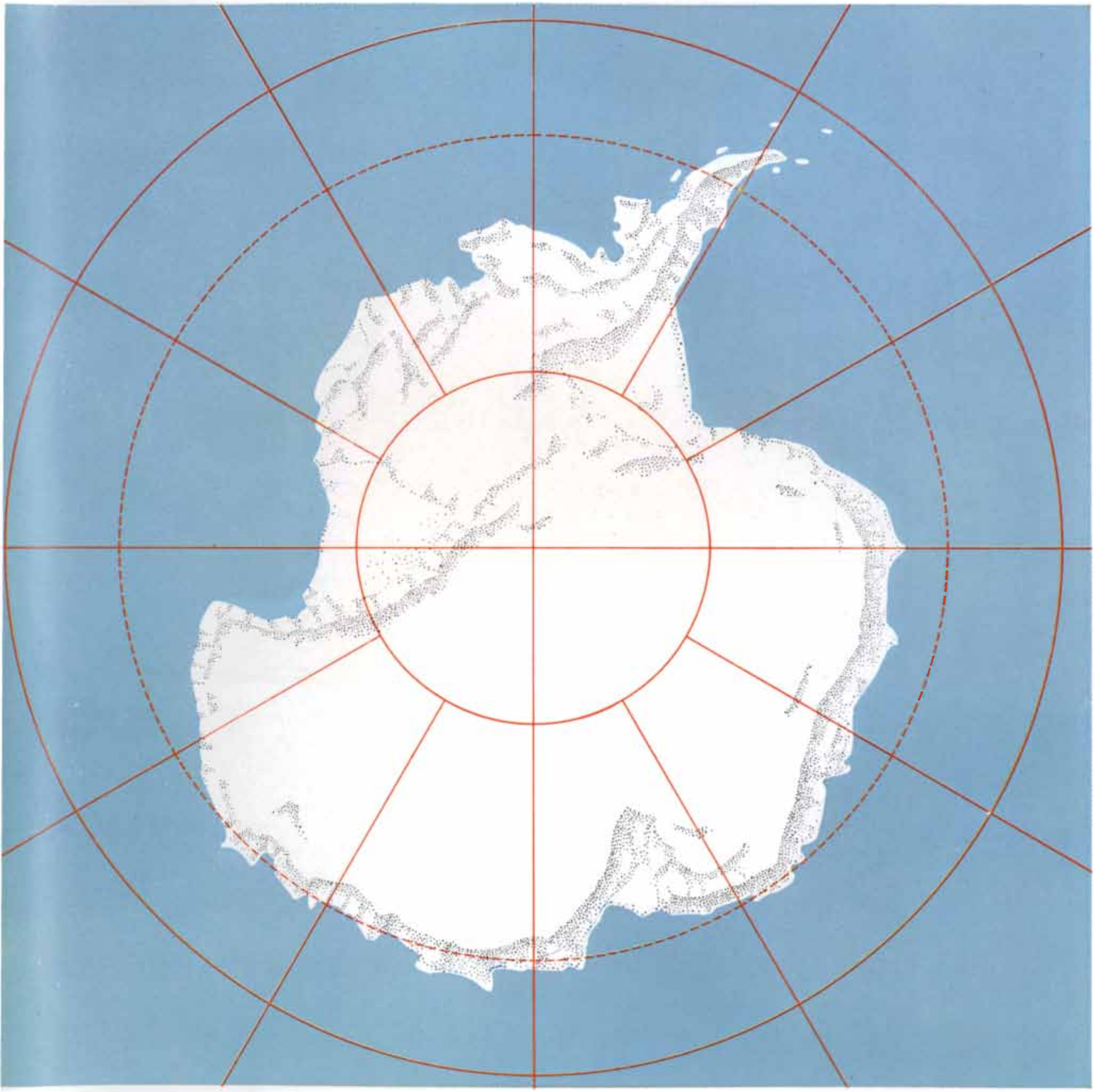
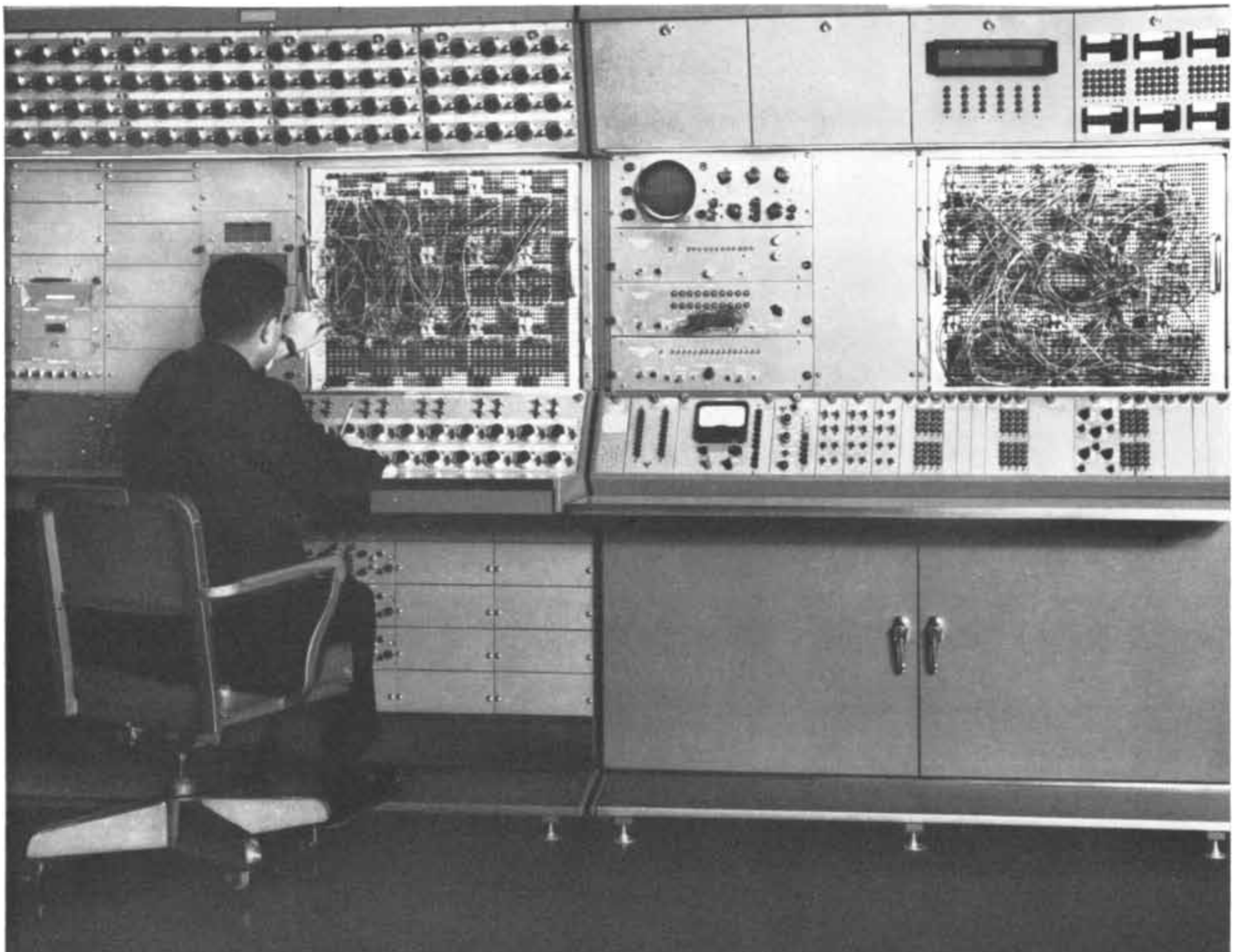
SCIENTIFIC AMERICAN



THE ANTARCTIC

FIFTY CENTS

September 1962



INTRODUCING THE MOST VERSATILE COMPUTER FOR DYNAMIC SYSTEMS SIMULATION

EAI HYDAC Computer, Series 2000, introduces a new dimension to computer simulation by combining analog and digital operation into one integrated system. HYDAC achieves a computational efficiency well beyond the limits of either analog or digital computers alone. Moreover, it offers an economical alternative to tying a complete data processing computer to an analog computer for hybrid computation.

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HYDAC vastly increases the range of dynamic simulations that can be performed by computers. Such applications include iteration and optimization studies, partial differential equation solutions, simulation of logic functions, transport delay and other auxiliary mathematical functions as well as high-speed incremental computation. Full information on HYDAC, the new computer for dynamic simulation, can be obtained by writing for Bulletin HC 6238.

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EAI

ELECTRONIC ASSOCIATES, INC. *Long Branch, New Jersey*

Established 1845 SCIENTIFIC AMERICAN September 1962 Volume 207 Number 3

ARTICLES

DEPARTMENTS

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THE COVER

The map on the cover symbolizes the subject to which this issue of SCIENTIFIC AMERICAN is devoted: the Antarctic. The modeling of the map outlines the relief of Antarctica: the great polar plateau toward the bottom, the Antarctic Peninsula at the top, the Ross Ice Shelf at the left.

THE ILLUSTRATIONS

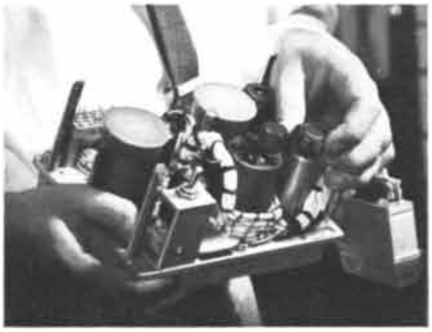
Cover map by Bunji Tagawa

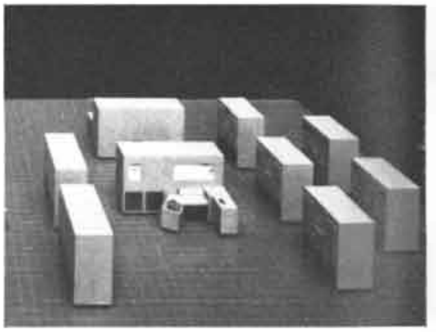
Page	Source	Page	Source
61	Emil Schulthess, Black Star	142	Bunji Tagawa
62–63	Bunji Tagawa	144–146	Alex Semenoick
64	New York Public Library	151	Ned A. Ostenso
65	Paul Popper, Ltd., from Photo Researchers, Inc.	152–153	Bunji Tagawa
66	James Egleson	154–160	Hatti Sauer
67	Hatti Sauer	163	John C. Behrendt
68	U.S. Navy for U.S. Geological Survey	164	Ned A. Ostenso
69	U.S. Navy	166	John C. Behrendt
70–73	U.S. Navy for U.S. Geological Survey	168	William E. Long
75–76	Henry Morozumi	170	U.S. Navy for U.S. Geological Survey
77	Wallace H. Campbell and Harold Leinbach	171	William E. Long
78–80	James Egleson	172–173	Bunji Tagawa
81	R. A. Helliwell	174–176	Thomas Prentiss
82	Joan Starwood	178	U.S. Navy for U.S. Geological Survey
83	Pacific Naval Laboratory	180	Thomas Prentiss
85	Emil Schulthess, Black Star (*top*); Morton J. Rubin (*bottom*)	182	J. M. Schopf
86	Emil Schulthess, Black Star	186	Emil Schulthess, Black Star
87	National Aeronautics and Space Administration–U.S. Weather Bureau (*top*), Alex Semenoick (*bottom*)	188–191	John Langley Howard
88–92	Irving Geis	192–193	Bunji Tagawa
93	Joan Starwood	194	John Langley Howard
94	Irving Geis	196	Eric Mose and Thomas Prentiss
113	Sovfoto	198	Patra McElwee
114–122	James Egleson	200–204	David Linton
124	Emil Schulthess, Black Star	206	Emil Schulthess, Black Star
132–133	Anthony J. Gow	208	National Science Foundation
134–135	David Linton	212	George A. Llano (*top, middle and bottom right*), William J. L. Sladen (*bottom left*)
136	Alex Semenoick	214–215	U.S. Navy
137	David Linton	216	Bunji Tagawa
138	Alex Semenoick	218	U.S. Navy
139	Joan Starwood	220	Robin Leech
140	Mary Russel	223	Roy DeCarava
141	Alex Semenoick	225	David Linton
		226–230	Thomas Prentiss
		238–244	Patra McElwee
		248–262	Roger Hayward

POLARIS—called "America's mightiest war deterrent"—relies on Librascope for target data-input units, ship's position-interpolation units, missile-motion units, guidance-correction input panels, alignment units, and erection units. Like the rest of the Polaris weapon system, these units were delivered ahead of original schedule.

ASROC—The computer which directs firing of the Navy's antisubmarine rocket weapon system, a mainstay of U.S. defense. It is one of the latest of 11 major Librascope contributions to ASW dating from 1940. Many of the underwater fire control systems in the Navy's antisubmarine fleet today were designed and/or built by Librascope.

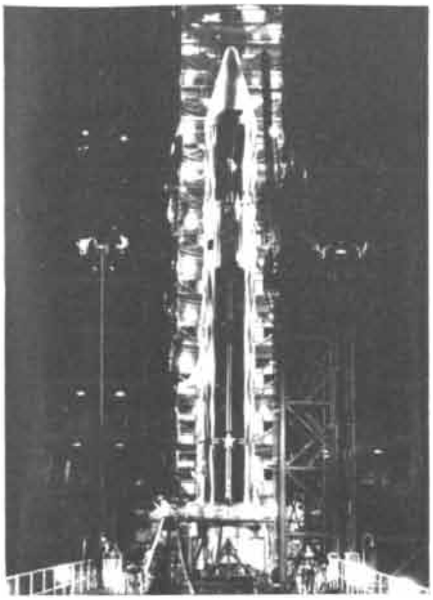
PENTAGON—After 1963, this Librascope multiple-computer system, a key subcomplex of USAF's 473L command-and-control system, will support U.S. global strategy. One of many new, large-scale computing complexes with which Librascope serves the growing needs of business management, science, and the defense establishment.





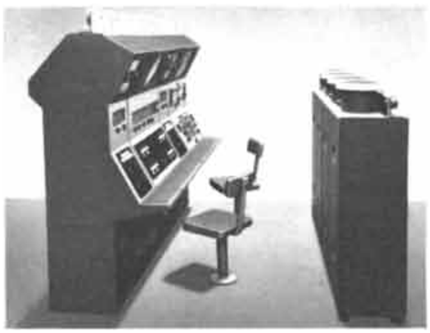
HOW LIBRASCOPE COMPUTERS AND DATA-PROCESSING SYSTEMS SERVE ADVANCED PROJECTS

From tactical weapon control to space research to Pentagon strategy, some of the nation's most advanced military and scientific projects depend on Librascope equipment for data interpretation and the control of weapons and operations. Dependability of performance is steeped in the maturity of Librascope experience that dates from the earliest years of computer technology. Above are examples of electronic and electromechanical



CENTAUR—The first computer designed to guide an exploratory instrument package to a soft landing on the moon will be carried aloft inside NASA's Atlas/Centaur spacecraft. One of the smallest and lightest general-purpose digital computers known, it is typical of many environmentally designed Librascope computers for space vehicles and missiles.

SUBROC—Fire control for the Navy's first four-phase ASW weapon system is furnished by this Librascope digital computer. It directs the complex target approach pattern of a subsurface-to-subsurface weapon with four modes of operation on every shot: underwater launching, atmospheric boost-glide trajectory, water re-entry and target contact.



AIRLIFT—This Librascope navigation/data-processing system will participate in global airlift missions aboard the C-141 turbofan transport. Inputs: heading reference, air data, TACAN, LORAN, radar celestial tracker. Outputs: to autopilot, flight-director computer, attitude director/indicator, horizontal-situation indicator, heading/bearing/distance indicator.

nerve centers produced by Librascope for systems in today's news. ☐ The needs of commerce and industry, too, are met by a wide variety of computers developed and produced by Librascope for scientific and engineering studies, operations analysis, product research, industrial process control, and air traffic control. ☐ Whether your project is industrial, military, or government, consider taking your computer-control, data-processing requirements to the developers of many major operational systems.

LIBRASCOPE DIVISION

GENERAL PRECISION

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TESTS OF YOUR READING YOU CAN MAKE RIGHT NOW

What is your present reading speed? A full column in this magazine ordinarily runs to around 440 words. Read any one of these columns now and time yourself with a watch having a second hand. If you take more than 55 seconds, it is practically certain that your speed and comprehension can be improved by the training and practice material in this program.

How many "fixations" do your eyes make on each line? In reading, your eyes actually move in little jumps, with momentary pauses in between called "eye fixations." Try reading the main article in this magazine. You should get across each line of this width and type size in not more than two "eye fixations." If there are more—if there are three, four or five—it shows your eye span is too narrow. It can be vastly widened by the exercises provided.

Do you find yourself reading word by word, instead of in groups of words or phrases? If so, you should subscribe to this study program by telegram.

Do you regress continually, looking back every line or so to check up on a word or words you either missed or misunderstood? Try this on any article in this magazine. If you find yourself regressing frequently, obviously this is slowing down your reading speed. In most cases this is pure habit, and with simple training can be almost totally eliminated.

How well do you retain what you read? Here is a fair immediate test. You probably read the major front-page news article in today's newspaper. Without referring back, write down in a few words specifically what the article was about, and the important places and persons mentioned. After you have done this, go back to the article and see how attentively you actually did read it. This will reveal your present standard of comprehension and retention. If it is unsatisfactory, it can be noticeably improved in as few as three lessons.

You should be aware of marked improvement in your reading speed and comprehension after trying this first lesson. If not, it may be returned within two weeks, together with the two instruments described below, and the trial subscription will be ended at once. That is, the first portfolio *need be paid for only if it is kept*. Contents of the portfolio: Basic Instruction Guide, Training Manual, Eye-and-Mind Practice Section, Reading-Pacer Practice Material, Speed-and-Comprehension Tests, Reading-Improvement Chart (to record your progress).

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is the monthly rental on a solid-state high-speed binary computer ideally suited to scientific applications—the GE-225

This low price includes a 4096 word magnetic core memory plus paper-tape reader and punch and the typewriter. For only $2675 you could have the same system with a card punch and reader in place of the paper-tape unit. This gives you all you need to handle scientific and engineering problems. You don't have to buy any "extra" features, and you can have 90 day delivery.

Why is the GE-225 such a successful scientific machine? Because it's designed strictly along big computer lines: high speed arithmetic, 18μs memory access, a full-scale scientific language, double-word capability, over 150 commands, including input-output.

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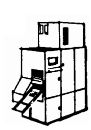
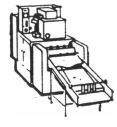
If you'd like to know more about how the GE-225 has been tailored to your scientific needs, write Mr. E. V. Scott, Manager of Scientific Sales, General Electric Computer Department, Section U9, Phoenix, Arizona.

Progress Is Our Most Important Product

GENERAL ELECTRIC





PROJECT: PROVE RELIABILITY

This research specialist is subjecting a military power package to programmed torture. Purpose . . . establishing design and hardware reliability. This type of practical research was applied to the development of a 700 HP aluminum compression ignition engine weighing about four pounds per HP.

A standard procedure at Caterpillar, testing of this type is used regularly with new components, engines and vehicles. A new facility has been completed which will expedite these engine testing programs through the built-in fuel, water, exhaust, control and instrument systems.

A six-winged building of 164,000 sq. ft., the new Engine Research and Development Laboratory houses a complex of 72 testing cells where a wide variety of engines can be tested.

Each cell is air conditioned to 75° Fahrenheit and is maintained at a slight vacuum. Each has its own inertia block to eliminate the transfer of vibration from one test zone to another. Each is completely soundproof. The researcher and the engine are separated by thick pane glass panels.

During testing, an automatic console control permits the researcher to subject the engine to any of the many stresses and strains it could encounter during its work life. With the flick of a switch or the turn of a dial, the specialist can adjust the water temperature of the cooling system, the horsepower, the oil and fuel pressure, the RPM, the load and torque, or many other conditions.

The effect these changing conditions have on the engine's performance is accurately measured at the console. Test results are correlated—and often predicted—by digital and analog computers. The analysis of these results is combined with the findings of a physical examination of individual parts for ways to provide maximum reliability.

Another building soon to be ready at the Technical Center is the Gas Turbine Engine Laboratory. Here will be housed facilities for the research group which has been exploring this exciting new engine concept for the past five years.

When the Center is completed it will consist of six buildings. It will house 1400 engineers, physicists, applied mathematicians, chemists, metallurgists, instrumentation specialists and laboratory technicians who are part of the Caterpillar research and development team.

It will provide needed additional space and facilities for the intensive research currently going on in metal fatigue, high-speed rotational phenomena, fluid mechanics, fuels and lubricants, special studies in basic materials, and dozens of other projects.

This type of research helps assure you of effective performance, with minimum maintenance, from specialized vehicles such as the AUET and eight-ton GOER vehicles, and new-concept power packages such as the LDS-750 and LVDS-1100 aluminum engines.

For more information about how Caterpillar's expanding R & D facilities can contribute to the solution of your ground mobility problems, write Defense Products Department, Caterpillar Tractor Co., Peoria, Illinois.

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SILICOLOGY

REPORTING ON:

An Innovation in Silicone Technology

New Organo-Silicone Surfactants: Water Soluble and Non-Hydrolyzable

Ten years ago, UNION CARBIDE invented and developed the L-520 type organo-silicone block copolymer . . . and now, UNION CARBIDE's research and development leadership scores another breakthrough with three new non-hydrolyzable organo-silicone copolymer compounds.

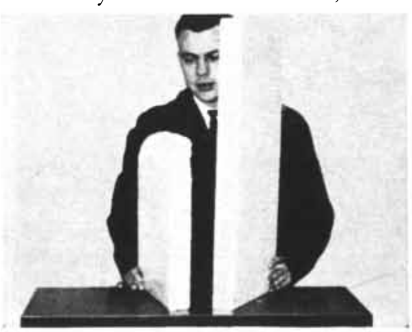
The new products—L-530, L-531 and L-5310—are stable in water, surface active, possess superior release and lubricating properties—*and are completely soluble in water, some alcohols and a number of other organic solvents.* As a result, these highly versatile silicones potentially can revolutionize the products of many industries—paint, plastics, automotive and others.

HOW THE COPOLYMERS ARE MADE

These new organo-silicones are the product of block-polymerization, as opposed to hetero-polymerization. They are formed by polymerizing a group of organic monomers, then a separate group of silicone monomers. When these groups are combined, they become a block copolymer. Result: an end-product which retains many of the properties of both starting materials while blending them into a workable whole.

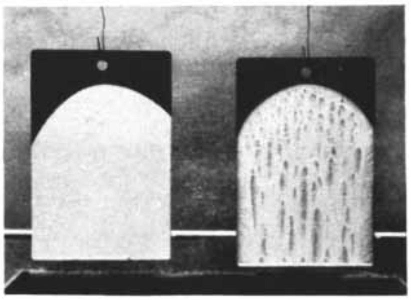
REMARKABLE VERSATILITY

Union Carbide's new non-hydrolyzable organo-silicone copolymers are already finding use as stabilizers for rigid polyether urethane foam. They provide more uniform cell structure—controlled so well that nearly all the cells are closed, resulting in much higher thermal insulating efficiency and excellent storage stability. Other interesting uses:



AS AN ANTI-FOAM—Their low surface tension makes them an excellent foam suppressant when added to a system where they're insoluble in the foaming medium. The chemical process industries should find interest in this new family of surface active agents with unusual solubility and anti-foam performance.

IMPROVED PAINT FLOW-OUT—Poor flow-out can occur in latex paints. Dimethyl silicones are effective flow-out agents, but they are not soluble and tend to form fisheyes and cause poor adhesion of subsequent coats. L-530 improves flow-out, minimizes adhesion problems.



NEW HIGH IN LUBRICITY—These new compounds far outperform dimethyl silicone oil in lubricity, exhibit a smaller viscosity change than petroleum oils when subjected to changing temperatures, and extend operating temperatures to 50°F or more above that of petroleum oils.

SUPERIOR RELEASE AGENT—Conventional silicones are excellent release agents, but their high surface activity and solubility often interfere with subsequent coating operations. L-530 fluids exhibit fewer undesirable side effects, and permit coatings on molded parts that are even, firmly adherent and less inclined to peel.

HIGH ANTI-STATIC AND ANTI-FOG PERFORMANCE—A coating of UNION CARBIDE L-530 or L-531 on vinyl phonograph records prevents a buildup of dust-collecting static. On eyeglasses, mirrors, automobile windshields, the new organo-silicones offer an excellent defense against fogging.

TECHNOLOGICAL LEADER

UNION CARBIDE is the leading innovator in silicone technology. Development of this new family of organo-silicone fluids is just one example of its research and development. In addition to its own resources, the Silicones Division also has the cooperation of the vast facilities of UNION CARBIDE Corporation and its Divisions.

If you have a production problem, we urge you to call your UNION CARBIDE Silicones Man. Whatever your needs in any field of silicones, he can fill them. For full information, send us the coupon now.

UNION CARBIDE

SILICONES

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Please send me data on UNION CARBIDE non-hydrolyzable silicone copolymers. I am interested in their ________ properties.

NAME ________

FIRM ________

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"Why we chose the NCR Computer." —S and W Fine Foods, Inc., *San Francisco*

"With the many items in our product line, we have urgent need for a data processing system which permits fast random access to data stored in our billing, accounts receivable, and inventory files. After a thorough investigation, we chose the NCR 315 Computer which features CRAM . . . Card Random Access Memory . . . as the one best suited to our particular data processing requirements.

"CRAM will enable us to store all the required billing, accounts receivable, and inventory data on-line with the computer. Then as sales data is introduced, the computer will make all the necessary billing extensions, post the accounts receivable, and reduce the separate inventories—all on an extremely fast random access basis.

"Being in a business where QUALITY is of paramount importance, we were very impressed with the quality built into the machines which make up the NCR 315 System. Similarly, we were impressed with the quality built into NCR's software—in both the standard programs and backup support offered.

"In summary, we are certain the NCR 315 CRAM Computer System will be a highly profitable investment."

J. Koregelos
Controller
S and W Fine Foods, Inc.

NCR PROVIDES TOTAL SYSTEMS—FROM ORIGINAL ENTRY TO FINAL REPORT—
THROUGH ACCOUNTING MACHINES, CASH REGISTERS OR ADDING MACHINES, AND DATA PROCESSING
The National Cash Register Co.•1,133 offices in 120 countries•78 years of helping business save money

NCR

LETTERS

Sirs:

May I offer a slight correction to L. Don Leet's article "The Detection of Underground Explosions" in your June issue?

Small earthquakes, recording comparably with the Bikini test Baker of 1946 (which was under water, not underground), often appear on Benioff seismograms with only the P phase and no subsequent identifiable motion. Our seismogram file, beginning with the first Benioff installations in 1931, includes thousands of such recordings. They are frequent at distances near 8,000 kilometers, that of the Bikini test Baker recording.

Otherwise the article is a reasonably good simplified summary of what was generally accepted about 1956, before the Rainier test and other significant developments. I recommend it to qualified students as an introduction to the problem before they go on to examine the great progress of the past few years.

CHARLES F. RICHTER

Professor of Seismology
Seismological Laboratory
Division of the Geological Sciences
California Institute of Technology
Pasadena, Calif.

Sirs:

I am puzzled by Professor Richter's letter. He fails to mention several important features of the combination of criteria the article explains. And he does not explicitly state that my proposals will not work. If his remarks are meant to imply this, I should like to point out that a single set of records from the three distance zones should establish the incorrectness of my position. If he, or anyone, will produce a set of seismograms from an earthquake that shows the characteristics I feel are unique for underground explosions, the argument is over. Nobody has done this to date.

In view of recent press releases from the Department of Defense, concurred in by the State Department and the Atomic Energy Commission, that there has been "little change" in previous conclusions about the difficulties of detecting underground nuclear explosions, it is a pity that Professor Richter has not

specified the great progress of the past few years to which he refers.

L. Don Leet

Seismograph Station
Harvard University
Harvard, Mass.

Sirs:

E. Cuyler Hammond's article on the effects of smoking contained a great deal of information without, it seems to me, giving the numbers that would be most meaningful to a reader. The author indicates that smoking shortens life, but then he lists only relative death rates. A little computation using an actuarial table and his relative death rates would show that a smoker of two packs a day has, at age 30 or 40, a life expectancy of something like eight years less than a nonsmoker; that if this smoker quits, he may recover around four of those years. The author might also estimate with somewhat less certainty that his statistics suggest that each cigarette smoked reduces the life expectancy of the smoker by around five minutes.

It is important that such computations based on the data be distinguished from the data itself, but I believe they clarify the meaning of his statistics sufficiently to be made and included.

Walter A. Harrison

General Electric Research Laboratory
Schenectady, N.Y.

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ANACONDA COMMENTS...

new facts about copper—man's oldest metal

NUMBER 7 OF A SERIES

ANACONDA COPPER: KEY ELEMENT IN COMMUNICATIONS CABLE FOR LEADING MISSILE DEFENSE PROGRAM

A complex communications cable, now in the making for an important missile defense GSE program, will be protected with a near-surface layer of corrugated Anaconda copper. This key element of the cable will shield strategic communications wiring from outside electrical and mechanical interference. Selecting a copper metal which met rigid strength and fabrication requirements, yet delivered the extremely high conductivity also specified, is a dramatic demonstration of Anaconda capability at work.

GSE requirement

Cable construction called for copper armor sheath of either soldered-joint dual 10-mil-thickness construction, or welded-seam single 20-mil-thickness construction. In this application, the welded-seam design was unquestionably preferable. However, material requirements then became critical. Not all coppers could be seam welded successfully by inert-gas, tungsten-arc welding techniques—and still withstand the corrugating operation without developing gross porosity and fractures.

Other limiting considerations were high conductivity: 96% IACS minimum requirement. And tensile strength: 35,000 psi, minimum after corrugation.

Anaconda solution

Several copper products were likely contenders. One type of copper, from a new production facility, was available in potentially adequate supply; this product was competitively priced—but untried.

The decision was made to try it, and to make refinements as they became necessary. Thus, Anaconda selected DLP (Deoxidized Low Phosphorus) Copper . . . and embarked upon a crash program to evaluate weldability, conductivity, and other properties indigenous to the application.

Anaconda American Brass Company cooperated closely with the copper refinery and the fabricators, Anaconda Wire & Cable Company and Simplex Wire & Cable Company, in the development of a DLP Copper strip that met all of the exacting specifications. The product is currently being supplied in 3600-foot coils, by Anaconda American Brass Company.

This Anaconda development work enables all strategic installations involved to utilize GSE communication cables sheathed with welded-seam DLP Copper.

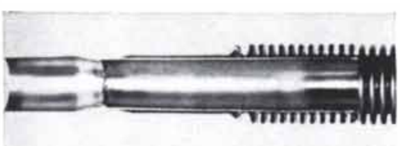
ANACONDA METAL HOSE MEETS HARSH ELEVATED-TEMPERATURE EXTREMES

Anaconda's Metal Hose Division has supplied core-tube assemblies for the heat exchanger system of the Hallam Nuclear Power facility, Hallam, Nebraska. The Hallam reactor, constructed by Atomics International, a division of North American Aviation, Inc., for the Atomic Energy Commission, will provide nuclear-initiated power for public consumption.

The heat exchanger system, built at the Griscom-Russell plant of Baldwin-Lima-Hamilton Corporation, consists of three evaporator and three superheater units—each of which, in turn, is comprised of a honeycomb bank of about 600 shroud and core tubes. Every shroud tube contains an Anaconda ¾″ OD stainless steel vacuum-insulated core tube, which is a duplex concentric assembly.

590°F Variation

Essentially, the commercial atomic power reactor utilizes heat extracted from liquid sodium to produce steam for the final source of power. The liquid sodium passes through the inside of the core tube, picks up nuclear-generated heat, and returns over the corrugated outside of the tube at a much higher temperature. To compensate for unequal thermal expansion, Anaconda produced duplex core tube with



a corrugated flexible outer section and a smooth inner section. The space between these inner and outer components is evacuated and leak tested during manufacture, and then filled with argon gas and sealed by Heliarc welding.

Result: Excessive thermal stress is minimized. The core tubes successfully withstand temperature differential ranging from 304 to 895°F.

The Hallam project called for 37,000 core tubes for its three generator units. This added up to 15 tons of thin wall stainless steel tubing in the rigid members, plus almost 2½ miles of corrugated flexible metal hose. Requirements, as might be imagined, were exacting; virtually every inch of tube had to be proved leakproof. Completing the order is dramatic evidence of Anaconda ability to meet new industrial challenges.

Baldwin-Lima-Hamilton built evaporator bundle being inserted in shell contains a honeycomb network of Anaconda core tube, built to withstand temperatures ranging from 304 to 895°F.

CALL ON ANACONDA

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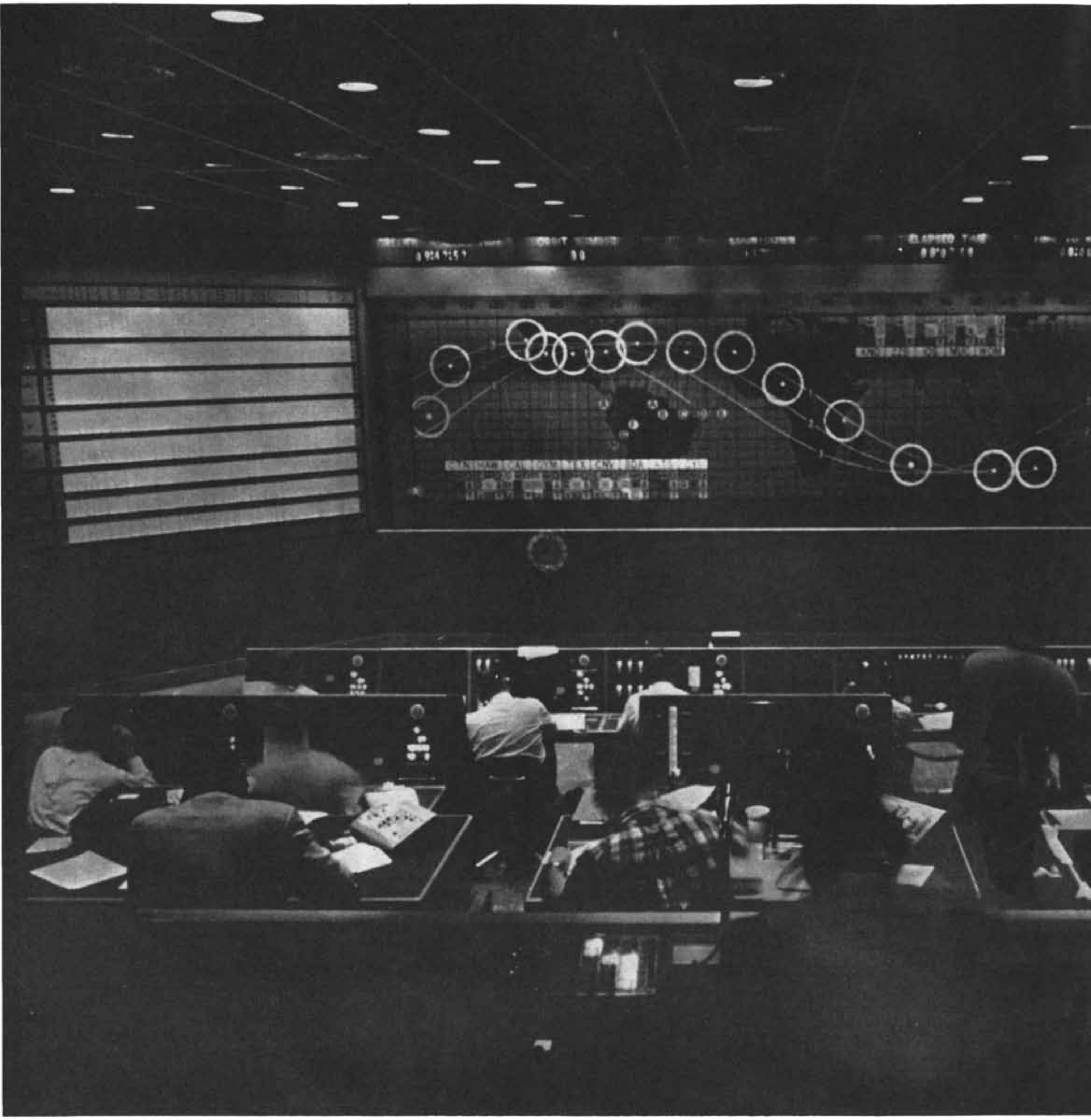

Challenging career opportunities at General Dynamics|Electronics – San Diego. Above is the NASA Project Mercury Control Room created by General Dyanmics|Electronics under

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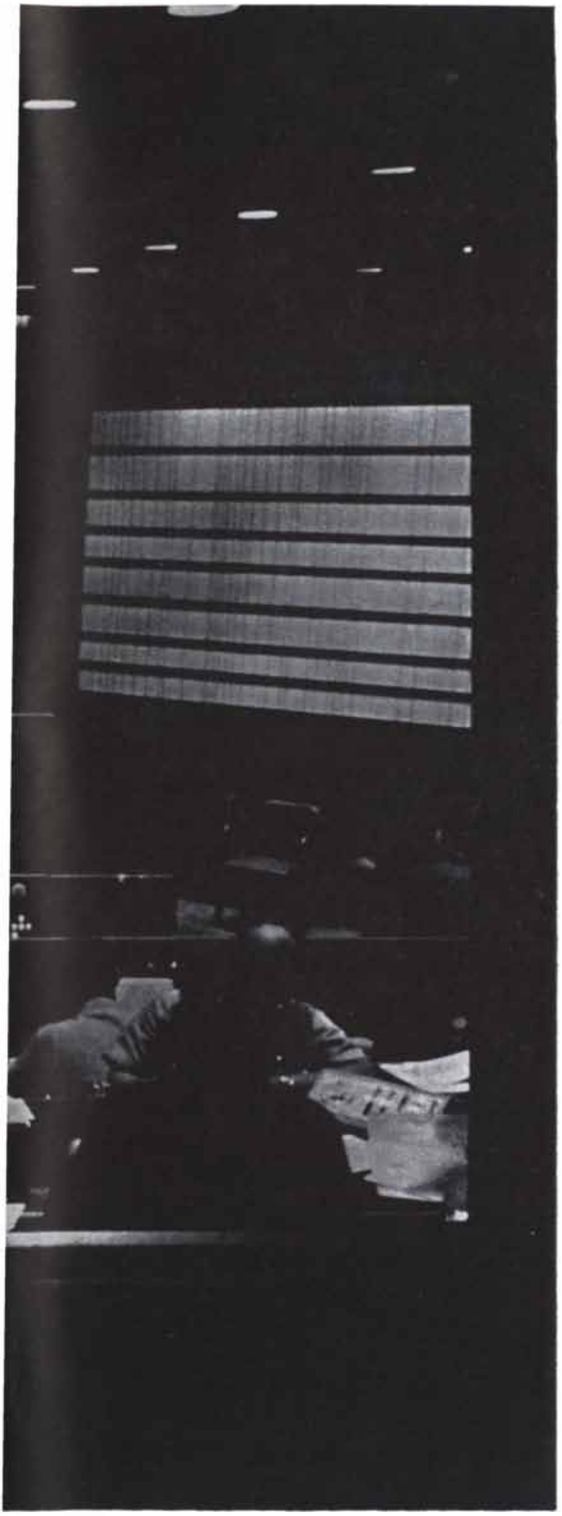
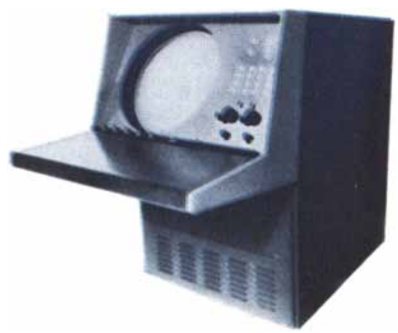


contract to Bell Telephone Laboratories for Western Electric Company.

Two new communications tools, perfected by General Dynamics | Electronics research and experience, offer marked advantages to a wide variety of users in the command and control systems field. They are the 3070 Communications Printer and the 1090 Direct View Display.

The 3070 Communications Printer operates at speeds from 400 to 5000 words per minute using standard computer or communications codes over telephone, telegraph and microwave links. The unit prints asynchronously utilizing an electrostatic process to produce highly legible, permanent copy. It is compact, reliable and quiet enough to use in an office.

The 1090 Direct View Display combines high speed, high resolution, compact dimensions, low cost and large 19-inch CHARACTRON® Shaped Beam Tube capable of displaying 1000 flicker-free characters simultaneously anywhere on the tube face. The unit is capable of tabular, situation or graphical presentations and is ideal for computer intervention, monitoring and retrieval jobs, laboratory, simulation, traffic control and surveillance work. If you would like more information about how these units can help you solve your command and control problems, write General Dynamics | Electronics, Dept. C-67, P. O. Box 127, San Diego 12, California.



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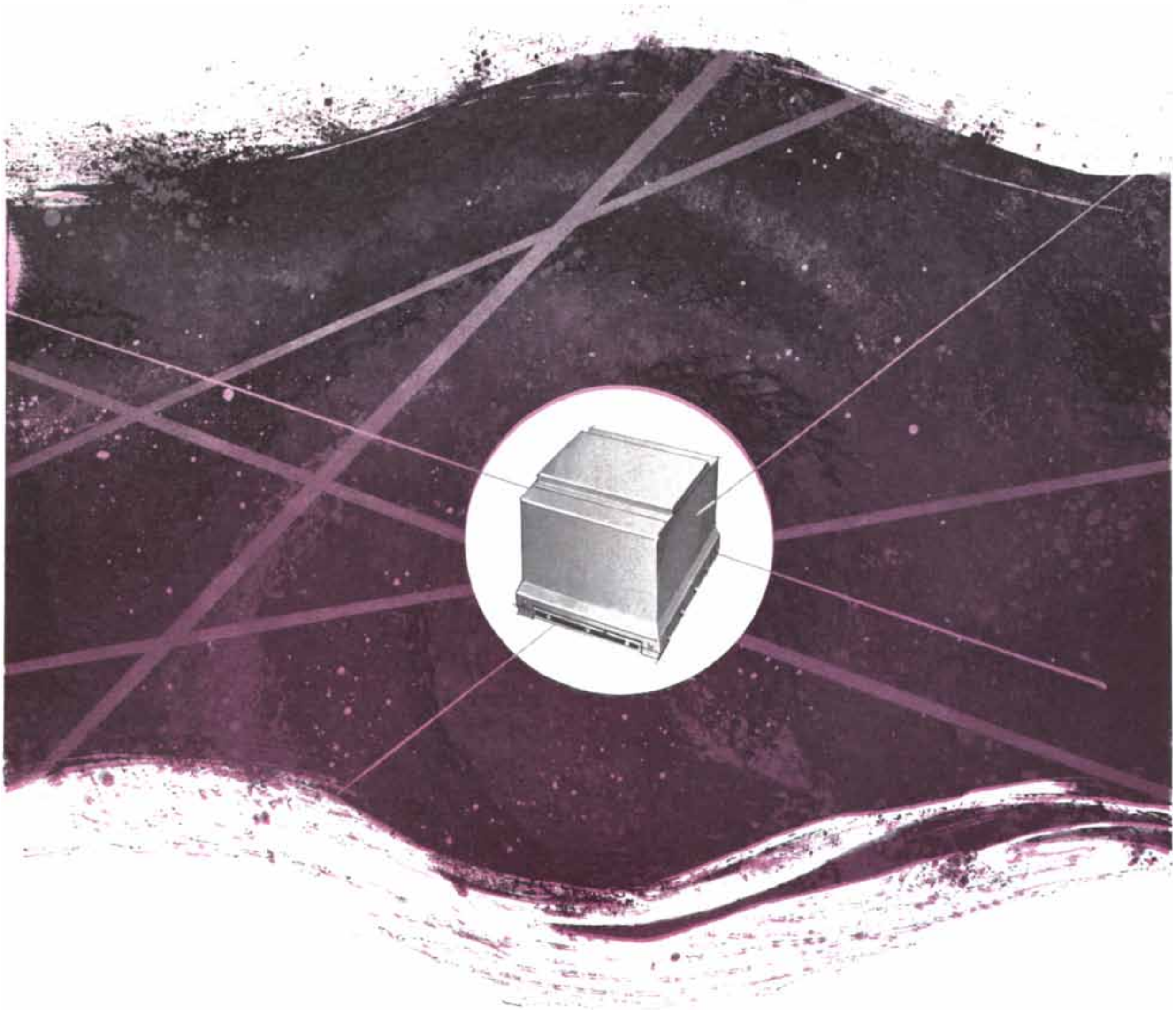

this computer withstands space age punishment

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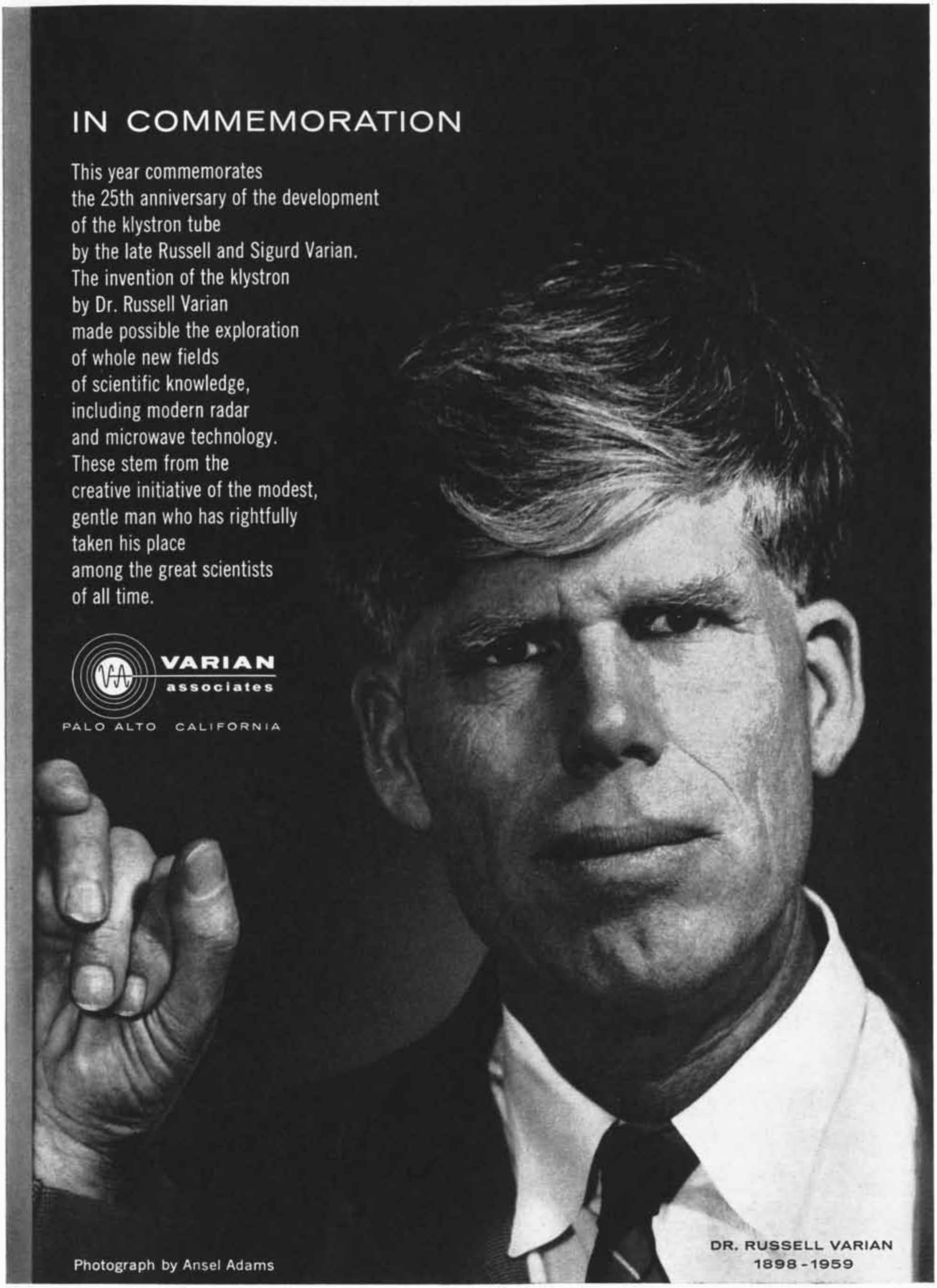

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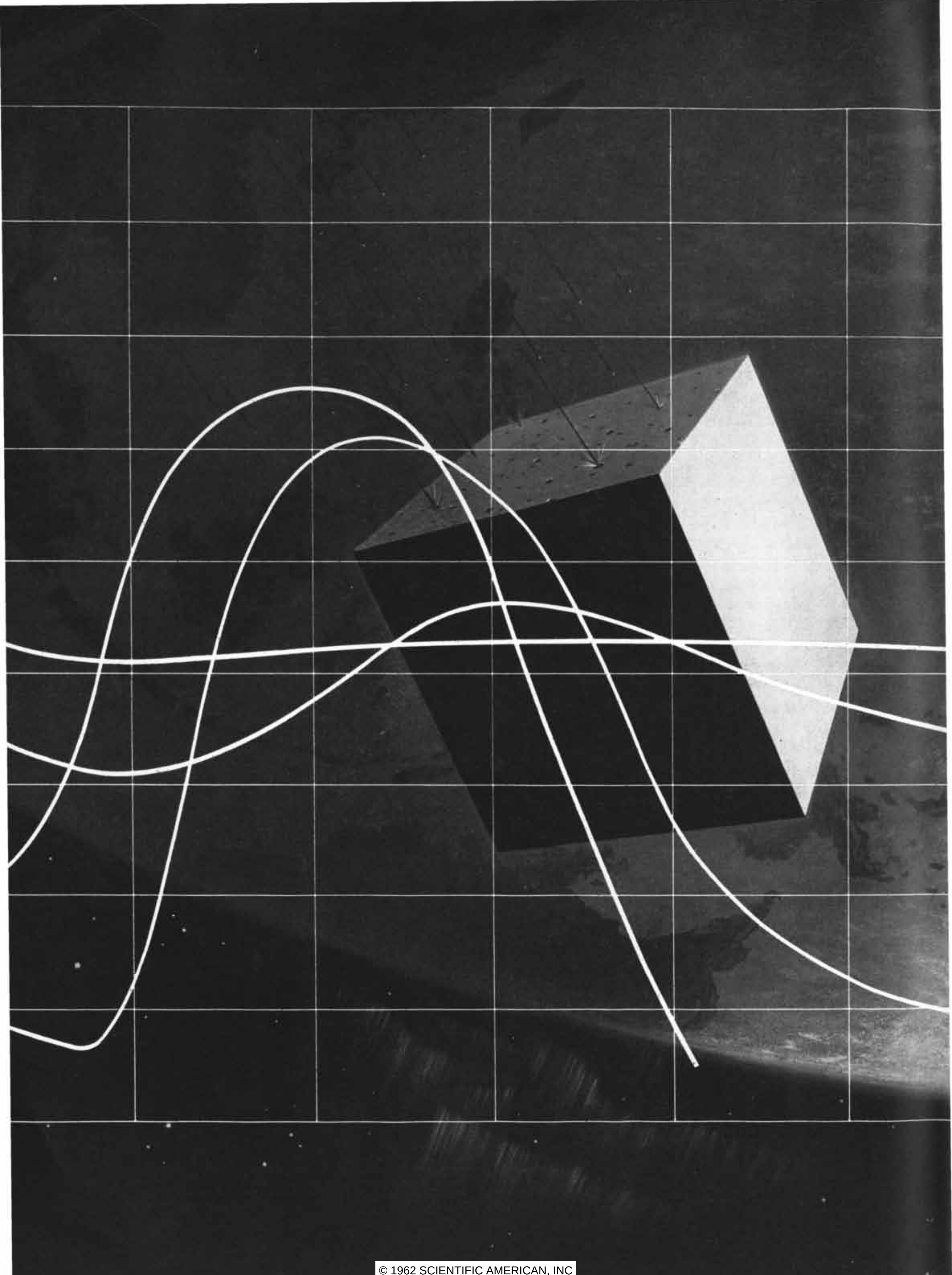

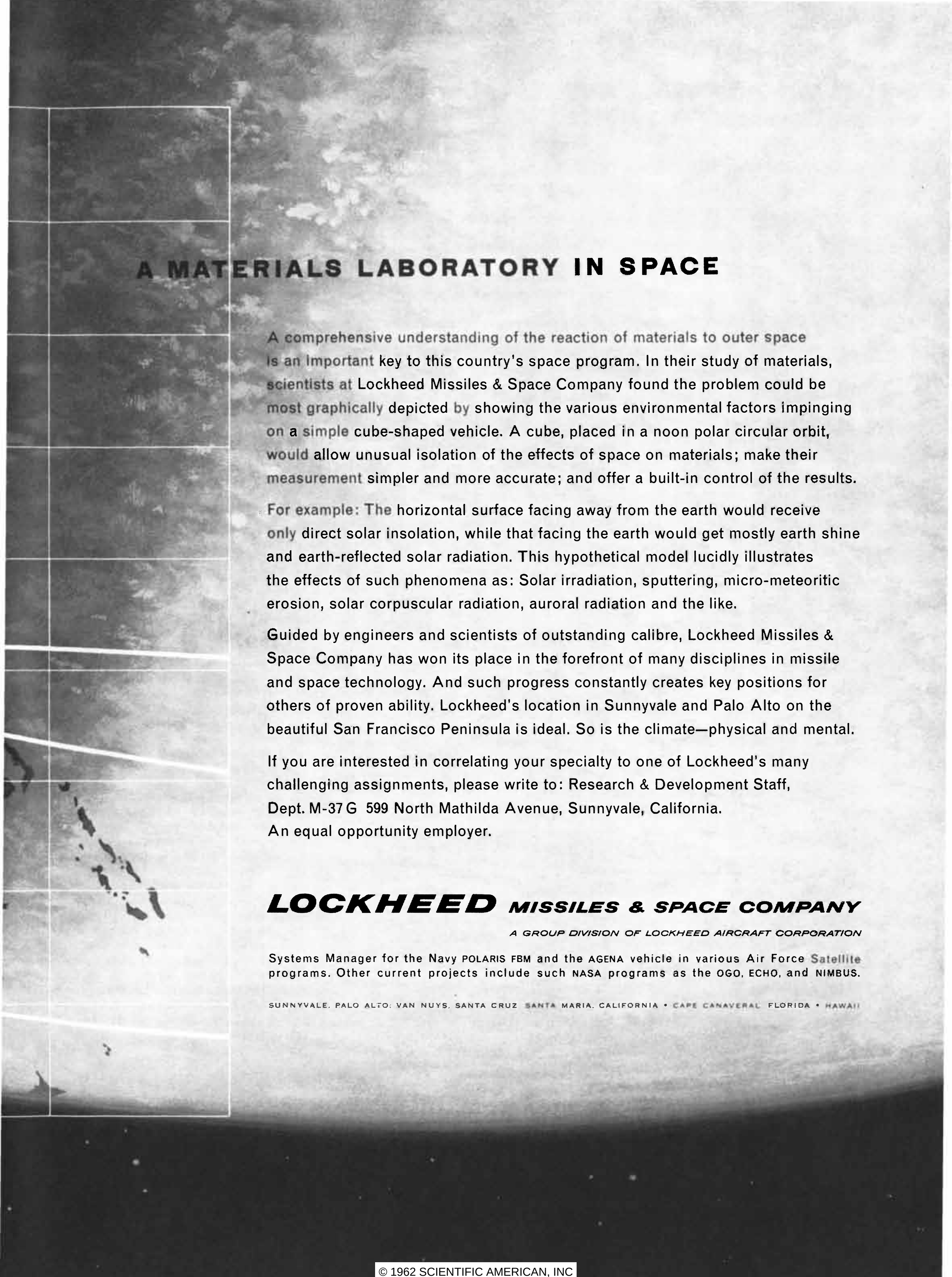
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Guided by engineers and scientists of outstanding calibre, Lockheed Missiles & Space Company has won its place in the forefront of many disciplines in missile and space technology. And such progress constantly creates key positions for others of proven ability. Lockheed's location in Sunnyvale and Palo Alto on the beautiful San Francisco Peninsula is ideal. So is the climate—physical and mental.
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50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

SEPTEMBER, 1912: "Replying to a communication from the Secretary of the Board of Harbor Commissioners in Los Angeles, Col. Goethals states that every effort is being made to complete the excavation and the work on the locks of the Panama Canal by June 30, 1913. He expects to see the level of Gatun Lake at 85 feet sometime in September, 1913. If this be accomplished and the first boat be successfully put through the canal, announcement will be made that it is in condition to pass shipping. This, the Colonel says, will allow of a year's tryout before the formal opening."

"Baron Nordenskjöld's classic feat of sailing completely around the northern coasts of Europe and Asia, accomplished in 1878–79, is likely to be repeated in the near future. The Russian ice-breakers *Taimyr* and *Waigatsch*, now engaged in a surveying expedition along the coasts of Kamchatka and arctic Siberia, may possibly continue westward all the way to Archangel, via the Arctic Ocean. A much more elaborate expedition, however, is being organized in Germany by Lieut. Schröder-Stranz, who proposes not only to make the Northeast Passage but also to spend three or four years in the journey, carrying out extensive scientific researches *en route*."

"The United States leads the world in total number of telephones by a wide margin. There are in the United States 67.4 per cent of all the telephones, and only 26.3 per cent in Europe. As against our seven and a half million telephones, the German Empire has but little over one million, whereas Great Britain comes next with 649,000 and France third with 232,700. There are in New York City alone more telephones than can be found in Belgium, Norway, Denmark, Hungary, Italy and the Netherlands combined. Chicago alone has more telephones than France, and Boston has more than Austria."

"The automobile industry, says *Electricity* (London), is showing a tendency to supersede nickel-plating by silver-plating for the bright parts of motor vehicles. Nickel-plating, notwithstanding its hardness, has the disadvantage that when exposed to the weather it becomes coated with a film of oxide hard to remove. Silver has a whiter color and is capable of a richer and finer polish. The surface does not peel or corrode and when tarnished is far more easily polished."

"Spitsbergen stands in wireless communication with the mainland of Europe through the stations of Greenharbor, near Hammerfest. We read in *Cosmos* that considerable trouble has been experienced through the interference of the aurora borealis, which at times almost totally obliterates the signals."

Scientific American.

SEPTEMBER, 1862: "Elias Howe, Jr., the well-known inventor of the sewing machine, has not only given thousands of dollars to the Union cause but has also joined the 17th Connecticut Regiment as a private, and with gun in hand and knapsack on his back is now serving his country in the defense of Baltimore."

"Since the experiments of Mr. Joule in obtaining a mechanical equivalent for a unit of heat, by proving that the temperature of a pound of water will be raised by 1° by the same quantity of power that will raise a weight of one pound 772 feet high, the theory that heat is a condition of matter and not a substance is more generally admitted than formerly. But the popular idea of a material heat is one from which it is very difficult to disembarrass the mind. But as the mind becomes familiar with the idea of heat as a sensation, the various changes of matter daily occurring in nature can all be satisfactorily viewed without recurring to the notion that any invisible substance is entering or leaving the particles."

"The works of A. Krupp, at Essen, Prussia, have obtained a world-wide celebrity for the production of the most massive and perfect steel castings. Krupp's display in the London Exhibition has astonished and puzzled the English workers in steel. The London *Engineer* states that Krupp's apparatus for making steel is the most gigantic in the world. He has a steam hammer that

weighs 50 tuns and an anvil that weighs 192 tuns, resting on eight blocks of cast iron, each weighing 135 tuns."

"Several miles of the underground railway under the streets of London are completed, a locomotive is on the track, and the whole will be opened to the public on the 1st of October next. The London *Times* states that the underground locomotive used condenses its steam and emits no smoke. The passenger carriages are lighted with gas, the tunnel is also lighted with gas and is well ventilated and dry. The intention is to run trains every ten minutes during the day, and the fares are to be lower than those of omnibuses for the same distance. In second-class carriages the fares are to be four cents for about four miles, and one train morning and evening is to run for two-cent fares."

"The *Great Eastern* arrived at her destination near Harlem in Long Island Sound on the 27th ult., with about 1,400 passengers and a general cargo. When passing Montauk Point she struck a sharp sunken rock, which opened a leak through which the water entered so fast that the pumps were unable to keep it down. Since the ship is divided into several water-tight compartments by bulk heads, only one has been filled by the leak. Her bottom has been examined and will be repaired before she proceeds on her return voyage. The damage is but slight and none of the goods were injured."

"A new development in the history of iron-clad ships has been made, for which the country is indebted to the genius of Com. Porter, the gallant destroyer of the once formidable rebel ram *Arkansas.* Unable to adopt for service in the Western rivers the heavy plating used on the *Monitor* and the *Ironsides*, Com. Porter conceived the idea of constructing the *Essex* in such a manner that most of the shot would be received at an angle and be compelled to glance off by an elastic backing to the plates. By careful experiments on targets he found that by using a peculiarly prepared lining of India rubber between the iron plates and the wooden backing, an iron armor only one inch thick would not be affected by a shot that would penetrate five inches of solid iron. The immense saving of weight and of expense effected by this important discovery will at once be appreciated. Indeed, it is the only method by which the use of iron-clad gunboats on our Western rivers is practicable."

The story of the indomitable spark plug and a World War I airplane engine called Liberty.

Before 1916 (and as early as 1860), spark plug insulators were made of porcelain, glass, mica and even forms of pottery.

These materials worked fine in low-compression engines. But not in the 12-cylinder, 420-horsepower Liberty Motor.

It created an immediate demand for insulator materials with better resistance to heat shock breakage.

Luckily, an insulator of clay, flint and feldspar satisfied the urgent needs of the old Liberty engine. Yet at best, it was a stopgap solution.

After World War I, other combinations were tried.

There was little progress.

(In a typical example, an insulator of fused quartz glass resisted heat but collapsed under mechanical shock.)

In 1930, the situation became critical.

Automobile engines were better. So were fuels.

They boosted requirements for spark plug insulators even higher.

Suddenly in 1932, word came that a German electrical firm had developed and marketed an *alumina* insulator.

Two years later limited numbers were used in the U.S.A. with good results.

But there was a hitch.

The German process didn't fit the mass production methods of this country's automobile industry.

And there was something else.

The threat of another war.

In the anxious months that followed, ceramic engineers buckled down with Alcoa® Tabular Alumina to work the bugs out of insulator production methods.

Meanwhile, the aircraft industry was struggling along with a mica-insulated plug.

Ever since World War I, strong feelings had persisted that mica was the best material for the job.

But that theory was shattered at Wright Field in 1940.

Advanced engine flight tests proved that temperatures attained by an insulator tip under take-off power were too high for mica.

Right then and there, our defense program could have been seriously crippled.

Except for one thing.

Ceramic engineers never gave up on the alumina spark plug insulator and it was ready when we needed it most.

The war years found alumina insulators in light, medium and heavy bombers, fighter planes, tanks and in nonmilitary equipment such as trucks, buses and passenger cars.

Of course, real progress came after the war.

Today, alumina insulators are in sports cars that bolt from zero to 100 mph in less than 15 seconds.

They're in jet aircraft that travel on the other side of the sound barrier.

They are in missile ignition systems that lift powerful rockets into space and in all internal combustion engines.

Since 1933, Alcoa Aluminas have been used in the production of spark plugs. This is one of the reasons why a broken spark plug insulator is almost a thing of the past.

Alcoa Aluminas are also used in nose cones, electronic parts, refractories, cutting tools, bearings—even gyroscopes.

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Motorola Integrated Circuit Electronics...

Types of circuits available; Advantages and disadvantages of hybrid types and functional electronic blocks; The approach to custom-designed circuits

In recent months a dramatic change has occurred in the electronics field.

The widely discussed era of integrated circuits electronics has graduated from an engineering vision to practical reality. And the next few years will find integrated circuits progressing from designers' drawing boards to production lines in electronic equipment ranging from space gear to consumer products.

The total impact of this new technology on the industry, and the magnitude of the envisioned progress is still a matter of widespread conjecture. Though by this time many facts have been substantiated, there is still considerable confusion and misconception as to what can and what cannot be done with integrated circuits *at this time*.

You may have heard, for example, that integrated circuits will greatly reduce equipment size and weight.

This is certainly true. In fact, size and weight reduction is the most dramatic advantage. What the transistor has done to vacuum-tube equipment of a decade ago, integrated circuits will ultimately do to present equipment. Thus, the erstwhile rack of complex equipment which the transistor reduced to single-drawer size, can be further cut to "match-box" proportions.

You've heard, too, that integrated circuits will improve equipment reliability.

And this should be true.

Though reliability is difficult to prove in integrated circuits, since interwoven components cannot be individually tested to their maximum ratings, none of the manufacturing processes by which integrated circuits are made (diffusion, epitaxial growth, alloying, etc.) is new. Through the *exclusive* use of these transistor-proven techniques, complete integrated circuits are expected to have the same order of reliability as other time and field tested semiconductor devices.

You may also have heard that integrated circuits will slash the cost of electronic equipment.

This, unquestionably, is one of the most compelling reasons for circuit integration – but it bears qualification.

Integrated circuits by the thousands are fabricated simultaneously. A single paper-thin wafer of semiconductor material contains hundreds of identical circuits, and dozens of wafers are processed simultaneously. The basic *material* cost of an integrated circuit is little greater than that of a transistor and, with reasonable yields, the cost of the circuit approaches that of the device. In addition, the assembly time of integrated circuit equipment will be but a fraction of that required for circuit wiring.

But the design and production of a functional electronic block circuit (those in which all component parts are fabricated on or within a *single* tiny block of semiconductor material) are as yet costly operations unless your requirements permit large scale use of identical circuits. The great cost-reducing features of such circuits become apparent only when quantity requirements are so large that distributed design costs do not add appreciably to the price of each unit. On the other hand, hybrid (multiple chip) integrated circuits can be built now at a fraction of the cost of functional electronic blocks in small quantities.

If you are in the equipment manufacturing field you may have the impression that integrated circuits will permit a reduction of your engineering staff.

This is probably not the case unless your equipment can be built entirely from a limited number of "stock" circuits. You will need a staff of specialists capable of correlating conventional circuit design with the unique requirements of integrated circuit technology. *Motorola* can provide design assistance, but retention of specific features of each manufacturer's equipment demands an in-house engineering effort.

Finally, you may have heard that integrated circuits limit equipment design flexibility due to the relatively small number of circuits currently available.

Nothing is further from the truth.

Today, the integrated circuit capability of *Motorola's Semiconductor Products Division* has been developed to the point where working samples of a broad range of custom-designed circuits are being delivered in less than six weeks after receipt of an order. Right now, much the same design flexibility obtainable with transistors can be achieved with integrated circuits.

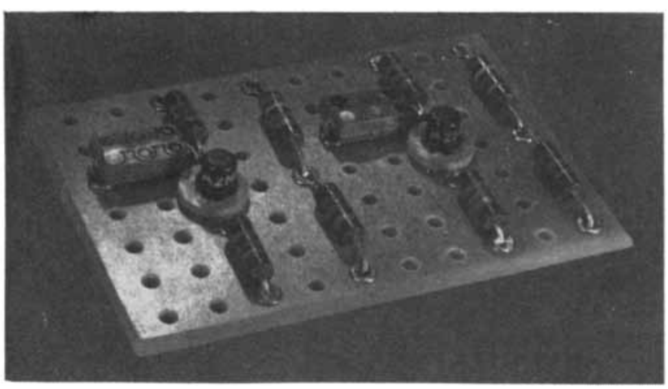
Types of Integrated Circuits

Today's integrated circuit technology involves basically two fundamental processes – a thin-film process, by means of which passive electronic components (resistors, capacitors, etc.) are deposited as material layers on a passive substrate, and a semiconductor device technology where both active and passive elements are formed on or within a tiny block of semiconductor material (silicon).

The semiconductor device technology utilizes multiple masked diffusion, surface layer passivation and patterned metal film alloying to make active and passive elements, all properly interconnected and isolated, in a single block. The ranges of component values are somewhat more restricted than in standard circuits and useful values of some functions (i.e. inductance) are difficult to obtain. Parasitics differ from those of conventionally wired circuits.

The thin-film technology utilizes multiple evaporation, sputtering, or vapor

Comparison of 50 mc amplifier breadboard using conventional components with equivalent integrated circuit (in center) dramatically illustrates space savings. Potential cost reduction of integrated circuits is indicated by simultaneous fabrication of dozens of identical circuits on portion of wafer shown at right. Elimination of interconnecting wires enhances reliability.



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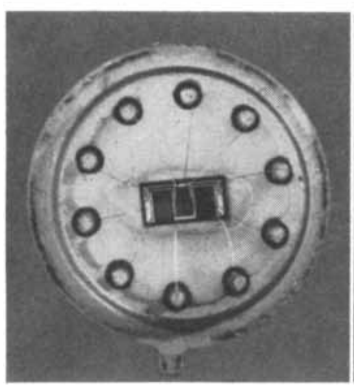
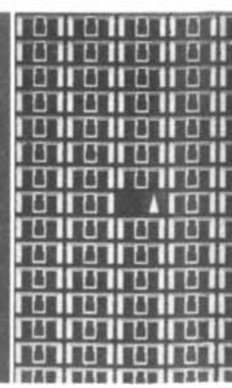
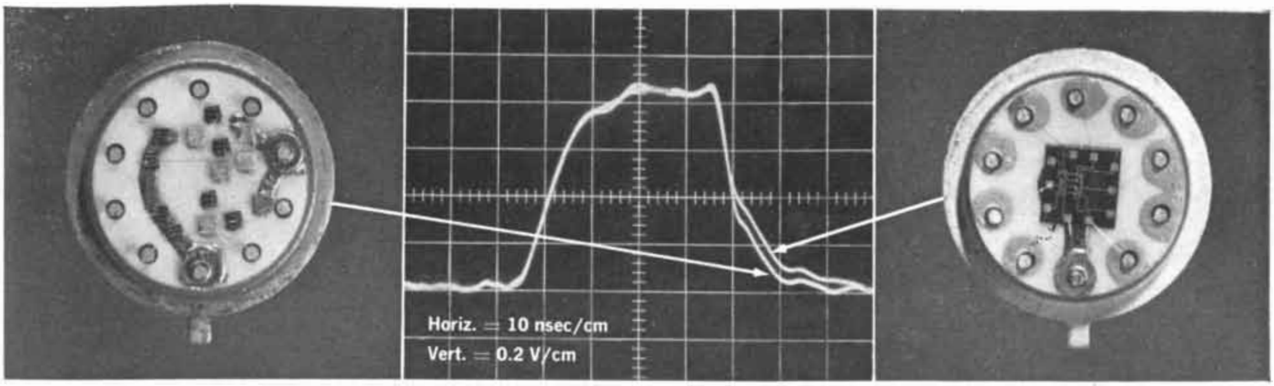






In custom design approach to integrated circuits, the equipment manufacturer's conventional wired prototype is converted into a multiple chip circuit (left) for evaluation. Necessary design changes can be made quickly and inexpensively at this stage.

Final single block circuit (right) offers mass-production cost savings. Comparison of output waveforms of multiple-chip and single block integrated circuits used in an operating arithmetic unit shows that performance of both types is quite similar.

decomposition to deposit (at the present time) the passive circuit components on an insulating (or dielectric) substrate. Active elements must be attached separately to their film circuits and, while the range of values of some components is greater than obtainable through semiconductor technology, such circuits require more material types and processes, and are often larger in size.

Motorola, through extensive research in both integrated circuit fields, has successfully developed a capability for combining the best features of both techniques in yet another, or third, technology—*compatible integrated circuits.* Playing a vital part in this process is the epitaxial growth technique that has recently made an explosive impact in the semiconductor field. Through this combination *Motorola* has produced integrated circuits with increased versatility, greater functional scope, tighter component tolerances and higher speed.

Custom Design Approach

As a first step, the equipment engineer must evaluate the complete system and determine whether to "integrate" all or a portion of the equipment. His next step is to produce conventionally wired prototype circuits for performance evaluation. Often parts values and other parameters must be changed to make the conventional design suitable for circuit integration. Usually this involves consultation with *Motorola* engineers.

Then comes the actual development of the integrated prototype. This can be started by the equipment manufacturer with special integrated components obtainable from the *Motorola Semiconductor Products Division.* These parts, each one individually packaged, have all the electrical characteristics of the elements in the final circuit, but they can be conventionally wired for integrated circuit evaluation and final modifications.

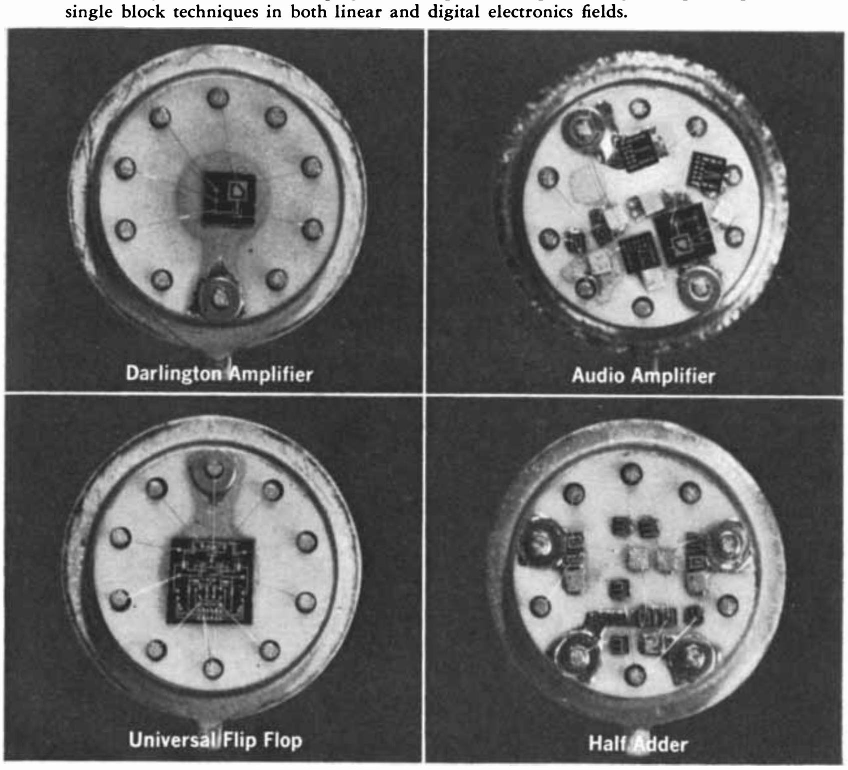
The next step, at *Motorola,* is to convert the equipment manufacturer's prototype into one or more hybrid integrated circuits in which parts identical to those of the prototype are bonded together on multi-lead headers. This becomes an interim circuit form which, in some instances, represents the final product.

Hybrid circuits have many of the same characteristics as fully integrated, single-block devices (see photos above). They have the additional advantages that production changes can be easily made and that design modifications are relatively simple and inexpensive. Moreover, they can be produced quickly at *Motorola,* since a great many integrated "components" are stocked for immediate use. The hybrid circuit, therefore, has much to recommend it as an interim, and for small runs, as a final product.

From the hybrid to the final single block circuit is a matter of developing the optimum pattern and the masks necessary for the various process steps. From a manufacturing standpoint, this is the most costly part of the entire operation. Still, it is entirely justified for equipments involving a large number of the same circuits. The reason — single-block circuits, after development, are the least expensive to make, and potentially the most reliable. With many individual bonding operations eliminated, it is the single-block circuit that offers the greatest cost-saving potential. It does this, however, at the expense of flexibility since such units cannot be modified during production without starting back at the beginning of the manufacturing operation.

The era of integrated circuits has arrived. They are *practical* and they are *available,* even though the future, unquestionably, will bring many improvements to this infant technology.

Integrated circuit capability of *Motorola's Semiconductor Products Division* is illustrated by practical circuits ranging from simple to complex, using multiple chip and single block techniques in both linear and digital electronics fields.



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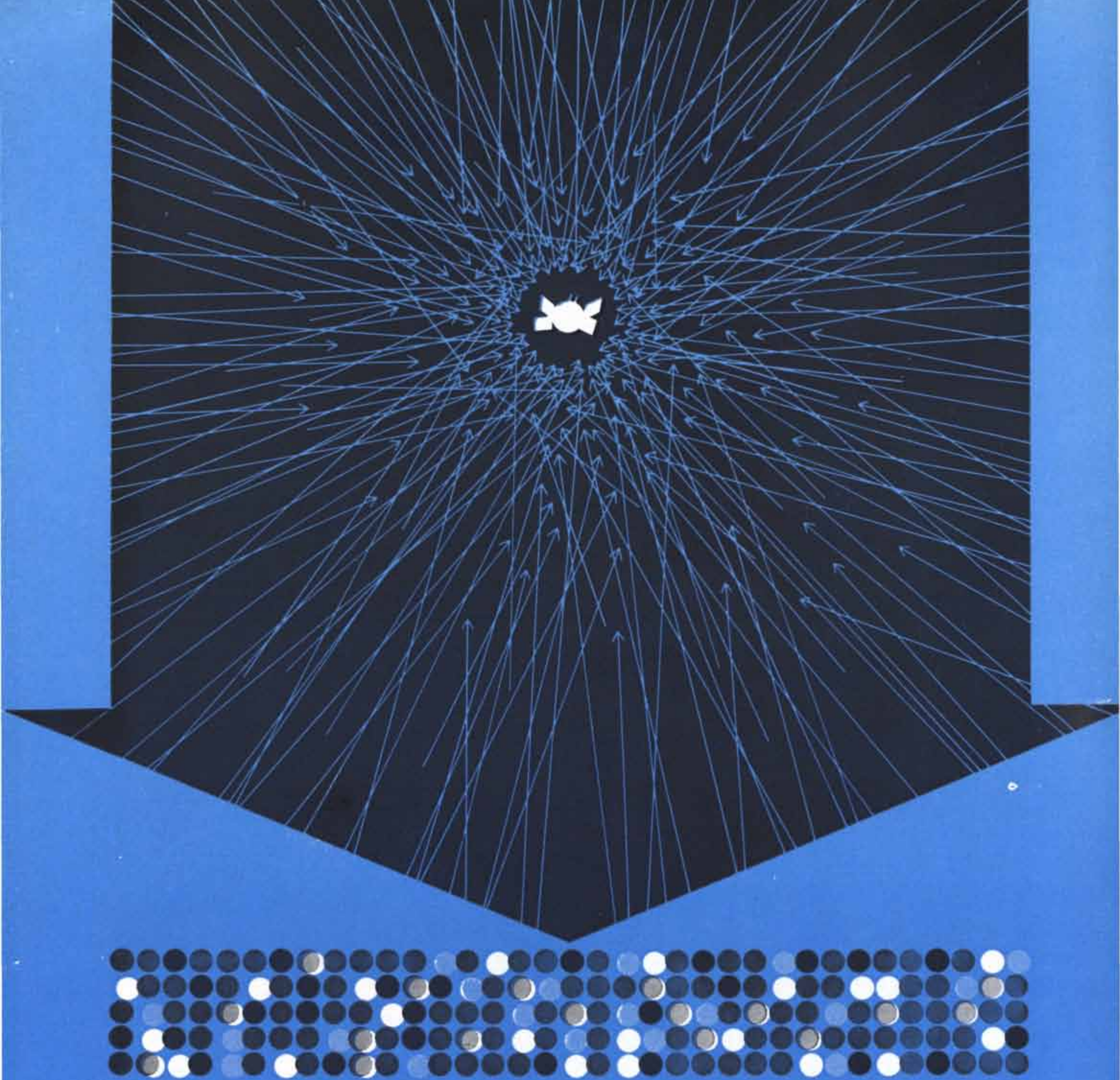


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1
8
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22
28
29

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RCA's COBOL has accomplished a phenomenal record for this giant aerospace researcher—producing 140 computer programs in half the usual time. Despite a 200 percent increase in computer workload! Despite many system changes! Despite entirely new areas of work assigned to the computer! Work force? Ten programmers, only one of whom had any previous computer experience.

Significantly, STL recovered the expense of initial installation (a one-time cost) in only four months. Savings in the first year will be substantial.

Elsewhere RCA's COBOL has also set dramatic records. More than 40 other users are training and programming with greater speed and ease than they believed possible.

To sum up—RCA's COBOL has sharply reduced the difficulties and expense in switching to electronic data processing . . . shaved valuable time off training programs and programming effort to get customers into full EDP production *faster*.

COBOL compilers are now available for the low-cost RCA 301 and medium sized 501®. Write RCA Electronic Data Processing, Cherry Hill, Camden 8, New Jersey.

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THE AUTHORS

A. P. CRARY ("The Antarctic") is chief scientist of the U.S. Antarctic Research Program for the National Science Foundation. Crary, who holds B.S. and Ph.D. degrees from St. Lawrence University and an M.S. degree from Lehigh University, worked as an oil prospector for private companies from 1935 to 1946, a period that included a year as project scientist at the Woods Hole Oceanographic Institution in 1942. From 1946 to 1960 Crary was project scientist at the Air Force Cambridge Research Center. In 1956 the National Academy of Sciences appointed him deputy chief scientist of the Antarctic program of the U.S. National Committee for the International Geophysical Year. Crary took his present post with the National Science Foundation in 1958. In 1952 Crary was landed on the ice at the North Pole to make geophysical measurements. In 1960 he went on an overland traverse from McMurdo Sound to the South Pole. Thus he is one of the very few men to stand at both the North and South poles.

SIR CHARLES WRIGHT ("The Antarctic and the Upper Atmosphere") is a physicist who has retired three times since 1947 and is currently engaged in research on geomagnetic fluctuations under contract to the Canadian Defence Research Board. Wright took B.A. and M.A. degrees at both the University of Toronto and the University of Cambridge before he joined the British Antarctic Expedition of 1910–1913 under Robert F. Scott. As glaciologist of the party he took part in all but the ill-fated final laps of the trip to the South Pole. He was a member of the search party that found Scott's last camp late in 1913. During World War I, Wright developed instruments and techniques for "trench wireless" communications that were later extended throughout the British Army zone in France. Joining the British Admiralty's research department after the war, he served in turn as Acting Deputy Director, Superintendent of the Admiralty Research Laboratory, Director of Scientific Research and Chief of the Royal Navy Scientific Service. The Admiralty recalled him from retirement in 1948 for two years as scientific adviser to the British Joint Services Mission in Washington. From 1952 to 1955 he was temporary director of the Marine Physical Laboratory of the Scripps Institution of Oceanography. Following another brief retirement he took up his present work in 1956.

MORTON J. RUBIN ("The Antarctic and the Weather") is Chief of the Polar Meteorology Research Project of the U.S. Weather Bureau. A graduate of Pennsylvania State University, Rubin first joined the Weather Bureau as an observer in 1937. From 1942 to 1949 he was a meteorologist for Pan American–Grace Airways, first in Peru and then in Chile. In 1949 he went to the Massachusetts Institute of Technology as chief analyst of a joint Weather Bureau–M.I.T. project in the analysis of weather maps of the Southern Hemisphere. When the Weather Bureau assumed full charge in 1952, Rubin became head of the project. M.I.T. awarded him an M.S. degree the same year. In 1955 Rubin was designated Project Officer of the International Geophysical Year Antarctic Weather Central then being established at Little America. Rubin was for 15 months liaison meteorologist at Mirnyy, the Soviet station in Antarctica. Rubin went to his present job on his return from Mirnyy in 1959.

V. G. KORT ("The Antarctic Ocean") is director of the Institute of Oceanology of the U.S.S.R. Academy of Sciences and professor of oceanology at Moscow State University. Born in Leningrad, Kort specialized in physical oceanography at Leningrad State University, where he received his degree in 1936. He acquired a doctoral degree in geography in 1952. During the International Geophysical Year he directed several oceanographic cruises aboard the research vessel *Ob* as part of the Soviet Marine Antarctic Expedition, which he discusses in his article. Kort has done research in the Baltic and Black seas as well as in the Arctic Ocean. Last year he directed an oceanographic cruise through the North Pacific Ocean aboard the *Vityaz.*

GORDON de Q. ROBIN ("The Ice of the Antarctic") is director of the Scott Polar Research Institute at the University of Cambridge. Robin was born and raised in Australia, where he received an M.S. in physics from the University of Melbourne before joining the Royal Australian Navy as an antisubmarine officer in 1942. At the end of the war (during which he had also seen service as a submarine officer with the Royal Navy) Robin became a research student in nuclear physics at Birmingham University. An earlier interest in the Antarctic reasserted itself, however, and Robin joined the British Falkland Islands Dependencies Survey, spending 1947 as meteorologist and officer in charge of the South Orkneys Station. He was appointed lecturer in physics at Birmingham University on his return. In 1956 he received a Ph.D. degree from Birmingham. He spent the following year at the Australian National University, and in 1958 he returned to England to take his present job.

G. P. WOOLLARD ("The Land of the Antarctic") is director of the Geophysical and Polar Research Center of the University of Wisconsin. Woollard, who founded the Center in 1958, received B.S. and M.S. degrees from the Georgia Institute of Technology in 1932 and 1934 respectively; he acquired A.M. and Ph.D. degrees at Princeton University in 1935 and 1937. After five years at the Woods Hole Oceanographic Institution, Woollard joined the faculty of Wisconsin in 1947.

GEORGE A. DOUMANI and WILLIAM E. LONG ("The Ancient Life of the Antarctic") are both research associates at the Institute of Polar Studies of Ohio State University. Doumani, who has had an Antarctic peak named after him, is a citizen of Lebanon and was graduated from Terra Sancta College in Jerusalem in 1947. He began working for the British Mandate Government that year, moved to Lebanon with the termination of the Mandate and in 1950 joined the Arabian-American Oil Company as a laboratory tester and petroleum inspector. He went to the University of California in 1953, where he acquired a B.A. in geological sciences and an M.A. in paleontology in 1956 and 1957 respectively. Long, who was raised in California and spent much of his time in the Sierra Nevada, decided to pursue geology as the right combination of education and "the less civilized out-of-doors activity." He took a B.S. at the University of Nevada in 1957 and an M.S. at Ohio State in 1961. Prior to his stint as a glaciologist at Byrd Station during the International Geophysical Year, Long had been an Air Force survival instructor from 1951 to 1955, had worked for the California State Snow Survey during the winters and had accompanied the California Himalayan Expedition to Makalu in 1954. He has spent the last two Antarctic summers as field leader of the Ohio State geological expeditions to the Ohio Range.

ROBERT CUSHMAN MURPHY ("The Oceanic Life of the Antarctic") is Lamont Curator Emeritus of Birds at the American Museum of Natural History. He has been research associate on the museum's staff since he retired in 1955. Murphy began his long and distinguished career as an ornithologist in 1911, when he became Curator of Mammals and Birds at the Brooklyn Museum, having acquired a Ph.B. from Brown University earlier the same year. In 1921 Murphy joined the American Museum of Natural History as Associate Curator of Birds, and in 1926 he became Curator of Oceanic Birds, the first such post at any museum. By this time Murphy had already led five expeditions to various parts of the world and had contributed largely to the establishment of marine ornithology as a distinct branch in the study of birds. In 1942 he was made chairman of the department of birds, which under his direction has developed into one of the finest in the world and now contains more than 800,000 specimens. Since his "retirement" Murphy has taken part in an oceanographic cruise to the eastern tropical Pacific, and in 1960 he served as zoologist aboard the icebreaker *Glacier* during the course of the first penetration by man into the Bellingshausen Sea in Antarctica.

GEORGE A. LLANO ("The Terrestrial Life of the Antarctic") is a member of the staff in the Office of Antarctic Programs of the National Science Foundation. Born in Havana, Cuba, in 1911, Llano was brought to the U.S. in 1917. He acquired a B.S. at Cornell University in 1935, an M.A. at Columbia University in 1939 and did graduate work at Harvard University before entering the Army Air Force in 1942. After an American-Scandinavian Foundation Fellowship took him to the University of Uppsala for a year, Llano returned to complete his Ph.D. degree at Washington University in St. Louis. From 1951 to 1957 he taught botany at the Air University at Maxwell Air Force Base. In 1957 and 1958 Llano participated in Antarctic research under the auspices of the National Academy of Sciences, and he served as secretary of the Panel on Biological and Medical Sciences of the Committee on Polar Research at the National Academy until 1960. He joined the National Science Foundation last year.

SIR GAVIN DE BEER, who in this issue reviews Theodosius Dobzhansky's *Mankind Evolving: The Evolution of the Human Species*, is director of the Natural History Department of the British Museum.

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Adhesion: describing an elephant of science

Adhesion has certain similarities to the elephant the blind men were asked to describe. This interdisciplinary subject has occupied the talents of the physicist, chemist, mathematician, metallurgist, and polymer scientist. But still, what adhesion is—its mechanisms and principles—seems to have eluded an overall scientific theory. Perhaps not for long.

Food for inductive thought is being gathered from fundamental research studies around the world. At the General Motors Research Laboratories, for example, recent experimental work by our polymer scientists has supported the idea that adhesion is dependent on:

(1) specific chemical groups in the adhesive film

(2) surface roughness of the metal substrate to which the polymeric film adheres.

Particularly, through a range of polymers synthesized in the lab, they have found that the more available the electrons in the chemical groups, the stronger the adhesion. Similarly, the rougher the metal surface, the more force required to break the adhesive bonds between the polymeric coating and the substrate.

