SCIENTIFIC AMERICAN

THE GREAT RACE OF 1895

ONE DOLLAR

May 1972

Gould Electric Vehicle Power Systems.

They're bringing peace and quiet back into your world.

There are federal laws against sounds over 90 decibels in factories. And Chicago prohibits trucks louder than 88 decibels. The blare of a rock band reaches the threshold of pain. Peace and quiet isn't just nice anymore. It's becoming a physical and psychological necessity.

Now quiet electric vehicles are more practical.

The Proud Inventors at Gould are creating battery power systems that help more people take advantage of quiet electric vehicles. One example is an "on-board" charger for lawn and garden tractors. And golf cars. You just plug them into any convenient outlet when they need recharging.

As the clamor for quiet grows, so do our markets.

Our electric vehicle power systems are also helping lift trucks, personnel carriers, delivery vans and mining equipment operate at a whisper. And in most cases, work more efficiently and economically than before.

We've made batteries for years. But now we see much of our business as providing clean, quiet power sources. And the demand for them is growing.

Electric vehicle power systems are important to us for another reason, too. They give our Proud Inventors an opportunity to be involved in improving our environment. The excitement and motivation this creates for them carries over to the contributions they make to our other product lines as well.

You'll be seeing the Gould name on a lot of new things.

Besides our electric vehicle power systems, we've also invented a more efficient heating element for forced air systems, a low cost rechargeable battery for small appliances, and biomedical equipment to monitor patients' vital signs.

Now, our Proud Inventors are also working on an energy absorbing bumper system for your car and a solution to automotive emissions. You'll be hearing more from us. Gould Inc., 8550 West Bryn Mawr Avenue, Chicago, Illinois 60631.

GOULD

the proud inventors

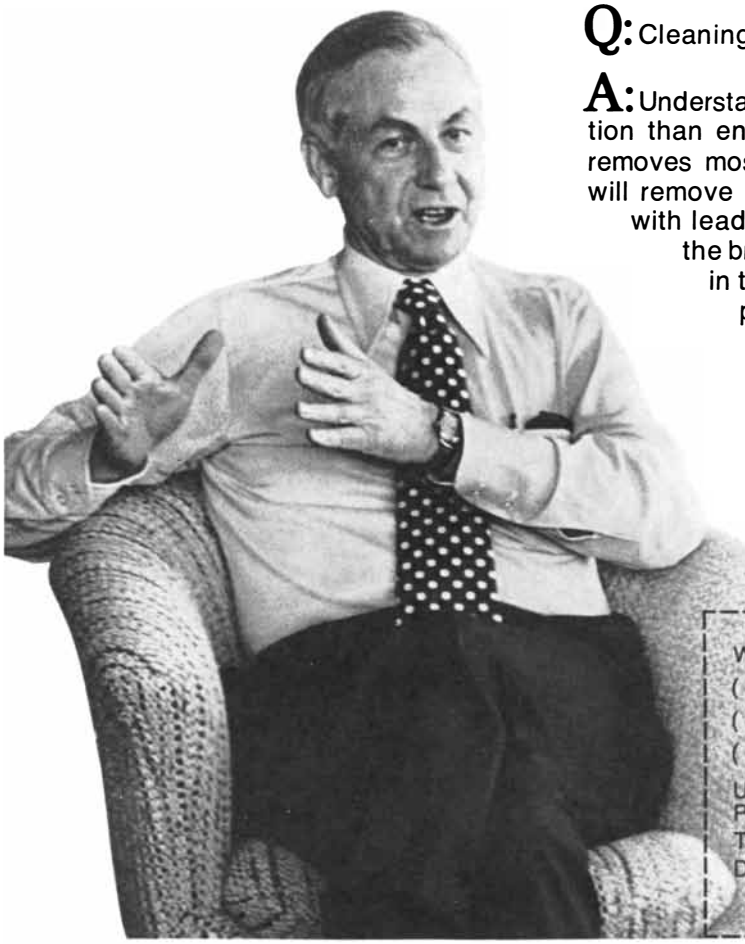
A CHIEF EXECUTIVE OFFICER SPEAKS HIS MIND. PORTION OF AN INTERVIEW WITH JOHN O. LOGAN, PRESIDENT OF UNIVERSAL OIL PRODUCTS COMPANY, DES PLAINES, ILLINOIS

Q: It's said that America's known supplies of oil and gas won't last the century. Can UOP solve that dilemma?

A: No company in the world has a broader capability than UOP to provide the technology needed.

Q: What are the facts?

A: Take the energy-gap. In the last 30 years, our company was the leader in doubling the mechanical energy from a barrel of crude. But the nation's most assured long term energy source is coal. UOP is exploring processes to make crude oil from coal... at an affordable price. We can also make substitute "natural gas" from coal. And we can even make high-sulfur soft coal a respectable fuel. We're working on that with Commonwealth Edison in the Midwest right now. Coal offers a tremendous energy potential!



Q: Cleaning up the environment is a buzz-word, too.

A: Understandably. The nation is creating more pollution than energy. UOP has a converter for cars that removes most exhaust pollutants. And the converter will remove pollutants for the life of the auto if used with lead-free high-octane gas. Our company has the broadest line of air-pollution control devices in the world. For ridding cement plants of that pall of dust. For removing bad odors from chemical plants. For eliminating nitric acid fumes.

UOP has the know-how and hardware to both create new energy-sources and assure waste-free use of them. Right now. We intend to do good—and make money. I find that exciting!

Write to Office of The President for details on:
( ) UOP's stake in the Energy Crisis
( ) UOP's stake in the Environment Crisis
( ) UOP's total Capabilities story

UOP, Universal Oil Products Company
Ten UOP Plaza
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UOP
The Answer Company

Established 1845 **SCIENTIFIC AMERICAN** May 1972 Volume 226 Number 5

ARTICLES

DEPARTMENTS

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THE COVER

The painting on the cover portrays the automobile that won an epochal race between Paris and Bordeaux in 1895 (see "The Great Automobile Race of 1895," page 102). The race was organized at a time when the automobile had not yet established itself as a viable means of transportation and when the question of whether the gasoline engine or the steam engine was superior had not been settled. Of 20 automobiles that started the race (there were also two motorcycles), 13 had gasoline engines, six had steam and one was electric. Of the nine cars that finished the 1,200-kilometer course from Paris to Bordeaux and back within the allotted span of 100 hours, eight had gasoline engines. A steam car finished ninth. The winning car was the Panhard & Levassor No. 5. It had a two-cylinder engine, a chain drive and solid rubber tires. The driver was Emile Levassor, who remained at the steering bar for the entire 48 hours 48 minutes that the car required to cover the course. The next car came in six hours later.

THE ILLUSTRATIONS

Cover painting by Ted Lodigensky

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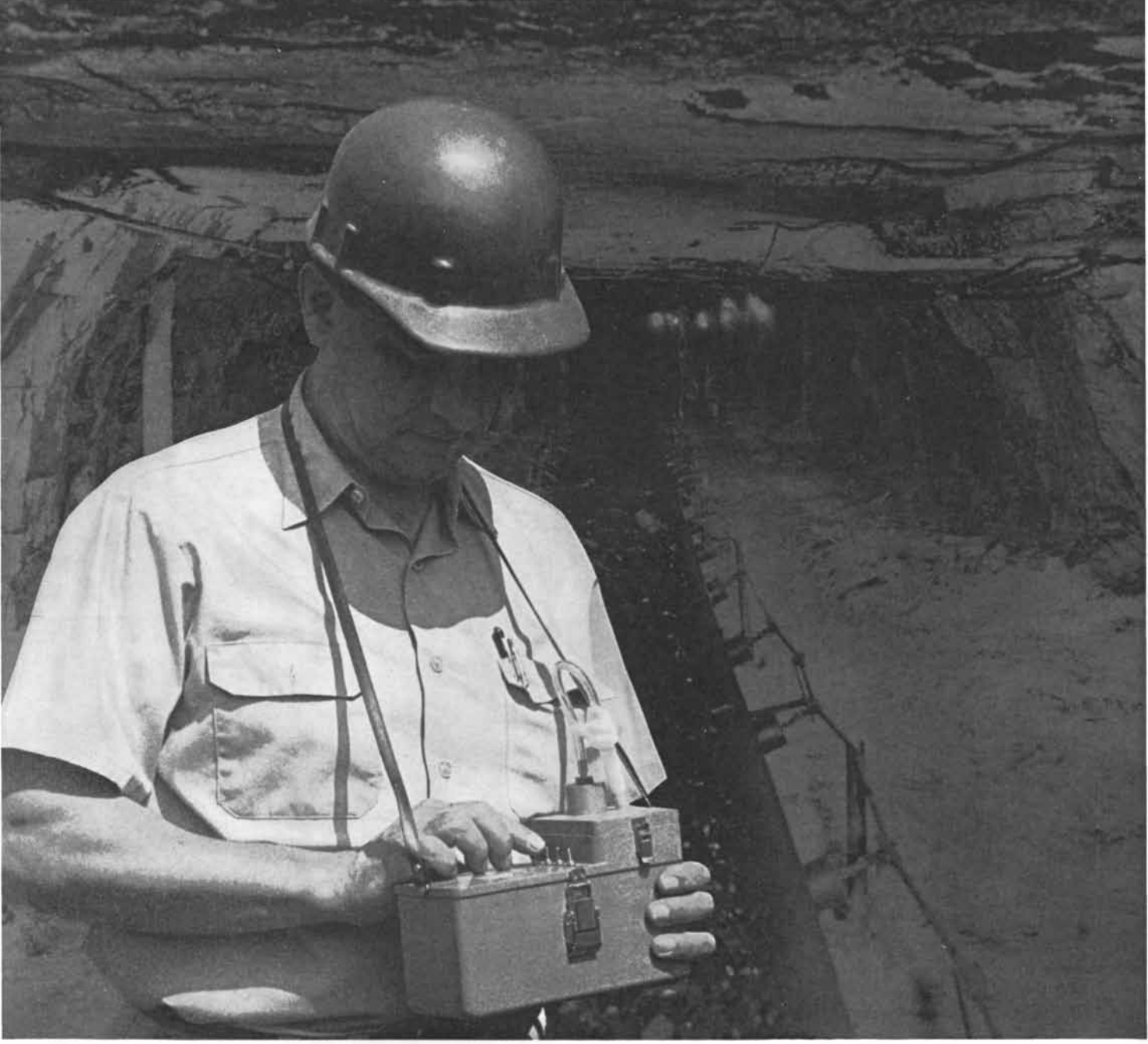


The 60 second dust check.

GCA made it happen.

Meaningful measurement of dust particles in mines or factories that might cause respiratory ailments has always taken days and sometimes weeks . . . while workers remained exposed to potentially hazardous conditions.

Now, GCA Corporation has the first portable instrument for on-the-spot accurate measurement of breatheable dust.

There's no waiting. In seconds, airborne dust concentrations are known. Immediately, the plant or mine operator can check dust control efficiency and see if the environment is within industrial hygiene safety limits.

But dust detection equipment is only one way GCA helps improve the environment.

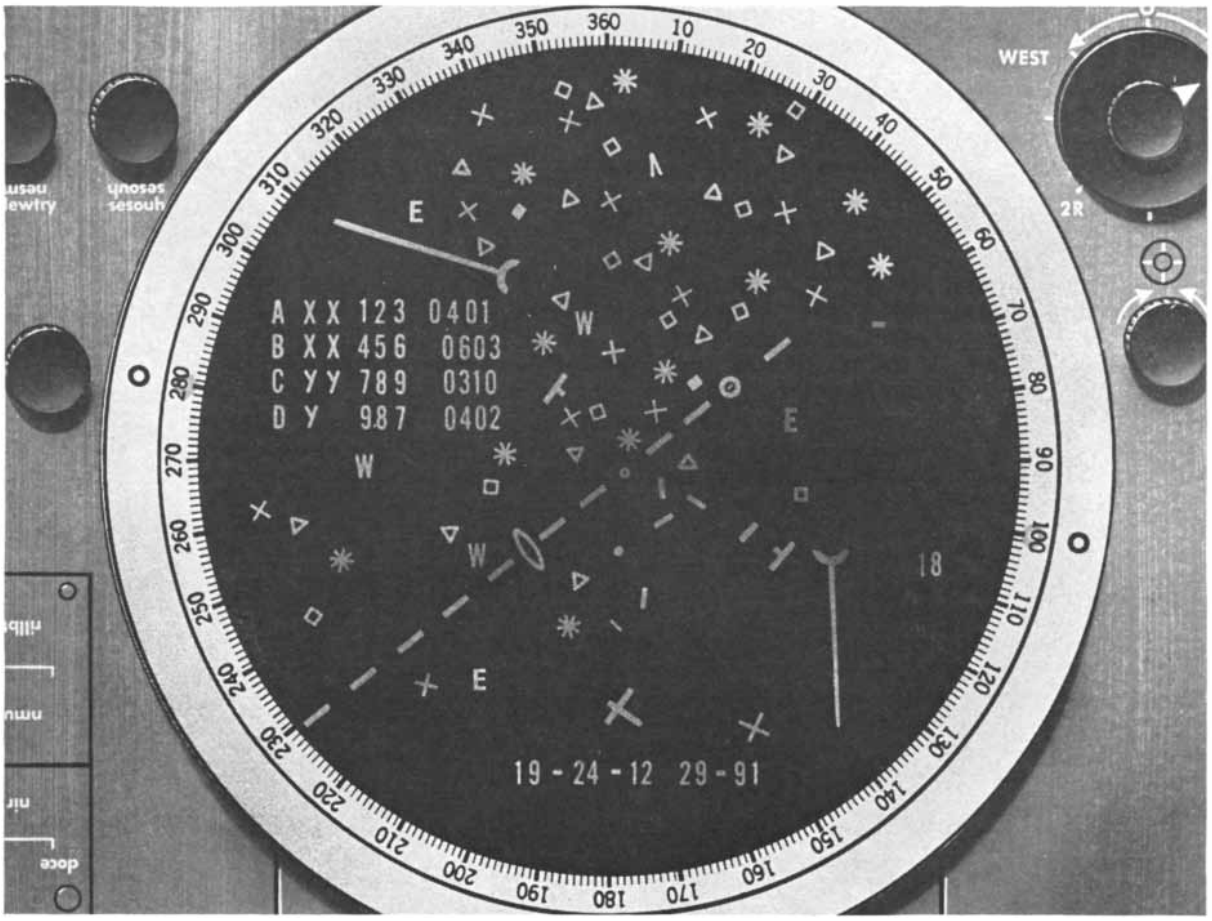
Right now in some of our projects we're researching new fabrics for better air filtration in industry; looking at automotive exhaust emission problems; developing better ways of handling power plant smoke; and working on a variety of other problems for federal, state and local agencies.

GCA also offers a line of air quality monitoring equipment and a monitor that detects water pollution in less than two minutes.

If new and better solutions to pollution problems would help your industry or community, call or write GCA Corporation, Burlington Road, Bedford, Mass. 01730.

GCA
CORPORATION

Can you find the aircraft headed for collision?

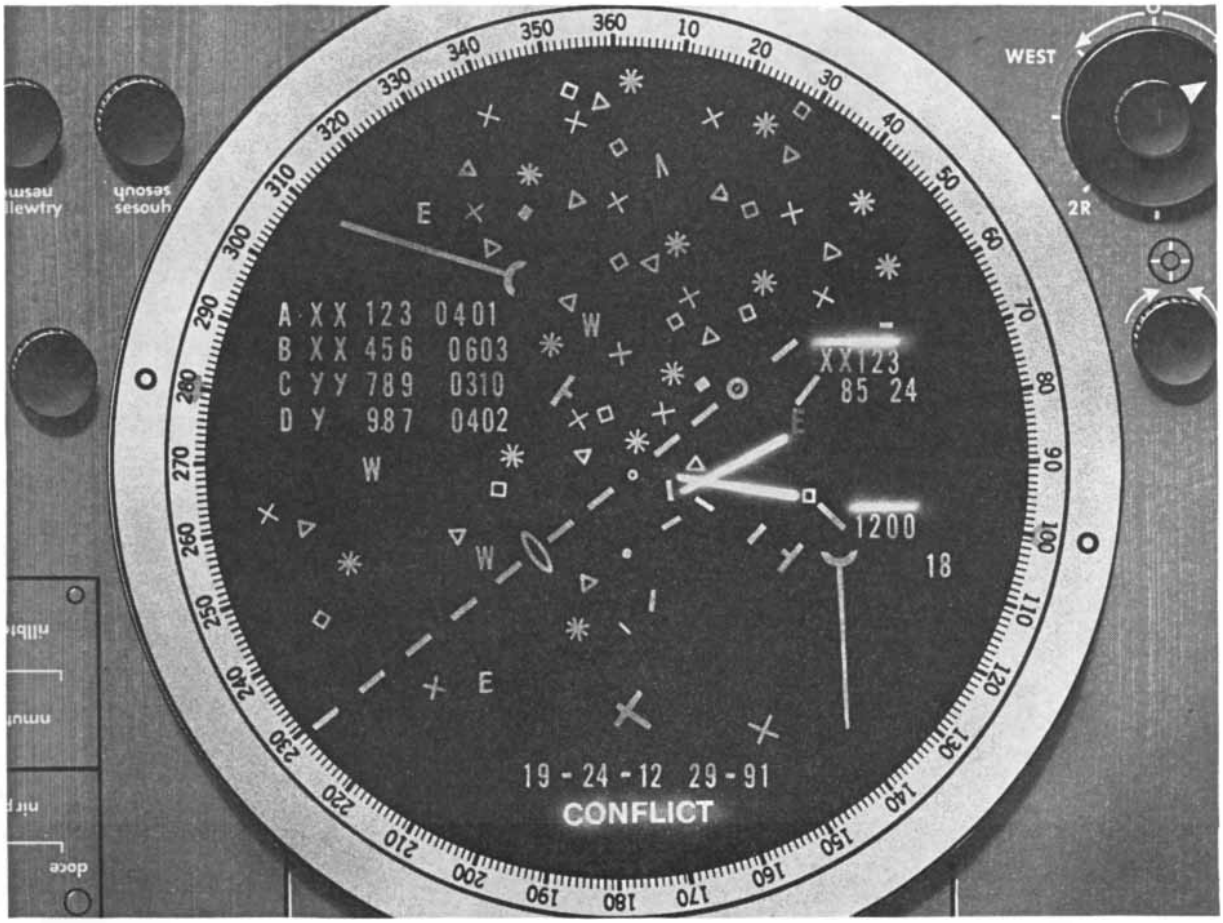


Goodyear STARAN: It's a new way

The STARAN™ computer helps air traffic controllers achieve better management of controlled aircraft by automatically tracking *all* the aircraft in the sky. With STARAN, reliable ground-based conflict prediction and resolution is now practical and economical—no costly equipment is required in the aircraft. Truly, STARAN is a new computer tool—available now—to enhance air safety and to relieve costly congestion.

STARAN is an associative array processor—"a

STARAN can.



# of thinking for air traffic control.

new way of thinking." STARAN uses *content addressability* to eliminate slow, word-by-word searches of data memories, and *array arithmetic* to process thousands of data streams simultaneously.

The STARAN computer has already proven its capabilities in operation at McGhee-Tyson Airport in Knoxville. You can see for yourself what STARAN can do, in a live demonstration of Air Traffic Control at TRANSPO '72. Or call Mr. Wayne Brubaker, 216-794-3631, or write Goodyear Aerospace Corporation, Department 911 AAQ, Akron, Ohio 44315.

SEE STARAN AT **TRANSPO '72** IN COVERED AREA "A", WASHINGTON, D.C. May 27—June 4, 1972

GOODYEAR AEROSPACE

LETTERS

Sirs:

May I offer two historical comments on "The Synthesis of Speech," by James L. Flanagan [SCIENTIFIC AMERICAN, February]?

The first concerns Baron Wolfgang von Kempelen, remembered for both his chess-playing and speaking machines. The chess-playing machine, called "The Turk" because of its appearance, shouted "Echec!" when it vanquished its opponents. Von Kempelen, referring to The Turk as a "mere bagatelle," freely acknowledged its sole merit: its ingenuity as a deception. Since The Turk lived for 85 years before its destruction by fire in Philadelphia, the ingenuity most probably did not, as Dr. Flanagan suggests, rest on the availability of a single legless chess expert. There was room in the machine for any chess expert of reasonable size. This has often been disclosed pictorially; David Brewster did so in his book on natural philosophy during the past century, and I have done so in my recent book on thinking.

Scientific American, May, 1972; Vol. 226, No. 5. Published monthly by Scientific American, Inc., 415 Madison Avenue, New York, N.Y. 10017; Gerard Piel, president; Dennis Flanagan, vice-president; Donald H. Miller, Jr., vice-president and secretary; George S. Conn, treasurer.

Editorial correspondence should be addressed to The Editors, SCIENTIFIC AMERICAN, 415 Madison Avenue, New York, N.Y. 10017. Manuscripts are submitted at the author's risk and will not be returned unless accompanied by postage.

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NAME

NEW ADDRESS

OLD ADDRESS

The second comment concerns the place of A. Melville Bell with respect to Dr. Flanagan's researches on sound synthesis. Melville Bell (Alexander Graham Bell's father) ought not to be remembered as an elocutionist, as Dr. Flanagan has implied.

Melville Bell held the position of Lecturer on Elocution at University College London, but his primary and preferred position was Professor of Vocal Physiology at the same institution. In this latter connection he wrote *Visible Speech,* the basis of all modern research on speech synthesis. Given any speech sound, Bell drew a picture of the vocal apparatus similar to the one in Dr. Flanagan's article, showing the position of articulators and designating the speech sound as voiced or unvoiced. The drawings were cumbersome, and Bell devised an elaborate system of symbols to replace the drawings. He devised still other symbols for transitions and pauses between speech sounds. Thus Bell had a code for every sound and every word in every language, just so long as the sound was generated by the human speaking apparatus; he could in fact record nonspeech sounds, including snoring, sucking, gargling, sipping, spitting, kissing and even dental-plate clicks.

The following is a condensed version of Bell's work, given by the English weekly *The Athenaeum:* "Mr. Alexander Melville Bell produces a method of writing sounds. It consists in picturing by totally new symbols the actions of the several organs of speech, tongue, lips, teeth, etc. . . . We, and many others, have seen this method tested in the following way. Mr. Bell sends his two sons out of the room, and then invites the company to make words in any language, pronounced rightly or wrongly, and sounds of any kind, no matter how absurd or original; for it is the success of this method that whatever the organs of speech can do, the new alphabet can record. Mr. Bell tries each sound himself, until the proposer admits that he has got it; he then writes it down. After a score of such attempts have been recorded, the young gentlemen are recalled, and they forthwith read what has been presented to them, reproducing to a nicety, amidst general laughter and astonishment, all the queer Babelisms which a grave party of philologists have strained their muscles to invent."

The story of Bell's visible speech does not end here. Henry Sweet extolled the virtues of visible speech and then devised his own broad Romic system of speech sounds, the direct precursor to our own phonemes. In 1912 George Bernard Shaw based his play *Pygmalion* on Bell's visible speech, and Sweet was given an immortality achieved by few men. Sweet was the prototype for Professor Henry Higgins, known to one and all in *My Fair Lady,* the musical adaptation of *Pygmalion.* In *Pygmalion* Henry Higgins said: "We'll set her talking; and I'll take her down first in Bell's Visible Speech; then in Broad Romic. . . ."

JOZEF COHEN

University of Illinois
Champaign, Ill.

Sirs:

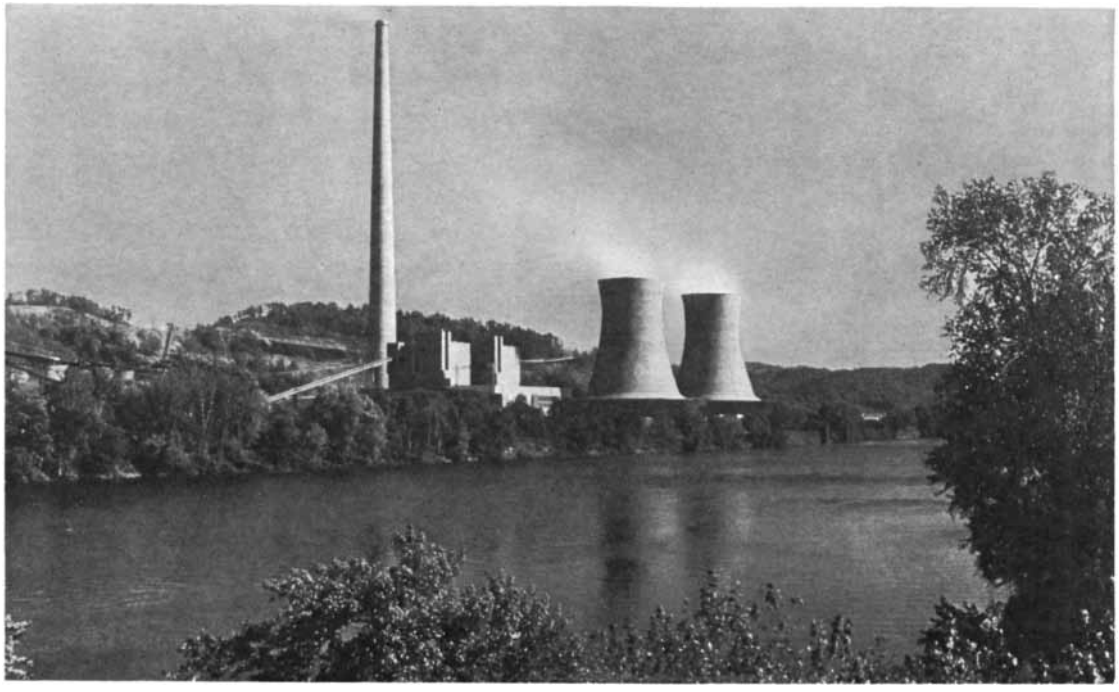
I enjoyed reading "The Talking Drums of Africa" in your December 1971 issue. The author tells of the good sound transmission in the cool of the evening. There is a definite reason for this. When the sun shines on the ground, the surface of the ground gets warm, and a temperature gradient develops in the first several hundred feet above the ground, which is in addition to the air's normal vertical temperature gradient. The velocity of sound in air decreases with decreasing temperature, so that there is a velocity gradient corresponding to the temperature gradient.

If the sound velocity is greater at the surface than it is higher up, as it is in this case, then the sound-ray paths curve upward in all directions away from a surface sound source, and the sound intensity received at a distant point on the surface is less than it would be if the rays were not upturning. In the cool of the evening, or over water or snow, this temperature gradient may disappear or even be reversed, in which case the ray paths are downturning, and the sound intensity received at a distant point on the surface is greater than it would be if the rays were not downturning.

The wind also has an effect. The velocity of sound relative to the ground is the velocity of sound relative to the air plus the velocity of the air relative to the ground. Thus the wind increases the velocity of sound (relative to the ground) in the direction the wind is blowing, and decreases it in the opposite direction. The wind velocity near the ground is less than it is higher up, because of the drag of the ground, so that the wind effects the sound-velocity gradient. The effect of the wind alone is to bend the sound-ray paths down (and improve reception) in the direction the wind is blowing, and do the opposite in the opposite direction.

These effects were clearly demon-

Marley®: growing with the power industry.



Huge new power plants, like this, have a giant thirst for cool water to condense spent steam and dissipate the heat. Since long before ecology became a household topic, Marley has been a partner in the power industry, supplying all the cool water needed, economically and with minimum effects on the environment.

By cooling the cooling water in a Marley tower, the same water can be used over and over again. This means a much smaller local water source is required. And there is no need to return hot water to lake or river.

This makes it possible to locate plants in more economical locations . . . near load centers, fuel sources, or on less costly real estate.

Marley cooling towers like these save thousands of kilowatts of energy, because gravity does the work. They're quiet, pleasing to the eye and so dependable that substantial amounts of money are saved in reduced maintenance and repair.

Building cooling towers of all types and sizes, within budget and on time, has been a Marley specialty for 50 years. In the last 12 years alone, Marley has built or is building cooling towers for over 40,000,000 kilowatts of generating capacity.

But the power industry is just one of the major markets contributing to Marley's growth in the U. S. and internationally. Would you like a copy of our annual report? Write The Marley Company, 5800 Foxridge Drive, Mission, Kansas 66202. Offices, plants and affiliates world-wide.

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MARLEY

CELEBRATING OUR 50TH YEAR.

strated by hundreds of air-wave shots (to determine surface distance) made on the Gulf Coast during seismic prospecting by the refraction method, under various conditions of sun and wind. It was common experience at points several miles downwind to record airborne-sound amplitude 10 times as great as at the same distance in the opposite direction. The effect of the temperature gradient was equally conspicuous.

Thus the reception of the sound of a drum, a gong or a voice may indeed be much greater along a wide river, or in the cool of the evening, or with a favorable wind. The refraction of sound waves, caused by velocity gradients in the medium, as discussed above, also takes place underwater and through the ground, with similar effects on the intensity of the energy received at distant points. This is taken into account in sonar and seismic studies.

The principles described here are well known to those working in these fields and may be of interest to your readers.

GORDON TAYLOR

Altadena, Calif.

Sirs:

Your story of Boston's burst tank of molasses ["Science and the Citizen"; SCIENTIFIC AMERICAN, March] brought back clear memories of my childhood and the usual Sunday walks with my father. We visited the North End shortly after the disaster and saw the fire hoses and pumps still working on filled cellars. The dynamics of flow was indelibly impressed on my mind, particularly by the steel columns of the elevated cut off as if by a giant snowplow.

However, your "282 feet in diameter" must have been circumference! This checks by memory and your volume.

JOHN C. GRAY

Cambridge, Mass.

EDITOR'S NOTE

The graph and the map and the accompanying table that appear on pages 25 and 26 of the article "Cable Television" (SCIENTIFIC AMERICAN, October, 1971) are based on information published in *CATV and Station Coverage Atlas,* copyright 1971 by Television Digest, Inc.

7 questions about learning to fly.

1. Can anyone learn to fly?
Yes, practically anyone can learn to fly a light airplane. No special qualifications are necessary except perhaps the desire to tackle something that's a little challenging, and the kind of a mind that enjoys the satisfaction of doing something out of the ordinary. More than three-quarters of a million men and women in the United States have their pilot license—and thousands more are taking lessons every day.

2. What are the physical requirements?
You just have to be in normal health; a simple physical exam is required and glasses are no deterrent. There is no maximum age limit; 16 is the minimum age for solo. A little wanderlust helps.

3. How long does it take to get a license?
Government regulations require a minimum of 35 hours of flying time for a Private License. So, if you start now and take only a few lessons a week, you could be a licensed pilot by mid-summer. Many people solo in a week's time.

4. How complicated is it to handle a plane?
Learning to control an airplane through the three dimensional realm of flight has to be one of man's most exhilarating experiences. Yet the handling is easy and requires only a light touch...slight back pressure on the wheel to climb, slight forward pressure to descend. A turn is what you'd expect: turn the wheel left to go left.

Take-offs are almost automatic; landings take more practice than anything. The person learning in a low wing airplane, like the Cherokee Flite Liner, has a distinct advantage because an invisible pillow of air builds up under the wing as it nears the ground, acting like a cushion to let you touch down nice and easy.

All the aspects of controlling the airplane come to you in easy, logical steps—one at a time—explained and demonstrated to you by the highly qualified, government-rated flight instructor at dual controls by your side. The carefully programmed sequence of teaching used at Piper Flite Centers assures that you'll make steady progress—with each new maneuver adding to your capability in logical fashion.

5. What about all those instruments?
Most of them are really the same as in your car or boat: speedometer, engine gauges, clock, tachometer, fuel gauge, plus an altimeter. Additional instruments make their usefulness evident naturally: an indicator shows rate of climb or descent, a compass tells direction.

6. Do I have to own a plane to enjoy flying?
No. You can rent an airplane just like you do a car. Also, it's common for two or more friends to share ownership. Flying clubs also enable many to fly inexpensively.

7. How do I get started?
See your nearest Piper Flite Center. The special Piper programmed training course takes you through 30 logical steps that assure you learning everything you need for your license. The most modern training equipment and systems are used to make sure you learn each step thoroughly. Many Piper Flite Centers now offer Cherokee trainers with air conditioning for added comfort—a Piper exclusive. Every instructor is a government-licensed professional. Students using the Piper Flite Center system normally get their license in about 20 percent less flying hours than the national average.

$5 for your first lesson.
An introductory lesson at a Piper Flite Center costs only $5. And a Special Flying Start Course offered only at a Piper Flite Center gives you four lessons, your own log book and preliminary ground school instruction for only $88.

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50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

MAY, 1922: "During the fiscal year 1922 the Federal budget allows for $105,000,000 of Federal funds to be spent on good roads, and nobody will begrudge this sum. The Department of Agriculture will take $48,000,000 out of Uncle Sam's pocket, the entire sum being expended for what we may recognize as research and education and information, plus the necessary administrative expenses. The Department of the Interior will get $34,000,000; the Department of Commerce will get $20,000,000, and in the other branches of the executive lesser sums will be expended. When we seek to isolate from the rest the specific items that go to research and direct service to the people, we find that the amounts are surprisingly small. While appreciating the improvement over the specific showing of past years, it is still possible to express regret that scientific research and the dissemination of information are allotted such meager sums in comparison with the expenditures for purposes that even their proponents must admit are less useful."

"Lectures given at various American centers of learning by Dr. F. W. Aston of Cambridge made a notable contribution to the general knowledge of the remarkable advances of the moment in physical chemistry. More and more it is coming to be taken for granted that the chemical elements are made up of identically the same stuff, and that they differ only in their structural arrangements. More and more the passage from one element to another that so dumbfounded science when it was first observed taking place spontaneously is coming to be a matter of course and something that we may ultimately hope to control."

"In a general way the public is aware that helium is non-inflammable, differing radically in this respect from the hydrogen that has hitherto been employed in balloons and dirigibles. The U.S. Geological Survey has concluded an exhaustive examination of our helium-bearing natural gas and has tabulated just where natural gas of this character can be found and given the percentages of helium present in each of these several fields. While helium may be found of use to man in many directions, and of peculiar value in studies having to do with very low temperatures, its most promising application seems to be in the field of lighter-than-air craft."

"The nature of light has been the subject of famous controversy. Newton, in subduing under the weight of his authority the wave theory of Huyghens, held that light consisted of discrete particles of matter shot off from the source, which bombarded the objects on which they fell and were reflected to the eye of the observer, there producing the sensation of sight. What finally discredited the corpuscular theory was the phenomenon of interference. This difficulty led to the formulation of the wave theory at the beginning of the 19th century. Recently, however, fresh phenomena have been observed that are difficult to explain on the basis of classical wave theory, and it seems not unlikely that we may have to turn to a theory more or less analogous to the corpuscular one of Newton."

"The ever-increasing practice of discharging oil and tar wastes into streams and harbors is affecting fish and fish industries. The fatal contamination that results from poisonous substances rejected by gas plants and petroleum distilleries, or dumped from tankers and oil-burning ships, must result in huge losses of food products and money. Remedial measures may be found in the commercial recovery of oils from drainage water, in the prevention of gas-house and refinery pollution with an increased use of wastes and in regulations forbidding the dumping of oil from ships in harbors or near spawning grounds and feeding areas."

SCIENTIFIC AMERICAN

MAY, 1872. "The most deadly physical danger in this country is the absorption of metallic poisons in water, food, medicines, washes, paints, dyes, enamels, etc., prepared and sold by the thoughtless and unprincipled. The demand of every thoughtful patriot should be that no kind of poison should be sold under any other than its proper name. The public is, and always will be, powerless to adequately protect itself against insidious poisons used in the many adulterations of the present day, and must perforce look for that protection to a government professing to guard the life and property of the citizen."

"Here is the business done by the Western Union Telegraph Company in one hour by means of one wire between New York and Boston employing the Stearns instruments for sending messages both ways at the same time. From New York to Boston, 72 messages; from Boston to New York, 62 messages. This remarkable improvement in telegraph instruments doubles the capacity of every existing wire without increasing the cost of maintenance."

"Not long ago the whole stock of the paraffin wax in the world did not exceed four ounces, which was carefully preserved in the laboratory of Professor Liebig as a chemical curiosity. There is now produced in Scotland alone a quantity of not less than 5,800 tuns annually."

"There has been a long felt want for a transparent material that could take the place of glass for many purposes, without the fragility of the latter substance. The substance that comes nearest to these requirements is mica, but in many respects this fails to meet the want. It would seem that the present resources of chemistry might be adequate to furnish to the world such a material as we have named. The man who could do this cheaply would supply a process of incalculable value."

"Next to the application of the spectroscope to practical astronomy the use of the photometer promises to be of the utmost importance. One of these is a recent invention by Zoellner of Berlin, which in fact is a polariscope connected with a telescope. In the polariscope a ray of light can be made to disappear and reappear alternately by turning an eyepiece made of Iceland spar, tourmaline or other proper material around its axis through an angle of 90° The disappearance and reappearance is gradual, and an angle of rotation from 0° to 90° can therefore be used as a measure of the intensity of the light, a stronger light requiring more rotation to be toned down to a certain standard than a weaker light. This technique will be useful for the observations of variable stars."

"The safety of Dr Livingstone, the celebrated African traveler, is now assured. Recent accounts state that he has arrived at Zanzibar from the interior of Africa."

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We thought that worth mentioning.

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One Peugeot owner leads to another

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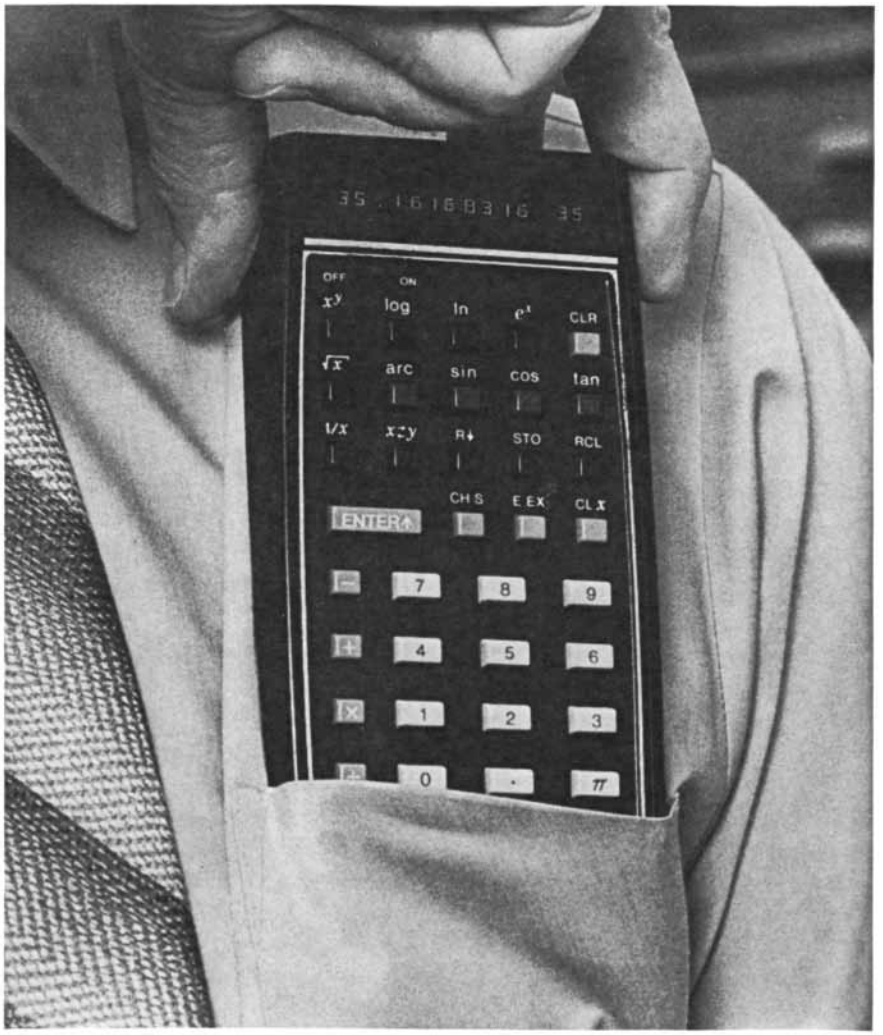

The HP-35 Shirt Pocket Calculator lets you make complex calculations like this one approximately five times faster than with your slide rule . . . with 10 place accuracy . . . and without a single scratch note!

$$\alpha_H = 1 + [3\times10^{-2}](10^{7.21}) + [8.7\times10^{-3}](10^{2.16})$$

$$pH = -LOG\sqrt{\frac{1}{\alpha_H}\left(\frac{3\times10^{-2}}{10^{11.7}} + \frac{8.7\times10^{-3}}{10^{7.21}}\right)}$$

**Chemists will recognize this as a calculation of the pH of a buffer solution for the mixture of Na_2HPO_4 @0.03 M/ℓ. and NaH_2PO_4 @8.7 x 10^{-3} M/ℓ.*

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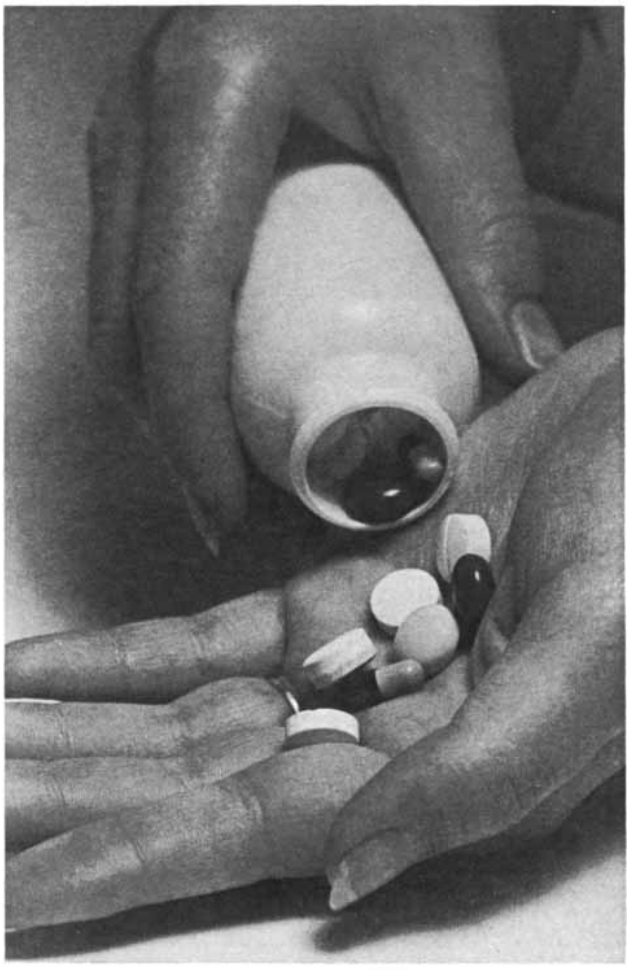

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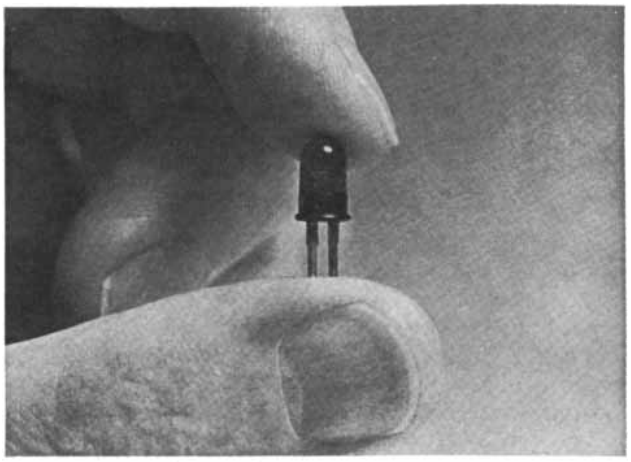

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THE AUTHORS

ARTHUR H. WESTING and E. W. PFEIFFER ("The Cratering of Indochina") are respectively professor of biology (and chairman of the department of biology) at Windham College and professor of zoology at the University of Montana. Separately and together they have made several trips to Indochina to study the environmental effects of modern methods of warfare, including the spreading of herbicides. Westing, who was graduated from Columbia College in 1950 with a degree in botany, took his master's degree and his Ph.D. in forestry at Yale University. He worked as a forester and teacher of forestry for a number of years before going to Windham College in 1966. Pfeiffer, who has been at the Missoula campus of the University of Montana since 1959, was graduated from Cornell University in 1937. He obtained his master's degree at the University of British Columbia in 1948 and his Ph.D. from the University of California at Berkeley in 1954.

P. A. MERTON ("How We Control the Contraction of Our Muscles") is lecturer in physiology at the University of Cambridge and a Fellow of Trinity College. Educated at Trinity and at St. Thomas's Hospital, he did research at the National Hospital, Queen Square, London, from 1946 until he went to Cambridge in 1957. "In 1952," he writes, "in order to work with Ragnar Granit at the Royal Caroline Institute, I sailed in a yacht to Stockholm and lived on board in the harbor for two years. This was the most exciting episode in my career." Merton adds that he subscribes to the view that "most scientists have only one new idea in their lives; if you have two or more, you are a Helmholtz. I had my idea in 1948 and write about it here."

ROGER PENROSE ("Black Holes") is professor of mathematics at Birkbeck College of the University of London. His interest in theoretical physics stems from a period (1957 to 1960) when he was a research fellow at St. John's College of the University of Cambridge, where in 1957 he obtained his Ph.D. He did his undergraduate work at University College London. Penrose comes from a scholarly family: his father is Lionel S. Penrose, emeritus professor of human genetics at the University of London; his brother Oliver is professor of mathematics at the Open University; his brother Jonathan is lecturer in psychology at Enfield Technical College and has frequently won the British chess championship, and his sister, Mrs. Shirley V. Hodgeson, is a physician. Penrose writes that most of his present research work is concerned with developing "twistor theory," which "provides an alternative framework for the description of basic physical processes." He says his hobbies include reading science fiction and making things with or for his three young sons. At one time, partly in collaboration with his father, he was involved in constructing geometric puzzles.

JOHN F. DEWEY ("Plate Tectonics") is professor of geology at the State University of New York at Albany. Born in England, he received his bachelor's degree and his Ph.D. at the University of London. He taught at the University of Manchester from 1960 to 1964 and at the University of Cambridge from 1964 to 1970, taking up his position at Albany in 1971. His research interests include the role of plate tectonics in the earth's history, identification of criteria by which old plate margins can be recognized, the evolution of mountain belts, and field research in the Appalachians, mainly in Newfoundland. He lists his outside interests as "gymnastics and skiing."

STANLEY J. DUDRICK and JONATHAN E. RHOADS ("Total Intravenous Feeding") are at the School of Medicine of the University of Pennsylvania; Dudrick is associate professor of surgery and Rhoads is professor of surgery and chairman of the department of surgery. Dudrick, who also is chief of surgery in the University of Pennsylvania Division of the Veterans Administration Hospital in Philadelphia, was graduated from Franklin and Marshall College in 1957 and obtained his M.D. at the University of Pennsylvania in 1961. Rhoads was graduated from Haverford College in 1928, received his M.D. at the Johns Hopkins University School of Medicine in 1932 and obtained the degree of D.Sc. (Med.) at the University of Pennsylvania's Graduate School of Medicine in 1940. He began his association with the University of Pennsylvania in 1932, when he became an intern at the university's hospital. His father was also a physician, as are two of his sons.

NORMAN HAMMOND ("The Planning of a Maya Ceremonial Center") is Leverhulme Research Fellow of the Centre of Latin American Studies at the University of Cambridge. He is also director of a project involving the investigation of the origins of classic Maya civilization and will be doing fieldwork in connection with the project during the coming year.

HAROLD C. FRITTS ("Tree Rings and Climate") is professor of dendrochronology at the University of Arizona. "I am basically a plant ecologist," he writes, "and conducted my first tree-growth research on a beech-maple forest in central Ohio. My interest in climate and meteorology along with investigation of tree growth led me to my present work. I spend leisure time around my home working on desert landscaping and am active in our local community school program, which is aimed at making the public schools serve all ages." Fritts was graduated from Oberlin College in 1951 and did his graduate work at Ohio State University, where he obtained his Ph.D. (in botany) in 1956. He taught botany at Eastern Illinois University for four years before going to the University of Arizona in 1960. He is associated with the university's Laboratory of Tree-Ring Research.

JACQUES ICKX ("The Great Automobile Race of 1895") is a free-lance automobile journalist and, as he puts it, "father of two gifted sons: Pascal, who passed the examination for an international pilot's license in January, 1949, at the age of 12 years and 10 months, and Jacky, Grand Prix driver and No. 1 challenger to Jackie Stewart" in automobile racing. Ickx himself was for some years a motorcyclist, winning in 1939 the motorcycle championship of Belgium. He started writing about automobiles in 1928, suspending the activity only during the German occupation of Belgium from 1940 to 1945, during which time he conducted a business in antiques. Concerning how he came to study the origins of the automobile, he writes: "I was an admirer of Teilhard de Chardin and particularly of Jacques Lafitte, a philosopher who transposed the theories of evolution to the sphere of machines. It occurred to me in 1958 that by studying a history so recent as the birth and so brief as the mechanical evolution of the automobile, one could perhaps test and eventually verify the theories of Teilhard and of Lafitte." Ickx is the author of *Ainsi naquit l'automobile* (*Thus was Born the Automobile*), which was published in 1962 and in a rewritten second edition in 1971. Ickx notes that he lives "by choice at the Priory of the Hermit [near Brussels], which is classified as a landmark dating to 1399."

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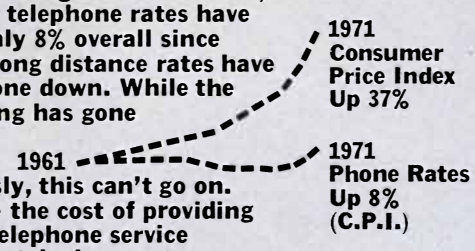

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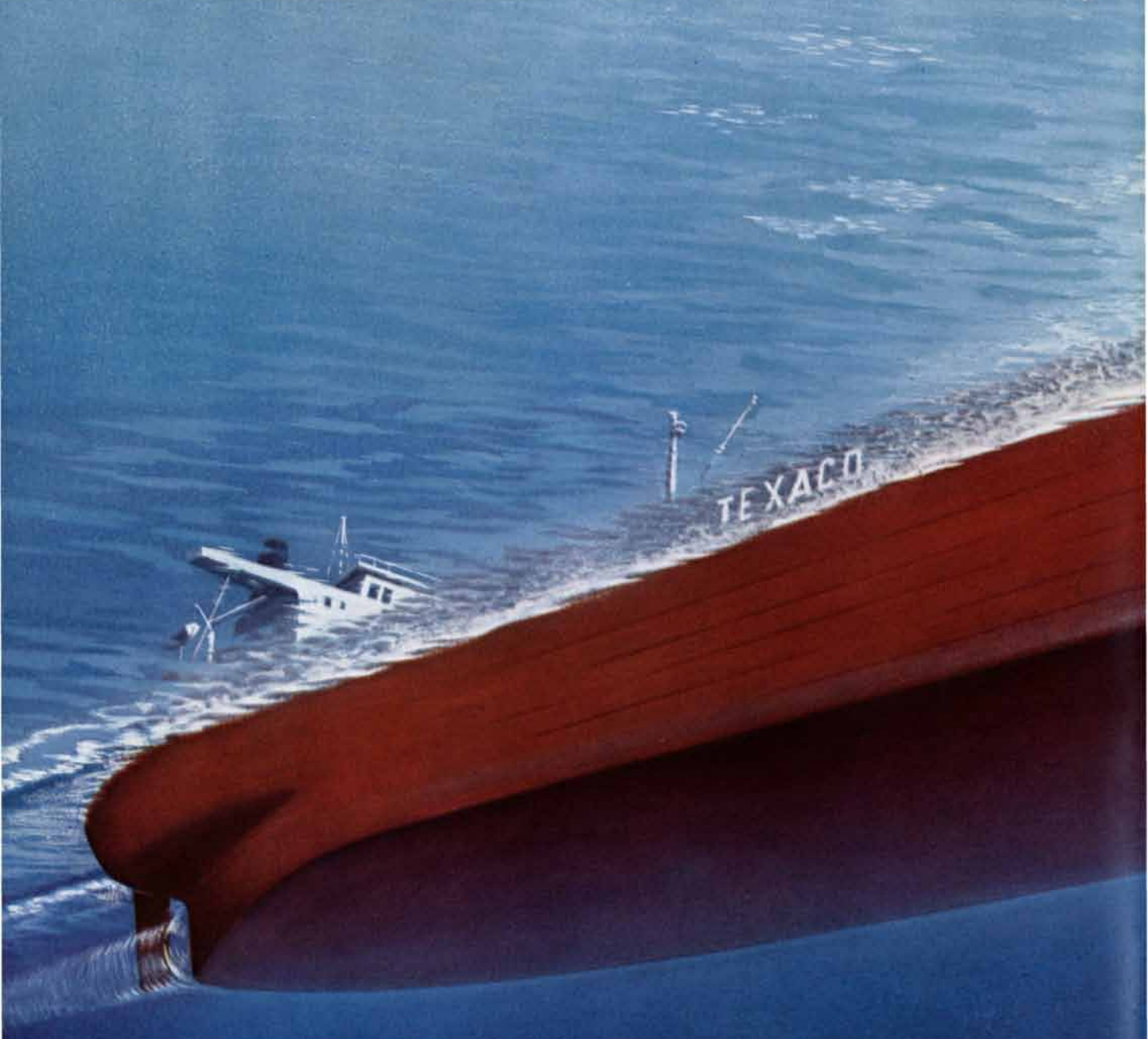

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CRATERED MANGROVE FOREST in Gia Dinh province in South Vietnam was photographed from a helicopter by Westing during a trip made by the authors in August, 1971, on behalf of the Scientists' Institute for Public Information. Heavy bombing damages trees in three ways: outright destruction, riddling of the timber by missile fragments and weakening of the trees through subsequent infection. In addition this particular tract of forest had been subjected to an earlier attack with herbicides. Water-filled craters in both timberlands and croplands have greatly multiplied the available breeding areas for disease-carrying mosquitoes.

CRATERED CROPLANDS in Long An province in South Vietnam were photographed from a helicopter by Gordon H. Orians of the University of Washington, who accompanied Pfeiffer on his first inspection tour of the war zone in March, 1969. The craters were made by 500-pound bombs dropped from B-52's. Such craters, which in this region remain filled with water during much or all of the year, are unsuitable for rice cultivation. For this reason, and because of the dangers of unexploded munitions and sharp bomb fragments buried in the ground, Vietnamese farmers have generally abandoned croplands that have been pocked by craters.

Established 1845 SCIENTIFIC AMERICAN May 1972 Volume 226 Number 5

The Cratering of Indochina

The countries of the area are pitted with an estimated 26 million bomb and shell craters. What are the long-term ecological effects of this massive physical alteration of the terrain likely to be?

by Arthur H. Westing and E. W. Pfeiffer

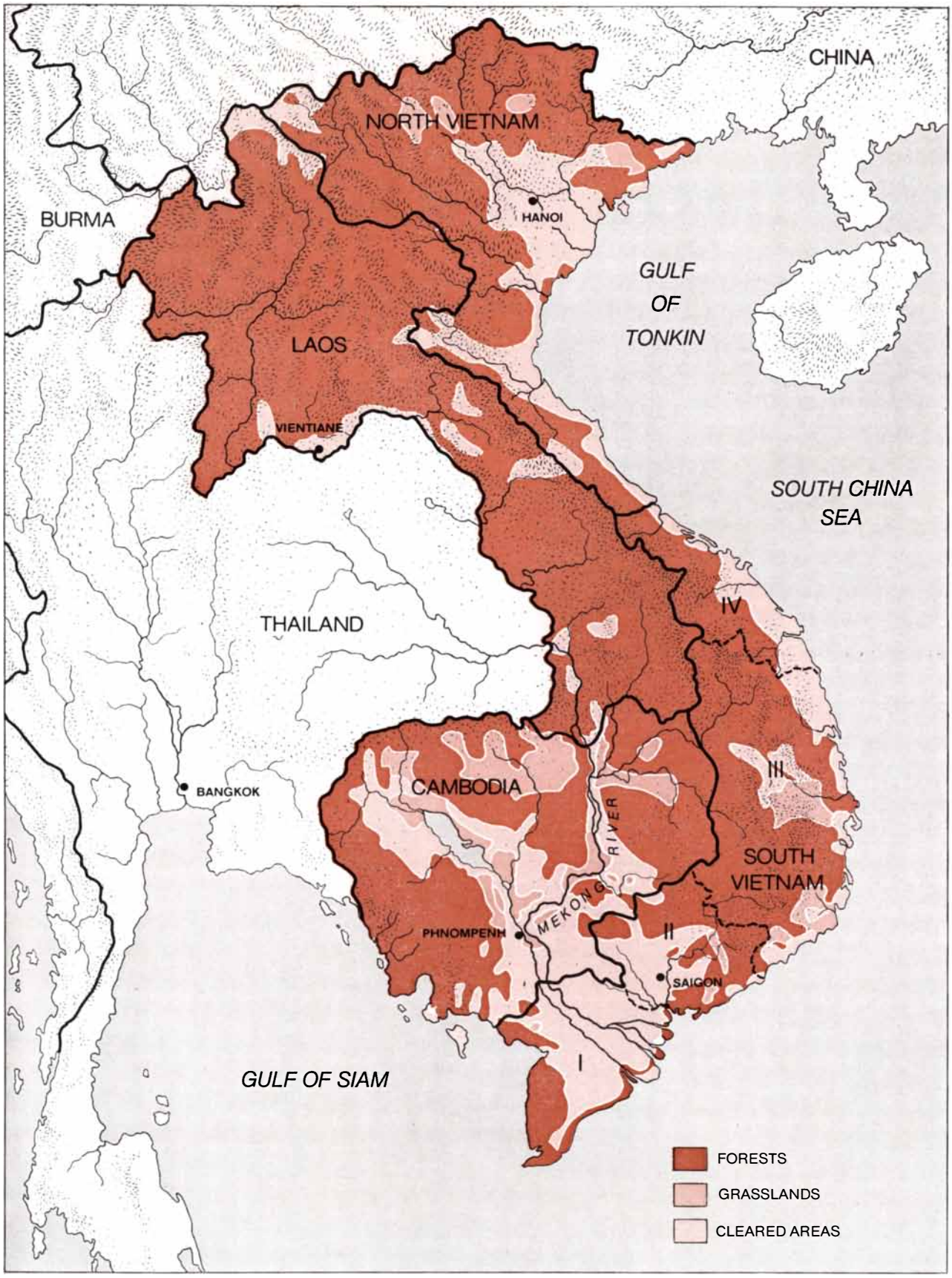
The unprecedented use of herbicides on a massive scale as an instrument of war in Vietnam has prompted several studies of the probable long-term effects of these chemical agents on the land of Indochina. Much less attention has been paid to the effects of the tearing up of the land by bombing and shelling. Yet the released tonnage statistics alone suggest that these effects must be sizable. In the seven-year period from 1965 to 1971 the area of Indochina, a region slightly larger than Texas, was bombarded by a tonnage of munitions amounting to approximately twice the total used by the U.S. in all the theaters of World War II.

During three tours of war zones of Indochina to assess damage done to the environment by herbicides, we became increasingly conscious of the ubiquitous scarring of the landscape by bomb and shell craters. From the air some areas in Vietnam looked like photographs of the moon. How would this cratering of the land affect life and the ecology in Indochina when its people attempted to pick up normal living after the war? It seemed that the physical alteration of the terrain by bombing might have created long-range problems fully as serious as those produced by the defoliation campaign (which had attacked more than five million acres of forest and cropland in Vietnam). In order to initiate investigation of the crater problems, the two of us went to Vietnam for a preliminary study in behalf of the Scientists' Institute for Public Information in August, 1971. From the U.S. Department of Defense we collected the limited information that was available to the public about the expenditures of munitions in Indochina. Then in the field we surveyed bombed areas on the ground and from the air (in helicopters) and interviewed many people, including farmers, lumbermen and other persons who had observed various effects of the bombing on the land, the economy and various occupations.

In the seven years between 1965 and 1971 the U.S. military forces exploded 26 billion pounds (13 million tons) of munitions in Indochina, half from the air and half from weapons on the ground. This staggering weight of ordnance amounts to the energy of 450 Hiroshima nuclear bombs. For the area and people of Indochina as a whole it represents an average of 142 pounds of explosive per acre of land and 584 pounds per person. It means that over the seven-year period the average rate of detonation was 118 pounds per second. These average figures, however, give no indication of the actual concentration; most of the bombardment was concentrated in time (within the years from 1967 on) and in area. Of the 26 billion pounds, 21 billion were exploded within South Vietnam, one billion in North Vietnam and 2.6 billion in southern Laos. The bombardment in South Vietnam represented an overall average of 497 pounds per acre and 1,215 pounds per person; the major part, however, was focused on two regions: the five northern provinces and the region around Saigon.

Craters pock every area of South Vietnam: forests, swamps, fields, paddies, roadsides. Certain areas, notably the "free fire," or "specified strike," zones, show severe cratering. We personally observed large areas that had been subjected to intensive transformation of the landscape in Tay Ninh, Long Khanh, Gia Dinh, Hau Nghia and Binh Duong provinces around Saigon and Quang Ngai, Quang Tin and Quang Nam provinces of the northern part of the country. And of course the concentration of craters is particularly marked in areas such as the demilitarized zone (DMZ) between North Vietnam and South Vietnam and the supply trails in southern Laos.

We were able to visit on foot an area in the Mekong Delta that had been until fairly recently a free-fire zone. The area was near the hamlet of Hoi Son about 30 miles south of My Tho. Farmers were being resettled there on their previously fought-over land because senior officials considered the region fairly secure. (The degree of security became evident during our stay when U.S. aircraft were observed rocketing and strafing only a few miles away.) Several families that had left the area a decade earlier because of fighting were interviewed, and they took us to three craters that they said had been made in 1967.

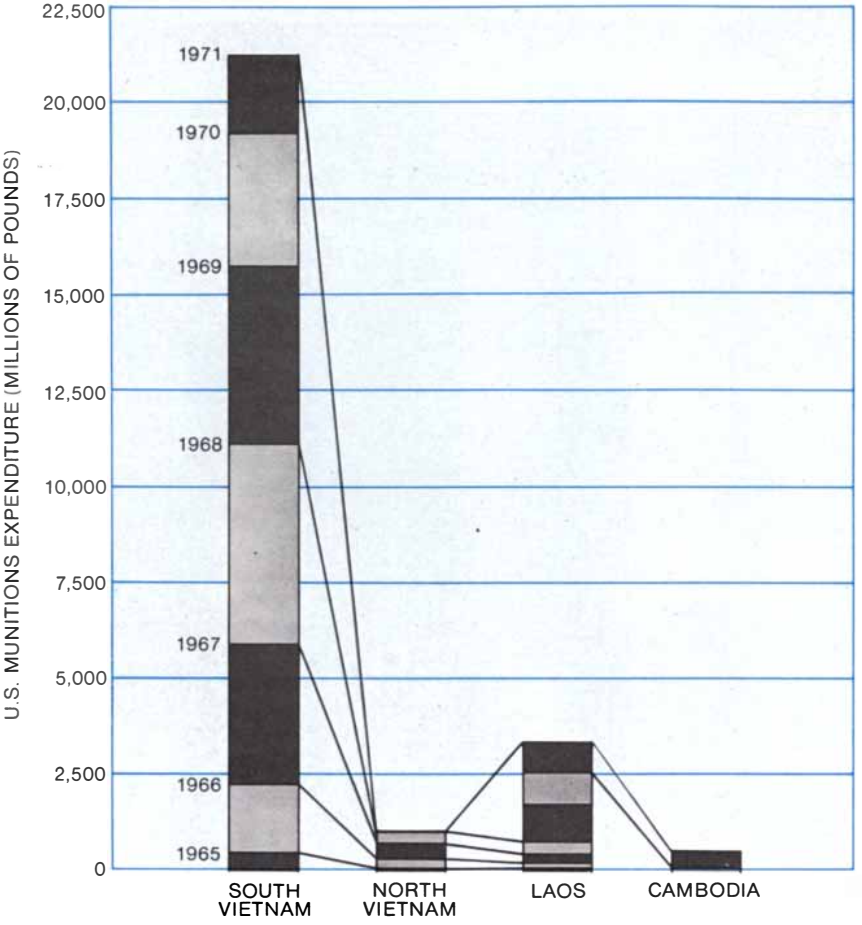


MAP OF INDOCHINA shows the general topography of the region and principal vegetation zones (*see key at lower right*). The U.S. armed forces regard South Vietnam as being divided into four major military regions, which are designated by Roman numerals.

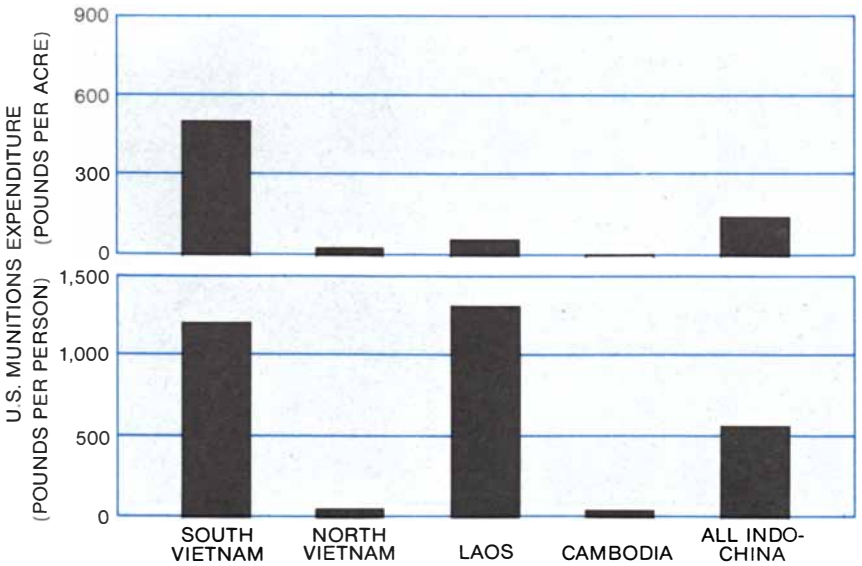
The craters had probably been produced by 500-pound bombs dropped by fighter-bombers. Each crater was about 30 feet in diameter, filled with water, and at the time of our visit was about five feet deep in the center. The entire immediate area had been a rice paddy, but during the years when no cultivation had occurred, the rice had been replaced by a very tall reed, genus *Phragmites,* which surrounded the crater at a distance of 10 to 20 feet. Growing from the rim of the craters and into the reeds was a species of relatively short grass, *Brachiaria,* and a taller grass, *Scirpus.* The farmers were growing seed rice near the craters and were plowing under the reeds and grasses in preparation for planting rice. It was obvious that they could not use the cratered areas for rice cultivation because the water was much too deep. The only apparent solution was to bring in soil from elsewhere, but this was obviously not practical.

We also observed at close hand many craters on the flat terrace lands northwest of Saigon that had previously supported an evergreen hardwood forest. In this area the craters generally contain no water during the dry season, so that their natural history is considerably different from the history of the craters of the Delta region that are permanently filled with water. The craters were very numerous in this area; there was at least one every 100 feet. Each crater was 20 to 40 feet across and five to 20 feet deep. There were many generations of craters from different air strikes. The most recent ones were bare of vegetation but contained some rainwater. (We observed these craters in the wet season.) In the older craters a few sprigs of grass, probably *Imperata,* were sprouting in the center. As the craters age grass grows radially, eventually covering the bottom to meet vines trailing down from the peripheral vegetation. There is some filling of old craters with soil washed down from the sides, but this is limited because old craters almost completely covered with grass were still five to 10 feet deep. They thus became permanent features of the landscape.

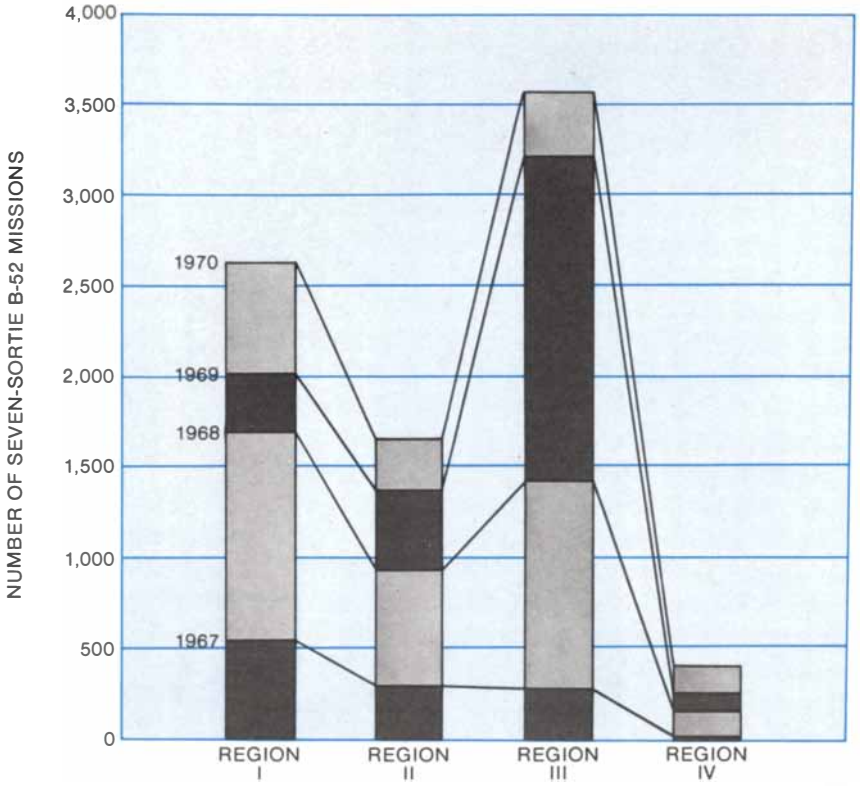
From the data available to us on the quantity of munitions expended we calculated tentative estimates of the total area affected by cratering and other damage to the land. For these estimates we had to make some very free and general assumptions. For example, we assume that about half (by weight) of the total amount of munitions employed in Indochina consisted of bombs, shells and other missiles that would produce cra-



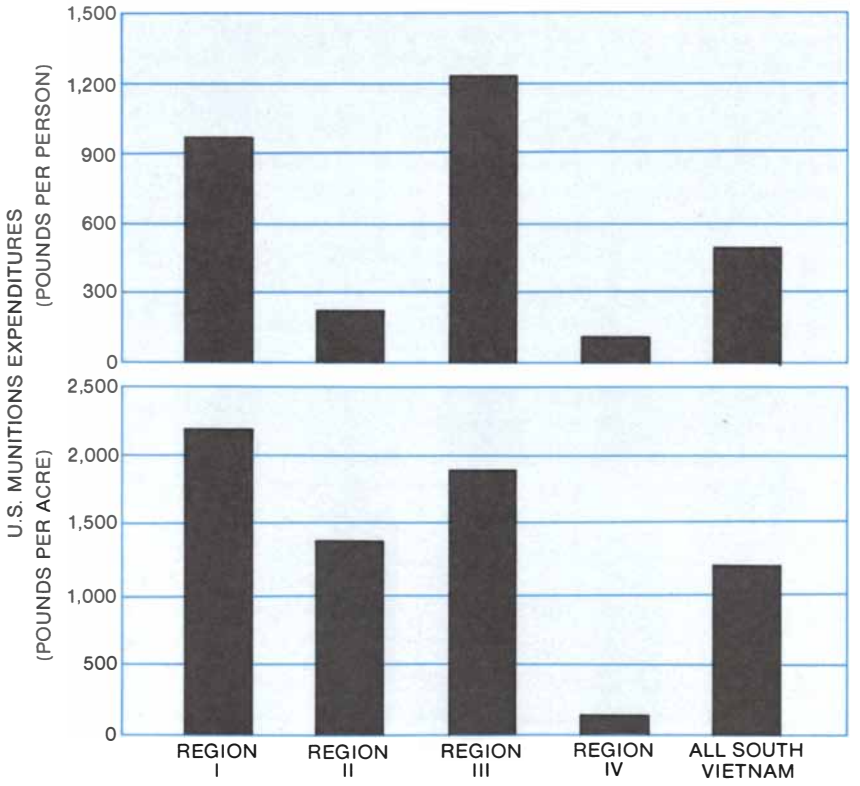
TOTAL U.S. MUNITIONS EXPENDITURES in Indochina for the seven-year period from 1965 through 1971 are broken down by country and by year in this bar chart. The bar for North Vietnam omits 1969 and 1970, years in which large-scale U.S. bombing of that country was suspended. The bar for Cambodia begins with 1970, the year in which U.S. and Republic of Vietnam forces launched a large-scale invasion of that country. The data were gathered from scattered Department of Defense sources in large part by Raphael Littauer and associates at Cornell University. (For lack of sufficient information all ground-based munitions, which comprise about half of the total, have been assigned to South Vietnam.)



IMPACT of total U.S. munitions expenditures on the land and people of Indochina is suggested by these two bar charts. The figures shown were calculated by the authors from the available data on the total quantity of munitions expended by U.S. forces from 1965 through 1971, together with estimates of the areas and populations of recipient countries.



B-52 MISSIONS over South Vietnam from 1967 through 1970 are broken down by military region and by year in this bar chart, based on data gathered by Littauer and the authors. A typical B-52 mission is assumed to comprise seven planes on the average and thus to deliver a total of 756 500-pound bombs. Breakdowns for other years were not available.



ALTERNATIVE METHOD of estimating the impact of total U.S. munitions expenditures from 1965 to 1971 on the land and inhabitants of South Vietnam by region was devised by the authors on the assumption that the relative B-52 activity from 1967 through 1971 among the four military regions of the country was proportional to overall munitions expenditures.

ters. We assume further that on the average each of the crater-producing missiles was equivalent to a 500-pound bomb and formed a crater 30 feet in diameter and 15 feet deep, displacing 131 cubic yards of earth. (A large proportion of the cratering has been produced by B-52 bomber raids; each of these big planes typically carries 108 500-pound bombs.) We also estimate that the fragments from each crater-producing missile were spread over an area of 1.25 acres.

