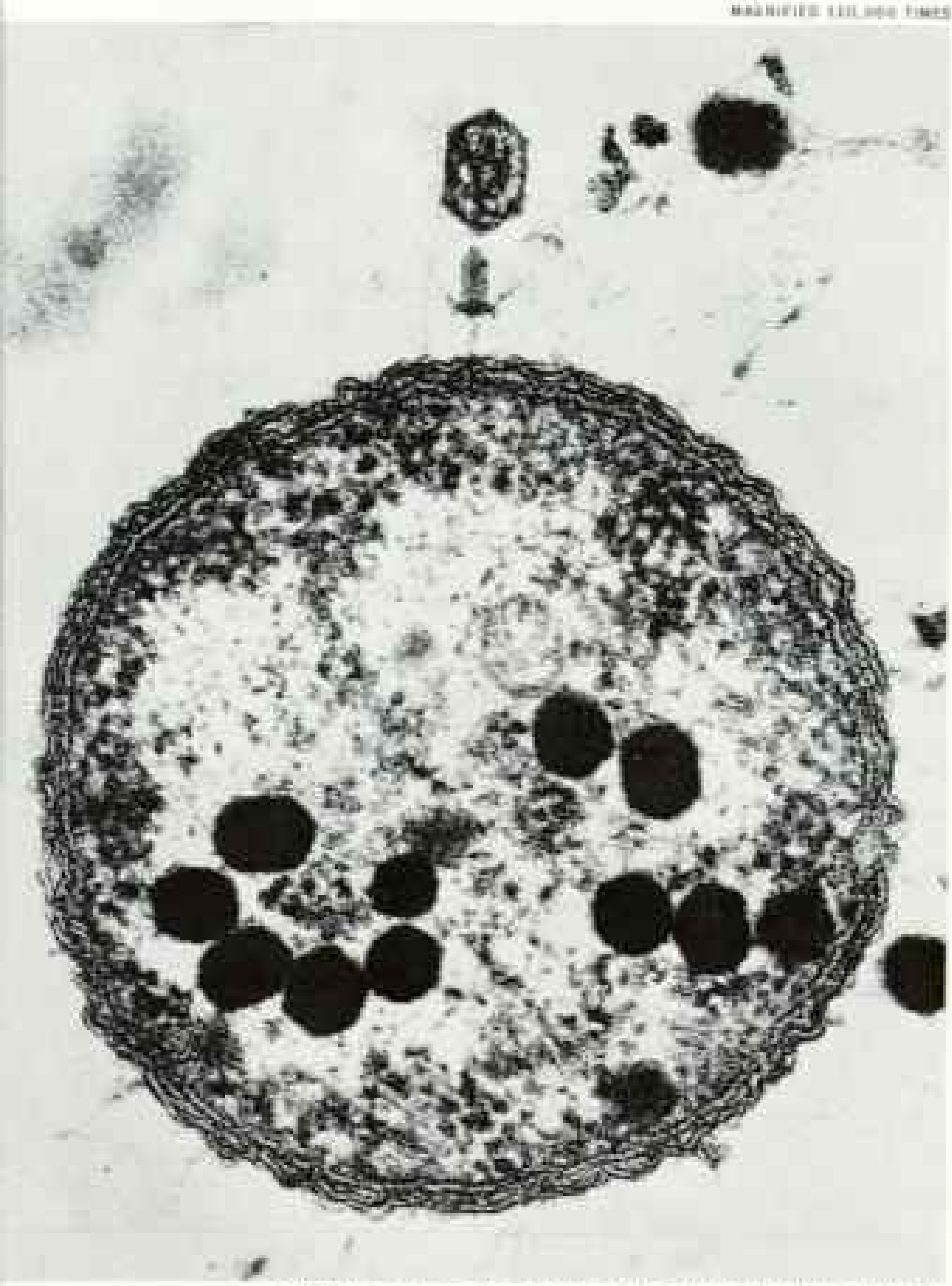


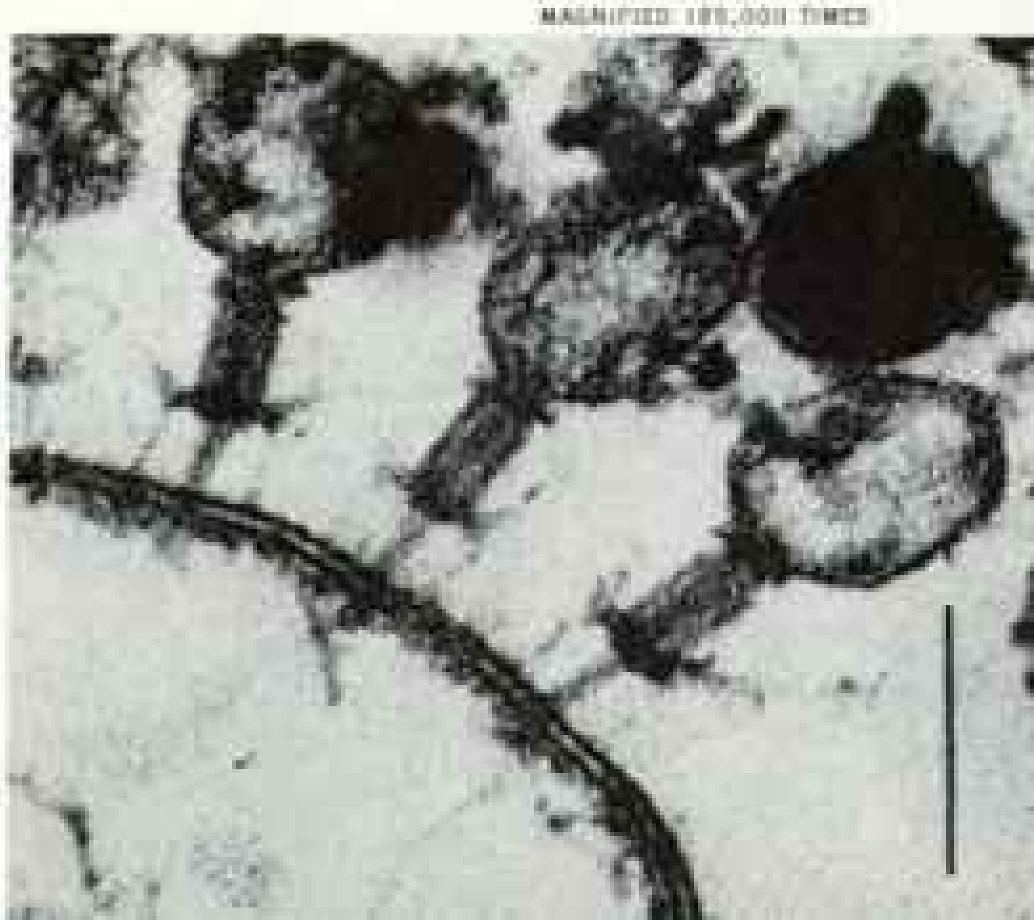
PHOTOGRAPHS BY LEE D. SIMON, INSTITUTE FOR CANCER RESEARCH, PHILADELPHIA

Viruses are old hands at altering DNA in living cells; scientists are new at the job. Simplified, here's how it's done (**diagram, above**): Isolate a convenient carrier of DNA. (With its small DNA, a plasmid from a bacterium is a good choice.) Then use enzymes to remove a section of "old" DNA, center, and splice on "new" DNA (red) from another organism. When this composite DNA is inserted into a cell, the result is a hybrid not found in nature. The fear: that, despite stringent research guidelines, virulent tailor-made bacteria might escape laboratories and cause new pandemic diseases.

Viruses cannot reproduce by themselves, so they take over the machinery of cells. One kind called T4 attacks the bacterium *E. coli* found in human intestines. Microhypodermics loaded with DNA, T4's alight on *E. coli*'s membrane (**below**), penetrate it, and squirt their DNA into the interior, where it forces the cell to produce more T4's (**left,** black spots).

Biologists hope viruses can be modified to carry human genes to cells lacking them, thus repairing genetic defects.

MAGNIFIED [illegible] TIMES



the world struggling to fit the words "deoxyribonucleic acid" into a catchy headline. Most opted to use the abbreviation DNA.

DNA. Almost overnight the announcement by Watson and Crick that they had determined the structure of that big molecule tied together some fifty years of disparate research in biochemistry, microbiology, and genetics. It forged biology into a radically new science. The DNA structure was a long-missing link.

The two main events in the life of most cells—dividing to make exact copies of themselves and manufacturing proteins—both rely on blueprints coded in our genes. By 1953 many biologists believed that genes were made of DNA. But no one could begin to say how that mysterious molecule carried so many precise instructions, until Watson and Crick discovered how it was constructed.

THE EASIEST WAY to visualize DNA is as an immensely long rope ladder, twisted around and around into a corkscrew shape. Straighten the ladder out and imagine: The sides of the DNA ladder are long chains of two substances, sugars and phosphates, in repeated sequences. These chains are the backbone of the DNA molecule; their structure never varies.

The real magic of DNA is performed by the rungs. The rungs are actually made in two parts, each part being firmly attached to one side of the ladder. These half rungs can be one of four types of little molecules—adenine, cytosine, thymine, or guanine. Each of these units—abbreviated A, C, T, and G—together with its attached segment of the DNA backbone, is known as a nucleotide.

Structurally, an A will make a rung only with a T, and a C mates only with a G. So the A-T, T-A, C-G, and G-C pairs are, in a sense, like a four-letter alphabet, with which messages can be spelled out (pages 365-7).

Before a cell divides, the DNA ladder splits down the middle. The A nucleotides separate from the T's, and the C's from the G's, much as the teeth of a zipper pull apart. Then floating nucleotides, which are always wandering freely thoughout the cell, are soon linked to appropriate partners on the dividing ladder. As this process continues, the cell creates *two* ladders of DNA—identical copies of its genetic blueprints. Now the cell can proceed with its own division.

Using these blueprints, the cell performs another crucial function: the manufacture of proteins—thousands of different types.

Each gene, or distinct segment of the long DNA strand, contains instructions for making one specific protein. The orders are coded into a precise sequence of nucleotides. To deliver those instructions from the DNA to the "workrooms"—the clusters of ribosomes where proteins are assembled—the cell employs a go-between: the messenger molecule, RNA.

To decipher the precisely arranged string of nucleotides, the protein-making ribosomes use what we call the genetic code.

First, recall that proteins are giant molecules made of many amino acids, typically several hundred of them. Although the code uses only 20 types of amino acids, they can be arranged in almost infinitely varied order to produce the incredibly complex array of

Handsome green prince of genetic research, an African clawed toad is put on display by Dr. Donald Brown of the Carnegie Institution. He used the species to isolate a specific gene whose function was known, one of the first scientists to do so. The isolation of the gene, which carries a blueprint used in ribosome building, lets researchers study the mechanisms by which genes turn on and off. Such breakthroughs promise greater understanding of how genes help shape life.

proteins needed to build a human body. Just as you can change the meaning of a sentence by rearranging its words, nature can "spell" an enormous vocabulary of proteins, using only the four nucleotides of DNA. Geneticist H. J. Muller once estimated that the number of different ways of putting together all the A's, T's, C's, and G's in a set of human chromosomes would be the figure 256 followed by 2.4 billion zeros.

My wife, Mary, calculated that it would take her 45 years, working 24 hours a day, just to write that number. Each of us, genetically, is an unfathomable long shot.

. . . a riddle wrapped in a mystery inside an enigma.

—WINSTON CHURCHILL

HAVING MAPPED THE CELL and decoded its DNA, biologists are now trying to understand how it accomplishes some of its amazing feats. Every cell, for instance, has its special chores. Each observes its own intricate calendar, knowing when to grow, when to divide, when to make hormones, when to die.

Many cells can actually tell time to within half an hour. Consider the cells of a cocklebur. This scruffy plant will not bloom if kept continuously in light, but give it just one nine-hour period of darkness—not eight and a half—and its cells trigger the entire blooming sequence.

I have often thought, as I impatiently waited for the asters in my garden to blossom or the tomatoes to ripen, of the inscrutable biological clocks operating within those flower and fruit cells. Cells have no consciousness, I have been repeatedly assured. Their life cycles are determined chemically by such outside influences as how long a period of sunlight excites their pigments, what the temperature is, and what other chemicals they come in contact with.

If the dividing of cells in a flower is not a conscious act, it is at least one of supreme design. The control of cell division in humans is even more impressive. A human cell in the laboratory, free from bodily influences, may divide some fifty times before dying. If all our cells divided that often, we would reach a weight of more than eighty trillion tons.

During a given moment in the life of a cell, thousands of events are being precisely coordinated at the molecular level, even though only a small fraction of a cell's genes are being expressed. There are countless triggers, red lights, green lights, and feedback channels involved in each response a cell makes.

At Harvard University, Dr. Mark Ptashne drew for me diagrams of how molecules called repressors switch genes on and off in bacteria and viruses. He might as well have been diagraming the circuitry of a big computer. Yet the regulation of human genes appears to be much more complex.

Studying how genes are turned on and off, however, is just one approach to understanding the intelligence of the cell. More and more, biologists are finding that some of this wisdom is built into the cell's surface.

The cell surface is like an ultrathin layer of heavy oil on water. That narrow periphery controls everything that goes in or out of a

Chromosome surgery

To operate on a living cell with even the smallest, sharpest scalpel imaginable would be like slicing onions with a chain saw. Dr. Michael W. Berns of the University of California at Irvine (**left**) focuses a laser beam through a microscope to cut so finely that just one part of one chromosome can be removed (**right**, arrow).

Image on screen at left is a human blood cell through which two holes have been drilled by a laser. How the cell reacts as specific components are destroyed will assist in determining the function of the missing parts.

MICHAEL W. BERNS, UNIVERSITY OF CALIFORNIA, IRVINE

MAGNIFIED 1,000 TIMES

cell. It is the face the cell shows to the outside world, and all that a cell needs to know about that world it must learn through intelligence agents in its surface.

Within this fatty membrane, protein molecules float like corks, often protruding from the top and bottom. Attached to many of these proteins are complex antennae made up primarily of sugars.

"These molecules that sit in the cell's surface are the first troops to see the world," Gerald Edelman told me at the Rockefeller University in New York City. "The molecules don't sit fixed. They move randomly, like a celebrant crowd in Times Square."

I SAW just how important these itinerant molecules are to a cell when I visited Dr. Thomas Humphreys' laboratory, thousands of miles from Times Square, at the University of Hawaii. Lab assistant Dale Sarver was chopping sponges apart when I arrived.

"Sponges are the lowest form of many-celled animal," Sarver told me. "They have a bit of a communications system—enough to close up when danger approaches—but no nerves. Basically they are just a colony of single cells."

"It was found around the turn of the century," Dr. Humphreys then explained, "that you could take a sponge apart, and its cells would come back together again. They have a way of knowing where they belong."

Dr. Humphreys ran a film showing, first, a suspension of cells from a white sponge that had been chopped up. Two of the cells seemed to be sniffing each other out, climbing all over one another until they found just the right position. Then, snap! They locked to each other and became a two-celled organism. A third cell approached, sniffed, and latched on. It was followed by dozens more.

"They reestablish a sponge that is an organism just like the original," said Dr. Humphreys. "Interestingly, when you put cells from two different sponges together, each will recognize its own."

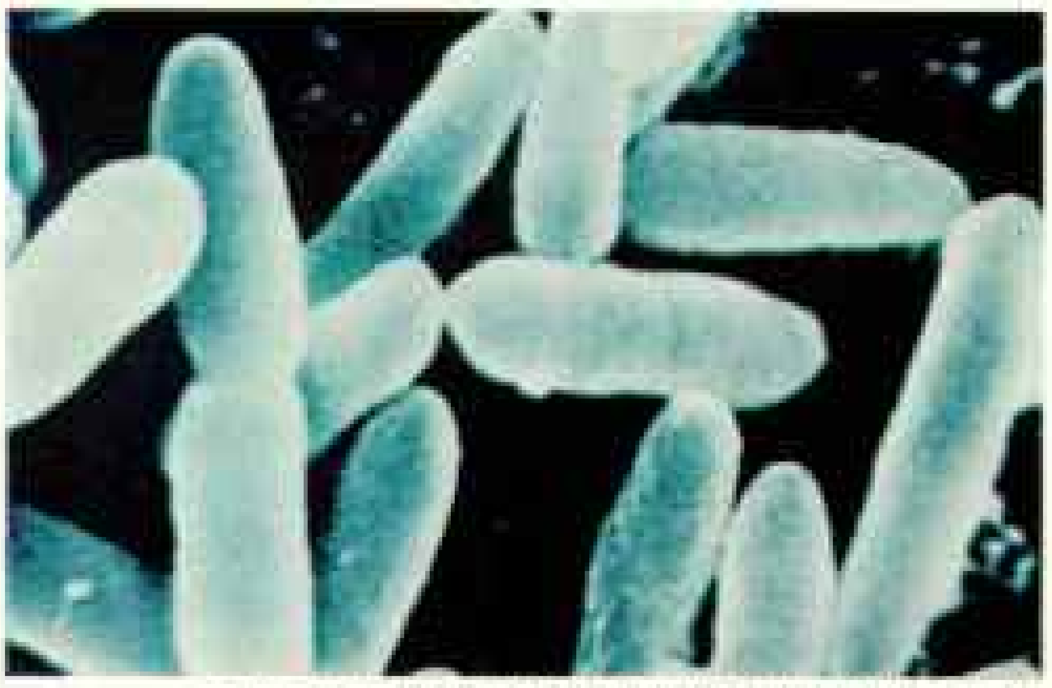
The next film sequence showed both white and red sponge cells. A red cell began sniffing a white, moving patiently all over the white's surface, as if looking for something.

"They are trying, but they can't quite make it," said Dr. Humphreys. Soon the red sponge cell gave up on *(Continued on page 378)*

Breeding a superbug to attack oil spills

From cloudy to clear, the two vials held by Dr. Ananda M. Chakrabarty (**above**) of General Electric's research center demonstrate genetically engineered bacteria's gluttonous appetite for oil. By combining four strains of oil-eating bacteria, Dr. Chakrabarty has created a corps of ultrasmall scavengers (**below**) that one day may devour oil spills.

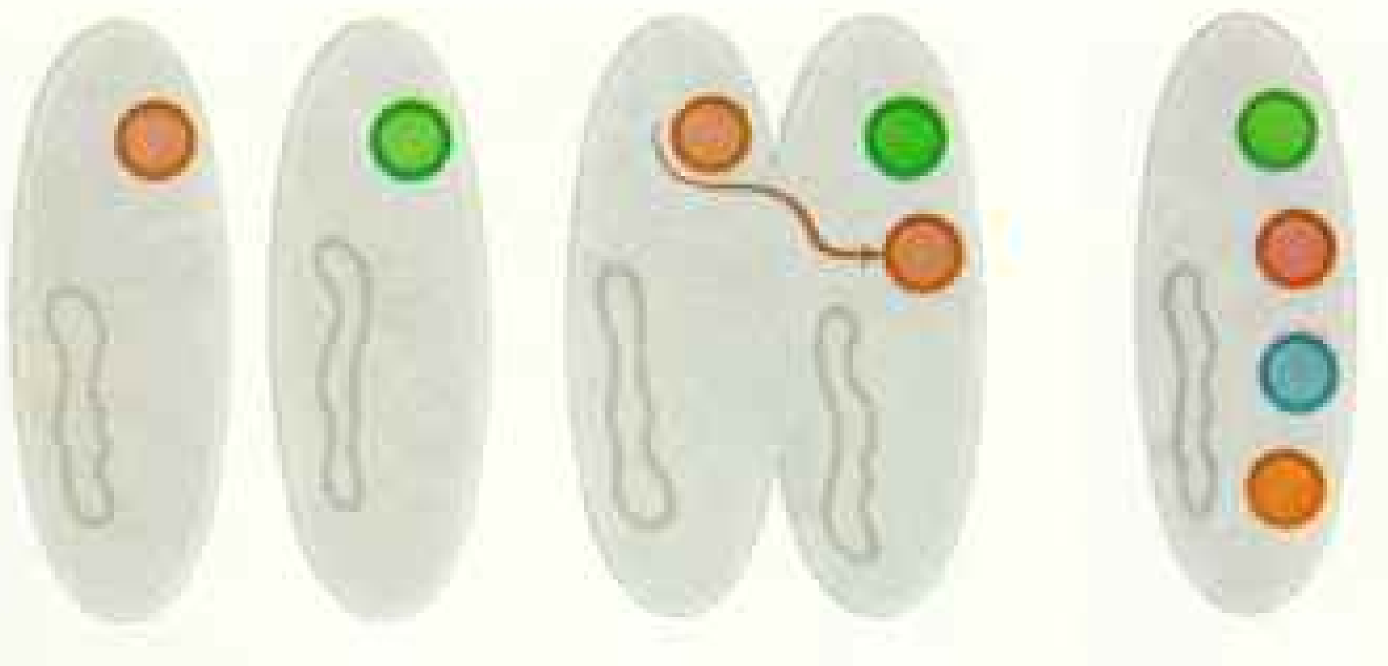
Natural bacteria aid in digestion and break down human wastes; perhaps a whole host of altered strains could help clean up our messy planet.



GENERAL ELECTRIC RESEARCH AND DEVELOPMENT CENTER (LOWER)

PAINTING BY NED SEIDLER, NATIONAL GEOGRAPHIC SOCIETY STAFF ARTIST

Feasting on oily waters, the superstrain *Pseudomonas* demonstrates its talents in the diagram above. Each of the four strains digests particular hydrocarbons of crude oil. But like a crowd jostling around a bargain counter, they function inefficiently. By taking a plasmid of one strain (**below,** green circle in diagram) that attacks specific hydrocarbons and then adding the plasmid of a different strain (red circle), a double-barreled strain is produced. Two more specialized plasmids are added (blue and orange circles). The completed bacteria are activated with ultraviolet radiation, so that they can reproduce with all four plasmids intact. The bacteria are now ready to feast.



In a mixture of oily water the bacteria digest their specified hydrocarbons (**above,** color-coded triangles in diagram)—up to two-thirds of the total oil present.

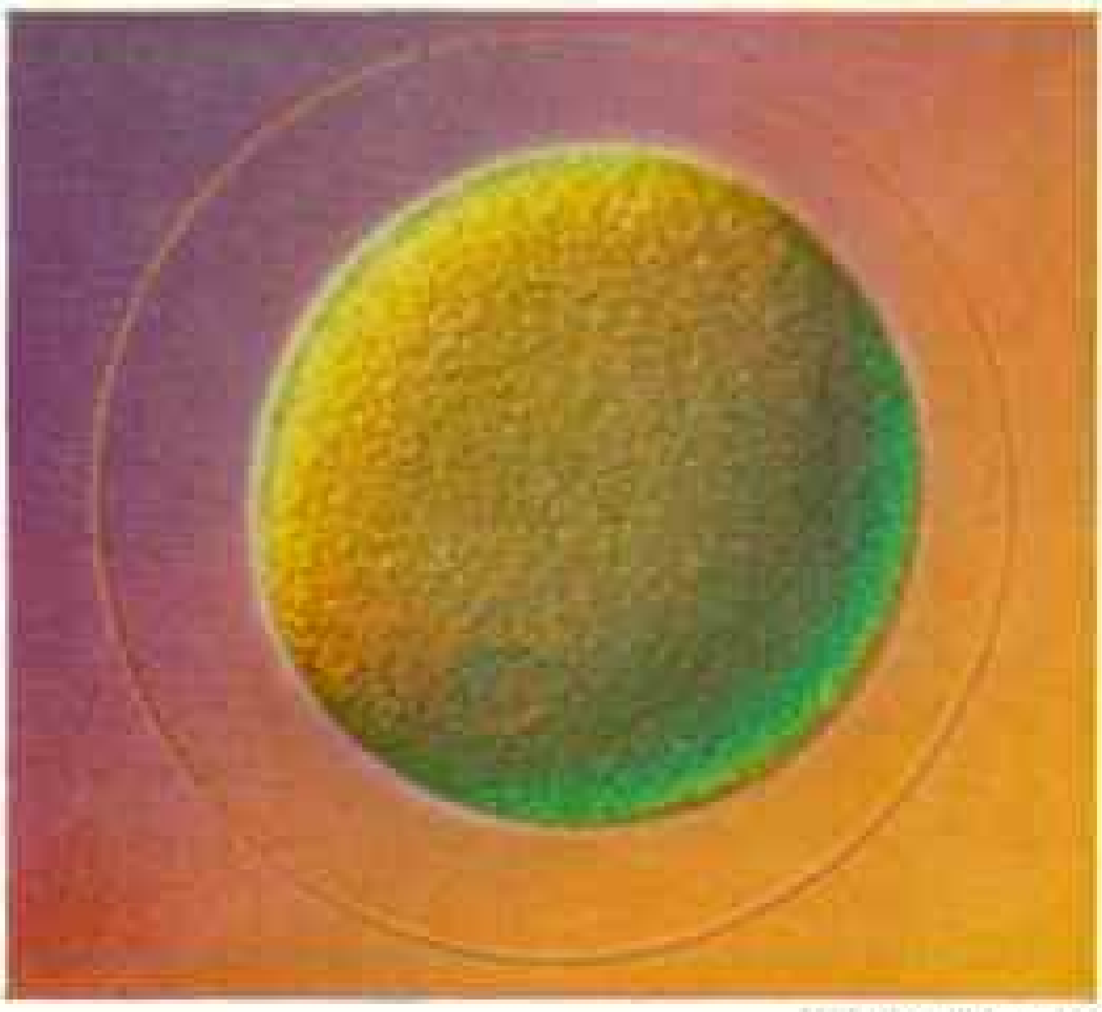
What remain are mostly the useful by-products water and carbon dioxide (circles and squares), and bacterial protein.