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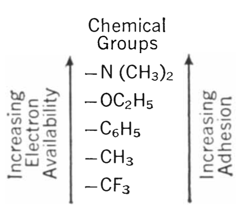

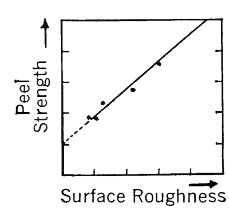

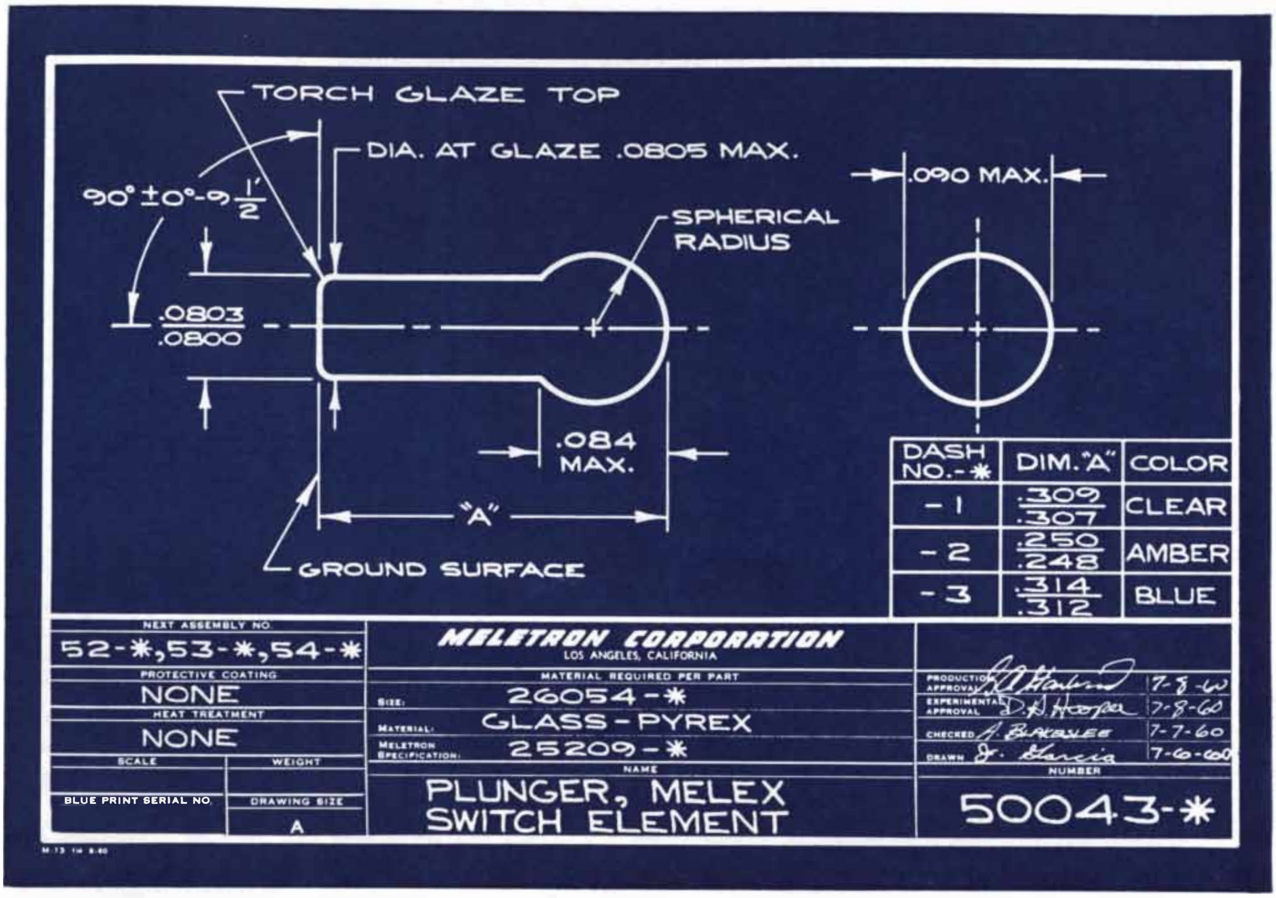

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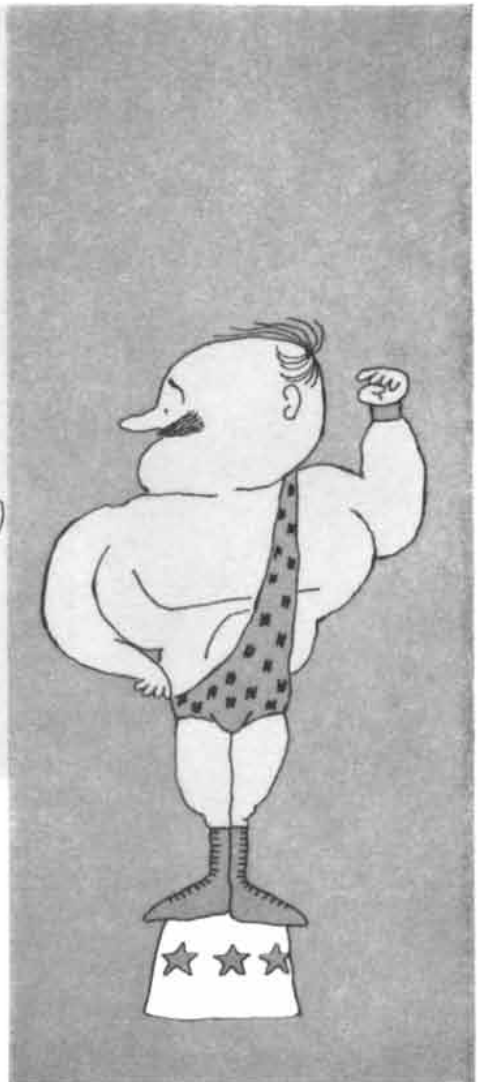

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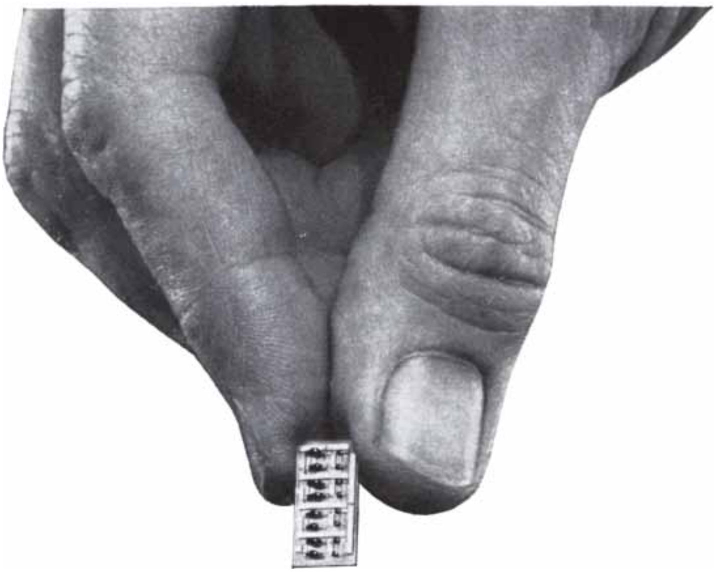
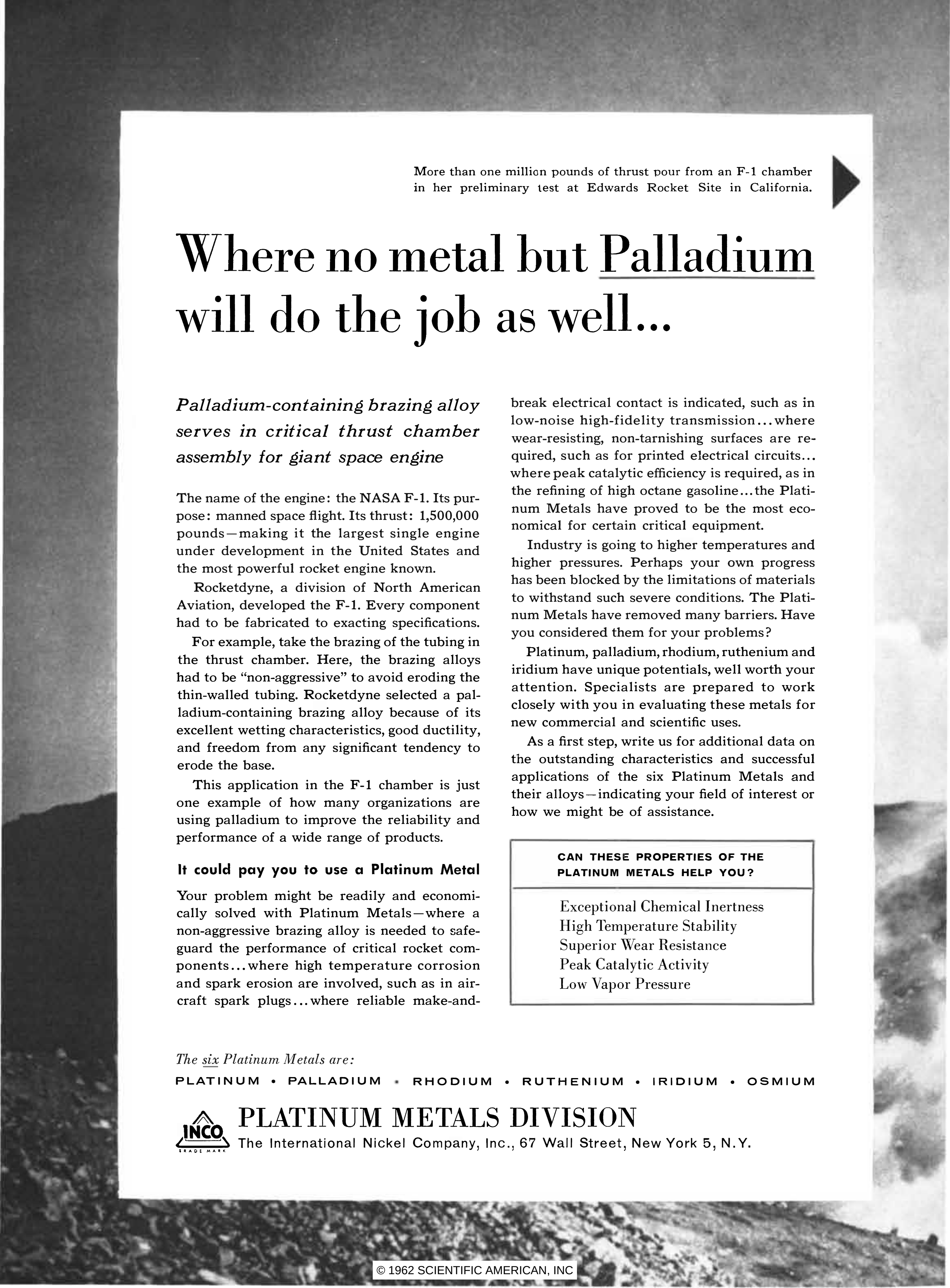
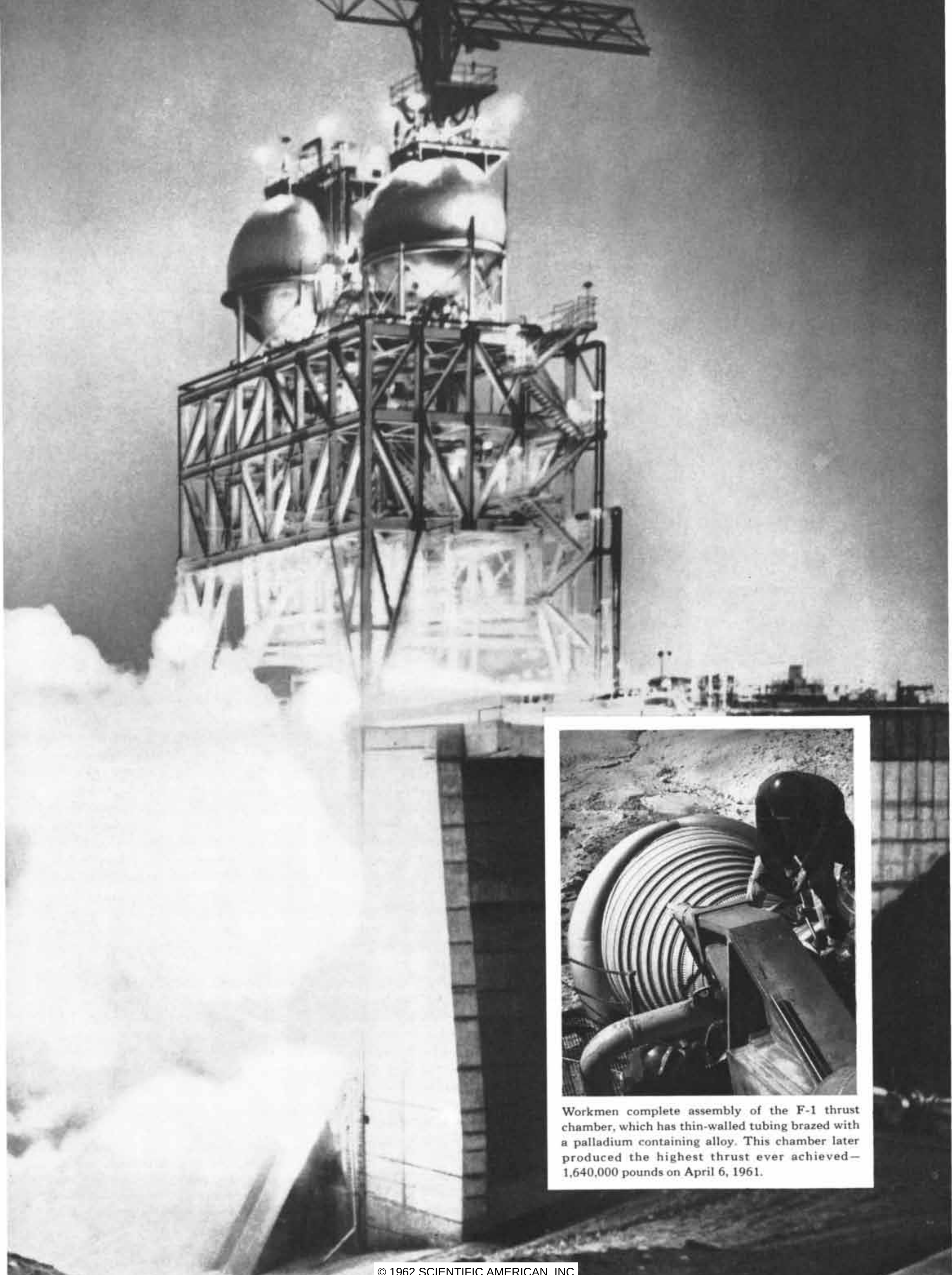






Workmen complete assembly of the F-1 thrust chamber, which has thin-walled tubing brazed with a palladium containing alloy. This chamber later produced the highest thrust ever achieved—1,640,000 pounds on April 6, 1961.

Established 1845 **SCIENTIFIC AMERICAN** September 1962 Volume 207 Number 3

The Antarctic

Scientists of 12 nations have occupied the last geographic frontier, in which they have a unique natural observatory to study the earth as a whole. Presenting an issue devoted to Antarctica and its environs

by A. P. Crary

The continent of Antarctica lies near the center of the earth's oceanic hemisphere, on the opposite side of the globe from the principal habitations of mankind. It is more than half again as large in area as Australia or the continental U.S., reaching from the South Pole to the 70th latitude around half of its perimeter. The bulk of Antarctica is ice—a true ice-age continental glacier that in some places depresses the block of the continent below sea level. In the depth of winter, pack ice frozen from the sea water doubles the area of this ice continent, reaching outward to the 60th parallel: the latitude of Leningrad in the Northern Hemisphere. Beyond the pack ice and out across the stormy ocean that isolates Antarctica from other land masses, the glacial cold pushes the oceanic and climatic boundary of the Antarctic region as far north as the 50th parallel: the latitude of Paris in the Northern Hemisphere.

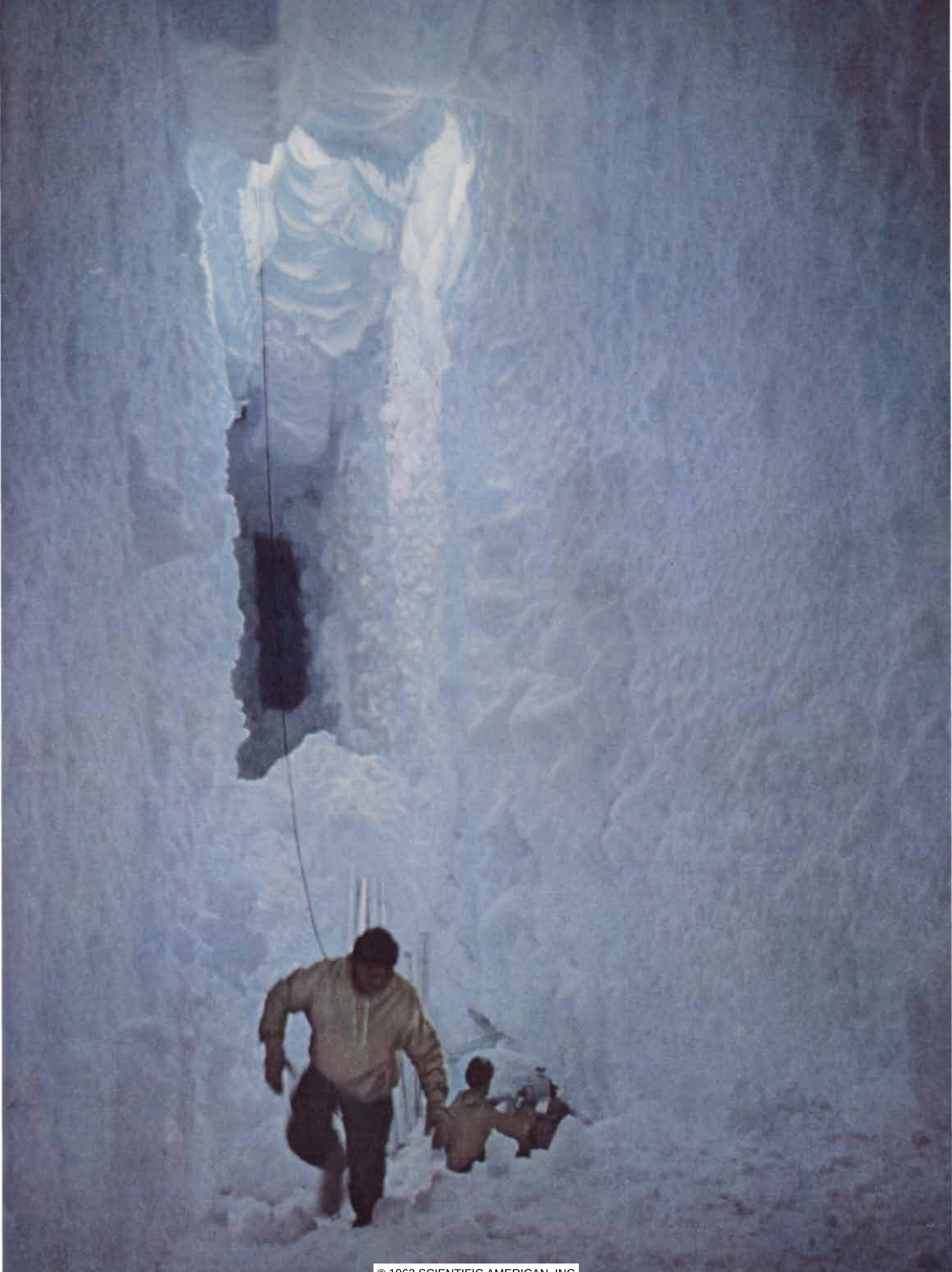
Man did not enter the Antarctic, a region that is so much more remote and hostile than the Arctic, until very recent times. It is less than 75 years since the first men set foot on the continent. For the past five years, however, the lights of human settlements have been burning on the Antarctic continent throughout the six-month darkness of winter. Although the winter population of Antarctica during this period has not exceeded a few hundred, the summer population has regularly run into the thousands, counting men engaged in work at sea, on the sub-Antarctic islands and in supply and support functions as well as those on the central continent. The new Antarctic community is unusual because it is international. The continent is occupied under the terms of a treaty, signed in 1959, which suspends national claims to territory there for 30 years and effectively reserves Antarctica to the interests of science for the duration.

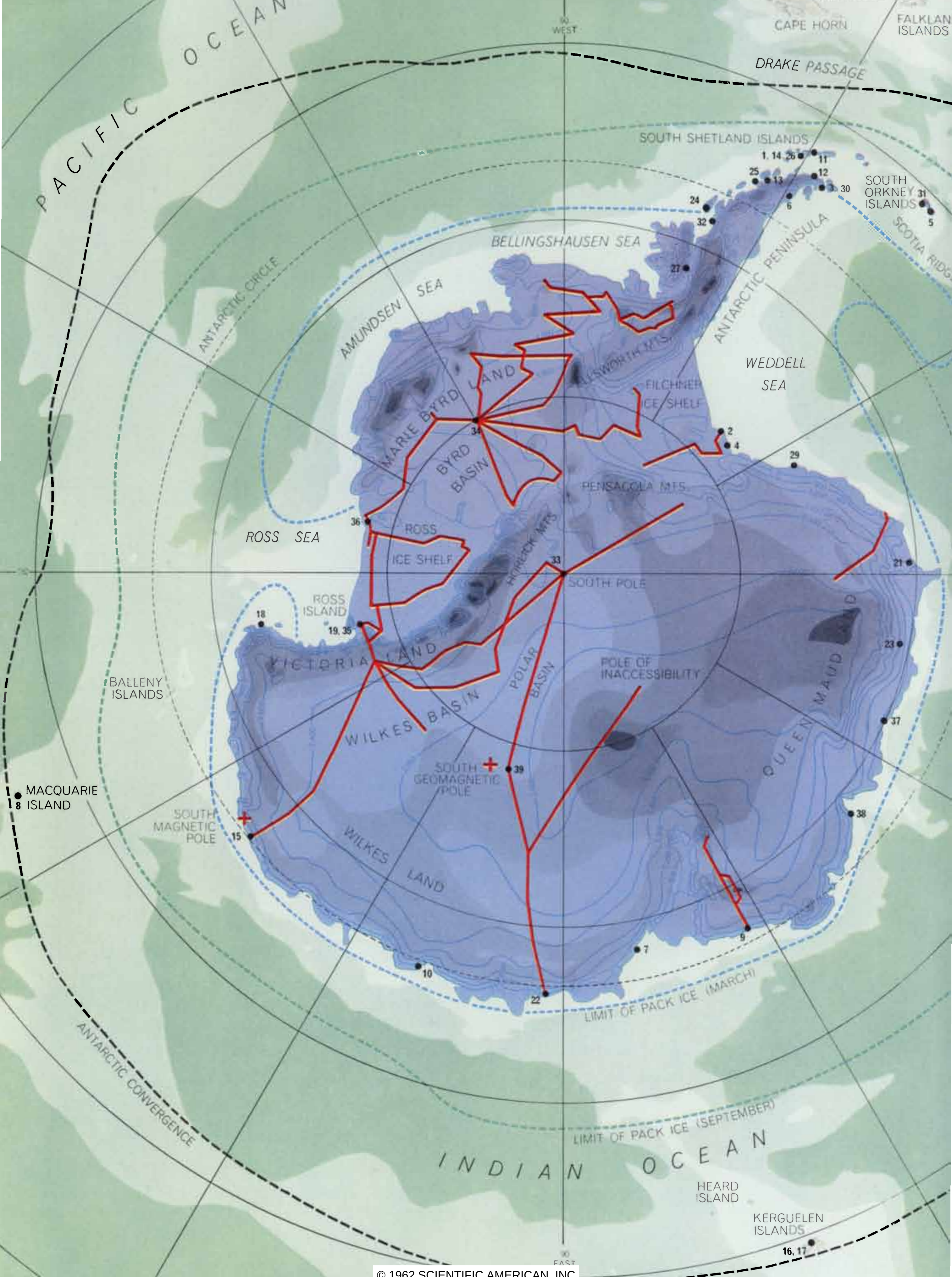
A threefold motivation is evident in the scientific work now under way in the Antarctic. In the first place, the region itself holds intrinsic interest. As the last terra incognita on earth, the Antarctic continent must be explored and mapped if only because it is there, and this task is a prerequisite to others. The life sciences also have important frontiers in the Antarctic. The land provides a minimal community of life for study of the interdependence of organisms at the limits of adaptation to desiccation and cold. The sea, on the other hand, sustains one of the most abundant and least known biological communities on earth, distinguished by the successful maintenance—but for the depredations of man—of the largest animals that have ever lived.

For another whole spectrum of interests, work in the Antarctic is essential to fill in gaps in the understanding of forces and processes that are world-wide in scope. Since Antarctica is the locus of the south geomagnetic pole, for example, it is obvious that observations there are needed to complete the picture of the earth's magnetic field. Related studies of the upper atmosphere are strengthened by co-ordinated observations at conjugate points—that is, at places in the Antarctic and the Arctic connected by a single line of force in the magnetic field. In the circulation of the lower atmosphere and of the oceans, the Antarctic plays a commanding role because it is a heat sink: radiating into outer space the enormous quantities of energy from the sun absorbed in the middle latitudes and carried southward by the meridional flow of air and water. Meteorologists and oceanographers also have a common concern in studies of the Antarctic glacier; since the glacier comprises 90 per cent of the earth's ice and locks up a significant fraction of the earth's waters, important problems in both of these fields turn on whether it is losing or gaining in volume.

Finally, the Antarctic may help in the solution of major questions about the structure and history of the earth. The 29 million cubic kilometers of the con-

ANTARCTIC CREVASSE is explored by glaciologists studying the annual deposition of snow in Antarctica. The tubes behind them are used to collect ice cores from the walls of the crevasse. Both men and equipment were lowered into crevasse by ropes.




PACIFIC OCEAN
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CAPE HORN
FALKLAND ISLANDS
DRAKE PASSAGE
SOUTH SHETLAND ISLANDS
SOUTH ORKNEY ISLANDS
SCOTIA RIDGE
ANTARCTIC PENINSULA
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SOUTH POLE
ROSS ISLAND
VICTORIA LAND
POLE OF INACCESSIBILITY
POLAR BASIN
QUEEN MAUD LAND
BALLENY ISLANDS
WILKES BASIN
SOUTH GEOMAGNETIC POLE
MACQUARIE ISLAND
SOUTH MAGNETIC POLE
WILKES LAND
LIMIT OF PACK ICE (MARCH)
ANTARCTIC CONVERGENCE
LIMIT OF PACK ICE (SEPTEMBER)
INDIAN OCEAN
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KERGUELEN ISLANDS
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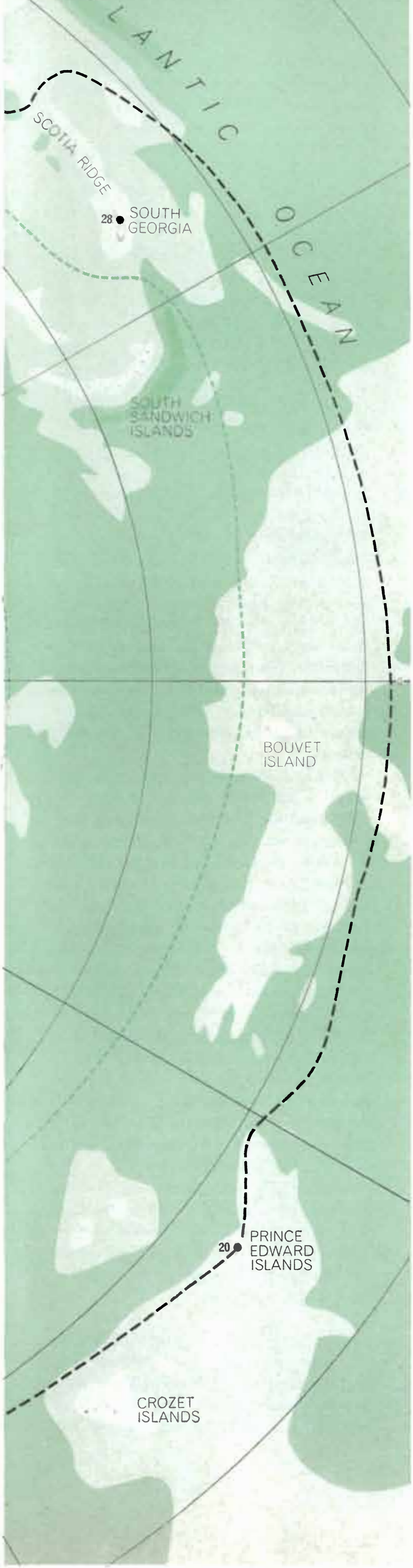
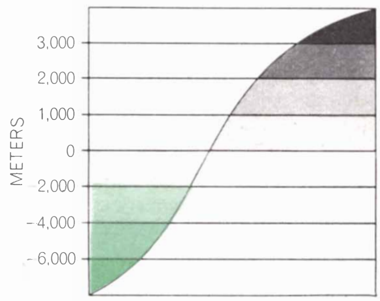


tinental glacier constitute the largest transient load superimposed on the earth's crust. For study of the rigidity and plastic flow of the crust and the underlying mantle, Antarctica presents a full-scale experimental model. Such study is not unrelated to speculation that has been stimulated by the more classical geology of Antarctica. Fossil evidence shows that the continent in the not too distant geological past nurtured an abundant flora. This knowledge has helped to revive interest in the hypothesis that all the Southern Hemisphere continents were once joined in a super-continent. (In one romantic 19th-century statement of the hypothesis the continent was called Gondwanaland.) Implicit in this idea is the notion of continental drift, the supposed migration of the continental blocks through the yielding mantle. Just why Antarctica was left behind in the migration of the continents and why the Northern Hemisphere should now be so favored by land are questions that have intrigued the geophysicist.

Antarctica figures no less dramatically in other lines of geophysical speculation. The oppositeness of the polar regions—



ACTIVE STATIONS

ARGENTINA
1 DECEPCIÓN
2 ELLSWORTH (CO-OP. U.S.)
3 ESPERANZA
4 GENERAL BELGRANO
5 ORCADAS
6 TENIENTE MATIENZO

AUSTRALIA
7 DAVIS
8 MACQUARIE ISLAND
9 MAWSON
10 WILKES (CO-OP. U.S.)

CHILE
11 CAPITÁN ARTURO PRAT
12 GENERAL BERNARDO O'HIGGINS
13 PRESIDENTE GABRIEL GONZALEZ VIDELA
14 PRESIDENTE PEDRO AGUIRRE CERDA

FRANCE
15 DUMONT D'URVILLE
16 POINTE MOLLOY
17 PORT-AUX-FRANÇAIS

NEW ZEALAND
18 HALLETT (CO-OP. U.S.)
19 SCOTT

REPUBLIC OF SOUTH AFRICA
20 MARION ISLAND
21 SANAE

U.S.S.R.
22 MIRNYY
23 NOVOLAZAREVSKAYA

UNITED KINGDOM
24 ADELAIDE ISLAND
25 ARGENTINE ISLAND
26 DECEPTION ISLAND
27 FOSSIL BLUFF
28 GRYTVIKEN
29 HALLEY BAY
30 HOPE BAY
31 SIGNY ISLAND
32 STONINGTON ISLAND

U.S.
33 AMUNDSEN-SCOTT SOUTH POLE
34 BYRD
35 McMURDO

INACTIVE STATIONS
36 LITTLE AMERICA (U.S.)
37 ROI BAUDOUIN (BELGIUM)
38 SHOWA (JAPAN)
39 VOSTOK (U.S.S.R.)

CONTOUR MAP OF THE ANTARCTIC shows the relief of the continental ice and land beneath it and the depth of the surrounding waters. The relief of the ice is given by the blue contour lines. The depth of the water is indicated in the tones of green on the accompanying key; the height of the land, in the tones of gray. The continental land that lies below sea level is outlined by the lightest shade of blue. The blue stippled areas are ice shelves. The colored broken lines show the limits of pack ice in March and September. The heavy broken line marks the Antarctic Convergence, which divides the Antarctic waters of low temperature and salinity from waters of higher temperature and salinity that support an entirely different biological community. The black circle around the South Pole is at 80 degrees latitude; each succeeding circle represents an interval of 10 degrees. The numbered black dots show the locations of the major scientific stations established by the nations participating in the Special Committee on Antarctic Research. Red lines trace routes of the major traverses across the Antarctic ice. Antarctica has a total area of 5.5 million square miles; along longitude 90 degrees east to 90 degrees west the continent measures about 2,800 miles. Line traced by the Horlick and Pensacola mountains divides the continent into two major geological provinces: West Antarctica (*upper section of map*) and East Antarctica.

the contrast between the oceanic Arctic and the continental Antarctic—has led some to suggest that the Antarctic was pushed up by the turnover of currents of fluid rock in the mantle as the Arctic was pulled down. On the other hand, the evidence indicating a close relation between the mountains of the Antarctic Peninsula and the great Andean range of South America would seem to fit Antarctica into a more conventional theory of the growth of continents. This postulates the building of island arcs off continental shores and the filling in or the uplifting of the sea floor between the islands and the continents.

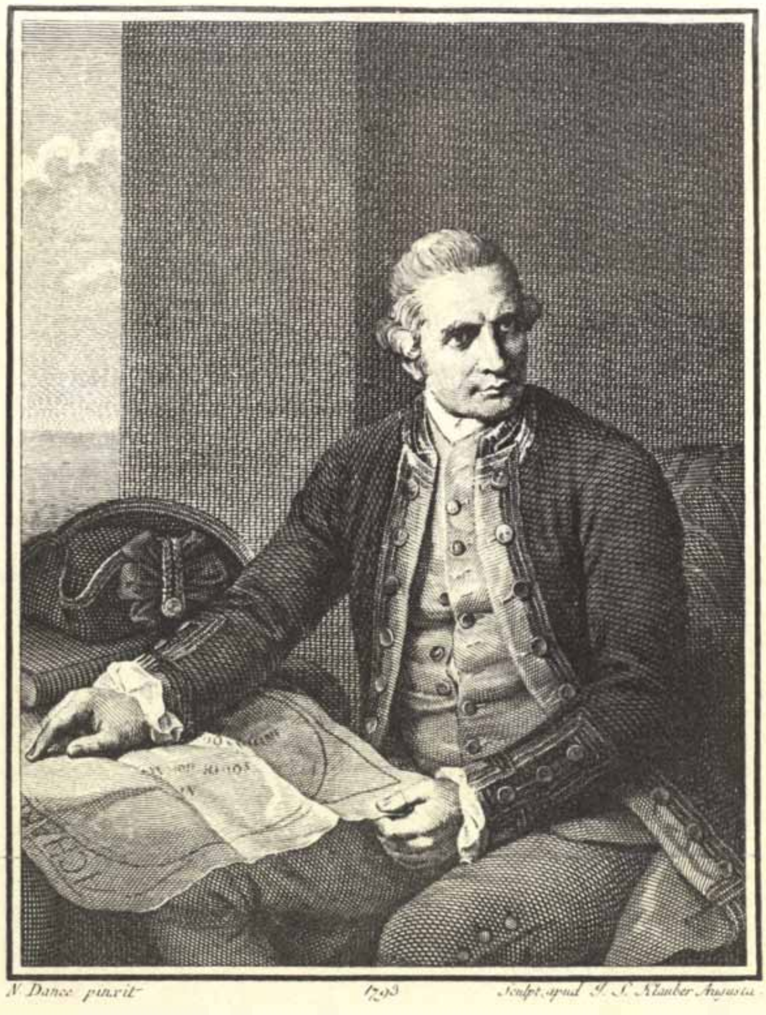
Thus the first few years of sustained work in the Antarctic have already brought this remote region to the center of interest in many fields of science. This issue of SCIENTIFIC AMERICAN is devoted to a reckoning of the present status of knowledge of Antarctica in its relation to the broad concerns of the various disciplines, with particular reference to the progress made in the past few years. The history of science in the Antarctic, however, goes back as far as the history of Antarctic exploration.

Science is exploration, whether it is the exploration of the atomic nucleus, calling for complicated equipment and highly technical training, or the exploration of an unknown continent and unknown seas, calling for gear and skills of a different sort. Both enterprises add to human knowledge, and it would be patronizing to regard those older voyages into the Antarctic as unscientific. There were, of course, other motives—adventurous, economic, imperial—and these were usually foremost. But the science of the times in which these expeditions were launched generally had a part. What is more, it is just as necessary for the science of today to journey to distant places in order to confront theories about the earth and its life with the test of observation in the field.

The first knowledge of the limits of the Antarctic came in the latter part of the 18th century from the work of the great British seaman James Cook, who brought the art of navigation to a high degree of perfection in a brilliant series of voyages over the Pacific Ocean from the ice of the Arctic to the ice of the Antarctic. Under sail many navigators explored the edges of the ice, made landings on the Antarctic islands and came in sight of the continent itself. The names of the Russian Thaddeus Gottlieb von Bellingshausen, the Englishmen James Weddell and James Clark Ross, the American Charles Wilkes and the Frenchman Jules Sébastien César Dumont D'Urville are remembered from those days in the place names of the Antarctic. No small contribution to the literature came from the logbooks of the sealers and whalers who opened up the region to exploitation early in the 19th century.

The first steamship to cross the Antarctic Circle was the *Challenger*, in 1874, and the first vessel to winter over in the ice was the *Belgica*, commanded by Adrien de Gerlache, in 1897. It was not until 1893 that a party made a landing on the continent, and the first expedition to winter on the continent was led by Carsten E. Borchgrevink, in the season of 1899–1900. There followed the continental expeditions of Robert Falcon Scott, Sir Ernest Shackleton, Roald Amundsen and Sir Douglas Mawson in the period before World War I. In 1902 Scott experimented with captive balloons for reconnaissance and in 1907 Shackleton, who was the first to enjoy the convenience of acetylene light, brought the first motor vehicle to the continent. The expeditions of Hubert Wilkins, Richard Evelyn Byrd and Lincoln Ellsworth in the period before World War II demonstrated the great usefulness of the airplane for penetration of the continent.

The era of expansive exploration now under way can be said to have had its beginning in the Norwegian-British-Swedish expedition of 1949–1952. This international enterprise conducted the



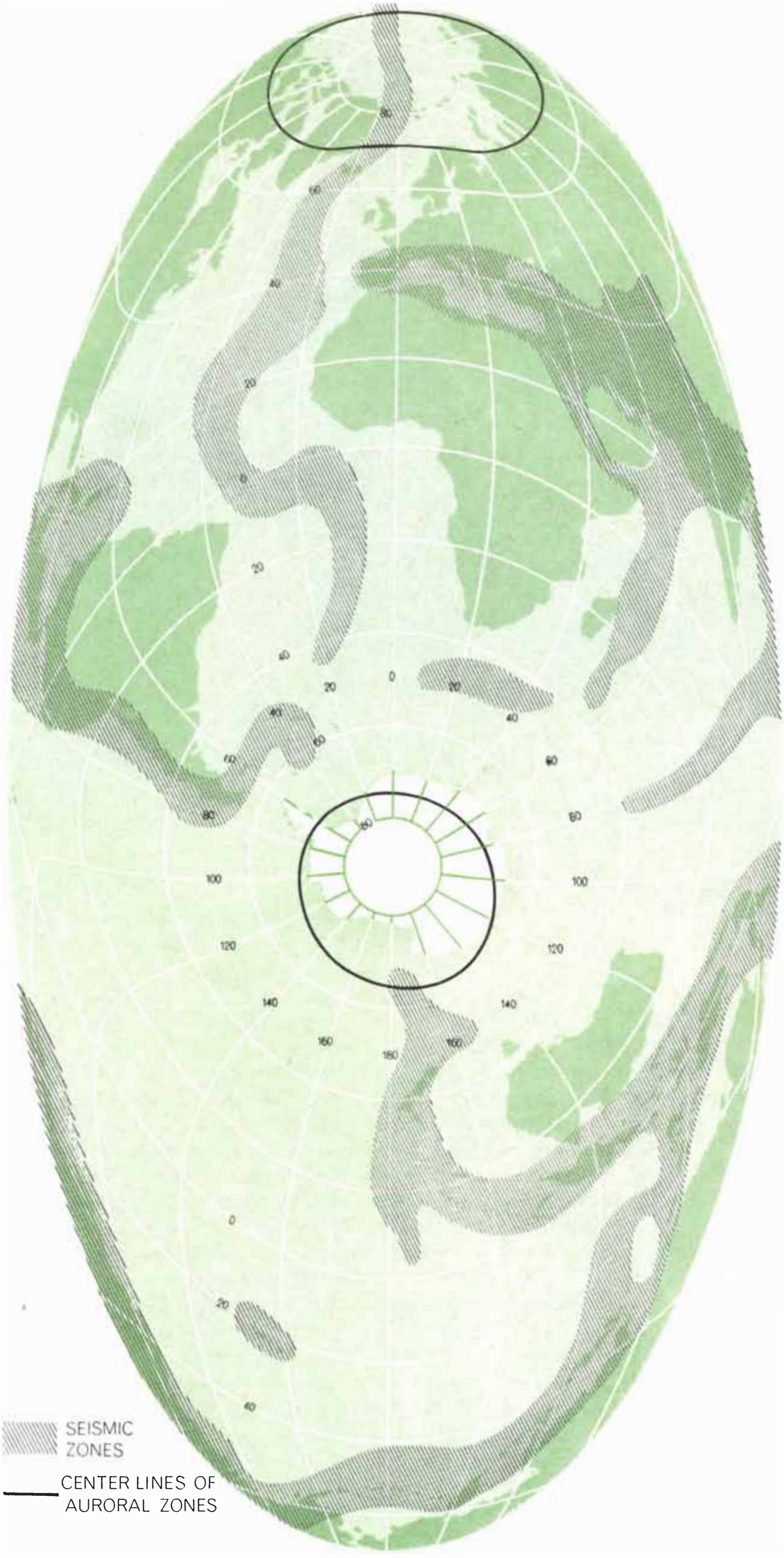
CAPTAIN JAMES COOK, 18th-century British explorer, was the first man to sail near the Antarctic continent. In 1772, on the ship *Resolution*, he set out in search of the "Southern Continent." He came within 150 miles of shore. Unable to get through the ice, he turned back.

ROBERT F. SCOTT AND HIS PARTY pose for a picture at the South Pole in January, 1912, after having found that Roald Amundsen had reached the Pole before them. From left to right are E. A. Wilson (*pulling a string to take the picture*), Scott, Edgar Evans, L. E. C. Oates and Henry R. Bowers. None of the members of the group survived the return trip from the South Pole.

first major traverses into the interior and laid a foundation for the Antarctic phase of the International Geophysical Year in 1957–1958. To the IGY, of course, one can trace the rapid advance of science into space as well as into the Antarctic. The present occupation of the continent dates from that highly successful undertaking. Recognition that work in Antarctica was bound to continue beyond the end of the IGY prompted the organization in 1957 of the Special Committee on Antarctic Research (SCAR). Through this agency the scientists of the participating nations get together to arrange the co-ordination of national scientific programs, standardization of instrumentation, exchange of personnel, mutual assistance on logistical problems and the presentation of results. SCAR embraces in its jurisdiction the oceanic islands as far north as the 40th parallel.

Such international scientific collaboration on mutually agreeable issues set the stage for an international diplomatic conference on the Antarctic held in Washington in October, 1959. The conference produced a treaty that was signed in December, 1959, and subsequently ratified by all the signatory nations. In addition to the freezing of territorial claims, the treaty calls for the demilitarization of all national bases in the Antarctic, with full unilateral rights of inspection; it bans nuclear explosions and the dumping of radioactive wastes; and it sets up machinery to promote international collaboration in scientific ventures. It may be argued that it was unnecessary to provide science with a freedom of action on the continent that was taken for granted during the IGY. The real usefulness of the treaty, however, will be demonstrated in its provision of means for equitable solution of other problems, perhaps economic, that may arise in Antarctica. Moreover, it sets valuable precedents for international understanding in other areas, such as the Arctic and outer space. The inspection provision may prove to be a primary innovation in international relations. In the Antarctic the treaty may encourage reduction of the number of those temporary and permanent bases, especially on the Antarctic Peninsula, that are admittedly occupied more for national than for scientific interests.

As of today nine nations maintain some 40 stations on the continent and on the Antarctic islands (which are acknowledged as national possessions under the treaty). The number of stations is indefinite because many are temporary or seasonal. At one early SCAR meeting a resolution was adopted implying that a nation must have wintering-over personnel in order to to be eligible for membership. Scientifically, however, such a restriction is meaningless; a geological party living in temporary shelter for three months in a summer can make enormous contributions to Antarctic science. A well-equipped and well-staffed oceanographic vessel, which does not qualify as a base at all, may make equal or even greater contributions. The number of bases and of personnel does not therefore serve as a valuable indicator of scientific activity. Nations active in the Antarctic are Australia, New Zealand,



SEISMIC AND AURORAL ZONES are shown in relation to Antarctica on this world map. Because earthquake waves from the seismic zones can travel to Antarctica (*white region*) without passing through a land mass, the continent provides a unique location for seismic observations. Black rings around polar regions mark mid-lines of the auroral zones. Auroras occur with greatest frequency in an area about 500 kilometers on either side of these rings.

Chile, Argentina and South Africa, all of which are Southern Hemisphere countries; the U.S., the United Kingdom, Norway and the U.S.S.R., all of which have Arctic territory or affiliations; Japan, which has an important interest in Antarctic whaling; France, which possesses the scientifically strategic sub-Antarctic islands of Kerguelen, Crozet and New Amsterdam; and Belgium, which sponsored the expedition of the *Belgica* in 1897. In the 1962 Antarctic program, however, Norway, Belgium and Japan are inactive.

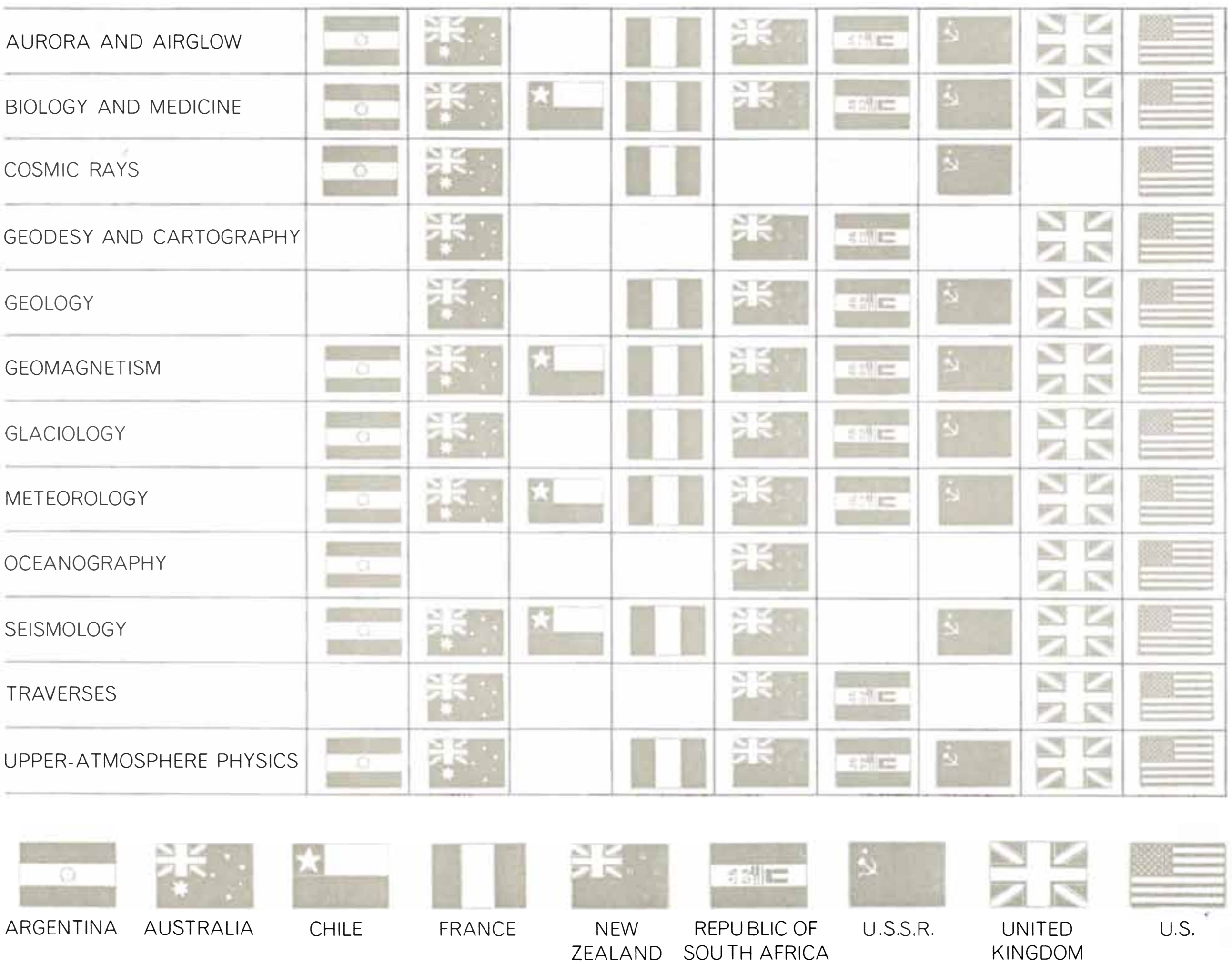
The United Kingdom maintains the largest number of active stations, seven on the Antarctic Peninsula and nearby islands, one on the continent and one on the sub-Antarctic island of South Georgia. Most of those stations are devoted to surface weather, geological and cartographical work, with more diversified programs at the peninsular stations. No nation at the beginning of 1957 was more experienced in polar operations or had more polar scientists than the U.S.S.R. In the Arctic the Soviet Northern Sea Route Administration had succeeded in making the Northeast Passage a practical reality [see "The Arctic Ocean," by P. A. Gordienko; SCIENTIFIC AMERICAN, May, 1961]. The same agency administers that country's Antarctic activities. These are centered in the coastal base at Mirnyy, which supports the largest scientific program on the continent. A contingent of 45 Soviet scientists is on hand for the summer season; Soviet workers have manned bases inland at the Pole of Inaccessibility, Vostok, Lazarev and Novolazarevskaya for various periods of time during the past five years. During the Antarctic summer of 1961–1962 Soviet scientists made their first flights into the continent, using four-engine jets. With aircraft to supplement their previous dependence on ground vehicles, they expect to expand their mapping and field exploration activities. The U.S.S.R. also supports an active oceanographic program in the Antarctic; the oceanographic vessel *Ob* spends several months each year in the Indian Ocean sector of what the Soviet scientists have come to call the Southern Ocean.

The Antarctic activities of the U.S. have been facilitated from the beginning of the IGY period by direct air support. Cargo planes fly almost on schedule during the summer from New Zealand direct to the ice strip of the central supply base on McMurdo Sound.

From there planes fly on to the permanent inland bases at Byrd Station and the Amundsen-Scott South Pole Station, which have been manned continuously since the summer of 1957. The Ellsworth and Wilkes stations, established during the IGY, have been turned over for administration to Argentina and Australia respectively; Hallett Station is a joint venture with New Zealand, and Little America Station, near the site originally occupied by Byrd in the 1930's, has been abandoned.

During the IGY period the U.S. parties did little or no mapping, geology or biology but stressed meteorology and upper-atmosphere physics—studies that are carried on in winter as well as summer. Ground traverses were also conducted for glaciological purposes. Now, however, an extensive cartographic program is well under way; some 300,000 square miles across the continent from the Ross Sea to the Weddell Sea and on the Antarctic Peninsula have been mapped by aerial photography with an adequate network of control points established by ground parties. At present geology and biology engage a large portion of the total effort. Plans also call for an upper-atmosphere station to be located in Ellsworth Land—with conjugate-point observations to be carried out in co-operation with a similar station in eastern Canada—and for a biological station on the Antarctic Peninsula. Moreover, U.S. scientists now have an oceanographic vessel, the *Eltanin*, operating in Antarctic waters. The mission for this vessel in the next year will be to survey the ocean that lies between the 80th and 170th meridians of west longitude and between the 50th parallel and the Antarctic pack ice. This vast stretch of islandless water is the oceanic antipode of the center of the continental mass of the Northern Hemisphere.

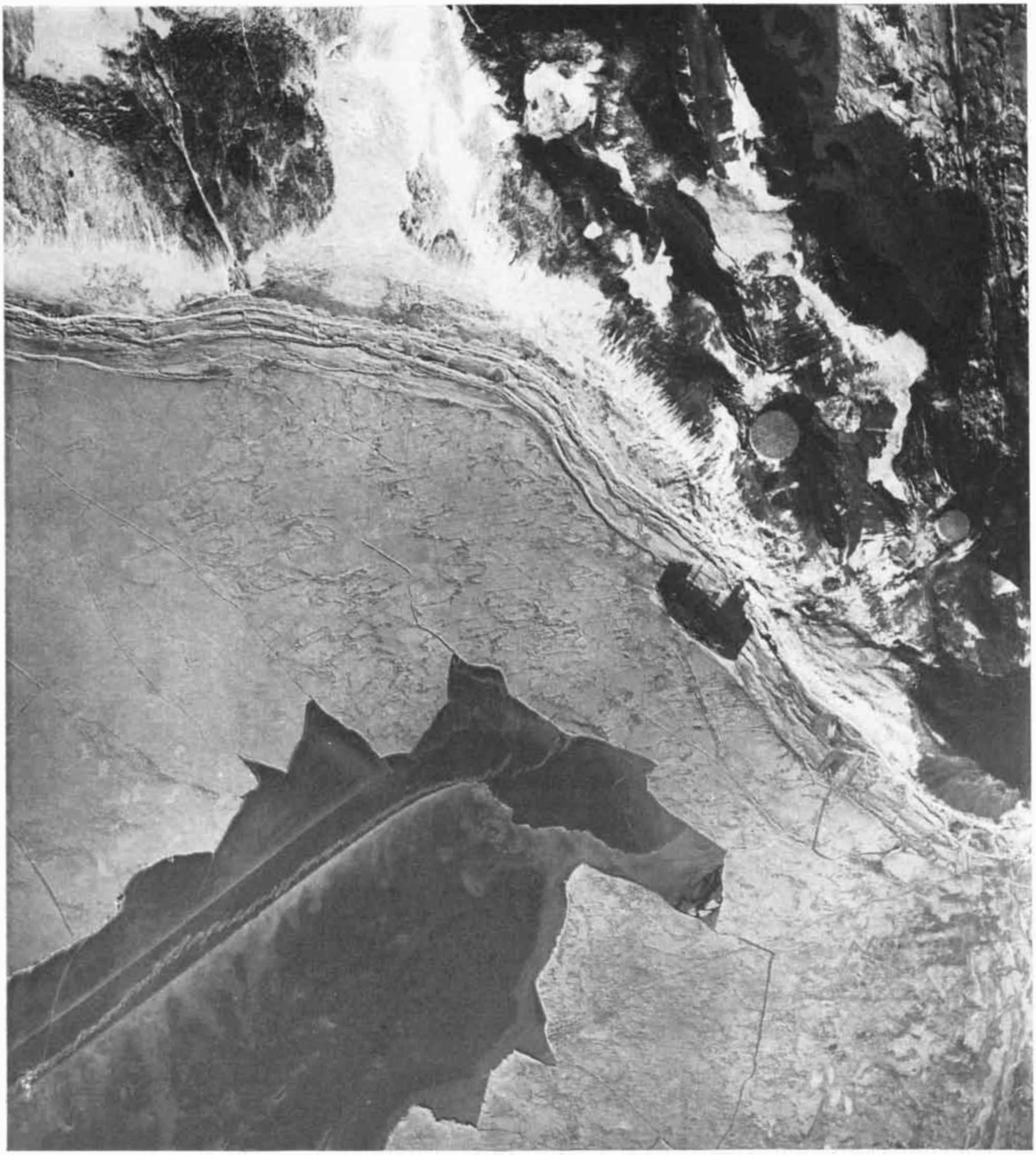
Some 7,500 miles of ground traverses over West Antarctica (the portion of the continent that lies west of the Greenwich meridian) have now confirmed that Antarctica is really not a single geographic and geologic entity but two. East Antarctica, the main portion of the continent as it appears on the map, is underlain by a stable continental shield. Like the shield areas of Australia, India, South Africa and Brazil, it is composed of ancient metamorphosed crystalline rocks of Pre-Cambrian age on which lie relatively undisturbed sediments. West Antarctica, on the other hand, is underlain by an island archipelago, which reaches northward on the map as the Antarctic Peninsula toward the tip of South America. Geologic evidence shows this part of the continent to be an extension of the Andean mountain chain, a part of the great circumpacific folded



SCIENTIFIC RESEARCH PROGRAMS carried out in Antarctica in 1962 are charted by nation and field of study. Each country participating in each of the programs listed is represented by its national flag. All countries are pooling the information gathered.

zone that was uplifted in the comparatively recent Tertiary period. The connecting link between the Antarctic Peninsula and the tip of South America, 600 miles away, is furnished by the Scotia Ridge. This is a huge undersea tectonic bight 2,000 miles in length that swings eastward and then westward, surfacing along the way to form the South Orkney, South Sandwich and South Georgia islands and rising again at Tierra del Fuego.

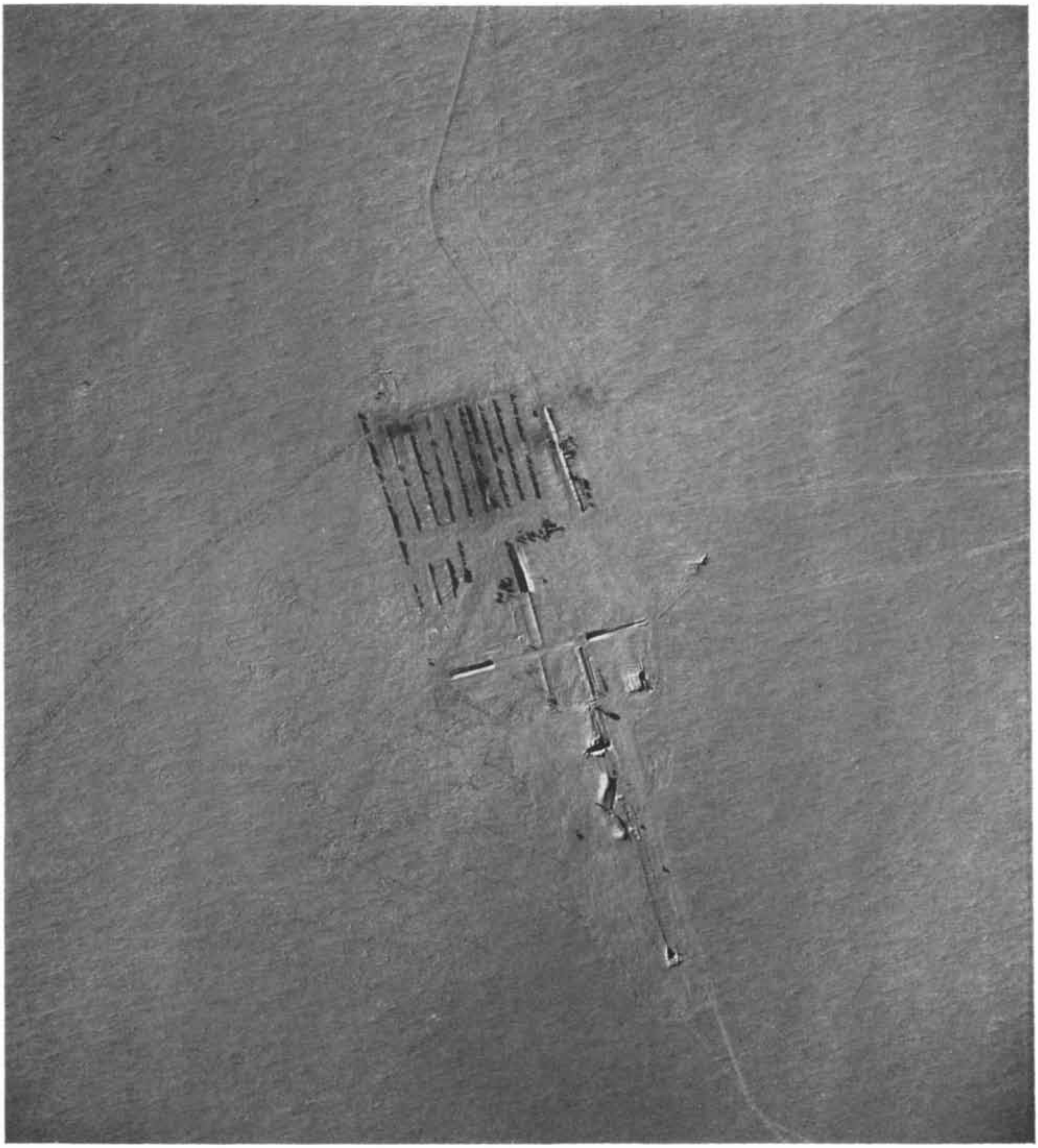
However distinct in structure the two parts of Antarctica may be, they are joined in a single continent by the overlying ice that forms the geodetic surface of Antarctica. As the map on pages 62 and 63 shows, the glacier not only is grounded below sea level in the trough between the eastern and western portions of the continent; it even depresses portions of the continental shield below sea level. But the mass of ice is so



PART OF McMURDO SOUND is shown in this vertical aerial photograph, made from a Navy aircraft at an altitude of 6,300 feet above sea level. The round shapes at right are 250,000-gallon fuel tanks for McMurdo Station. At lower left is the path cut by an icebreaker for a tanker. Fuel will be piped from the tanker to the ship lying offshore and thence to the station's fuel-supply tanks.

enormous that it makes Antarctica the loftiest of continents, giving it an average height above sea level greater than that of any other. The rock shows at the surface only where mountain peaks rise through the ice and along a few escarpments, on headlands and in scattered bare patches around the coasts.

To the total geographic area of Antarctica, ice adds some 800,000 square miles of territory that is underlain by water rather than by land. This is the shelf ice, which roofs over the inner reaches of the Ross and Weddell seas and elsewhere smooths the outline of the continent. From the shelves and from the mountain glaciers that face directly on the sea, great icebergs break loose to drift on the circumpolar ocean. Some of these icebergs have no counterparts in the Arctic seas. As large as the state of Connecticut, they are capable of drifting for years and of making the full circumpolar circuit around the continent.



BYRD STATION, constructed underground, is reached by means of ramps cut into the snow. The ramps and their entrances form a roughly cross-shaped pattern in this photograph, made from a Navy aircraft flying 11,300 feet above sea level. Rows of black dots at center are the shadows of supplies standing on elevated platforms. Markings in snow are tracks of the excavating equipment.

TRIMETROGON PHOTOGRAPH of Alice Glacier in Victoria Land was made from an altitude of 20,000 feet above sea level by a Navy photo-mapping aircraft. Sky is visible at far right and at far left; at lower left is the wing tip of the plane. Below the horizon at left is the Beardmore Glacier; below the horizon at right is the Queen Alexandra Range. Dark lines running through

Most of the ice that bars approach to the continent around its entire periphery, however, is sea ice such as forms in the Arctic Ocean. Between summer and winter the margin of the pack ice oscillates back and forth from roughly the 70th out to the 60th parallel.

Because the ice reflects most of the solar heat directly back into space, it is calculated that the combined reflecting surface of the continental and oceanic ice increases the temperature difference between the Antarctic and equatorial regions by a factor of two or more. The north-south heat gradient, thus amplified, sets the vast oceans of air and water in motion along the lines of longitude over the Southern Hemisphere. At right angles to the heat gradient, the rotation of the earth exerts another force, known as the Coriolis force, which causes the movement of the air to veer from west to east. The westerly winds in turn drive the ocean currents from west to east. Between the 48th and 65th latitudes, a stretch of 1,000 miles, only the southern tip of South America breaks the expanse of ocean; between the 55th and 65th latitudes there is a belt of uninterrupted ocean 600 miles wide. As a result, the famous westerly winds of the "roaring forties," the "howling fifties" and the "screaming sixties" and the powerful Antarctic Circumpolar Current are able to swing in a complete circle around the globe.

The movements of air and water carry the climatic and oceanic influence of Antarctica far north of the margin of the pack ice. The natural boundary of the Antarctic region is set by the Antarctic Convergence. This is a narrow zone in the water masses surrounding the continent where abrupt changes in temperature and density divide the cold Antarctic water of low salinity from the waters of the northern oceans. The Convergence moves northward and southward with the seasons and with dynamic changes in the oceanic circulation. In the Antarctic summer month of February this boundary lies roughly halfway between the southernmost points of South America, South Africa and Australia and the nearest points on the Antarctic continent.

The unique geography of the Antarctic region, so forbidding to most human activities, makes it a great natural laboratory for the study of major questions about the earth as a whole that cannot be approached so advantageously elsewhere. Polar stations, for example, are essential to investigation of the upper atmosphere. In the Antarctic the three

the glacier are crevasses. Three cameras are used simultaneously in trimetrogon photography. The center camera is aimed straight down; each of the others is at a 60-degree angle to the vertical. Trimetrogon photographs are made every 30 seconds along a predetermined flight line. They are being used by the U.S. Geological Survey to make the first accurate topographical maps of Antarctica.

southern poles of the earth—the geographic, magnetic and geomagnetic poles (the south pole of the extended magnetic dipole field)—are all located on land, where secure year-round observatories can be maintained. Moreover, the low level of man-made radio noise and of thunderstorm noise in the Antarctic makes for better monitoring conditions on all frequencies.

For the purposes of the meteorologist and oceanographer the circulation of the Antarctic ocean and atmosphere presents in each case a pattern of geometrical simplicity that approximates the theoretical model. The glaciologists are approaching the completion of the enormous task of determining the thickness of the ice over the continent. They can now turn to study of the ice budget of the Antarctic, of the deformation and flow of the ice and of the climatic history of the continent as it is recorded in the depths of the ice. With the ice burden reliably estimated, geophysicists can turn to study of the dynamics of the underlying crust. Antarctica provides the ideal observatory for investigation of the crustal character of the Southern Hemisphere. The continent itself is distinguished by its seismic quiet, either because it has become tectonically inactive even in its western parts or, as has been suggested, because it is literally weighed down by the icecap. In either case the absence of local seismic noise makes it possible to record fainter earthquake signals from elsewhere. Because the continent faces on the ocean all around the perimeter, signals from many earthquakes arrive undistorted by travel in continental masses. Some of the earthquake recordings can be employed to make sensitive studies of the Antarctic continent's own substructure.

The crustal investigation will help to settle the controversies around questions of continental growth and drift that the surface geology of Antarctica has helped to excite. The geological prospecting of the continent has not yet produced its last surprise, for it has barely begun. Beyond the meager sample of geological history that is exposed on land, the geologists can look forward to study of the marine sediments. Over a stretch of ocean bottom reaching out 200 to 700 miles all around Antarctica, icebergs have rafted and deposited a rich till of continental rock. The first sampling of these deposits has already produced significant fossils. The well-established connections between the ancient flora and fauna of Antarctica and the other continents of the Southern Hemisphere now play a pivotal role in efforts to reconstruct the paleogeography and paleoclimate of the world as a whole.

As a result of the present isolation of the continent, the community of life extant there now is one of the few that present a natural assemblage of organisms uncontaminated by the activities of man. The rising need for food sources to meet the needs of an expanding world population furnishes a compelling practical reason for deeper study of the rich marine life in the Antarctic.

One can, of course, list equally tangible prospective benefits to justify other Antarctic studies: eventual additions to the world's mineral resources, improvement in radio communication, more reliable weather forecasts and so on. Such reckoning helps to justify for politician and taxpayer the $100,000 to $200,000 that it costs to put a scientist on the Antarctic continent. The figure

McMURDO AND SCOTT STATIONS, established by the U.S. and New Zealand respectively, are located on Hut Point Peninsula. The peninsula is at the right in this photograph, which was made from a Navy aircraft flying 16,000 feet above sea level. On the horizon at center is Mount Erebus. To the right of the peninsula is the Ross Ice Shelf; to its left is Erebus Bay, which opens into McMurdo Sound. In the center foreground is a pair of crossed airstrips. The tiny dots adjacent to them are airplanes on the ground.

is small compared with the cost of putting a man on the moon. But the polar scientist, no less than the space scientist, must acquit his public responsibility to see that his undertakings are well conceived and diligently pursued. Both have the good fortune to be backed by a constituency that is convinced of the intrinsic worth of basic science and recognizes the unpredictability of its practical benefits. The Antarctic continent holds out still another challenge. Under the provisions of the Antarctic Treaty, national claims to territory there have been at least temporarily abandoned. Antarctica can become a laboratory not only for the physical and life sciences but also for the development of international co-operation and understanding. There will be increasing opportunities for scientists of many nations to work together on this truly international continent to enlarge the heritage of all mankind.

EDGE OF ROSS ICE SHELF was photographed from a Navy aircraft flying at an altitude of 4,400 feet above sea level. The shelf, which extends all the way to the horizon, has a depth of as much as 1,000 feet and is elevated about 100 feet above the water. The light areas in the ice on the Ross Sea (*at right*) are newly formed ice. The narrow fissure near the edge of the shelf in the foreground outlines an iceberg in the process of calving. The wider fissures to its left and above it are crevasses.

The Antarctic and the Upper Atmosphere

The lines of force in the earth's magnetic field bend down over the poles; hence the Antarctic is a key location for observing the interaction of the field and charged particles from the sun

by Sir Charles Wright

At first thought it might seem a bit odd to go all the way to the Antarctic to study the upper atmosphere. The atmosphere is above us wherever we are, and its higher regions, beginning at about 50 kilometers (30 miles), lie almost wholly beyond the influence of surface climate. Yet the properties of the upper atmosphere in the regions of the poles differ crucially from those at middle latitudes. This is due to the earth's magnetic field.

As almost everyone knows, the earth has a "dipole" field that in the large resembles the field of a gigantic bar magnet running not quite through the center of the globe and tilted at about 11 degrees to the spin axis. At the surface the dipole field is badly distorted by magnetic minerals in the crust. Even the magnetic poles themselves, if they are taken to be the places where the dipping needle points straight down, do not coincide with the dipole axis [*see illustration on page 80*]. With increasing distance from the surface the irregularities tend to disappear. For most upper-atmosphere work the dipole axis is assumed to pass through the center of the earth. The poles of this "centered approximation" geomagnetic axis are located at 78.5 degrees north latitude, 69 degrees west longitude (in northwest Greenland) and 78.5 degrees south latitude, 111 degrees east longitude (not far from Vostok, the Soviet station on the Antarctic plateau).

Imagine the axis as a straight line connecting the axis poles and extending indefinitely into space in both directions. Everywhere along the axis the lines of force of the geomagnetic field run vertically through the upper atmosphere, perpendicular to the earth's surface. The greater the distance from the axis, the more the field tilts away from the vertical. In the plane of the magnetic equator it is horizontal, or parallel to the surface.

Why should changes in the inclination of imaginary lines of force affect the characteristics of the tenuous gas high in the atmosphere? The answer lies in the charged particles streaming down into the atmosphere from the sun. To the particles a line of force represents a very real barrier when approached at right angles. If the particles come in parallel to the line of force, it serves as a guide down which the particles travel, twisting around the line in a helical path. The effect of the earth's field is to divert incoming charged particles away from the geomagnetic equator, where they approach the lines of force perpendicularly, and to funnel them toward higher magnetic latitudes, where the lines of force point downward toward the earth's surface. As a result the upper atmosphere is a much livelier and more interesting place in the region of the poles, especially in the circumpolar zones where auroras occur regularly.

If the situation were completely symmetrical, every phenomenon near one pole would have its exact counterpart near the other. As a matter of fact there is now enough evidence to show, or at least to suggest strongly, that major upper-atmosphere events in one hemisphere are mirrored in the other. Of course the events are not precisely the same or precisely simultaneous. One of the incentives to Antarctic research is the comparison of phenomena there with those that have been more thoroughly studied in the Arctic. This should help the investigator to reach a detailed understanding of the complex interactions of atmosphere, magnetic field and solar emanations. Some observations must be carried out simultaneously in both hemispheres at conjugate magnetic points, that is, at opposite ends of the same line of force.

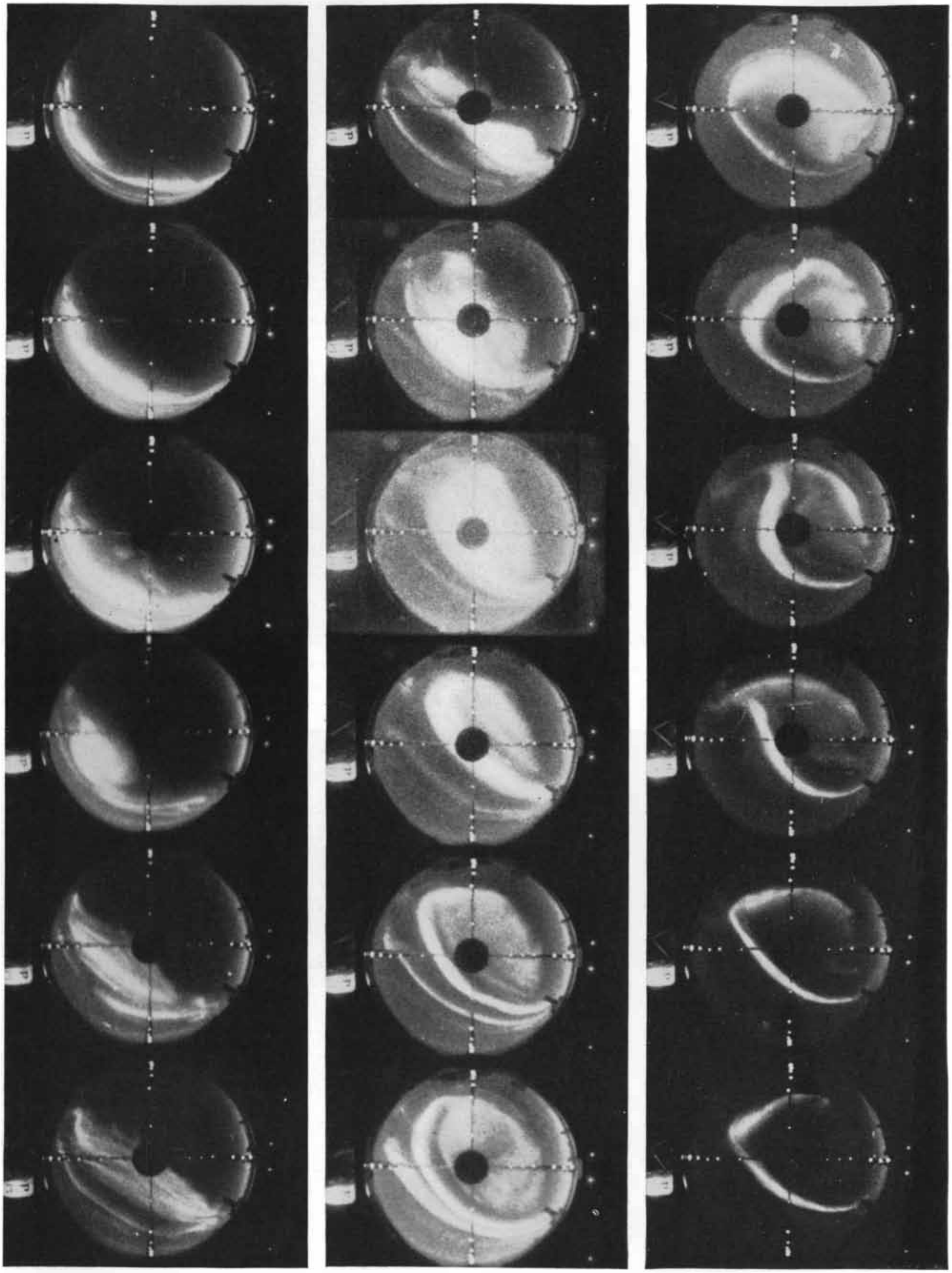
In addition to providing a comparison with the Arctic, the Antarctic is in many ways the more convenient high-latitude observatory, as A. P. Crary has pointed out in the preceding article. The ice sheet, inhospitable as it may be, offers a solid base for permanent stations, in contrast to the Arctic Ocean. Already the available transport facilities make large regions of Antarctica easier to reach than corresponding points in the Northern Hemisphere. Comparative freedom from thunderstorms and from man-made sources of electrical interference are additional advantages.

Beginning during the International Geophysical Year, a wide and varied program of upper-atmosphere research has been under way in the Antarctic. Although the program is now a few years old, definitive results are only just beginning to emerge. Almost every experiment is a major undertaking that may take a whole season to set up. A few months of operation produces roll upon roll of paper records or case after case of photographs that often require more time to analyze than to collect. The work has barely begun. In this article I shall necessarily have more to say about the subjects being investigated than about what has been learned.

In any discussion of upper-atmosphere effects, pride of place must go to the aurora. Only a handful of people have been so fortunate as to see it in its full development in Antarctica (even today hardly anyone is there during the long winter night), but Indians, Eskimos, miners and trappers know its counterpart in northern Canada. The regions where auroras are most common—in-

SUNLIT AURORA (*above*) is a rare sight. Sunlight usually blots out aurora. Photograph was made in April, time of sunset before long night of polar winter. Sun is below the horizon.

ACTIVE AURORA (*below*) resembles undulating drapery. These are the first color photographs of the aurora ever made at the South Pole, which lies on the inner edge of the southern auroral zone.



ALL-SKY PHOTOGRAPHS of an aurora at the South Pole show its development over a period of 24 minutes. The series starts at top left and ends at bottom right. The all-sky images were made by photographing a shiny metal ball from above. These photographs and the color photographs on the preceding page were made by Henry Morozumi of the Radioscience Laboratory at Stanford University. His Antarctic studies were made under the auspices of the Arctic Institute of North America and the State University of Iowa.

deed, where they take place practically every night—are called the auroral zones. They are a pair of rings surrounding the axis poles at a distance of about 23 degrees. Outside and inside the rings auroras are less frequent.

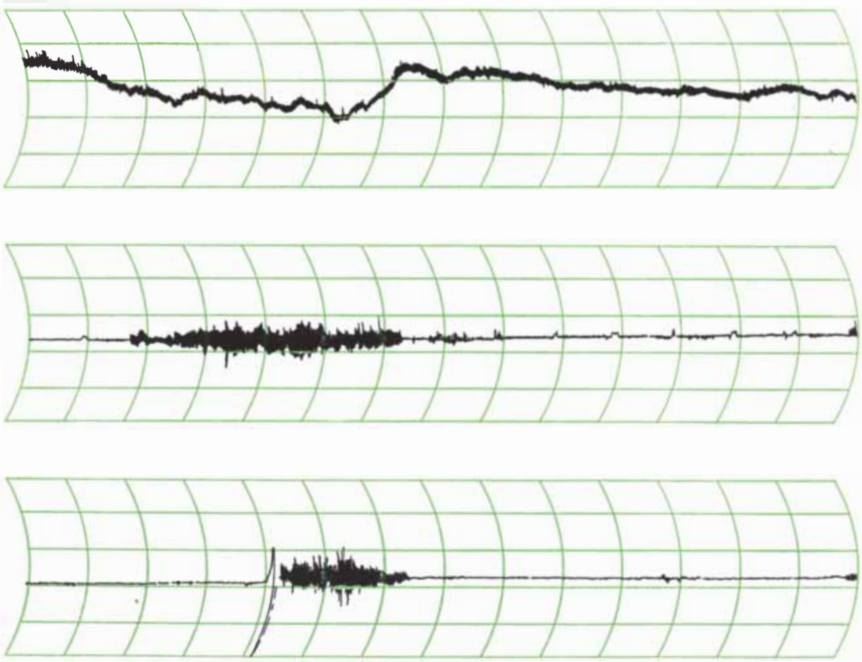
Generally speaking, an observer in the Northern Hemisphere sees auroras from the outside, or south of the zone. He discovers first a pale glow low on the horizon toward the axis pole. Soon the low auroral glow becomes a quiet greenish-yellow arc stretching across the sky nearly along a magnetic latitude. The first arc rises gradually toward the zenith, followed by a second, third and perhaps even a fourth, moving in stately parade. On a night of quiet aurora some or all of the arcs may pass the zenith about midnight and then go back, disappearing toward the axis pole. During nights when the earth's magnetic field is disturbed auroras become active just before midnight, the arcs changing into groups of discrete rays that arrange themselves parallel to the almost vertical magnetic lines of force. The general color remains a pale greenish yellow, but often it brightens and shows a reddish tinge, particularly along the lower edges of the rays. Even a vivid blue or apple green can appear intermittently. Sometimes the bands of rays appear to fold on themselves, forming "draperies" and "curtains" that move about and change form. This pulsating aurora signals the breakup of the display. After midnight the rays fade and disintegrate.

So few people have watched auroras from within the zone that it is hardly possible to speak of their typical appearance from such vantage points. As a member of Robert F. Scott's Antarctic expedition of 1910 to 1913 I was privileged to observe and report on the aurora from well inside the zone. As in the north, a glow on the horizon was followed by the stately approach of quiet arcs. Since I was between the axis pole and the auroral zone, I saw the arcs moving inward toward the pole. Only rarely did they rise to the zenith and pass overhead. When they did, they showed the quick changes of shape and color characteristic of pulsating auroras. Afterward they broke up into the separate rays and draperies of an active aurora. They did not return as arcs to their place of origin. Usually the active-aurora breakup coincided with increased magnetic activity that appeared at a time of day when such activity was normally slight.

It must be admitted that geophysicists still do not agree completely on the origins of the aurora. But seeing is believing, and the sight of the aurora overhead, waxing and waning in tune with fluctuations of the geomagnetic field, gives a measure of confidence in the idea of a connection between magnetic and auroral activity. At the same time there is an undoubted correlation with solar activity. The most widely accepted explanation for the aurora is that protons and electrons from the sun bombard oxygen atoms and molecules and nitrogen molecules in the upper atmosphere, exciting them into luminescence. The auroral zones are regions of maximum activity because the earth's magnetic field usually dumps most of the solar particles into the atmosphere there. The quiet aurora, always present somewhere in the auroral zones, can probably be ascribed to the "solar wind," a continuous stream of charged particles sent out by the sun.

The number of active auroras increases and decreases with the 11-year cycle of solar activity. The peak of auroral activity, however, seems to lag a year or two behind that of solar activity. By far the most spectacular and widespread auroras follow strong flares on the sun. After a flare the solar wind becomes a gale of varying force and speed. Some extremely energetic charged particles hit the earth's atmosphere within a few hours, but most arrive as clouds of plasma (ionized gas) beginning a day or so later. This indicates a modest speed of 1,600 kilometers (1,000 miles) per second for the trip from the sun to the earth. The "slow" particles continue to arrive for two or three days after a strong flare, showing that the plasma clouds are much wider than the distance traveled daily by the earth in its course around the sun. Plasmas, being good electrical conductors, probably carry entangled with them some of the sun's intense local magnetic fields. These strong fields imprison particles of much higher energy than those constituting the majority of the cloud. Data from satellites lend considerable support to this idea, helping to explain the detection of high-energy particles arriving at the same time as the lower-energy plasmas.

Although much remains to be learned about the behavior of clouds of solar particles, it seems certain that when one of them meets the earth's magnetic field some 10 to 15 earth radii out, it deforms the field, driving it inward. This would push each successive loop in the lines of force into the lower latitudes. As a result

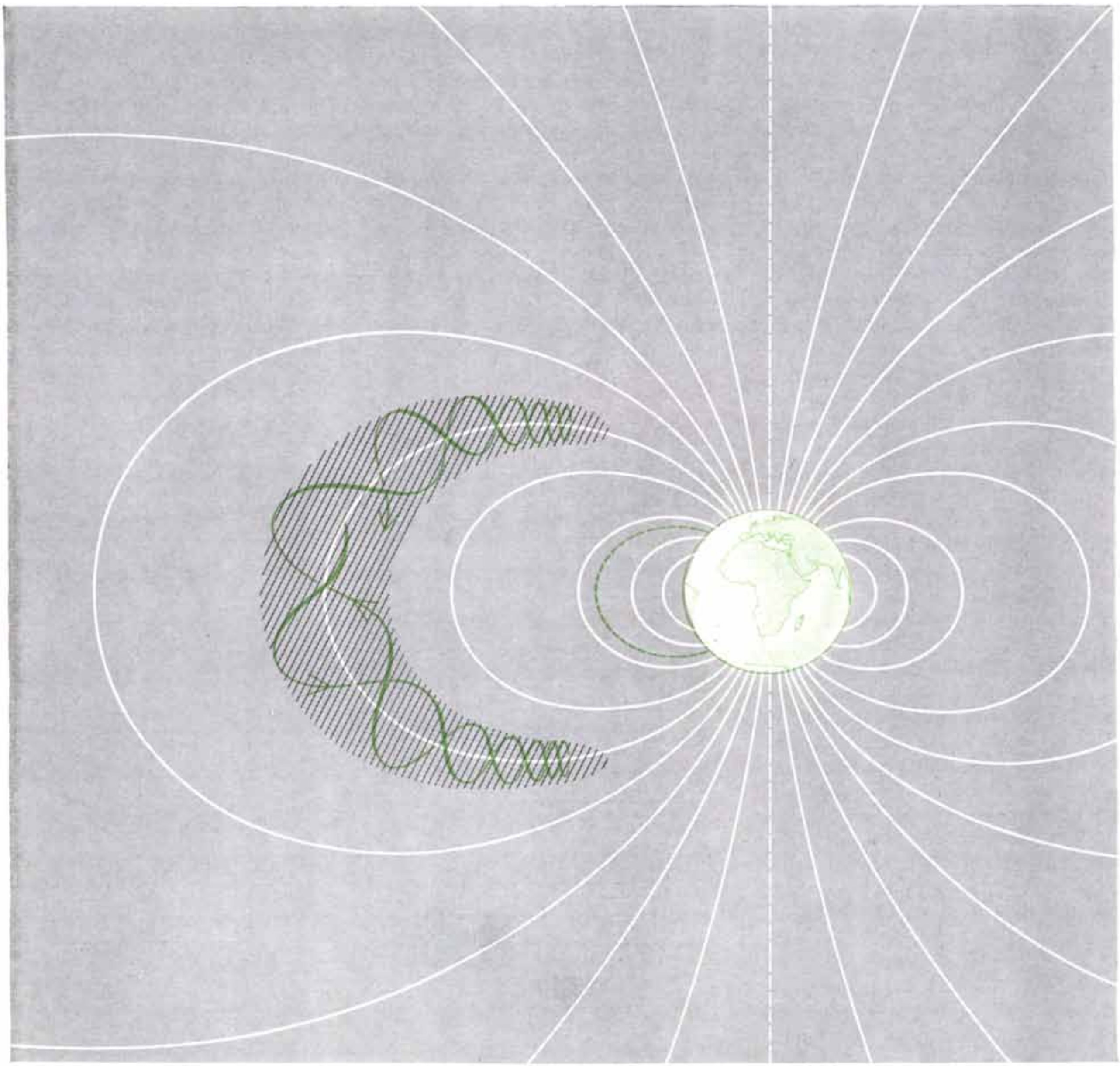


SIMULTANEOUS ACTIVITY in the ionosphere, the earth's magnetic field and the aurora was recorded in Alaska over a period of several hours. During the active period cosmic noise dropped as a result of absorption by the ionosphere (*top*), micropulsations of earth's magnetic field increased (*middle*) and rapid changes or coruscations in the aurora also occurred (*bottom*). The three recordings were made by Wallace H. Campbell of the National Bureau of Standards and Harold Leinbach of the University of Alaska.

the auroral zones are also shifted into lower latitudes. The disruption of the earth's magnetic field is called a magnetic storm.

Many of the higher-energy particles in solar clouds are thought to break through the boundaries of the earth's magnetic field only to be captured by the field farther in. These make up the outer part of the Van Allen radiation belt, which is normally about six earth radii out. There the trapped particles spiral around the magnetic lines of force, dancing back and forth between the two auroral zones where the field becomes strong enough to reflect them. At each end some escape from the "dance floor" to play a role in producing auroras.

During periods of relative solar inactivity Van Allen belt electrons have been found down as low as 100 kilometers in an area that includes the northern auroral zone. The electron flux, as a matter of fact, reaches its maximum in the zone. It is reasonable to expect that solar gales would push the Van Allen zone closer to the earth during an active magnetic-auroral period, together with the lines of force. It is also reasonable to assume that the changes during an active aurora may result to some extent from the capture of new supplies of particles as they enter the earth's magnetic field. These incoming particles are responsible for huge electric currents in the upper atmosphere above the auroral zones, measured in hundreds of thousands of amperes. Such currents flow even in times of quiet aurora, although they are much smaller then. The return path goes partly inside the auroral zones and partly through the atmosphere at lower latitudes. Large variations in the currents reveal themselves as magnetic



LINES OF FORCE of the earth's magnetic field (*white*) trap electrically charged particles from the sun in the outer portion of the Van Allen radiation zone (*hatching*). The spirals represent the motion of a trapped particle gyrating back and forth from the Northern to the Southern Hemisphere along a line of force. Actually such a spiral is extremely tight. The broken colored line nearer the earth is the path of a mid-latitude "whistler," an electromagnetic disturbance below radio frequency, generated by lightning.

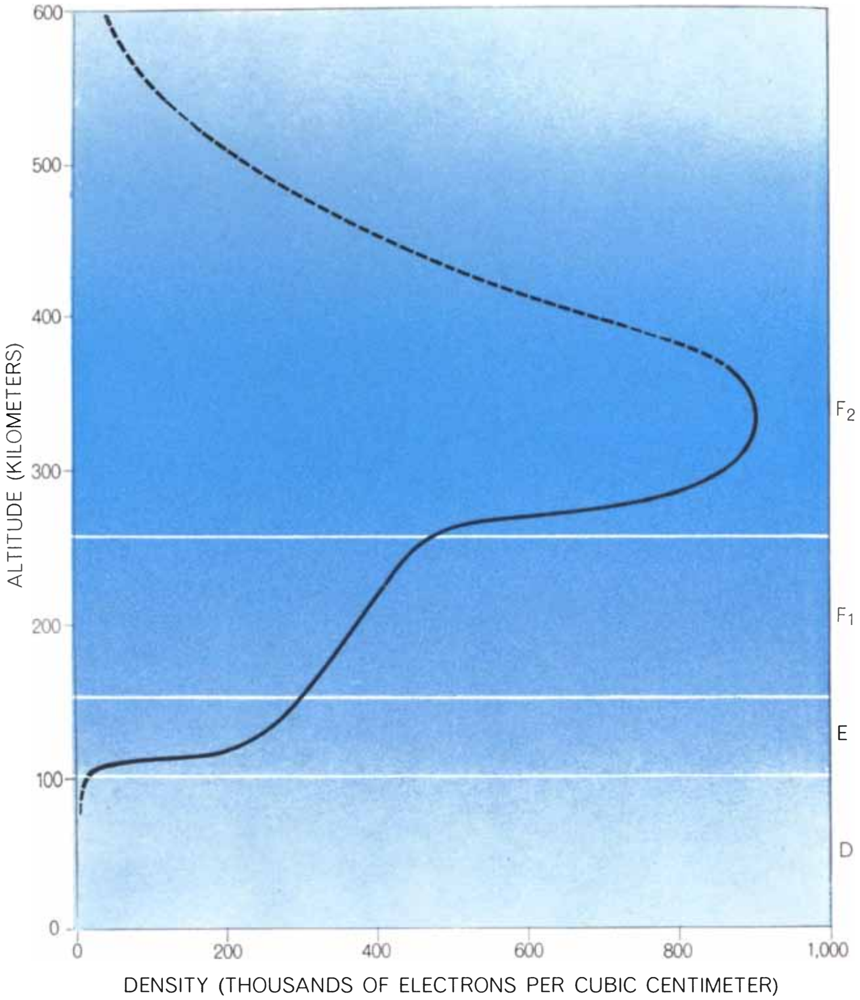
storms that often begin suddenly and virtually at the same time everywhere on earth.

Some of the foregoing picture is still theoretical and most of it is painted only in broad strokes. To fill in the details will require more observations of auroras in both hemispheres and accurate measurements of their size, location and movements. In this work the human eye must be supplemented by other instruments. During the IGY about two dozen all-sky cameras (consisting of a convex mirror facing up at the sky with a camera pointed down at its center) were operated in the Antarctic and 90 such cameras in the Arctic. Each of these instruments provides a photographic record of the progress of auroras over the entire part of the sky visible from its location [*see illustration on page 76*].

To find the position of an aurora, a pair of simultaneous photographs is made with ordinary cameras spaced about 40 kilometers apart. The position is determined from the relation of the auroral features to the background stars in the pictures. Such photographs have demonstrated that the bottom of the aurora is never lower than 65 kilometers (40 miles), whereas the top has been measured at altitudes up to 900 kilometers. The arcs are seldom more than two or three kilometers thick and sometimes are less than a few hundred meters thick. As is known from reports of widely scattered observers, a single aurora can extend for thousands of kilometers, sometimes stretching roughly from east to west over a large part of the globe.

Even cameras cannot tell the whole story, since the aurora is invisible in daylight. Powerful radar sets are now detecting echoes from daytime auroras. The resolution is much lower than that of the camera or the eye, and many details are lost. Nevertheless, radar can be used during the long Antarctic day, and it will make feasible the extremely important task of comparing simultaneous auroras in the two hemispheres.

By no means all the charged particles in the upper atmosphere come directly from the sun. Many originate in ionization of atoms and molecules of the air by solar X rays and ultraviolet rays. The ionized atoms and their accompanying free electrons are responsible for the conducting regions called the ionosphere. Different ions predominate at different heights and the number of electrons varies, giving rise to more or less distinct layers—labeled in ascending order D, E, F_1 and F_2—from 75 kilometers to 350 kilometers. Since the particles are produced largely, if not entirely, by solar radiation, the make-up of the ionosphere varies widely with the time of day and with the season.

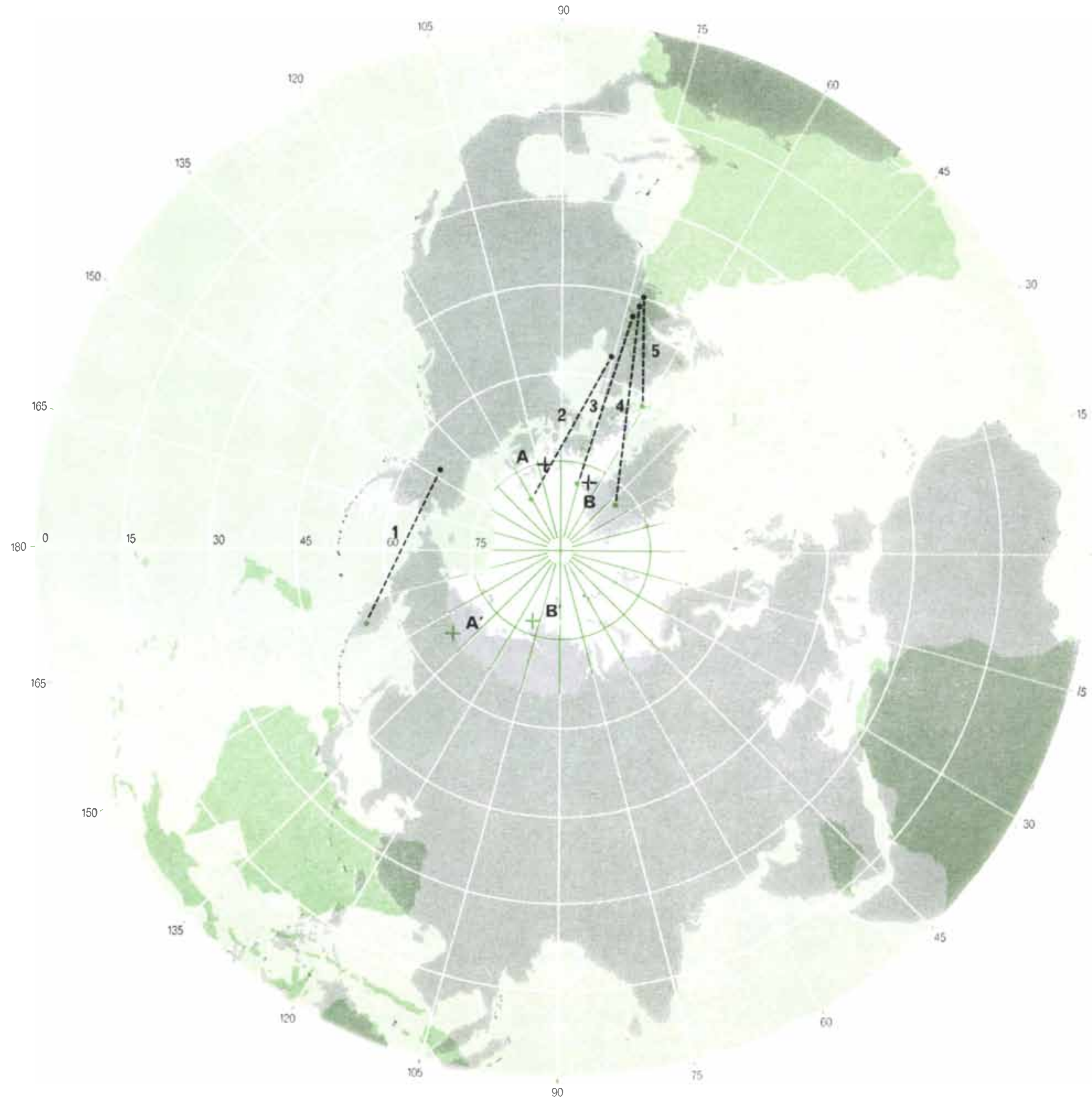


IONOSPHERE is region of many electrically charged particles, as measured by electron density. It is a part of the upper atmosphere, above 99.98 per cent of the air. The colored tone reflects electron densities as indicated by the curve. In reality the boundaries of the four regions, D, E, F_1 and F_2 are not so definite as the white lines would indicate. The regions tend to intermix and to move up and down. The broken lines indicate uncertainty.

Studies in Antarctica are helping to round out the picture of the behavior of the ionosphere. They have also uncovered a puzzle. During the entire Antarctic night the number of free electrons in the F_2 layer above the South Pole waxes and wanes every 24 hours. Yet there is no sunlight at all. Either the pulsation is caused by bulk transport of electrons from illuminated regions of the atmosphere or some agency other than solar radiation helps to ionize the air at the F_2 level.

As a practical matter the ionosphere must be regularly monitored in the Antarctic to help maintain communications. When the normal complement of electrons is augmented by a burst from a solar flare, the D layer absorbs short-wave radio signals. Often the effect is severe enough to black out all radio communication and therefore also to ground all aircraft. Operations in the Antarctic are always subject to interruption by ionospheric storms. Consequently a considerable effort goes into measurements that show what radio frequencies will travel best through the ionosphere at any time.

Still another source of charged particles in the upper atmosphere deserves to be mentioned: cosmic radiation. The particles that make up cosmic rays have an enormous range of energies. All but those of the lowest energies come from outside the solar system; some may even originate outside our galaxy. These have enough energy to pierce the geomagnetic field, and they pour down fairly evenly over the globe. At the low-en-



CONJUGATE POINTS

1 MACQUARIE ISLAND, AUSTRALIA—COLLEGE, ALASKA
2 BYRD, ANTARCTICA—GREAT WHALE RIVER, QUEBEC
3 ELLSWORTH, ANTARCTICA—ST. LAWRENCE VALLEY, QUEBEC
4 SKY-HI, ANTARCTICA—LAURENTIDES PARK, QUEBEC
5 DECEPTION ISLAND, ANTARCTICA—HANOVER, NEW HAMPSHIRE

POLES

A—A′ MAGNETIC (DIP) POLES
B—B′ GEOMAGNETIC AXIS POLES (CENTERED APPROXIMATION)

CONJUGATE-POINT STATIONS, geomagnetic axis poles and magnetic poles in Southern and Northern hemispheres are shown on this map. Southern Hemisphere stations and poles are in color, Northern Hemisphere counterparts in black. Northern Hemisphere (*gray*) appears as though viewed from below through a transparent globe. The compass points to the familiar magnetic poles. They are also called dip poles because in theory a compass directly over one should point or dip straight down. Local magnetic conditions within the earth determine the positions of the dip poles, which move many kilometers each year. The geomagnetic poles are the points at which the lines of force of the earth's magnetic field go straight out into space. The axis of these poles does not pass through the center of the earth; the geomagnetic axis poles shown here are approximations to an axis that does pass through the center. These approximate geomagnetic poles are used for most upper-atmosphere calculations. The location of conjugate points (the two ends of one line of force of the earth's magnetic field) seems to differ for different phenomena and at different times.