On the basis of these assumptions (some of which are supported by actual measurements) we estimate that the number of craters produced in Indochina by the bombardments from 1965 to 1971 totaled some 26 million, covering a total area of 423,000 acres and representing a total displacement of about 3.4 billion cubic yards of earth. The area of missile-fragment spread totals 32.6 million acres, if we disregard overlap. Again we note that South Vietnam has borne the brunt of this damage. In the period mentioned (through 1971) South Vietnam is estimated to have received about 21 million craters, covering all together about 345,000 acres, and to have had millions of acres contaminated by missile fragments, even allowing for overlap. The total area of the country is 42.8 million acres.

Let us now examine some specific effects, for the present and for the future, of this massive application of "landscape management" by high explosives. There is evidence from previous wars that the effects will be long-lasting. A decade after the end of World War II the craters of heavily shelled areas on Okinawa were still barren of vegetation and reddened by rusting shell fragments. On Eniwetok craters were clearly in evidence two decades after the war. Four decades after World War I vegetation in the Negev desert of Israel outlined the craters from that war, and even in France's Verdun area many of the World War I craters are still clearly visible and in some cases to this day are devoid of vegetation.

To begin with, we can see that the displacement and scattering of soil and subsoil from the craters in Indochina have given rise to harmful physical consequences. (Over the seven years the displacement of soil by bombardment in Indochina proceeded at a rate of nearly 1,000 cubic yards of soil per minute.) In hilly terrain the tearing up of the soil promotes erosion. In Indochina, where some of the soil is vulnerable to laterization (hardening to a bricklike state), the removal of vegetation and humus may

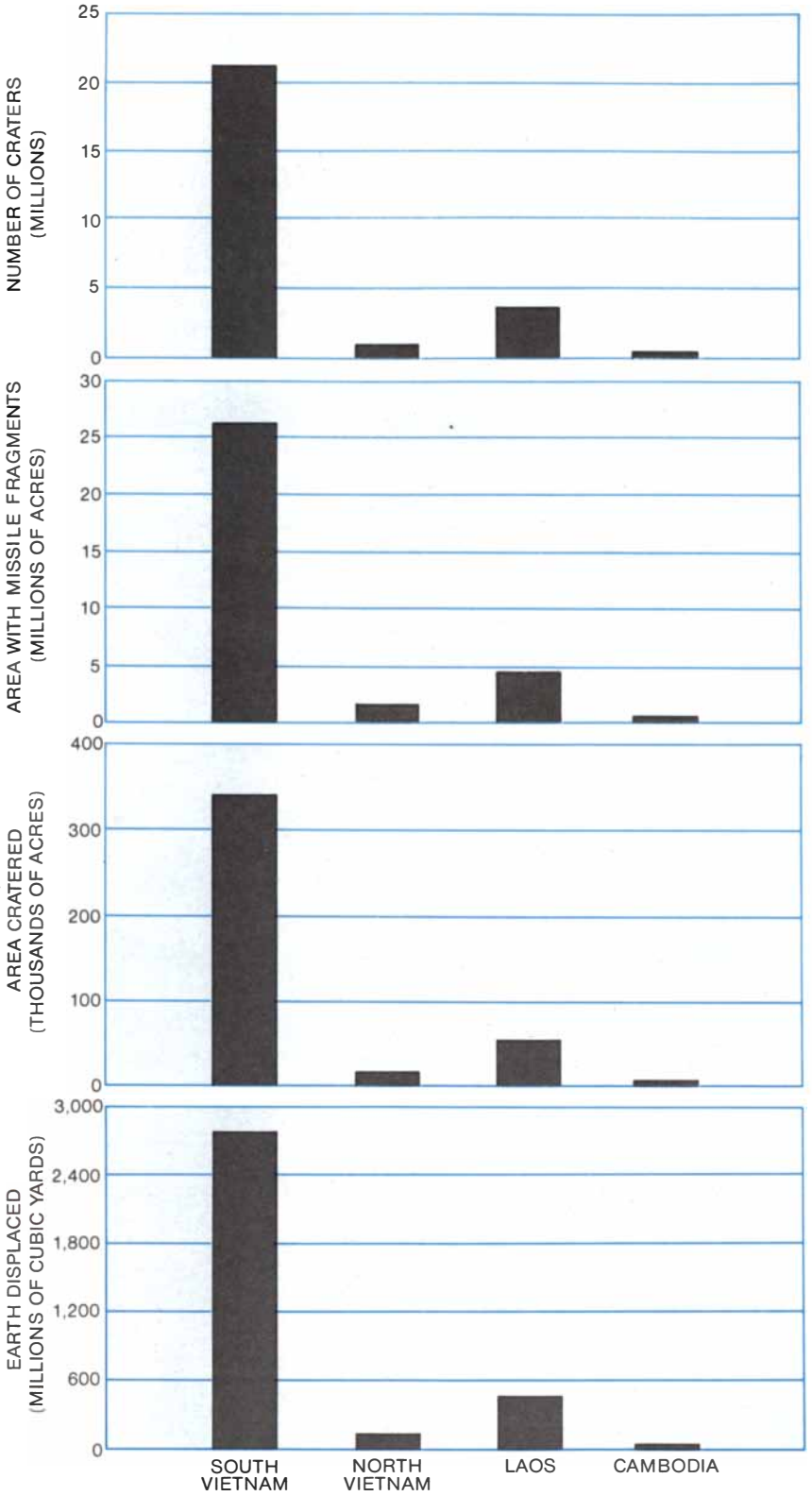
make the area in and around craters permanently barren. At the least it has resulted in colonization of cratered regions by weedy, worthless grasses and shrubs. Furthermore, the deep craters have made many areas almost impassable for travel.

Many of the craters, particularly in the Delta and coastal regions, have penetrated the water table and remain filled with water during much or all of the year. They have thereby probably become breeding grounds for mosquitoes, greatly increasing the hazards of malaria and dengue fever for the population. Reports by military authorities indeed confirm that "malaria has been causing increasing concern in Vietnam" and has spread to previously unafflicted areas.

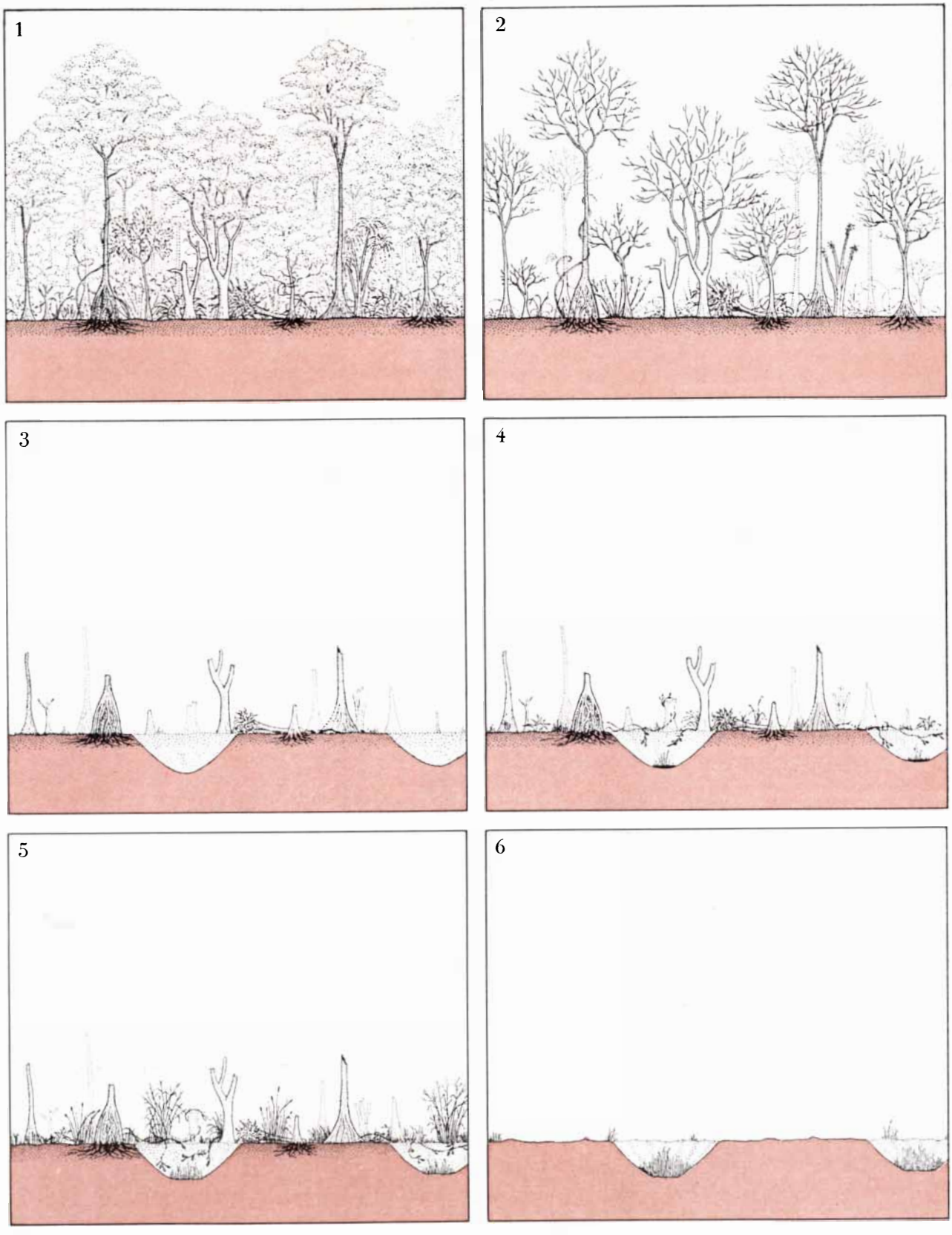
The impact of cratering on agriculture has been substantial. Farmers in South Vietnam, notably in the Mekong Delta, have been reluctant or unable to attempt to reclaim rice paddies or other farmlands that have been pocked by craters. One of the important deterrents is the presence of unexploded munitions buried in the ground. A number of farmers have been killed by the detonation of such shells or bombs by their plows. Moreover, the ubiquitous missile fragments in the ground cut the hooves of the water buffaloes used as draft animals, causing infection and death of the animals. The unexploded bombs and shells lying about in the soil of Indochina are known to number several hundred thousand. Bombing has also disrupted rice-growing in Indochina by breaking up many of the intricate irrigation systems, and in some areas near the seacoast it has opened the land to encroachment by salt water.

The timber industry of South Vietnam, potentially one of the most important elements in the region's predominantly agricultural economy, has been particularly hard hit by the bombing. It has catastrophically slashed the values of the once prime timberlands northwest and northeast of Saigon, for example. The heavy shelling and bombing have damaged the trees in three ways: outright destruction, riddling of the timber by missile fragments and subsequent weakening of the trees through infection by wood-rotting fungi.

The forests have been bombarded by ordnance so intensively that the trees are filled with metal shards; one millowner told us that four out of five logs he receives have metal in them. Although the sawmill operators make laborious efforts to chop out the pieces of metal, they are only partly successful, with the result that they have a high



ECOLOGICAL IMPACT of bombardment on the countries of Indochina for the seven-year period from 1965 through 1971 is assessed in this illustration in terms of number of craters, area covered by bomb and shell fragments, area cratered and amount of earth displaced. Owing to the unavailability of precise information from the Department of Defense, the authors were forced to make the following assumptions: that half of all the air and ground munitions expended in Indochina have been of the kind that produce craters, and that these are all the equivalent of 500-pound bombs. (Although the number of craters is thereby underestimated, their combined dimensions and impact probably are not.) They also assumed that the zone of flying metal fragments associated with each crater is 1.25 acres. Finally, they assumed that each crater is a cone 30 feet in diameter and 15 feet deep.

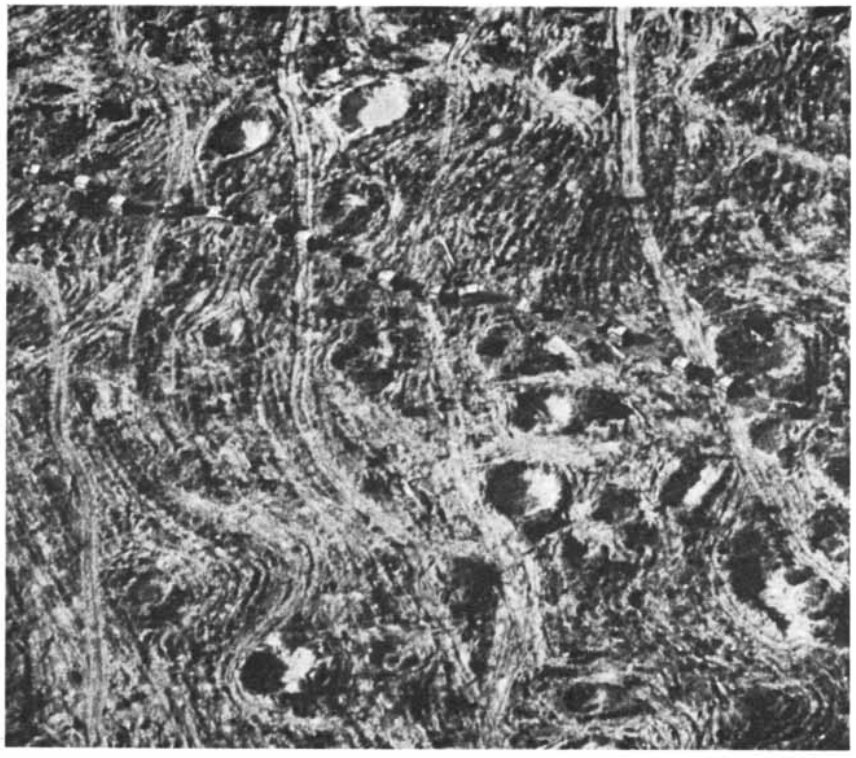


EFFECTS of defoliation, bombing and plowing on a typical evergreen hardwood forest in South Vietnam (*1*) are summarized in this sequence of highly idealized drawings. Most mature trees in such a forest are killed by defoliation (*2*), leaving a thick understory of useless broad-leafed brush, vines, bamboo and tall grass. Comparatively recent craters are bare of vegetation but often contain a little rainwater during the wet season (*3*). Somewhat later a few sprigs of grass, probably cogon grass (*Imperata*), sprout in the middle (*4*). As the crater ages further the grass grows radially, covering the bottom to meet vines trailing down from the peripheral vegetation (*5*). There is some filling of the crater with soil washed down from the sides, but this is limited. Broad-leafed plants generally do not invade these holes. Plowing is occasionally added to clear vegetation remaining between the craters (*6*).

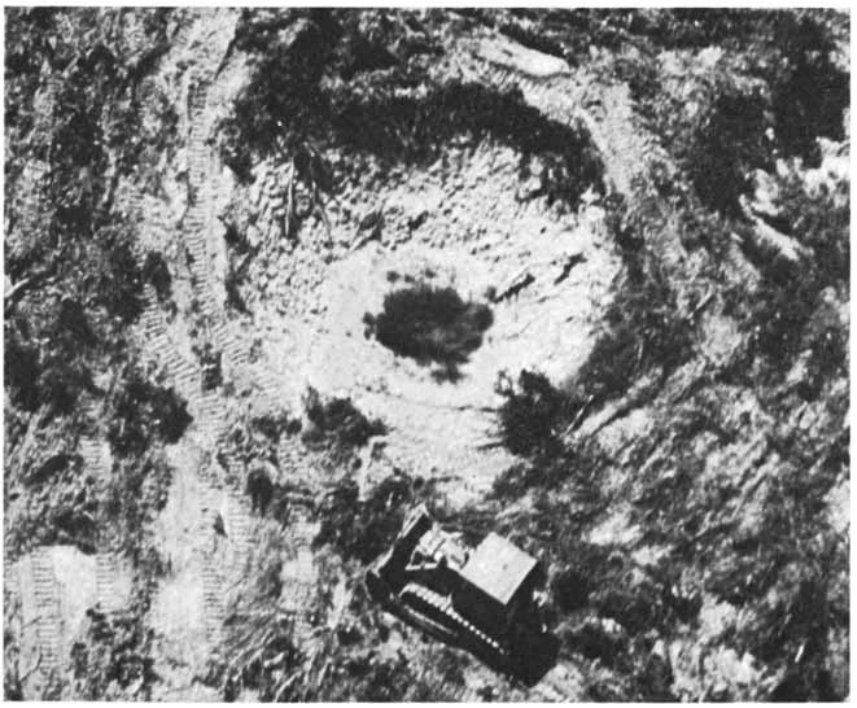
rate of destruction of their saw blades by still embedded metal. In trees left standing the missile-fragment wounds provide ready entry for fungal rot. In some tree species the rot progresses so rapidly that if they are not harvested immediately after the metal attack they soon become almost worthless. Apparently the main South Vietnamese timber trees lose about 50 percent of their value in two or three years from this cause. Rubber trees are particularly susceptible to the fungal rot initiated by missile-fragment wounds; they become so weakened that they are felled by any high wind. A French official of a rubber plantation told us he had lost 80 percent of his trees within two years after a bombardment of his plantation.

Loggers in the battle zones of South Vietnam find that the damaging of timber by munitions is causing them a loss of more than 30 percent in the price received for the logs (although the severance tax remains the same). In addition the profusion of craters impedes the hauling of their logs to the mill. Often they must cut the logs to a short length (instead of the desirable 90 feet that is possible under normal circumstances) to allow sufficient maneuverability to skid them around the craters. During a survey in a high-flying helicopter of a mountain forest near Da Nang we saw many craters on the mountainside and along the ridges with severe accompanying erosion; they had been produced by a single B-52 raid about a year and a half earlier. We also observed another significant type of damage: large areas of the forest had been burned out, apparently by incendiary attacks with napalm, white phosphorus and flares.

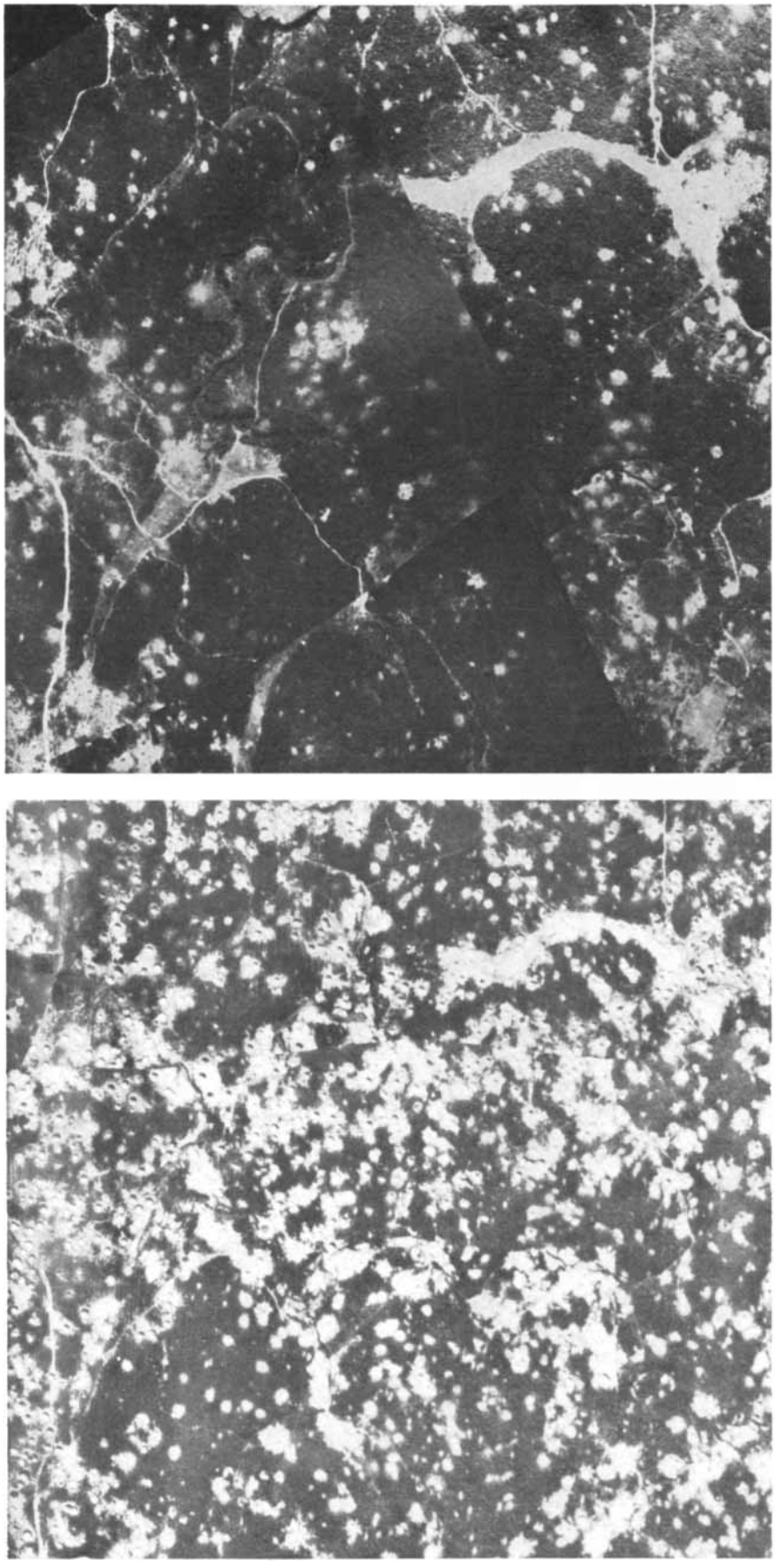
Bombardment and defoliation are by no means the only methods used by the U.S. military in its struggle with vegetation in Indochina. Beginning in the mid-1960's a vast program of systematic forest bulldozing has been developed. The employment of massed tractors organized into companies for extensive forest clearing had apparently replaced the use of herbicides to deny forest cover and sanctuary to the other side. The effectiveness of the tractors, called Rome plows, is in some ways clearly superior to that of chemicals and is probably more destructive to the environment. When we visited a land-clearing operation in August, 1971, we watched about 30 such plows (20-ton Caterpillar tractors fitted with massive 11-foot-wide, 2.5-ton plow blades and with 14 tons of armor plate) scrape clean the remaining few areas of the Boi Loi Woods northwest of Saigon. We learned that in the



LARGE PLOWS have been used by the U.S. Army in South Vietnam to destroy vast stretches of vegetation in order to deny cover to the enemy. According to information released by the Army, at least three-quarters of a million acres were cleared in this manner through mid-1971, and this total is being added to at the rate of about 1,000 acres per day. The swaths cut by such plows, often scraped down to the infertile subsoil, are invaded by cogon grass or remain barren and subject to erosion. In this photograph, made by Westing in August, 1971, a line of heavy vehicles, including both plows and tanks, can be seen wending its way across a thoroughly cratered and plowed landscape in Tay Ninh province.



CLOSEUP AERIAL VIEW shows a U.S. Army plow clearing the area around a large B-52 bomb crater. The machine is basically a 20-ton Caterpillar tractor fitted with a massive 11-foot-wide, 2.5-ton plow blade and with 14 tons of armor plate. Crater is several years old.



HIGH-ALTITUDE PHOTOGRAPHIC MOSAICS of an area in the demilitarized zone between North Vietnam and South Vietnam show the scene before (*top*) and after (*bottom*) a period of intense B-52 and tactical air strikes in 1967. The photographs were made by the U.S. Air Force. The larger bomb craters measure between 20 and 40 feet in diameter.

26 days prior to our visit the company had cleared 6,037 acres. Four other companies were also in operation and these five units had cleared a total of 750,000 acres as of August, 1971. We visited an area that had been plowed several years previously and it had regrown to cogon grass (*Imperata*), making further successional stages to the original hardwood forest very unlikely.

A study by U.S. agents has determined that about 10 percent of the agricultural land of South Vietnam has had to be abandoned because of the destruction wrought by bombardment and other weapons used in this war. It has been a war against the land as much as against armies. Indeed, it appears that one of the main strategies of our military effort has been to disrupt and destroy the social and economic fabric of rural, agricultural Vietnam in order to drive the peasant population into areas under central control and to deprive the guerrilla enemy of a power base.

Only about 5 to 8 percent of the U.S. bombing missions in Indochina have been directed at tactical military targets, that is, in direct support of troops. The rest of the bombing missions are described as "harassing" or "interdiction" attacks. They are also referred to as strategic bombing missions. Whereas the targets of strategic bombing in World War II were the factories, port cities, railroads and so forth of the enemy, in the Indochina war the strategic targets are the land and forests of Indochina because they give cover and sanctuary to the other side. It is important to note here that whereas factories, ports and other man-made sources of production can be rapidly rebuilt, as demonstrated in Europe and Japan, it is doubtful that many of the forests and lands of Indochina can be rehabilitated in the foreseeable future.

From 1966 on the B-52's carried out incessant attacks on a schedule of almost daily missions. From an altitude of 30,000 feet, where they are usually unheard and unseen from the ground, they have been sowing systematic destruction. A typical B-52 mission, comprising seven planes on the average, delivers 756 500-pound bombs in a pattern that saturates an area about half a mile wide and three miles long, that is, nearly 1,000 acres. Thus on a schedule of four or five missions per day of seven sorties each, such as was followed during 1971, the B-52's alone were creating about 100,000 new craters each month. Unfortunately the release of air-war data is now severely restricted.

The cumulative impact of the munitions attack on the land has to be seen to be grasped fully. Reports by military observers speak of the landscape's being "torn as if by an angry giant," and of areas of the green delta land's being pulverized into a "gray porridge." Our brief survey has only suggested some of the grim consequences for the present and future life of the inhabitants of Indochina. Still to be assessed are the effects of the persisting bombardment on the people's habitations, on the animal life and general ecology of the region. The damage caused by the large-scale disorganization of the environment may be felt for centuries.

Meanwhile the steady bombardment and shattering of the land, shielded from the Western world's view and concern by the wide Pacific Ocean and the supposed "winding down" of the war, goes on with no end in sight.

Senator Gaylord Nelson of Wisconsin has introduced in the Senate a bill to provide for a study by the National Academy of Sciences "to assess the extent of the damage done to the environment of South Vietnam, Laos and Cambodia as the result of the operations of the Armed Forces of the United States ... and to consider plans for effectively rectifying such damage."

Senator Nelson declared:

"There is nothing in the history of warfare to compare with [what we have done in Indochina]. A 'scorched earth' policy has been a tactic of warfare throughout history, but never before has a land been so massively altered and mutilated that vast areas can never be used again or even inhabited by man or animal.... These programs should be halted immediately before further permanent damage is done to the landscape.

"Our program of defoliation, carpet bombing with B-52's and bulldozing... did not protect our soldiers or defeat the enemy, and it has done far greater damage to our ally than to the enemy.

"The cold, hard and cruel irony of it all is that South Vietnam would have been better off losing to Hanoi than winning with us. Now she faces the worst of all possible worlds with much of her land destroyed and her chances of independent survival after we leave in grave doubt at best."

PERMANENCE OF SHELL CRATERS as a feature of the landscape is demonstrated by this photograph of a large number of old shell craters in a field near Verdun in northeastern France. The photograph was made in 1964 by Alfred Eisenstaedt almost five decades after the end of the World War I Battle of Verdun. It is reproduced here with the kind permission of *Life* magazine.

How We Control the Contraction of Our Muscles

Voluntary muscular movements are driven by a servomechanism similar in many respects to the automatic feedback system employed to control power-assisted steering in an automobile

by P. A. Merton

Psychophysics is the branch of experimental science that deals with the relation between conscious mental events and physical events within and without the body. Most psychophysics is sensory psychophysics, which deals with the relation between a physical stimulus and the resulting sensation experienced by the subject. The object of sensory-psychophysical experiments is to gain understanding of the physiological mechanisms that lie between the stimulus and the sensation, and to be able to draw inferences about what goes on inside a sense organ, a nerve or the brain. Measurements of subjective sensory thresholds in any sensory mode (tactile, visual, auditory or whatever), perceptions of color matches and judgments of the pitch of a note or the direction of a sound are examples of sensory-psychophysical observations. Sensory psychophysics is an old and highly respectable subject. In the hands of such investigators as Thomas Young, Jan Purkinje, Hermann von Helmholtz, James Clerk Maxwell, Lord Rayleigh and their modern successors it has told us a great deal about vision, hearing and other senses. Young's celebrated three-color theory of color vision, published in 1802, was formulated entirely on psychophysical evidence and is the basis of modern color photography and color television.

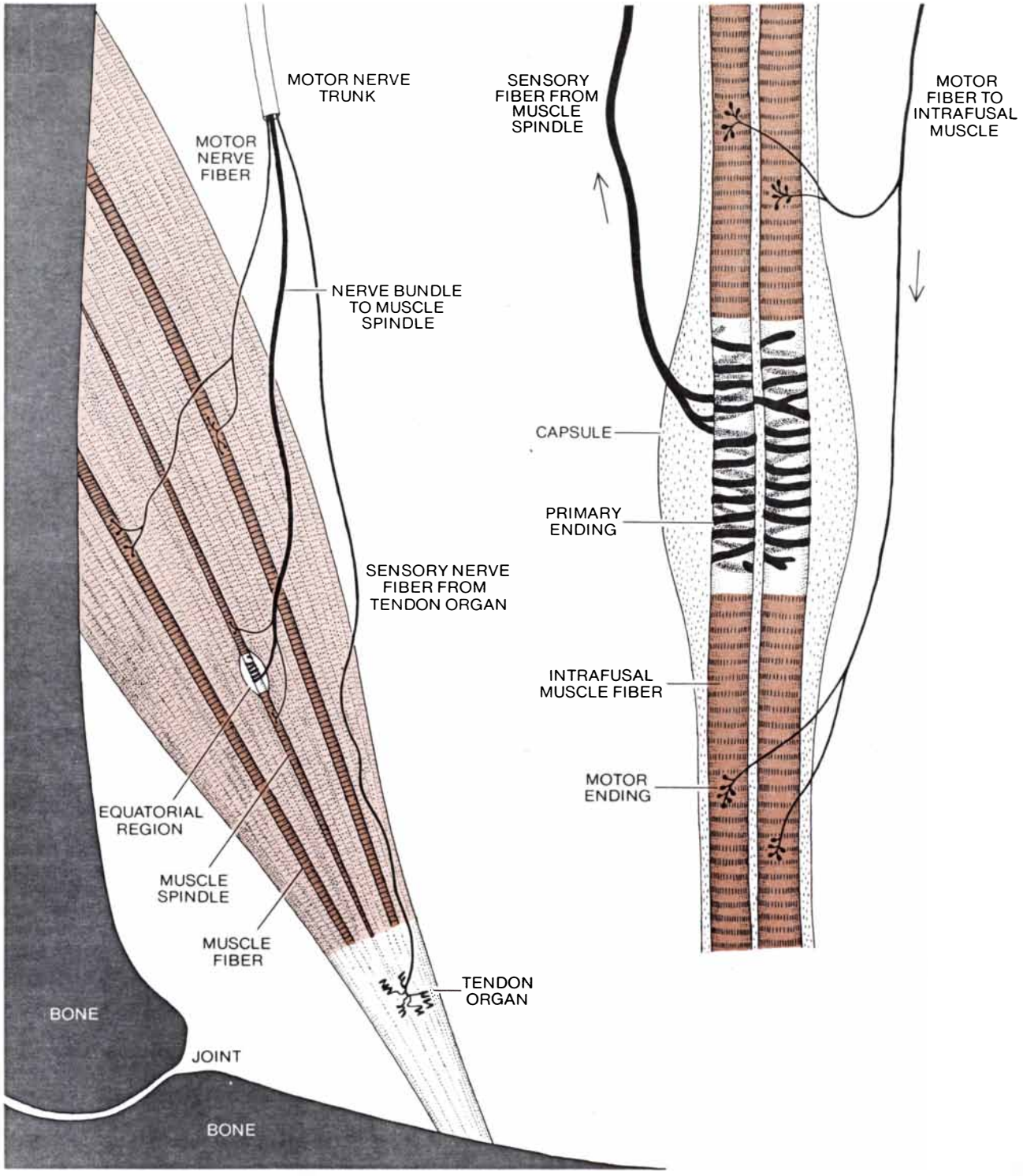
The other branch of psychophysics, motor psychophysics, does not have these credentials. It deals with the reciprocal problem, the relation between a conscious effort of will and the resulting physical movement of the body. It is just as important to know how we move as how we feel, but on the motor side much less has been achieved, partly, I suspect, because physiologists for metaphysical reasons feel that conscious volition is a faintly disreputable thing for them to have dealings with.

In sensory psychophysics it is easy to find illustrative examples of sensory phenomena that have an analytical character, that is, examples that provide some insight into sensory mechanisms, but on the motor side it is not so easy. I can think of one striking instance. A motor psychophysical fact of immense everyday importance is the individuality of a person's signature. Whenever Mr. *X* makes the appropriate volitional effort and signs his name, it always comes out the same (or enough so to be recognizable) and different from what anyone can write if he tries to write the same name. This is not an analytical observation; it is just a mysterious physiological fact, which we take for granted because we are so familiar with it. What does tell us something, however, is the further observation that if Mr. *X* takes a piece of chalk and signs his name in large letters on a blackboard, it again comes out the same. The muscles used are different but the individuality remains. From this observation we learn something about the organization of the motor system.

In this article evidence from both branches of psychophysics is taken into account, but the main object is to redress the balance in favor of the motor side. In more concrete terms we ask: What has been learned by making observations on voluntary movements in man about the physiological mechanisms that make our muscles do what we expect of them? Not, of course, very much. The title of this article is somewhat pretentious, as titles will be. There are a few definite phenomena to describe. With them we reach a new point of view, from which I hope we can see a general line of advance. I shall stick to simple movements and not come close to explaining the individuality of handwriting. (That subject was introduced partly to advertise the fact that sensory physiologists do not have all the glamor problems.) It will be useful to start by drawing an analogy between the human body and an automobile.

In the old days the steering wheel of a motorcar was directly connected to the road wheels by a series of levers and linkages, and the brake pedal similarly applied pressure directly to the brake shoes. On coming to a hill a gear-shift could be moved to engage a suitable pair of gears to climb the hill with.

Today, in order to enable the driver, no matter how frail, to control a massive vehicle with the flick of a wrist or ankle, sophisticated mechanisms have been developed to assist with steering, braking and gear-shifting. All these mechanisms have devices (sensors, we may call them) that measure some physical variable (for example brake pressure or engine revolutions) and use the "feedback" information from them to control the mechanism that assists the driver. Let us concentrate on the mechanism that assists with steering. In its essentials it works as follows. Each position of the steering wheel corresponds to a certain angle of the front road wheels that the driver would like them to assume with respect to the fore-and-aft axis of the chassis. A sensor at the bottom of the steering column detects the difference between this "demanded" position and the actual position of the road wheels. Signals from



ARRANGEMENT OF SENSE ORGANS in a typical muscle is indicated in these simplified diagrams. The proportions in the diagram at left are highly distorted. A real muscle fiber is only about a tenth of a millimeter in diameter, but it is often several centimeters long. A muscle spindle is somewhat thinner; it consists of even finer specialized structures called intrafusal muscle fibers. Only two ordinary muscle fibers and one spindle are depicted in detail; a real muscle may contain tens of thousands of muscle fibers and hundreds of spindles. The diagram at right gives an enlarged view of the equatorial region of a muscle spindle. Wrapped around the intrafusal muscle fibers are the terminations of the sensory nerve fiber; the function of these sense endings is to respond to mechanical deformation by causing nerve impulses to be sent up the sensory nerve. In the equatorial region the cross striations, which ai an indication of the presence of a contractile mechanism within tl fiber, are absent. Hence when the intrafusal fibers contract, this region is extended and excites the sensory endings, just as if tbe region had been extended by stretching the entire muscle and the spindle within it. In this diagram only two intrafusal fibers are shown; a real spindle often has half a dozen or more. Moreover, intrafusal fibers come in two distinct varieties, only one of which is shown here. Another complication is the fact that there are three distinct kinds of motor nerve to the intrafusal fibers. In a real spindle the equatorial region is also much longer than depicted here. Photomicrographs showing the innervation of a tendon organ and the equatorial region of a muscle spindle appear on page 34.

the sensor, called the misalignment detector, are used to turn on a small servomotor (from the Latin *servus,* meaning slave), which turns the road wheels in such a direction as to cancel the misalignment. Thus the road wheels are made to point in the direction the driver wants, without his having to exert himself. As he turns the steering wheel the road wheels follow automatically.

Such is power-assisted steering. An engineer calls it a follow-up servomechanism. An important point to note is that, the function of the device being to help the driver automatically, he does not want to be bothered with the details of its operation; in particular he would only be distracted from his task of keeping his eyes on the road to see where to steer if signals from the sensor were relayed to him. They give information that is relevant only to the functioning of what ought to be a completely subservient mechanism, and they should remain private to that mechanism.

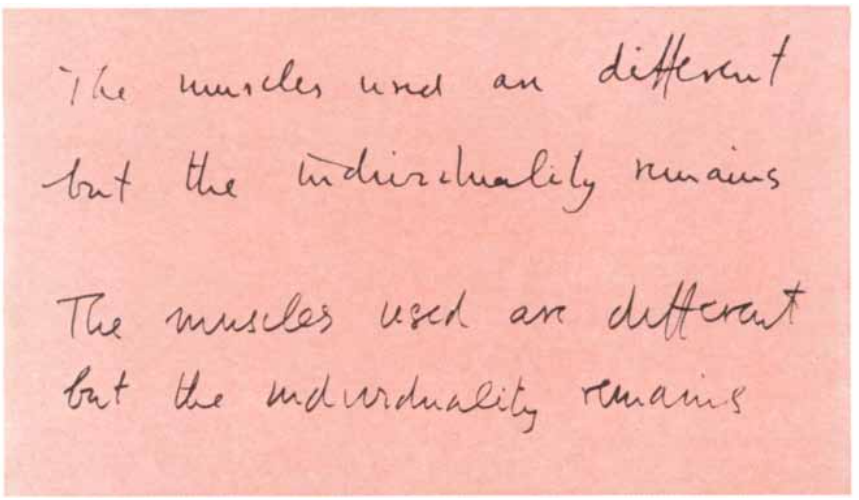
Power-assisted steering relieves the driver of physical effort only; other such devices relieve him of mental effort too. The automatic transmission, for example, does away with the need to decide when to change gear, as well as the need to perform the change. In an aircraft the automatic pilot does everything and leaves the human pilot completely free.

In the human body there are numerous automatic feedback mechanisms of this kind controlling physiological functions without any mental effort on our part. For instance, the blood pressure and the output of the heart are controlled so as to suit the current needs of the body; we are quite unaware of the functioning of these systems and of the signals from the pressure sensors in the walls of the arteries and elsewhere that are a part of them.

Such mechanisms are commonplace physiology; they are in the textbooks for medical students and nurses. When we come to muscle, however, the situation is different. To return to our analogy, in the case of the automobile we know what we want to control—direction, speed or retardation—and the problem is to design servomechanisms to help the driver, with appropriate sensors in each instance. The signals from the sensors are just part of the engineering technology, and so we do not display them on dials on the dashboard. They would only put the driver off. In the human machine we have muscles to control. How do we do it? Do the orders to contract go directly from the brain? Presumably not, since on examination it appears that muscles, like the automobile, are equipped with sensors of their own, of whose signals the owner of the muscles, like the owner of the automobile, remains unaware. Presumably, like the sensors in the automobile, they are taking part in automatic mechanisms that assist the subject in controlling his muscles. What are they helping to control? Muscle tension perhaps? It could be; some of them measure tension. Length? Others of them respond to changes in muscle length. A combination of tension and length? Sometimes tension and sometimes length? Now we see the nature of the problem. It is the inverse of the automobile designer's. We are presented with the sensors and we have to discover what the mechanism they are part of was designed to do. What precisely do we ask of our muscles that they need these confidential sensors to make them do it? It is by no means obvious.

Having thus briefly sketched the picture, let me now go into the physiology in more detail. It falls into two sections. The first presents the evidence that muscles incorporate sensory receptors of whose signals we are not consciously aware; the second discusses what is known of the mechanisms in which they take part.

In the 18th century the great Swiss physiologist Albrecht von Haller established for the first time that the internal organs of the body, such as the heart, the stomach and the brain, are in general insensitive to the kind of stimuli that are so readily felt by the skin: pricking, pinching, cutting, burning and so forth. It is this fact that enables surgeons to perform operations on, say, the brain substance with only local anesthesia around the incision. In his studies of muscle Haller found that stretching a muscle by pulling gently on the tendon exposed in a wound in a human subject did not cause sensations of either movement or tension. (Pulling hard, however, is painful.) Reflecting on Haller's observations, one can perceive that the viscera and the muscles are really in different categories. It is not at all surprising, when one comes to think of it, that the liver should be insensitive to cutting with a knife or burning with a cigarette; such stimuli would be so rare without the animal's getting an earlier and more effective warning from the abdominal skin that to develop a system to report them would give the animal a negligible evolutionary advantage, whereas sensitivity to mechanical contacts, which the skin preeminently possesses, would very likely be a positive disadvantage. Imagine what life would be like if throughout it one were as vividly aware of the beat of one's heart as the surgeon who puts a finger on it exposed during an operation! With muscle, however, it is quite otherwise. It might be useful for us to be conscious of how extended our muscles are at any moment, since that determines the position of our limbs, and also to know their rate of shortening or elongation and the tension in them. If we are to be-

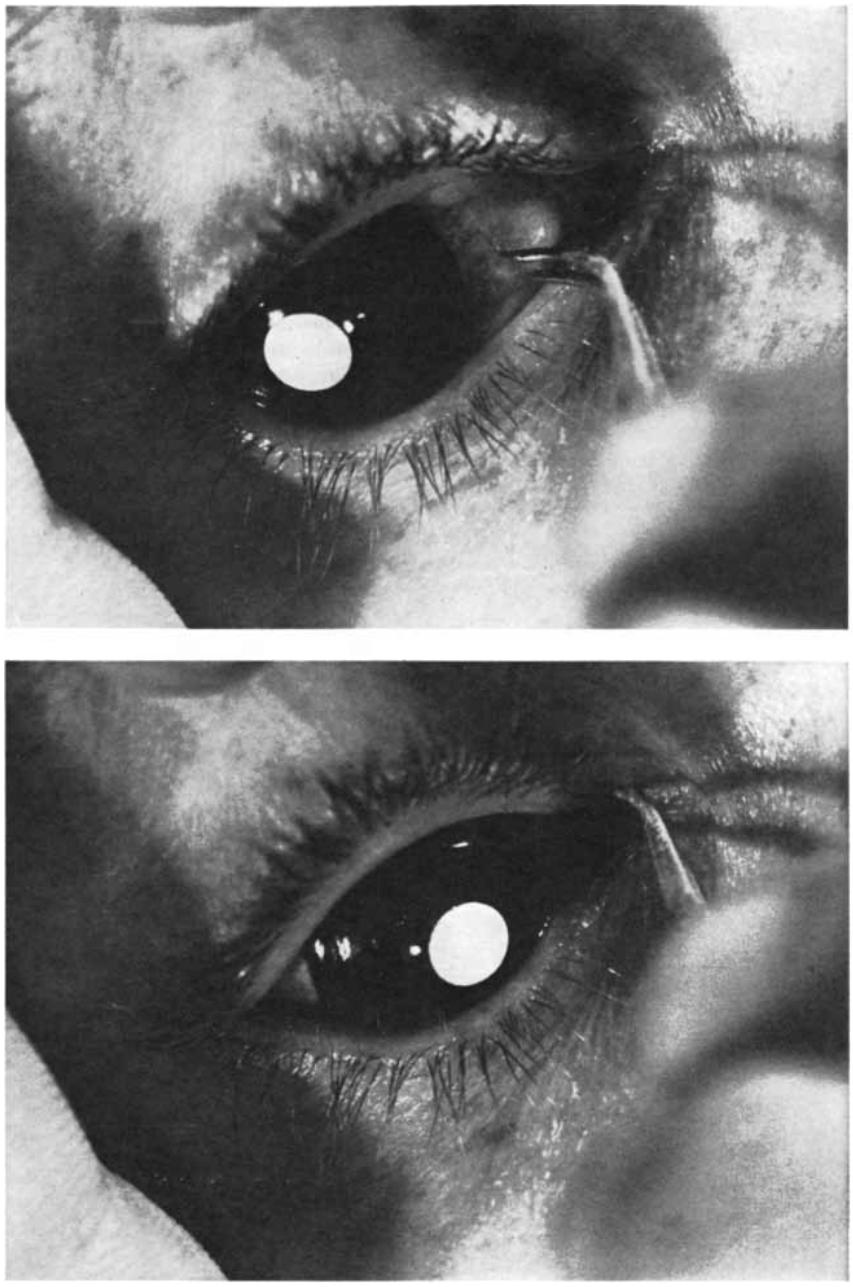


STRIKING EXAMPLE of a simple experimental observation that provides some insight into the organization of the motor psychophysical system is represented by these two handwritten versions of a sentence taken from the text of this article. The sentence was written large on a wall with a felt-tipped pen (*top*) and small on a piece of paper with a fine mapping pen (*bottom*). The writing on the wall is about 10 times larger. The large writing was done by movements of the wrist, elbow and shoulder, whereas the small writing used muscles in the hand itself. Nevertheless, the character of the writing is the same in both cases.

lieve Haller, this is just what they do not tell us. For this and other reasons that will shortly emerge we find that, whereas the insentience of the viscera has long been received as physiological dogma with a status comparable to the circulation of the blood, the insentience of muscle has often been called in question and probably cannot be regarded as universally accepted even today.

For me the question was both raised and answered the day I read the arguments of Helmholtz, published in 1867 in his *Handbook of Physiological Optics.* Helmholtz reached the same conclusion as Haller by experiments with the eye, which have the merit that anyone can repeat them and convince himself of the facts. Helmholtz starts with the familiar observation that if one takes hold of the skin at the outer corner of the eyelids and jerks it sideways, the eye itself is moved and what one sees with that eye appears to jump about. On the other hand, we know that if one moves one's eyes voluntarily, the scene one is looking at does not appear to jump. Helmholtz argues as follows. In both cases the image of the external world moves over the retina as the eye moves. When one moves one's eyes actively, by voluntary effort, one allows for the eye movement and does not interpret the movement of the image on the retina as signifying a movement of the external world. When the eyes are moved passively by an external pull, however, one interprets what one sees as if the eye had remained still. The movement of the image on the retina is assumed to be due to a movement of the external world and not to a movement of the eye. Hence we only know in which direction our eyes are pointing when we move them voluntarily, and this must be because we make an unconscious estimate of the effort put into moving them. (We have a "sense of effort.") Sense organs in the eye muscles (or elsewhere around the eye, if there are any) do not tell us which way our eyes are pointing, because when the eyes are moved passively, we do not seem to know they have moved.

This argument, as it stands, is not conclusive, because when the eyelids are pulled, the sense organs in the eye muscles or elsewhere might not be excited in the same manner as when the eye is turned normally by the contraction of its muscles. The apparent movement of the external world during a passive movement of the eye might therefore be due to a misjudgment of the eye's direction rather than to a complete ignorance of its movement.



INSENTIENCE OF EYE MUSCLES was demonstrated a few years ago by means of an ingenious experiment devised by G. S. Brindley, now at the Maudsley Hospital in London. In these photographs, made in the course of the experiment, Brindley is manipulating the author's eye with forceps to test whether, after blinding it with a black cap, there was any awareness of passive movements. There was not. The white spot on the cap is to give an indication of eye position. The eye and the lids were treated with local anesthetic.

This objection, as Helmholtz argues, can be answered by considering afterimages. If one stares fixedly at a bright light for 15 to 30 seconds (please, not the sun!), then on looking elsewhere an afterimage of the bright light is perceived and persists for a minute or so. When an object is fixated steadily, the afterimage likewise stays still, but when the gaze is shifted, the afterimage also moves. This, of course, refers to active voluntary eye movements. In passive movements quite the opposite is found. No matter how hard one pulls on the eyelids the afterimage appears to remain completely stationary. In order to be certain of this phenomenon it is necessary to view the afterimage against a featureless background, such as a sheet of plain paper held close to the eye; otherwise the concomitant apparent jerking around of external objects may make the judgment difficult. Hence during passive movements we interpret

what we see precisely as if the eye had not moved at all. It is not a matter of a quantitative misjudgment. The reader is encouraged to repeat for himself these crucial observations and reflect on the compelling conclusions Helmholtz drew from them.

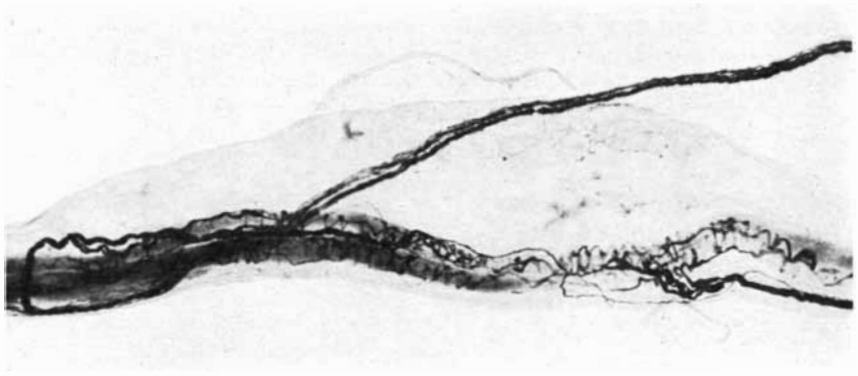
A few years ago my friend G. S. Brindley (now at the Maudsley Hospital in London), who has a genius for settling or eliminating argument by incisive experiment, proposed that we confirm Helmholtz directly by blinding an eye with a black cap on the cornea (the eye's transparent front surface) and then moving the eye around with forceps to see if the subject could feel the movement. (Pain was prevented by instilling generous quantities of local-anesthetic eye drops.) The test proved that subjects are quite unaware of large passive rotations of the eye in its socket of 30 degrees or more; they do not know the eye is being manipulated at all unless the forceps happen to touch the eyelid. Another important point was that if the subject was invited to voluntarily move his eyeball while the forceps were gripping it, he was unable to tell whether the experimenter holding the forceps was allowing the movement to take place or was preventing the eye from moving.

The unequivocal conclusion of all these experiments is that we have no sense organs in the eye muscles or near them that tell us which way our eyes are pointing. We normally know which way we are looking, but only because an internal "sense of effort" gives us an estimate of how much we have exerted our eye muscles. If voluntary movements are artificially impeded, or if passive movements are imposed, we absolutely do not know what is going on—unless we can see and reason back from the visual illusions we receive.

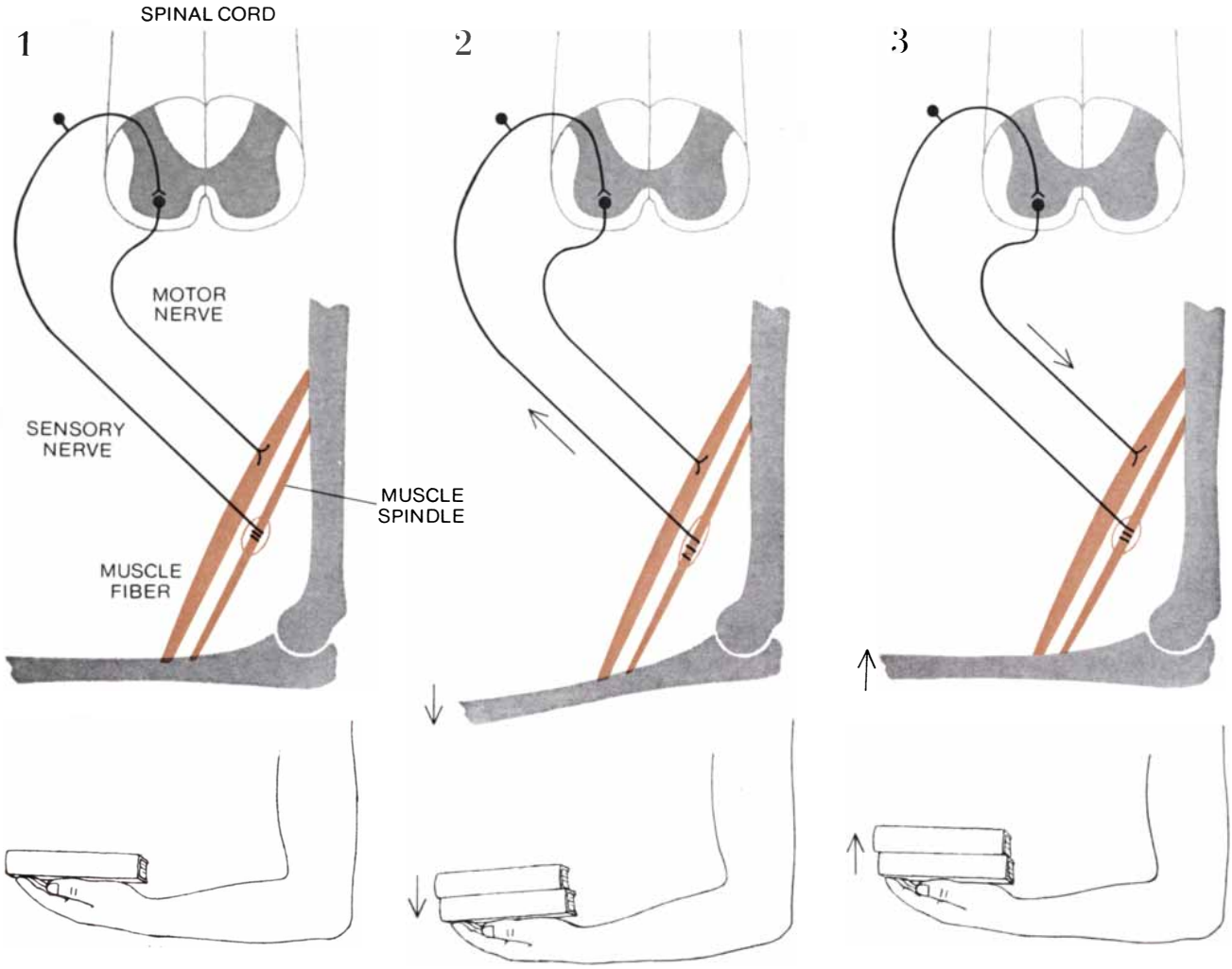
So much for the eyes. In the limbs the same facts are less easily demonstrated. To use Haller's method with patients whose tendons have been exposed under local anesthetic in the course of an orthopedic operation is one possibility, but it does not satisfy the powerful compulsion that all investigators in sensory physiology have to try it for themselves. A paper on visual illusions in which the author had not experienced the phenomena himself is almost unthinkable, and rightly so. What better way could he have of satisfying himself that they were correctly reported? Hence it is desirable to find a method for studying muscular sensibility in ordinary limb muscles of healthy subjects. The difficulty, of course, is to devise a way of stretching a muscle without the subject's knowing what is being done, since he can feel pressure on the skin or the movement of a joint. Local anesthesia of an extremity provides an answer. Investigators have variously injected local anesthetic around the joint at the base of the big toe or at the base of a finger, or have anesthetized the entire hand by cutting off the blood supply with a pneumatic tourniquet around the wrist for about 90 minutes. Movement of an anesthetized digit then stretches the muscles that move it, which lie above the anesthetized region. My collaborators and I use the top joint of the thumb, which has the advantage that only one muscle (lying well up in the forearm) flexes it, whereas the joints of the fingers are operated by more than one muscle, some in the hand and some in the forearm. Thus when the thumb is anesthetized by a tourniquet at the wrist, voluntary movements of the top joint are unimpaired in strength. We have also used injection of local anesthetic around the base of the thumb.

The uniform result of numerous experiments is that, with an adequate depth of anesthesia, the subject (whose eyes are shut) cannot tell in what position the experimenter is holding the top of his thumb, or whether he is bending it backward and forward. This is true only provided that the movement is not rapid and that the thumb is not forcibly extended or flexed at the limits of its range of movement. It is also the case

TENDON ORGAN contains sense endings that signal to the nervous system the tension in the part of the muscle in which they lie. A typical location of a tendon organ is shown in the diagram on page 31. The single sensory nerve fiber that services the tendon organ has been made to appear black in this photograph by means of a special silver stain. The nerve fiber divides many times, terminating in very fine branches with knobs at the ends. These structures, in some unknown way, sense the deformation produced by tension and cause nerve impulses to be sent up the sensory fiber at a rate that is determined by the tension. This tendon organ was dissected out of the leg muscle of a cat; it is about half a millimeter long. Surrounding one end are the remains of muscle fibers. Both photographs on this page were made by Colin Smith, Michael Stacey and David Barker of the University of Durham.



EQUATORIAL REGION of a muscle spindle dissected from the leg muscle of a rabbit appears in this photomicrograph; the part shown is about a millimeter long. Again the nerve fibers and nerve endings have been stained with a silver stain, making it possible to distinguish clearly the equatorial capsule, the intrafusal muscle fibers and the sensory endings wrapped around them. The nerve ending to the right is a primary ending; its sensory nerve fiber enters from lower right. The other ending is a secondary ending; its nerve fiber enters from upper right. The finer nerve fibers are part of the motor nervous system.



STRETCH REFLEX is mediated by the nervous mechanism depicted in this highly schematic illustration. A muscle is under the influence of the stretch reflex when it is engaged in a steady contraction of a voluntary nature, as when a person's elbow is flexed steadily against a load (*1*). A sudden unexpected increase in the load (*2*) stretches the muscle, causing the sense ending on the muscle spindle to send nerve impulses to the spinal cord (*upward arrow*), where they impinge on a motor nerve cell at a synapse and excite it. As a result motor impulses are sent back down to the muscle (*downward arrow*), where they cause it to contract (*3*). More complicated nervous pathways than the one shown may also be involved in the stretch reflex. Any real muscle is, of course, supplied with many motor nerve fibers and spindles. In addition the synaptic connections to even a single motor nerve cell are multiple.

that if the subject attempts to flex his thumb, he cannot tell whether he has been successful, or whether the experimenter has prevented it from moving Thus with skin and joint sensation eliminated the thumb behaves just like the eye. Muscle *is* insentient.

I have already argued that one would not on general grounds expect the liver, say, to have sensibility like the skin's. Indeed, if one looks at the liver through a microscope, it has none of the elaborate apparatus of sensibility seen in the skin—no network of branching nerve fibers ending in a variety of characteristic sensitive structures: the sense organs. The same goes for other viscera. Muscles are not so obliging. They are supposed to be insentient, but when we look inside them, they turn out to be full of sense organs, and very fine sense organs at that. The principal kind, the muscle spindles, are the most elaborate sensory structures in the body outside of the eyes and ears. This deep paradox (for which the reader has already been prepared) is at the back of everything in this article. All the essential facts that create it have been known since 1894, when Sir Charles Sherrington proved conclusively that there were nerve fibers going to the muscle spindles that belonged to the body's system of sensory nerves, and hence established that the muscle spindles were sense organs. Unfortunately in those distant days Sherrington was insensitive to the class distinction between the information on the road sign that tells the driver to turn right and the information from the sensors in his power-assisted steering gear that enables him to do so effortlessly (between, one might say, the different types of information required by the legislature and the executive). He allowed himself to be persuaded that Helmholtz had been wrong and that his own discovery showed that muscles were sentient after all.

Sherrington had thus taken the view that in effect there was no paradox, and his influence was so immense that it was 60 years before the true situation was at last clearly perceived. By this time the paradox had much less impact, since physiologists had discovered many of the facts about the muscle spindle needed for its resolution. Before going on to these facts I should finish the present story.

In the past few years the paradox has been given a further twist. Several

groups of workers on both sides of the Atlantic, whose members are too numerous to name individually, have found that signals from muscle sense organs find their way to the cerebral cortex. It seems that they get to the cortex but we remain unconscious of them. This is very surprising. No one imagines for a moment that we do not make use of all the information our eyes send to the cerebral cortex to build up the picture of the outside world we consciously perceive, and I am sure that a few years ago any ordinary physiologist would have been prepared to extend this point of view to sensory information of any kind that could be shown to get to the cortex.

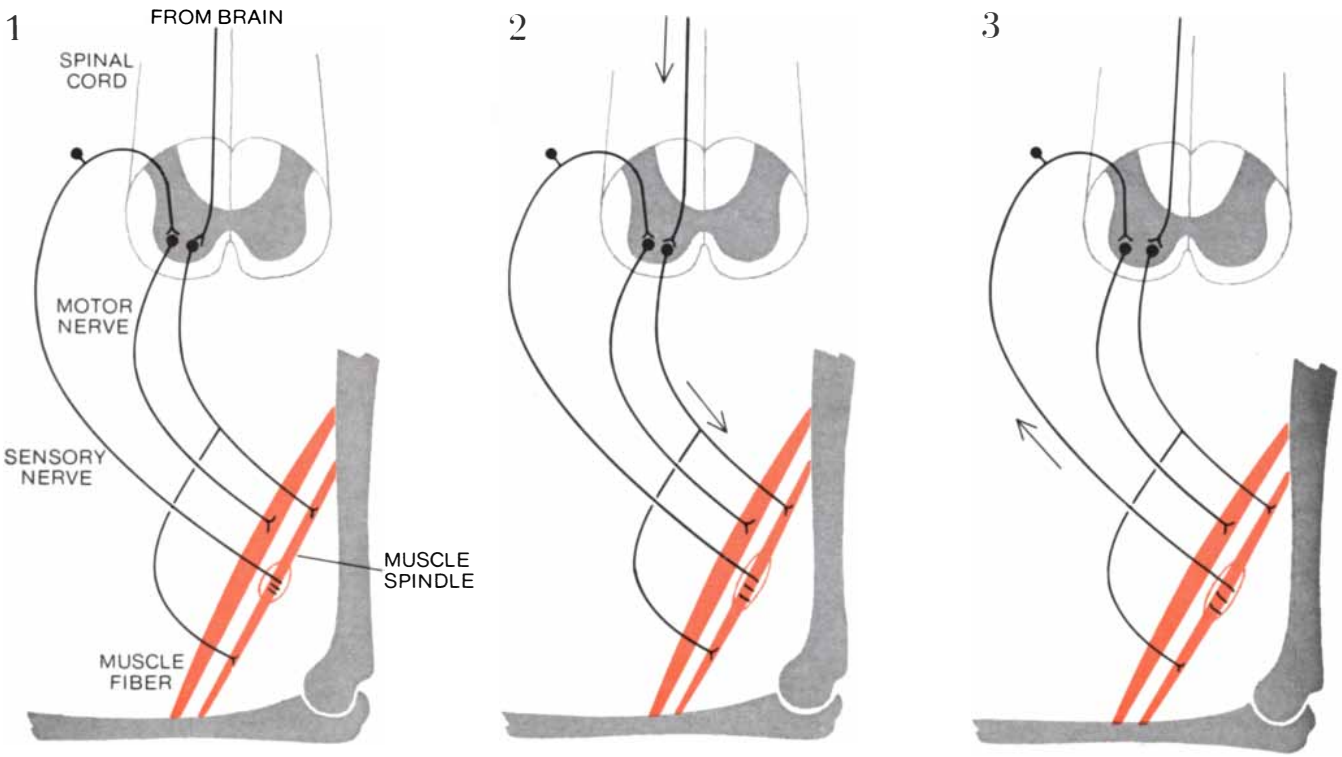
The evidence for what I have just said is not complete. The animal most resembling man in which signals from muscle sense organs have been shown to reach the cortex is the baboon. It seems unlikely that they do not reach the cortex in man, and equally unlikely that a baboon should be conscious of the signals from its muscles when a man is not. A strong hint also comes from the cat. John E. Swett and C. M. Bourassa of the Upstate Medical Center of the State University of New York showed that muscle sense organs send signals to the cat's cerebral cortex, but unlike signals from the skin (or for that matter from the eyes or ears) they cannot be used to set up a conditioned reflex. Without explaining what is meant by this fact in detail one can say that it strongly suggests the cat is not conscious of the signals from its muscles.

The first part of this article was intended to introduce the reader to the idea that muscle organs function at a subconscious level in a purely subservient role. Like the perfect servant, they work so unobtrusively that we are unconscious of them, but the findings about cortical projection begin to strain the analogy. The eccentric 18th-century scientist Henry Cavendish reportedly dismissed any servant he caught sight of. He wrote down what food he wanted and it was put out for him. It would have been going too far to expect the butler to wait on him at table without betraying his presence, but that is what the muscle sense organs seem to manage to do!

Scarcely less remarkable than the mere existence of the muscle spindles is the fact that they (the most important of the two kinds of muscle sense organ) are themselves contractile. This is a unique property among sensory structures. That was perfectly clear to Sherrington in 1894, but it still remains one of the most challenging observations in the physiology of the motor system; even if the interpretations to be put forward later in this article are on the right lines, it is most improbable that they are more than one facet of the truth.

Muscle spindles (they are called spindles because they are long and thin and have pointed ends) consist of a bundle of modified muscle fibers, the intrafusal muscle fibers (from the Latin *fusus*, meaning spindle), with the sensory nerve fibers wrapped around a short specialized region somewhere near the middle of their length. The stimulus that excites a muscle spindle is the stretching of this specialized sensory region. Now, as I have said, the muscle spindles are contractile. They are not, however, equally contractile along their entire length; the contractile apparatus fades out in the sensory region, and the middle of the sensory region, where the sense endings connected to the largest nerve fibers lie, probably does not contract at all. When the spindle contracts, these sense endings (known as the primary endings) are stretched by the contraction of the remainder of the spindle and discharge nerve impulses.

The next point to observe is that the



SERVOMECHANISM involved in the control of voluntary muscular contractions is shown here. The basic diagram (*1*) is the same as it is in the illustration of the stretch reflex, but with provision made for signals from the brain to cause the muscle spindle to contract by way of a special motor nerve fiber. When a signal is transmitted along this special fiber (*2*), the spindle contracts, exciting the spindle sensory ending, just as if the spindle had been stretched. Consequently a contraction of the main muscle is excited by way of the stretch-reflex pathway (*3, 4*). In a real muscle this picture is further complicated by the existence of a direct pathway

muscle spindles lie among the ordinary muscle fibers (the much larger red stringy structures, visible to the unaided eye, that actually do the work) and share their attachments to bone or tendon. Hence they change length as the main muscle fibers change length. If a contraction of a muscle spindle, which excites its primary ending, is succeeded by an equal contraction of the main muscle, the stretch will be taken off the sensory region and the ending will be silenced. The spindle primary, in fact, is sensitive to the difference in length between the spindle and the main muscle fibers; it is a misalignment detector. It discharges if contraction of the spindle is not matched by contraction of the main muscle, or, vice versa, if extension of the main muscle is not accompanied by relaxation of the spindle. There is no obligation for the muscle spindles and the main muscle to contract and relax together, because the motor nerve fibers that run to them and carry the nerve impulses from the central nervous system that cause them to contract are largely separate. The spindles could therefore be activated while the main muscle remained passive, and vice versa.

Having seen the circumstances under which nerve impulses are discharged by the spindle primary endings, the next question is: What do these impulses do when they reach the central nervous system? Their best-established function is to excite an automatic contraction—the stretch reflex—in the muscle from which they come. This they do, at least in part, by impinging directly on those nerve cells in the spinal cord that give rise to the motor nerve fibers to the muscle in question.

The most familiar manifestation of the stretch reflex is the knee jerk, widely used in medicine to test the state of the nervous pathways concerned. A physician strikes the tendon below the kneecap with a rubber hammer, and in a healthy subject the muscles that straighten the knee briefly contract involuntarily. The effect of striking the tendon is slightly and suddenly to stretch these muscles, and so to excite their muscle spindles. The tendon itself has no part in the sensory mechanism. The tendon jerk is quite transient, but under suitable circumstances a slower, sustained extension of a muscle will result in a sustained reflex contraction. If the reaction in a patient who is otherwise relaxed is exaggerated, the limb is said to be "spastic," that is, affected by spasm.

Human muscles in general can be shown to be under the influence of the stretch reflex when they are engaged in steady contractions of a voluntary nature. The main evidence for this is that if a subject is invited, say, to flex his elbow steadily against a load, it is found that a sudden unexpected increase in the load, which causes his elbow to extend, calls up a larger contraction of his biceps muscle, and conversely a decrease in load causes a relaxation. Electrical recording methods reveal that these reactions begin so soon (within about a twentieth of a second) that they must be automatic, reflex responses.

It has been realized for half a century that the stretch reflex confers valuable self-regulating properties on a muscle, causing it automatically to adjust to changes in load, without any need for the orders that the brain sends down to be altered. Everyone believes the reason the horse does not sag at the knees when Douglas Fairbanks leaps from the castle parapet onto its back is that the horse's leg muscles immediately respond to the extra strain by way of their stretch reflexes. If this interpretation is correct, we have one answer to the question: What does the horse expect of its muscles? In this situation it expects them not only to exert enough force to support its body weight but also to adjust automatically to extra weight. Clearly what the horse really wants is for the length of the muscles to be kept roughly constant so that posture is maintained. The stretch reflex can achieve this result for the horse because it is based on a sensor—the muscle spindle—that measures length, or, to be more exact, differences in length.

What happens when it is desired that the muscles should execute a movement, not merely maintain a stationary posture or some other steady contraction? The obvious trick is to cause the spindles to contract at the desired rate so that the sensory endings on the spindles will be excited if the main muscle does not itself keep up with the spindles, that is, does not contract at the desired rate. In this way the advantages of automatic compensation for changes of load by means of the stretch reflex could be retained during active shortening. Contraction of the spindles would in effect drive the main muscle by means of the stretch reflex, turning on more contraction if an unexpected obstruction were met with, or if the rate of shortening for any other reason fell behind, and, vice versa, damping down contraction automatically if the load unexpectedly diminished, or if for some other reason the movement undesirably accelerated. Within the past year C. D. Marsden, H. B. Morton and I have obtained direct evidence that this kind of rapid, reflex compensation does in fact occur during voluntary movements in man.

In this mode of operation the stretch reflex, as the reader will have perceived, functions as a follow-up servomechanism, closely analogous to power-assisted steering in an automobile. Contraction of the spindle corresponds to turning the steering wheel, shortening of the main muscle to turning of the road wheels, with the spindle sensory ending acting as the misalignment detector. The subject can demand of his muscles either a certain limb position or a certain rate of change of limb position, and within limits (limits not yet known in quantitative terms) his demands will be automatically met by his muscle servo.

That, in brief outline, is as far as we have gone in understanding how, when we make a voluntary effort, the muscle sense organs act at a subconscious level to ensure that our muscles do what we expect of them. Many facts have had to be left out and without doubt many more remain to be discovered. To attempt any account at this stage requires a certain presumption. I can only hope that when the whole truth emerges, it will prove to be an extension and not a contradiction of the story I have told here.

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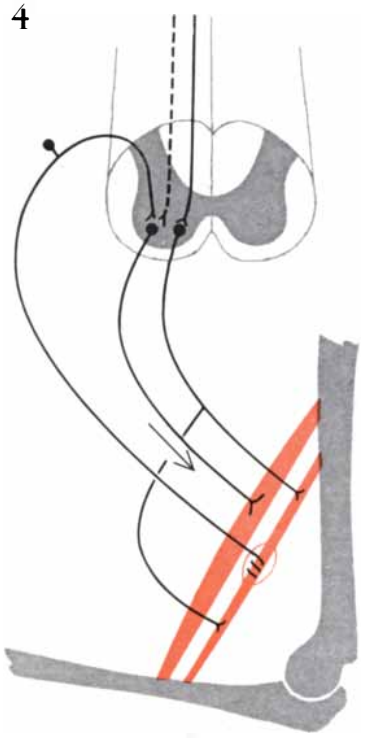


(*broken line in diagram 4*) **from the brain to the main motor nerve cells. In the power-steering analogy this pathway corresponds to a direct connection between the steering wheel and the road wheels of an automobile.**

BLACK HOLES

If a massive star collapsed to a sufficiently small volume, light could not escape from it. A rotating black hole could account for the radiation of gravitational waves from the center of the galaxy

by Roger Penrose

In about five billion years the sun will have consumed so much of its hydrogen in thermonuclear reactions that it will evolve to a star of the type known as a red giant. Standard theory predicts that the sun will grow to some 250 times its present diameter of 850,000 miles, devouring Mercury, Venus and probably the earth in the process. Its substance will then be only a tenth as dense as air. (At present the average density of the sun is a fifth the density of the earth.)

As it consumes more and more of the available nuclear fuel (helium and heavier elements as well as hydrogen), the bloated sun will reverse its expansion and contract down through its present diameter to a mere one-hundredth of that diameter, or roughly the size of the earth. It will then have evolved into a white dwarf and its contraction will halt. The electrons of its atoms will have become packed together so tightly that one of the laws of quantum mechanics will come into play and give rise to an effective pressure strong enough to prevent further contraction. The law is the Pauli exclusion principle, which states that no two electrons can occupy the same energy state. By this time the sun's density will be enormous; a ping-pong ball filled with its substance would have the mass of several elephants. All that remains for it is to cool off to its final dead state as a black dwarf.

No substance on the earth has a density remotely approaching the density of a white dwarf. Nevertheless, many white dwarfs (and red giants) are observed in the heavens. They are part of the evolutionary history of perfectly normal stars such as the sun. Moreover, the theory of stellar evolution to a white dwarf fits these observations closely. Not all stars, however, can follow this "normal" evolutionary path. In Subrahmanyan Chandrasekhar's theoretical investigations of stellar structure in 1931, he found that there was a maximum mass above which a white dwarf cannot sustain itself against further gravitational contraction. The gravitational pull toward the star's center would be even greater than the counteracting pressure from the action of the Pauli exclusion principle on the electrons. This maximum-mass limit is not much greater than the mass of the sun. Chandrasekhar's original limit was about 1.4 solar masses; more recent computations give an even lower value. Many observed stars have a mass greater than 1.5 solar masses. What can be their ultimate fate?

Consider a star that has twice the mass of the sun. Like the sun, it will expand to enormous size after consuming much of its original hydrogen fuel. Then it will contract again. It has no stable equilibrium state that will enable it to settle down as a white dwarf. Therefore the star, or a substantial portion of it, will collapse through the white-dwarf dimension. Owing to the extreme temperatures and densities that are involved, it will undergo processes that lead it to explode catastrophically. Such exploding stars, called supernovas, have been observed in our galaxy (the last one was described by Johannes Kepler in 1604) and in other galaxies. A supernova will outshine even an entire galaxy for a few days. Perhaps as much as 90 percent of the star's mass could be ejected. Only a collapsed core of the star would remain at the center of a rapidly expanding cloud of gas. (The Crab Nebula is such a cloud.) The core is much too small and compressed to form a white dwarf; it can find equilibrium only as a neutron star.