PURE DNA REFINED FROM URCHIN SPERM

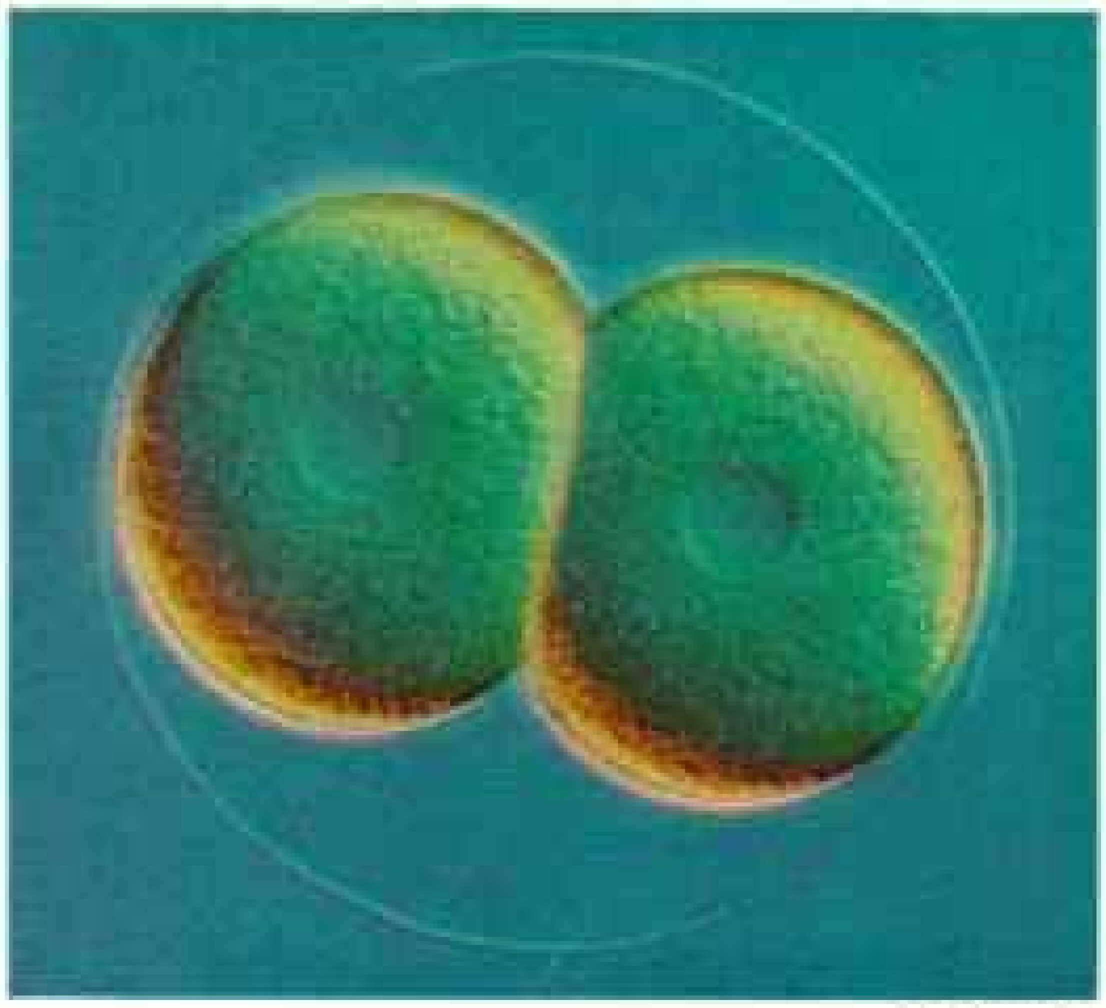
Life divides to multiply

Tame-looking as it clings to a glass stirring rod (**left**), pure DNA lacks the frantic animation of its source, sea urchin sperm (**below**), shown swarming over an egg. The fusion of sperm and egg—each supplying half the hereditary characteristics of the new organism—ensures species continuity and diversity. As the egg divides, its chromosomes double and pull apart to provide identical genes

URCHIN SPERM ON EGG, MAGNIFIED 5,000 TIMES; ALL OTHER MAGNIFICATIONS ON THIS PAGE, 500 TIMES



FERTILIZED URCHIN EGG



TWO-CELL STAGE

DIVIDING CLUSTER

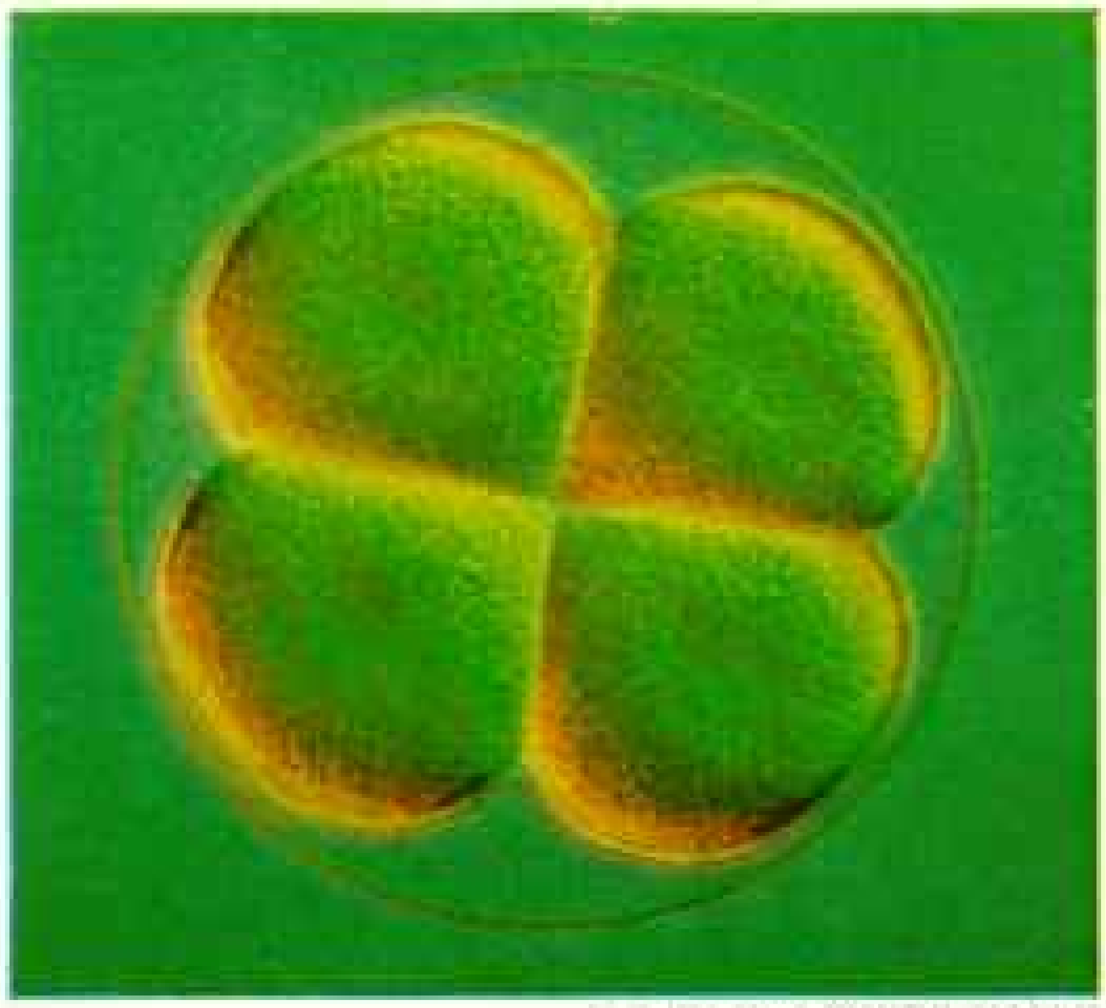
CELLS DIFFERENTIATE

for two cells (detail, **below**). From a single fertilized egg to an adult urchin, photographs on the lower two rows of these facing pages trace the process. Increasing to four, and geometrically to a cluster, the cells continue to multiply.

Then, within the uniform cluster, one of the most profound and mysterious of all biological transformations begins. Cells specialize to form tissue and organs. In the urchin a primitive gut starts to form (bottom row, second from left). The organism develops through the larval stage, metamorphoses, and ultimately reaches maturity. This adult is being injected with a saline solution to release sperm for experiments (**lower right**).

Extracted from sperm, strands of urchin DNA can be mapped and analyzed. Caltech lab technician Maggie Chamberlin (**below**) uses a digitizer to measure DNA fragments from a projected photograph of prepared urchin DNA taken with an electron microscope.

CHROMOSOMES PART AS CELL DIVIDES; MAGNIFIED 20,000 TIMES



FOUR-CELL STAGE, MAGNIFIED 600 TIMES

BRUCE DALE (OPPOSITE TOP LEFT AND BELOW); OTIS IMBODEN (ABOVE); MIA TEGNER, SCRIPPS INSTITUTION OF OCEANOGRAPHY (OPPOSITE TOP RIGHT); AND GEORGE WATCHMAKER AND HECTOR TIMOURIAN, LAWRENCE LIVERMORE LABORATORY

ADVANCED LARVA, MAGNIFIED 125 TIMES

ADULT URCHIN

the white and moved to another red, with which it quickly paired.

Dr. Humphreys and his colleagues recently have identified a particular molecule in the cell surface, one of the large proteins with sugars bonded to it. This molecule apparently acts like a critical piece in a jigsaw puzzle. Only if it is there will two sponge cells recognize each other and fit together.

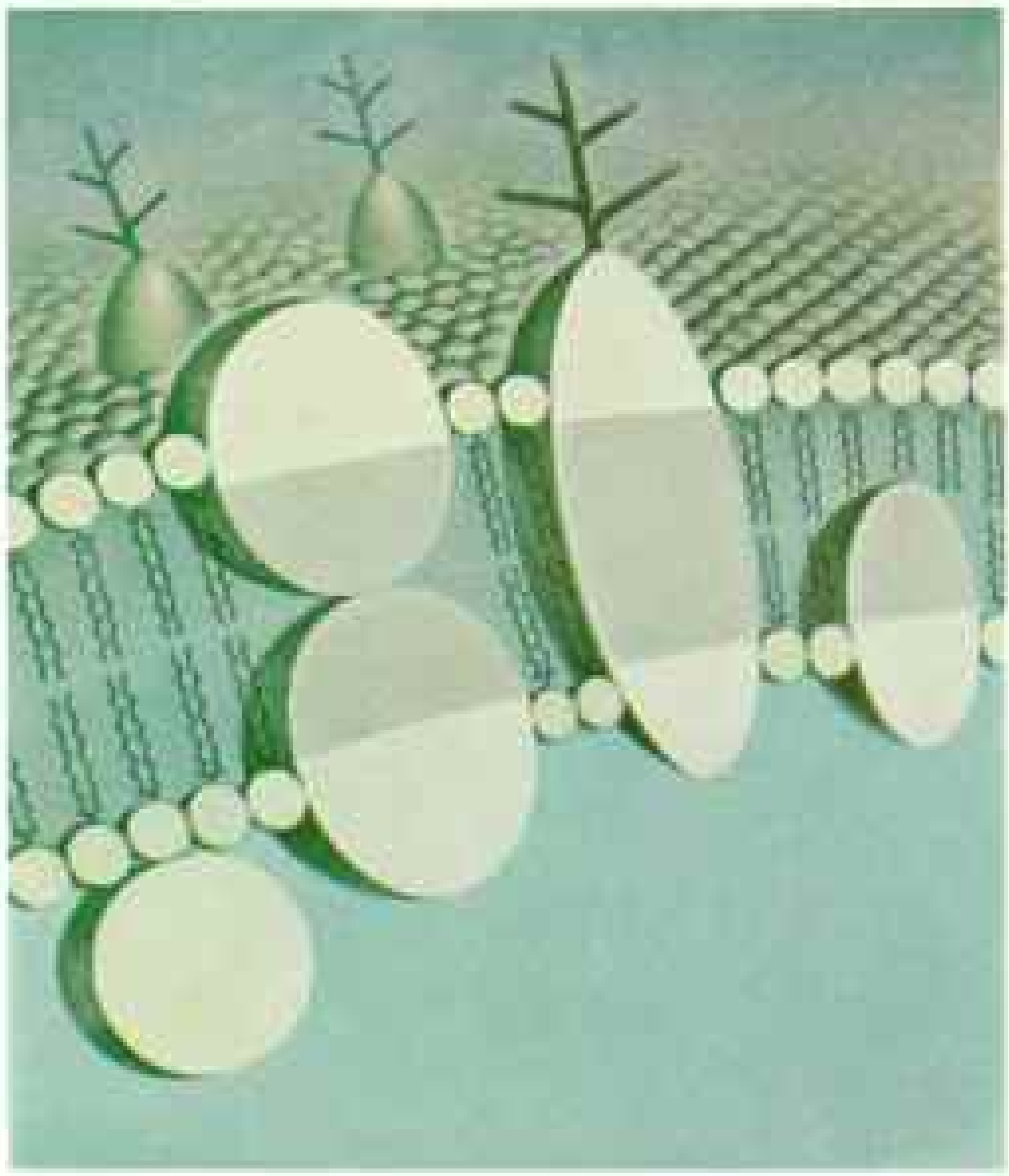
Biologists find such "recognition molecules" all over the cellular world. Hormones, which govern body processes ranging from heartbeat to hunger, latch onto their target cells through recognition molecules. It is the recognition molecules on our red blood cells that make us type A, B, AB, or O. We recognize an odor because its molecules fit the shape of specific receptors in our nose cells. The most intensely studied recognition molecules today, however, are the ones that play the pawns in our body's immune system.

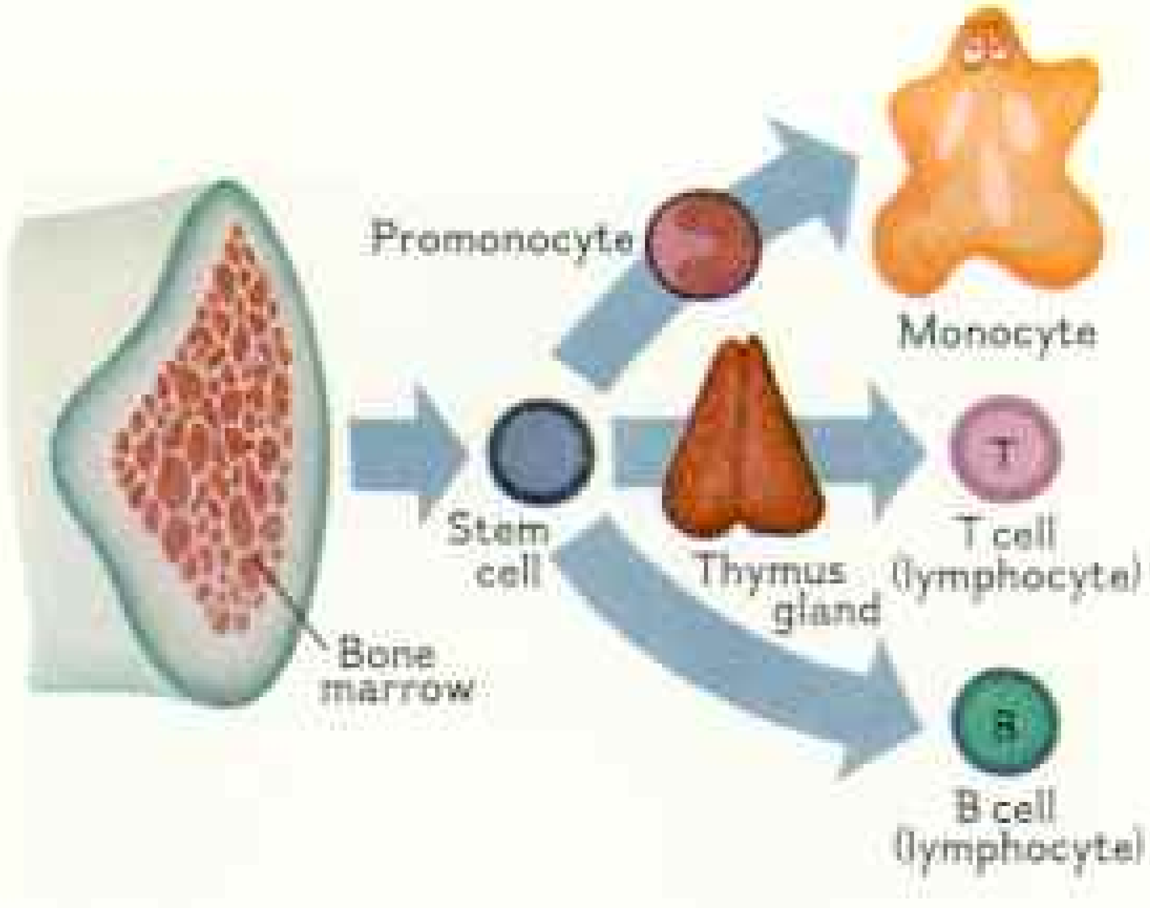
Not only in his thoughts, his feelings, and his will, but in the chemical markings of his body each human individual is unlike any other that has ever existed.

—S. E. LURIA, "LIFE—THE UNFINISHED EXPERIMENT"

ONE OF THE PRIMAL NEEDS of an organism is to recognize its own cells. Otherwise, it might destroy itself. Consequently, each of our cells has embedded in

How our immune system





PAINTING BY DAVIS MELTZER

Early warning

Buoys in a shallow sea, protein molecules float in the oily cell membrane. With branching "antennae," or receptors, they sense the environment beyond the membrane and transmit messages to the interior. Some messages are routine. For example, when you suck a lemon, molecules in the juice mesh with specific receptors in taste-bud cells. But certain messages trigger responses from cells of the immune system. Recognizing alien antennae on bacterial molecules, the cells signal a counterattack.

The defenders

The defense department of the body's immune system headquarters in bone marrow, which continuously produces cells that are processed into three specialized divisions. One division becomes promonocytes, then monocytes—the potential attack force. Altered by the thymus gland, a second division becomes T cells, the signal corps. The third division becomes B cells, the supply corps. These three divisions make a highly mobile, coordinated brigade capable of detecting and destroying an invader.

its surface recognition molecules that are uniquely our own, markers of our biological individuality. These surface markers are probably the reason, for instance, that a transplant patient's immune system triggers the rejection of another's heart or kidney.

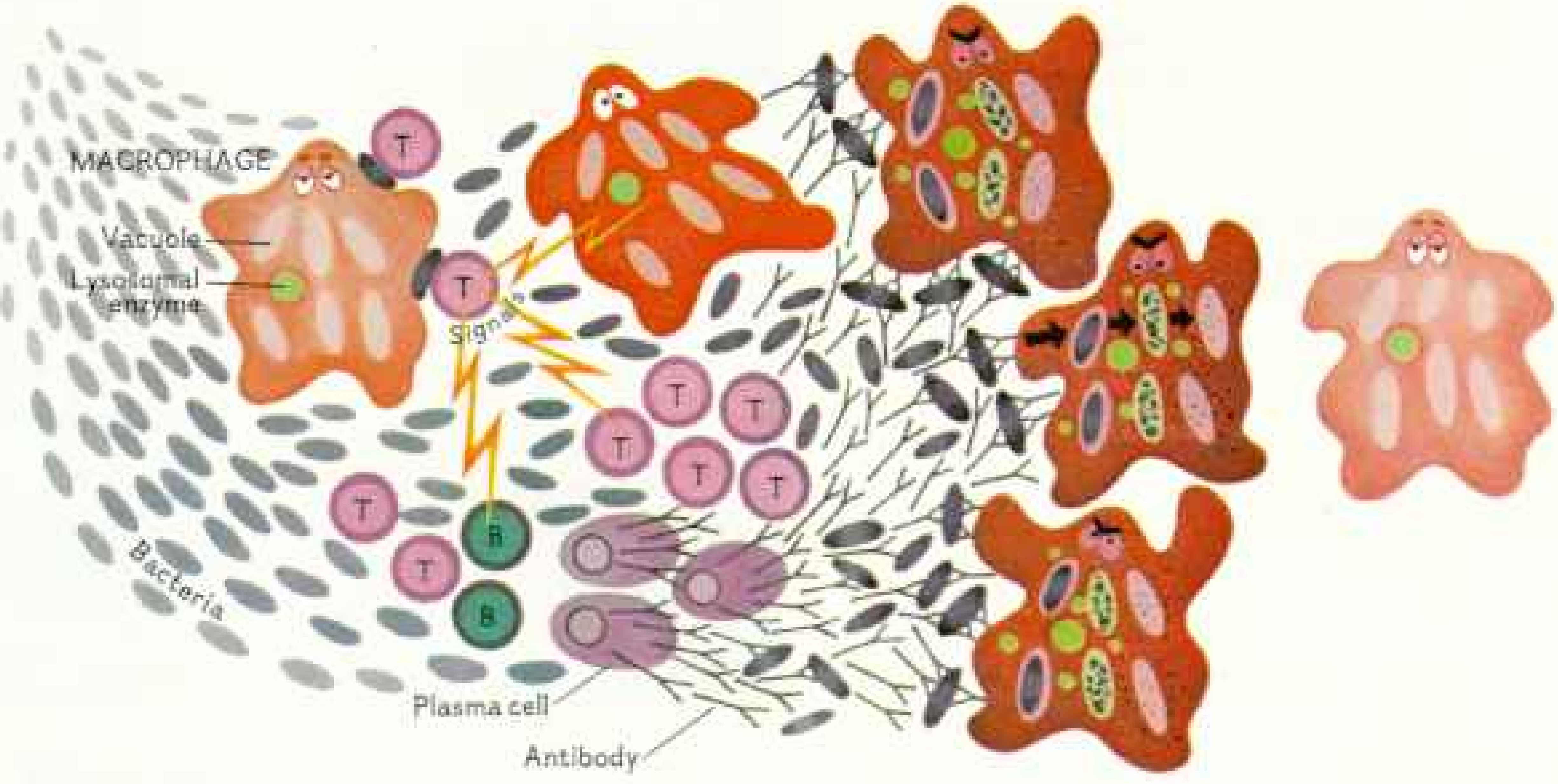
The immune system also uses another sophisticated group of recognition molecules, called antibodies, to help it in identifying and eliminating such invaders as bacteria and viruses. The body manufactures many thousands of different types of antibodies, each one shaped to recognize a specific intruder.

They are not large, these antibodies. A thimble would hold more than a quintillion. Some circulate through the body, binding to intruders and to scavenger cells known as macrophages, which ingest the foreigners.

Antibodies aid also in another of the immune system's lines of defense, that manned by white blood cells called lymphocytes. Many have antibodies on their surfaces, and when they recognize an invader, a complex reaction ensues (diagrams, below). Some lymphocytes, once alerted by their recognition molecules, attack the invaders themselves. These so-called T cells begin to divide, quickly creating an army of identical defenders. They also summon macrophages to the scene and stimulate other lymphocytes, called B cells, to multiply and produce great numbers of the specific antibody needed to help deactivate the invader.

Usually when an antibody makes a match,

wages war on infection



Battle cry: Search and destroy

Bacteria invade, perhaps through a tiny scratch, and begin to multiply. Some become stuck to monocytes, activating them into more aggressive macrophages. Circulating randomly, T cells adhere to macrophages and to the bacteria. This linkage stimulates T cells to send three messages. One: Activate and summon more macrophages. Two: Produce more T cells. Three: Signal B cells to proliferate and become plasma cells that produce and release antibodies—Y-shaped molecules. Antibodies latch onto intruder molecules, or antigens, on bacteria and link the yoke of the Y to them. The shaft of the Y attaches to macrophages. They, in turn, envelop the bacteria, which are consumed by enzymes and become harmless debris.

Victory

Bacteria destroyed, macrophages take a breather. The immune system presents two urgent challenges: Can it be suppressed safely so the body will accept tissue transplants? Can it learn to recognize all cancer cells and destroy them?

Tay-Sachs disease

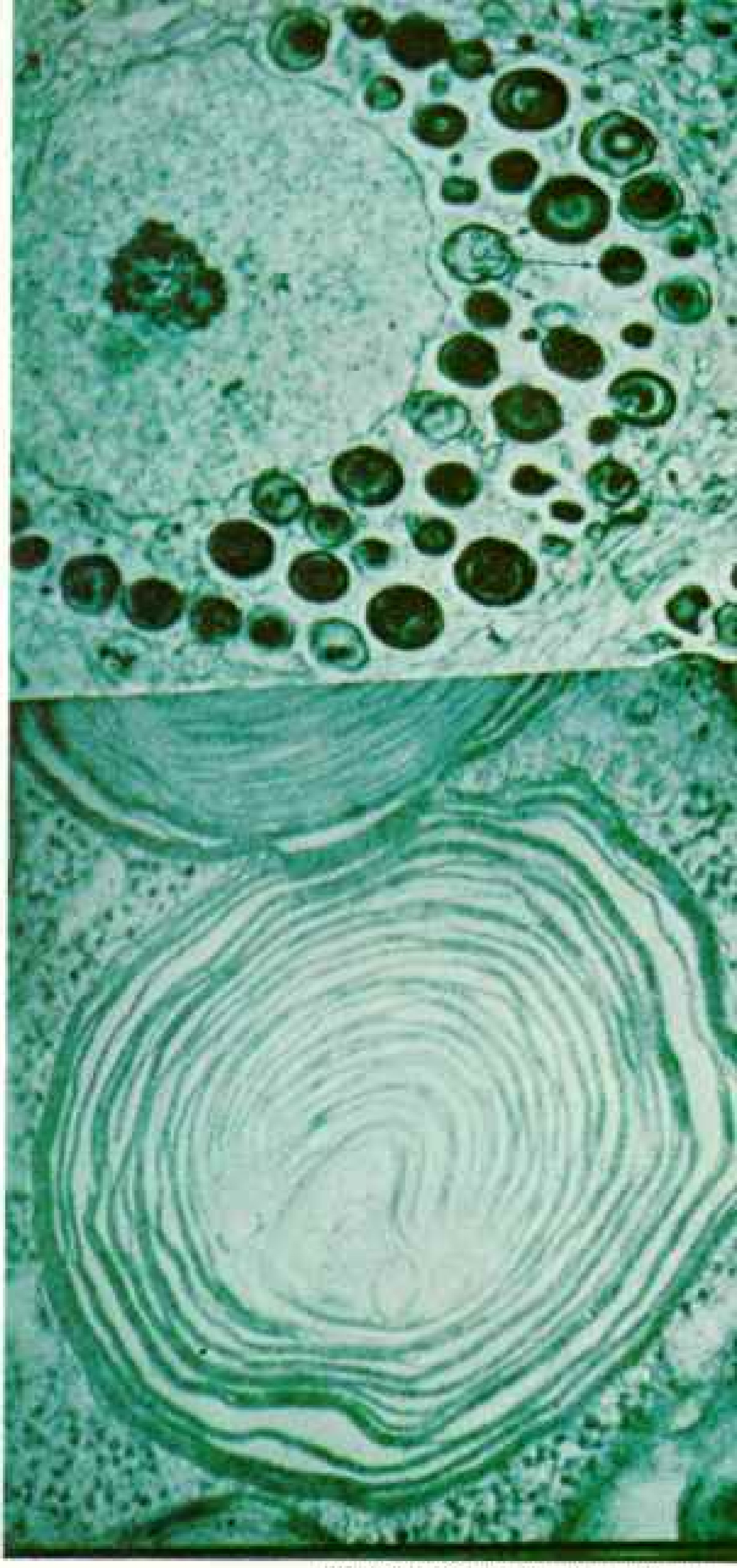
For about six months after birth the infant develops as healthy, happy, and bright; everything seems fine. Then physical and mental deterioration set in, progressing until the loss is total, with death inevitable.

A child afflicted with Tay-Sachs disease inherits from each parent a recessive gene that permits buildup of a fatty substance around cells of the nervous system. Dr. John O'Brien of the University of California at San Diego (**far right, above**) discovered the missing gene-coded enzyme that normally controls harmful fat accumulation. He also perfected a blood test to screen potential carriers. Lecturing with a light pointer, he indicates a telltale spot on the retina characteristic of the disease; other slides show the lethal buildup around a cell nucleus (**right above**) and a single fatty particle, highly magnified (**right**).