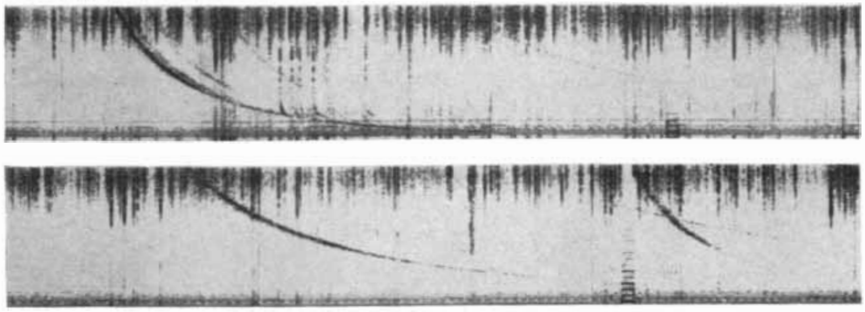
ergy end of the spectrum, however, the cosmic radiation apparently consists of a fairly constant number of particles from outside the solar system and a varying number that come from the sun itself. These solar particles are strongly influenced by the earth's magnetic field, and very few of them are detected near the geomagnetic equator. Observations from balloons and satellites have shown that when low-energy cosmic rays increase (usually after a solar flare), the curve showing numbers of particles arriving at different magnetic latitudes remains nearly horizontal for low and middle latitudes and turns sharply upward in high latitudes. This is known as the latitude-knee effect. If the explanation is correct, the "knee" should disappear, or at least become less prominent, during a period of solar quiet. The question will be tested in the Antarctic during the International Year of the Quiet Sun (IQSY) in 1964 and 1965.

One of the most interesting programs of Antarctic research is the study of low-frequency electromagnetic disturbances. In moving through the atmosphere long electromagnetic waves (that is, waves of low frequency) are strongly affected by the earth's magnetic field. Some of them even seem to follow lines of force, in which case they can be reflected so that they oscillate back and forth between magnetically conjugate points in the two hemispheres.

The best-known example of the phenomenon is the "whistler." A whistler is a radio signal lasting a second or two and sweeping (usually downward) in frequency from about 30,000 cycles per second to at least 400 cycles per second. This is well below the lowest broadcast band and extends into the audible frequencies. (To be heard, of course, the electromagnetic waves must be converted to sound waves by a radio receiver.) For some years it has been known that whistlers originate in lightning discharges. Each discharge generates waves over a broad range of frequencies, some of which are heard as the familiar clicks of radio static. As they move through the upper atmosphere, the waves are slowed down by the free electrons. The degree of slowing down depends on the electron concentration, the frequency and the magnetic field along the path; for a given concentration the longer waves slow down more than the shorter ones. The result is to turn the original click into a drawn-out whistle. Under certain circumstances a whistler may rise in frequency or rise and fall simultaneously. In the latter case its sound spectrogram has a noselike shape, hence the name "nose whistler."

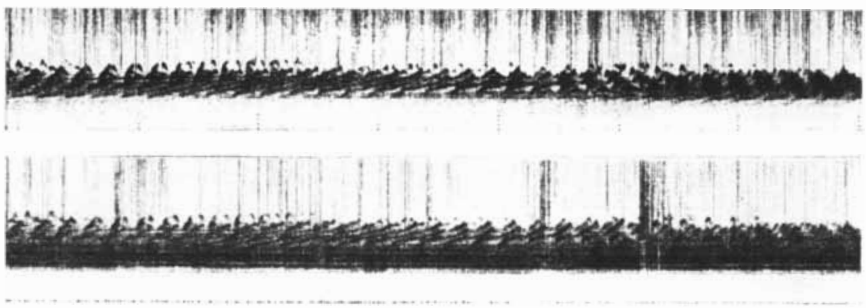
Early studies showed that a disturbance must travel many thousands of kilometers to be stretched out into a whistler. It was finally found that the lightning-generated waves move along a line of force of the earth's magnetic field, bouncing back and forth between the conjugate points where the line comes to earth in the Northern and Southern hemispheres. Whistlers that originate in lower latitudes, therefore, do not get far from the earth's surface, but those from higher latitudes follow lines of force out many earth radii. When they start near the geomagnetic poles (it is possible to generate whistlers artificially in the absence of storms), they should travel beyond the outer reaches of the Van Allen belt. Such waves would furnish a means of studying the electron content of the far outer atmosphere, thousands of kilometers above the ionosphere. So far, however, the important experiment of recording and analyzing whistlers at conjugate points well inside the auroral zones, near the geomagnetic axis poles, has not been carried out.

About two years ago R. A. Helliwell of the Radioscience Laboratory at Stanford University proposed to the Canadian Defence Research Board's Pacific Naval Laboratory, with which I am associated, that we co-operate in an experiment at Byrd Station in Antarctica and its conjugate point in Canada. The Pacific Naval Laboratory welcomed the proposal as affording us an opportunity we had long discussed: to obtain simultaneous high-latitude conjugate measurements below the frequency range of whistlers. The mouth of the Great Whale River, where it empties into Hudson Bay,

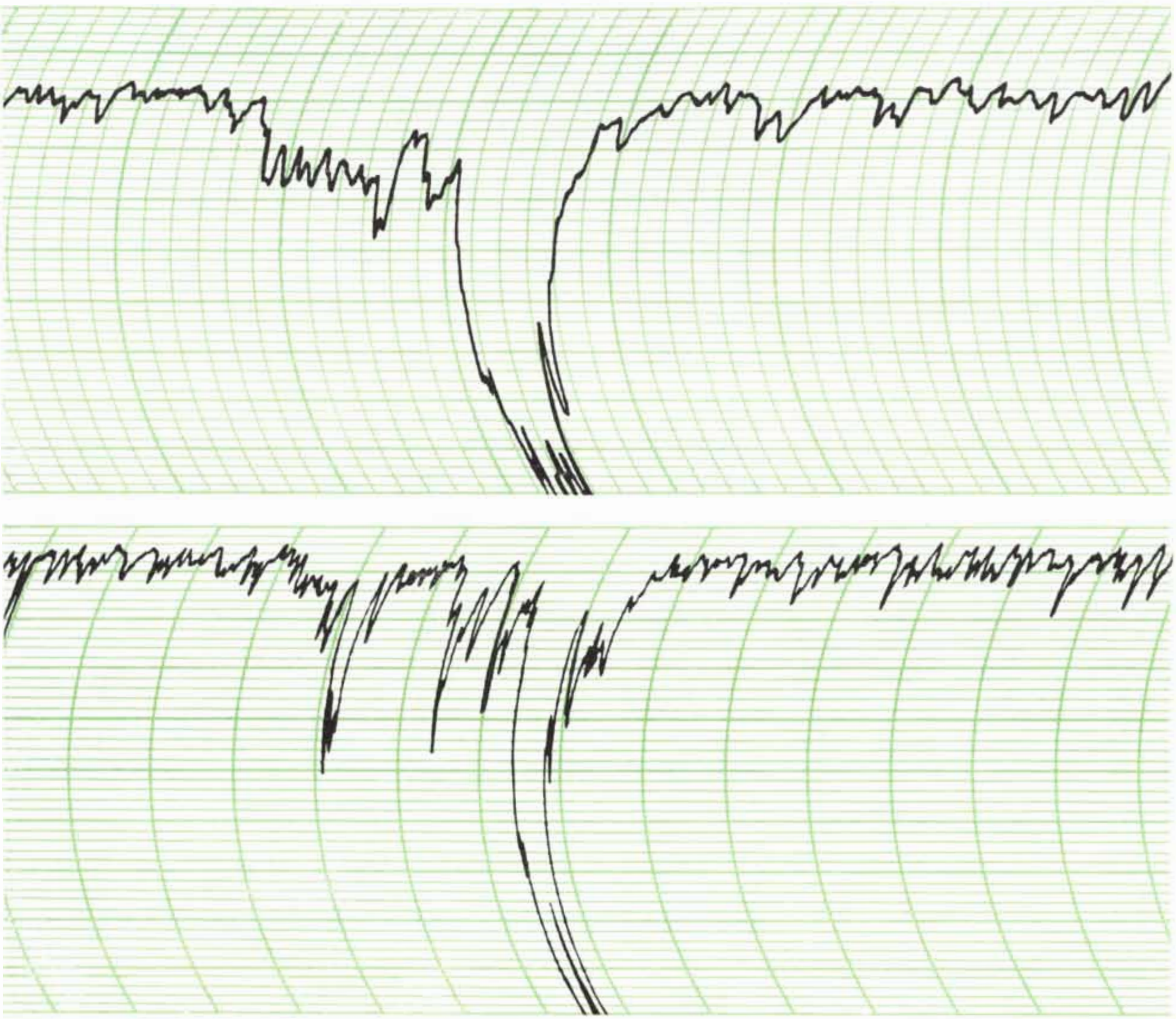


WHISTLER SPECTROGRAMS show "one hop" whistlers (*left at top and right at bottom*), which have traveled once through upper atmosphere, and a two-hop whistler (*left at bottom*), which has made two trips. Vertical scale is from 8,000 cycles to zero.

"NOSE WHISTLERS" are simultaneous rising and falling tones that join smoothly to "draw" a nose on the spectrogram. Two such whistlers, traveling several paths, can be seen. Top frequency here is 16,000 cycles. Source clicks of the whistlers are marked at left by broken lines. Records such as this permit measurement of electron density along the path traveled by the nose whistler. R. A. Helliwell of Stanford University recorded the whistlers.



"DAWN CHORUS" is a twittering noise of unknown origin that occurs in early morning at middle and high latitudes. These recordings, covering about a minute, were made simultaneously at conjugate points in Alaska (*top*) and New Zealand during Helliwell's program.



SIMULTANEOUS ENHANCEMENT in oscillations of the earth's magnetic field appears on records covering 14 minutes at the conjugate-point stations—Great Whale River in Canada (*top*), and Byrd in Antarctica (*bottom*). Oscillations are of several seconds' period.

SERIES OF SPIKES appear together on magnetic records at Great Whale (*top*) and Byrd (*bottom*). They seem to come from multiple flashes of intense lightning and could travel through earth-ionosphere cavity, possibly guided by earth's magnetic field.

was selected as the northern conjugate point. The Pacific Naval Laboratory also installed equipment at Fort Churchill, which is close to the auroral zone and about 1,000 kilometers west of Great Whale, but this turned out to be an extremely noisy site. Our various receivers were designed to cover the range of electromagnetic waves between 22,000 cycles per second and 1/300 cycle per second (corresponding to a period of five minutes). The long-period waves below about three seconds' period (1/3 cycle per second) fall into the range of geomagnetic micropulsations, named for their very small amplitude or energy [see "The Longest Electromagnetic Waves," by James R. Heirtzler; SCIENTIFIC AMERICAN, March]. These are detected as disturbances in the earth's magnetic field. The preliminary records at Byrd and Great Whale show a number of micropulsation events occurring almost simultaneously. This indicates that they are directed by, or are at least closely associated with, the magnetic-field line that joins the two stations.

A little below the whistler range, however, waves from lightning strokes no longer travel along magnetic-field lines. Instead they move through the "earth-ionosphere cavity," the region between the surface of the earth and the reflecting layers of the ionosphere. This is shown in part by the fact that the waves propagate only in certain modes, the first three of which are in frequency bands centered around 8, 14 and 19 cycles per second [*see illustration on this page*]. The cavity resonates at these frequencies and acts as a wave guide in transmitting the disturbance from a lightning source to the recording site.

In this frequency range between whistlers and geomagnetic micropulsations our records also show some much larger high-amplitude spikes arriving simultaneously at both stations [*see bottom illustration on opposite page*]. Recent analysis of some of the records indicates that larger spikes may well come from multiple flashes of lightning of high intensity. Apparently the spikes travel through the earth-ionosphere cavity, but even there the guiding effect of the magnetic field may be important. To determine this, observations should be made at other places.

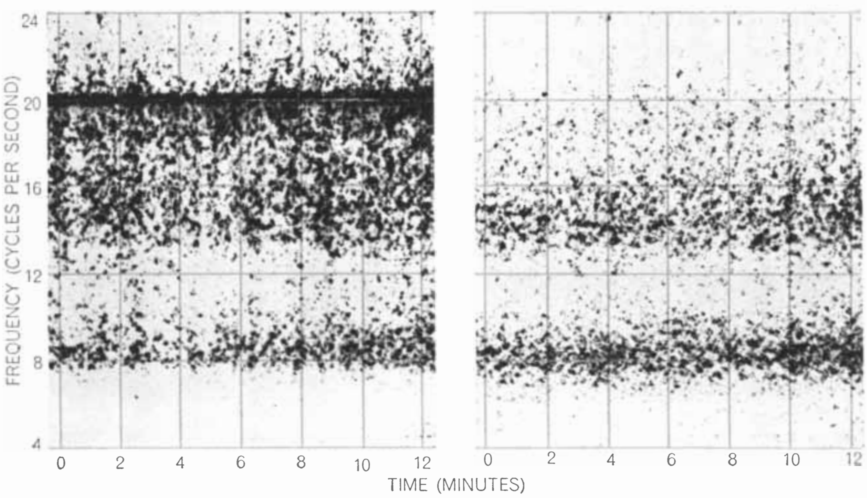
Below the lightning-induced frequencies is a sort of no man's land, extending from approximately five cycles per second to about 1/3 cycle per second. It seems generally to be avoided by both the geomagnetic micropulsation activity and the electrical-storm regime, but it is invaded from both sides during general magnetic or local electrical storms. Normally the background activity at Byrd and Great Whale in this region is barely perceptible: about a hundred-millionth the amplitude of the earth's magnetic field. Occasionally mysterious strong signals at about one cycle per second show up.

In the geomagnetic micropulsation range some of the waves seem to travel along the magnetic field lines and some do not. The longer-period disturbances are of especially large amplitude in the auroral zones. This indicates that they are propagated parallel to the field lines. The shorter-period waves do not show such enhanced amplitude in the auroral zones and so are probably propagated at large angles to the lines of force of the magnetic field.

Several times during the early part of the conjugate-point experiment we picked up, almost simultaneously, bursts of micropulsations two to eight minutes long. They came just after the time of day normally free from disturbances, and they were recorded at Fort Churchill also, but usually not simultaneously. We suspect that they were associated with auroras, since an aurora was reported at the time from Great Whale. Byrd Station, however, was in continuous daylight, and the aurora, if any, was not visible there. The experiment has been continued into the Antarctic winter. When the more recent records from Byrd Station have been analyzed, the question may be definitely settled. It is particularly interesting that these brief events favor the hours of 2 a.m. to 4 a.m. (Greenwich Mean Time) at both stations.

To someone whose experience in Antarctic research goes back to the days of Scott and Shackleton, the progress that has been made in transport and in instruments is staggering. It is quite an experience to fly up the Beardmore Glacier toward the Pole in a couple of hours, while remembering the two months of hard sledging that the journey once required. Fifty years ago a gravity reading took us five hours of observation daily for three days, not to mention the nightly star observations to correct our chronometers. Today the whole affair is accomplished in five minutes.

Yet this very progress raises a further challenge. New approaches and new techniques are needed to exploit fully the opportunities for research in the Antarctic. At present it is not easy to introduce them. During the winter the Antarctic is cut off from the rest of the world by lack of transportation. The opportunities for trying new things are limited by the equipment one has at hand or can make up from the scant local resources. Thus the testing of a new idea usually has to wait for a year at least, and not everyone has that much time to spend. The only cure would seem to be an uninterrupted system of air transport during the winter between McMurdo Station and the permanent stations at Byrd and elsewhere. At the same time the facilities at McMurdo should be expanded to make possible the design and building of new equipment there.



RESONANCE BANDS of cavity between earth and ionosphere are at about 8, 14 and 19 cycles per second in simultaneous recordings from Great Whale (*left*) and Byrd stations. Heavy line at 20 cycles in the Great Whale record is due to local interference. These pulsations did not travel along a magnetic line of force, although lightning caused them.

The Antarctic and the Weather

By dissipating heat into space, the Arctic and Antarctic balance the earth's heat budget. Unlike the Arctic, the Antarctic seldom gives rise to sharp changes in temperature in the middle latitudes

by Morton J. Rubin

It is a familiar observation that climate around the world is largely determined by latitude, proximity to the great oceans and the topography of the land mass. Similar climates are therefore found in many different places. The climate of the Antarctic, however, is unique. Except for latitude, the Antarctic is the antithesis of the Arctic. The Arctic is almost entirely ocean with a perimeter of land; the Antarctic is almost entirely land with a perimeter of ocean.

Both regions, however, serve the same thermodynamic function in keeping the world's heat budget in balance. This function is to accept huge quantities of heat, transported poleward by the atmosphere and oceans, and to dissipate the heat into space in the form of long-wave radiation. All bodies not at absolute zero radiate heat, and the radiation intensity is proportional to the fourth power of the absolute temperature. For purposes of heat dissipation, therefore, a large, cool radiator can be just as effective as a small, hot one—and the Antarctic, by any definition, is huge.

One way to define the Antarctic is to characterize a polar climate as one in which there is either perpetual snow and ice or one in which it is too cold for trees to grow, meaning that the warmest month is below 10 degrees centigrade (50 degrees Fahrenheit). According to this definition the Antarctic polar climate covers about three times the area of its Arctic counterpart. The principal explanation for this is that the ocean surrounding the Antarctic readily transfers the incoming solar heat to deeper waters, thereby maintaining a fairly uniform surface temperature and effectively minimizing the heating of the atmosphere by the water in summer. In contrast, when the sun's radiation strikes the land around the perimeter of the Arctic, the heat is taken up within a few feet of the surface, raising its temperature and that of the air above.

Before the International Geophysical Year meteorologists had little firm knowledge of Antarctic conditions. They did not know, for example, exactly how much solar energy reached the Antarctic snow surface. They even lacked information about air temperatures over most of the continent. As data collected over the past six years have been analyzed, a number of unsuspected features of the Antarctic weather have come to light. They are concerned chiefly with the heat budget, with the short-period and seasonal temperature fluctuations, with the patterns of atmospheric circulation and with seasonal changes in the ozone content of the atmosphere.

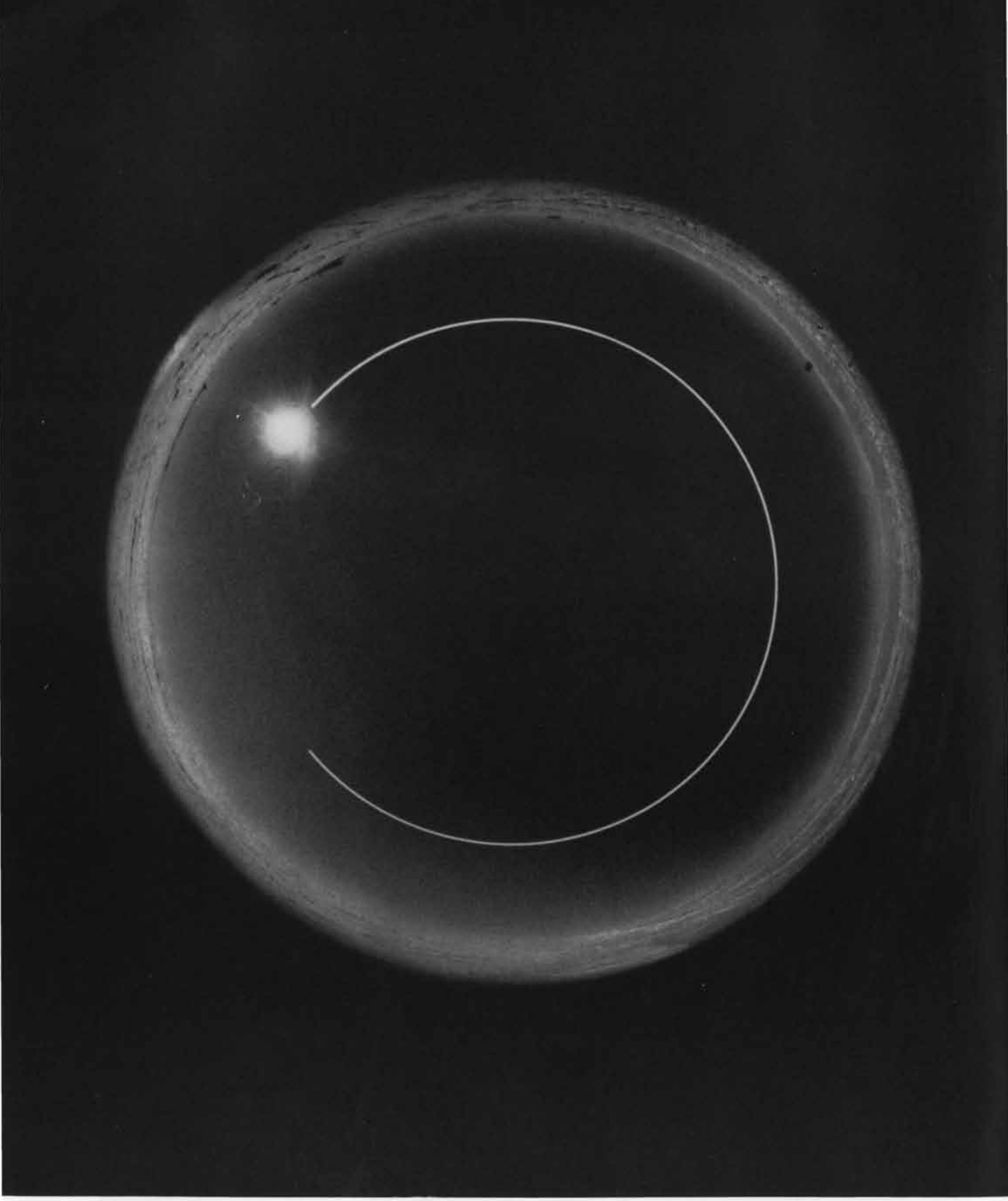
The Antarctic atmosphere is almost free of dust and other pollutants. More significantly for the climate, the atmosphere contains only about a tenth the concentration of water vapor found at temperate latitudes. The water vapor content is low simply because very cold air cannot hold much moisture. As a result most of the Antarctic receives no more precipitation than a desert does. Also because of the low water vapor content, the Antarctic atmosphere is relatively transparent to long-wave heat radiation. Except in a narrow portion of the infrared spectrum, atmospheric water vapor strongly absorbs long-wave radiation originating at the earth's surface and reradiates much of it back to the surface. Lacking a heavy protective blanket of water vapor, the Antarctic readily radiates heat energy into space. The relation between atmospheric temperature and water vapor content is mutually reinforcing. Arctic air, being generally warmer than Antarctic air, holds more water vapor and therefore captures more of the heat radiating from the ground (or water) below.

Because the earth is at perihelion (nearest the sun) during the Antarctic summer, about 7 per cent more solar energy reaches the top of the Antarctic atmosphere in midsummer (December) than reaches the top of the Arctic atmosphere in midsummer (June). Moreover, because of the elevation of the south polar plateau the sun's rays have about 30 per cent less mass of air to traverse than radiation reaching the North Pole and are therefore less attenuated by scattering and reflection. At the South Pole in the midsummer month of December about 36,000 calories per square centimeter reach the top of the atmosphere [*see illustration on page 90*]. After allowing for atmospheric absorption and cloudiness, about 79 per cent of this radiation, or 28,500 calories per square centimeter, reaches the snow surface. About 76 per cent of the incoming radiation is immediately reflected back into space, leaving some 6,900 calories per square centimeter to warm the snow. Comparable measurements made on the Arctic ice island T3, floating within five degrees of the North Pole in the Arctic summer, show that about 22,000 calories per square centimeter reach the ice surface and, after reflection, only about 5,900 calories are left for warming each square centimeter of ice.

If only the solar input were involved, one would expect the Arctic basin to be colder in midsummer—and hence throughout the year—than the South Pole. But this is not the case. Monthly mean temperatures at the South Pole range from −25 to −62 degrees C. (−13 to −80 degrees F.), whereas in the Arctic basin the range is only from about 0 to −35 degrees C. (+32 to −31 degrees F.).

SUNDOGS, or parhelia, often appear as bright spots of color on the vivid halos surrounding the Antarctic sun. The halos are formed by ice crystals in the atmosphere. The photograph was made by Emil Schulthess near the South Pole during the Antarctic summer.

WAVE CLOUDS form downwind from Mount Erebus, the only active volcano in the Antarctic. The presence of such clouds shows that the wind is steady and that it has been set in undulant motion by passing over the mountain. Picture was made by the author.

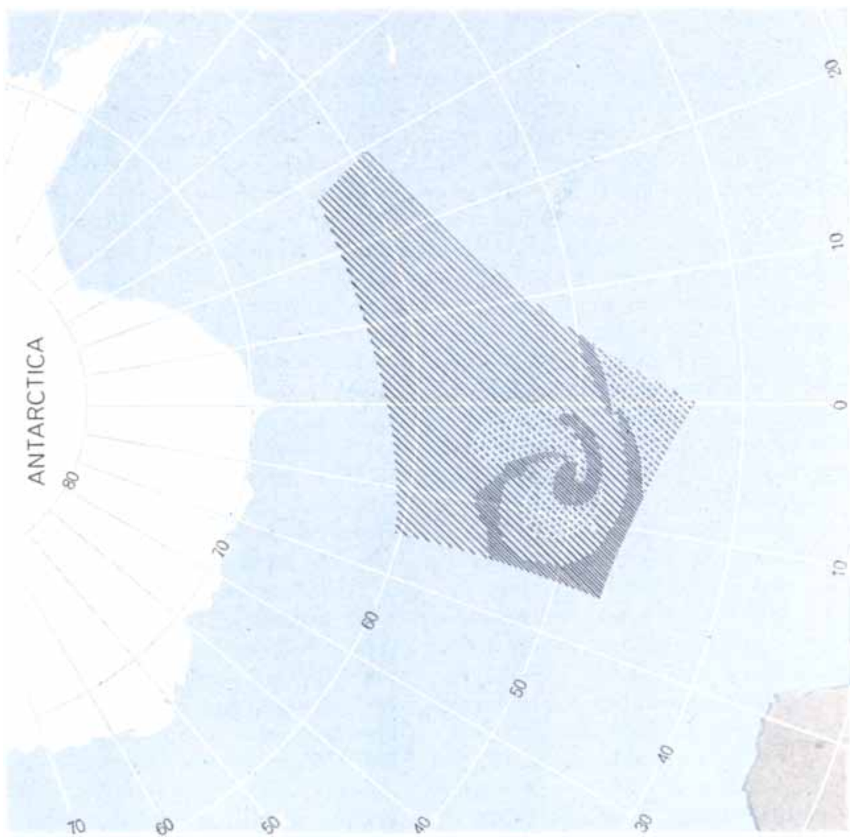


MIDSUMMER SUN was photographed at the South Pole with a 180-degree "fish eye" camera pointed at the zenith. The horizon forms a 360-degree frame around the picture. The exposure began at 8:41 a.m. Greenwich Mean Time on December 29 and ended 18½ hours later at 3:15 a.m. the next day. The picture, made just a week after the summer solstice, is oriented with noon at the top and midnight at bottom. The camera that made the picture was built by Schulthess and used by Robert D. Favreau, an Air Force navigator.

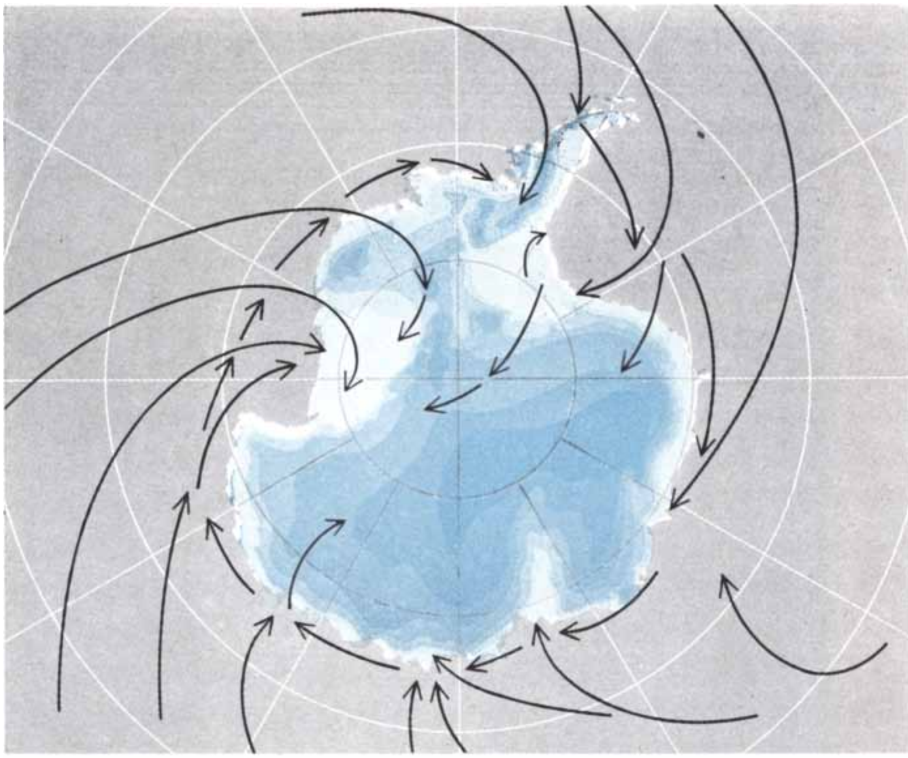
The explanation for the higher temperatures in the Arctic is the greater north-south exchange of air and the moderating influence of the Arctic Ocean, which seldom lies more than five meters below the ice surface. Since sea water has to be warmer than — 1.9 degrees C. to remain unfrozen, the ocean provides a vast reservoir of heat all year long. This heat passes through the ice and warms the atmosphere. In the Arctic basin in winter (September through April) there is a net upward flow of thermal energy from ocean to atmosphere of about 7,670 calories per square centimeter. At the South Pole, in contrast, the net upward flow of heat during the winter is only 1,300 calories per square centimeter. This represents heat that has been stored in the upper 10 meters of snow during the summer, when the snow temperature rises about 20 degrees C. above its wintertime low.

If one considers only the exchange of long-wave heat radiation (rather than total heat flux) between snow and atmosphere, the atmosphere provides twice as much heat to the snow surface in winter as it does in summer. This is because the air generally is warmer than the snow surface in winter, whereas the air-snow temperature difference is greatly reduced or even reversed in summer. Conversely, the loss of surface heat through long-wave radiation in summer is twice as large as the loss in winter. In winter there is usually a strong temperature inversion in the lower atmosphere over the South Pole. This means that the air temperature rises with increasing altitude instead of falling, as it normally does. Consequently the air at an altitude of several hundred meters in winter is warmer than the snow, with the result that more long-wave heat radiation passes from the air to the snow than passes from the snow to the air. In the summer, as the snow warms up and the temperature inversion disappears, the snow is often warmer than the atmosphere and the net flow of long-wave radiation is reversed.

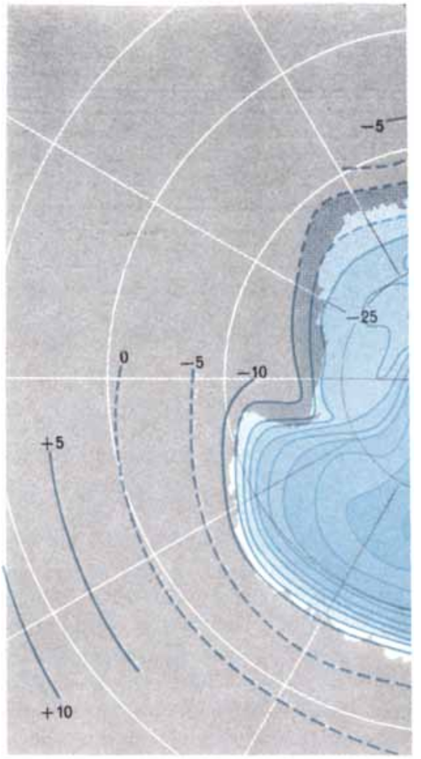
If one considers the over-all heat balance of the top 10 meters of Antarctic snow, it is evident that the inflow and outflow for the full year must be in very close balance; otherwise the Antarctic would gradually become warmer or colder. Except for a brief period in summer, when the surface is heated by the sun and the net heat flux is downward, the polar region radiates more energy than it receives, so that it has a net radiative loss over the year [*see bottom illustration on page* 93]. For the year as a whole



VAST CYCLONE in the South Atlantic, photographed by the meteorological satellite *Tiros IV* on May 18, 1962, is typical of the great storm systems, recognizable from their swirling cloud patterns, that "ventilate" the Antarctic. These storms transport heat and moisture from lower latitudes, where there is a surplus of solar radiation, to the Antarctic, where there is an annual deficit. The area covered by the *Tiros* photograph is shown on the map.



WINTER STORM TRACKS, plotted schematically for the surface, swirl around the Antarctic and move inland most readily where continental elevation is lowest. Shading indicates surface elevation in 600-meter steps. The storm tracks were charted for August, 1958, at IGY Weather Central by Jan Alt of France, Pavel Astapenko of the U.S.S.R. and Nicholas Ropar of the U.S.



MEAN TEMPERATURES correlate closely with latitude and elevation. The values are a composite of surface air temperatures and

the region poleward of about 37 degrees latitude also has a negative radiation budget. This loss is made up by warm air and water vapor carried poleward from the region between 37 degrees north and 37 degrees south, which has a positive radiation budget. This form of heat transport is called advection. When warm air passes over a cooler surface, in addition to radiational exchange, energy is transferred by direct conduction, promoted by the turbulent flow of the air; the process is called eddy heat flux. If the advection is insufficient to overcome the loss by radiation, the surface temperature falls; if it exceeds the radiative loss, the temperature rises. It is this interplay of radiation, advection and eddy flux that causes the temperature fluctuations even in the dead of winter over the south polar plateau, just as it does elsewhere in the world.

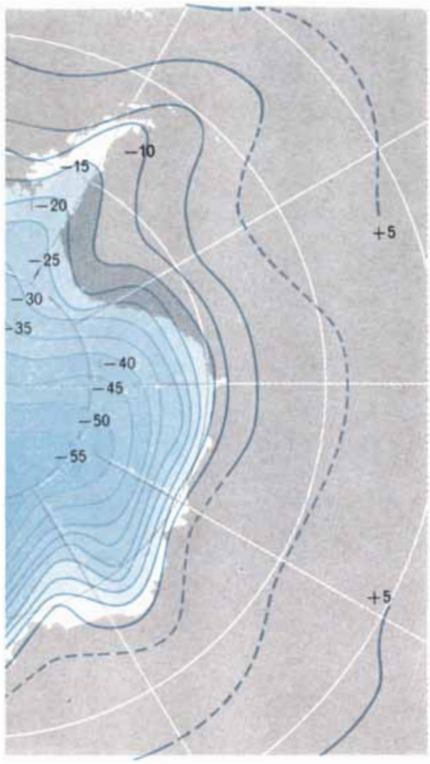
The net loss of radiant energy through the top of the Antarctic atmosphere cannot yet be accurately measured, but enough data have now been gathered to estimate within reasonable limits the amount of advected energy that must flow into the Antarctic to balance the radiative loss. The warm inflowing air carries energy in two forms: "sensible" heat, the kind of heat that is sensed by a thermometer and that is made available when a mass of any kind is simply cooled from a higher to a lower temperature; and "latent" heat, which represents the heat released when a vapor condenses to a liquid without a change in temperature, or when a liquid freezes into a solid of the same temperature. In the atmosphere enormous amounts of latent heat are released when water vapor turns into rain or snow.

The sensible heat carried into the Antarctic by winds can be computed quite well from wind and temperature vertical soundings made at a network of stations around the periphery of the Antarctic. The sensible heat inflow comes to about 11.5×10^{21} (115 followed by 20 zeros) calories per year.

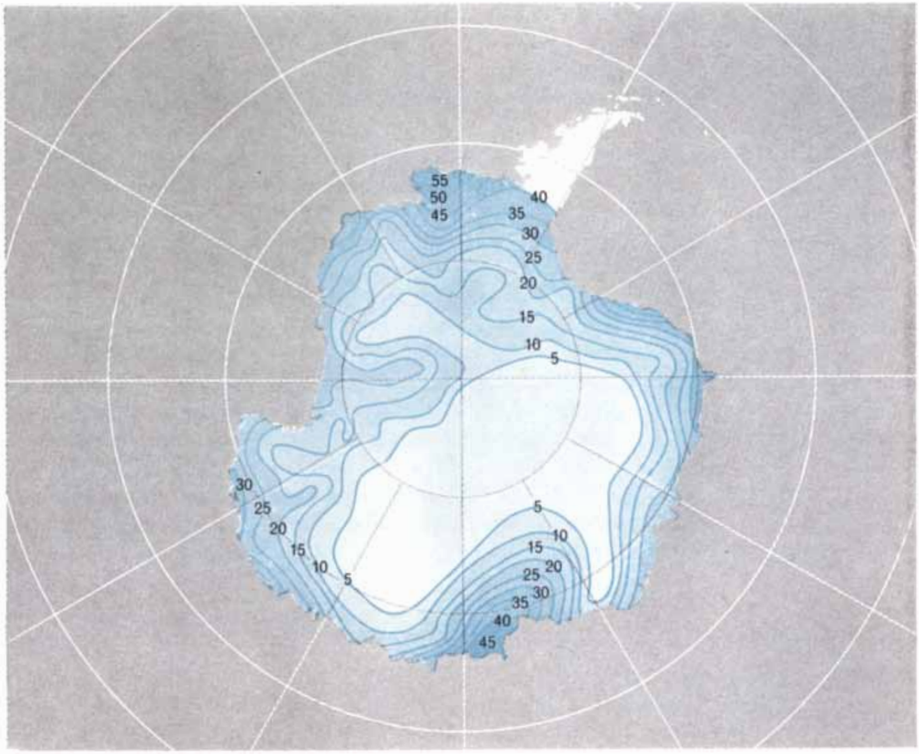
The latent heat inflow could be computed accurately if one knew the annual precipitation over all of Antarctica. The precipitation has now been estimated in two different ways, which show reasonable agreement. The first method combines direct measurement of annual snowfall, using arrays of stakes as snow gauges, and estimates of past snow accumulation based on the thickness of snow layers measured in pits dug two meters or more deep. This method indicates an annual snow accumulation equivalent in depth to 14.5 centimeters of water. To this must be added an estimate for losses due to snow drifting, surface melting and evaporation, which together raise the total annual precipitation to an equivalent of between 14.6 and 19.2 centimeters of water.

The second method of estimating precipitation is based on an estimate of the total amount of ice and snow that leaves the Antarctic every year in all forms. These losses include the melting and "calving" of ice shelves, the continental ice sheet and glaciers at the coastal periphery, as well as the snow driven off the continent and out to sea by the wind. Other losses result from surface-melting runoff and evaporation inland. The aggregate losses, summarized in the table on page 93, indicate an annual precipitation equivalent to between 10.8 and 16.6 centimeters of water.

The total inflow of latent heat computed from the highest and lowest of the precipitation estimates is between 1×10^{21} and 1.8×10^{21} calories per year. Combining the average of these values with the much larger amount of sensible heat carried into the Antarctic by the winds indicates an annual heat inflow of about 13×10^{21} calories per year. This is about 7,000 times more energy than is represented by the world's total annual production of electricity. It will be interesting to see if these heat



those 10 meters below the surface, which are constant the year round. Minus 55 degrees centigrade is equal to −67 degrees Fahrenheit.



ANNUAL ACCUMULATION OF PRECIPITATION, expressed as water equivalent in centimeters, is shown for the Antarctic, excluding the Antarctic Peninsula. The mean value for the whole continent is about 14.5 centimeters. If account is taken of various losses, such as snow drifting off the continent, the precipitation may amount to as much as 19.2 centimeters of water.

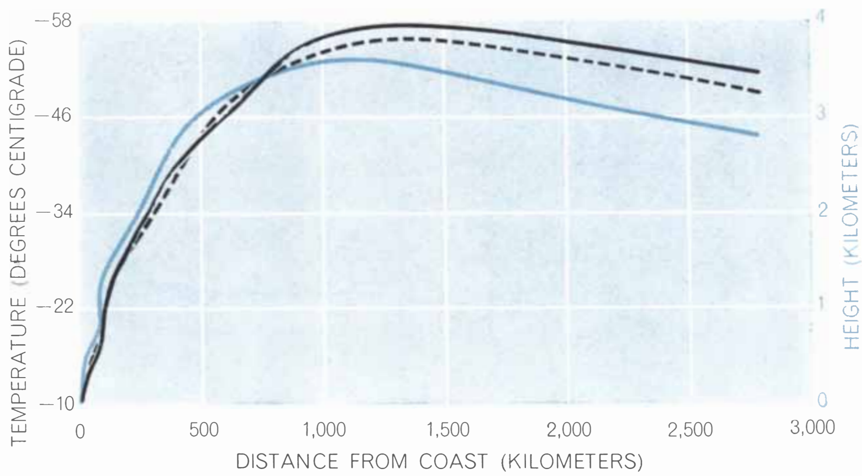
inflow estimates agree with the radiation loss measurements that should be available in the next year or so from *Nimbus,* the weather satellite that will be placed in polar orbit.

The surface temperature in the Antarctic is largely controlled by latitude and altitude [*see bottom illustration on this page*]. For example, the annual mean temperature at the South Pole, 2,800 meters (9,200 feet) above sea level, is −51 degrees C. On the polar plateau about 1,600 kilometers (1,000 miles) away and some 3,400 meters (11,200 feet) above sea level, site of the Soviet base of Vostok, temperatures average about five degrees less, the lowest on earth. These extreme temperatures result from the low humidity, the long hours of darkness, the weak transport of heat from lower latitudes and, finally, the intense radiation loss at the snow surface due to the clear skies and low humidity.

In three successive winters (1958, 1959 and 1960) at Vostok Station the lowest recorded temperatures were: −87.4 degrees C. on August 25, −85.7 on August 23–24 and −88.3 on August 24. (The lowest of these figures is equivalent to −127 degrees F.) At Vostok the sun comes above the horizon after the long winter night on August 22 or 23. Therefore the minimum temperature occurred each year within one or two days after the sun had come up.

The annual range of mean monthly temperature is greatest (more than 30 degrees C.) at the interior stations and least (less than 20 degrees C.) at the coastal stations [*see top illustration on page 91*]. At the high-altitude stations deep in the interior the major drop in temperature is largely completed by the time the sun has set for the winter. This is the "coreless winter" phenomenon. It is observed at all Antarctic stations and also in the Arctic.

A striking feature of Antarctic weather is the prevalence of strong, steady downslope winds along the coast. Known as katabatic winds, they are

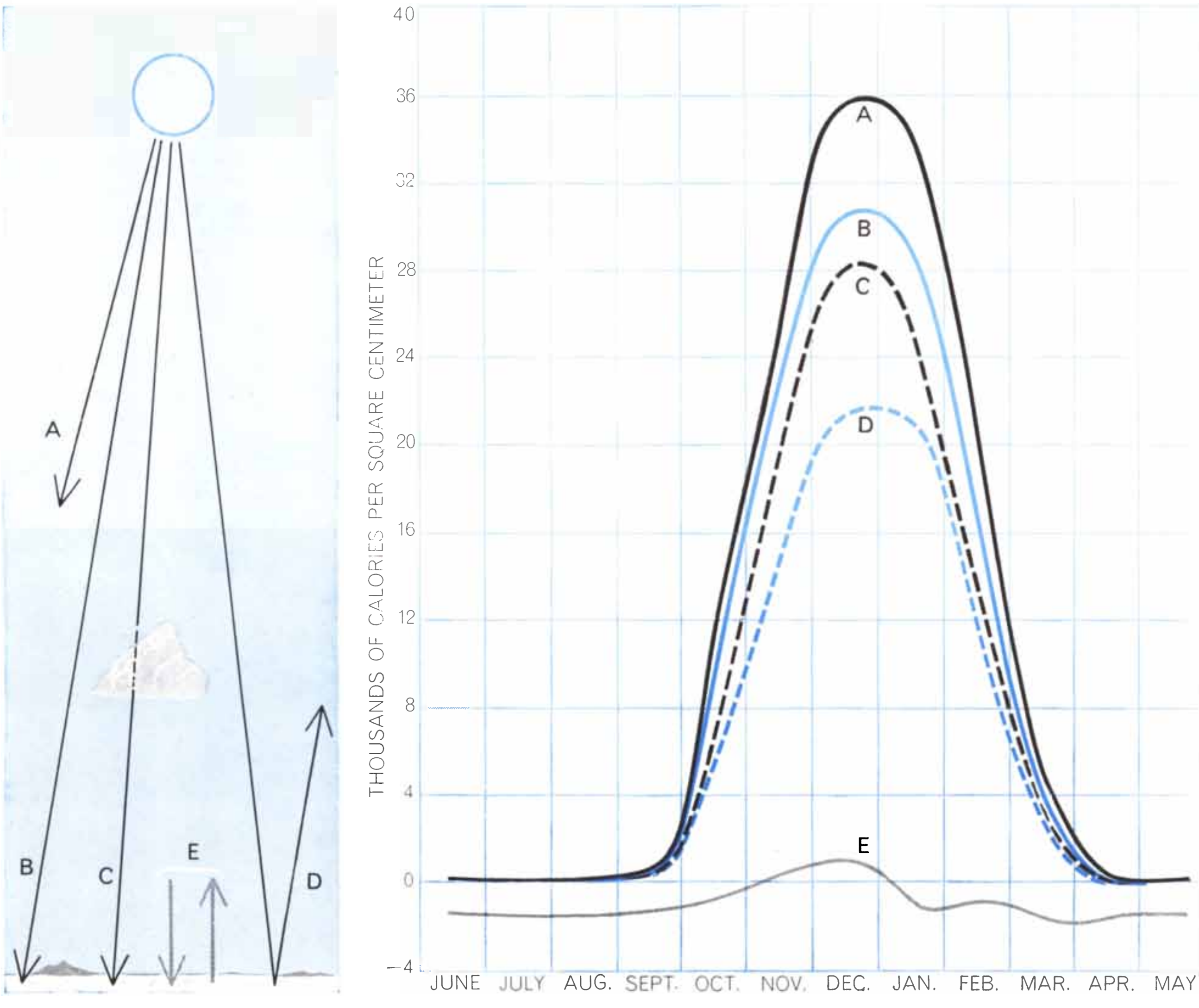


TEMPERATURE DETERMINANTS in the Antarctic are elevation above sea level and latitude. The colored line shows the elevation from the coast to the South Pole as measured between 93 and 107 degrees east longitude. Broken line is the annual mean air temperature at several stations. Solid line is the constant temperature recorded below the snow surface.

roughly proportional in strength to the steepness of the continental slope. For a moderate slope a typical wind speed is 20 knots. The strong radiational cooling of the surface air forms a shallow layer of cold air that flows downward in a uniform stream, rarely changing direction more than 30 degrees throughout the year. Katabatic winds are often only a few hundred meters in depth and flow smoothly until a critical velocity is reached, when they go suddenly into a "hydraulic jump," characterized by strong gustiness. The jumps appear suddenly and are responsible for the brief localized Antarctic "blizzards," during which no snow actually falls and there may even be clear skies above. In the interior of the continent milder katabatic winds give rise to fascinating rippled snowdrift patterns called *sastrugi*.

Measurements of the ozone content of the Antarctic atmosphere have turned out to be of particular interest to meteorologists. Ozone is formed in the stratosphere by a two-step process. A quantum of far-ultraviolet radiation from the sun first dissociates the oxygen molecule into its own two constituent atoms. One atom of oxygen (O) then reacts with a molecule of oxygen (O_2) to form ozone (O_3). The significance of ozone for life on earth is that it strongly absorbs practically all the sun's near-ultraviolet radiation, and in the process ozone is decomposed into atomic and molecular oxygen. The rates of the reactions are such that sunlight produces a constant layer of ozone with maximum concentration at a distance of between 15 and 20 kilometers above the earth's surface in Antarctica. Expressed as a fraction of the total atmosphere, ozone is only a few parts per million.

Once the sun sets in the Arctic or the Antarctic, no more ozone is generated in the stratosphere; the amount present tends to maintain itself, unless ozone is carried in or out by the winds. Therefore a comparison of the wintertime ozone content of the Arctic and Antarctic atmosphere could provide a measure of the strength of the meridional (north-south) circulation, other factors being equal. On the basis of preliminary measurements it appears that the Antarctic stratosphere contains less ozone than the Arctic stratosphere, indicating a weaker meridional flow in the Southern Hemisphere than in the Northern Hemisphere.



SOLAR RADIATION at the South Pole falls far short of balancing the annual quantity of long-wave radiation leaving the snow surface. The diagram at left shows the various radiation components plotted in the five curves at the right. The curves represent: the theoretical value of solar radiation reaching the top of the atmosphere (*A*), radiation received at the surface when the sky is clear (*B*), average value of radiation reaching the surface (*C*), radiation reflected by the snow (*D*), net radiation absorbed or given off by the snow (*E*). Only for about two months in midsummer (November and December) does the south polar snow collect more energy from the sun than it radiates into space. The annual deficit is made good by atmospheric heat from lower latitudes.

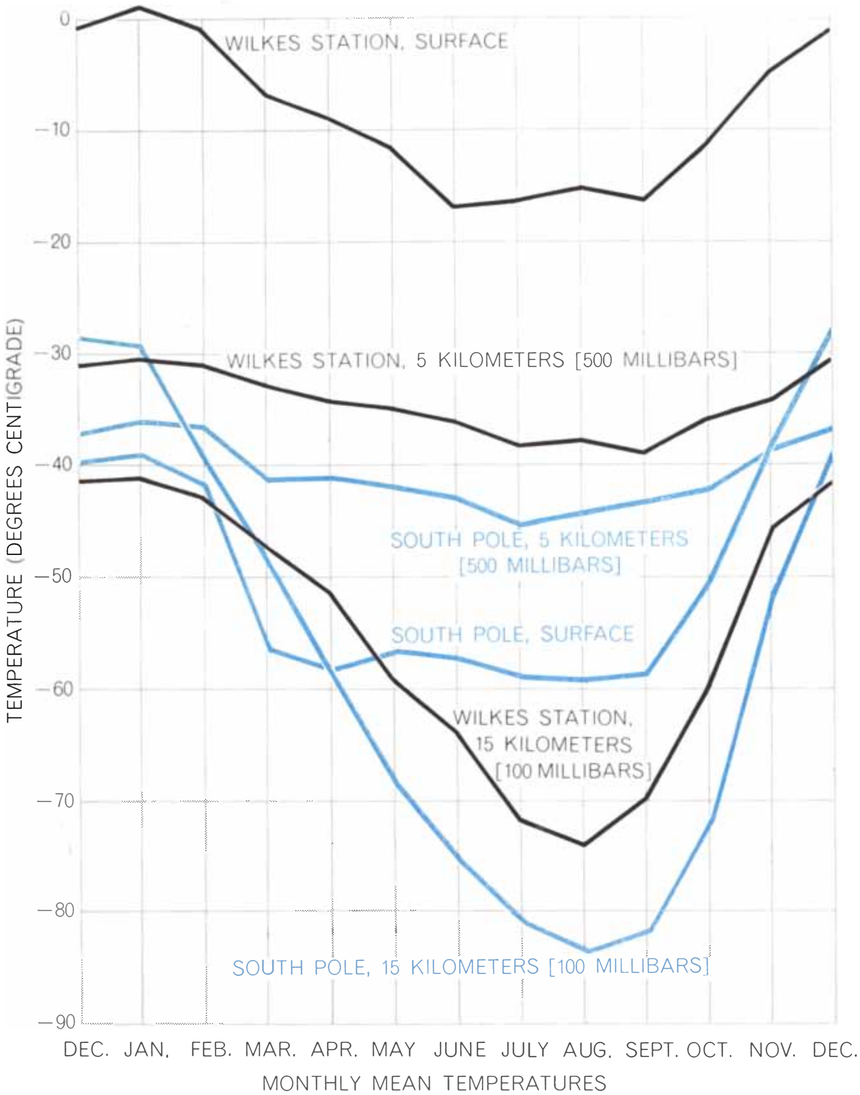
Supporting evidence is found in stratospheric temperatures. In the Antarctic they fall steadily after sunset, reaching a minimum at the very end of winter. In the Arctic sharp rises in stratospheric temperature are noted even in midwinter, indicating the arrival of warm air from lower latitudes.

It is more difficult to account for the seasonal variation in surface ozone over the Antarctic. Again on the basis of limited data, it appears that ozone in the lower atmosphere reaches a maximum during winter, with highest values along the coast. For example, surface ozone at Little America ranges from a monthly average of about 15 micrograms per cubic meter in the summer to a maximum of 60 micrograms in the winter. The average annual value of 43 micrograms per cubic meter is about 25 per cent higher than the average value for North America. At the South Pole the surface ozone seems to be only about half of the value at Little America.

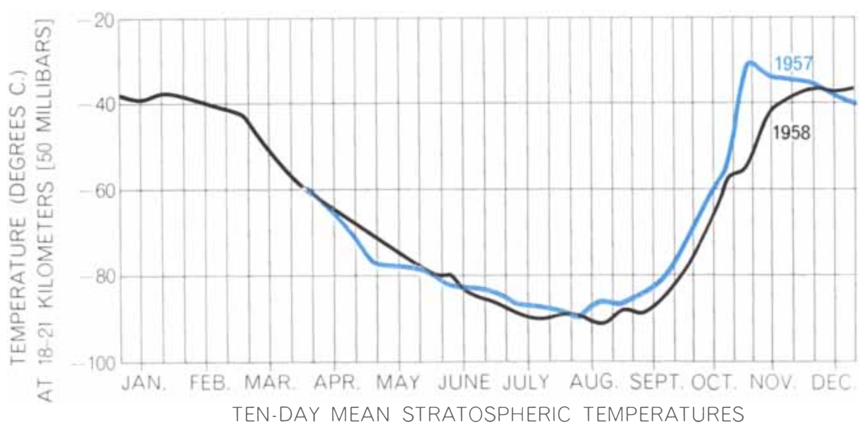
One hypothesis (put forward by the late Harry Wexler, W. B. Moreland and W. S. Weyant of the U.S. Weather Bureau) suggests that ozone-rich stratospheric air from equatorial regions is carried into the troposphere through what is called the mid-latitude tropopause break [*see illustration on page 94*]. Subsequently the ozone is carried across the Southern Ocean, which surrounds the Antarctic, by the vigorous winter storms that move around and into the continent. Once the ozone-bearing air masses penetrate the Antarctic they are cooled, whereupon they sink and are carried northward again in a thin surface layer.

Another possibility that has occurred to me is that some of the surface ozone is formed locally over the continent by static electricity generated in the dry air during the wintertime Antarctic blizzards. Like the first hypothesis, this one is consistent with evidence that winds blowing out of the continent along the coast contain more ozone than winds blowing from the ocean.

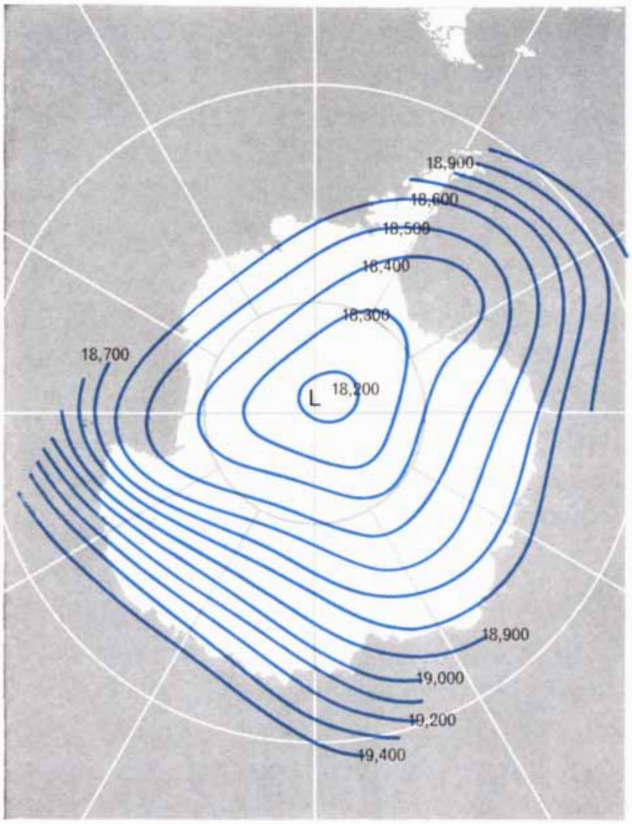
As might be expected, the temperature cycle of the Antarctic stratosphere differs from that of the surface, where the coldest day of the year in the interior tends to fall a day or so after the return of the sun. In the stratosphere the warming begins a few weeks before the sun comes up and reaches its maximum before the sun is at maximum elevation. The details of the stratospheric warming have been different in each of the six years of Antarctic records. Generally, however, two basic patterns can be discerned [*see bottom illustration at right*].



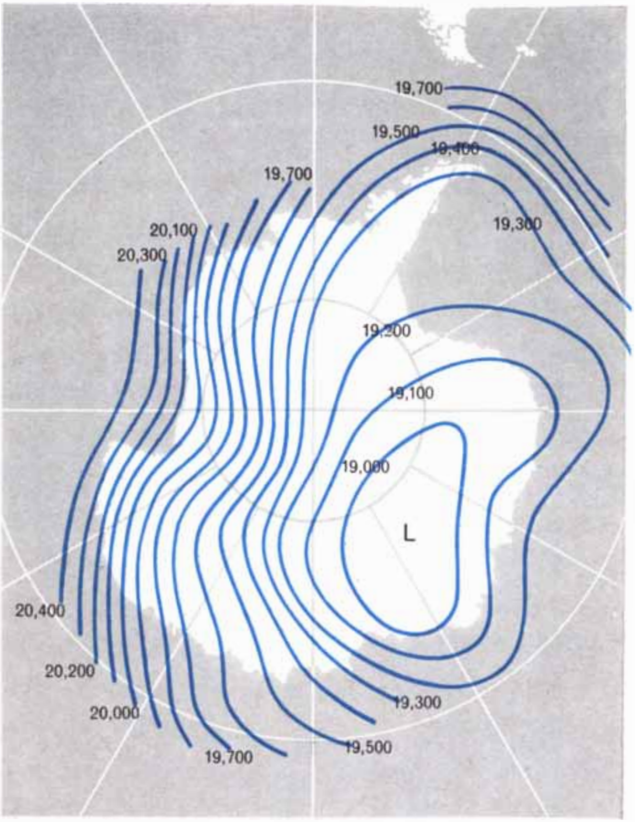
MEAN MONTHLY TEMPERATURES at the surface, in the mid-troposphere (five kilometers) and in the stratosphere (15 kilometers) are plotted for Wilkes Station, on the Antarctic coast, and for South Pole. Note constancy of winter surface temperature at the Pole.



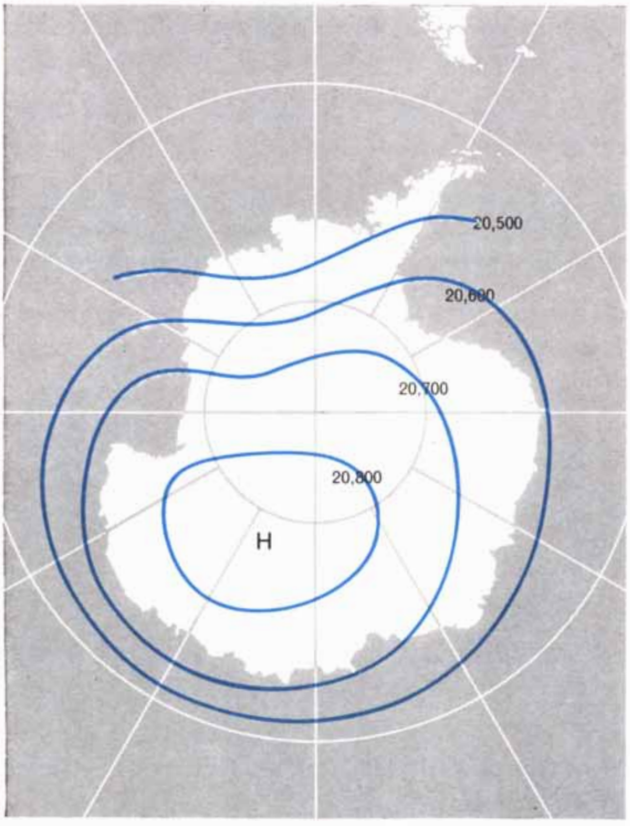
STRATOSPHERE TEMPERATURES at 10-day intervals at the South Pole in 1957 and 1958 show two characteristic types of springtime warming. In 1957 the temperature reached an early peak, then dropped. The data in the chart were plotted by Ropar and Thomas Gray.



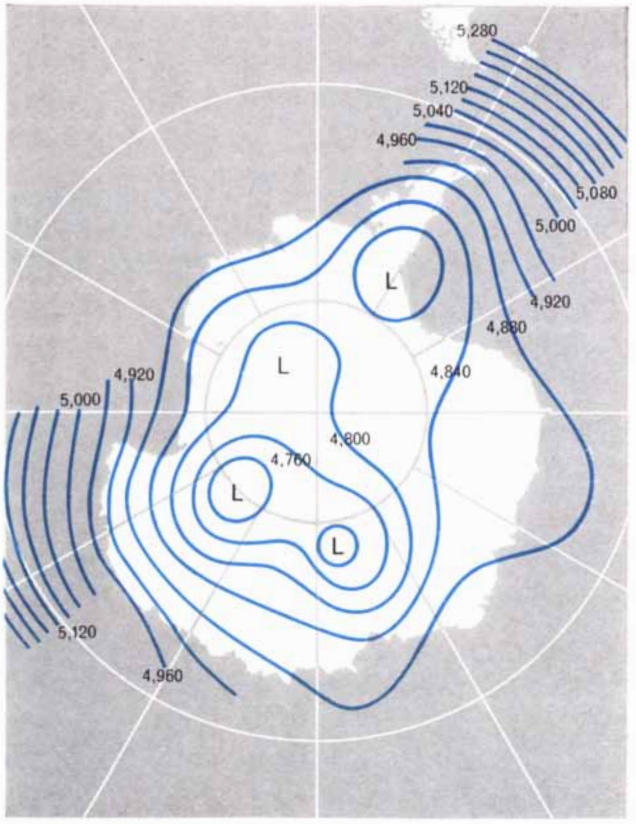
MIDWINTER CIRCULATION in the Antarctic stratosphere is characterized by a low-pressure center over the Pole and strong zonal westerly winds. The chart is for July 14–16, 1958, and shows the altitude, in meters, of the 50-millibar constant-pressure level.



EARLY SPRING CIRCULATION (October 24–26, 1958) shows the low centered over the high continental plateau. The shift accompanies the first phase of spring warming. The close spacing of altitude lines indicates a continuation of strong westerlies.



EARLY SUMMER CIRCULATION (November 21, 1957) shows that the winter low has been replaced by a high, evidence that the sun has returned and that stratospheric warming is nearly completed. This chart and two above were prepared by Ropar and Gray.



WINTER CIRCULATION in mid-troposphere (about five kilometers above the surface) shows a more complicated pattern than that in the stratosphere. This is an average plot of the 500-millibar surface for August, 1958, made by Alt, Astapenko and Ropar.

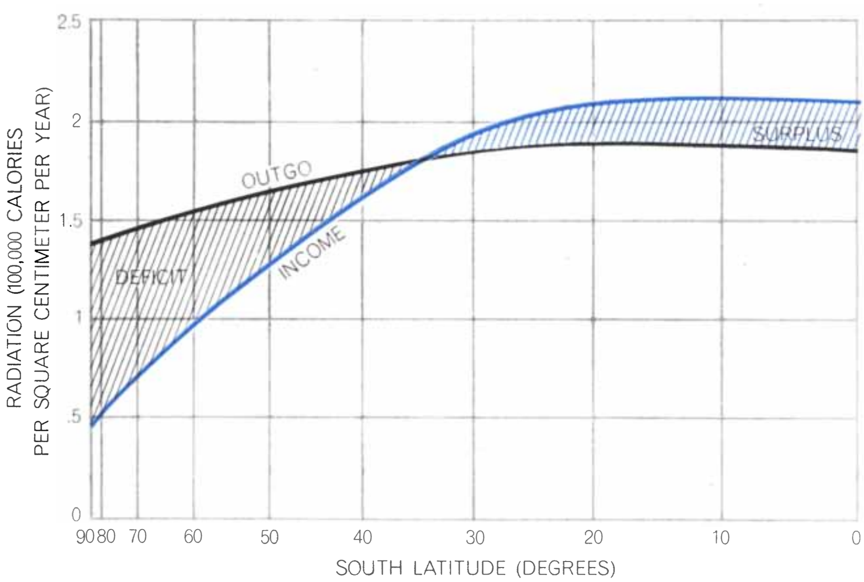
One pattern is a rapid rise to an early temperature maximum, followed by a return to normal summer levels. The second pattern is a slower and steady rise to summer levels. The year-to-year variation shows that the return of the sun is not the only factor at work. Also involved is the general redistribution of the hemispheric air mass and heat through horizontal and vertical motions of the atmosphere.

The variation in stratospheric warming appears to be tied most closely to variations in the circulation of the stratosphere itself. In the winter a strong cyclonic vortex (which moves clockwise in the Southern Hemisphere) forms in the stratosphere and persists until early spring [*see top illustrations on opposite page*]. The vortex is generated by the strong north-south temperature gradient, which causes air masses in the direction of the South Pole—or in the direction of the high polar plateau—to be progressively denser. In effect the lines of equal density in the atmosphere form a bowl over the continent, high at the perimeter and low at the center. As the air in the bowl begins to flow toward the center it is impelled eastward (clockwise) by the rotation of the earth, creating a cyclonic vortex. The broad belt of zonal westerlies reaches a velocity of 200 knots in the core of the polar jet stream, which extends upward to the limit of balloon soundings: 25 to 30 kilometers. These strong winter westerlies inhibit exchange of air with the rest of the Southern Hemisphere and help to bring about steadily falling temperatures, which, in turn, help to maintain the vortex. This is the classic model of a hemispheric circulation: a cold central core and relatively smooth temperature gradient running outward to the Equator. In the spring the warming pattern of the Antarctic stratosphere is influenced by the varied movement of the vortex and of the jet stream embedded in it. With the arrival of the sun the zonal westerlies weaken and allow a greater influx of warm air from lower latitudes.

The circulation in the Antarctic stratosphere is markedly different from that in the Arctic. There the cyclonic vortex often breaks down even in midwinter, allowing cold air masses to pour south into Canada, Europe and Asia; at the same time warm air pushes north into the Arctic. It is tempting to assign the instability of the Arctic vortex to surface geographical features. The cold continental masses in the Northern Hemisphere surround a relatively warm ocean and are interspersed with other

LOSS DUE TO:	MASS (10^{13} GRAMS)		EQUIVALENT LATENT HEAT (10^{21} CALORIES)		EQUIVALENT PRECIPITATION (CM. OF WATER)	
	A	B	A	B	A	B
OCEANIC MELTING						
ICE SHELF	.163	.326	.111	.222	1.2	2.4
ICE SHEET, GLACIERS	.002	.002	.001	.001	.0	.0
CALVING						
ICE SHELF	1.035	1.035	.704	.704	7.7	7.7
ICE SHEET	.067	.067	.046	.046	.5	.5
OUTLET GLACIER	.174	.174	.118	.118	1.3	1.3
SUBTOTAL	1.441	1.604	980	1.091	10.7	11.9
DRIFTING SNOW	.020	.500	.014	.340	.1	3.7
SURFACE MELTING	.000	.074	.000	.050	.0	.5
EVAPORATION	.000	.063	.000	.043	.0	.5
TOTAL	1.461	2.241	.994	1.524	10.8	16.6

ANNUAL ANTARCTIC PRECIPITATION can be estimated by assuming that snowfall is in annual balance with the amount of ice lost from the continent. The first two columns differ chiefly in the estimate of snow lost from the continent by drifting. The major loss is "calving" of the great ice shelves. The third and fourth columns indicate the amount of latent heat that must be released in the atmosphere when water vapor condenses and freezes to produce the amount of ice (in the form of snow) shown in the first two columns. The last two columns show the annual precipitation needed to match the ice-mass loss.



EARTH'S HEAT BUDGET calls for a balance between incoming solar radiation and outgoing long-wave radiation. Between 37 degrees north and south of the Equator there is a surplus of income over outgo. Poleward from 37 degrees north and from 37 degrees south there is a deficit. The atmosphere and oceans carry heat from regions of surplus to regions of deficit. The chart uses data of H. G. Houghton of Massachusetts Institute of Technology.

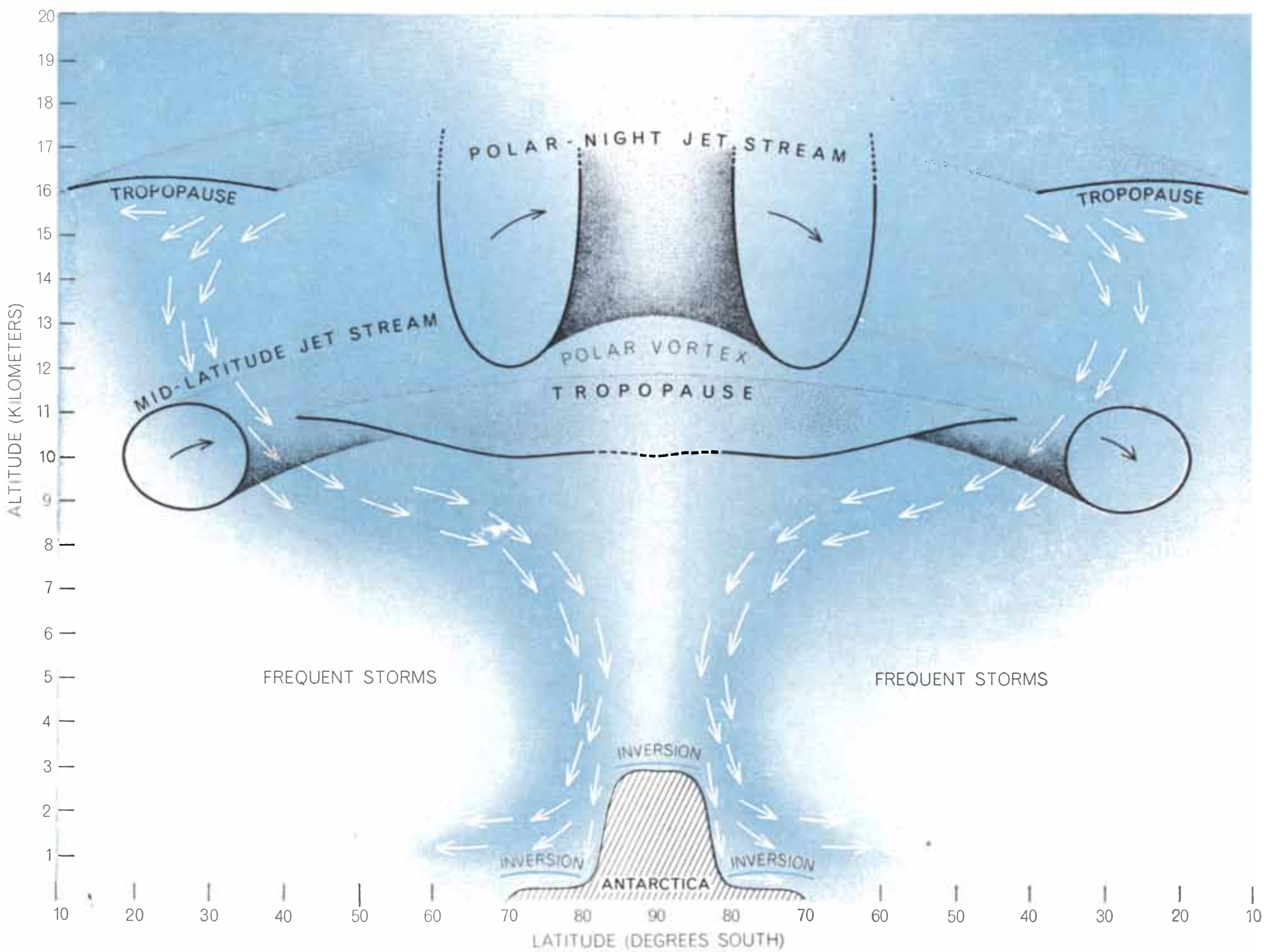
relatively warm oceans, which combine to upset the north-south temperature gradient needed to support a strong zonal circulation.

In the troposphere of the Southern Hemisphere a zonal circulation also predominates in winter [*see illustration at bottom right on page 92*]. The strength of the westerlies in the Southern Hemisphere is considerably greater than that of the Northern Hemisphere, and significantly less meridional exchange takes place across the broad stretches of ocean. Outbreaks of polar air do occur, however, when the large-scale circulation becomes "turbulent." Sub-Antarctic and Antarctic air on occasion has been known to reach southern Brazil, South Africa and southern Australia.

Compared with the Northern Hemisphere, however, there are fewer outbreaks of cold air that penetrate to low latitudes and fewer incursions of warm air into the high latitudes. The Southern Hemisphere's lack of continental masses extending from polar to temperate and tropical latitudes is one reason for the difference. The meridional exchange of heat that is effected through these motions in the atmosphere—and by the transport within the oceans—tends to keep the heat budget in balance over the whole earth.

In the southern troposphere large cyclonic storm systems form over the ocean, moving generally from west to east and southward toward the Antarctic [*see illustration on page 88*]. Some of the storms move across Antarctica from the Ross Sea to the Weddell Sea, as well as in the opposite direction. Some are blocked by anticyclonic ridges in the atmosphere, and practically none move onto the high central core of the Antarctic. It is these cyclonic storm systems, which are a significant part of the general circulation, that "ventilate" Antarctica and transport heat and moisture into the continent. Wherever the storm tracks move in from the sea the regions below will tend to have heavier snowfall than regions where the tracks move outward from the interior. Numerous but short-lived cyclonic systems in the lower layers of the atmosphere tend to form around the edge of the continent, but they do not contribute significantly to the large-scale north-south exchange of heat and moisture.

Much work still remains to be done before meteorologists can claim to have a comprehensive understanding of the role the Antarctic plays in the climate of the planet. In the years to come much should be learned from new research vessels such as the National Science Foundation's *Eltanin*, from an expansion of the radiosonde and radiometersonde networks, from constant-level balloon observations, from air-borne determinations of ice and surface reflectivity and from polar-orbiting satellites.



OZONE TRANSPORT SCHEME has been proposed to account for the unexpectedly high ozone values found in the lower Antarctic atmosphere during the winter. Ozone formed in the sunlit stratosphere is transported to lower altitudes and higher latitudes through a gap in the tropopause associated with the mid-latitude jet stream. (The tropopause is the boundary between troposphere and stratosphere.) The ozone-rich air is swept into the Antarctic circulation, where it is finally carried off the continent in a shallow surface layer. This explanation is by the late Harry Wexler, W. B. Moreland and W. S. Weyant of the U.S. Weather Bureau.

Kodak reports on:

a fish anesthetic . . . what finance expects of electronics . . . a motion picture to move bosses

What a screening program can turn up

These perch are asleep. One of them is breathing 57 times a minute and the other 80. The water in which they are sleeping contains *Quinaldine* (EASTMAN P216) and is at 75°F. We started at 5 p.p.m. with the slower-breathing fish. When he was still awake after 25 minutes, we brought the quinaldine level up to 7.4 p.p.m. and introduced the second fish. Within 10 minutes they were both asleep.

They have been sleeping for 4 hours. When we rap the tank, they make short, vigorous darts and doze off again. They seem limp when handled gently.

As soon as the picture was snapped, we put them in fresh water. Within one minute they were swimming smartly. Within 10 minutes they calmed down into the normal upright position. What they would have eventually died of if returned to the lake, how many healthy descendants they would have spawned, and whether they would have been good to eat we do not know.

We were a little surprised to learn that Bruce Muench of the Illinois Department of Conservation has found that such a relatively simple and cheap compound as quinaldine anesthetizes fish with no evidence of damage; but then chloroform, which is known to anesthetize people, is even simpler.

We don't consider this particularly entertaining and will drag our feet about filling orders for quinaldine from home addresses. People like mosquito-abatement officials who have fish to transport can get prompt service from Distillation Products Industries, Rochester 3, N. Y. (Division of Eastman Kodak Company), which also gives qualified investigators prompt service with some 3900 other EASTMAN Organic Chemicals.

How to fabricate photographically

"Photography provides a quick, easy, and reproducible system of weight control," says a new data book of ours, illustrating the perils in out-of-context quotations. The weight control it talks about has nothing to do with embonpoint, and the photography isn't even based on silver halide. It is based on the photosensitivity of certain monomers and on the chemical resistance that the resulting polymers have toward reagents as mighty as hydrofluoric acid and aqua regia.

The growth of this branch of photography proves it was just what the space age was waiting for; the reduction in weight of the age's playthings without sacrifice of strength is but one aspect of photography's importance as the newer kind of fabrication. The changes it has wrought in the whole art of electronics are now recognized in financial circles as profound. If it has gone that far, readers here addressed will have doubtless passed some time ago the stage of wonderment at it all. Nevertheless, guidance on technique may still be badly needed.

The new book doesn't so much guide as inform. (Let your conscience be your guide, assisted by a lawyer who closely follows the patent situation proliferating as a result of industry's heavy investment of brainpower in the field. Most important firms are reasonable about licenses.) The book brings together a lot of hot tips on preparing the many kinds of substrate, applying our various resists, preparing the coatings for exposure, developing them, choosing the proper etchants or electroforming solutions for use with stainless steel, glass, gold, germanium, etc. As for the strictly photographic information contained, we offer suggestions for determining correct exposure, where "correct" means maximizing the tolerances in all other steps of the process and has nothing to do with photography's traditional interest in tone reproduction.

If you happen to know a Kodak Graphic Arts Dealer, call up and ask for the $1 data book, "Kodak Photosensitive Resists for Industry." We would much appreciate your kindness in ordering it that way because we have just about all we can do answering specific questions. If you don't even know what a Kodak Graphic Arts Dealer is, send the dollar to Eastman Kodak Company, Graphic Arts Division, Rochester 4, N. Y. At least this will give us an opportunity to introduce you to the dealer.

Huntley with rope

Our principal business is the manufacture of photographic materials. Therefore we must tell the world that photography is very useful. The world, however, knows this already. When you tell somebody something he already knows, you run a risk of boring him. Fortunately, if he himself regards the message as a doctrine worth preaching, he will pay attention, will applaud, and will help round up an audience.

In this case, we assume that he has charge of photographic operations in a businesslike organization. We assume further that he is not lazy and would rather see those operations expand than diminish.

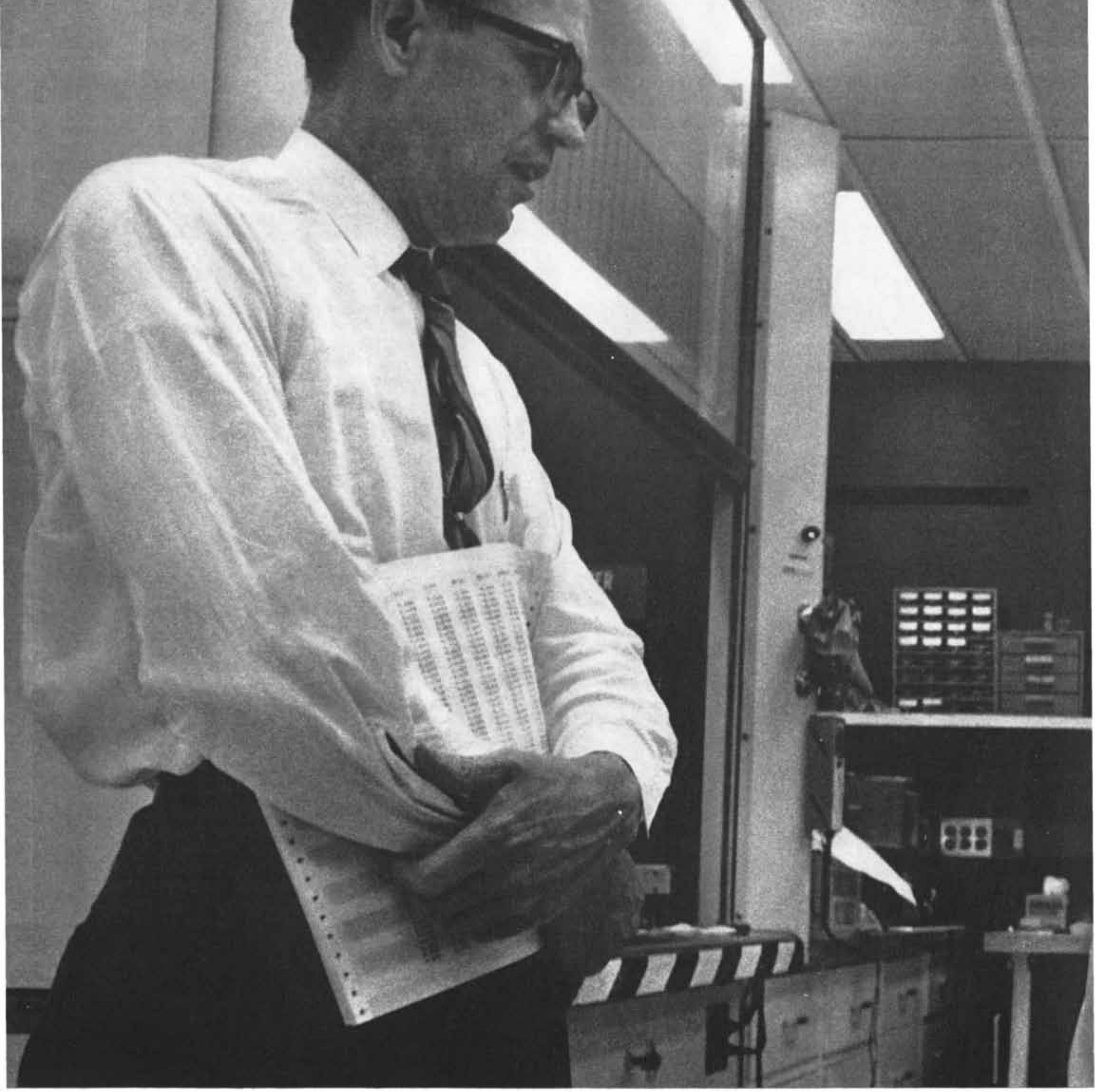
We have made him a 42-minute movie to show. Instead of spending all that time singing paeans, the movie tries to stimulate his colleagues and his bosses to think up functions for him that might not have occurred to them.

Mr. Chet Huntley, no paean singer, narrates. We take you inside a cake being baked in Dayton. We puzzle you with a monstrous camera intended to take pictures in Cincinnati without perspective. We show you how they test a new hydrofoil on Lake Washington and what nooks and crannies a camera can explore when fitted with fiber optics. We take you to lots of places, starting on a classy note with the hunt for anti-matter at Brookhaven.

If we create the impression that the great linear accelerator there is nothing but another camera accessory, do not conclude that perspective is being shunned in Rochester as well as in Cincinnati. Historians of science differentiate between the "low technology" that civilizations evolve over the millenia for hewing the wood and drawing the water of everyday life and the "high technology" that is called into existence by the demands of pure science and then very kindly lowers a rope to haul up the "low technology." Maybe 1520 feet of movie film narrated by Mr. Chet Huntley with music and color to dispel boredom is better than rope.

To book a showing of "Photography at work . . . a progress report" write Eastman Kodak Company, Professional Photographic Sales Division, Rochester 4, N. Y.

This is another advertisement where Eastman Kodak Company probes at random for mutual interests and occasionally a little revenue from those whose work has something to do with science

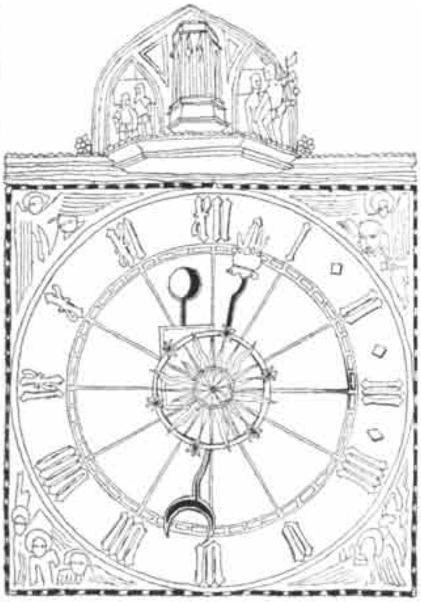


In a few minutes he'll telephone the

The data he's gathering is of little use until it's assembled, integrated with other data, and studied mathematically. IBM's new family of computers, the 7040 and 7044 Data Processing Systems, offer a solution. You can use IBM TELE-PROCESSING® Systems to communicate with them via telephone, telegraph and private line networks.

But use with TELE-PROCESSING Systems is just one example of versatility. The new 7040 and 7044 offer a broad range of options which permit you to match the system you choose to your own individual computing requirements.

Your IBM Representative can describe in detail the many optional features available including input/output channels, combinations of input/output devices as well as processing unit options.



SCIENCE AN

The Thalidomide Syndrome: II

In her article "The Thalidomide Syndrome" [SCIENTIFIC AMERICAN, August] Helen B. Taussig of the Johns Hopkins School of Medicine remarked that a "lucky combination of circumstances" had kept thalidomide-containing drugs off the U.S. market. In West Germany, England, Canada and other countries where the drug had been on sale, it has caused crippling deformities in thousands of newborn infants and perhaps thousands more infants still unborn. The few cases of such births in the U.S. had all been traced to supplies of the drug procured by the patient or physician from sources abroad. It now appears, however, that samples of the drug from a domestic source, the Wm. S. Merrell Company of Cincinnati, have been in circulation in this country.

Anthony J. Celebrezze, newly installed as Secretary of Health, Education and Welfare, revealed that the drug company had distributed these samples to 1,248 physicians around the country for use in "clinical investigation." A survey by Federal and local public health officers showed that at least 15,904 patients, including 3,272 women of childbearing age, had received the drug from these physicians. None of the 207 women known to be pregnant has yet been delivered of a deformed child. But since the drug was not recalled by the manufacturer until March and as many as 22,984 doses of the drug were found in the possession of 74 physicians as late as July, it is too early to say whether the clinical testing of the drug may not have caused additional cases of the syndrome.

Under its existing statutory authority the Food and Drug Administration moved to tighten controls over the clinical-testing procedures of the pharmaceutical industry. The new regulations—subject to amendment and not enforceable for 60 days—would empower the agency to halt a clinical trial on evidence that there is doubt as to the safety of a drug.

In Congress sentiment revived in favor of the more stringent provisions for regulation of the drug industry contained in draft legislation sponsored earlier in the present session by Senator Estes Kefauver. The proposed legislation would allow the Food and Drug Administration to remove a drug from the market on a finding that it posed a hazard to public health and not solely, as now provided, on the finding of "positive evidence that it is harmful."

Follow the Leader

In the past 12 months the nuclear testing game of follow-the-leader has loosed more megatons of nuclear energy than all the explosions in the entire 17-year period since Alamogordo. The latest round began last September 1, when the U.S.S.R. broke the three-year test moratorium with a series of multimegaton atmospheric explosions. The U.S. retaliated first with a series of small underground tests and then, beginning in April, with atmospheric tests. The U.S. series was drawing to a close when in early August the U.S.S.R. started up again with a test in the atmosphere. At Geneva meanwhile the U.S. reopened negotiation of a ban on further testing of nuclear weapons, citing a "considerable amount of new data" on the problem of detecting underground tests.

U.S.-Soviet negotiations toward a test ban got under way in 1958, when scientists of the two nations drew up the specifications for the technical measures necessary to police such a ban. In particular they agreed that a network of 180 seismic stations would suffice to detect and identify any underground nuclear explosion. Soon afterward U.S. investigators reported new data indicating that the "Geneva network" would be inadequate for the identification of low-yield underground explosions or of larger shots concealed by detonation in certain kinds of geological formation or in natural or man-made caverns. The U.S. called for reconsideration of the technical agreement, and negotiations bogged down for two years.

The broad outlines of the present U.S. position were sketched by President Kennedy at his press conference on August 1. He said that "new technical assessments . . . give promise that we can work toward an internationally supervised system of detection and verification for underground testing which will be simpler and more economical" than that contemplated in previous U.S. proposals. The system would call for fewer seismic stations (perhaps as few as 80), would permit them to be manned by the nationals of the countries in which they are located and would require fewer on-site inspections by an international control agency. At Geneva these proposals brought the U.S. closer to the compromise position advanced by the eight neutral participants in the disarmament conference. The first Soviet response was negative, but the negotiation of a test ban was under way again.

Portrait of Telstar

Telstar, the remarkably successful experimental communication satellite sponsored by the Bell System and launched on July 10, is an impressive demonstration of the depth and facility of the electronics art.

The 170-pound satellite, built by the Bell Telephone Laboratories, is 34½ inches in diameter and occupies an orbit inclined 45 degrees to the Equator, ranging in altitude from 579 to 3,454 miles (within 50 miles of the intended orbit). Telstar uses 15 watts of energy supplied by 3,600 solar cells to operate electronic circuits containing 1,064 transistors, 1,464 diodes and a single vacuum tube: a 2¼-watt traveling wave tube a foot long and a quarter-inch thick. The 2,528 semiconductors were selected from 58,800 whose performance had been carefully observed for several months. More than 90 per cent of the semiconductors are employed in two radio receivers and two decoders (provided in duplicate to ensure reliability) that are used for receiving command signals and for telemetering technical data from Telstar to earth. The technical data consist of 115 measurements, made every minute, of Van Allen radiation and other environmental conditions and of the performance of equipment inside the satellite.

The circuit that actually relays television and other signals uses a combination of 14 transistors and the traveling wave tube to amplify the incoming signal about 10 billion times. The signal is received at 6,390 megacycles and transmitted at 4,170 megacycles. Because the signal radiates in all directions, its strength at the ground is between a billionth and a ten-billionth of a watt. It is received in the U.S. by a horn antenna with an opening of 3,600 square feet and is amplified by a ruby maser cooled to the temperature of liquid helium. Comparable equipment has been installed in England and France.

Before the end of 1962 one or two more Telstars may be placed in orbit. Also scheduled for launching this year are *Relay*, a communication satellite built by the Radio Corporation of America, and *Echo II*, a reflecting satellite balloon 135 feet in diameter and 20 times more rigid than *Echo I*.

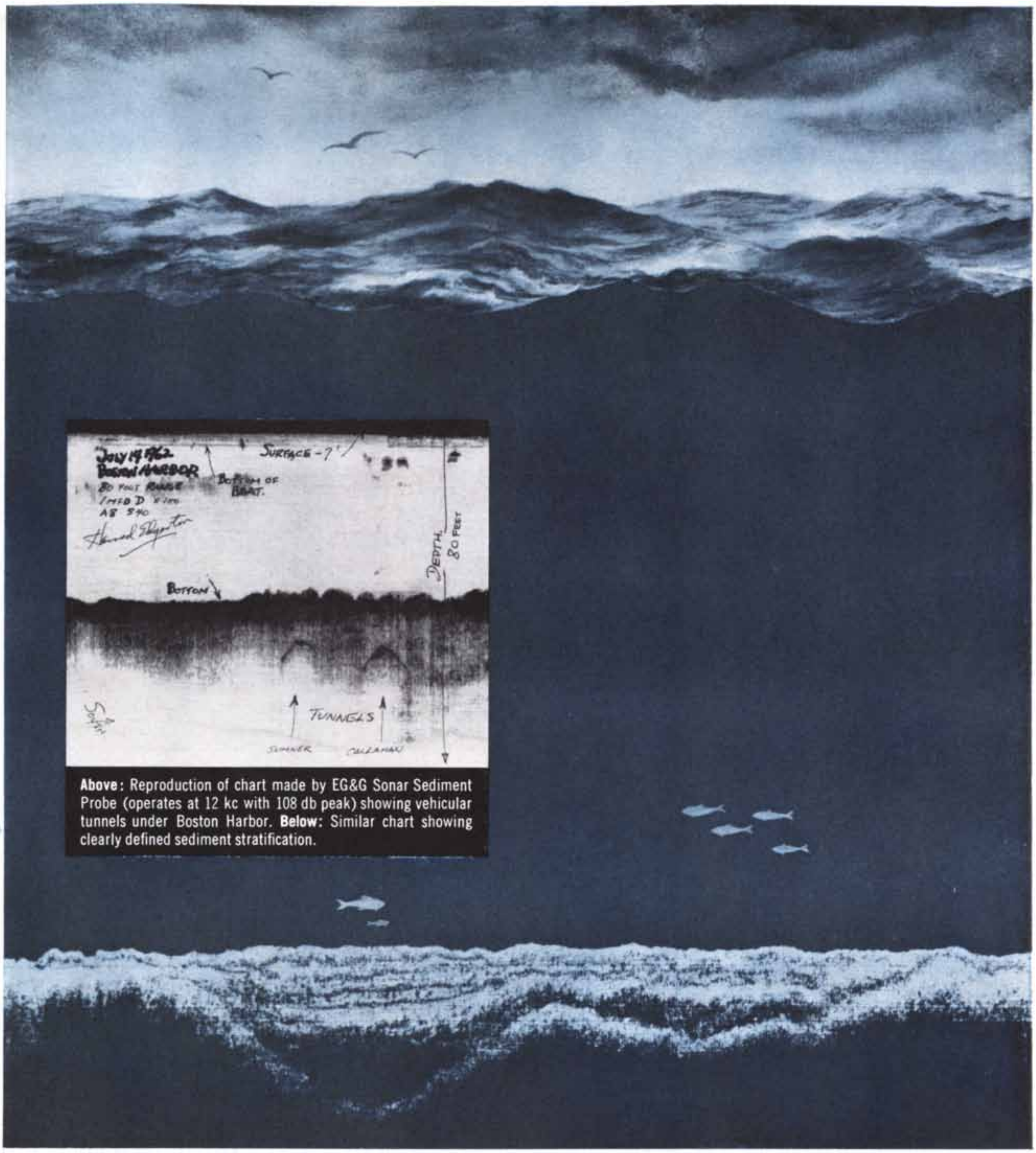
The New A.E.C.