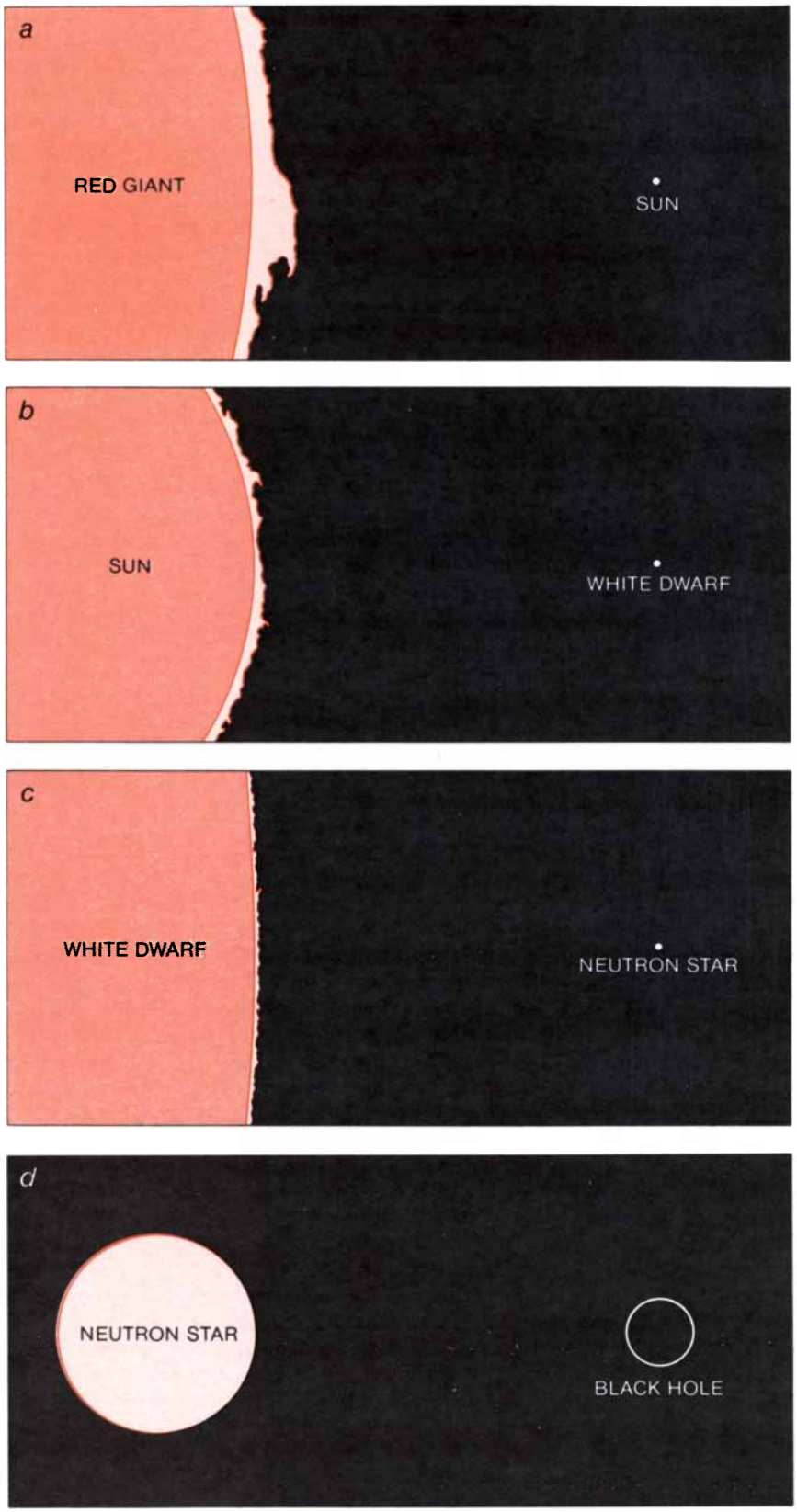
Even by comparison with a white dwarf a neutron star is tiny. The reduction from a white dwarf to a neutron star is even more than the reduction of 100 to one from the sun to a white dwarf, or probably rather more than the approximate reduction of 250 to one from a red giant to the sun. A neutron star may be only 10 kilometers in radius, or only about one seven-hundredth the radius of a white dwarf. The density of a neutron star could be more than 100 million times the extraordinary density of a white dwarf. A ping-pong ball filled with material from a neutron star would have the mass of a large asteroid such as Juno, a minor planet 118 miles across. The star's density would be comparable to the density of a proton or a neutron; indeed, a neutron star can be regarded as an oversized atomic nucleus, the only essential difference being that it is bound together by gravitation rather than by nuclear forces. Most of its electrons have been pushed into its protons, with the result that the protons have become neutrons. It is now the Pauli exclusion principle acting on the neutrons that supplies the effective force preventing further collapse.

This picture of a neutron star was predicted theoretically by J. Robert Oppenheimer, Robert Serber and G. M. Volkoff in 1938 and 1939. For many years astronomers doubted that neutron stars could actually exist. Since 1967 the observational situation has changed drastically. In that year the first pulsars were observed. The theory of pulsars has developed rapidly since then, and it now seems virtually certain that the radio and optical pulses emitted by pulsars owe their energy and extraordinary regularity to the presence of a rotating neutron star. At least two pulsars reside inside supernova remnants, one being the Crab Nebula, giving further support to the theory that pulsars are in fact neutron stars.

As in the case of white dwarfs, there is a maximum possible mass above which a neutron star would not be able to sustain itself against still further gravitational contraction. There is some uncertainty as to the exact value of this maximum-mass limit. The original value given by Oppenheimer and Volkoff in 1939 was about .7 solar mass. More recently values of up to three solar masses have been suggested. These higher values take into account that the heavy subatomic particles called hyperons may be present in addition to ordinary neutrons and protons. In any case the correct limit could not be more than a few solar masses, and there are stars whose mass is more than 50 times the mass of the sun. What can be their eventual fate? It is very unlikely that such stars would, either in a final collapse or at some earlier stage, inevitably throw off so much of their material that their mass would always fall below the limit required for a stable white dwarf or a neutron star. What other forms of condensed matter could exist, with densities even in excess of the fantastic value that is maintained inside a neutron star?

Theory tells us that although greater densities can be achieved, it is not possible to obtain any further stable equilibrium state. The gravitational effects become so overwhelming that they dominate everything else. Newtonian gravitational theory becomes quite inadequate to handle the problem and we must turn to Einstein's general theory of relativity. In doing so we are led to a picture so strange that even a neutron star seems commonplace by comparison. This new picture, originally put forward by Oppenheimer and Hartland S. Snyder, has earned the appellation "black hole."

A black hole is a region of space into which a star (or a collection of stars or other bodies) has fallen and from which no light, matter or signal of any kind can escape. What further contraction is necessary for a neutron star to be compressed to the size of a black hole? Consider an object of one solar mass. We have seen that the sun has a diameter some 70,000 times greater than the diameter of a neutron star, and that a red giant has a diameter about 20 million times greater than the diameter of a neutron star. In view of these large differences in size it is perhaps surprising to find that a neutron star would have to contract only to approximately a third of its diameter to become a black hole. Larger black holes are also possible, but they would be the result of the collapse



COMPARATIVE SIZES of a red-giant star, the sun, a white-dwarf star, a neutron star and a black hole are illustrated. The red giant (*a*) has approximately the same mass as the sun, yet its diameter of about 200 million miles is 250 times larger than the sun's. The sun (*b*) has 100 times the diameter of a white dwarf of the same mass. The diameter of a white dwarf (*c*), which is roughly the same as the diameter of the earth, is about 700 times greater than the diameter of a neutron star with the mass of the sun. The neutron star has only to collapse to a third of its diameter to form a black hole (*d*). The black hole is no more than four miles across although it has the mass of the sun. Its radius is proportional to its mass.

of a star, or collection of bodies, whose final total mass was greater than the sun's. The linear dimension of the hole is proportional to the hole's mass.

The general theory of relativity plays a significant role in the theory of neutron stars, even before the extreme conditions of a black hole are reached. Physical theory has worked well in the description of stars of enormously different sizes and densities. From this point of view there would seem to be little reason to doubt the slight extrapolation needed to cover the case of a black hole. Such a view, however, is not quite fair. The part of physical theory on which the detailed description of a black hole depends, namely the general theory of relativity, cannot be said to have played an irreplaceable role in observational astronomy. The possibility that the general theory of relativity is wrong must be seriously considered. The observational and experimental tests of the general theory that have been successfully conducted are still not very numerous. Although there is no conflict between the theory and the observations, these observations still do not point conclusively in the direction of the general theory. There is still scope for alternative theories of gravitation.

It must nonetheless be said that the general theory of relativity is an excellent theory; it is almost certainly the most satisfactory theory of gravity available to us. Furthermore, the Brans-Dicke-Jordan scalar-tensor theory, which can be regarded as the most serious rival to the general theory, leads to a black-hole picture identical with the one arising from Einstein's theory. Even in Newtonian theory a situation similar to a black hole can arise. As early as 1798 Pierre Simon de Laplace predicted from Newtonian mechanics that a sufficiently massive and concentrated body should be invisible because the escape velocity at its surface would be greater than the speed of light. Therefore a photon, or particle of light, emitted radially from the surface would fall back to the surface and so not escape to be observed at large distances from the body. This description is perhaps arguable, but it shows that there is a situation to be faced even in Newtonian theory. Having made these observations, however, I shall now restrict the discussion to considerations totally within the bounds of the general theory of relativity.

To begin with, let us consider the present standard picture of a black hole. The black hole is characterized by a spherical surface whose radius is proportional to the hole's mass. This surface is called the "absolute event horizon"; its defining property is that signals emitted inside it cannot escape, whereas from any point outside it signals can be emitted that do escape. The size of the sphere for any mass, that is, the radius of the event horizon, can be calculated by multiplying twice the mass by the universal gravitational constant and dividing the result by the speed of light squared ($2mG/c^2$). Performing this calculation for the sun yields the result that the sun would have to be collapsed into a sphere four miles in diameter; the absolute event horizon would be the surface of this four-mile sphere.

The body whose collapse was responsible for the black hole's existence has fallen deep inside the event horizon. The gravitational field inside the event horizon has become so powerful that even light itself is inevitably dragged inward regardless of the direction in which it is emitted. Outside the event horizon light escapes if it is aimed suitably outward. The closer the emission point is to the event horizon, the more the wave front of the emitted signal is displaced back toward the center of the black hole. We may intuitively regard this displacement as being caused by the effect of the gravitational attraction on the motion of the light. The light seems to travel more easily in the direction of the gravitating center of the black hole than it does in the outward direction. Inside the event horizon the inward pull has become so strong that the outward motion becomes altogether impossible. On the event horizon itself it is possible for light to "mark time," forever hovering at the same distance from the center of the black hole.

This behavior applies not only to light but also to any signal or material body. The velocity of light is still the limiting velocity even inside the event horizon. The special theory of relativity still holds locally, although it is not evident from this picture. The local frames of reference, in terms of which the special theory of relativity is normally described, are themselves falling rapidly inward to the gravitational center.

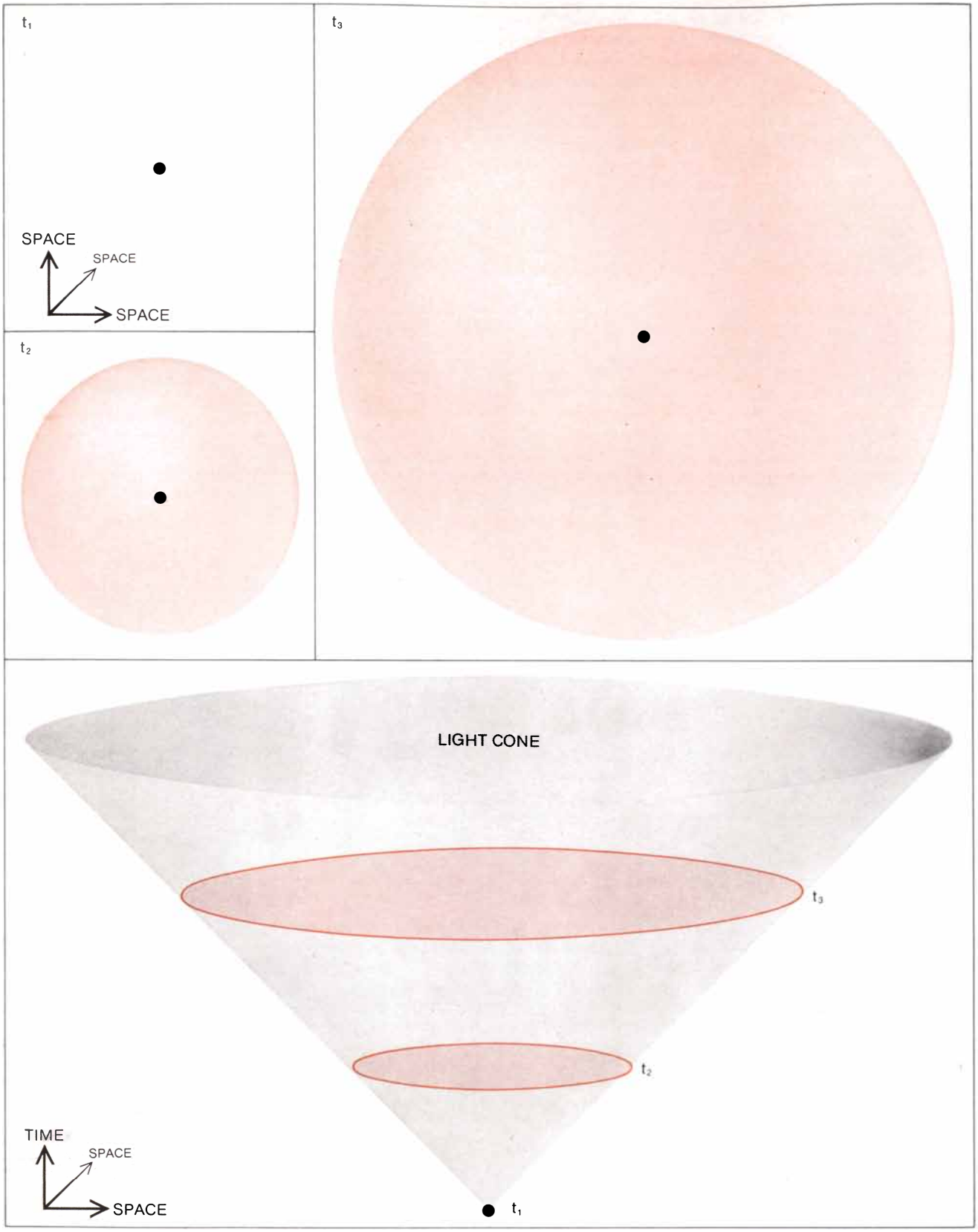
It is much more satisfactory to give a space-time description of the situation rather than the purely spatial one given so far. A space-time representation suppresses one of the spatial coordinates and substitutes a time coordinate. It gives an instantaneous picture of what is going on at all times, obviating the need for many sequential "snapshots" of a developing situation.

Consider a light flash emitted in all directions from a given point in ordinary space. The wave front of the flash would be a sphere centered on the emitting point and growing larger each moment at the speed of light. A purely spatial representation of the flash would be a sequence of spheres, each sphere larger than the preceding one, marking the position of the light flash's spherical wave front at a given moment in time. A space-time representation of the light flash, however, would be a cone whose vertex represents the time and place at which the light flash is emitted, the cone itself describing the history of the light flash.

By the same token the history of a star's collapse down to a black hole can best be depicted in a space-time representation [*see illustration on page 43*]. The locations of the light cones at various points in space-time show how light signals propagate in the gravitational field. At some points the light cones are drawn as being tipped over, but this is not something that would be noticed by a local observer. Such an observer would follow a path in space-time that proceeds into the interior of the light cone; his speed can never be greater than the speed of light, and only inside the light cone is this criterion met. By taking a horizontal section through the space-time picture we get a spatial representation of the situation [*see illustration on page 42*].

What is the fate of the original body that collapsed to produce the black hole? Assuming that exact spherical symmetry is maintained right down to the center, the answer provided by the general theory of relativity is a dramatic one. According to the general theory, the curvature of space-time increases without limit as the center is approached. Not only is the substance of the original body squeezed to infinite density at the center of the black hole—that is, effectively crushed out of existence—but also the vacuum of space-time outside the body becomes infinitely curved. The effect of this infinite curvature on a hapless observer, were he foolhardy enough to follow the body inward, would be catastrophic. He would feel tidal forces across his body that would mount rapidly and would reach infinity within a finite period of his experienced time.

The gravitational tidal effect is the most direct physical manifestation of space-time curvature. Einstein pointed out that the gravitational force on a body can be eliminated at any one point simply by choosing a frame of reference that is falling freely. He gave the famous



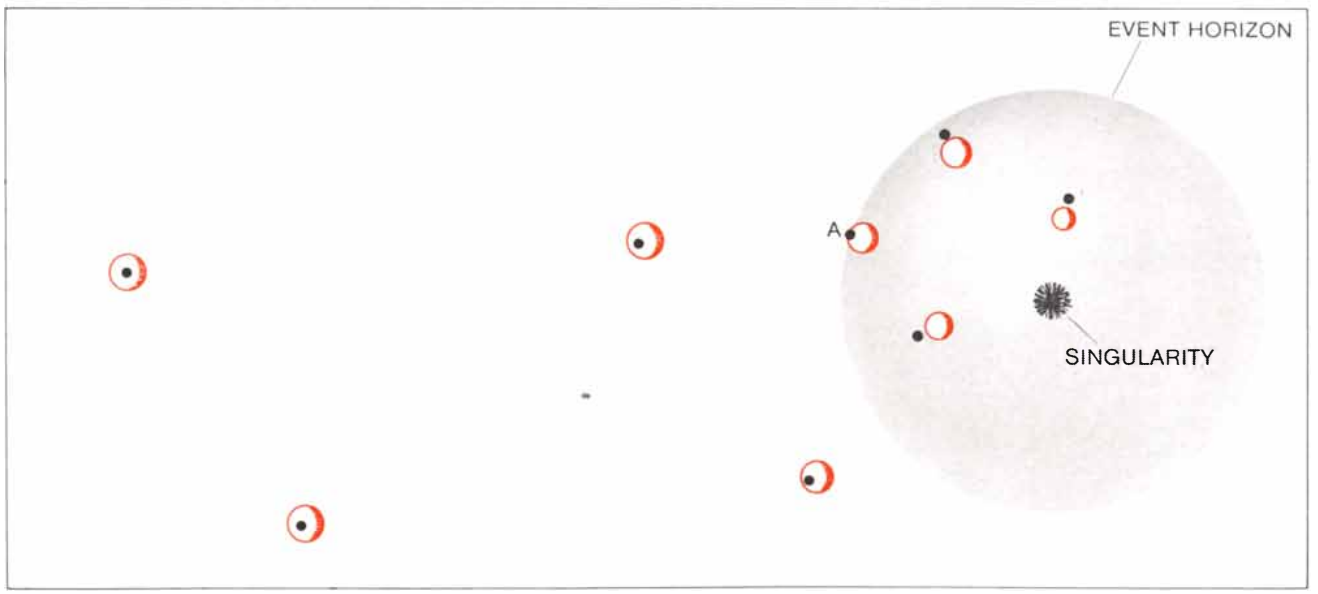
PURELY SPATIAL REPRESENTATION of the history of a light flash emitted from a point would be successive snapshots of the light's spherical wave front expanding through space (*top*) at given instants of time: t_1, t_2, t_3 and so forth. A space-time representation of the same event would be a light cone with its apex at the point emitting the light (*bottom*). In order to picture a light cone, one of the spatial dimensions must be suppressed. The space axes are depicted in the horizontal plane; the time axis runs vertically with time increasing upward. The circles (*color*), foreshortened to ellipses, intersecting the light cone are the instants t_1, t_2, t_3 at which the snapshots were taken in the spatial representation. The space-time light cone shows in one diagram the continuous history of the expanding wave front of the light signal, obviating the need for many sequential snapshots of the developing situation.

example of an elevator that broke its cable and fell toward the earth. Any passenger inside would be falling at the same rate as the elevator. He would therefore feel no net gravitational acceleration and would float free of gravity inside the elevator. Such elimination of the gravitational force by free fall is now a familiar feature of space travel. The tidal effect, however, cannot be so eliminated and is therefore a true manifestation of the gravitational field. Imagine an observer falling freely in the earth's field. Suppose he is surrounded by a sphere of particles that he initially observed to be at rest with respect to himself. The Newtonian gravitational field of the earth varies as the inverse square of the distance between it and any other body, pulling more strongly on objects closer to its surface than on objects farther away. This nonuniformity of the gravitational field tidally distorts the sphere of particles into an ellipsoid [*see top illustration on page 44*]. The earth's ocean tides are an example of the effect; in this case it is the earth experiencing the tidal force of the moon.

The tidal effects encountered in the solar system are small; the largest actually occurs at the surface of the earth itself and is due primarily to the earth's gravitational field. These tidal effects are not noticeable at all on a laboratory scale. To put it another way, the curvature of four-dimensional space-time at the earth's surface is not significant over laboratory dimensions. The degree of space-time curvature can be stated in terms of radius of curvature. The smaller the curvature of space-time, the larger the corresponding radius of curvature, just as in three dimensions the smaller the degree to which the surface of a sphere is curved, the larger its radius of curvature. The radius of space-time curvature at the surface of the earth is approximately the distance of the earth from the sun. (That is a pure coincidence; the sun is itself irrelevant to this particular tidal effect.) Thus the earth does not curve space-time much compared with laboratory dimensions. The tidal effect at the surface of the sun is even less because of the sun's lower average density. In fact, the radius of space-time curvature at the sun's surface is approximately twice the distance from the earth to the sun. Hence the sun curves space-time less at its surface than the earth does at the earth's surface.

At the surface of a white dwarf the degree of space-time curvature is much greater; the radius of curvature is of the same order as the radius of the sun: about 500,000 miles. The tidal effects near a white dwarf would be very noticeable to an astronaut in orbit around the star. The man's head and feet would experience forces in different directions of perhaps a fifth of the total force he would feel standing on the earth. At the surface of a neutron star, however, the tidal effects are by ordinary standards enormous. There the radius of space-time curvature is only about 30 miles. It is clear that no astronaut in a low orbit around a neutron star could possibly survive; even if he curled himself into a small ball, the gravitational acceleration at various parts of his body would differ by several million times from the gravitational acceleration (g) at the surface of the earth.

In principle instruments could be built to withstand such tidal forces. They would have to be built very small to keep the forces down, since the tidal force is proportional to the size of the object on which it acts. Imagine now that such an instrument fell into a black hole of one solar mass. As it crossed the event horizon it would experience tidal forces about 30 times the tidal forces it would feel at the surface of a neutron star. The instrument could remain intact, however, since the forces on its constituent parts would still be small. The tidal forces would rise rapidly as the instrument approached the center of the black hole, ripping apart in turn the material of the instrument, the molecules of which the material was composed, the atoms that constituted the molecules, the nuclei of the atoms and finally even the elementary particles that a moment previously had been the building blocks of the nuclei. Moreover, the entire process would not last more than a few milliseconds. What we have is a model of the



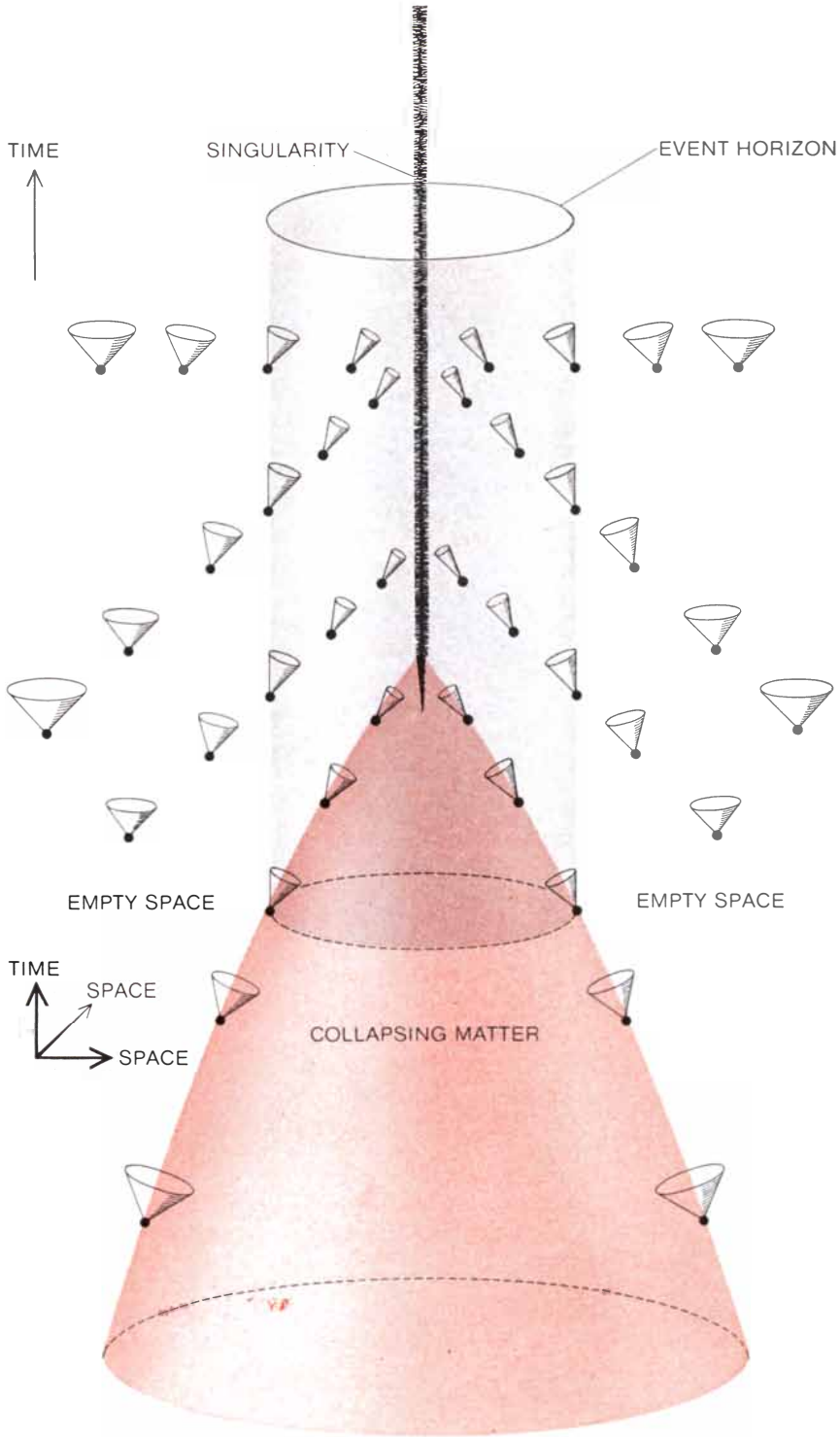
EVENT HORIZON (*gray sphere*) **is the boundary of the black hole. Signals cannot escape from the inside of the event horizon but must propagate toward its center. In this spatial representation a light signal originating at any one of the points shown occupies at the next instant a spherical surface** (*small circles*) **known as its wave front. At large distances from the black hole the point lies at the center of this surface. At smaller distances the spherical surface is displaced by the strong gravitational attraction of the black hole. The spherical wave front of a point exactly on the event horizon touches the event horizon internally and never escapes** (*A*).

creation of the universe in reverse and on a much smaller scale. The initial "big bang" of the cosmological models is what is called a space-time singularity: the curvature of space-time becomes infinite. The situation inside a black hole leads also to such a singularity, but of a time-reversed character.

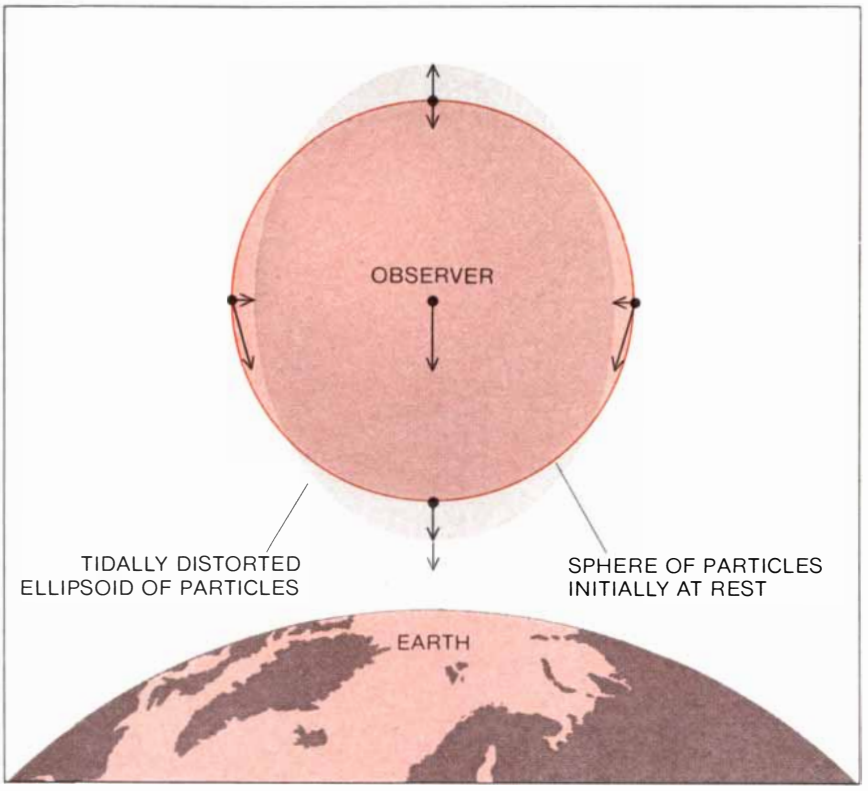
There are many questions that must be raised concerning the acceptability of this picture as a realistic description of something that actually happens in nature, quite apart from any doubts one might have about the validity of the general theory of relativity. In the first place, can we be sure that enough is known about the nature of matter under the extreme compressions required to form a black hole for these predictions to carry conviction? What role does the assumption of exact spherical symmetry play in the discussion? To what extent does the black-hole picture fit in with astronomical observations? Let us consider these questions in turn.

The question concerning the excessive densities—densities somewhat greater than that of nuclear matter—involved in the creation of a black hole is not nearly as serious as it might seem at first. Even if it were argued that present physical knowledge is inadequate at such densities (which is probably not the case), the argument could only shed doubt on the collapse picture for the least massive of collapsing bodies. The density of any body is proportional to its mass divided by its radius cubed; the radius of a black hole is proportional to its mass. These two facts mean that the density at which a black hole is formed would be inversely proportional to the square of the mass.

A black hole with a mass ranging from 10,000 to 100 million solar masses is considered a possible candidate for what might inhabit the center of a galaxy. A collapsing mass equal to 100 million solar masses would reach a black-hole situation when its average density was roughly the density of water. The tidal effects at the event horizon are also proportional to the inverse square of the mass of the hole. Thus for a body of 100 million solar masses these tidal effects would be somewhat less than those produced at the earth's surface. An astronaut could pass through the event horizon without the tidal forces' affecting him. He would not notice anything particular happening as he crossed the event horizon. (In any case the exact location of the horizon is not something that can be discerned by local measure-



SPHERICAL GRAVITATIONAL COLLAPSE of a star can be depicted in a space-time diagram in which two of the three space dimensions are plotted horizontally and the time dimension is plotted upward. The star collapses until its gravitational field becomes so strong that light cannot escape, creating an event horizon. The matter of the star collapses down to a "singularity" of zero volume and infinite density where the present laws of physics break down. The propagation of light signals from various points is indicated by light cones. The light from points closer to the strongly attracting singularity is displaced more toward the singularity than light from points farther away. Even though the light cones are depicted tilted near the singularity, the special theory of relativity still holds for the local frames of reference of the light cones and the speed of light is still the limiting velocity. Compare this space-time representation of the behavior of light near the event horizon with the purely spatial representation on the opposite page. The spatial representation may be taken to be a horizontal section through the above space-time picture.



GRAVITATIONAL TIDAL EFFECT is the most direct manifestation of space-time curvature. If an observer falls freely in the earth's gravitational field, he feels no net force. If he is surrounded by a sphere of particles (*color*) that are initially at rest in relation to him, he can notice the nonuniformity of the Newtonian gravitational field as a tidal effect that distorts the sphere into an ellipsoid (*gray*). Tidal effect is a true manifestation of the gravitational field and cannot be eliminated by a change in the observer's frame of reference.

ments.) And the astronaut would have a few minutes to enjoy the experience of life inside a black hole before the tidal effects mounted to infinity. For a black hole of 10 billion solar masses he would have about a day. As for the large tidal effects and densities encountered inside the black hole, this is a matter that involves certain implications of the general theory of relativity, to which I shall return.

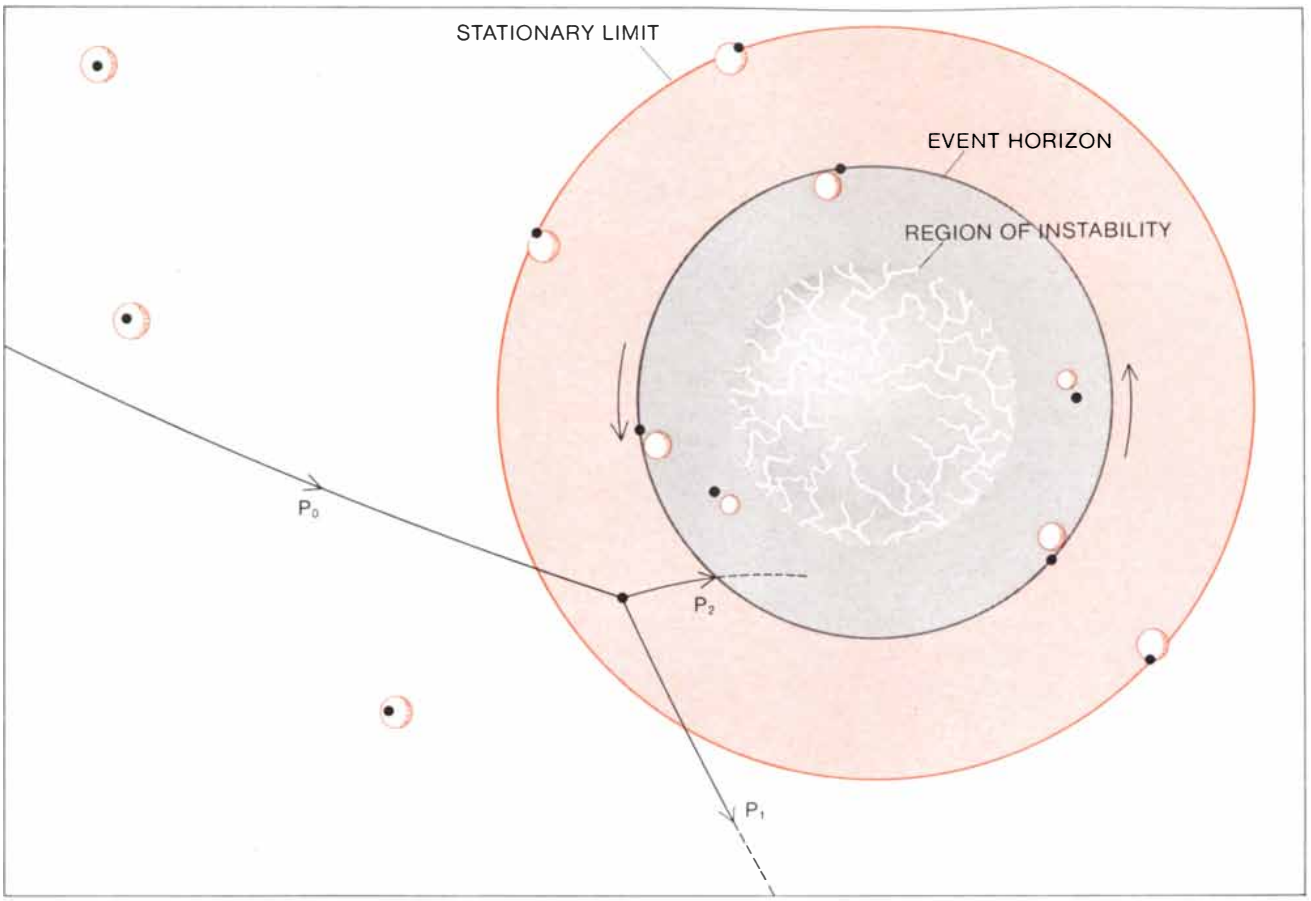
The question concerning the role played by the assumption of spherical symmetry is much more serious. If we do not assume spherical symmetry, then we cannot appeal to the exact solutions on which we have based the foregoing discussion. Furthermore, even if we assume that initially the deviations from spherical symmetry are slight, we should have every reason to expect that near the central point these asymmetries would be enormously magnified. Might not the different portions of the collapsing body miss one another? Perhaps they could reemerge after a close encounter and bounce out again. Even if they did not, can we say anything about the final configuration of the gravitational field resulting from the collapse? It is fortunate that, owing to some general theorems that have been proved over the past several years, a complete picture of asymmetrical collapse has emerged.

Considering the picture in a little detail, suppose that a massive star or a collection of bodies collapses and that deviations from spherical symmetry are at first comparatively small. We can establish that a point of no return has been passed if a certain criterion is satisfied. That criterion can be stated in several different ways, but the following is the simplest. Imagine that a flash of light is emitted at a point in space-time. If the event is depicted in a space-time representation, the flash of light will be the light cone of the point. The light rays start out from the point by diverging in all directions. When they pass through matter or through a gravitational field, the matter or the field has a focusing effect on the rays. If enough matter or a sufficiently strong gravitational field is encountered, the amount that the rays diverge can be reduced to such an extent that it is actually reversed, that is, the rays start to converge. The required criterion for a point of no return is that every light ray from the space-time point encounter enough matter or gravitation for the light cone to be reconverged. It is not hard to show from simple order-of-magnitude estimates that, for sufficiently large collections of mass, the criterion can indeed be satisfied before densities or curvatures become excessive, and without any assumption of symmetry.

Once this criterion is satisfied, a number of things can be said. In the first place, according to a precise theorem in the general theory of relativity put forward by Stephen Hawking and the author, it follows that somewhere there must be a space-time singularity. A singularity is a region of space-time where physical theory breaks down. Here the singularity is a region where we must assume that infinitely strong gravitational tidal forces deform and squeeze matter and photons out of existence. Physicists are unhappy with a theory that predicts the evolution of a truly singular physical state for matter. In the past whenever a singularity was encountered in a theory, it was generally a warning that the theory in its present form was breaking down and new theoretical tools were needed. In the case of black holes we are again being presented with a situation of this kind, but one more serious than before. Here the singularity refers to the very structure of space and time.

There are two distinct possibilities at this stage. It may be that the resulting singularity is such that signals can escape from it and be observed at large distances. This is the more alarming of the two possibilities, and it is also the more conjectural. Such a singularity is called naked. The possibility of naked singularities is alarming because the physical effects of near-infinite space-time curvatures are quite unknown. If these effects can influence the outside world, then an essential uncertainty is introduced into physical theory.

On the other hand, it is possible that the singularities resulting from gravitational collapse are always hidden from view, as was true in the spherically symmetrical situation. In this case the essential uncertainty does not arise. The assumption that only this less alarming possibility can arise in gravitational collapse is what is called the hypothesis of "cosmic censorship." This hypothesis simply forbids a naked singularity. There is perhaps some slight theoretical evidence in favor of the hypothesis, but

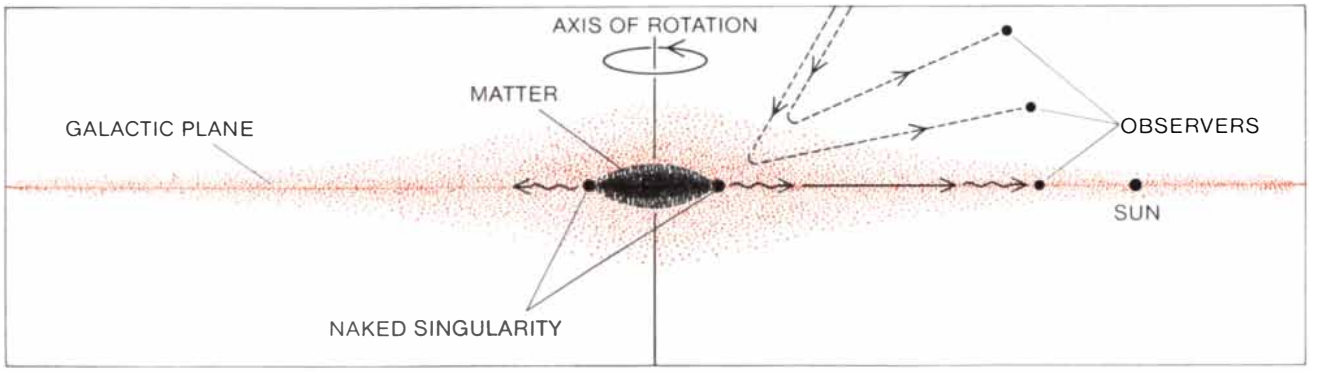


ENERGY CAN BE EXTRACTED from a rotating black hole even though no material object can escape once it has fallen below the event horizon (*solid gray*). In the case of a rotating black hole the event horizon rotates. The stationary limit is a spheroidal surface (*color*) on which it is necessary for a signal or a body to travel with the speed of light in order to "stay in the same place" as viewed from infinity. If a particle, P_0, drops from infinity to within this surface, it is possible for it to divide in two in such a way that one component, P_2, falls into the black hole but the other component, P_1, escapes back to infinity with more mass-energy than the initial particle P_0. In this way P_1 extracts some of the rotational energy of the black hole. The location of the internal singularity is uncertain when perturbations in addition to rotation are present, but it is most likely to be along or inside central region of instability.

the situation is inconclusive at the moment. I would personally tend to believe in the hypothesis in situations that initially do not differ too much from spherical symmetry. In more extreme situations the question is quite open. Perhaps there is even observational evidence against the hypothesis of cosmic censorship.

If we assume that the hypothesis is indeed true, then much can be said. Once the focusing criterion is satisfied, the hypothesis of cosmic censorship implies that an absolute event horizon will arise. This horizon will have a well-defined area of cross section that has a tendency to increase with time and can never decrease. Thus black holes tend to grow and cannot shrink. It seems reasonable to suppose a black hole, if left undisturbed, would settle into a stationary state. One might think that such stationary states of black holes could be very complicated owing to the large number of possible configurations of matter that could collapse down to the black-hole size. Some remarkable recent work by Werner Israel, Brandon Carter and Hawking has shown that this is not the case. Only a very restricted class of stationary black-hole configurations can arise. They are uniquely characterized by the value of the mass, spin and charge of the hole. Einstein's equations for the general theory of relativity have been solved explicitly by Roy P. Kerr and Ezra Newman for these configurations. The reason the asymmetries present in the collapsing body do not show up in the final state of the black hole is that once the hole is formed the body that produced it has little influence on its own subsequent behavior. The black hole is best thought of as a self-sustaining gravitational field governed by the internal dynamics of the general theory of relativity. These dynamics allow the asymmetries in the gravitational field of the hole to be carried away in the form of gravitational waves.

We have seen that a material object, once swallowed by a black hole, cannot escape. On the other hand, there are mechanisms whereby some of the energy content of the black hole can be extracted. One such mechanism would allow two black holes to coalesce. This process would be accompanied by the copious emission of gravitational waves, whose total energy should be a substantial fraction of the initial rest-mass energy of the black holes. Another mechanism would be to allow a particle to fall into a region close to the event horizon of a rotating black hole. The particle splits into two particles in such a way that one falls into the hole and the other escapes back to infinity with more mass-energy than the initial particle had. In this way rotational energy of the black hole is transferred to the particle mo-



ROTATING SINGULARITY may explain the copious emission of gravitational waves from the center of the galaxy. Calculations show that certain types of naked singularity can be observed only from one plane. Lines of sight "bounce out" if they are not in this plane. If such a singularity were the source of gravitational waves, it would beam them in one plane. If this plane happened to be the plane of the galaxy, then the sun and the earth, which are also in the galactic plane, would be in the path of emission of the waves.

tions outside the hole [*see illustration on preceding page*].

Let us now consider the situation inside the black hole and the existence of the space-time singularity. Since "singularity" means a region where physical theory breaks down, we have the curious situation here that the general theory of relativity is predicting its own downfall. Perhaps we should not be too surprised, however, since we are treating the general theory of relativity only in its capacity as a classical theory. It is to be expected that when space-time curvatures become sufficiently enormous, quantum effects must play a dominant role. When the radius of space-time curvature becomes as small as, say, 10^{-13} centimeter (roughly the radius of an elementary particle), then the theory of particle physics, as it is currently understood, must break down. If the radius of space-time curvature ever becomes as small as 10^{-33} centimeter, we must apply quantum mechanics to the structure of space-time itself. At present there is no satisfactory theory for such application.

The final question is: What is the observational status of black holes? A number of claims and counterclaims have been made over the past year or so, but at present it seems that no unambiguous conclusions can be drawn. The main discussion centers around double-star systems in which one component is the suspected black hole and around multiple-star systems such as a globular cluster. The presence of a black hole could be ascertained by its gravitational influence on other bodies, affecting their motions. If an invisible object is thereby detected whose mass is too large for it to be a white (or black) dwarf or neutron star, then the case for its being a black hole is a strong one.

There is another aspect to the role of black holes in observational astronomy. We can compare the situation to the case of neutron stars. For many years astronomers had attempted to detect neutron stars by searching for certain effects, such as X-ray emission, that had been predicted to accompany their presence. When neutron stars were finally detected, they were discovered by an effect that was totally unexpected and is still not really satisfactorily explained: the emission of rapid, regular, sharp pulses of electromagnetic radiation characteristic of a pulsar. It is quite possible that the detection of black holes will also come about because of some equally unexpected side effect. There is no shortage of unexplained phenomena in astronomy today that might conceivably be relevant. There is the apparently phenomenal energy output of quasars and radio galaxies, the explosions in the center of galaxies, the anomalous red shifts in the spectra of some quasars and galaxies, and the discrepancies in the measurements of the mass of galaxies. Serious questions remain even about the spiral-arm structure of normal galaxies. Above all, there is the apparent observation by Joseph Weber of the University of Maryland of gravitational waves emanating from the center of our galaxy [see "The Detection of Gravitational Waves," by Joseph Weber; SCIENTIFIC AMERICAN, May, 1971]. If these waves are emitted continuously in all directions from the galactic center, the energy they carry would result in a loss of mass from the galaxy of many thousands of solar masses per year. Such a number would seem to be in gross contradiction to other observations.

The theory of black holes has not led to a convincing explanation of this phenomenon or of any of the other phenomena mentioned above, but the subject is still young. In the case of Weber's waves the best hope would seem to be some mechanism whereby the waves might be strongly beamed in the galactic plane. The sun is close to the galactic plane. With such beaming it could be that Weber's detectors are picking up a high proportion of the energy emitted at the galactic center. If that is the case, all the observational conflicts could be removed. Attempts have been made to explain such beaming on the basis of the existence of a large, strongly rotating black hole at the galactic center, but so far these attempts have not been very convincing.

It may be that no explanation based on black holes can be made to work. If Weber's observations remain, then rather than abandon the general theory of relativity (except in regions of large space-time curvature where we might expect the classical theory to break down anyway) we may prefer to seek an explanation in terms of naked singularities. It is worth pointing out that some of Kerr's solutions of Einstein's equations embody naked singularities and that Carter has calculated that any effect originating at a naked singularity can be observed in only one plane. If this phenomenon somehow applied to the center of our galaxy, we could imagine the singularity's being responsible both for the existence of the galactic plane and for Weber's gravitational waves. This would remove the observational discrepancies, although it would be a radical explanation of Weber's observations. In comparison black holes can now be regarded as being "conventional"; indeed, for this reason they must be preferred a priori in any attempt at explanation. Yet nature does not always prefer conventional explanations, least of all in astronomy.

We want to be useful ...and even interesting

Expression of faith

Science isn't all it's cracked up to be, according to readily available curbstone opinion. There have been indications that a few prominent names in American industry have come to share this opinion, however reluctantly. Not Kodak. We seem to be plowing ahead as though there were no tomorrow. Or to put it more sharply, because there *is* a tomorrow.

This year—this month in fact—we began giving prizes to brilliant high schoolers at the International Science and Engineering Fair. Now! With the Sputnik scare receded 15 years into ancient history!

These prizes, as well as over 200 regional ones, are awarded for effective use of photography in a science project. It figures. Good for business.

Good for business at a different level is the program of Eastman Kodak Research Grants. This vehicle of old-fashioned faith in science has been plowing on through thick and thin for years at selected universities and colleges. They are selected not by contests but by a simple-minded criterion: we know them well.

Some are known as well to the rest of the world. They are fountainheads. In their debt stands any business that builds technology on science.

Random samples of facts recently learned with the help of Kodak bucks on campuses and scattered to the four winds by scholarly dispersal mechanisms:

The 4-element, 6-atom molecule formamide exists in interstellar space and has been identified by microwave spectroscopy.

The route by which nature synthesizes nicotinic acid in green plants is quite different from the route followed in molds and animals, including man.

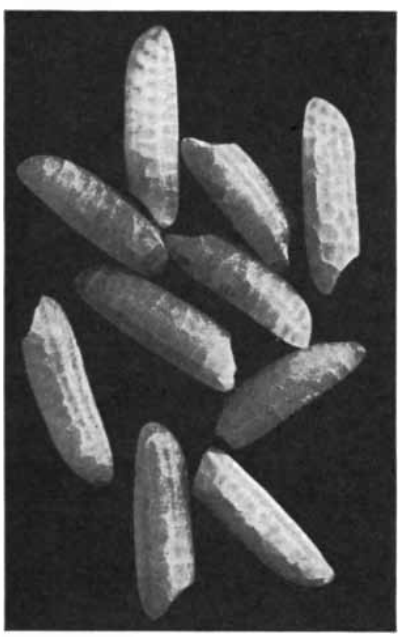
In a reaction such as $F + H_2 \rightarrow HF^{\dagger}(v) + H$, the HF product is highly excited vibrationally. Its average energy content accounts for more than 60% of the exothermicity. Such studies provide new insights into some elementary chemical reactions.

Light waves may be used as a kind of radar to follow the Brownian motion of macromolecules in solution.

In the CS_2/O_2 electrically pulsed laser system, the lasing is done by CO that is produced by oxygen atom attack.

When a molecule absorbs light, the manner in which the energy is redistributed within its structure governs the subsequent photochemical reactions.

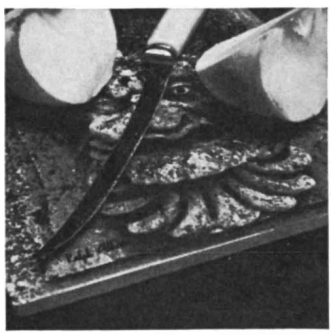
Getting in close



If you had some rice grains and wanted to make a point about the cracks in them, it would be well to know a thing or two about photographic lighting. Otherwise the fanciest of cameras and the finest of films won't help. In conveying unadorned fact, one sometimes needs quick, convenient photography and sometimes eloquent photography. Kodak, a house built on convenient photography, considers its books on technique for eloquence to be products worth their price just as much as camera and film.

One such book is H. Lou Gibson's "Close-up Photography and Photomacrography," a hard-cover production that belongs in any library serving patrons whose interests encompass more than interpersonal relations. Carries a jacket price of $10. Order from a photographic dealer as Kodak *Technical Publication No. N-16. Separately bound without hard covers, the two subjects each carry a $2.75 price. Note that the second of the subjects is not photomicrography but photomacrography, the photography of subjects which visually require a hand lens but not a compound microscope.*

Photography was invented in France to speed up production of popular art. Now French producers of popular art



—as can be seen here in a photograph reproduced as continuous tones of pigmentation beneath the glaze of a ceramic surface—may be leading the way again 133 years later in a lesser second phase. The image is laid down by KODAK CERMIFAX Photopolymer Solution. Ceramic pigment is absorbed in inverse proportion to exposure. Also used are KODAK CERMIFAX Diluant and KODAK CERMIFAX Mordant. All three are made by Kodak-Pathé in France.

U. S. pioneers, artistic or technological, will need enough motivation to overcome paucity of experience here with the process. If undaunted, write Dept. 926, Kodak, Rochester, N.Y. 14650.

Far, far better-established is etch technique. "Photofabrication Methods with KODAK *Photosensitive Resists," a brand-new profusely illustrated manual, contains not a word about Cermifax products, yet is well worth $1.75. Order from Dept. 454, Kodak, Rochester, N.Y. 14650 as publication P-246.*

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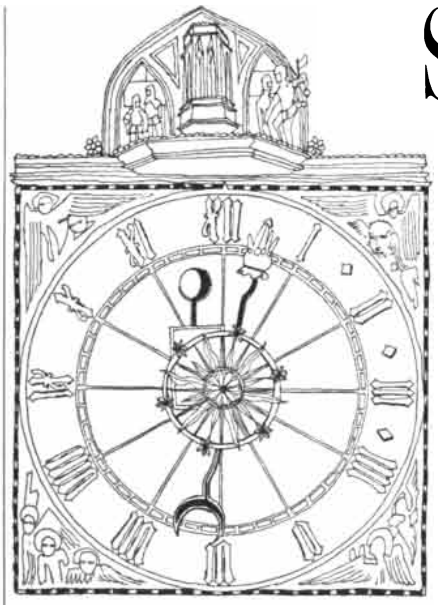

N.I.E.

A National Institute of Education will shortly be established as a result of a provision incorporated by Congress in the Higher Education Act. According to the Committee on Education and Labor of the U.S. House of Representatives, it is intended to "do for education what the National Institutes of Health are doing for health." The new agency will be part of the Department of Health, Education, and Welfare, as the National Institutes of Health are. As defined by the Houes committee, the new institute will be a focus for educational research and experimentation, providing in those areas "leadership of a national agency with high visibility and institutional strength."

Most of the research now done by the U.S. Office of Education would be transferred to the new institute. Commenting on the transfer, the House committee said: "Office of Education research has been plagued by a negative image—for management resulting in research of poor quality and of little substance; for failure to focus on genuine problems in education, and for insensitivity to any interests but those of the established educational leadership." The legislative scheme for avoiding such problems includes personnel policies that "can be attractive to highly creative and independent scholars who have difficulty operating in a normal bureaucratic setting." Moreover, the committee said, "a separate research and development agency is freer to foster approaches significantly different from existing institutional patterns than is an agency closely tied to those patterns through its major support functions."

Technology Assessment (Cont.)

After lying dormant for several years, a bill to establish an Office of Technology Assessment has been passed by the House of Representatives and appears likely to be approved by the Senate. As defined in the bill, "the basic responsibilities and duties of the Office shall be to provide an early warning of the probable impacts, positive and negative, of the applications of technology and to develop other coordinate information which may assist the Congress in determining the relative priorities of programs before it."

Underlying the original proposal was the belief that in a market economy decisions to pursue or not to pursue a particular application of technology were made almost entirely for economic reasons, with little or no opportunity for consideration of such matters as pollution or the misapplication of resources. In that form the idea did not stir much interest in Congress. What apparently got the legislation moving was Congressional frustration in obtaining adequate technical information from the executive branch of the Government on such executive-branch proposals as the supersonic transport and various anti-ballistic-missile systems.

The strength of Congressional feeling was reflected in a House amendment that changed the Technology Assessment Board (the policy-making body of the proposed assessment agency) from a mixture of legislators, Government officials and private citizens to an entirely Congressional body. Many members of Congress appear to believe the office will be able to give Congress a "go" or "no go" answer on proposed applications of technology or on dealing with undesirable effects of existing applications. Another body of opinion holds that about the best the agency will be able to do is illuminate issues.

On the Metric Road

The Administration has asked Congress to set the U.S. on the road toward adoption of the metric system

THE CITIZEN

within the decade. Following recommendations made in the U.S. Metric Study, which was conducted by the National Bureau of Standards between 1968 and 1971 at the request of Congress, the proposed legislation would create a National Metric Conversion Board to plan and coordinate a voluntary conversion process whereby metric units would become the predominant language of measurement. The 25-member board would consist of 21 private citizens appointed by the President and of four members of Congress. It would consult widely with business, labor, consumers and standard-setting bodies.

Explaining the proposal to a group in Denver, Lewis M. Branscomb, director of the National Bureau of Standards, put forward several reasons that moved the Administration to press the metric issue. One is to help the U.S. maintain a competitive position in world trade at a time when almost all the other major industrial nations have adopted the metric system or committed themselves to doing so. Another has to do with the fact that such bodies as the International Organization for Standardization and the International Electrotechnical Commission, in which the industries of some 65 nations are participating, are adopting a large number of international standards in order to eliminate technological barriers to trade. "If we stand by while they write their industrial technology into what will be a package of at least 10,000 metric industrial standards," Branscomb said, "then the process of going metric will mean to convert to foreign industrial practice. If, instead, we get in there in the next 10 years and get our technology written into those international standards, those other nations will have to change to our technology at least as often as we do to theirs."

The Mariner Becomes a Viking

What is the encore in the U.S. space program to the extraordinarily successful explorations of Mars by the Mariner spacecraft? It is the Viking Project, which is scheduled to launch two unmanned vehicles toward Mars in 1975. The project is described in some detail in a recent issue of the journal *Icarus*.

The emphasis of the project will be on detecting the presence or absence of

life. Both of the Viking spacecraft will consist of an orbiter and a lander, each with a lifetime of many months. The two craft will be launched separately by Titan III/Centaur vehicles in the summer of 1975 and will arrive in orbit around Mars a year later. Three mapping experiments will be performed by the orbiter to select the low, damp, warm region most likely to support life. A pair of high-resolution cameras will scan the surface. An infrared spectrometer will map the distribution of atmospheric water and an infrared radiometer the distribution of surface temperature. These instruments will also operate when the lander is on the ground.

As the lander enters the atmosphere it will measure the flux of charged particles as a function of altitude to provide data on the interaction of the solar wind and Mars's atmosphere. Pressure and temperature will also be measured as functions of altitude. On the ground for the next 90 days the lander will continue to measure pressure, temperature, wind velocity and humidity throughout each daily cycle in order to help reconstruct the physical processes near the landing site.

A small seismometer will monitor Mars's seismic activity. An array of magnets will determine the ferromagnetic characteristics of the surface. Two cameras a meter apart will send back television pictures of the local terrain to assist reconstruction of the planet's geological history. A mass spectrometer will analyze the soil samples and the atmosphere at the surface for both major and minor constituents that may have chemical or biological significance. An extending arm with a scoop will gather soil samples from an area within 10 feet of the lander to test them for the presence of possible biological organisms.

Lively Rhodopsin

A recent experiment demonstrating that molecules of rhodopsin (the protein responsible for detecting light in the rods, or visual receptor cells, of the retina) are free to rotate in a fluid medium within the cell membrane may have an important bearing on future studies of the structure and transport properties of biological membranes in general. The experiment is reported in a recent issue of *Nature New Biology* by Paul K. Brown of Harvard University. In an accompanying article Richard A. Cone of Johns Hopkins University discusses some of the implications of Brown's finding and presents the results of his own further investigation of the rotational diffusion of rhodopsin molecules in the rod membrane.

Brown's experiment was designed to measure the dichroism (the tendency to absorb light from different directions differently) of isolated frog retinas and also of the outer segment of single rods. It had been known for some time that dark-adapted rods are dichroic from the side, with light polarized perpendicularly to the long axis of the rod being absorbed much more effectively than light polarized parallel to the rod. This dichroism implies that the chromophore, or color-bearing appendage, of the roughly spherical rhodopsin molecule is oriented parallel to the disklike convolutions of the cell membrane that are stacked to form the cylindrical outer segment of the rod. Within the plane of the membrane, however, the chromophore appears to be oriented at random, since rods viewed end on are not dichroic.

One would expect in this case to be able to induce dichroism by partially bleaching the rhodopsin chromophores with plane-polarized light directed along the long axis of the rod. When this experiment was first attempted in 1960 by W. A. Hagins and W. H. Jennings, however, they were surprised to find that the retina did not become dichroic. To explain the absence of dichroism Hagins and Jennings suggested as the most plausible of three possibilities that the rhodopsin molecule may be free to rotate within the membrane.

It is basically this suggestion that has now been confirmed by Brown, who showed that a frog retina, after being fixed with glutaraldehyde, is rendered highly dichroic in an end-on view by a partial bleach with polarized light. Brown concludes that this finding, along with other evidence, "supports the hypothesis that rhodopsin is free to undergo Brownian rotation in the membrane, and that glutaraldehyde forms cross-links which prevent this rotation."

Brown's results, as he points out in his article, "imply that following a flash bleach with polarized light, a normal retina should become dichroic for as long as it takes the rhodopsin molecule to undergo rotational diffusion by Brownian motion." It is precisely this "transient photodichroism" that Cone reports observing in his experiments. Using the decay rate of the dichroism induced in a frog retina by a polarized flash of light as a direct measure of the time it takes for rhodopsin to "relax" in the receptor membrane, Cone estimates that the relaxation time of rhodopsin is on the order of 20 microseconds. He points out that "the site rhodopsin occupies in the membrane must therefore be highly fluid."

According to Cone, all of this raises the distinct possibility that rhodopsin, by virtue of its ability to "tumble" freely in the membrane, acts as a light-activated "diffusional carrier" that transports calcium ions in the membrane. Since small changes in calcium concentration are known to elicit large changes in the sodium permeability of the rods, this conjecture could then help to explain the extraordinary sensitivity of the rod, which has been shown to respond to the arrival of a single photon of light.

Although such diffusional carriers have long been thought to play an important role in membrane transport, so far no membrane protein has been shown to have sufficient mobility to act as an efficient carrier. The experiments of Brown and Cone suggest that rhodopsin may be such a molecule.

The Sensuous Teen-ager

Among women between 14 and 19 in the U.S. the rate of illegitimate births has more than doubled since 1940. Does this reflect a revolutionary change in the sexual mores of American youth? After a detailed analysis of the comparative statistics, Phillips Cutright of Indiana University enters a strong dissent. What teen-agers are doing today, Cutright reports in *Family Planning Perspectives,* is little different from what they were doing in the 1940's. The birthrate has risen not because of "casual and generalized coition of unprecedented proportions," as many have supposed, but because of two physiological changes that have taken place in the past 30 years.

The first change is that today's teen-agers are generally in better health than the adolescents of the preceding generations; this has reduced the number of spontaneous abortions and has accordingly increased the number of illegitimate births. The second change concerns the average age of menarche: the onset of menstruation. In the U.S. that age has declined in the period from the 1930's to the 1960's from 13½ years to 12½ years. Teen-agers today are therefore exposed to a longer interval of risk of pregnancy than teen-agers of the 1940's were.

Cutright concludes that the much touted sexual revolution is largely nonexistent, even though the myth of widespread teen-age promiscuity has "engaged the . . . prurient envy or blind rage . . . of many adults." One clear-cut change in mores does appear: the number of

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young women who are pregnant when they marry is about 10 percent greater than it was in the 1940's. The sexual revolution therefore appears to be confined to an increase in intercourse among "girls involved with males who will become their husbands."

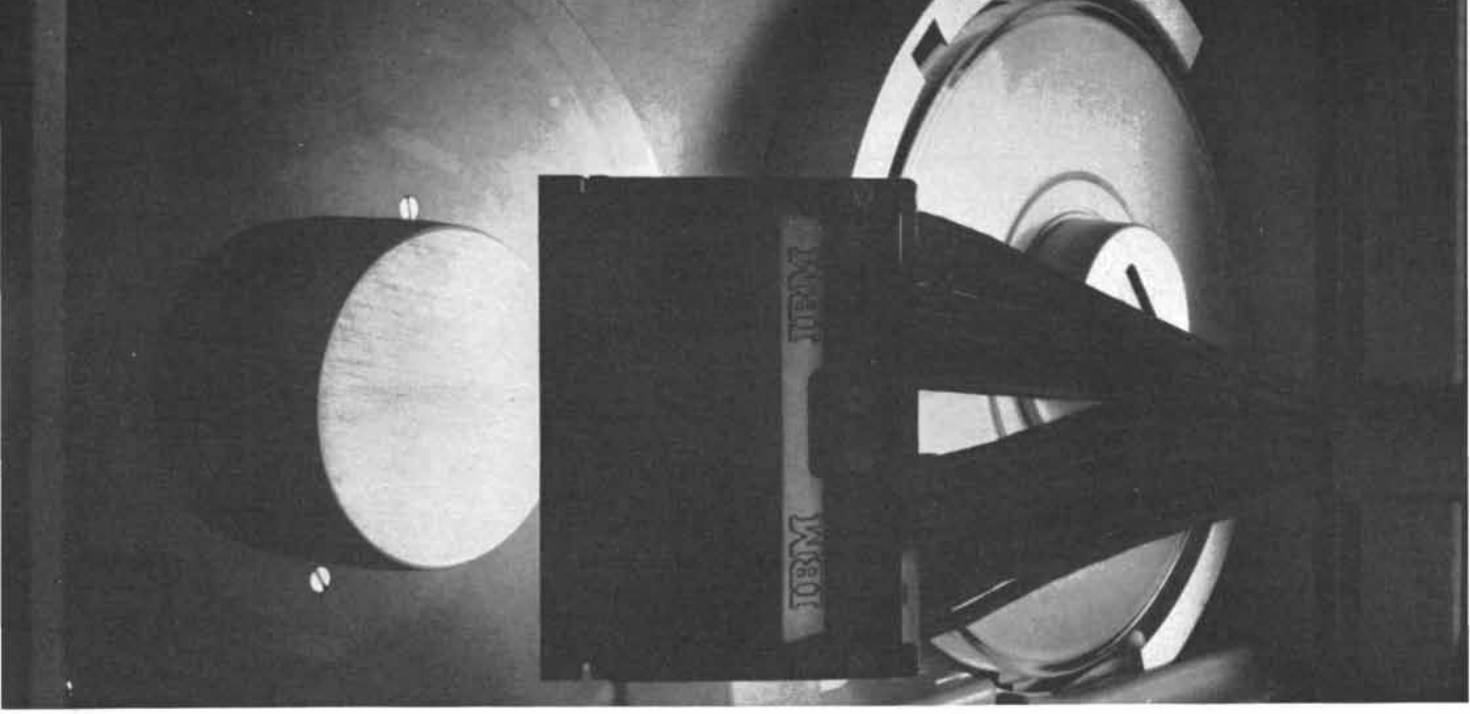
The Aggressive Stare

Staring is a characteristic signal of aggressive intent in chimpanzees, gorillas and other lower primates. The response to such a threat usually is flight, submissive display or, in some circumstances, attack. To what extent is staring an aggressive stimulus in human interactions? To answer the question a group of psychologists at Stanford University (Phoebe C. Ellsworth, J. Merrill Carlsmith and Alexander Henson) conducted a series of street experiments. They had confederates stand at street corners and stare at people who were waiting for the traffic light to change to green. Their finding: Staring at humans can "elicit the same sort of responses that are common in primates." According to their report in the *Journal of Personality and Social Psychology*, people who realized they were being stared at crossed the intersection faster than people who were not being stared at.

In the first experiment 77 male and female drivers unwittingly served as subjects. A researcher riding a motor scooter would stop at an intersection with a red light and wait for a car to pull up alongside. The researcher would then turn and stare at the driver. The stare was always delivered "with the naked eye," and the researcher maintained an impassive, neutral expression throughout the staring period. A stopwatch was used to measure the staring time and the time it took the driver to cross the intersection after the light had turned green. The procedure for the no-stare control group was identical except that the researcher merely glanced at the driver to determine sex and age. The mean crossing time for drivers who were stared at was 1.2 seconds less than it was for those in the control group.

To find out if a "drag-race challenge" was responsible for the increased speed of the drivers who were stared at, the researchers put aside the motor scooter and stood on the sidewalk to conduct the experiment. Again drivers who were stared at fled across the intersection 1.2 seconds faster than drivers who were not stared at.

In both experiments the drivers crossed the intersection significantly faster when the researcher was a female.



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This sex effect was puzzling, since it occurred in both the stare and the no-stare conditions. A third experiment with a larger number of researchers was set up. Once again staring had an accelerating effect on the drivers, but statistical analysis showed that there was no significant relation between either the sex of the researcher or the sex of the subject and the effects of staring. "Evidently," the investigators write, "the [sex] effects observed in the first two experiments were due to idiosyncratic characteristics of the particular experimenters used."

The discovery of the staring effect opens up some interesting new lines of research. Is a stare always perceived as a threat, even in the absence of other aggressive cues? The impact of a stare may be mitigated if the starer responds to the other person by smiling or talking. Perhaps a stare is interpreted as an invasion of personal space rather than as a signal of hostile intent. Ellsworth, Carlsmith and Henson conclude that these and other questions are ready to be tested by experiment in the laboratory.

Countermeasure

The illicit excavation of antiquities, which has long dismayed archaeologists, is by no means confined to such places as the jungles of Southeast Asia and Central America. Perhaps the hardest-hit area is the British Isles, where the precise location of many ancient monuments is public knowledge and the protection of their buried contents is spotty. The editors of *Current Archaeology,* Andrew and Wendy Selkirk, have now proposed a countermeasure against one group of "treasure hunters": those armed with metal-detecting devices who search the ruined villas and temples of Roman Britain intent on locating and looting hoards of coins. By their thefts the looters first of all destroy the coins' context within the site. Further, the looters usually sell what they find surreptitiously, thereby eliminating the crucial historical link between the coins and their actual place of discovery.

The Selkirks propose that interested archaeologists arm themselves with a few ounces of tacks or similar scrap and seed the metal over the surface of the Roman sites most frequented by looters. This stratagem would make the sites permanently unrewarding to anyone using a metal-detector. "A handful of tintacks, scattered in an instant," the Selkirks suggest, "will keep a treasure hunter busy for hours."

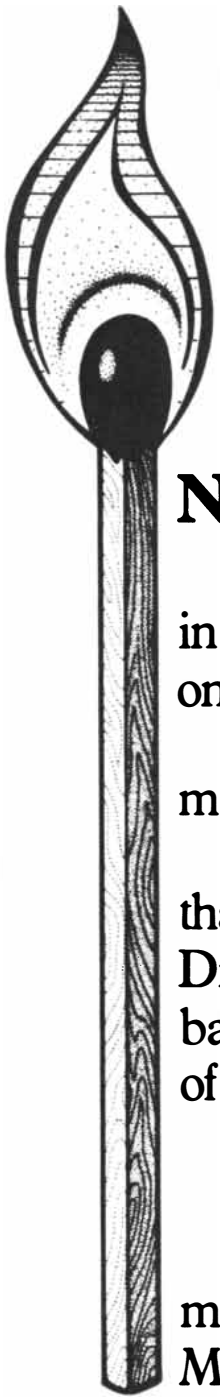

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PLATE TECTONICS

The earth's surface is divided into a mosaic of rigid, shifting plates. As they move apart, slide past each other and converge, new crust is generated, continents drift and mountains are formed

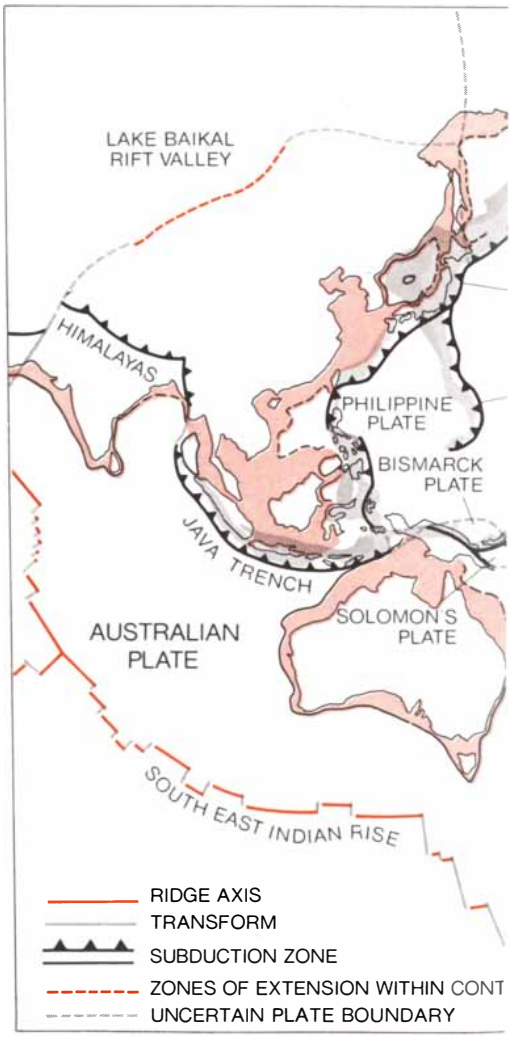
by John F. Dewey

It has long been observed that mountains, volcanoes and earthquakes are not randomly distributed over the earth's surface but are found in distinct and usually narrow zones. To account for these evidences of instability in the earth's crust many hypotheses have been put forward. They have included such diverse notions as global expansion, global contraction, the effect of lunar tidal forces and wholesale uplift or foundering of large segments of the earth's crust. One other explanation—continental drift—was advanced from time to time but was unpalatable to most geophysicists because it seemed to violate what was known about the mechanical properties of the earth's crust. Nevertheless, continental drift seemed to explain geological similarities between continents thousands of miles apart. It also explained why some continental margins, for example those of South America and Africa, match each other so precisely.

Within the past 10 years continental drift has been placed on a firm foundation by the development of the concept of sea-floor spreading, originally proposed by the late Harry H. Hess of Princeton University. Sea-floor spreading involves the notion that the floor of the ocean is continuously being pulled apart along a narrow crack that is centered on a ridge that can be traced through the major ocean basins. Volcanic material (liquid basalt) rises from the earth's mantle to fill the crack and continuously create new oceanic crust.

The concept might have been difficult to confirm except for the fortunate fact that the polarity of the earth's magnetic field periodically reverses. It had been observed from magnetometer surveys that rocks of the ocean floor exhibit a zebra-stripe pattern in which the intensity of magnetization changes abruptly in linear ribbons parallel to the nearest oceanic ridge. In 1963 F. J. Vine and D. H. Matthews of the University of Cambridge proposed that the magnetic pattern was evidence of both sea-floor spreading and reversals of the earth's magnetic field. To many geologists the one seemed almost as improbable as the other. Vine and Matthews argued that as the basaltic liquid rose into the axial crack of the oceanic ridges and solidified it would become magnetized in the then prevailing direction of the earth's magnetic field. If new oceanic crust was continuously generated, as Vine and Matthews believed, one should find that each ridge axis is bordered symmetrically by pairs of parallel strips whose direction of magnetization is the same, that is, both normal or both antinormal. The hypothesis was strikingly confirmed in many traverses across oceanic ridges. Furthermore, a time scale of magnetic reversals has been developed showing that the rate of sea-floor spreading is between two and 18 centimeters per year.