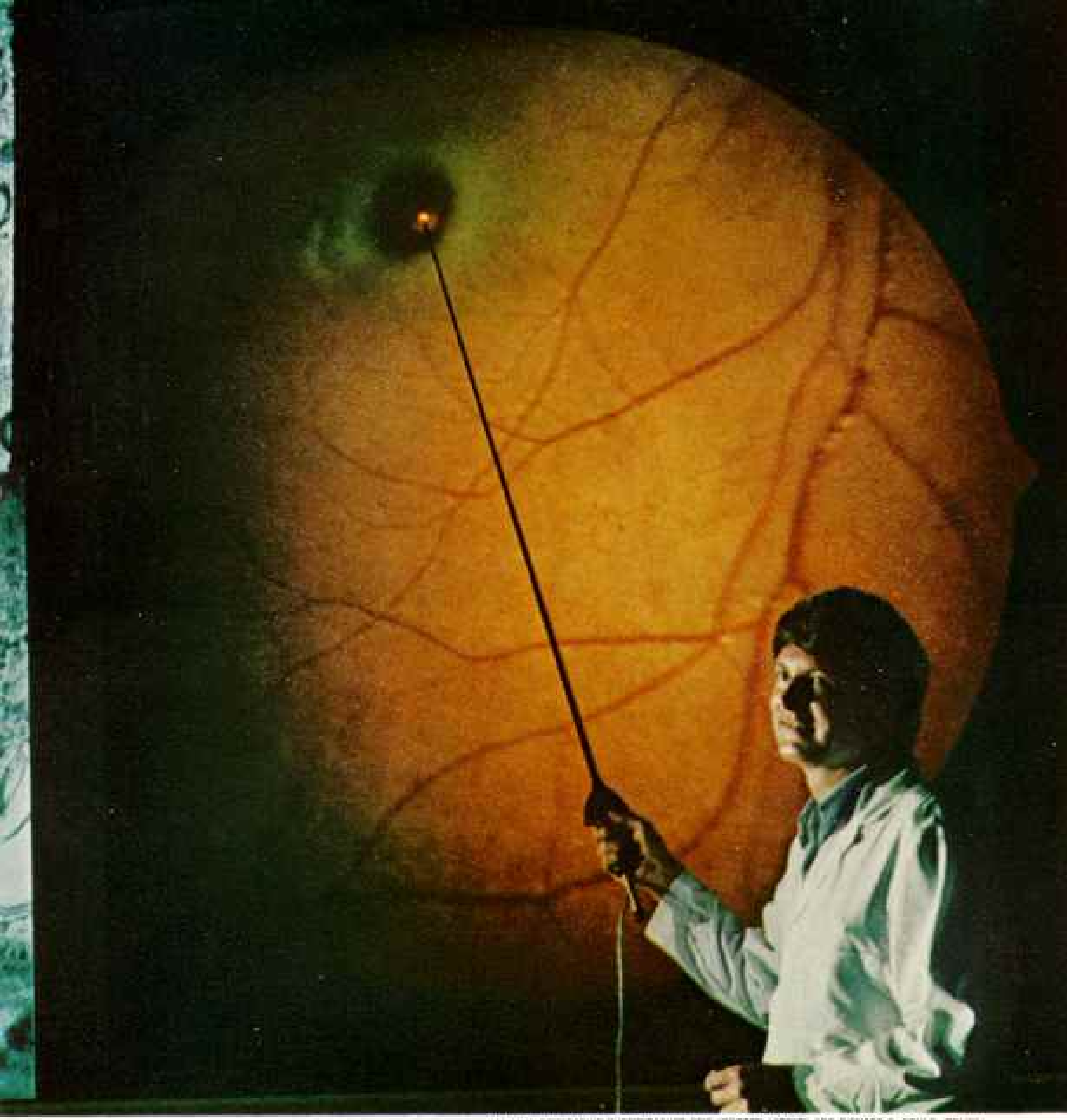
Although anyone can carry the Tay-Sachs gene, it is most common among persons of eastern European Jewish heritage. When both parents are carriers, each pregnancy holds a 25 percent chance of producing the affliction.

At Kingsbrook Jewish Medical Center in Brooklyn, which specializes in caring for victims (**right, below**), doctors routinely give tests for early diagnosis. Even when both parents have been identified as carriers, they may still raise a healthy family. By testing a sample of the amniotic fluid surrounding the fetus, Tay-Sachs can be detected. If the test is positive, doctors may discuss with the parents the difficult option of terminating the pregnancy.

But how happy a negative test! Such a test had predicted that half-day-old David (**far right, below**) would be a healthy son to Richard and Barbara Gould—and a brother for their daughters Maile and Tammy, who flashes the victory sign.

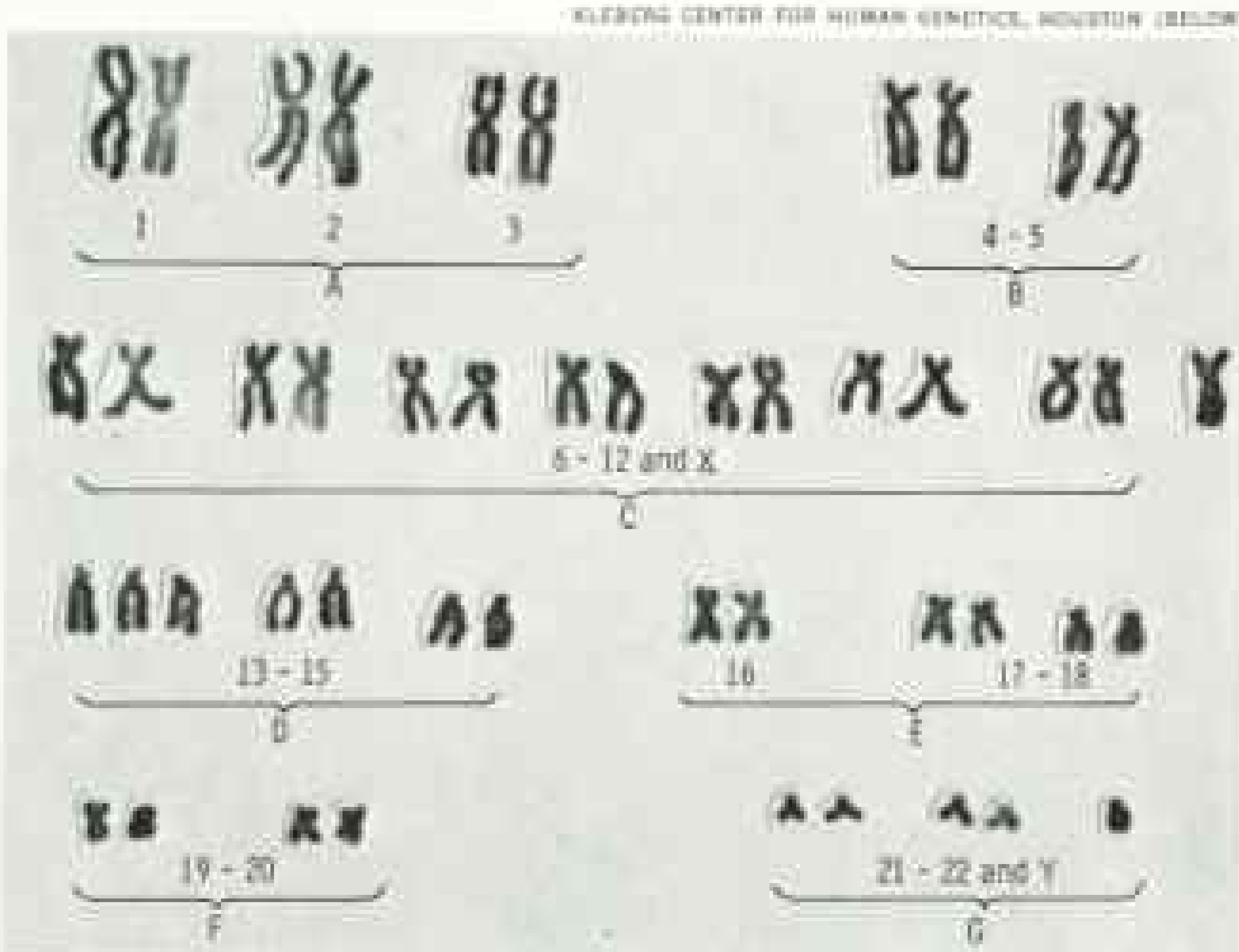


MAGNIFIED 19,000 TIMES (TOP); AND 100,000 TIMES



NATIONAL GEOGRAPHIC PHOTOGRAPHER OTIS IMBODEN (ABOVE) AND RICHARD E. GOULD (BELOW)

KLEBERG CENTER FOR HUMAN GENETICS, HOUSTON (BELOW)



Prenatal testing

Sometimes there is good reason to suspect a fetus may be heir to a gross genetic defect. Here obstetrician Dr. Sheldon Cherry (**above**) withdraws amniotic fluid by means of a needle piercing his pregnant patient's abdomen. The chromosomes, normally in pairs, are analyzed for defects. One such (**left**) shows an extra copy of chromosome number 13, which would lead to early death because of gross abnormalities.

our immune system fights off the intruder without our even being aware of the war; occasionally our protectors lose, and we come down with a cold, the flu, or worse.

But even when it loses, the memory of the battle lingers. The next time the same invader appears, our response is better, quicker. We have, in other words, become immune.

The cells of the immune system are prime subjects of study in man's war on cancer. For one thing, a cancer cell often sprouts abnormal recognition molecules, which should be red flags to the immune system.

"Why don't we reject our own cancer cells? That is a major question here," said a researcher at the National Cancer Institute in Bethesda, Maryland. "Maybe we do. Maybe we reject hundreds every day and there's just one that's missed, and that's the one that gets us."

A hen is only an egg's way of making another egg.

—SAMUEL BUTLER

ONE OF THE MOST ACTIVE AREAS in biology today is called differentiation—or how cells become different from each other.

Each many-celled creature starts out in life as a single fertilized egg cell. Then division begins, each new cell acquiring identical genes. But soon different sets of genes turn on in different cells, producing different traits. New cells become more specialized, at first as inner body or outer body, later as liver, eye, or skin.

"Differentiation is to me biology's most challenging problem," Beatrice Mintz told me at the Institute for Cancer Research in Philadelphia. She showed me her unique approach —a mouse, quite normal in appearance, but with black and white stripes.

"You are looking at what would have been two mice," she said. "This animal has four parents."

But it was Dr. Mintz who had really made the mouse, and, with her collaborators, thousands more like it. She had taken embryos only a few cell divisions old out of mice from two different strains. In this case, one strain had the genes for a black coat and the other for a white coat. She then placed the two embryonic clumps in a dish, dissolved the envelopes around each embryo, and placed the two clumps of cells together. She later inserted the new composite embryo into the uterus of a surrogate mouse mother. When born, the baby mouse was a mosaic of two kinds of cells, each with the traits of one pair of parents.

Dr. Mintz's mice let her monitor how pigment cells first develop, and, through the color markers, trace the cells' lineage as the embryos mature. Biologists have bred many genetically uniform strains of mice. Apart from color differences, some have various genetic disorders, some are susceptible to certain cancers. Beatrice Mintz's mice offer one way to identify which cells first deviate from normal and then to learn how their interactions with other cells during development may contribute to diseases.

I saw many other approaches to the problem of differentiation.

When I mentioned Donald Brown's name to a fellow biologist, she said: "Oh, yes. The Frog Man." That nickname is understandable. Frog posters, statues, mobiles, ash trays, and candles dominate his Baltimore lab of the Carnegie Institution of Washington (page 371).

"It is my fate," he explained, "to receive for every present a frog of some kind."

Dr. Brown has four rooms that he calls his "frog farm." They are furnished with bathtubs, which, whenever we walked through the door, erupted with the frantic splashing of hundreds of finny feet.

"Why do blood genes work in blood cells, but not in liver cells or skin cells?" That is how Don Brown explains his basic field of study. One reason he uses frogs is because their embryos are easy to experiment with.

BY STUDYING what RNA the frog embryos' genes are making at any one time, biologists learn a great deal about how gene activity changes as an animal develops. They have discovered some surprising and still perplexing things about the nature of DNA.

For one, an animal cell carries many copies of some genes and only the basic pair—one from each parent—of others. Also, large amounts of DNA have no apparent function. Nobody knows why it is there.

What all that extra DNA is doing is one of biology's great riddles. Dr. Brown suggests that some of it is used for genetic control: "There are genes that regulate the genes that make the protein."

Dr. Brown in 1971 isolated an animal gene whose function was known, the second biologist in history to do so, after Dr. Max Birnstiel of Scotland in 1966. Both scientists were working with frog DNA. Now Dr. Brown is trying to isolate the gene responsible for making silk in the silkworm.

"Our ultimate goal is to make these genes work in test tubes," he told me. With the genes freed from the complex chemical chatter within a cell, biologists could discover more easily the mechanisms that turn them on and off.

The introduction of such genes into a bacterium, a recent accomplishment, has potential practical application. If the gene that codes for insulin, say, could be isolated and put into bacteria, the bacteria might be turned into little insulin factories that drug companies could harvest. Other bacteria might be designed to manufacture antibiotics.

At General Electric's Research and Development Center in Schenectady, New York, Dr. Ananda M. Chakrabarty showed me a remarkable man-made bug. He put genes of four different oil-eating bacteria into a single

strain, which can consume crude oil far faster than the other four working independently. Superbug, as members of the press dubbed it, is still in the test stage, but could turn into a new tool for combating oil spills (page 374-5).

Superbug, Dr. Chakrabarty assured me, will not be able to escape and thrive in car gas tanks or invade the oil fields of the earth. It could not survive in such environments.

However, the thought of such man-made bugs being accidentally loosed on the world is exactly what is bothering many biologists today. Man is on the brink of creating new forms of life, and it is only fitting that high-ranking biologists called their recent moratorium to confer and consider what they are about to do. An alien gene placed in a common bacterium, for instance, could create a seriously infectious new creature.

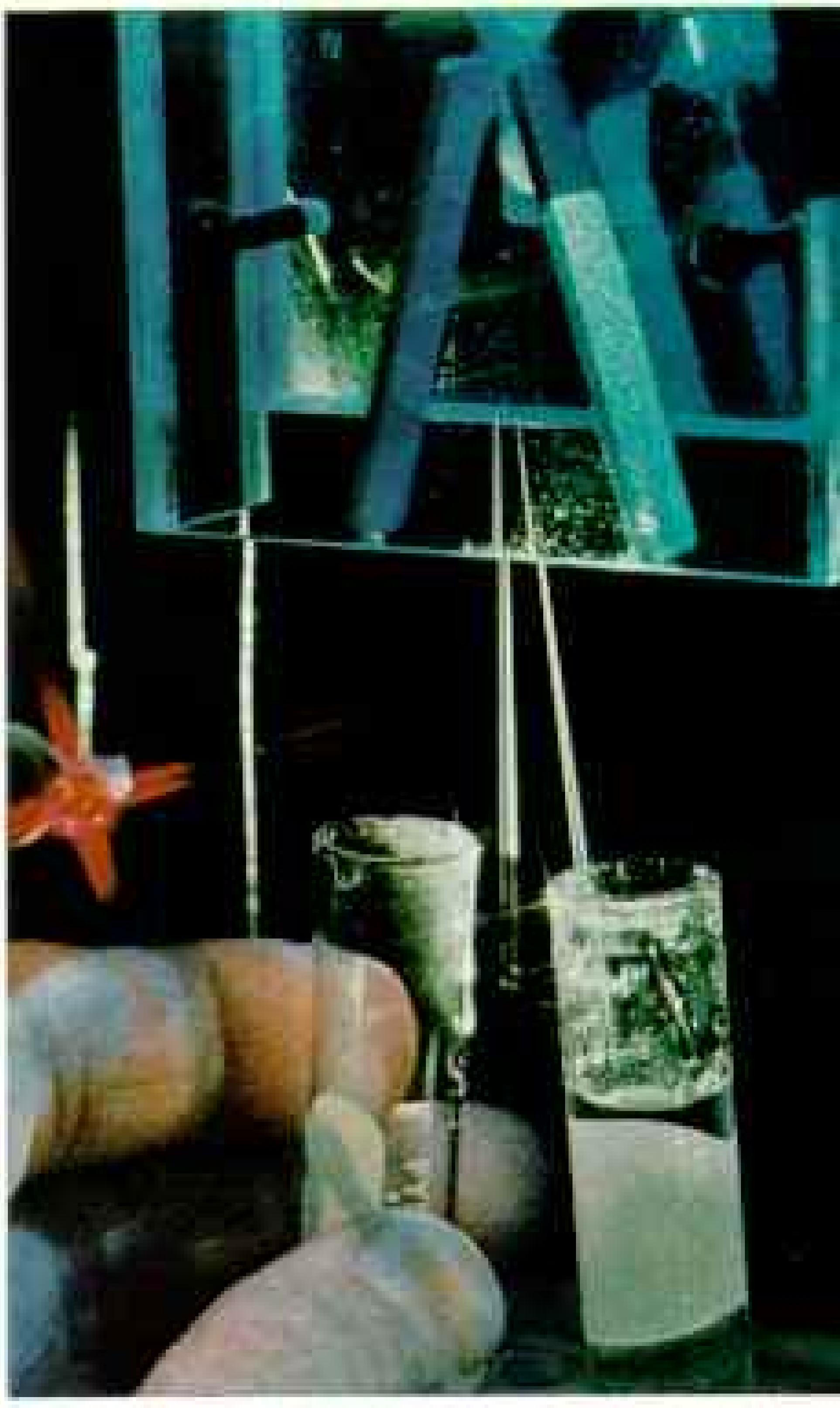
Most biologists believe the guidelines they painstakingly worked out should make the odds against such a biological accident more than a million to one. The guidelines ban the most hazardous types of DNA experiments. Moreover, scientists have recently developed a supposedly safe strain of bacterium—that is, one that cannot survive should it escape the nurturing conditions of the laboratory.

But despite the stringent new precautions, questions remain. We are entering a terrain whose ecology we only dimly understand.

The new biological techniques promise knowledge of inestimable value about the basic processes of life. But can truly safe guidelines be written when we know so little about the environment we are about to disturb? Also, the scientific laurels such work could yield are enormously tempting. What is to prevent an overzealous researcher from bending the guidelines a bit? What will forestall sloppy work? Can scientists of all other nations be persuaded to impose similar restraints upon themselves? The risks may be remote, but the questions are real.

Beyond bacteria, many biologists now talk about manipulating genes in humans. But first they must learn to locate the one they want to work with out of the roughly one

Chromosome sleuthing by computer



Study of some chromosome defects requires that enormous numbers be sorted. Scientists at Lawrence Livermore Laboratory in California have developed a sorter (**right**) that inspects 100,000 chromosomes a minute. Abnormal chromosomes can be deflected from the vertical stream into a tilted test tube for further study.

To scan chromosomes for detailed analysis, the laboratory married a computer to a microscope (**left**). Though this system, called CYDAC, is a tool of basic research, it can also be used for clinical diagnosis. For example, after examining in the usual way the chromosomes from an amniotic tap, a physician got ambiguous results; perhaps the baby would be normal, perhaps not. CYDAC predicted no problem. Result: healthy baby, happy mother.

hundred thousand different genes each of us possesses. Until recently that seemed more daunting than untying the Gordian knot. But now a technique called cell fusion is helping to cut through the genetic jungle.

I watched Dr. Hayden Coon of the National Institutes of Health fuse the cells of a hamster and a human. To me the elaborate ritual seemed almost like sorcery. Researchers have fused human cells with mouse, chicken, and even mosquito cells. There is no possibility, however, of creating a monster with the head of a man and the tail of a mouse. Fused cells of different animals will not develop beyond a colony of single cells.

What fused cells will do, however, is lose the chromosomes of one species—in stages. For instance, each time hamster-human cells divide, some human chromosomes disappear.

So, if a scientist wants to know what chromosome a specific gene is on—say, the one that controls the making of enzyme X—he monitors the division of the fused cells. Every time a human chromosome disappears, he determines whether the fused cell can still make enzyme X. If not, the gene controlling enzyme X was on the chromosome he lost.

"This makes it possible," explained Dr. Coon, "to map every testable function of human cells and to find out on which chromosome each controlling gene is located."

LOCATING SPECIFIC GENES is an essential preliminary to seeking cures for genetic diseases. Gene manipulation may someday eliminate heartbreaking situations like the one I witnessed at the Kingsbrook Jewish Medical Center in Brooklyn.

A baby girl lay pathetically motionless in a crib in the Tay-Sachs disease ward. I watched her mother softly brush the child's hair.

"I know she can't see or hear me," her mother told me, "but this is the only thing I can do for her."

The child had become a vegetable because her cells lacked one specific gene. As a result, her nerve cells could not make an enzyme they needed to break down a particular fat.

The fat was building up, destroying her cells and gradually her entire nervous system.

There is no cure for Tay-Sachs disease, but it is one of a growing list of inherited disorders for which specific missing enzymes have been identified (pages 380-81). Many major diseases from diabetes to cystic fibrosis are caused by missing or defective genes.

A few days after visiting the Tay-Sachs ward, I watched, with a shudder, as New York City obstetrician Sheldon Cherry pierced the abdomen and womb of a pregnant patient with a long hypodermic needle. It was painless, the young woman assured me, as Dr. Cherry drew a sample of amniotic fluid, the liquid that cushions a baby in the womb.

Analyzing cells in this fluid, technicians can tell whether a fetus is afflicted with Tay-Sachs or any of the other diseases for which the causative missing enzyme is known.

At the University of California at San Diego I asked John O'Brien, one of the leading researchers on Tay-Sachs disease, whether biology might not come up with a way of dealing with disorders of the genes.

"One thing we can think about for the distant future," Dr. O'Brien answered, "is gene replacement—to make the missing gene itself. Then we might be able to tailor a virus that can carry the gene into the cell."

AND THAT BRINGS US to one of the strangest of all living things—if indeed it does have life. A virus is basically a little package of genes that invades cells and can cause problems ranging from the common cold to polio. Some biologists argue that viruses are not technically alive, because they lack the machinery to reproduce themselves. Instead, viruses invade a cell and commandeer its reproductive equipment.

At Caltech, virologist Bill Wood showed me electron-microscope pictures of the virus he studies, one called T4. T4 looks remarkably like the lunar module that landed Apollo astronauts on the moon. However, it behaves more like a mosquito, alighting on the cell surface, driving a tubular shaft into the cellular innards, and then squirting in its own genes.

Some viral genes attach themselves to the host's DNA. This kind of virus can cause cancer in some animals, and perhaps in man, by changing the instructions the DNA sends to the rest of the cell. But because they do act as a shuttle into the gene pool of the cell, viruses are potentially a key tool of genetic engineers.

Genetic engineering conjures up the image of a drugstore scientist taking vials of genes—one for beauty, one for athletic prowess, one for brains—and injecting them into an egg cell to make a custom-ordered embryo. One of the resulting "eugenic" men or women might be a delight, two good company, but three or more a drag on the diversity that life and most living things require.

How far off is genetic engineering? In a sense, it is here. The men who isolate genes and crudely transplant them into bacteria are the pioneers.

"It would take at least five years to identify and locate the gene whose absence is responsible for Tay-Sachs disease," Dr. O'Brien told me. "Then we would have to decide whether we want to produce the gene artificially. Making a gene would be a very big, expensive effort. We have to ask whether, relative to such other needs as the conquest of cancer, it is worth the time and money."

What about the prospects for genetically engineering traits like intelligence, beauty, or superhuman strength into human cells?

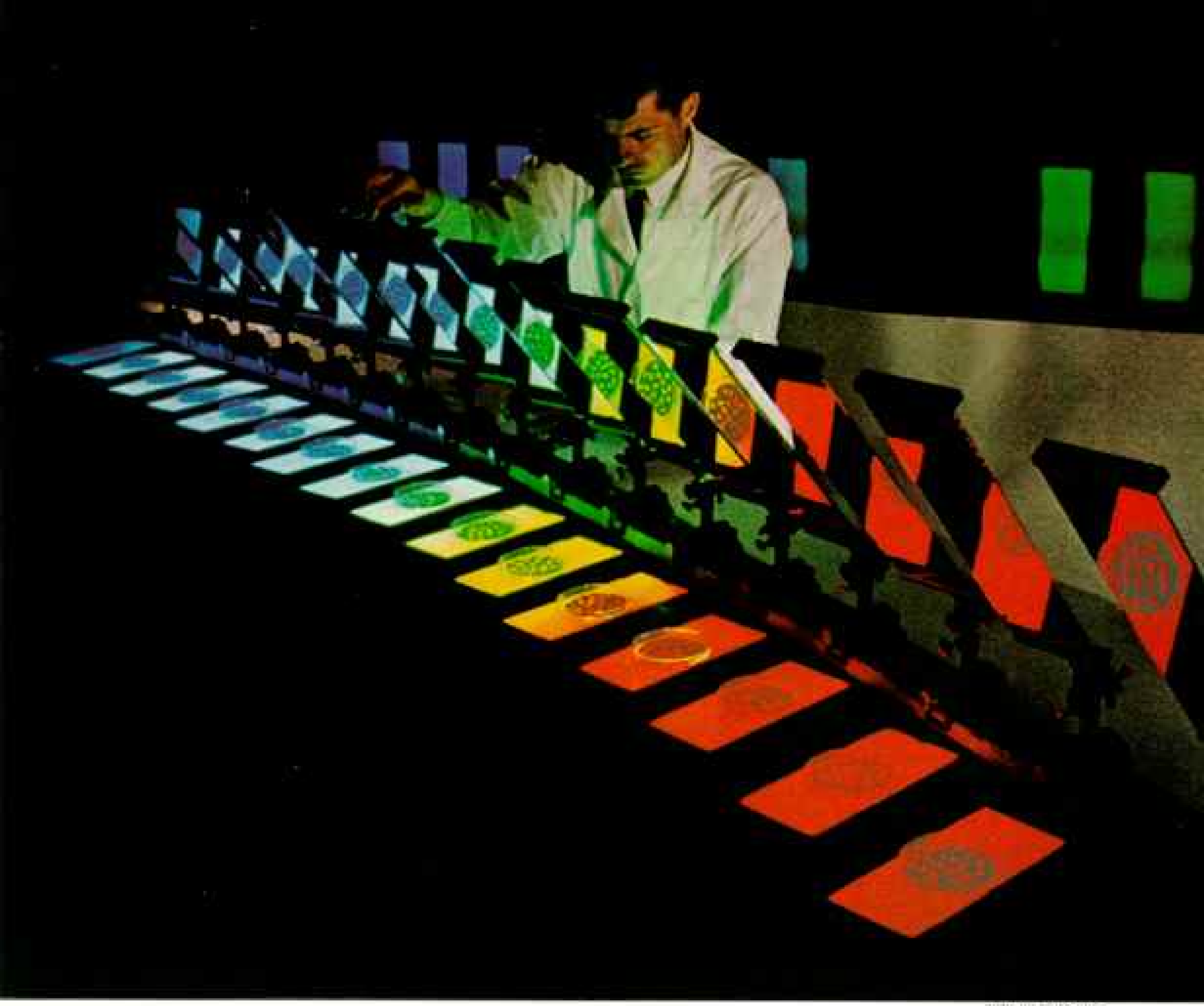
Dr. O'Brien emitted something between a sigh and a laugh. "There are thousands of genes involved in each of those traits. We can't begin to define intelligence genetically. What you ask is like going to the star Alpha Centauri. It is technically feasible; we know we can go there if we want to spend the time and the money it would take. But to modify the human genetic pool in the way you suggest is so far from our current capabilities that it will be many generations after we are dead before mankind can begin to think seriously about doing it."

Genetic engineering with plants is not science fiction any more. It's here.

—TOSHIO MURASHIGE,
UNIVERSITY OF CALIFORNIA AT RIVERSIDE

"PLANTS ARE much more satisfying than bacteria," Peter Carlson said as we walked past tall stalks of corn and pushed aside a thicket of tobacco leaves in his greenhouse. He plucked a gardenia near the greenhouse door and handed it to me.

"In nature a gardenia can't mate with an



BOTH BY FRITZ GORO

New light on photosynthesis

Directly or indirectly, all higher life depends on photosynthesis, the process by which green plants utilize sunlight to convert carbon dioxide and water into food and energy, with oxygen as a by-product. Chlorophyll makes the process go.

At Argonne National Laboratory in Chicago, light has been broken into a spectrum (**above**) to study the effects of various wave lengths on seedling and root response. The pigment phytochrome triggers important growth functions. Overall, high-intensity red light was found to promote photosynthesis most effectively.

Stimulated by blue light (**left**), green chlorophyll in a quartz container re-radiates red light. In a plant such energy would be used in the photosynthetic conversion.

orchid," the Michigan State University botanist said. "But now we've found a way around that. It is possible to release plants from the restrictions of sex."

Gardenia-orchids. Corn-sorghum. Wheat-soybeans. Or "pomatoes"—hypothetical vegetables with the fruit-bearing foliage of a tomato and the tuberous roots of a potato. To some botanists, it is just a matter of time until almost any type of plant can be hybridized with another (pages 390-91).

Their technique, which is just in its infancy, is first to dissolve the tough cell wall that encapsules plant cells. Then they fuse the naked cells, or protoplasts, from two different plants. Finally—and so far this has been accomplished only with cells from two types of tobacco—they grow the fused cells into full-blown plants. More dramatic hybrids than tobacco have been fused, but the techniques for growing the fused cells into mature plants remain to be worked out.

That does not mar the enthusiasm of the men and women in the field.