After more than a month during which three scientists constituted its entire membership, the Atomic Energy Commission has been restored to full strength by the appointment of two lawyers, John Gorham Palfrey and James Thomas Ramey, to take the place of two lawyers who had resigned. Palfrey has been professor of law and government at Columbia University and dean of Columbia College. He has done research on legal and political aspects of atomic energy and has served on the A.E.C. staff. Ramey has served for the past six years as executive director of the Joint Congressional Committee on Atomic Energy. Earlier he worked for the Tennessee Valley Authority and the A.E.C.

Palfrey and Ramey may serve only short terms. It has been reported that the President next year will ask Congress to replace the present five-man A.E.C. with a single administrator. The commission now consists of chairman Glenn T. Seaborg, a chemist; Leland J. Haworth, a physicist; Robert E. Wilson, a chemist and chemical engineer; and Palfrey and Ramey.

No 600-Foot Telescope?

Secretary of Defense Robert S. McNamara has canceled construction of the Navy's 600-foot radio telescope



Above: Reproduction of chart made by EG&G Sonar Sediment Probe (operates at 12 kc with 108 db peak) showing vehicular tunnels under Boston Harbor. **Below:** Similar chart showing clearly defined sediment stratification.

EG&G PROBES THE OCEAN'S INTERFACES

☐ EG&G's oceanographic instruments set a standard for those who probe the ocean's interfaces — optically and acoustically.

☐ The company's solidly established sponsored research capabilities and product development skills are expanding rapidly and substantially. The most recent addition to EG&G's line of oceanographic equipment is the Sonar Sediment Probe. Nicknamed the "mud penetrator," by its developer, Dr. Harold E. Edgerton, it provides a bottom profile chart which accurately shows sediment strata as deep as forty feet below the bottom surface. It has been used successfully in such diverse applications as locating cement flood control mattresses in the Mississippi River and revealing buried archeological relics in the Mediterranean Sea.

☐ Other well-known EG&G equipment includes buoy-mounted electronic marker beacons; compact, high-intensity, "man-overboard" flashers; sonar boomers; sonar positioning pingers; and complete stereo and motion-picture systems for underwater photography at depths to more than 35,000 feet.

☐ Openings now exist at EG&G for ocean-sciences-oriented technical personnel to take part in EG&G's growing oceanographic activities — R&D, equipment development, and specialized surveys. EG&G is an equal opportunity employer, and invites your inquiry.

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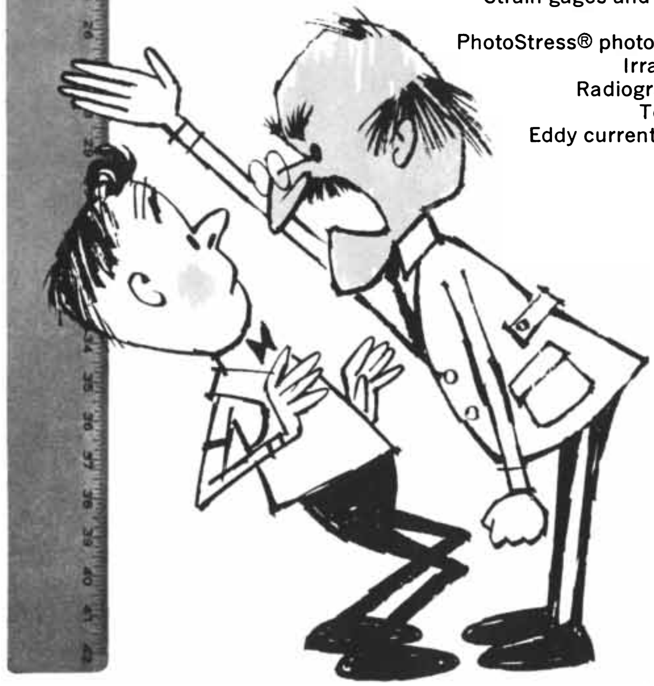
WESTERN OPERATIONS: P.O. BOX 1912, LAS VEGAS, NEV. — SANTA BARBARA AIRPORT, P.O. BOX 98, GOLETA, CALIF.



because of rising costs and a decline in its potential military value. The 30,000-ton structure at Sugar Grove, W.Va., would have been by far the world's largest fully steerable radio telescope [see "The 600-Foot Radio Telescope," by Edward F. McClain, Jr.; Scientific American, January, 1960]. More than $41.7 million had already been spent on it and an additional $53.8 million had been obligated. When finished in 1964, according to the latest estimates, its cost would have exceeded $200 million.

The telescope was to have been used for secret military work half of the time and for scientific studies the other half. According to a report in *The New York Times*, its primary purpose was to pick up radio messages transmitted elsewhere in the world by detecting their reflections from the moon. Although the Navy did not confirm this, it explained that such missions can now be carried out by satellites and new electronic instruments. In theory the telescope would have had an effective range of 38 billion light-years, 19 times farther than the range of the 200-inch optical telescope on Palomar Mountain. It was expected to contribute to the solution of such basic problems as the origin, age, size and nature of the universe. No other Government agency appears likely to take up the costly project where the Navy has left off.

Efficient Beam

A solid-state device announced recently by the Lincoln Laboratory of the Massachusetts Institute of Technology is said to convert electric current into infrared radiation with remarkably —and at the moment mysteriously—high efficiency: "virtually 100 per cent." Made of gallium arsenide and operated as a diode, it emits a beam that, according to the Lincoln Laboratory workers, can be focused well enough to transmit signals over line-of-sight distances up to 30 miles. The beam intensity responds to variations in the input electrical signal as fast as 100 megacycles per second. With this band width it could accommodate 20 television channels or 20,000 telephone circuits. When the efficiency of the present experimental device is understood, and if it can be duplicated in production, the diode will have important applications in communications.

Although infrared waves (like those of visible light) are absorbed by clouds, rain or snow, they pass freely through ionized gases, which stop radio waves. One possible use for the diode would be to pierce the ionized air layer surrounding space vehicles re-entering the

Space Power Systems

A variety of accessory space power systems, some integrated with thermal control, are being developed by Sundstrand Aviation-Denver. Some are now ready for the company's new advanced test facilities.

Many ways have been explored to provide reliable power in Space Vehicles for communications, guidance, control, life support and the multitude of normal and emergency functions associated with space missions. One company accomplished in this specialized field is Sundstrand Aviation—Denver, a division of the Sundstrand Corporation. They have developed a variety of approaches, each one designed to meet the specific and diverse requirements inherent in each of the missions contemplated in the U. S. Space Program. These development projects, under contract for both military and civilian agencies, are logical undertakings for Sundstrand where work has centered primarily in the fields of advanced turbine research, cryogenic and storable propellants and specialized pump development. They also have been engaged in applied research under USAF contract in the growth and advanced technology of solar dynamic machinery.

Sundstrand-developed space power systems include:

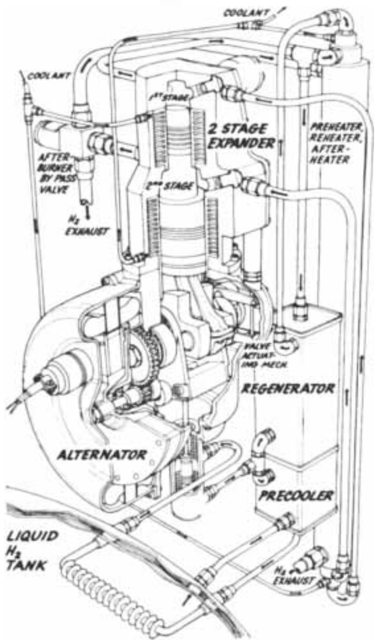
THE X-20 (DYNA-SOAR)

Sundstrand currently holds the USAF contract with the Boeing Company for the accessory power unit of the X-20 manned space vehicle. All electrical and hydraulic power for the operation of accessory equipment is supplied by this unit, which consists of a cryogenic multistage single disk turbine prime mover driving a 12 KVA alternator, hydraulic pump, and a tach generator. This contract resulted from a successful three-year turbo-machinery development program by Sundstrand.

THE CRYHOCYCLE-R

The Cryhocycle-R (reciprocator) is the name given another Sundstrand power unit, designed for long duration, low power output with integrated thermal control. This unit develops up to 10 KW of electrical power using hydrogen and oxygen as propellants. Briefly it functions in this manner: waste heat is utilized from the electrical system of the space vehicle and the body heat of its occupants to expand cold gas (hydrogen) in the cylinders, forcing the pistons to move. The engine drives a generator, supplying electrical power for the vehicle.

The CRYHOCYCLE-R utilizes a unique liquid hydrogen pump, developed by Sundstrand engineers, which raises low pressure fluid (20 to 30 psi) to a pressure of 2250 psi. The fluid is then evaporated to a gaseous state, producing useful cooling in the process. High inlet pressure at the first stage of the CRYHOCYCLE-R makes possible extremely low specific fuel consumption, the aim of the pump design.



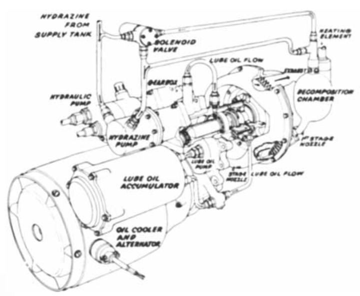
The pump is additionally unique in its ability to operate as a compressor of gaseous hydrogen. This makes feasible the incorporation of first stage recirculation in the CRYHOCYCLE-R, lowering the specific fuel consumption still further.

The hydrogen which powers the CRYHOCYCLE-R is stored as a liquid until ready for use in the expansion engine. Some hydrogen in vapor form may escape the tank under zero gravity conditions and enter the system fuel lines along with the useable liquid hydrogen. A Sundstrand liquid-vapor separator, a porous ceramic barrier, when saturated with liquid, continues to pass the liquid but prevents passage of gas, thus insuring a continuing flow of pure liquid hydrogen.

The CRYHOCYCLE-R system can operate for as long as three weeks on a very small supply of gas, occupies little space, and requires no radiators for thermal control, making it an excellent choice for advanced manned space missions.

THE STORABLE PROPELLANT SPACE POWER SYSTEM

Under U. S. Air Force contract, Sundstrand has designed, developed, and tested a space power system fueled by hydrazine. It offers indefinite storability and instant restarts limited only by fuel. (Available with an electric heating element for starting or small oxidizer tank for hypergolic start.) Both models utilize high performance, open cycle, monopropellant fueled turbomachin-



ery. Both accomplish the objective of efficient conversion of chemical energy to electrical and hydraulic power. Normal rated output is 10 kva at 0.85 power factor (electrical) and 14 gpm at 2700 psig (hydraulic). Either unit may operate on its own fuel supply, or on residual booster fuel at normal booster tank pressure. Each incorporates components required to convert the low pressure hydrazine to required decomposition chamber pressures. This Sundstrand SPS is adaptable to many space power applications, such as vehicle re-entry or orbital rendezvous operations where high power outputs are needed for relatively short durations (MTBF—750 hours).

EXPANDING SPACE AGE ROLE

These and other systems under Sundstrand development are rapidly reaching flight qualification. For these tests, the Company has added new facilities to its Denver operation, including a space vacuum altitude environmental test chamber, capable of simulating, under dynamic gas flow, altitude conditions up to 135,000 feet. This chamber was designed for evacuation of 2000 degree F gases at weight flows of 1000 pounds/hour.

Also, a Rucker centrifuge 22 feet in diameter with a capacity of a 650 pound maximum test item weight on either or both ends of the arm has been installed. It is rated at 20,000 g pounds, or 65 g's within 48 seconds. A two-pass, 40 gpm, 3000 psig hydraulic system and a hot gas exhaust rotary joint are also part of the installation.

If you would like to work with the Sundstrand engineering team, finding practical solutions to challenging space power problems, write to: Personnel Director.

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atmosphere and thus overcome the radio blackout that now cloaks their re-entry. In general the large channel capacity of radiation in or near the visible portion of the spectrum makes them potentially valuable as communication relays, particularly at high altitudes, where there are no clouds.

In contrast to the optical maser, a light-producing device that also has possibilities as a message sender, the gallium arsenide diode does not emit coherent radiation; that is, the waves are not all in step. Nevertheless, the beam can be focused sharply by conventional optical means. The wavelengths fall into a narrow band—about 100 angstrom units (hundred-millionths of a centimeter) wide—at a central frequency that depends on the operating temperature. At 77 degrees centigrade above absolute zero, when the efficiency is highest, the central wavelength is about 8,600 angstrom units.

The diode is made by diffusing a spot of zinc on a piece of gallium arsenide the size of a pinhead. Current flowing through the junction raises electrons in the semiconductor to an energy level higher than normal. On returning to their original state and filling up the "holes" created by their absence, the electrons emit infrared radiation. Theoretically the process is extremely efficient, but until now the efficiency has not been realized in practice. Robert J. Keyes and T. M. Quist, who built the device, have not yet learned exactly what energy levels are involved in the transitions, nor what mechanism has made possible the achievement of practically the full theoretical efficiency. They suspect an unidentified impurity in their crystals. All the high-efficiency units made so far come from one of two crystals grown at the Lincoln Laboratory. Material from other crystals does not perform so well.

German Measles Virus

The virus of German measles, or rubella, an illness that can cause severe defects in an unborn child if contracted early in pregnancy, has been isolated. It appears to be a distinctive type, unrelated to any other known virus.

Although no reports have yet appeared in technical journals, three groups, which worked independently of one another, have announced the isolation and identification. They are Edward L. Buescher and his co-workers at the Walter Reed Army Institute of Research, Thomas H. Weller and Franklin A. Neva of the Harvard School of Public

Health and John L. Sever and Gilbert M. Schiff of the National Institute of Neurological Diseases and Blindness. Successful isolations have also been accomplished in at least five other laboratories, enlisted by the Buescher group for confirmatory studies.

The effect of rubella on unborn children was discovered in Australia in 1941. Recent studies suggest that defects may occur in as many as 50 per cent of infants born to mothers who contract the disease during the first month of pregnancy and in 20 per cent of babies whose mothers are infected during the second or third month. These figures are uncertain, however, because of the difficulty of diagnosing rubella. Identification of the virus should resolve the question by making possible specific diagnostic tests. The discovery may also lead to the development of a vaccine.

Genetic Lock

How are the genes turned on and off? Every living cell contains in its chromosomes, coded in molecules of DNA (deoxyribonucleic acid), all the genetic information needed for its replication. Yet even in single-celled organisms such as bacteria not all the information is utilized at all times in the life cycle, and in multicellular organisms most cells become specialized and therefore need very little of the total amount of information. A possible mechanism for turning off the information flow has been suggested by Ru-chih C. Huang and James Bonner of the California Institute of Technology, who had set out to solve another puzzle: the role of the protein that also forms part of chromosomes. Writing in *Proceedings of the National Academy of Sciences,* they propose that the protein serves to lock and unlock the genes.

Huang and Bonner extracted the chromatin (chromosomal substance) from embryo pea plants and found that it is about one-third DNA, one-third a protein called histone, one-sixth protein other than histone and one-sixth RNA (ribonucleic acid). The nonhistone protein includes the enzyme RNA polymerase, which facilitates the synthesis of "messenger" RNA. This substance is the direct product of genetic activity; its role is to transfer from DNA to other parts of the cell the instructions for the synthesis of specific proteins.

When suitable "building blocks" (riboside triphosphates) are added to isolated chromatin, messenger RNA is synthesized, but at a slow rate. If the

histone fraction is removed from the chromatin, however, the rate of RNA synthesis increases fivefold. From this and other observations Huang and Bonner have concluded that the function of histone is to bind DNA and block the expression of particular genes, depending on the needs of a particular cell at a particular time.

Protein Key

The method by which amino acid building blocks are put into their proper place in protein synthesis has recently been clarified. It has been known for several years that each of the 20-odd amino acids found in plant and animal proteins is "recognized" and carried to its proper position on a template by a specific kind of soluble ribonucleic acid (sRNA). The template consists of another form of RNA called messenger, or template, RNA, which is bound to a cellular particle called a ribosome. What was not known was how each sRNA and its amino acid got to the right place on the template. There seemed to be two possibilities: the template is keyed either to fit the shape of the amino acid or some portion of the sRNA molecule.

The investigation that decided between these alternatives was carried out by François Chapeville and Fritz A. Lipmann at the Rockefeller Institute, Günter von Ehrenstein of Johns Hopkins University and Bernard Weisblum, William J. Ray, Jr., and Seymour Benzer of Purdue University. Their experiments, which they describe in *Proceedings of the National Academy of Sciences,* were performed on a system containing natural ribosomes and sRNA, obtained from the colon bacillus. To this mixture they added a synthetic polynucleic acid that acts as template RNA on which one particular amino acid, cysteine, is preferentially incorporated into polypeptides (short-chain protein analogues). The cysteine was labeled with the radioactive isotope carbon 14 so that it could be traced into the polypeptide.

It happens that cysteine can be converted to another amino acid, alanine, simply by removal of a sulfur atom. The trick of the experiment was to attach cysteine to its appropriate sRNA and to convert it into alanine while it was en route to the template. The question was: Would the template be "fooled"? It was. In other words, the template is evidently keyed to the sRNA, not to the particular amino acid attached to it.

Basic Research at Honeywell
Research Center
Hopkins, Minnesota

Correlation of Mechanical Properties and Microstructure of Polytetrafluoroethylene

Metallurgical techniques applied to the study of a polymer have enabled scientists to correlate the mechanical properties with its microstructure leading to possible improvements in its properties.

Polytetrafluoroethylene (PTFE) has the lowest coefficient of friction of any solid. Being chemically inert it is also impervious to almost everything except liquid metals. These characteristics have prompted its use in many design situations. PTFE, however, has a high degree of cold flow, low tensile strength and low hardness limiting its applications.

The chemists have clearly described PTFE's molecular properties. Its mechanical properties as measured by the engineer are readily available.

It now appears that the techniques of the metallurgist may be useful in determining what mechanical phenomena occur in PTFE under varying conditions which in turn may lead to improving its properties by changing its microstructure. The goal is to correlate mechanical properties with microstructure and propose a physical model.

Studies of the fracture surface of PTFE, made heretofore by Bunn and his associates, have indicated a structure consisting of a polycrystalline aggregate having individual crystallites of long chain molecules assembled side-by-side to form fairly thin sheets.

Since PTFE normally contains from 20% to 50% non-crystalline material, a more specific definition of the compound's microstructure requires a more definite indication of where the non-crystalline material is located.

Honeywell scientists have made a number of experiments which throw further light on the microstructure of PTFE.

Fracture surfaces were obtained by impacting the specimens at liquid nitrogen temperatures. These surfaces were replicated with collodion. This collodion layer was then shadowed with chromium and carbon-backed in a vacuum chamber for observation with an electron miscroscope.

The first phenomenon observed was the variation in the size of the band structure or crystallites induced by varying the cooling rate from the sintering temperature. Quenching in iced water produced crystallites averaging 0.2μ by 10μ. Cooling at 180°C per hour resulted in crystallites averaging 0.4μ by 50μ. Cooling at 150°C/hr. produced dimensions of 1μ by 100μ. At all cooling temperatures, however, the distance between the striations of the crystallites remained at approximately 200 A.

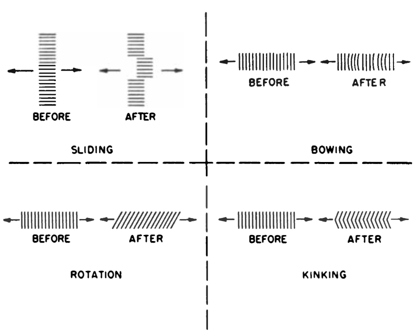


Illustration A

In the course of the deformation experiments at room temperatures, comparison was made of specimens before and after deformation. This revealed two general types of distortion within a band. First, there was a relative displacement between the striae in the band; second, there was a change in the geometrical shape of the striae.

As shown in diagrammatic illustration A, these deformations took the form of sliding, rotation, bowing and kinking. Sliding occurred when the tensile axis was nearly parallel with the striae; rotation was more common when the striae were perpendicular to the stress. Incidentally, neither of these cases involved a distortion of the individual striae. Bowing and kinking, although present, appeared to a lesser degree.

However, when the temperature was changed bowing and kinking became more pronounced. At —196°C, only kinking and bowing occurred; at —70°C kinking, bowing and sliding were in evidence; at 0°C all four modes were present (kinking, bowing, sliding and rotation).

An interesting feature of the microstructure of the deformed PTFE was the manner in which the striae themselves responded to stress. They either underwent bowing or kinking or slipped past one another. There was no indication that the individual striae had ruptured.

The fact that the striae slipped easily past one another indicated the presence of a finite layer between the striae which deformed very readily. This and other observations led to the proposal that the band structure which constitutes PTFE consists of two phases, with the crystalline striations or platelets separated from one another by a viscous non-crystalline matrix.

Continued research should eventually lead to methods of improving the mechanical properties of PTFE. It may also provide a better understanding of other polymers, elastomers and epoxy resins.

If you are engaged in scientific work involving PTFE and wish to know more about Honeywell's research in this area, you are invited to correspond with Mr. Charles J. Speerschneider, Honeywell Research Center, Hopkins, Minnesota.

If you are interested in a career at Honeywell's Research Center and hold an advanced degree, you are invited to write Dr. John Dempsey, Director of Research at this same address.

Honeywell

First in Control

Why so many?

We admit it.

Amphenol, more than any other connector manufacturer, accepts responsibility for confronting you with a seemingly endless selection of rack and panel connectors.

There's a good reason.

For some uses, a ten-contact connector the size of an Idaho potato will do just fine. In others, ten connections must be squeezed into a space no bigger than a jelly bean. Still other applications have unique requirements that relate to environment or mating force—even the technical skill of the operator.

WHY WE DO IT

We make a lot of different rack and panel connectors because it takes a lot to satisfy the wide range of applications.

For example: the Amphenol Blue Ribbon® rack and panel connector is widely used in "blind" mating applications. Part of Blue Ribbons' popularity is due to the fact that they mate with a smooth and gradual wedge-like force. Because they mate so smoothly, the "feeling" of correct alignment is unmistakable.

Another advantage of the Blue Ribbon design is the wiping action that occurs as connectors mate. Each time Blue Ribbons are mated, contact surfaces are wiped clean. Combine wiping action with high mated contact pressure, and the result is an extremely low-resistance connection.

THINKING SMALL?

As fine a connector as we know the Blue Ribbon is—it's just not right for the real tiny stuff. Thus, as miniaturized electronic equipment became popular, Amphenol engineers developed the Micro Ribbon®—a rack and panel connector utilizing the ribbon contact principle, but in as little as one-half the space. Further development produced a circular Blue Ribbon connector which crammed 50 contacts into a diameter just under 3 inches.

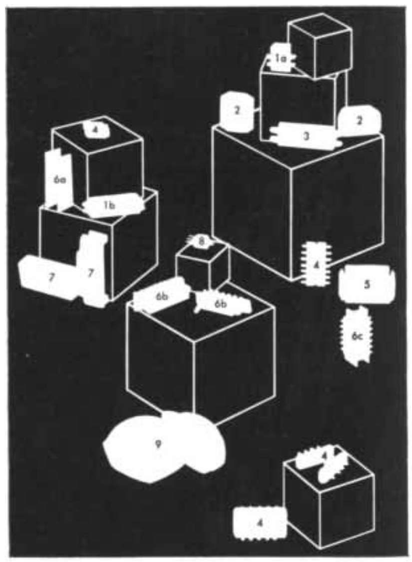
Also, there's the question of terminating rack and panel connectors. Often, confined quarters or complex wired harnesses can tax the dexterity of even the most skilled worker.

To solve this problem, Amphenol engineers developed rack and panel connectors with Poke-Home® contacts. Poke-Home contacts make it possible to terminate conductors independent of the connector. Contacts are crimped, soldered, or even welded to conductors, then inserted into the connector. Besides simplifying assembly, Poke-Home contacts can be easily removed *after* assembly should circuit changes or repairs later become necessary. Needless to say, Amphenol rack and panel connectors with Poke-Home contacts (Min-Rac 17®, 93 and 94 Series, for example) are popular items with engineers who are forced to think small, spacewise.

BEATING THE ELEMENTS

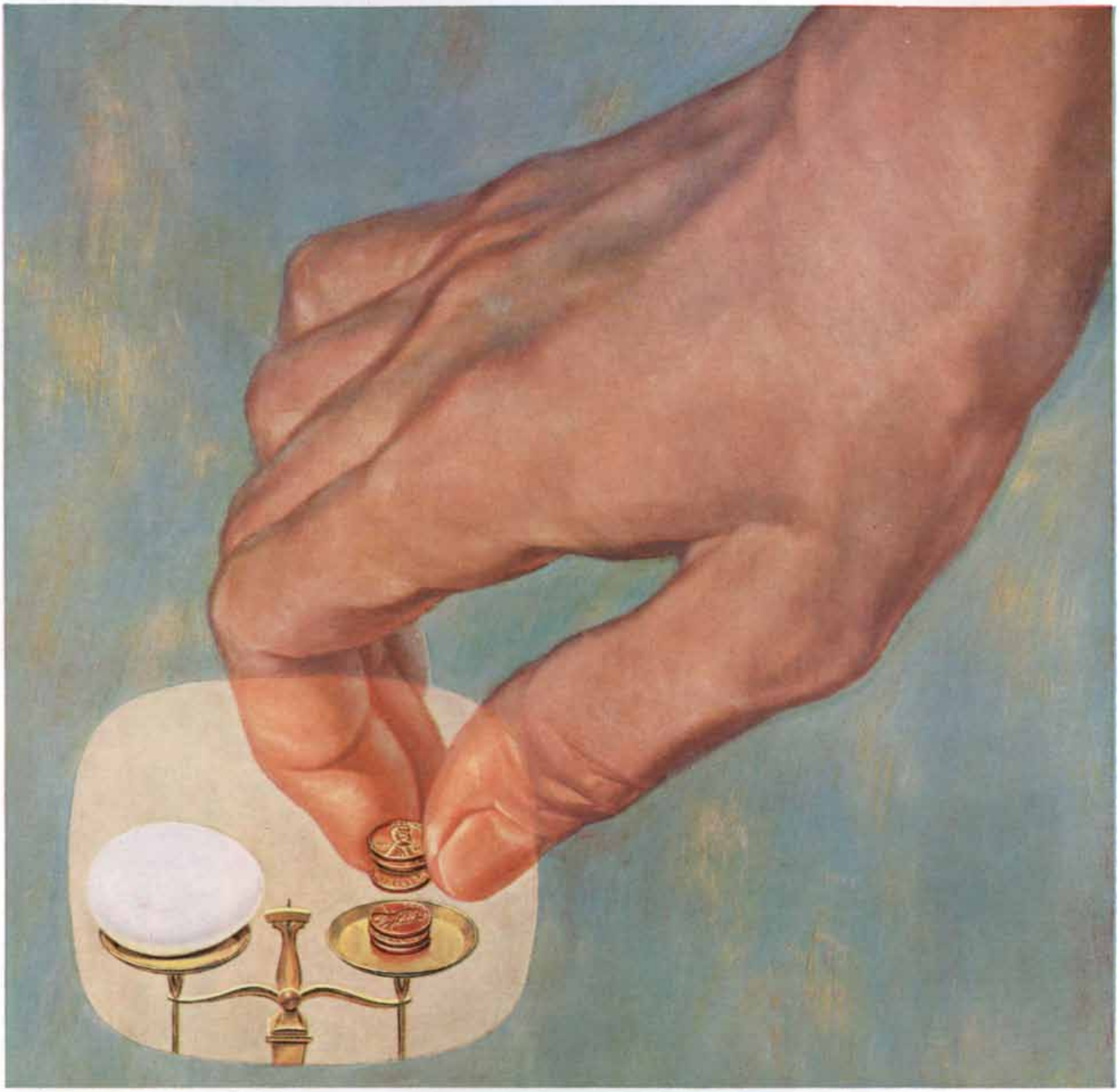
There's a need for environmentally resistant rack and panel connectors, too. High performance aircraft, missiles and space craft led to the development of Amphenol 126 and 217 Series environmentally sealed rack and panel connectors. (The 217 offers the added feature of Poke-Home contacts.) Other Amphenol rack and panel connectors can accommodate coaxial connectors; many can be supplied with hermetically sealed contacts. There are rack-to-cable connectors available in every series. There are super-economy types and super-reliable types.

So, when you have a rack and panel connector problem, contact an Amphenol Sales Engineer (or an authorized Amphenol Industrial Distributor). With the broadest line of rack and panels in the industry—if he can't solve it, no one can. If you prefer, write directly to Dick Hall, Vice President, Marketing, Amphenol Connector Division, 1830 South 54th Avenue, Chicago 50, Illinois.



Amphenol connectors shown on the opposite page are: **1**—Min-Rac 17 with (a) crimp-type contacts and (b) solder-type contacts **2**—94 Series **3**—Micro-Ribbon **4**—126 Series Rectangular **5**—93 Series **6**—Blue Ribbon with (a) barrier polarization, (b) pin polarization and (c) keyed shell and barrier polarization **7**—126 Series "CNI" **8**—126 Series Hexagonal **9**—Circular Blue Ribbon

AMPHENOL **Connector Division** / Amphenol-Borg Electronics Corporation



Let's look at the price of eggs

What did you pay for eggs this week? Probably a little more or a little less than last week. Prices of things go up and down because of many factors . . . such as supply and demand, wages, materials and shipping costs, and needed profits. It all gets more complex when you consider taxes and competition, or compare our economy to that of other countries. ▶ Now millions of people can learn more about economics from a stimulating series of television programs on *The American Economy*. Conducted by leading educators and economists, "College of the Air" will describe how our economic system works . . . how it provides stability and growth . . . how it enhances individual freedom. Starting in September, *The American Economy* will appear on the CBS television network as five one-half hour programs per week for 32 weeks . . . equal to two semesters of college classes. ▶ With the belief that only through broader education can we meet the growing needs of tomorrow, American business is giving financial support to "College of the Air." The people of Union Carbide are proud to be among the donors to such a worthwhile project.

A HAND IN THINGS TO COME

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The Antarctic Ocean

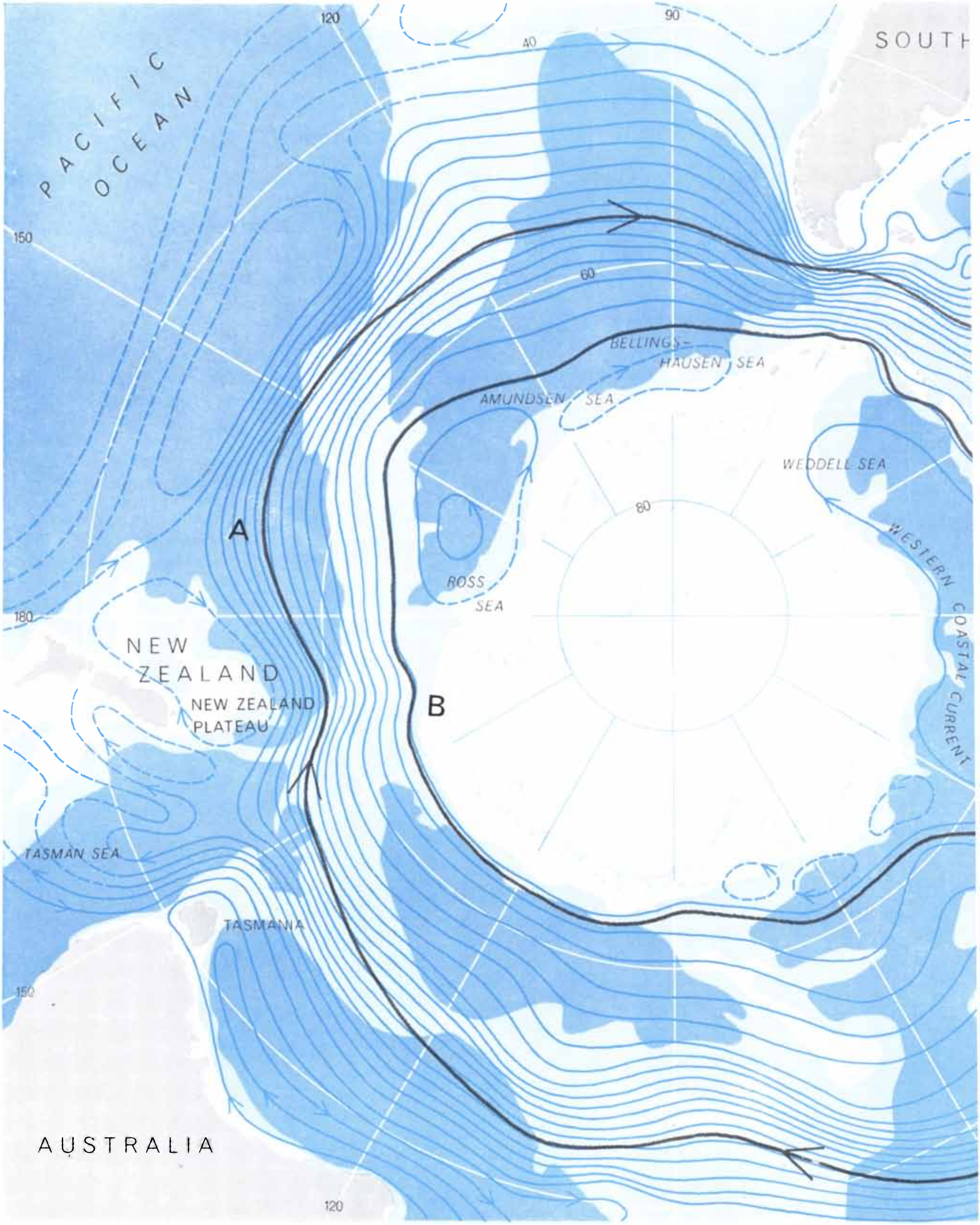
The Atlantic, Pacific and Indian oceans meet in a distinct body of water that wheels around Antarctica. It absorbs heat from the other oceans and its cold bottom waters creep beyond the Equator

by V. G. Kort

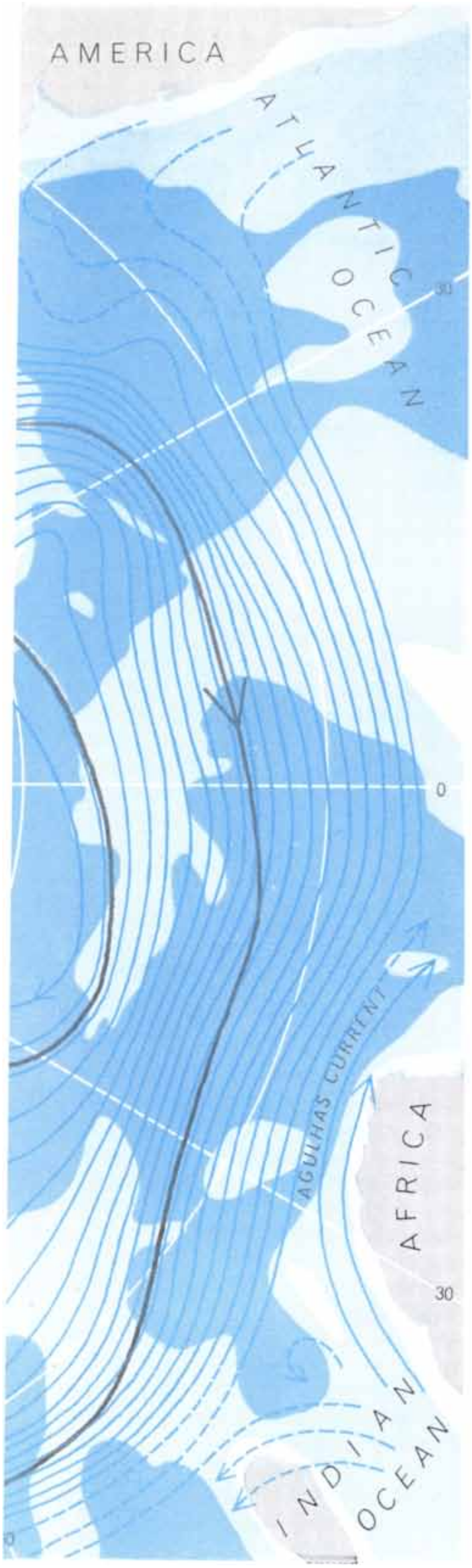
Ordinary maps usually show the Atlantic, Pacific and Indian oceans extending all the way to the frozen shores of Antarctica. To the oceanographer the water surrounding the Antarctic continent is not merely a confluence of three oceans but an ocean of itself, often known as the Antarctic, or Southern, Ocean. Although neither name has won international recognition, the latter is preferred by British and Soviet oceanographers. The Southern Ocean is unique in that it completely encircles the earth, unbroken by a continental land mass. In this great circumpolar expanse of water, driven eastward by the prevailing winds, the narrowest constriction is the 1,000 kilometers (620 miles) that separate South America from the Antarctic Peninsula. Elsewhere the distance between Antarctica and the nearest continent is more than 2,000 kilometers of open water.

The northern boundary of the Southern Ocean cannot be rigidly defined. Sometimes it is taken to be the region of the Antarctic Convergence, between 50 and 60 degrees south latitude, where surface waters flowing generally north converge with waters flowing generally south. The result is a marked change in temperature and salinity and an even sharper change in the character of the marine life [see "The Oceanic Life of the Antarctic," by Robert Cushman Murphy, page 186]. According to another definition, which I prefer, the Southern Ocean can be regarded as extending northward to about 40 degrees south latitude, or approximately the southern coasts of Africa and Australia. Here there is another transition in flow,

SOVIET RESEARCH VESSEL *Ob* took part in the Soviet Marine Antarctic Expedition in the years 1956 to 1959. It and other vessels provided deep hydrologic observations from Antarctica to the coasts of South America, Africa, Tasmania and New Zealand.



ANTARCTIC CURRENT FLOW has been computed from data collected during the International Geophysical Year by the Soviet Marine Antarctic Expedition. The volume of transport between adjacent flow lines is 10 million cubic meters per second. The Antarctic Convergence (*A*), where temperature and salinity change abruptly, coincides with the region of heaviest flow. The Antarctic Divergence (*B*) coincides with the region of minimum flow near the Antarctic coast. The Subtropical Convergence, which can be



regarded as the northern boundary of the Southern Ocean, cannot be very accurately defined, but it generally follows the northern limit of the flow lines plotted here.

temperature and salinity designated the Subtropical Convergence. The Subtropical Convergence also marks the approximate limit of the northward drift of ice from the Antarctic. If 40 degrees south latitude is taken as the boundary, the Southern Ocean covers about 75 million square kilometers, nearly six times the area of the Antarctic continent. This is 22 per cent of the total area of all the oceans. The heat content of the Southern Ocean, however, is only 10 per cent of the oceanic total. It is apparent that this vast expanse of water, ranging in temperature from about —1.8 to 10 degrees centigrade (28.8 to 50 degrees Fahrenheit), exerts a great influence on the climate of the entire planet.

The interaction of the water masses of the Southern Ocean and the atmosphere over it was an important aspect of the program of the International Geophysical Year. Extensive oceanographic observations were conducted in Antarctic waters from 1956 to 1959 by the research ships of Argentina, Australia, France, Japan, New Zealand, the U.S. and the U.S.S.R.

One of the tasks of the Soviet Marine Antarctic Expedition was to obtain more precise values of water transport and current flow in the Southern Ocean. It had previously been established that the strong western winds set up a current that travels around the Antarctic continent. It was also known that frigid waters flow down from the shores of the continent and slowly travel northward along the bottom into the Atlantic, Pacific and Indian oceans. At the same time an equivalent volume of warmer water travels southward at intermediate depths to replace the water flowing northward below it [*see illustration on page 118*].

One of the first attempts at a quantitative estimate of Antarctic water transport was published in 1942 by Harald U. Sverdrup, then director of the Scripps Institution of Oceanography in La Jolla, Calif. His values were based on hydrologic observations carried out in cruises of the British research ship *Discovery* and the cruises of other research vessels. Although it is possible to make a rough estimate of surface currents by determining how much a ship is carried off its course, the oceanographer must resort to other methods for estimating the volume and velocity of currents below the surface. The standard method used by Sverdrup and others, including ourselves, involves measuring the temperature and salinity of the ocean at various depths. From these values one can calculate the relative fields of pressure, which must be converted to absolute fields. This is done by making assumptions as to the topography of the sea surface or the current velocity at some particular depth. The final step is to calculate the field of motion from that of pressure.

Sverdrup calculated the total west-to-east water transport in the Southern Ocean across three sections: between Antarctica and South Africa, between Antarctica and Tasmania (the island off the southern coast of Australia) and between Antarctica and South America (the Drake Passage). His values for total water transport in a layer from the surface to a depth of 3,000 meters across these sections were respectively 120 million cubic meters per second, 150 million cubic meters per second and 90 million cubic meters per second. The smallest of these values, that for the Drake Passage, is more than 400 times the volume of water carried by the Amazon, the world's largest river. It is evident that if 150 million cubic meters per second flows into the Pacific Ocean between Antarctica and Tasmania, some 60 million cubic meters must be diverted northward into the Pacific, since only 90 million cubic meters can be found moving into the Atlantic through the Drake Passage. One would also have to explain how this 60 million cubic meters per second is replenished.

To check Sverdrup's calculations, the Soviet Marine Antarctic Expedition used observations carried out primarily from the 12,000-ton diesel-electric research ship *Ob*. Deep hydrologic observations of temperature and salinity were made from the continental shelf of Antarctica to the coastal waters of South Africa, New Zealand (as well as Tasmania) and South America. The map at left shows in detail the path of the entire Antarctic Circumpolar Current as computed from our data. It can be seen that the maximum current flow is in the zone of the Antarctic Convergence.

In general our figures for transport across the three principal sections do not show such great variations as those computed by Sverdrup. Nevertheless, variations remain, and as I discuss them it may help the reader to follow the flow chart on the next page. For the three principal sections the average values in millions of cubic meters per second are:

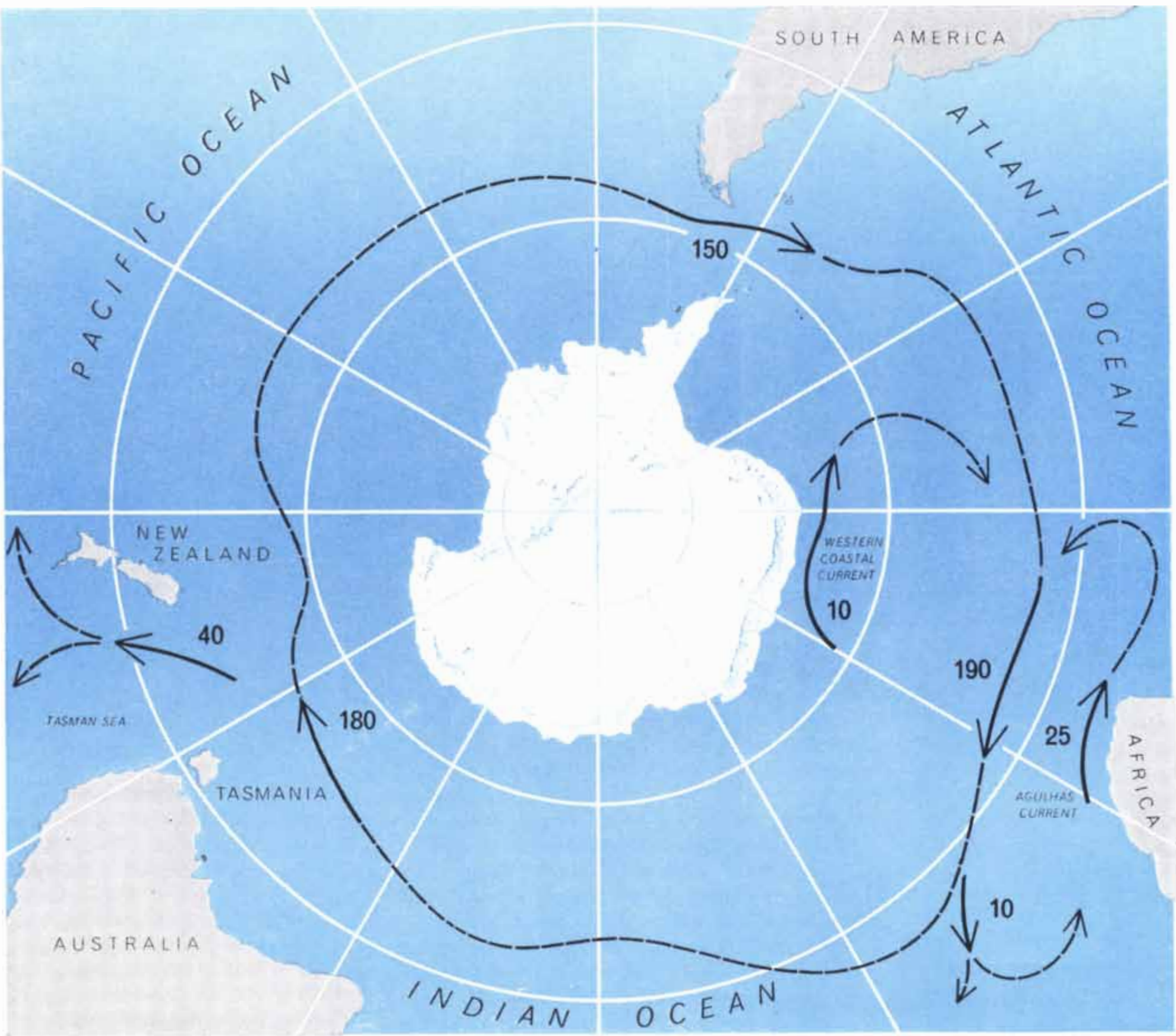
Antarctica to Africa	190
Antarctica to Tasmania	180
Antarctica to Cape Horn	150

The flow of 190 million cubic meters per second represents water moving eastward from the Atlantic into the Indian Ocean, mainly between 38 and 56 degrees south latitude. To the north of this region, between 38 degrees and the African coast, about 25 million cubic meters of water per second is carried in the opposite direction—westward—from the Indian Ocean into the Atlantic by the Agulhas Current. South of 56 degrees south latitude an additional 10 million cubic meters per second is carried westward by the Antarctic Western Coastal Current.

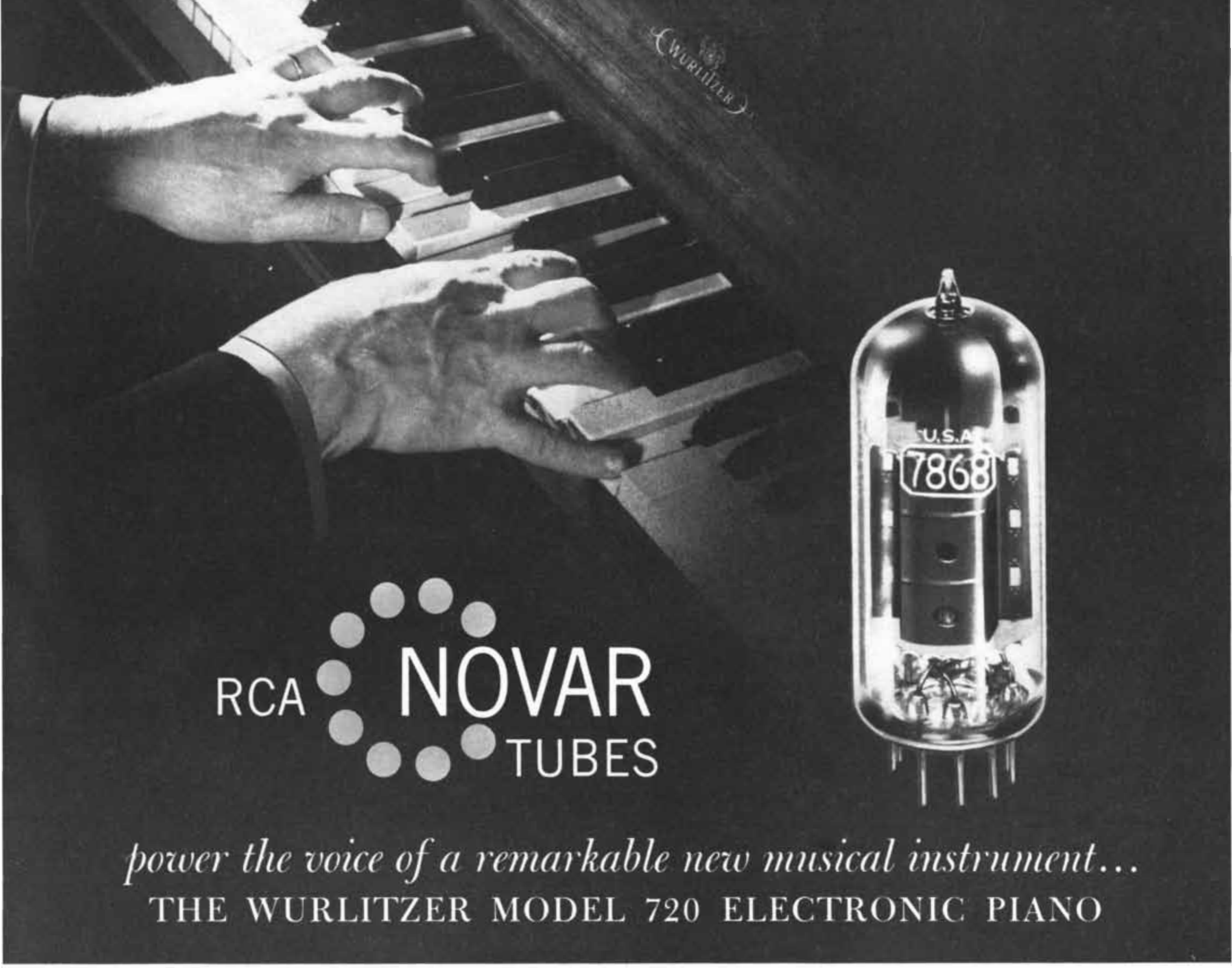
If one now looks at the flow through the section between Antarctica and Tasmania one sees that the volume of water leaving the eastern end of the Indian Ocean is 180 million cubic meters per second, or 10 million less than that entering from the Atlantic. It appears, therefore, that 10 million cubic meters per second is diverted into the circulation of the Indian Ocean and partially makes up for the outflow carried west by the Agulhas Current. The balance of this current consists of 10 million cubic meters per second provided by the West Australia Coast Current and five million provided by river discharge and by Pacific water flowing through the Indonesian straits.

To the east of Tasmania the Antarctic Circumpolar Current branches and sends almost 40 million cubic meters per second northward into the Tasman Sea, which lies between Australia and New Zealand. Whereas 180 million cubic meters per second enters the Pacific Ocean (including the Tasman Sea) from the Indian Ocean, only 150 million cubic meters per second enters the Atlantic Ocean from the Pacific Ocean through the Drake Passage. The deficit of some 30 million cubic meters per second is accounted for partly by evaporation in the Pacific, partly by movement of water into the North Pacific and partly by transport back into the Indian Ocean across the northern coast of Australia.

Finally we observe that the 150 million cubic meters per second entering the South Atlantic through the Drake Passage is 40 million less than the volume leaving the Atlantic between South Africa and Antarctica. Of this deficit about 35 million cubic meters per second is compensated for by the Agulhas



WATER TRANSPORT SUMMARY, in millions of cubic meters per second, shows how the Circumpolar Current varies in volume as it passes between Antarctica and other land masses. Largest diversion occurs where current meets the New Zealand Plateau.



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The problem is solved with the new Wurlitzer Model 720 vacuum-tube console electronic piano—one of the most important new musical instruments since the electronic organ.

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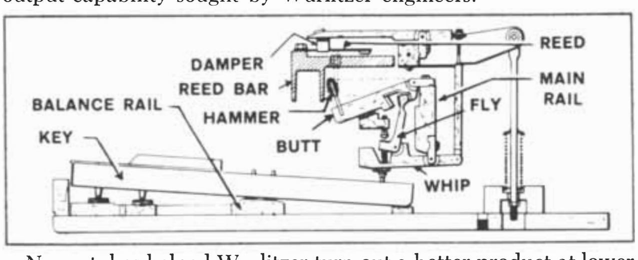
RCA NOVAR TUBES ASSURE TONAL FIDELITY • In such an instrument, sound quality is the critical element—the key to customer acceptance. For this reason Wurlitzer engineers selected RCA-7868 novar power pentode tubes for the audio output stage, to serve as the "voice" of the Model 720 piano.

Novar Tubes were selected only after comparative tests with other power output tubes. They were chosen because they provide at low cost the necessary high power sensitivity and high power output capability sought by Wurlitzer engineers.



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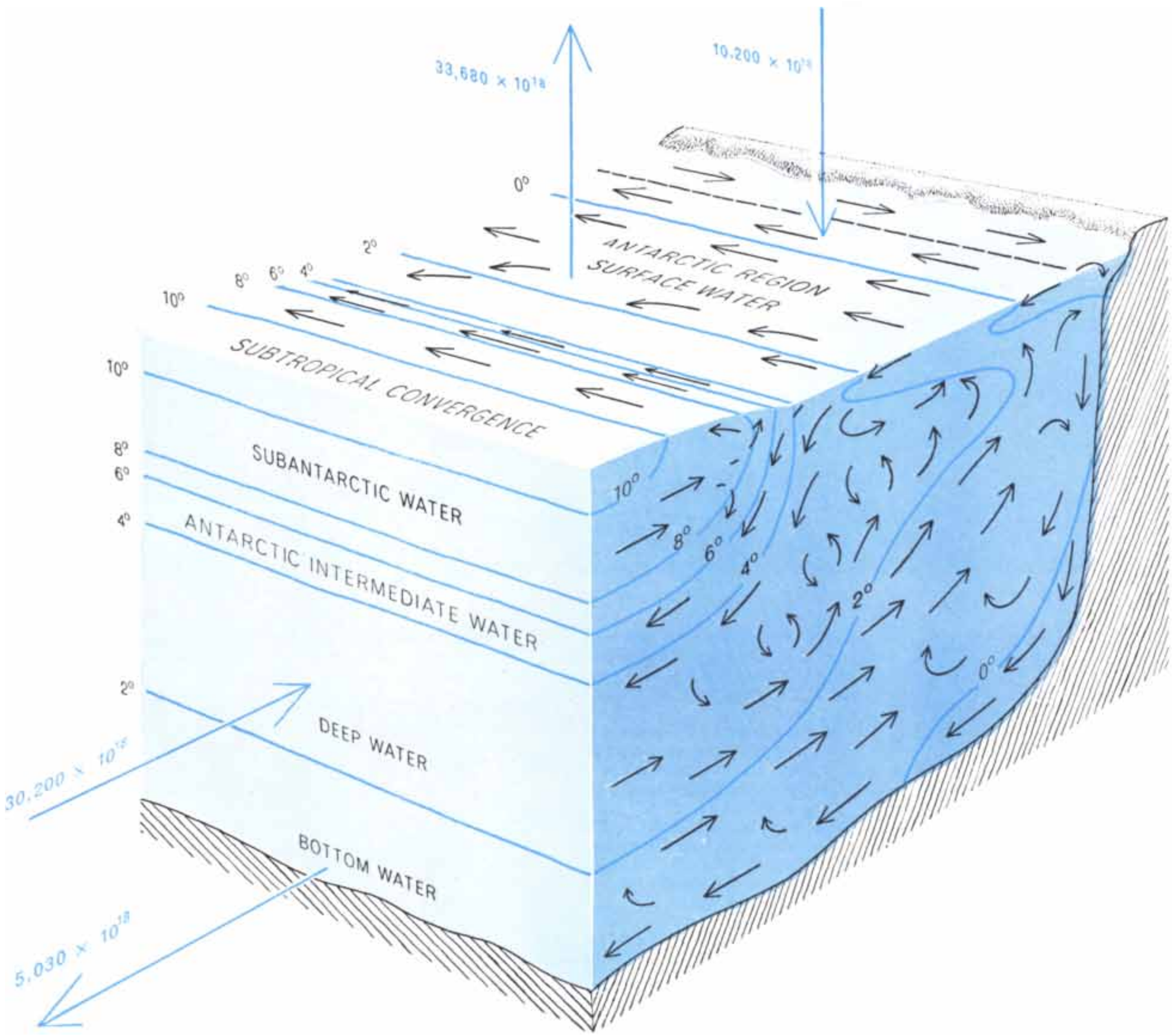
Current and the Antarctic Western Coastal Current. The remaining five million or so is supplied by melted ice carried southward from the Arctic Ocean and by river discharge. In spite of the approximate nature of these transport figures, they provide a reasonable account of the water exchange between the great ocean systems.

A study of the transport pattern of the Antarctic Circumpolar Current reveals that all changes in its direction are closely correlated with changes in the topography of the ocean bottom. This is particularly clear in the region south of Tasmania. Under the influence of the western edge of the New Zealand Plateau a significant fraction (more than 20 per cent) of the Circumpolar Current is diverted northward into the Tasman Sea, and the remaining mass is deflected to the south. The result is a sharp southward displacement of the Antarctic Convergence.

Hydrologic data collected close to the Antarctic shelf indicate strong cyclonic (clockwise in the Southern Hemisphere) and anticyclonic circulation patterns in the vicinity of the Weddell, Ross, Amundsen and Bellingshausen seas. The largest of the anticyclonic patterns appears to lie in the region to the northeast of the Ross Sea. The most extensive cyclonic circulation is between Africa and Antarctica.

A second task of the Soviet Marine Antarctic Expedition was to estimate the meridional flow of deep water: toward and away from the Antarctic continent. More than 35 years ago Georg Wüst, who is now at the Lamont



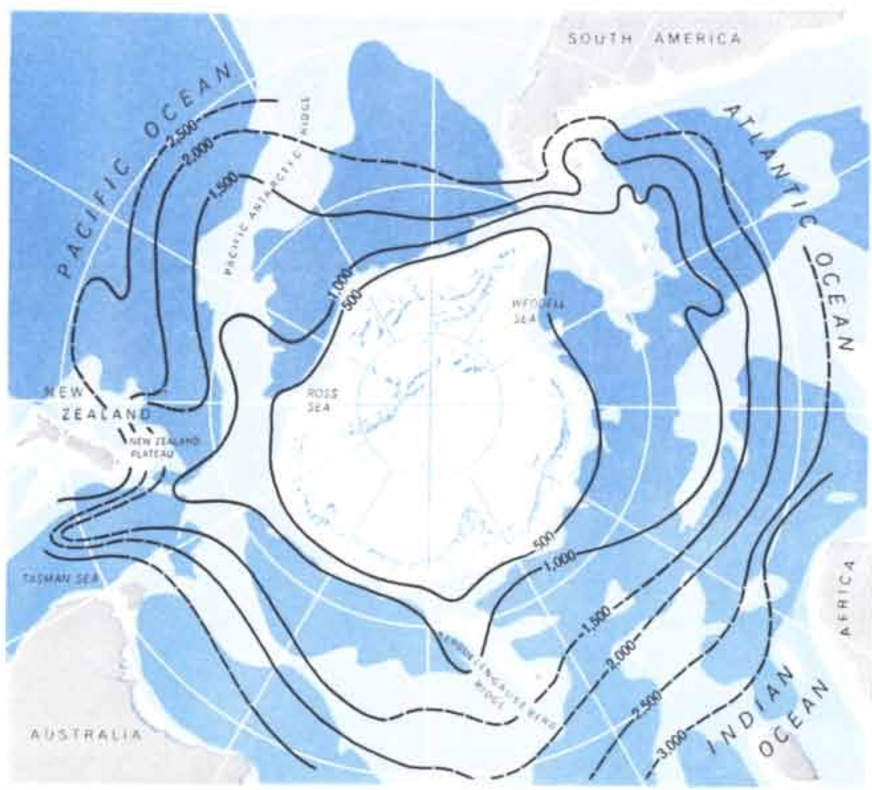
COMPLEX FLOW of currents in the Southern Ocean is depicted in this schematic view based on the work of Harald U. Sverdrup. Water cooled by the coastal ice masses of the Antarctic continent (*right*) sinks and flows northward along the bottom. An equal volume of warmer "Deep water" flows southward to replace it. The Antarctic Convergence is formed where south-flowing water of 8 to 10 degrees centigrade meets much colder surface water flowing away from the Antarctic. Figures at left in color, computed by the author and his associates, show the amount of heat, in calories, transported annually by the deep and bottom waters. Other figures in color show that the heat given off to the atmosphere by the Southern Ocean greatly exceeds the heat received from the sun.

Geological Observatory of Columbia University, analyzed deep observations made in the Atlantic Ocean by the German research ship *Meteor* and concluded that Antarctic waters cross the Equator and penetrate as far as 40 degrees north. Soviet observations carried out in the Indian Ocean by the *Ob* indicate that Antarctic waters penetrate to the Arabian Sea and the Bay of Bengal, both of which lie some 10 to 20 degrees north of the Equator.

Because of the absence of a reliable theoretical model, the meridional transport is more difficult to compute than the circumpolar transport. Our semi-empirical method of computation depended on measurements of temperature and turbulent exchange of heat at various depths. When observations made on nine meridional sections were analyzed, the mean northward transport of bottom waters around the whole perimeter of the Antarctic continent turned out to be something more than 800 million cubic meters per second, or more than five times the flow rate of the Antarctic Circumpolar Current itself. To replace this huge outflow a mighty layer of deep warm water, equal in volume, crosses the perimeter of the Southern Ocean from the north.

Knowing the water exchange between the Southern Ocean and adjacent oceans and knowing water temperatures, it is possible to make a rough estimate of the amount of heat exchanged. First, however, it is necessary to determine the amount of solar radiation absorbed at the surface of the water and the amount of heat radiated from the surface back into the atmosphere. Data obtained in the third and fourth cruises of the *Ob* in summer (February) and winter (August), together with observations made at the Soviet Antarctic stations of Mirnyy and Lazarev and elsewhere, were used to estimate the radiation balance of the Southern Ocean to 40 degrees south latitude. It was found that the Southern Ocean gives off annually to the atmosphere nearly 34×10^{21} (34 followed by 21 zeros) gram calories and takes up from it only slightly more than 10×10^{21} gram calories. The heat given off serves to warm the frigid Antarctic air masses as they travel over the Southern Ocean on their way northward.

It is apparent that the main source of heat received by the Southern Ocean is the deep waters that carry it in from the north. Our estimates show that these waters annually bring in approximately



HEAT DISTRIBUTION in the Southern Ocean in summer (October through March) has been estimated by Soviet oceanographers. Figures represent the heat content, in thousands of calories, of a column of water a square centimeter in cross section extending from the surface to the ocean bottom. Heat content is proportional to number of degrees between the average water temperature and the freezing point of sea water, multiplied by the depth.

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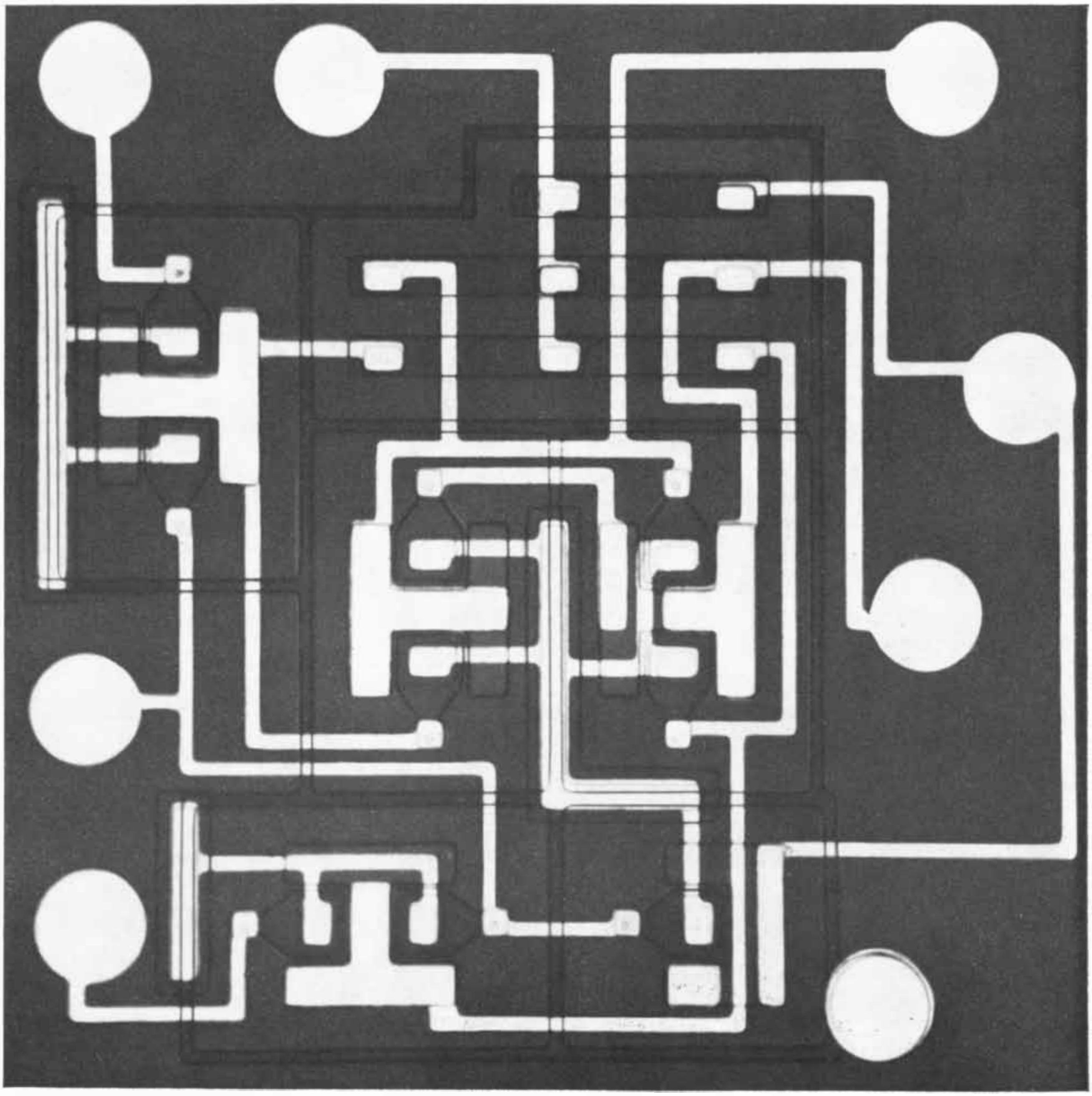

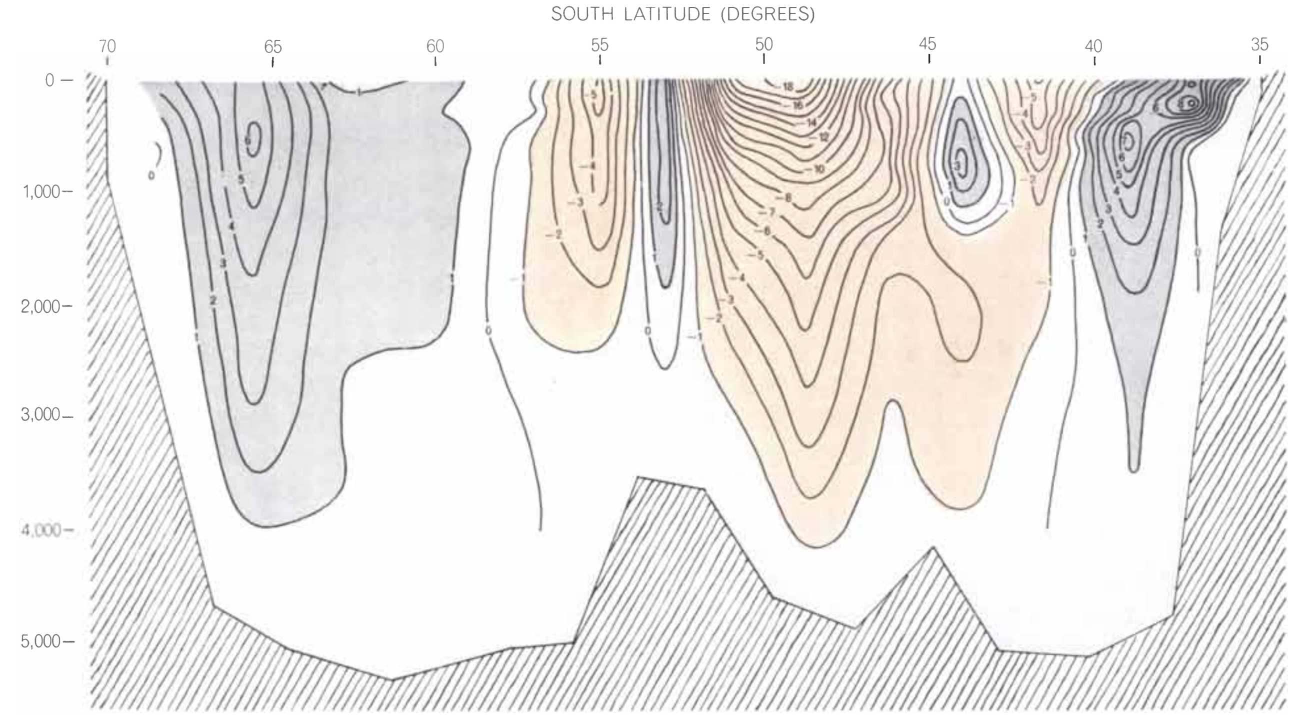

CURRENT VELOCITY DISTRIBUTION is shown for the oceanographic section between Antarctica (*left*) and South Africa. Figures give velocity in centimeters per second. The predominantly eastward flow is indicated by negative values and colored areas. The westward flow at right is produced by the Agulhas Current. Westward flow at left is the Antarctic Western Coastal Current.

30×10^{21} gram calories. This value represents the heat released when some 800 million cubic meters per second of deep water at 1.2 degrees C. is chilled to the mean temperature of .2 degree prevailing near the coast of Antarctica. The equal volume of bottom water flowing northward carries with it about 5×10^{21} gram calories of heat.

These figures derived in different ways yield income and outgo energy values that are in reasonable, if not complete, balance. The income is 10×10^{21} gram calories of solar energy plus 30×10^{21} gram calories delivered by deep waters from the north, for a total of 40×10^{21} gram calories. The outgo is roughly 34×10^{21} gram calories lost to the atmosphere plus 5×10^{21} gram calories carried north in bottom waters, for a total of approximately 39×10^{21} gram calories.

One can see from the above analysis that the thermal influence of the Southern Ocean is two-sided. First, and most important, the Southern Ocean takes up from adjacent oceans a considerable amount of heat and expends it in warming up the cold Antarctic air masses, thereby exerting a decisive influence on the atmospheric circulation of the Southern Hemisphere. Second, the cold waters of the Southern Ocean penetrate into the adjacent oceans and noticeably cool their deep layers.

The interplay of water temperature and currents in the Southern Ocean can be brought out by charting the pattern of heat distribution in the water surrounding Antarctica. To do this one integrates two factors: the average water temperature from the surface to the bottom and the water depth. One can then calculate the heat content of a column of water a square centimeter in cross section extending from the surface to the bottom. In our calculations we regard the heat content of sea water at its freezing point (around −1.8 degrees C.) as being zero. Thus a cubic centimeter of water one degree above freezing is said to have a heat content of about one gram calorie. The pattern of heat distribution of the Southern Ocean in the Antarctic summer is shown in the map on page 120.

It can be seen that the coldest region of the Southern Ocean is the Weddell Sea, which lies within a huge cyclonic system. This system draws a vast quantity of water from the Antarctic Circumpolar Current and transports it southward to the great ice shelf of the Weddell Sea, where the water is intensively cooled. As a result the region is literally a factory of cold waters.

Picked up again by the Antarctic Circumpolar Current, the refrigerated waters are carried eastward until, on reaching the New Zealand Plateau, some 40 million cubic meters per second is deflected into the Tasman Sea. The tongue of frigid water penetrating northward shows up clearly in the heat-distribution map. As the Circumpolar Current moves east into the South Pacific it is again deflected sharply northward under the combined influence of the Pacific-Antarctic Ridge and the anticyclonic circulation near the Ross Sea. The cold shelf waters of the Ross Sea also contribute to the outflow of cold water to the north. The net effect of these great diversions is to make the Pacific Ocean somewhat colder than the Indian Ocean and substantially colder than the Atlantic Ocean. According to the data of my colleague V. N. Stepanov, the annual mean heat content of the Pacific Ocean is 1,746,000 gram calories per square centimeter, compared with 1,783,000 for the Indian Ocean and 1,989,000 for the Atlantic Ocean. The mean heat content of the Southern Ocean is approximately half of these values, which accounts for the statement that it contains only about 10 per cent of the world's oceanic heat while representing 22 per cent of the world's oceanic area.

The exceptional intensity and stability of the Antarctic Circumpolar Current offer the investigator an attractive opportunity for testing theoretical models of the flow of a homogeneous fluid

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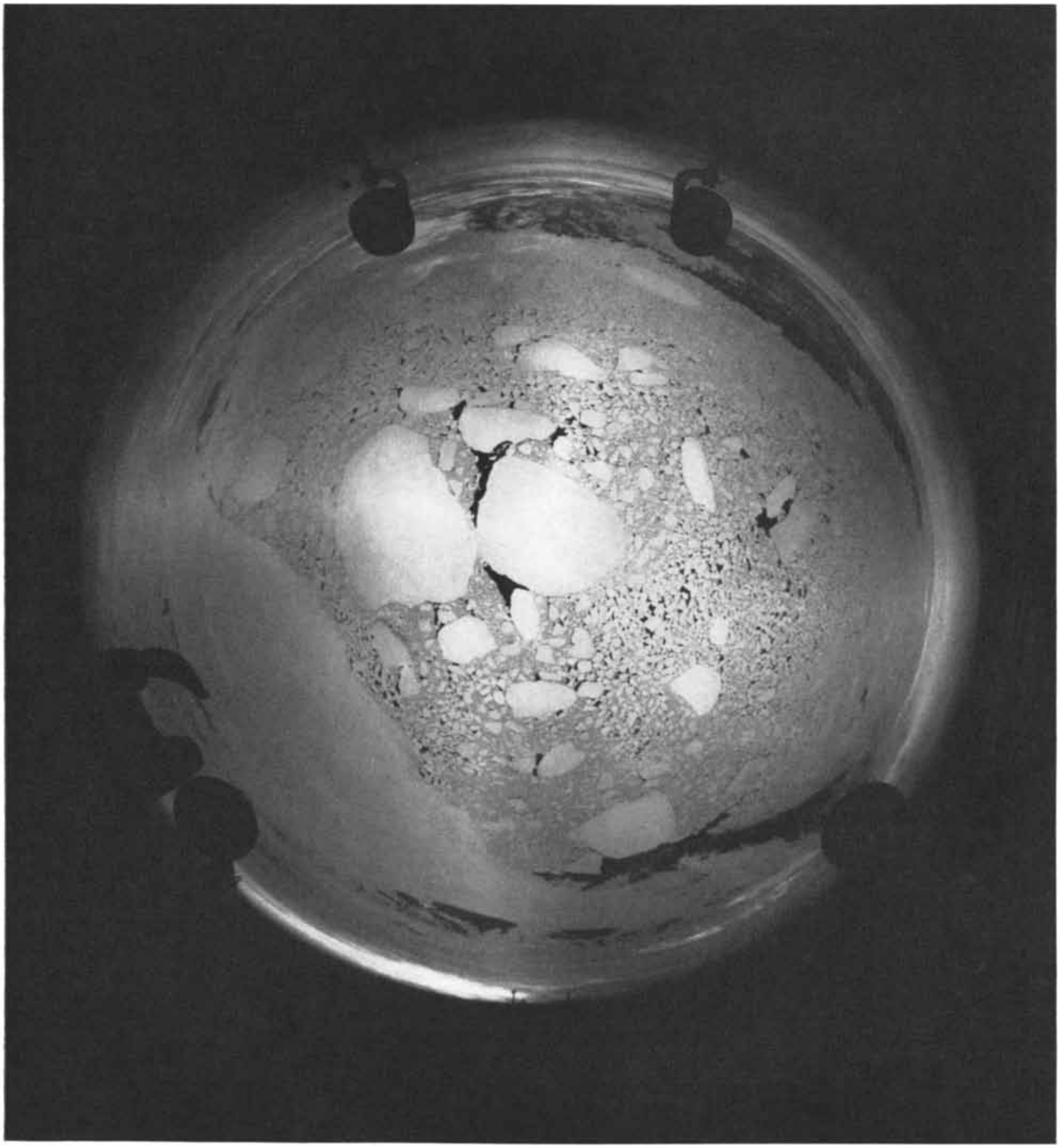
The first comprehensive description of the dynamics of the Southern Ocean was published 25 years ago by G. E. R. Deacon, now director of the National Institute of Oceanography in England. Subsequently Sverdrup developed the concept that the Antarctic Circumpolar Current is the sum of a pure wind-driven current in the surface layers of the ocean and of a gradient current, due to density variations, acting through the whole water mass. Sverdrup was also the first to call attention to the influence of bottom topography on the Circumpolar Current. Since then the leading students of the dynamics of the Southern Ocean have treated the Circumpolar Current as a current driven through a channel by a steady zonal wind.

The main objective of the theoretical studies, conducted primarily by U.S., French, German and Japanese investigators, has been to compute the volume of water transported by the Antarctic Circumpolar Current and to provide mathematical models describing how the current is influenced by bottom topography. Although such studies have usually led to unrealistically high values of



FLOATING PACK ICE at Moubray Bay, adjacent to Hallett Station on the Ross Sea, was photographed from 8,000 feet by Emil Schulthess, using his homemade "fish eye" camera. The round objects at the edge of the picture are the four wheels of the helicopter.

water transport, they all confirmed that the transport is caused by wind.

The theoretical models developed prior to the IGY program left unanswered the question of whether the current is a continuous flow through the whole body of the ocean, from surface to bottom, or whether it has deep countercurrent or transverse circulation. The models also had difficulty explaining the mechanism of the formation of convergent and divergent zones of flow in the surface layers of the oceans; these zones are the Antarctic Convergence, the Antarctic Divergence and the Subtropical Convergence, which navigators in these regions have long recognized by changes in water and air temperature. Finally, the models could not assess quantitatively the influence of bottom topography on the Antarctic Circumpolar Current.

Data collected during the IGY program have made it possible to start solving some of these problems. For example, detailed deep observations of temperature and salinity, and of the distribution of oxygen and other elements, show that waters in the Antarctic Circumpolar Current move eastward through the whole body of the Southern Ocean. The structure of this current, however, is complicated. The total flow breaks into separate streams with fast-moving cores. Elsewhere, in certain regions, countercurrents run westward. The illustration on page 122 shows a characteristic structure of the Circumpolar Current in the section between South Africa and Antarctica, along 20 degrees east longitude.

With the new evidence that the flow of Antarctic waters embraces the whole body of the ocean, it becomes easier to explain the role of large-scale submarine trenches and ridges. The bends in the stream lines, as charted on pages 114 and 115, are formed by the joint influence of bottom topography and the Coriolis force, which results in the deflection of the Antarctic Circumpolar Current to the north over a rising bottom and to the south over a falling bottom.

With these qualitative observations as a starting point, a new theoretical model of the Antarctic Circumpolar Current has been developed by V. M. Kamenkovitch, one of my colleagues at the Institute of Oceanology of the Soviet Academy of Sciences. The model yields values of water transport that agree reasonably well with the values actually observed in the Circumpolar Current.

Another worker at our institute, J. A. Ivanov, has been examining the forma-

tion of ocean "frontal" zones, such as the zone of the Antarctic Convergence. He finds that seasonal changes in the geographical position of this zone correlate rather closely with seasonal changes in the meridional component of air pressure gradients over the Southern Ocean.

Harry Wexler, the late director of research for the U.S. Weather Bureau, concluded independently that the Antarctic Convergence is caused by meteorological factors. Wexler believed, moreover, that wind strength determines whether a frontal zone will be a convergence or a divergence. Klaus Wyrtki, a German investigator, has reached much the same conclusion. Thus, as a result of the combined efforts of the oceanographers of several countries, the dynamic processes in the Antarctic waters have received a more or less satisfactory physical explanation.

This does not mean, of course, that oceanographers have no more work to do in the Southern Ocean. I shall mention only one outstanding gap in our knowledge. The volume of water exchanged between the Southern Ocean and the oceans to its north varies considerably from season to season and from year to year. Such variability cannot help but influence the heat exchange of the Southern Ocean and therefore the atmospheric circulation over it. At present, however, we lack a quantitative estimate of this variability.

To fill this gap in knowledge we need a sharp increase in radiation measurements on research ships and at all island stations. There should be an international effort to make systematic deep observations over a period of many years in several sections across the Antarctic Circumpolar Current, repeating the measurements made most recently by the Soviet Marine Antarctic Expedition. In addition, periodic observations, at three-to-five-year intervals, should be made in large meridional sections extending from the coast of Antarctica to the northern latitudes in each of the adjoining oceans, the Atlantic, the Pacific and the Indian.

Such observations will provide the data necessary to reveal variations in the exchange of heat between the Southern Ocean and its neighbors to the north and to show how this heat exchange influences both atmospheric and oceanic circulations. A thorough understanding of these mechanisms will be of invaluable help in making long-range forecasts of weather and climate for the entire planet.

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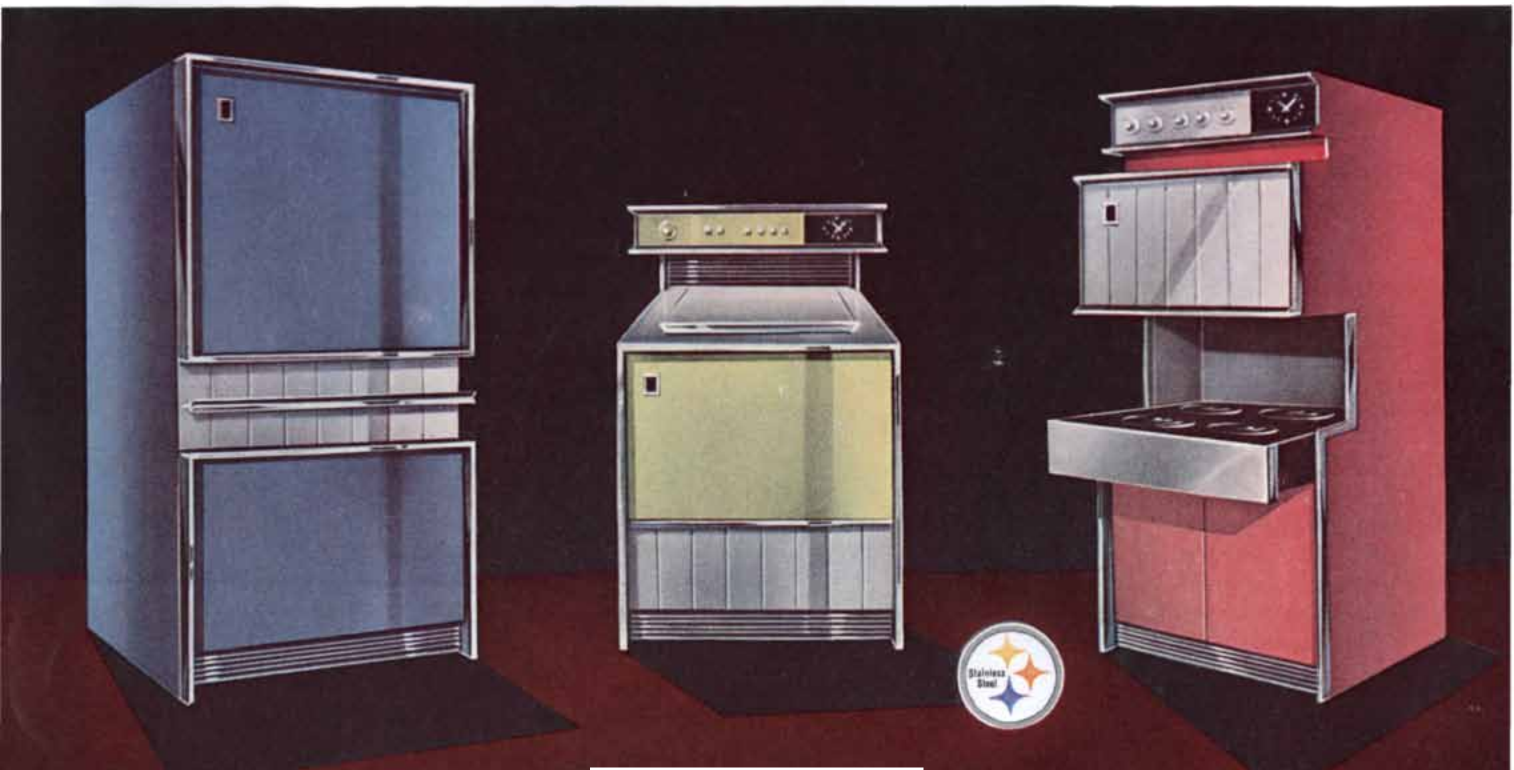

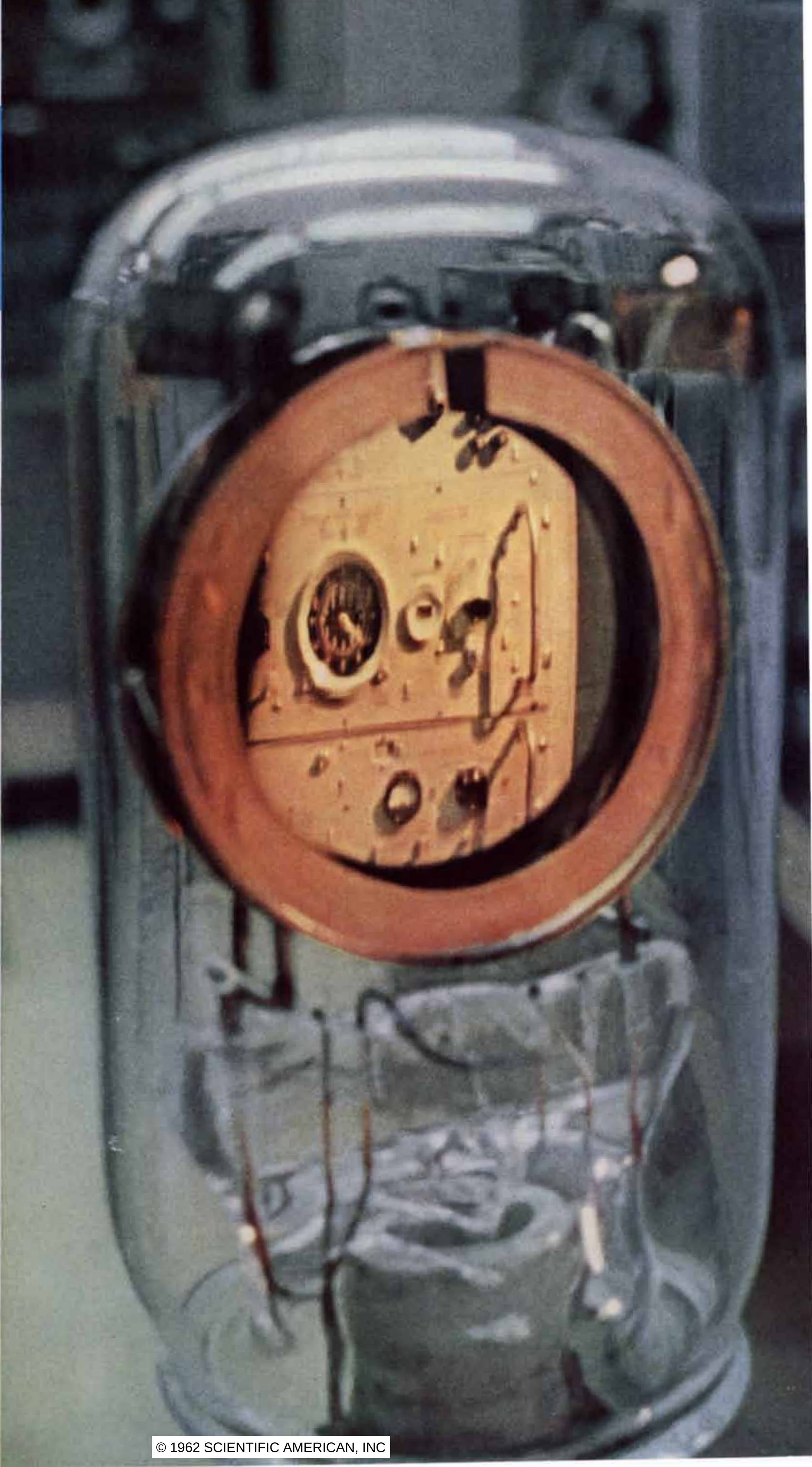

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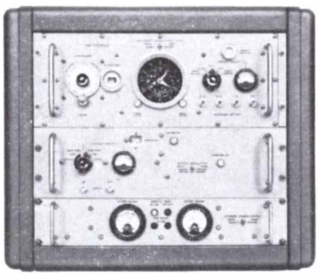
Finally, the crystal's characteristic curves are plotted and the optimum temperature for operating stability is determined. The crystal is then housed permanently in its oven, and the oven set to the optimum temperature. Under extreme environment this temperature varies less than ± 0.01°C.



The stability and reliability thus achieved have made Hewlett-Packard frequency/time standard systems widely used references in laboratories concerned with precise measurement. The typical hp system shown here includes (top to bottom) hp 113BR Frequency Divider and Clock, hp 103AR Quartz Oscillator and hp 725AR Standby Power Supply. Model 113BR provides time signals precise to 1 microsecond, and allows accurate system calibration with WWV standards broadcasts; price, $2,750. Model 103AR provides 1 MC and 100 KC sinusoidal outputs whose guaranteed long-term stabilities are 5/10^{10}/day and whose short term stability is such that 1/10^{10} can be expected under laboratory conditions; price $2,500. Model 725AR powers the oscillator and clock and assures continued operation in the event of line power failure; price, $645.

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The Ice of the Antarctic

Some 2,500 miles across and an average of more than a mile thick, the Antarctic glacier is one of the major features of the earth's surface. Whether it is growing or shrinking is still undetermined

by Gordon de Q. Robin

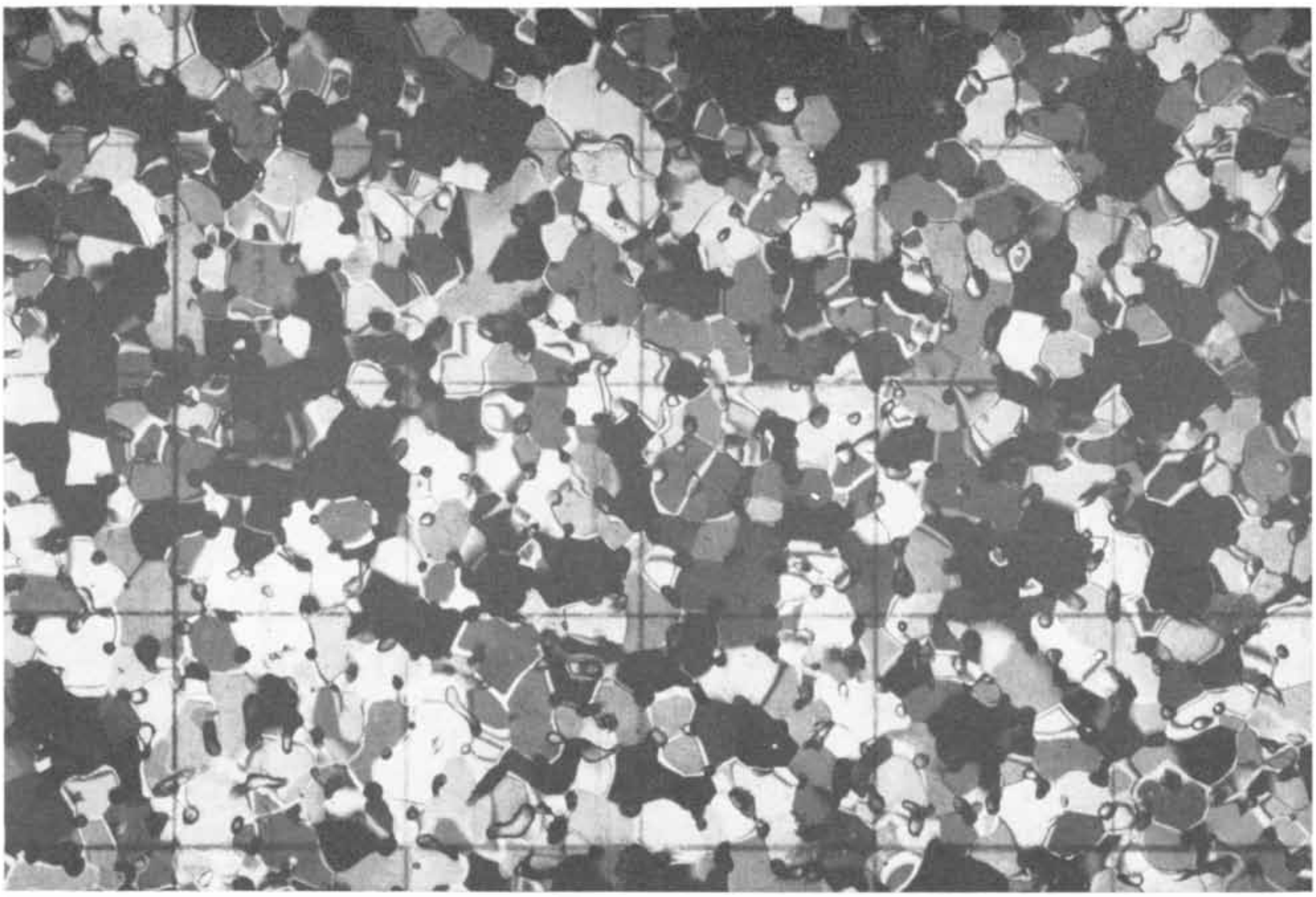
The vast ice sheet of the Antarctic dominates all other features of the region. The most interesting geophysical problems of the Antarctic have to do with the warping of the earth's crust by the weight of the ice. The weather and climate of the Antarctic, and the ways in which they differ from the weather and climate of the Arctic, are largely determined by the ice sheet. The meteorology in turn governs the character and motions of the surrounding ocean and the native forms of marine and terrestrial life, to say nothing of the activities of human visitors. For other parts of the world the ice sheet represents a potential source of water sufficient to raise sea level by an amount that would flood all major seaports and low-lying land areas.