It is now clear that virtually all of the present area of the oceans has been created by sea-floor spreading during the past 200 million years, or during the last 5 percent or so of the recorded geologic history of the earth. The creation of new surface area means either that the earth has expanded dramatically or that surface area is somewhere being destroyed at the same rate at which it is being created. There is good evidence that the earth has not expanded more than about 2 percent in the past 200 million years. Thus there must be, in general terms, a global conveyor-belt system or surface motion that links zones of surface creation and surface destruction.



MOSAIC OF PLATES forms the earth's lithosphere, or outer shell. According to the recently developed theory of plate tectonics, the plates are not only rigid but also in constant relative motion. The boundaries of plates are of three types: ridge axes, where plates are diverging and new oceanic floor is generated; transforms, where plates slide past each other, and subduction zones, where plates converge and one plate dives under the leading edge of its neighbor. Triangles indicate the leading edge of a plate.

The concept of sea-floor spreading has now been joined to the earlier idea of continental drift in a single unifying theme called the theory of plate tectonics. The geometric part of the theory visualizes the lithosphere, or outer shell, of the earth as consisting of a number of rigid plates. The kinematic part of the theory holds that the plates are in constant relative motion: they can slide past each other, they can move apart on opposite sides of an oceanic ridge or they can converge, in which case one of the plates must be consumed. Let us now see how various instabilities in the earth's crust can be visualized in terms of plate tectonics.

Earthquakes

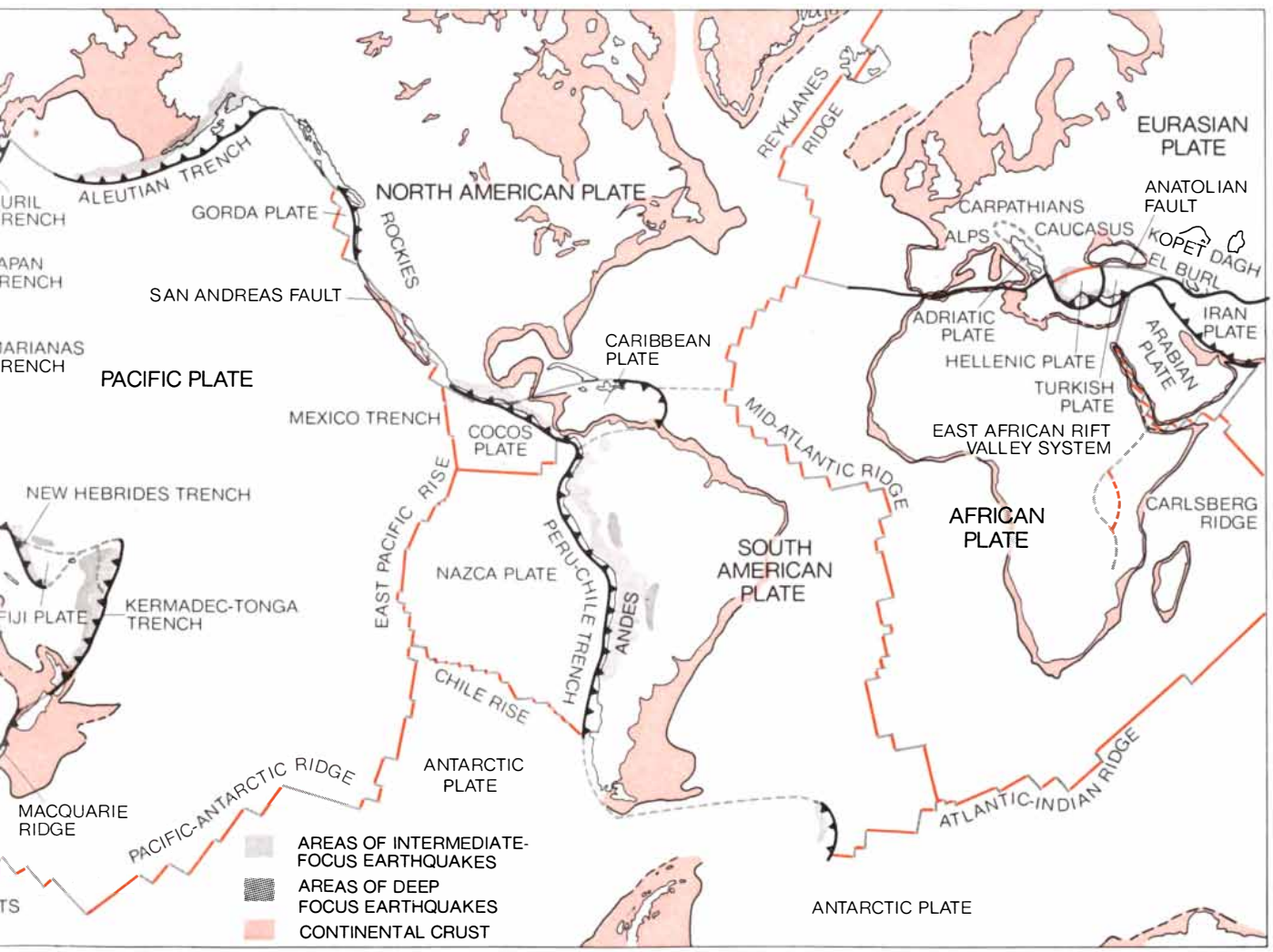
Most earthquakes occur in narrow zones that join to form a continuous network bounding regions that are seismically less active. The seismic network is associated with a variety of characteristic features such as rift valleys, oceanic ridges, mountain belts, volcanic chains and deep oceanic trenches [*see illustration below*]. The seismic areas mark the boundaries between plates, which are largely free of earthquakes. There appear to be four types of seismic zone, which can be distinguished by their characteristic morphology and geology.

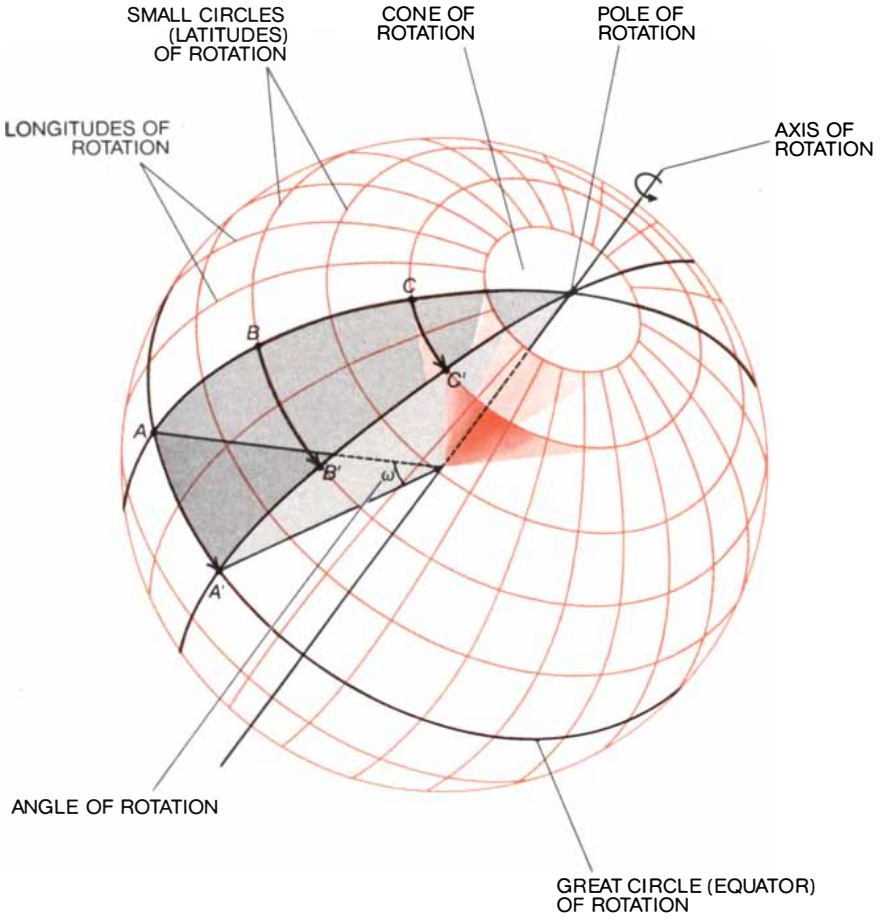
The first type is represented by narrow zones of high surface heat flow and basaltic volcanic activity along the axes of mid-oceanic ridges where earthquakes are shallow (less than 70 kilometers deep). The axes of the ridges, of course, are the active sites of sea-floor spreading. In Iceland, where the Mid-Atlantic Ridge rises above sea level, the spreading rate has been measured at about two centimeters per year.

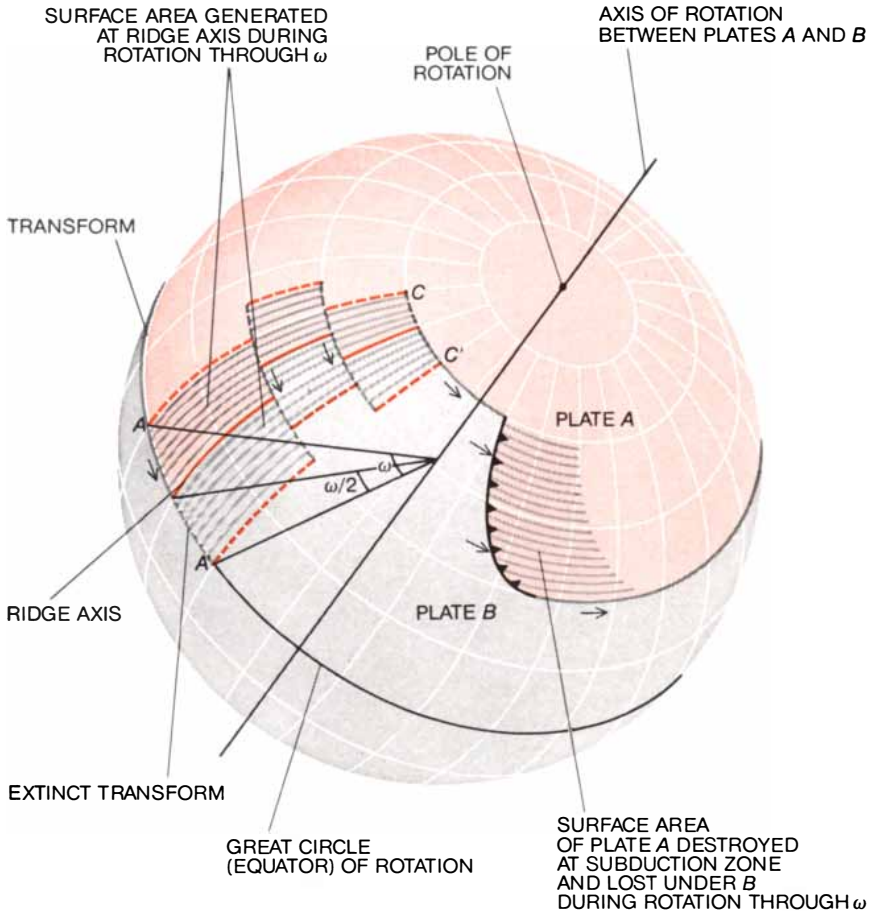
The second type of seismic zone is marked by shallow earthquakes in the absence of volcanoes. A good illustration is the region around the San Andreas fault in California and around the Anatolian fault in northern Turkey, along both of which large surface displacements parallel to the fault have been measured [see "The San Andreas Fault," by Don L. Anderson; SCIENTIFIC AMERICAN, November, 1971].

The third type of seismic zone is intimately related to deep oceanic trenches associated with volcanic island-arc systems, such as those around the Pacific Ocean. Earthquakes there can be shallow, intermediate (70 to 300 kilometers) or deep (300 to 700 kilometers), according to where they take place in the steeply plunging lithospheric plate that borders the trench. Thus the earthquake epicenters (the points on the surface above the initial break) define a geologic structure dipping down into the earth away from the trench. These inclined earthquake zones, called Benioff zones, underlie active volcanic chains and have a variety of complex shapes.

The fourth type of seismic zone is typified by the earthquake belt that extends from Burma to the Mediterranean Sea. It consists of a wide, diffuse continental zone within which generally shallow earthquakes are associated with high mountain ranges that clearly owe their existence to large compressive forces. Earthquakes of intermediate depth occur in some areas such as the Hindu Kush and Romania. Although deep-focus







earthquakes are rare, they have been recorded in a few places, for example just north of Sicily under the Tyrrhenian volcanoes.

An earthquake results when stresses accumulate to the point that rocks in the earth's crust break. The breakage is the consequence of brittle failure of the rock (in contrast to plastic deformation, which can relieve stresses slowly). The first seismic waves to leave the region of the break (the hypocenter) are waves of alternate compression and rarefaction generated by the sudden release of elastic energy. After an earthquake one finds that the seismological stations that have received the first waves can be assigned to one of four geographic quadrants. In two of the quadrants, lying opposite each other, the first waves are compressional; in the other two quadrants the first waves are rarefactional.

The quadrants define the orientation of two nodal planes on one of which a sudden slip has presumably produced the earthquake. The intersection of the nodal planes is the null direction, or intermediate stress axis, parallel to which effectively no strain occurs. The line bisecting the quadrant in which the first motion is compressional defines the direction of least principal stress, parallel to which there is extensional strain. The bisector of the rarefaction quadrant defines the direction of the maximum principal stress along which there is compressional strain.

Lynn R. Sykes of the Lamont-Doherty Geological Observatory of Columbia University has applied this analysis to the seismic belts of the world and has shown systematically that the ridge axes are in tension, that there is lateral movement along the second type of seismic zone and that compression dominates the third and fourth types. Thus seis-

AXIS OF ROTATION can be selected in such a way (*top illustration at left*) that a set of two or more points lying on the surface of a sphere (*A*, *B*, *C*) can be moved by a rigid rotation around that axis to new positions (*A'*, *B'*, *C'*), preserving the original geometry of the set. A unique axis can be found only if the initial and final positions of two or more points are known. Similarly, the relative motion of two rigid plates can be described as a rigid rotation around a suitably selected axis of rotation (*bottom illustration at left*). Plate *A* is designated as fixed while plate *B* is rotated anticlockwise, as viewed down the axis of rotation. As plate *B* rotates through angle omega (ω), new surface area is added symmetrically to both plates at the ridge axis, which itself travels through an angle equal to one-half omega.

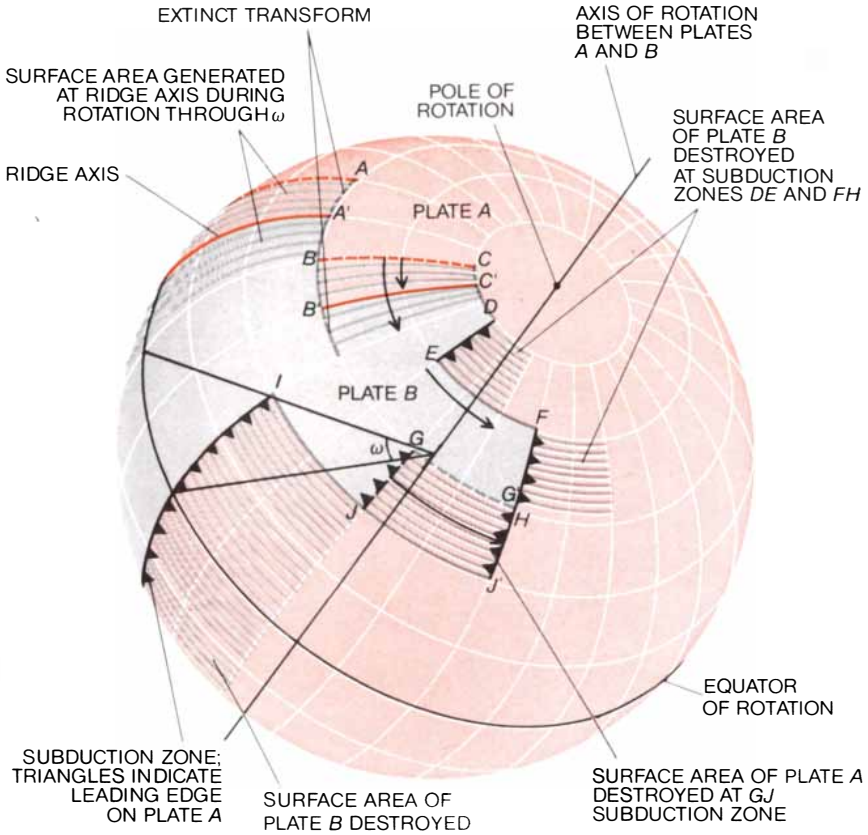
mology emphasizes that there are three kinds of plate boundary: boundaries across which plates are pulled apart, boundaries along which plates slide past each other and boundaries across which plates converge. Since rock material does not pile up indefinitely in the compressional zones, it follows that somewhere there must be zones in which plates are consumed.

The Plate Mosaic

One can therefore construct a model of global surface displacement involving a mosaic of plates each of which exhibits one or more of the three types of boundary. At ridge axes plates separate and new surface area is generated by the continuous accretion of new oceanic crust at the trailing edges of the plates. At transform faults plates slide past each other and surface area is neither created nor destroyed. At subduction zones one plate is consumed and slides down into the mantle under the leading edge of another plate.

Plates vary greatly in size from the six major plates, such as the plate that carries virtually the entire Pacific Ocean, down to very small plates, such as the plate that is essentially coextensive with Turkey. Moreover, plate boundaries do not always coincide with the margins of continents; many continental margins are peaceful earthquake-free nonvolcanic regions. Hence plates can be partly oceanic and partly continental or they can be entirely one or the other. This fact overcomes one of the traditional objections to continental drift, namely the mechanical difficulty of having a geologically weak continent plow its way across a strong ocean floor. According to the plate-tectonic view, continents and oceans are rafted along by the same crustal conveyor belt.

A look at the boundary around the African plate reveals two important consequences of plate motion. The greater part of the boundary is a ridge axis extending from the North Atlantic into the Indian Ocean and the Red Sea; thus the entire African plate must be growing in area. This behavior in turn means that plates elsewhere on the globe must be getting smaller. The second consequence of the growth of the African plate is that the Carlsberg Ridge in the Indian Ocean is moving away from the Mid-Atlantic Ridge, illustrating one of the essential corollaries of plate kinematics: plate motion is relative. There is no coordinate system within which absolute plate motion can be defined except a system defined in relation to a particular plate or plate boundary that is arbitrarily chosen as being "fixed."

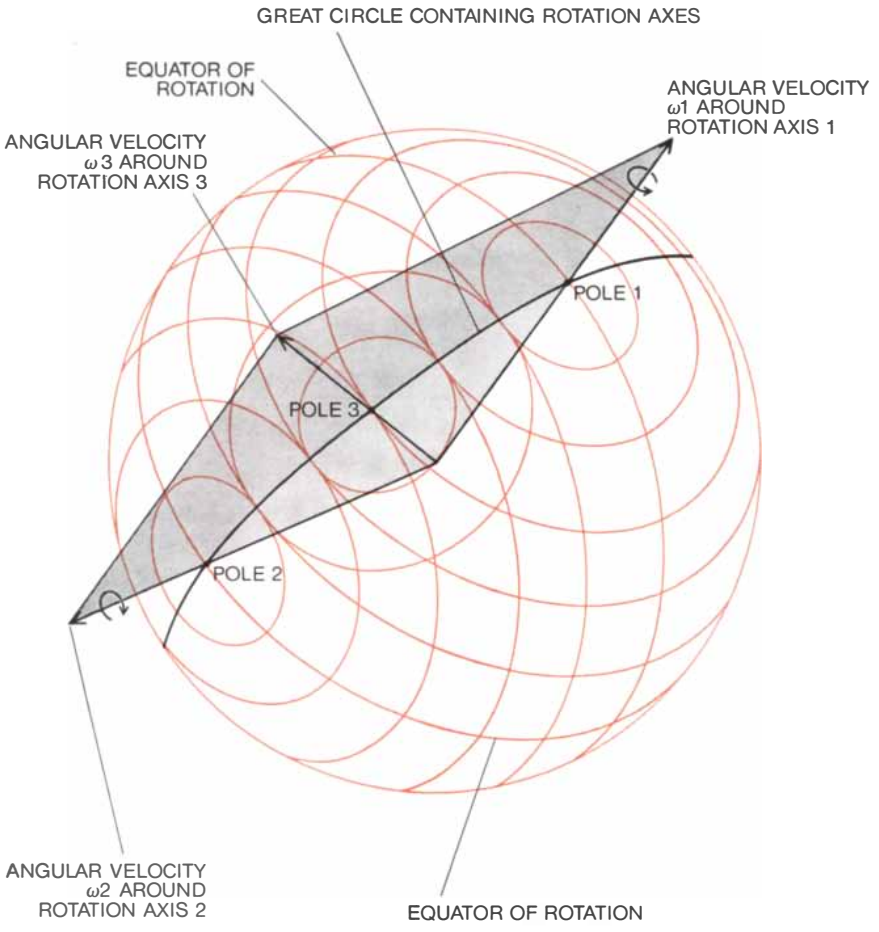


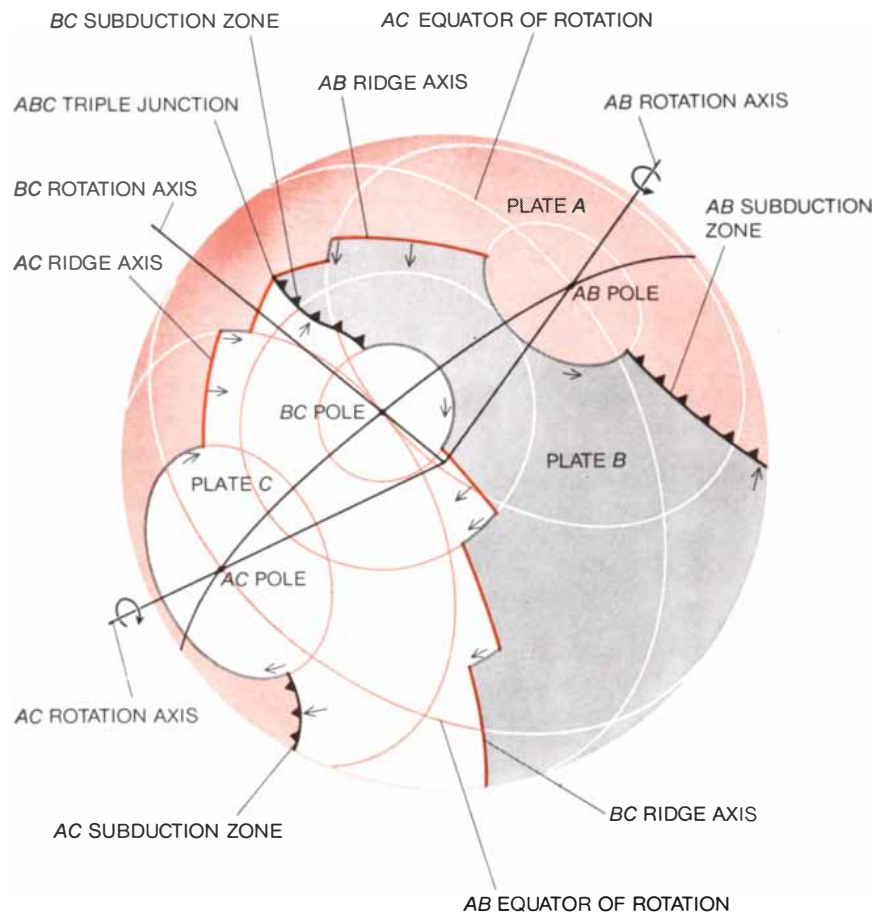
THREE KINDS OF TRANSFORM can exist as segments of a single plate boundary: ridge axis to ridge axis (*AB*), ridge axis to subduction zone (*CD*) and subduction zone to subduction zone (*EF, GH, IJ*). Plate *A* is again assumed to be fixed while plate *B* rotates anticlockwise. Ridge-axis-to-ridge-axis transforms (*AB, A'B'*) maintain a constant length because new surface area is generated symmetrically at ridge axes. Transforms joining ridge axes to subduction zones decrease or increase in length at half the transform slip rate. In the example depicted here *CD* shortens to *C'D*, but if the leading edge at subduction zone *DE* were on plate *A* (as in the case of *GJ*), *CD* would have lengthened. Transform *EF* maintains a constant length, whereas *GH* shortens to zero length and *IJ* lengthens to *IJ'*.

The basic assumption that plates are rigid is essential to plate tectonics and appears to be justified by the fact that excellent restorative fits can be made between many pairs of continental margins. (In making such a fit the margin is typically defined as the 1,000-fathom isobath on the continental shelf adjacent to the continent.) Similar fits can be made with even greater precision between pairs of magnetic anomalies symmetrically disposed on each side of a ridge axis. If plates had been distorted as they evolved, these fits could not be made. As further confirmation of rigidity, profiles produced by seismic reflection have shown that sediments laid down on the oceanic crust as it moves away from a ridge axis form undistorted flat layers.

The fact that rigid plates are in relative motion on a spherical earth means that a displacement between any two plates can be described by a rotation around an axis passing through the center of the earth. The intersection of this axis with the earth's surface is termed the pole of rotation [*see illustration on opposite page*]. This concept was first applied by Sir Edward Bullard, J. E. Everett and A. G. Smith of the University of Cambridge to demonstrate the fit of the continental margins around the Atlantic Ocean. Relative surface motion between two plates proceeds along circles of rotation around the axis of rotation. The circles can be considered as latitudes of rotation from zero radius at the pole of rotation to a maximum at the equator of rotation. Relative plate motion is best described, however, as an angular velocity, since the velocity along rotation circles increases from zero at the pole of rotation to a maximum at the equator of rotation. The nature of displacement across a plate boundary is therefore entirely dependent on its orientation with respect to the circles of rotation.

Of particular interest are boundaries parallel to rotation circles. At these boundaries are faults where surface area is conserved; such faults are called trans-





form faults. Great circles drawn perpendicularly to transform faults that are segments of one plate boundary will intersect to define the rotation pole. Plate boundaries oblique to circles of rotation are either ridges or subduction zones, depending on whether plates are separating or converging across them. The increasing rate of plate separation across ridge axes with increasing distance from the pole of rotation is reflected by a progressively increasing distance between particular magnetic anomalies and the ridge axis. Similarly, the rate of plate convergence at subduction zones increases away from the pole of rotation. A particularly good illustration is afforded by the New Zealand–Tonga seismic zone. That part of the zone south of New Zealand has only shallow earthquakes; intermediate-focus earthquakes start in New Zealand and deep-focus earthquakes north of New Zealand [*see illustration on pages 56 and 57*]. This suggests a progessive northward increase in convergence rate across the subduction zone, so that the downgoing plate reaches progressively deeper levels.

Separation rates across ridges where plates are moving apart can be directly deduced from magnetic-anomaly patterns, but there is no direct method for deducing convergence rates across subduction zones where one plate is diving under another and creating a trench. Close attention has therefore been given to plate boundaries where individual segments are a ridge, a transform fault and a subduction zone, because the angular velocity of relative motion deduced for a ridge segment also applies to a trench segment. The angular velocity can be directly translated into a circle-of-rotation velocity for any circle of rotation that crosses the subduction zone,

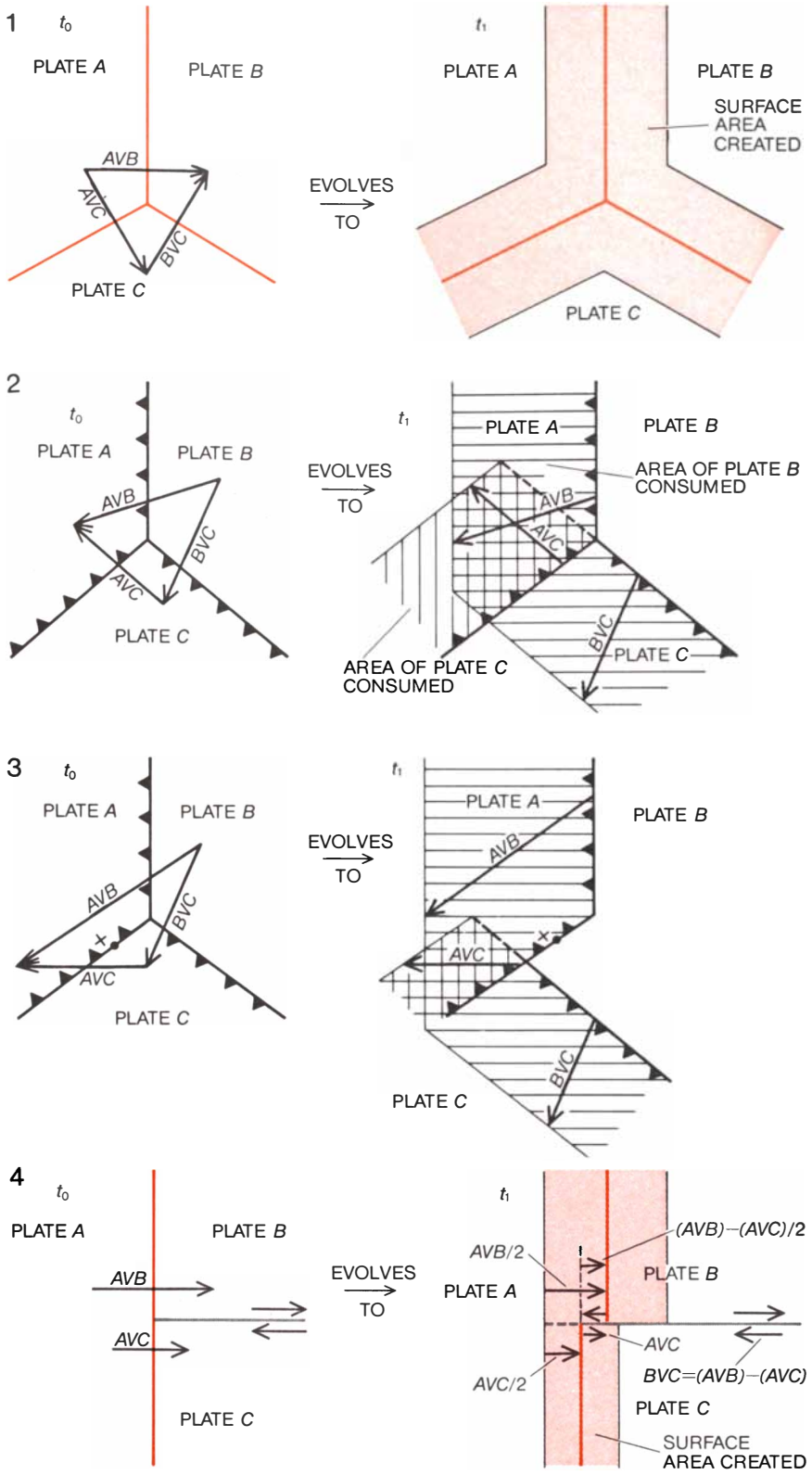
THIRD AXIS and angular velocity of rotation are defined (*top illustration at left*) as the vector sum of two others. If one knows the angular velocities of two rigid rotations around two axes (*1 and 2*) passing through the center of a sphere, one obtains their vector sum to determine the angular velocity around a third axis (*3*) lying in the same plane as the first two. In the example illustrated the poles of rotation axes *1* and *2* are 90 degrees apart and the angular velocities around them ($\omega 1$ *and* $\omega 2$) are equal, so that the pole of the third axis lies midway along a great circle between poles *1* and *2*. Similarly (*bottom illustration at left*), if one knows the axes of rotation and the angular velocities that describe the relative motion of plates *A* and *B* and plates *B* and *C*, one can ascertain the rotation axis (*BC*) that describes the relative motion of plates *A* and *C*.

depending on its "rotational latitude." Although there is no apparent geometric reason why ridges should lie parallel to longitudes of rotation, they appear in most cases to approximate this relation. Furthermore, the symmetrical distribution of paired matching magnetic anomalies with respect to the ridge axis where they were generated indicates that new crustal material is added symmetrically to the trailing edges of the diverging plates.

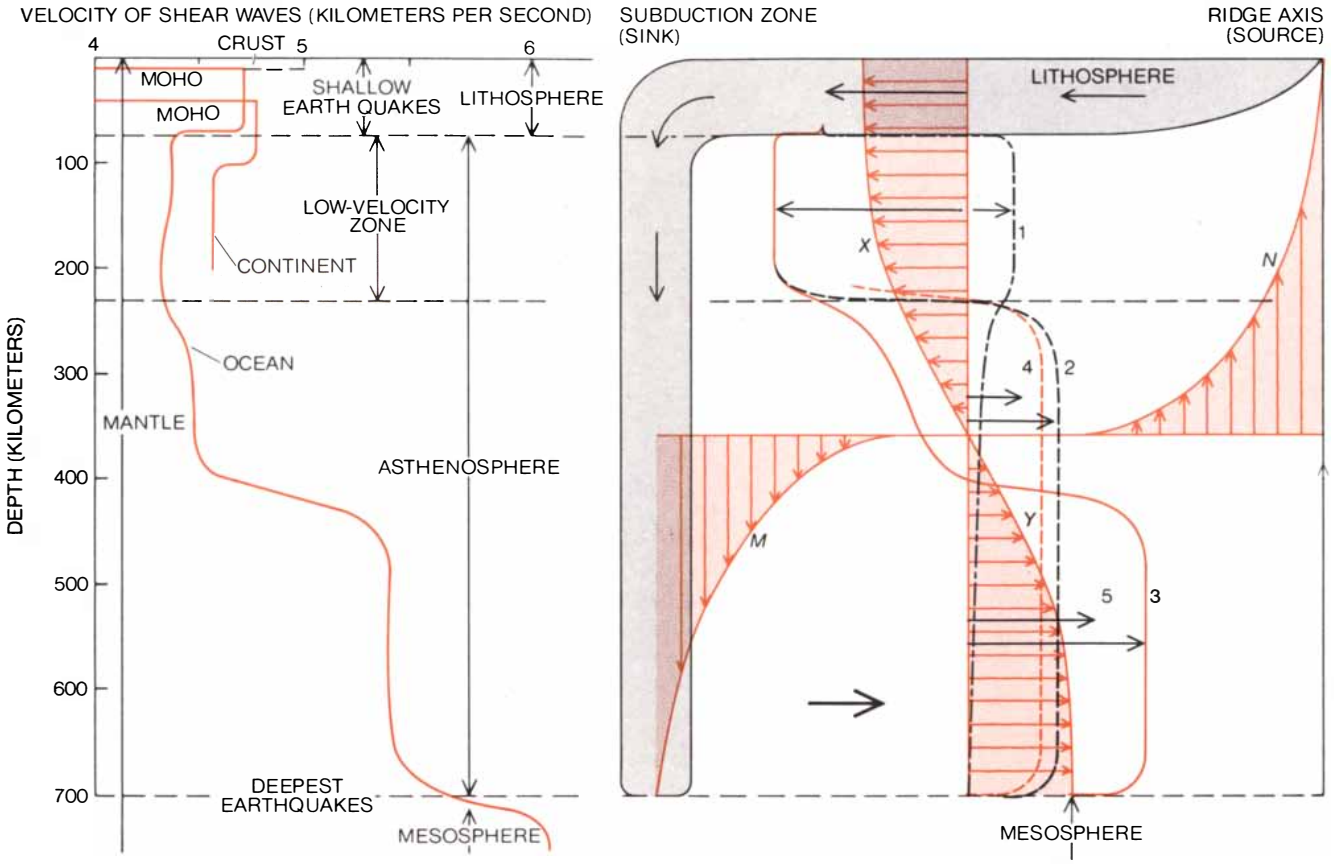
For some reason, perhaps one related to the driving mechanism for plate motion, straight ridge-transform boundaries are a mechanically stable configuration. Subduction zones are generally curved, perhaps also for mechanical reasons, and convergence directions can be right-angled or oblique to them, according to whether they are right-angled or oblique to rotation circles. One may pass in gradations from pure subduction to pure transform motion along a single plate boundary; therefore the orientation of a subduction zone, unlike the orientation of a ridge or a transform fault, is a poor guide to the relative direction of displacement.

The axial spreading zone of oceanic ridges is not a continuous feature. It is interrupted and offset by transform faults that in some places create high submarine cliffs. Transform faults were formerly thought to be lines along which the ridge axis had been displaced from a once continuous zone, since they continue as bathymetric features beyond the offset ends of the ridge axis. J. Tuzo Wilson of the University of Toronto argued, however, that they are simply offsets of the spreading axis and form an integral part of a single boundary. He coined the term transform fault to describe them because they merely transform relative motion between the two ridge segments. Seismic first-motion studies confirmed Wilson's prediction of transform motion; further support is provided by the observation that earthquakes are restricted to that portion between the offset ends of the ridge axis.

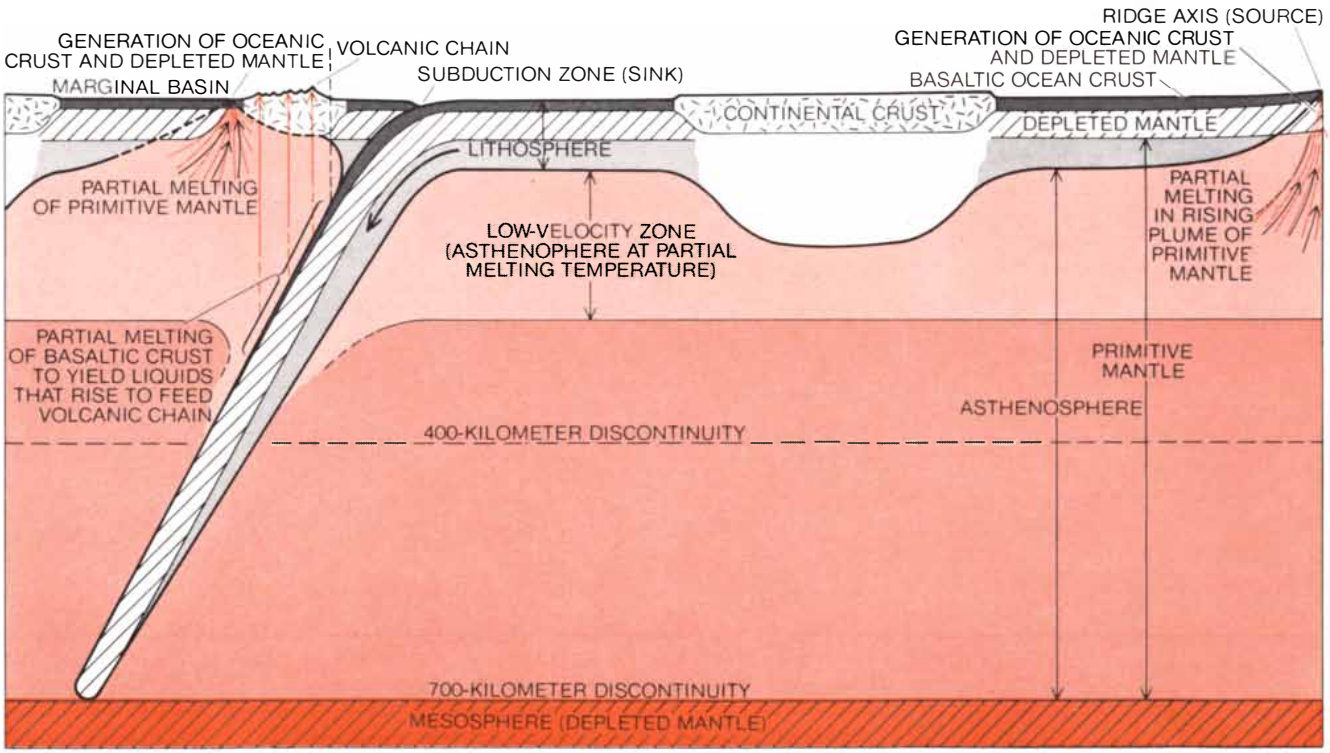
The active portion of a transform fault defines part of a circle of rotation. Similarly, the inactive continuation of a transform fault beyond the offset ridge axis defines circles of rotation for the previous history of plate divergence across the ridge axis; it represents earlier circles of rotation "frozen" into adjacent oceanic crust generated earlier. This is of fundamental importance for two reasons. First, the excellent circle-of-rotation lines described by inactive transform faults justify the assumption that relative motion between two plates can be described in



FOUR TRIPLE JUNCTIONS are depicted with their velocity triangles at time t_0 and their configuration at time t_1. Ridge axes are solid color; subduction zones are solid black; transforms are gray. A triple junction involving three ridges (*1*) is always stable. When three subduction zones meet (*2 and 3*) and two leading edges lying on plate *A* do not form a straight line, the triple junction is stable only when the *A* v. *C* velocity vector is parallel to the leading edge of plate *C* (*2*). Otherwise (*3*) the triple junction moves. Thus at some time between t_0 and t_1 the triple junction moves past point *X*. Before the time of movement the relative motion at *X* is *A* v. *C* and thereafter *A* v. *B*. The last diagram (*4*) depicts how it comes to pass that a triple junction involving two ridges and a transform can have the configuration at t_0 only instantaneously since the triple junction evolves immediately to t_1, in which plates *B* and *C* are separated by the transforms and the ridge is thus offset.



VARYING VELOCITY OF SHEAR WAVES in lithosphere and asthenosphere (*left*) suggests models showing how mass-transfer circuits (*right*) introduce new plate material at ridge axes and consume it at subduction zones. The velocity of shear waves decreases at 70 and 150 kilometers under oceans and continents respectively. Evidently mass-transfer circuits extend to a depth of at least 700 kilometers. Material descending at sinks (under curve *M*) must be balanced by material rising at sources (under *N*), and the upper lateral transfer (under *X*) must be balanced by return flow (under *Y*). Five shapes are suggested for lateral-transfer gradients.



LITHOSPHERE PLATE of solidified rock serves as a thermal boundary conduction layer "floating" on molten or semimolten rock of the asthenosphere. In this schematic view the lithosphere is thicker under the continent it is rafting toward a subduction zone, where the plate descends into the mantle under leading edge of another plate. New oceanic crust is steadily being added at ridge axis.

terms of a rigid rotation around a fixed pole. Second, it provides the key to working out past plate motions. The inactive transform faults give the direction but not the rate of old displacements. Rates, however, can be deduced from the spacing of magnetic anomalies of known ages.

Walter C. Pitman III and Manik Talwani of the Lamont-Doherty Observatory have devised a simple but elegant technique using well-defined pairs of magnetic anomalies of known ages and fracture-zone orientations for computing plate displacements in the central Atlantic Ocean for the past 180 million years. First they assumed that successive pairs of magnetic anomalies were generated at the ridge axis and moved apart on rigid plates. They then found a series of rotation poles around which they could fit the pairs of progressively older magnetic anomalies; the series ended with a rotation that fitted the continental margins of Africa and North America. Reversing this sequence gives the kinematics of plate divergence that records the history of the opening of the central Atlantic Ocean.

A consequence of the symmetrical generation and asymmetric destruction of surface area, at ridge areas and subduction zones respectively, is that transform faults can retain a constant length or can change their length [*see illustration on page 59*]. Transform faults that join ridge axes, or subduction zones with leading edges on the same plate, stay the same length. Where transform faults join subduction zones with leading edges on different plates, they lengthen or shorten, depending on whether the leading edges face away from or toward one another. A transform fault that joins a ridge axis to a subduction zone increases or decreases in length depending on which plate the leading edge lies on.

If the axes and angular velocities of rotation between two pairs of plates (*A* and *B* and *A* and *C*) are known, the axis and angular velocity of rotation between the third pair (*B* and *C*) can be calculated [*see illustration on page 60*]. This means that if ridge-axis segments fall along the boundaries between *A* and *B* and *A* and *C*, the relative motion of *B* and *C* can be found. Xavier le Pichon of the Center for the Study of Oceanography and Marine Biology in Brittany developed this technique for computing the relative motions between the six largest plates and was thus able to work out convergence directions and rates across all the major subduction zones.

With the same technique Pitman has computed the relative motion of Africa and Europe for the past 80 million years. During this time North America and Africa have been parts of separate plates moving apart around a sequence of rotation axes as the central Atlantic has widened. North America and Europe have been similarly moving apart but around a different sequence of rotation axes. Therefore there has been relative motion between Africa and Europe. This motion has been complex but the net effect has been to nearly eliminate a formerly wide oceanic region between the two continents.

Since relative displacements are along circles of rotation, the relative motion between three plates cannot be described by the customary velocity vector triangle except instantaneously at a point. If, however, we are interested in relative motions in an area of the earth's surface so small that it may be regarded as a flat surface, with the result that circle-of-rotation segments are virtually straight lines, the velocity vector triangle is a convenient device for illustrating relative motion. A small area of great interest is one where three plate boundaries join to form a triple junction. Triple junctions are demanded by plate rigidity; this is the only way a boundary between two rigid plates can end. D. P. McKenzie of the University of Cambridge and W. Jason Morgan of Princeton University have analyzed all possible forms of triple junctions with velocity vector triangles and have shown that they can be stable or unstable depending on whether they are able or unable to maintain their geometry as they evolve [*see illustration on page 61*].

Plate Thickness and Composition

So far we have considered those essential aspects of plate geometry and evolution that can be treated from a surface point of view. We have not yet inquired into the thickness and composition of lithosphere plates. It has been known for many years from gravity and seismic-refraction measurements and from general considerations of mass balance that the continents are underlain by a relatively light "granitic" crust about 40 kilometers thick and the oceans by a denser "basaltic" crust only about seven kilometers thick. Both continental and oceanic crust are underlain by a mantle of denser material. The junction between crust and mantle is the "Moho," or Mohorovicic discontinuity. It was the goal of the now abandoned Mohole project to drill through the relatively thin oceanic crust into the mantle.

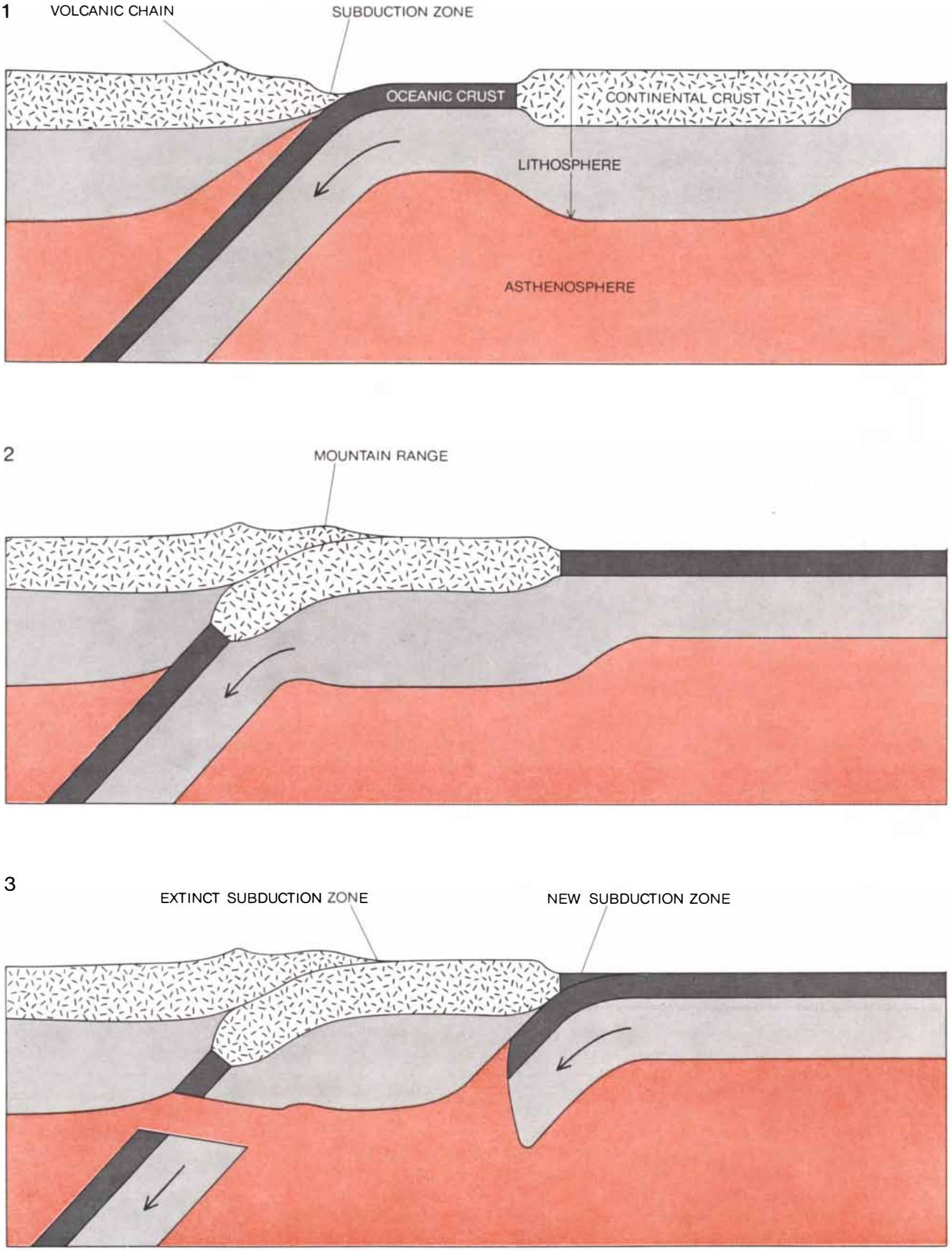
Plates must be at least as thick as the oceanic and continental crust because some plates have oceanic and continental portions between which there is no differential motion. It was thought for many years that the Moho might be an important physical discontinuity of mechanical decoupling on which large crustal displacements proceed. It is now clear that if there is a zone of decoupling between an outer rigid shell and a less viscous layer below, it is considerably deeper than the Moho.

The best evidence for the thickness of plates comes from seismology. The velocity of seismic waves is dependent on the density and flow properties of the rock through which they pass; it is high in rigid, dense rocks and low in less rigid, lighter rocks. Moreover, an increase in confining pressure increases the velocity of waves and an increase in temperature decreases it. Although confining pressure must increase with depth, recent studies indicate that the velocities of shear waves suddenly decrease below a surface about 70 kilometers under the oceans and about 150 kilometers under the continents [*see top illustration on opposite page*]. Shear-wave velocities then increase with depth, with marked increases between 350 and 450 kilometers and just above 700 kilometers.

These data suggest that an outer rigid layer 70 to 150 kilometers thick (the lithosphere) lies above a weaker and hotter layer (the asthenosphere) that becomes increasingly viscous with depth. The thickness of the lithosphere therefore probably constitutes the thickness of the rigid plates, and the lithosphere is discontinuous at plate boundaries. Earthquakes present a test of this hypothesis, since the cold, rigid lithosphere is probably their source. The distribution of earthquakes should thus provide a guide to the thickness of the lithosphere and to its distribution where it descends in subduction zones into the interior of the earth.

Ridges and transform faults are characterized by earthquakes whose depth extends to about 70 kilometers. The inclined zone of intermediate and deep-focus earthquakes indicates the descent of the lithosphere into the asthenosphere, where it is consumed at subduction zones.

Bryan L. Isacks and Peter Molnar of the Lamont-Doherty Observatory, working with seismic first-motion records, have analyzed the stresses in descending lithospheric plates. They find that the stresses are consistent with those that would be expected if a cold slab of bending lithosphere were to meet increasing resistance as it descended into



COLLISION OF CONTINENTS occurs when a plate carrying a continent is subducted at the leading edge of a plate carrying another continent (*1*). Since the continental crust is too buoyant to be carried down into the asthenosphere, the collision produces mountain ranges (*2*). The Himalayas evidently formed when a plate carrying India collided with the ancient Asian plate some 40 million years ago. The descending plate may break off, sink into asthenosphere and a new subduction zone may be started elsewhere (*3*).

an increasingly viscous asthenosphere. Where the cross section of the lithosphere is curved (at subduction zones) its upper part is under tension, suggesting elastic bending. Where the lithosphere has descended only a short distance into the asthenosphere it is under tension along its length, indicating low resistance to its descent. Continuously inclined seismic zones, representing slabs of lithosphere that have descended to lower parts of the asthenosphere, are characterized by compression along the slab. This fact suggests that the downgoing lithosphere is put into compression as it meets increasing resistance to its descent. An instructive case is where there is a gap in the inclined seismic zone, suggesting a discontinuity in the downgoing slab. Earthquakes above the gap indicate tension; earthquakes below it indicate compression. Evidently part of the slab has broken off and is descending at a faster rate than the remainder.

The general kinematics of plates—their growth and consumption—requires some form of mass convection, or mass-transfer circuits, in the mantle. Heat flow to the earth's surface is highest along ridge axes; it declines rapidly to a low plateau value across the plates and falls to a minimum at subduction zones. Therefore the lithosphere may represent a cold, rigid boundary conduction layer that is created at the hot ridge "sources" and destroyed at the cold subduction-zone "sinks." Any acceptable model for the geometry of the mass circuits in the earth's mantle must satisfy a number of conditions.

Conditions to Be Met

First, there must be a gross balance between vertical mass transfer at sources and sinks and lateral mass transfer by plate motion and motions in the asthenosphere. Second, the 700-kilometer limit on the depth of earthquakes and the abrupt increase in shear-wave velocity that marks the bottom of the asthenosphere imply that the mass-transfer circuits involve only the lithosphere and the asthenosphere. Third, the boundaries along which new crust is being generated on the earth exceed in length the boundaries where crust is being destroyed, so that plates are generally consumed at individual sinks faster than they are created at individual sources. Fourth, a simple geometric consequence of the fact that plates can change their surface area is that plate boundaries can move in relation to other plate boundaries. This fact implies that mass-transfer circuits must also change their geometry as the plates evolve. Fifth, mass-transfer circuits cannot take the form of simple, regular convection cells linking sources and sinks with an upper lateral transfer and a lower return flow because there is no simple one-to-one relation between sources and sinks.

There are several great circles around the earth along which one can cross two ridge axes without an intervening subduction zone or can cross two subduction zones without an intervening ridge axis. Circuits involving mass-transfer rates of up to 10 centimeters per year must be accompanied by convective heat transfer, because thermal inertia prevents the elimination by conduction of temperature differences between different parts of the circuit. This condition is reflected in the persistence of earthquakes in a plunging slab down to depths approaching 700 kilometers. It is not clear, however, whether convective mass transfer and heat transfer is the cause or a consequence of plate motion. The models for relative lithosphere-asthenosphere motion at the top of page 62 illustrate this difficulty. They are all certainly far too simplistic. Indeed, the relative surface motions of plates may not be a guide to motions in the asthenosphere.

Let us consider a model in which the crust, lithosphere and asthenosphere are linked in a simple source-to-sink system [*see bottom illustration on page 62*]. The lithosphere in this model acts as a cold boundary conduction layer to a hotter asthenosphere, the upper part of which (the low-velocity zone) is probably near its melting temperature. Tension induced by plate separation at the ridge axis reduces the confining pressure in the low-velocity zone under the ridges. Reduction of confining pressure causes partial melting of primitive mantle in the low-velocity zone and the rising of a mush of crystals and liquid, with the result that the ridges are broadly uplifted. As the column of partially molten material rises it undergoes further partial melting; eventually the basaltic liquid rises to fill the crack continuously generated by plate separation. The liquid cools and crystallizes to form the basaltic oceanic crust and leaves under it a depleted layer of mantle.

Where plates descend into the asthenosphere, their leading edge carries a chain of volcanoes; thus one infers that the volcanic rocks are linked in some way with the descending plate. Because the volcanic rocks are less dense than the basalts of the oceanic crust, it is likely that they are formed by partial fusion of the oceanic basalts with other material as the basalts are carried down into the hot asthenosphere. The depleted mantle in the plunging plate is denser than the primitive asthenosphere through which it sinks, both because it has had a lighter basaltic fraction removed from it under the ridge axis and because it is cooler. Therefore once a plate has begun to descend in a particular subduction zone it is likely to continue until the plunging plate meets increasing resistance deep in the asthenosphere.

Since continental crust is only about 40 kilometers thick, whereas plates are 70 kilometers or more thick, the continents ride as passengers on the plates. In the framework of plate tectonics continental drift is no more significant than "ocean-floor drift." Nevertheless, continents, unlike oceans, impose certain important restraints on plate motion. The narrow, sharply defined trenches and the regularly inclined earthquake zones sloping away from trenches indicate that oceanic lithosphere is easily consumed by subduction, probably because it has a thin, dense crust. Intracontinental seismic zones associated with mountain ranges exhibit compressional deformation over a wide area, which implies that continental lithosphere is hard to consume because it has a thick, relatively buoyant crust.

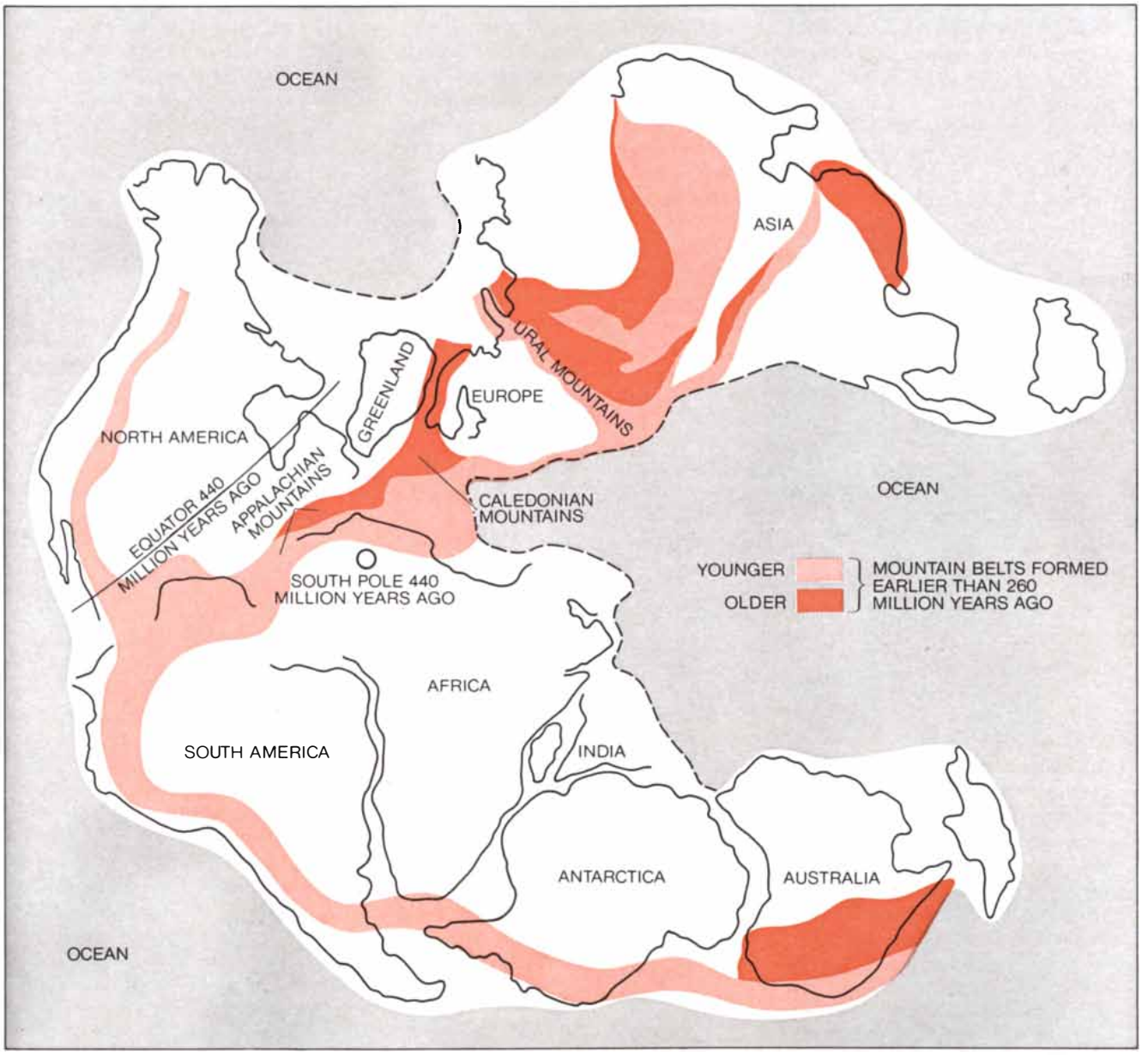
Within the Alpine-Himalayan mountain belt are narrow zones characterized by a distinctive assemblage of rocks, known as the ophiolite suite, whose composition and structure suggest that they are slices of oceanic crust and mantle. If they are, ophiolite zones mark the lines along which continents collided following the contraction of an ocean by plate consumption [*see illustration on opposite page*]. The small oceanic areas within the Alpine belt, such as the Mediterranean Sea and the Black Sea, may be remnants of larger oceans that once lay between Africa and Europe. Evidently lithosphere carrying light continental crust is difficult to consume, as is indicated by the marked scarcity of intermediate-focus and deep-focus earthquakes in zones where continents have collided. Thus it seems that continental collision terminates subduction along the collision zone. This implies that mass-transfer circuits must be drastically rearranged after the collision of continents, since a major sink is eliminated. As a result new sinks may form in oceans elsewhere.

As we have seen, any hypothetical driving mechanism for plate motion must meet a number of conditions. At present some form of thermal convec-

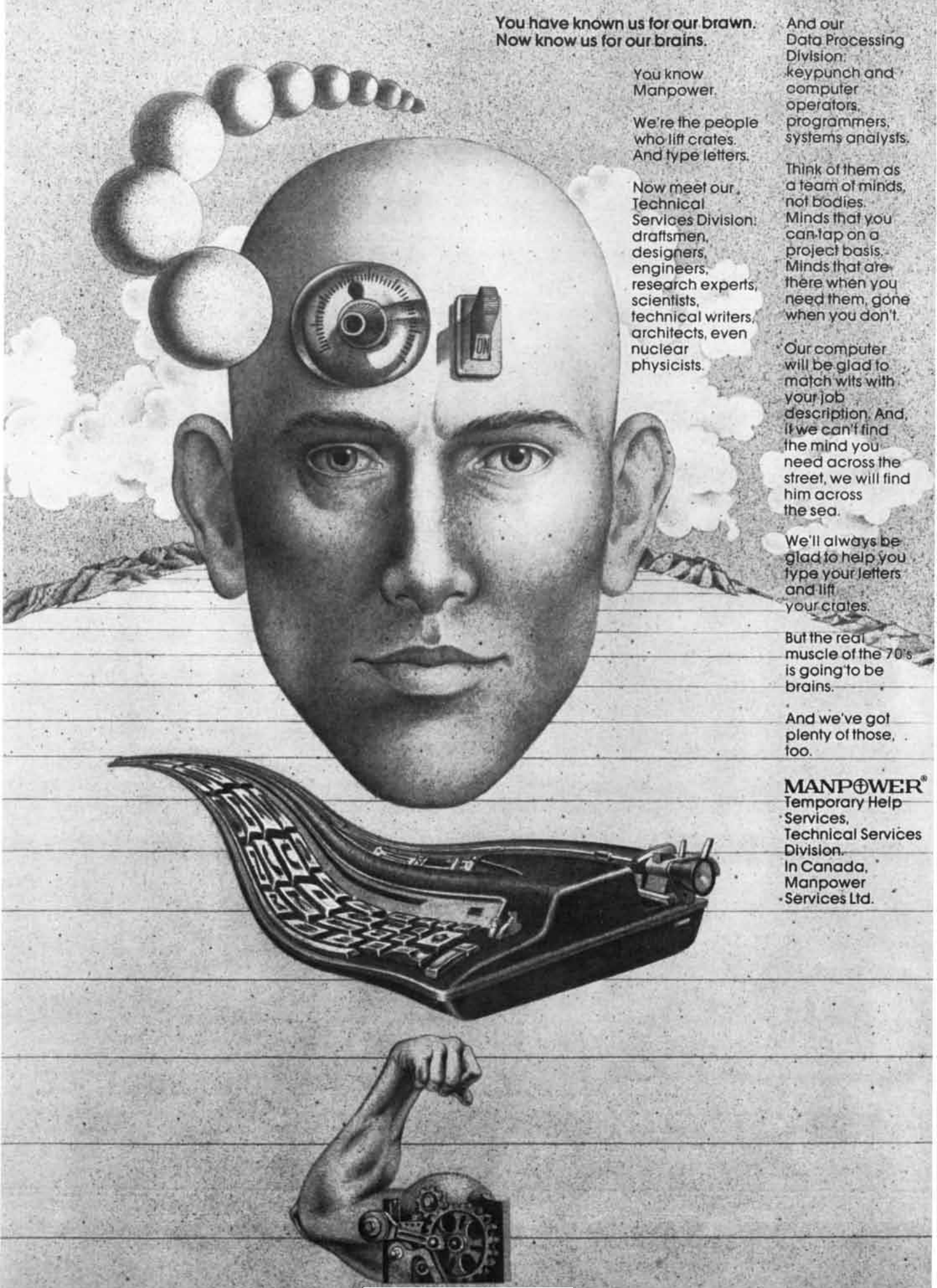
tion in the upper mantle seems to hold the most promise, but other mechanisms have been suggested that may play some role in plate dynamics. These mechanisms include the retarding effect of earth tides raised by the gravitational attraction of the moon, the possible pull exerted by a plate "dangling" in the asthenosphere and forces created by plates sliding down the slight grade between sources and sinks. It is also possible that some small plates are mechanically driven by the effects of relative motion between adjacent larger plates. For example, the westward motion of the wedge-shaped Turkish plate with respect to the Eurasian plate may be caused by its being squeezed like an orange seed between the Arabian and the Eurasian plate.

Extinct Plates

It is now certain that plate tectonics has operated for at least the past 200 million years of earth history. During this time virtually all the present oceans were created and others were destroyed. Two hundred million years ago the major continental masses were assembled into the single supercontinent Pangaea [*see illustration below*]. It is therefore legitimate to ask if the breakup of Pangaea some 180 million years ago marked the beginning of plate tectonics. Geologic studies of mountain belts older than 200 million years strongly indicate that they owe their origin to processes operating at plate boundaries that are now extinct. The Ural and Appalachian-Caledonian mountain belts, which lie within ancient Pangaea, have narrow zones where ophiolites are found. These old ophiolite zones, like those in the Alpine-Himalayan mountain belt, thus mark the sites of vanished oceans. This implies that the Urals, for example, were created by the collision of two conti-



ANCIENT CONTINENT OF PANGAEA is reconstructed by fitting together the major continental land masses. Pangaea started to break up about 200 million years ago with a rift between Africa and Antarctica. Other rifts allowed South America, Australia and India to drift into their present positions. Mountain belts formed more than 260 million years ago are shown in shadings that distinguish younger and older belts. These mountain belts indicate lines of collision between continental fragments antedating Pangaea. Thus a prior collision of North America and Africa formed the younger part of the Appalachians 260 million years ago. Such a collision would explain how Equator and South Pole of 440 million years ago were brought close together after formation of Pangaea.



nental masses and that the ophiolites were generated by sea-floor spreading at a ridge axis before the continents were brought together.

Large-scale horizontal motions of continents before 200 million years ago are supported by other lines of reasoning. Glacial deposits and other data indicate that about 400 million years ago a south polar ice cap covered the Sahara. At the same time eastern North America lay near the Equator. On the Pangaea reconstruction these close polar and equatorial positions are incompatible: they indicate that Africa and North America were separated by an ocean some 10,000 kilometers wide. The contraction of this ocean and the resulting collision of North America and Africa were probably largely responsible for the growth of the Appalachian mountain belt [see "Geosynclines, Mountains and Continent-building," by Robert S. Dietz; SCIENTIFIC AMERICAN, March]. It seems a reasonable assumption that long, narrow, well-defined zones of mountain-building were established along zones of plate convergence. If this is the case, plate tectonics has been operating for the past two billion years.

The absence of well-defined zones of mountain-building older than two billion years suggests, however, that some mechanism other than plate tectonics, at least as we know it at present, was responsible for the evolution of the earth's crust in earlier epochs. The ancient "shield" regions of the continents, which contain rocks older than 2.4 billion years, are characterized by rocks distributed in swirling patterns over areas so wide they can hardly be explained by processes arising at the boundaries of rigid plates. Evidently the shield areas were stabilized about 2.4 billion years ago, and by some 400 million years later a lithosphere with sufficient rigidity to crack into a plate mosaic had developed.

This does not necessarily mean that plate tectonics as we know it today began two billion years ago. Mountain belts older than 600 million years do not have ophiolite complexes like those of the younger mountain belts, indicating that sea-floor spreading before 600 million years ago generated a different type of oceanic crust and mantle. Geological data suggest that plates may have been getting thicker and that plate boundaries may have become more narrowly localized with time.

An exciting corollary of plate tectonics is that it provides a means whereby the total volume of continental crust can increase with time. We have seen that the primitive mantle of the asthenosphere undergoes partial melting to liberate a basaltic liquid that rises and cools to form the oceanic crust on the ridge axis, and that partial melting of the oceanic crust on a descending plate may yield the liquids that erupt to build the volcanic chains on the leading edge of plates. Volcanic rocks, with their deep-level intrusions of liquids that crystallized before they reached the surface, have the same bulk composition as that of the continental crust. The volcanic chains may therefore be sites where strips of embryonic continental crust are generated. Since they lie on the leading edge of plates, their destiny is to collide with other volcanic chains or with various kinds of continental margin. In this way new strips of light continental crust will be added to continental margins.

As we have seen, the arrival of a continental margin at a subduction zone blocks further plate consumption at that site. Thus the oceanic ridge provides an effective means of growing continental crust, but there is no means of destroying such crust. This implies that the total volume of continental crust has been increasing for the past two billion years. One should not conclude, however, that strips of new crust have been added to the continents as a succession of regular concentric rings. Rather, discontinuous strips have been added at different times, reflecting the complex interaction of continental margins with the plate-boundary mosaic.

Although there are geologic phenomena that plate tectonics does not yet obviously explain, and although the driving mechanism is obscure, these deficiencies do not constitute rational objections to the theory of plate tectonics. One of the serious mistakes that many earth scientists made in the past was to reject continental drift because it was not clear how or why it occurred. The remarkable success of plate tectonics has been not only that it provides a consistent logical framework that draws together such diverse phenomena as sea-floor spreading, continental drift, earthquakes, volcanoes and the evolution of mountain chains but also that it has been successfully quantified and tested to the point where its essential core can no longer be questioned.

The essential core of plate tectonics is the geometric evolution of plates and the kinematics of their relative motion. It is of paramount importance to fully explore all the geometric and kinematic aspects of plate evolution if we are ever to understand the dynamics of plate motion and the geologic corollaries of plate tectonics.