"Corn is a very important crop in our country, but it isn't drought resistant," said Dr. Carlson. "Sorghum is drought resistant. Wouldn't a cross between them be ideal!"

"Suppose you could introduce into wheat the nitrogen-fixing genes that some bacteria have," suggested Toshio Murashige, horticulture professor at the University of California at Riverside. "Can you imagine how much we'd save on fertilizer?

"Or say you'd like to grow a navel orange in your backyard in Baltimore. There are frost-resistant types of citrus. Their fruit, unfortunately, tastes awful. But they have the genes that enable the tree to stand up to freezing weather. We may be able to isolate those genes someday, and put them in a tree whose fruit is good-tasting."

. . . this really is the major problem of biology. How did this complexity arise?

—FRANCIS CRICK, "OF MEN AND MOLECULES"

EVEN AS THEY EXPLORE the advancing frontiers of genetic engineering, biologists still confront the deep, basic mystery of science: How did it all begin?

Like an agitated firefly, the coil in the glass globe sputtered sparks of electricity.

ALL BY FRITZ GORO

Carrots and clones

That single, mature cells contain all the genetic instructions needed to produce complete plants has been known since Dr. F. C. Steward's demonstration at Cornell University in the 1950's. He placed tiny plugs from carrot slices (**above**) in glass flasks containing a solution that caused them to grow. As the flasks slowly revolved, they released free cells that developed into normal carrot plants, genetic copies of the original carrot (**below**).

Carbon-copy animals, termed clones, have been made by a related process. The nucleus of an unfertilized frog egg is destroyed. The nucleus of a cell from a donor tadpole is inserted. From that union grows a frog genetically identical to the donor. Although cloning has not yet been accomplished in lower mammals, much less man, the possibility raises fundamental social, ethical, moral, and religious questions. Engineered plants could be an agricultural blessing, engineered humanity a horror.

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"This is the primitive atmosphere," said Stanley Miller, chemistry professor at the University of California at San Diego, as he pointed to the transparent mixture of gases inside the globe. "And this represents the primitive ocean," he said, indicating a pool of water in the bottom of his apparatus.

The atmosphere Stanley Miller was recreating was that of the ancient earth. Dr. Miller astonished his colleagues in 1953, when, as a graduate student at the University of Chicago, he used a similar contraption to produce a mixture of amino acids, the building blocks of proteins.

Since then scientists have created not only amino acids, but most of the other important basic molecules of life out of the raw materials of the earth's early atmosphere—methane, hydrogen, water vapor, ammonia, nitrogen, and carbon monoxide. They have done it not only with an electric charge, but also with ultraviolet light and heat, each of which would have been abundant on the newly formed planet.

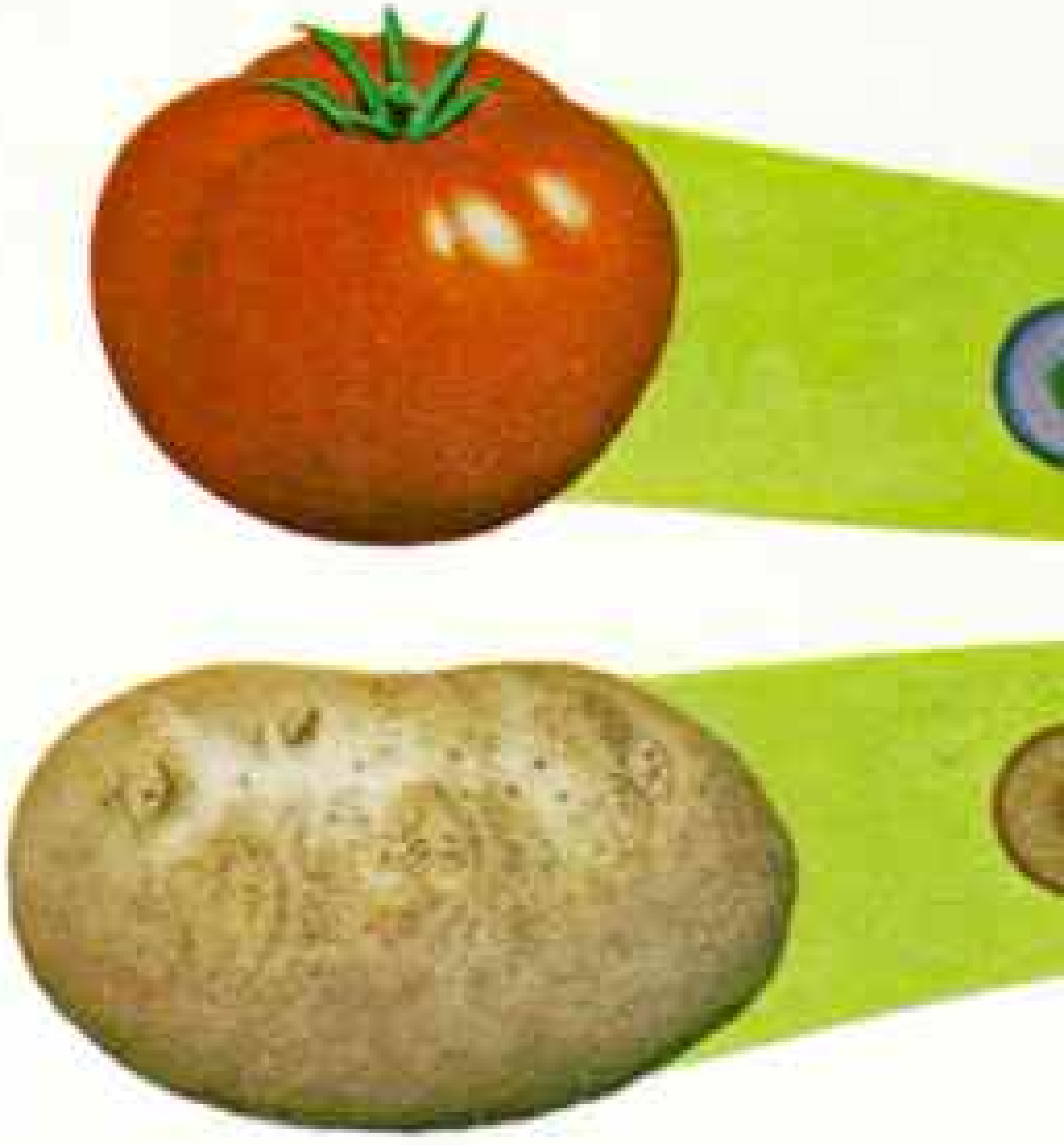
Much to their frustration, however, biologists can still only speculate on how these simple organic molecules emerged through the eons as proteins and genes.

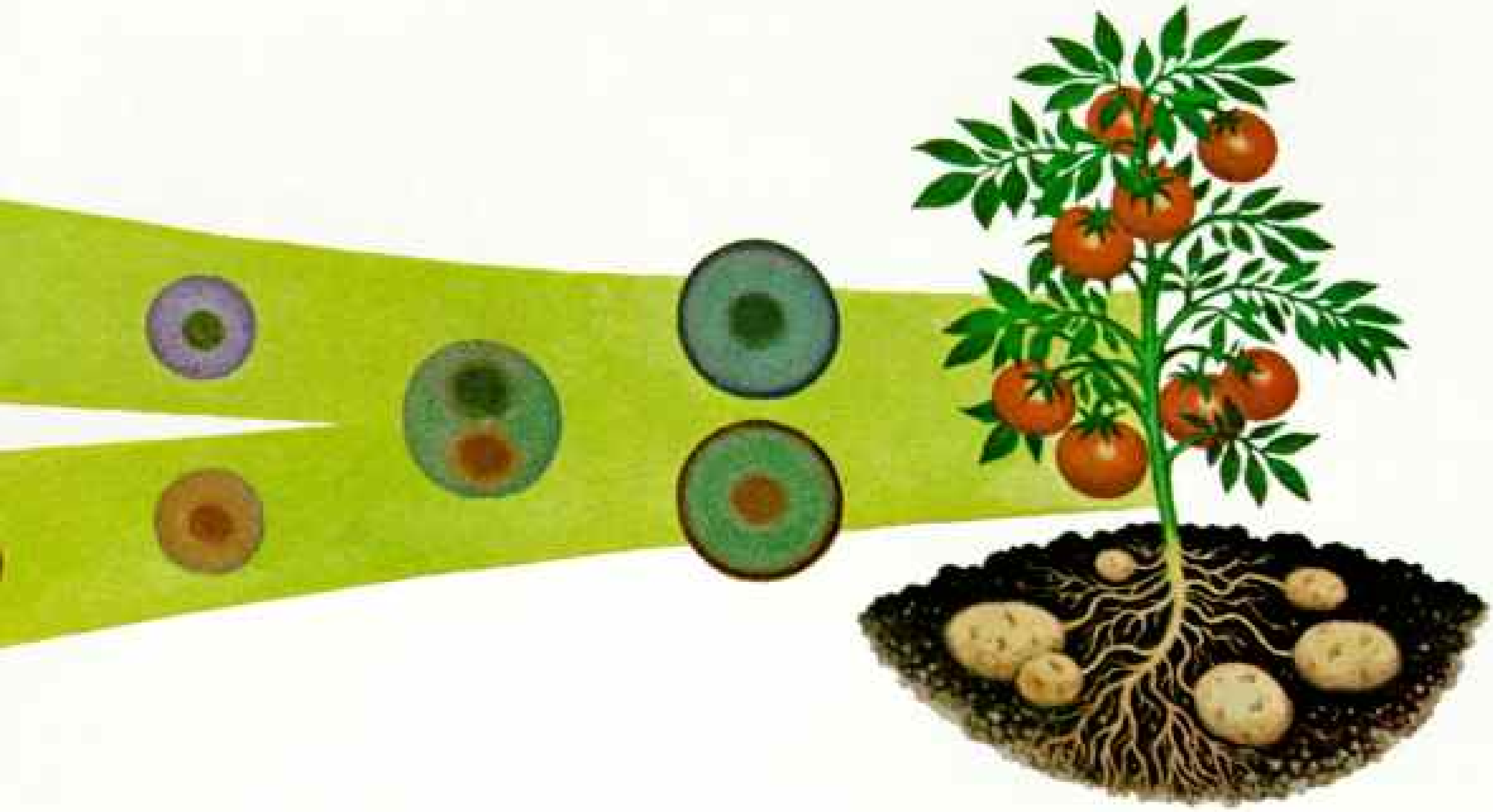
MORE BAFFLING still is how these proteins and genes got together in the first self-replicating cell. The odds against the right molecules being in the right place at the right time are staggering. Yet, as science measures it, so is the time scale on which nature works. Indeed, what seems an impossible occurrence at any one moment would, given untold eons, become a certainty. And after that first cell appeared, it would be as certain that bacteria, algae, and higher forms of life could result from the wondrous mechanisms of nature.

Interestingly, astronomers have recently found many of the simple precursor molecules of life, such as hydrogen cyanide and formaldehyde, in interstellar space. And scientists have identified amino acids in a freshly fallen meteorite found in southern Australia in 1969.

"The organic compounds they are finding in interstellar space are the same chemicals that we work with," Dr. Miller explained.

"The formation of the basic building blocks of life is (Continued on page 395)



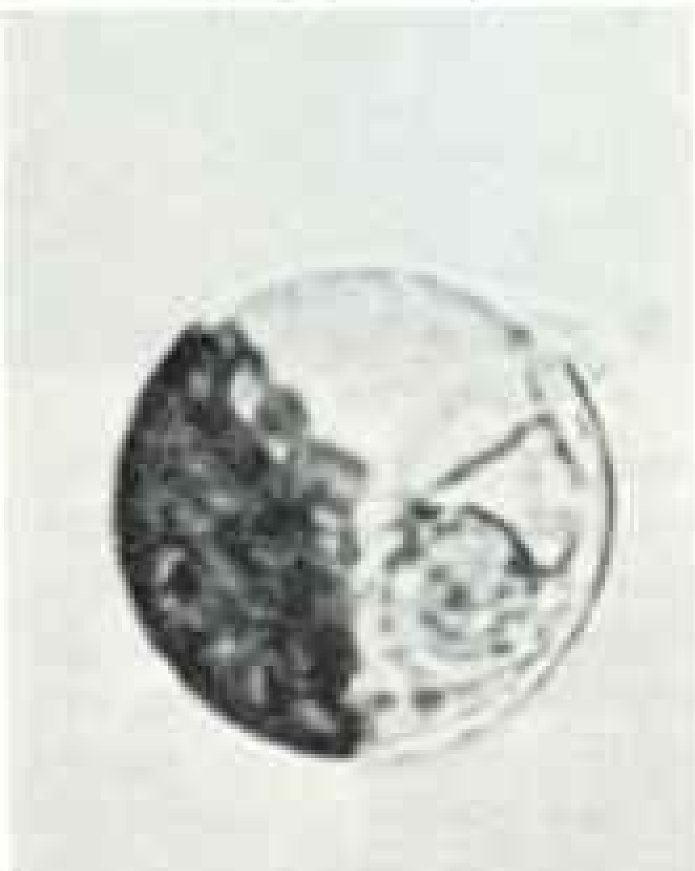


Fusing a "pomato"

Take one cell each from a tomato and a potato; dissolve the cell walls (**diagram, above**). Fuse the unsheathed cells, or protoplasts, into one cell, which then divides, bearing characteristics of both original cells. Plant and—in theory—grow a pomato in your garden. In actual practice, Dr. Peter Carlson (**left**), inspecting wheat in his Michigan State laboratory, has grown a hybrid tobacco by fusing protoplasts from two natural species of tobacco.

Dr. K. N. Kao of Canada's National Research Council has fused dissimilar species in experiments. In one, the dark protoplast of barley (**below, left**) begins to fuse with the light protoplast of soybean. The fused cell divides as would a natural species—to a point. Dr. Kao's superhybrids have yet to grow beyond the hundred-cell stage. Still, the promise is enormous: hybrids designed to make their own fertilizer through nitrogen fixing, to be adaptable to a wide range of climates and soils, to be disease and pest resistant. A hungry world looks on.

MAGNIFIED 1,500 TIMES, LEFT AND ABOVE



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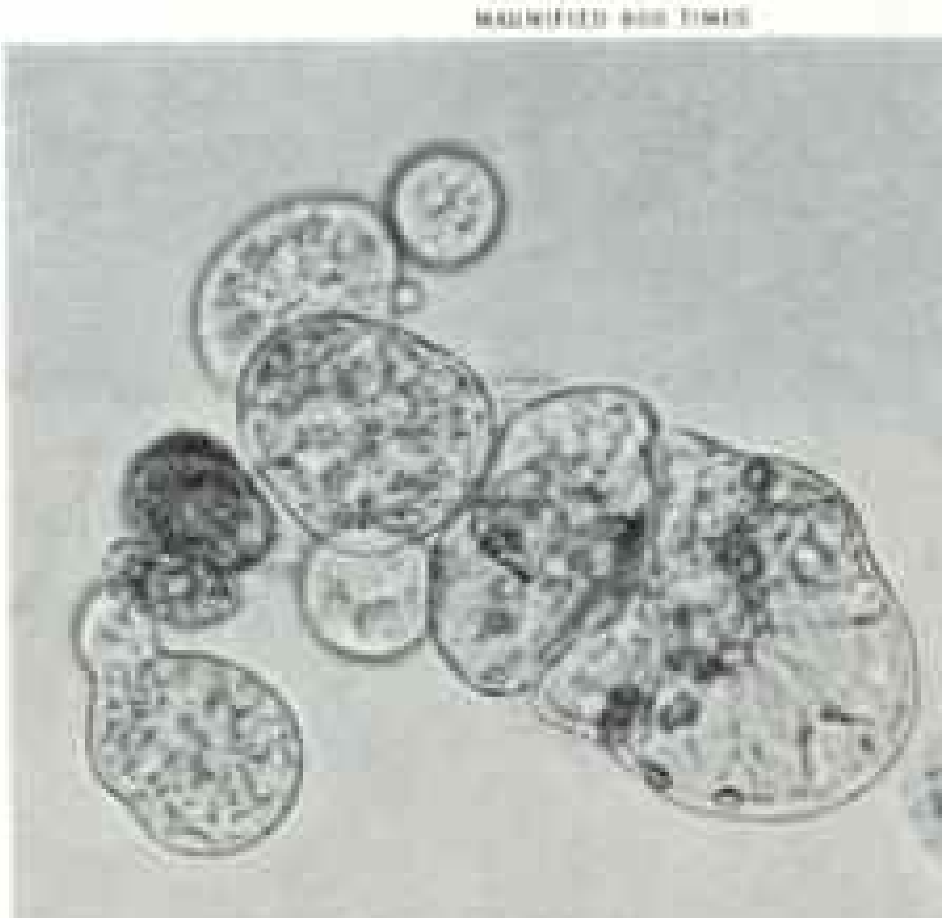


KUO NAN KAO, PRAIRIE REGIONAL LABORATORY, NATIONAL RESEARCH COUNCIL OF CANADA (BELOW) AND BRUCE DALE (BELOW, LEFT)

Life takes hold on an infant planet

Barren land. Air unfit to breathe. Time: about four billion years ago. Young earth is without life. The sun beats down; storms lash the coasts; volcanoes pour hissing lava into the shallows. These natural jolts fuse simple molecules into more complex ones, and for millions of years the number and complexity of molecules increase in the vast mixing tank of the sea.

Amino acids are synthesized, interact with each other, and primitive protein is fashioned, perhaps as a wormlike molecule. These proteins join with primitive nucleic acids, and thereafter protein building becomes self-sustaining.

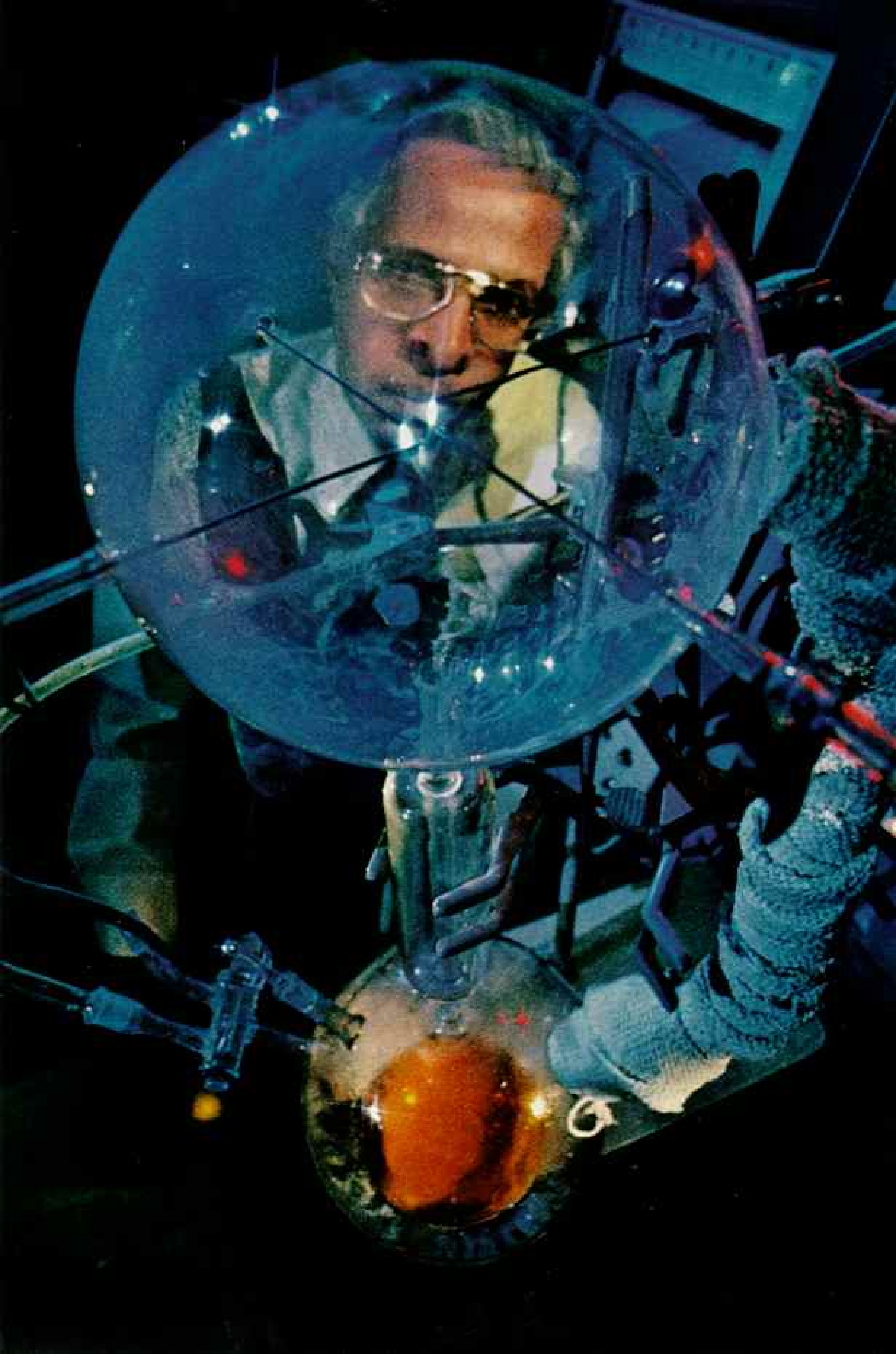
A DNA-like nucleic acid directs amino acids to build proteins that

PAINTING BY DAVIS MELTZER

in turn fuel DNA replication and more protein building. Life has begun, but it is tenuous. Not until the first cell appears, perhaps a pale sphere enclosing a strand of DNA, can life take a firm hold.

According to widely held theory, this is the most plausible explanation of the chemical evolution of life. From that first life, scientists conclude, development progressed to amoebalike organisms, to the trilobite common in fossil beds, and on to the population of the planet.

The first part of life building, the synthesis of organic compounds from ammonia, methane, and water, has been duplicated by scientists, including Dr. Cyril Ponnamperuma (**following page**), who has written: "It is with a feeling of awe and inadequacy that we approach the task of proposing in scientific terms the sequence of events in the universe which culminated in the appearance of life."



(Continued from page 390) going on in the universe on a large scale," said Caltech biologist Norman Horowitz matter-of-factly.

Faced with such evidence, many scientists conclude that on countless warm planets, not too far from the billions of suns like ours, life, much as we know it, must exist.

DESPITE THE RAPID PROGRESS of recent years, I finished my survey feeling that the new biology has, in fact, opened up more questions than it has answered. Many are profound social questions, and we must begin grappling with them now:

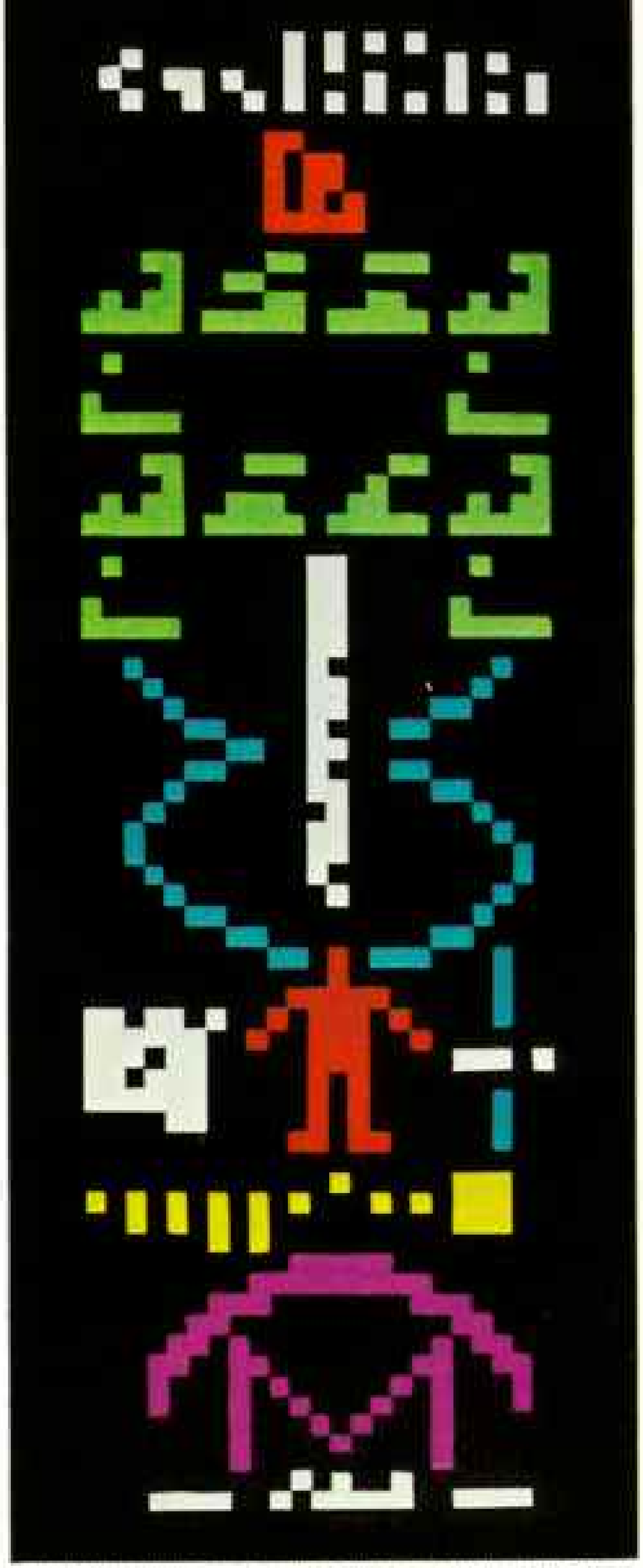
Do we have the right to develop novel forms of life for our own purpose? Should we try to control our own physical destiny? If so, who is to decide what man should become? Dare we try to manufacture genes to cure illness, knowing that such techniques can spawn the weapons of a horrible biological war?

Should we seek to manipulate the immune system to make all types of organ transplants commonplace—with the possibility that some lives might be extended indefinitely? How do we protect the diversity of our species from those who might want to "improve" it with clones of its ideal specimens?

Many ethical decisions will have to be made someday, particularly as the new biology advances our knowledge of the mind. Fortunately, the human brain still confounds science. Even if we knew all there is to know about how a cell works, we would still be baffled. How nerve cells create emotions, thoughts, behavior, memory, and other perceptions cannot yet, if indeed ever, be described in the language of molecular biology.

Despite these ever-present weighty questions, I returned from my biological journey with literally a new perspective on life. Every trip produces new acquaintances. But what an unforgettable crew I had met this time!

When I breathe now, I often think of all that my mitochondria are doing for me. When I eat, I know my ribosomes have been busily assembling enzymes to digest my dinner. When I catch cold, I root for my antibodies and hope that my lysosomes will dine well on the intruding germs. Most often, however, my thoughts return to that dollop of DNA I stirred at Caltech. After all, how often can anyone say he has looked so closely at the basic mystery of life? □



NATIONAL ASTRONOMY AND IONOSPHERE CENTER, CORNELL UNIVERSITY (ABOVE)

Who's out there?

Scattered through interstellar space and found in meteorites, organic molecules seem plentiful across the universe. Where else could life have evolved? Astronomers calculate about a billion billion livable planets with primitive atmospheres like those swirling in Dr. Ponnamperuma's flasks (**left**). In 1974 a powerful coded radio signal, converted here to a multicolored visual display (**above**), was sent into space from the giant antenna at Arecibo Observatory in Puerto Rico. The stick figure in red might amuse or confuse our cosmic cousins. But they should recognize the blue spirals. Because whoever else is out there is probably made of DNA.

THE NEW BIOLOGY: II

The Cancer Puzzle

NATIONAL GEOGRAPHIC PHOTOGRAPHER STEVE RAYMER

By ROBERT F. WEAVER, Ph.D.

Neither plant nor animal, the lowly slime mold (**left**) may offer scientists a clue to the Jekyll-and-Hyde transformation of a healthy cell to a runaway cancerous one. By learning how this simple one-celled organism changes function, researchers hope to uncover the mechanisms that alter human cells.