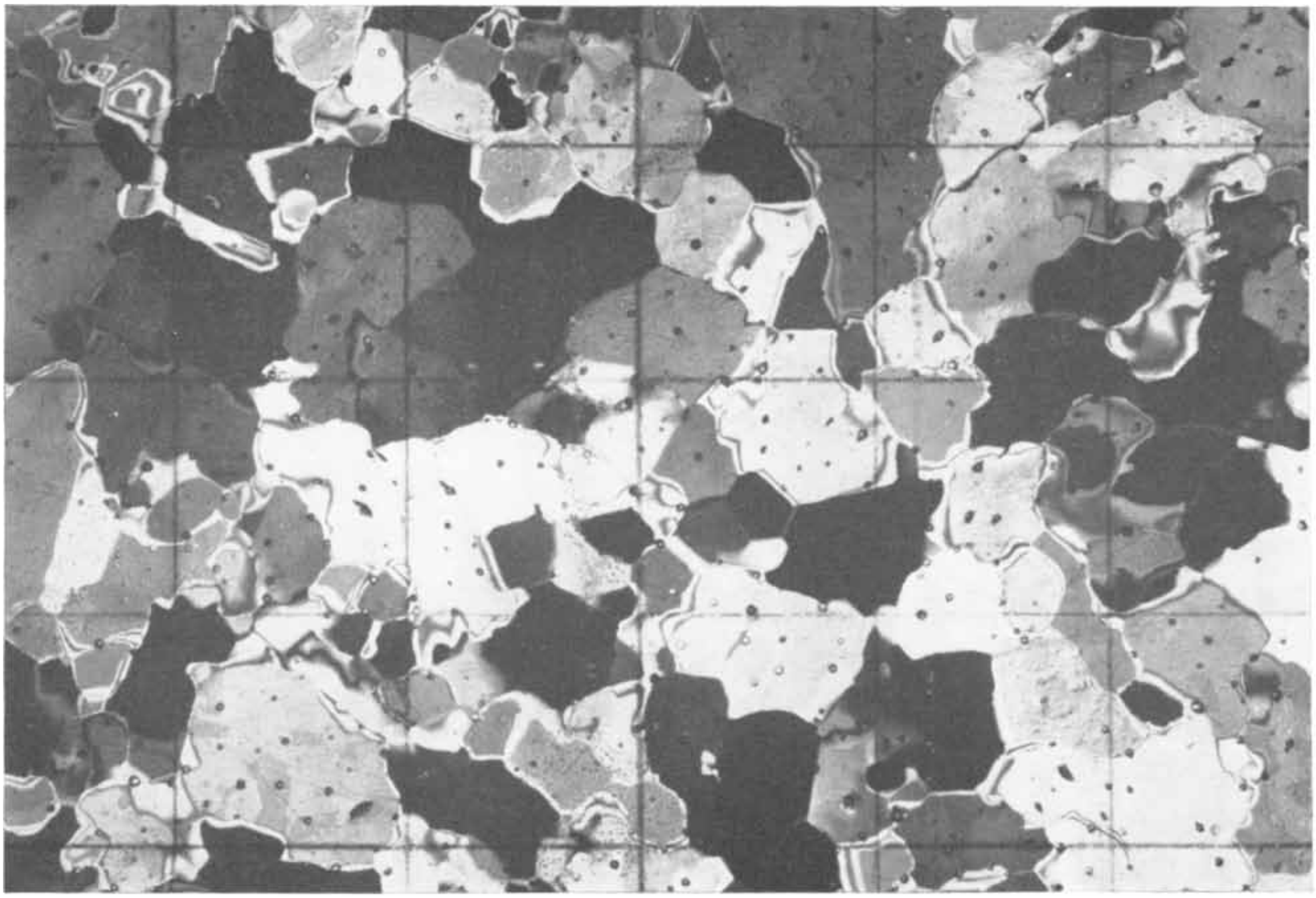
DEEP ICE-CORE DRILLING is done with this well-drilling rig at Little America on the Ross Ice Shelf. The drill derrick is 38 feet high. The photographs on these two pages were made by Anthony J. Gow of the U.S. Cold Regions Research and Engineering Laboratory.

Just how much ice is there in the Antarctic? Like most questions about the Antarctic, this one can as yet be answered only roughly. For more than a century Antarctic expeditions have been engaged in determining the area of the Antarctic continental glacier, and this broad but straightforward undertaking is almost finished. Until about 10 years ago, however, the thickness of the ice was a matter of almost pure conjecture. In the past decade a number of measurements have been made—enough to provide a large-scale picture of the entire ice sheet even though substantial gaps remain.

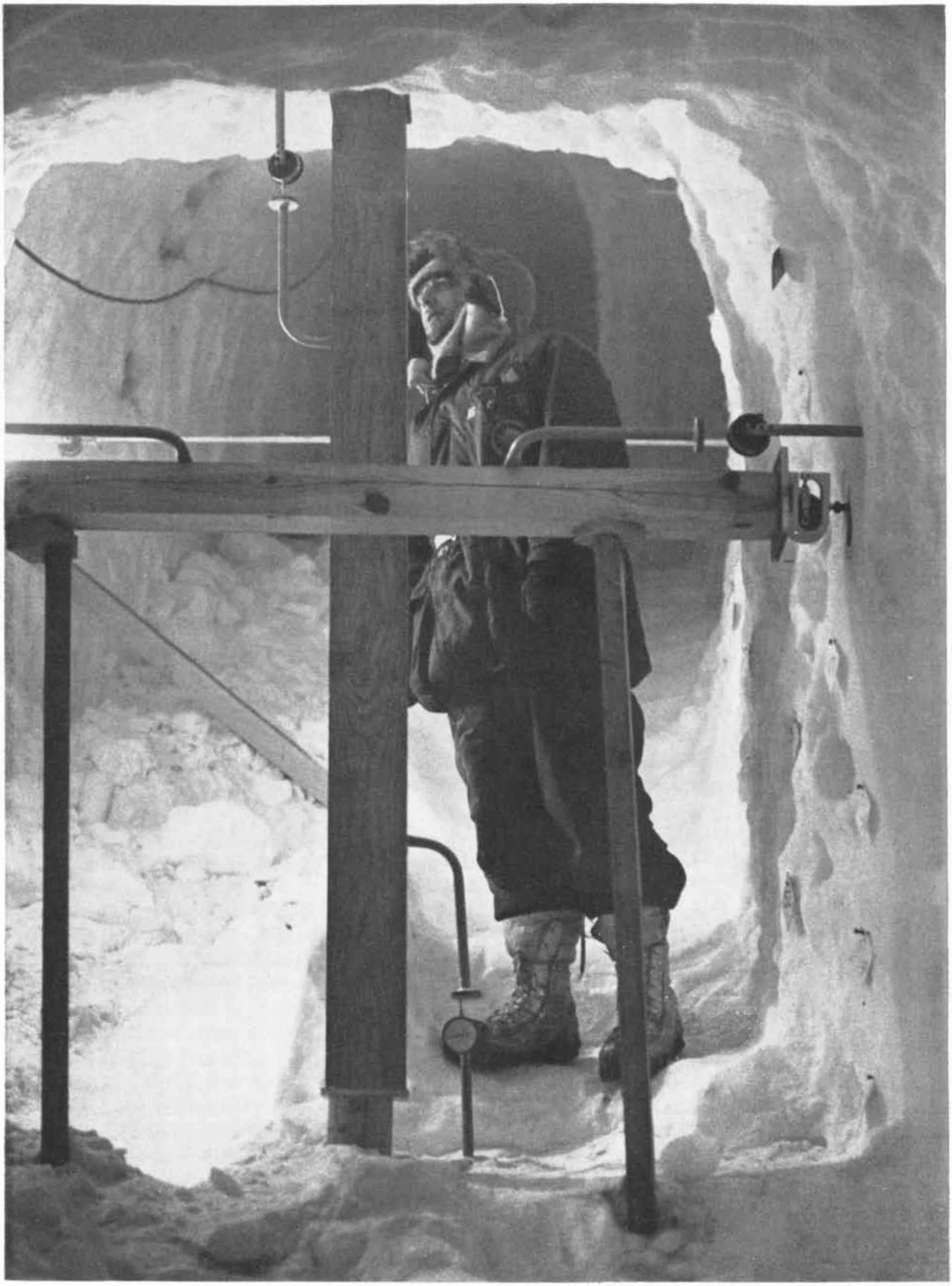
All the thickness measurements are based on seismic shooting. In this technique an explosive charge is set off at the surface or in a hole a few tens of meters deep. Seismic waves traveling outward from the explosion are refracted in passing through regions of different density and are reflected from any surface where the density or elasticity increases abruptly. Seismometers at various distances from the source record the time required for the reflected or refracted waves to reach them. With enough data it is possible to deduce the paths of the waves, their velocities and therefore the depth of various layers under the surface.

Reflection shooting, or echo sounding, is the simpler of the seismic methods and the one more commonly used. In principle it works like echo sounding at sea: the depth is computed from the time required for a signal of known velocity to travel down through the ice and back up again after being reflected by the rock surface underneath. In practice, however, a number of factors com-





ICE SECTIONS from depths of 71 (*top*) and 300 meters (*bottom*) at Byrd Station are magnified 3.25 diameters (a grid square represents one square centimeter). The numerous tiny gray, white and black spherules are air bubbles trapped in the ice. With increased depth ice crystals tend to become larger and air bubbles smaller. The deeper ice was deposited as snow about 1,600 years ago.



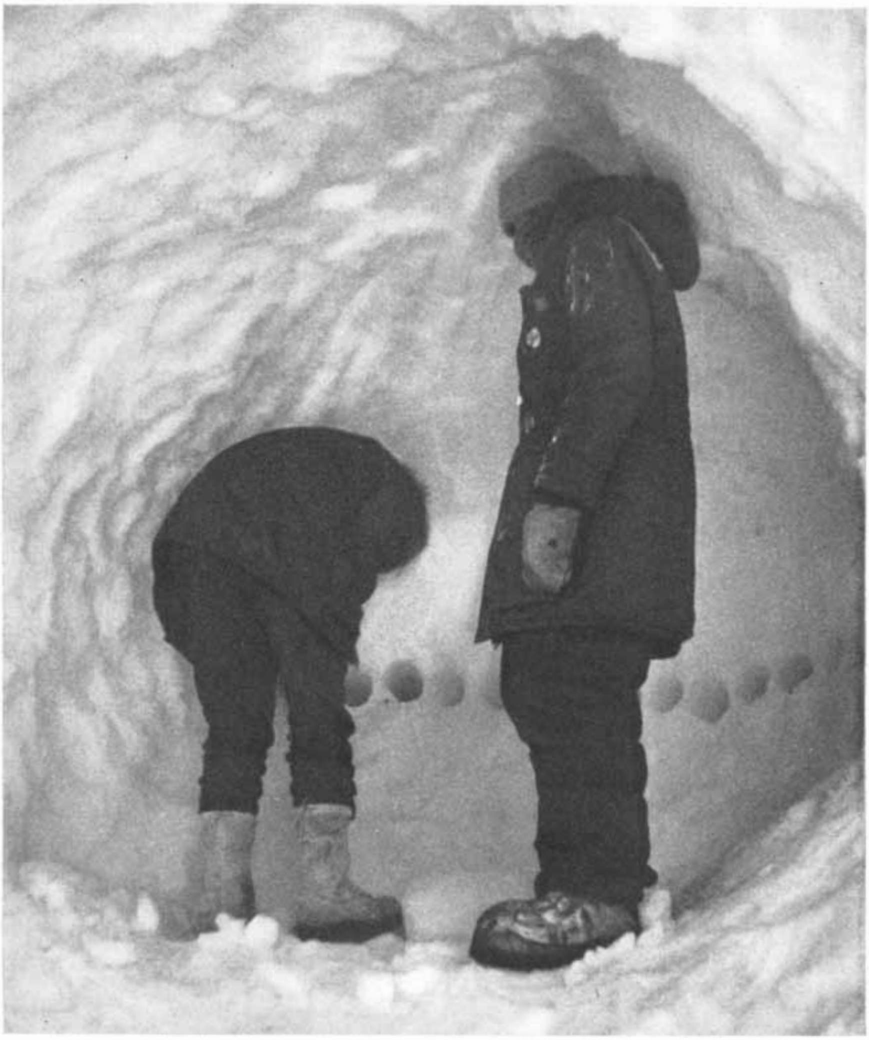
"SNOW MINE" at the South Pole is a tunnel that descends 90 feet below the surface. Sets of gauges (*in crossbar arrangements like the one seen here*) have been installed at several levels in the mine to measure the pressure on the tunnel walls and the rate at which they are moving together. The temperature in the mine is constant at — 61 degrees Fahrenheit. Glaciologist checking gauges is Gow.

bine to make reflection shooting on the ice sheet considerably more complicated and difficult. To begin with, the recording seismometer cannot be located at the point of explosion; the movement of the ice is too violent. Second, the surface of the rock below the ice may not be horizontal; thus seismic waves reflected from the rock may arrive at an angle. Corrections for such geometrical factors, however, can be easily applied. A more serious problem arises from the variety of motions that can travel through ice. Whereas water transmits only compressions (P waves), ice, like the solid earth, also transmits transverse vibrations (S waves) and circular, or rolling, vibrations along the surface (L waves). It is not always easy to pick out the desired signal—P waves reflected from the rock surface below the ice—from the mélange of wave types that reach the recording station [*see illustration on page 139*].

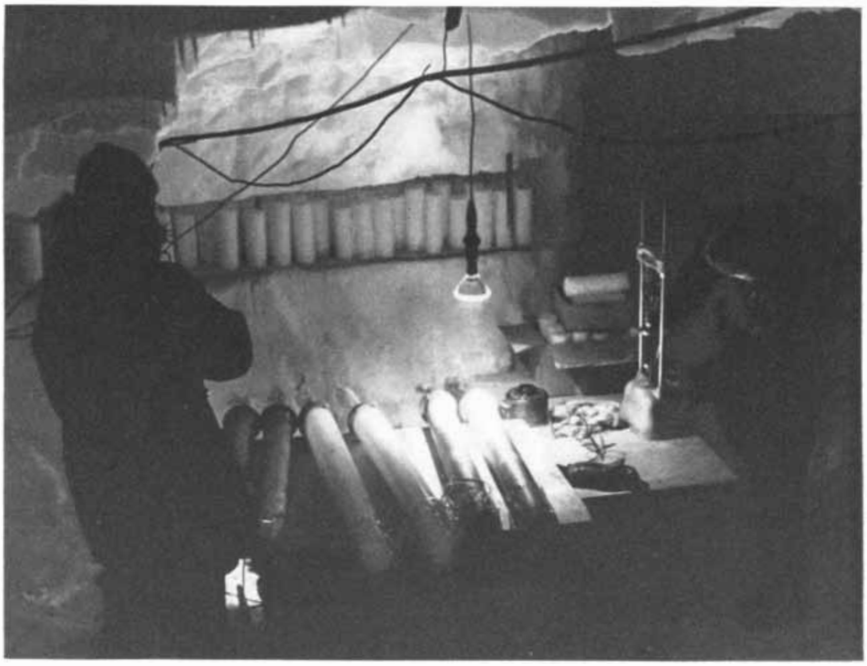
Still another complication is introduced by the varying density of the snow and ice and the varying speed of seismic waves in their upper layers. Over most of Antarctica the temperature does not rise enough in summer to melt the snow at the surface and allow it to turn into ice by refreezing. Instead the fallen snow gradually hardens into the solid but porous intermediate stage between snow and ice known as firn, or névé, which is compressed into ice at a certain distance below the surface. The density of Antarctic firn usually starts at .3 to .4 gram per cubic centimeter near the surface and increases with depth. Between 50 and 100 meters (some 150 to 300 feet) it reaches a value of about .82 gram per cubic centimeter. At this point the material is no longer porous and is classified as ice. It still contains small air bubbles, which are squeezed further until, at a depth of 150 meters or more, the density of the material is close to that of pure ice. In general the density increases more rapidly with depth in the coastal regions than it does in the colder plateau of the interior.

The velocity of seismic waves through a given material is roughly proportional to its density. Consequently the waves from an explosion speed up as they move deeper into the firn and then into ice of increasing density. Conversely, the waves reflected from the bottom begin to slow down when they reach the firn layer. To correct for these effects in an echo-sounding measurement it is necessary to know the exact relation of velocity and depth. This can be learned by refraction shooting.

Because of their increasing speed,



DRILLING ICE CORES in wall of the snow mine at the South Pole are René O. Ramseier (*left*) and Edward J. Oliver of the U.S. Cold Regions Research and Engineering Laboratory.

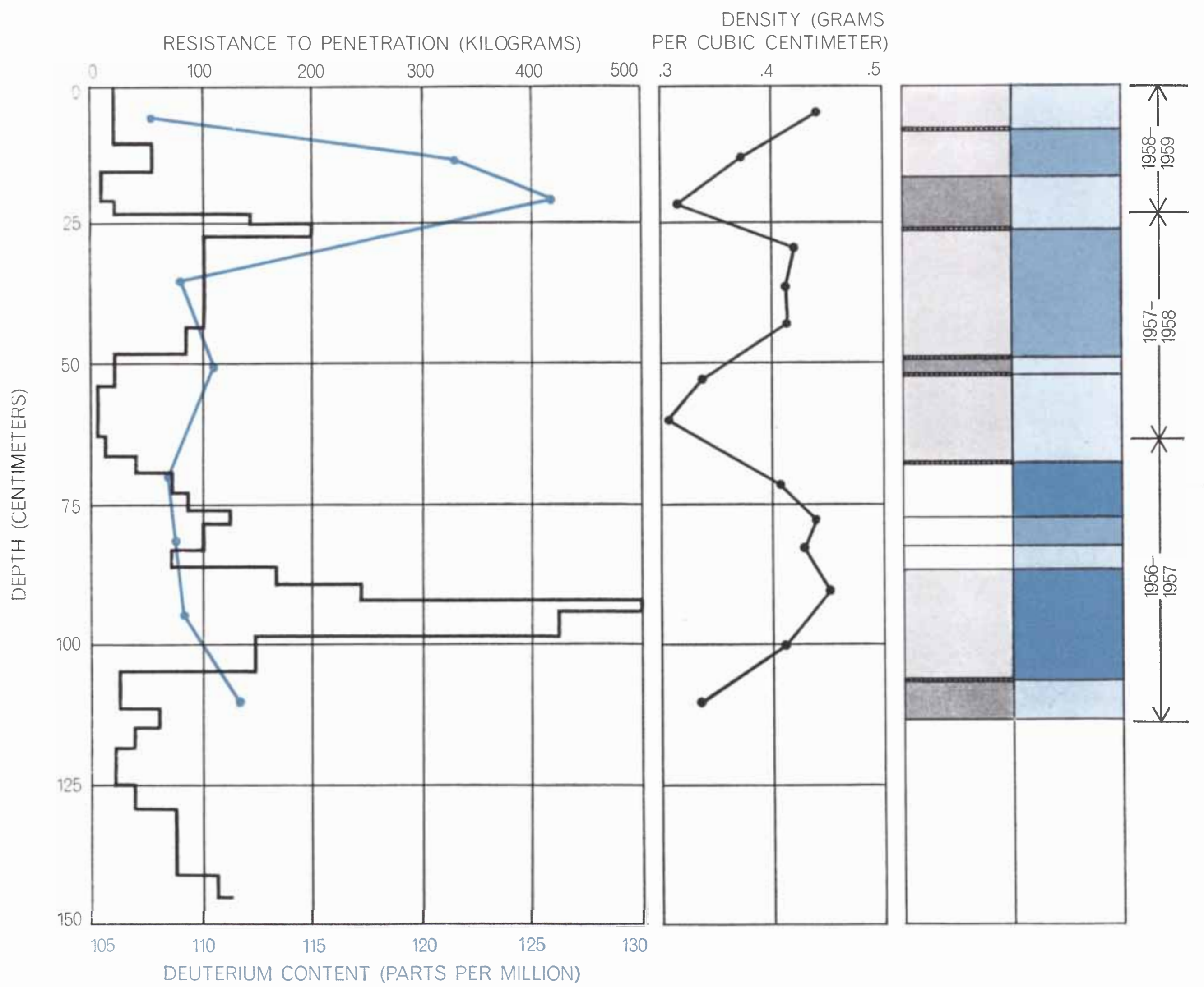


"WORK ROOM" of the snow mine also provides storage space for snow samples (*on shelf in background*). The steel tubes on the worktable are containers for melting ice cores. Oliver looks on as Ramseier tests the strength of a firn sample in a compression gauge.

waves traveling obliquely down through the firn are refracted continuously and increasingly upward. Some of them are bent enough to return to the surface without ever leaving the firn layer. Of these the waves arriving at more distant points from the explosion will have penetrated deeper [*see top illustration on page 138*]. Travel times are recorded at a number of stations ranging out to a few hundred meters from the source. From a plot of the times against distance the change in velocity with depth can be computed.

Once the seismic waves reach ice of maximum density they travel at practically constant speed until they come to the underlying rock. There the portion of the energy that is not reflected enters the rock, speeds up and is refracted in an upward direction. As explained in the following article ["The Land of the Antarctic," by George P. Woollard, page 151], a wave refracted along the rock surface and leaking back into the ice will overtake waves traveling entirely through the ice at some distance from the source. If the speed in the rock is known, the depth of the ice can be computed from the distance at which the refracted waves begin to arrive first. This offers an accurate check on depth measurements by echo sounding. Deep refraction shooting, however, requires a heavy explosive charge and a line of receiving stations perhaps 20 kilometers long. It is an expensive and difficult procedure in the Antarctic and has only been carried out in about a dozen places.

All seismic measurements in Antarctica are plagued by noise. The winds that continually buffet the snowy expanses set up vibrations in sensitive seismometers. Reverberations persist longer at low temperatures. Because of its refractive properties the firn layer acts as a wave guide, trapping a large part of the energy from shallow explosions and converting it to surface waves. When the firn temperatures are colder than 30 degrees below zero centigrade, which is the case on most of the Antarctic plateau above elevations of about 2,000 meters (6,600 feet), the large surface waves cause prolonged intermittent noise on the seismic records, possibly as a result of the collapse of weak layers in the firn. These disturbances make the



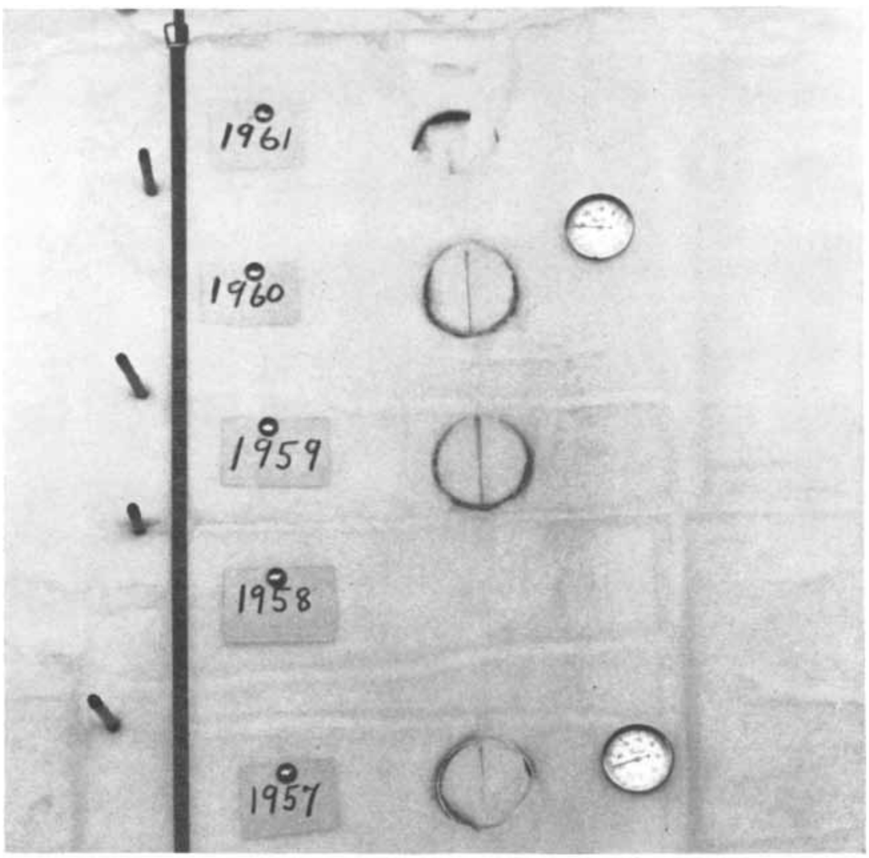
STRATIGRAPHIC DATA from a French station in Adélie Land reflect the seasonal variations in temperature and precipitation. The significance of the deuterium content is explained in the text. Years at right indicate when various layers were first laid down.

faint echoes almost impossible to detect. The only way to overcome the difficulty is to fire the explosion at such a depth that little energy is captured in the surface layers. Near the edge of the plateau shot depths of 12 meters (40 feet) sometimes give satisfactory results, but in general it is necessary to go down 30 to 60 meters.

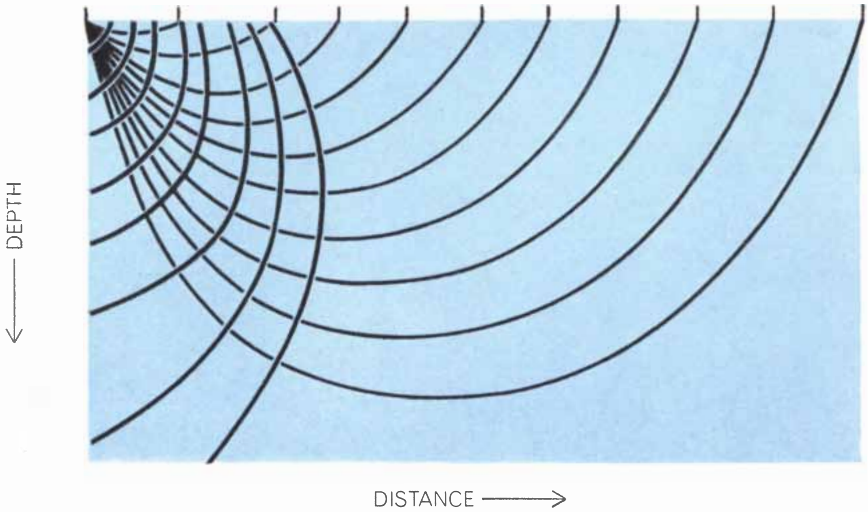
Every reading on the Antarctic plateau is more or less obscured by noise. One cannot easily assess the reliability of results without seeing the seismic records, and few have been published so far. At the South Pole in particular different workers have measured different depths. The author would assess the present situation as follows: Most results in areas with a surface elevation of less than 2,000 meters can be considered well proved. They cover the periphery of the continent to about 200 kilometers in from the coast, as well as most of West Antarctica. Farther inland there have been enough measurements using shot depths of 30 to 60 meters to show that the great ice thicknesses found near the coast continue and that the subglacial floor of East Antarctica lies near and even below sea level in several regions. Although it seems likely that some depths reported for the Antarctic plateau will need revision, any changes will probably be of regional rather than continental significance.

In addition to making echo soundings, most of the parties that have recently traversed Antarctica have measured the value of gravity at intervals as short as three to five kilometers. The force of gravity at any point depends on the mass of the material under that point, and so variations in thickness of the ice will cause small variations in gravity. With rock of normal density underneath, a change of ice thickness of about 14 meters (45 feet) will produce a change of one part per million in gravity. Modern gravimeters can easily measure such small differences, but difficulties arise in interpreting the readings, because a change in surface elevation of only three meters will also produce a gravity change of one part per million. Variations in elevation between successive observation points should therefore be measured to an accuracy of about one meter, and for similar reasons changes in latitude should be determined to about a tenth of a mile. This accuracy is now attainable, so that gravity measurements can furnish a useful indication of the variation in ice thickness. In some cases, however, local changes of rock density below the ice can be confused with changing ice thickness, and the

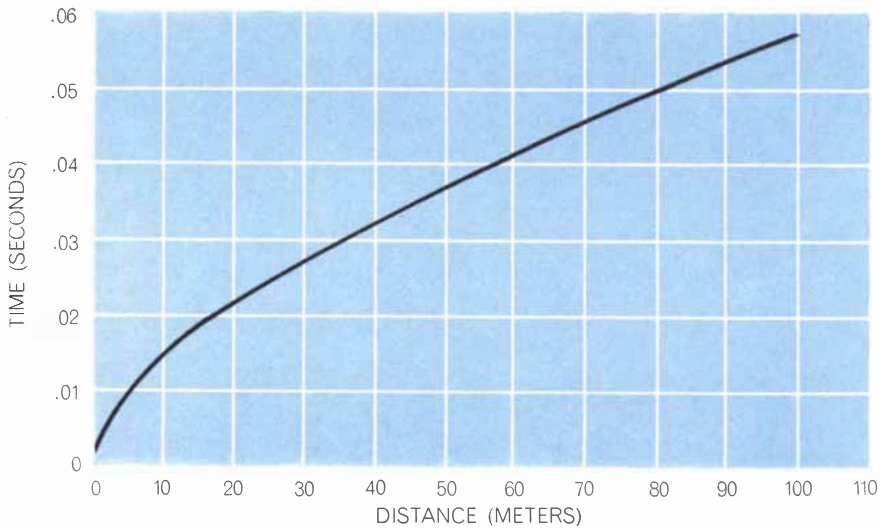
LAYERS OF SNOW are marked out with pencils by Gow at the beginning of a "pit study." The pit, which is about eight feet deep, is located near the snow mine at the South Pole.



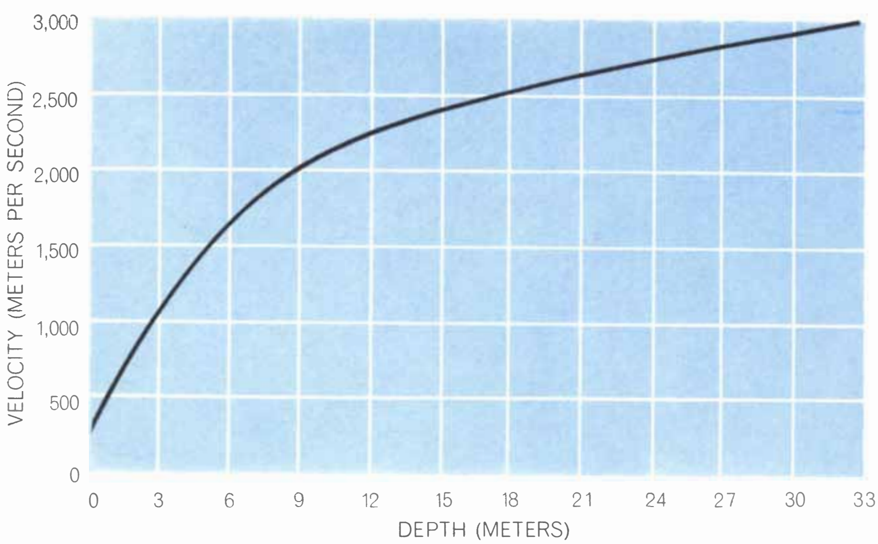
LAYERS ARE LABELED according to the year in which they were originally laid down. Separate layers can be distinguished easily even without the cards that date them. Three snow samples still to be extracted are at center. The gauges measure snow temperature.



SEISMIC-WAVE VELOCITY in firn increases continuously with depth, causing continuous wave-front deformation (*lines curving down to left*); the steeper the wave path (*lines curving up to right*), the farther it is from point of explosion when it reaches surface.



TRAVEL TIME of seismic-shot disturbances, when they are plotted as a function of distance, give a graph the slope of which at any point is the reciprocal of the velocity. The graph shown here is typical of shallow-refraction travel-time plots obtained in Antarctica.



CHANGE IN VELOCITY of seismic waves with increased depth is plotted. Such velocity-variation graphs are derived from travel-time plots like the one in the middle illustration.

changes of gravity anomalies from one region to another, discussed by Woollard in the following article, mean that gravity results must be adjusted by reference to seismic shooting measurements at intervals of about 80 kilometers (50 miles).

Putting together all the measurements made so far, it appears that the mean thickness of the 11.5 million square kilometers (4.4 million square miles) of the Antarctic ice sheet, excluding the floating ice shelves, must be more than 2,000 meters (6,600 feet) and possibly as much as 2,500 meters (8,200 feet). What if the ice were to melt? Since the area of the oceans is about 32 times the area of Antarctica, for each 34 meters (112 feet) of ice melted off the Antarctic ice sheet, sea level would rise one meter (3.3 feet). Total melting of the ice would raise the worldwide sea level by about 60 meters (200 feet) if the Antarctic continent did not rise up or the ocean floor sink when the ice load was transferred to the oceans. If the ocean floor were to sink, the estimate of the rise in sea level would have to be reduced to 40 meters (130 feet).

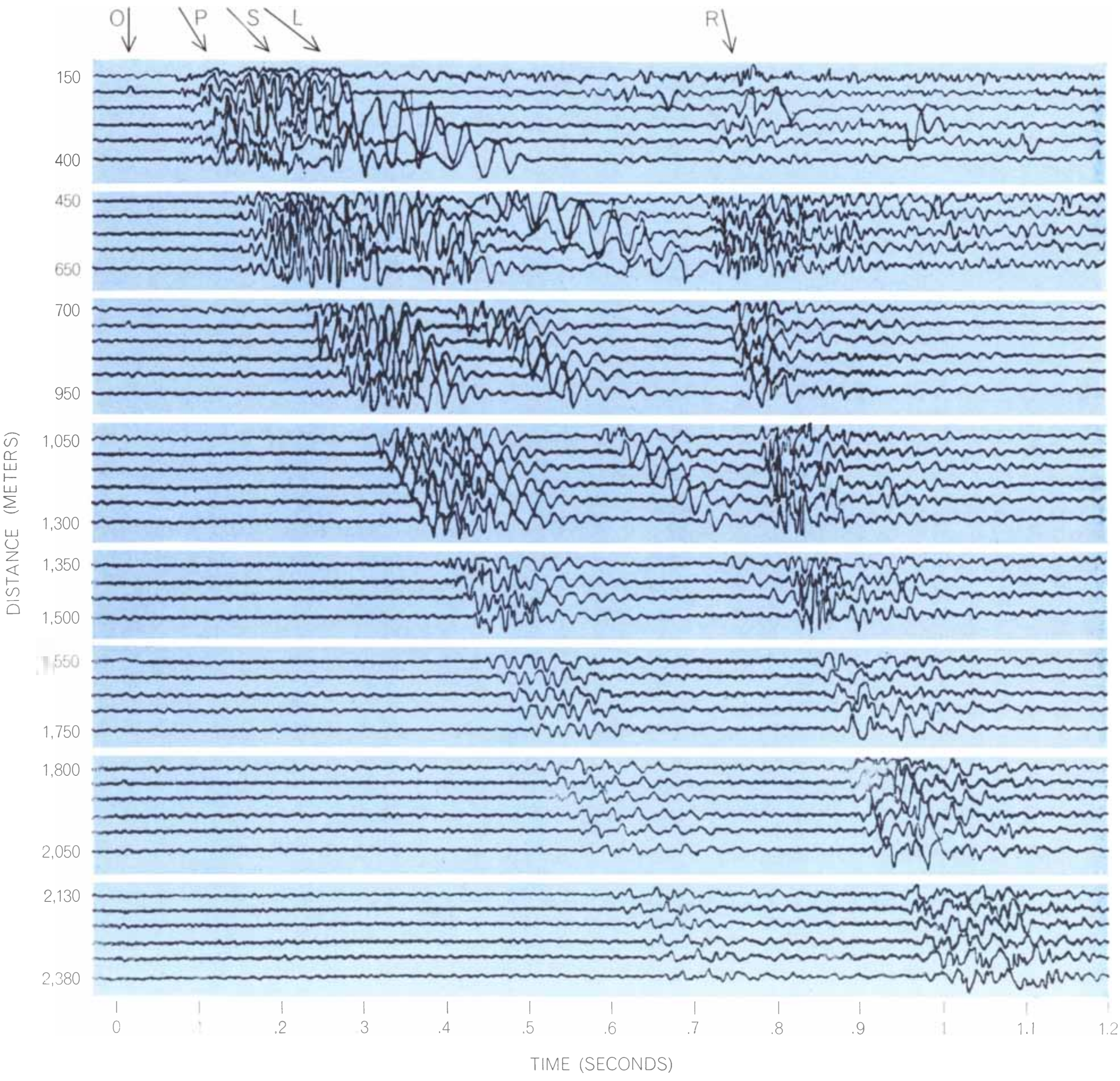
Now that the present quantity of ice has been established, the next question is whether it is now increasing or decreasing, and how fast. Every year an average of 30 to 60 centimeters (one to two feet) of snow falls on Antarctica. Some blows into the sea and a little evaporates, but most remains to be gradually compressed into a layer of ice with an average thickness of 10 to 20 centimeters, which weighs one to two million million tons.

Recent exploration has shown that the surface slopes down toward the coast all over the continent; therefore the ice flows everywhere toward the sea. The ice discharges into the ocean either directly from glaciers or by way of the large floating ice shelves surrounding much of the continent. The problem is to determine whether or not this outflow is in balance with the annual accumulation over the continent.

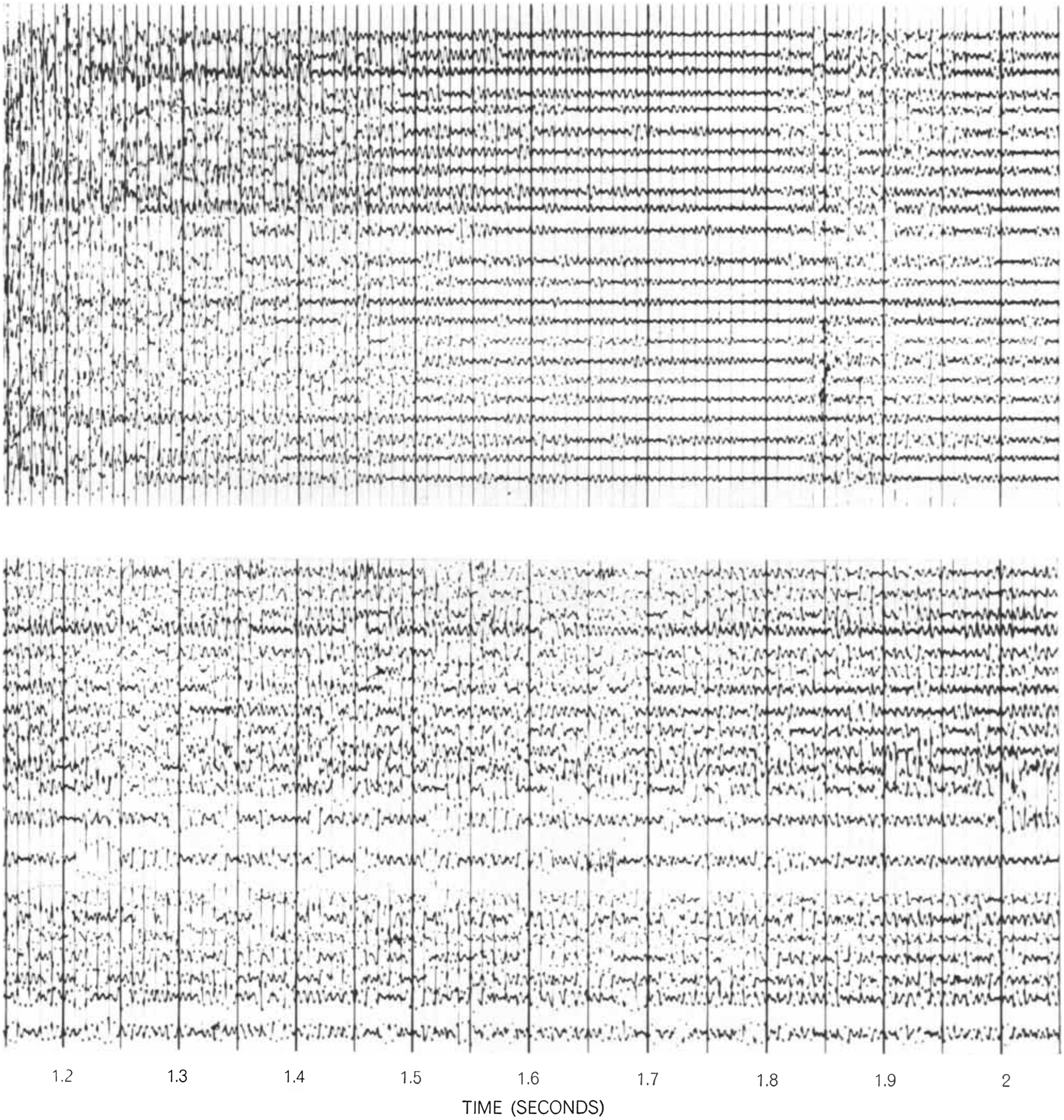
The loss of ice over the entire continent is extremely difficult to measure. Measurements have tended to be confined to the more accessible glaciers. There are satisfactory figures for the outward creep of smooth areas of ice near coastal mountains but very little data on the velocity and thickness of the wider and more rapidly flowing glaciers, which are often impassable to surface vehicles because of heavy crevassing. Ideally all discharges should be measured along the line at which the glaciers start to float, since beyond this line the effect of melting will not change the sea level. In practice it is easier to observe the movement of the seaward face of ice shelves, but in order to relate this movement to the discharge of inland ice one must allow for accumulation on top of the shelves and for possible melting on the bottom.

The most recent estimates of the annual ice budget range from a gain of 1.32 million million tons to a loss of .41 million million tons. These figures are equivalent respectively to the addition of 9.9 centimeters (3.9 inches) of water over the entire continent and to the subtraction of 3.1 centimeters (1.2 inches). The corresponding effect on sea level ranges from a drop of 3.6 millimeters (.14 inch) to a rise of 1.1 millimeters (.04 inch). Estimates of annual loss still vary more widely than do the figures for annual accumulation. It will probably be another decade or two before the budget method can provide a moderately accurate answer to the mass-balance problem.

The most direct indicator of changes in the ice mass is the level of the ice with respect to protruding mountains and nunataks. Unfortunately such features are confined to the borders of East and West Antarctica. Seismic and gravitational methods, with a potential accuracy of the order of five or 10 meters, are inadequate to detect the small changes in thickness that may be occurring. Even if their accuracy is improved, the difficulty will remain of repeating a measurement at precisely the same point, because positions on a moving ice sheet can be fixed only by relatively inaccurate astronomical methods. The surface of the high central dome of the ice sheet cannot be rising more than six to 10 centimeters (two to four inches) per year,



SEISMIC SHOOTING produces a variety of disturbances that can travel through ice: compression (*P*), transverse (*S*) and surface (*L*) waves; *R* is a compression wave reflected from the rock below the ice; *O* indicates the shot instant on all traces, which are the records obtained by the French Polar Expeditions in 1952 of eight shots on the Greenland ice sheet. Six seismometers, 50 meters apart, were used for each shot. Distance of closest and farthest seismometers for each shot appears at left. Some traces are omitted.



ECHO SOUNDING, or reflection shooting, is complicated by "noise" that often drowns out a reflected wave. In two seismic records obtained by A. P. Crary in the Antarctic, echo appears clearly after 1.8 seconds in one (*top*), but is lost in the other (*bottom*).

the rate of precipitation in this region. Therefore it may take as much as a century before present methods of direct observation can establish whether or not the level of the central part of the ice sheet is changing and, if so, how fast.

One experimental approach remains: to try to deduce the variation of the Antarctic ice mass indirectly from the observed changes in world-wide sea level. According to the most widely accepted figure, the sea level has been rising at about 1.2 millimeters per year during the first half of the 20th century. It is possible that variations in the mean temperature of the oceans together with changes in the mass of glaciers outside Antarctica can account for this rate of increase. About all one can say at present is that the observed rise in sea level casts doubt on the larger rates of fall predicted by some Antarctic ice budget figures.

Finally, the problem of variation in the mass of ice can be attacked theoretically, by applying what is known about the mechanical properties of ice. Over the past 12 years laboratory and field studies have provided a considerable amount of data on the flow of ice under stress. The rate of flow is small under small stresses, but it increases rapidly, approximately in proportion to the cube or fourth power of the applied stress. A thick ice sheet that discharges into deep ocean on all sides, and therefore has a constant base area, will flow faster or slower in such a way that changes in the rate of accumulation have little effect on the total mass. Computations show that halving or doubling the annual snowfall on the Antarctic continent is unlikely to change the equilibrium value of the ice thickness by more than 10 per cent, which would correspond to a change in sea level of four meters (13 feet). Moreover, it would take some thousands of years for the ice sheet to reach its new equilibrium.

How well does the theory fit the available evidence? One test is to compare different ice sheets. The illustration on this page shows profiles across four ice sheets that rest on bedrock lying within a few hundred meters of sea level. Although the underlying rock surface varies considerably, and the accumulation ranges from 50 centimeters per year in central Greenland to less than 10 centimeters per year on the high Antarctic dome, the ice profiles are much alike, as the theory predicts.

Although the Antarctic ice sheet is now probably quite stable, it has changed substantially over long periods of time. Some exposed mountains show evidence of erosion and deposition by ice that must have been at least 600 meters (2,000 feet) thicker than at present. The increase was most likely due to an enlargement of the base area. Lowering of sea level by the formation of ice sheets in the Northern Hemisphere would have caused the grounding of large areas of ice shelves around Antarctica. The shelves would then have thickened until they reached a value appropriate to inland ice. If this explanation is correct, evidence of the greatest former thickening should be found in today's coastal areas. This seems to be the case from the limited observations made so far.

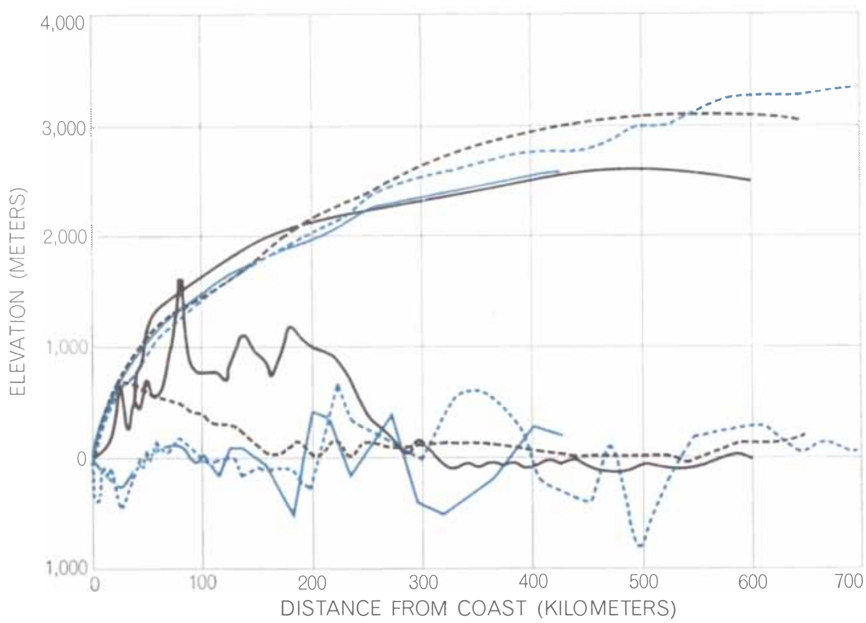
The parts of Antarctica most vulnerable to any general warming of climate appear to be the ice shelves, with an area of about two million square kilometers (800,000 square miles), and those sections of the inland ice resting on rock that is well below sea level. Melting of the ice shelves would not affect sea level. If all the vulnerable inland ice were to melt, the total ice mass of Antarctica would decrease by 10 to 20 per cent and sea level would rise by two to six meters (seven to 20 feet).

In the foregoing discussion of glacial flow and equilibrium it has been assumed that the ice spreads out uniformly under its own weight. Some glaciers, however, have a tendency to move in surges. It is therefore worth considering whether or not the Antarctic ice sheet is likely to undergo a catastrophic advance on a large scale. Some surges are thought to take place in glaciers with bottom temperatures slightly below the melting point. When the solid ice is subjected to a large enough force, it begins to flow. This releases frictional heat that melts the bottom surface of the ice, thereby allowing it to flow much faster and producing a surge. In the case of Antarctica, bottom temperatures have not been measured directly below thick inland ice. The theory of heat conduction, however, indicates that bottom temperatures are probably at the melting point under the central part of the ice sheet and under rapidly moving discharge glaciers. Colder bottom temperatures are more likely under the outer parts of the ice sheet. Since faster discharge glaciers cut through these outer areas, one would not expect the ice to surge over a large part of Antarctica at one time.

So much for large-scale studies of the Antarctic ice sheet. Another line of investigation is concerned with the details of its stratigraphy. Close to the surface the firn is divided into distinct layers differing from one another in density, hardness, crystal size and texture. The layering reflects seasonal variations in temperature and precipitation, and it affords a means of deducing the net annual accumulation in most areas [*see illustration on page 136*].

In recent years the development of isotope techniques has provided a further powerful tool for stratigraphic studies. Most of the molecules in atmospheric water vapor are composed chiefly of oxygen of atomic weight 16 and hydrogen of atomic weight one. There is also, however, a small percentage of oxygen 18 and hydrogen 2, or deuterium. When ice forms from water vapor in clouds, the heavier molecules tend to freeze first. Therefore as a cloud becomes progressively colder, for example when it moves up a mountain range, the concentration of deuterium and oxygen 18 tends to fall. Cloud temperatures also vary with season and location on earth, becoming colder as one moves toward the poles. Consequently the amount of the heavier isotopes in snow and ice varies with season and decreases at higher latitudes with lower mean annual temperatures [*see illustration on page 144*]. Striking seasonal variations in the ratio of oxygen 18 to oxygen 16 have been found in Greenland in 800-year-old ice at a depth of 300 meters. At this depth other types of stratification have practically disappeared. Isotope studies therefore provide a means of measuring the variation in precipitation in ice sheets over the past 1,000 years and more.

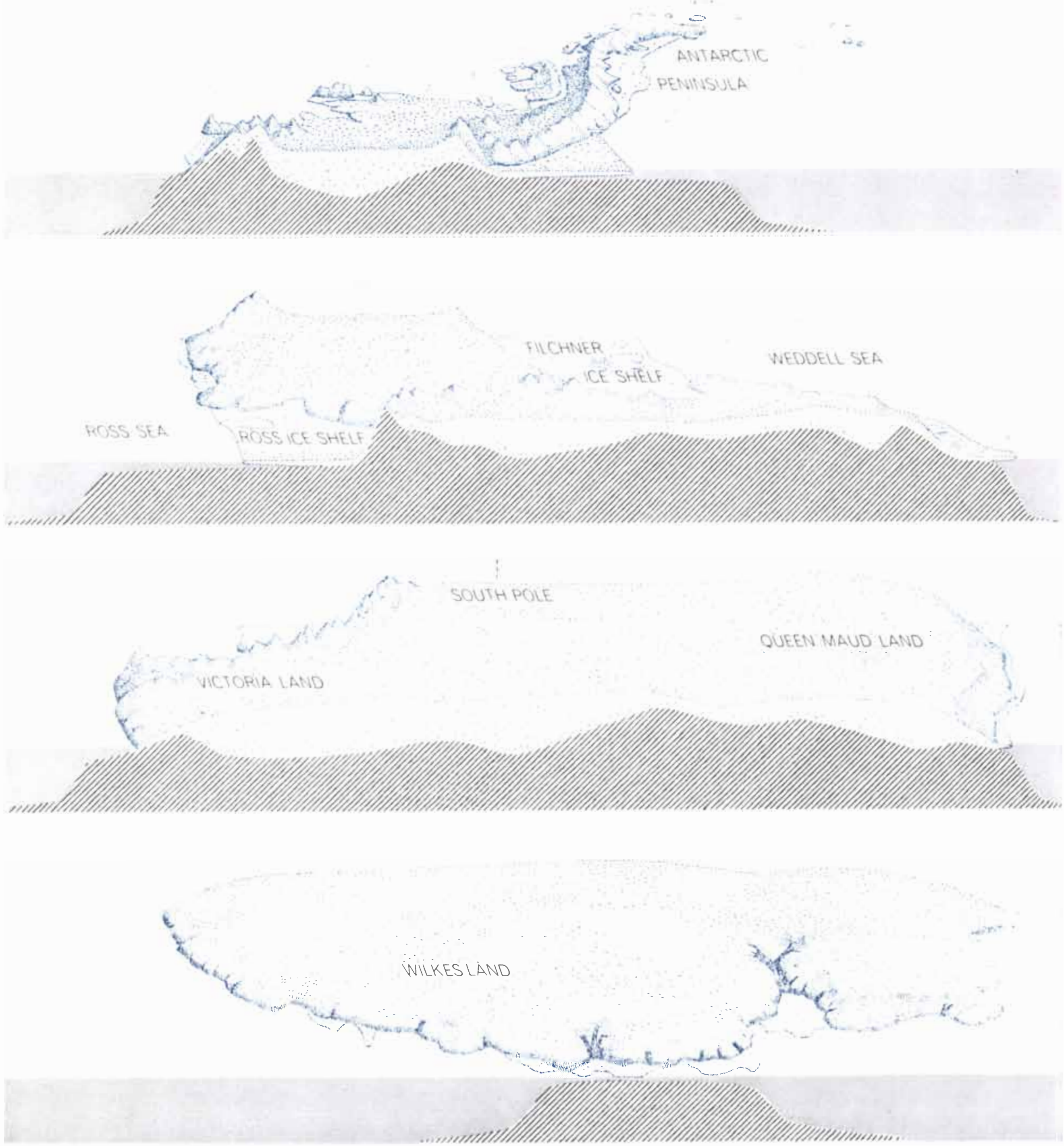
The possibility of using isotope ra-



SIMILARITY OF ICE-SHEET PROFILES, in spite of differences in the rock surfaces underlying them and in accumulation rates, confirms the theory of ice flow discussed in the text. Key to ice and rock profiles is at top right; vertical scale is greatly exaggerated.

tios as a type of "fossil" temperature indicator also appears promising. Here matters are complicated by the fact that ice formation represents only one side of the evaporation-precipitation cycle. If a world-wide climatic change were to lower the temperature of the whole cycle, the amount of different isotopes precipitating in any given region might not change with temperature as it now does. Hence it seems that the fossil temperature technique may be limited to detecting relative changes of temperature among different regions rather than global variations in climate.

Another isotope technique, which has been used only in Greenland so far, is carbon-14 dating of the carbon dioxide in air bubbles trapped in ice. Several tons of ice must be melted to provide enough carbon dioxide for each determination. P. F. Scholander of the Scripps Institution of Oceanography has carried out several measurements on ice discharged by glaciers into the fiords of western Greenland. The oldest sample obtained was 3,100 years old, plus or minus 150 years. Oxygen isotope ratios in the same material, determined by the Danish glaciologist W. Dansgaard, in-



FOUR SECTIONS through the Antarctic ice sheet (*color*) and the continent and continental shelf (*hatched areas*) are based on data obtained largely in the past decade. One section (*bottom*) passes only through the continental shelf. At the edge of the shelf the land mass begins to slope rapidly downward. On the greatly exaggerated vertical scale used here, one inch equals 9,800 meters.

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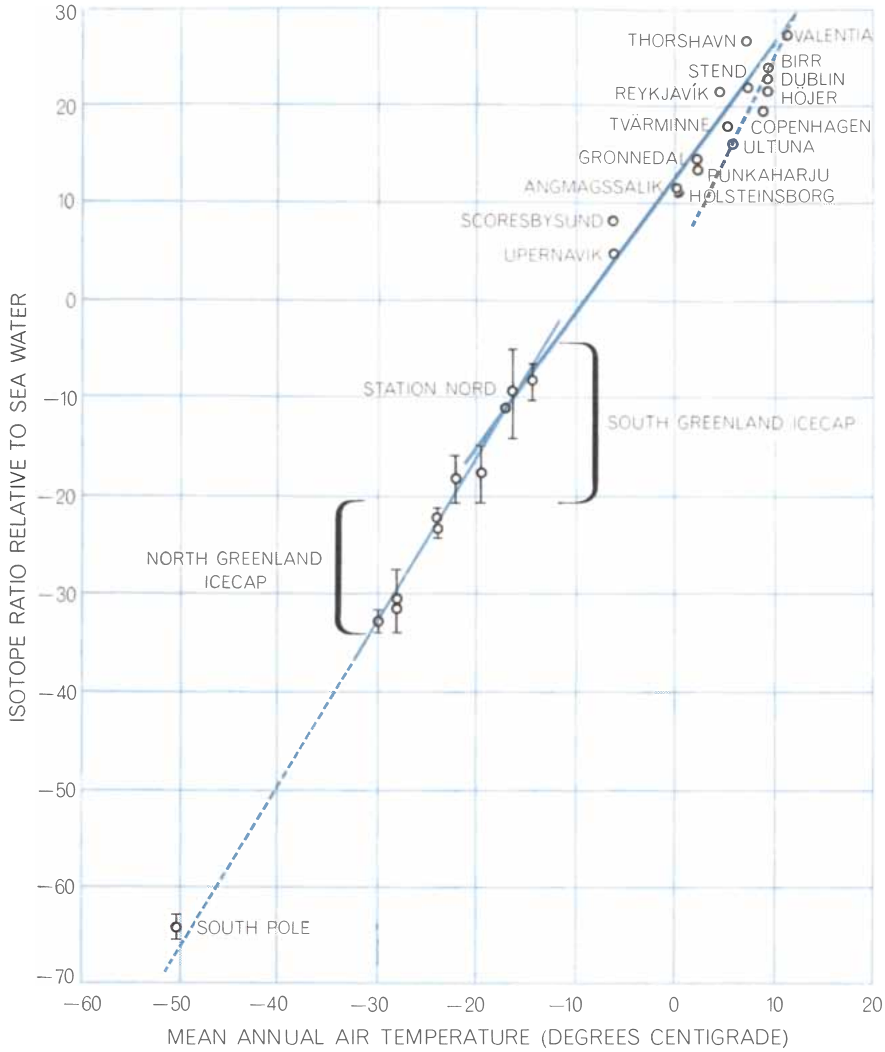


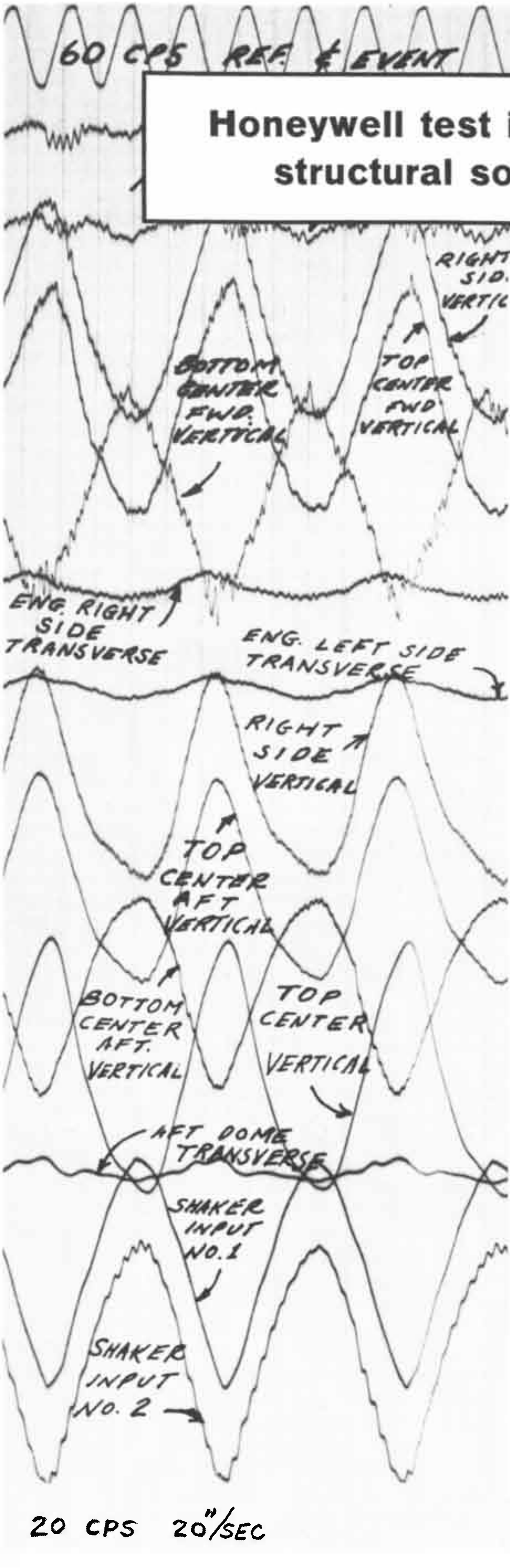
CLOSE CORRELATION between ratio of oxygen 18 to oxygen 16 in precipitation (compared with that in sea water) and temperature makes possible study of past precipitation at depths where other data are lacking. Illustration is based on study by W. Dansgaard.

dicated that the ice was deposited at a mean annual temperature of 30.6 degrees below zero C. At present such temperatures are found on the ice sheet some 460 kilometers in from the coast of Greenland. This distance, combined with the age of the sample, indicates that the ice has moved an average of 170 meters per year. Mean velocities of 110 to 270 meters per year were computed for seven younger samples, all in approximate agreement with the estimated velocities for a stable ice sheet.

Now that it is feasible to date stratigraphic layers in ice over periods of 1,000 years, glaciology can provide data of interest to other fields of study. The applications to climatology have already been mentioned. It is possible that changes in the composition of the atmosphere can be traced by analysis of trapped bubbles. Any substance deposited from the air—micrometeorite material from space, dust from volcanic explosions, microorganisms and so on—is preserved and can be dated in the polar ice sheets. A deep-drilling rig that has been tried out in Greenland will probably be moved to the Antarctic during the coming summer season. This equipment will produce cores of ice adding up to a depth of 2,500 meters, representing the accumulations of tens or hundreds of thousands of years.

Glaciology may also contain valuable lessons for geologists. Glaciers and ice shelves constitute a mass of material of reasonably well-known physical properties that is spreading out under its own weight and folding and shearing. The earth's crust and mantle appear to be subject to somewhat similar systems of stress and strain. Ice deforms on a scale of magnitude intermediate between those of the laboratory and those of the solid earth, and it deforms with sufficient rapidity so that its motions, unlike most

Honeywell test instrumentation records structural soundness of missiles



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The Honeywell LAR 7400 FM tape system stores 14 channels of data

A battery of multiplexed Model 1012 Visicorders directly records 112 parameters of information

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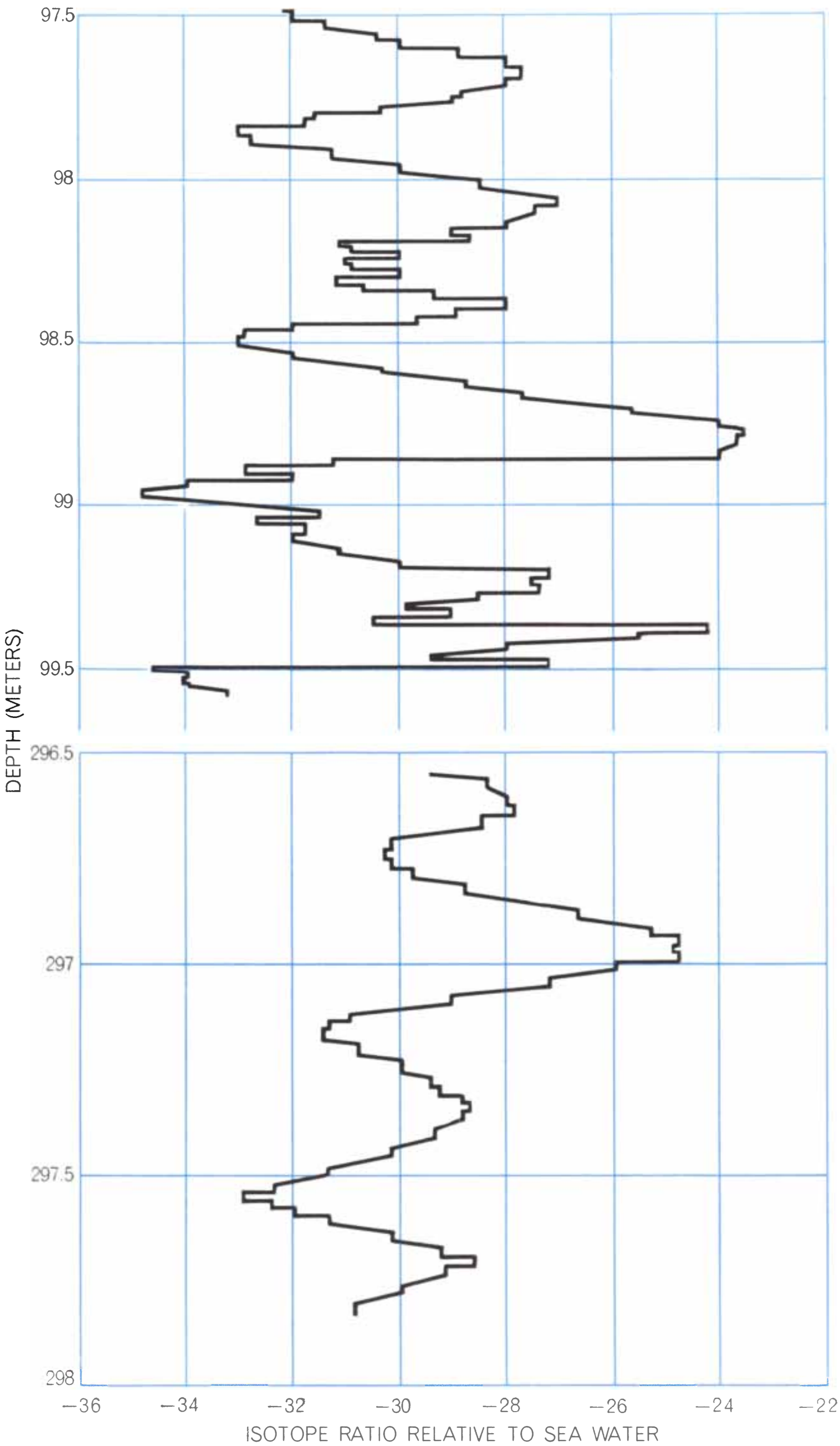
earth movements, can be measured in a short space of time. Glaciology may even be able to throw light on the mystery of continental drift. Johannes Weertman of Northwestern University has recently made a detailed study of the forces governing the thickness and spread of the Antarctic ice shelves. He has shown that, assuming a mean temperature difference of no more than 30 degrees in the earth's mantle under the different oceans, the same kind of force could make the continents wander over the face of the earth.



SEASONAL VARIATIONS in precipitation on the Greenland icecap are reflected in this graph, which shows variations in the ratio of oxygen 18 to oxygen 16 (compared with the same ratio in sea water) at different levels of a deep bore hole. The summer snows have the highest values; winter snows, the lowest. At 300 meters the ice is about 800 years old.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The Land of the Antarctic

Because most of it lies below the ice, which in some places pushes it below sea level, it is explored by such methods as setting off explosions and analyzing the reflected and refracted seismic waves

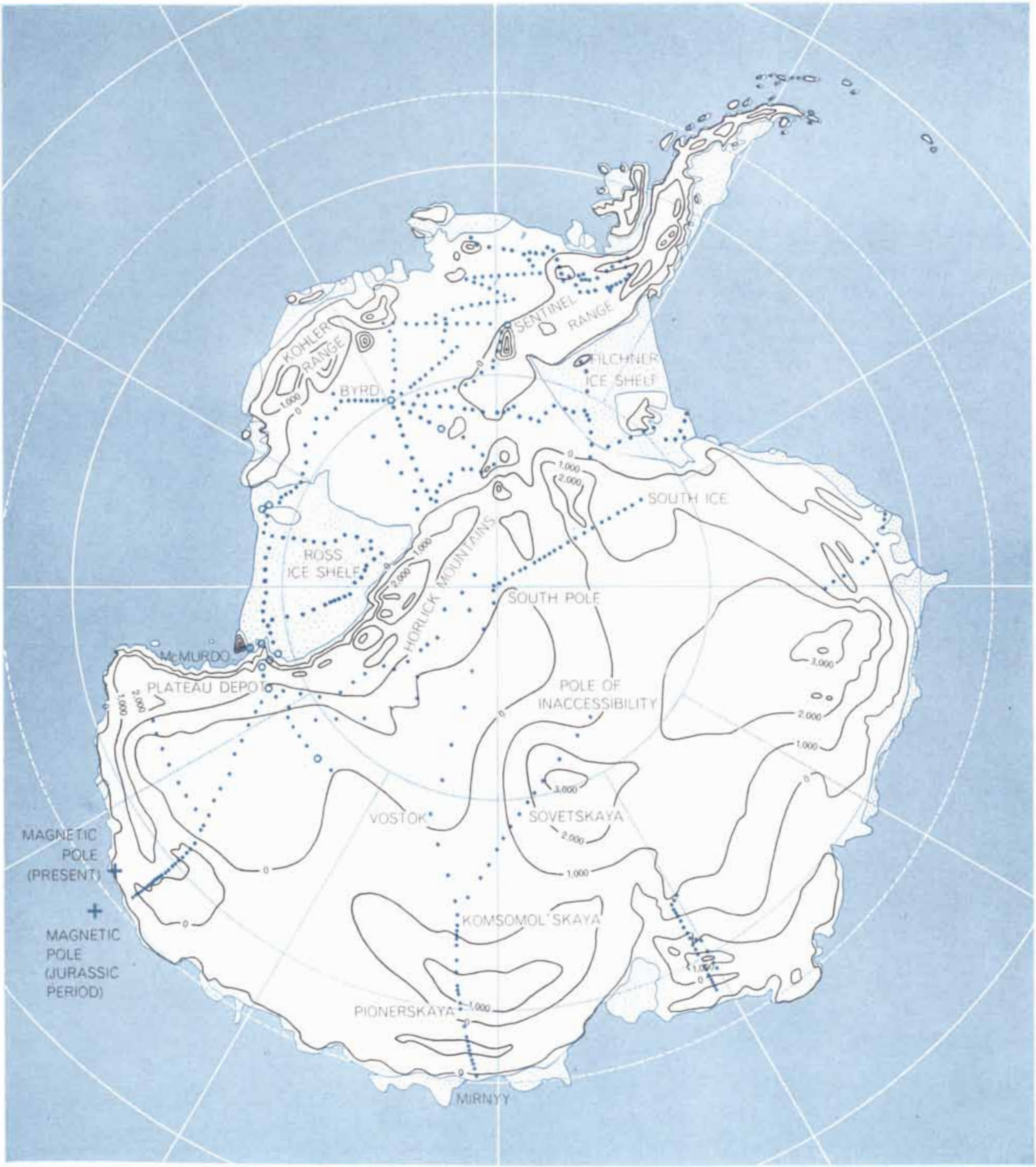
by G. P. Woollard

Before the International Geophysical Year very little was known about the continental land mass below the ice of Antarctica, and that little was derived almost entirely from observations around the continent's edges. Soundings in the surrounding ocean had shown that the Antarctic continental shelf lies at a depth of about 400 meters (1,300 feet), compared with a depth of 100 meters for the shelves of all the other continents. It could be seen that the enormous mass of overlying ice is pushing down the earth's crust. Ancient raised beaches along the coast, standing 100 meters above the present sea level, indicated that the crust had at one time been depressed even farther. On the floor of the surrounding ocean was found a roughly circular pattern of rises lying about 18 degrees from the

SEISMIC REFRACTION SHOT sends up a geyser of snow in Marie Byrd Land. This photograph was made in January, 1958, during the Sentinel Range traverse, by Ned A. Ostenso of the Geophysical and Polar Research Center of the University of Wisconsin.

coast line. This feature presumably represents a compensating bulge in the crust caused by displacement of plastic material from the mantle below the depressed continent. The rock surface itself emerges in only a few places in Antarctica: outcroppings in low coastal areas, the cliffs forming the inner boundary of the Ross Ice Shelf, and a few nunataks—mountain peaks—sticking up through the ice on the high plateau.

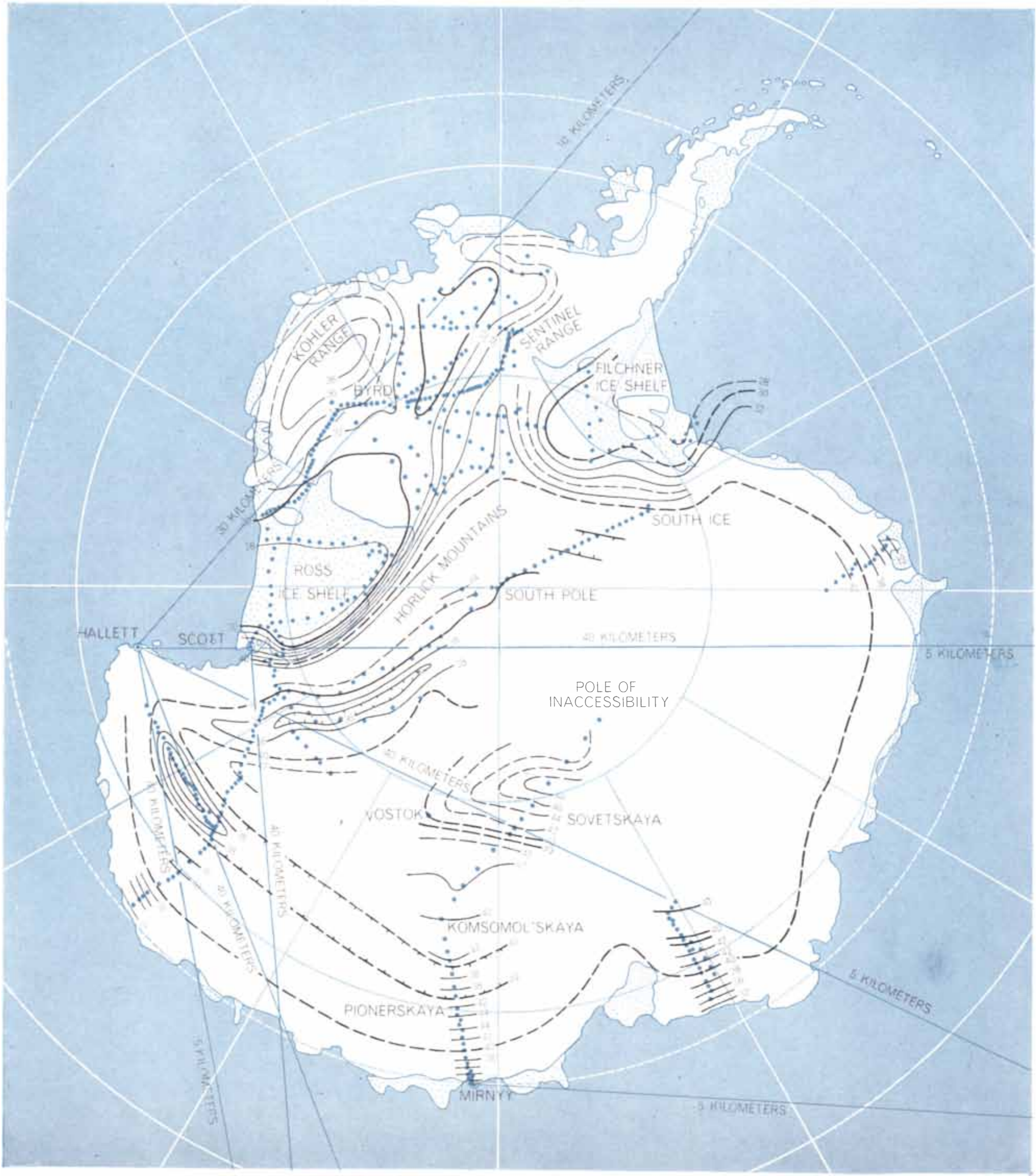
Two great embayments, marked by the flat, low-lying ice of the Ross and Filchner ice shelves, face each other across the continent; this suggested a connection through the intervening rock. The connection was envisioned as a huge trough that divided Antarctica into two parts. There was, however, no direct evidence for it. The surface of the continent below the ice had been measured only along a single path about 650 kilometers (400 miles) long, by a Norwegian-British-Swedish expedition from



ANTARCTIC LAND MASS, as the contour lines (*in meters*) show, does not for the most part exceed an elevation of 3,000 meters above sea level. Open dots mark the locations in the Antarctic at which seismic refraction measurements have been taken (*see upper illustration on page 154*). The much more numerous solid dots represent the points at which seismic reflection measurements were made.

1950 to 1952. This traverse delineated an extremely rough rock surface, lying well below sea level in many places.

One of the chief aims of the IGY program was to obtain more information about the land below the ice. Ground traverse parties, each made up of five or six men and equipped with two snow-going caterpillar tractors (Sno-Cats), covered a total of approximately 10,000 kilometers. In addition two- and three-man teams traveling by airlift made some 20 spot landings to fill out the picture in critical areas. Both the ground and the airlifted groups took readings of gravity and magnetism and probed the subsurface structures by setting off explosive charges and observing the transmission times for reflected or refracted seismic waves. Of course the seismic reflection observations described in the preceding article, by which the thickness of the Antarctic ice was determined, also served to trace out the

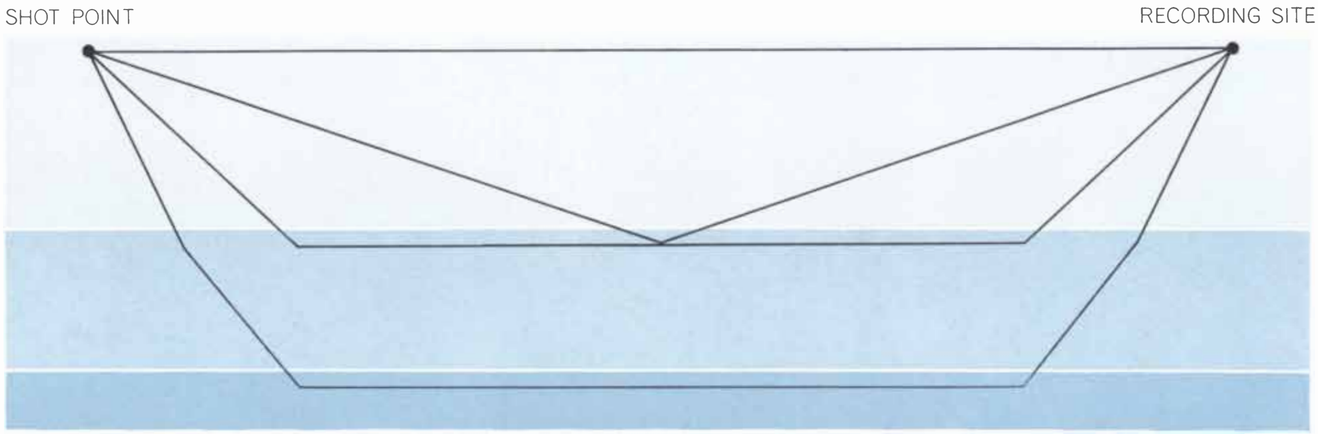


DEPTH OF BASE OF ANTARCTIC LAND MASS in kilometers below sea level is indicated by the contour lines and their associated numbers. The measurements on which the contours are based were made at the points represented by solid dots. Figures for crustal thicknesses along colored lines were deduced from dispersion of earthquake surface waves recorded at Hallett, Scott and Mirnyy.

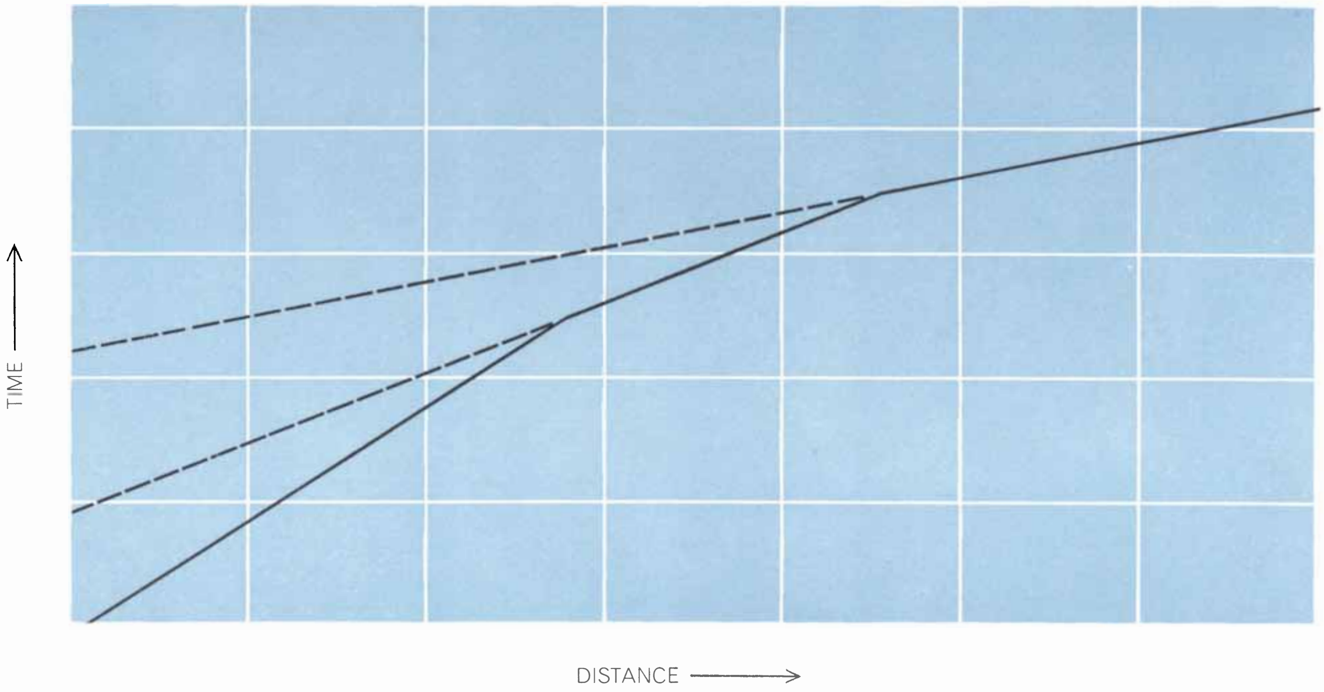
topography of the continent. But reflection measurements by themselves are often subject to considerable uncertainty, and most of those carried out in Antarctica give only the depth to the surface of the underlying rock. Much more informative depth figures are obtained from seismic refraction measurements [see "Seismic Shooting at Sea," by Maurice Ewing and Leonard Engel; SCIENTIFIC AMERICAN, May]. Moreover, seismic refraction observations can provide information about the physical nature and the thickness of the various layers that make up the earth's crust.

Like the shallow-refraction method for studying the upper layers of the ice, the deep seismic refraction technique can only be applied if the speed of seismic waves increases with depth. As Gordon de Q. Robin explains in the preceding article, the top 50 meters of the ice are characterized by a continuous increase in density and in the velocity with which seismic waves are propagated. Oblique rays are thus bent continuously upward. The earth's crust, on the other hand, is made up of more or less distinct layers, differing from one another in density, composition and in the speed at which they transmit seismic waves. Because the lower layers have been subject to greater pressures over longer geologic periods, they are generally characterized by higher densities and propagation velocities. When a ray passes downward obliquely through the crust, it is refracted upward at each interface between layers.

At every interface there is a critical angle of incidence for which the refracted ray travels along the surface of



REFRACTION SHOOTING provides information about the various layers of the earth's crust. Of the four shot waves represented here, the first travels directly along the surface of the top layer, the second is reflected and the bottom two are refracted (i.e., bent). As explained in the text, the first wave to arrive at the "recording site" comes from the deepest layer, the second from the next deepest layer, and so on. The increased speed of sound in the deeper layers overcomes the time necessarily lost in traveling a longer path.



PLOT OF FIRST ARRIVALS of shot waves recorded at various distances from a shot point (*see top illustration*) contains data about three layers. Each section of the plot (*black line*) represents a layer; its slope equals the reciprocal of the speed of sound in that layer. Extrapolation to zero distance (*broken lines*) is the basis for calculating the time required for sound to pass through the top (*bottom left section*) and middle layer (*middle section*). Layer thickness is determined from time interval and speed of sound.

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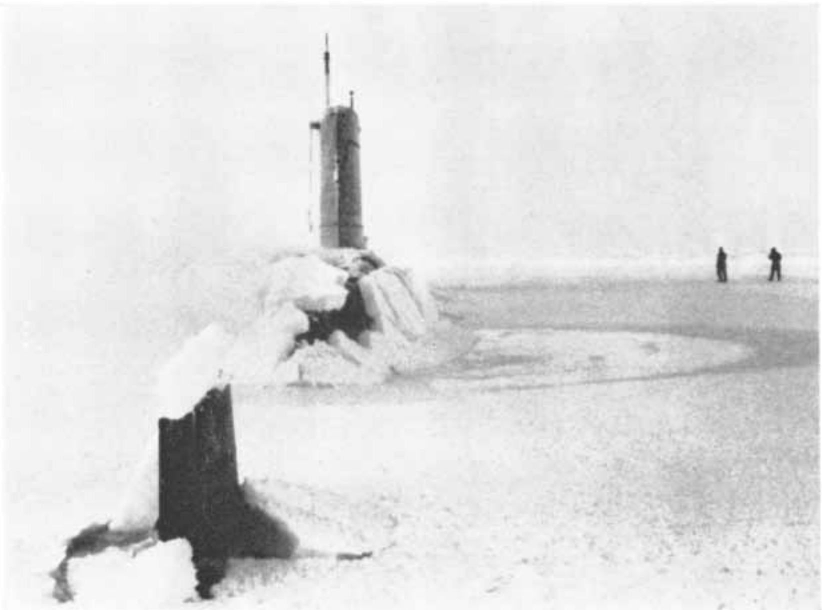

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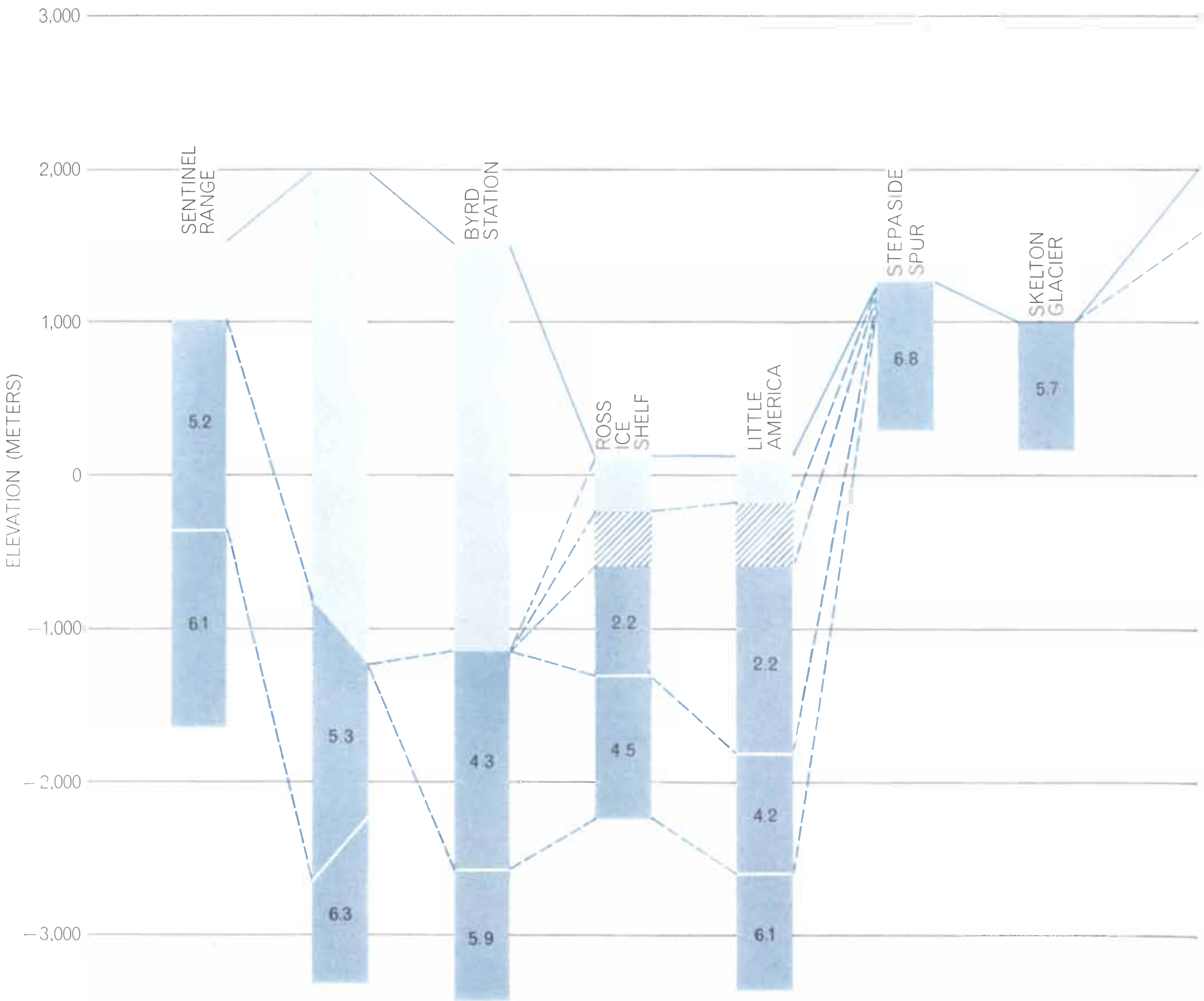
VITRO CORPORATION OF AMERICA • 261 MADISON AVENUE • NEW YORK 16, NEW YORK the lower layer. As the disturbance moves horizontally along the top of the lower layer part of its energy is communicated to the material lying directly below, and part is refracted back into the upper layer. This latter part returns to the surface, traveling upward at an angle that is the mirror image of the angle of incidence.

To carry out a refraction measurement, seismometers are located along a line at successively greater distances from the point of explosion. The first waves to arrive at the instruments nearest the source will have traveled straight through the ice. At a certain distance away these are overtaken by waves refracted through the first rock layer, the higher speed in rock more than compensating for the increase in the length of the path. At some still greater distance the once-refracted waves are in turn overtaken by those that have penetrated the next deeper layer, and so on. From a plot of the times of arrival at various distances, the velocity of seismic transmission in each layer can be deduced [*see lower illustration on page 154*]. With the velocities established, it is possible to calculate the depths of the successive boundaries and to make a good guess as to the physical constitution of the various layers of rock.

The depth to which refraction measurements extend depends on the amount of energy put into the ground by the explosive shot. Recognizable signals must also be recorded over a horizontal distance three or four times greater than the depth to be investigated. If the layers slope, a reading taken uphill from the source will give too high a velocity and one taken downhill too low a velocity. By reverse shooting, recording travel times in both directions over the same path, the true velocities and depths can be determined, as can the inclination of the layer.

Seismic refraction studies are by far the most accurate as well as the most informative of the available techniques for studying the Antarctic continent. To set out the necessary arrays of recording stations over the Antarctic snow, however, is a difficult and time-consuming job. It is also costly in terms of the



SCHEMATIC PROFILE from the Sentinel Range in West Antarctica to Victoria Land in East Antarctica is based on the 12 seismic refraction measurements made so far on the Antarctic continent. The numbers indicate the speed of sound in kilometers per second.

amount of explosive and the logistic support required.

Because of these difficulties only 12 deep seismic refraction measurements have been made so far on the entire continent, and only seven of these have extended to any great distance into the crust. The results summarized in the illustration on these two pages show that the constitution of the upper crust itself does not vary significantly from western to eastern Antarctica. The near-surface geology, on the other hand, exhibits marked differences both as to the elevation of the rock surface and the amount and kinds of sedimentary layers present.

Obviously a great deal remains to be done. Many more refraction measurements are needed on the continent, particularly measurements extending deep enough to plumb the entire thickness of the crust. The studies should also include the surrounding ocean, out to 2,400 kilometers (1,500 miles) from the coast of Antarctica, in order to determine the basins and rises in the sea floor around the continent. Only then will it be possible to draw a complete picture of the mechanical behavior of the crust under its load of ice and thereby arrive at a better understanding of its elastic properties.

It is much easier to record a seismic reflection than a seismic refraction, since only one array of seismometers is required. In Antarctica many more reflection measurements have been made than refraction measurements [*see illustration on page 152*]. Most of the traverse parties did only reflection shooting. Some of the observations are of doubtful accuracy because of high noise levels.

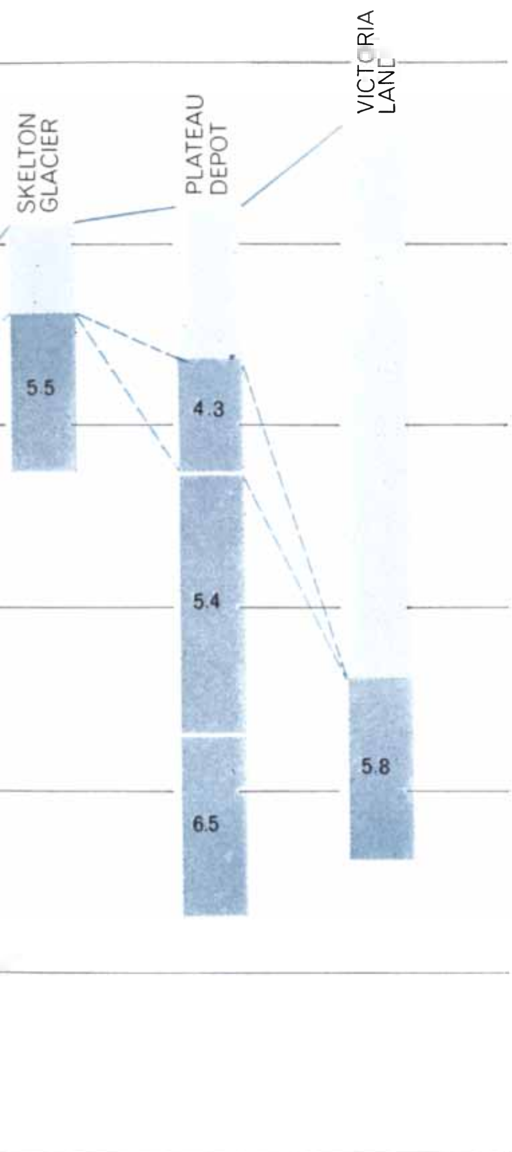
Simpler still than seismic observations are gravity measurements. They were carried out at every point where explosives were set off and, on the average, at six places in between. They serve to check the depth figures obtained from reflections and to trace the configuration of the rock surface from one seismic measurement point to the next.

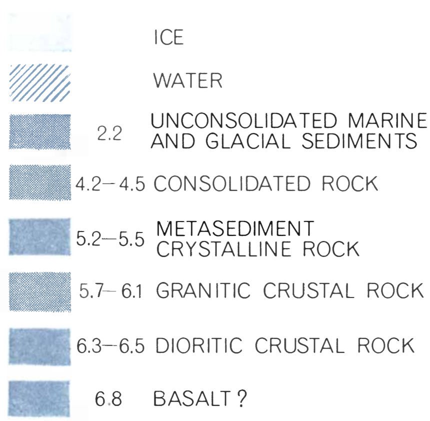
The most reliable gravity determinations are made with pendulums. The period of a given pendulum, or the time for one swing back and forth, varies directly with the force of gravity. By timing some hundreds of thousands of swings at two different places, the difference in period, and therefore the difference in gravitational force at the two sites, can be measured very precisely. The method is cumbersome: hours or days are required to make a single measurement, and the pendulum must be handled and transported with great care.