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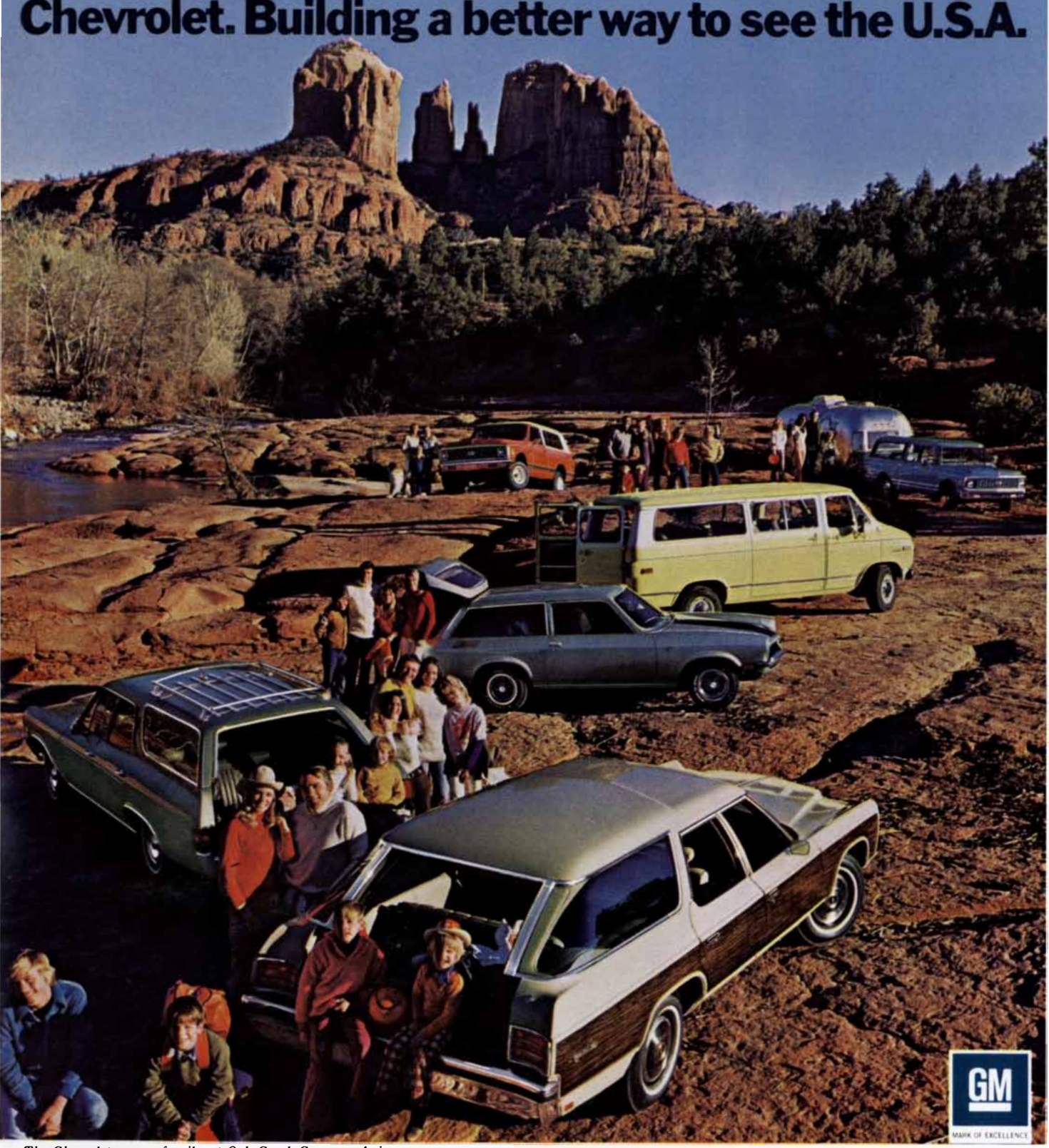

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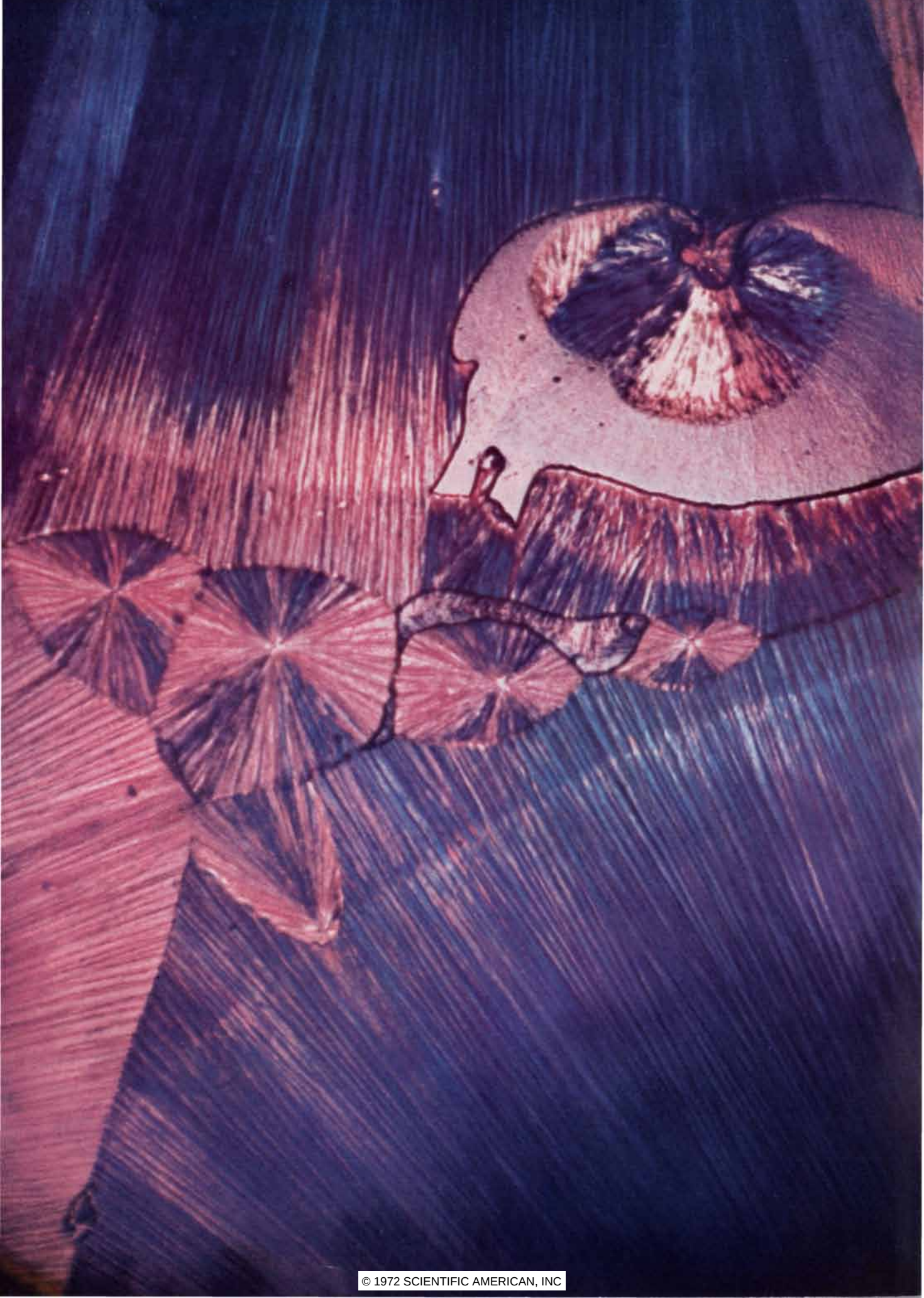
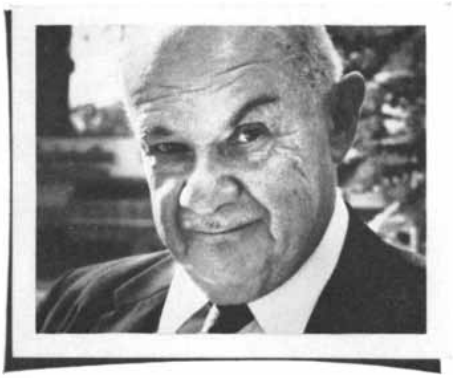


Vishniac on Vishniac on Polaroid Land Film



Roman Vishniac, perhaps the world's most highly acclaimed photomicroscopist, is a man of enormous and varied talents. He was recently the subject of an award-winning television special on NBC, "The Great Little World of Dr. Roman Vishniac."

"When I took this assignment, I had never used Polaroid Land film before. But it has been a revelation to me. It gives me what I never realized I needed. Immediate proof of what's really happening under the microscope. And proof of whether my imagination was right.

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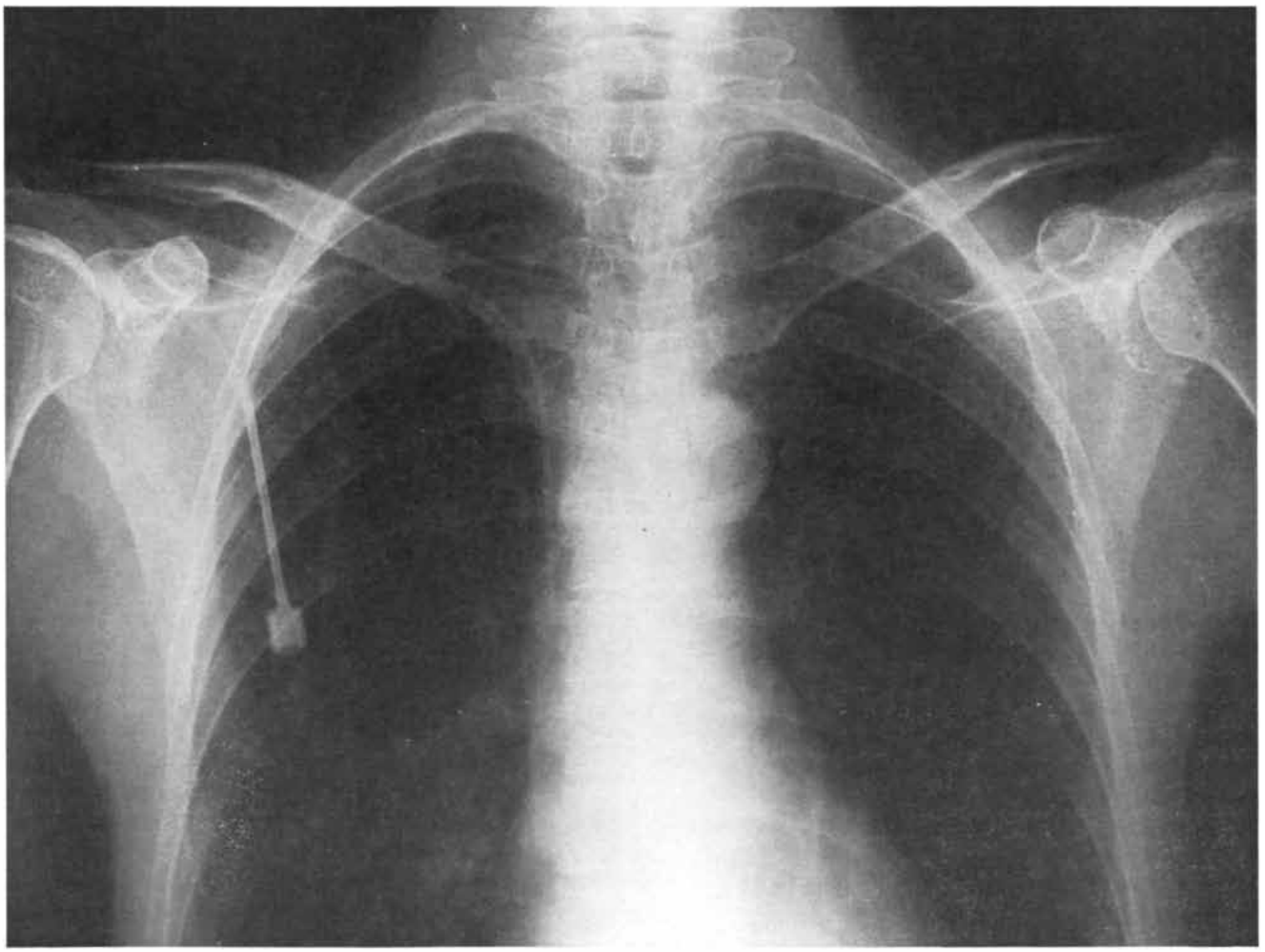
It is now possible to feed a person entirely by vein for prolonged periods. The technique provides sufficient calories, amino acids and other nutrients to promote growth, weight gain and wound healing

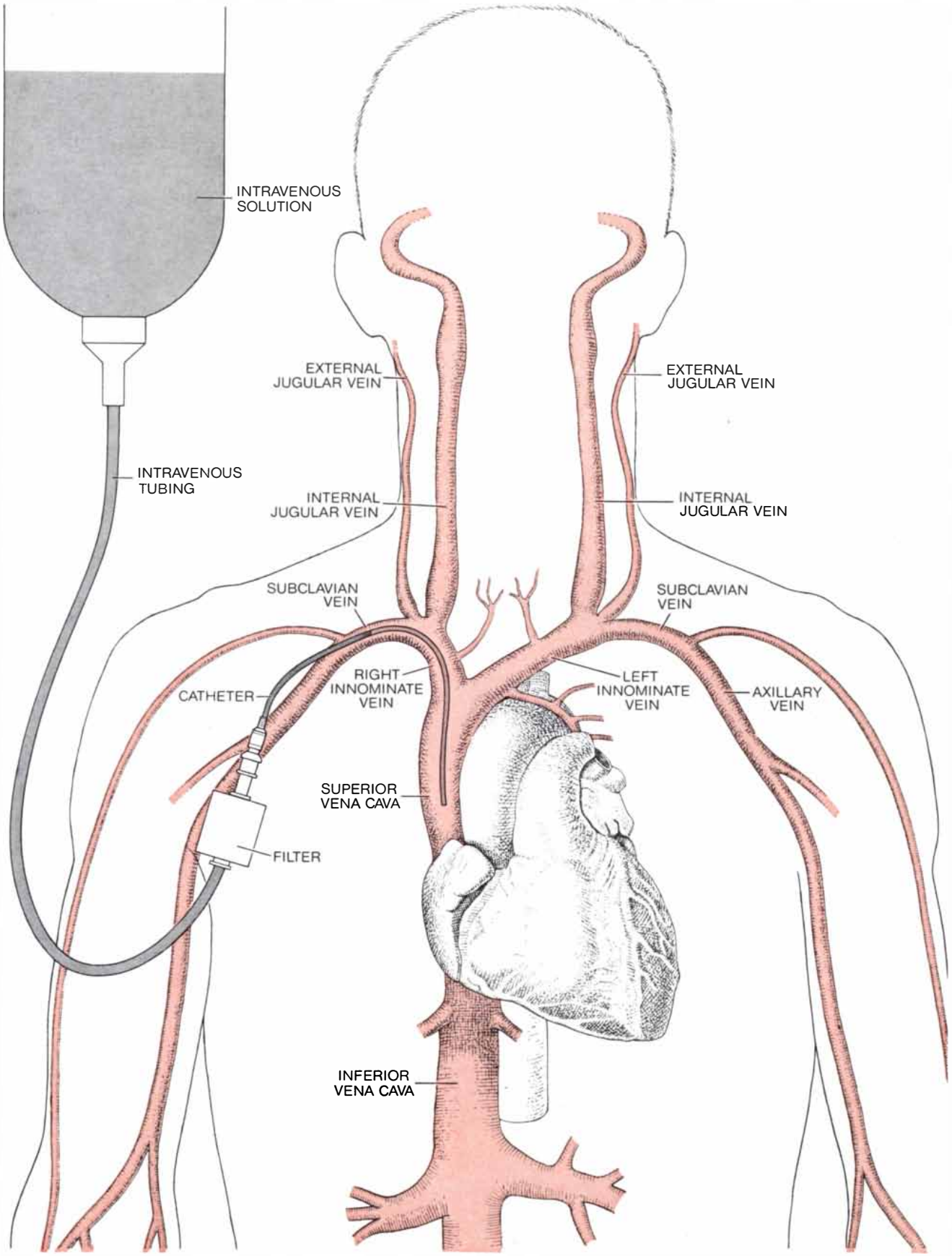
by Stanley J. Dudrick and Jonathan E. Rhoads

When the digestive system of a hospital patient cannot maintain his nutrition, it is a common practice to feed the patient through a peripheral vein in the neck, an arm or a leg. Although the technique of intravenous feeding has advanced in each decade of this century, there have been serious limitations in the daily amount of nutrient that can be administered. As a result many critically ill patients have been faced with slow starvation. In particular, individuals with diseases of the alimentary tract that usually can be alleviated or cured surgically often had a poor prognosis for recovery from the operation because of malnutrition. Such patients are highly susceptible to postoperative complications and failure of wound healing.

In the past few years a safe and effec-



CHEST X RAY shows position of catheter tubing through which the nutrient solution is fed directly into a large vein near the heart. The thin catheter tubing still is attached to the needle used to introduce the catheter into a vein below the right collarbone. The tip of the inserted catheter can be seen near the spinal column. Infusion of nutrients through the catheter can begin immediately.



CONCENTRATED NUTRIENT SOLUTION is infused through a catheter directly into the superior vena cava, the one-inch vein that returns blood to the heart from the upper part of the body. The high volume of blood flow in this large vein quickly dilutes the solution to a safe level. The catheter is inserted into the right subclavian vein and pushed along until the tip of the catheter is in the superior vena cava. The catheter can also be inserted through the left subclavian vein or one of the jugular veins. If the nutrient solution is continuously infused for 24 hours a day, the patient will receive enough nourishment for him to be able to gain weight.

tive technique for feeding a patient entirely by vein has been developed at the University of Pennsylvania School of Medicine. The technique of total intravenous feeding has proved to be a valuable adjunct in the treatment of virtually every disease of the alimentary tract where oral feeding is ill-advised. It also promises to become a tool of considerable usefulness in nutritional and biochemical research.

The idea of introducing substances directly into the bloodstream goes back to the discovery of the circulation of the blood by William Harvey in 1616. Physicians and scientists subsequently began to experiment with intravenous injection and blood transfusion in animals. In 1656 the architect Sir Christopher Wren, using a goose quill attached to a pig's bladder, injected ale, wine and opium into the veins of a dog. In 1667 a French physician, Jean Baptiste Denis, attempted a blood transfusion from a lamb to a man. Blood transfusions between men followed. The lack of proper sterilization techniques and the ignorance of blood chemistry led in many cases to complications and death.

Intravenous feeding had its beginning in 1843, when the French physiologist Claude Bernard infused sugar solutions into the veins of animals. By the end of the 19th century the intravenous infusion of saline or sugar solution into human patients was widely practiced. In the 1940's there were unsuccessful efforts to provide the total nutritional requirement with solutions of amino acids and glucose administered through one of the peripheral veins. In the 1950's the emphasis was on perfecting fat emulsions as a concentrated source of intravenous calories. Fat provides nine calories per gram, whereas sugars or proteins yield only about four calories per gram. Ethyl alcohol yields seven calories per gram but only limited amounts can be tolerated by intravenous infusion.

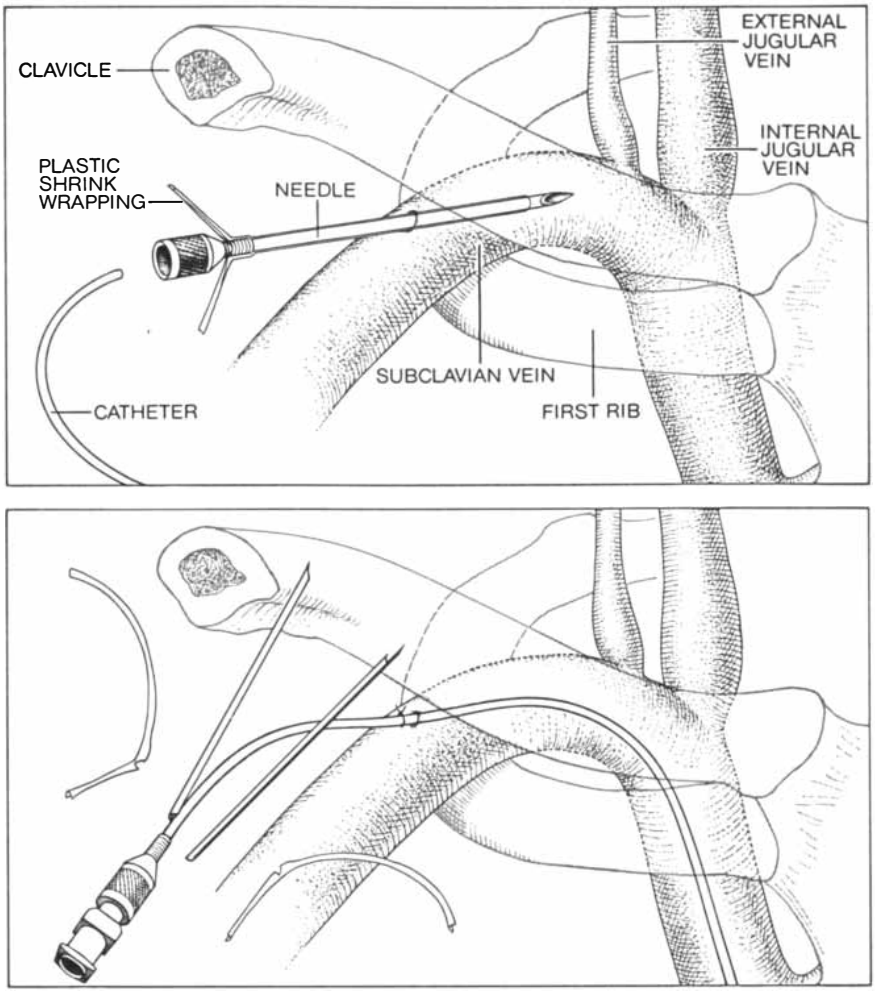
For a time it seemed that a mixture of fat emulsions, sugars, protein hydrolysates (proteins broken down into their constituent amino acids), vitamins and minerals could provide total intravenous feeding. Problems arose, however, with the fat emulsions. The fat had to be completely emulsified and the emulsion had to be stable under a variety of conditions. Fat particles that are too large will occlude capillaries in the lungs, brain and elsewhere, occasionally with fatal results. The U.S. Food and Drug Administration withdrew intravenous fat emulsions from the market in 1964.

One of the limitations of intravenous feeding is the total amount of water the average sick adult can handle in a day: about three liters. Larger amounts carry the threat of pulmonary edema, which is extremely dangerous. Moreover, when the solution is infused, as is customary, through one of the veins of the neck, arms or legs, the concentration of the nutrients is limited to about 10 percent. Higher concentrations frequently lead to inflammation and occlusion of the veins and blood clotting.

Thus the few safe nutrients—glucose and amino acids—that the body can assimilate from the blood yield only four calories per gram. These nutrients must be diluted to a tenth of their maximum concentration, so that each liter of 10 percent intravenous solution provides about 400 calories. Since the limit in standard intravenous feeding is three liters per day, the total caloric intake normally is limited to 1,200 calories per day. This falls short even of the basic energy requirements of the body. An individual at rest and not digesting food consumes about 1,400 calories per day.

When the patient has a fever, the metabolic energy expenditure increases about 8 percent per degree Fahrenheit. After major surgery, such as the removal of a stomach ulcer, the energy needs run at least 5 percent above the basal level. Daily requirements in the range of 7,000 to 10,000 calories have been recorded in patients who had suffered burns over half of the body's surface.

The principal energy stores of the body are in the form of fat. To convert fat into energy efficiently, however, the body requires some carbohydrate. The carbohydrate sources are glucose in the blood and glycogen in the liver and skeletal muscles. These carbohydrate stores are exhausted by a day or two of starvation. Thereafter the body produces the carbohydrate it needs by breaking down its protein, and a protein deficiency may quickly develop. In general,

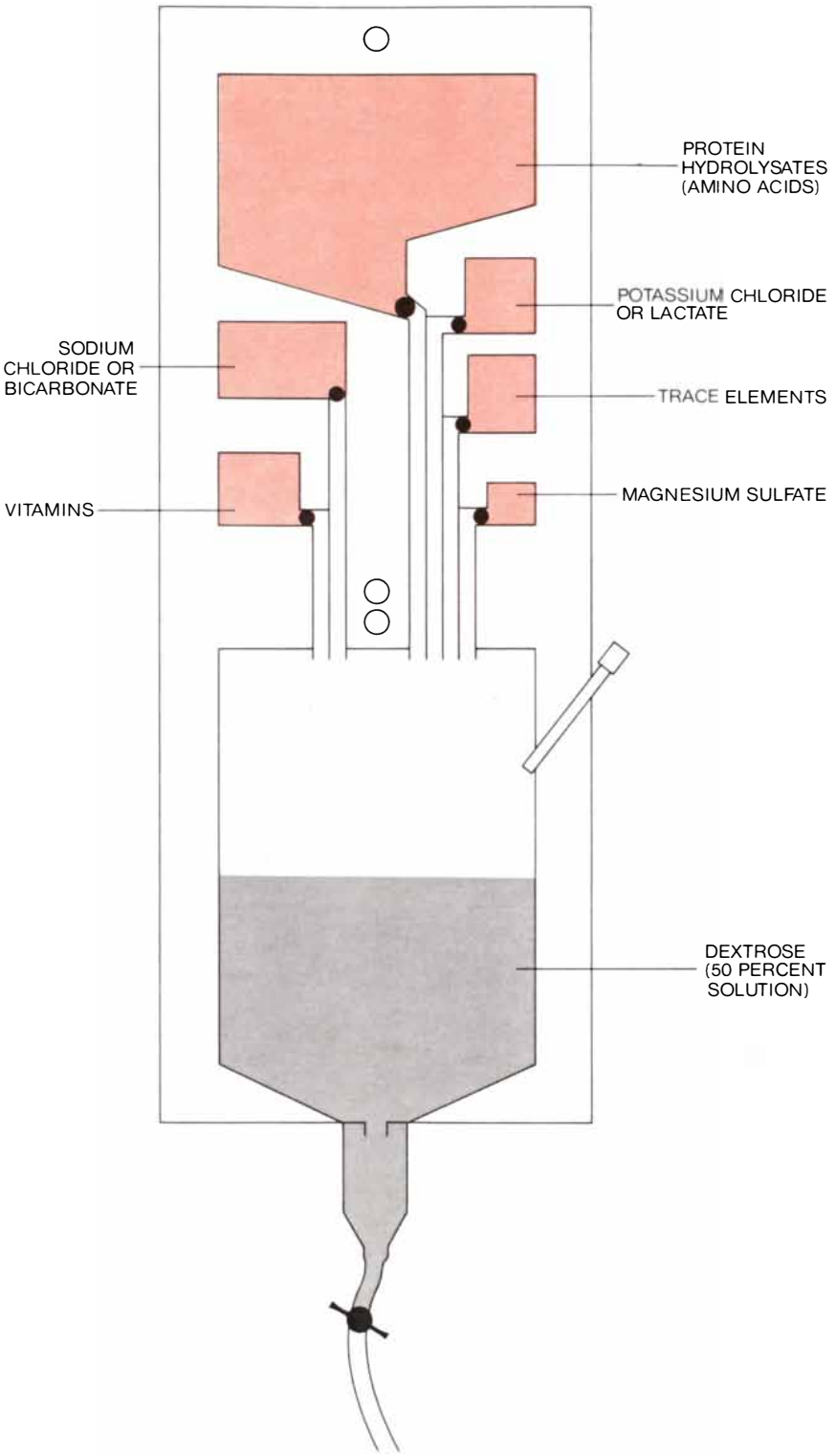


SPLIT NEEDLE specially developed for total intravenous feeding vein puncture is held together by a shrink-wrap plastic. After the hollow needle has been inserted into the vein (*top*) a catheter is pushed through the needle and into the superior vena cava. The needle is pulled out and its plastic wrapping is peeled off (*bottom*), thus allowing the needle to split apart. The tube from the nutrient solution is connected to the exposed end of the catheter.

standard intravenous feeding through a peripheral vein is adequate for short-term supplementary nourishment. In the average patient it can supply adequate amounts of water, electrolytes, vitamins and minerals but only enough food energy to maintain the functioning of the central nervous system. For its additional energy needs the body must cannibalize its own tissues.

With the development of better drugs for increasing urine output it became possible to give larger volumes of the 10 percent nutrient solution and to remove the excess liquid by the use of diuretics. In this way the volume of intravenous feeding was increased to five or even seven liters per day in patients with good kidneys. The drawback is that constant attention must be paid to the patient's dynamic balance of water and electrolytes.

It occurred to us at the University of Pennsylvania School of Medicine that infusing the solution directly into a large vein would allow the use of a higher nutrient concentration. Theoretically the high blood flow in a large vein would promptly dilute the solution to a safe level. In 1965 we demonstrated the validity of this concept by feeding beagle puppies exclusively by vein for periods of up to 36 weeks and achieving normal growth and development. The puppies received a 30 percent nutrient solution through a plastic catheter that had been inserted into the superior vena cava, the large vein in the chest that returns blood from the upper half of the body to the heart.



CONTAINER for mixing components of a total intravenous diet solution is shown schematically. Development of prepackaged plastic containers with individual compartments for each component would lessen the risk of contamination from airborne microorganisms.

The success of total intravenous feeding in animals led to the formulation of intravenous diets for human patients. The first person to respond to long-term total intravenous feeding was a female infant who had been born with a useless cordlike fibrous structure in place of a major portion of her small and large intestines. The infant underwent massive surgery shortly after birth. In spite of heroic efforts to feed her intravenously by conventional methods her weight declined continuously, and 19 days after birth she appeared to be at the point of death. Her weight had declined from five pounds two ounces at birth to four pounds. Then a catheter was inserted into her superior vena cava and infusion of a concentrated nutrient solution was begun. After 45 days her weight had nearly doubled to seven and a half pounds, and the infant had begun to grow. At six months of age she had received 97 percent of all her nutrition by vein and continued to grow and develop normally [*see illustration on page* 79]. At one year she had more than tripled her weight at birth. She eventually achieved a maximum weight of 18½ pounds during 22 months of intravenous feeding.

In another case a 17-year-old boy with a history of gastrointestinal problems developed abdominal pain and fever. In three months his weight had dropped from 205 to 145 pounds. X-ray studies revealed severe intestinal inflammation in the lower right abdomen and an associated mass that completely obstructed

his right ureter: the tube from the kidney to the bladder. After three days of total intravenous feeding the abdominal mass was reduced sufficiently for the ureter to have opened, and the boy's pain and fever had disappeared. During seven weeks of intravenous feeding at 5,000 calories per day he gained 12 pounds, and the intestinal inflammation had also disappeared. He was discharged on no therapy other than a low-roughage diet and tranquilizers. He returned to his original weight and has had no further problems for more than a year.

The value of being able to feed a person entirely by intravenous transfusion, particularly when the digestive system is impaired, was demonstrated again in the case of a 46-year-old man who had had three feet of his bowel removed by surgery. He developed signs of a bowel obstruction and within two weeks underwent another operation in which another foot of bowel was removed. For a time after the operation he appeared to be doing well, but the sutures in his bowel did not hold and about three weeks later fecal material began to leak through the wound. Even though he had lost 30 pounds by this time, oral feeding had to be stopped. He was started on a regimen of total intravenous feeding and broad-spectrum antibiotics. Ten days later the fecal leakage had stopped, the wound began to heal and the patient began to gain weight. Within 40 days he was able to eat again. Total intravenous feeding had significantly reduced the ravages of the "short-gut syndrome" by providing a rest period for the alimentary tract. The patient had received a total of 176 liters of intravenous nutrient solution and had gained 11 pounds without eating or drinking at all. Following his discharge from the hospital he returned to his normal weight in three months and resumed his previous employment and activities.

The basic nutrient solution for total intravenous feeding is about six times more concentrated than blood and consists of 20 to 25 percent dextrose, 4 to 5 percent protein hydrolysate and 5 percent minerals, vitamins and other necessary nutrients. Pure crystalline amino acids can be used in place of the protein hydrolysate. The nutrient solution must be sterile and must not produce fever. The food in it must be in the forms that are normally found in the blood. The ingredients must not result in blood clotting or the occlusion of blood vessels. Finally, the solution must enable the body to maintain its normal concentrations of various essential ions such as

BASE SOLUTION	ADULT	INFANT
VOLUME (MILLILITERS)	1,100	720
CALORIES	1,000	660
COMPONENTS	GRAMS	
GLUCOSE	212	20
PROTEIN HYDROLYSATE (AMINO ACIDS)	37	20
	MILLIEQUIVALENTS	
SODIUM	40–50	20
POTASSIUM	30–40	25
CALCIUM	4 5–9	20
MAGNESIUM	4–8	10
PHOSPHATE	4–10*	25

VITAMINS (ADDED ONCE A DAY)	ADULT	INFANT
	USP UNITS	
VITAMIN A	5,000–10,000	3,000–4,000
VITAMIN D	500–1,000	300–400
	INTERNATIONAL UNITS	
VITAMIN E	2.5–5	1.5–2
	MILLIGRAMS	
VITAMIN C (ASCORBIC ACID)	250–500	150–200
NIACIN	50–100	30–40
VITAMIN B-1 (THIAMINE HYDROCHLORIDE)	25–50	15–20
VITAMIN B-2 (RIBOFLAVIN)	5–10	3–4
VITAMIN B-3 (PANTOTHENIC ACID)	12.5–25	7.5–10
VITAMIN B-6 (PYRIDOXINE HYDROCHLORIDE)	7.5–15	4.5–6
VITAMIN K (PHYTONADIONE)	5–10*	1–1.5
FOLIC ACID	.5–1.5*	.5
	MICROGRAMS	
VITAMIN B-12 (CYANOCOBALAMIN)	10–30*	1

MINERALS (ADDED ONCE A DAY)	ADULT	INFANT
	MILLIGRAMS	
IRON	2–3*	.5–1
TRACE ELEMENTS	—	—

*OPTIONAL

TYPICAL NUTRIENT SOLUTIONS for the average adult and average infant are shown. The base adult solution can be prepared in single units by mixing 750 milliliters of 5 percent dextrose and 5 percent protein hydrolysate with 350 milliliters of 50 percent dextrose and then adding vitamins and minerals. Mixing must be aseptic and preferably should be done under a laminar-flow, filtered-air hood. Solutions for infants are prepared the same way.

sodium, calcium, magnesium, potassium, chloride, phosphate and bicarbonate.

Strict aseptic procedure during preparation of the nutrient solution must be followed to avoid contamination by bacteria, fungi and other harmful agents. The basic solution can be formulated in bulk lots or in individual units. At the Hospital of the University of Pennsylvania the basic solution is prepared in bulk and sterilized immediately after mixing by passing it into sterile bottles through a cellulose membrane filter with pores .22 micron in diameter. The solution cannot be sterilized by the usual steam-autoclaving method because heating tends to cook it. (It turns brown.) Samples from each lot of solution are tested for the presence of bacteria, fungi and fever-producing substances.

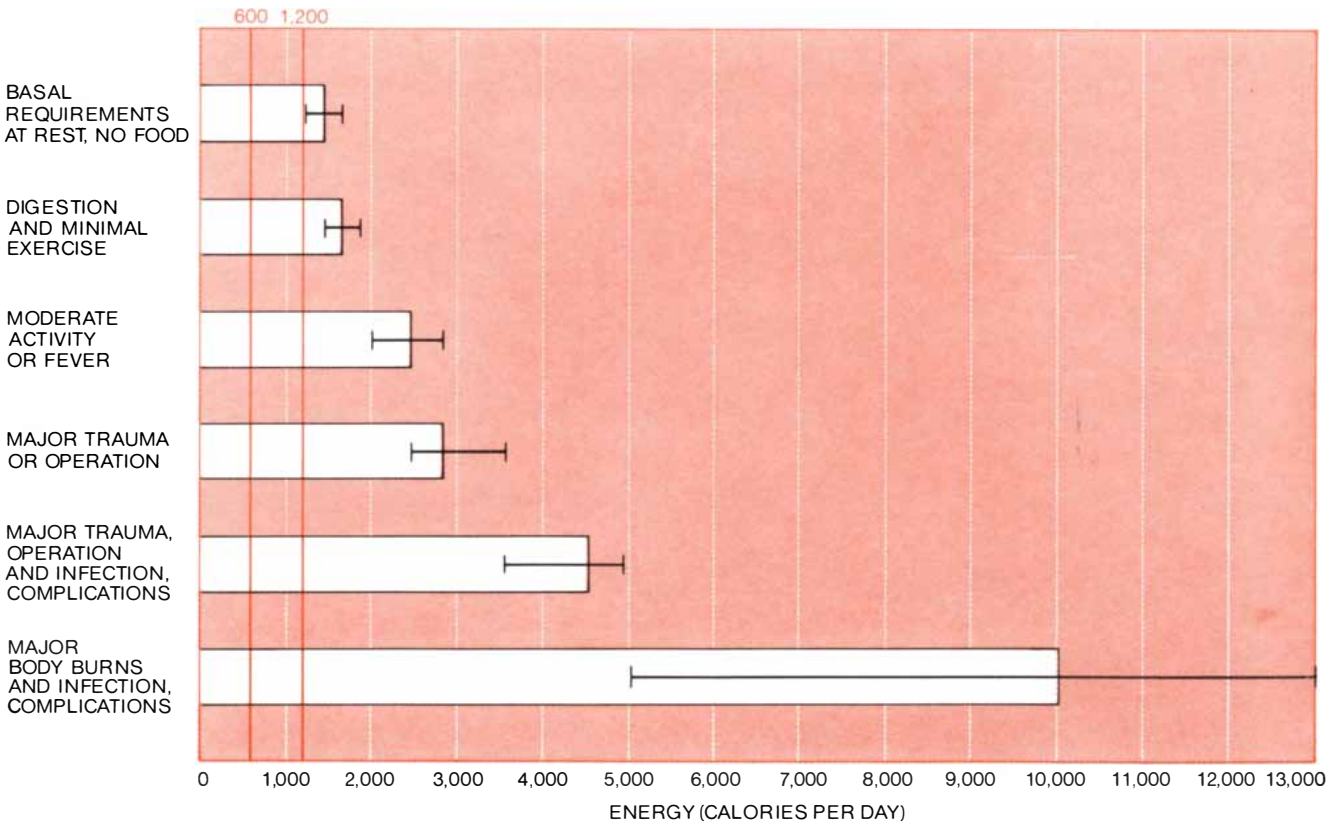
The minerals are added to the basic solution just before infusion. The vitamins are added daily to one bottle of the solution. The necessary trace elements (such as cobalt, copper, iodine, manganese, molybdenum and zinc) are present as contaminants in most intravenous solutions, particularly those containing protein hydrolysates.

For normal growth and development in newborn infants, who have no appreciable nutrient stores, more complete mixtures are required for daily infusion [*see illustration on preceding page*]. The standard adult formula must be modified for patients with heart disease, liver disease or kidney dysfunction. Morover, it is often necessary to modify the nutrient solution during the course of intravenous feeding, depending on the patient's metabolic response. No single intravenous nutrient solution can be ideal for all conditions in all patients at all times, or for the same patient during the various phases of treatment.

The solution is administered through a polyvinyl (or siliconized rubber) catheter inserted into the superior vena cava by way of a subclavian vein or an external or internal jugular vein [*see illustration on page 74*]. Insertion of the catheter can be accomplished safely and effectively in 99 percent of the patients if the proper procedures are followed. Strict aseptic techniques, including sterile surgical gloves and instruments, are crucial. The skin of the lower neck, shoulder and upper chest is shaved, cleaned with ether or acetone to remove skin oil and prepared with tincture of iodine, just as the skin is prepared for a major surgical operation. A local anesthetic is injected; then a split hollow needle specially developed for the purpose is inserted into the subclavian vein. An eight-inch catheter is introduced into the vein through the needle and pushed into the superior vena cava, which is about an inch in diameter. The needle is withdrawn and split away, leaving five and a half inches of catheter within the central venous system. The catheter is fixed in place firmly with a suture. After chest X ray has confirmed the accurate positioning of the catheter the infusion of the nutrient solution can begin.

In infants who weigh less than 10 pounds the relatively small subclavian vein can make percutaneous puncture of the vein difficult and hazardous. A safer procedure is to insert a smaller catheter into an external or internal jugular vein at the base of the neck. The exposed portion of the catheter can be tunneled under the skin behind the ear to prevent the tube's being kinked by the infant's movements.

Safe long-term intravenous feeding calls for meticulous care of the catheter. The intravenous tubing is changed at



METABOLIC ENERGY REQUIREMENTS for the average adult under various conditions of stress are shown by the bars in this graph. The black lines indicate the range of variation for different individuals. The basal requirement of an adult at rest and not eating is about 1,400 calories per day. Standard intravenous feeding with 5 percent dextrose can supply about 600 calories per day. When the solution concentration is doubled to 10 percent, feeding through a peripheral vein can provide only about 1,200 calories per day. With total intravenous feeding the patient can normally obtain 3,000 calories per day and in some cases up to 4,000 calories per day. Intake of 10,000 calories per day has been possible only with a combination of oral food intake and total intravenous feeding.

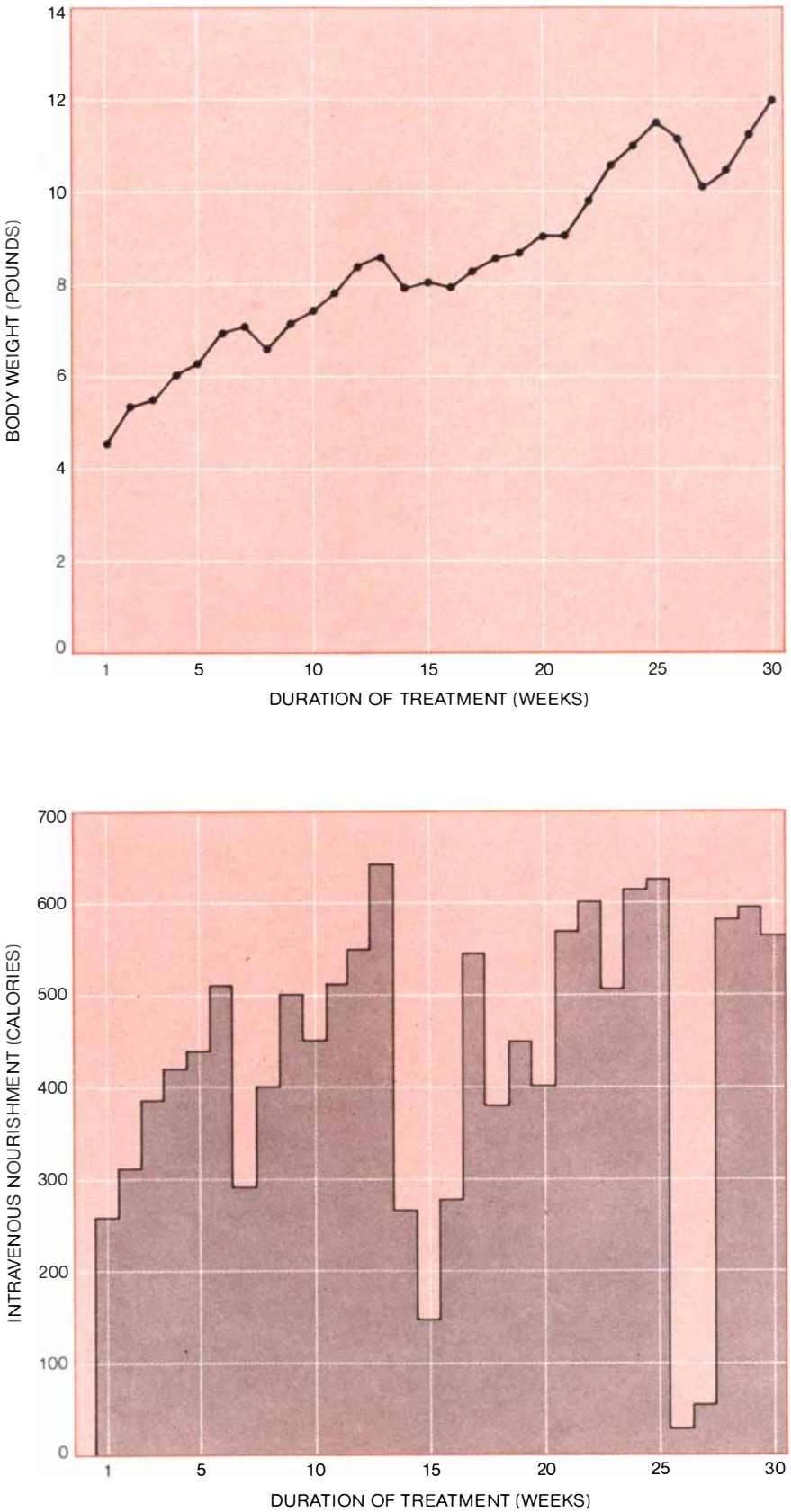
least three times a week. With proper maintenance each catheter can be left in place safely for about 30 days. The catheter should not be used for taking blood samples, measuring blood pressure or administering medication. Indeed, it should be regarded as the patient's lifeline.

Although blood clotting is theoretically a possibility with the use of long-term catheters and concentrated nutrient solutions, we have not observed any clotting of the superior vena cava in the more than 1,400 patients treated in this way at the Hospital of the University of Pennsylvania. The large blood flow in the vein provides a dilution factor of 2,000 or 3,000. Well-maintained aseptic conditions can practically eliminate the hazard of blood clotting. Of course, much care must be taken to avoid the accidental puncture of a major blood vessel or the lung.

The concentrated nutrient solution must be continuously infused 24 hours a day at a constant rate to maintain maximum assimilation of the nutrients without exceeding the patient's metabolic capacities for water, dextrose, amino acids or minerals. The sugar is either broken down immediately to release energy and carbon dioxide and water or is converted into glycogen, which is stored in the muscles and liver. The amino acids are utilized for the synthesis of proteins and body tissue or are broken down to release energy, carbon dioxide, water and urea.

The carbon dioxide, water and urea are easily excreted through the lungs, kidneys and in sweat. There are virtually no solid wastes to be eliminated through the bowel. The infrequent stools of patients on total intravenous feeding consist of mucus, bile, bacteria and cells sloughed off from the intestines. The activities of the digestive tract can be reduced to about 10 to 25 percent of normal with total intravenous feeding. The stomach and bowel shrink in length and in diameter, and a condition of true "bowel rest" can be achieved. It may take from several days to a few weeks for the alimentary tract to be restored to normal on resumption of oral feeding, but no long-term adverse effects have been observed.

If the solution is infused too rapidly, the capacity of the kidney to retain dextrose can be exceeded and the sugar can be lost in the urine, carrying with it some of the minerals, vitamins and amino acids. This not only is wasteful but also can lead to dehydration with convulsions or coma. In patients with impaired



WEIGHT GAIN of the first infant to be nourished entirely by total intravenous feeding paralleled the normal rate for infants. The infant girl underwent massive intestinal surgery shortly after birth, and in spite of great efforts to feed her intravenously by conventional methods her weight dropped from five pounds two ounces to four pounds. She began to gain weight immediately with total intravenous feeding; within four weeks she surpassed her birth weight. During the 22 months of intravenous feeding the infant reached a weight of 18.5 pounds. The lower graph shows the weekly average of calories given intravenously.

kidneys the amino acids may aggravate an already excessive retention of urea; such patients are given solutions with only the minimal amounts of the essential amino acids. The amino acid composition should be modified if the patient has a certain type of liver disorder.

Basic guidelines for safe intravenous feeding include daily measurement of body weight and water balance. Serum electrolytes, blood sugar and urea nitrogen in the blood should be measured daily until they are stabilized and then measured every two or three days. The urine sugar concentration should be measured every six hours. Liver and kidney function should be evaluated initially and then every two or three weeks. Periodic measurement of arterial and central venous pressure, blood acidity and dissolved gases may be indicated in the management of patients with heart, kidney, lung or metabolic disorders.

In newborn infants the nutrient solution can be best delivered at a constant rate by means of an external-action pump. Syringe pumps cannot be employed because the risk of contamination is high. A fine filter between the pump tubing and the catheter prevents the transmission of microorganisms and other contaminants. The filter also prevents air embolism, because air cannot pass through the filter pores after the filter has been moistened. Similar filters with larger pores can be used with adult patients. With patients who are capable of walking, the intravenous-feeding bottles (or plastic bags) can be attached to rolling poles so that the patient can engage in the exercise essential for optimal nutrition and recovery.

The prevention of infection is of paramount importance to the success of long-term total intravenous feeding. If the necessary aseptic and antiseptic procedures are followed conscientiously, the chances of infection are low. In addition, since the nutrient solution is a good culture medium for bacteria and fungi, the preparation of the solution, the changing of bottles and the replacement of tubing should be handled under conditions that ensure asepsis.

Fever or infection in a patient does not rule out total intravenous feeding. On the contrary, in a critically ill patient infection intensifies the need for nutritional support. Although seeding of the catheter by microorganisms circulating in the blood is a possibility, it has not been a significant problem. It is a cardinal rule, however, that whenever it is suspected that an infection may be caused by the catheter, the catheter should be removed immediately.

Total intravenous feeding has proved itself in the treatment of 1,300 adults, some for as long as a year, and in the treatment of more than 100 infants, some for as long as 22 months. Weight gain, wound healing and improved health have been observed in the large majority of cases. Before total intravenous feeding had been developed, patients with severe inflammation or ulceration of the digestive tract had a poor prognosis for survival. Often food taken by mouth is not properly absorbed by the diseased intestine, and the food can actually exacerbate the disease. With total intravenous feeding such individuals can now be given sufficient nourishment to achieve a state of tissue synthesis and weight gain. Patients with a deep ulcer or fistula (leak) of the alimentary tract that has perforated through the abdominal wall, so that food and fluid are actually lost through the opening, have in the past been extremely resistant to both surgical and nonsurgical treatment. With total intravenous feeding more than half of the patients have shown spontaneous healing of the fistula and the rest have improved sufficiently to be better risks for surgery. Patients with severe inflammatory disease of the intestinal tract may also show spontaneous remission of the disease on this regimen.

Patients with impaired liver function or with kidney failure have been supported adequately by the total intravenous feeding of specially formulated solutions. In patients with complicated major burns as much as 6,000 nutrient calories per day has been given by vein to supplement oral or tube feedings of 4,000 to 5,000 calories. In infants total intravenous feeding has proved capable of supporting normal growth and development until oral feeding can begin.

There are many other applications of total intravenous feeding in internal medicine, pediatrics and surgery. In addition the technique promises to be a powerful tool for basic investigations in biochemistry, pharmacology and nutrition. The role of hormones, amino acids, vitamins, minerals and fatty acids can be studied in animals and in man under conditions of control formerly unattainable. The degree to which immune mechanisms can be altered by intravenous diets of selected amino acids may be of significance in facilitating successful tissue transplants. Most potential applications of total intravenous feeding remain to be explored.

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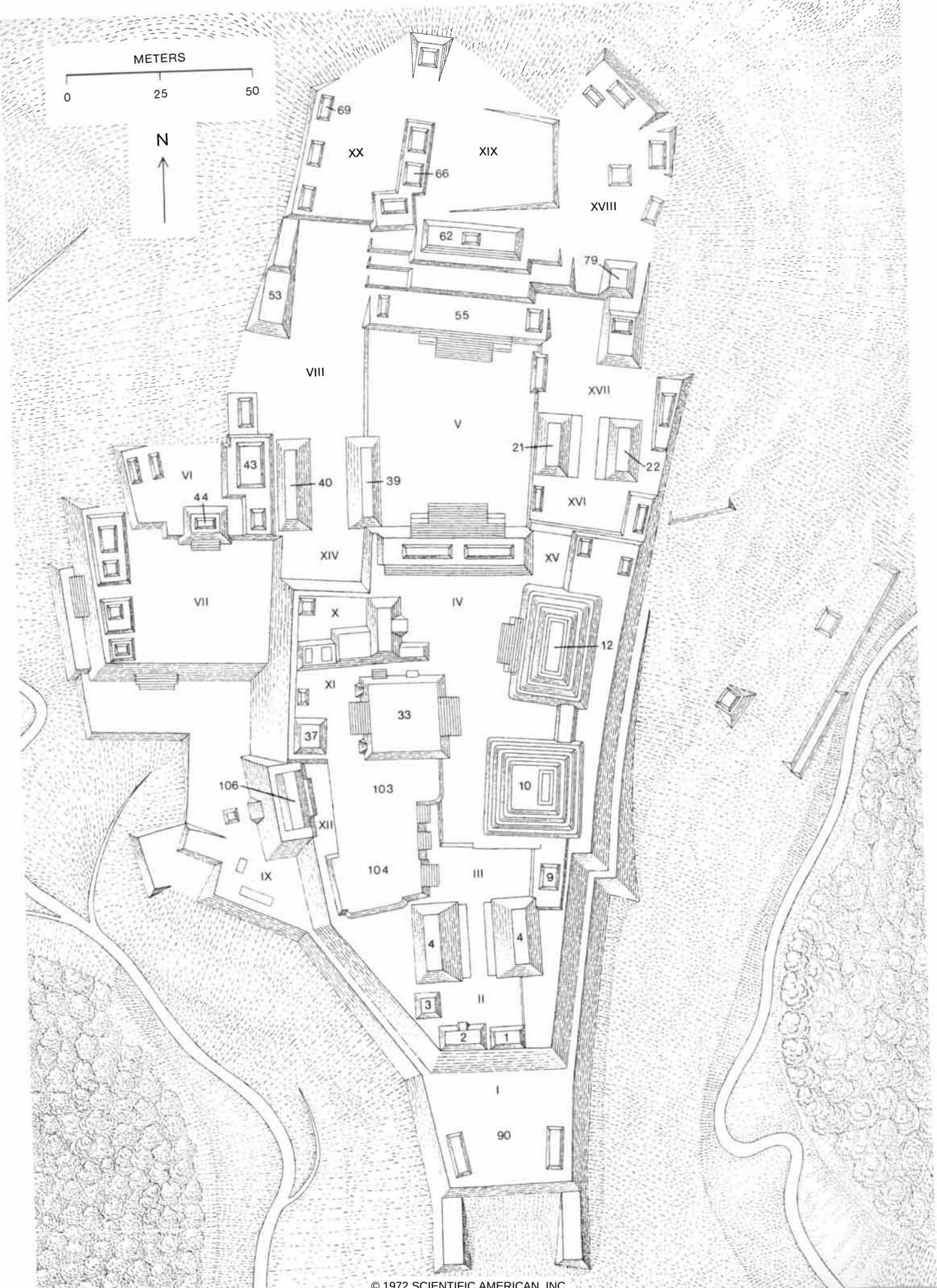


The Planning of a Maya Ceremonial Center

The center at Lubaantún in British Honduras called for a huge investment in labor and materials. When a choice had to be made between cutting costs and adhering to the plan, the plan won out

by Norman Hammond

Among the pre-Columbian civilizations of the New World the Aztec and Inca empires that the conquistadors overthrew are commonly believed to have been the most advanced, but this distinction may well belong to the Maya, whose culture reached its apogee in the first millennium of the Christian Era during what is known as the Classic period. The brilliance of Maya aesthetics is apparent in Classic stucco work, vase-painting and fresco; the intellectual achievements of the Classic period include not only a written language but also calendric and astronomical studies of a high order. Classic Maya civilization was centered in the lowland jungle province of Petén in Guatemala and in adjacent Belize (British Honduras), extending northward and westward into Mexico and southward and eastward into Honduras and El Salvador.

The civilization of the Classic period flourished within a surprisingly loose framework compared, for example, with the partly contemporaneous pre-Columbian culture centered on Teotihuacán a few hundred miles away in the Valley of Mexico. In the first half of the first millennium the rulers of Teotihuacán built one of the largest and most precisely planned urban complexes known in ancient times [see "Teotihuacán," by René Millon; SCIENTIFIC AMERICAN, June, 1967]. Where the Maya held sway in the tropical lowlands, however, there were no such cities. The numerous population was scattered among widely dispersed farmers' hamlets. Living in relative isolation and sheltered in dwellings built of perishable materials, the great majority of the Maya supported themselves by raising crops (principally maize and beans) in forest clearings they prepared for planting by the slash-and-burn method. At intervals were a few clusters of more permanent structures built of stone, but these were not cities in any conventional sense; the most spectacular of their masonry edifices are lofty pyramids like those the first Spaniards saw used as temples in Aztec Mexico. As a result it has become customary to call these clusters of stone buildings "ceremonial centers."

From an economic viewpoint the construction of a Maya ceremonial center constituted an enormous investment in energy and materials. More than a century of archaeological investigation has shown that within a range of regional variation the centers are all much alike architecturally. Where uneven terrain had to be leveled, this was achieved by building foundation platforms of rough stone rubble retained by masonry walls. Rising from these foundations are stone structures arrayed around a number of open plazas.

Each structure consists of a freestanding masonry wall that encloses a more or less rectangular area, filled with rubble up to the height of the retaining wall; in general the greater the area enclosed, the higher the wall. On top of these structures stood superstructures of various kinds. It is customary to call the superstructures on high pyramidal substructures "temples" and those on lower and more extensive substructures "palaces." Most of the superstructures on lower and smaller substructures, having been made of perishable materials, have entirely disappeared; many are known to have been residences, whereas others are buildings of unknown purpose.

Amid the cluster of interconnected plazas with structures grouped around them, each Maya center is likely to have one or more "ball courts." Unlike the term palace, the term ball court is not guesswork. It is known from sculptured monuments that these distinctive structures were used for playing a game that might be described as a cross between volleyball and soccer. Each ball court consists of a pair of steep rubble mounds faced with masonry; these mounds form the sides of a long, narrow field of play where the Maya engaged in the ritual contest they called *pok-ta-pok*.

In most Maya centers built during the Classic period the plaza in front of the major temple pyramid contained sculptured stone monuments that archaeologists call by the Greek name "stelae." These bear the images of rulers, some of them shown with their captives, and long hieroglyphic inscriptions that seem to contain historical information. The portions of the inscriptions that record dates in Maya calendric notation can be read. The dates inscribed on stelae and on sculptured altars at the Classic sites of Piedras Negras and Yaxchilán, two ceremonial centers on the Usumacinta River in the Petén region, and Quiriguá, a third center to the southeast, seem to record events in the lives of several rulers. The first of these dated monuments was erected during the third century of the Christian Era and the last at the end of the ninth century.

The emphasis in recent years on settlement-pattern research in the Maya area has resulted in the common presumption that the location and layout of

CEREMONIAL CENTER at Lubaantún consisted of 11 major structures and many minor ones grouped around 20 plazas. A number of these are identified in the map on the opposite page by Arabic and Roman numerals respectively. Construction of the center began in the eighth century after Christ, late in the Classic Maya period, and continued for 150 years.

ceremonial centers and the distribution of settlements around them are due solely to environmental dictates, without the deliberate planning apparent in such places as Teotihuacán. On the other hand, the social investment in labor and materials required for the construction of such a center suggests that a certain amount of consideration must have gone into the work: the marshaling of labor, the specification of dimensions, the collecting of vast amounts of rubble fill and masonry facing blocks, and the feeding of all these things into the construction program. The successful integration of such elements and the abilities of a range of specialized artisans argues strongly in favor of a preordained plan, and one that specified the layout and subsequent function of the site.

My opportunity to seek evidence for Maya planning came recently. The occasion was the surveying and excavation of Lubaantún, a small Maya ceremonial center in the Rio Grande basin of southern Belize. Field studies were pursued there, primarily under the sponsorship of the University of Cambridge and the Peabody Museum of Archaeology and Ethnology of Harvard University, in 1970. Three main programs were undertaken. The first was the detailed mapping of the center and of a sample of the surrounding settlement area; this work was done by Michael Walton, a professional architect, and Basilio Ah, a local Mopan Maya Indian with previous mapping experience. The second program called for excavation at the center to determine both the sequence of construction and the dates of occupation. The third was an ecological survey of the Rio Grande region, including a study of the local geology by John Hazelden of the University of Cambridge, to determine what kinds of natural resources—building stone, materials for tools, forest products for construction, plants for medicine and ritual, wild game and other foodstuffs—were or had once been locally available.

Lubaantún lies in the foothill zone of the Maya Mountains [*see illustration on opposite page*]; it occupies a long sloping ridge that runs from north to south. To the east and west the ridge falls away steeply and is bounded by creeks. The slope of the ridge is gradual, eventually descending sharply to the level of the Rio Columbia, a branch of the Rio Grande that passes a few hundred meters south of the site. Stream erosion has carved the surrounding land into a maze of low, round-topped hillocks; as a result the ridge is the only fairly level tract of any size in the area.

The region around Lubaantún is well endowed with natural resources. The Rio Columbia contains an abundance of freshwater mollusks. It also provides a waterway, navigable by canoe, that runs via the Rio Grande all the way to the Caribbean; the seacoast is some 25 kilometers east of Lubaantún as the crow flies. Hazelden's survey showed that thinly bedded sandstone, limestone and siltstone are available along the riverbanks and in the nearby foothills, and that all the stone needed for the center could have been quarried within a radius of three kilometers. Potter's clay is also found along the river, and such forest products as copal gum, valued by the Maya as incense, can be gathered on the wooded coastal plain. Moreover, the foothill zone where Lubaantún is situated has some of the most fertile soil in all southern Belize. There is game in the hills and on the coastal plain, waterfowl

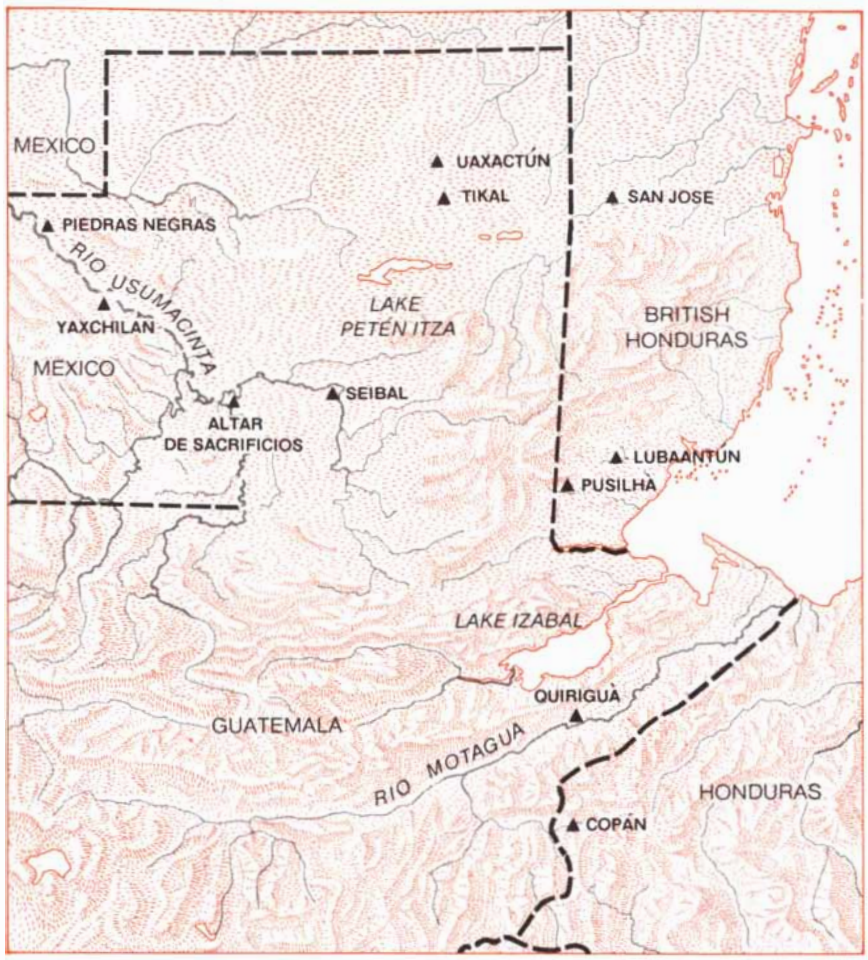
PETÉN LOWLANDS of northern Guatemala border on Mexico to the north and west and on Honduras and British Honduras to the south and east. Twelve lowland Maya centers of the Classic period are shown; the region is shown in more detail on the opposite page.

in swampy areas, and mollusks, crustaceans and fish along the coast. The canoe route to the coast covers 90 kilometers, or almost four times the straight-line distance, and might be thought to have been traveled infrequently by the people of Lubaantún. When Elizabeth S. Wing of the Florida State Museum analyzed the animal remains we recovered at the ceremonial center, however, she found that nearly 40 percent of them were of marine origin.

Our excavations showed that when the Lubaantún center was founded early in the eighth century, it consisted of a single large platform covering an area of some 2,500 square meters on the part of the ridge that was later occupied by an open plaza we have designated Plaza IV [*see "b" in illustration on pages 88 and 89*]. On the north side of this first platform stood a series of narrow rubble-filled substructures faced with stone. We were surprised to find that the original construction had begun so late; by early in the eighth century the Late Classic florescence of Maya civilization was already at its height. As will be seen, the lateness of the date has important historical implications.

In any event the first platform at the center was almost completely buried under later construction. In the second phase of the work two more large platforms were built north and south of the first, and large plaza areas were laid out beyond the north platform [*see "c" in illustration on pages 88 and 89*], quadrupling the area of Lubaantún. At one side of the north platform, facing what was later to be Plaza IV, the builders raised their first temple pyramid. We have designated it Structure 12. Its present size is the result of later construction that has entirely engulfed the original pyramid. Construction of a ball court on the southern extension completed the second-phase work at Lubaantún.

The first undeniable evidence that planning outweighed expediency in the building of the center appeared during the third phase of construction. Early work during the third phase had extended the north platform southward until it covered most of the 2,500-square-meter platform built in the first phase. It was then decided to enlarge the first pyramid and add two new ones. The size of these, as planned, meant that space in the center of the site was going to be very short indeed; for the first time a crucial decision was forced on the rulers of Lubaantún. Was the site to be extended still farther north and south along the ridge,



LUBAANTÚN IS SITUATED in the foothills of the Maya Mountains, an isolated highland area in southern British Honduras. It is among the last of the centers built by the Maya.

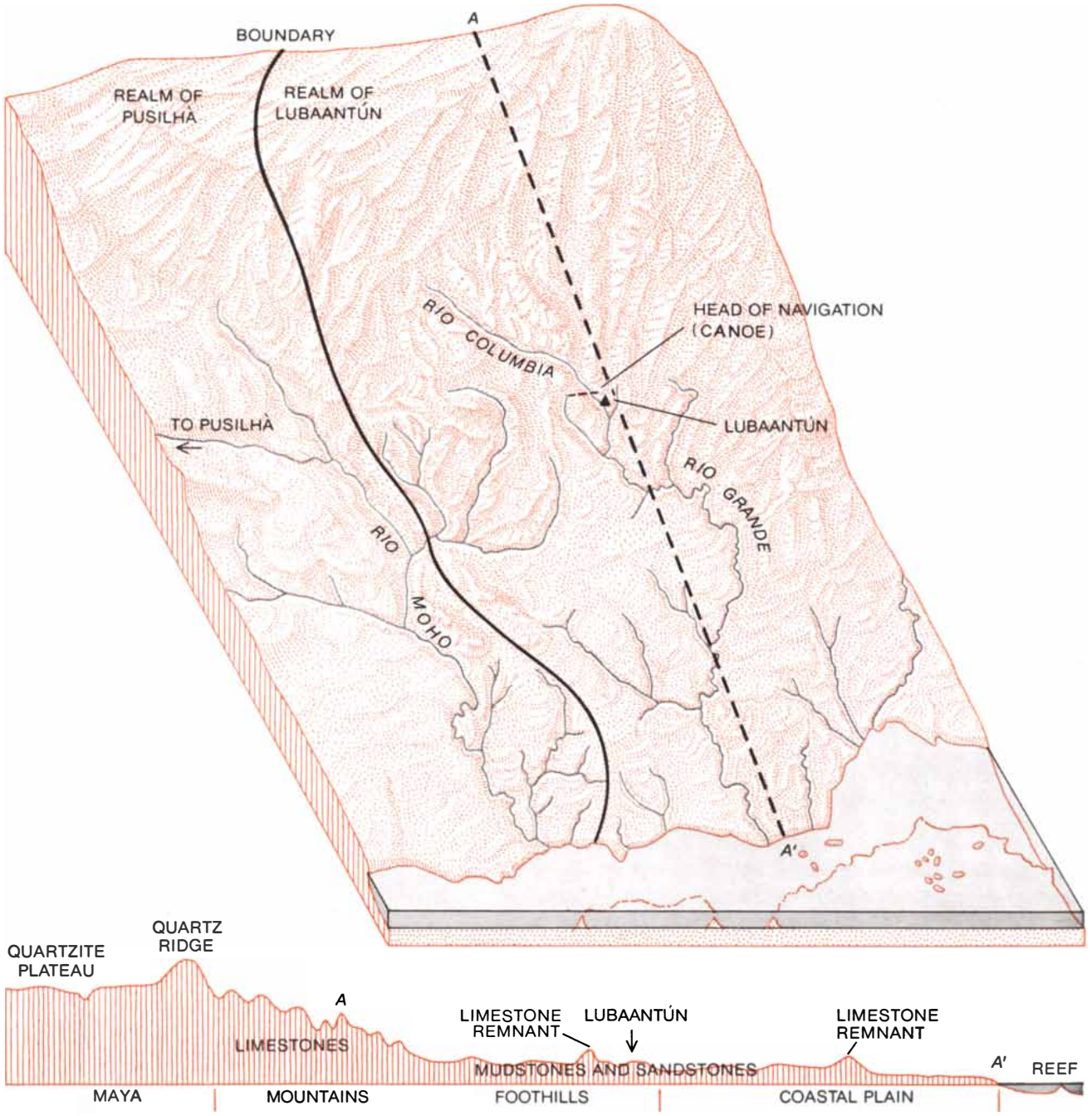
where the shallow curve of the crest meant that a large surface area could be gained with the construction of a relatively shallow platform? Or was centralization more important than economy and should the center be expanded laterally even though the acquisition of a small area meant the construction of high platforms and the investment of a prodigious amount of labor and material resources? The latter decision was taken, and the growth of Lubaantún changed from modification of the local topography to the creation of an artificial topography [*see "d" in illustration on pages 88 and 89*]. The retaining walls that gained the builders six meters' horizontal space to the east and west are multiterraced and more than 11 meters high. The amount of rubble that fills the space between ridge slope and wall must exceed 3,000 cubic meters. It is hard to imagine clearer proof that the planned layout of Lubaantún was sufficiently important to force the builders to overcome the limitations of local topography.

In the fourth phase of construction at the center still more artificial topography was created. Just beyond the newly extended main platform was a gully cut by a small stream on the west side of the ridge. This watercourse was now covered by rubble-filled platforms, forming a series of broad plazas that led down the steep slope almost to the bank of the creek at the bottom [*see "e" in illustration on pages 88 and 89*]. Whether the most southerly part of this extension was built during the fourth phase or the fifth remains uncertain. In any event the major enterprise during the fifth and final phase of construction at Lubaantún was the refurbishing of the central part of the site. Broad staircases were built at the north and south ends of Plaza V, and a second ball court was constructed on a new platform east of the plaza. At the same time a new staircase was added to Structure 12, the largest of the temple pyramids at the site.

The building of Lubaantún, which had been in progress for between 100 and 150 years, was now essentially complete. Begun early in the eighth century,

the work ended not long before the ceremonial center was abandoned sometime between A.D. 850 and 900. The plan of Lubaantún that we have now is a palimpsest, so to speak, of all five periods, but it is essentially the plan of the site as it was functioning at the time of its abandonment. It is only at this period that we can fully comprehend the zonal structure and traffic pattern within the ceremonial center.

As a result of the mapping project we know not only the total number of edifices that were built at Lubaantún but also exactly where they stood in relation to one another and the exact dimensions of each. The structures range in height from as little as 20 centimeters to more than 12 meters and in basal area from 40 square meters to more than 500 square meters. As at other Maya ceremonial centers, each structure served as a foundation for some kind of superstructure. Elsewhere a number of these superstructures, in particular the temples and palaces, were built of stone and still survive. At Lubaantún, however, all the superstructures apparently were built of wood and no longer exist. They presumably had walls of poles and roofs of palm thatch, like the Maya houses in the vicinity today. Fragments of the clay that was daubed on the pole walls of one temple have been preserved by fire; the impressions show that the poles were a little over three inches in diameter.

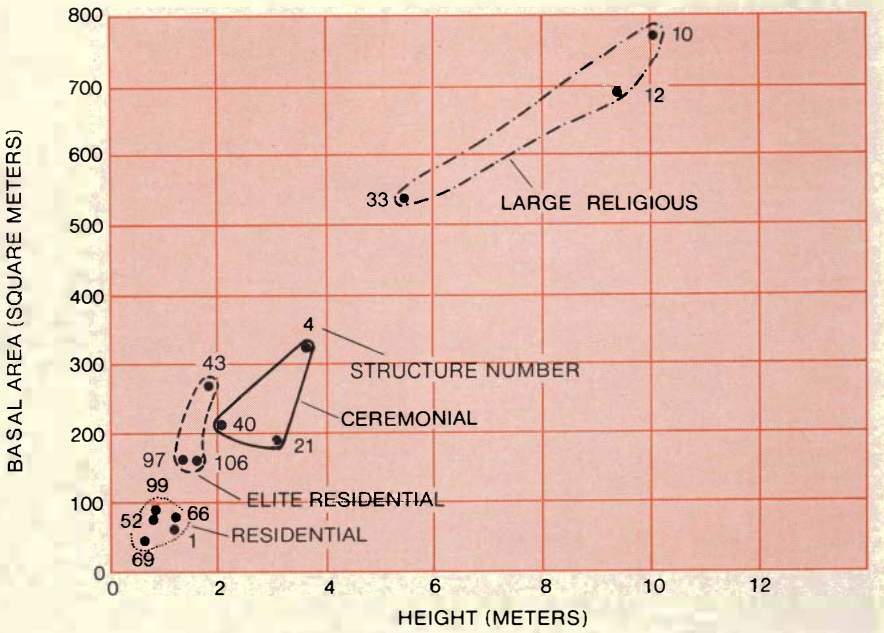


REALM OF LUBAANTÚN extended northwest some 25 kilometers from the foothills of the Maya Mountains to the highland plateau and southeast another 25 kilometers to the low-lying Caribbean coast and the sheltered waters of the barrier reef offshore (*see cross section at bottom*). The region controlled by the ceremonial center consisted of some 1,600 square kilometers, and the population may have numbered 50,000. The soil in the foothills was fertile, and the realm was rich in raw materials and wild foods.

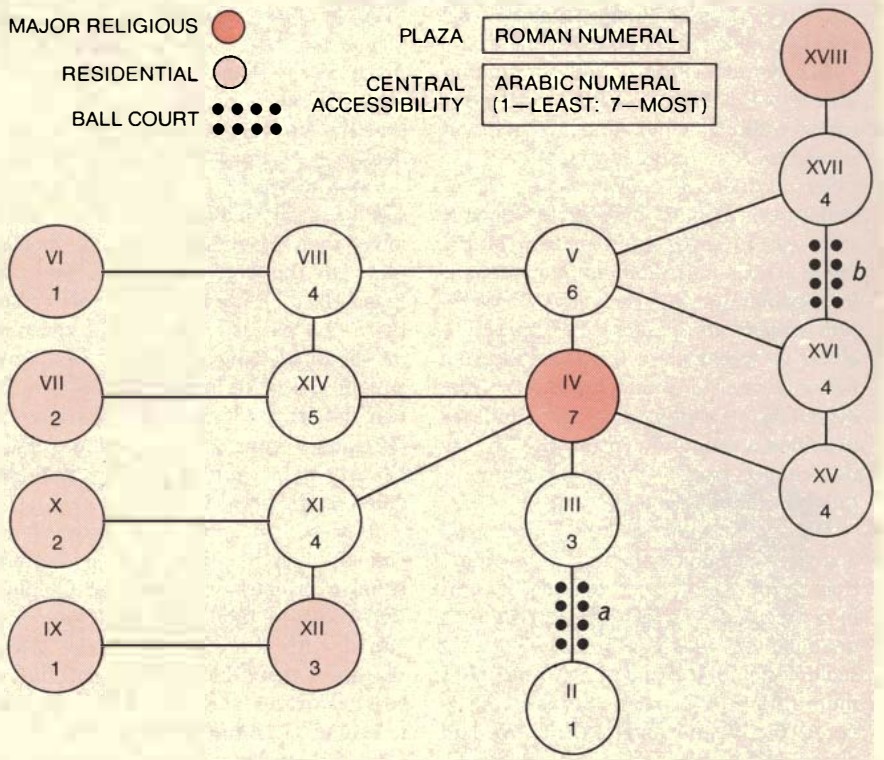
When we compared the dimensions of the various foundation structures, we found that they fell into four distinct clusters. The pyramids are at the top of the scale; the smallest of the three has a basal area of more than 500 square meters and is more than five meters high. Our system of classification placed structures this large or larger in the "religious" category. At the bottom of the scale are numerous small, low structures, all less than 1.2 meters high and 100 square meters in area. We assume that they were house foundations and have classified them as "residences." Between these extremes are two groups of structures with dimensions that overlap with respect to area but not with respect to height. The structures of the smaller group range from more than 1.2 meters in height to less than two meters; none is less than 150 or more than 280 square meters in basal area. On the basis of size and location we have dubbed this group of structures "elite residences." The structures of the larger group, ranging in height from two to 3.6 meters with a basal area as large as 330 square meters, include the two Lubaantún ball courts and a number of other structures that are neither obviously residential nor obviously ritual. We have placed all of them in a nonspecific category: "ceremonial structures."