"... a savage cell which somehow ... corrupts the forces which normally protect the body, invades the well-ordered society of cells surrounding it, colonizes distant areas and, as a finale to its cannibalistic orgy of flesh consuming flesh, commits suicide by destroying its host."

PAT MCGRADY,
"THE SAVAGE CELL"

A WELL-KNOWN story of six blind men and an elephant tells how each man tried to understand the beast by touching only one part. Naturally, the one who felt the trunk got a far different impression from the one who grasped a tusk.

I sometimes think of the cancer puzzle this way, because scientists see it from so many different points of view. It is no surprise that the virologist sees cancer as a response to a tumor virus, the geneticist discerns an effect caused by a genetic mutation, and the developmental biologist points to an abnormal cell differentiation. Even though none of us perceive in so restricted a fashion as the blind men in the story, the puzzle remains in pieces, some of which are missing. We cannot yet see the whole elephant.

Why can we prevent polio with relatively simple vaccines, cure pneumonia with antibiotics, and yet make only modest inroads against cancer? One reason is that cancer is not one disease, but many. The human body contains more than a hundred different types of cells, and each of these can go awry in its own distinctive way. The cancer puzzle is a whole series of puzzles.

On the other hand, we recognize certain characteristics common to most cancer cells. The most obvious trait of these savage cells is that they run amok. They go out of control. Consider, for example, what happens when you cut a finger accidentally. Very quickly the cells around the incision receive a signal to divide more rapidly and heal the wound. Then, as soon as they accomplish the job, another signal tells them to slow down. Normal cells always obey this slow-down sign, preserving an exquisite balance between old cells dying and new cells appearing.

But renegade cancer cells no longer obey. They continue to divide without control until their voracious appetites overwhelm their host.

Cancer cells show a distressing ability to invade the tissues around them, disrupting them and robbing them of food. Worse, they metastasize, or spread. For instance, cancer cells may break off from a bone tumor, migrate through the bloodstream, and establish new tumors in the lungs. Once a tumor has metastasized, the cancer is much harder to treat. This points to the importance of frequent physical examinations and prompt attention to the seven warning signals publicized by the American Cancer Society.

These two characteristics of cancer cells—lack of control over growth and tendency to invade—imply a third quality: the ability of cancer cells to pass the malignant properties on to their progeny, cell division after cell division.

What triggers a perfectly normal cell to lose control and become a runaway? First of all, there are environmental agents—substances in the air we breathe, the water we drink, or the food we eat. The World Health Organization estimates that these agents may be associated with 60 to 90 percent of all human cancer.

Sir Percival Pott first drew a connection between chemicals and cancer more than two hundred years ago when he discovered the high incidence of scrotum cancer in chimney sweeps. The constant exposure of these unwashed boys to carcinogens (cancer producers) in soot inevitably took its toll.

These carcinogens are predominantly hydrocarbons, similar to those found in cigarette tar. Scientific data released by the Surgeon General of the United States support unequivocally the link between cigarette smoking and cancer; 90 percent of all lung-cancer patients are smokers.

Another environmental factor is radiation. The sun's ultraviolet light, for example, can cause genetic mutations in exposed skin cells, sometimes leading to cancer. In fact, extensive, long-term exposure to sunlight, especially among light-skinned people, makes skin cancer one of the most common types.

Emissions from radioactive materials can also make cells go wild, as illustrated by the tragic case of the watch-dial painters of the early 20th century. These women used a luminous paint containing the radioactive element radium. To keep a fine tip on their paintbrushes, they twirled them between their lips. The radium they absorbed in this way led to a high rate of bone disease, including cancer.

VIRUSES are a second cause of cancer, at least in some animals. These agents are tiny packages of genes without life of their own that are capable of infecting cells and converting them to virus-reproducing machines.

Peyton Rous of the Rockefeller Institute performed the classic tumor-virus experiment in 1911 when he showed that he could produce a malignant tumor called a sarcoma in a chicken by injecting it with a filtered extract of a tumor from another chicken. The filter removed all animal cells and bacteria, leaving only viruses as possible seeds of cancer.

Using similar techniques, virologists have linked tumor viruses with cancer in many species of birds and mammals, including primates. Because no one would ever intentionally perform these experiments on people, we do not have absolute proof that viruses cause any human cancer. But studies suggest such a relationship, and it would be odd indeed if viruses caused cancer in lower mammals but not in humans.

If viruses cause cancer, why doesn't cancer seem to be contagious? In some animals it can be. There are strains of mice in which almost all the females fall prey to mammary carcinoma, or breast cancer. These "high incidence" mice inherit a tendency to contract the disease. However, if they are suckled by substitute mothers of a "low incidence" strain, only about a third of them actually develop it. This suggests that the milk of the high-incidence mother contains some cancer-producing agent. In this case it turns out to be an RNA virus, one that has genes made of RNA instead of DNA, the usual genetic coding material.

But the normal way tumor viruses act may be much more insidious than simple contagion. A controversial theory holds that all of us have, in all our cells, genes for an RNA tumor virus. They may have entered our ancestors' cells eons ago and have been passed to us along with our genes for eye color, stature, and so forth.

Normally, these genes do no harm, but they sometimes switch on at the wrong time, with disastrous results.

As implausible as this theory may sound, there is some experimental evidence to support it. For example, we can grow chick-embryo cells in the laboratory where no tumor viruses get to them. But if the experimenter perturbs these cells with chemicals or radiation, they begin producing RNA tumor viruses. This seemingly

ALL BY PAUL A. ZAHL, NATIONAL GEOGRAPHIC STAFF

Dramatic shift of slime mold from amoebalike feeding to plantlike reproduction begins when sunlight triggers changes in cell behavior. Droplets appear (**left**), producing tiny stalks (**middle**) and then thick clusters of spores (**right**), which germinate new life. When researchers better understand this process, they may be closer to a cancer cure.

spontaneous generation of viruses means that the chick cells contained in their genes, all along, the blueprint for an RNA tumor virus.

This is not so surprising when we realize that tumor viruses operate by wedging new DNA into the very genes of their hosts. Once this new DNA is in place, it may behave just as normal host DNA and be passed on from one cell to the next forever after.

A THIRD possible factor in the cause of cancer is simply our bodies' inevitable imperfection. Nature has endowed us with nearly perfect machinery for running our cells' lives and especially for reproducing our genes. But a certain amount of imperfection remains, and this allows for that rare mistake that will improve our genes rather than harm them. Without such errors, indeed, evolution would be much slower and our ancestral life forms might yet be muddling about in their primeval ooze. The price we pay for accelerated evolution is a small, but significant, tendency to make mistakes. A mistake or series of mistakes in the genes that control cell division could free the cell from its normal restraints, with dire results.

A final factor does not bear directly on the cause of cancer, but is nevertheless an important element in the development of the disease. This is the body's invaluable immune system, which fights disease. Many investigators suspect that cancerous cells arise daily in all of us, but they are different enough from our normal cells that they alert the immune system, which kills them before they cause trouble. Rarely, this immune system fails to operate, or a new cancer succeeds in eluding it until the cancer is too big to destroy.

We suspect that the system begins to fail in aging animals, which might explain why cancer is primarily a disease of older people. But there is evidence that cancer cells can also camouflage themselves by hiding their surface antigens. These proteins ordinarily serve to alert the body's immune defenses, but if they are hidden, the tumor can grow with impunity.

We have examined several probable causes of cancer, but we have not really probed the critical cellular events that lead the cell to break its bonds and begin growing wildly. To understand these events is to be able to try to reverse them and thereby cure the disease. But this understanding is the most elusive of all.

Some scientists view the problem in strictly genetic terms: Cancer is caused by mutations, alterations in a cell's DNA, so that a key gene, or group of genes, no longer works properly. These mutations may be caused by known carcinogenic agents including chemicals, radiation, and perhaps tumor viruses.

Others take a broader approach: Cancer may also have a more subtle cause, one that does not involve changes in the genes themselves. To understand this, consider the normal development of a human fetus. At an early stage of the baby's life in its mother's womb, it consists of only a few cells, all identical in appearance. Then by a wonderful but still very mysterious process, some of these cells differentiate, or change, to liver cells, others to brain cells, and so forth until a complete baby takes form.

And yet, virtually all the cells in the baby's body, whether they are liver cells or brain cells, contain precisely the same genes on identical strands of DNA. This means that a liver cell somehow keeps its genes for brain proteins turned off and switches on its liver-specific genes.

In the same way, cancer may represent an abnormal type of differentiation in which certain "normal" genes cease to function, as "malignant" genes are turned on. Such a switch ought to be reversible, and experiments suggest that cancer can indeed be turned off.

One of the most dramatic of these experiments concerns a kidney tumor in the leopard frog. In the 1960's Dr. Robert G. McKinnell and his colleagues at Tulane University in New Orleans took nuclei containing complete sets of genes from such tumor cells and placed them in frog eggs whose own nuclei had been destroyed. It is wonderful enough that some of these "fertilized" eggs grew into tadpoles; it is marvelous that the tadpoles were completely free of cancer.

If an irremediable change had occurred in the tumor cells' DNA, this defect would without a doubt have been passed on to the eggs along with the donor nuclei, thus leading presumably to cancer in the recipients. But no sign of cancer appeared. In the environment of healthy egg cytoplasm, the donor nucleus acted normally, whereas in the old tumor cell it was a partner in malignancy.

WHAT FACTORS influence genes to behave normally in one context and abnormally in another? Perhaps this is almost the same as asking what causes ordinary cell differentiation. I feel certain that the answer to this question is a key piece in the cancer puzzle.

In my laboratory at the University of Kansas, we are attacking this question by studying differentiation in a primitive form of life known as a slime mold. In nature, this usually bright-yellow mass of protoplasm lives on the damp forest floor, feeding on rotting leaves and tree stumps. Such a simple organism, neither animal nor plant, which is not known to get cancer, may seem an unlikely subject for cancer research. But its simplicity (belied by its long Latin name, *Physarum polycephalum)* and its distinct stages of differentiation make it much easier to study than mouse or man.

We are focusing on one type of differentiation in the slime mold: sporulation, or the development of spores. When the yellow, growing slime mold runs out of food, it crawls up into the sunlight. Then it undergoes a profound change, sending up slender stalks with multiheaded black caps containing thousands upon thousands of dormant spores. The wind carries many of these spores to new regions where food abounds. There the spores germinate, and the life cycle begins anew.

During sporulation certain genes that are needed for spore formation seem to switch on while others necessary only for growth turn off. This gene switch-on, switch-off probably also occurs during the devastating transformation of a normal cell to a cancer cell. It is true that we are studying the turn-on of sporulation genes rather than cancer genes, but gene turn-on is such a fundamental life process that it is likely to work the same way in both cases.

Mike Wormington, a graduate student in my laboratory, has demonstrated that light triggers sporulation by activating one of the slime mold's yellow pigments. When he isolates and purifies this pigment from the slime mold, shines a bright light on it in the test tube, and then injects the activated pigment into a starved, unilluminated slime mold, the latter, to our great satisfaction, almost always sporulates.

Mike and three other students, Chong-Gun Cho, Dennis Byrne, and Bob Herman, are now tackling the more difficult problem of tracing the steps that must intervene between pigment activation and ultimate sporulation. These are the steps that we expect will be analogous to those in cancerous transformation.

Even if cancer were not a momentous problem, the quest for an understanding of cell differentiation would keep us coming back to the lab each morning, our hearts beating a little faster as we open the drawer to see whether our slime mold has sporulated overnight in response to its latest injection. But we also hope that a better understanding of cell differentiation in this lowly creature will contribute, in its small way, to a solution to the cancer puzzle. □


fig: A
D
fig: B C
fig: G
fig: E
fig: F

THE NEW BIOLOGY: III

Seven Giants Who Led the Way

Paintings by NED SEIDLER

Text by RICK GORE

BOTH NATIONAL GEOGRAPHIC STAFF

FOR HOW many milleniums has man marveled at the force that sprouts a seed and drives its green shoot toward the sun? Or pondered the puzzle of how like begets like? To ancient harvesters and herders these mysteries of life were the workings of unpredictable spirits. Early Greeks, however, made the study of life a science.

Aristotle, the first great biologist, deduced that life begins in advanced animals when an "innate heat" in the male seed energizes and gives form to a shapeless embryo in the female. But he was baffled by the origin of small creatures that lacked obvious seeds or eggs. Well beyond the Middle Ages, serious men maintained that toads arose from the mud, maggots from rotting meat, and snakes from a lady's tresses dropped into a rain barrel.

Not until the invention of the microscope and the discovery of the cell in the 17th century did biological reality begin to emerge. The medieval mind had ranked life in degrees of perfection, from angel to man to vermin. As it became clear that all creatures were built from cells, the logic of the old chains of being no longer held.

In the mid-1700's Swedish botanist Carolus Linnaeus gave a new order to the living world, pioneering the system we now use to classify all plants and animals into kingdoms, phyla, classes, orders, families, genera, and species. Man soon had to accept, not without resistance, that he himself was an animal. In 1858 German pathologist Rudolf Virchow theorized that all living cells arise from preexisting living cells. A year later Charles Darwin made the stunning proposal that modern species had actually evolved from simpler life forms.

Biologists then found that the juices within the cell, the very catalysts of life, are built from the same lifeless elements that compose air, earth, and ocean. Today laboratories are competing intensely to explain how these chemicals—DNA, RNA, and myriad proteins—work their wonders.

Progress in biology comes mostly through the thousands of unsung experimenters who slowly develop and test hypotheses. Yet biology has known giants whose contributions, either through a lifetime of effort or one brilliant insight, have broken ground for immense harvests of knowledge.

LEEUWENHOEK

"No more pleasant sight has met my eye than this of so many thousands of living creatures in one small drop of water," wrote Anton van Leeuwenhoek in 1676. With his discovery of protozoa and bacteria, Leeuwenhoek, an unschooled Dutchman, astonished the 17th-century intellect. Today we would scarcely recognize his lenses as microscopes. Some of them, smaller than peas, were set into large metal light shields, like the one on the table. Many had to be hand-held before the light. Until his death at 90, Leeuwenhoek drew and described the domains of nature, from the housefly to microbes from his own mouth, here drawn and designated A to G on a work sheet. To discover why spices such as pepper, shown dissolved in vials, and nutmeg, at right, pricked the palate, he examined their particles for tiny barbs.

DARWIN

When Charles Darwin sailed in H.M.S. *Beagle* in 1831, an epic voyage of science had begun. The marvelous variety of life he saw intrigued him, filling his mind and notebooks. Why, for instance, did the tiny Galapagos Islands harbor so many finches, each with a different beak suited to its special feeding habit, such as cracking hard seeds? How had leaf-shaped insects developed their camouflage? Why are some orchids shaped to fit their pollinators? Why do the embryos of different species look so similar at early stages? Why do fossils of prehistoric animals resemble living creatures like the armadillo? In South America he found the

remains of horses and giant sloths; why had they become extinct there?

In 1859 he finally published his answers. His mildly written, scholarly book, *The Origin of Species*, thundered through scientific, religious, and intellectual circles. "Can we doubt," Darwin wrote of his theory of evolution through natural selection, "that individuals having any advantage however slight over others would have the best chance of surviving and procreating their kind?" Or that "... any variation in the least degree injurious would be rigidly destroyed."

Here, said Darwin, was the principle nature uses to regulate the development of life on earth.

MENDEL

With a garden spade and basic mathematics, Gregor Mendel (**left**) found in the backyard of his Austrian monastery what had eluded science's most luminous minds: the laws of heredity.

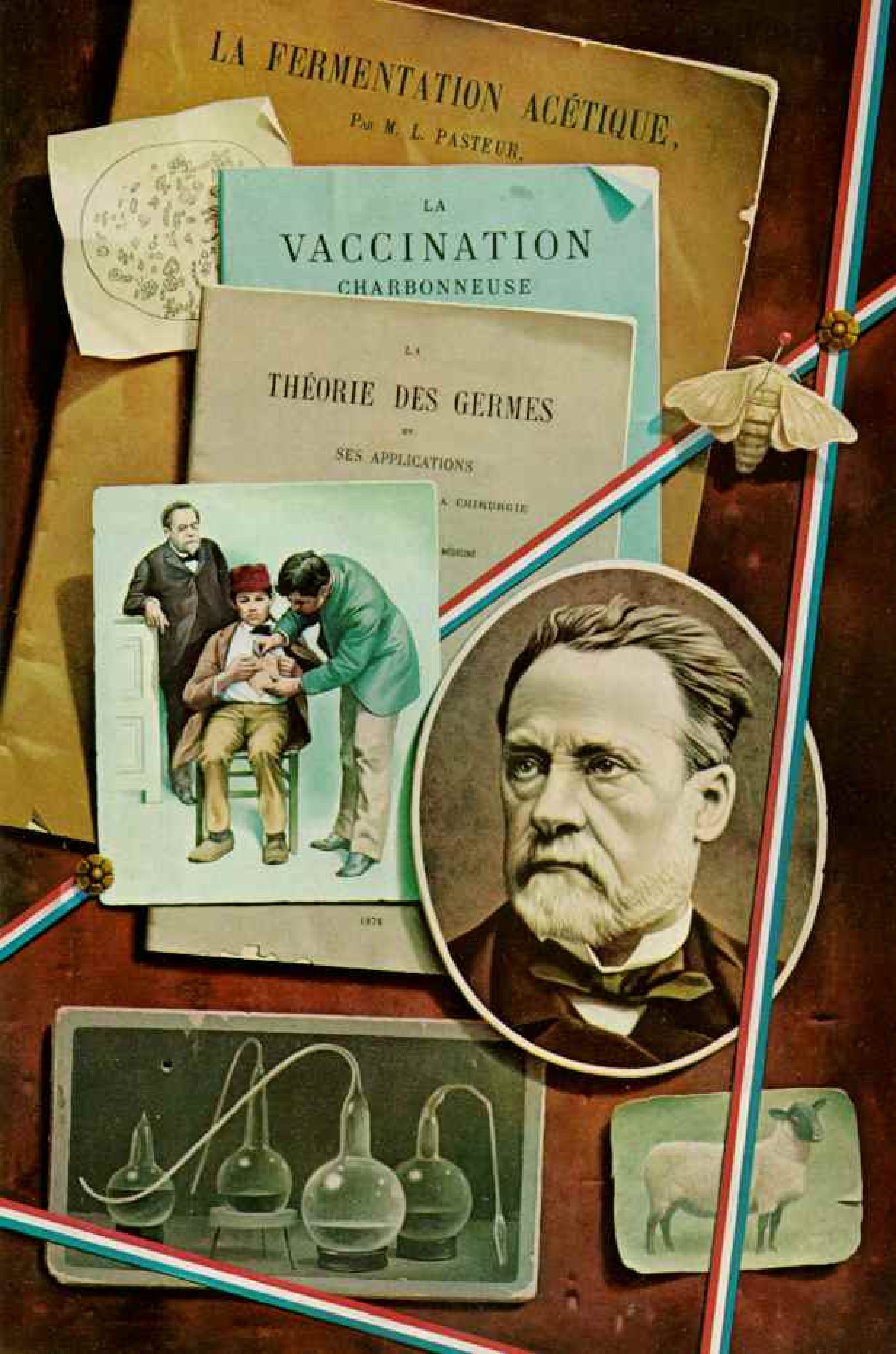
Mendel crossbred garden peas to determine how offspring resemble their parents. He found, for instance, that the hybrid seeds from crossing a green and a yellow pea produced an F_1 generation of plants bearing only yellow peas. However, the F_1 plants, when self-fertilized, produced an F_2 generation in which one out of every four plants produced green peas. When these green peas self-fertilized, they produced only greens. As for the remaining F_2's, one produced only yellow offspring, while the rest produced three yellows for every green. Yellow coloring was what Mendel termed dominant; green was recessive. The three-to-one ratio in which these traits reappeared in succeeding generations led Mendel to propose that inheritable characteristics are passed on, not randomly, but by discrete factors we now call genes. Unfortunately, Mendel was ignored. Not until 1900, 16 years after his death, did the scientific world discover the grand achievement of this modest monk.

PASTEUR

In the 1860's Louis Pasteur taught the French how to keep wine from souring. That alone would have made him a national hero. Pasteur (**right**) proved the yeasts that turn grape sugars into wine are living beings, and that fermentation is a product of their digestion. This showed that basic life processes are chemical reactions. Therefore, killing the yeasts by gentle heating, or pasteurization, prevented the wine from going bad.

Pasteur destroyed the popular belief that microorganisms and other low forms of life generate spontaneously from dust, rotting meat, or dung. Each microbe, he proved, comes from an existing microbe. Pasteur was the first to establish the basic cycle of life: that all living beings eventually become food for microorganisms, which in turn become fodder for new life.

Pasteur concluded that such microbes, or germs, are what cause disease, and he became an early crusader for the use of antiseptic techniques. He also developed vaccines against rabies and, working with sheep, against anthrax.

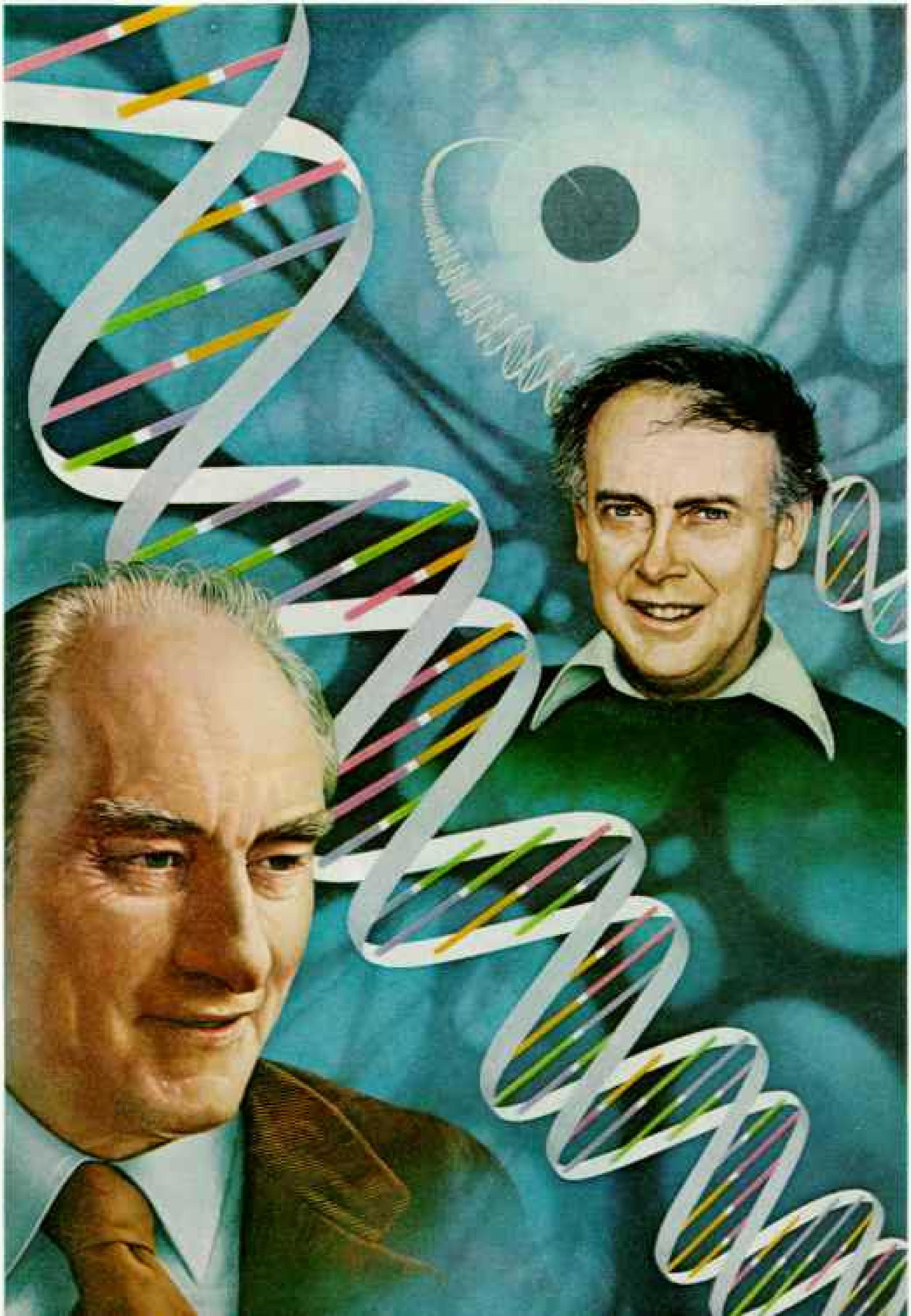

LA FERMENTATION ACÉTIQUE,
Par M. L. PASTEUR,
LA
VACCINATION
CHARBONNEUSE
LA
THÉORIE DES GERMES
SES APPLICATIONS

MORGAN

For nearly twenty years Thomas Hunt Morgan's "fly room" at Columbia University was alive with bottlefuls of the fruit fly *Drosophila*—and with some of the greatest minds in genetics. *Drosophila* multiplies rapidly and has only the four pairs of chromosomes symbolized in black above. Morgan found it ideal for studying how specific traits are transmitted through many generations. Charting the family trees of fruit flies with such mutations as stunted wings, asymmetric bodies, and mismatched eye coloring, Morgan elaborated on Mendel's proposals, working out the details of inheritance. Thanks largely to Morgan's 1926 book, *The Theory of the Gene*, genetics was accepted as a legitimate arm of biology.

WATSON AND CRICK

In college, American biologist James D. Watson studied birds, avoiding "taking any chemistry courses that looked of even medium difficulty." Nevertheless, in 1951 Watson (right), as a postdoctoral student in England, teamed up with British physicist Francis Crick. A year and a half later the two had solved one of biology's great riddles: the molecular structure of the chemical DNA. Their double-helix, or spiral, model first suggested the mechanisms a cell's DNA uses to store its genetic blueprints and pass them on to its offspring. This insight sparked a golden age of molecular biology, one that has brought us to the brink of manipulating our own genetic inheritance. □



California's Surprising Inland Delta

By JUDITH AND NEIL MORGAN

Photographs by CHARLES O'REAR

A GENTLE THRASHING SOUND came with dawn's velvet rosiness, and we awoke to find branches of a willow tree reaching through the open door of our rented houseboat. It was an unexpected welcome on our first morning in the California Delta, a jigsaw maze of rivers, sloughs, and diked islands.

As we slept, we had been lifted six feet among the limbs by a tide pushing sixty miles upriver from San Francisco Bay. Now we seemed alone in a gooseneck of the little Mokelumne River, its murky green waters overhung by trees and walled by peat-dirt levees thick with blackberries.

Suddenly shredding the silence, a yellow biplane zoomed up from behind the levee, turned, and disappeared. The faint scent of chemicals drifted back. Curious, we jumped ashore and clambered to the levee's crest.

Stretching away like a vast pie pan, twenty feet deep, was an island swept green with fields of sugar beets, asparagus, and corn. The

Two's a crowd in the Stockton Deep Water Channel, but these houseboaters in the heart of California ignore the passing freighter. Around them, waiting to be explored, lie some 700 more miles of sheltered, largely uncrowded waterways.

biplane skimmed below us, dusting fertilizer. Two brown plumes of peat dust rose in the air, marking the movement of distant tractors. At our feet, rusty pipes siphoned river water over the levee to the fields. Nothing else linked this scene of mechanized farming with the water labyrinth behind us.

Few but farmers and pleasure boaters know this delta, and they are curtained from each other by 1,100 miles of levees that rim 55 islands reclaimed from marshland. This is the water crossroads of California, where the state's longest rivers—the Sacramento and San Joaquin—meet to flow westward to San Francisco Bay and the Golden Gate. Like coastal deltas it is triangular, but this one lies inland, behind mountains. It extends no more than 70 miles on any side (map, right).