A much simpler instrument is the spring gravimeter. Basically nothing more than an extremely accurate spring scale, it consists essentially of a small weight hanging from a thin spring of wire or quartz. The amount of stretching of the spring at any given location can be related to the force of gravity there. The gravimeter weighs only a few pounds and can be carried anywhere. It gives a reading in three or four minutes. No two gravimeters are precisely the same, however, and the individual instruments tend to drift in the course of time. Therefore spring gravimeter measurements are always taken relative to the reading of a base station where the force of gravity has been established with pendulums.

By international agreement the Helmert Tower in Potsdam has been adopted as the world reference point for gravitational measurements. The value of gravity there is 981.274 gal. (This unit, named for Galileo, expresses the force of gravity in terms of the acceleration it will give to a falling body: at the Helmert Tower a body in free fall would speed up by 981.274 centimeters per second per second.) A number of primary gravity bases have been set up over the earth, in each case by comparing the period of a specific pendulum with the period of the same instrument at Potsdam (or at a base previously tied to Potsdam). As one of the first steps in the IGY program a primary base was established at McMurdo Sound, where the value of gravity was found to be 982.9928 gal. With McMurdo as reference point a network of secondary bases was established over Antarctica, using spring gravimeters transported by air. These bases provided the control for the over-snow traverse observations.

To extract useful information from gravity measurements the geophysicist focuses attention not on the total force recorded at any point but on the gravitational anomaly—the discrepancy between the actual reading and the theoretical value at that point. In arriving at the theoretical figure he applies Newton's law, which says that the gravitational pull exerted by the earth at any point varies inversely with the square of the distance to the center. First he allows for the elevation at Potsdam, computing the value of gravity at sea level there. Then he makes two adjustments that depend on the latitude of the point





The speed of sound in water is 1.5 kilometers per second. Probable material corresponding to figures is keyed at lower right. Composition of Stepaside Spur is not yet certain.

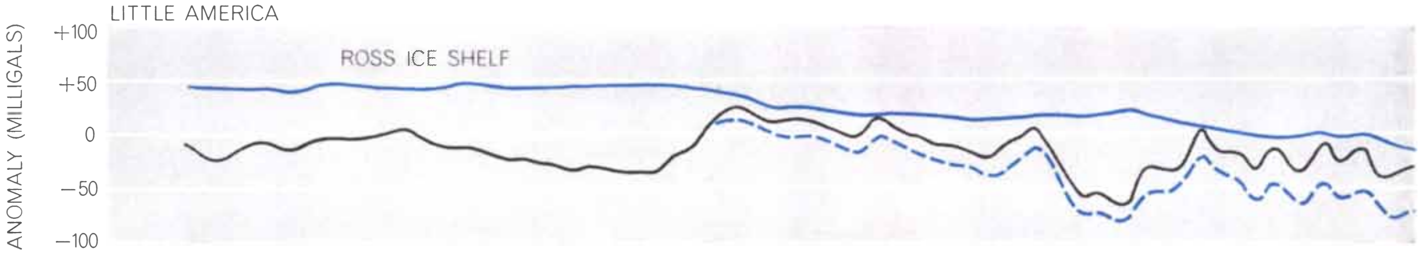
of observations. Because the earth is flattened, points nearer the poles than Potsdam is are also slightly nearer the center and therefore subject to a larger gravitational force; points nearer the Equator are farther from the center and the force is correspondingly weaker.

The second factor that varies with latitude is centrifugal force. As the earth spins on its axis it tends to whirl objects on its surface out into space. The force, which partially offsets gravity, is greatest at the Equator, decreasing to zero at the geographic poles.

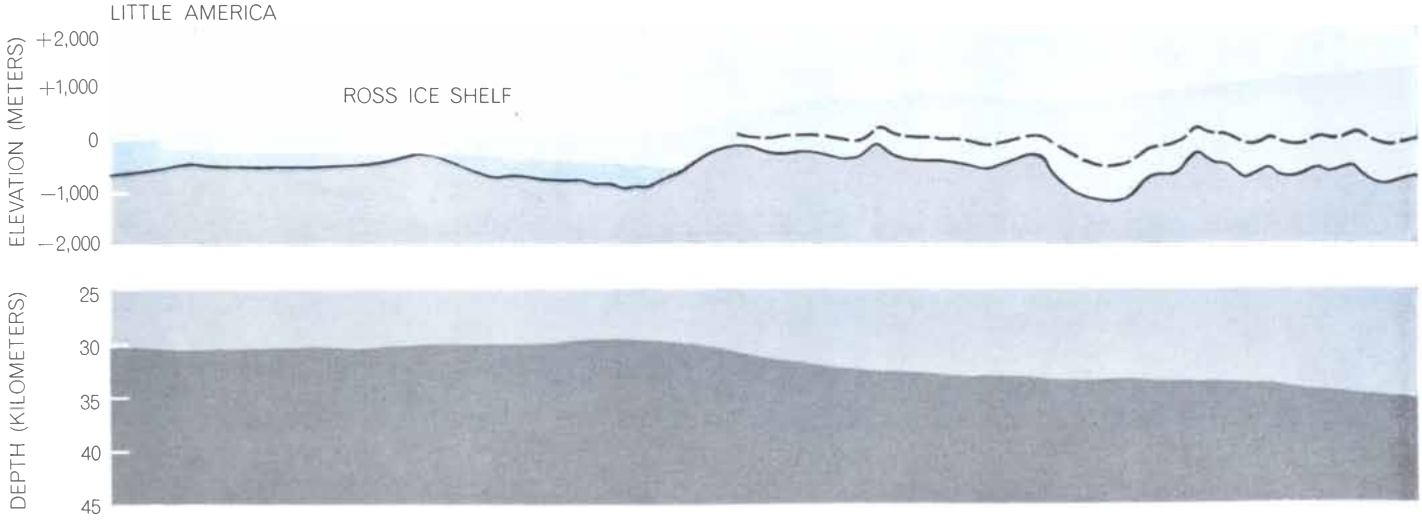
Correcting the Potsdam value to sea level and adjusting for latitude gives the theoretical value of gravity at sea level at any point. For measurements made above sea level, the theoretical value must be reduced to take into account the extra distance to the center of the earth. The difference between the resulting figure and the actual reading is called the free-air anomaly. As the name implies, it does not give effect to the additional mass of earth between the point of measurement and sea level. This mass increases the theoretical force of gravity, and therefore it partly offsets the adjustment for elevation alone. The difference remaining between the observed and the theoretical values after this final correction is known as the Bouguer anomaly.

Toward the end of the 19th century, as accurate gravity measurements began to accumulate, an unexpected relation emerged. Over any considerable area free-air anomalies averaged zero, regardless of changes in elevation from one point to another. Bouguer anomalies, on the other hand, became increasingly negative with elevation; that is, the actual force of gravity fell shorter of the theoretical value the higher the point of measurement. Evidently the effect of the extra mass from sea level up to the point of measurement is almost exactly canceled by a deficiency in mass below sea level. The explanation generally accepted today is that the earth's crust is floating on the denser plastic material of the mantle underneath. The higher the light crustal material projects above sea level at any point, the deeper it must extend into the mantle, just as high icebergs extend deeper into the water than low ones. If the total weight of the crust is supported by the underlying mantle, the pressure at some depth below the crust, just under the deepest crustal root, will be equal everywhere, since floating bodies displace their own weight. This situation is known as isostatic equilibrium.

If the crust actually floats, it must have no stiffness, and over long enough distances this appears to be the case. But over shorter distances the crust does exhibit some strength and is able to support localized changes in topography without local compensating changes in crustal thickness. Therefore in areas of marked surface relief the free-air anomalies vary with the topography: they are positive on mountain peaks and negative in deep valleys because there are no complementary variations in mass at the bottom of the crust. Between the extremes of no isostatic compensation, where the free-air anomalies completely reflect changes in surface elevation, and full compensation, where the free-air



GRAVITY ANOMALIES were measured on the traverse from Little America to Byrd Station. The free-air anomaly (*black line*) closely approximates the corresponding rock surface (*see illustration below*); the Bouguer anomaly (*broken colored line*) is also shown corrected to the rock surface (*colored line*). Both anomalies and the correction to the rock surface are explained in the text. One



ROCK AND MANTLE PROFILES from Little America, at the edge of the Ross Ice Shelf, to Byrd Station represent the results of both seismic measurements and the measurement of gravity anomalies. The broken line represents the position that the present rock anomalies average zero, there are all degrees of partial compensation through flexure of the crust. The degree of flexing depends on the load, the base area, the thickness of the crust and its elasticity. The crust can be compared to an ice sheet on a lake. The ice might sustain the weight of a man without bending at all (no compensation); it might support a small car with some visible bending (partial compensation); and it might give way completely under the weight of a three-ton oil truck, which would float independently (complete compensation). It is estimated that the earth's crust is completely compensated for surface mass distributions more than 250 kilometers in width.

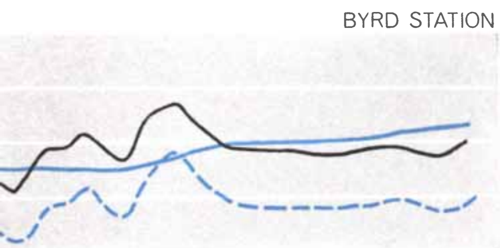
The relation of free-air anomalies to local, uncompensated mass distributions provides a means for studying the topography of the rock surface beneath the ice of Antarctica. Consider the traverse from the Ross Ice Shelf to Byrd Station [*see upper illustration below*]. The free-air anomaly values are markedly irregular, whereas the elevation profile of the ice surface describes a smooth transition from sea level to an elevation of 1,513 meters (4,970 feet) at Byrd Station. Clearly the anomaly variations are related not to the relief of the ice surface but to the sub-ice mass distribution. The difference in density between ice and average rock material (.9 gram per cubic centimeter for ice compared with 2.67 grams per cubic centimeter for rock) is considerably greater than the difference between different kinds of rock, which seldom exceeds .7 gram per cubic centimeter. Consequently the largest part of the local variations in the free-air anomalies must be caused by variations in the elevation of the underlying rock surface rather than changes in the constitution of the rock. From the anomalies alone, however, it is impossible to tell whether the local variations are superimposed on a plane surface, a broadly undulating surface or even a buried mountain range of such size that its gross mass is compensated. All one can say is that there are peaks and valleys. Assuming a differential of 1.77 grams per cubic centimeter between the densities of ice and rock, it can be calculated that a change of one milligal (thousandth of a gal) in the measured free-air anomalies corresponds to a change in elevation of about 13.5 meters in the rock surface.

To establish the surface on which the relief is superimposed requires a number of seismic depth measurements. Taking one of the seismic depth sites as a starting point, one can use the change in free-air anomaly values to construct, in fair detail, the configuration of the underlying rock surface to the next seismic site. Since gravity readings can be completed in a few minutes, they provide a most valuable adjunct to seismic reflection measurements, each of which takes two to three hours.

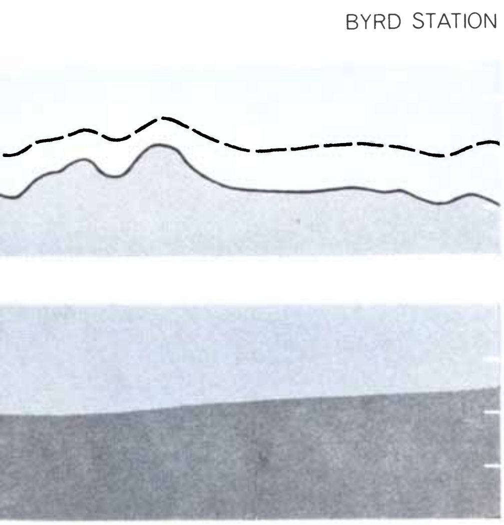
The illustrations on the next page compare the seismic and gravity depth measurements for several Antarctic traverses. Examination of the two profiles shows that the gravity results can be made to fit the seismic data by tilting the curve in fairly large sections. This indicates that partial isostatic compensation, and not local variations in the density of the rock, accounts for most of the differences. In some cases gravity-derived profiles may be more accurate than the seismic measurements made so far. Two such cases are the results obtained by the British Trans-Antarctic Expedition of 1956–1957 and the Soviet expedition to the Pole of Inaccessibility in 1958–1959 [*see middle and bottom illustrations on next page*]. Seismic measurements repeated at three points along the route of the British expedition have shown that the gravity-derived section is more reliable than the original seismic one. As yet it is not known which of the two sets of data from the traverse to the Pole of Inaccessibility is the more reliable.

In gravity studies on other continents Bouguer anomalies can be reduced to sea level by using a standard value for the average density of rock, and the resulting figures provide an indirect method for studying variations in crustal thickness. When the standard density value is applied to the Antarctic data, the Bouguer anomalies exhibit the same local mass irregularities as do the free-air anomalies. In order to deduce the crustal mass distribution it is necessary to make a realistic correction to the theoretical value of gravity for the mass of the actual column of material between the point of measurement and sea level. Above sea level the Bouguer correction may therefore consist of two parts, representing ice and rock. Where the rock surface lies below sea level one must subtract the gravitational effect of the total ice column and then add back a correction for the portion of ice below sea level, based on the density difference between ice and rock. A proper correction to bedrock level smooths out the Bouguer anomaly profile. Along the traverse from the Ross Ice Shelf to Byrd Station the change in the corrected values suggests a gradual downwarping of the crust beneath the icecap. That this is in response to the increasing load of ice is evident from the fact the bedrock surface remains essentially at the same level. Since the free-air anomalies average close to zero over the entire profile, the ice load is isostatically compensated. Assuming the original rock surface was also in isostatic equilibrium before glaciation, the elevation of a superimposed layer of rock having a mass equal to that of the ice will mark the mean position of the original surface. The thickness of an equivalent rock layer therefore indicates the amount of crustal warping that has taken place. On this basis it is calculated that the crust in the Byrd Station area has been warped down about 900 meters. Presumably the crust would also rebound by the same amount if the ice were to melt. The equivalent rock profile along the traverse from the Ross Ice Shelf shows that this portion of western Antarctica must originally have been an island archipelago with much of the surface below sea level.

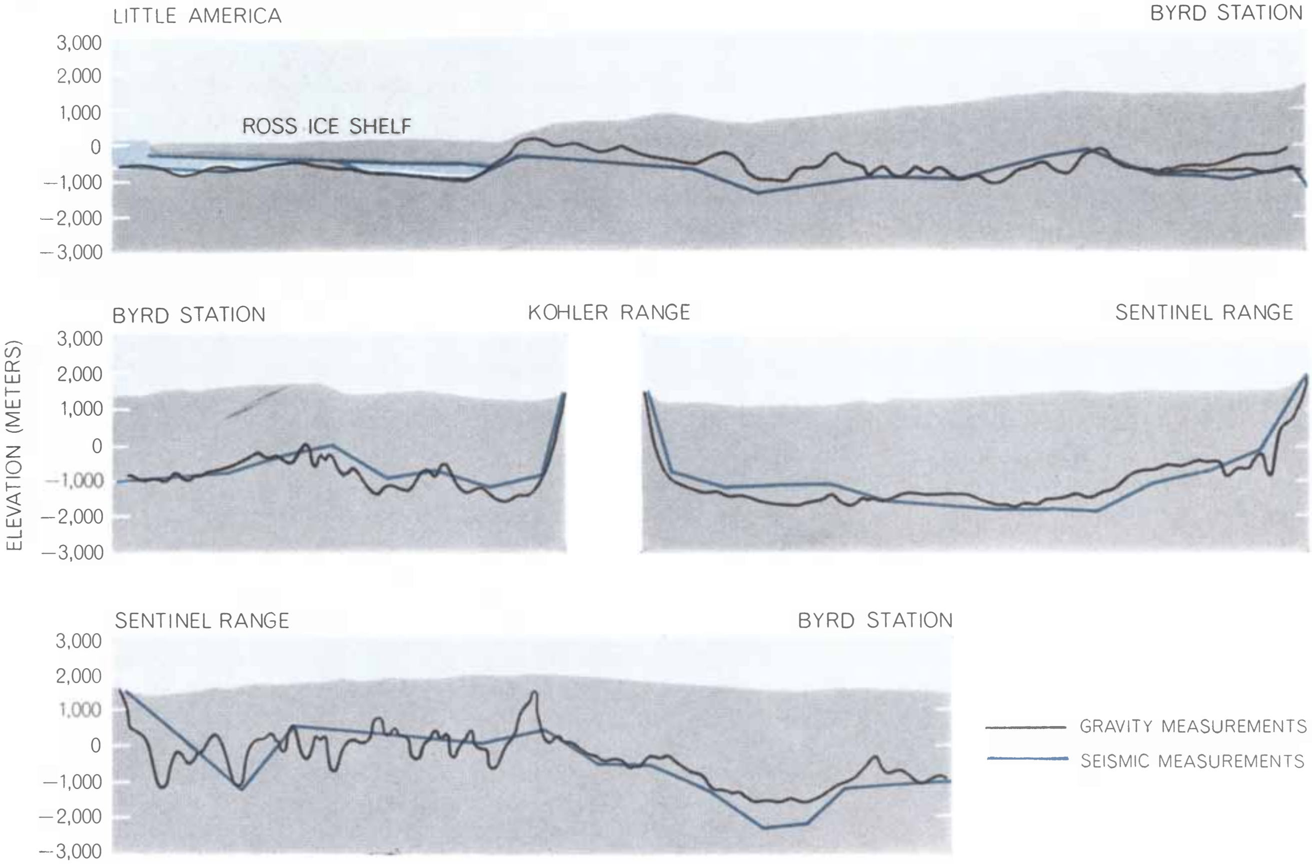
Once the outline of the top of the



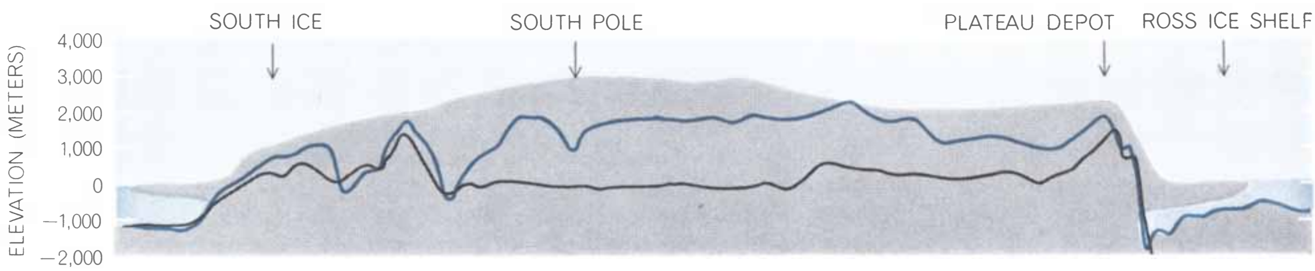
milligal is the gravitational force that will cause a falling body to accelerate at a rate of .001 centimeter per second per second.



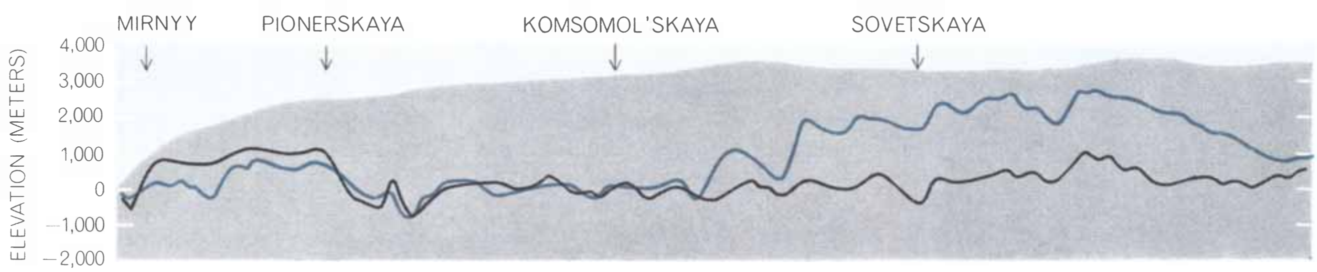
surface would assume if it were not pushed down by mass of the continental ice sheet.



SEISMIC AND GRAVIMETRIC DATA obtained on traverses by U.S. investigators are the basis for profiles depicted here. With some exceptions the two profiles agree fairly well. Key at lower right also applies to the other two illustrations on this page.



BRITISH PROFILES of Antarctic bedrock depicted here represent the seismic and gravimetric data obtained by the British Trans-Antarctic Expedition of 1956–1957. As explained in the text, gravitational profile is apparently more reliable than seismic one.

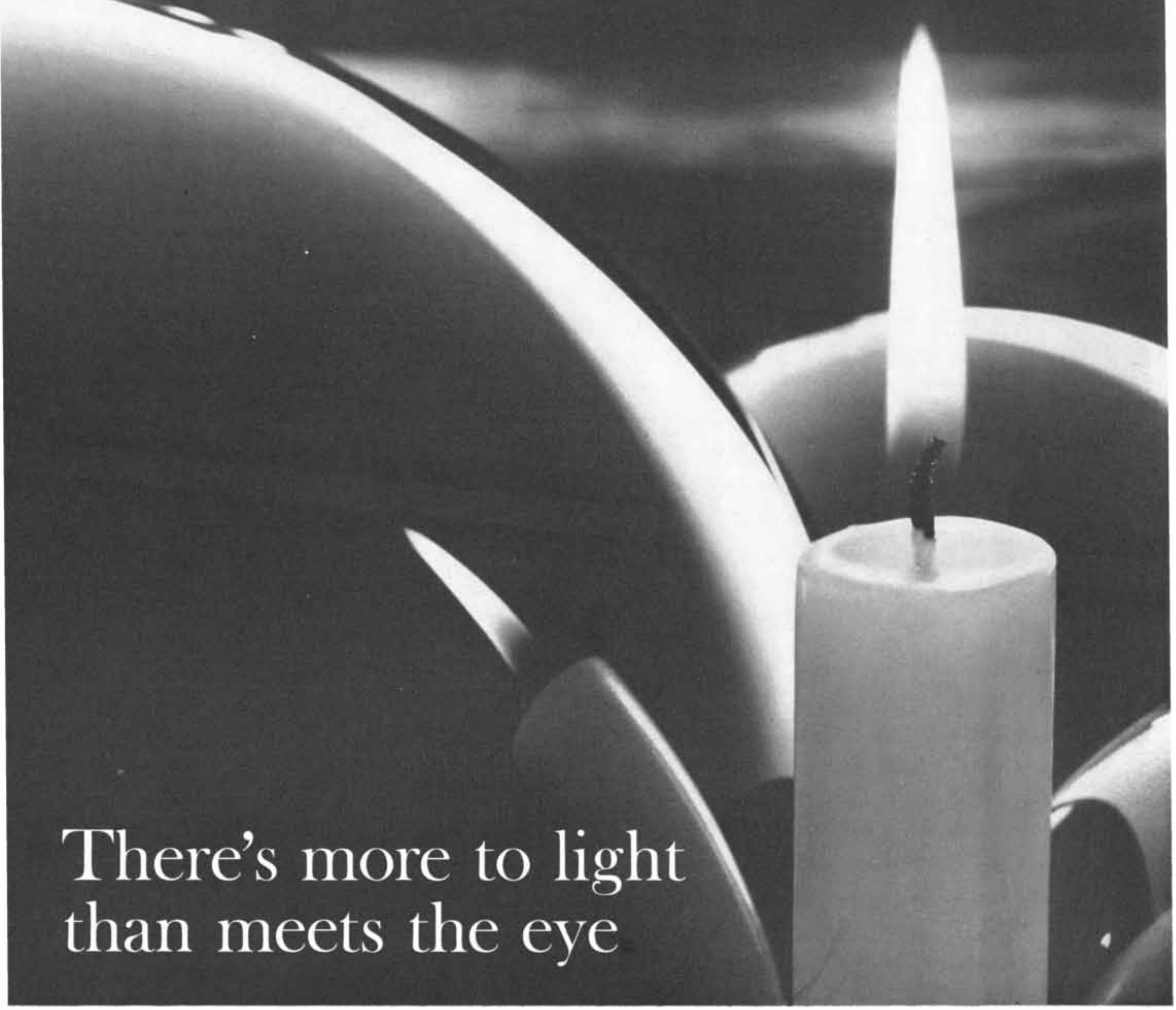


SOVIET PROFILES are based on data obtained on the traverse to the Pole of Inaccessibility in 1958 and 1959. Although there are considerable differences between the profiles obtained by the two methods, it is not yet known which profile is the more reliable.

crust has been determined, the next step is to estimate the crustal thickness. In the absence of seismic refraction measurements one can make an approximation by reference to refraction data from other parts of the earth. In general the crust at sea level is found to be some 33 kilometers thick. Judging by observed velocities of deep seismic waves, the crust is on the average .43 gram per cubic centimeter lighter than the mantle material underneath. Equilibrium conditions for a floating crust then require that an increase of one kilometer in surface elevation be compensated by an increase of 6.8 kilometers in the depth of the compensating crustal root projecting down into the mantle. At Byrd Station, where the equivalent rock column for the 2,645 meters of ice sheet is about 900 meters thick, the synthetic rock surface elevation is 215 meters below sea level. This means a negative compensating root of 215 × 6.8, or about 1,500 meters. Subtracting both this and the 215-meter surface deficit from 33 kilometers gives a crustal thickness of 31.3 kilometers.

Another way to arrive at the thickness is to start with the Bouguer anomaly corrected to the actual rock surface. At Byrd Station this anomaly is + 20 milligals (that is, the measured value exceeds the theoretical value by 20 milligals). Assuming that the density difference is .43 gram per cubic centimeter between crust and mantle, it can be computed that 20 milligals of Bouguer anomaly corresponds to 1.1 kilometers of compensating crustal root. The positive value of the anomaly indicated that the point of measurement is closer than normal to the heavier mantle material; in other words, the crust is thinner. If a thickness of 33 kilometers corresponds to zero Bouguer anomaly, the thickness at Byrd Station is 33 minus 1.1 minus .2 (the depression below sea level), or 31.7 kilometers. The two computations agree quite well.

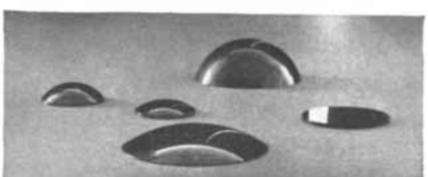
Turning now to the observations in eastern Antarctica, where the polar icecap reaches its maximum elevation, it is apparent that the crustal profile differs markedly from that of western Antarctica, although the load of ice is about the same. For example, Soviet measurements conducted at the Pole of Inaccessibility indicate a surface elevation of 3,820 meters, with nearly 3,000 meters of ice overlying the bedrock, which is 850 meters above sea level. The synthetic equivalent rock elevation of 1,850 meters indicates a crustal warping of 1,000 meters. This is not far from the



This candle is producing two kinds of light. One is the visible light you see. The other is "invisible" light—or infrared energy. This energy is produced not only by the flame, but by the candle itself. Because in the strange world of infrared, *all* objects which are "warm"—above absolute zero—radiate. In fact, Hughes infrared detection equipment could measure the infrared energy produced by an ice cube 5 miles away! Hughes scientists and engineers have been applying the science of "invisible light" to problems of national defense for well over a decade. Their work has produced striking results—such as the capability to sense distant temperature variations as small as 1000th of a degree.

Hughes infrared search, detection and track systems, being manufactured for our front line interceptor aircraft, can locate potential attackers by the infrared they generate. This allows the interceptor to attack its quarry without revealing its own presence. The Falcon infrared air-to-air missiles (a backbone of our air defense program with over 10,000 having been delivered by Hughes) have repeatedly demonstrated extremely high striking accuracy at competitive weapons meets.

Infrared techniques are exceptionally useful in space applications. A Hughes stellar tracker utilizing visible light will help navigate the Surveyor lunar landing vehicle on its 240,000-mile trip to the moon. This



Hughes infrared search-track sensor head designed for interceptor aircraft enables pilots to detect "bogies" by the infrared they generate. The infrared system works effectively even against very low altitude targets.

Infrared windows—since glass is not transparent to infrared, "windows" and lenses of other materials, such as silicon or germanium, must be used. Hughes manufactures many types of such optical components.

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value over most of western Antarctica. The bottom of the crust, however, evidently lies much deeper than it does in the west. Both types of estimate yield a crustal thickness of about 48 kilometers. Confirmation of the large contrast in thickness has come from the velocity dispersion of earthquake surface waves from distant sources traversing the Antarctic continent. These waves, for which the crust acts as a wave guide, travel at different speeds depending on their wavelength. The amount of spread, or dispersion, varies with the thickness of the crustal layer. Observations over different paths to the permanent recording seismograph stations in Antarctica indicate a mean crustal thickness of 40 kilometers beneath the eastern part of the continent and a thickness of 30 kilometers beneath the western part. The same measurements show that the crust beneath the adjacent ocean ranges from five to 10 kilometers in thickness.

It should be mentioned here that earthquake waves reaching Antarctica carry much more geophysical information than concerns the continent itself. In fact they constitute the best means for studying the entire three-dimensional structure of the earth. Conditions in the interior of the earth are inferred from the behavior of earthquake body waves that travel a more or less direct route through the globe from the source to a seismological station. The farther apart the source and the station, the deeper the wave will have penetrated. Recordings of body waves from the most distant earthquakes show compressional vibrations but none of the transverse, or shear, vibrations that are also set up by the earthquakes. Evidently the deep interior of the earth can transmit compressional waves but not shear waves, which means that it must be

DISTANCE IS MEASURED between shot point and recording site with a tellurometer. Perry Parks of the Geophysical and Polar Research Center speaks to a colleague at the recording site. This photograph was made by John C. Behrendt, also a member of the Center.

liquid. Both the absence of shear waves and the observed refraction of compressional waves show that the liquid core begins at a depth of about 2,900 kilometers (1,800 miles). They also suggest a solid inner core at a depth of 5,400 kilometers (3,350 miles).

The study of this basic structure of the earth is hindered by the fact that most of the world's seismographic stations are located in the Northern Hemisphere. Their distribution with respect to major earthquake centers makes it difficult to collect data over all distances and therefore for all depths of penetration. Moreover, the noise level at most stations is high because of local seismicity, man-made vibrations or both. Noise often masks arrivals from distant earthquakes.

The establishment during the IGY of a network of seismographic stations in Antarctica provided a solution to these difficulties. The continent is seismically quiet—only one earthquake originating there has been recorded since the beginning of the IGY in 1957—and there is no man-made noise from traffic or other sources. In addition, the unique position of Antarctica, in the center of an oceanic hemisphere with an open aspect to most of the world's belts of seismic activity, means that the stations there can receive waves from all distances from 500 miles to 12,000 miles (measured along the surface), with no intervening continents to affect travel times or signal amplitudes. This is true both of body waves and surface waves. Although earthquake observations in the Antarctic will not yield up their full potential of information for several years, the program may well turn out to be one of the most valuable of those initiated during the IGY.

To return to the examination of the Antarctic continent itself, a valuable supplement to seismic and gravity methods can be provided by air-borne magnetic measurements. They furnish the best available means for determining the depth of the crystalline rock surface below the sedimentary rocks at the base of the ice in seismically unexplored areas as well as for charting tectonic trends. Although a considerable body of data has been recorded, it has yet to be reduced and analyzed.

Even more interesting than local variations in the geomagnetic field is the location of the South Magnetic Pole itself. Contrary to what might be expected, the position of the Magnetic

SEISMIC DISTURBANCES generated by explosive charges are detected by geophones, such as the one located on top of the snow next to Ostenso, who is setting some out in preparation for a shot. Phones are hooked up to recording equipment in Sno-Cat at right.

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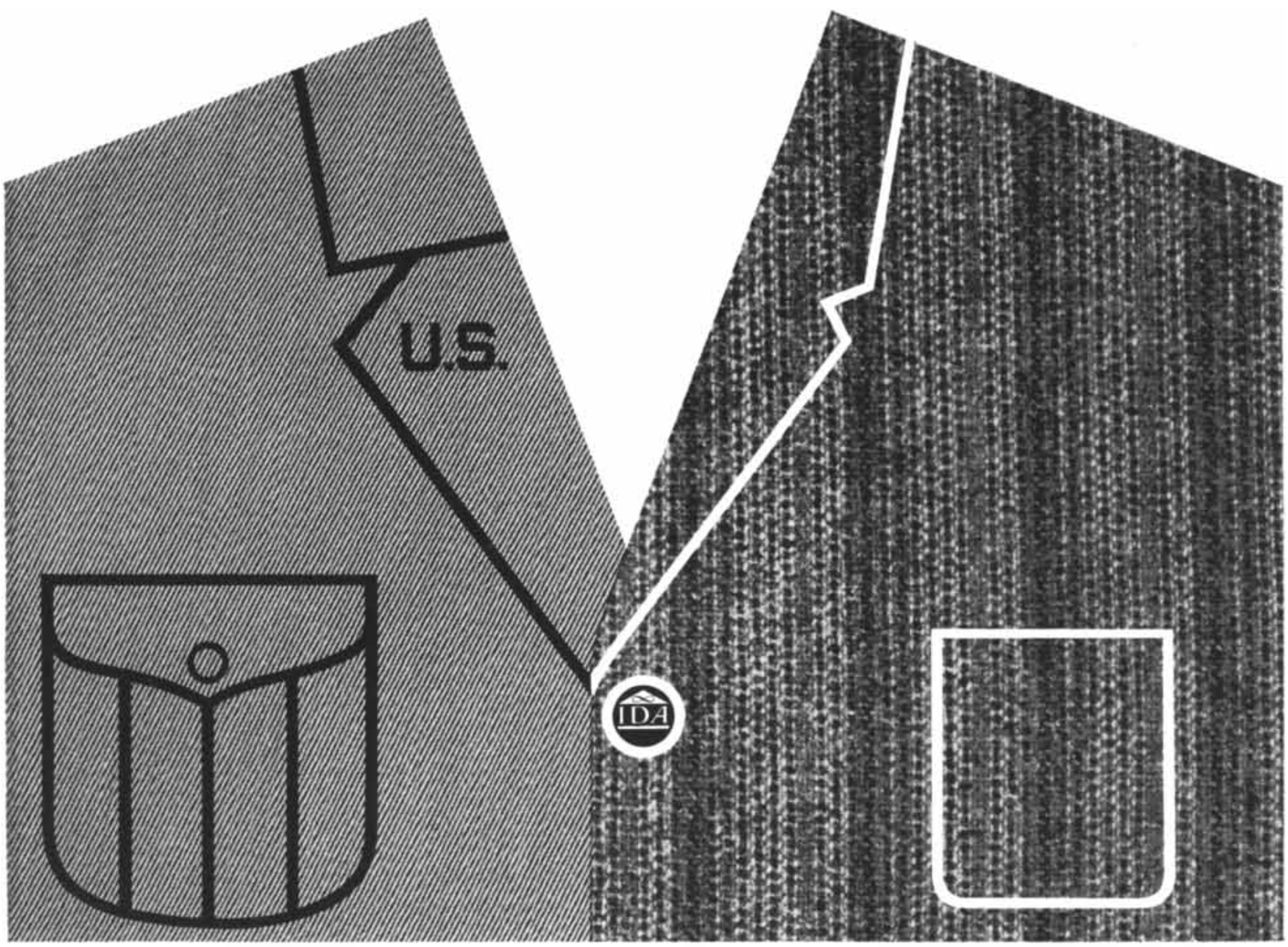

Pole appears to be changing rapidly. Over the past 50 years it has migrated some 800 kilometers; during the past eight years it has migrated 150 kilometers! At present it is on the Adélie Coast at about 67 degrees south latitude and 143 degrees east longitude. So much recent migration makes plausible a still greater wandering over geologic time. The direction of remanent magnetism in rocks that were laid down or that crystallized at a known time on the geologic scale gives information about prehistoric locations of the poles. Studies of rocks in Antarctica indicate that the Magnetic Pole occupied a position on the opposite side of the continent, at about 65 degrees south latitude and 140 degrees east longitude in Jurassic time, between perhaps 170 million and 140 million years ago. In the early Paleozoic, about 500 million years ago, it was located not far from the Tonga Islands at about 30 degrees south latitude and 160 degrees west longitude. According to the accepted theory of the source of the earth's magnetic field, the Magnetic Pole should always lie not too far from the axis of rotation. If so, either the crust as a whole or the Antarctic continent itself must have moved over the surface of the earth.

The idea of continental migration is not new. According to a theory dating back to 1885, Antarctica, together with Australia, South America, South Africa and India, once formed a single continental land mass known as Gondwanaland. In early Mesozoic time, about 200 million years ago, Gondwanaland presumably broke up into separate continents and these subsequently drifted to their present positions. As the following article makes clear, this long doubted theory is strongly supported by geological evidence and the distribution of various fossil plants and animals. Meanwhile it has proved quite difficult to reconcile the various lines of evidence and put together a unified picture of world geography during past ages. But one thing does seem certain: that the various continents have changed position not only with respect to the North and South poles but also with respect to one another.

The ancient forests of Antarctica, now visible as coal beds, demonstrate unequivocally that the continent has not always been at the bottom of the world, buried beneath snow and ice. It is not yet possible to say where the continent was when the lush plant life flourished. Once the question has been answered and the pattern of continental drift has been established, the next step will be to discover the mechanism of the drift. In this, as in all large-scale studies of the earth's structure and history, the Antarctic continent will continue to occupy a key position.

CHARGE IS SET for a seismic shot by Thomas Laudon of the Geophysical and Polar Research Center. Hole for charge is at lower right. Photograph was made by Behrendt.

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LARGE FOSSIL LEAF of the plant *Glossopteris*, found in Permian sandstone, testifies to the favorable climate that prevailed in Antarctica some 250 million years ago. Associated with coal and fossil wood, the leaf provides a link to deposits on other continents.

FOSSIL LOG, photographed by Long in the same Ohio Range formation as the *Glossopteris* leaf, was formed when iron oxides replaced the wood of a tree trunk buried in alluvial deposits. Its 34 well-defined rings indicate rapid growth in a temperate climate.

The Ancient Life of the Antarctic

The puzzle of Antarctic history is that ice now covers a land where forests once grew in a temperate climate. This suggests that the continents or the poles, or both, may have wandered

by George A. Doumani and William E. Long

The first parties to venture ashore on Antarctica at the turn of the century were astonished to find signs that plants and animals had once thrived in this barren and remote land. The trunks of petrified trees, the imprint of leaves in the rocks and the fossil verdure of coal seams all showed beyond doubt that mild and favorable climates in ages past had fostered life here in vigor and abundance. These discoveries conjured up an exotic vision, as Charles Hedley wrote in 1912, "of rippling brooks, of singing birds, of blossoming flowers, and forest glades in the heart of Antarctica."

During the past decade systematic sampling and study of the rock outcrops and the few regions that are free of ice have placed the first scattered fossil finds in the context of a broadly sketched history of Antarctica and its role in the history of life. The crustal block of the continent has proved to be as ancient as that of most other continents. It has been shown that life appears in the Antarctic sediments as early as anywhere else in the world. The record thereafter reveals the same mighty succession of plant life from the first aquatic forms to the immediate ancestors of contemporary forest trees. Although the fossil faunas are sparser, it is clear that over long ages Antarctica was equally hospitable to animal life.

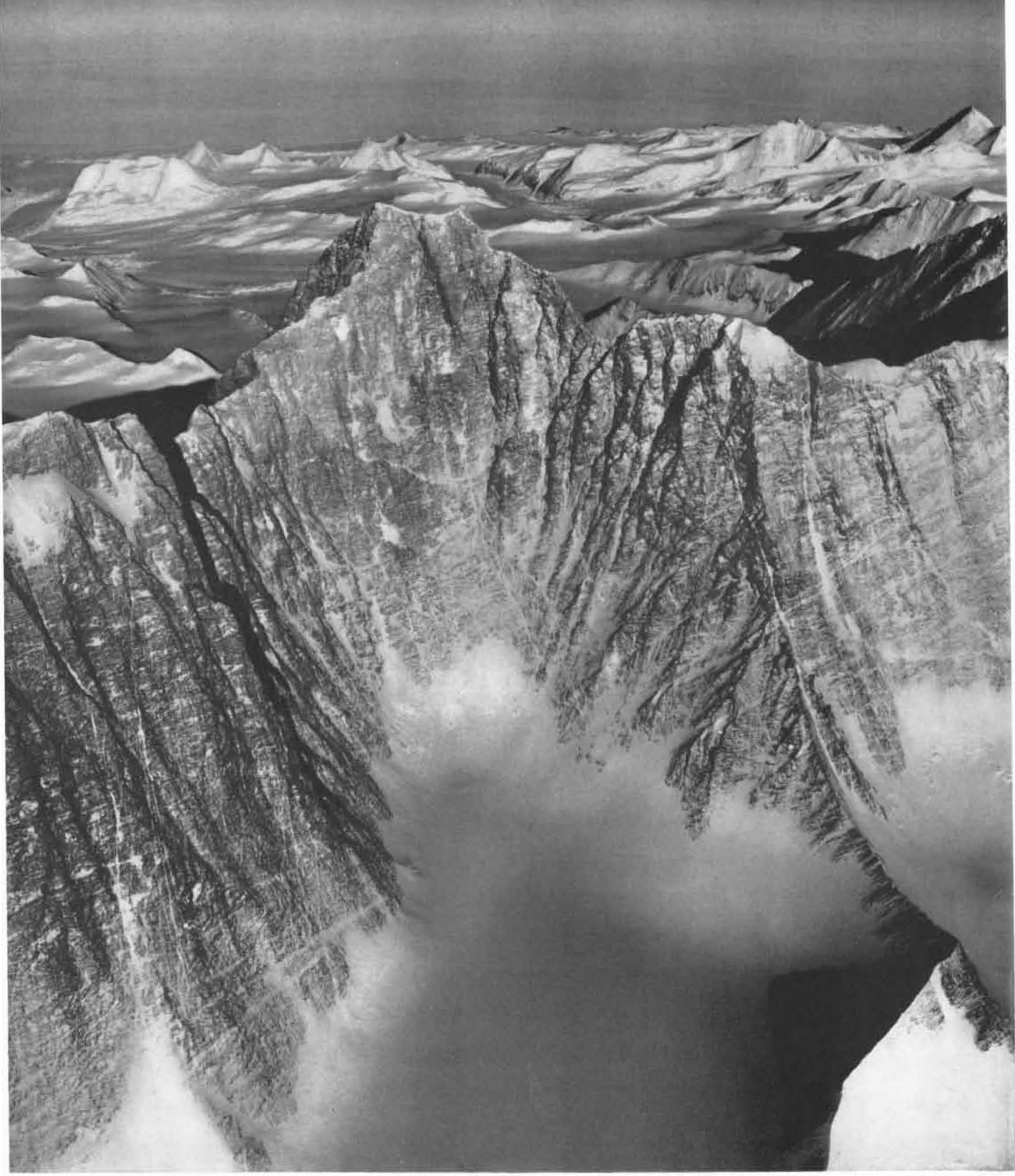
Not all the rocks contain fossils. Periods of mountain building and glaciation in the distant past erased much of the record that is not concealed by the continental icecap. But the story of Antarctica as now worked out agrees well with the established history of the continental land masses of the Southern Hemisphere. In fact, the story seems to supply the missing link in the chain of events recorded in India, South Africa, South America and Australia—places as far removed from one another as they are from the South Pole. The new understanding conjures up a still stranger vision of Antarctica: the heartland of a vast continent that once united all the Southern Hemisphere land masses. Whether or not Gondwanaland ever existed, the ancient life of the Antarctic compels serious reconsideration of the hypothesis of continental drift. This is the idea that the continents did not always occupy their present positions on the map of the world and have drifted like great rafts over the plastic underlying mantle. It is difficult otherwise to reconcile the geology and paleontology of Antarctica with the isolation of the continent on the bottom of the globe.

The Antarctic continent resembles other continents in the major features of its structural make-up. It consists of a basement complex that shows much evidence of the intrusion of fluid magmas from below and reworking by erosion from above. Until very recently geologists had to depend on the presence of vestiges of life to assign relative ages to the rocks that contain them; there was no practical and accurate way to date non-fossil-bearing rocks. Now, from knowledge of the half lives of radioactive isotopes of the elements and by measurement of the ratios of parent and daughter isotopes in the rocks, it is possible to compute the absolute ages of igneous and sedimentary formations. Employing these methods, Soviet geologists have dated the origin of outcrops near Mirnyy Station in East Antarctica at about 1,450 million years ago.

Such an age is in line with that of other continents. A second group of rocks located in the Bunger Hills and Wilkes Station region, also on the eastern side of the continent, has been assigned an age of about 1,050 million years. These rocks must represent intrusive bodies of granite or the action of forces strong enough to deform and alter what is now the basement complex. Such activity probably persisted through the first half of the life of the continent up to about 700 million years ago. Rocks of this age have been reported from several places around the east coast of Antarctica. In such late Pre-Cambrian or early Cambrian rock the Soviet geologist B. V. Timofiev has reported the finding of sporelike microfossils. It was during this period that living forms the world over began to leave recognizable remains in sedimentary rocks.

The oldest macrofossil found in Antarctica is that of an archaeocyathid, a common coral-like marine organism, similar to specimens from the Cambrian rocks of Australia and faraway Siberia. It was found in 1909 by members of Sir Ernest Shackleton's party in a boulder of limestone displaced from its original site by glacial transport and deposited in the debris at the foot of Beardmore Glacier south of the Ross Ice Shelf. More recently another limestone boulder containing many archaeocyathids was dredged from the ocean floor on the other side of the continent, near the South Orkney Islands. Since the ocean bottom all around the continent is littered with glacial debris rafted seaward by the ice, it can be confidently inferred that the South Orkneys boulder came from inland, possibly from highland areas near the Pole.

Associated with the archaeocyathids in this find are the calcium carbonate structures of microscopic algae and fragments of trilobites, the primordial ancestors of the huge class of arthropods that embraces the modern insects, arach-

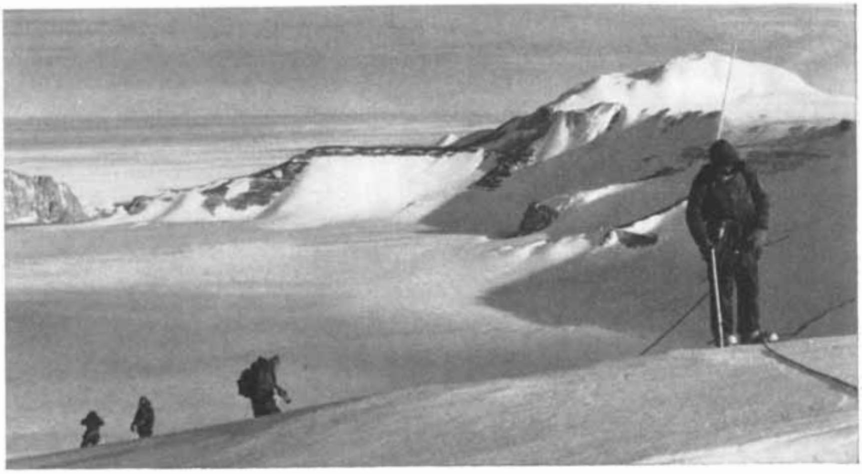


ANTARCTIC GEOLOGY, largely buried beneath ice, is revealed in mountain ranges, rock outcrops and dry valleys. This aerial photograph made by the Navy for the U.S. Geological Survey shows Mount Tyree, one of the highest peaks on the continent, which towers 16,400 feet above sea level in the Sentinel Range of the Ellsworth Mountains of West Antarctica. These mountains were formed within the past 50 million years when intense forces folded, uplifted and metamorphosed huge thicknesses of sedimentary rock.

nids, crustaceans and other such jointed-leg animals. The small size of the archaeocyathids suggests a deep-water habitat, but the cleanliness of the limestone matrix and the presence of algae should probably be taken to indicate deposition in shallow, clear water, with a minimum amount of agitation, under climatic conditions that were unfavorable for rapid, luxuriant growth. These organisms, now long extinct, are good horizon markers of the Lower Cambrian period of about 600 million years ago. The Antarctic specimens exhibit characteristics of archaeocyathids of that age in South Australia.

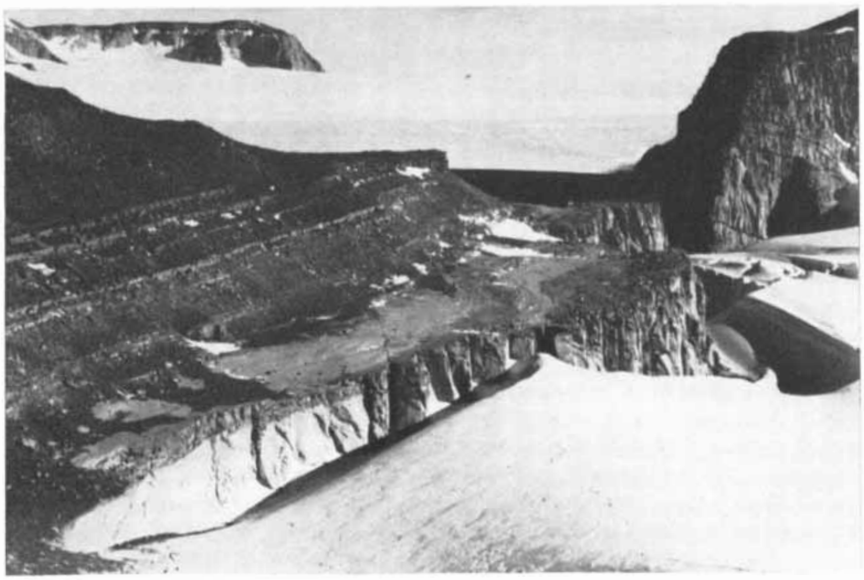
The basin in which these Cambrian fossils and sediments were deposited probably lay just to the west of the present-day mountainous belt that reaches toward the Pole from Victoria Land and includes the Queen Maud and Horlick ranges. Gradually the floor of this basin subsided and the nearby land areas became active with uplift and volcanism. Poorly sorted debris from the new land was dumped into the sinking trough, accumulating to a depth of up to 15,000 or 20,000 feet. By late Cambrian or early Ordovician times (about 500 million years ago) compression of the earth's crust crumpled the sediments of the sinking basin, forcing the seas farther away from the center of the continent and exposing considerable areas of the sedimented bottom. Today these sediments are called the Robertson Bay group, after the representative formation at that location on the coast near the Ross Sea. Granitic bodies forced their way up into the overlying sediments in the course of this episode of mountain building; radioactive-isotope dating of the granite confirms the date of about 500 million years ago. The slow but relentless forces of erosion then began to break down these land masses and put an end to the history of the building of the basement complex.

The younger rocks of the continent begin with the Devonian strata, about 400 million years old. They are less disturbed by mountain-building processes and are rich in fossils. Devonian rocks were first found in Antarctica in 1910 by Frank Debenham, a geologist with the last Scott expedition; they were pieces of black shale containing some fish remains similar to fossils found in late Devonian black shales in the Great Lakes region of North America. Of far greater consequence was the discovery in 1958, in the course of the International Geophysical Year, of early Devonian sandstones and shales in the



GEOLOGICAL PARTY is shown climbing in the Ohio Range of the Horlick Mountains, where the Gondwana deposits described in the text were found. Mount Glossopteris rises at right, 4,000 feet above the level surface. Discovery Ridge is the dark, flat ridge at center.

NORTHERN ESCARPMENT of the Ohio Range is seen in this photograph made, like the others on this page, by Long. The cliff in the foreground is composed of wind-eroded sandstone. In the background, sedimentary layers can be seen lying on an ancient erosion surface.

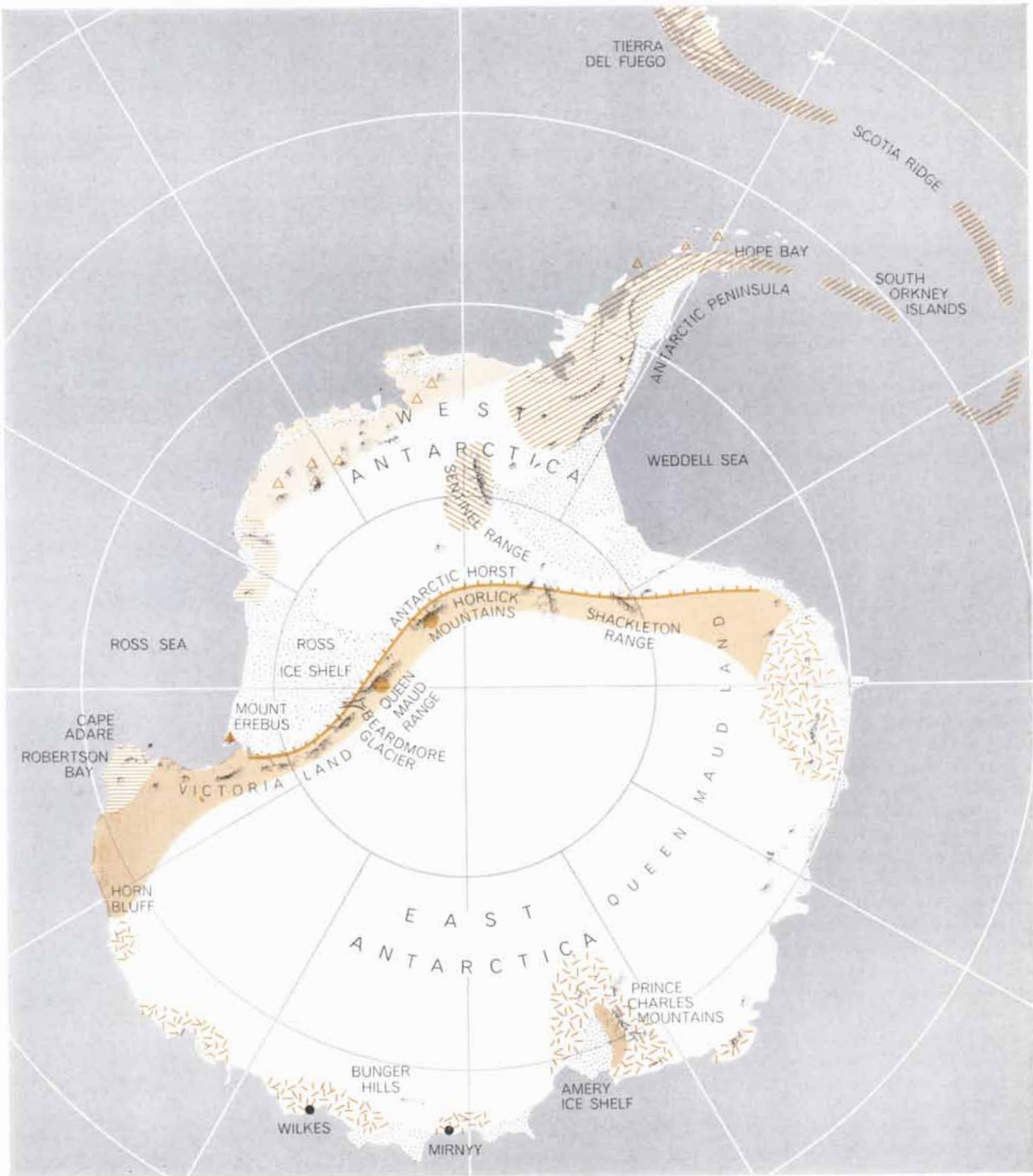


SUCCESSION OF STRATA is shown in this Discovery Ridge scene. A Devonian erosion surface is exposed (*smooth surface at center*). On it Devonian seas deposited fossil-rich sands (*horizontal layers on slope at left*). Much of this Devonian sandstone was eroded away by glaciers that deposited a thick layer of tillite (*dark rock high on slope at left*).

Ohio Range of the Horlick Mountains. Unlike the earlier find, these rocks are *in situ* and form part of the spectacular escarpment along the northern margin of the range. The sandstones are dirty, rich in fossil invertebrates and interbedded with dark shales containing the remains of primitive plants.

The fossils collected from the Ohio Range now include brachiopods (scallop-like prototypes of modern bivalves), gastropods (prototypes of modern whelks and snails) and a large variety of other mollusks, a coral and trilobites. This diversified assemblage is the first of its kind ever collected in Antarctica. The specimens run large in size and have thick shells. Impressions of razor clams measure nine inches in length, and the trilobites appear to have been a foot long. The presence of brachiopods of the genus *Lingula* provides strong evidence that the climate was warm.

Plants and their spores found in asso-



GEOLOGICAL MAP of Antarctica is far from complete. Here the generalized geological provinces thus far identified are shown, with the most common types of rock indicated in each. West Antarctica is a region of highly folded mountains and subglacial basins;

ciation with these animals have been identified by James M. Schopf of the U.S. Geological Survey and Ohio State University as belonging to a primitive vascular (that is, stemmed and leaved) variety. All indications point to an environment of shallow, warm waters with a sandy, slightly muddy bottom as being characteristic of Devonian times in that region. The dark shales containing the plant remains were probably deposited in intermittent marsh and brackish water environments. In general it can be said that the Lower Devonian fossils of Antarctica differ from those of the Northern Hemisphere and resemble more closely the South African and South American faunas of the same period. It is most striking to realize that they lie within 300 miles of the South Pole.

The Middle Devonian period does not appear in the fossil record as yet, and the Upper Devonian is represented only by the fish in the black shale picked up by Debenham in 1910. What followed in the immediate post-Devonian period, however, is dramatically portrayed by one of the most fruitful finds in Antarctic geology to date. In 1960 our group from Ohio State University discovered that the Devonian rocks in the Ohio Range are overlain by a considerable thickness of glacier-deposited tillite. These deposits indicate severe climatic conditions and possibly a continental glaciation comparable to that of today. Great masses of ice spread over the continent, clearing away the Devonian sediments in some regions, polishing and

ESCARPMENT

ACTIVE VOLCANO

INACTIVE VOLCANO

TILLITE

PRECAMBRIAN IGNEOUS AND METAMORPHIC ROCKS

ANDEAN SEDIMENTARY AND IGNEOUS ROCKS

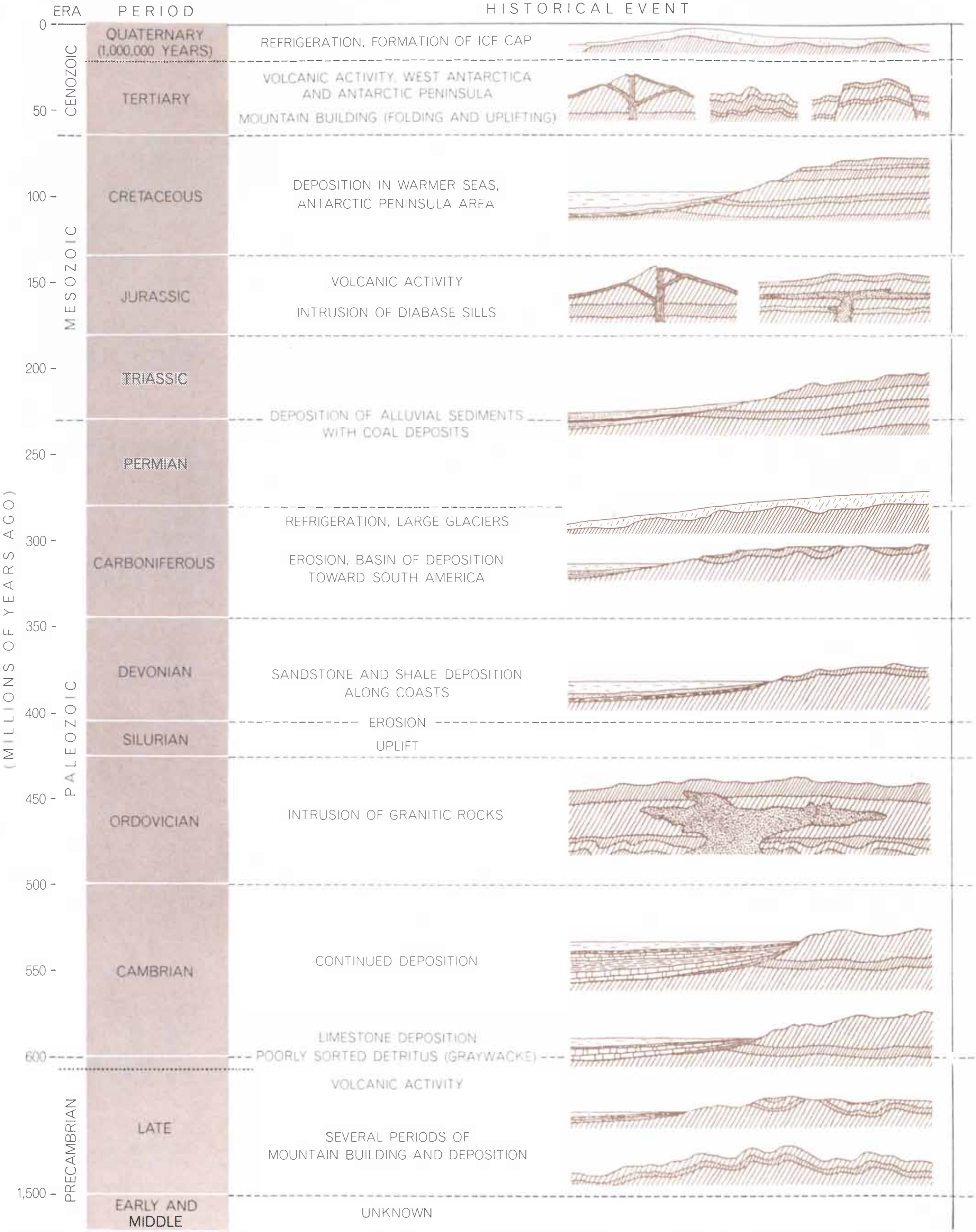
FOLDED METAMORPHIC SEDIMENTARY ROCKS

HIGHLY FOLDED METAMORPHIC ROCKS

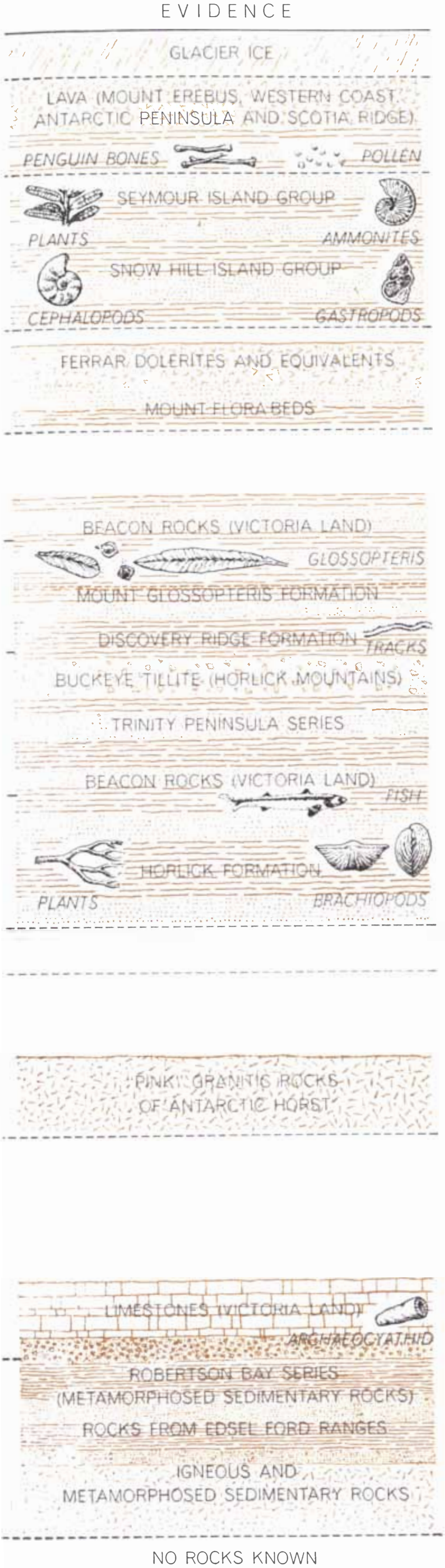
SEDIMENTARY ROCKS ON GRANITIC BASEMENT

VOLCANIC MOUNTAINS

East Antarctica, still largely unexplored, seems to be a more level, unfolded plateau.



GEOLOGICAL HISTORY of Antarctica is shown in this chart. An approximate time scale and the major geological periods are indicated at left. The next column lists and illustrates schematically the succession of geological events, the fossil and rock evi-



dence for which are shown at right. Many gaps and uncertainties remain in the record.

grooving the exposed basement rock and depositing as much as 900 feet of tillite in the Ohio Range.

The onset of this ancient ice age is not precisely dated, but the indications are clear that the glaciation came between the Devonian and Permian periods. The history of Antarctica in this latter, closing period of the Paleozoic era, some 250 million years ago, is richly preserved in the fossil flora found in a sedimentary sequence that lies on top of the glacial deposits in the Ohio Range. The most striking testimony to the richness of this record are the numerous coal beds as much as 13 feet thick. In the bedding planes, the large tongue-shaped leaf of the well-known Permian plant *Glossopteris* is profusely displayed.

The sandstones in which the coal beds occur are plainly terrestrial in origin, above sea level at the time of deposition. High percentages of feldspar in the sandstone indicate that granitic mountains were eroded to provide a source of the fine-grained sand particles spread by streams and deposited on flood plains. The abundance of coal and fossil flora in other forms suggests a lush, green vegetation in a humid, swampy environment. Large petrified tree trunks, as much as 24 feet in length and two feet in diameter and with prominent growth rings, are embedded in the sandstone. They evoke a picture of a fast-growing Temperate Zone rain forest not unlike that of Washington and Oregon. Rivers and streams meandering across great alluvial plains must have undermined and buried these trees where they fell. The plant remains became a part of stagnating swamps and formed peat bogs that were later transformed to coal. Although it is difficult to reconstruct the Permian topography of Antarctica, it appears that the uplands from which the sediments were eroded lay in the same relative direction from the coal beds as the South Pole does today. But those uplands may not have been at the South Pole then, even though an ice-free polar region might have a climate fit for a flourishing vegetation during a warm period in the earth's climatic cycle.

Coal measures and strata bearing *Glossopteris* have been known in Antarctica since 1901, when Hartley T. Ferrar, the geologist attached to Scott's first expedition, found carbonaceous streaks in the sandstones of Victoria Land and called these beds the Beacon sandstone. Rocks of similar description and age have been found around the edge of the continent, at such widespread localities as Horn Bluff, the Amery Ice Shelf and the Shackleton Range. What gives the new finds in the Ohio Range significance is the association of these Permian deposits with the underlying glacial tillite. Similar associations have been found in India, Madagascar, South Africa, South America, New Zealand and Australia. Whenever they occur, these deposits—essentially glacial formations that underlie a varied thickness of continental deposits rich in plant remains and coal—are referred to as representing Gondwana deposits (named after Gondwana, a region in India). This and other parallels in the geological record of the land masses of the Southern Hemisphere suggest that much closer ties must have existed among them in the past. As early as 1885 the Austrian geologist Eduard Suess was moved to postulate the existence in past ages of a gigantic continent that he called Gondwanaland.

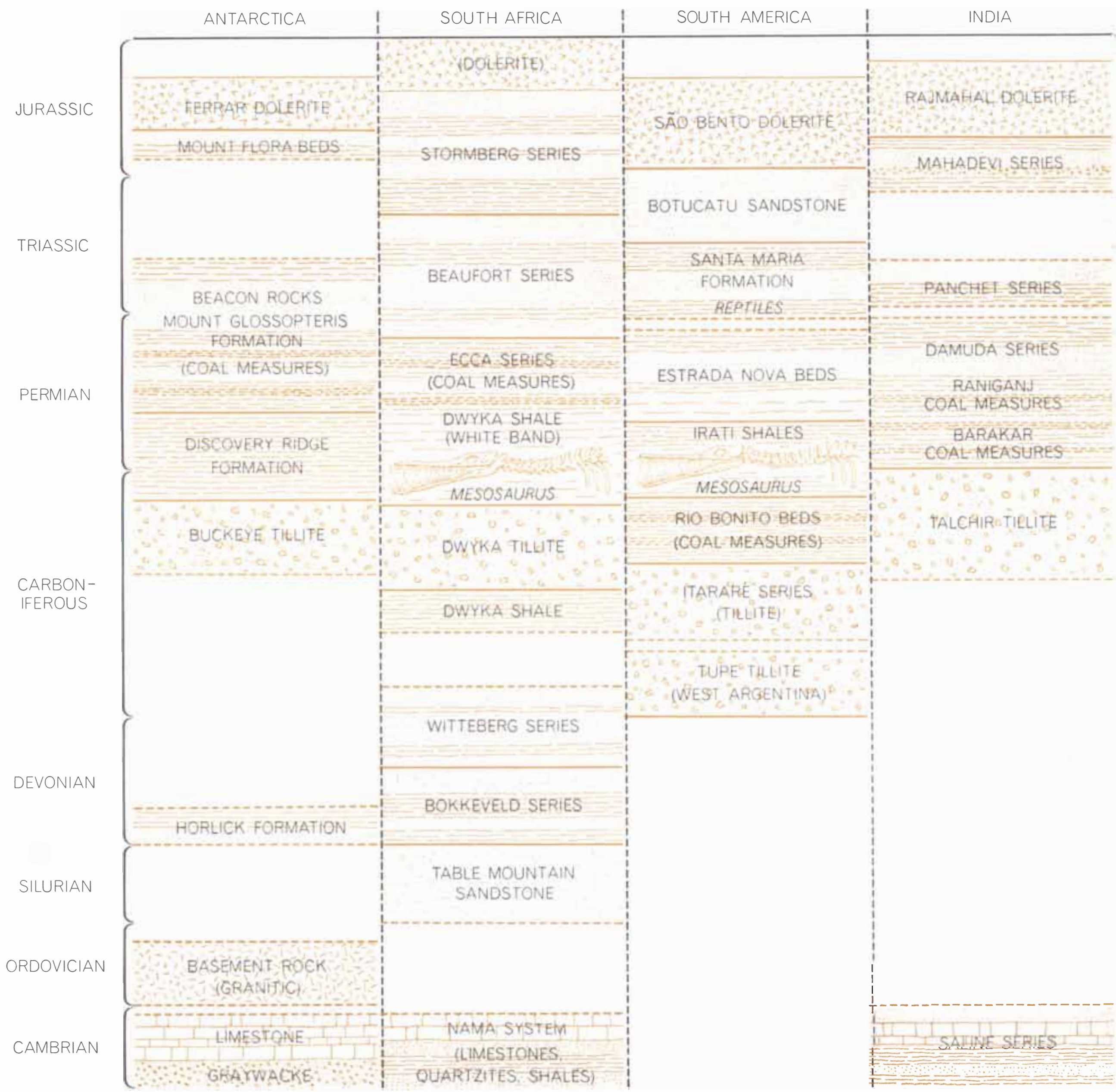
From Cape Horn to the tip of the Antarctic Peninsula the distance is roughly 1,000 kilometers (600 miles) across the Scotia Ridge. This is the nearest any other continent of the Southern Hemisphere comes to Antarctica. Around other points of the compass much greater distances separate the seventh continent from the nearest land masses. Distances of the same order of magnitude separate these land masses from one another. Geographically and climatically they have little in common, and none of them bears any resemblance to Antarctica.

In spite of present geography, however, the record of geological history, augmented by recent work in Antarctica, must now be pressed again. The post-Devonian glacial episode, which some geologists have regarded as a local event on each of the present continents, assumes hemispheric dimensions once more with the discovery of the considerable deposits of tillite in the Horlick Mountains. Especially close parallels can be seen between the Antarctic formations and the classic Gondwana section of South Africa [*see illustration on next page*]. Everywhere the Gondwana association is dominated by the abundant leaves of the *Glossopteris* flora, and also almost invariably includes plants of other genera, *Noeggarathiopsis*, *Gangamopteris* and *Schizoneura*. The assemblage is much less diversified than the contemporary floras of the Northern Hemisphere, and these plants dominate virtually all the habitats in the Gondwana area. Evidence for a common history is to be seen even in the present-day economics of the Gondwana lands. The wealth of coal laid down in continental deposits and the dearth of oil in marine deposits support the idea that in ages past the Southern Hemisphere was a land hemisphere rather than an ocean hemisphere.

Gondwana deposits also show a common assemblage of distinctive terrestrial and aquatic reptiles. None of these has yet been found in Antarctica. The most promising is the free-swimming reptile *Mesosaurus,* which inhabited river mouths now distantly separated in Brazil and South Africa. Careful search of the Permian deposits in the Ohio Range has so far failed to produce any vertebrate remains. The hunt is encouraged, however, by the finding of impressions of trails and tracks on bedding planes. There is still a possibility of finding remains of *Mesosaurus* or its contemporaries in these deposits.

The Antarctic coals are of "high rank" —that is, anthracitic and low in volatile components rather than bituminous. This indicates that the plant debris must have been buried under enormous thicknesses of sediment. Around 180 million years ago, in the Lower Jurassic period, hot molten material invaded the sediments from below, baking the deposits and altering the coal in some cases so that it became graphitic.

As the recent discovery of the Antarctic Gondwana formations suggests, the open terrain and exposed rock of the eastern continental land mass have not yet been thoroughly explored and picked over by geologists. But it is apparent that the record of the past 250 million years, embracing most of the Mesozoic era and all of the Tertiary and Recent periods, is largely hidden by the continental ice sheet. For insight into

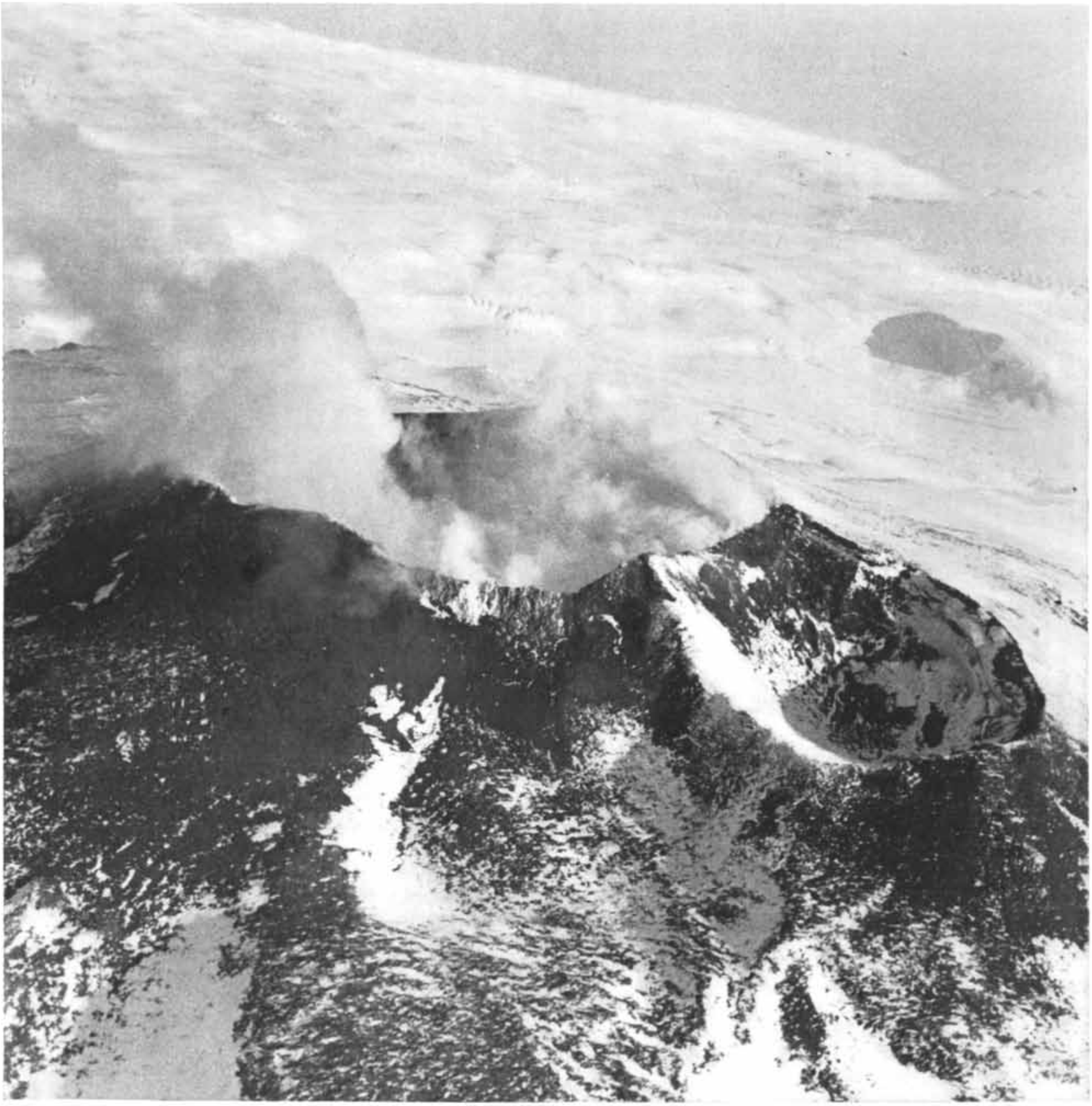


ANTARCTIC STRATA are correlated with those in three other areas in this chart. The most striking correlation is found at the so-called Gondwana levels, where glacial debris, or tillite, lies under continental sediments rich in plant and animal fossils. The close correspondence of these levels in regions that are now widely separated suggests that they once formed a single land mass.

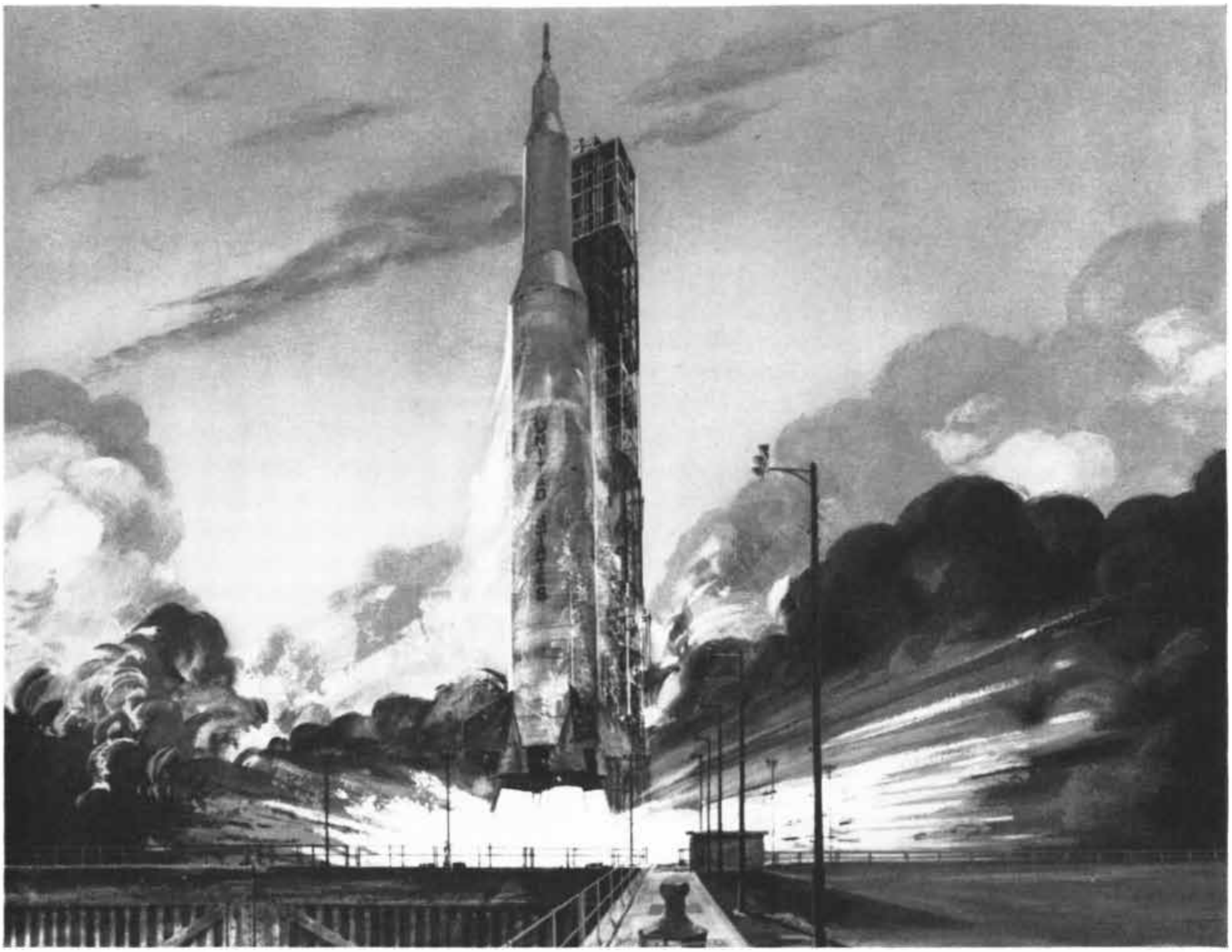
these later periods one must turn to the exposed lands of the Antarctic Peninsula and the islands of the Scotia Ridge.

The history of West Antarctica is more closely related to the Andean province of South America than to the main continental land mass of Antarctica. In 1895 the Polish geophysicist and meteorologist Henryk Arctowski, who made the first landing on the continent with Carsten E. Borchgrevink, noted that the geology of the Antarctic Peninsula is nearly a mirror image of Patagonian geology and suggested the name Antarctandes for the mountains of West Antarctica. Here a large marine basin, the limits of which are not determined, was accumulating sediments during the Jurassic period. The sedimentary rocks now uplifted on South Georgia and other islands of the Scotia Ridge as well as on the peninsula itself bear the record of this span of years.

Between 1901 and 1903 the rich fossil deposition of the Jurassic was first sampled at Hope Bay on the northern tip of the Antarctic Peninsula. More than 61 species of plants have now been identified, and it is clear that the Jurassic landscape was as luxuriant as the Permian of 100 million years before, even though no Jurassic coals have yet come to light. One may judge that the climate was warm, perhaps even tropical. The fossils are found in black shales that are interbedded with volcanic rocks. Most likely the seas in which these sediments accumulated were part of a shallow shelf area adjacent to the deeper trough to the north. Compared with the strata from the Permian period in the interior of the continent, which lie flat in the horizontal planes in which they were deposited, the flora from the



MOUNT EREBUS, the only active volcano in Antarctica, is on Ross Island at the end of a long chain of extinct volcanoes running down the Antarctic Peninsula and along the coast of the continent. An extinct crater is visible here to the right of the main crater.



ADVANCED SATURN, shown in artist's concept above, will be the free world's largest rocket, standing some 350 feet high and measuring 33 feet in diameter. Takeoff weight will be approximately 6,000,000 pounds. A National Aeronautics and Space Administration program, Saturn will be used to power orbital and space flights, including the three-man Apollo vehicle's lunar flight. Saturn will be able to place 100 tons in earth orbit, or transport several tons of instruments to Mars. Boeing holds NASA contract to develop, build and test the S-IC first-stage booster, comprising five engines developing thrust equal to about 160 million horsepower.

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MISSILE LAUNCH. U. S. Air Force photo shows Boeing B-52H launching a hypersonic Skybolt, the nation's first air-launched ballistic missile, now under development. Versatile B-52 missile bombers also carry and launch supersonic Hound Dog missiles, as well as bomb-bay weapons, enabling it to strike a number of military targets on a single mission.

BOEING

Jurassic and later periods in West Antarctica all occur in beds that have been strongly folded.

Through the Tertiary period, which embraces most of the earlier part of the past 100 million years, West Antarctica was involved in the great mountain-building processes that elevated the Andean chain of South America. The highest of the Antarctic mountains are in the Sentinel Range, where the Vinson Massif rises to 16,800 feet. The continental land mass was meanwhile in the throes of the different mountain-building process of block faulting and uplifting, without intense lateral folding and deformation. As the end result the Horlick and Queen Maud mountains and the mountains of Victoria Land stand as examples of the block-fault mountain structure; the area has been called the Antarctic Horst.

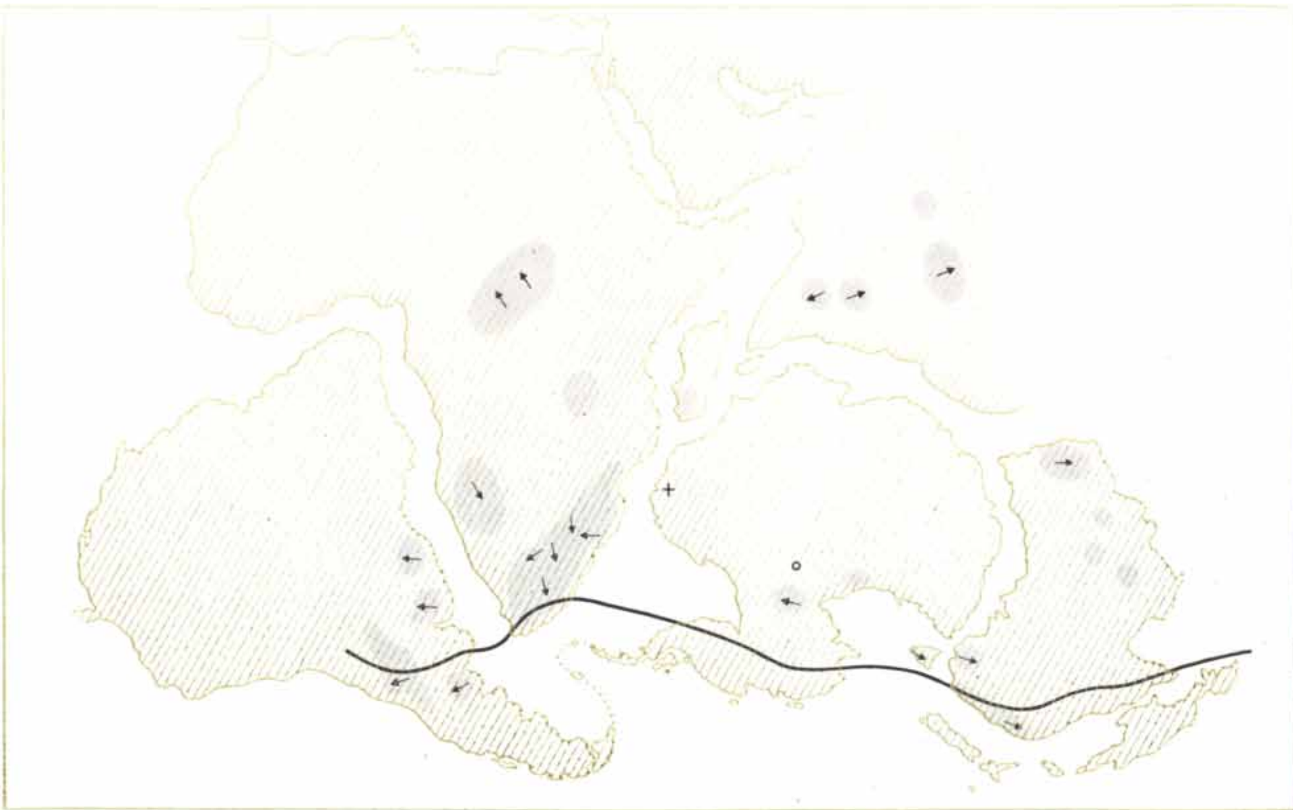
These profounder disturbances were accompanied by outbreaks of volcanism in both regions. Large volcanoes pierce through the present ice sheet, with calderas of collapsed craters several miles in diameter giving evidence that they attained elevations of 16,000 feet at maturity. Mountain building waned in most of the region during the late Tertiary, but volcanism continued and even persists in the Scotia Ridge and in the Ross Sea area. There Mount Erebus remains the only living volcano in Antarctica.

Throughout the Tertiary the climate remained sufficiently warm to support the growth of plants. Fossils of the ancestral stock of the Southern Hemisphere conifer *Araucaria* and the southern beech *Nothofagus* both occur in the Tertiary flora of Hope Bay in association with other woody temperate or subtropical species, reflecting the continuation of more genial climatic conditions on the Antarctic Peninsula some 50 million years ago. The fossil record of the peninsula also shows abundant mollusks, brachiopods, cephalopods (prototypes of the modern chambered nautilus), fishes and early penguins.

Beginning around the middle of the preceding Mesozoic era and continuing through the Tertiary period, however, the similarity of these faunal assemblages with those of areas farther north had already begun to decrease. The change can be traced from identical to similar to closely related and then to distantly related life forms. By mid-Tertiary times the austral fauna shows considerable isolation. Elsewhere in the world mammals had already become the dominant land animals, but there are no signs of this development in Antarctica. Thus although Antarctica remained in the mainstream of floral evolution through the genesis of seed-bearing plants, as represented by *Araucaria* and *Nothofagus,* it somehow missed the culmination of the evolution of animals.

Toward the end of the Tertiary, as recently as a few million years ago, the continental mass of Antarctica had assumed an outline differing only slightly from its present shape. At this time the climate began to change. Ice began to accumulate on Antarctica contemporaneously with the Pleistocene glaciation that took over the Northern Hemisphere about a million years ago. The present Antarctic ice sheet is probably a continuation of that glaciation.

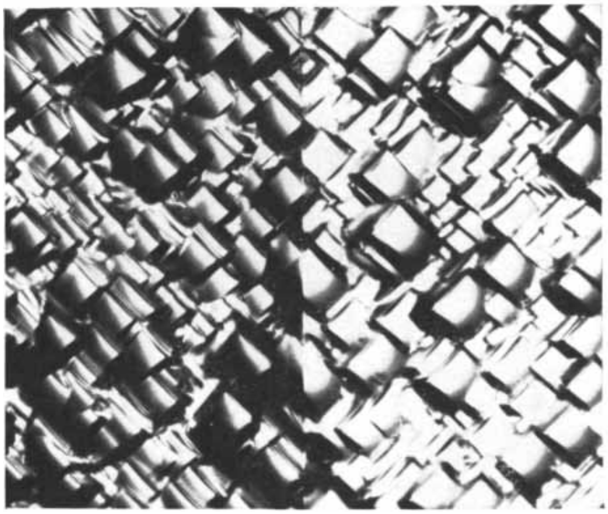
Although Antarctica today is isolated by geography, its geology gives it close



GONDWANALAND and continental drift offer one possible explanation for geological similarities between Antarctica and the other Southern Hemisphere land masses. The evidence includes the jigsaw fit of South America and Africa. Moreover, there are linear basins of sedimentary accumulation, called geosynclines, in four of the continents. When the continents are fitted together as shown, these isolated basins line up in what Alex. L. Du Toit called the "Samfrau" Geosyncline (taking the name from letters in the words South America, Africa and Australia), the axis of which is shown here by the heavy black line. Deposits of glacial tillite at approximately the same level in each of the continents are indicated by the gray tone. The short arrows show the direction of movement of the glaciers. Small black circle marks South Pole; cross indicates where Du Toit thought Pole may once have been.

ties to the world across the surrounding Southern Ocean. Animal affiliations between Antarctic and other Southern Hemisphere forms can be explained by migration; transport by birds, wind or water may explain the relation between plants found in now distant land masses. But these mechanisms cannot account for the dispersal of such endemic, place-bound forms as the sedentary brachiopods. These animals are neither swimmers nor floaters; their free-swimming or drifting larval stage is a matter of hours or of several days at most. The oceanic deeps that separate the Southern Hemisphere land masses and isolate Antarctica present insurmountable bar-

LEAF OF GLOSSOPTERIS is a significant marker of the Gondwana deposits that have been identified in five continents. This fossil leaf, photographed by James M. Schopf of the U.S. Geological Survey, is embedded in sandstone from the Orange Free State in South Africa, some 4,000 miles across the ocean from the site where the leaf shown at the top of page 168 was found.



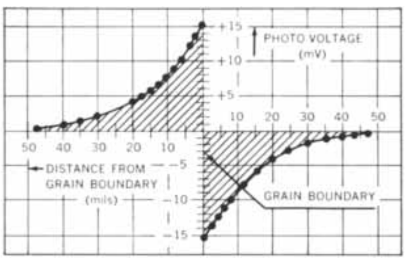
Photomicrograph of the surface of a bicrystal with 100 plane etch figures (1200 x magnification).

Photosensitive Semiconductor Devices

One of the most recent advances in the field of photosensitive semiconductors is the semiconductor bicrystal. Though it resembles the phototransistor in its mode of operation, the bicrystal offers a number of superior characteristics for light-sensitive applications. Our Solid State Department is exploring these in considerable detail.

Bicrystals are formed by growing together two differently oriented monocrystals, resulting in a grain boundary interface. In n-type germanium this layer has p-type character and is extremely thin—less than a barrier layer. A spot of light traversed from one side of the block to the other across the grain boundary produces a sharp discriminating voltage response, as shown below.

Bicrystals offer a number of unusual characteristics, among them: response speed as much as 100 times faster than conventional germanium cells (at frequencies as high as 10^7 cps), high sensitivity at low voltage, probable resistance to nuclear radiation, no inherent limit to optical resolution (because of the extreme thinness of the grain boundary layer), and ability to work as a field effect amplifier almost independent of temperature in the range from 4° to 300° K.



These unique characteristics immediately suggest bicrystal application in tracking and guidance devices, in sensing and control systems, in laser communications systems, and as a-c generators.

We've also developed a diffused silicon photodiode with high response speed (less than 0.1 μsec) and low dark current (less than one μa at room temperature). This pinhead-sized diode is well suited for array arrangement and promises to be invaluable in photoactivated systems for analog-to-digital converters, punched card or tape-reading, optical memory circuits, curve followers, etc.

Then there is the new Bendix photopotentiometer, a device of particular value to the designer of miniaturized systems. In this, a bar of semiconductor contains a p-n junction parallel to the length of the bar. Because a narrow beam of light moving along the exposed p-n junction serves as the wiper, the photopotentiometer is frictionless and noise free. Applications include analog position or orientation sensing, and pressure or acceleration transducing, among others.

Bendix research embraces a complete range of disciplines including acoustics, nuclear, data processing, microwave, fluid power, lasers and masers, guidance, electronics, solid state physics, and mechanics. Motivation: to develop new techniques and hardware for producing complete, integrated, advanced systems for defense, industrial and commercial applications. Inquiries are invited. We also invite engineers and scientists to discuss career position opportunities with us. An equal opportunity employer. Write Director, Bendix Research Laboratories Division, Southfield, Michigan.

Research Laboratories Division

THE Bendix CORPORATION

WHERE IDEAS UNLOCK THE FUTURE

riers to dispersal of such organisms. In the history of these animals dispersal is invariably achieved by spread along shore lines. Land bridges reaching in various directions have accordingly been postulated. But there are no vestiges of these bridges to be seen; such steppingstones as the Society Islands in the Pacific and Tristan da Cunha in the Atlantic all fail, because they are relatively new volcanoes originating from the ocean floor and in no way related to the ancient mainlands of Africa, South America and New Zealand.