When we marked the structures on the site map according to this four-category classification, an interesting correlation emerged. The structures surrounding any particular plaza usually belonged in the same category. Plaza IV, with its three pyramids, is a prime example; it is the only one of the 20 plazas at Lubaantún that belongs in the "religious" category. Furthermore, the five plazas immediately contiguous to Plaza IV all belong to the "ceremonial" category, and six of the seven most remote plazas at the site fall in the "residential" category. The master plan for Lubaantún seems to have called for a religious core surrounded by an inner zone of ceremonial plazas and an outer zone of residences. Such a layout follows a simple concentric-zone model, modified at Lubaantún only by the requirements of topography.

Common sense suggests that the traffic plan for such a concentric-zone model would call for residential areas with low accessibility and public areas with high accessibility. Religious areas would be either accessible or secluded depending on the nature of the cult. For example, if access to a central religious area was



MEASUREMENT OF THE STRUCTURES at Lubaantún showed a proportional relation between height and basal area. When both measurements are plotted on a graph, the structures typically fall within one of four clusters. The pyramids of Plaza IV cover the most area and are the highest of all the structures at the site. Adjacent to the more remote plazas were the lowest and smallest structures; these had presumably been house foundations. Of the structures in two intermediate clusters, the higher were probably foundations for buildings that served "ceremonial" purposes; the lower may have been occupied by the elite.



PLANAR GRAPH OF THE PRINCIPAL PLAZAS at Lubaantún and their interconnections allowed a topological analysis of the accessibility and centrality of each. An index of central accessibility showed that Plaza IV, the religious center of the site, was the most centrally accessible, with a maximum index value of 7. Of the eight least accessible plazas, all with an index value no greater than 3, six were bordered by small, low structures that were probably occupied by houses. A major difference is evident between the first ball court at the site, which was quite private (*a*), and the second, which was more public (*b*).

LUBAANTÚN GREW in the five phases outlined in this sequence of illustrations. The center after its completion is shown schematically at far left (*a*). In the first construction phase (*b*) a rectangular platform covering 2,500 square meters was built astride the north-south ridge that forms the long axis of the site. During the second phase (*c*) another platform was added to the south of the first, and plaza areas and a third platform were added to the north. The first pyramid at the site was built on one side of the north platform and the first ball court was built on the south platform. During the third phase (*d*) a southerly addition to the north plat-

restricted, this fact would suggest worship of an exclusive and elitist nature.

In order to test this hypothesis we conducted a topological analysis of the potential traffic flow at Lubaantún without regard for the presumed functions of the plazas as deduced from the categories of structures surrounding them. Our first step was to reduce the pattern of the major plazas and their interconnections to a planar graph [*see bottom illustration on preceding page*]. The graph enabled us to calculate for each plaza an index of centrality and an index of accessibility. Combined, these indexes provided a rating of central-accessibility that ranged from a minimum value of 1 to a maximum value of 7.

We then compared the topological analysis with our estimates of the functions served by the various plazas. Our hypothesis of low accessibility in residential areas was confirmed. The most secluded of all the plazas, with the minimum rating of 1, were the plazas numbered VI, IX and XVIII, which we had classified as residential, and Plaza II, which we had classified as ceremonial. The next most secluded, with ratings of 2 or 3, were the residential plazas numbered VII, X and XII and a second ceremonial plaza, Plaza III. The most centrally accessible plaza at the site, with the maximum rating of 7, proved to be Plaza IV, the religious center of the site.

The fact that two ceremonial plazas, Plaza III and Plaza II, were among those with minimal accessibility ratings meant that the site layout called for a striking decline in accessibility southward along the central axis of Lubaantún. The accessibility rating of Plaza III is four points lower than the rating of its neighboring plaza to the north, and the rating of Plaza II is the minimum possible. Since these two plazas form the end zones of the first ball court built at Lubaantún and because the ball court can only be reached by way of Plaza IV, the site's religious center, the question arises: Were playing and watching the ball game restricted activities?

It is known from early Spanish accounts that the Maya ball game had ritual overtones; sculptures at Chichén Itzá indicate that some matches even ended with the sacrifice of the losing players. Taking this evidence and the restricted access at Lubaantún into consideration, it seems probable that if any part of the religious practice during the early days at the ceremonial center was confined to the elite, that part was the ball game.

The Spanish accounts, however, indicate that for all its ritual overtones the ball game was open to public view. This suggests that the fact the second ball court at Lubaantún, the one constructed late in the history of the center, is located in a much more public part of the center is significant. The second court lies just off Plaza V, a highly accessible area: plazas XVII and XVIII, which are its end zones, also rate high in accessibility. Perhaps a change in Maya attitudes regarding the esoteric nature of the game occurred in the interval between the building of the first court and the building of the second. If that is what happened, the trend toward a more public ritual that seems evident in the middle of the ninth century at Lubaantún persisted throughout the post-Classic period and on down to the time of the Conquest.

In summary, the traffic-flow analysis confirmed our commonsense hypothesis that the center's residential areas were secluded and its public areas more accessible. Concerning the question of whether the religious observances were public or restricted, common sense had identified Plaza IV, with its three pyramids, as the religious center of Lubaantún. By showing that Plaza IV was also the most accessible plaza at the site, traffic analysis suggests unrestricted public access to religious activities.

Plaza V, just to the north, ranks next in accessibility. This open area, with its

form covered up most of the first-phase platform at the site, and adequate foundations for two more pyramids were provided by new platforms built over the steep east and west slopes of the ridge. Construction in the fourth phase (*e*) included a series of platforms on the west slope that descended almost to the creek at the bottom of the ridge. In the final phase the main construction (*f*) consisted of a second ball court east of Plaza V and new staircases for Plaza V and for Structure 12, the first of the pyramids at the center. Growth of the center to the east and west regardless of the immense cost indicates the builders' adherence to a fixed plan.

broad stairways, is perhaps the most spacious of all the plazas at Lubaantún, and its high accessibility strengthens our suspicion that, with or without the contiguous Plaza VIII, this was the marketplace for the center. Finally, the fact that for a century or more the only ball court at Lubaantún was an area with sharply restricted access suggests that, at least until very late in Classic times, the ball game was confined to an elite group within a well-stratified society.

Perhaps it is not too much to propose here a wider archaeological application of assessments of this kind. Analysis of the centrality and accessibility of the different areas that make up "palace" complexes in, for example, Mesopotamia or Crete or Mycenaean Greece might suggest functions quite different from those enshrined in long accepted but essentially poetic phrases such as "the queen's antechamber" or "lustral area."

Why was Lubaantún built where it was? The answer to the question is suggested by the results both of our mapping and ecological surveys and of our excavations. These show that the influence of the ceremonial center was felt not only adjacent to but well away from the site itself. Most of the low, round-topped hills on all sides of Lubaantún are surmounted by small masonry and rubble platforms; the dressed-stone retaining walls are one or two meters high and the rubble serves to level off the summit. These structures, on a smaller scale, are exactly like the great platforms at Lubaantún. Furthermore, they support house foundations in numbers sufficient to indicate that 1,200 to 1,300 people resided within a one-kilometer radius of the ceremonial center. This is scarcely a large population, but it is as densely concentrated as the local topography permits.

These hill platforms and house foundations represent a social investment in labor and materials that, although it is dispersed, is comparable to the more concentrated investment that produced the complex structures of the ceremonial center. The scale of the work also implies an adequate supply of food for the inhabitants of the district, which suggests in turn that location of the center in the belt of fertile soil along the foothills of the Maya Mountains was scarcely accidental.

Why was the center built, however, at precisely this place? The soil zone extends a considerable distance to both the northeast and the southwest, which suggests that factors in addition to the prospect of good crops must have entered into the decision to build the center here. One of the factors must have been the propinquity of the site to the Rio Columbia. Not only was the stream a source of water and the mollusks from it a reliable source of protein (their shells appeared by the thousands in our excavations) but also the head of navigation by canoe lies near Lubaantún. Goods coming upstream from the Caribbean would have been transferred from canoe to porter in this area. Moreover, this spot is also where the main overland trail along the base of the foothills crosses the river. Lubaantún was thus in a position to control canoe traffic to and from the coast and overland traffic along the foothills. In effect, the center dominated the entire Rio Grande basin, a "realm" extending for some 50 kilometers from the high plateau of the Maya Mountains southeastward to the Caribbean shore. The entire realm is some 1,600 square kilometers in extent; its population may have numbered as many as 50,000.

Our excavations made it clear that Lubaantún was the center of a flourishing regional marketing system. From the Maya Mountains came the metamorphic rock used to make not only axe heads of stone but also the *manos,* or stone rollers, and *metates,* or shallow stone troughs, that are used together to grind maize. From the Caribbean coast, which was as far away in the opposite direction, came marine shells used for

ornaments and the seafood that forms such a high percentage of the animal remains at the site. In addition, trade extended far beyond the frontiers of the realm. Two sources in the highlands of Guatemala, identified by Fred H. Stross of the University of California at Berkeley, provided obsidian, which can be flaked into fine blades with a razor-sharp edge. Also from the highlands came tripod *metates* made of lava. From the south came plumes from the cock quetzal to adorn the rulers of Lubaantún and from an unidentified highland source came jade for their jewels.

In exchange for these imports the inhabitants of Lubaantún evidently traded the beans of the cacao tree, which are used to make chocolate and were the universal currency of Middle America in pre-Columbian times. As I have noted, the soil around Lubaantún is fertile. A study of all the soils in the region in terms of their utility to the Maya of the Classic period was conducted recently by Charles Wright of the United Nations Food and Agriculture Organization. He found that Lubaantún stands in the center of the largest zone of top-quality soil for cacao-tree culture in all of southern Belize. As Spanish records attest, cacao beans were traded between this lowland area and the highlands of Guatemala in post-Conquest times. That the tree and its fruit were known in Lubaantún is apparent from a figurine of the Classic period excavated there; it depicts a musician wearing a cacao-pod pendant [*see illustration at left*]. It seems clear that the prosperity of the realm was in large measure due to its possession of one of the sources of this scarce product, which was in constant demand. The trade with the Guatemalan highlands, where a completely different range of resources was available, was in many ways a form of economic symbiosis, existing for the mutual benefit of both partners and fostering diplomatic as well as commercial contacts that it was mutually useful to maintain.

MUSICIAN WEARING A PENDANT in the form of a pod from the cacao tree is the subject of a figurine of the Classic period found at Lubaantún. Evidence that cacao was known to the people of Lubaantún, taken together with evidence that local soils are particularly suited to raising cacao trees, suggests that cacao beans were exchanged for foreign imports.

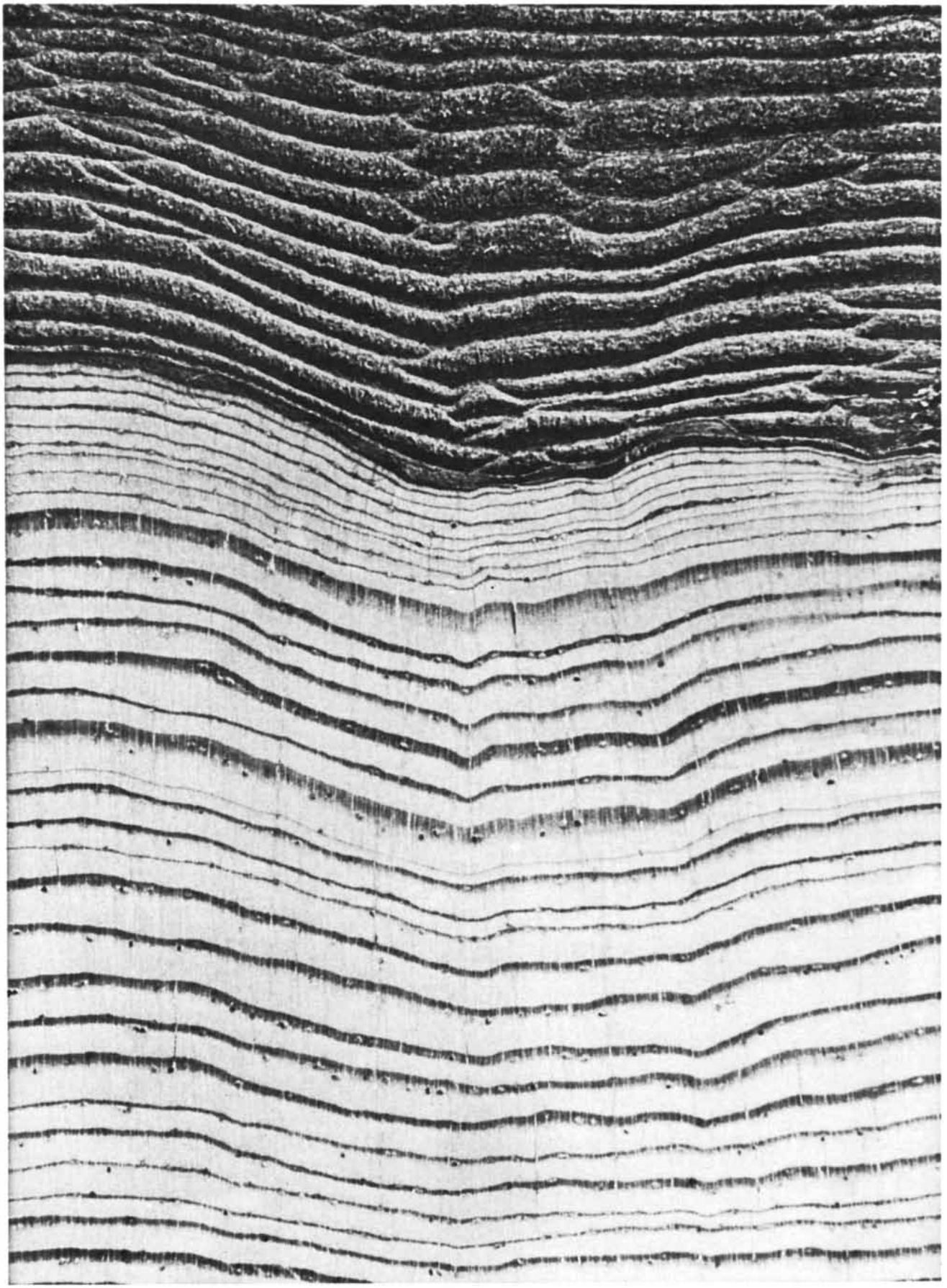
The question of why Lubaantún was built when it was remains unanswered. The entire Rio Grande basin appears to have been unoccupied territory until the eighth century, when the center was founded. So far not a single object made before Late Classic times, not even a potsherd, has been discovered at any site in the region. To the southwest of the Rio Grande basin another Maya site, a ceremonial center named Pusilhà, has been discovered in the basin of the Moho River. Some 20 stelae have been found there; the dates they bear range from A.D. 573 to 731. Pusilhà was therefore functioning as a ceremonial center during all of the seventh century. Moreover, the most recent of the Pusilhà stelae dates and the presence there of Lubaantún-style figurines show that the center was still occupied well after the foundation of Lubaantún.

Pusilhà was flourishing before Lubaantún was even built. This fact has given rise to a number of cause-and-effect hypotheses. According to one of them, the Maya who built Lubaantún were former residents of the Pusilhà realm who migrated northward as a re-

sult of population pressure or political expansion within or beyond that realm. Another hypothesis, first advanced in 1938 by Sylvanus Griswold Morley, suggested that political control had been transferred from Pusilhà to Lubaantún in the eighth century, the time when the Maya at Pusilhà ceased to raise stelae. According to the Morley hypothesis, the halt in stela-raising was evidence that the use of Pusilhà as a ceremonial center had also ceased.

The Morley hypothesis, applied more generally, has been the controlling model for much of the speculation about the collapse of Classic Maya civilization. In this view the end of the "stela cult" at each ceremonial center marked the end of the religious, political, administrative and commercial control exerted by the realm's rulers. Our studies at Lubaantún cast doubt on that line of speculation. Although this Late Classic ceremonial center exerted control over a wide realm for some 150 years, not one stela, sculptured or plain, appears to have been raised there. It thus seems clear that the presence of the stela cult was not crucial to the exercise of effective religious, political and commercial control. If a center such as Lubaantún could flourish without instituting such a cult, then other ceremonial centers could have continued to exercise authority after stelae were no longer raised. Excavation at Maya sites of the Classic period to obtain articles for carbon-14 or thermoluminescence analysis might well shed more light on the decline of Maya civilization than do hypotheses that depend on the terminal dates preserved on stelae.

The stelae cult might better be viewed as a product of ideological fashion than as an integral part of the social and economic infrastructure that supported the culture of the Maya for more than 2,000 years. Maya ceremonial centers, if Lubaantún is a fair example, drew their power not so much from the gods as from the integration of a broad range of economic resources. The economic effort may often have included, as it did at Lubaantún, the exploitation of a commodity in great demand. Seen in this light the Maya ceremonial center seems to have been more the focus of a regional marketing system and, as a result, a seat of administrative and political power than the headquarters of a primarily religious institution. In almost every aspect except population density the Maya centers equate in form and function with the preindustrial cities of the Old World.



EFFECT OF SMOG on a Jeffrey pine that was growing in a forest near Los Angeles may be indicated by the narrowed rings and a reduced amount of latewood in the last nine years of the tree's life. The abnormal ring pattern developed several years before the tree showed foliage damage and was cut down. Last ring formed appears as several small lenses of wood just inside the bark, which is at top.

TREE RINGS AND CLIMATE

It is well known that tree rings reflect the age of a tree. Variations in the ring pattern of many trees in a region can be statistically analyzed to determine climates of the past

by Harold C. Fritts

It is well known that counting the number of rings in the trunk of a tree is a way of determining the tree's age. Closer observation reveals distinct variations in the widths of annual rings in certain trees, suggesting that changes in the environment affected the growth of the tree. If by pursuing this notion one finds that the trees of a given area have a similar pattern of ring widths, one can develop a picture of the fluctuations in climate in the region over a period of years. By finding dead trees that overlap in time the ones for which ring patterns have been dated, one can go backward in time to obtain a longer record of climatic fluctuations.

The possibility of extracting information from tree rings in this way has given rise to the rapidly expanding discipline of dendrochronology, from the Greek *dendron,* meaning tree. The discipline has several branches: dendroclimatology, which employs dated rings to yield information on past climate; dendroecology, which investigates past and present environmental factors as reflected in their effects on tree growth, and dendrohydrology, referring to what tree rings tell about past variations in water runoff in an area. Moreover, tree-ring patterns have provided a valuable means of dating archaeological and geological events as far back as 8,000 years before the present.

It should be emphasized that not all trees are suitable for dendrochronology. A tree that grows in a benign climate, always having an adequate supply of water and favorable temperatures, is not likely to show much variation in its annual ring growth. One can determine the age of such a tree readily enough, but that is about all the information obtainable from an unvarying ring-width pattern. For a dendrochronological study to be effective the trees must be in an area where climatic or environmental factors limit growth and the critical conditions vary in intensity from year to year. For example, in the U.S. Southwest the limiting factor is precipitation; in northern Alaska it is temperature. A dry year in the Southwest will produce narrow tree rings (perhaps in the following year rather than in the dry year), whereas years with higher precipitation and soil moisture will result in wider rings. In this way a pattern of ring widths is formed in all the trees of the region affected by the particular climatic factors.

With distinctive patterns of wide and narrow rings in a number of trees, one is in a position to do cross-dating, that is, to match the ring patterns in one tree with corresponding patterns in other trees. (It is not necessary to cut down a tree to ascertain the ring-width pattern. The usual procedure is to take a thin horizontal core from a tree trunk with a boring tool, leaving the tree essentially unharmed.) Cross-dating is the most important technique of dendrochronology. It provides the basis for accurately establishing the year-to-year chronology of varying widths, which reflect the conditions that affected the growth of the trees in a region. Cross-dating also is a tool that can be employed to date specimens of wood of unknown age. The pattern of wide and narrow rings in such a specimen is compared with the pattern in other trees of the region, a pattern termed the mean or master chronology. If the specimen came from a site near the trees used to develop the master chronology and was contemporaneous with any part of the known and dated ring sequences, the patterns will match at some point and the specimen can be dated. Usually a minimum of 50 years is necessary for cross-dating to be reliable.

Chronologies are constructed and extended back from the age covered by living trees by cross-dating older pieces of wood with ring-width patterns that partly match the patterns of dated wood [*see top illustration on next two pages*]. The chronology for the Southwest has been extended back to 273 B.C. by means of wood from a number of archaeological sites. The chronology developed from the bristlecone pine in eastern California is nearly 8,200 years in length. Since trees of this species live for thousands of years (the oldest living one known is 4,600 years old), it does not require a large number of specimens to develop a long chronology. Moreover, the chronology can be lengthened by means of fragments from dead trees. For example, living trees may have enough rings to be dated back to the year 2000 B.C. If one obtains a fragment of a dead tree with the later portion of its ring pattern coinciding with the early portion of the ring pattern of the living trees, the fragment will carry the chronology back in time, exceeding the maximum age of the living trees.

Tree-ring dating is not always as straightforward as I may have made it seem. For example, a tree may appear to produce more than one ring in a year. (A band of small, thick-walled cells characteristic of the latewood usually formed near the outer boundary of a ring is found in the middle of the ring, surrounded by the large, thin-walled cells characteristic of the earlywood; as a result there appear to be two rings.) Alternatively the tree may not form a ring in all parts of the stem. Anomalies of the first type are called false or double rings, and those of the second type are called partial, locally absent or missing rings, depending on how they look in a particular part of the stem. The dendrochronologist must be alert to such possibilities. He can spot these difficulties by

examining the synchrony or lack of synchrony in rings and cell structure in all his specimens and can correct for them in order to obtain an accurate chronology [*see illustration below*].

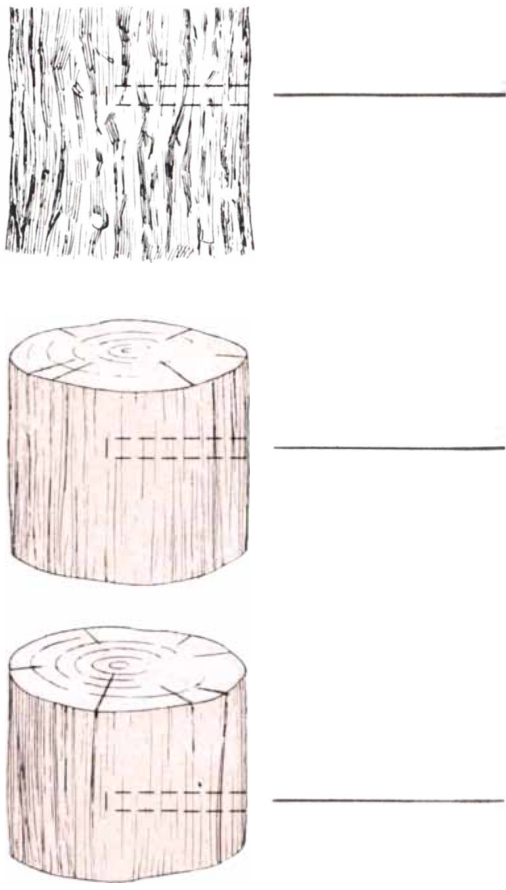
Another corrective procedure that dendrochronologists employ is called standardization. It is directed not only at the fact that ring widths vary with changes in the environment but also at the decrease in ring width with increasing age of the tree. Age effects must be estimated and discounted if the object of a tree-ring study is to find out about variations in climate. Standardization corrects a ring-width chronology for the decrease in width with increasing age of the tree, and the transformed values are called ring-width index values. By this procedure the larger variability in ring width of the younger and faster-growing parts of a tree is made comparable with the smaller variability in the older portions of the tree. The standardized index values are usually calculated for all measured specimens and then averaged to obtain the mean growth chronology for a sampled site.

On the other hand, standardization can blur some of the effects the dendrochronologist would like to perceive. If climate changes slowly over a long period of time, distinguishing the effects of the climatic change from the effects of the increasing age of the trees is difficult. Standardization may obscure some of the long-term growth changes that arise from trends in climate. In addition the plant community may change slowly with gradual changes in climate: with increasing drought weaker trees die off, and the roots and branches of remaining trees, relieved of competition from neighbors, grow into the vacated spots. With increasing moisture many seedlings are established, intensifying competition on the site. The trees that remain alive are the ones that have withstood the change in climate. Their ring widths show the initial change in climate, but they are not likely to reflect with great sensitivity the continuing long-term effects. Their ring chronology will show the year-by-year and decade-by-decade changes in moisture, but because of the standardization procedure and the slowly changing condition of the plant community the ring patterns may not clearly reflect the persistence of a climatic change over a century or more.

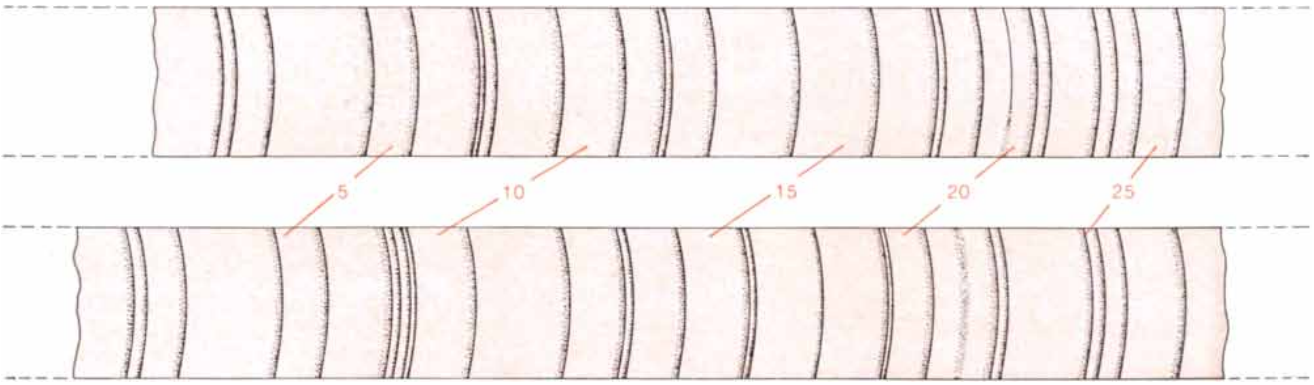
Climate is not the only factor affecting ring structure. Internal growth regulators, stored food, competition and disease influence the growth of trees. The relative importance to growth of these factors and the climatic ones may vary depending on the species of tree and the conditions of the site.

A dendroclimatologist, seeking to reconstruct variations in past climate, tries to exclude or minimize the effects of as many nonclimatic factors as possible by choosing extreme sites where climate is almost always the limiting factor in the growth of trees. He also prefers a site where man has not altered the forest, thereby introducing nonclimatic effects on tree growth. Since the dendroclimatologist fortifies his findings with an abundance of samples, he can disregard specimens with rings he cannot crossdate, such as samples with anomalous growth patterns caused by insect damage, fire, grazing and a number of other factors. On the other hand, a dendroecologist may want to preserve some of the information the dendroclimatologist wants to minimize, because anomalous growth in certain trees may yield clues on a stand's environmental history.

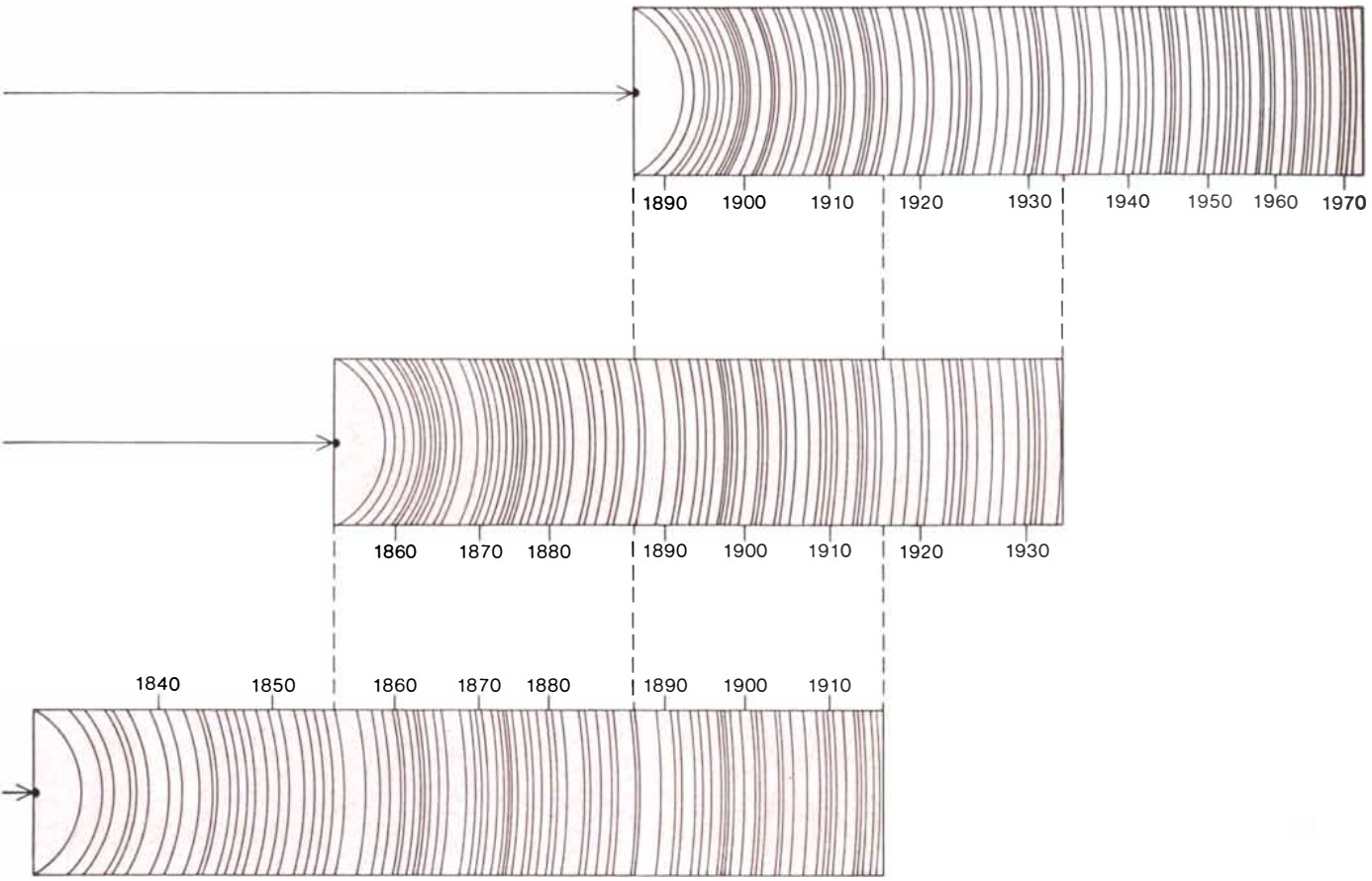
Assuming the objectives of a dendroclimatologist, it is possible to describe the predominant relations that link the important climatic factors—precipitation and temperature—to low growth. Suppose the trees being studied are evergreen conifers growing under the arid and warm conditions typical of the Southwest. During the growing season low precipitation and high temperature mean that the moisture content of the soil is low and the amount of solar radiation reaching the tree is high. The tree undergoes water stress and the needles heat up, resulting in reduced net photo-



LONG-TERM CHRONOLOGY is established by finding wood from dead trees with ring patterns that overlap the characteristic ring-width pattern of trees still living in a



CROSS-DATING OF SPECIMENS is a means of finding and correcting for aberrations in ring-width patterns. At left the ring-width patterns of two specimens are depicted schematically, with every fifth ring or apparent ring numbered. The patterns match until the ninth ring. Close inspection reveals that rings 9 and 16 of the lower specimen are narrow and do not appear in the upper specimen.

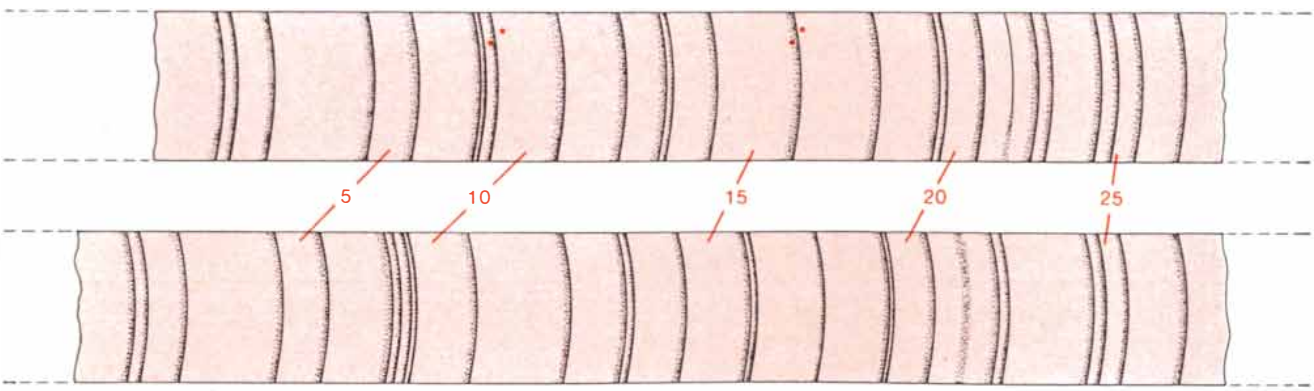


region. A core removed from a radius of a living tree (*top*) establishes a chronology extending from the present year to the year the tree started to grow. Similar cores removed from old wood found in buildings or on the ground under conditions that preserved the wood make it possible to carry the chronology back in time from the point of overlap with the dated cores to the time when the older tree started to grow. Long chronologies are established by studying cores of the bristlecone pine, which lives for thousands of years.

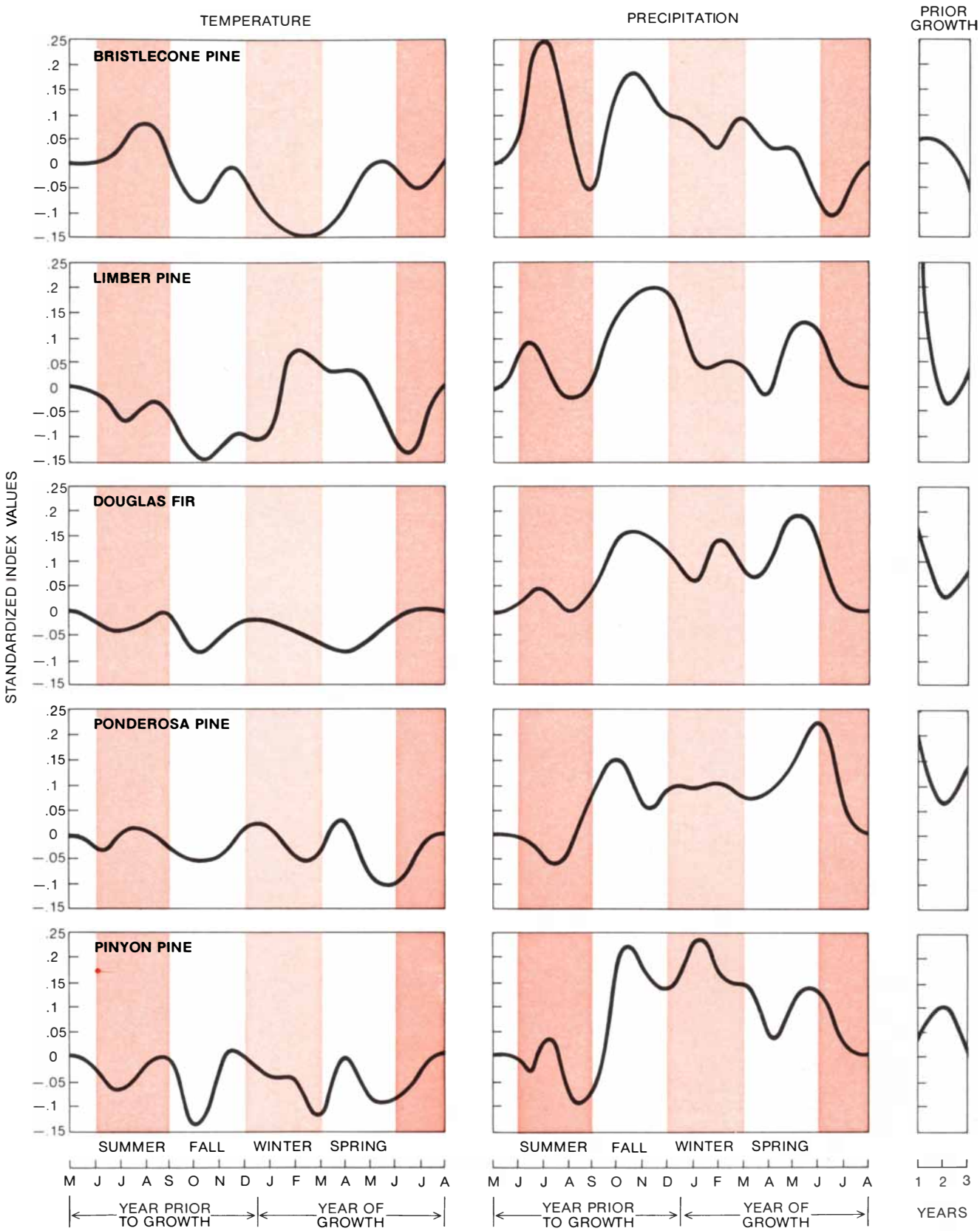
synthesis, less translocation of food and of growth regulators and less production of cell parts and cell products. A narrow ring is formed. Similar conditions before the growing season result in less assimilation and storage of food and therefore in less potential for rapid growth during the growing season.

The foregoing list of relations resulting from low precipitation and high temperature could be expanded considerably; I have described only the principal ones. Many of the relations have been borne out by field and laboratory investigations and appear to be reasonable explanations of statistical results. For example, water stress, transpiration, net photosynthesis and growth have been measured in the ponderosa pine in the mountains near Tucson. The measurements showed significant net photosynthesis in the nongrowing season, even in the middle of winter, as long as the tree did not suffer water stress and daytime temperatures were above freezing. Drought conditions in fall, winter or spring caused increased water stress, which decreased transpiration and reduced net photosynthesis.

The end product of photosynthesis is



Ring 21 of the upper specimen has an intraring band of latewood, which is recognized in the lower specimen by its indefinite boundary as a false ring. At right the same two specimens are shown with corrected numbering. The positions of the rings missing from the upper specimen are marked with two dots each. By such procedures the exact year for each ring of each specimen is established.



SPECIES RESPONSE FUNCTIONS, which are also called transfer functions, are calculated by computer analysis of temperature, precipitation and annual ring width. The climatic factors represent mean monthly temperature and total monthly precipitation for the period from May through March immediately preceding the growing season and the period from March through July, which is the growing season. Each of the plotted values represents the average relative effect of temperature or precipitation for the particular month, or the relative effect of prior growth, on the size of the ring. Values above zero indicate that above-average conditions of temperature, precipitation or prior growth are associated with above-average ring width; values below zero, an opposite or inverse association with ring width. Plots represent average relation for each species calculated for 120 different forest stands.

glucose, which the tree employs in making other carbohydrates, fats and proteins. The accumulation of stored food during the winter has been demonstrated in seedlings of Douglas fir. Cell division in the spring is known to be rapid if the concentration of available food in the tree is high and other conditions are favorable. Conversely, after a winter that is unfavorable to net photosynthesis a tree is likely to have little accumulated food, and a low rate of growth results, producing a narrow ring. Indeed, recent statistical studies show that for many arid-site trees investigated in dendrochronology the climate during fall, winter and early spring has a greater influence on ring width than the climate during the growing season.

Until recently dendrochronologists in the U.S. gave most of their attention to arid sites, inferring correctly that ring width represents the integrated effects on growth of low precipitation and high temperature throughout the year. With the experience gained at such sites dendrochronologists have begun to study trees in less extreme places. In these areas each tree-ring chronology must be calibrated with variations in climate to assess which climatic factors have limited growth and are recorded in the varying widths of the rings. Calibrations using many variables are obtained rather easily with the aid of high-speed computers and the relatively sophisticated statistical techniques of multivariate analysis. The results of such analyses produce response functions (sometimes called transfer functions), which can be plotted to show the mean responses of different species of trees to conditions of temperature, precipitation and prior growth [*see illustration on opposite page*]. The response functions that my colleagues and I at the Laboratory of Tree-Ring Research of the University of Arizona have plotted for several arid-site tree species show larger values for precipitation variables than for temperature variables. Such findings represent part of the statistical evidence that precipitation and the resulting soil moisture constitute a more important control of growth in the sampled trees than temperature does.

Looking more closely at the illustration, one sees that the growth of the pinyon pine, which is found at the lowest altitudes, is affected more by winter climate than the other four species represented are. The growth of the bristlecone pine, which is found at the highest altitudes, is affected more by the climate of summer, particularly the summer climate of the previous year. In general high precipitation and low temperatures during most months of the year are favorable to growth, although there are a few months when the opposite conditions are found to be favorable. A significant amount of growth in a year may also be related to above-average growth in prior years.

The differences in response functions among samples of a given species of tree show variations associated with differences in topography, elevation and local conditions of the site. Such factors are known to modify the microclimate and thus to alter its effect on growth. Hence the dendroclimatologist's procedure of calibration, by computing a response function, measures the climatic information in ring-width chronologies. It can also provide the biologist with a method for assessing in considerable detail how specific climatic factors affect variations in the annual productivity of a forest stand as measured by ring widths.

Large high-speed computers also make it possible to assess simultaneously the relation of climate to several tree-ring chronologies. My colleagues Marvin A. Stokes, Charles W. Ferguson and Linda G. Drew have developed a network of chronologies for a large number of sites in western North America. Departures from normal in the size of dated growth layers are plotted on maps and contoured for different intervals of time to give a picture of what the climate was in a region at a particular epoch [*see illustration on next two pages*]. The map and the multivariate-analysis procedure reveal many similarities in past and present growth patterns, but they also reveal times when the amount of tree growth over wide areas differed from what is observable at the present time, reflecting different climatic patterns.

Another example of how tree-ring analysis can be employed to explore the past involves atmospheric pressure, which is an easily and commonly measured variable of weather and climate. Meteorologists have systematically collected pressure data over the land and ocean surfaces of the Northern Hemisphere for many years. Although atmospheric pressure does not directly limit tree growth, it is related to the conditions of moisture and temperature that do limit growth. I have worked on this problem with three meteorologists: T. J. Blasing of the University of Arizona, Bruce P. Hayden of the University of Virginia and John E. Kutzbach of the University of Wisconsin. We reasoned that if the record of tree growth in North America, as observed in tree rings, was related to climatic factors resulting from patterns of atmospheric pressure, the tree-ring configurations might be calibrated with configurations of pressure. With such calibrations in hand, one could reconstruct pressure patterns of times before meteorological measurements were systematically made.

We attacked this statistical problem with the computer. With the results obtained we prepared maps that cover a large portion of the Northern Hemisphere back to the year 1700. We are now studying ways to improve and extend the pressure records over a wider area and farther back in time and to reconstruct the patterns of precipitation and temperature as well.

The pressure maps derived from tree-ring data are not as reliable as actual measurements of pressure, but they do provide the first precisely dated information on pressure—and, by inference, on the generalized weather patterns over the North Pacific and large areas of North America—prior to the historical records. Our hope is that the maps will be further refined and will eventually be of aid to meteorologists who are modeling the present circulation in the atmosphere. Information of the kind yielded by the maps may also help to distinguish between natural variations in climate and inadvertent modifications of climate introduced by the activities of man.

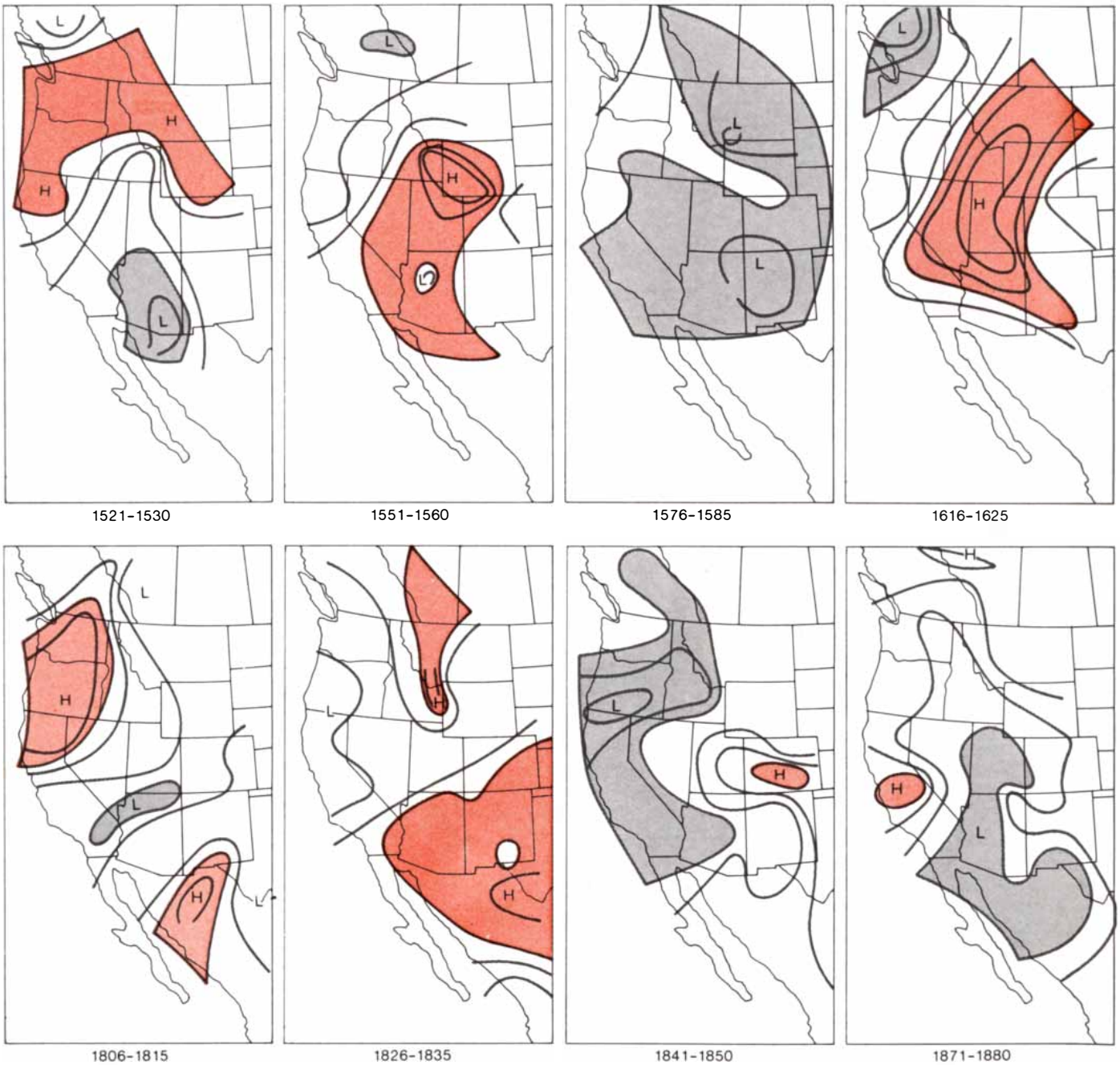
My colleague Charles W. Stockton and I have employed multivariate procedures to calibrate spatial and temporal variations in ring widths with the annual stream flow representing runoff from the watershed where the trees grow. By means of the calibration we converted the long record of tree rings to estimates of the flow in years when no record of stream flow was available. Reconstructing stream flow in this way is particularly helpful in western North America, where records of stream flow cover a short period of time and where the variation in runoff from one year to the next and one decade to the next may be substantial.

Our group applied a cursory analysis of this kind to the virgin annual runoff (the measured flow corrected for what was diverted to irrigation) of the Colorado River measured at Lees Ferry. The mean annual runoff for the period from 1896 to 1962 was 15.1 million acre-feet, whereas the mean annual runoff estimated by tree-ring analysis for the period from 1564 to 1962 was 13 million acre-feet. Thus the short-term measurements exceed the calculated long-term mean by 14 percent. The improved sta-

tistics we have obtained can be helpful in decisions on future designing and managing of reservoirs and on ecological use of the watershed. The adjusted statistics are also more likely than the short-term measurements to portray the future distribution of extreme droughts and other infrequent hydrologic events because they are based on a longer period of time.

A recent dendrochronological study may help the Canadian government to make decisions in the management of the W. A. C. Bennett Dam in the Peace-Athabasca delta region of Alberta, including the regulation of flows so that the natural ecological balance of the region is not upset by the dam. Water levels in channels, sloughs and minor depressions in the delta are directly related to the water level of Lake Athabasca. Ring widths from white spruce trees growing along these waterways were calibrated with the water levels measured in the lake for a 33-year period (1935 to 1967) before the dam was put in operation. After calibration the variations in ring widths were employed to reconstruct the lake levels back to 1810. The reconstruction indicated more fluctuation in the lake level before 1935 than was measured between 1935 and 1967. If the Canadians wish to return the delta region to the conditions represented by the longer period, the analysis of tree rings tells them they may need to provide for more fluctuation in lake levels than is indicated by the measurements made from 1935 to 1967.

Dendrochronological investigation has been applied widely in geology. From the ages of trees it has been possible to estimate the minimum age of floodplains, glacial moraines and other recently exposed geological substrates, since the



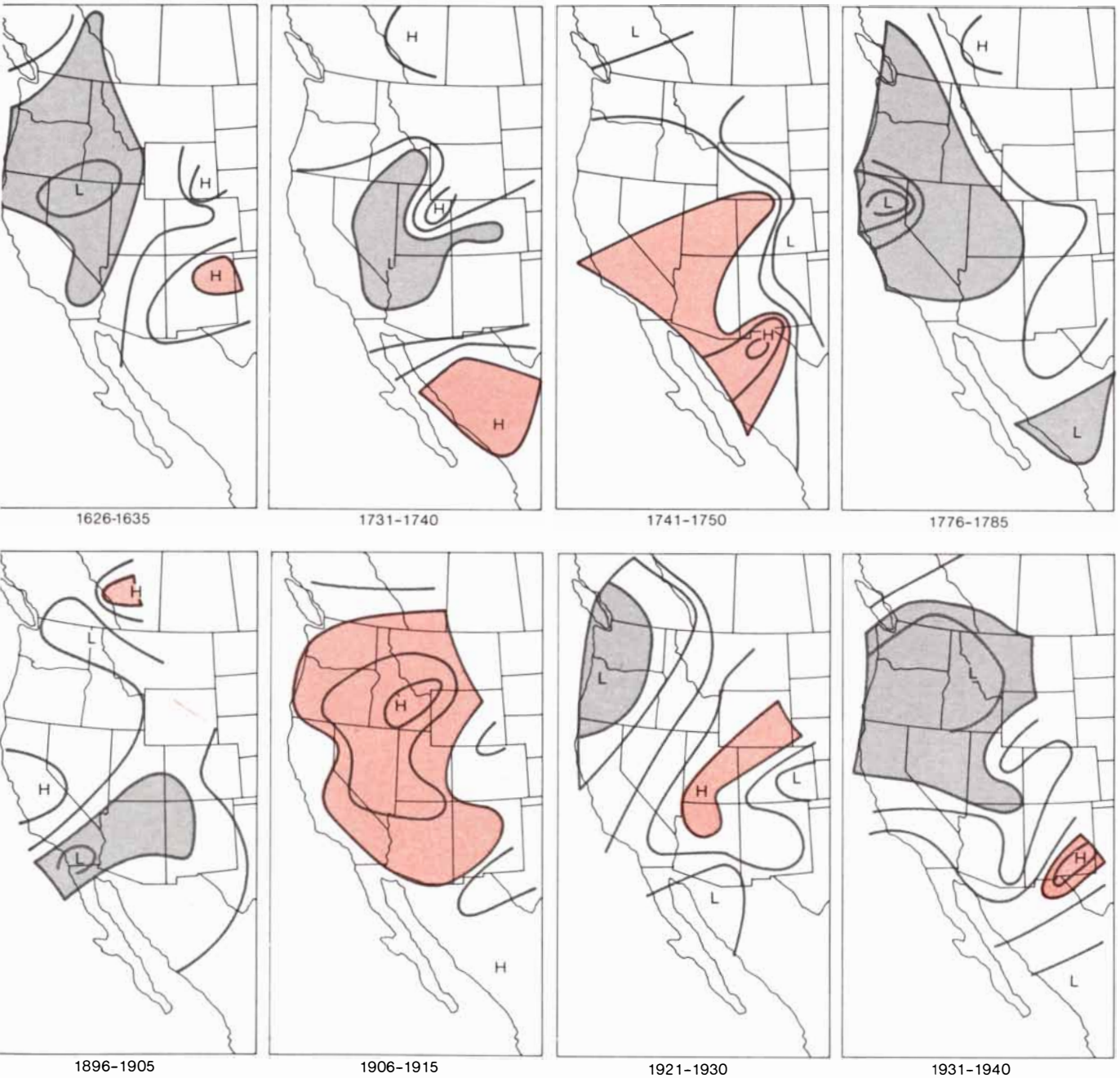
CLIMATIC FLUCTUATIONS in western North America are indicated by analysis of ring-width patterns dating back to 1521. The maps show decades when large regional departures in ring-width index values occurred. The contour lines join areas of equal de-

tilting or the injury of trees by advancing glaciers, landslides, avalanches, floods and earthquakes often causes a change in the growth pattern of the tree and is reflected in the rings.

My colleague Valmore C. LaMarche has pioneered in new ways of using dated tree rings to measure erosion rates and to study the frequency of floods, fires and earthquakes in California. He and Harold A. Mooney of Stanford University have dated living and dead trees at high altitudes and compared the information with dating done by Ferguson at low altitudes to trace past fluctuations in the timberlines. Another recent study by LaMarche and me relates ring widths in trees from high altitudes in the Alps to the advance and retreat of alpine glaciers. The study succeeded because the physiological response of the trees to climate was found to be similar to the relation between glacier size and changes in climate. Hence variations in ring widths from old trees at high altitudes provided a means of reconstructing the behavior of the glaciers.

My colleagues W. J. Robinson and J. S. Dean have plotted and contoured the past ring-width variation near archaeological sites. They plan to apply multivariate techniques to decipher climatic conditions from the growth rings of trees used by the inhabitants.

Tree-ring dating of beams and charcoal from prehistoric structures has made the dating of archaeological sites in the Southwest extremely precise. The rings of the bristlecone pine have played a significant role in the radiocarbon dating of archaeological sites in Europe. Indications that dates obtained from the radioactive isotope carbon 14 became increasingly too young for events before about 1500 B.C. were confirmed by the



parture in index values from a mean value; areas of particularly high (*H*) or low (*L*) departure from the mean are shaded. The indicated growth patterns before and after 1900 show certain similarities and also marked differences, indicating differences in climate.

long bristlecone-pine chronology developed at the Laboratory of Tree-Ring Research first by the late Edmund Schulman and then by Ferguson [see "Carbon 14 and the Prehistory of Europe," by Colin Renfrew; SCIENTIFIC AMERICAN, October, 1971]. The inferred cause of the discrepancy is that radiocarbon is less abundant now than it was in ancient times. As a result of the work of Schulman, Ferguson and Paul E. Damon of the University of Arizona and of Hans E. Seuss of the University of California at San Diego and others a correction curve for carbon-14 dates has been built up from the tree-ring dates. The resulting revision in carbon-14 dates appears likely to lead to fundamental reinterpretations in archaeology.

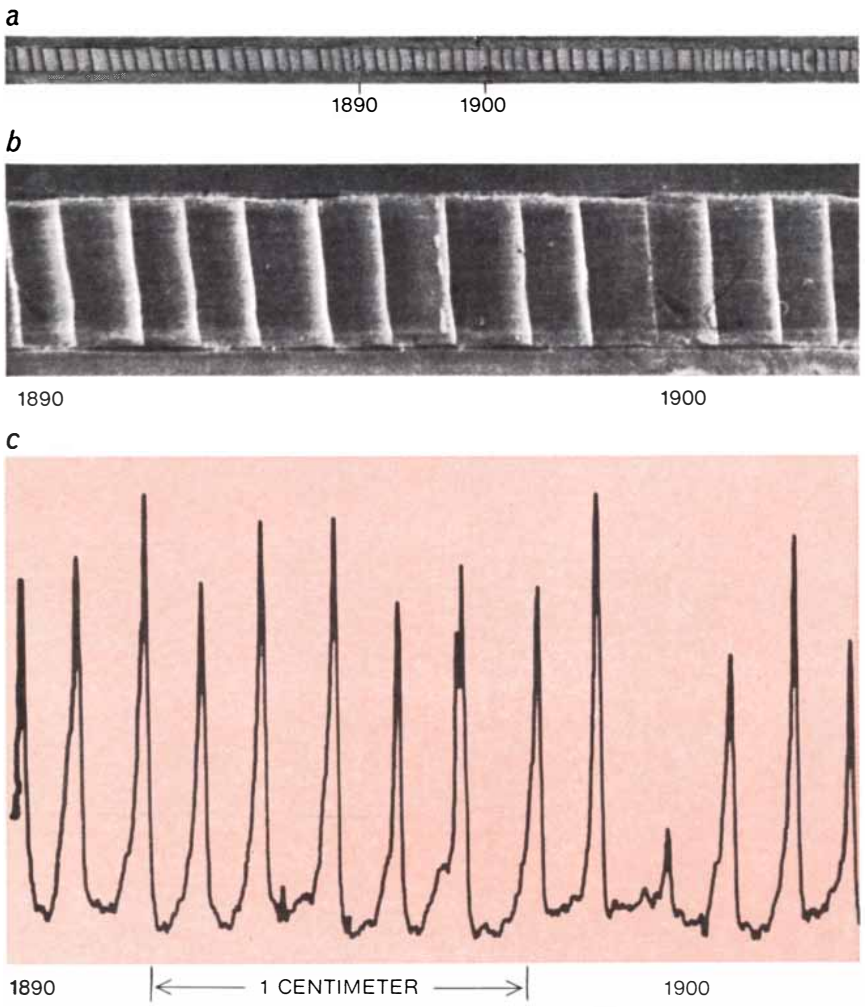
Dendrochronology also holds promise for assessing the impact of man on the environment. Bohuslav Vinš of the Forestry and Game Management Research Institute in Czechoslovakia has conducted research on industrial smoke and its effect on the growth of trees. I have sampled trees in a forest near Los Angeles that were thought to have been killed by the smog of the city. A considerable reduction in ring width can be observed in the tree stems corresponding to the last eight to 10 years before the trees died [*see illustration on page 92*]. The finding suggests that tree-ring analysis can help to diagnose the effect of pollution before trees die.

Work of this kind will undoubtedly entail complications, as is indicated by a recent study by William Clark Ashby of Southern Illinois University and me. We undertook to determine through tree rings if inadvertent climatic changes had occurred in the vicinity of La Porte, Ind., where an increase in rainfall had been attributed to industrialization and the resulting air pollution. We found that oak rings neither supported nor refuted the possibility. The reason was that we could not disentangle the climatic information in the ring-width chronology from changes in growth resulting from other disturbance of the trees or possibly from the growth-inhibiting effect of pollutants that the trees may have absorbed. At first the rise in rainfall appeared to result in increased growth. As both the amount of pollution and the anomaly in rainfall reached their apparent maximum, however, growth became markedly reduced. The experiment suggests that there is no simple formula for analyzing tree rings. Statements about past growing conditions based on variations in ring widths must be considered as speculation or, at best, inferences resting on certain assumptions unless the ring widths are calibrated with the assumed limiting factor and statistically significant relations are shown to exist.

A new technique that may greatly increase the amount of information that can be extracted from tree rings has been devised by Hubert Polge of the National Center for Forest Research in France and developed by Marion L. Parker of the University of British Columbia. It employs X rays to obtain photographs of changes in cell and wood density within a ring [*see illustration at left*]. Such changes are apparent to the eye but difficult to measure; if they can be ascertained objectively, they will provide a means of analyzing with increased sensitivity the effects of environmental changes on the growth of a tree, particularly subtle changes during the growing season.

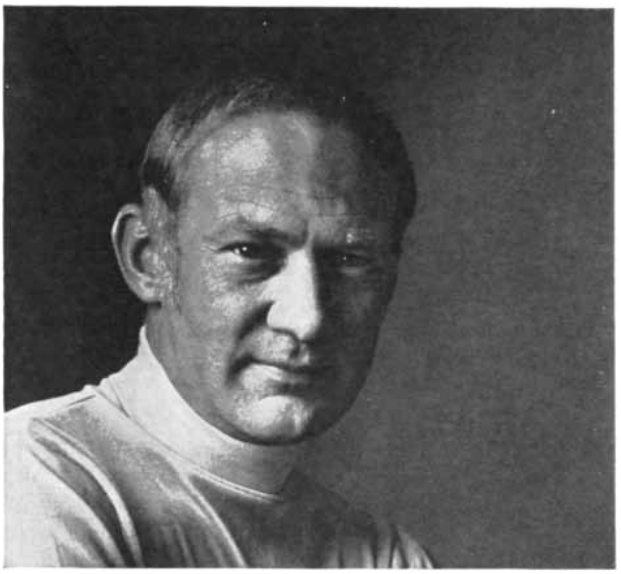
The method involves scanning an X-ray negative with a beam of light and measuring with a photocell the intensity of the light transmitted by the film. Variations in intensity can be converted to units of wood density. Polge and Parker have evidence that X-ray analysis will be particularly valuable for studies in temperate regions and on moderately moist sites, where variations in the environment during the growing season are often more highly correlated with changes in cell structure and wood density than with variations in ring width.

It seems likely that when this system is perfected and used in conjunction with multivariate analysis of cell density (as well as ring width), the dendrochronologist will be able to recover a great deal more information on past environmental conditions than is possible now. The rapid development of these new techniques and the proliferation of applications to problems of man's environment represent the beginning of a new era for dendrochronology.



X-RAY TECHNIQUE yields increased information on wood density and thus on the climatic factors influencing the growth of the tree in particular years. A core extracted from a tree is mounted (*a*) and X-rayed. An enlarged portion of the X-ray negative (*b*) is scanned with a beam of light and a photocell. Resulting electrical output can be calibrated (*c*) in terms of wood density, which is low for earlywood cells and high for last-formed latewood cells.

"After our first Moon landing, I resolved I would never publicly endorse any product or service unless I sincerely believed in it."



Apollo 11 Astronaut, Buzz Aldrin, discusses the Computerized Self-Analysis system in every 1972 Volkswagen.

"Everything after a Moonwalk is a letdown.
You can't top it.
So instead, you adjust.
You adjust to a world that's a far cry from perfection."

Or at least the kind of perfection that took Buzz Aldrin to the Moon and then brought him back within a quarter mile of an aircraft carrier carrying the President of the United States.

Then it's over and there he is. With a Doctor of Science degree from MIT and a walk on the Moon under his belt, in a world, that at times, seems absolutely chaotic.

Then, something comes along that makes a great deal of sense to him.

And he becomes enthused:

"In analogy with the manned space flight programs, past, present and future—of Mercury, Gemini, Apollo, Sky Lab and Space Shuttle—which pioneered computer check-out systems, the present VW system compares with the early Mercury flight of Shepard, Grissom and Glenn."

Volkswagen's new Computerized Self-Analysis system.

To Buzz Aldrin, it's a **"great step forward in the area of troubleshooting of automobiles."** To you, if you own a 1972 Volkswagen, it means getting the most advanced automotive check-up there is.

"The car, truly, is wired along the same principle of a space craft."

(Nothing like asking the man who manned one.)

How the system will work at VW Dealerships:

In its simplest terms, it's a network of check points and sensors throughout the car; each sensor reporting the condition of various key points in the car to one central socket in the back of the car.

The socket, when plugged into a computer, which will be at Volkswagen dealers starting later this year, will actually report the condition of your car directly to you.

Things like your electrical system, cylinder compression and front wheel alignment will all be checked without human error.

Altogether, 60 vital service points will be checked. The results will then be printed out on a sheet of paper, in plain English, for you to read.

"Keeping that print-out sheet after each check-up is like checking-in with Mission Control when you're 200,000 miles out in space. It gives you a nice, secure feeling." It also gets you home quicker.

"The technical advances of the system amaze me, of course, but the speed of operation amazes me even more." To check cylinder compression the conventional way today, a mechanic has got to do the following: remove each spark plug, insert a gauge, crank the engine, take a reading, make a decision and then put each spark plug back.

At top speed, the procedure takes 10 minutes and 40 seconds for four cylinders.

With the new VW system, it takes 60 seconds.

To check out your electrical system, you need a great deal of knowledge, equipment, and 9 minutes and 40 seconds.

With the new VW system, your electrical system is checked out in less than 2 minutes.

At top speed, it takes the best mechanic using the best equipment 4 minutes to check out your front wheel alignment.

With the new VW system, elapsed time is 60 seconds flat.

So there you have it.

Instead of a mechanic telling you what's wrong with your car, now your car and your dealer's computer can tell you.

It took Volkswagen 7 years and enough money to develop and market an entirely new automobile to come out with the Computerized Self-Analysis system.

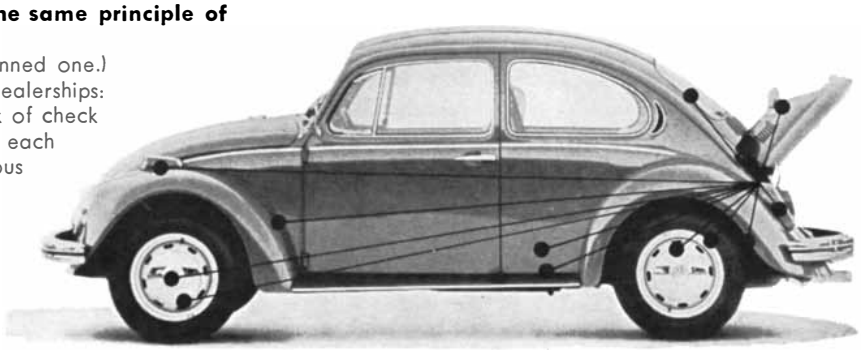
Why such a concentrated effort on service instead of, let's say, a new, longer, lower, wider Beetle?

Basically for the same reason Colonel Buzz Aldrin decided to publicly support it.

The reason is known as progress.

Postscript: *Earlier this year, Volkswagen felt it had something advanced enough to show, not only to a man who walked on the Moon, but also a man who was intimately familiar with the subject of computerized check-out and testing.*

After a series of meetings and after seeing the system in operation and after learning of the plans to bring in the computers starting later this year, Colonel Aldrin's response, very simply, was: ***"I'm impressed."***



The Great Automobile Race of 1895

This event, covering a difficult 1,200-kilometer course from Paris to Bordeaux and back, established the viability of the automobile and the superiority of the internal-combustion engine over steam

by Jacques Ickx

The birth of anything, living or inanimate, is generally considered to occur at the moment when it becomes viable. In this sense we can fix a definite date for the birth of the automobile. It came into the world as a lively, healthy phenomenon on June 13, 1895. The idea of an automobile had had innumerable conceptions and miscarriages prior to that time, but on that date the horseless carriage at last emerged as a useful creation ready for growth. The labor that led to its "delivery" was an event now long since forgotten but one that created worldwide excitement at the time. It was called "the Great Paris-Bordeaux-Paris Race."

A century of abortive efforts to produce a viable motorcar had set the stage for the drama. The efforts had begun even before James Watt's invention of the steam engine, although they were not serious until Oliver Evans in the U.S. and Richard Trevithick in England had developed high-pressure steam engines with a power-weight ratio appropriate to self-propelled vehicles. The attempts by Trevithick and many others to develop a road vehicle at the beginning of the 19th century were unsuccessful primarily because the leaf-spring suspension had not yet been invented. It was to be the railroads that would first introduce travel by machine.

Starting in 1858, with the further development of the steam engine, efforts to build a road vehicle were renewed, at first with no greater success. Finally in 1873 the French inventor Amédée Bollée *père* made steam-driven cars possible and indeed capable of high performance. They did not become practicable for general use, however, and after 12 years of tinkering Bollée abandoned his experiments, having concluded that the future belonged not to the steam car but to the emerging new "thundering engine" powered by gasoline.

The need for motive power in light industry had stimulated much work on the creation of an internal-combustion engine. It was first realized in a reliable form by Nikolaus August Otto of Germany with his construction of the four-stroke engine that was to be the basic forerunner of the modern automobile power plant. The company for which Otto worked, Gasmotorenfabrik Deutz, was not interested in developing motorcars. It remained for two independent German inventors, Carl Benz and Gottlieb Daimler, to take up the problem.

Benz concentrated on producing a three-wheeled vehicle propelled by an Otto engine running at 250 revolutions per minute. He turned out his first vehicle and road-tested it in the streets of Mannheim in 1886. Meanwhile Daimler, the former general manager of Gasmotorenfabrik Deutz, and his "disciple" Wilhelm Maybach had devoted themselves to the goal of developing a light engine that would be marked by a high shaft speed to give a favorable ratio of power to weight. They reached 720 r.p.m., which was a fantastic shaft speed in their day. A motorcycle powered by a Daimler engine ran in 1886 and a buggy in 1887.

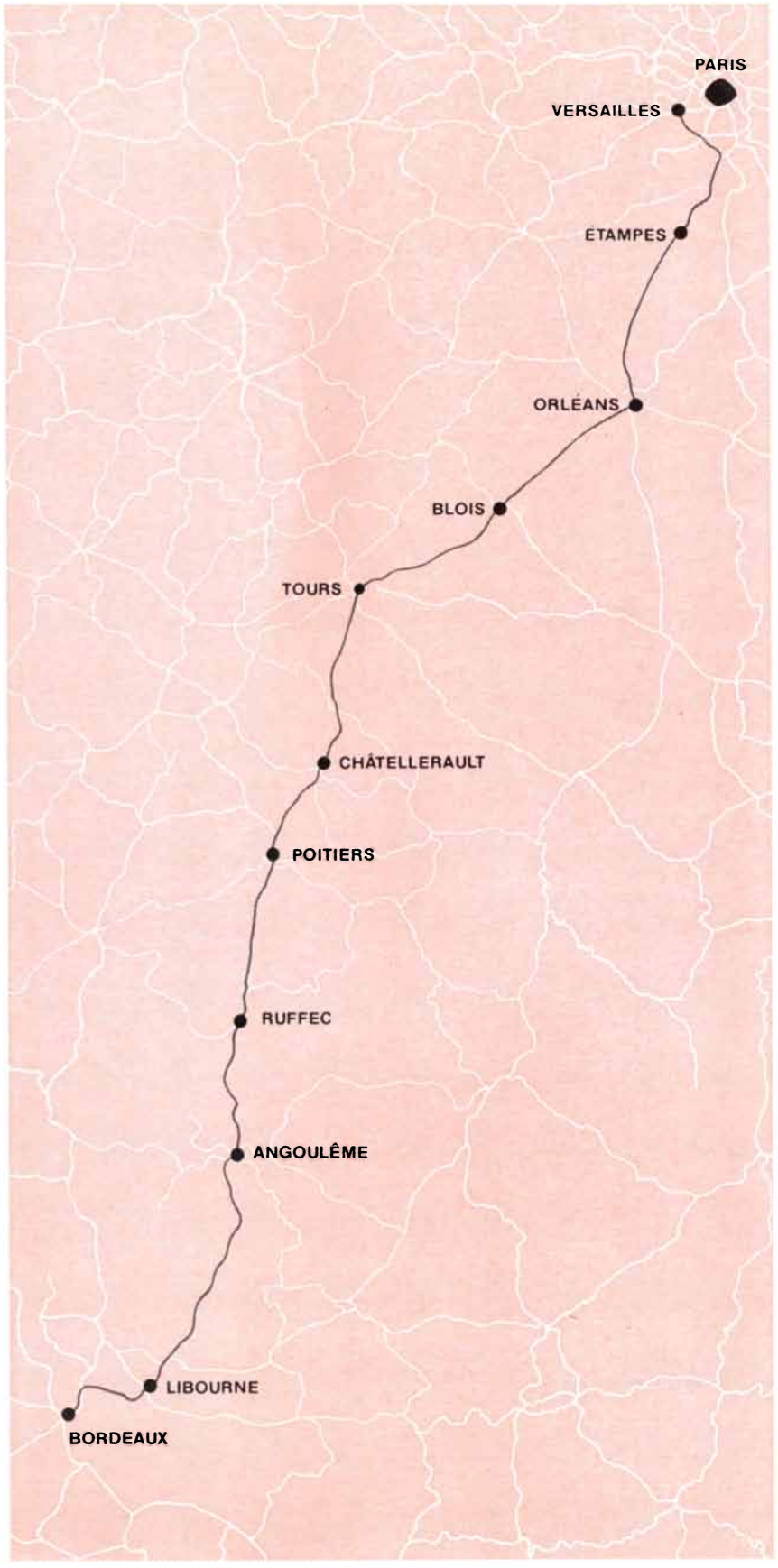
Neither the Benz nor the Daimler demonstrations generated any great stir. Benz's successive three-wheelers found no buyers. As for Daimler, he was not interested in building road vehicles; his curious object was to produce a universal engine that could be used in every way for every purpose. Hence the gestation of the automobile might have dragged on for some time had it not been for the intervention of an enterprising widow.

Daimler's representative in France was Edouard Sarazin, a Belgian who had unsuccessfully tried to bring the new technique to the attention of carbuilders in Paris, particularly his friend Emile Levassor, who in association with René Panhard ran a workshop with 50 employees for the manufacture of internal-combustion engines. When Sarazin met a premature death in 1887 at the age of 47, his widow, a Frenchwoman from the Midi, obtained from Daimler the right to continue her husband's work in France. Mme Sarazin had fallen in love with Levassor, which doubtless intensified her efforts to put the Daimler engine before him. At all events the Panhard & Levassor organization ultimately bought the French production rights to the engine.

Levassor's intention was to build the motors and leave to others the task of installing them in automobiles. Accordingly he took considerable trouble to approach Armand Peugeot, an important industrialist of Doubs (near the German border) who ran three big workshops manufacturing tools, household equipment (particularly coffee grinders) and bicycles. He offered Peugeot the Daimler motor on an exclusive basis in return for a minimum purchase of 30 motors a year. This would have been an enormous order for the time, and Peugeot declined, reserving the right to acquire Daimler motors for automobiles as he went along.