Green Heart of the Golden State

The California Delta is an isolated remnant of other times, woven in its own watery web near the center of the nation's most populous state. Only nine of its islands have towns, none larger than about 1,000 residents. No major highways cross it, and Californians in a hurry avoid its ponderous drawbridges and tiny cable ferries. Some farm islands, owned by affluent city dwellers or corporations, are inhabited only by foremen and laborers living in barracks. Others, like Bethel, are rimmed with marinas serving pleasure boaters from the cities. Some, like Venice, are owned by hunting clubs. Their cornfields lure ducks and geese migrating along the Pacific flyway.

The people of the delta recall the passage of years not by civic triumphs but by natural disasters. The levees give them a tenuous hold on the land. It can be lost when floodwaters from winter rains and melting Sierra snows surge through the delta on their way to the Pacific, or wind-whipped tides drive up from the sea. Even a tiny burrowing animal can cause a catastrophe by weakening a levee against the gnawing current.

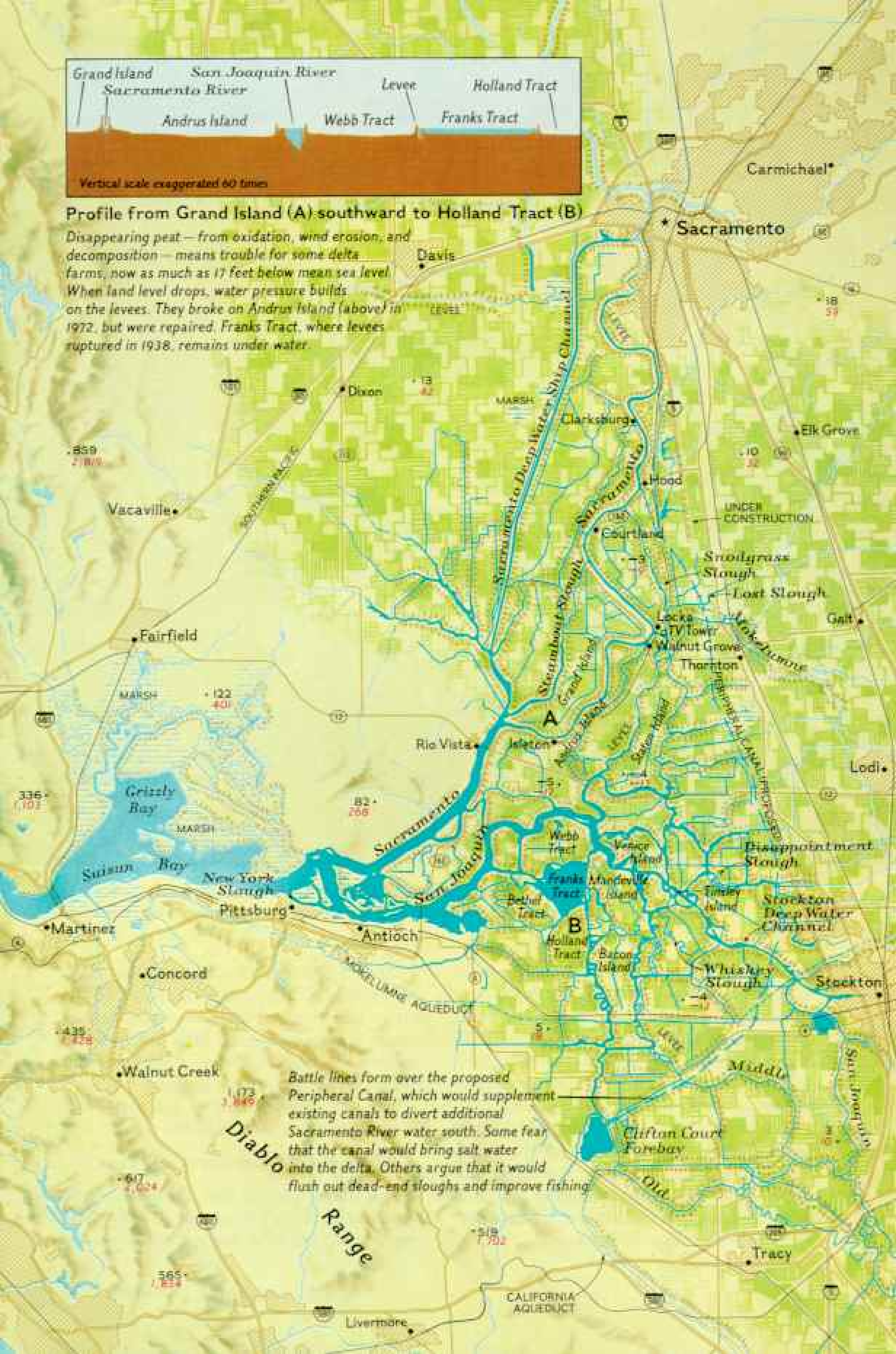
We stood atop a levee one day with Ed Wilson, a marina owner who serves as a trustee of the Andrus Island levee district. From beneath his battered cap brim, Ed looked warily out on the broad waters.

"Everything depends on these levees, and when they go it's chaos," he said. "We had a break here in 1972, in the middle of the night. That water was like a torrent, rushing into

The soil's so rich that "anything grows"

IN THE 1850's it was just a swamp to be bypassed by gold-rush prospectors. When the gold fever died, farmers-turned-forty-niners turned farmers again, diked swampland by shovel and wheelbarrow, and planted wheat. They reaped a phenomenal 50 bushels to the acre (today Kansas averages about 35), and the great California land rush was on.

Battalions of Chinese, paid as little as 13 cents for each cubic yard of dirt moved, built more levees. Later, steam-powered clamshell dredges did the work for five cents a yard. By 1930 more than 700,000 acres had been reclaimed. Delta soil—rich peat in the south, rich loam in the north washed down from mountain gold workings—ranks among the world's best. The problem is, some of it is vanishing.



Profile from Grand Island (A) southward to Holland Tract (B)

Disappearing peat—from oxidation, wind erosion, and decomposition—means trouble for some delta farms, now as much as 17 feet below mean sea level. When land level drops, water pressure builds on the levees. They broke on Andrus Island (above) in 1972, but were repaired. Franks Tract, where levees ruptured in 1938, remains under water.

Battle lines form over the proposed Peripheral Canal, which would supplement existing canals to divert additional Sacramento River water south. Some fear that the canal would bring salt water into the delta. Others argue that it would flush out dead-end sloughs and improve fishing.

Grow Italian tomatoes in the U. S.? "Can't be done," they told Brooklyn-born Tillie Lewis (**above**), who nevertheless did it. Starting with borrowed money and three bags of

the island, carrying boats with people sleeping in them down into cornfields. It knocked over houses, ruined farms. Finally tore a hole 400 feet wide and drove 3,000 people off the island. It's crazy, but no one was killed."

It took four weeks to close the gap and five months to pump the island dry enough so its people could start over. Some reestablished mobile homes close to the site of the break. Among them was Helen McBurney, a surgeon's widow who had moved to the delta from San Francisco. She and her cat Squeaker were there the night of the flood.

"At first I thought it was an earthquake," she recalled. "My mobile snapped off its fittings and smashed into trees. Other houses caught fire when electric lines snapped. By the time the rowboats rescued Squeaker and me, the water was up to my waist.

"I'm back because I love this place. But now I keep a dinghy tied to the porch."

Fields Below River Level Will Burn

Like those who till the lowlands of the Netherlands, delta farmers are strong-willed men and women who live with the threat of

seeds, she created an empire of *pomodoros*—the pear-shaped tomatoes prized for Italian sauces. Bound for cans or catsup, other tomatoes ride a conveyor in Thornton.

ruin. Their risks are heightened by the instability of the peat. It was formed over the millenniums by rotting reeds and the bulrushes known as tules. Because it has little mineral content, peat is powdery and compacts easily. Wheels sink and spin in dry peat and bog down in wet peat. Because the peat is organic, treacherous fires may smolder beneath its surface and entrap horses and men. Winds during spring planting whip up dust storms that sting the skin, damage machinery, and lower the islands one to three inches a year. Yet fertility is extraordinary.

"Peat is full of nitrogen," Percy Stambaugh told us at his home beside Steamboat Slough on Grand Island. "I was with the county's farm agency here for 32 years, and I'll tell you, this is the richest land in the world."

We visited Percy and his red-haired wife, Pauline, in their fine Victorian farmhouse, its window shades drawn against the heat of July. It was built 93 years ago on a site that Pauline's English grandfather had bought after he sailed around Cape Horn to follow the gold-rush throngs to California. Both she and her mother were born in this house.

"There weren't as many levees in the delta in mother's time," she said as we sat in their high-ceilinged kitchen, poring over family records from the attic. "When it rained in the spring and the rivers rose, this was an ocean. The house has been moved back three times so they could widen the levee."

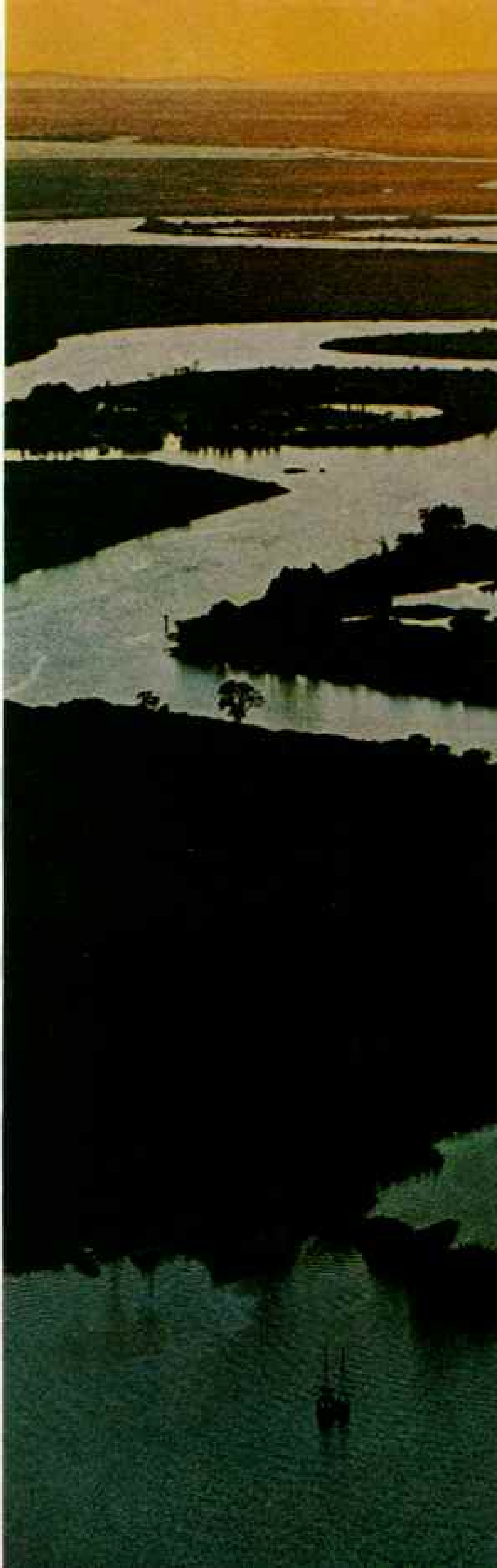
Paddle-wheelers Raced to the Goldfields

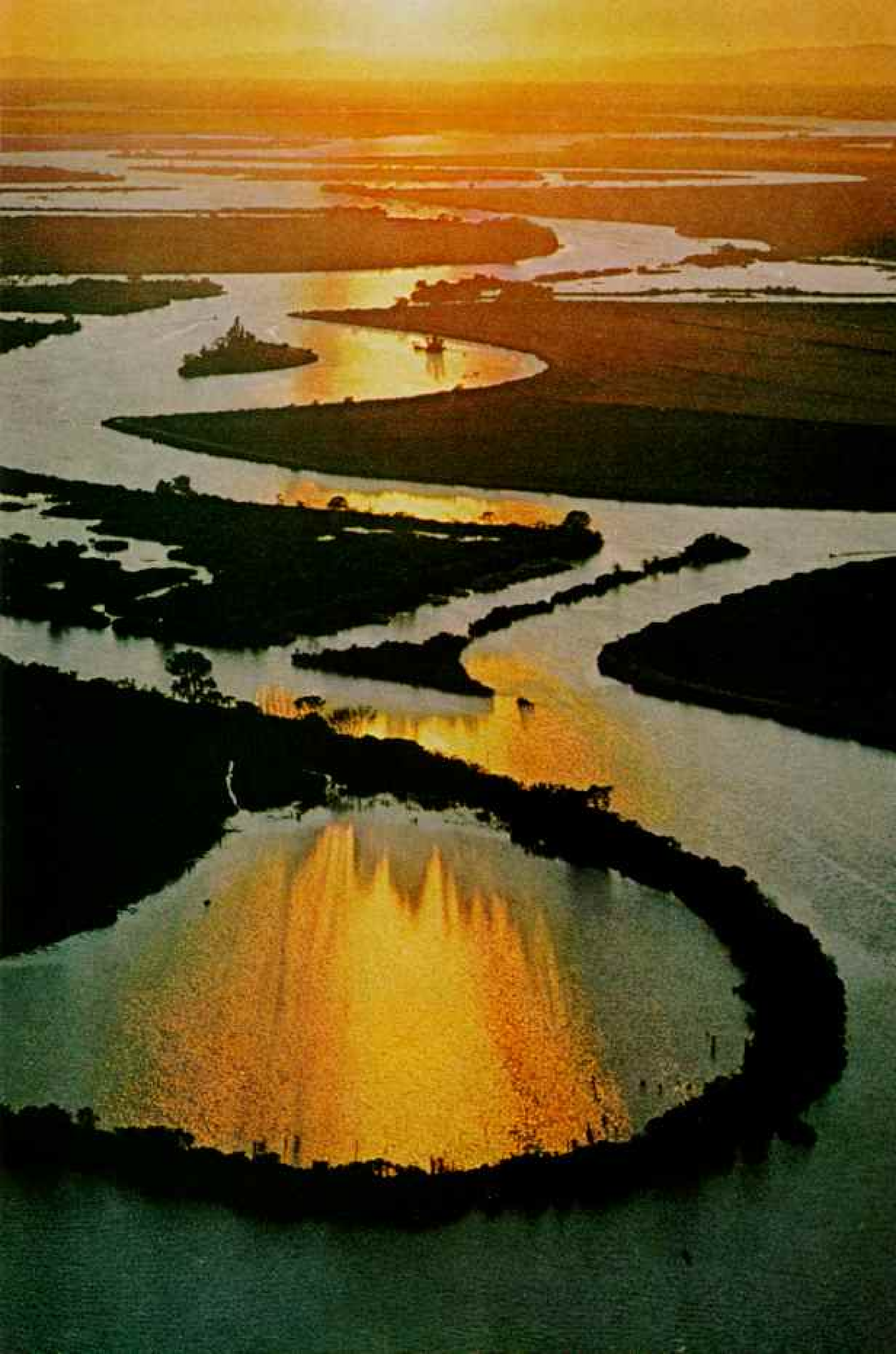
Only Indians and beaver trappers knew the region before the gold rush. Then Steamboat Slough became a shortcut for paddle-wheel steamers racing between San Francisco and Sacramento. Fragments of old wrecks still are found in these channels, sunk there by boiler explosions that killed passengers and ignited tule fires. When fortune failed to strike, wise miners turned to farming, and some planted orchards here on Grand Island.

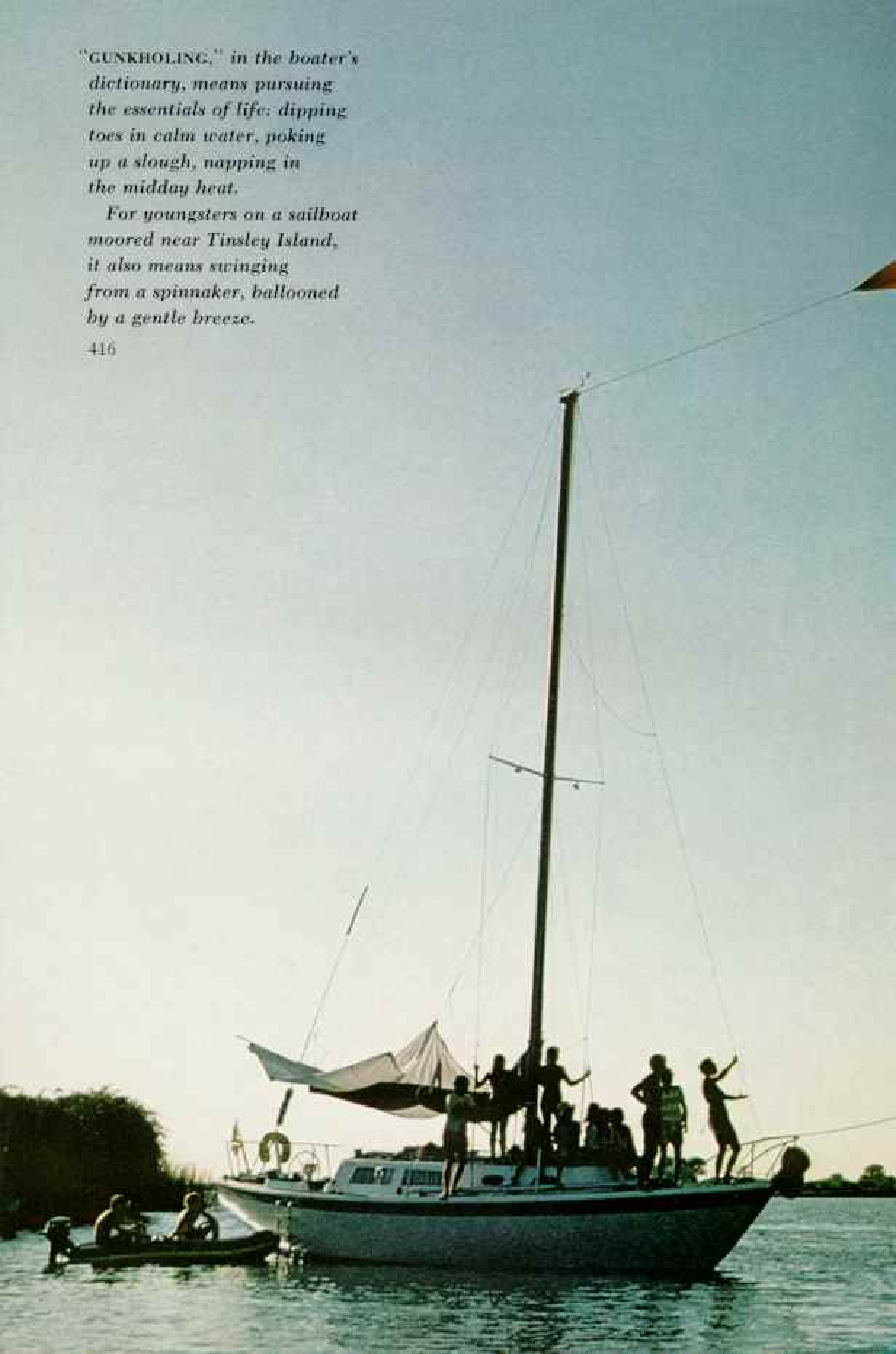
Percy led us out back, beneath giant silver maples, and into the deep shade of a 4,000-tree Bartlett-pear orchard. Then we walked in a cornfield where tall stalks hid the sky. "This corn," he said, "can get 14 feet high."

With the Stambaughs we drove serpentine routes through the delta, visiting old ranches lined with magnolias and cottonwoods, elms and oleanders, palms and pines. Passing wine-grape vineyards, Percy drove at a crawl, so as not to raise dust. We walked through fields of sugar beets *(Continued on page 418)*

"Shootin's good" on Staten Island, where duck hunters wait. Such delta names as Staten Island and New York Slough recall the crowded East. But residents like it as it is (**right**), a rhapsody of sun, land, and water.







"GUNKHOLING," *in the boater's dictionary, means pursuing the essentials of life: dipping toes in calm water, poking up a slough, napping in the midday heat.*

For youngsters on a sailboat moored near Tinsley Island, it also means swinging from a spinnaker, ballooned by a gentle breeze.

and ripe wheat, dazzling gold safflower and pale-green asparagus ferns.

Ten miles northeast of the Stambaugh farm he stopped to kick the dirt in a plowed field. It broke into heavy chunks.

"When you get clods like this, you're out of the delta," he said. "The peat is gone. You're in cattle country."

Two Ways to Pick Pears

We turned south to the village of Courtland and followed the sound of mariachi music and the aroma of barbecue to a shady school yard and the annual Pear Fair. Jim Dahlberg, a pest-control adviser, was presiding over a booth where delta farmers, whose pear orchards are among the most productive in the world, were bringing their prize fruit.

"The largest so far is 15 ounces," he said. "But we'll get bigger ones by evening. The record pear was picked in 1973. It weighed two pounds, four ounces."

Nearby, in Dennis Leary's orchard, pear pickers—many of Mexican and Filipino descent—got off labor contractors' buses and leaned ladders against the trees. They picked by hand, easing the fruit into shoulder bags.

"There are two ways to pick pears," said Gary Hori, a young Japanese-American who supervised the packing shed. "Either by the hour or the piece. If you pay by the piece, your pickers tear along and hurt the pears. We go by the hour to be kind to our fruit."

Across the Sacramento River we visited the huddle of plank sidewalks, leaning walls, and overhanging balconies called Locke (pages 422-23). It is only three blocks long, with fewer than 80 residents. But it holds bittersweet ties for many elderly Chinese.

Their ancestors came as laborers to the delta from the goldfields, and later from gangs that laid the early railroads. In the 1850's some of them built the first levees with shovel

Working nine hours a day, seven days a week, migrant field hands don't have much time to go to market. So the market comes to them: At a camp near Clarksburg, a vendor offers clothing and radios.

Migrants follow crops all across the western United States. Other workers, such as these watching an illegal cockfight near Isleton (**right**), stay in the delta year-round.

and wheelbarrow, then farmed the land they had helped to reclaim. Always they sought to live among themselves; Locke is the last of their frail wooden villages to escape fire. As we strolled a narrow street, three venerable Chinese stared silently past us as if to erase our presence or theirs.

Pauline Stambaugh tried a door but found it bolted. "I was postmistress right there for 23 years," she said, peering through a cracked and dusty window. "It was the Depression, and I needed a job. Locke was wide open then —fan-tan parlors, opium dens, girls. But you didn't have to see anything. I could speak a little Chinese, and the people trusted me. If they were sick, I'd call the ambulance or tell the doctor what was wrong. If strangers came, the Chinese wouldn't speak until I said it was OK. But then people started moving to the cities, and one day Locke just didn't need a post office anymore."

To build a better mansion than had one of his neighbors, banker Louis Myers spent more than $300,000. European craftsmen molded tile, sculpted walnut paneling, cut marble, and installed a bowling alley in the basement of River Mansion (**left**) on Steamboat Slough. Rain-chilled from a night when his levee broke, Myers got pneumonia and died in the still-unfinished house in 1922.

Fruit painted on a pony's hide (**above**) celebrates Courtland's annual Pear Fair. The crop brings millions of dollars to delta orchardists and ranchers each year.

At sundown we returned to our houseboat among the trees of Snodgrass Slough. Early the next morning we hiked back to Locke along a railroad track and watched the village awaken with the melancholy groans of an old ship cut adrift. Frayed ropes that once had been clotheslines banged in the wind between flaking walls; rippled boardwalks creaked underfoot in reply. Finally a key turned in the door of the Yuen Chong Market, and we went in to visit Connie King, who bridges the ethnic gap in Locke and often acts as interpreter.

"We have mostly old bachelors left in Locke," she said. "Our town is slowly dying. Our children are gone. We have maybe six teenagers, but they'll go after they finish high school in Courtland. There is nothing for them here."

Will the Last Chinese Town Disappear?

Ping Lee, a leader among the Chinese who remain in these river towns, is a merchant in nearby Walnut Grove.

"Locke may be the only town left in America that was built entirely by Chinese," he said. "It should be preserved. The Locke family heirs own the townsite and want to sell, but our people can't afford to buy. We're looking for a way to save Locke."

Walnut Grove is much more substantial. It was founded early in the gold-rush years as a port for river steamers. It has small Chinese and Japanese neighborhoods on the east bank of the Sacramento. On the west, across a drawbridge, lacy Victorian houses flirt with the solid brick homes of merchants and farmers. The volunteer fire department maintains two trucks on the east bank and three on the west, in case the bridge is up.

From Walnut Grove, Warden Bill Slawson patrols the delta in his outboard skiff, checking fishermen's licenses and pursuing hunters tempted to excess by the abundance of waterfowl. Over his basement bar he has posted the code once used by the late Judge Milo Dye to classify offending fishermen. In his records a fisherman was marked R for Regular, L for Lied, H for Hid the Fish, H & L for Hid the Fish and Lied, and S for Stinker.

"Sometimes the guys I stop ask me how I can cover such a big territory," Slawson said, his eyes bright with fun. "I tell them, 'See that television tower? I'm up there watching you with binoculars all the time.' "

Tallest Tower in California Hums

One clear morning Orris Grefsheim, a young engineer, escorted us up that 1,548-foot tower in a small drafty elevator. It is the tallest structure in California, and the ascent takes twenty minutes. From the top, through orange steel webbing, we watched cars and boats move below. There was no sound but the faint hum from miles of guy wires holding us steady in the air.

We moved cautiously out on a catwalk and studied the madcap maze of waterways. Power boats trailed their white plumes, and the bright canvas patches of sailboats danced in the sun. Water-skiers traced graceful arcs. Lost Slough, choked with water lilies, was a dazzle of color. Along the banks of the Meadows, a favorite houseboating area near Locke, we spotted our own boat at anchor, half hidden by trees. Twelve miles to the south in the Stockton ship channel, an ocean freighter sliced cautiously through the cornfields.

Where road traffic is sparse, ferries shuttle between islands. Most are cable guided and operate only in daylight, like the four-car ferry to Venice Island. Beside that ferry landing one morning we joined Lou Sparrenberger, a weather-beaten figure who delivers mail by speedboat six days each week to 22 islands along a 70-mile route through the delta.

"Light mail today," he said happily, wedging a Stockton Post Office letter bin near the wheel of his outboard. "You should see it at Christmas. I carry hams and turkeys and packages, and barely have room to move."

At Mandeville Island's Labor Camp 27, where the smell of fertilizer hung in the air from fields behind the levees, a dark, pretty

Its clapboard houses now bent with age, Locke in the twenties roared as field workers streamed into its saloons and casinos. Just a few score, mostly Chinese, live here now. In Isleton, young girl in a red sweater darted, waving, to meet us. Lou, clinging to the dock with one hand, pulled the rope on a mailbox and took out three letters addressed to Mexico. In their place he left a Sears catalog, *TV Guide*, and a letter from Jalisco marked SPECIAL DELIVERY.

"It must get lonely here for these workers," Lou said. "But I tell them not to let their families spend extra. My deliveries are as special as you can get."

Soon the banks splayed away, leaving us in a choppy inland sea. "This is Franks Tract," Lou shouted, gripping the wheel. "The largest open water in the delta, and the roughest. The wind can beat you to death. This was all a farm island before the levee broke in 1938. Cost too much to pump it out, so they left it. Great place to catch striped bass—unless you get your line tangled in an old harvester."

It seemed wrong to be there, like walking on a grave, and we were glad to pull into a snug channel and tie up by a clump of cottonwoods at Happy Isle. Lou jumped out to greet Vera and Carl Maertins, two jovial refugees from city life who leased this five-acre island in 1963. "We've been picking blackberries," Vera said. "Come have some."

We sat beneath alder trees on a tidy lawn beside a rotted rowboat in which tomato and squash plants blossomed.

"There's no telephone, no road, no ferry," Vera said. "We keep our car on the levee road across the slough and go over by outboard when we need to go to market."