The obstacles to dispersal are surmountable, however, if proximity can be allowed. If the Southern Hemisphere land masses were joined together at some time in their geologic history, most of the questions about the distribution of life in these regions can be answered.

Geology and paleontology do not furnish the only evidence in support of the idea that the present Southern Hemisphere land masses represent fragments of a former great continent that broke up and drifted apart. The simplest clue is the geodetic one suggested by the jigsaw fit of the east coast of South America and the west coast of Africa. Much has been written about continental drift, and its influence waxes and wanes in the literature of geology. The past decade's work in Antarctica has played an important role in the revival of interest in the hypothesis.

To the independently compelling fossil evidence the latest paleomagnetic studies lend great force. Since primary considerations require that the Magnetic Pole be located somewhere in the vicinity of the pole of the earth's rotation, the odd directions pointed by the fossil magnetism of the rocks around the world are more readily explained as evidence of continental wandering [see "The Land of the Antarctic," by George P. Woollard, page 151]. If this sounds fantastic, those 24-foot trees, those layers of abundant leaves and those thick seams of coal all in strata that are under an ice sheet two miles thick are no less so. If the continent did not wander, where was the Pole when the continent was green? Where was the continent if the Pole did not wander? Ice and coal are not deposited in the same polar region under the same climatic conditions. Yet in Antarctica they coexist!

This coexistence forcibly demands an explanation. The seventh continent holds a master key to the earth's ancient history.

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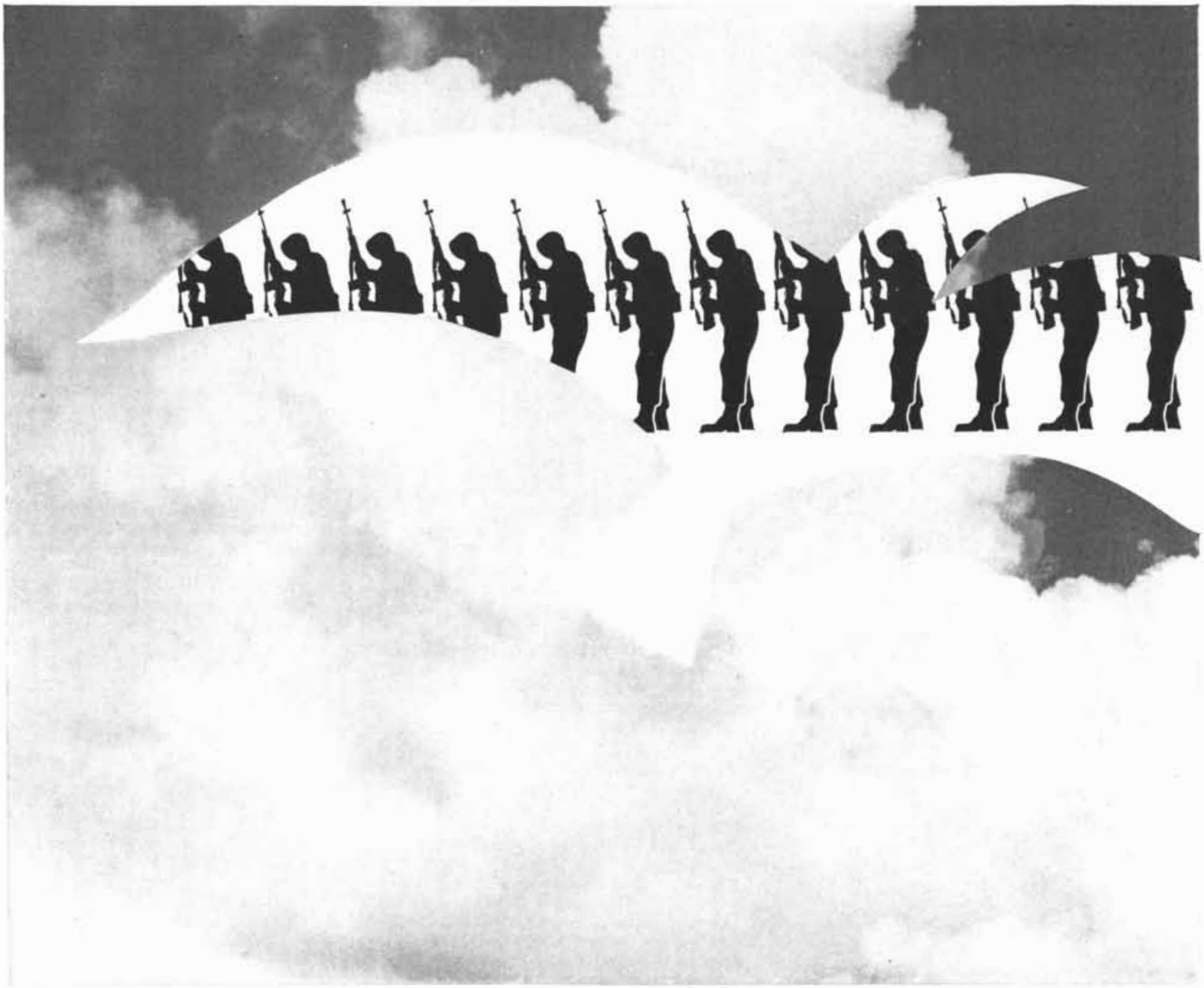


The Oceanic Life of the Antarctic

The waters around Antarctica, which support few species but large populations, are one of the richest biological provinces on earth. The key organism in the simple food chain is the shrimplike krill

by Robert Cushman Murphy

A marine biologist with his townet can locate the Antarctic Convergence, that outer oceanic frontier of the Antarctic, as readily as an oceanographer can with his instruments for measuring the salinity, temperature and flow of the waters. When *Euphausia superba,* the red shrimplike crustacean commonly called krill, shows up in the net, all hands can be certain that their ship has passed southward across the Convergence. The krill symbolizes life in the Antarctic more aptly than any penguin does. It is the key organism in the shortest food chain of one of the most abounding provinces of life on earth. Feeding directly on the one-celled plants of the sea, the krill in turn supports not only fish but also penguins and vast populations of winged sea birds, seals and whales. Thus in Antarctic waters the building of the body of the blue whale, the largest animal that has ever lived, goes on at only one remove from the organic fixation of the radiant energy of the sun by microscopic plants. Thanks also to the immense fertility of the water, maintained by the upwelling of mineral nutrients from below, the 12 million square miles of Antarctic ocean are richer in life than any other comparable oceanic area.

Throughout the region the abundance of life at sea contrasts with the poverty of life ashore. Especially on the Antarctic continent proper, the community of terrestrial life presents a study in adaptation to the extremes of cold and desiccation [see "The Terrestrial Life of the Antarctic," by George A. Llano, page 212]. Hence the vast bulk of Antarctic life is marine. The land provides little more than a breeding place for birds and mammals that have otherwise forsaken it for the sea. Under the steady circumpolar drive of the prevailing westerly winds and the eastward-moving current at the Antarctic Convergence, the whole vast region tends toward considerable uniformity in the distribution of its living forms. For this reason the Antarctic offers an admirable field for elucidation of the broad principles of marine ecology.

The unparalleled lushness of the Antarctic Ocean arises from the turnover of the waters of the Atlantic, Pacific and Indian oceans set in motion by the bottom current of chilled water that runs outward from the continental shelf of Antarctica. The surface water is rich in nitrogen, bound in nitrate and nitrite salts; nitrogen-liberating bacteria, plentiful in warm seas, are scarce or inhibited in Antarctic water. The phosphate content is so high that it is never fully utilized by the microscopic plants of the plankton, as is common in summer in northern temperate latitudes. Whereas lime is scarcer than it is in ocean waters that are supplied by continental runoff in the north, silica is abundant. Silica is preponderant, therefore, in the hard parts of the plants and invertebrate animals of the plankton. The one-celled algae, for example, appear in the siliceous, snowflake diatom forms rather than in the limy dinoflagellate forms that prevail elsewhere in the world ocean. Since the capacity of water for dissolved gases varies inversely with temperature, the amount of oxygen in Antarctic water is of the order of 95 per cent of saturation in winter, with frequent supersaturation. Oxygen content is lowest in late summer, when temperatures are highest, but it is ample even then.

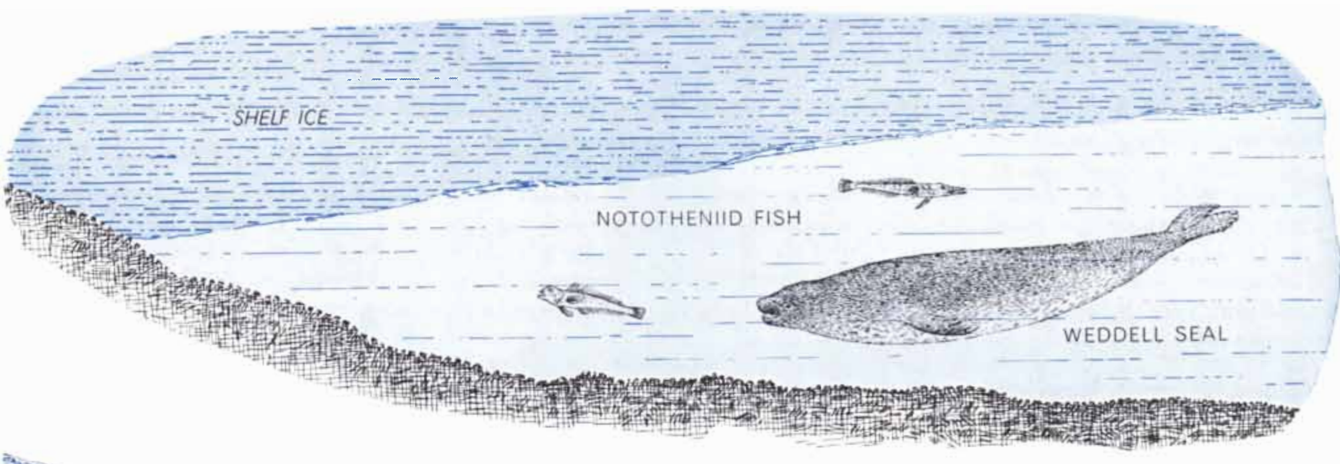
With a constant supply of nutrients for diatoms and other one-celled plants, which are the pasture of the sea, the stage is set for maintaining the pyramid of oceanic life. In addition to the food chain centered on the krill and other euphausians, there are chains in which squids or small schooling fishes supply the staple food of larger fishes, petrels, penguins, seals and whales; these cycles are less well known. No matter what links form the chain, the primary foodstuff is ultimately restored to the water in the form of excreta and dead bodies, broken down by bacterial decay. Upwelling then returns it to the surface layer, where photosynthesis takes place, and the whole process is repeated. In the Antarctic, sea water is not to be regarded as merely saline H_2O. It is also a broth that has been physiologically conditioned by the metabolism of organisms, to the general benefit of their populations.

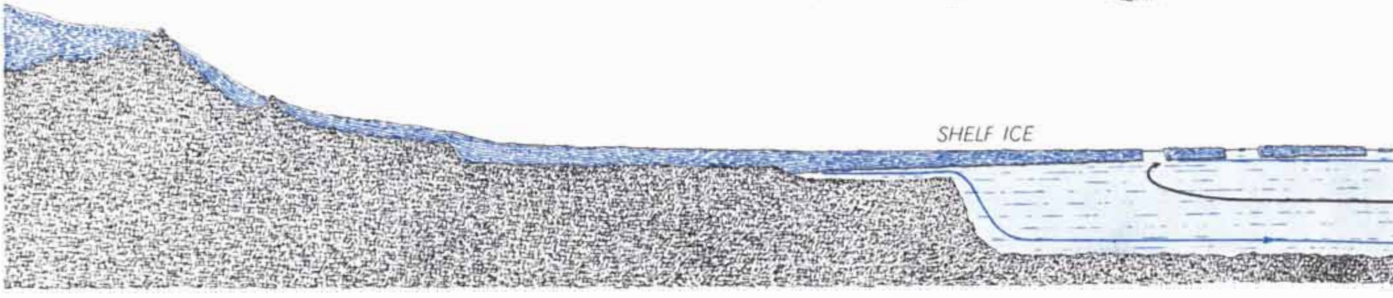
In a surprising way the very coldness of the water accounts in part for the unique wealth of Antarctic marine life. As long ago as 1908 Jacques Loeb, then at the University of California, demonstrated that the duration of life and the rate of development respond differently to temperature. Working with sea urchin eggs, he found that reduction of temperature by 10 degrees centigrade theoretically increased the length of life 1,000 times, whereas the corresponding period of development was increased only about three times. From this he concluded that the chemical processes controlling development are altogether

ANTARCTIC SPECIES thrive in a world of ice and water. The crabeater seals and emperor penguins in the aerial photograph on the opposite page are on an ice floe off Cape Crozier on Ross Island. Leopard seals prey on penguins, but only in the water.

different from those causing old age and death. The sense of Loeb's discovery is demonstrated in the Antarctic water. There, at a temperature of 0 degrees C., individual organisms have longer life spans. As a result many more successive generations of each species of marine organism live contemporaneously than exist in warmer waters. On the other hand, the number of species in each great family of plants and animals native to the Antarctic is small in comparison with that of the tropics. Therefore in general it can be said of Antarctic waters that they abound in larger numbers of fewer kinds of plants and animals than milder oceans do. The same is also true of the higher vertebrates—the birds and mammals—that surmount the pyramid of Antarctic marine life.

Echo-sounding gear has shown that the animals of the plankton in the Antarctic, as in other oceans, congregate in layers at various depths and in sufficient density to return a blurred echo. These "deep scattering" layers migrate vertically in the course of the day, usually sinking during daylight hours and rising toward the surface at night. In some Antarctic species an annual cycle of horizontal migration is superimposed on this diurnal oscillation; certain crustaceans tend to drift northward during the summer and descend at the Antarctic Convergence into deeper southward-moving water masses. They thereby



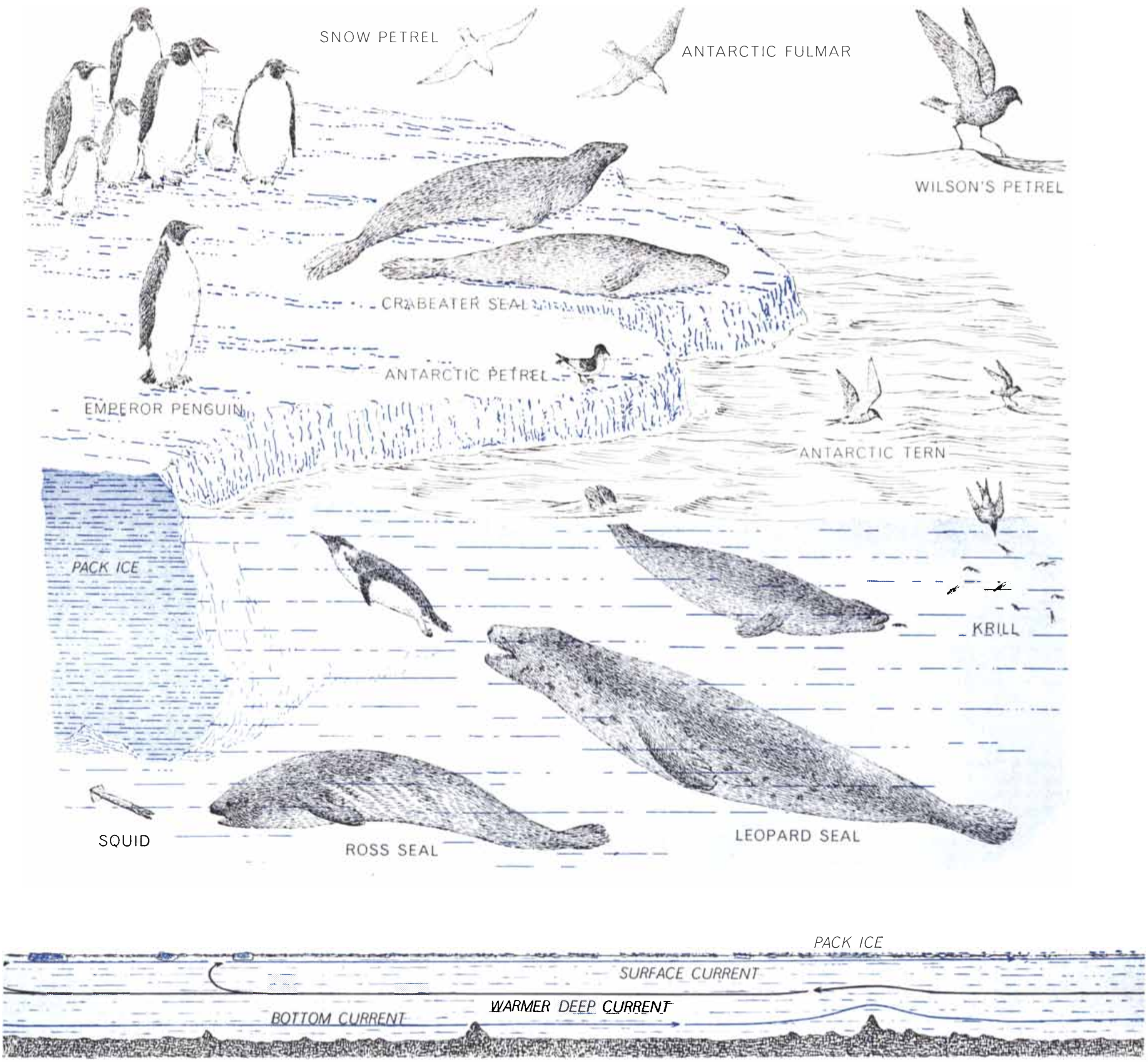


MARINE ANIMALS of the Antarctic are seen in their normal surroundings on this page and the next three pages. Their approximate distribution on the mainland, shelf and pack ice and Antarctic islands and in the open sea is indicated by the schematic cross sec-

maintain a favorable latitudinal placement by means of a vertical circular overturn. Francis C. Fraser of the British Museum has observed that in addition to such seasonal migration the krill carries out migratory movements in correlation with successive stages in its life history. Larval forms appear to congregate in southward-flowing waters between the surface and the bottom. Upward movement then brings a constant replacement of adolescents at the edge of the pack ice, after which the maturing organisms are carried northward at the surface as far as the Antarctic Convergence.

Since the upper Antarctic water masses flow eastward under the influence of the prevailing westerly winds, the movement of the zooplankton also has an eastward component that promotes high uniformity in the distribution of species around the polar continent. As a result the distribution of animals that feed on the plankton shows a corresponding uniformity. Under particular circumstances, given peculiarities in oceanic circulation or the availability of especially favorable breeding places, some species cluster in more or less constant nodes of concentration. A few species, such as the chin-strap penguin, seem to be only now at the point of extending their ranges "all the way around."

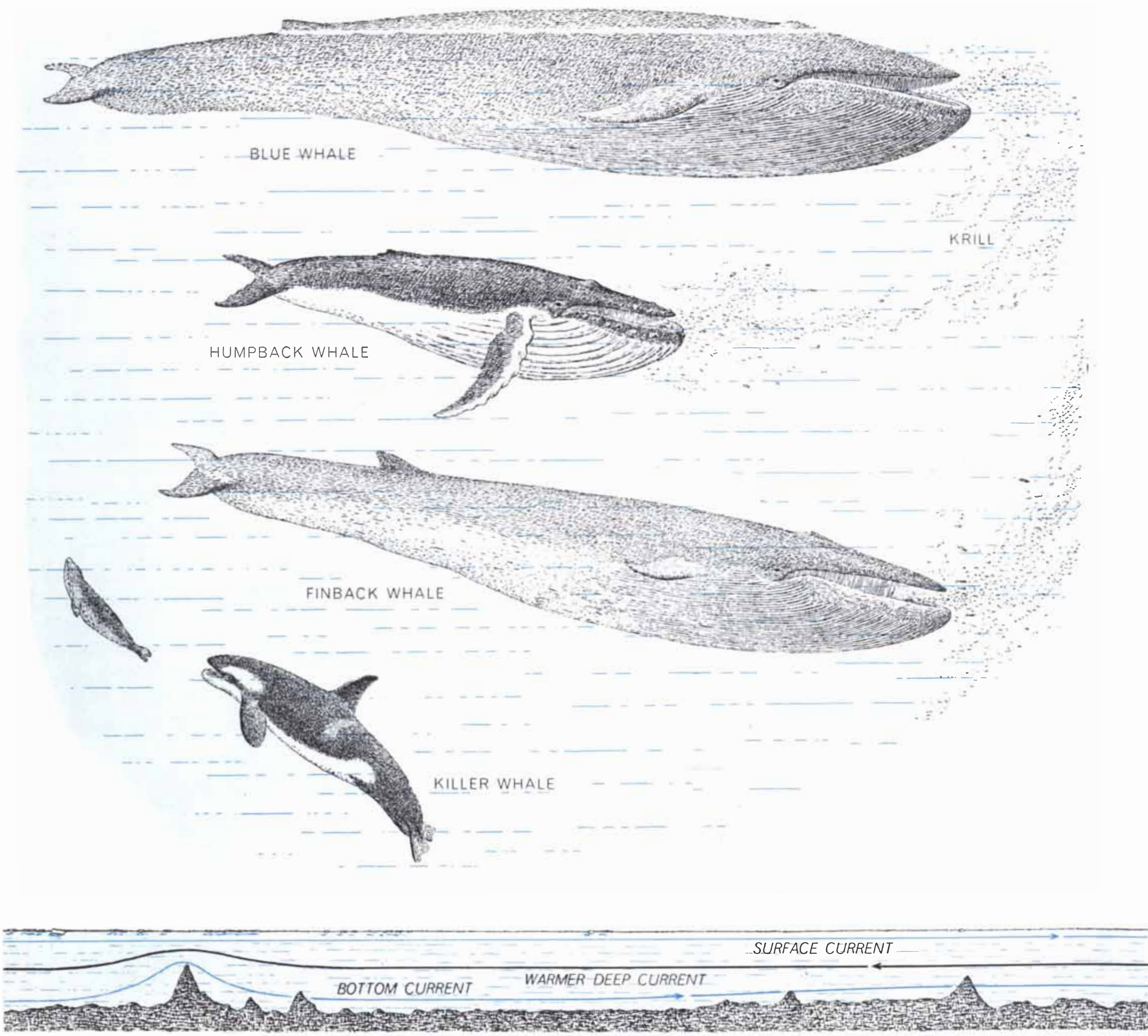
Although even less is known about



tion across the bottom of the four pages. The leopard seal, normally a creature of the outer pack ice, comes in close to shore to prey on penguins. Of the winged birds, only the Antarctic skua, the Antarctic tern and a few of the petrels actually breed on the mainland.

the bottom of the Antarctic Ocean than about its overlying waters, it appears that the community of life in the depths reflects the same circumpolar pattern, with a more or less well-defined northern boundary at the Convergence. Since the Convergence is generally thought of as a surface or near-surface phenomenon, the reason for the sharp transformation at the bottom below it is not immediately clear. It may be related to differences in the rain of organic detritus from waters near the surface. The bottom world of mollusks, brachiopods, pycnogonids, echinoderms, corals, tunicates, hydroids, holothurians and marine worms largely remains to be explored. Of particular interest are the sponges, which seem to be represented here in greater profusion than they are in tropical oceans. Sponges are usually held to have gained their ascendancy in the Cretaceous period of from 140 million to about 70 million years ago, but some zoologists believe that their true climax is today and in the Antarctic.

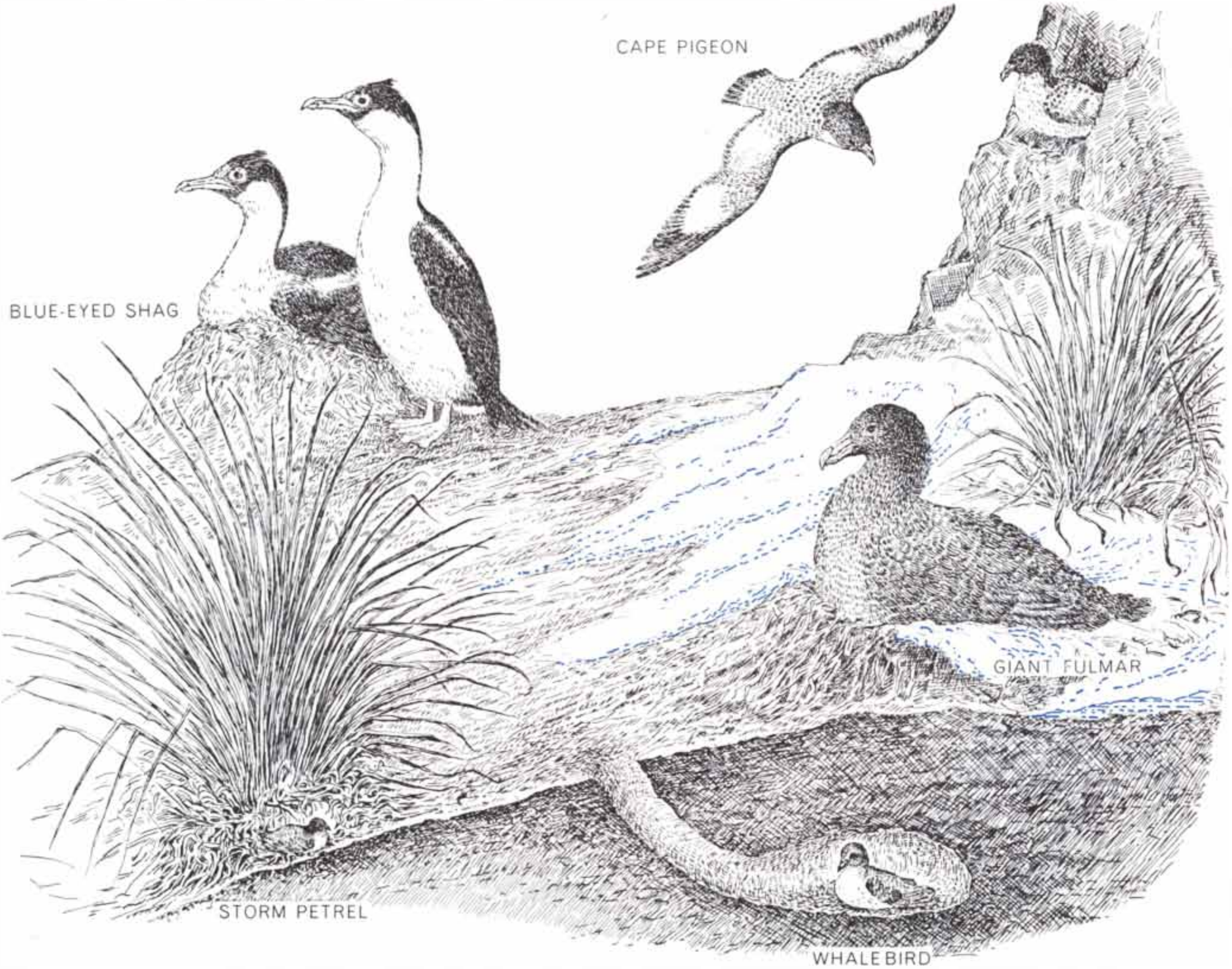
In contrast to the rich life of the deep waters, the coast line of Antarctica and the shores and submerged ledges of the Antarctic islands are surprisingly barren of bottom life and fish. Large attached algae are scarce in the intertidal band on the coasts. Perhaps only because rising and falling ice scrapes the rock clean, the absence of wrack of any sort in the dark but clear water below

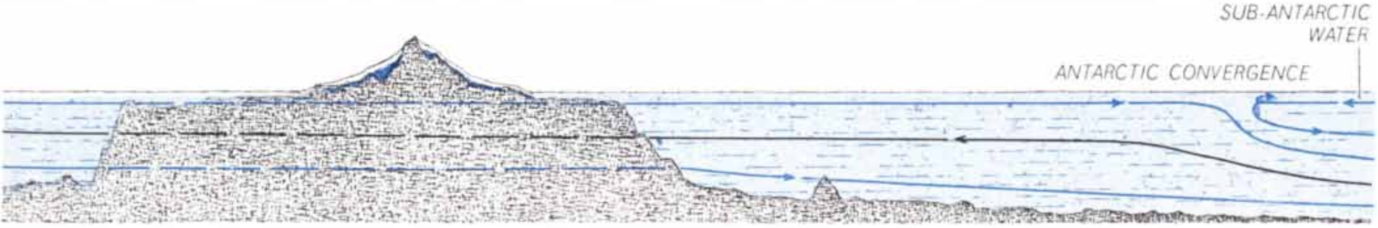


ANTARCTIC OCEAN, rich in plant and animal plankton, is a favorite feeding ground for whales. The blue whale, the largest creature on earth, feeds on swarms of the crustacean *Euphausia superba*, or krill, as do the humpback and finback whales and many

the cliffs of the continent and its neighboring islands is one of the striking distinctions of the area. In addition, the thickness and density of the fast ice and close-in pack ice filter out sunlight. Photosynthesis is feeble or gives out altogether, and the ecological system is vitiated. Most of the animals seem to be wandering carnivorous types.

As for the vast regions of water that underlie the great ice shelves of the Antarctic continent, such as those of the Ross and Weddell seas, it has long been held that these are quite deficient in life. This supposition has been upset recently by the finding of large fishes together with bottom invertebrates frozen *in situ* and exposed well above sea level on the wind-scoured surface of the Ross Ice Shelf near the U.S. base at McMurdo Sound. These remains, on top of ice more than 100 feet thick, had apparently been trapped by freezing at the bottom of the shelf when ice touched the sea floor. Thereafter they were brought up slowly as the wind ablated the upper surface of the shelf and new ice nourished the bottom. Preliminary carbon-14 dating indicates that it may have required about 1,100 years for these specimens to work their way up through the ice. If the explanation of how they did so is correct—and there seems to be no other explanation—it confirms a glaciological hypothesis advanced 40 years ago. It also serves as a stimulus for the chal-



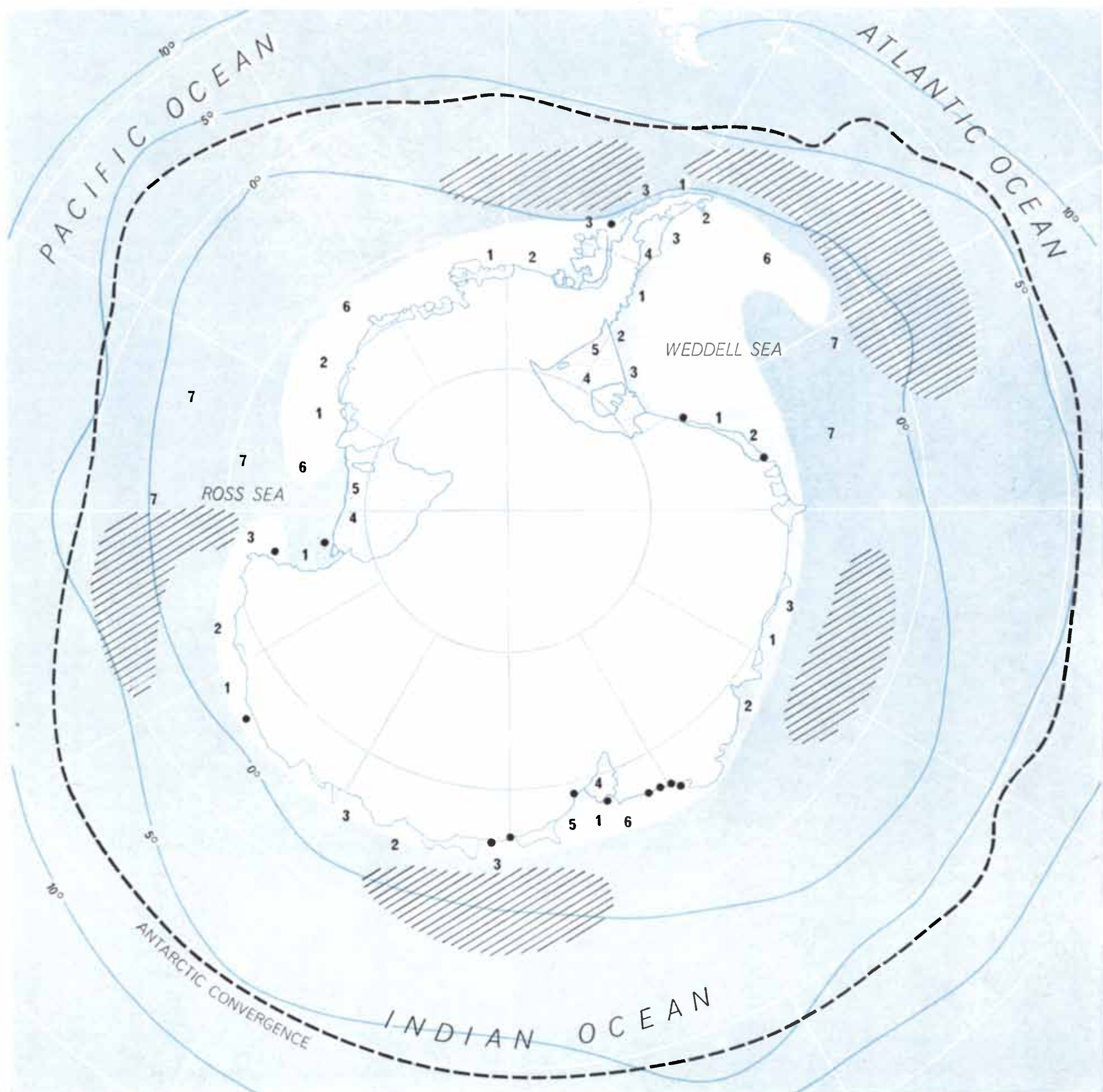


fishes, seals and birds of the Antarctic. The killer whale preys on seals and other whales. The drawing at the right illustrates the multiple use of the small areas available for nesting on most of the Antarctic islands, with several species of birds crowded together.

lenging task of exploring the underside of the ice shelves, surely one of the strangest of environments.

The size of some of the fishes, ranging from 40 to 150 pounds, was another surprise. Nearly all the previously recorded members of the endemic Nototheniid group to which they belong were relatively small.

The hagfishes, rays and eelpouts are among the few fishes of northern affinities that have representatives in the Antarctic. The order of Nototheniiformes embraces 90 per cent of all the fishes found in the pack ice waters; few, if any, of these fishes range beyond the border of the Antarctic Zone. Certain species bear chin barbels, with or without terminal "baits." Some of them look like sculpins; others might be called crocodile-headed or dragon-headed, as reflected in such generic names as *Bathydraco* ("depth monster"). Those of less forbidding appearance are commonly called Antarctic cod, although another Antarctic family, the Muraenolepidae, is more closely related to the true cods. One curious family in this order, the ice fishes (Chaenichthyidae), includes species that have no circulating red blood; the recent discovery by the Soviet worker L. D. Martsinkevitch of hemoglobin-bearing corpuscles in certain visceral organs of these fishes only partly clears up the respiratory mystery. As among other groups of Antarctic animals, the southernmost Nototheniids tend to be completely circumpolar,



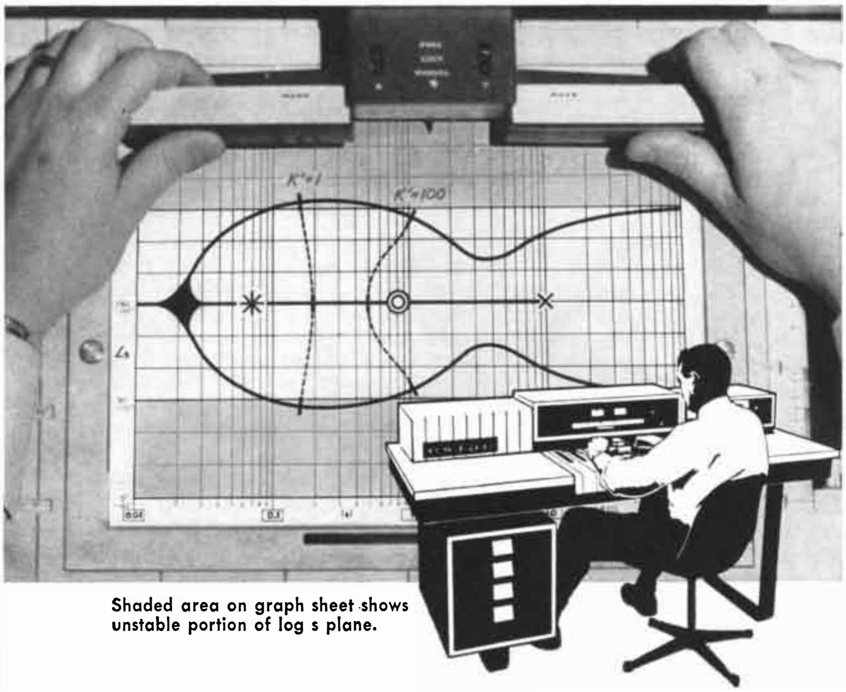
HABITATS of the most important marine animals of the Antarctic continent and its surrounding waters are shown on this map. In the case of emperor penguins the known rookeries are marked, and major concentrations of whales are shown. In the case of the other animals the numbers are spotted to indicate their approximate sequence as one approaches the Pole rather than specific sites at whereas kinds that are characteristic of less polar waters are likely to be limited to different peripheral areas. From all of these observations ichthyologists conclude that the Antarctic fish fauna must have evolved during a period of cold isolation, dating perhaps from the earlier half of the Tertiary period, which is reckoned as running from about 70 million years ago to the beginning of the Pleistocene, one million years ago.

A complete chapter in an early work on the natural history of Iceland consists of the single sentence: "There are no reptiles in Iceland." For the same reason this discussion must now skip from fish to the warm-blooded vertebrates.

Like the submarine denizens of the Antarctic waters, the birds exhibit a degree of endemism that suggests long isolation. Penguins, of course, come first to mind. Actually penguins are Southern Hemisphere birds, one of several disparate types of wingless bird that evolved on islands and subcontinents below the Equator in the absence of four-footed predators. The ranges of penguins are by no means restricted to the Antarctic; some kinds are of temperate or subtropical distribution. Yet there are four or five substantially Antarctic types. The point is made more forcefully by the petrels: here is an avian order as worldwide as salt water, but it has a sizable number of exclusively Antarctic forms. Ignoring the trifling representation of land birds in the outer sub-Antarctic islands—including the pipit of South Georgia, the southernmost of all terrestrial birds—the typically Antarctic species are sea birds and ought to be of as much interest to the oceanographer as they are to the ornithologist. There are about

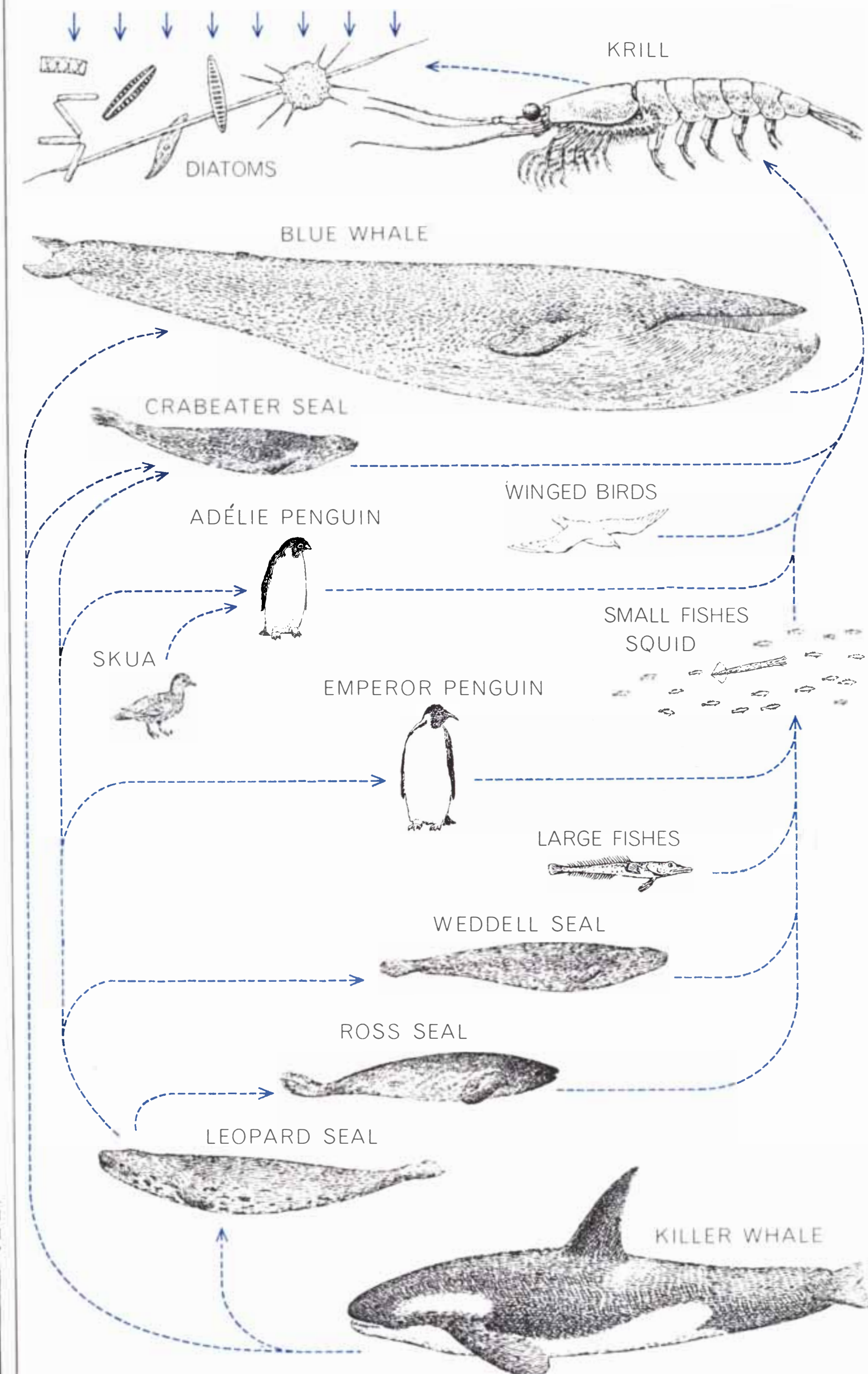
PERMANENT PACK ICE
WHALES
● EMPEROR PENGUIN ROOKERIES
1 ADÉLIE PENGUIN
2 SKUA
3 ANTARCTIC TERN AND PETRELS
4 WEDDELL SEAL
5 ROSS AND CRABEATER SEALS
6 LEOPARD SEAL
7 NOTOTHENIIFORM FISHES

which they congregate. The domain of the key crustacean *Euphausia superba* extends from near the coast to the Convergence.

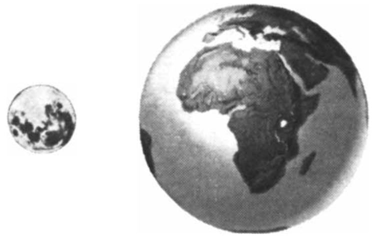


30 species that can be reckoned as Antarctic; of these some 15 nest on the Antarctic continent itself. This is not a large number, but the size of many of the populations of each species is exceedingly large.

The discrepancy between the number of species and the number of individuals conforms to the general pattern of life in the Antarctic region. It can also be correlated with a similar discrepancy between breeding space and food resources. The supply of food is enormous, but suitable nesting places are relatively scanty. This leads to great concentrations of birds in the available terri-



FOOD CYCLE of the marine animals is based on the krill *Euphausia superba*. This crustacean feeds on diatoms: microscopic marine plants that utilize the energy of the sun (*short arrows*) to transform nutrients in the water into living tissue. The krill is in turn the food of whales, penguins and other birds, the crabeater seal, squids and fishes. In addition to this basic cycle there is predation by seals, penguins and large fishes on squids and small fishes; leopard seal preys on penguins and other seals and the skua eats penguin eggs and chicks.



NEW HOPE FOR UNDER-DEVELOPED NATIONS RESULTING FROM BASIC SPACE RESEARCH

Lunar and space missions such as Project Apollo seldom seem, in their far-out glamour role, to be closely related to that great fundamental... mankind. Yet one single aspect of the Apollo program —fuel cells—holds a vast amount of hope. Especially for under-developed nations.

Often referred to as "continuous batteries," fuel cells convert chemical energy directly to electrical. They are the newest power sources to emerge from scientific research into the realm of practical engines. The specific cell system aboard Apollo will be a Hydrox® unit, reacting hydrogen and oxygen, and is the result of research at Leesona Moos Laboratories, one of the first in America to undertake studies on fuel cells. Hydrox will supply electrical power for vehicle control, communications, and numerous other power needs aboard this lunar mission. Marking the first such use of these new power sources, the Hydrox installation will inaugurate a new age in the generation of electrical power. Final engineering and manufacture of the units for Project Apollo will be carried out by Pratt & Whitney Division of United Aircraft, under license from Leesona Corporation.

But space missions are only the first part of the story. At the same point in time that Leesona Moos began studies of Hydrox fuel cells, a concomitant project was undertaken to develop an even more advanced system... a cell using air as oxidant and inexpensive hydrocarbons or their derivatives as fuels. These hydrocarbon-air (Carbox®) and mixed-gas/air (Aminox™) developments of Leesona Moos do not require reactants of high purity, and are very flexible from a logistics point of view. Low cost and readily available fuels are used, and the universal oxidizer—air—supplies the other portion of the reaction mix. Because the fuel cell is an extremely efficient engine—efficiencies of up to 70% are attainable, vs. 30% for a conventional diesel—the result is an exciting new means of generating electrical power at low operating expenditure. Pratt & Whitney Aircraft in the United States, and Energy Conversion Ltd.,* of England, are carrying out further developmental engineering on these systems under license from the Leesona Corporation.

These new Leesona power sources, of high efficiency and low fuel costs, can readily be seen to provide the world with an entirely new type of electric generator. Fuels of the hydrocarbon variety are fairly abundant throughout the world. The fuel cell, though scientifically sophisticated, is neither unwieldy nor complex in its operation, and requires little maintenance. Units with power levels from those required for a one-family dwelling up to communal or industrial ground-power stations have been projected in Leesona Moos studies, and found feasible.

The impact Carbox and Aminox can have on the emerging countries is readily understandable. The development of a nation can almost be measured by its ability to produce and consume electrical power. In this mechanized world, virtually all industry waits on the availability of electricity. If an emergent economy must hold off its development until completion of large-scale hydroelectric projects, a distinct problem of time and expenditures arises. If, on the other hand, the nation had access to Carbox and Aminox type fuel cell systems, which could be tailored to the need and would operate on locally available fuels, the basic first step toward an industrialized economy and higher living standards would be achieved.

Leesona believes its efforts, plus the great additive capabilities of our United States and international partners, will soon result in working installations of the Carbox and Aminox systems to advance the standards of all mankind. Meanwhile, the sibling Hydrox system supplies power for a moon voyage. And research continues.

**Energy Conversion, Ltd., is a new corporation founded by four British companies: National Research and Development Corporation; British Petroleum Company, Ltd.; British Ropes, Ltd., leading manufacturer of rope and steel cable; and Guest, Keen, and Nettlefolds Group, major steel manufacturers.*

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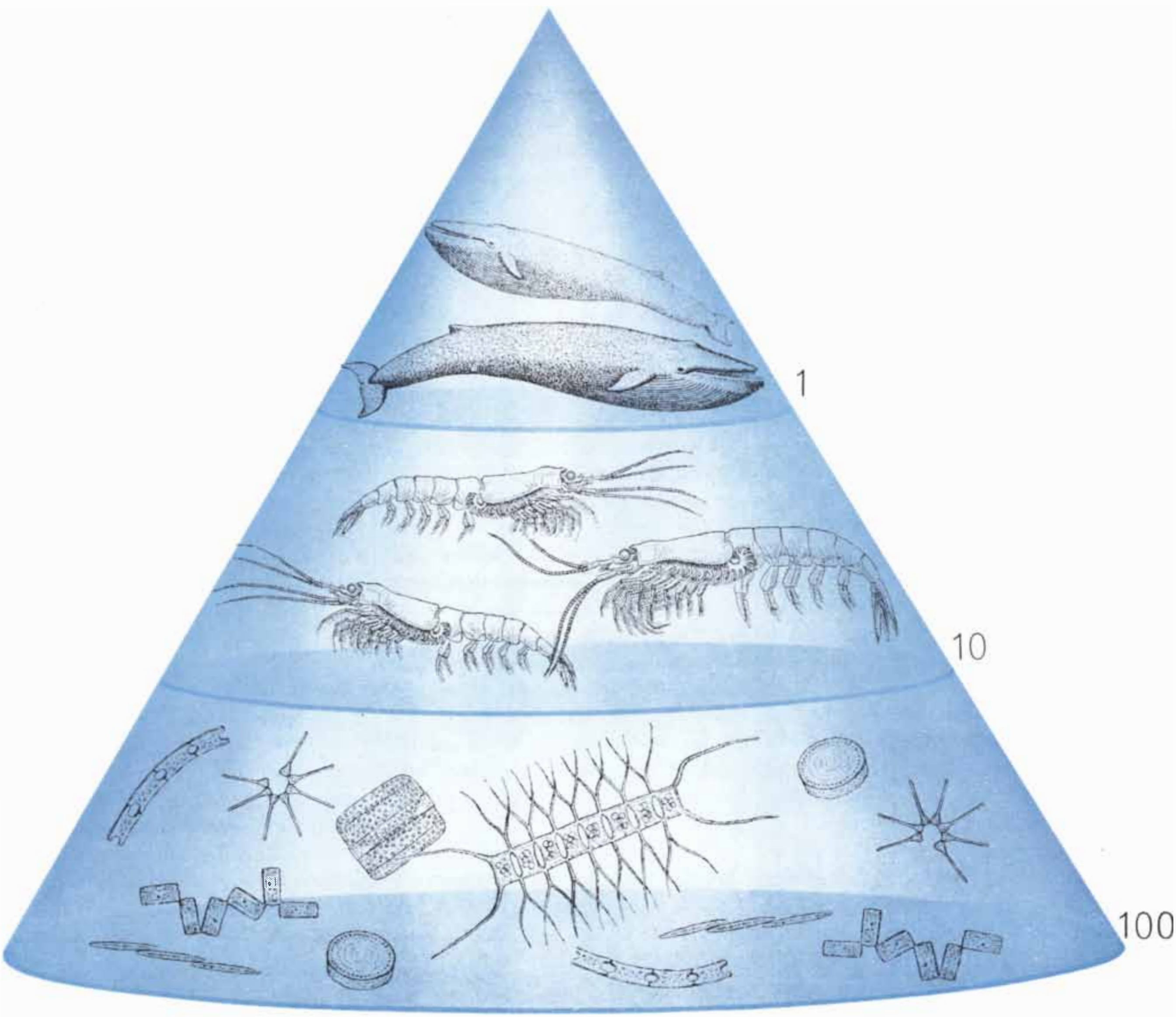
A Division of Leesona Corporation • 90-28 Van Wyck Expressway • Jamaica 18, New York • AXtel 7-4400 tory ashore as well as to an interesting multiple use of the territory. Giant petrels, for example, are to be seen nesting on open flat surfaces, with smaller burrowing petrels in the ground around and beneath them, storm petrels in the intervening hummocks of lichens or mosses and still other birds occupying adjacent ledges and rocky niches or rock piles at the foot of talus slopes.

Prominent among the members of certain communities is the sheathbill (*Chionis*), an aberrant relative of the snipes, which is a shore bird in heritage but a sea bird in habitus. I have motion pictures of the sheathbill showing that it excretes drops of brine through its nostrils, a faculty supposedly reserved to "sea birds" and dependent on special salt glands in their nostrils. The sheathbill is the only bird without webbed toes that breeds in the Antarctic. As a scavenger and a hanger-on around the breeding sites of penguins, petrels and cormorants, it gets its food from the sea but, so to speak, secondhand. The same is true of the Antarctic skua, a relative of the gulls, which preys on the eggs and chicks of penguins. Since the International Geophysical Year the skua has been accommodating itself increasingly to leavings found around scientific stations.

In climatic conditioning and adaptation there are, of course, degrees of "Antarcticity" among the Antarctic birds. The wandering albatross is Antarctic in the sense that it nests on islands south of the Convergence, but only one member of its family, the light-mantled sooty albatross, penetrates deeply into the Antarctic Zone. Among penguins, the emperor and the Adélie breed on the shores of the Antarctic continent, whereas the chin-strap, gentoo and macaroni penguins occupy outer but still Antarctic belts. The emperor penguin is beyond doubt the most polar of all birds. Its range extends no farther south than that of the Adélie and less so than that of the snow petrel. But its imperial title is clinched by the fact that it breeds in the midwinter dark on the fast ice of the continent, carrying and incubating its single egg on top of its feet. By this regime, unique among all birds, the emperor incidentally escapes the preda-



SIMPLIFIED FOOD CHAIN shows how each step in the process involves a "diminishing return." That is, it takes 100 units of phytoplankton, such as diatoms, to grow 10 units of krill, which in turn is enough to grow only one unit of its predator, the whale.

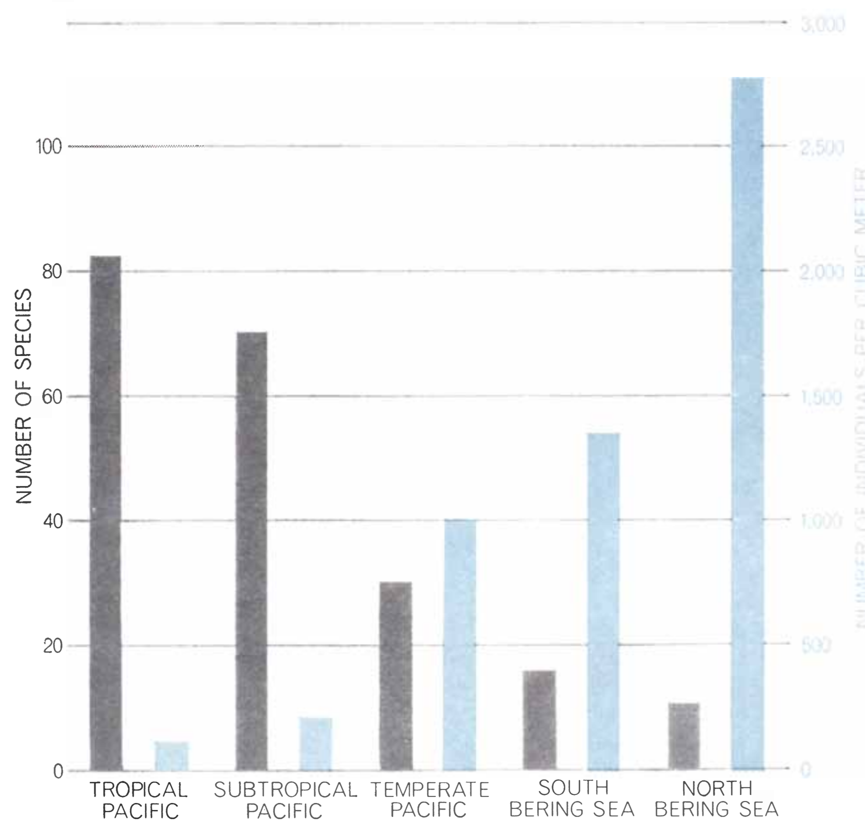
tion of the skua, which winters on the northward oceans.

The 11 petrels that breed in the Antarctic Zone represent 11 different genera, which in turn include every natural subdivision of the order, from great albatrosses to tiny storm petrels. The zonal ties of these birds, however, vary widely. Only the snow petrel (*Pagodroma*) is unequivocally restricted to Antarctica. Other species nest there but may migrate to milder zones or even beyond to the tropics. Such diversity has obvious evolutionary significance: the species that make the farthest seasonal departures, Wilson's petrel for instance, have temperate and subtropical relatives. The more exclusively Antarctic petrels belong to the group known as the fulmars, which in both north and south polar regions are associated with water of minimum temperature.

For food both the endemic forms and the seasonal invaders prey primarily on krill, squids and a scattering of other invertebrates; the snow petrel, however, regularly captures many small surface fish in the pack ice. Although the rigorous environment exacts a high egg and chick mortality among all of these birds, adult viability seems to be exceptionally favorable. Recoveries made after intervals of one or two years have many times shown banded petrels still linked with their former mates and nest sites. The hazards of predators, such as the skua, and the severe physical milieu are alike weighted heavily against immature stages of all Antarctic species. But a single egg, produced only once a year, is sufficient to maintain populations estimated to be among the largest in the class Aves.

Of the three Antarctic terns, one (*Sterna virgata*) barely merits the designation, having a limited range on islands south of the Indian Ocean. The second, the Antarctic tern (*Sterna vitata*), is truly Antarctic, nesting on many islands in the circumpolar ring and even on parts of the continent; it is a coastal and relatively landbound bird. The third is the Arctic tern (*Sterna paradisea*), which migrates southward when winter approaches in the high Northern Hemisphere latitudes and probably enjoys more annual daylight than any other animal. During the Antarctic summer it waxes fat on krill in the pack ice.

The occurrence of four endemic spe-



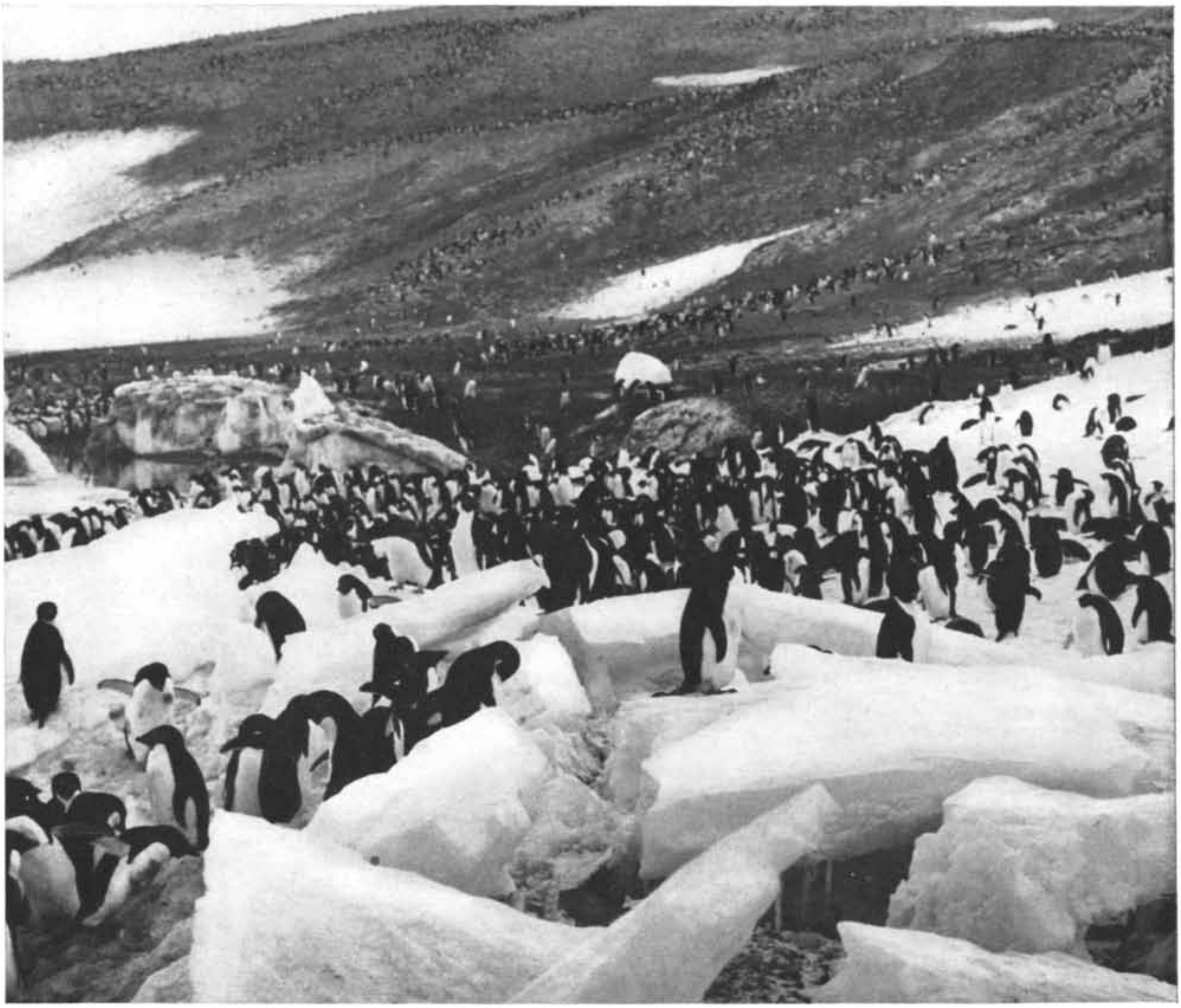
TEMPERATURE DEPENDENCE of species and numbers is illustrated by this chart based on a study by A. K. Brodskij of *Calanus*, a crustacean, in the Northern Hemisphere. As the water becomes colder the number of species found in the upper 50 meters decreases (*gray bars*), but the number of individuals in a given volume increases (*colored bars*).

cies of seal again suggests the isolation of the Antarctic through a prolonged period of evolutionary history. The Antarctic seals appear to be genetically remote from the northern seals and still more so from their neighbors just beyond the Convergence: the southern fur seals and sea lions. All four of the typically Antarctic seals belong to the family (Phocidae) of the common harbor seal. All the species have undergone the same evolutionary divergence committing them more completely to life in the sea, a divergence that is beautifully expressed in both structure and function. They cannot "gallop" on all fours when ashore; their hind limbs, their principal means of propulsion while swimming, are trailed when they are out of water, forming merely a tail end to the body. In forward movement on land or ice, however, the hitching of the forelimbs is augmented by eellike sinuations. One of the species, the leopard seal, even manages to wriggle along on a flat surface with its foreflippers appressed against its sides. All the species, incidentally, mate in the water.

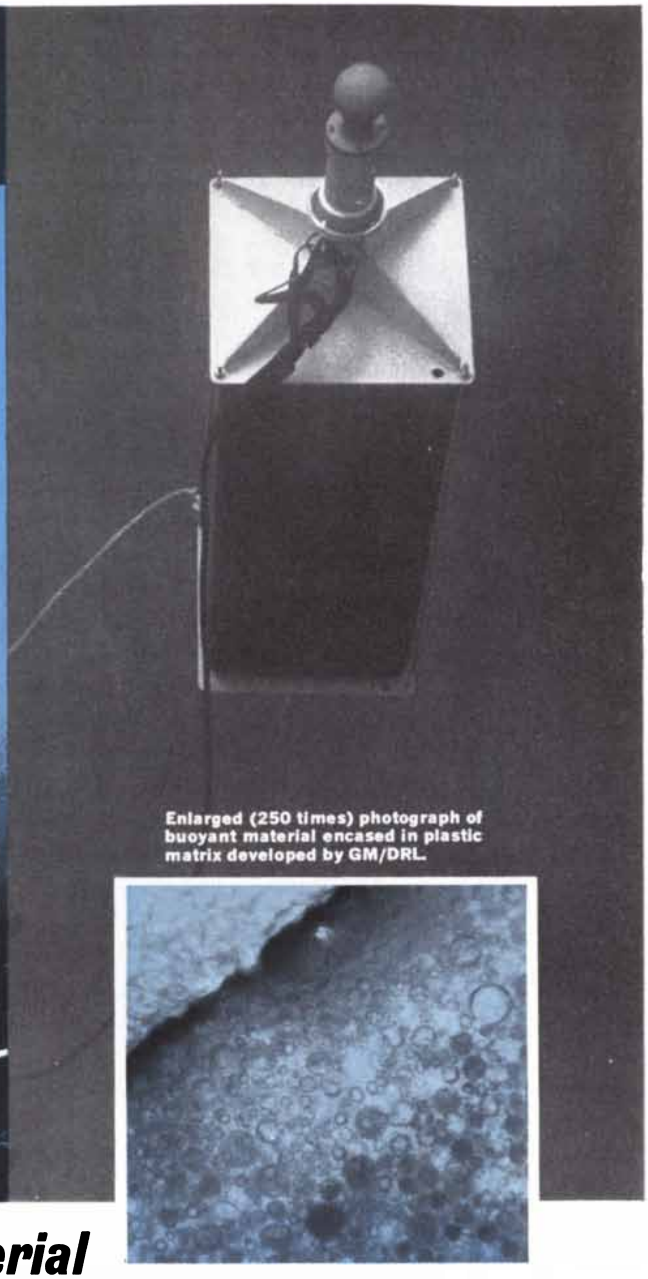
As oceanic rather than land animals, the Antarctic seals are circumpolar in distribution. But their ecological niches are so distinct that they completely escape interspecific competition. Only one of them, the crabeater seal, has a relatively large population. The rarest, the Ross seal, may total fewer than 50,000 animals.

The first seal to be expected on a southward voyage would be the leopard seal, named for its color pattern, its ferocity or both. This animal is a solitary, large-headed predator, its jaws armed behind the sharp canines with rows of magnificent tridentated teeth. It also has anatomical specializations for swallowing large gobbets of food, one of these being a flat, ribbon-like windpipe that takes up no room in its throat except when the animal is actually drawing breath. Primarily a devourer of penguins (I have taken 160 pounds of penguin remains from the stomach of a female leopard seal on South Georgia), the leopard seal has also been seen dismembering the young of other seals. It is chiefly an inhabitant of the outer pack ice but it follows the migratory Adélie penguins down to the ice foot of the continental coast. Females, larger than males, attain a length of about 13 feet.

Next on a southerly course would be the crabeater, more properly the krill-eater, seal. The bulk of its food is the same reddish euphausian that is the mainstay of Antarctic whales and birds. Its cheek teeth are imitation baleen: the



ADÉLIE PENGUINS congregate in large rookeries at the beginning of the Antarctic summer, hatch their eggs in December and remain ashore until the young can swim, in February. Then the Adélies move out to feed in the pack ice as the emperors come south.



Enlarged (250 times) photograph of buoyant material encased in plastic matrix developed by GM/DRL.

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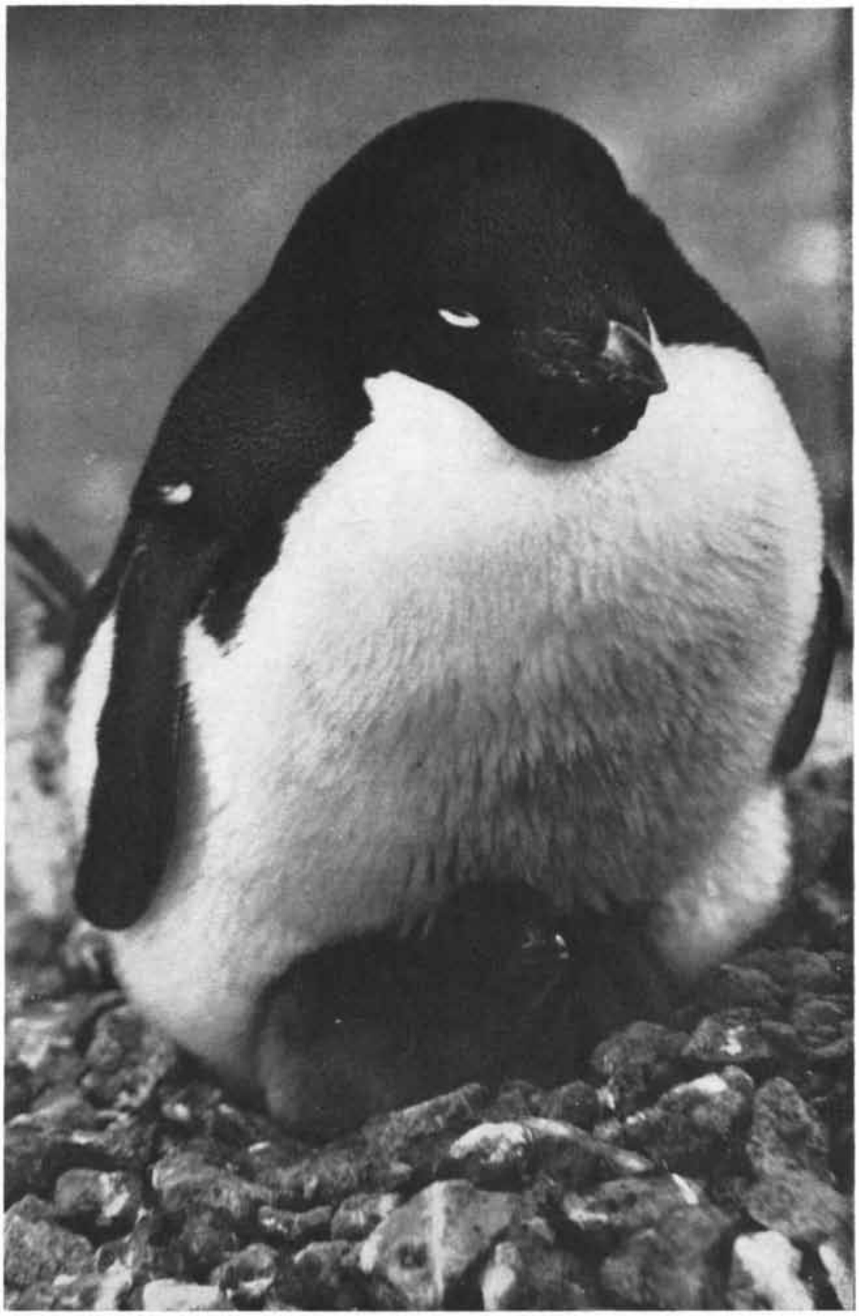

ADÉLIE PARENT shelters its chick beneath its warm body. Adélies prefer to build pebble nests on exposed or lightly snow-covered ground. Emperors incubate and hatch eggs on ice.

cusps interlock, forming a strainer functioning like that in the mouth of a whalebone whale. It can leap out of water like a penguin and it has a long conical head. Often met in big groups in the ice floes and usually reluctant to be stampeded from its basking place, the crabeater is the pack ice seal. Strangely, however, numerous bodies of crabeater seals have been found high up in the dry valleys on the continent of Antarctica, mummified by freezing and desiccation. Carbon-14 dating has recently shown some such examples to be more than 2,000 years old. A recent report by John H. Dearborn of Stanford University supports the opinion long held by George A. Llano, the author of the following article, that such carcasses chiefly represent young seals that had remained too late in autumn on the surface of the ice. When the leads froze over, they had no choice but to scatter aimlessly, gradually losing weight and starving. Those that died on the fast ice were rafted out to sea at the spring breakup; those that wandered inland left the famous and formerly puzzling mummies.

The Ross, or singing, seal (*Ommatophoca rossi*), named in honor of the Ant-

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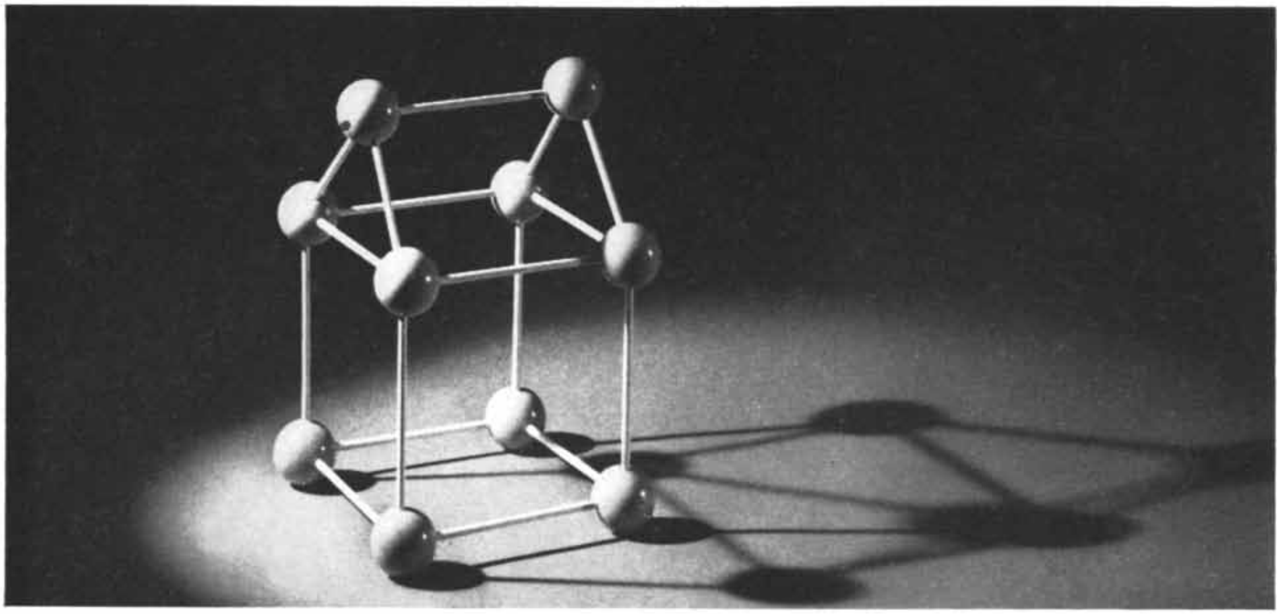

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arctic explorer James Clark Ross, is the rarest and least known of the Antarctic species. It is a creature of dense and tight pack ice and has almost never been found anywhere else. The smallest of the several south polar seals, attaining a length of about eight feet, it has a stout, turtle-necked appearance and its short head can be drawn backward more or less within the skin folds. Only a few score Ross seals have ever been observed and little has been learned directly about their life history. But the exceptionally large eye, the heavy, pressure-resistant

LEOPARD SEAL, a voracious enemy of penguins, cruises in the water near an ice floe (*top picture*). Adélies escape (*bottom picture*) by propelling themselves out of the water to the ice, where the seal cannot overtake them. Adélies can shoot as high as seven feet.

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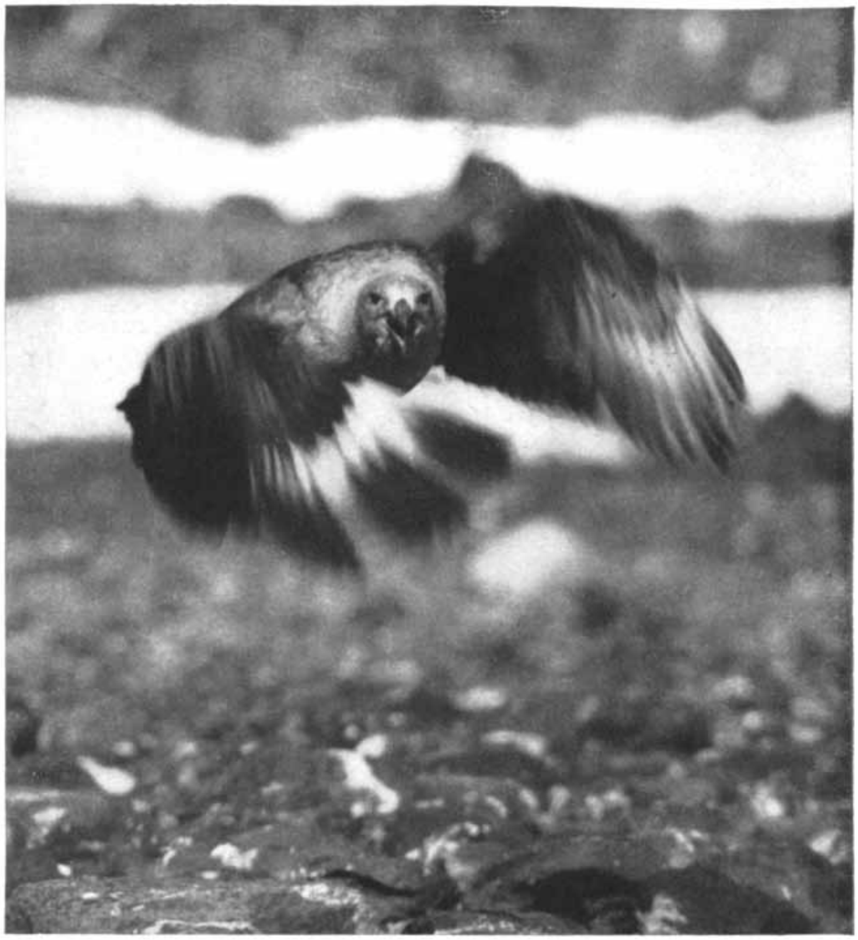

SKUA, called the eagle of the Antarctic, screams across a penguin rookery in search of stray chicks. Skuas start to breed in the Antarctic just as the Adélie chicks are being hatched.

construction of neck and thorax, the great size of both fore and hind flippers, and the reduction of the dentition to a series of curved, delicate and extremely sharp spikes enable one to surmise that it is a deep diver for the squids on which it mainly subsists. Squids, by the way, are the most numerous of all higher invertebrates in the ocean and several species are known only through examples recovered from the stomachs of sperm whales or seals.

The most polar seal of all is the Weddell seal, a denizen of the fast ice all around the continent. It is nonmigratory, remaining at high latitudes, except for stragglers, throughout the winter night. Its food consists of fish, together with squids and bottom invertebrates, which it must capture in the season of complete darkness as well as in the summer daylight. Edward Wilson, who died with Scott on the return from the South Pole, aptly matched the habits of the Weddell seal with those of the emperor penguin, whereas the crabeater could be likened to the Adélie penguin.

The canine and caniniform incisor teeth of this seal function as an extremely efficient saw for cutting through thick and flinty ice. It swings its head in a semicircle and splinters and pulverizes the ice below its snout. The water temperature in winter, only a degree or two below the freezing point of fresh water, is much higher than that of the atmosphere. The Weddell seals are able to keep "warm," therefore, by remaining submerged throughout much of the colder season. Their snorts and calls can be heard through the ice from air-filled chambers kept open with their circular saws. In common with most other seals they carry their unborn pups to a late stage of development; weaning and independence come at an earlier age than they do for most large mammals. The pups first enter the water when they are only about three weeks old.

Recently Carl R. Eklund of the Polar Branch of the Army Research Office and Earl L. Atwood, Jr., of the U.S. Fish and Wildlife Service have applied the technique of visual sampling and statistical analysis in an effort to estimate the populations of three of the Antarctic

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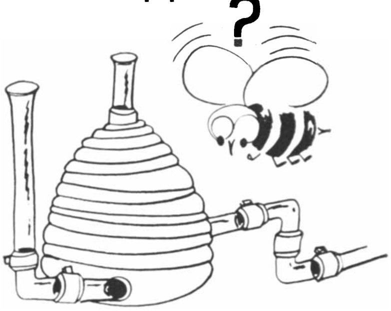
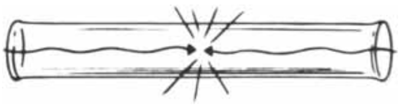


Bees, for example. They go in and out of indoor hives through glass pipe.



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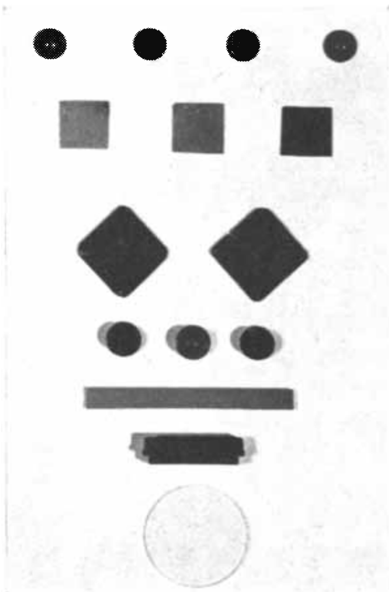

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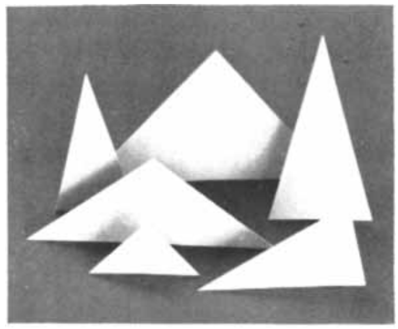

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seals, the leopard, Ross and crabeater. They conclude that the Ross seal population may be larger than hitherto suspected. The species clings, however, to areas of very dense pack ice, which, before the advent of modern naval icebreakers, had never been penetrated by ships. Eklund and Atwood tentatively find that Ross seals may make up .8 per cent of the total population of these three Antarctic species, leopard seals 2.2 per cent and crabeaters 97 per cent. Converted into demographic numbers, this would mean about 50,000 Ross

FROZEN REMAINS of large fish were found on the exposed ice of the Ross Ice Shelf in 1960. Carbon-14 dating established that the carcasses were about 1,100 years old. Apparently the fish had been trapped when ice touched the sea floor. As the bottom ice melted and the top was eroded by wind, the remains slowly worked their way up through 100 feet of ice.

LARGE FISH, a Nototheniid 52 inches long and weighing 58 pounds, was caught with the aid of a seal. The men were preparing to pull up a fish trap when a seal burst through a hole in the ice holding the fish in its mouth. The men, less surprised than the seal, got the fish.

seals, 150,000 leopard seals and between five million and eight million crabeaters.

Although whales range all the oceans of the world, the Antarctic is the region in which they are found in greatest abundance. It is also the home of a few kinds that are restricted or adapted to the peculiarly severe environment. Today whales constitute the chief commercial resource of the Antarctic. Overfishing has been rampant, in spite of earnest efforts toward international regulation. In a single season of the peak period, about 1937, more than 45,000 whales were killed south of the Antarctic Convergence.

Any doubt about the thoroughness of modern techniques of exploitation is dispelled by figures showing the successive reduction of one species after another, beginning with the humpback whale. The latter, a relatively small, fat and easily handled whale, at first made up nearly 100 per cent of the catch. It now constitutes less than 2 per cent. Today whales are taken on quota and during a limited season in "blue whale units," according to which each of the smaller species is assigned a ratio to the size of the biggest animal of all. The right whale, formerly the most valuable of the whalebone whales, has had to be given special international protection, and harpoon guns, or the still newer and more efficient electrocution, now bring the other major baleen species—the humpback, the sei, the finback and the blue—into the hold of the modern whaling ship. Female whales accompanied by calves are legally protected at all times.

All the species of the genus *Balaenoptera* filter crustaceans out of the water through their baleen. The sei whale, and to a certain extent the finback, also capture good-sized fish.

The entire lives of the southern whales are dominated by the seasonal breeding and feeding migrations. It is the presence of the richest of pastures that brings these giant animals to Antarctic waters, where they reach their peak numbers about February and are at a minimum in July and August. The Antarctic also nurtures a host of lesser cetaceans about which little is yet known. They include such baleen species as the little piked whale (*Balaenoptera acutorostrata*), beaked or toothed whales such as *Berardius bairdii*, the pygmy right whale (*Neobalaena*) and the ferocious killer whale (*Grampus orca*), the whale that is the predator of whales and other mammals of the sea.

GREEN ICE ALGA, one of the most common plants of Antarctica, is usually found on damp rocks. Here it is growing in clear ice.

RED SNOW ALGA gives a rosy tint to the snow fields above Wilkes Station. It grows only near open water and in melting snow.

YELLOW CRUSTACEOUS LICHEN (*Xanthoria*) grows near bird rookeries, forming bright patches on the nitrogen-enriched rocks.

ORANGE CRUSTACEOUS LICHEN (*Caloplaca*) also grows near bird rookeries. The growing edge forms arcs on the rock surface.

GRASS *Deschampsia* is one of three flowering plants on the continent. *Deschampsia* grows only along the Antarctic Peninsula coast.

BLUE-GREEN ALGA grows in spaced, bushlike clumps on sterile ground. Plant was photographed at Gneiss Point in Victoria Land.

The Terrestrial Life of the Antarctic

It is as poor as the oceanic life is rich. There are no terrestrial vertebrates and only three flowering plants. The fauna is made up of tiny invertebrates; the flora, of such primitive plants as lichens

by George A. Llano

The continent of Antarctica occupies most of the earth's surface enclosed within the Antarctic Circle. The corresponding portion of the Arctic is largely covered by water. Yet the Antarctic has far less to offer by way of terrestrial life, either plant or animal, than does the Arctic. The "friendly Arctic," as the explorer and anthropologist Vilhjalmur Stefansson called it, harbors more than 100 species of flowering plants, an abundance of lichens and mosses, a great variety of insects and land birds, and such terrestrial mammals as lemmings, hares, foxes, wolves, bears, caribou and musk oxen. Antarctica nurtures only three flowering plants and not a single land vertebrate. The penguins, sea birds and seals that come ashore on Antarctica must all be regarded as animals of the ocean, because that is where they find their food [see "The Oceanic Life of the Antarctic," by Robert Cushman Murphy, page 186]. The humble community of landbound life is closely dependent on the bounty of the sea. The principal source of nutrients for the algae, mosses and lichens that make up the vegetation of Antarctica is the excreta of birds that feed in the seas and nest on the land. On this vegetation feed springtails and certain mites. Here the food chain ends; there is no evidence that these lowly invertebrates are eaten by other organisms.

The terrestrial life of the Antarctic holds interest precisely because of its paucity and the simplicity of its life cycles. There are many questions to be answered about how living organisms manage to survive in this region at all. Both plants and animals subsist on a minimum of resources. They suspend their life processes, including the process of development, through the long periods when conditions are unfavorable, and they retain the capacity to revive and even to flourish in the fleeting periods when conditions become propitious. In the rigorous economy of the food chain, the Antarctic community presents a model for study of the interdependence of living forms that ties together every biological community. A full understanding of this remote province of life can only come with knowledge of the origin and relations and the past and present distribution of the existing organisms. Such investigation is bound to clarify the history of the continent through geologic time.

The first reason for the biological poverty of Antarctica is obvious. With the exception of the exposed peaks of mountain chains and some patches of bare ground near the coasts—in all, 3,000 square miles out of 5.5 million square miles—the land is completely and solidly encased in hard-packed snow and blue glacier ice. Elsewhere in the world some interchange of terrestrial plants and animals is carried on between continents by winds and ocean currents. Antarctica is largely excluded from this traffic because it is isolated by great masses of pack ice, fast ice and shelf ice, which persist throughout the year, and by the wide surrounding belt of deep, cold ocean. The winter temperatures on the continent are, of course, the coldest on earth. But even at the height of the Antarctic summer the ambient temperature at the most favorable localities still hovers around the freezing point. An even more severely limiting condition than the cold is drought—Antarctica is a desert. The region of heaviest precipitation, the Antarctic Peninsula, receives only 20 inches a year; the figure is much lower in other regions. Except on the peninsula, all the precipitation is in the form of snow; it is available to plant growth only when it is converted to the liquid state, and then it is subject to evaporation by the strong, dry winds.

It is clear, therefore, that the terrestrial environment of Antarctica is singularly unsuited for the growth of vegetation. Since plants, directly or indirectly, furnish the primary basis of animal life, the Antarctic fauna is correspondingly impoverished. Antarctica is the only continent that lies wholly outside the limit of the growth of trees. The tree line in the Southern Hemisphere terminates at about the 54th latitude, along the north shore of the Beagle Channel of Tierra del Fuego, some 700 miles north of the farthest northward extension of the Antarctic Peninsula. The only three flowering plants, the herb *Colobanthus crassifolius* D'Urville and two species of the grass *Deschampsia* (*D. parvula* and *D. elegantula*), are relatively recent invaders. They have gained a foothold only along the west coast of the peninsula from Hope Bay southward to Anvers Island, at the 64th latitude, which can be taken as the "flowering-plant line" of the Southern Hemisphere. At no locality within this range is any of these plants abundant. Compared with specimens seen on the Antarctic islands, the continental plants are stunted and rarely found in flower. The *Deschampsia* grasses grow throughout the sub-Antarctic, but their appearance in the South Shetland and South Sandwich islands has been attributed to the wide-ranging activities of the early 19th-century sealers who ravaged the rookeries of the fur seals on these islands.

The local topography, no less than general climatic conditions, has influenced the evolution and distribution of living things in the Antarctic. It is

DRY-VALLEY REGION in Victoria Land near McMurdo Sound is the largest stretch of ice-free land in Antarctica. It is, however, a desert, as hostile to life as the Antarctic ice. This photograph, made from a Navy aircraft flying at 15,700 feet above sea level, shows dry valleys on each side of a mountain range. Other dry valleys lie behind Taylor Glacier, which is at upper right. The tilelike formation on the soil in the foreground and in other parts in the photograph is called patterned ground. This formation, found in both the Arctic and the Antarctic, is produced by the action of frost in the upper layers of the soil. This action heaves the soil upward into regular polygonal patterns.

the peculiarity of physical relief that brings a mountain peak above the ice and frees a slope or valley of permanent ice and snow cover. Most of the open terrain appears in the Antarctic Peninsula, in the system of dry valleys of Victoria Land near McMurdo Sound and in the "oases" on the Antarctic coast facing the Indian Ocean.

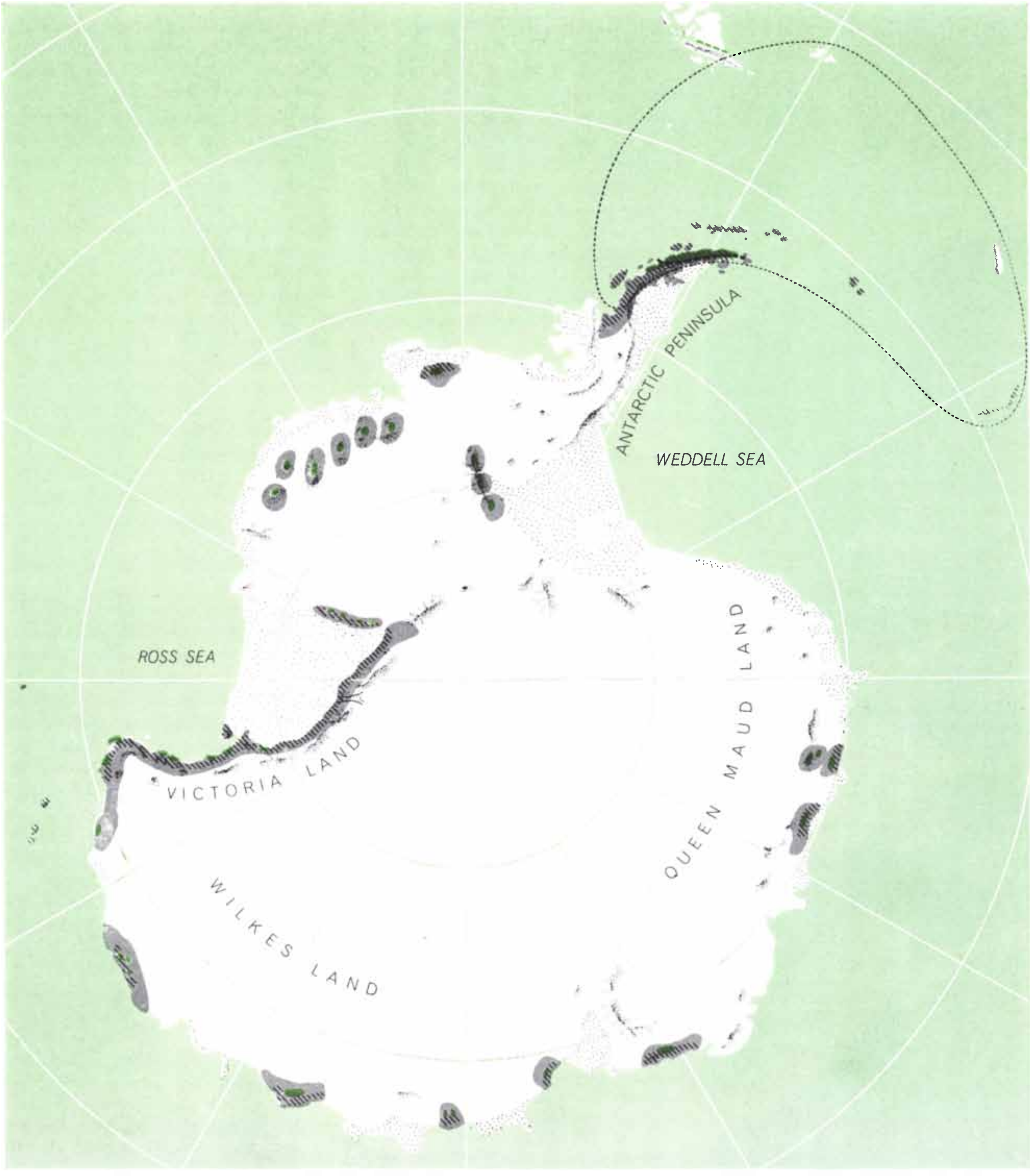
As the presence of the flowering plants suggests, the Antarctic Peninsula offers a climate less hostile to life. The terrain here is no better than it is in the rest of the continent; more than three-quarters of the region is overlain with snowdrift slabs and highland and glacier ice, which, on the east coast, joins with the shelf ice along almost the entire front facing the Weddell Sea. Even on the west coast, in spite of the prevailing westerly wind and ocean current, the total extent of shelf ice is considerable. Nonetheless there is water to encourage the growth of plants. On the outer tip of the peninsula, north of the 66th latitude, it rains and drizzles in most months of the year. Farther south the vegetation is irrigated by the runoff of melt water from the surrounding ice and snow during the austral summer.

The climate at McMurdo Sound is characterized by lower temperatures and much lighter precipitation, all in the form of snow. At the height of summer, from November through January, when the average daily hours of bright sunshine are longest, air temperatures have been known to rise not much more than two or three degrees centigrade above freezing. Across from Ross Island in the lee of the dominating Royal Society Range lie the largest contiguous stretches of bare land in all of Antarctica. This is the dry-valley region, 10 to 15 miles wide and at least 100 miles long, with a rugged relief, ranging from 3,000 feet to mountains as high as 13,000 feet. Throughout the valleys there are almost innumerable small and large alpine glaciers and a few outlet glaciers of the continental icecap that is contained behind the Royal Society Range. In spite of the fact that this ice-free west side of McMurdo Sound is a few degrees warmer than the windward east side, many of the massive blue-hard ice fronts barely show a trickle of water in midsummer. Light snowfalls on the upper slopes, however, leave an unmistakable snow line across the face of the mountains at about 3,500 feet above sea level; this soon vanishes when the snow melts away. Here, along the line of melt water, a few colonies of crustaceous lichens can be found. On the valley floors are scattered ice-covered lakes of various sizes, all showing evidence of evaporative shrinking and all more or less saline as a result. The pebbles, stones and boulders are faceted and polished, scarred, gouged and sculptured by the winds.

The deathlike silence of these arid, cold desert valleys is made the more poignant by the mummified carcasses of seals that one encounters here and there. These mysterious remains appear in sufficient number to rule out mere individual aberrant behavior. The mystery is deepened by the carbon-14 dating that shows them to be as much as 2,500 years old and by the finding that their resting places apparently mark the feet of glaciers that have long since retreated up the valleys.