Panhard and Levassor were now obliged to look into making automobiles themselves. The production of Daimler motors in France began in 1890, and almost immediately afterward both Panhard & Levassor and Peugeot made prototype vehicles. The Panhard & Levassor machine was in the form of a carriage; the Peugeot was rather like a

WINNING CAR in the race was the Panhard & Levassor entry shown here at the start of the race (*top*) and after its victorious finish (*bottom*). At the starting point in Versailles the occupants are Emile Levassor (*left*) and his mechanic, Charles d'Hostingue. Together they covered the entire course of almost 1,200 kilometers in 48 hours 48 minutes, with Levassor doing all the driving. At the finish the car is being escorted to an exposition that was organized for vehicles completing the course. The occupants are an official, who is wearing a top hat, and a mechanic, who is driving. Flowers have been heaped on the rear of the car to celebrate the victory.



COURSE OF RACE is depicted on a map showing the roads between Paris and Bordeaux as they existed in 1895. The communities named were checkpoints for the race. Levassor had a relief crew at Ruffec; he arrived so early that they were not there, so he continued on.

four-wheeled bicycle. By the second half of 1891 both companies had achieved a certain amount of success. The Panhard & Levassor vehicle had covered the 225 kilometers (140 miles) between Paris and Étretat in two days. The Peugeot quadricycle, participating unofficially in a bicycle race, had covered the 1,200 kilometers (745 miles) from Paris to Brest and back to Paris in 10 days.

Panhard & Levassor took the lead in the production of its vehicle; it had made five improved machines by October, 1891. Peugeot, however, had also produced additional vehicles by the first days of 1892. The interest aroused by the new machines now brought Carl Benz the customers he had been awaiting in vain for his three-wheeled vehicles.

By 1894 it seemed that the horseless carriage might be ready to give a better account of itself. A total of some 200 Panhard & Levassor, Peugeot and Benz vehicles had been built, and there was an assortment of various other motorcar prototypes in France, some of them steam-powered. The automobile was still only in the fetal stage, however, as far as its technical and social impact was concerned. Very few people had ever seen one of the horseless carriages; at least nine-tenths of the population did not even know they existed. Pierre Giffard, the editor of France's largest daily newspaper, *Le Petit Journal*, was inspired to sponsor a show designed to bring the automobile to public attention and at the same time promote his newspaper's circulation.

The event would be a run from Paris to Rouen and back: a modest distance of 126 kilometers (about 78 miles). The cars able to reach the finish within a set limit of 12½ hours were to be judged on the basis of safety, comfort and economy of performance. It was to be a demonstration of the utility of the horseless carriage as a means of transportation, not as a sport vehicle. The regulations stipulated that the speed of the cars would not be recorded, because, Giffard said, a speed of 16 to 17 kilometers per hour was sufficient for the run.

There were 102 entries in "the Race of the Horseless Carriages." Most of them were for vehicles that did not yet exist and that were intended to utilize astonishing sources of energy: the weight of the occupants, levers, pedals, compressed air, a hydraulic motor—even an animal motor. All the fantasies, all the dreams, all the illusions of misunder-

stood inventors were included in the list. Hence only 25 cars appeared at the elimination tests of July 19, 20 and 21, 1894, which called for covering 50 kilometers in four hours. Twenty gasoline- and steam-powered vehicles met the test. The gasoline-powered cars were five Panhard & Levassors (four of which were entered by the builder), seven Peugeots (five of which were entered by the builder), a Benz and a Gautier with a Daimler motor; the steam-powered vehicles were a de Dion–Bouton tractor towing an open carriage, a Serpollet omnibus, a Scotte omnibus, an old steam tricycle and two Le Blant delivery trucks with Serpollet motors.

In the run from Paris to Rouen and back Giffard hoped that the cars would proceed one after the other about 150 meters apart. Some of the cars, however, could not go fast enough to keep up with the car ahead, and some could not go slow enough to stay behind. As a result when the cars reached Mantes for the midday rest, some were an hour ahead of schedule and some an hour behind. Therefore Giffard decided to let the cars proceed at their own pace in the afternoon run. This presented an opportunity for a race between the steam-propelled de Dion–Bouton machine and one of the gasoline-driven Peugeots, and the race was won by the de Dion–Bouton. The impromptu match gave rise to the legend that the Paris-Rouen-Paris run was a race, whereas it was only, as it was intended to be, a reliability trial. In this trial 13 of the 14 gasoline-driven cars met the requirements and only one of the seven steam vehicles (the de Dion–Bouton) did so. The first prize was shared by Panhard & Levassor and Peugeot. The second prize went to the firm of Bouton.

The de Dion–Bouton machine had been sponsored by the wealthy Comte de Dion. Immediately after the finish of the run the Count, knowing that his vehicle was the fastest, proposed for the following year a race on a much more ambitious scale. Giffard declined to go along, but the Count's fellow contestants were willing. The *petroliers* (builders of internal-combustion-engine cars) were confident that their products would perform, provided that the race was over a distance great enough to demonstrate their engines' reliability and durability.

The Count and the others drew up an audacious set of plans and conditions for the race. It was to cover a distance of about 1,200 kilometers over the road from Paris to Bordeaux and back to Paris. The race would be run nonstop, night and day. All repairs along the way were to be made by the drivers and their crews with tools to be carried in the vehicles. Each car was to have all its seats occupied by passengers, and to be eligible for the first prize a car would have to carry at least four people. A carbuilder was not allowed to enter more than one car of the same type. A draconian condition required the contestants to complete the 1,200-kilometer run within 100 hours. Considering that the average cruising speed of the cars of the time was not much more than 25 kilometers per hour, this was a formidable challenge.

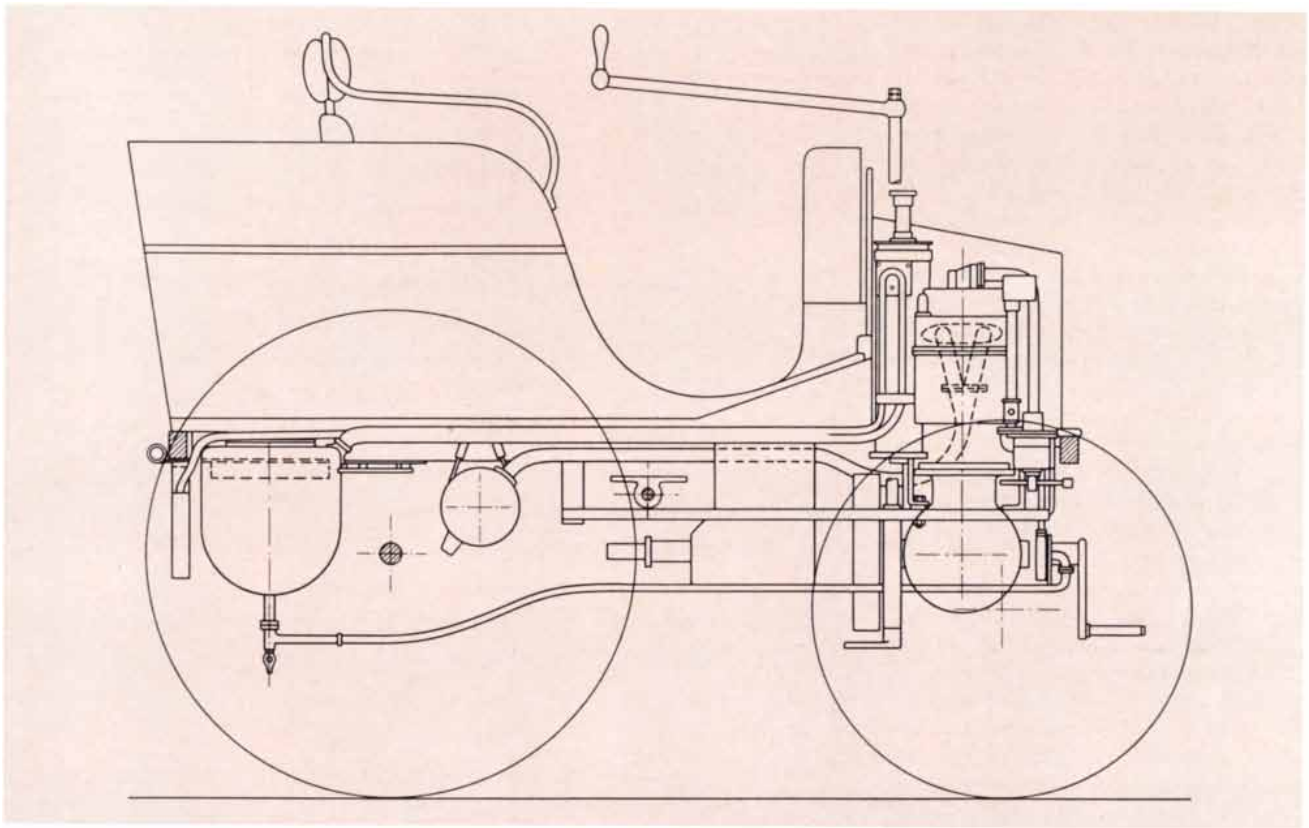
RACE NUMBER	CAR	TYPE	PROPULSION	FINISH
5	Panhard & Levassor	Two-passenger prototype	Gasoline	1
15	Peugeot	Two-passenger classic	Gasoline	2
16	Peugeot	Four-passenger phaeton	Gasoline	3
8	Peugeot	Four-passenger vis-à-vis	Gasoline	4
12	Benz	Four-passenger vis-à-vis	Gasoline	5
7	Panhard & Levassor	Four-passenger classic	Gasoline	6
28	Panhard & Levassor	Six-passenger prototype	Gasoline	7
13	Benz	Four-passenger phaeton	Gasoline	8
24	Bollée "La Nouvelle"	Seven-passenger omnibus	Steam	9
1	de Dion-Bouton	Four-passenger tractor	Steam	No
3	de Dion-Bouton	Four-passenger break	Steam	No
6	Panhard & Levassor	Two-passenger classic	Gasoline	No
14	Hildebrand & Wolfmuller	Motorcycle	Gasoline	No
18	Gautier	Two-passenger classic	Gasoline	No
20	Serpollet	Four-passenger classic	Steam	No
21	Serpollet	Four-passenger prototype	Steam	No
25	Jeantaud	Four-passenger	Electric	No
26	Rossel	Four-passenger vis-à-vis	Gasoline	No
37	Vincke & Delmer	Five-passenger	Gasoline	No
42	Millet	Motorcycle	Gasoline	No
43	Gautier-Wehrle	Four-passenger back-to-back	Steam	No
46	Peugeot/Michelin	Two passengers, pneumatic tires	Gasoline	No

STARTING VEHICLES are identified according to the numbers they bore in the race and according to type. Of 97 vehicles entered for the competition only 22 started, and only nine finished within the allotted span of 100 hours. Although the Panhard & Levassor No. 5 finished first, it did not qualify for the first prize because it was a two-passenger vehicle and the rules of the race stipulated that to be eligible for the prize a car would have to carry at least four passengers. Accordingly the third-place Peugeot No. 16 was the official winner.

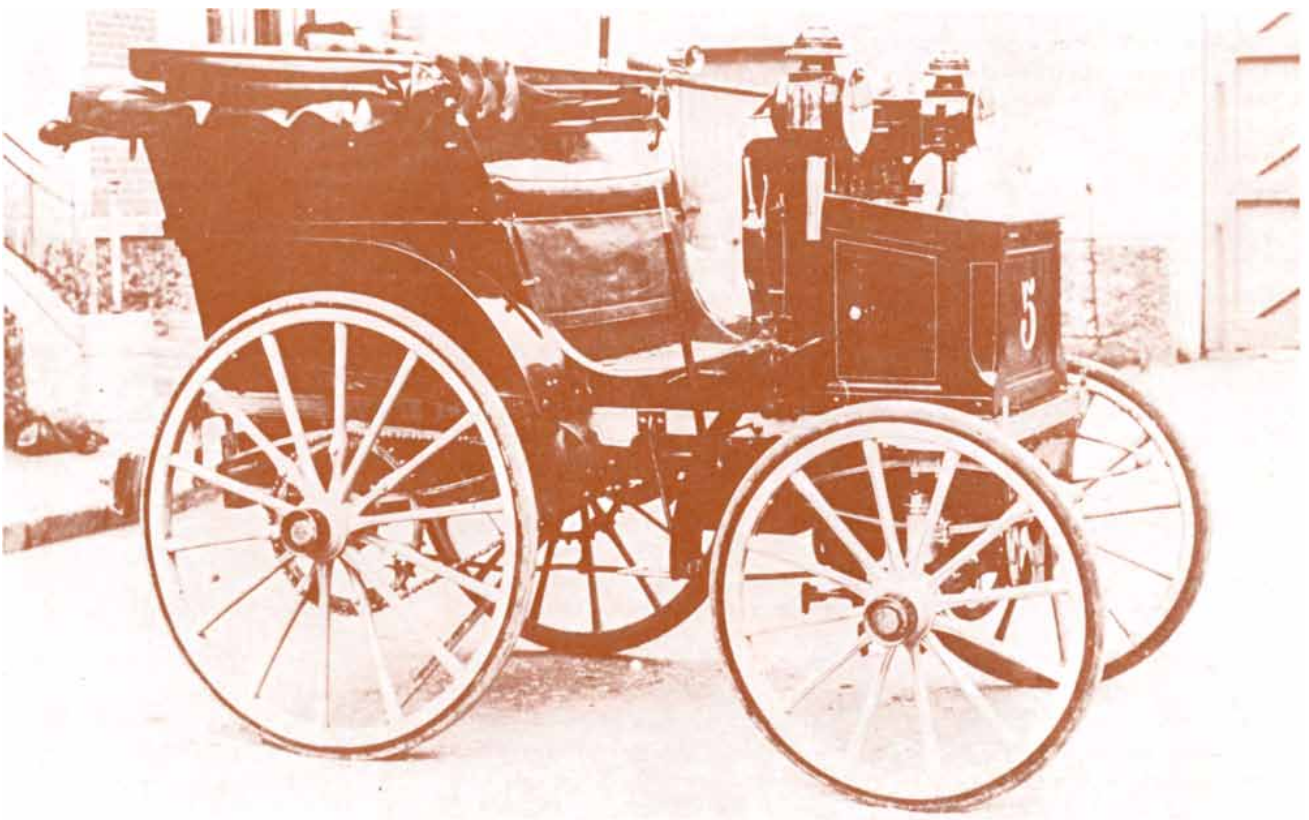
The Comte de Dion personally raised 69,000 francs for prizes and expenses of the event from his friends, notably James Gordon Bennett, the founder of the Paris edition of the *New York Herald* and a racing enthusiast. The organizing committee for the race was formed at a meeting in the Count's hotel on the Quai d'Orsay; the distinguished assembly included his fellow car-makers, political officials, journalists, sportsmen, engineers and men of wealth. The date for the start of the race was set for June 11, 1895.

The list of entries grew to 97, but only 23 vehicles were to gather for the competition. There were six steam-propelled cars: two de Dion–Boutons, two Serpollets, a Gautier-Wehrlé and the antique Amédée Bollée *père* omnibus *La Nouvelle*. The gasoline-propelled vehicles numbered 14: four Panhard & Levassors, three Peugeots, a Peugeot-Michelin, a Gautier, a Rossel, two Benzes, a Vincke & Delmer and a Lepape. There were also a Jeantaud electric car and two motorcycles: a Millet and a Hildebrand & Wolfmuller.

We can quickly dispose of 10 of the entries. The Lepape car, which had two driving front wheels, two steering rear



MANUFACTURER'S PLAN for the Panhard & Levassor No. 5 is represented in a side view based on a factory design that was only recently found to be still intact. The original drawings also included a vertical view of the framing and a sketch of the motor.



SIDE VIEW of No. 5 shows how closely the design drawing was followed. The engine is at the front, accessible from side panels. The steering mechanism is the single handlebar. The car had a three-speed gear arrangement, a chain drive and hard-rubber tires.

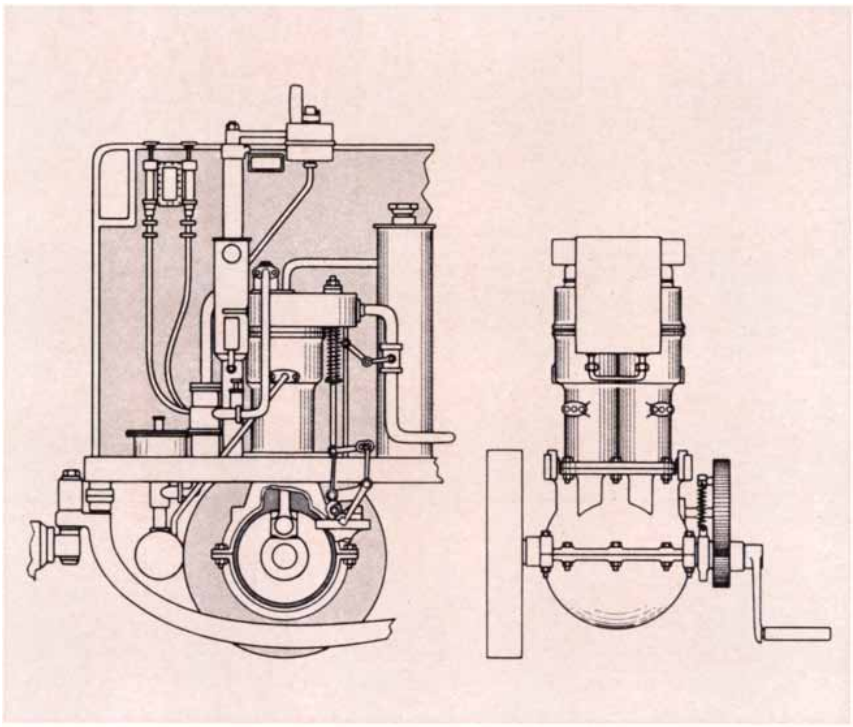
wheels and a friction transmission on the flywheel of a three-cylinder planetary motor, never reached Versailles. One of the Serpollets, a prototype with advanced steering and close-set front wheels, got no farther than Versailles. The 118 kilometers from Paris to Orléans were too much for the Gautier, the Rossel, the Gautier-Wehrlé, the Jeantaud electric car (which had to change its batteries every 20 kilometers) and the Millet motorcycle (propelled by a five-cylinder planetary motor built into the rear wheel). Angoulême (at 446 kilometers) was the end of the line for the Belgian Vincke & Delmer (it collided with a cart), the de Dion–Bouton tractor of the Paris-Rouen-Paris run (it had been lagging since the start) and the Hildebrand & Wolfmuller motorcycle.

This leaves what might be called the serious contestants. They were the two Benzes (coming from Mannheim and driven by Germans), the second Serpollet, the three Peugeots (all of which had participated in the Paris-Rouen-Paris run) and two classic Panhard & Levassors (also veterans of Paris-Rouen-Paris). The Panhard & Levassors, the two-seat No. 6 and the four-seat No. 7, were equipped with an oversize Daimler motor, a Maybach jet carburetor (on which Levassor had exclusive rights) and a new transmission with steel-toothed gears and two chains.

Then there was *La Nouvelle,* the doughty relic from 1880, and four prototype vehicles. One was the Peugeot-Michelin, a machine developed by the brothers André and Édouard Michelin for the purpose of demonstrating a remarkable innovation: the pneumatic automobile tire. Called *l'Éclair* (*Lightning*), it was a combination of an ancient Peugeot chassis and a Daimler marine engine. It had no differential gearing, which accounted for the zigzag trajectory that had given the car its name. Behind the two occupants of the car was an immense compartment carrying not only tool kits but also some 30 tires.

The second prototype also foreshadowed a future development. The Panhard & Levassor No. 28 was a heavy six-seater with an eight-horsepower rear motor that was a giant for its time. The last two prototypes represented the most advanced techniques in the two contemporary power plants: steam and gasoline.

The de Dion–Bouton No. 3 carriage repeated the technical features and construction of the Paris-Rouen-Paris tractor but in more modest proportions. Its motor developed only 11 horsepower instead of 20, but the entire machine weighed only 538 kilograms (about 1,200 pounds). This meant that it could be mounted on light wheels with steel spokes and solid rubber tires. It was as fast as the de Dion–Bouton tractor and much more maneuverable. Moreover, it was self-sufficient for 70 kilometers because it had a water reserve of 200 liters.



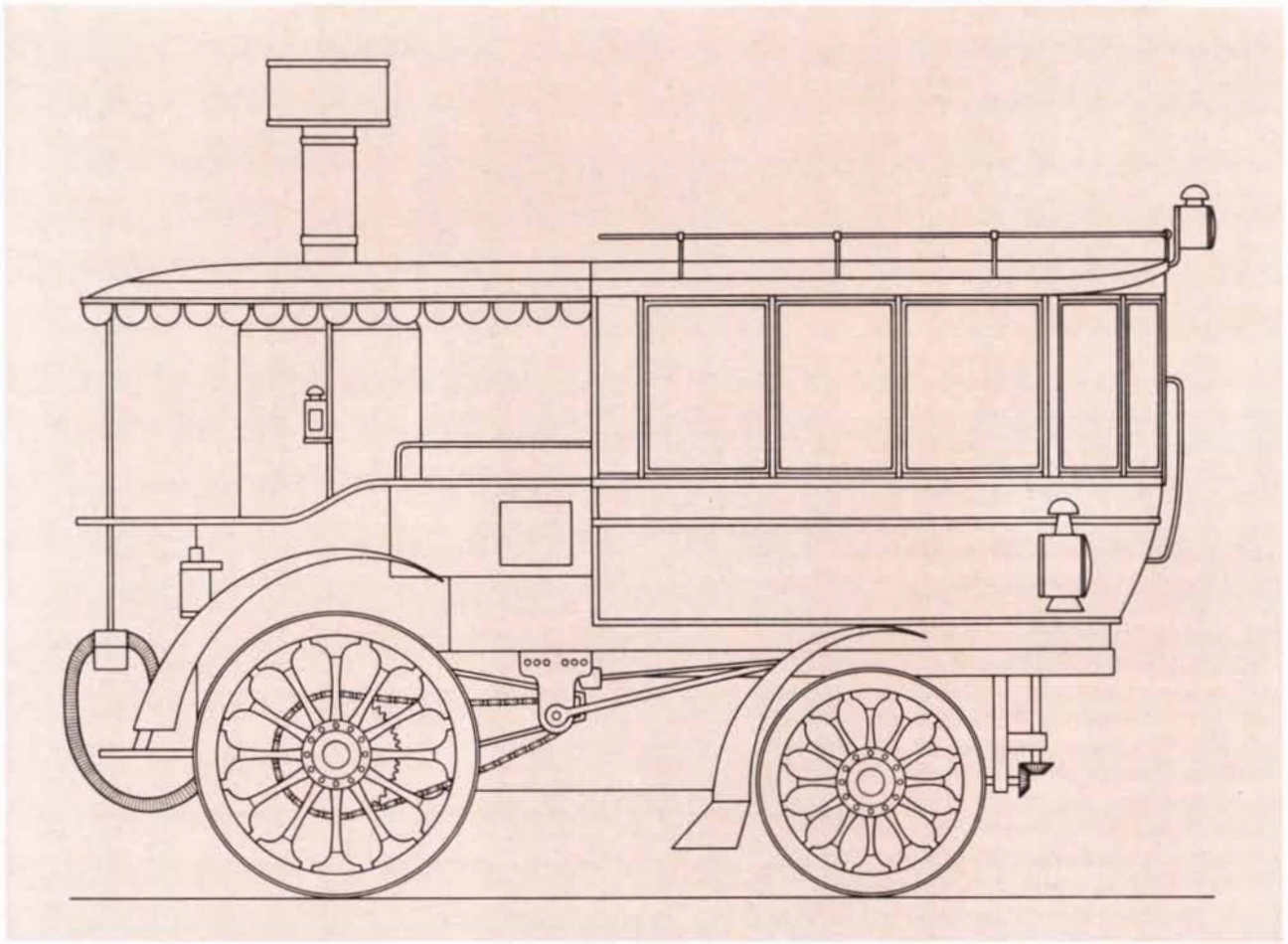
PHOENIX MOTOR of No. 5 is depicted on the basis of drawings made at the time the automobile was in the design stage. The Phoenix was a two-cylinder in-line engine weighing 83 kilograms but surpassing the power of the 140-kilogram Daimler *V* engine that was its predecessor. The engine had only one breakdown during the Paris-Bordeaux-Paris race.

The Panhard & Levassor No. 5 emerged as the first grand touring car in automobile history. It duplicated the structure of the classic Panhard & Levassor, but it was more elegant in its proportions. Among its assets were a weight of barely 604 kilograms (compared with 650 for the classic two-seater), the first complete gearbox (with the gears bathed in oil and protected from road dust) and a secret weapon that calls for a fuller description: the Phoenix motor.

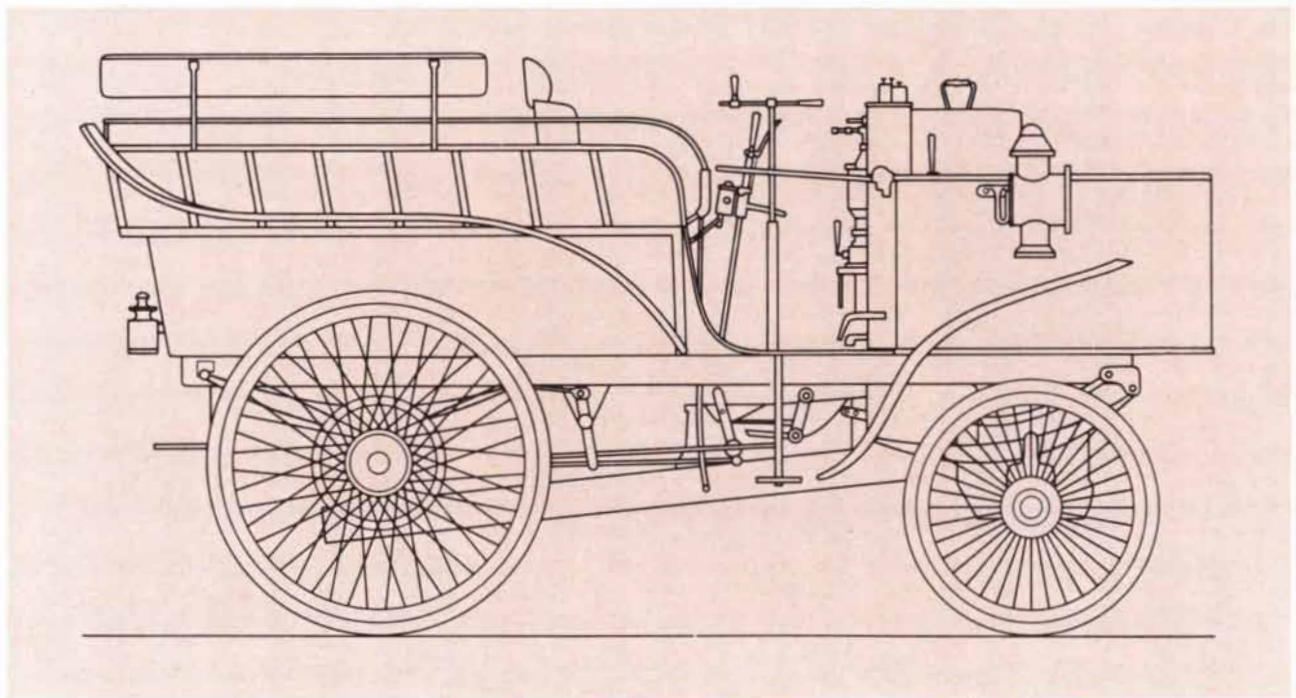
The Phoenix was the newest creation of Daimler and Maybach, a perfectly functioning two-cylinder in-line engine that weighed only 20 kilograms per horsepower compared with 40 kilograms for the most recent version of its predecessor: the two-cylinder *V*-type motor. More precisely, it developed 4.2 horsepower at 800 r.p.m. for a weight of 83 kilograms instead of 3.5 horsepower at 720 r.p.m. for a weight of 140 kilograms.

The Phoenix had been produced by Daimler and Maybach outside the firm of Daimler-Motoren-Gesellschaft; Daimler had founded the company, but he was now in a state of cold war with it. That was why the motor did not carry the name of Daimler, which belonged by contract to Daimler-Motoren-Gesellschaft. And since the motor did not bear the Daimler name, Levassor had been able to use it exclusively, as he had done with the Maybach carburetor, instead of having to share it with Peugeot on the terms of their contract on the Daimler motor.

Car No. 5 could attain the formidable speed of 30 kilometers per hour, and Levassor did not hesitate to plan his race on the basis of an average speed of 20 kilometers per hour. Several days before the race he refined his estimate to 22 kilometers per hour. In entering cars with only two seats Levassor had imposed on himself the serious limitation of having available in case of breakdown only two men instead of four. Moreover, since in order to be eligible for the first prize a vehicle had to carry four people, he had also forfeited winning the first prize. He had not forgotten the lesson of the Paris-Rouen-Paris run. He understood very well that the public, whose favor it was essential to court,



STEAM OMNIBUS, named *La Nouvelle*, was entered by Amédée Bollée. Although the name means "the new," the machine had been in existence since 1880. Among other things, its facilities for the Paris-Bordeaux-Paris race included a kitchenette and a toilet.



STEAMER entered by the Comte de Dion was this "break," or wagon-like vehicle, which failed to finish because of a broken universal joint. A year earlier De Dion's other entry, a steam tractor, had won an impromptu race with a gasoline-powered automobile.

would accept as the real victor only the driver who crossed the finish line first. Panhard & Levassor's entry of two two-seaters had caught Peugeot's attention, and he included a two-seater among his entries.

With the advantage of hindsight one can say that the Great Paris-Bordeaux-Paris Race was destined to be fought out by the de Dion–Bouton No. 3, the Panhard & Levassor No. 5 and the ancient Bollée (whose performance was not dependent on untested new equipment). This was not perceived in the newspaper dispatches of the time, perhaps because the journalists believed it was impossible to predict the reliability of any mechanical device. Instead they confined themselves to estimating the respective chances of steam and gasoline (which showed that they had not understood the verdict of Paris-Rouen-Paris) and coming to the conclusion that steam-driven cars were speedier than gasoline-propelled ones but that the latter required less upkeep on the road. They were careful, however, not to take sides.

Prediction was further complicated by a tactical question. The organizers of the Great Race had never entertained the idea that the entire distance was to be covered with one man at the wheel. Article 11 of the regulations had recognized in advance that crews would have to be changed in the course of the race. How were the relays to work?

The Panhard & Levassor, de Dion–Bouton and Benz entries had adopted the simplest system: divide the course into three sections. A first crew would go as far as Ruffec (405 kilometers), a second would go on to Bordeaux and back to Ruffec while the first crew rested, and the first crew would take the vehicle back to Paris. The Peugeot entries attempted to be more methodical. They divided the course into six sections of about 200 kilometers; at each stage half of the crew would be replaced, so that there would always be someone present who had been able to observe the performance of the machine over the preceding section.

The Serpollet entries chose sections of 150 kilometers; when one team was relieved, it would take the train to rejoin the vehicle for the next section. Finally there was Amédée Bollée *père*, whose vehicle had six seats. He decided to cover the entire route with the same team, its members taking turns at sleeping during the race. He had therefore installed in *La Nouvelle* a kitchenette and a toilet. In addition there was a device of his own invention fastened to the wheels that ran a paper tape on two spools announcing such pertinent information (by means of symbols) as the irregularities of the terrain, changes in level, sharp turns and dangerous downgrades. In order to set up this tape with rigorous precision, Bollée's son Léon had surveyed the entire route in advance with a bicycle that carried the same contraption. The bicycle was now perched on the roof of the vehicle; it would enable someone to go for help in case of need.

The race was to start at the Palace of Versailles. The route ran to Bordeaux by way of Étampes (38 kilometers), Orléans (118 kilometers), Blois (175 kilometers), Tours (235 kilometers), Poitiers (338 kilometers), Ruffec (405 kilometers), Angoulême (446 kilometers) and Libourne (551 kilometers), each of these towns serving as a checkpoint. The first section, from Paris to Étampes, was over a second-rate road and involved climbing three steep hills. The total distance of the round trip (back to Versailles and then to Paris) was 1,183 kilometers.

At 10 o'clock on the morning of June 11, 1895, the entrants met at l'Arc de Triomphe at the head of the Champs Élysées and set out in a procession for Versailles. At noon the contestants were sent off in the race at about two-minute intervals in the following order: the Peugeot No. 15, the de Dion–Bouton No. 3, the Peugeot No. 8, the Benz No. 12, the Panhard & Levassor No. 5, *La Nouvelle* and the Peugeot No. 16, followed by the rest.

Although the organizers of the contest had designed it as a technical contest, it actually took on the character of a suspenseful sporting event. The run developed a series of melodramatic incidents, and the spotlight of public interest fell more on the human contestants than on their machines. Up to that time the drivers of the experimental motorcars had been disregarded as being colorless mechanics, receiving little more attention than would be given the engineer of a railroad locomotive. Now, however, the Great Race would create a new type of celebrity: the racing driver who, as "king of the wheel," was to win fame, glory and fortune in the automobile age.

As could have been predicted on the basis of speed potential, Bollée had the fastest time halfway along the first leg (to Étampes), with the Comte de Dion four minutes behind (on time) in his No. 3 (driven by the Comte de Chasseloup-Laubat), followed by Levassor in his No. 5. For Bollée it seemed a good opportunity to stop and correct a tight connecting rod. The rod was wrapped in wet rags to cool it off; when the crew started the car again, they forgot to remove the rags, which became fouled in the mechanism and caused irreparable damage. Bollée and his sons managed to mend the broken parts somehow, but these precarious repairs failed repeatedly at intervals of about 100 kilometers. He just managed to continue heroically to a late finish, completely out of the running.

At Étampes the Comte de Dion arrived first, with a four-minute lead (in corrected time) over Levassor. His car required 10 minutes of maintenance work, however, and Levassor, experiencing no delay, forged ahead. De Dion passed him again on that leg. At the second checkpoint, Orléans, he had rebuilt his lead to six minutes (corrected time), and on the third leg to Blois, which the Comte de Chasseloup-Laubat covered at the extraordinary average speed of 35 kilometers per hour, De Dion raised his lead to 19 minutes. On the following leg, just as he was entering Vouvray at sunset, he was overtaken by disaster. A universal joint broke, and it could not be repaired with the facilities carried in the car. By this time the second de Dion–Bouton entry (the tractor) was also in difficulties, and the other steam vehicles in the race were late. The internal-combustion engine was already demonstrating its superior reliability, with gasoline-propelled vehicles now holding the first eight places.

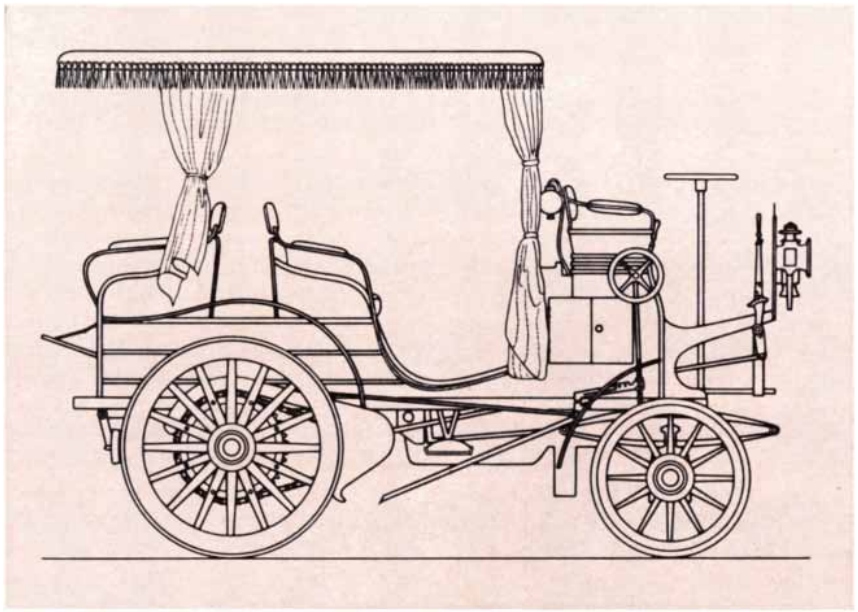
Levassor arrived at Tours at 8:40 P.M. Unaware that he had a lead of more than an hour and a half over the second vehicle, the two-passenger Peugeot, he did not tarry but pressed on at full speed. The Paris papers of the next morning, giving an account of the race to this point, reported with wonderment that Levassor had averaged 27 kilometers per hour for the distance from Versailles to Tours. Levassor continued his pace through the night, although he had only four carriage lamps to light his way, and he arrived at Ruffec three hours before his scheduled time (on the basis of an average speed of 22 kilometers per hour). The relief crew he had expected to take over there was not yet on hand. Disregarding assurances by the officials that his lead was so great he could well afford to wait for his relief men, Levassor, who had already driven for 15 hours, got back behind the wheel to push on for 15 more. At precisely 10:40 A.M. on the 12th, just 22 hours 30 minutes 30 seconds after he had left Versailles, he arrived at Bordeaux, beat-

ing the record of racing cyclists for this course by more than four hours.

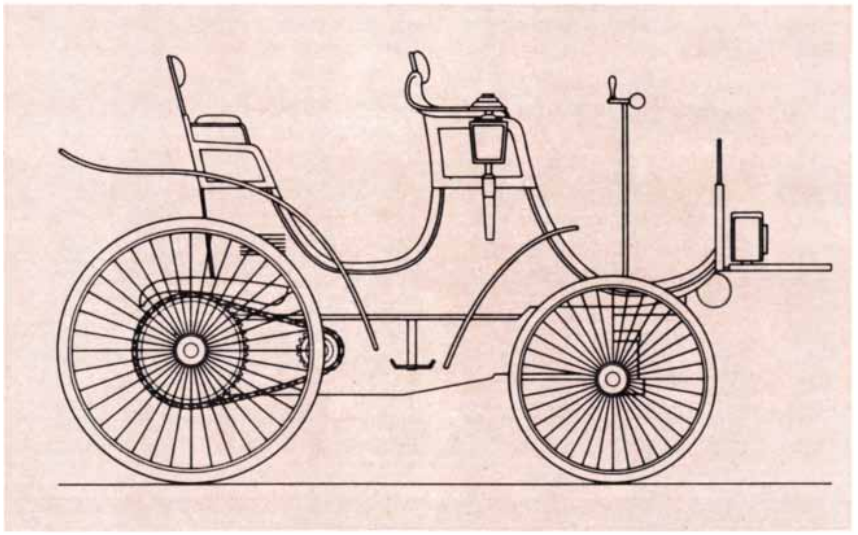
Levassor did not even leave his seat; after a four-minute pause for the refueling and servicing of the car, he set off on the return to Paris. He had reached Libourne, more than 32 kilometers from Bordeaux, before he met the second car in the race, still on its way to Bordeaux. It was not the Panhard & Levassor No. 6 that he had hoped to see but the Peugeot two-seater. His advantage now amounted to 64 kilometers, equivalent to more than three hours. Levassor did not pass the third car, the Peugeot No. 8, until he had reached Guitres. The fourth car made its appearance 34 kilometers farther along; it was the Peugeot No. 16.

An hour later Levassor believed he would surely see his No. 6, but this time it was the heavy Panhard & Levassor No. 28, on which he had not counted. The sixth car, the Benz No. 12, did not go by until about 3:00 P.M.; it was 8½ hours behind. Thirty-five minutes later Levassor came to the Panhard & Levassor No. 7, the classic four-seater that had been entrusted to an exclusively amateur crew (to prove that the presence of professional mechanics was not essential in running an automobile).

Thus a provisional grouping was established in the following order: one Panhard & Levassor, three Peugeots, a second Panhard & Levassor, a Benz, a Serpollet and a third Panhard & Levassor. To Levassor this signified that De Dion and Bollée, his two principal adversaries, were out of the contest. On the other hand, No. 5 was the only one of the Panhard & Levassor vehicles that could still block the massive success of the Peugeots. It was absolutely necessary that No. 5 reach the finish line.



HEAVY PROTOTYPE CAR was No. 28, one of four vehicles entered in the race by the partnership of Panhard & Levassor. It was a six-passenger, eight-horsepower automobile.



OFFICIAL WINNER of the race, No. 16, was one of three Peugeots entered. It finished behind the Panhard & Levassor No. 5 and the Peugeot No. 15, both ineligible as two-seaters.

Levassor was of course exhausted. His mechanic Charles d'Hostingue kept offering to take his place at the wheel, but Levassor refused. In the grip of a kind of superstition, he felt that his motor had signed a contract with him and with him alone, and that it would fall apart if he ceased to control it all by himself and in every detail. At about 4:30 P.M. No. 5 arrived at the checkpoint at Angoulême. It was there that he found the Panhard & Levassor No. 6. About 10 hours earlier it had reached the checkpoint at Ruffec in third place. In trying to overtake the second-place Peugeot the new driver had struck a curb and broken a wheel. The wheel had had to be repaired at a blacksmith's, which resulted in the car's being disqualified at the next control point.

This incident confirmed Levassor in his conviction that he could not count on anyone except himself. He had already begun to mull over an idea. In the 23 kilometers from Angoulême to Ruffec he met the de Dion–Bouton tractor, the Hildebrand & Wolfmuller motorcycle and the second Benz, which had traveled half as fast as he had. When he arrived at the Ruffec control point, 33 kilometers farther on, there was a most unexpected scene. This time the reserve crew was at its post and was ready to take the wheel of No. 5. Now, however, Levassor, who had been driving for 30 hours, did not want to turn over his post, even to the crew of his choice. He announced that he would take the car to Paris himself.

When Levassor insisted on remaining at his post, d'Hostingue refused to abandon his own. The two of them, exhausted but stubborn, departed to cope with a second night on the road. It must have been a terrible ordeal. First of all, on the leg from Ruffec to Poitiers the engine began to sputter. The ignition-timing mechanism was jammed with dust. (There were no distributors in those days.) In the evening semidarkness Levassor and his assistant took the mechanism apart, freed the stuck parts, repolished the scarred surfaces and re-

CHEERING CROWD AT FINISH suggests how the race, which was well publicized throughout France for several days, captured the public imagination. The cloud of dust at the left indicates the position of Levassor's car as it approached the finish line; a wheel of the car is visible between the man who is waving his top hat and the man who is evidently about to remove his top hat.

assembled the mechanism, all within 22 minutes. After Poitiers it was the driver who gave out. Levassor fell asleep at the wheel and plunged into a bank off the road. Fortunately the only damage was a dented fender and a wrenched lantern. In the chill of a very cold night the two pioneers in summer clothes hurried on, singing loudly to keep themselves unfrozen and awake. At exactly 57 minutes 30 seconds after noon on June 13 the Panhard & Levassor No. 5 crossed the finish line.

The Panhard & Levassor had covered the course of 1,183 kilometers in an elapsed time of 48 hours 48 minutes—nearly 12 hours less than Levassor had dreamed possible. Levassor, 52 years old, had driven it almost nonstop, with only brief halts for maintenance and clearing through checkpoints. For the entire distance the vehicle had managed to achieve an average speed of 24.24 kilometers (15.07 miles) per hour.

The two-passenger Peugeot came in second, five hours 47 minutes after Levassor. The contest for first prize under the rules of the event devolved into a close race between the two four-passenger Peugeots, No. 8 and No. 16. The latter car nosed out the victory by just one minute, in a total elapsed time of almost 60 hours. After these four cars the rest of the finishers arrived one by one at long intervals stretching over June 14 and 15. The first Benz came in fifth, the Panhard & Levassor four-passenger classic sixth, the heavy Panhard & Levassor seventh, the second Benz eighth, and finally, bravely lumbering in at 90 hours, the Bollée managed to finish under the 100-hour time limit.

We must not overlook the Michelin enterprise. Although the brothers did not finish within the time limit, they had nevertheless achieved a milestone. For a car to run on pneumatic tires was almost incredible at the time. Indeed, before the race the brothers had had to deflate one of their tires to demonstrate to skeptics that the tires really ran on air. The tires were still in an early stage of development; during the race they lasted for no more than about 150 kilometers. Teams of cyclists had to be called on to accompany the car and help change the tires, and each change took about 30 minutes. *L'Éclair* encountered many other troubles; finally some wheel spokes broke and the crew found it necessary to have a blacksmith forge replacements, which caused the car to be disqualified. Still, unpromising as the birth of their tire may have been, the Michelins had demonstrated one of the most essential elements in the making of the modern automobile. The pneumatic tire, useful for the bicycle, was indispensable for the motorcar.

Levassor, however, remained the great hero of the Great Race and the automobile's birth. He was greeted by an enthusiastic crowd at the end of the race, and after his death (of an embolism, only two years later) a massive monument in his memory was erected in Paris. From the lessons learned in the race Levassor decided that the No. 5 should be the basis for a production model with certain improvements, particularly a four-speed gearbox, and that the next steps should be an ignition-timing mechanism enclosed in a casing and a four-cylinder engine powerful enough to enable the machine to climb hills without faltering and provide a reserve of power in level locomotion.

The most important effect of the Great Race was its firing of the public imagination. It is no exaggeration to say that the 1895 event, truly a spectacular birth, was the seminal stimulus that ushered in the new age of technology and the transformation the automobile has brought about in the life of man.

MATHEMATICAL GAMES

Challenging chess tasks for puzzle buffs and answers to the recreational problems

by Martin Gardner

Everyone who calls a [chess] problem "beautiful" is applauding mathematical beauty, even if it is beauty of a comparatively lowly kind. Chess problems are the hymn-tunes of mathematics.

—G. H. HARDY,
A Mathematician's Apology

It has been this department's policy to avoid chess problems of the type "Mate in *n* moves" on the assumption (perhaps a mistaken one) that too few readers play chess and that even among those who do too few like chess problems. This month, however, in tribute to the battle between Boris Spassky and Bobby Fischer for the world chess title, we consider a variety of what are called chess "task" problems. They have so little in common with actual play that they are of more interest to puzzle buffs than to serious chess players. True, a knowledge of chess rules is essential. Apart from that, even a tyro is as likely as a grand master to be able to solve the task.

What is a chess task? It is a chess problem where a person seeks an objective in a way that maximizes or minimizes one or more parameters. Among chess players the best-known task question is: What is the shortest possible game? The answer, of course, is the "fool's mate." White opens with, say, P–KB4. Black replies P–K3. If White foolishly moves P–KN4, Black checkmates on his second move, Q–R5.

The shortest game ending in perpetual check was published in 1866 by one of the great pioneer chess problemists, Sam Loyd. It is

1. P–KB4	1. P–K4
2. K–B2	2. Q–KB3
3. K–N3	3. Q × P (ch)

Black now has a perpetual check by moving his queen back and forth from the square it is on to Black's R3 square.

A much more difficult task was also posed in 1866 by Loyd. What is the shortest game ending in stalemate? Loyd's spectacular 10-move solution has never been surpassed:

White	*Black*
1. P–K3	1. P–QR4
2. Q–R5	2. R–R3
3. Q × QRP	3. P–KR4
4. Q × BP	4. QR–KR3
5. P–KR4	5. P–KB3
6. Q × QP (ch)	6. K–B2
7. Q × NP	7. Q–Q6
8. Q × N	8. Q–KR2
9. Q × B	9. K–N3
10. Q–K6 (stalemate)	

The final position is shown in illustration *1* on the opposite page. In 1882 a search began for the shortest "no capture" stalemate that left all 32 men on the board. The present record, 12 moves, was found by C. H. Wheeler in 1887. It was forgotten, then rediscovered independently by several men, including Loyd and Henry Ernest Dudeney (who gives it as Problem 349 in his *Amusements in Mathematics*). In January, 1906, Loyd published in *Lasker's Chess Magazine* a hilarious commentary on the game, pretending to explain the strategy behind each crazy move and calling attention to a five-move mate overlooked by Black when he made his final stalemating move. (Loyd's commentary can be found in Alain C. White's *Sam Loyd and His Chess Problems,* 1913, pages 128–129, currently available as a Dover reprint.)

Illustration *2* shows how 30 men, the largest number known, can be placed in a legal position—a position that can result in actual play—such that no move is possible by either side: a double stalemate. It was published in 1882 by G. R. Reichelm, who also showed how the position could be reached in 25 moves. Note the pattern's twofold symmetry.

Another remarkable task solved by Loyd is to play the shortest game ending with only the two kings on the board. Loyd's 17-move solution is given in Alain White's book as Problem 116. The two kings are left on their own pawn squares. Different 17-move solutions were later found by others, with the kings left on other cells. No one has found a 17-move game leaving the kings on their own starting squares. The two-king ending is rare among task problems in that 17 moves (by each player) can be proved an absolute minimum. Fifteen captures must be made by each side, but neither player can capture on his first move, and one more noncapture move can be proved necessary.

Dudeney later found a 17-move game (Problem 352 of his *Amusements*) that eliminates only the 14 pieces (nonpawns) of both sides, leaving both kings and the 16 pawns on their starting cells. Curiously, every move by Black is a mirror copy of White's preceding move. Here again, 17 moves can be proved minimal.

Along similar lines, one of Dudeney's great achievements was a 16-move game ending with all 16 of White's men on their starting cells and Black with only his king on the board. After Dudeney published this game [*see illustration 3*] Loyd discovered that White could checkmate in three moves. This is another minimum, since no shorter mate is believed possible with Black's lone king on any other cell. Can the reader work out the mate before it is revealed next month? Dudeney's game (Problem 351 of his *Amusements*) was reduced by a half-move in 1898—that is, the final position is achieved after White's 16th move—but then there is no mate in three because it is Black's turn.

A special class of task problem is known as a "one-move construction task" because only immediately possible moves are considered. A classic example is the task of placing the eight pieces of one color so that the largest number of moves can be made. The proved maximum of 100 was achieved by M. Bezzel in 1849 (see page 62 of *The Sixth Book of Mathematical Games from Scientific American*). If all 16 men of one color are used, the maximum was believed for 10 years to be 119 moves until Nenad Petrovic increased it in 1949 to 122 [*see illustration 4*]. When I first saw this pattern, I was unable to count more than 104 moves until I realized that a promoted pawn must become one of four different pieces, each of course a different move. (Modern chess laws do not allow a pawn on the eighth rank to remain a pawn.) The record for the 16 black and white pieces is 173, for all 32 men it is 164, and for a legal position with no pro-

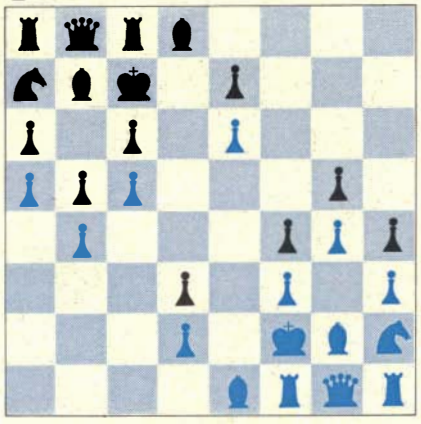
moted men or promotion moves it is 178. The present record for an illegal position is shown in illustration 5. By arranging the colors of the border queens as shown, W. A. Shinkman, in 1923, achieved 412 moves. Captures are, of course, counted as moves.

The minimum number of moves for the eight pieces of one color is 10 (see my *The Unexpected Hanging and Other Mathematical Diversions*, page 88). The same position also minimizes the number of pieces (three) among the eight that are able to move. Ten also is the record for minimum moves when the 16 pieces of both colors are used. In 1923 T. R. Dawson found the record minimum for all 32 men in a legal position [*see illustration 6*]. Only two moves can be made. E. Fielder showed in 1938 how the same 32 men can be legally placed so that only

1

Shortest stalemate game

2



Double stalemate with 30 men

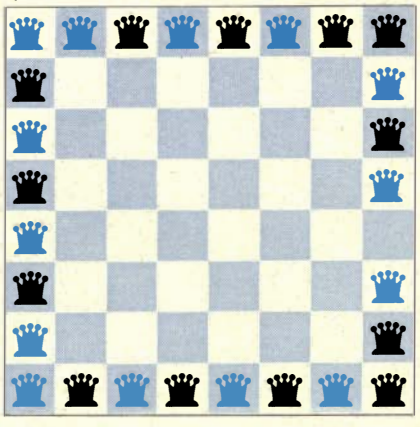
3

White to mate in three moves

4

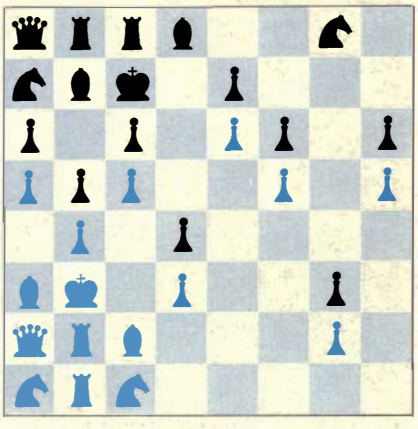
122 moves

5



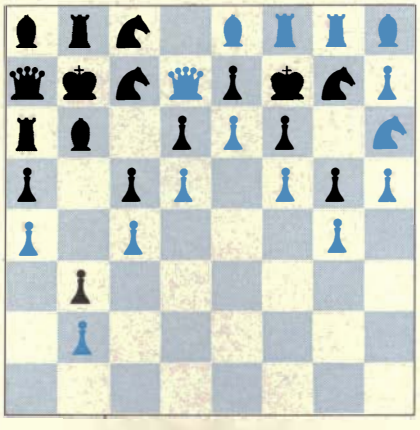
412 moves

6



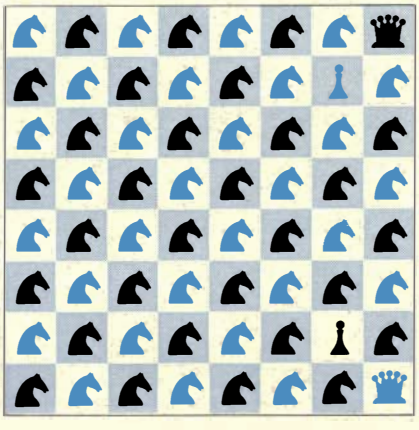
Two moves

7



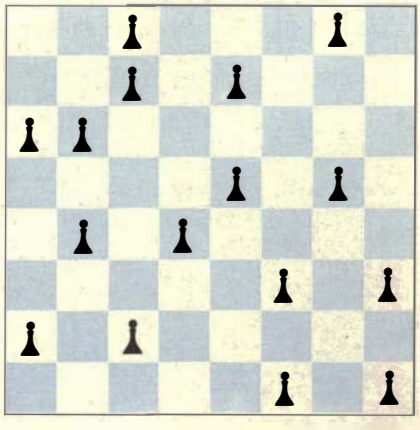
Only white queen can move

8



338 captures

9



No three pawns in line

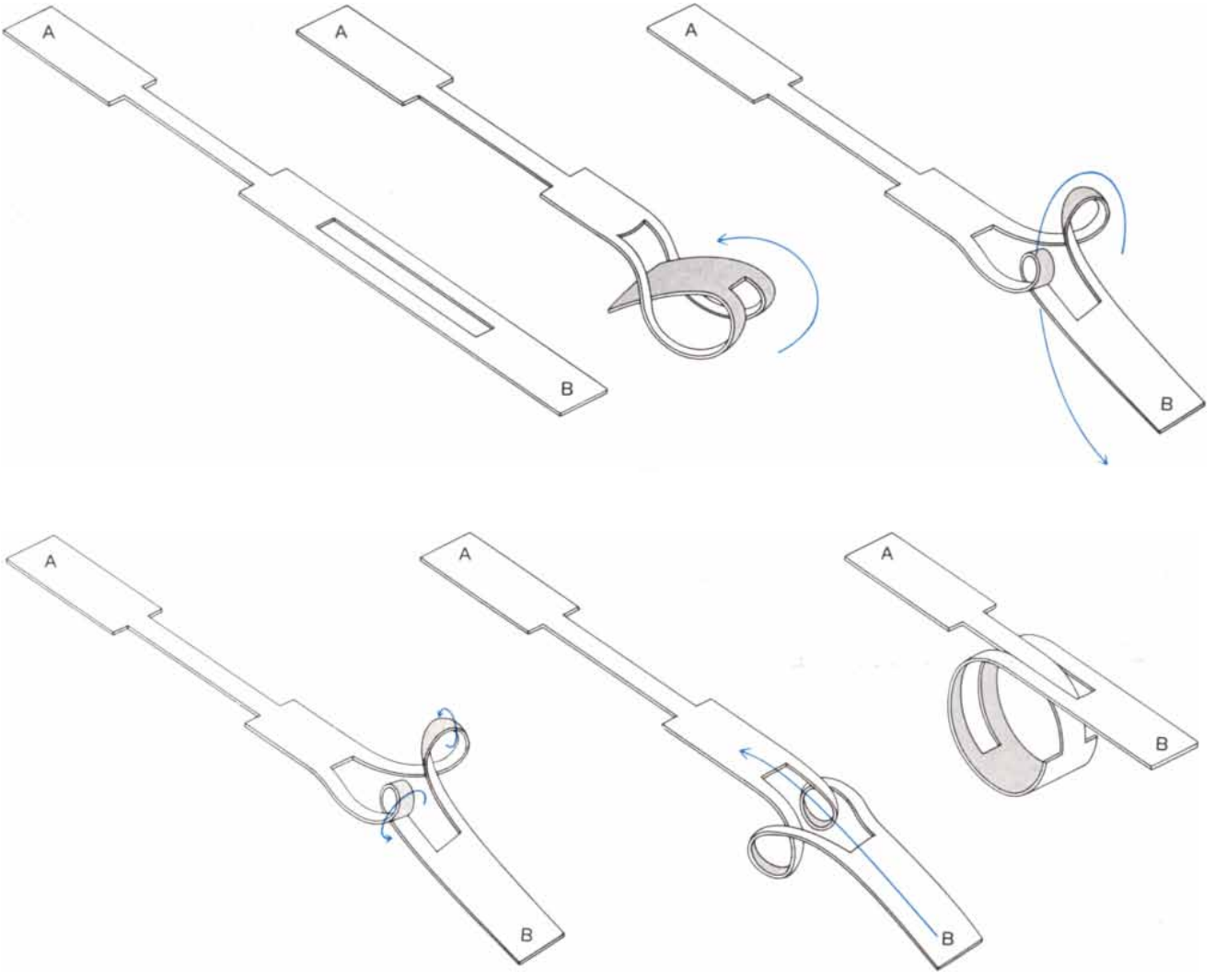
one man (the white queen) can move [*see illustration 7*]. No one has yet found a way to place legally all 32 men so that no move is possible.

There are many legal ways to place the 16 nonpawns to achieve a maximum of 46 captures, and all 32 men can be legally placed to allow 88 captures. How about illegal positions? If 32 black knights go on black cells and 32 white knights on white cells, 336 captures are possible. This was considered the maximum for many decades until 1967, when T. Marlow ingeniously substituted two queens and two pawns for four knights to raise the record to 338 [*see illustration 8*].

I have touched on only a small fraction of tasks concerning moves and captures. Space does not allow discussing the hundreds of tasks involving checks, discovered checks, mates, selfmates, stalemates, forced captures (every move a capture), forced checks, forced mates and so on. Of special interest to combinatorial mathematicians are one-move construction tasks involving the placing of a specified set of men so that a maximum or a minimum number of cells are attacked or unattacked, or to achieve some other goal that does not involve moves or captures. A classic problem of this type (see Chapter 16 of *The Unexpected Hanging*) is to place eight queens (the maximum) so that no queen attacks another. The similar tasks of maximizing the number of nonattacking rooks (8), bishops (14), knights (32) and kings (16) are considered in the same chapter. A more difficult problem is to place 16 pawns (the maximum) so that no three are in a straight line. Lines are not restricted to rows, columns or diagonals but may have any orientation. Think of each pawn as a point in the center of the cell it occupies. No three such points may be colinear. One of many solutions is shown in illustration 9. It is the only one in which two pawns occupy central cells.

Another difficult task of the same general category is to place eight queens so that 11 vacant squares are not attacked. There are at least six basic ways to do it (the exact number is not known), one of which will be given next month. Eleven unchecked cells is undoubtedly maximum, although no proof is known to me.

A generalization of this problem—placing n queens on an order-n square to leave a maximum number of unattacked vacant cells—has not, to my knowledge, been fully analyzed. When n equals 1, 2 or 3, it is easy to see that no cell may be unchecked. When n equals 4, only one cell may be unchecked. For n equals 5 the problem is suddenly nontrivial. Three cells may be unattacked, but the pattern is difficult to find and also



Solution to loop problem

unique, except for rotations and reflections. Can the reader find it before it is given next month? The maximum number of unattacked cells when n equals 6, 7, 9, 10, 11, 12 is believed to be 5, 7, 16, 21, 27 and 36 respectively.

The minimum number of queens needed to attack all vacant cells of square boards is a general problem that has been thoroughly explored for boards of order 2 through 13. Since no piece attacks the cell it is on, the problem falls into three main groups: solutions in which no queen attacks another, or all queens are attacked, or some but not all are attacked. On the standard chessboard five queens are required in all three cases, and there are hundreds of solutions. Two tasks of this type on smaller boards are particularly pretty because each has only one basic solution. Can the reader put three queens on an order-6 board so that all vacant cells are attacked? Can he put four queens on an order-7 board so that all vacant cells are attacked and no queen attacks another?

Four queens can be placed on the order-8 board so that a maximum of 58 vacant cells are checked, leaving only two unchecked empty cells. There are many ways to eliminate those two squares by adding a single rook, bishop or king, but to check all vacant cells with four queens and a knight seems to have only one basic solution, which was first published by J. Wallis in 1908. Can the reader discover it? (Hint: The four queens must leave three of the vacant cells unchecked.)

It is easy to prove that nine kings, eight bishops or eight rooks are needed to attack all vacant cells on a standard chessboard. Much harder to find is the unique pattern by which 12 knights (the minimum) check all vacant cells. (It was given in this department in October, 1967.) To attack all 64 squares requires 14 knights, or eight rooks, or 10 bishops, or 12 kings.

The eight pieces of one color can attack all 64 squares only if the bishops are on the same color. With bishops on opposite colors 63 squares is maximum. A reader who gave no name or address recently sent me the result of his long search for a way to eliminate one of these eight pieces and still attack all vacant cells. He found how to do it by dropping a bishop. I do not know if his beautiful solution is unique (aside from rotations, reflections and trivial rearrangements of the rooks and queen) or if the task can be solved by dropping a knight or the king instead of a bishop. The unknown reader's solution will be published next week. To make the task completely clear: Place a queen, king, two rooks, two knights and a bishop on a chessboard so that all vacant cells are in check.

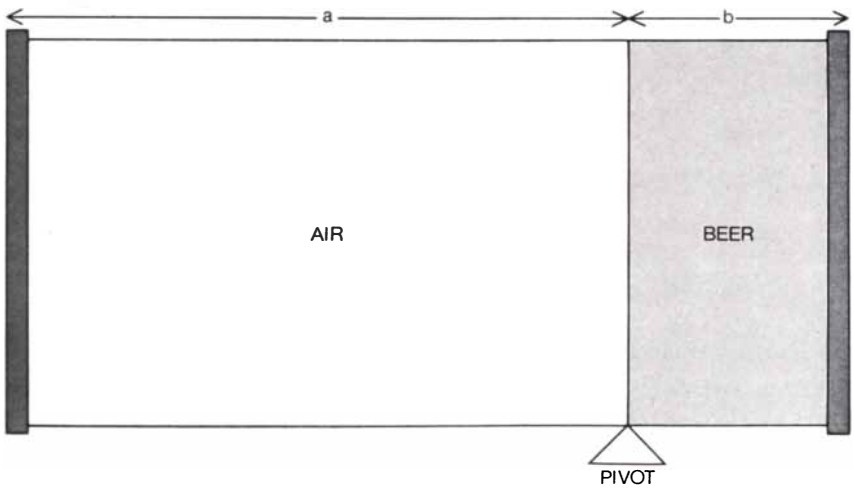
SPINS	A	B	C	D	E	F
1	1	2	5	4	3	0
2	0	1	2	5	4	3
3	5	4	3	0	1	2
4	5	4	3	0	1	2
5	4	3	0	1	2	5
FINAL SCORES	15	14	13	10	11	12

Solution to D. St. P. Barnard's problem

For readers who may want to go more deeply into this obscure corner of chess recreations, here is a quick checklist of basic references. The classic first book on chess tasks is Alain White's *Les tours de force sur l'échniquier,* Paris, 1906. White's material was updated and expanded in many new directions by Thomas Rayner Dawson (who edited England's *Fairy Chess Review* until his death in 1951) in *Ultimate Themes.* This rare 28-page booklet was privately issued in 1938. More recent results are in Anthony S. M. Dickins' *A Guide to Fairy Chess,* privately printed in 1967 but now available in a revised edition as a Dover reprint (1971). *Records in One-Mover Chess Construction Tasks,* by Dickins and W. Cross (1970), is an eight-page listing of more than 100 current records. Only maximum tasks are covered, and although references are cited of where solutions were first published, the actual patterns are not given. The booklet is available for $1 postfree from The Q Press, 6a Royal Parade, Station Approach, Kew Gardens, Surrey, England. Dickins, a leading expert on unorthodox chess, is the founder of the Q Press and the magazine *Poetry.*

Dudeney's *Amusements* (a Dover reprint) has a chess section crammed with tasks, although many of the answers have been superseded. See also Chapter 6 of W. W. Rouse Ball's *Mathematical Recreations and Essays* (Macmillan, 12th edition, 1972), Chapter 2 of Joseph S. Madachy's *Mathematics on Vacation* (Scribner's, 1966) and Chapter 3 of A. M. Yaglom and I. M. Yaglom's *Challenging Mathematical Problems,* Volume I (Holden-Day, 1964). The Yaglom brothers refer to a Russian booklet by L. Y. Okunev, *Combinatorial Problems on the Chessboard* (1935), which I have not seen.

Finally, a four-page periodical on chess tasks, *Chess Ultimates,* made its appearance in April, 1970, edited and published at irregular intervals by Thur Row, 12039 Gardengate Drive, St. Louis, Mo. 63141. The subscription rate,



The balanced beer can

as well as the price of back copies, is 20 cents per issue. About 15 issues have appeared so far.

The answers to last month's nine recreational puzzles are given below:

1. How to form a loop with the Rolamite band while end *A* is taped to a tabletop is shown in the illustration on page 114.

2. The first two rows of the chart [*see top illustration on preceding page*] show the results of the first two spins. The first spin was given last month, and we were told that *D* had the highest total after the second spin. This could happen only if the wheel distributed the points as shown in the second row. Now comes the tricky part. Every opposite pair of digits on the disk used in the game add to 5. This means that every spin will give a combined sum of five points to each pair of players seated opposite each other—namely *AD*, *BE* and *CF*. At the end of the game, which has five spins, each of these pairs of players will have a combined sum of 25 points.

We know that *A* won the game. Since his was the highest score, *D* (who sits opposite) must have ended with the lowest score. *D*'s final score must be less than 13, otherwise *A*'s final score would be smaller. *D*'s final score cannot be 12. True, *A* would score 13, but then a player of the pair *BE*, as well as a player of the pair *CF*, would necessarily score 13 or better, preventing *A* from being the highest scorer.

As we have seen, *D* cannot score more than 11. He already has nine points at the end of the second spin, therefore at least one of the three remaining spins must give him zero. Since the order of the results of each spin cannot affect the final scores, we can assume that *D* scored zero after the third spin. This determines the points for the other players as indicated in the third row of the chart.

On the next two spins *D*'s points can only be 0–0, 0–1, 1–1 or 0–2. We test each in turn. If 0–0 or 0–2, *A* will tie with someone on his final score. If 1–1, *F* gets 5–5 and wins with a score of 15. Only 0–1 remains for *D*. This makes *A* the winner, with 15 points, and enables us to complete the chart as indicated. We do not know the order of the last three spins, but the final scores are accurate. The problem is No. 2 in D. St. P. Barnard's first puzzle book, *Fifty Observer Brain-Twisters* (Faber and Faber, Ltd., 1962).

3. The formation rule for H. S. M. Coxeter's frieze patterns is that every four adjacent numbers

$$\begin{matrix} & b & \\ a & & d \\ & c & \end{matrix}$$

satisfy the equation $ad = bc + 1$.

4. Walter van B. Roberts answered his beer-can problem this way: "Imagine that the beer is frozen so that the can of beer can be placed horizontally on a knife-edge pivot and balanced with the can's top to the left. If it balances with the pivot under the beer-filled part, adding more beer would make the can tip to the left, whereas removing beer would make it tip to the right. If it balances with the pivot under the empty part, the reverse would be true. But if it balances with the pivot exactly under the beer's surface, any change in the amount of beer will make the can tip to the left [*see bottom illustration on preceding page*]. Since in this case the center of gravity moves toward the can's top when any change is made in the amount of beer, the center of gravity must be at its lowest point when it coincides with the beer's surface.

"With the can balanced in this condition, imagine that the ends are removed and their mass distributed over the sides of the can. This cannot upset the balance because it does not shift the center of gravity of the system, but it allows us to consider the can as an open-ended pipe whose mass per unit length on the empty (left) side is proportional to the weight of an empty can, whereas the mass on the beer-filled right side is proportional to the weight of a full can. The moment of force on the left is therefore proportional to the weight of an empty can multiplied by the square of the length of the empty left side, and the moment on the right side is similarly proportional to the weight of a full can multiplied by the square of the length of the beer-filled right side. Since the can is balanced, these moments must be equal.

"Pencil and paper are now hardly required to deduce that the square of the length of the empty part divided by the square of the length of the full part equals the weight of a full can divided by the weight of an empty can, or, finally, that the ratio of the length of the empty part to the full part is the square root of the ratio of the weight of a full can to an empty one."

Expressed algebraically, let a and b stand for the lengths of the empty and filled parts of the can when the center of gravity is at its lowest point and E and F for the can's weight when empty and full. Then $a^2E = b^2F$, or $a/b = \sqrt{F/E}$.

In the example given, the can weighs nine times as much when it is full as it does when it is empty. Therefore the center of gravity reaches its lowest point when the empty part is three times the length of the full part, in other words, when the beer fills the can's lower fourth. Since the can is eight inches high, the level of the beer is $8/4 = 2$ inches.

5. Regardless of which coin Smith chooses, the game is fair. The payoff matrices show [*see illustration at left*] that in every case the person least likely to win (because he has only one coin) wins just enough when he does win to make both his expectation and that of his opponent zero.

As David L. Silverman suspected when he found this solution, the problem is a special case of the following generalization. If a set of coins have values

	75	50	25	0	
WIN	75	75	75	75	SUM=300
LOSS	−100	−100	−100	0	SUM=300

	125	100	25	0	
WIN	−50	−50	125	125	SUM=150
LOSS	−50	−50	−50	0	SUM=150

	150	100	50	0	
WIN	−25	−25	−25	150	SUM=75
LOSS	−25	−25	−25	0	SUM=75

Payoffs for player with silver dollar (top), *half-dollar* (middle) *and quarter* (bottom)

that are adjacent in the doubling series 1–2–4–8–16... and the game is played as described last month, it is a fair game regardless of how the coins are divided. We assume, of course, that each player has at least one coin and that each value is represented by only one coin.

Unfortunately my statement of the problem was ambiguous, and many readers were confused. I should have made clear (the fault was mine, not Silverman's) that after the coins are divided each player is assumed to *own* his coins, making it a zero-sum game.

6. The maximum number of nonoverlapping triangles that can be produced by seven, eight and nine lines are 11, 15 and 21 respectively [*see illustration at right*]. These are thought, although not yet proved, to be maximal solutions.

7. $532 \times 14 = 98 \times 76 = 7{,}448$.

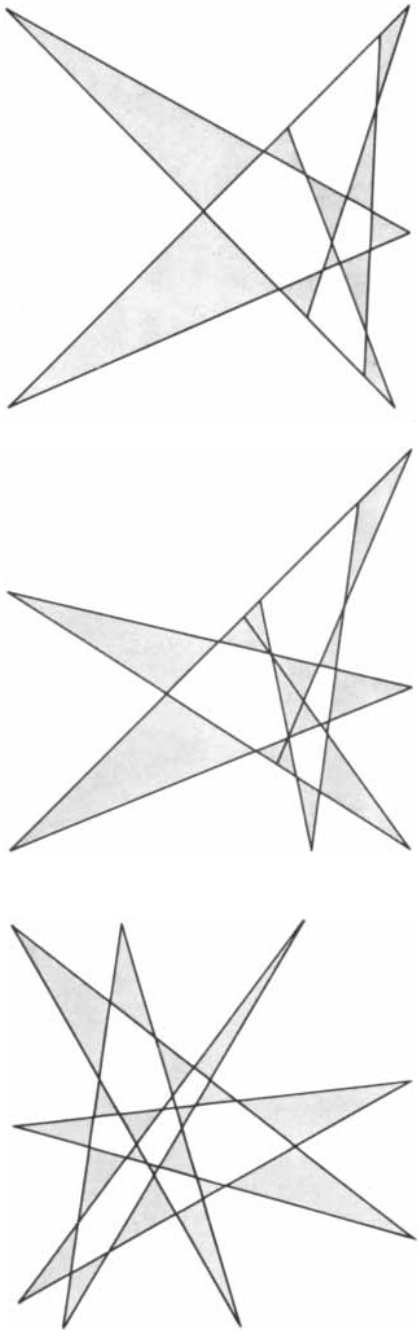
8. If n is odd, it is obvious that there is no solution. If n is even but not a multiple of 4, an odd number of checkers must be jumped on the final move. This would necessarily leave a single checker in the row, therefore the assumption that there is a solution when n is not a multiple of 4 must be false.

If there are $4n$ checkers, the problem can be solved by working it backward according to the following algorithm. Start with $n/2$ kings in a row. Take the top checker from either of the two middle kings, jump over the largest group of kings and put down the checker as a single man. On the next backward move take the top checker from the other middle king and jump in the same direction as before, jumping one fewer checker. Follow this procedure until all kings in the direction of the first jump are eliminated. Take the top checker from the inside king and jump in the same direction as the previous jumps, moving it over the proper number of checkers. Continue this procedure, always in the same direction, until all the kings are reduced to single men. When these moves are taken in reverse order, they provide one solution (there are many others) to the original problem.

9. Here are six possible explanations of the ski tracks:

(1) The skier bumped into the tree but protected himself with his hands. Keeping one ski in place, he carefully lifted his other foot and moved to the lower side of the tree. With his back against the tree, he replaced his raised foot and ski on the other side, then continued down the slope.

(2) The skier slammed into the tree with such force that his skis came off and continued down the slope without him.



Solution to triangle problem

(3) Two skiers went down the hill, each wearing only one ski.

(4) One skier went down the hill twice, each time with one ski on one foot.

(5) A skier went down a treeless slope, moving his legs apart at one spot. Shortly thereafter a tree with a sharpened trunk base was plunged into the snow at that spot.