It can be lonely in winter. "I get kind of island bound when the tule fog settles in and you can't see across the river," Vera admitted. "But it never lasts long."

"Beefaloes" May Bring Cheaper Meat

As we skimmed away down Middle River, a train whistle sounded overhead, and the engineer waved as he clanked over a trestle.

"That's the Amtrak from Oakland," Lou said, checking his watch. "He's late today too. Usually we pass before noon."

Islands deep in fragile peat will not support the weight of cattle, but on nearby Holland

Patrick Chinn stands with his grandfather in the family general store (**left**). Patrick's great-grandfather came from China to work on the Northern Pacific Railroad. Mrs. Yasu Kawamura (**right**), who came to Walnut Grove in 1913, learned to speak only a little English. But she's never forgotten ikebana—flower arranging—a skill learned in her native Japan.

Wheat for India, walnuts and canned asparagus for Europe, cattle feed for Japan—delta harvests go nearly around the world from inland ports at Stockton and Sacramento. Like a swarm of yellow-backed beetles, trucks wait to unload their wheat on a pier at the Port of Stockton (**right**).

The Liberian freighter *Basil III* (**above**) maintains a seven-knot pace in the narrow Sacramento ship channel. If the skipper went much faster, his wake might damage the man-made banks.

The freighter is hidden to its gunwales by the levee, boundary between water and earth in the delta and guarantor of privacy. Pleasure boaters can't see the farmers. Farmers can't see the boaters. "But we hear the water-skiers," says a farmer's wife. "Them and their darn noise!"


CASE

Tract, where the soil is sandier, we saw hundreds of animals called "Beefaloes." A crossbreed of cattle with buffaloes, Beefaloes—which are three-eighths buffalo—are long and graceful, with small heads and high haunches.

"They calve easily, thrive in hot or cold weather, and fatten on roughage," said Ray Arnett of the World Beefalo Association. "They'll eat almost anything, and reach market weight in half the time a beef steer takes. The meat tastes good, and it's high in protein. We think Beefaloes can lower meat prices when enough of them become available for slaughter."

Innovation is a tradition in the delta. In a riverfront house at Rio Vista we talked to Albert (Fum) Jongeneel, a genial giant of Dutch parentage who was born in these nether lands and has been a leader in agricultural change.

"Once," he said, "I supervised farming as many as 20,000 acres in the delta. Used to have 300 workhorses; now you can't find one. Delta farming started with Chinese field hands, then Japanese, Italians, Portuguese, and Hindus. After a while they make a stake and go on their own. In the 1930's the Filipinos came and finally the Mexicans. Mostly now it's machines. But they cost so much I don't see how a young person can get started farming today. Down the street they make tomato harvesters that cost $110,000 each."

Huge Picking Machines Take Over

The search for machines has obsessed Fum. He developed a mechanical beet harvester, then challenged experts at the Davis campus of the University of California to invent a tomato harvester. They succeeded in developing a hybrid tomato sturdy enough to survive such a machine, one that ripens uniformly so that the whole vine can be harvested at once. The harvesting machine that followed has eliminated the use of most field laborers in the California tomato harvest, which provides 85 percent of the nation's processed tomatoes, many of them grown in the delta.

In late summer and early fall, big trucks heaped high with tomatoes inch along delta roadsides like scarlet necklaces, waiting their turn to unload in processions that reach half a mile in length and continue day and night for 13 weeks. The tomatoes are processed at factories that ring the delta. Nearly all the tomato paste and half the catsup consumed in the United States come from these canneries.

In the clattering, hissing hubbub of a cannery at Thornton we watched torrents of red spurting into 55-gallon drums.

"About 60 percent of our tomatoes go into juice," shouted George Cox, the manager.

Tons of Tomatoes for Spaghetti Sauce

The name Tillie Lewis has meant much to tomato people for years. We found her at her English-style manor in Stockton (page 412).

"The harvest is just beginning," she said. "I would guess it will be a 6,500,000-ton crop. That's 650,000 tons for us. We're 10 percent of the California tomato industry."

Tillie was a Brooklyn girl who, as a teenager, helped out in a wholesale import market and wondered why American tomato paste was less piquant than Italian. The secret, she decided, was the pear-shaped Italian tomato called *pomodoro*.

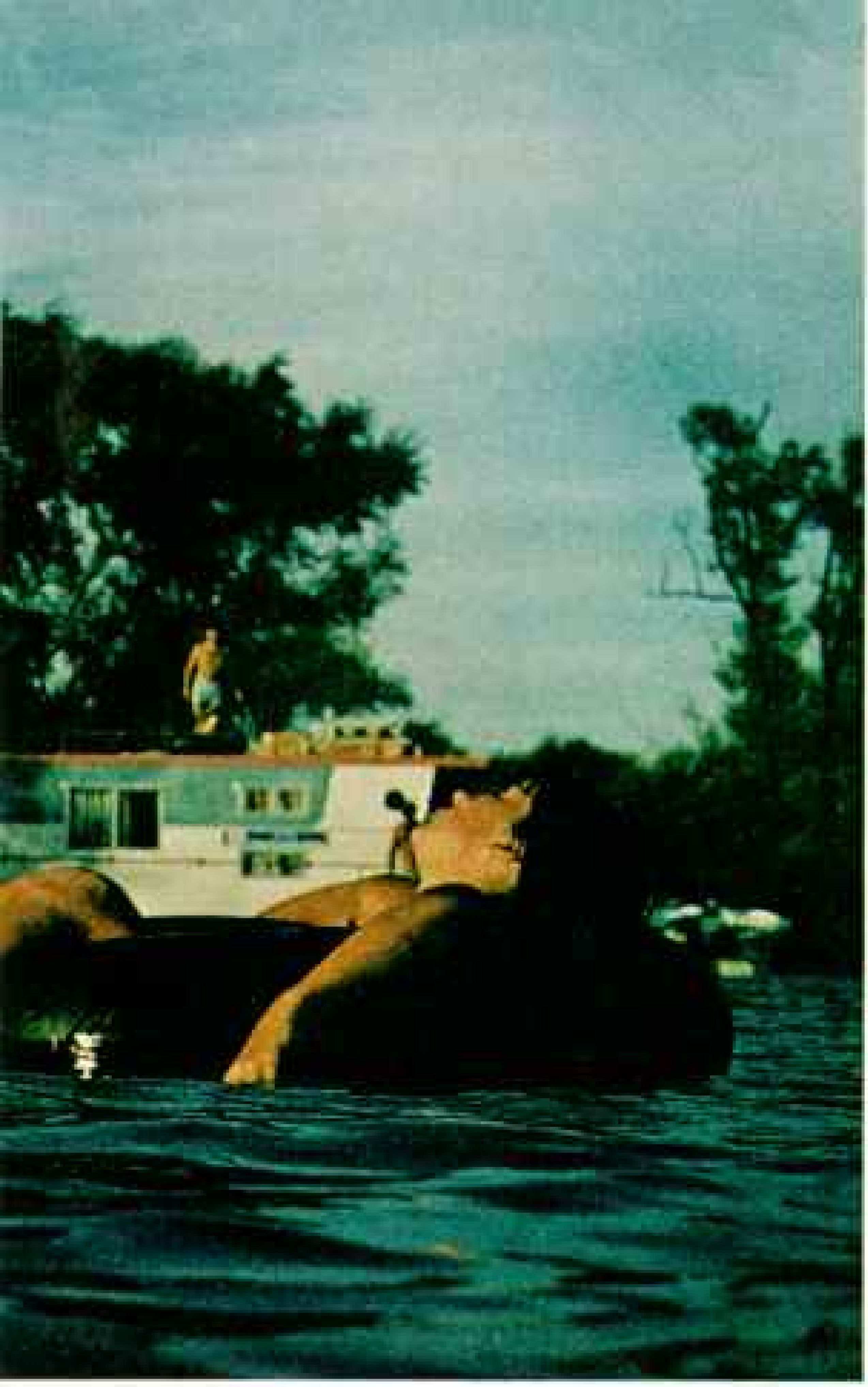
"It won't grow in this country," she remembers being told. But in 1935, after traveling in search of soil and climate like those of Naples and Palermo, she borrowed $10,000 and leased 20 acres of delta farmland to plant pomodoros. In 1966 she sold her firm to New York's Ogden Corp. for $14,500,000 and joined Ogden's board.

"I used to climb up on a box to watch the tomatoes roll past," she said. "It's a beautiful sight. At my plant one day in 1936, at the height of the harvest, a man ran up to me—you could always see me because of my long red hair—and said: 'The boilers are down! It'll take 36 hours to fix them. What will we do?' In that time, enough tomatoes would have spoiled to take the year's profits.

"I had to get steam, so I thought and thought, and finally raced for the Santa Fe station. They rented me two locomotives for 15 dollars. We shunted them to the plant,

Label the lighter fields corn, wheat, and safflower, the darker ones asparagus, berries, tomatoes, and pears. But color them all bountiful. Some corn farmers in the Clarksburg area of the delta harvest around 200 bushels to the acre—about twice as much as the average yield in Iowa, heart of the U. S. corn belt.

Wary of the suction created by a ship in the Stockton channel (**below**), boaters hang on to their craft. Bow waves from a freighter once heaved 600-pound cement blocks off an island and washed a sleeping camper into a slough. Stern waves carried the man back ashore, still in his sleeping bag. Mad, wet, cold, and minus most of his clothes, he called the sheriff, who called the Coast Guard, who suspended the speeding pilot for 30 days.



Disappointment Slough is anything but that for gunkholing youngsters (**above**). After a day of diving and lounging, or even shampooing (**below**), most folks find time becoming as placid as the delta's waters.

strung up a pipe, and saved the crop. In this business you can never give up."

It has always taken boldness to succeed in the delta. The clamshell dredge improved on the Chinese shovel and wheelbarrow for building levees. Pumps were brought in to maintain delta farms that lay below sea level. Seeking ways to keep the hooves of their horses and mules from sinking in the peat, farmers devised awkward 12-inch-wide horseshoes to distribute the animals' weight.

Delta Tractors Gave Birth to Army Tanks

When we visited Michael N. Canlis, sheriff of San Joaquin County, we learned more about strange delta machines. His office is a bunker of memorabilia second only to Stockton's Pioneer Museum, of which he is president.

"A lot of this stuff will go to the museum as soon as there's room," he said, moving an old fire bell from a chair. "See this newspaper? I've been reading about Benjamin Holt. He was a combine builder here at the turn of the century. Farmers came to him because their equipment was sinking in the peat.

"He tried all kinds of outlandish solutions, including a wide-wheeled steam tractor that stretched 46 feet across. Then he invented a tractor that laid its own track. That was in 1904. He called them "Caterpillars" because of the way they crawled.

"In 1915 Winston Churchill became convinced that a land destroyer based on the Holt Caterpillar-tractor principle could be used against German trench lines. A model was built in England in secrecy. To cover the mission, word went out it was to be a water tank for use in Egypt. The name 'tank' stuck."

Other delta innovators, too, have sent their products afar. One August day Dick Stephens led us through a labyrinth of riverfront sheds at Stockton where his father, Theodore, began a custom-yacht business, Stephens Marine, in 1902. In a loft where the temperature stood at 100° F., Peter Goulandris was kneeling over the plans of a 92-foot fishing yacht for his father, Nicholaos, one of the Greek shipping titans. In another shed an 85-foot cruiser for two Venezuelan families was about to slide down the ways.

We wondered at finding Stephens—a name known among yachtsmen worldwide—in a farm town like Stockton. "Our family farmed too," Dick said. "There weren't many bridges in the delta, and my father saw the need for boats. Produce buyers were the first customers. By the 1920's we were building yachts."

Next to a stately 1920's Stephens yacht of teak and brass at the family-owned marina on the Stockton channel, we boarded a sleek fiberglass patrol boat with Sgt. Wilbert Vieira, a Portuguese-American who heads Sheriff Canlis's four-boat delta patrol. We rode along as Sergeant Vieira nosed up beside boats to ask to see their registrations and to give urgent lectures on boating safety.

It was a Saturday afternoon, and sailboats tacked through phalanxes of speedboats, cruisers, and barges. Pleasure-boat operators are unlicensed, and there are problems. "It's like taking a busy freeway and saying you can go dance on it, skate on it, anything you want," Sheriff Canlis had said.

Winter storms add danger. "Old logs off levee walls go barreling down the sloughs," he said. "Oil drums tear loose from docks and come at you like bowling balls."

We veered off to Disappointment Slough, walled by thick tule islands, and on to Whiskey Slough, where a few shanty barges marked the hideaways of river recluses.

"Most of the old-timers are gone," Vieira said. "A lot of them once lived on homemade boats or in tin shacks up these sloughs. Then the delta was discovered by the pleasure boaters, and the solitude disappeared."

Too Much Pumping Threatens the Delta

More worrisome than lost solitude, however, is the growing threat to the delta's supply of good water. Fresh water is the delta's life. Its farms, its boating, its fishing, its commerce—all depend on it. But already millions of gallons of water are being pumped each year from the delta to arid central and southern California. Now many farmers fear the Peripheral Canal, a proposed 43-mile diversion that would take Sacramento River water southward around the east side of the delta for export to the south (map, pages 410-11). The canal carries both threat and promise for farming and fishing.

Water engineers and attorneys have lined up on both sides. At the center of the storm is Governor Edmund G. Brown, Jr., who in 1975 delayed construction of the canal. He placed its potential cost at $600,000,000 and asked for further study.

Already harassed by levee breaks, flooding, and their disappearing peat lands, delta people are understandably edgy at any new menace. In 1975 a state study described hundreds of miles of substandard levees—some more than a century old—and raised the prospect of mass flooding. Yet the cost of reinforcing all delta levees is estimated at $128,000,000. Political support for such funding is in doubt.

Eugene Begg, a University of California soils expert, has studied the delta for more than 15 years. He showed us Bacon Island, whose surface has dropped 15 to 20 feet since it was first cultivated in 1915. Oxidation of peat and blowaway are the causes. Tilling the soil aggravates both.

"Peat is a nonrenewable resource. When it's gone, it's gone," he said. "The lower these islands get in relation to the water, the greater the differential pressure on the levees. There's a far greater chance for levee breaks than many farmers have faced up to. Someday they may have to stop farming."

Residents Defy Flood and Fire

But academic logic figures without the grit of men like Butch Franscioni, the mayor of Isleton, who has lived and farmed on Andrus Island since 1924. He became a symbol of delta doggedness during the 1972 flood that ruined his farm, his home, and his village. As waters from the levee break crossed the island to lap at the edge of Isleton, he refused to issue an evacuation order.

A temporary dike was thrown up. When it collapsed at 9:30 on the second night, floodwaters knocked out Isleton's water and sewage plants and left Franscioni no choice. As wrecked boats slammed through ruined pear orchards, he led his people off the island.

"It was 70 years since the last big flood on Andrus Island," he said as he prepared to preside over a recent weekly council meeting in the little Isleton city hall. "Maybe it'll be 70 years until the next one."

A taut, stooped man of 75, he then sat down with his council to plan the future. The only interruption came when the fire alarm sounded and Cecil Tomlin left to dispatch the town fire truck. In a few minutes he dashed back.

"What was it?" Butch asked.

"Peat fire."

"In the delta," Butch sighed, "even the earth burns." □

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One last look?

THROUGHOUT INDIA a panorama of animal life is threatened by human competition for food and habitat. Even in sanctuaries the painted stork (**above**) must share its nesting ground with cattle, and the endangered great Indian rhinoceros (**upper right**) falls prey to poachers. To report on India's struggle to save her wildlife, we marshaled a team of journalists, including Australian photographer Stanley Breeden (**right**) and senior staff writer John J. Putman. Their account leads this issue (page 299). Such timely reports are an important part of NATIONAL GEOGRAPHIC. Nominate a friend for membership now.

STANLEY BREEDEN (TOP LEFT AND RIGHT) AND KAY WILLIAMS

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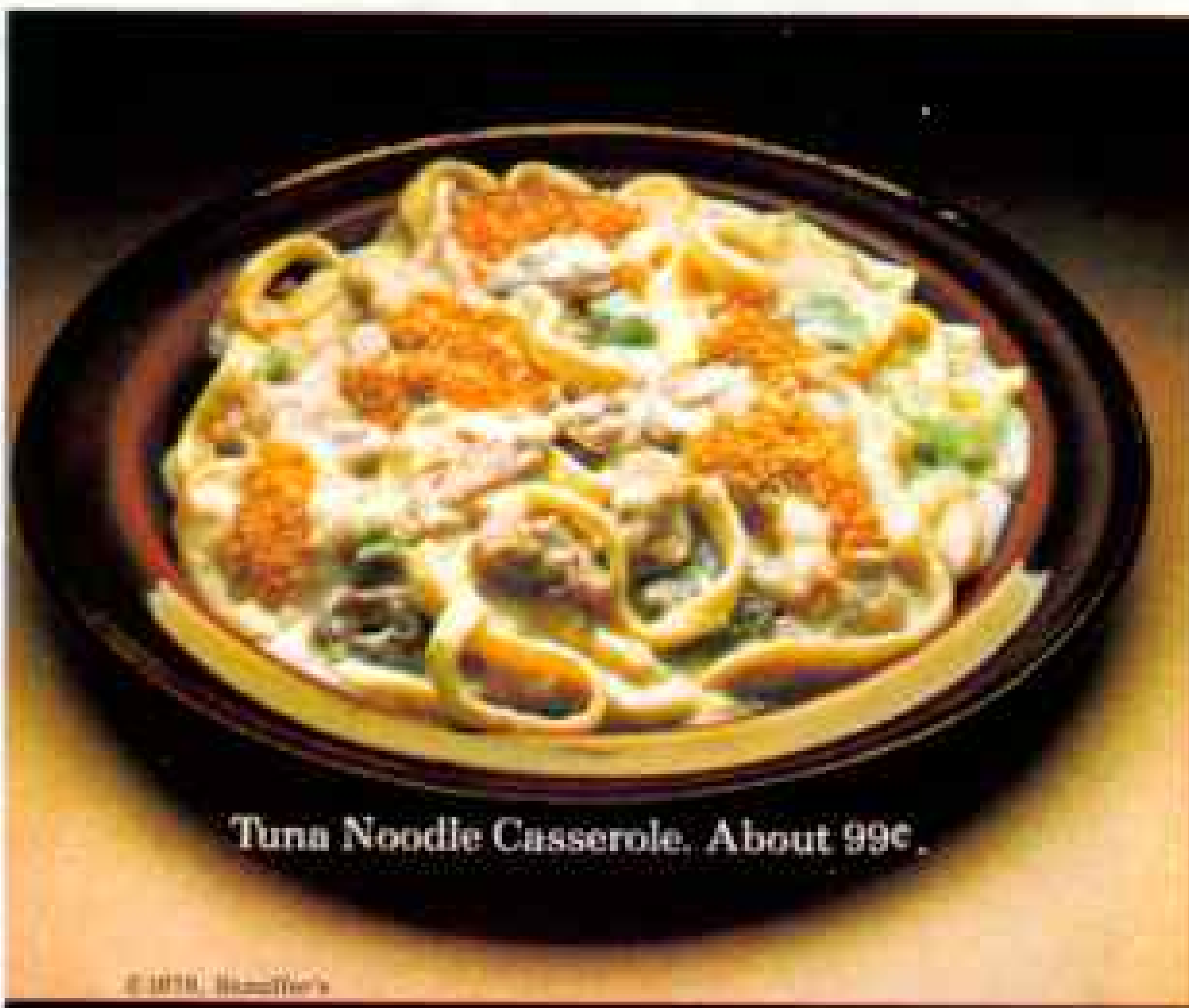

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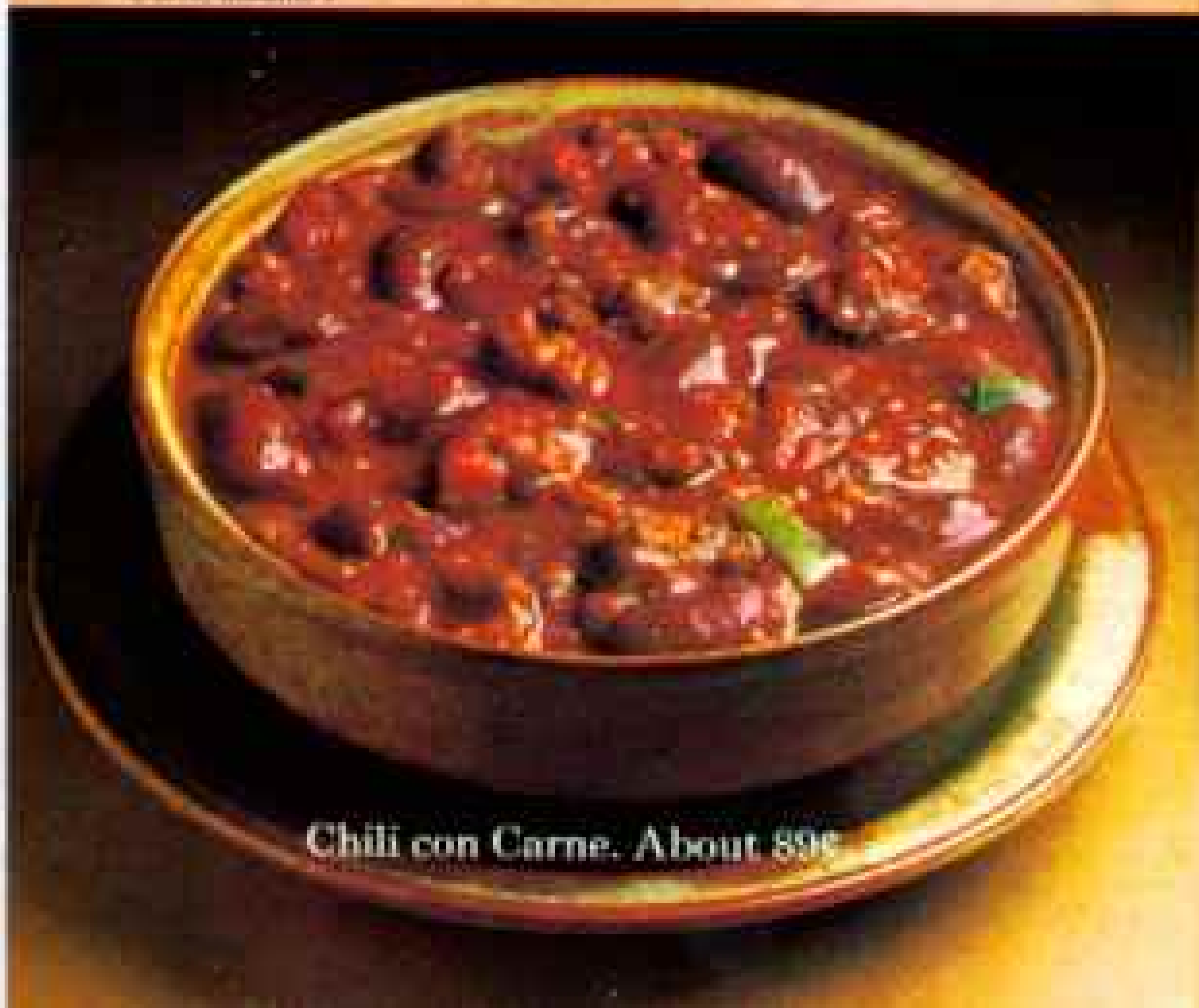

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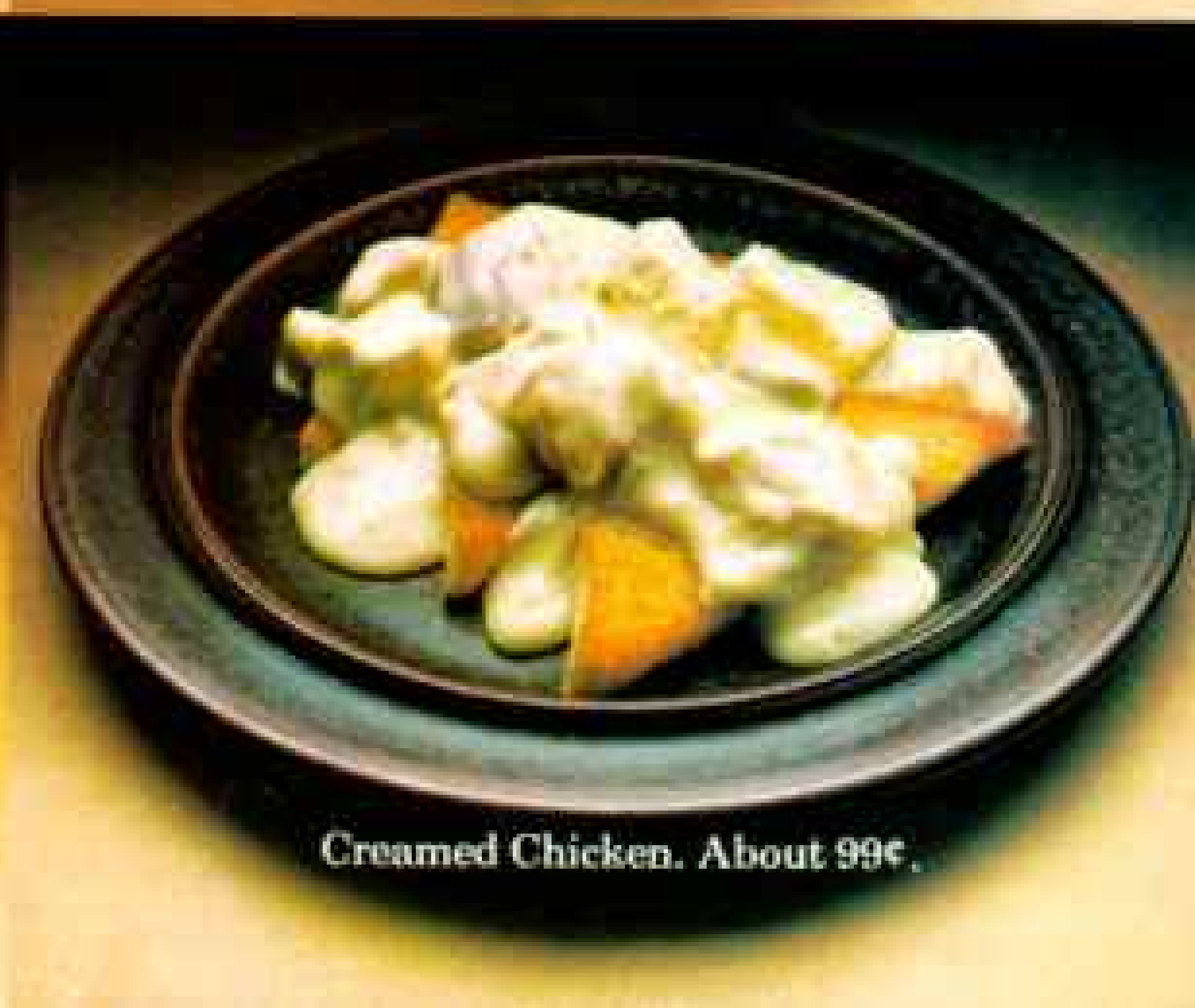

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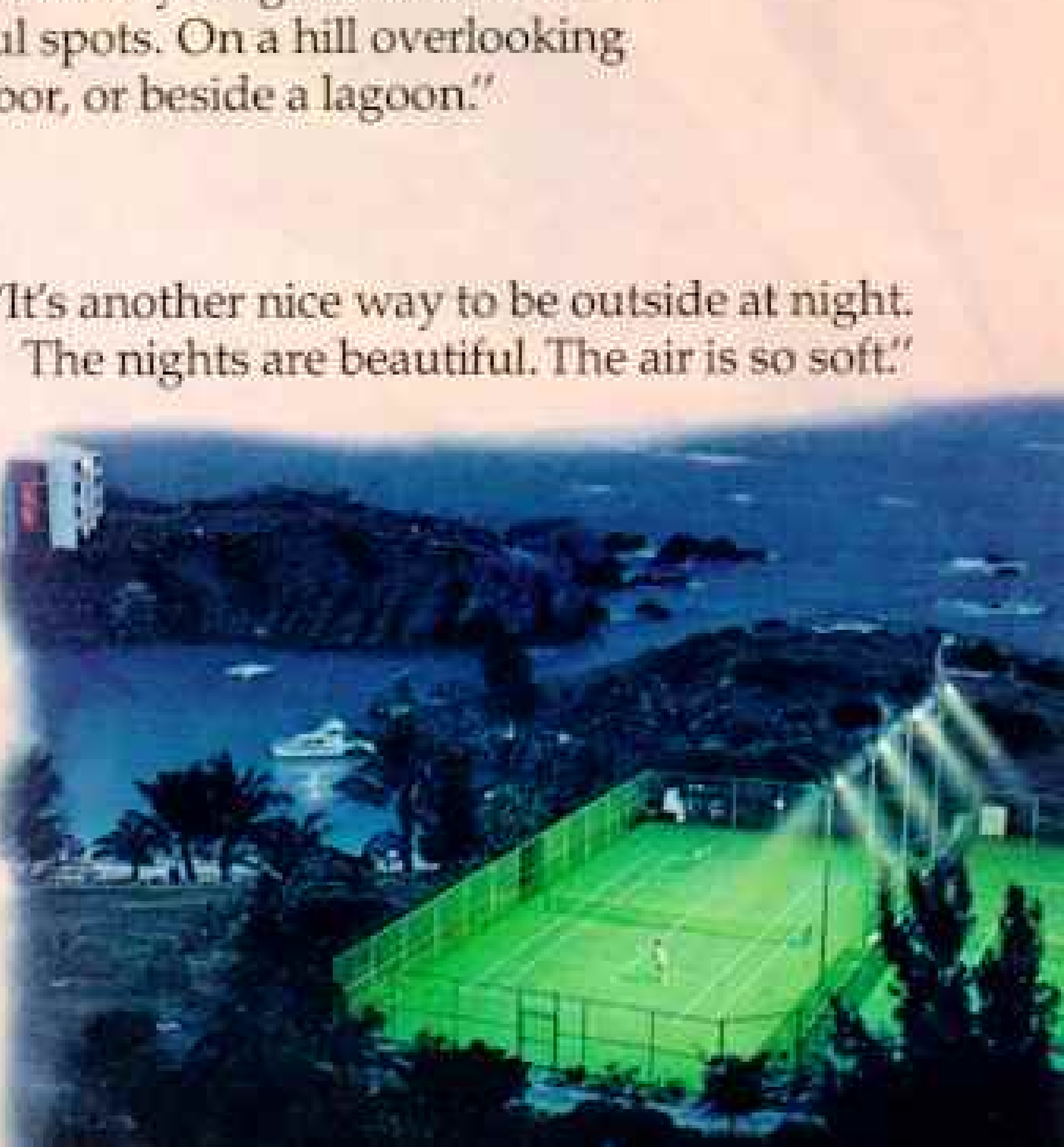

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Blue crab: main cog in an "immense protein factory"

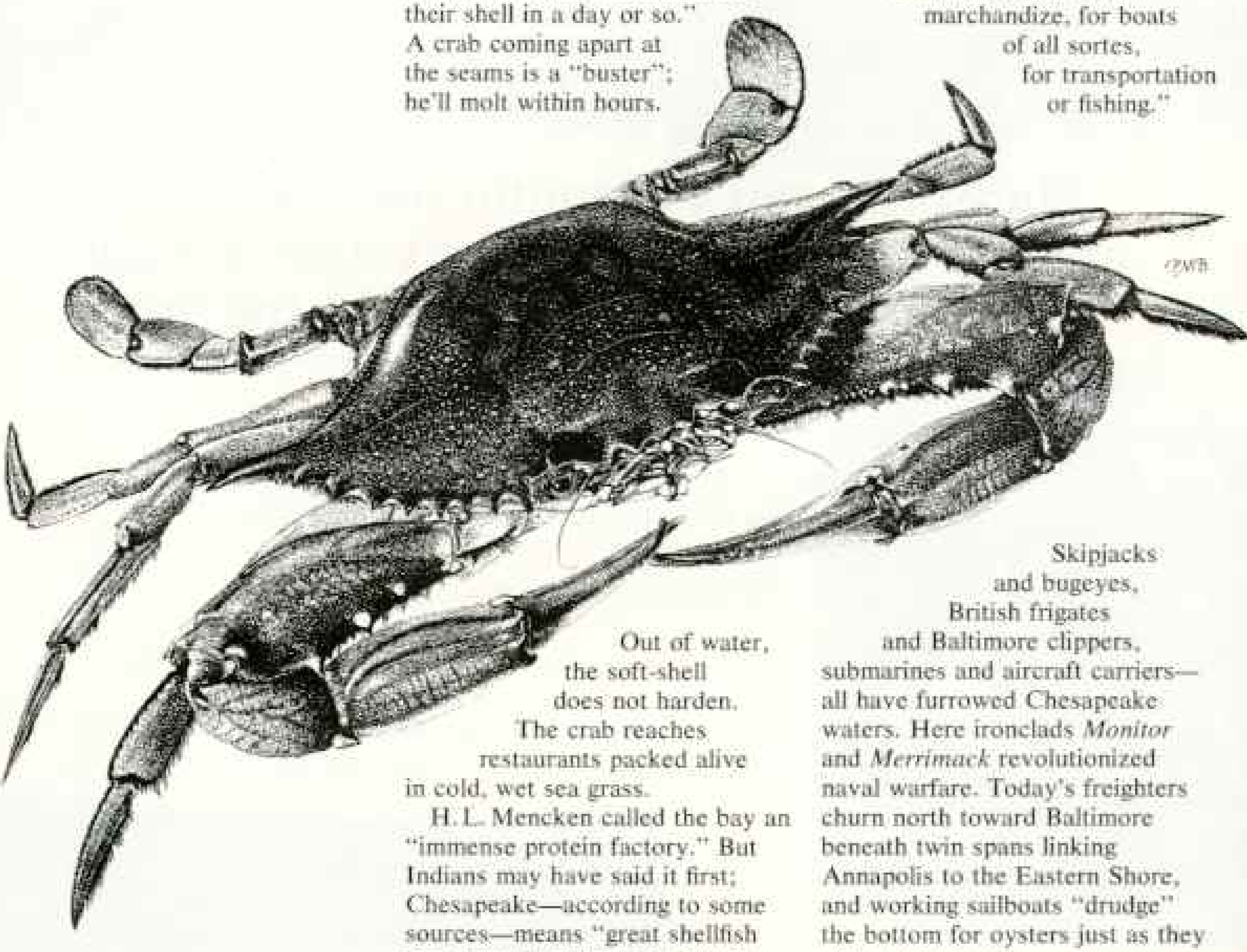
Chesapeake Bay watermen annually harvest millions of pounds of the blue crab *(Callinectes sapidus).* The succulent crustaceans will be steamed, stuffed, deviled, shredded into salads, patted into crab cakes, and, in their soft-shell state, eaten whole.

Baymen keep a sharp eye out for crabs about to shed their exoskeletons. A Tangier Island packer can spot a peeler by its paddlelike backfin: "Crab with a white edge to his paddle, he's got about a week to go. Pink rim, he'll shed in three days. When they gets red in the paddle, they'll shuck their shell in a day or so." A crab coming apart at the seams is a "buster"; he'll molt within hours.

Clams and crabs abound. To hear a waterman talk, it's a good thing only two or three crabs survive from the million or more eggs a female carries. Otherwise, "the world'd be et up by crabs."

Some 150 rivers, branches, creeks, and sloughs bearing names such as Crab Alley, Ape Hole, and Bullbegger flow into Chesapeake Bay. From the mouth of the Susquehanna to the Virginia capes, the bay washes more than five thousand miles of shoreline.

Capt. John Smith observed in 1612: "the waters, Isles, and shoales, are full of safe harbours for ships of warre or marchandize, for boats of all sortes, for transportation or fishing."



Out of water, the soft-shell does not harden. The crab reaches restaurants packed alive in cold, wet sea grass.

H. L. Mencken called the bay an "immense protein factory." But Indians may have said it first; Chesapeake—according to some sources—means "great shellfish bay," and it is that yet. Despite the overfishing that depleted the world's finest natural spawning beds, the bay still leads the country in oyster production.

Skipjacks and bugeyes, British frigates and Baltimore clippers, submarines and aircraft carriers—all have furrowed Chesapeake waters. Here ironclads *Monitor* and *Merrimack* revolutionized naval warfare. Today's freighters churn north toward Baltimore beneath twin spans linking Annapolis to the Eastern Shore, and working sailboats "drudge" the bottom for oysters just as they did a century ago.

The Chesapeake Bay waterman is but one of the unique people readers meet in the wide-ranging pages of NATIONAL GEOGRAPHIC.

In an independent survey of high school and college instructors, fifty per cent agreed:

STUDENTS WHO TYPE USUALLY RECEIVE BETTER GRADES.

For years, we at Smith-Corona have believed that typing can help students do better. But even we were impressed when we learned

that half of the high school and college instructors agreed that typing does help students improve their spelling; typing does help students improve their punctuation; typing does help students organize their thoughts; and that students who type usually receive better grades.

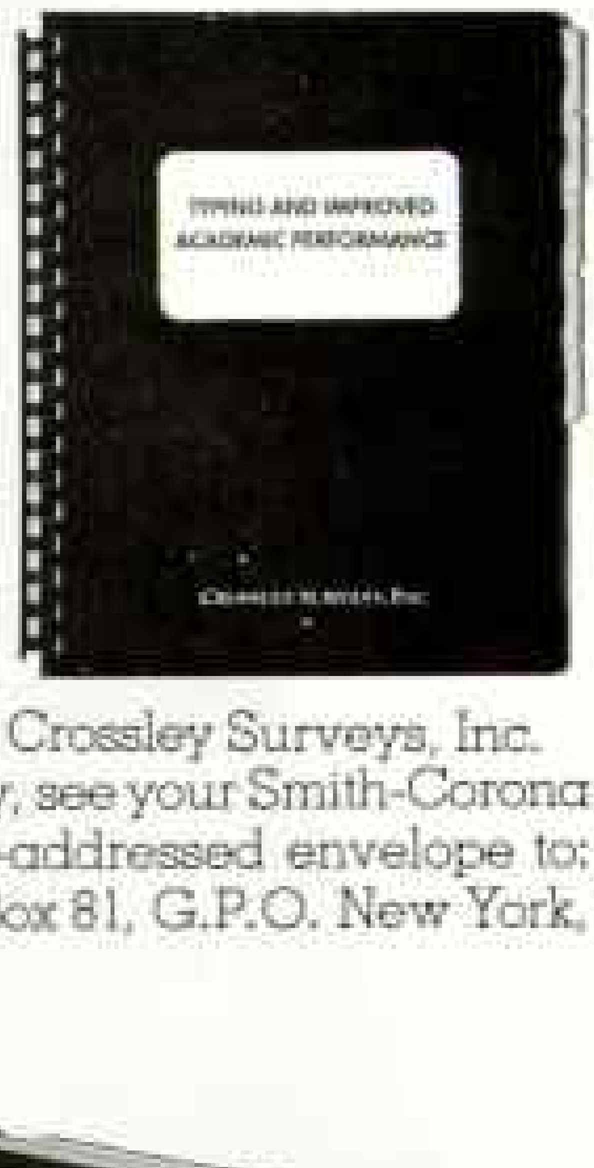
(Though a student's ability and the subject being taught are factors, fifty per cent of the instructors polled agreed... students who type usually receive better grades.)

If there is a student in your family, wouldn't this back-to-school time be the perfect time to purchase a typewriter. We suggest the electric portable that is already being used more than any other. The Smith-Corona® Cartridge Ribbon Typewriter.

This portable allows students to change ribbons by simply snapping in a cartridge. And there are five different color cartridges students love to use for emphasizing thoughts. There is a snap-in correction cartridge that allows students to correct errors and resume typing in less time than it takes you to read this sentence. And there is a carbon film cartridge that makes type from our portable look like type from far more expensive executive typewriters. The carbon film cartridge is perfect for a student's term papers and reports.

You should also know the Smith-Corona Cartridge Ribbon Typewriter is engineered to the same standards of durability, performance and design that made Smith-Corona typewriters Number One on campus... before cartridges ever came along.

SEND FOR A FREE SYNOPSIS OF THIS SURVEY.



Smith-Corona has prepared an easy-to-read synopsis of Typing and Improved Academic Performance, an independent survey of 400 high school and college instructors by Crossley Surveys, Inc.

For your free copy, see your Smith-Corona dealer or send a self-addressed envelope to: Smith-Corona, P.O. Box 81, G.P.O. New York, N.Y. 10001.

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QUALITY.

Quality in a small car. What does this mean to you? To Toyota it means an automobile that's inexpensive, not cheap. The new generation of Toyota Corollas are built with quality. The proof? 9 out of 10 Toyota cars sold in this country since 1958 are still on the road today. Quality. You asked for it. You got it. Toyota.

Quality is durability and how a car handles the road. Power assisted front disc brakes help you maintain control. MacPherson strut front suspension helps keep the ride smooth and unit body welded construction helps keep the Corolla tight and virtually rattle free.

Toyota's quality is in a line, not one car. No matter what your space needs you'll find it in one of ten Corollas: the Hardtop, 2-Door Sedan, 2- or 4-Door Deluxe Sedan, 5-Door Wagon, the new Sport Coupe or the new Liftback™ with a split, fold down rear seat. And there's a sporty equipped SR-5 model of the Hardtop, Sport Coupe and Liftback.

YOU ASKED FOR IT.

A quality car can be economical. The Toyota Corolla gets great gas mileage. Note: 1976 EPA tests, with 5-speed overdrive transmission, 39 mpg on highway, 24 city. These EPA results are estimates. The actual mileage you get will vary depending on your driving habits and your car's condition and equipment. California EPA ratings will differ. An automatic transmission is available on Deluxe models.

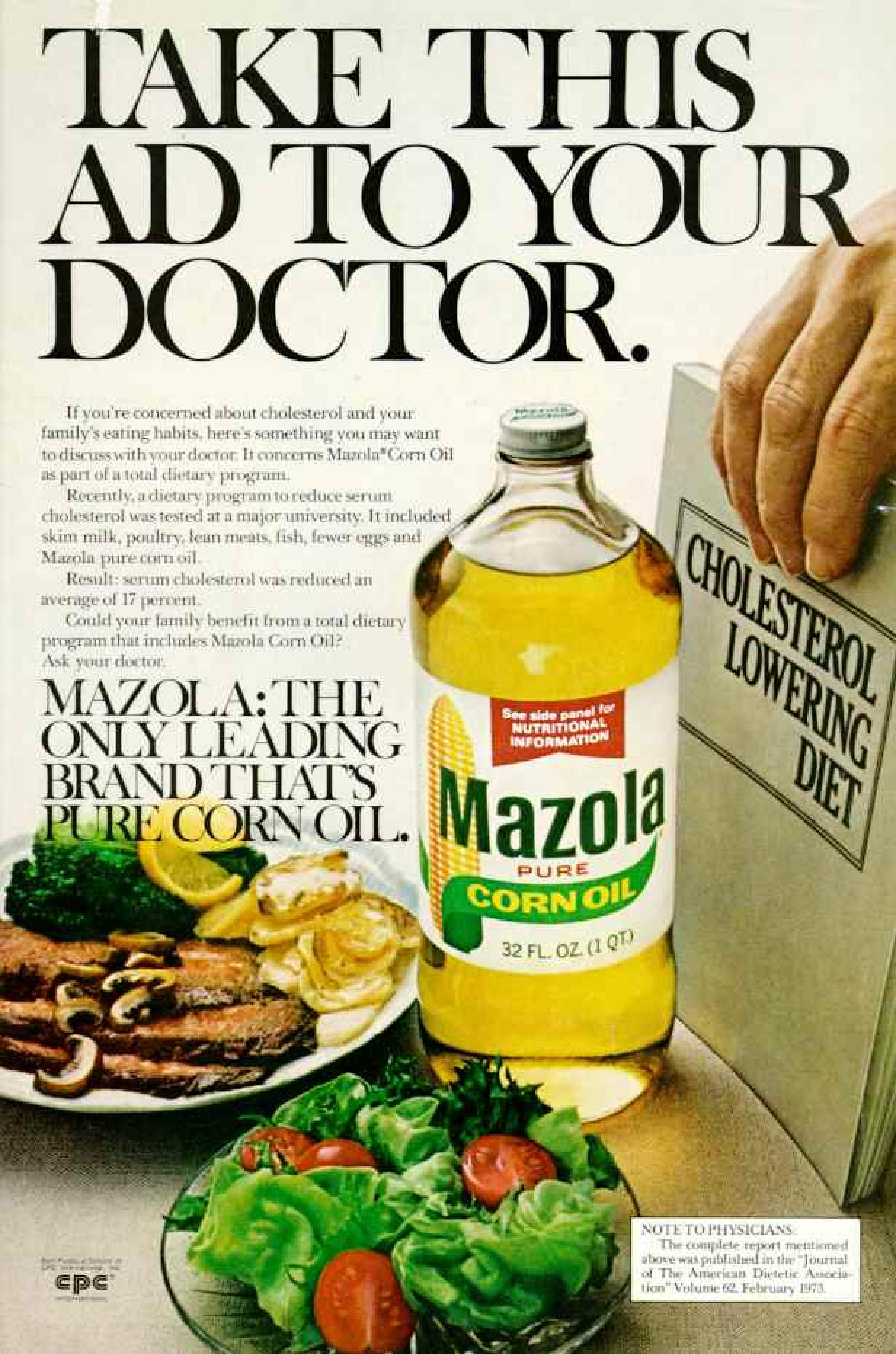
Quality. You asked for it. You got it at nearly 1,000 authorized dealers across the U.S. These same dealers comprise a network of service departments with Toyota trained mechanics. The new generation of Toyota Corollas. If you can find a better built small car than a Toyota... buy it.

YOU GOT IT.

Corolla SR-5 Sport Coupe

Corolla SR-5 Liftback

A NEW GENERATION OF **TOYOTA** COROLLAS


TAKE THIS AD TO YOUR DOCTOR.
If you're concerned about cholesterol and your family's eating habits, here's something you may want to discuss with your doctor. It concerns Mazola® Corn Oil as part of a total dietary program.
Recently, a dietary program to reduce serum cholesterol was tested at a major university. It included skim milk, poultry, lean meats, fish, fewer eggs and Mazola pure corn oil.
Result: serum cholesterol was reduced an average of 17 percent.
Could your family benefit from a total dietary program that includes Mazola Corn Oil? Ask your doctor.
MAZOLA: THE ONLY LEADING BRAND THAT'S PURE CORN OIL.
See side panel for NUTRITIONAL INFORMATION
Mazola
PURE
CORN OIL
32 FL. OZ. (1 QT.)
CHOLESTEROL LOWERING DIET
NOTE TO PHYSICIANS:
The complete report mentioned above was published in the "Journal of The American Dietetic Association" Volume 62, February 1973.
cpc

Behind its good looks is quiet dependability.

Do handsomely by your slides with this Kodak Carousel custom H slide projector.

It's good-looking so you don't have to hide it away somewhere between shows.

It's quiet so it doesn't interfere with your enjoyment.

It's dependable because gravity drops each slide in place. It's easy to use. It has push-button remote control, both forward and reverse. Autofocus too, so you usually have to focus only the first slide.

See the custom 840H (shown) at your photo dealer's. It's less than $250. Other Kodak Carousel projectors start from less than $95.

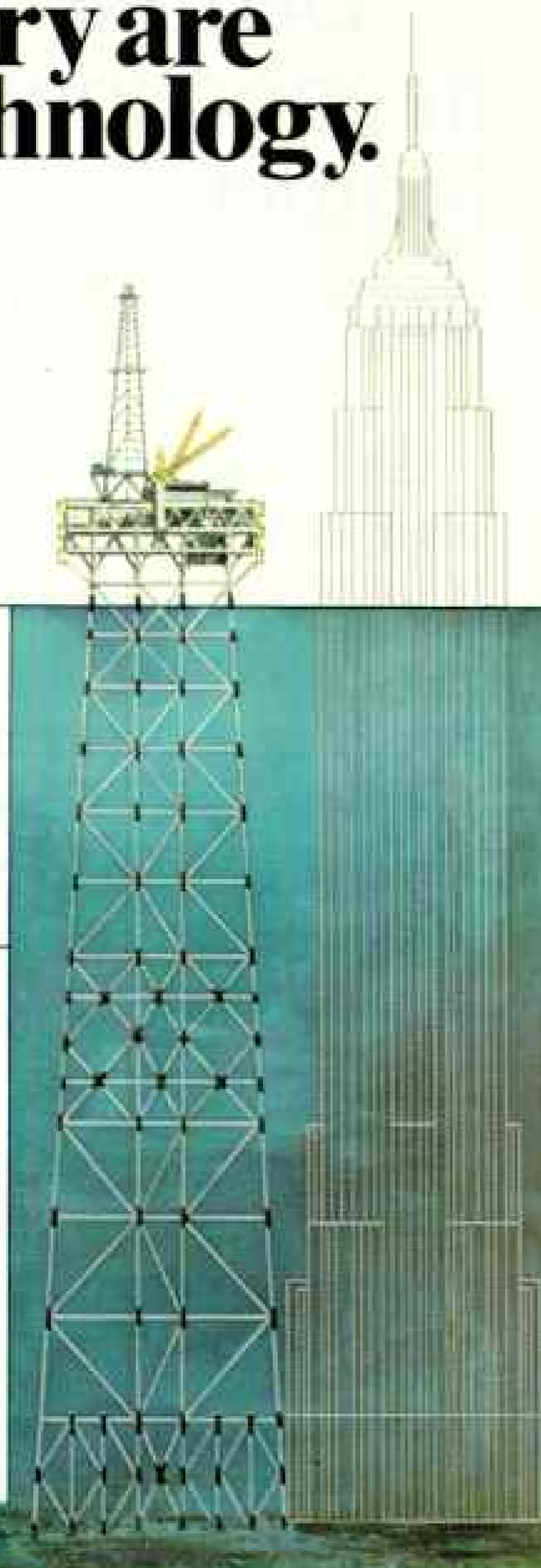
Prices are subject to change without notice.

Kodak Carousel custom H projectors.

Kodak

Two of the most valuable resources an oil company can offer our country are experience and technology.

At Exxon we have 94 years of both.



WHO'S REALLY QUALIFIED TO TACKLE AMERICA'S ENERGY NEEDS? EXPERIENCED COMPANIES WHO CAN TAKE THE TECHNOLOGY THEY'VE DEVELOPED IN ONE AREA AND MAKE IT WORK IN ANOTHER. EXXON HAS BEEN DOING IT—FOR YEARS.

The world's tallest offshore oil platform—recently launched in California.

Exxon has come a long way since drilling its first oil well back in the 1880's. That one was on land.

In 1948, we drilled one of America's first offshore oil wells in the Gulf of Mexico.

Today, the experience we gained from drilling these wells and thousands of others is helping us carry our search for gas and oil into far deeper and more difficult waters.

To meet these new challenges, Exxon scientists and engineers have had to develop new generations of drilling platforms—like the one you see at the right. It's the tallest offshore oil platform ever built—towering nearly as high as the Empire State Building. When completed, it will be capable of producing oil and gas in ocean depths of 850 feet.

Tomorrow, no one can be certain where the search for oil will lead. But, we'll be there—with even more experience working for you.

Energy for a st

Our experience searching for oil and gas is helping us uncover usable new deposits of uranium.

It's not surprising that Exxon is in the uranium business.

We spend millions of dollars each year exploring for oil and gas in sedimentary rock. And it just so happens that uranium ore is also found in the same kind of rock.

Today, Exxon's uranium mine in Wyoming supplies nearly 8% of our country's uranium oxide—the basic raw material used to make nuclear fuel for electric generating plants.

Using what we've learned about refining oil to help turn coal into other forms of energy.

America has nearly half the Free World's coal reserves. This is equal to twice the energy of all the oil in the Middle East.

Right now, Exxon scientists are working on new ways to help America use more coal by turning it into other forms of energy—synthetic gas and oil. Someday, these synthetic fuels could help supplement our dwindling supplies of natural gas and oil and help reduce our dependence on foreign oil.

This synthetic fuels technology is a new application of similar technology being used by Exxon for refining oil. It's also a good example of how Exxon's experience in one energy area is being put to work in another.

We're taking solar energy out of the lab and putting it to work.

An Exxon solar device is now powering a railroad crossing signal in Georgia. Another is running a police radio station in Montana. Others are bringing educational television to remote villages in Africa and Asia.

Solar power could become an important part of America's future energy mix. That's why we're committing money and some of our best brains to the task of turning the sun into energy you can use.

A good way to judge a company's experience is to look at the experience of the people who work for it.

Since 1882, Exxon has grown from just a few dozen workers in the U.S. to nearly 47,000 today. During this time, our people have learned a lot about supplying energy.

They built the world's first oil tanker. Their gasoline helped get the Wright brothers off the ground. They developed the first carburetor de-icer for automobiles, the first engine detergent. They invented butyl rubber. The first multigrade motor oil. And more.

Today, the men and women of Exxon are still working hard to provide more energy for a strong America.

rong America


"Rebuilding these rural roads will cost billions."
"The cost of neglecting these roads is immense."
Both true statements. Both consider costs, but from different viewpoints. Which costs more: updating? Or not?
Modernizing all our rural roads would be a staggering job. 3.2 million miles are involved: 84% of all U.S. roads. Most were built over 40 years ago for Model A cars and light farm trucks. 30 MPH speeds. Many have lanes less than 12 feet wide. They cross 200,000 bridges, many obsolete; go over 38,000 railroad crossings, less than half with warning lights. Cost to upgrade these roads? The government says $108 billion! Many people honestly question such an expenditure.
Yet, rural roads—cracked, potholed, blind-cornered — must carry our farm crops to market. And supplies to farms: fertilizers, feeds, fuels, pesticides, machinery. Bad rural roads increase food costs by increasing transportation costs. They waste time, fuel; take lives. About 25,000 in 1975. Fatal accident rates are higher on rural roads.
What to do? We can't make every road a superhighway. But we can't deny the benefits good roads bring to cities and farms. If America's farm production is to expand, rural transportation must keep pace. We should give rural road improvement the priority it deserves.
Caterpillar equipment is used to build and maintain roads and to power trucks. We believe good roads are essential to an efficient, total transportation system.
There are no simple solutions. Only intelligent choices.
CATERPILLAR
20
20
MPH

Twindow insulating glass, comfort with a view.

Herculite K safety glass for patio doors.

Mirrored wardrobe doors of High-Fidelity float glass.

PPG glass gives you the world.

The hushed beauty of a snowfall. The serene shadows of a summer evening. The fire of autumn. The newness of spring. And even you at your beautiful best.

Only glass gives you all that. And PPG gives you more ways than anybody to share in the beauty of glass.

Our Twindow* insulating glass proves two panes are better than one. It helps reduce heat loss and condensation. So you have a clear, comfortable view practically all winter long.

Herculite* K tempered safety glass is safer than regular glass because it's stronger. And, if it breaks, it crumbles into small pieces that reduce the chance of serious personal injury. So it's ideal for patio and storm doors.

And our High-Fidelity* float glass mirrors give you—you, in an incredible variety of styles. One, shown above, hides a closet, then opens to give you a fabulous full-length, three-way view.

There's a world of things glass can do for your home, and nobody can do it better than PPG. Ask your builder or architect. Or write for a free, idea-packed copy of "All American Homes," PPG Industries, Inc., Dept. N2-96, One Gateway Center, Pittsburgh, Pa. 15222.

PPG: a Concern for the Future

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