(6) The skier wore stilts that were high enough and sufficiently bowed to allow him to pass completely over the tree.

THE AMATEUR SCIENTIST

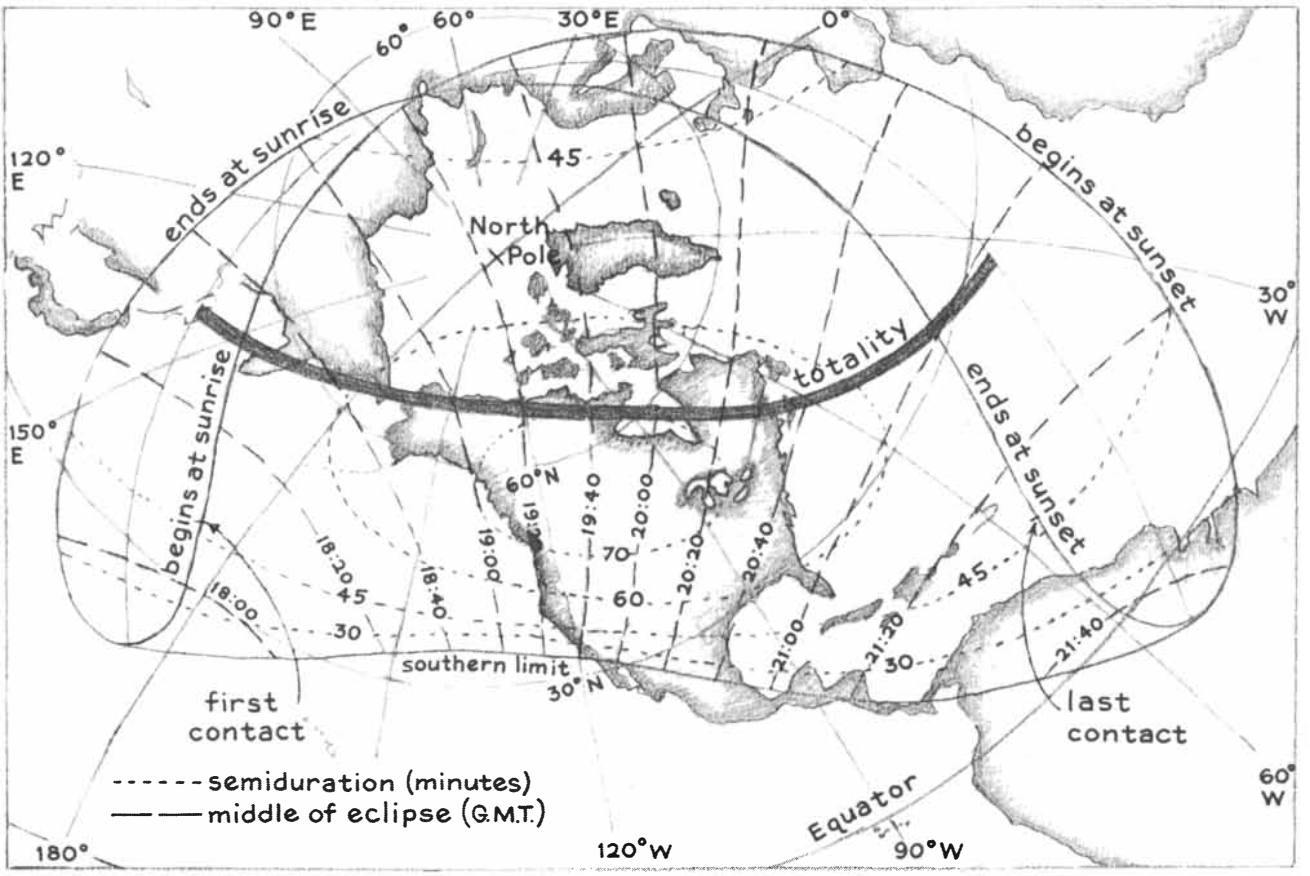
Advice is offered on equipment and safety procedures for a forthcoming solar eclipse

Conducted by C. L. Stong

On July 10 the sun will be totally eclipsed along a path 110 miles wide extending from eastern Asia across Alaska and Canada to a point in the southern Atlantic about 1,000 miles off the coast of Africa. The partial phase of the eclipse will be visible in the northern half of the Western Hemisphere, the northern coast of South America and western Europe from Spain through the Scandinavian peninsula. Only one more total eclipse of the sun will be visible in North America in the 20th century. For this reason many people from the U.S., Canada and Mexico are planning to observe the event either in Alaska, where the moon's elliptical shadow will pass just inside the Arctic Circle, or in the Canadian provinces of Quebec, New Brunswick and Nova Scotia.

George G. Manning of New York, who has had the privilege of observing many eclipses, points out that observing one can be hazardous, particularly for an inexperienced layman viewing with an improvised filter. Discussing techniques for observing the sun safely and for making photographs of either the partial or the total phase, Manning writes:

"The trick of observing and photographing the sun successfully lies in reducing the intensity of the light by a factor of at least 100,000 without degrading the quality of the image. The reduction can be accomplished in several ways, including the use of various filters. Some filters consist of a transparent sheet of gray glass or plastic. They transmit more or less light depending on the tone of the gray. They are known as neutral-density filters because they transmit all colors equally. Their neutrality, however, does not necessarily extend beyond the visible spectrum. For example, filters made of gelatin or plastic (such as the Eastman Kodak Wratten No. 96) are dense in the visual and photographically active portions of the spectrum but are relatively transparent to infrared rays that can permanently damage the eye. Many clear, thin materials are also transparent to infrared. During past eclipses



Geographical limits of the July 10 solar eclipse

laymen have suffered eye damage by looking at the sun through such improvised filters as blackened photographic film and sheets of glass coated with soot.

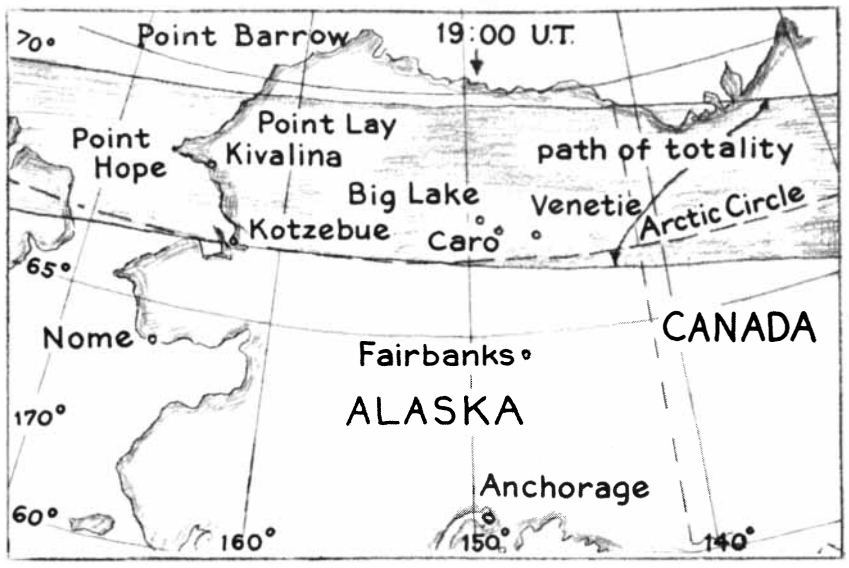
"Most filters that are safe for visual observation operate on the principle of reflection. Some types consist of a highly reflective metallic coating deposited on an optically flat sheet of glass. The metal reflects both visible and infrared rays, and the glass absorbs any ultraviolet rays transmitted by the metallic coating.

"Neutral-density filters are rated in terms of density, which is defined as the logarithm of the reciprocal of transmittance. For example, assume that a filter transmits .00001 of the light, a reduction of 100,000 in brightness. The reciprocal of the transmittance is 1/.00001, or 100,000. The logarithm (to the base 10) of 100,000 is 5. The filter is designated No. 5. Similarly, a filter that transmits a tenth of the light is designated No. 1, a filter that transmits a hundredth of the light is designated No. 2 and so on. The numbering system enables the experimenter to determine by simple addition the optical result of combining two or more filters. A No. 4 and a No. 2 filter combined have a density of 6. The transmittance of the combination is 1/1,000,000. (Note that the number of zeros in the divisor is equal to the numeral that designates the density—6 in this case.) The combination would reduce the brilliance of the light a millionfold. The sun is about a million times brighter than the full moon. Hence when the sun is viewed through a No. 6 neutral-density filter, it looks about as bright as the full moon.

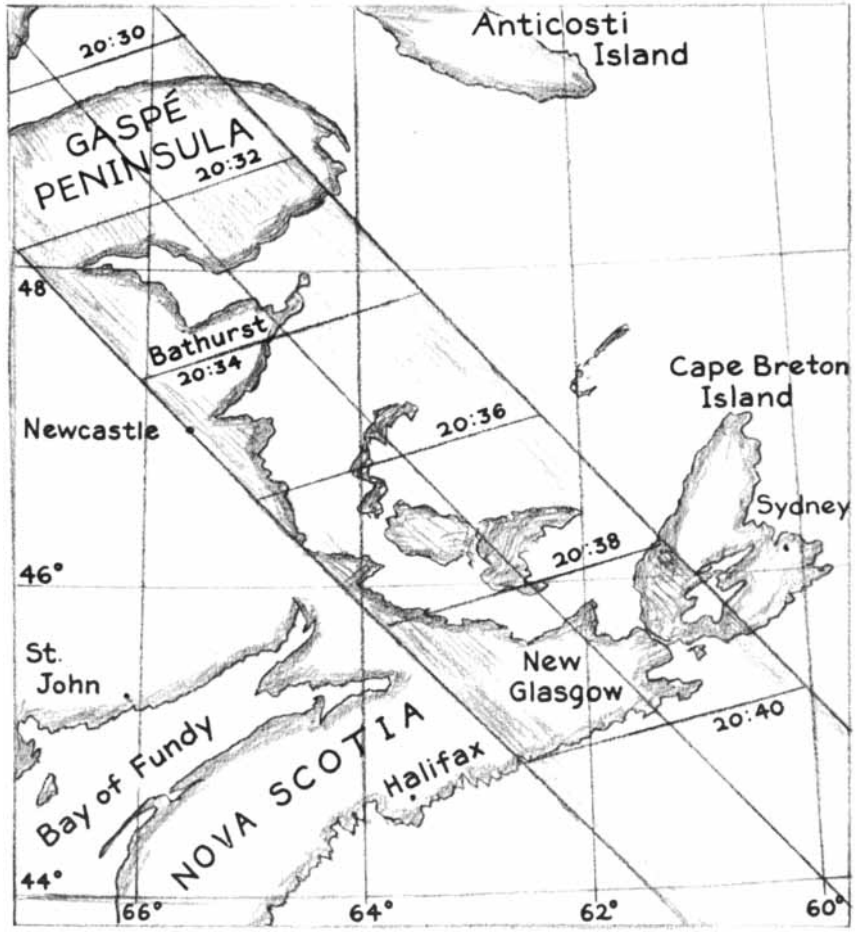
"A number of schemes have been devised for reducing the brightness of sunlight that emerges from the eyepiece of a telescope. The simplest and perhaps the safest system consists in fully covering the front of the telescope with a mirror that reflects the unwanted light and heat directly toward the sun. The mirror is coated with a metallic film equivalent in density to a No. 5 filter. The mirror consists of a metallic coating deposited on a sheet of glass whose surfaces are parallel and polished to within a fraction of a wavelength of optical flatness. Filters of this kind have recently become available at reasonable prices. They are made by the Bausch & Lomb Company (Box 938, Jamestown, N.Y. 14701). The filters are manufactured in three sizes (for telescopes of 4¼, six and eight inches) and are currently priced at $20, $35 and $50 respectively.

"Assume that the intensity of the sunlight has been satisfactorily reduced by this filtering technique or by another of the several systems that will be discussed. The photographer who is intent on photographing an eclipse next confronts the problem of determining the size of the sun's image at the focal plane of the camera. When the sun is photographed with an ordinary camera that has the customary 50-millimeter lens, the solar image is about half a millimeter in diameter, comparable to the width of the period at the end of this sentence. The size can be increased by an objective lens of greater focal length.

"The diameter of the sun's image can be calculated roughly by dividing the fo-



Path of totality in Alaska



Path of totality in eastern Canada

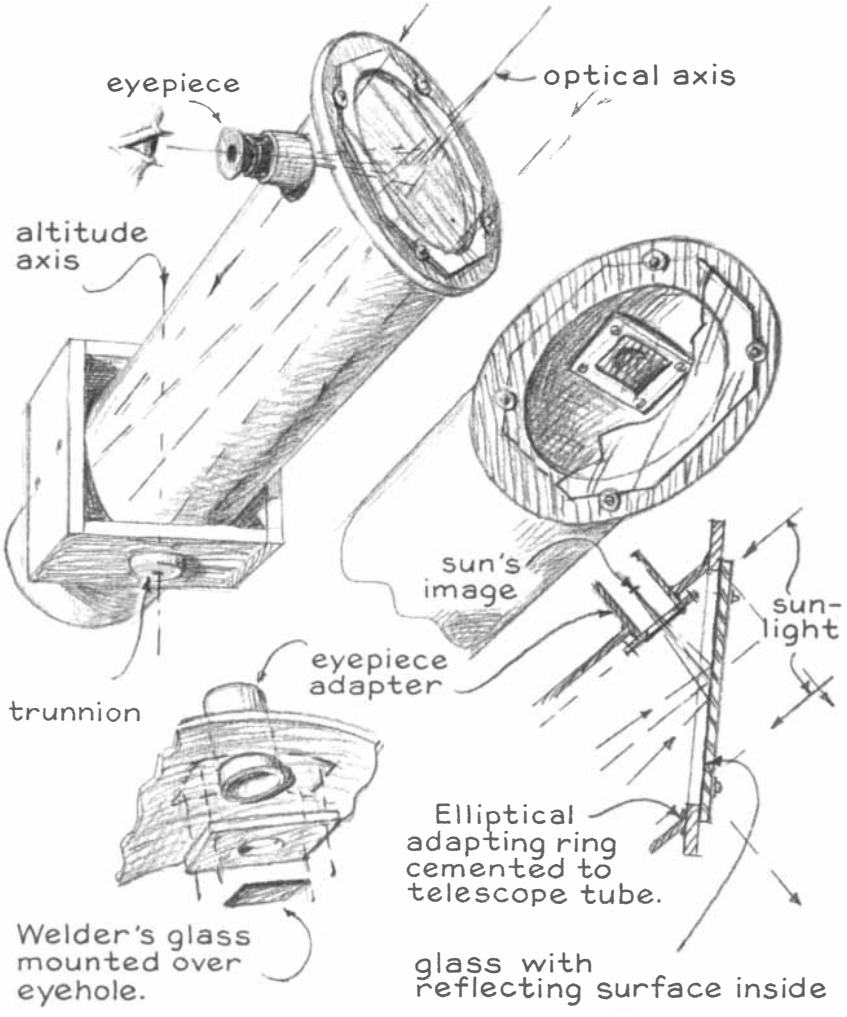
cal length of the objective by 100. For example, an image of the sun approximately half an inch in diameter is focused in the plane of the film by a lens of 48 inches focal length. The exact diameter of the image is calculated by multiplying the focal length of the lens (or mirror) by the angular diameter of the sun in minutes of arc and dividing the product by 3,438. On July 10 the angular diameter of the sun will be 31.4633 minutes of arc. The diameter of the sun's image when the sun is photographed on that date with an objective lens of 48 inches focal length will be $48 \times 31.4633/3{,}438 = .439$ inch.

"For photographing the partial phases of the eclipse a focal length of between 1,000 and 2,000 millimeters is suggested. Achromatic lenses of adequate size for photographing a solar eclipse are fairly inexpensive: a lens with a focal length of 1,270 millimeters and an aperture of 51 millimeters is available from the Edmund Scientific Co. (300 Edscorp Building, Barrington, N.J. 08007) for $13.50 (Catalogue No. 30,190). Six-inch reflecting telescopes of *f* /8 focal ratio, which are made by thousands of amateur telescope-makers, are also adequate. The observer can make reasonably good photographs of the eclipse by coupling a 60-millimeter spotting telescope to a 35-millimeter reflex camera of the single-lens type. An apparatus of this kind has the advantages of variable focal length, compact size and general utility.

"Observers who photograph the total phase must perform several operations within a rather short time. The maximum period of totality during the July eclipse will be only 155.6 seconds. On the basis of my own experience I recommend the following procedure. Just before totality remove the filters from the camera. If the objective is adjustable, set the instrument to *f* /8. Adjust the shutter for minimum exposure. As totality begins, make an exposure at every possible shutter setting, for example 1/1,000, 1/500, 1/250, 1 125 and so on. As totality ends be prepared to photograph the 'diamond ring' effect. Replace the filters as quickly as possible. The corona, which becomes visible at totality, will probably be more extensive than it was during the 1970 eclipse. For this reason those who plan to photograph the full corona should use a lens of not more than 600 millimeters focal length.

"All equipment needed for the project should be assembled well in advance of the expedition. Practice operating the camera and inserting the filters until the routine becomes automatic. The proper exposure interval for the partial phase should be determined experimentally before the eclipse by photographing the sun. First, make a record of the filter combination and focal ratio that will be used during the eclipse. I suggest a focal ratio of *f*/16. Make a series of exposures covering the entire range of available shutter speeds. Keep a record of the shutter speed at which each frame is exposed. Select the most pleasing photograph and note the shutter speed at which it was taken. Use that shutter speed for photographing all partial phases of the eclipse. A rigid but adjustable tripod is essential for supporting the camera or the telescope. Operate the shutter with a cable or an air-pressure release to avoid jiggling the camera.

"If the film is to be developed by a commercial laboratory, include a normal pictorial scene at one end of the roll as a guide for the technician who will cut the film into individual frames. As a precaution against the accidental loss of the film I ordinarily make one exposure of a poster that includes my name and address. I usually buy several rolls of film at a time and make sure that they have the same emulsion number, which is printed on the box, usually above the expiration date. I use one roll for determining the proper exposure time for the partial phase and store the remaining rolls in a freezer until the day before the eclipse. Refrigeration minimizes changes in the response characteristics of the film. I recommend Kodak Kodachrome X and High Speed Ektachrome film for color pictures. Do not try to increase the speed by forced processing. It is not needed and tends to degrade the quality of the pictures. For black-and-white photographs I recommend film of moderate grain size with an exposure speed rating of ASA 50 to 100. Your results will be best if you process the films yourself."



Features of John A. Dobson's telescope

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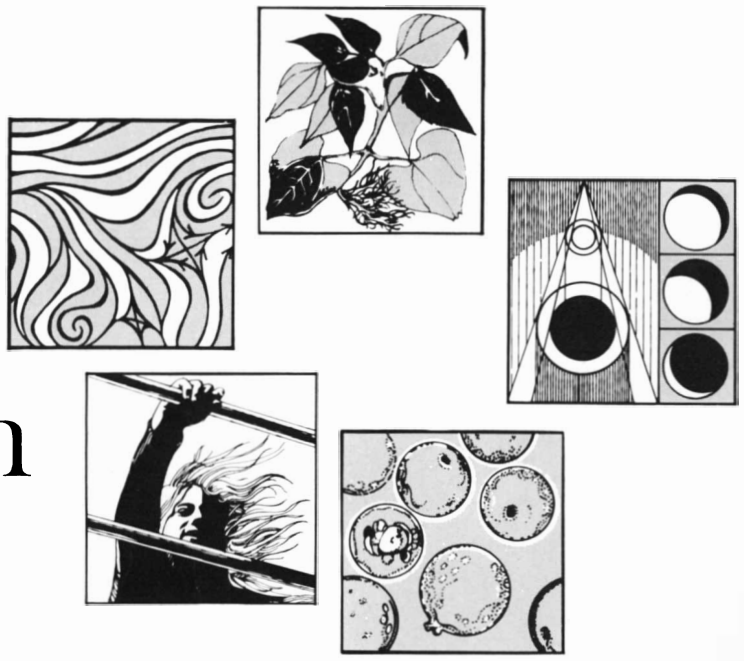

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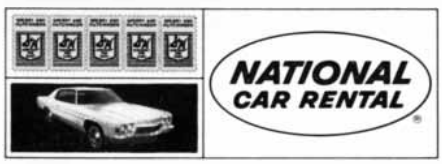

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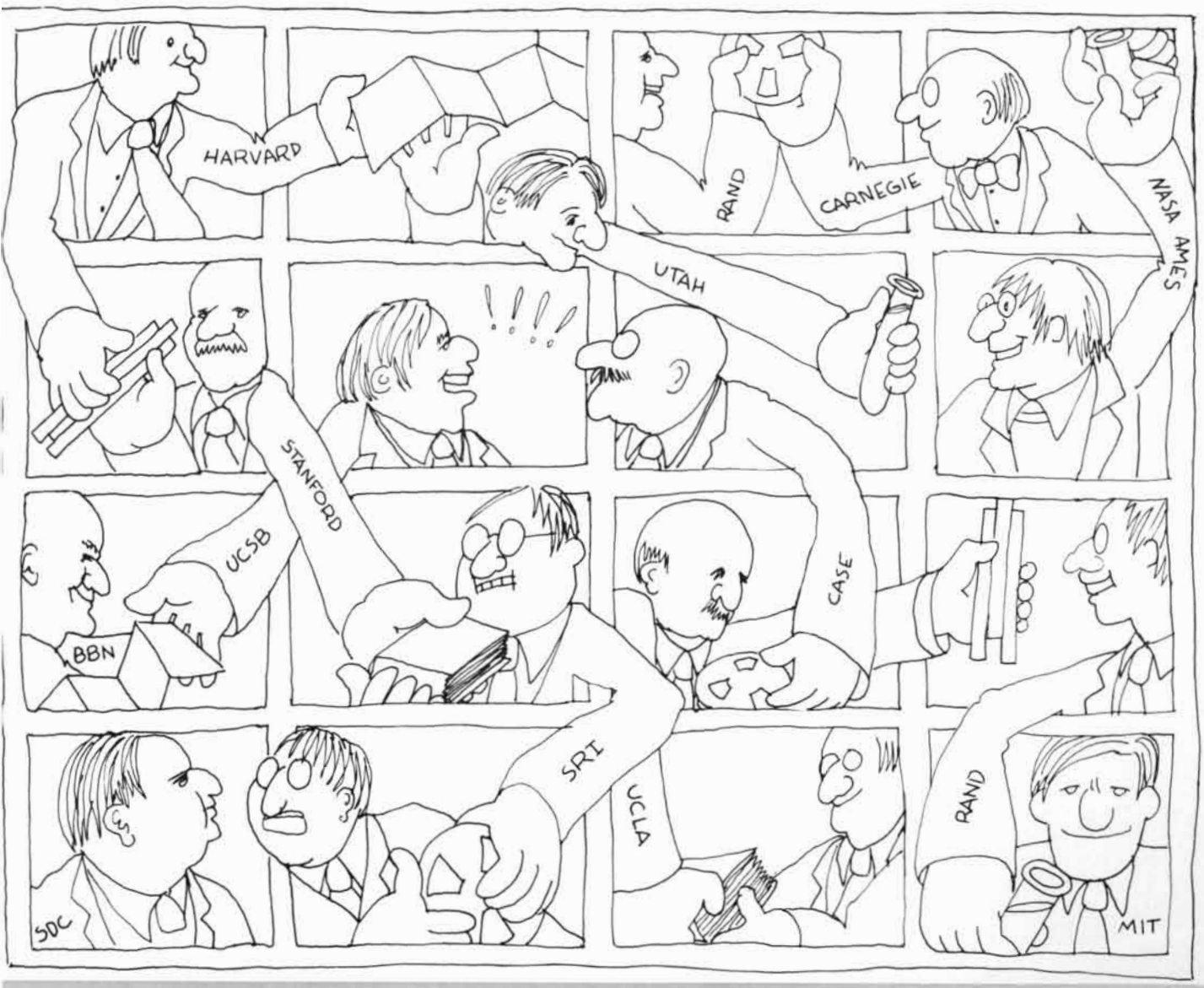

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have done so have reported that they felt no discomfort even though the infrared rays cooked their retina. Unlike the cornea, the retina has no sensory nerves.

The partial eclipse can be observed safely, but indirectly, by projecting the image of the sun on a white screen. To observe the projected image use two sheets of cardboard about a foot square. Make a pinhole in the center of one of the sheets. Hold it up to the sun. Support the second sheet a foot or so behind the perforation. The pinhole will act as a small lens. The projected rays cast an image on the second cardboard that can be examined harmlessly.

A larger and sharper image can be projected by a telescope. Support the cardboard screen a few inches beyond the eyepiece. Focus the solar image on the cardboard by pulling the eyepiece a little way beyond the position at which distant objects are normally seen most clearly. Do not look into the objective end of the telescope when the telescope is pointed at the sun; the reflected image can damage the eye.

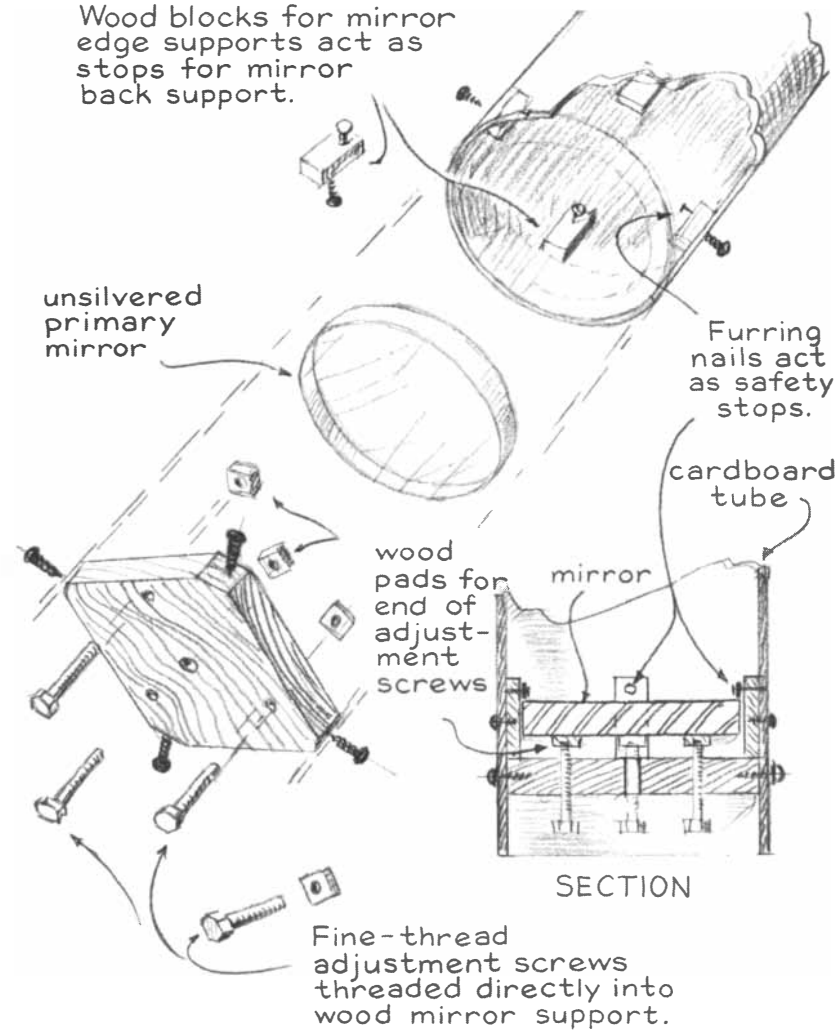
The classical technique of viewing the sun directly through a telescope involves the use of a Herschel wedge, which is a thin prism of glass with faces that make an angle of about 10 degrees. One face of the wedge is polished optically flat. The prism is installed in the telescope at an angle such that light is reflected from the flat face into the eyepiece. The flat face reflects only about 5 percent of the incident light. The remaining light proceeds through the prism to the second face, where 5 percent is again reflected, but at an angle such that these rays do not enter the eyepiece. The rest of the light, about 90 percent, proceeds through the prism and falls on the inner wall of the telescope, where it is absorbed. Although the light reduction thus achieved is insufficient, a No. 4 neutral-density filter can be inserted between the wedge and the eyepiece for safe and comfortable viewing.

Reflecting telescopes of the Newtonian type can be modified for viewing the sun by substituting the wedge for the diagonal mirror that normally diverts the converging rays into the eyepiece. The wedge and the neutral-density filter are available from the Edmund Scientific Co. (Catalogue Nos. 30,266 and 2,729, price $5.50 and $2 respectively). Do not attempt to use an absorption filter at the eyepiece without the wedge. Heat developed by concentrated sunlight can melt plastic and shatter glass.

An excellent telescope for viewing the sun that amateurs can make in a matter of hours has been developed by John A. Dobson of San Francisco. The instrument is essentially a reflector of the Newtonian type. The intensity of the light is reduced in three steps. Light enters the telescope through a beam splitter, or reflecting filter, that is set at an angle of 45 degrees with respect to the optical axis of the objective mirror. The filter occupies the normal position of the diagonal mirror and is supported by the end of the tube, which is cut at an angle of 45 degrees [*see illustration on page 120*]. Dobson explains details of the construction as follows:

"I mount a piece of welder's glass over the lower end of the eyepiece tube to serve as an absorption filter. The objective mirror is unsilvered. The beam splitter covers the entire front opening of the telescope tube. The tube is cut off at an angle of 45 degrees at a point such that the projected axis of the eyepiece tube intersects the center of the lower surface of the beam splitter. For small-aperture telescopes (three to four inches) the beam splitter is cemented with blocks of leather to three equidistant points around the end of the tube after the welder's glass has been cemented over the eyepiece tube. For larger telescopes the beam splitter is supported by an elliptical ring of plywood glued to the front of the tube.

"For the beam splitter I use a partially transmitting mirror of evaporated chromium deposited on twin-polished plate glass 1/4 inch thick. 'One way' mirrors of this kind are used by casinos and supermarkets to discreetly keep an eye on the customer. They are available from dealers who specialize in mirrors. The beam splitter is cemented to the tube with the metal side down, that is, with the reflective side facing the objective mirror. The metallic film reflects most of the light and heat away. About 95 percent of the transmitted light passes through the objective mirror. About 2 percent of the total sunlight is reflected from the objective mirror to the beam splitter, where the rays con-

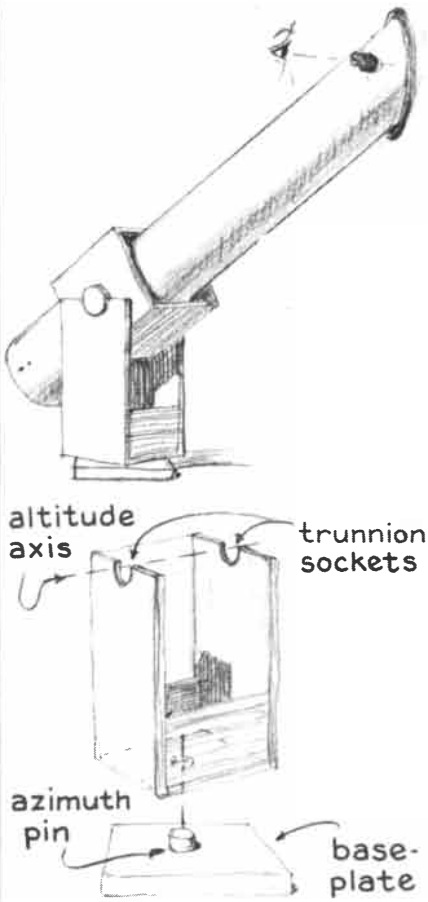


Details of the mirror cell of the telescope

verge through the welder's glass to the focal plane of the eyepiece. I have found by experiment that if the beam splitter transmits about half of the light, a No. 8 welder's glass transmits an image of the sun that can be viewed with comfort. When I use beam splitters of higher or lower transmission, I choose welder's glass of greater or lesser density, such as a No. 6 or a No. 7. The glasses are available from dealers in welding supplies. (The buyer should be aware that the numbering scale for welder's glass differs from the one for neutral-density filters.)

"Telescopes of this design are unobstructed reflectors. Resolution is limited only by the quality of the optical surfaces and the turbulence of the sky. Turbulence in the tube of the telescope remains low because most of the heat that would generate convection currents is diverted by the beam splitter."

Those who do not own an objective mirror for a telescope can make one for observing the sun in the course of a weekend. The job is fairly easy because the figure of the mirror becomes essentially spherical at a focal ratio of $f/10$ or more. If abrasive powder is sandwiched between a pair of glass disks that are equal in diameter, the surfaces will automatically grind to a spherical figure when one glass is stroked back and forth on top of the other disk. By using abrasives of successively finer particle size and finishing with rouge applied to a disk of pine pitch, the glass can be polished to a circular figure. Even a beginner can make an acceptable three-inch mirror of 30-inch focal length within four working hours [see "The Amateur Scientist," SCIENTIFIC AMERICAN; November, 1959].



Homemade telescope mount

It has often been observed that about half of the labor of making a reflecting telescope is spent on the mirror and half on the mounting. Dobson has developed a mounting that is exceptionally easy to make, highly functional and inexpensive. The accompanying illustrations depict the details of the construction. The mirror assembly, its adjustable mounting cell, the diagonal beam splitter and the eyepiece assembly are supported by a cardboard tube. The tube is clamped at its balance point by a rectangular box made of wood. The trunnions turn in sockets atop a cradle. For the smoothest action tack pads of Teflon spaced about 120 degrees apart to the inner face of the sockets. A hole in the bottom of the cradle makes a sliding fit with a centered pin in the baseplate. The telescope turns in azimuth around the pin on three blocks of Teflon.

Inexpensive telescopes of relatively long focal length have become available in recent years. They can be adapted for observing the eclipse by those who may not feel up to making their own instrument. Representative is a three-inch Newtonian reflector that is available from the Edmund Scientific Co. (Catalogue No. 80,162) for $59.50. A Herschel wedge that is interchangeable with the diagonal mirror is available from the same source, as is a companion sun filter. In addition a special bracket can be obtained for mounting a camera rigidly to the telescope. Edmund also has a fixture for displaying a magnified image of the sun on a small self-contained screen.

Those who would like to observe at the professional level should not overlook the Questar, a compact telescope that has an equivalent focal length of 1,245 millimeters when it is coupled closely to a camera. Specially designed accessories for this instrument include a sun filter, a camera and a power supply of variable frequency for tracking the sun automatically. The instrument is available from the Questar Corporation (Box 120, New Hope, Pa. 18938).

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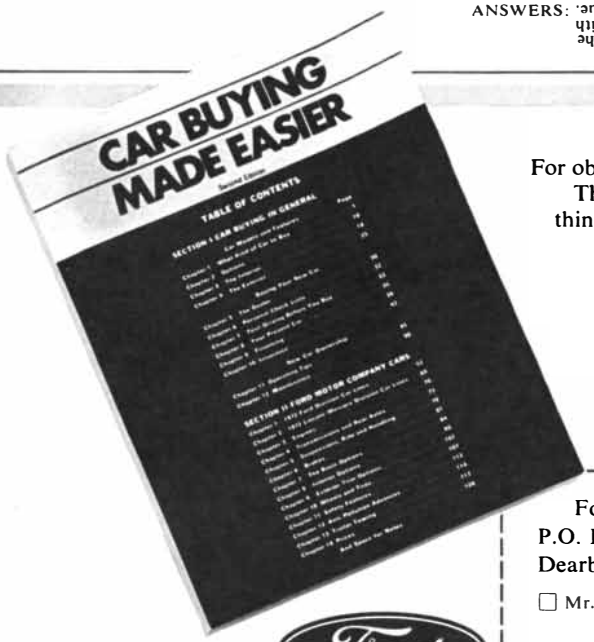

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BOOKS

Five kinds of scientific inquiry, and the functioning of science in the U.S.

by Philip Morrison

THE DESIGN OF INQUIRING SYSTEMS: BASIC CONCEPTS OF SYSTEMS AND ORGANIZATION, by C. West Churchman. Basic Books, Inc. ($10). SCIENCE: GROWTH AND CHANGE, by Henry W. Menard. Harvard University Press ($10). Professor Churchman is a philosopher of science who is no stranger to mathematics, to computation or indeed to the deep metrological foundations of physics. In *The Design of Inquiring Systems*, where no graph or diagram breaks into the type and only a few sentences of statistical summary enter, he is all philosopher. His medium is the warmly but carefully written word, his message a kind of "endless approximation" to the explanation of the concepts that form the title. The topic of the book is plain enough: Can human beings reasonably plan systems of men or machines that are able to improve on what one mind can do to create new knowledge?

The bulk of the volume is an analysis of gaining knowledge, cast in the form of a classification of systems, in which the categories used are modeled on the epistemological issues raised by five philosophers, four of them classical. The Leibnizian inquirer, for instance, is based on form: it builds nets of acceptable unit statements that are based not on inputs from without but on innate ideas of form. Many artificial intelligence devices today, like the immune system of the body and much of modern science (and one current school of linguistic thought), fit into this class. It works not with truths but with contingencies; it builds models. Above it all, structuring the best—nay, the only—possible world stands God.

Then comes the Lockean system; worried about reality, it seeks to enforce the simple man's view that seeing is believing. Every net must be unraveled back to simple inputs if it is to be credible. Its believably ordered structures are not innate but conventional. Libraries seem to be examples of this scheme. Here the guarantee of reality turns into the agreement among informed systems. Then there is Kant. Systems named for him lie in a way between the other two. For Kant there are a few indispensable a priori structures. They are not innate: they are against Leibniz. They evidently transcend conventions as well: they are against Locke. Hegelian systems come next. Such systems design through conflict: they make drama, mapping every conflict—a thesis and its antithesis—onto a wider map, which can be thought of as passing a wiser judgment. The author even lists an explicit set of logical operations that describe this scheme. That the task ends at all, let alone ends usefully, is Hegelian optimism.

The final class of systems is named after the American philosopher of the last generation, E. A. Singer, Jr., who was the teacher of Churchman's teacher. The Singerian system takes off with the study of measurement, not as a logical exercise but as an operational one. Singer broadens even Hegel. He invokes an explicitly unending process; for instance, if all measures of one length should come to agree, a refinement is to be sought; thus the accuracy of the meter rises from inspection by unaided eye to inspection by microscope to laser interferometry. Final control is nowhere; adjustment is everywhere; in the end the entire social system must enter the design. The transient guarantor becomes the figure of the hero; in the Singerian system progress may or may not be certain, but process there surely is.

To this bald account it should be added at once that Churchman is far richer, more nonlinear and more subtly qualifying than all that. In his yeasty mix of computers and theology and decision theory, three accounts of real experiments enliven the argument. One experiment is a Leibnizian effort, the development of a net of inductive rules that might program the automatic identification of a complex organic compound by the study of its fragments as they are observed in the mass spectrometer. The chemists did better than the program.

The second experiment was a Hegelian one, a dialectic by radio broadcast. Here the listener heard first an expert rationalization of the Federal research and development budget, a Lockean consensus like some White House paper. Then a debate followed in normal fashion, different data being cited by the debaters. Next came a dialectical discussion, where both sides began with identical data. Listeners were asked to react; classroom experiments of the same kind were carried out and evaluated for changes.

In the third experiment the theory of system design was viewed as a theory of education. A group was given a problem where the right performance is hard to perceive. The experimenters teach a "stooge" the correct answer. The scheme was run through often, with many variations in attitudes, data, outside pressures and the like. This was intended to simulate the Lockean way: How does expert knowledge induce consensus? The results of the experiment were "promising, terribly difficult, almost impossible to evaluate ... like any other plausible technique of education." The philosophy of science was not like this in cooler times.

In the end, within a few speculative chapters, Churchman grapples with the social troubles of the times. He recognizes that it is not in the creation of new discoveries in science that our deepest problems lie. It is in the need to create inquiring systems in which Everyman plays inquirer, the natural mode of human beings. Inducing passive appreciation is unacceptable as the public share of scientific inquiry; it is plainly belied by the analysis. After all, inquiry includes social values as well as physics. How can "the ordinary man [come] to feel the act of discovery as part of his own natural life"? The book ends with a question, the only proper conclusion of philosophical discussion. The endless

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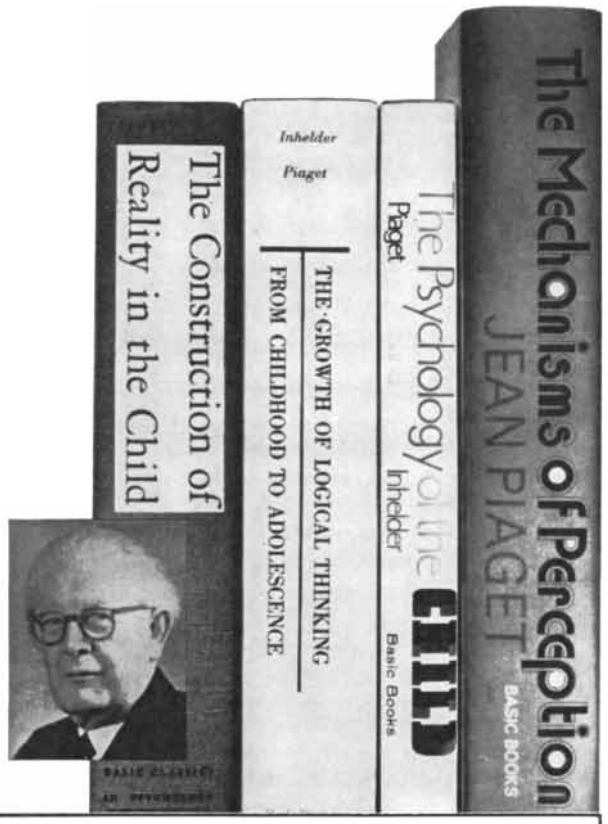

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approximation adds another recursive term.

If one clear defect can be seen in these modeling studies, it is a defect of time scale. Everyman knows that games are not life; a system that grows exponentially (such growth seems to be a key property of the inquiring systems we know about) can hardly be designed for permanent operation unless it remains remarkably simple. It evolves; what the designers knew must soon become negligible compared with what the system knows. Perhaps the Singer mode contains this insight, exactly as the other categories each reflect a wisely chosen portion of the whole. A more central modeling of the overwhelming feedback from the inquiry to the inquirer, who changes unrecognizably in scale as he works, still needs to be found.

Science: Growth and Change, by an oceanographer who writes and thinks as tight as a ship and yet as wide as the sea, is very different. It is all empirical and tentative, matching one reflective, blunt and cheerful man's experience against the data: 55 graphs and nine tables crowd a brief, quite personal book. With dollar figures, age distributions, lists of names, counts of citations and papers, it is a contribution to the sociology of science as it functions in the U.S. today.

Menard, both a researcher and an administrator, entered this mode during a bout with real inquiring systems: he worked for some time in those offices that surround the White House on future Federal support for his science. What captured his attention was the discovery that there is a limited discrete universe in which science maps tolerably well: the universe of scientific journals, technical papers, citations and their authors from the days of Gresham College and the Academy of the Lynxes right up to the latest computer-generated KWIC index.

What Menard has done with verve and plenty of hard facts is to examine the texture of the long-range exponential growth of papers (the doubling time is 15 years for science as a whole, and for individual sciences as well) to reveal what some threads are. It is no surprise that the whole is the sum of parts whose growth typically rises and flattens out. New entrants and new subfields maintain the swelling growth. The experience of Menard's own science (geology) and particularly of his subdiscipline (marine geology and geophysics) is most cogent. Marine geology now doubles about every five years. But the science as a whole lay "dormant," doubling only in 40 years, from the turn of the century until about 1955. Its style was bibliographic, classificatory, marked by constant restatement of diverse views, pedantic, jargon-filled ("Is the Boulder 'batholith' a laccolith?" was one title), elderly. "The literature" was large and mainly old; the geologist studied not so much the earth as the papers.

The big geological research agencies themselves turned old and static. For each new problem Congress or the states built a new agency. Why not? Would you give a new problem, say the geology of the West, to the old Coast Survey, which was seized with the problem of keeping ships off reefs? Nowadays would you assign a new problem to Agency X, which begins work with "all higher-level technical positions filled by men educated in X some 20 to 40 years before ... with fully operational bowling leagues, bridge clubs, and ... a staff with large quantities of accrued annual leave"? No, like Congress, you would opt for a hungrier new agency, Z. And Z will mature in turn.

The issue is plain: "For American science in general, if fiscal winter comes, can bibliographies be far behind?" This is historicity dominant; no doubt of it, growth is the key problem of science even more clearly than of the wider world. Solutions are less clear, to Menard as to all of us. Graduate students ought to understand the difference among subfields (study Menard!) but that is by definition an answer only for the minority. Some kind of time-sharing is needed: is it early retirement, multiple retraining, regional research, public education or perhaps even euthanasia for aged organizations?

With typical activism, Menard proposes a national industrial General Union of Technologists and Scientists. The Teamsters run the trucks and thus they are listened to. This group would run innovation in the entire economy, from the computers to the gas and oil finds. It will control the labor force of science, engineering and technology; full employment, pay for students, reeducation, early retirement, paid retraining. Only our smug elitist self-image, he holds, stands in the way. Perhaps he is right; one is certainly inclined to sign up. But even broader questions surface, which lie athwart the entire future of man in society.

MOSQUITOS, by J. D. Gillett. Weidenfeld & Nicolson, London ($15.22). Little enough do we know about ourselves, yet among the millions of living species *Homo sapiens* is by far the best-studied biologically. Next come single domesticated species, perhaps cattle or maize or even the honeybee. No group of living forms, however, has been so intensively studied as the mosquitoes; we now catalogue 2,500 species (listed in the appendix of this book) of these "tiny flying machines." Most of our interest has been shown during the 20th century; it was only after the turn of the century that it became certain that life and death were determined for millions of human beings by their relationship to the mosquito.

For men mosquitoes are ubiquitous flying syringes, computer-guided, incubating in flight some deadly dose of millimeter-long filiary worms, of microscopic malarial protozoa or of a hundred invisible viruses, such as the agent of yellow fever. In the Arctic or in New Jersey mosquitoes carry less terror, but their hum still spells misery to a great many human beings. The red itching wheals the bites raise are signs of allergic response to the salivary injection made by the insect; the first bite of a novel species will produce no reaction at all. Immunity to the mosquito bite can be won in the end.

The study of mosquitoes has grown to a profession, embracing many disciplines of biology and medicine. It has journals of its own; *Mosquito News,* for example, is cited often among the 450-odd references in this volume. It has a history (going back to classical antiquity), heroes (such as Sir Patrick Manson and Walter Reed), even martyrs (such as Jesse Lazear, who died as a result of the tests of yellow-fever transmission Reed led in Cuba in 1900). The deepest impression made by this fascinating volume is the intricacy and aptness of adaptation shown by this skein of tiny beings, woven over 50 million years into the tapestry of life.

Professor Gillett is a veteran student of the mosquito; he has worked in the field and at the laboratory bench, seeking behavior and its roots in structure at all levels. He reports his own staunch work in mapping the time and altitude pattern of mosquitoes feeding in the Uganda rain forest. Those data were hard-won. You built a set of platforms every five meters up the tall trunks of the canopy trees. The platforms were manned day and night by four catchers on a four-hour watch with glass trapping tubes. (The men acted as their own bait.) The stinging latex of the strangler figs and the bites of the ants "did not help

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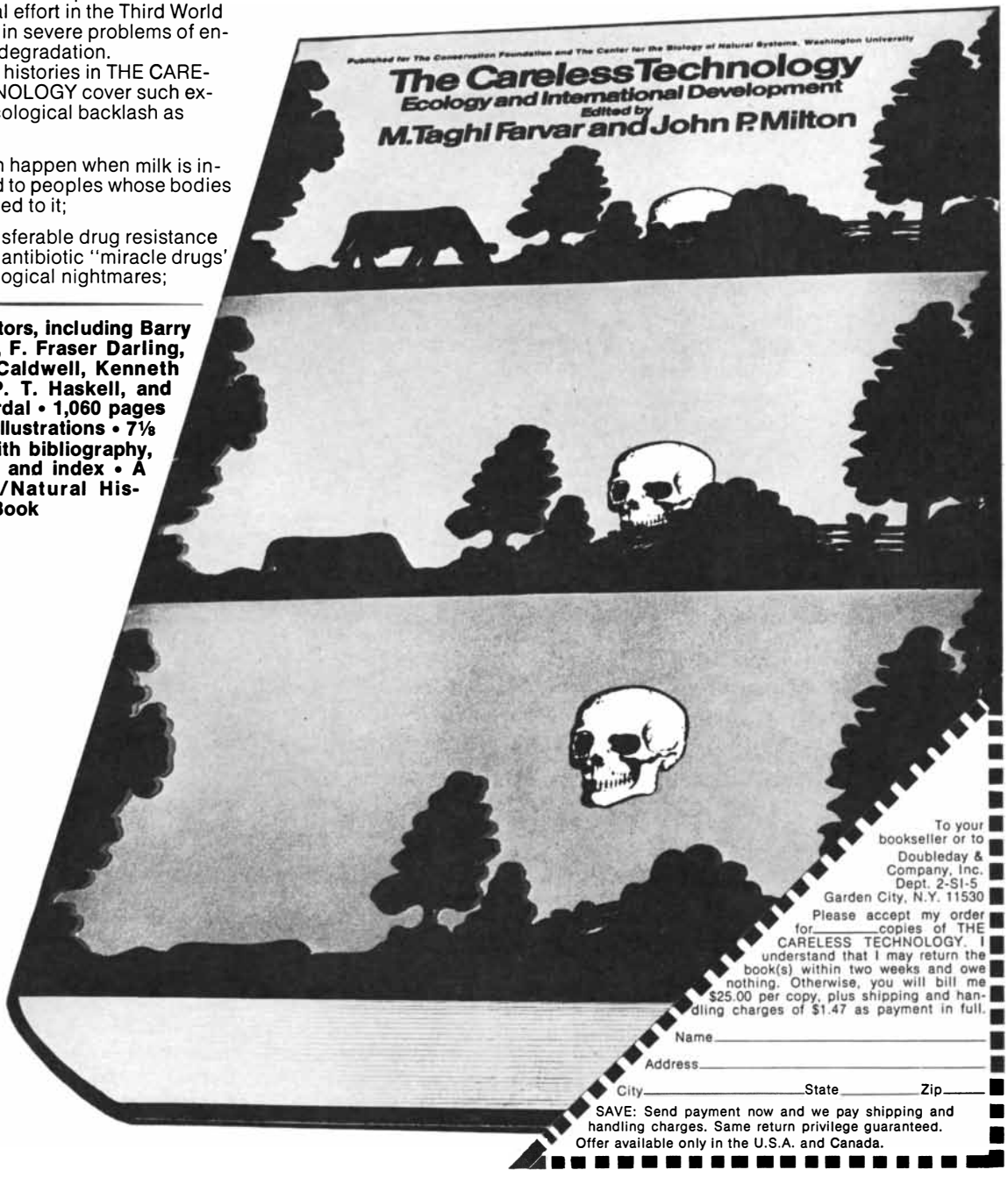

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either." The men caught insects on their arms at two sites for 40 days and 40 nights. Below the catchers was a ground party fighting boredom and on-duty sleep with "some of the finest drummers in the land . . . on the official payroll."

There was a short, sharp peak of biting every day within 20 minutes after sunset in the highest canopy. The insects at that hour and level belonged to a single infectious species. The hypothesis that treetop monkeys could support yellow fever was demonstrated. Only one species of monkey, the red-tailed guenon, leaves the canopy, to seek bananas grown in clearings at the forest edge. Carrying fever, but not very ill, it links the virus cycle of its canopy to human beings through a mosquito of another species that lives in the banana grove, where it can bite both other monkeys and man.

In East Africa the fever is a rural disease, yet on Kilimanjaro it is unknown. There are man-biting mosquitoes of the infectious species "in fantastic number" on the mountain, but below the banana groves the forest has all been cleared away. Above the groves in the high mountain forest there are still plenty of monkeys and mosquitoes; here the weather is so cool that the virus multiplies too slowly to become dangerous during the life-span of any mosquito. In South America monkeys infected with the same virus are too sick to forage; they die without ever leaving the canopy. Mosquitoes alone can carry the canopy fever to mankind, but only by way of men who enter the forest and fell the high trees, thus exposing themselves to the canopy mosquitoes that live 30 meters high in the foliage. In tropical America the fever is an occupational disease of jungle woodcutters. It looks as though yellow fever is a post-Columbian disease: the American monkeys are little adapted, and for them the virus is still virulent. Urban yellow fever, the classical scourge from Baltimore to Rio de Janeiro, has gone with control of the "domesticated" mosquitoes.

Not since the books of F. M. Burnet a generation ago has such a remarkable tale of detective epidemiology been so well told. Yet this story is found in only a chapter or two of Professor Gillett's literate, personal, well-illustrated and convincing work. His overall theme is the biology of mosquitoes, and the link with man, after all, appears very late in their epic.

Mosquitoes have two lives: a larval life as a creature of the undersurface of water and an adult life in deft flight. Some mosquito species lives in every kind of water, whether it is limpidly pure, foul with fecal matter or even a seawater pool. The kind of water chosen for egg-laying and larval growth is fastidiously precise, species by species. The most important malarial mosquito in Africa lives as a larva almost exclusively in open puddles, fully exposed to the sun. It prefers small earth-walled containers: the water-filled footprints of man or hippopotamus are typical, wherever the vegetation is missing.

One yellow-fever vector in Africa favors the little thumb-sized pools in the leaf plumes of plants such as the pineapple and the banana. The "domesticated" species are often those that dislike earth-walled containers. Once they bred only in holes in trees or rocks, never in pools in the ground. Now they happily occupy old tins, broken bottles, discarded tires and rain gutters. There is one species that frequents the water held delicately in the concave top of some toadstools! Such wild adaptive radiation reminds one of the whimsy of a fairy tale.

The mosquito needs two foods, one for fuel and one for structure: flower nectar and blood. In most species the males can get by on the protein taken in their predatory larval stage. Only the egg-laying female takes the blood meals that bind insect to primate. Some species are choosy in the wild, although in the laboratory most will take blood from any vertebrate host. Others are omnivores, even in free life: "In addition to people, I have personally taken this species in the act of feeding on chickens, a frog, toads, monkeys, dogs, cattle, horses, donkeys, and one elephant."

Time and chance have made mosquito life more intricate than a work of human art, even viewed on the gross scale of our eyes, our ears and our vulnerable skins. We cannot ignore mosquitoes and say live and let live. We will not, however, crudely "conquer" them; our strategy must be built, like our admiration, not on ignorance or arrogance but on a deeper understanding of the laws that mutually govern all life, "the biter and the bitten."

CHINA, by Yi-Fu Tuan. Aldine Publishing Company ($5.95). THE PREHISTORY OF CHINA: AN ARCHEOLOGICAL EXPLORATION, by Judith M. Treistman. The Natural History Press, Doubleday & Company, Inc. ($5.95). The microwaves from Intelsat IV F-4 brought us a flood of images—images of China old and new, the Wall as well as the social unity and decency that has replaced the obscene disorder and fragmentation wreaked on old China for a century by foreign cannon and foreign greed. The population fell by almost 100 million between 1850 and 1915, between natural and man-made disasters. It is right to read now not only the new times but also the eternities. China sums up to more than a third of mankind's history; to know her is to know humanity in depth. Yi-Fu Tuan, professor of geography at the University of Minnesota, has produced a small, rich, rather personal study of the wide landscape of China as hand and mind have changed it since Neolithic times and before. Crudely put, China is a vast slope to the Pacific, from the highest plateau in the world falling by "a series of giant steps separated by rises." The three great rivers drain to the sea, cutting the famous heroic gorges in the barriers they find.

Since the time of Peking man the plateau has risen markedly, perhaps by 8,000 feet. Thus the west of China is dry, since no monsoon can come from the Indian quarter. The east is middling rainy in the north and genuinely monsooned in the south. Over the north there spreads the fine windblown loess—the "yellow earth." It can cover even the Great Wall for long stretches, and it so silts the waters of the Yellow River that the riverbed is high above the valley floor. "On a windy winter day in North China . . . the world . . . seems to be made of one material—loess: the soil is loess; houses are made of pounded loess bricks or dug out of loess; roads are tracks sunken in loess; vegetation is coated with loess, and the blueness of the sky itself is compromised by yellow veils of loess."

Most of the lowlands north and south alike have been deforested by the needs of men for cropland, for the timber buildings of cities and for fuel. Coal has therefore been burned widely since the 12th century, before Newcastle. Even ink, the medium of the most civilized art of China, has taken its tree toll: " 'The brushes of the vast T'ang bureaucracy were rapidly bringing baldness to the T'a-hang Mountains' " as the pines were burned for the needed soot.

Urbanism is old in China. Walled villages are found in the Neolithic. It is held by some that by the Former Han (about the time of Christ) few northerners lived outside a walled enclosure. The cities were microcosms quite literally; many closely fulfilled the ritual cosmological pattern of orientation and squared subdivisions that mirrored the

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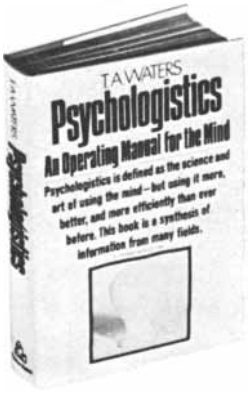

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heavenly order. Their character has changed greatly: "cities of the T'ang type were pretty quiet at night"; "the broad avenues were eerily empty except for a few . . . night riders on some official mission." In Marco Polo's time Mongol Cambaluc, a four-square and 12-gate city near the present Peking, was the active capital. Marco thought the southern city of Hang-chou was the greatest in the world, with an animated life until very late into the night.

Shanghai in the 1930's, a city built by the intruding West, breathed sheer excitement marked by intolerable contrasts: "On a cold night one may be obliged to step over the . . . body of a beggar into the warm lushness of a first-rate restaurant. The worship of money and complete amorality seemed . . . something that one could inhale, smell or touch . . . but . . . a city, if it is to be livable and humane, must strive for something less exotic." For a long time now the large cities of China have been ringed outside the walls not by urban sprawl but by a fertile zone extending "as far as a man can walk and return in one day." The fertilizer that flows from the cities as human manure balances the flow of crops into the city. In the southern deltas the ring is larger; canal transport spreads the exchange. This pattern has begun to change; Peking has a large, patchy industrial ring beyond the walls, but we know that the road from the airport still has the old look.

The Prehistory of China is an up-to-date account of what has been learned of life in China from Peking man to the dawn of copious written history at about the time of Athens. The author writes with a deliberate successful effort to look "over the wall," to evoke individual and social life, not merely pottery patterns and chronologies. She sees modern China as being continuous with the prehistoric past. "There is no cu'mination, no climax. . . . A national style of life is gradually formulated. . . . The south, with its massive irrigation-cultivation, became a major resource of food for the north and raw materials for manufactories everywhere. The bureaucracy that grew out of the administrative needs of the north fostered the literate arts, philosophy, and science."

The most interesting tale in this brief readable review (which lacks the documentation of a reference work) concerns the wonderful pieced ceramic molds, their surface decorated by engraved clay stamps in subtle symmetrical combinations, into which were cast the magnificent bronzes of the Shang. (One marvelous elephant-on-elephant is shown in the book.) "How close we are to the invention of printing, how close to the use of formalized ideographic writing." The oracle-bone inscriptions of this period present on tortoiseshell 3,000 characters, only a third of which have been deciphered. These first Chinese characters were painted with a brush and then carved into the tortoiseshell with tools of bronze and jade. Writing was not very familiar then, around 1500 to 1200 B.C. The scribes use many forms of a single character, and the characters still are largely pictographic. Typically there is mirror writing across the cracks in the tortoiseshell.

MODERN ANALYTICAL CHEMISTRY, by W. F. Pickering. Marcel Dekker, Inc. ($13.75). Sherlock Holmes would while away long rainy evenings on Baker Street with a session with test tube and Bunsen burner. He always identified the unknown compound pretty well. As recently as 15 years ago just about every sophomore in a variety of scientific majors took and disliked a term or two of "quant." Classical even then, it was a tedious set of reaction steps, carefully ordered and meshed to avoid interferences, ending up in weighing some "sparingly soluble" product. It was a cookbook course; what else could it be? The art one gained was truly the property of only a few.

Analytical chemistry is not like that any longer. It is more important than ever; from the clinical laboratory to the nuclear reactor, from the chronological isotope studies of the geochemist to the gas chromatography of the affluent controller, more rapid, more sensitive, more immediate analysis is a key to science, pure and applied. Automatic devices take command, even within good old "wet chemistry." This textbook by a level-headed Australian chemist is not for the general reader; it is too full of facts and arguments. It is nonetheless about the best place to gain a quick impression of the transformation of the analytical chemist during the past 30 years, and it will serve student and browser alike as an overall coherent introduction and as a guide to the more detailed literature. The author manages to treat with understanding at the undergraduate level well over 50 techniques of analysis in the decade during which automatic methods are likely to spread to "most routine chemical analyses."

How does an automatic wet analyzer work? A few dozen little cups on a turntable receive the samples. A roller pump,

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a couple of dozen programmed rollers squeezing as many plastic tubes, peristaltically meters in reagents and propels the samples through the system. Air bubbles are added in precise sequence to the stream as the pump works. These bubbles divide samples and reagents into discrete digitized segments. They also scrub the tube walls clean.

The entire closed tangle of tubing, glass and plastic, is specific to a process but is easily changed. Quick-heating blocks or slow-incubating baths are available; special processes, such as dialysis through membranes, are accomplished in specially made cells. Mixing and time delays are provided by long coils. Unwanted fractions are sent out to waste.

Finally the sensing stage is reached. Typically a dye reagent is added, the drop is measured by a photoelectric photometer and the result is recorded. Next sample. The information can of course be got out in many ways: flame emission spectra, ultraviolet absorption, fluorescence, beta-ray or gamma-ray counts are all fully practical. One commercial analyzer can perform 12 distinct clinical biochemical tests with good accuracy on a single two-millimeter sample of blood serum, at the rate of one sample per minute. (Clinical laboratory fees appear to stay about the same, or to rise only a little, but your physician now gets a dozen numbers, not just one, from a single stab at your finger.)

Many nonchemists have seen the handy meters that have served for a generation to register the concentration of hydrogen ions in a water solution. These devices work by measuring the electric potential developed by dipping into the solution a thin glass bulb filled with acid. Nowadays the result is presented digitally by integrated circuit. The trick was the glass: it quickly exchanged alkali ions with hydrogen ions at fixed potential differences. This, of course, is a *p*H meter. Now you can measure in the same way a couple of dozen specific ion concentrations, say chlorate or nitrate. This calls for even trickier glass. The ingenious developments in microanalysis are perhaps the least thoroughly treated in this book, which aims mainly at schemes that are used very widely: spectrometry in every wave band, ion exchange, electrochemistry, solvent extraction and the like. Holmes would find only occasional joy in this treatment, but it seems well suited to the racked plumbing of the chemistry laboratory of today, and it is a prelude to the black boxes of tomorrow.

BIBLIOGRAPHY

Readers interested in further reading on the subjects covered by articles in this issue may find the lists below helpful.

THE CRATERING OF INDOCHINA

ECOLOGICAL EFFECTS OF THE VIETNAM WAR. E. W. Pfeiffer in *Science Journal*, Vol. 5, No. 2, pages 33–38; February, 1969.

ECOLOGICAL EFFECTS OF THE WAR IN VIETNAM. Gordon H. Orians and E. W. Pfeiffer in *Science*, Vol. 168, No. 3931, pages 544–554; May 1, 1970.

IMPACT OF THE VIETNAM WAR. Committee Print of the U.S. Senate Committee on Foreign Relations. U.S. Library of Congress, June 30, 1971.

FORESTRY AND THE WAR IN SOUTH VIETNAM. Arthur H. Westing in *Journal of Forestry*, Vol. 69, No. 11, pages 777–783; November, 1971.

LAND WAR. E. W. Pfeiffer and Arthur H. Westing in *Environment*, Vol. 13, No. 9, pages 2–15; November, 1971.

HARVEST OF DEATH: CHEMICAL WARFARE IN VIETNAM AND CAMBODIA. J. B. Neilands, Gordon H. Orians, E. W. Pfeiffer, Alje Vennema and Arthur H. Westing. The Free Press, 1972.

HOW WE CONTROL THE CONTRACTION OF OUR MUSCLES

TREATISE ON PHYSIOLOGICAL OPTICS: VOL. III. Hermann L. F. Helmholtz. English translation by James P. C. Southall. Dover Publications, Inc., 1962.

POSITION SENSE AND SENSE OF EFFORT. P. A. Merton in *Homeostasis and Feedback Mechanisms*. Symposia of the Society for Experimental Biology, Vol. 18, pages 387–400; 1964.

THE INNERVATION OF MAMMALIAN SKELETAL MUSCLE. D. Barker in *Ciba Foundation Symposium: Myotatic, Kinesthetic and Vestibular Mechanisms*, edited by A. V. S. de Reuck and Julie Knight. Little, Brown and Company, 1967.

SERVO ACTION AND STRETCH REFLEX IN HUMAN MUSCLE AND ITS APPARENT DEPENDENCE ON PERIPHERAL SENSATION. C. D. Marsden, P. A. Merton and H. B. Morton in *The Journal of Physiology*, Vol. 216, pages 21–22P; July, 1971.

PROJECTION FROM LOW THRESHOLD MUSCLE AFFERENTS OF HAND AND FOREARM TO AREA 3a OF BABOON'S CORTEX. C. G. Phillips, T. P. S. Powell and M. Wiesendanger in *The Journal of Physiology*, Vol. 217, pages 419–446; September, 1971.

BLACK HOLES

GRAVITATION THEORY AND GRAVITATIONAL COLLAPSE. B. K. Harrison, K. S. Thorne, M. Wakano and J. A. Wheeler. University of Chicago Press, 1965.

NONSPHERICAL GRAVITATIONAL COLLAPSE: DOES IT PRODUCE BLACK HOLES? Kip S. Thorne in *Comments on Astrophysics and Space Physics*, Vol. 11, No. 5, pages 191–196; September–October, 1970.

INTRODUCING THE BLACK HOLE. Remo Ruffini and John A. Wheeler in *Physics Today*, Vol. 24, No. 1, pages 30–41; January, 1971.

PLATE TECTONICS

SPECULATIONS ON THE CONSEQUENCES AND CAUSES OF PLATE MOTION. D. P. McKenzie in *Geophysical Journal of the Royal Astronomical Society*, Vol. 18, No. 1, pages 1–32; September, 1969.

MOUNTAIN BELTS AND THE NEW GLOBAL TECTONICS. John F. Dewey and John M. Bird in *Journal of Geophysical Research*, Vol. 75, No. 14, pages 2625–2647; May 10, 1970.

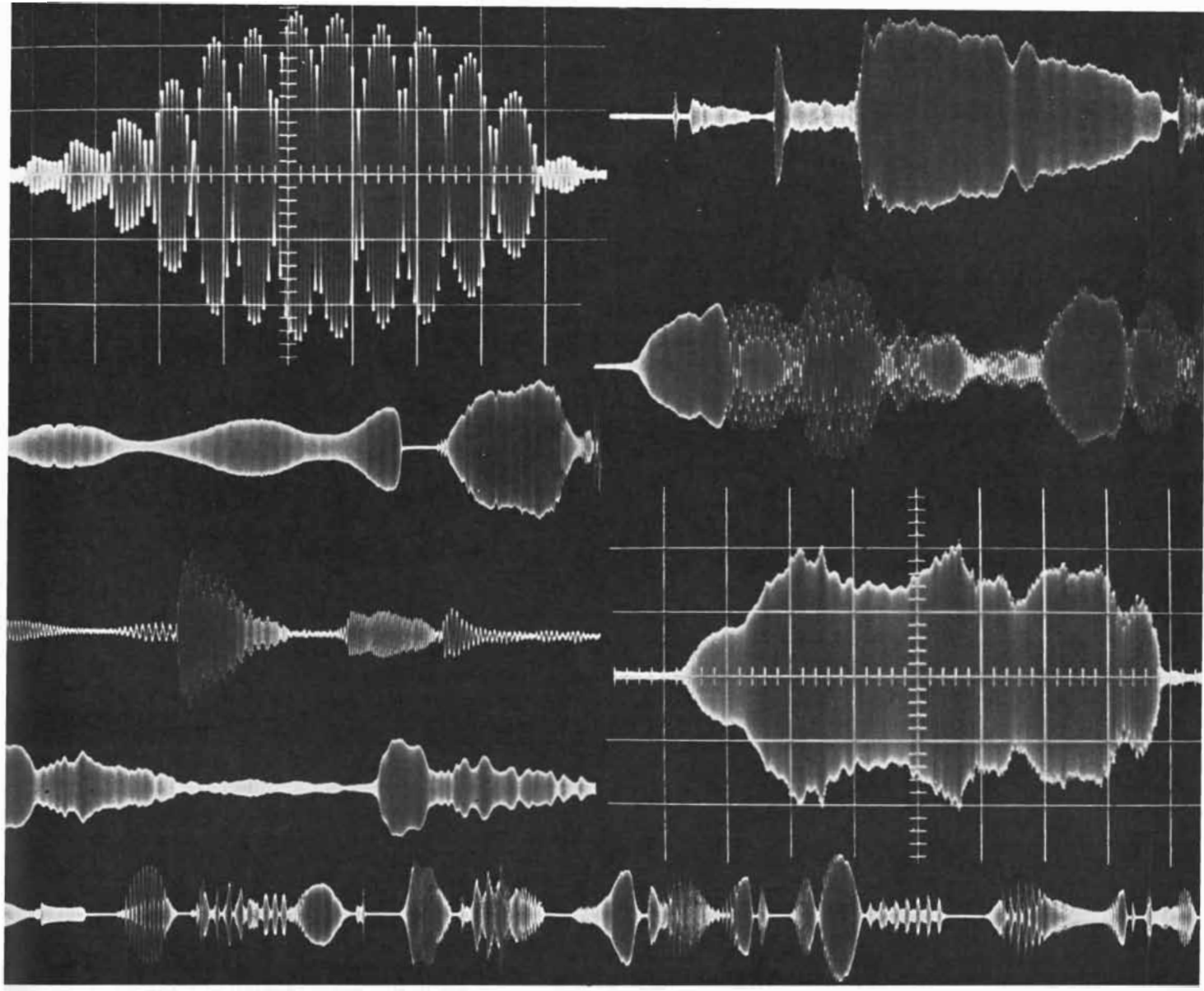
TOTAL INTRAVENOUS FEEDING

GROWTH OF PUPPIES RECEIVING ALL NUTRITIONAL REQUIREMENTS BY VEIN. Stanley J. Dudrick, Harry M. Vars and Jonathan E. Rhoads in *Fortschritte der parenteralen Ernährung*. Symposium of the International Society of Parenteral Nutrition, 1966; West Germany, 1967.

GROWTH AND DEVELOPMENT OF AN INFANT RECEIVING ALL NUTRIENTS EXCLUSIVELY BY VEIN. Douglas W. Wilmore and Stanley J. Dudrick in *Journal of the American Medical Association*, Vol. 203, No. 10, pages 860–864; March 4, 1968.

LONG-TERM TOTAL PARENTERAL NUTRITION WITH GROWTH, DEVELOPMENT, AND POSITIVE NITROGEN BALANCE. Stanley J. Dudrick, Douglas W. Wilmore, Harry M. Vars and Jonathan E. Rhoads in *Surgery*, Vol. 64, No. 1, pages 134–142; July, 1968.

CONTINUOUS LONG-TERM INTRAVENOUS INFUSION IN UNRESTRAINED ANIMALS. S. J. Dudrick, E. Steiger, D. W. Wilmore and H. M. Vars in *Laboratory*



OSCILLOSCOPE TRACINGS OF BIRDSONG FROM "HOW BIRDS SING," BY CRAWFORD H. GREENEWALT, NOVEMBER, 1969.

THE SEPTEMBER ISSUE OF **SCIENTIFIC AMERICAN** WILL BE DEVOTED TO

COMMUNICATION

Animal Care, Vol. 20, pages 521–529; 1970.

INTRAVENOUS HYPERALIMENTATION. Stanley J. Dudrick and Jonathan E. Rhoads in *Critical Surgical Illness,* edited by James D. Hardy. W. B. Saunders Company, 1971.

THE PLANNING OF A MAYA CEREMONIAL CENTER

MAYA ARCHAEOLOGIST. J. Eric S. Thompson. Robert Hale Limited, 1963.

LOCATIONAL ANALYSIS IN HUMAN GEOGRAPHY. Peter Haggett. Edward Arnold (Publishers) Ltd., 1965.

THE RISE AND FALL OF MAYA CIVILIZATION. J. Eric S. Thompson. University of Oklahoma Press, 1966.

MAYA HISTORY AND RELIGION. J. Eric S. Thompson. University of Oklahoma Press, 1970.

EXCAVATIONS AT LUBAANTÚN 1970. *Antiquity,* Vol. 44, pages 216–223; 1970.

TREE RINGS AND CLIMATE

TREE-RING BULLETIN: VOLS. 1–30, 1934–1970. Tree-Ring Society, Laboratory of Tree-Ring Research. University of Arizona.

TREE-RING EVIDENCE FOR CLIMATIC CHANGES IN WESTERN NORTH AMERICA. Harold C. Fritts in *Monthly Weather Review,* Vol. 93, No. 7, pages 421–443; July, 1965.

GROWTH RINGS OF TREES: THEIR CORRELATION WITH CLIMATE. Harold C. Fritts in *Science,* Vol. 154, No. 3752, pages 973–979; November 25, 1966.

AN INTRODUCTION TO TREE-RING DATING. M. A. Stokes and T. L. Smiley. University of Chicago Press, 1968.

THE GREAT AUTOMOBILE RACE OF 1895

LE GÉNIE CIVIL: REVUE GÉNÉRALE DES TECHNIQUES, Paris. 1895 collection.

L'ILLUSTRATION, Paris. 1895 collection.

LA NATURE: REVUE DES SCIENCES ET DE LEURS APPLICATIONS, Paris. 1895 collection.

THE AMATEUR SCIENTIST

THE SCIENTIFIC AMERICAN BOOK OF PROJECTS FOR THE AMATEUR SCIENTIST. C. L. Stong. Simon and Schuster, Inc., 1960.

AMATEUR TELESCOPE MAKING: BOOKS I–III, edited by Albert G. Ingalls. Scientific American, Inc.

SOLAR ECLIPSE PHOTOGRAPHY FOR THE AMATEUR. Eastman Kodak Company, 1969.

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