Such soils as Antarctica affords for the growth of plants are mainly alkaline and composed of finely crumbled and unweathered rock and sand. Much of it shows no evidence of organic carbon except near bird rookeries, where guano and other nesting debris give the ground a distinct grayish coloration, or where decomposition below growing patches of mosses and lichens leaves a weak humus layer. The bacterial flora of such soil appears to be much the same as that found elsewhere in the world. It includes typical bacillary, coccal, spiral and filamentous forms. Since bacteria on dust particles air-borne from other continents may replenish the bacterial populations, it is not known to what extent the various species survive in the Antarctic milieu. Enough samples of ice and snow have been examined, however, to reveal that they persist even in this unfavorable habitat in detectable numbers. The presence of microorganisms typical of soils in temperate climates suggests that the Antarctic soils may sustain an organic cycle comparable to that of developed soils. During the summer season of 1961–1962 two important steps in the vital nitrogen cycle were demonstrated in the cold soils around McMurdo Sound with the isolation of two strains of nitrogen-fixing bacteria found also in the Arctic. The grass and the mosses support the usual epiphytic bacteria. Fungi are rare in Antarctica. Among the higher orders of life in the soils of certain areas are some of the tiny multicelled animalcules that are found in Temperate Zone soils, and even nematodes and some potworms.

Only on the Antarctic Peninsula is the continent's complete assemblage of plants to be found—the three flowering plants and three species of liverwort as well as numerous species of mosses and lichens. Some of the mosses have spread successfully around the coasts of the continent, and on occasion they even show up on the inland isolated peaks of the snow-buried mountains called nunataks. The greater dependence of the



DISTRIBUTION OF PLANT LIFE in Antarctica is shown on this map. Since the continent is still largely unexplored, the map can show only reports of scattered collections. It is known, however, that plant life is most abundant along the moister, warmer coast and mosses on moisture, however, limits their distribution, and they can be thought of as the oceanic element in Antarctic vegetation.

In sheer mass the algae are the most abundant plants in the Antarctic, and they grow on the open ground and in ice and snow as well as in water. One form of alga growth is seen, for example, along the sterile front of the Wilson Piedmont Glacier in Victoria Land, opposite McMurdo Station. From some distance away it looks like a shadow faintly outlining a drainage pattern from the base of a snowbank. On closer scrutiny the shadow resolves into a scattering of small, brittle, rosette-shaped clumps of blue-green algae, each bushlike growth spaced neatly from its neighbors. The whole effect reminds one of the manner in which chaparral grows in the Death Valley area of California. Another bright green form grows on damp rocks and is also observed growing in clear ice built up by the dripping of melt water from the rocks. In all some 10 genera of terrestrial algae have been identified in the McMurdo region; all appear to be typical of those found in alkaline soils in the temperate zones.

When conditions are just right, blooms of snow alga give their rosy hue to snow fields. This somewhat infrequent development requires that the snow be softened by the summer sun to the point where it begins to dissolve into many-branched streams. The alga in question appears to be restricted to the coasts; it has not been reported on the inland ice plateau nor does it appear when the snow remains firm and does not thaw. In January of this year many acres of snow on the Wilkes Land coast were tinted with the red snow alga.

The more familiar sort of aquatic algae put in their appearance in melt water

RANGE OF FLOWERING PLANTS *(DESCHAMPSIA, COLOBANTHUS)*

SOUTHERN LIMIT OF HEPATICS (LIVERWORTS)

ALGAE

TREE LINE

MOSSES

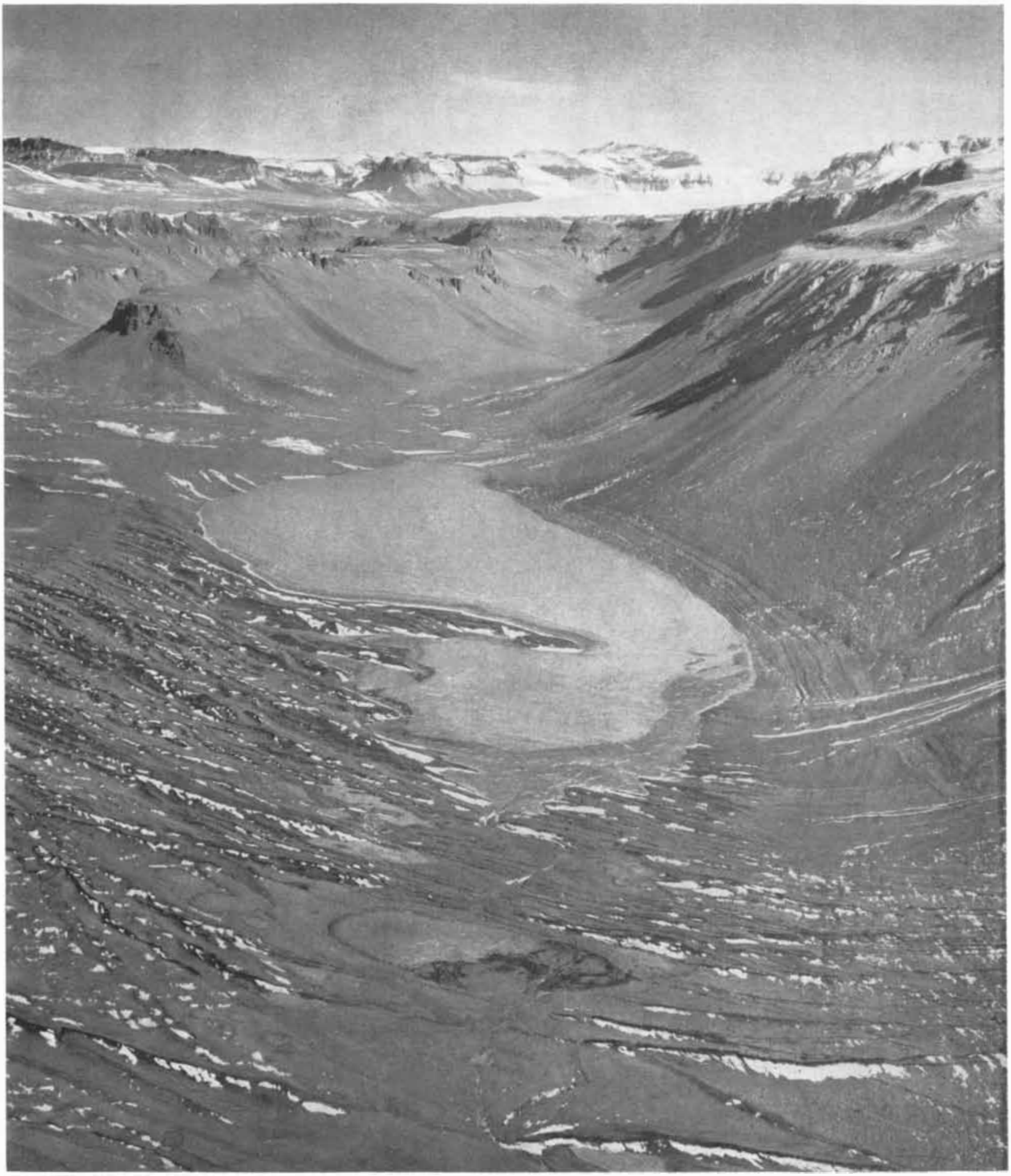
LICHENS

that the flowering plants are confined to the northern part of the Antarctic Peninsula.

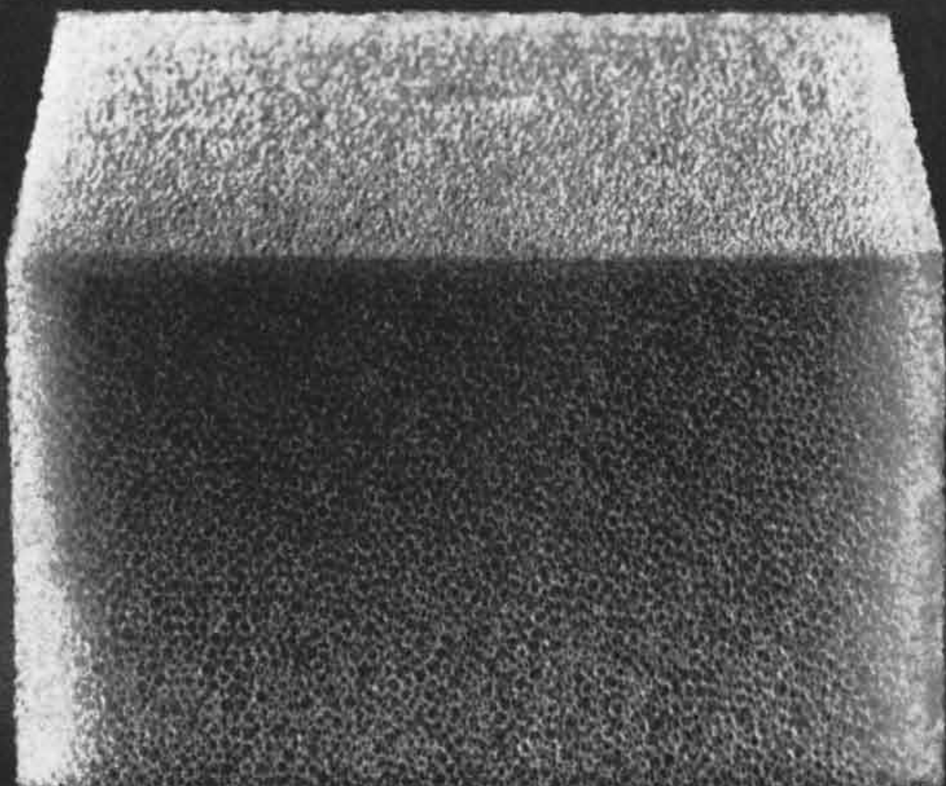
pools. On Seabee Hook near Cape Hallett, where the water from the snows on higher slopes is enriched with nitrogen and phosphate as it flows through and over the guano beds of the penguin rookery, one is struck by the paddy-like arrangement of the deep green, light green and blue-green algae-colored patches of water scattered among the higher, gray-tinted ridges that mark the successive stages in the growth of the hooked-bay beach.

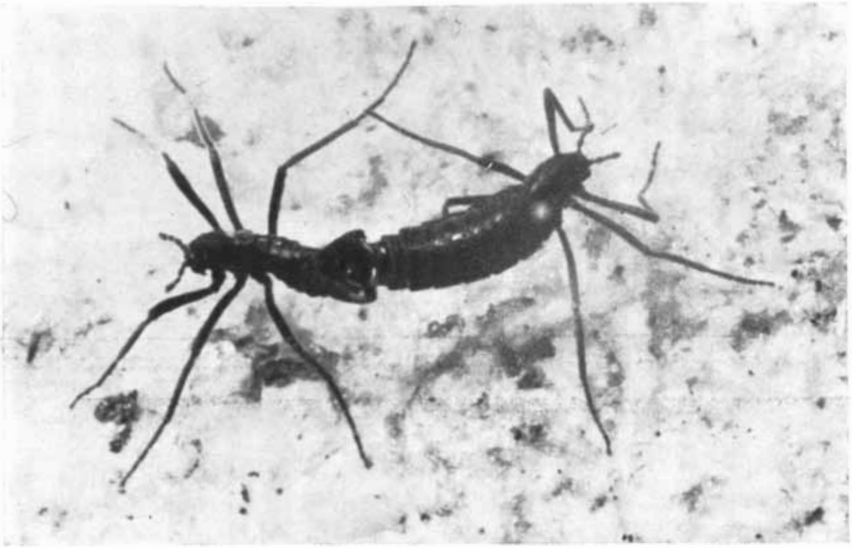
In general algae are tolerant of a wide variation in environmental conditions. Yet they do not always grow in the available fresh-water habitats, especially in the sterile dry-valley region. And there are hundreds of square miles of ice-free land too dry to support vegetation of any type, no matter how minimal its requirements.

The plant that best withstands the prevailing desiccation of the Antarctic climate is the lichen. Indeed, lichens



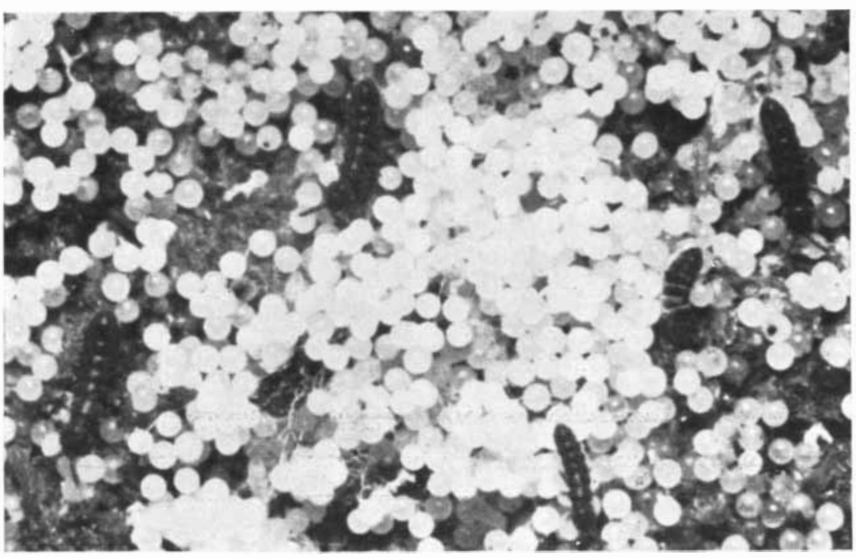
LAKE VANDA in Wright Valley is typical of Antarctic dry-valley lakes. It is covered with ice and highly saline and therefore cannot support plant or animal life. The lake is gradually shrinking in size, as indicated by the terracing along its right-hand shore.





WINGLESS FLY ***Belgica antarctica*** **is the largest terrestrial animal on the continent. It lives on rocks in ice-free areas. Magnification in these three photographs is 20 diameters.**

FREE-LIVING MITES also live on exposed rock surfaces. Both the flies and the mites were photographed on the Antarctic Peninsula. The insects also inhabit areas farther inland.



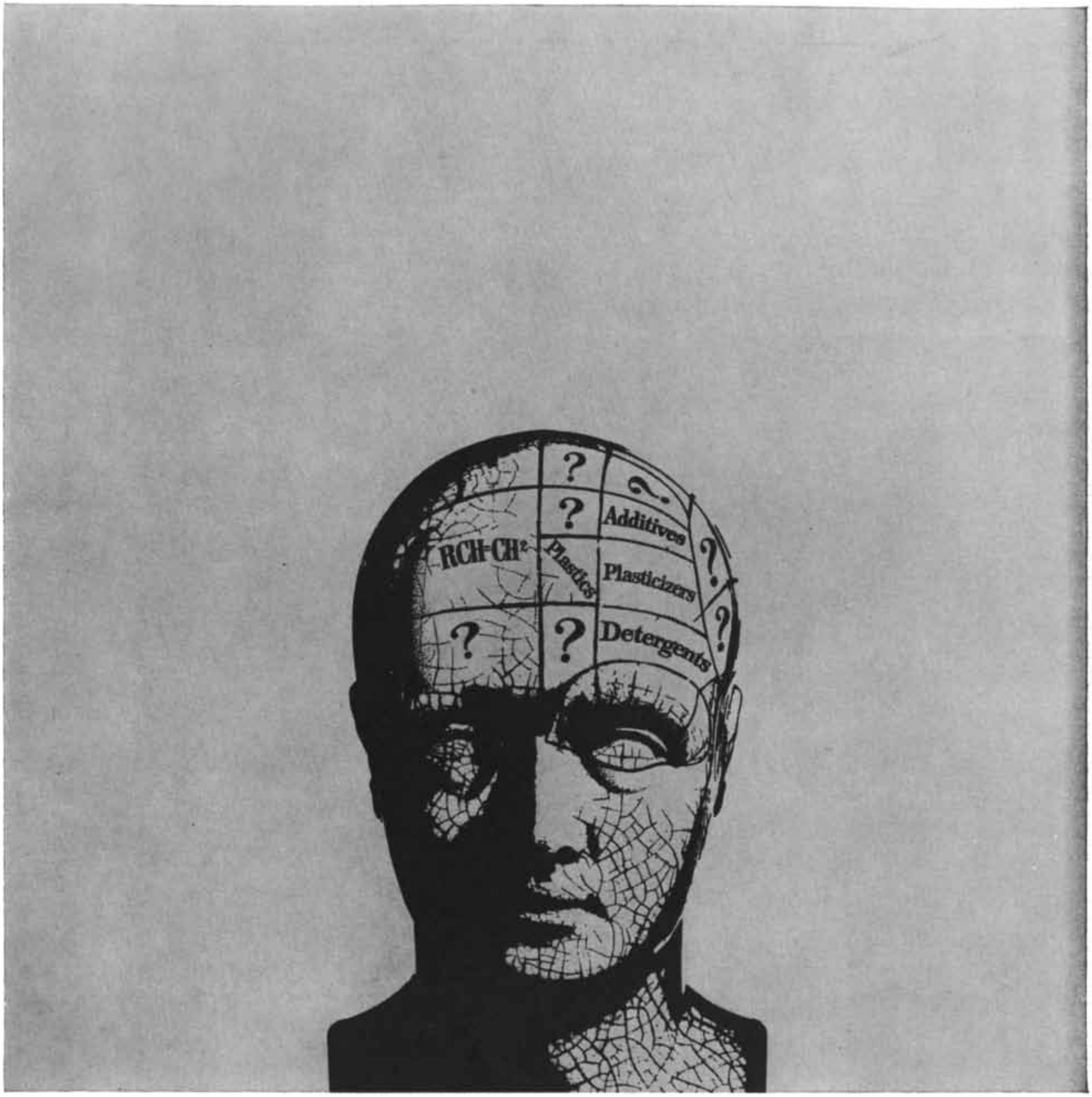
SPRINGTAILS (*Collembola*) were found on Deception Island. Round objects are eggs. These three pictures were made by R. E. Leech of Bernice P. Bishop Museum in Hawaii.

grow even on the inland peaks and have been reported within a few degrees of the geographic pole. They mark the inner limit of life on the frozen continent. Whether exposed to the extreme of cold or of drought, the lichens are able to survive because they can persist in the dormant state for long periods. In order to succeed and spread, however, they must still be able to grow, and their metabolism, no less than that of other living organisms, requires some fluids and nutrients. The variation in the lichen vegetation of Antarctica over even small areas is striking and illustrates the response of these plants to the occasional cover of snow that, on melting, provides the only source of moisture and to tiny amounts of nutrient derived from the excreta of birds and carried as dust particles for long distances on the wind.

Among the many variables on which the life of the lichens depends, it is surprising to realize that the supply of heat is reasonably dependable. Paul A. Siple of the Army Research Office observed that the dark rock of inland nunataks near the Rockefeller Mountains on which he found lichens growing absorbed considerable heat in the course of the long polar days. In the Horlick Mountains, four degrees from the geographic pole, it was found that rock temperatures soared within three hours from −15 degrees centigrade (5 degrees Fahrenheit) to 27.8 degrees C. (82 degrees F.). Thus when the sun shines, these polar plants are immersed in a microclimate not much different from a warm summer's day in the Temperate Zone, a microclimate that is contained entirely within the layer of warm air that lies immediately above the rock.

The Haupt nunataks on the coast of Wilkes Land barely rise above the ice. They suggest the general condition that may have prevailed throughout Antarctica during the Pleistocene epoch. Most of the rocks are flush with the surface and are surrounded by hollows where the heat absorbed by the rock has melted away the snow immediately adjacent, leaving each rock surface separated from the snow by a small air space. Practically all the rock thus exposed is covered with lichens. The growth extends below the level of ice, out of the wind, moist with seepage from blown snow particles that fall on the warming rock and appropriately lighted and temperature-controlled by the encasing "greenhouse" of translucent ice and snow.

The Antarctic lichens belong to families with wide distribution around the



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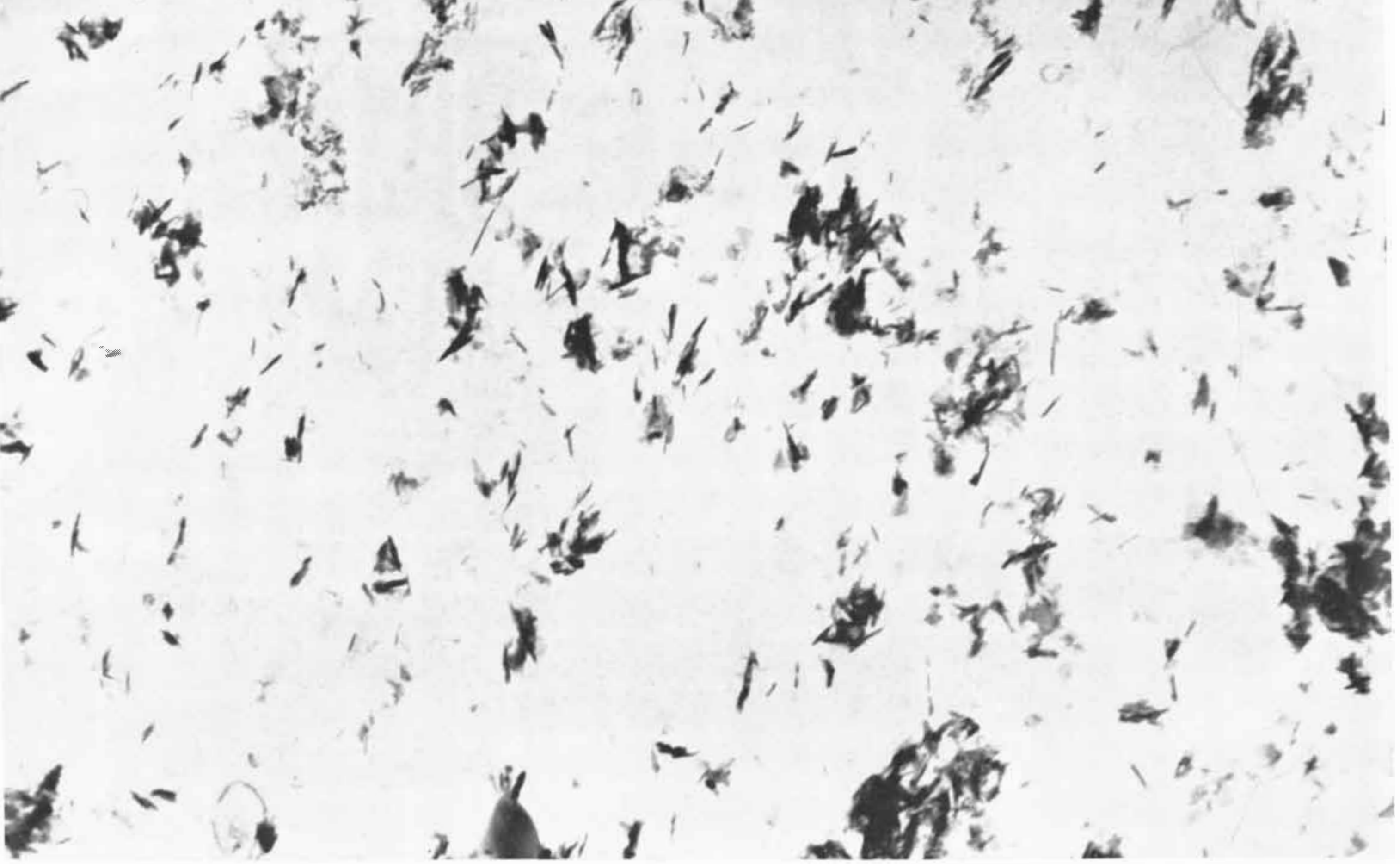
globe. They serve therefore as useful indicators of the relation between the vegetation of Antarctica and the rest of the Southern Hemisphere. They may also provide clues to the origin of the present plant life of the continent. Do the lichens of today represent a stock that has persisted in protected refuges on the seventh continent throughout the ice age? Or are they recent newcomers from ice-free periglacial regions that invaded Antarctica from other continents as the ice withdrew during intervening warm periods? Some Antarctic lichens must be between 500 and 1,000 years old, as indicated by their size and estimated or observed rate of growth, but this does not answer questions that involve truly geologic time periods.

Still another realm of terrestrial Antarctic life, as yet little explored, is that contained in the fresh-water ponds. Many of the ponds found inland are permanently ice-covered; others thaw out completely only during the height of summer. The ponds that remain frozen into the summer season often contain appreciable quantities of a coarse green alga embedded in the ice and visible to some depth. When the individual strands come close to the surface, the dark stems and thallus absorb enough light to melt small pools of water. The tip of the plant may therefore lie in a miniature aquarium no larger than a half-dollar, pliant, revived and to all appearances photosynthetically active. Paradoxically the high light intensity at the peak of the growing season often appears to be a severely limiting factor for the biological activity of the plants, which must compress a year's growth cycle into the brief span of the summer's melting.

Many of the ponds in the coastal areas are shrinking in size. The former levels of the impounded waters can be traced by the succession of miniature terraces composed of dried and soil-compacted algae blown into windrows along the old margins of the ponds. Carbon-14 dating of such alga deposits

ANTARCTIC HERB (*Colobanthus crassifolius* D'Urville) was found in blossom on the Antarctic Peninsula about 20 years ago and is preserved in a herbarium specimen at the New York Botanical Garden. The roots can be seen in soil in which plant is embedded.



Typical aluminum powder metallurgy alloy dispersoids are so fine they require 25,000X magnification to examine.

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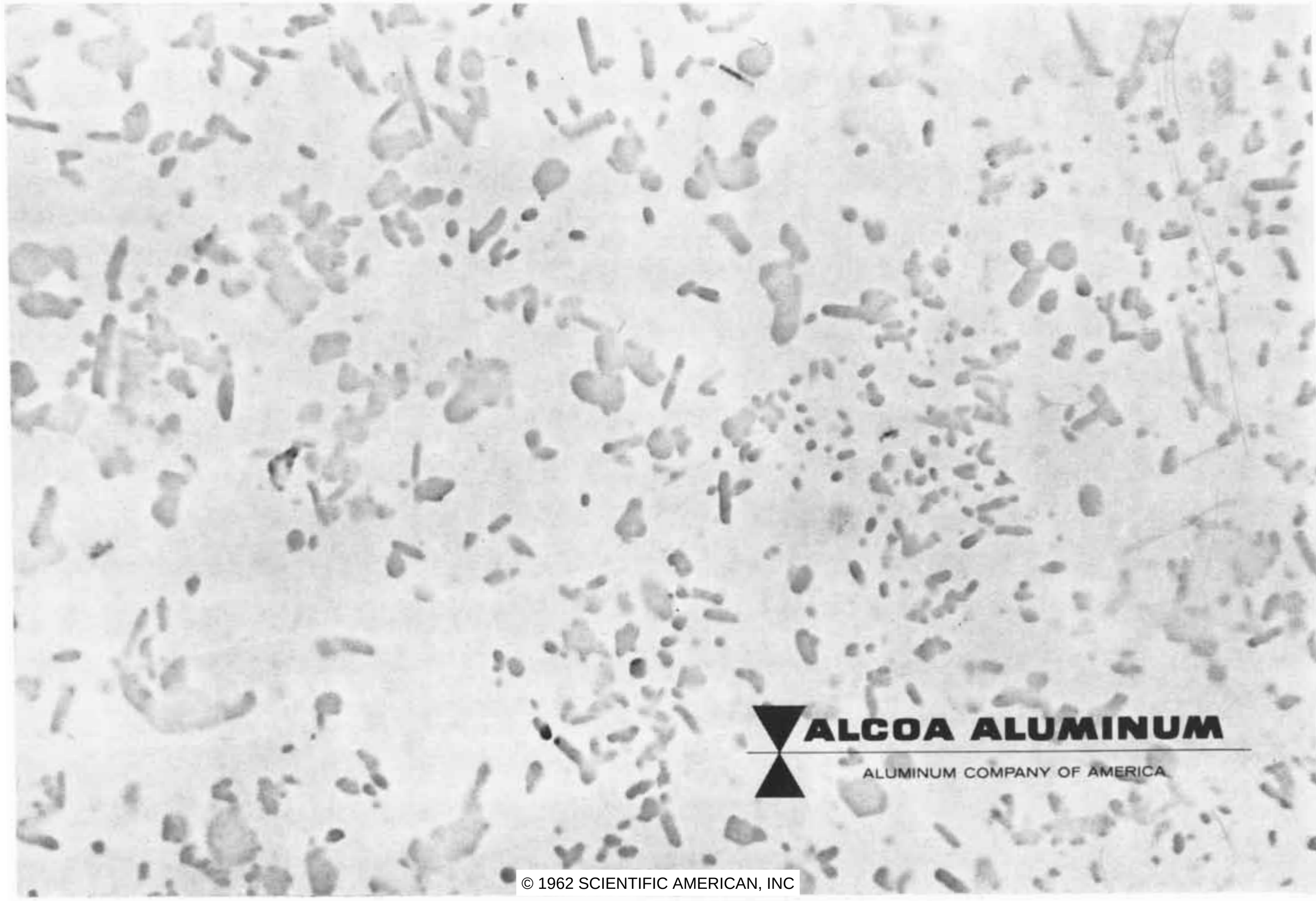
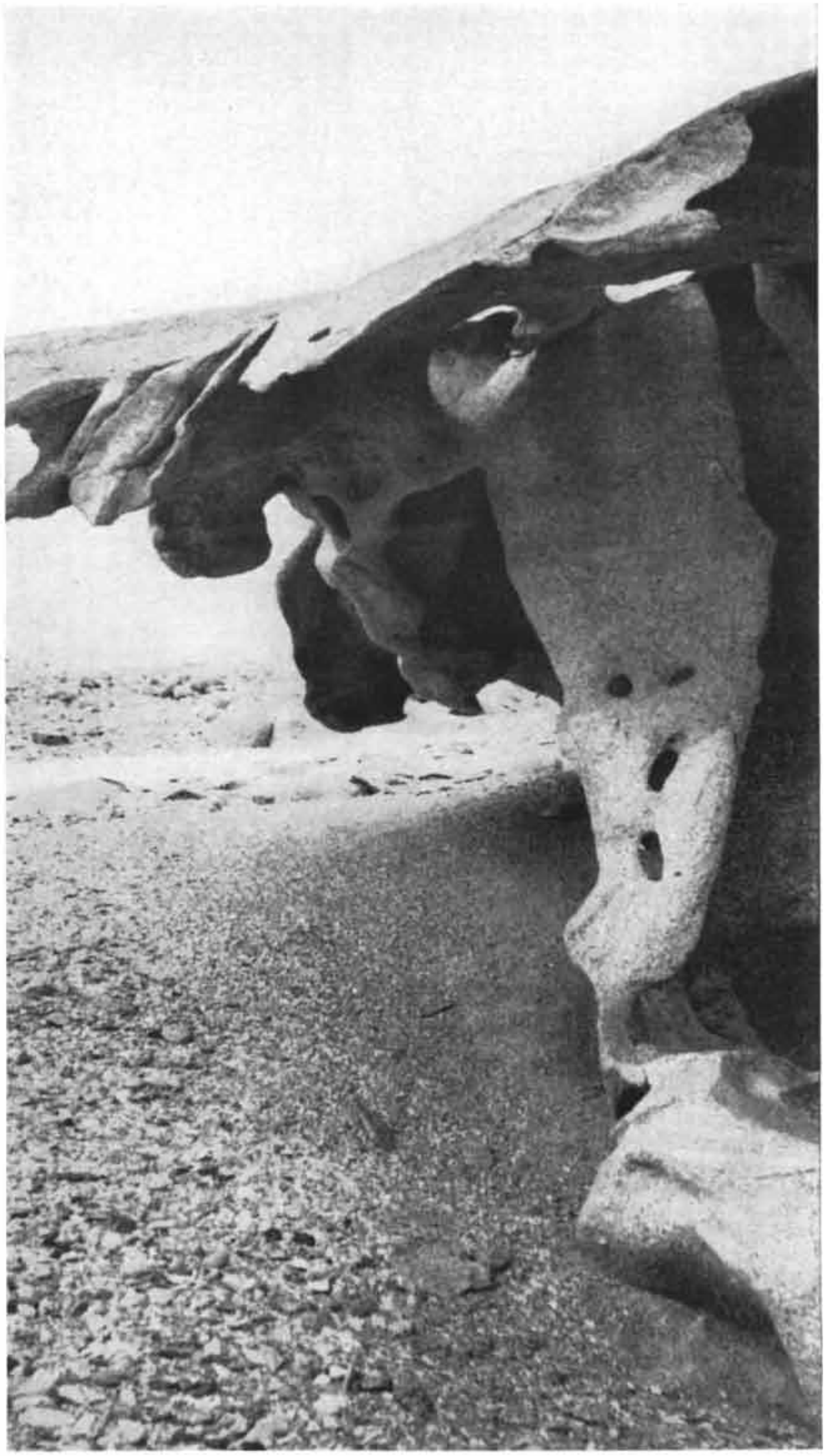


in Victoria Land indicate a minimum age of 6,000 years.

Skuas frequently congregate on and about the open fresh-water ponds, where they can be seen bathing and swimming. As a result the birds contribute appreciable quantities of organic nitrogen and salts to the water. The measurable change in the salt concentration apparently raises the melting point in addition to increasing the biological productivity of the water. The organisms of the fresh-water habitats follow the same pattern of kind and number so apparent among the plants and animals of the sea, which is characterized by large numbers



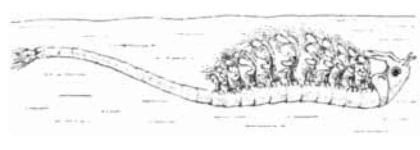
STRANGELY ERODED ROCKS, like this one in Taylor Valley, are common in Antarctic dry valleys. Wind-blown quartz particles produce the formations in less than 1,000 years.

of a few kinds. Diatoms and the coarser multicellular green and blue-green algae are the primary sources of food on which the bacteria and larger microscopic animals depend. In the somewhat saline ponds of the Wright Valley the presence of sulfate-reducing bacteria has been demonstrated; these organisms carry on the sulfur cycle by precipitating iron sulfide in the presence of organic matter supplied by algae. On the next level of the food chain, the fresh-water communities show a modest diversity of pond life: single-celled protozoa and multicelled rotifers (wheel animalcules) and tardigrades (water bears), threadworms and flatworms. These micrometazoans are principally bottom feeders, mostly entangled among the filamentous algae that settle to the bottom in mats or drift in windrows into the shallows. The rotifer *Philodina gregaria* occurs in great numbers, packed in patches one rotifer thick and clearly visible as brilliant red areas on the bottom, growing even under a relatively thick ice cover. One species of rotifer inhabits the salt ponds.

Antarctic fresh-water ponds have no snails, insects or fish. The melt water pools of the Antarctic Peninsula and the oasis lakes, however, support a tiny shrimplike crustacean; this ranks as the highest form of aquatic animal life on the continent.

On the land, insects and arachnids constitute the highest form of native life. Some 50 species have been identified, principally ticks, lice, mites, springtails and a wingless fly. About half of the species are parasitic; they include the biting lice and parasitic mites found on birds and the sucking lice found on seals. These can be disregarded in the count of the true inhabitants of Antarctica, since their whole existence is given to the body of the host they attend.

Among the remainder the fly *Belgica antarctica*, barely a half-centimeter in length, is the largest terrestrial inhabitant of Antarctica. It breeds in the brack-



FAIRY SHRIMP (*Branchinecta granulosa* Daday) is the only fresh-water crustacean in the Antarctic. The animal is drawn 13 times its actual size from a specimen collected in a melt water pool on Lagotellerie Island.

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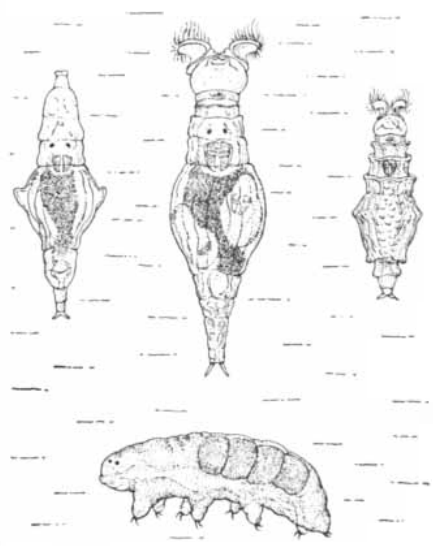
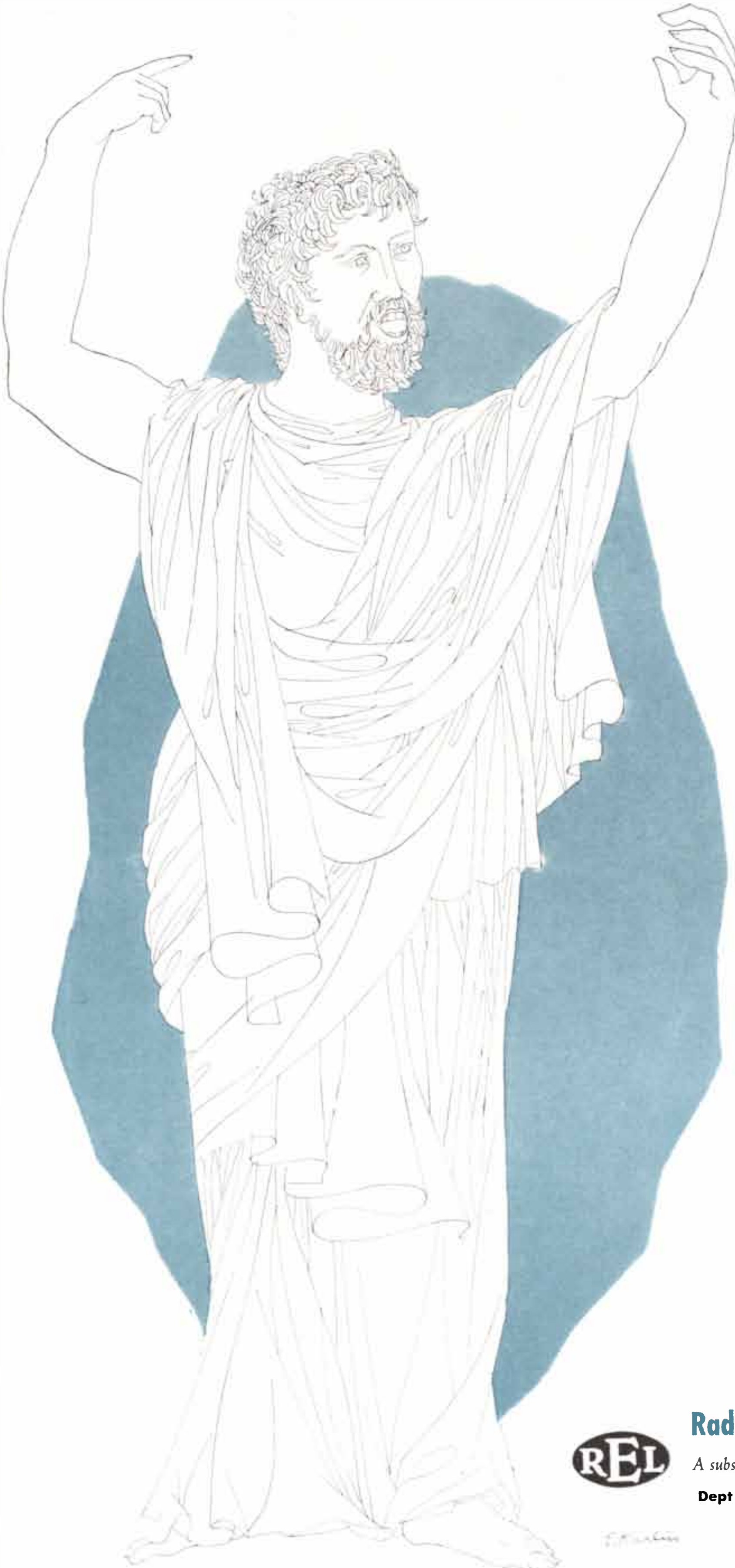
Recomp

Recomp is a product of Autonetics Industrial Products · Autonetics is a Division of North American Aviation ish coastal pools of the Antarctic Peninsula and is known also in corresponding habitats of Tierra del Fuego and the continent of South America. The most numerous and widespread organisms are the springtails, or *Collembola,* and mites, the distribution of which appears to be largely guided by the winds. Springtails and mites have been collected from sea level to 1,800 meters (6,000 feet) at the 77th latitude, where winter temperatures go as low as –65 degrees C. (–85 degrees F.) for long periods, and as far inland as the 84th latitude. Springtails turn up in all kinds of soil but are more often associated with mosses than with lichens. Mites seem to be particularly tolerant of low temperatures and have been found farthest from the coast and highest in latitude. Neither mites nor springtails are found in the dry valleys or in other locales of comparable cold and dryness. They become active when the sun warms up the rocks under which they congregate, in avoidance of direct exposure to the bright light of the continuous polar summer days. As Ove Wilson of the University of Lund observed, the habitat under the stones "is sometimes the warmest spot in the world of the mite, and that seems to be the deciding factor, because the metabolism can start only at a certain temperature." The Antarctic springtails and mites show no seasonal growth or breeding periods. When it turns cold, they become dormant at whatever stage of development they have reached and remain so until



MICROSCOPIC ANIMALS found in Antarctic fresh-water pools include several species of rotifer, seen at the top of this drawing, and of tardigrade, seen at the bottom. The drawings are 130 times actual size.



HE SPOKE FOR THE CAESARS AND THE CENTURIES

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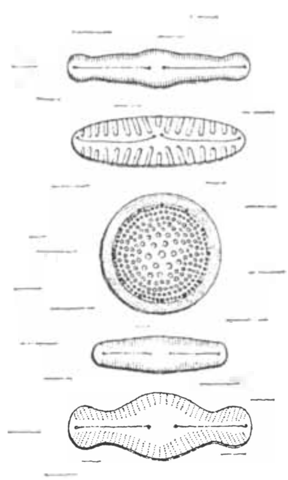
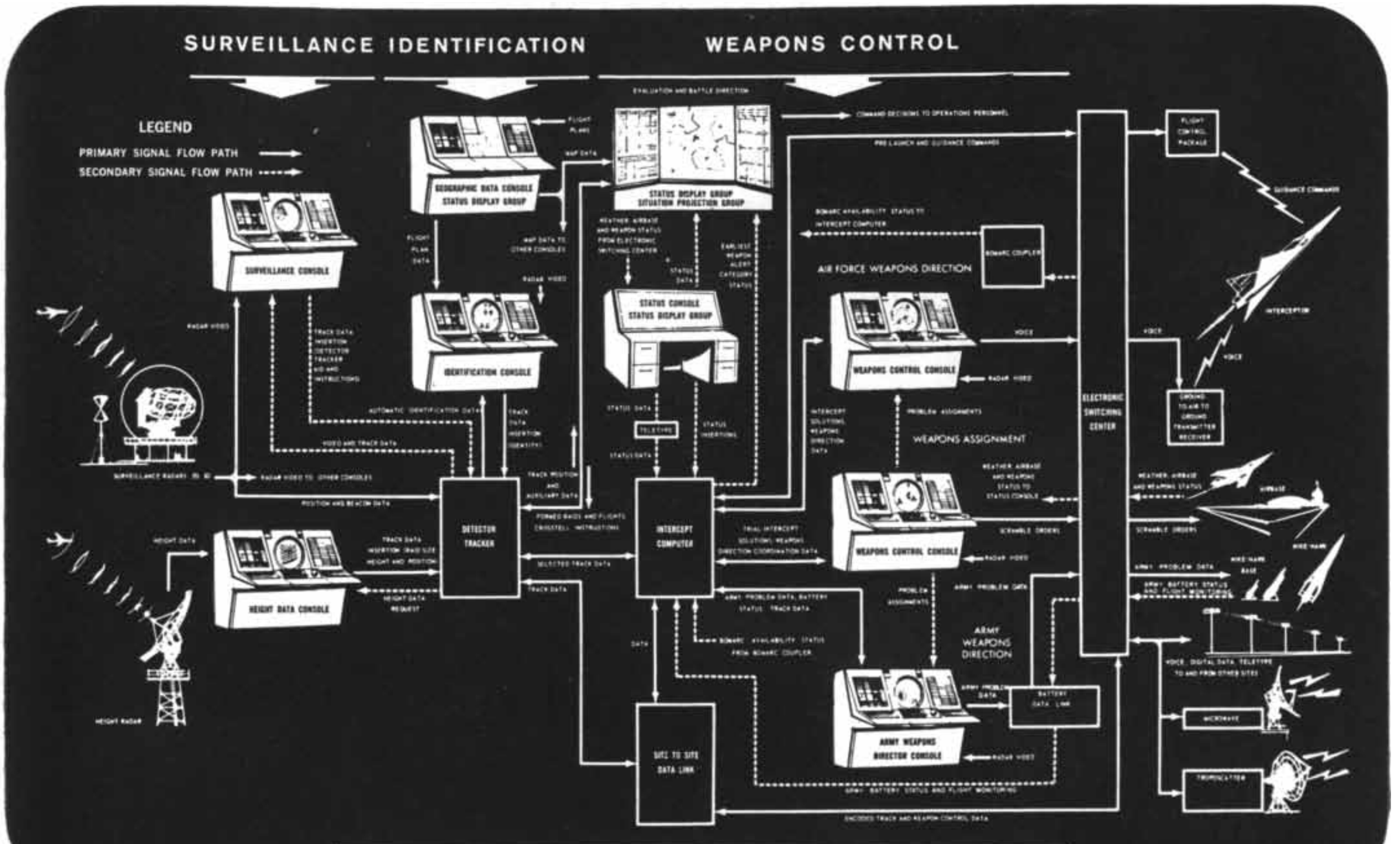
the warming rocks revive them into activity.

Man has not yet succeeded, by either accident or design, in introducing a new plant or animal into Antarctica, nor does it appear that the experiment would succeed under the environmental conditions now prevailing on the continent. In the complete absence of vegetation, the hardy Mongolian ponies brought by Scott and his company to Antarctica could not have survived without the care of their handlers. Dogs have been imported to haul sledges; when they are allowed to run loose, they terrorize the penguins, whose utter unfamiliarity with this kind of enemy makes them easy prey. But dogs make almost no impression on the tough-hided Weddell seal and would probably come off second best in an encounter with the leopard seal. In 1958, when the Japanese expedition hurriedly withdrew from Showa Station, 15 sledge dogs were left behind. The following year's expedition found only two of the animals still alive; the other 13 may have fallen down crevasses, been carried out to sea on ice floes or been eaten by the survivors. Cats have appeared at one time or another in Antarctic camps but none have turned feral; this has happened on some sub-Antarctic islands, where the cats subsist on introduced mice and rats and native birds. The rat, already counted as a pest in the islands, has yet to be reported on the continent, even in the environs of the year-round stations. On the other hand, as long as men in the more favorable climates of the world foster science, it appears that man must be counted as a new permanent denizen of the Antarctic.



FRESH-WATER DIATOMS found in Antarctica are drawn 1,200 times actual size. These specimens are from Cape Adare.

Engineers & Scientists



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MATHEMATICAL GAMES

Tests that show whether a large number can be divided by a number from 2 to 12

by Martin Gardner

A dollar bill that I have just taken from my wallet bears the serial number 61671142. A schoolboy could say at once that this number is exactly divisible by 2 but not by 5. Is it divisible—from now on the word will be used to mean divisible without a remainder—by 3? By 4? By 11? Few people, including many mathematicians, know all the simple rules by which large numbers can be tested quickly for divisibility by numbers 1 through 12. The rules were widely known during the Renaissance, before the invention of decimals, because of their usefulness in reducing large-number fractions to lowest terms. Even today they are handy rules for anyone to know. For a devotee of digital puzzles the following rules are indispensable.

To test for 2: A number is divisible by 2 if and only if the last digit is even.

To test for 3: Sum the digits. If the result is more than one digit, sum again and continue until one digit remains. This final digit is called the digital root of the number. If it is a multiple of 3, the number is divisible by 3. If it is not a multiple of 3, its excess over 0, 3 or 6 is the same as the remainder when the original number is similarly divided. Example: The serial number of the bill has a digital root of 1. Therefore when the number is divided by 3, the remainder will be 1.

To test for 4: A number is evenly divisible by 4 if and only if the number formed by its last two digits is divisible by 4. (This is easy to understand when you reflect on the fact that 100 and all its multiples are evenly divisible by 4.) The dollar bill's serial number ends in 42. Because 42 has a remainder of 2 when divided by 4, the serial number, when divided by 4, will have a remainder of 2.

To test for 5: A number is divisible by 5 if and only if it ends in 0 or 5. Otherwise the last digit's excess over 0 or 5 equals the remainder.

To test for 6: Test for divisibility by 2 and 3, the factors of 6. A number is divisible by 6 if and only if it is an even number with a digital root divisible by 3.

To test for 8: A number is divisible by 8 if and only if the number formed by its last three digits is divisible by 8. Otherwise the remainder is the same as the remainder when the original number is divided by 8. (This rule holds for all powers of 2. A number is divisible by 2^n if and only if the last n digits form a number divisible by 2^n.)

To test for 9: A number is divisible by 9 if and only if it has a digital root of 9. If not, the digital root equals the remainder. The serial number of the bill has a digital root of 1, therefore it has a remainder of 1 when divided by 9.

To test for 10: A number is divisible by 10 if and only if it ends in 0. Otherwise the final digit equals the remainder.

To test for 11: Take the digits in a right to left order, alternately subtracting and adding. Only if the final result is divisible by 11 will the original number be divisible by 11. (It is assumed that 0 is divisible by 11.) Applied to the number on the bill, $2 - 4 + 1 - 1 + 7 - 6 + 1 - 6 = -6$. The final figure is not a multiple of 11, therefore neither is the original number. To determine the remainder, consider the final figure. If it is less than 11, and positive, it is the remainder. If it is negative, add 11 to find the remainder. If the final figure is more than 11, reduce it to a number less than 11 by dividing by 11 and putting down the excess. If the excess is positive, it is the remainder you seek; if it is negative, add 11. (In the example, $-6 + 11 = 5$. This tells you that the bill's number, divided by 11, has a remainder of 5.)

To test for 12: Test for 3 and 4, factors of 12. The number must meet both tests to be divisible by 12.

The reader has surely noticed a singular omission from the foregoing rules. How does one test for 7, the divine number of medieval numerology? It is the

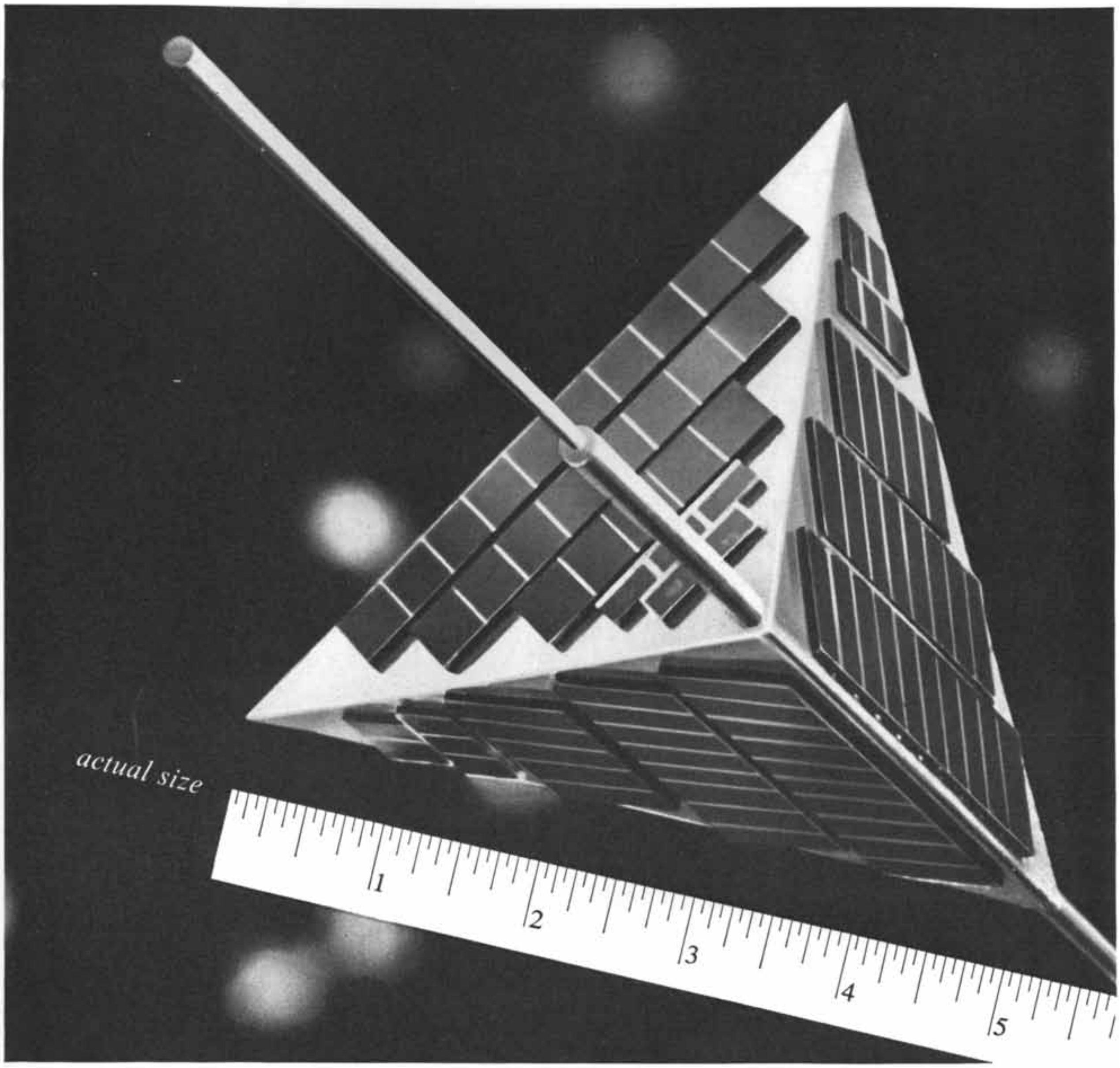
only digit for which no one has yet found a simple rule. This disorderly behavior on the part of 7 has long fascinated students of number theory. Dozens of curious 7 tests have been devised, all seemingly unrelated to one another; all, unfortunately, are almost as time-consuming as the orthodox division procedure.

One of the oldest of such tests is to take the digits of a number in reverse order, right to left, multiplying them successively by the digits 1, 3, 2, 6, 4, 5, repeating with this sequence of multipliers as long as necessary. The products are added. The original number is divisible by 7 if and only if this sum is a multiple of 7. If the sum is not a multiple, its excess over a multiple of 7 equals the remainder when the original number is divided by 7. This is how the method is applied to the number on the bill:

$$\begin{array}{r} 2 \times 1 = 2 \\ 4 \times 3 = 12 \\ 1 \times 2 = 2 \\ 1 \times 6 = 6 \\ 7 \times 4 = 28 \\ 6 \times 5 = 30 \\ 1 \times 1 = 1 \\ 6 \times 3 = 18 \\ \hline 99 \end{array}$$

Ninety-nine divided by 7 has an excess of 1. This is the remainder when the bill's number is divided by 7. The test can be speeded up by "casting out 7's" from the products: writing 5 instead of 12, 0 instead of 28 and so on. The sum will then be 22 instead of 99. The test is really nothing more than a method of casting multiples of 7 out of the original number. It derives from the fact that successive powers of 10 are congruent (modulo 7) to digits in the repeating series 1, 3, 2, 6, 4, 5; 1, 3, 2, 6, 4, 5... (Numbers are congruent modulo 7 if they have the same remainder when divided by 7.) Instead of 6, 4, 5 one can substitute the congruent (modulo 7) multipliers −1, −3, −2. The interested reader will find it all clearly explained in the chapter on number congruence in *What Is Mathematics?* by Richard Courant and Herbert Robbins. Once the basic idea is understood it is easy to invent similar tests for any number whatever. For example, to test for 13 we have only to note that the powers of 10 are congruent (modulo 13) to the repeating series 1, −3, −4, −1, 3, 4... This series is applied to a number in the same manner as the series in the test for 7.

What series of multipliers results when we apply this method to divisibil-



The world's smallest satellite has been developed by Space Technology Laboratories. Its shape will be different from all other satellites before it. STL engineers and scientists have used a tetrahedral configuration to bring about some remarkable characteristics in a space vehicle. There will be no need for batteries nor regulators in flight. The satellite will have no hot side, no cold side. It will require no attitude control devices. No matter how it tumbles in space it will always turn one side toward the sun to absorb energy, and three sides away from the sun to cool instrumentation and telemetry equipment inside. It can perform isolated experiments in conjunction with other projects. Or it can be put into orbit by a small rocket to make studies of its own, up to five or more separate experiments on each mission it makes.

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496

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The analysis of stresses caused by thermal shrinkage has always been a knotty problem, especially in complex three-dimensional shapes. The two figures above compare the results of a complex analysis (A) with an experimental photoelastic study (B) so that even nonscientific members of the solid propellant community can see the progress we have made in three-dimensional stress analysis. The photoelastic picture shows the "fringes" from a slice of a thick-walled cylinder of photoelastic resin cast into a steel tube, with the resin shrinkage producing the same distribution of stresses that occur upon cooling a rocket motor. The analytical figure shows the calculated contours of tensile stress using the computer to handle the finite-length problem through the stress function technique. ■ The success demonstrated by these illustrations shows the progress that may be realized when scientists with diverse interests, such as stress analysts, grain designers, organic chemists, and rheologists, work toward a common goal in an environment conducive to research. Management people would say that we have improved our communication; we scientists say we have improved our ability to handle difficult design problems.

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SOLID ROCKET PLANT / Sacramento, California ity by 3, 9 and 11? The powers of 10 are congruent (modulo 3 and modulo 9) to the series 1, 1, 1, 1..., so we arrive at once at the previously stated rules for 3 and 9. The powers of 10 are congruent (modulo 11) to the series −1, +1, −1, +1..., which leads to the previously stated rule for 11. The reader may enjoy finding the multiplier series for the other divisors to see how each series links up with its corresponding rule or, in the cases of 6 and 12, leads to other rules.

A bizarre 7 test, attributed to D. S. Spence, appeared in 1956 in *The Mathematical Gazette* (October, page 215). Remove the last digit, double it, subtract it from the truncated original number and continue doing this until one digit remains. The original number is divisible by 7 if and only if the final digit is 0 or 7. This procedure is applied to our serial number in this manner:

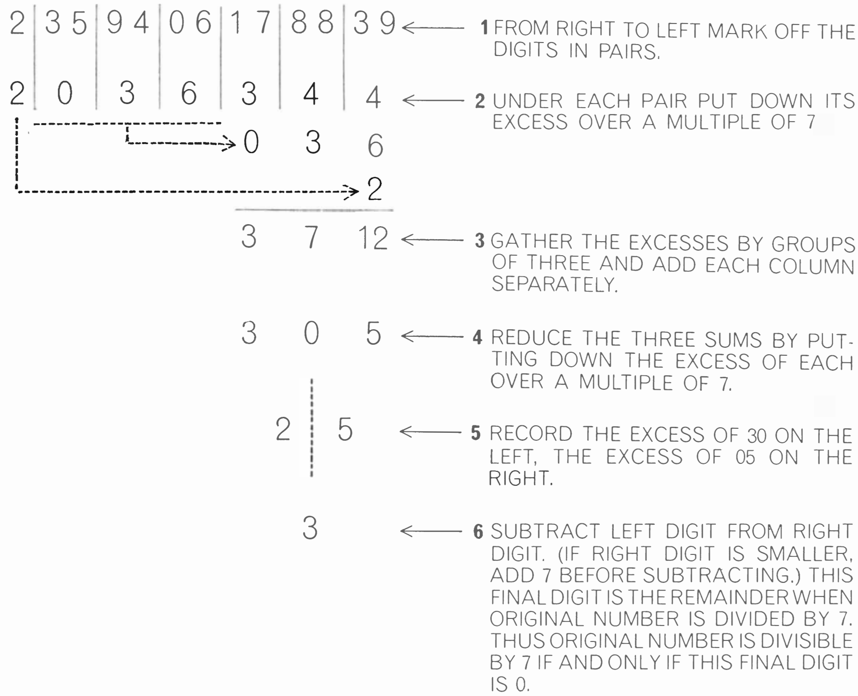
```
61671142
       4
6167110
      0
616711
     2
61669
   18
6148
 16
598
16
43
6
−2
```

The final digit is not divisible by 7, therefore neither is the original number. A defect of the system is that it gives no clue to the remainder.

The 7 test that seems to me the most efficient, especially when applied to very large numbers, is one developed by L. Vosburgh Lyons, a New York neuropsychiatrist. It is disclosed here for the first time in the illustration on the next page, where the steps are applied to an arbitrary 13-digit number. The method is extremely rapid when applied to a six-digit number; one has only to build a triangle of three digits, then two, and then a final digit that provides the remainder.

Working with this method, Lyons has discovered many remarkable six-digit-number feats of the "lightning calculator" type. For example, ask someone to chalk on a blackboard any six-digit number that is *not* divisible by 7. Suppose he writes 431576. You propose to alter quickly each digit in turn, forming six new numbers, each a multiple of 7.

To do this, first write the number six



The Lyons test for 7

times in a square array (as shown at the left in the illustration on page 240), leaving a blank space for the last digit in the first row, the next to last digit in the second row and so on. (The spaces are labeled A to F only to help the explanation; when the trick is performed, the six spaces are left blank.) Having already tested the number to make sure it is not divisible by 7, you have determined that it has an excess of 5. Obviously 1 must be placed in space A instead of the original 6 to make the top number a multiple of 7.

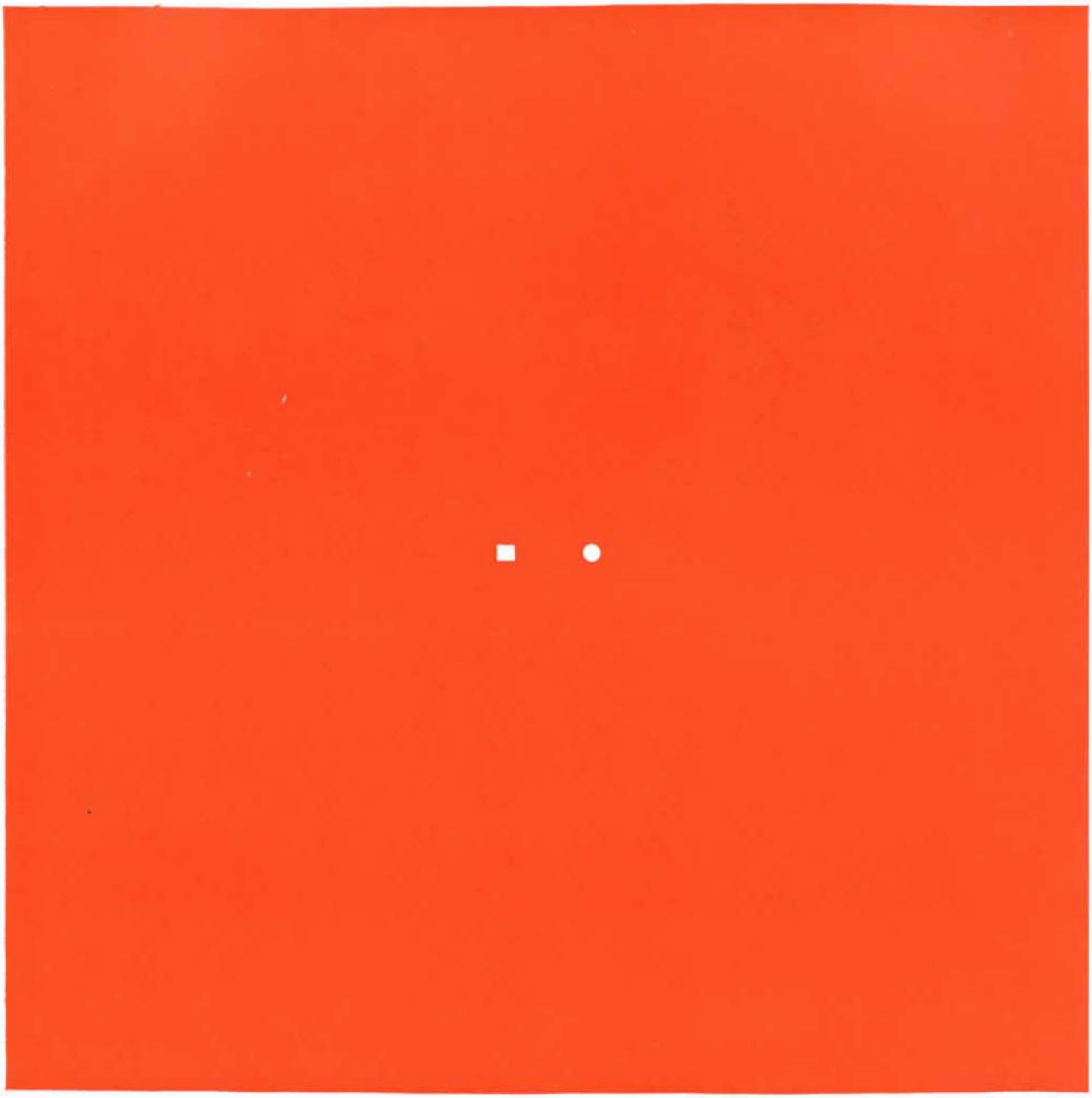
The remaining five blanks can now be filled in rapidly. In row 2, consider the number B6. Above it is 71, which has an excess of 1 when divided by 7. You must therefore place a digit in space B so that the number B6 will also have an excess of 1. This is done by placing a 3 in space B. (In your mind, simply subtract 1 from 6 to get 5, then ask yourself what two-digit multiple of 7 ends in 5. The answer can only be 35.) The number C7 is handled in the same way. Above it is 53, which has an excess of 4, so to give C7 a similar excess you put 6 in space C. Continue in similar fashion with the remaining rows. The final result is shown at the right in the illustration. Each row is now divisible by 7. To a mathematician familiar with the difficulties of testing divisibility by 7, the feat is quite astonishing.

A knowledge of divisibility rules often furnishes short cuts in solving number problems that otherwise would be enormously difficult. For instance, if nine playing cards, with values from ace to 9, are arranged at random to form a nine-digit number, what is the probability that it will be divisible by 9? Since the sum of the digits from 1 to 9 is 45, which has a digital root of 9, you know at once that the probability is 1 (certainty). Four cards, from ace to 4, are randomly arranged. What is the probability that this four-digit number is divisible by 3? Bearing in mind the rule for 3, you know immediately that the probability is 0 (impossible). A puzzling stunt can be performed with such a number. While your back is turned, ask someone to add a five to the number, at either end or between any two cards. With your back still turned, appear to concentrate and announce that by clairvoyance you have discovered that the new number is now divisible by 3.

Until the answers appear next month, the reader may enjoy testing his skill on the following digital puzzles, all intimately related to this month's topic.

1. A person older than nine and younger than 100 is asked to write his age three times to make a six-digit number (e.g., 484848). Prove that the number must be divisible by 7.

2. Seven different playing cards, with values from ace to 7, are shaken in a hat, then taken out singly and placed in a



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row. What is the probability that this seven-digit number is divisible by 11?

3. Find the smallest number that has a remainder of 1 when divided by 2, a remainder of 2 when divided by 3, a remainder of 3 when divided by 4, a remainder of 4 when divided by 5, a remainder of 5 when divided by 6, a remainder of 6 when divided by 7, a remainder of 7 when divided by 8, a remainder of 8 when divided by 9 and a remainder of 9 when divided by 10.

4. A child has at his disposal n small wooden cubes, all the same size. With them he tries to build the largest cube he can, but he discovers that he is short by exactly one row of small cubes that would have formed an edge of the large cube. Prove that n is divisible by 6.

5. What is the remainder when 3, raised to the power of 123,456,789, is divided by 7?

6. Find four different digits, excluding 0, which cannot be arranged to make a four-digit number divisible by 7.

The problems are easier than one might think at first, once they are approached properly, except for the last one, which seems to yield only to brute hammer-and-tongs methods. But any reader who solves all six will find that he has had a stimulating workout in elementary number theory.

Readers were asked last month to explain a magic trick in which five cards are selected, one of the five is chosen, then the magician arranges the other four in whatever order he chooses. The four cards are taken to the magician's assistant, who, after looking them over, names the chosen card.

Since none of the four cards can be the selected card, it is necessary only to code the name of one of 48 cards. The magician and assistant have agreed on an order for all 52 cards, so that each card can be assigned a number, from 1 to 52, in the agreed-on hierarchy. The four cards that carry the code will then represent four numbers that can be designated A, B, C, D in order of rank. These four cards can be arranged in 24 different ways, exactly one-half of 48. The 48 cards (one of which must be coded) are thought of as ordered according to the ranks of their assigned numbers, then divided in half, half consisting of the 24 lower cards, the other half consisting of the 24 higher cards. Suppose the chosen card is the 17th card in the "low" group. The number 17 can be communicated by the ordering of the four cards, but one additional signal is needed to indicate whether it is the 17th card in the "low" or the "high" group.

The problem that remains, then, is how to communicate this final yes-no signal. It cannot be communicated by the ordering of the four cards. The problem was stated in such a way as to rule out various other methods that suggest themselves, such as marks on the cards, the choice of the person who takes the cards to the assistant, the use of a container for the cards, the procedure to be followed, the time at which the cards are taken to the assistant and so forth.

One subtle loophole was not ruled out: the hotel room in which Mrs. Eigen waited. The Eigens had taken *two* rooms, adjoining and connecting. Victor Eigen did not give the number of his hotel room until after the card had been selected. He arranged the four cards to code a position from 1 to 24, then transmitted the final clue—whether the high or the low group was involved—by choosing one of his two rooms. Mrs. Eigen simply went to the door at which she heard knocking. This information, combined with the four-card code, was sufficient to pinpoint the selected card.

In June readers were asked for their best solutions to a solitaire game on a 6 × 6 square [*see top illustration on page 243*] with counters on all cells

4	3	1	5	7	A
4	3	1	5	B	6
4	3	1	C	7	6
4	3	D	5	7	6
4	E	1	5	7	6
F	3	1	5	7	6

4	3	1	5	7	1
4	3	1	5	3	6
4	3	1	6	7	6
4	3	6	5	7	6
4	7	1	5	7	6
3	3	1	5	7	6

A calculation stunt involving divisibility by 7

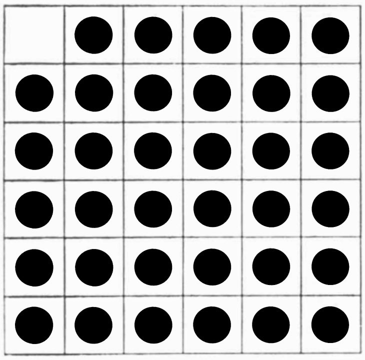
except 1. The problem called for jumping all counters but one, the last counter to rest on cell 1.

Robin Merson, who works on satellite orbit determinations at the Royal Aircraft Establishment in Farnborough, England, sent a simple proof that at least 16 moves (a chain of jumps counts as one move) are necessary. The first move is 3–1, or its symmetrical equivalent. This places a counter on each corner cell. It is impossible for a corner piece to be jumped, therefore each corner piece must move (including the counter at 1, which must move out to allow a final jump into the corner). These four moves, added to the first, bring the total to five. Consider now the side pieces on the borders between corners. Two such pieces, side by side, cannot be jumped; therefore for every such pair at least one counter must move. On the left and right sides, and on the bottom, at least two pieces must move to break up contiguous pairs. On the top edge (assuming a 3–1 first move) one piece will suffice. This adds seven moves, carrying the total to 12. Consider next the 16 interior cells. A block of four (e.g., 8, 9, 14, 15) cannot be jumped until at least one man has moved. It is easy to see that a minimum of four interior pieces must be moved to break up all interior four-cell blocks. This brings the total of required moves to 16. Merson's shortest solution was 18. He wondered if the gap could be narrowed.

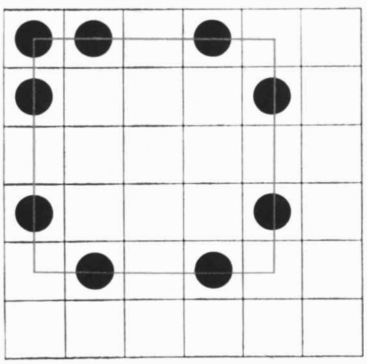
To my amazement, one reader, John Harris of Santa Barbara, Calif., came through with the ultimate—an elegant 16-move solution: 13–1, 9–7, 21–9, 33–21, 25–13–15–27, 31–33–21–19, 29–27, 16–28, 24–22, 18–16, 6–18, 36–24–12, 3–15–17, 35–33–21–23, 4–16–18–16–4, 1–3–5–17–29–27–25–13–1. Note that the final move is an "eight-ball sweep." The middle illustration on the opposite page shows the pattern just before this last move.

The longest possible final chain is nine jumps. This was achieved by Donald Vanderpool of Towanda, Pa., at the close of an 18-move solution: 13–1, 9–7, 1–13, 21–9, 3–15, 19–21–9, 31–19, 13–25, 5–3–15, 16–4, 28–16, 30–28, 18–30, 6–18, 36–24–12–10, 33–21–9–11, 35–33–31–19, 17–15–13–25–27–29–17–5–3–1. The position before the final sweep is shown in the bottom illustration on the opposite page. Vanderpool also investigated low-order rectangular boards with a vacant corner cell, the last piece to occupy that cell. He reports no solution possible on 3 × 2, a unique six-move solution (easily proved the minimum; readers may enjoy finding it) on the 3×4, and generalized solutions for any $3 \times 3n$ board when n is greater than 1, and any $3 \times 3n + 1$ board. No solution has yet been found for the 3×5, or any other board of order $3 \times 3n + 2$.

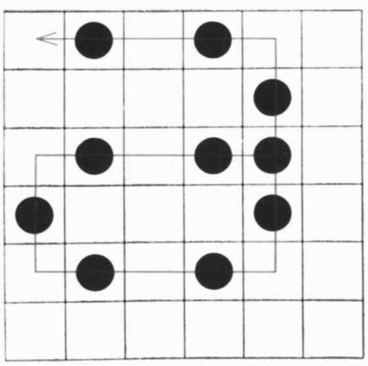
Space makes it necessary to defer discussion of many letters that dealt with solitaire theory. Michael Rubenstein of Cleveland Heights, Ohio, called atten-



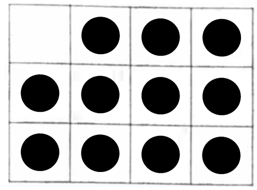
The 6×6 problem



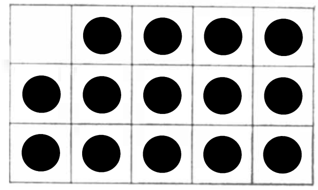
Eight-ball-sweep solution



Nine-ball-sweep solution



The 3 × 4 board



The 3 × 5 board

tion to an analysis of solitaire by B. M. Stewart in his *Theory of Numbers.* Sheldon B. Akers, Jr., a mathematician at the General Electric Electronics Laboratory in Syracuse, N.Y., devised an ingenious procedure, essentially the same as the Charosh method reported in June, by which a single number is assigned to any given solitaire position. All positions with the same number are considered "equivalent" in the Charosh sense.

Robert L. Hutchings, a student at Magdalene College, Cambridge, reported an exciting breakthrough. He and a group of friends have gone beyond Charosh' analysis: they have discovered criteria with which one can demonstrate the impossibility of solving many problems that are in fact impossible but could not be ruled out by Charosh' method. Hutchings' group hopes to publish its results soon.

Gary D. Gordon, a physicist at the RCA Astro-Electronics Products Division in Princeton, N.J., reported a remarkable discovery that he made 15 years ago: The solution to every solitaire problem, on any board, that has identical first and last moves is reversible. That is, the jumps can be taken in reverse order. This should not be confused with Leibniz' method of working backward by starting with an empty board. The beginning position remains the same; only the order of the jumps is reversed. Thus in Harris' 16-move solution to the 6 × 6 problem, the reversed solution starts with 13–1, continues with 25–13, 27–5 and so on, taking in the reverse order the jumps in the final eight-ball sweep. The result is a new solution in 31 moves. As far as I know, this beautiful symmetry property is nowhere mentioned in the literature on solitaire.

NUCLEAR SCIENTISTS & ENGINEERS

OBJECTIVE AT UNITED NUCLEAR:

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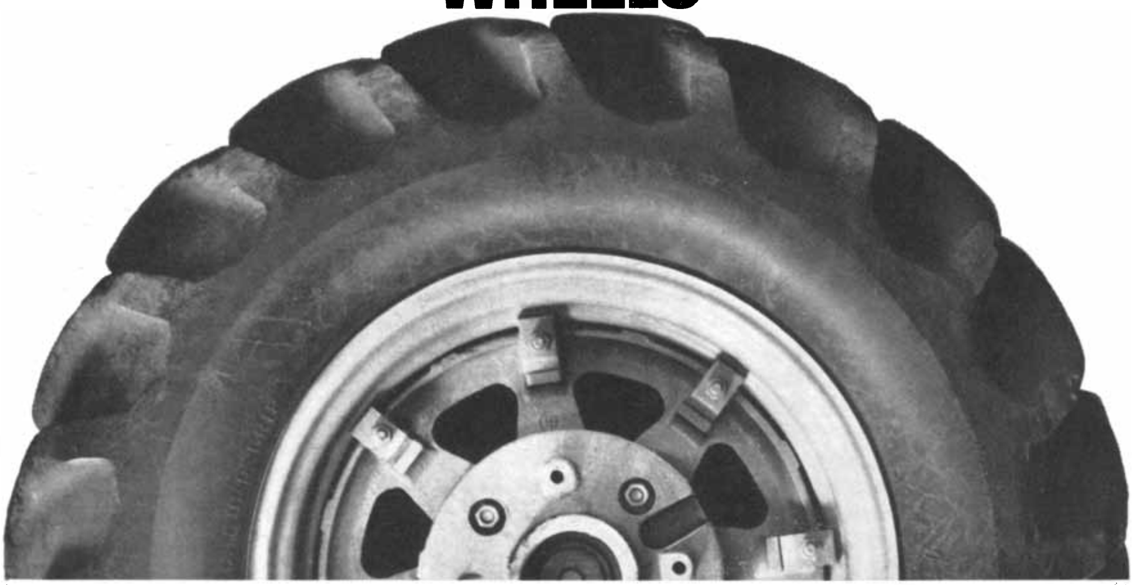

In essence the problem is: design, build and test a full-scale nuclear power plant with overland portability that will significantly extend the mobility of the modern mechanized army. The Military Compact Reactor (MCR) is being developed by United Nuclear Corporation and General Motors Corporation, Allison Division, under contract to the AEC. United Nuclear is undertaking all nuclear phases of the program. ☐ MCR will be a high-temperature, liquid-metal-cooled system, capable of generating 3000 KW. Its light weight and mobility will make it compatible with military field operation. MCR will also have important civilian defense and natural disaster emergency applications. ☐ Pioneering advances required call for a new order of shielding efficiency and very-high-performance methods of heat transfer. ☐ United Nuclear is uniquely equipped to solve the new problems posed by MCR. The company's nuclear experience reaches back to the beginning of the atomic era. Many of its scientists and engineers have 10 or more years in the field; an exceptional number hold PhD's. Some of the important programs, most of which are active and continuing, include: Supplying nuclear fuel elements and cores for naval propulsion reactors / Health Physics Research Reactor (FAST BURST) for BREN program, Nevada Test Site and Oak Ridge studies / High-performance liquid-metal loops for NASA experimental programs / Design of BR-2, a large, versatile materials and engineering test reactor for Centre d'Etude de l'Energie Nucleaire, Mol, Belgium / PLATR program for conducting heavy water nuclear parameter studies in a zero-power critical system / Development of unique analytical techniques leading to substantial shield weight reductions. ☐ United Nuclear is engaged in every commercial phase of the nuclear energy cycle, starting with its own uranium mines and mills, extending through fuel element and reactor core design and fabrication to delivery of complete nuclear plants.

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THE AMATEUR SCIENTIST

How to build a polarograph, a sensitive instrument for making chemical analyses

Conducted by C. L. Stong

A fascinating and essentially simple electroplating process known as polarography has in recent years been developed into an exquisitely sensitive method of chemical analysis. As a means of identifying chemically reducible constituents in compounds and measuring their respective concentrations, it surpasses spectrography in sensitivity and matches the analytical power of radiochemistry. Yet in its essentials the polarograph has changed little since its invention in 1925 by the Czechoslovakian chemist Jaroslav Heyrovský. In its simplest form the instrument consists of a small electrolysis cell and a battery and volt-microammeter. Positive ions of substances in the electrolysis cell pick up electrons at the negative electrode of the cell; this neutralizes the charge of the ions and transforms them into atoms. Heyrovský observed that if the area of the cathode is very small, the voltage at which ions acquire electrons from it is characteristic of each substance and that the accompanying current varies in direct proportion to the concentration of the substance that is under analysis. To make an analysis he simply added the unknown substance to a solution of a substance known as a supporting electrolyte, gradually increased the voltage across the cell from zero and simultaneously measured the current. A graph made by continuously plotting the applied voltage against the current served both as a qualitative and a quantitative analysis of the unknown compound.

In spite of the simplicity and power of the method, polarography attracted little interest immediately following its invention, largely because characteristic voltages had been determined for only a few substances. But by 1940 both the theory and the procedural details had been reported in some 2,000 papers and a comprehensive treatise had been compiled by I. M. Kolthoff of the University of Minnesota and James J. Lingane of Harvard University (see "Bibliography"). These publications laid a foundation of information for the explosive growth of the method in recent years. In 1959 Heyrovský received the Nobel prize for originating polarography, and today no chemical laboratory is considered complete without the instrument.

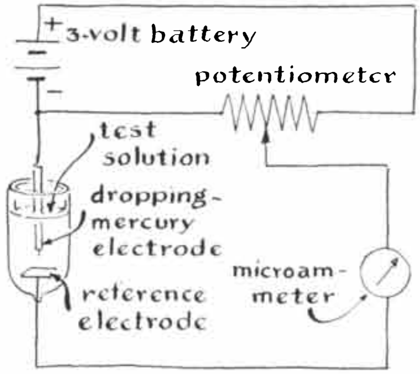
Commercial polarographs range in price from $500 to $2,000. But Sam Epstein, chief chemist of the Federated Metals Division of the American Smelting and Refining Company in Los Angeles, has designed an instrument that can be constructed at home for less than $75. It detects and measures substances diluted to .0001 mole per liter of solution. (One mole is equal to 6.02×10^{23} atoms or molecules of any substance.)

"The principal distinction between the polarograph and other devices, such as *p*H meters, that employ electrolysis cells," Epstein writes, "is found in the negative electrode (cathode), which consists of a small drop of mercury that constantly renews itself as mercury flows from an elevated reservoir through a capillary tube. This arrangement continuously removes from the vicinity of the cathode the products of electrolytic reaction that would otherwise interfere with the analysis. The positive electrode, which has a large surface compared with that of the cathode, is most commonly a pool of mercury at the bottom of the cell or a saturated-calomel electrode, the construction of which will be described.

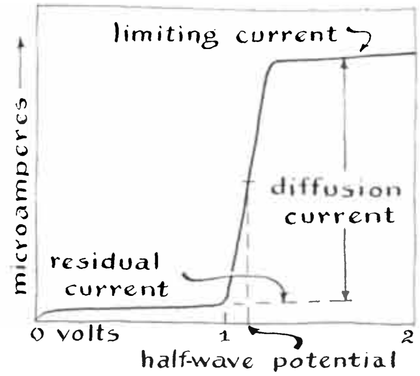
"The accompanying circuit diagram [*top left on next page*] indicates the basic simplicity of the polarograph. To measure the characteristic potential at which an oxidized substance is reduced, the electrolysis cell is first filled with supporting electrolyte; one of the most frequently used is an aqueous solution of potassium chloride. The electrolyte provides a conducting path through the cell but does not interfere with the reduction of specimen compounds because potassium ions decompose at a higher potential than do most other substances. Now suppose that a small amount of nickel is added to the electrolyte in the form of a salt and that a gradually increasing voltage is applied to the cell. The resulting current—consisting of electrons flowing into and charging the cathode in addition to a few electrons associated with the reduction of impurities in the electrolyte—will amount to only a fraction of a microampere until the voltage exceeds the potential at which nickel ion decomposes. In effect the junction between cathode and solution constitutes a high-resistance circuit. At a sufficient potential, electrons are transferred from the cathode to neighboring ions of nickel; the current increases to a maximum limited only by the rate at which nickel ion diffuses from the electrolyte to the surface of the cathode. The rate of diffusion is governed by the concentration of nickel ions in the solution. The difference between the residual current and the maximum, or 'limiting,' current is known as the diffusion current and is proportional to the concentration of nickel ion. Atoms of metallic nickel so reduced deposit on the cathode, as in conventional electroplating, and form an amalgam with the mercury.

"The decomposition potential is often difficult to determine precisely. It has therefore become standard practice to observe the slightly higher voltage that corresponds to the point on the graph midway between the residual current and the limiting current. The graph, incidentally, is conventionally referred to as the polarographic wave and the voltage at which reduction occurs as the half-wave potential [*see illustration at top right on next page*]. Tables of characteristic half-wave potentials for many elements and compounds can be found in most chemical handbooks.

"A practical polarograph designed for amateur construction requires only five resistors of half-watt size, a two-watt



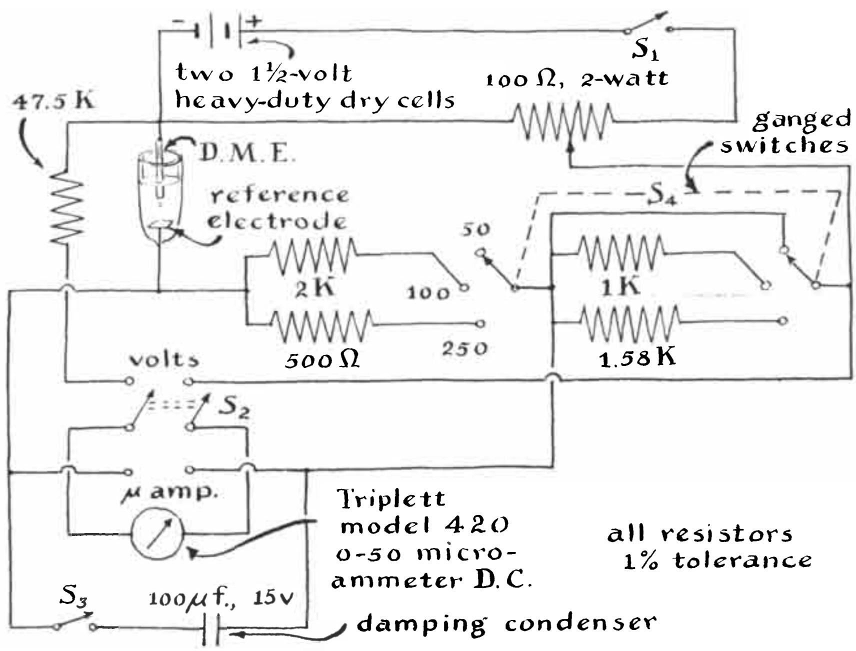
Circuit diagram of simple polarograph



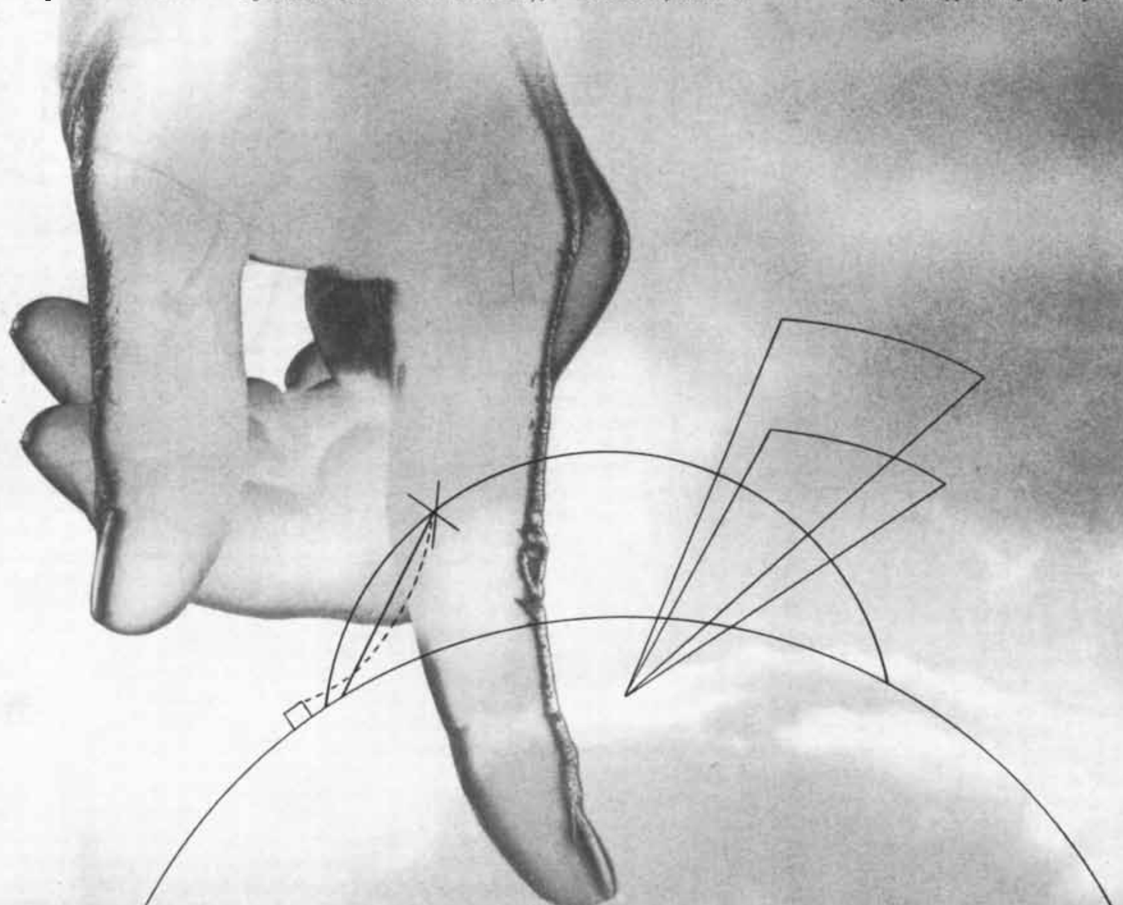
Idealized polarographic wave

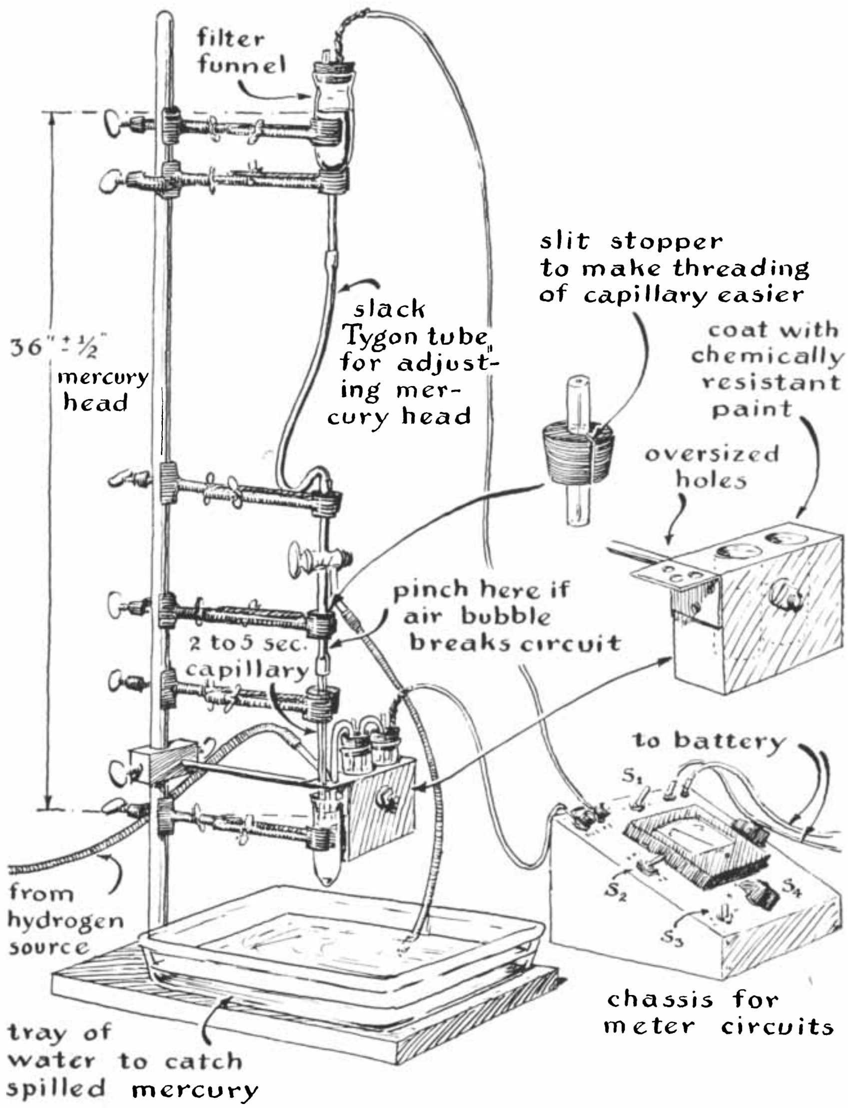
potentiometer, a 100-microfarad capacitor, a microammeter and the electrolysis cell assembly together with four switches, a three-volt battery and mounting hardware. The accompanying circuit diagram [*below*] depicts what is in effect a simple volt-microammeter with a self-contained battery. When the double-pole, double-throw switch is in one position, the meter indicates the voltage across the cell; with the switch in the other position, the current is indicated in microamperes. The capacitor merely suppresses the movement of the pointer as drops of mercury, falling from the cathode, periodically interrupt the current. The rotary selector switch adapts the meter for measuring voltage in three ranges, $\times 1$, $\times 2$ and $\times 5$, without readjustment of the battery voltage.

"A centrifuge tube of approximately 40-milliliter capacity serves as the electrolysis cell, and the cathode is a capillary tube approximately 21 centimeters long, supplied by mercury from an elevated reservoir as shown in the accompanying drawing [*page 250*]. The flexible tubing between the reservoir and the cathode capillary should include a two-way stopcock for draining mercury from the apparatus after use. The bore of the capillary should not exceed .002 inch, and the lower end should be cut square so that it is perpendicular to the bore within five angular degrees. The height of the mercury reservoir should be adjusted so that mercury flows from the capillary at the rate of one drop every three or four seconds. The capillary should be clamped to operate vertically. Electrical contact between the mercury and the meter circuit must be made by



Schematic diagram of Epstein polarograph

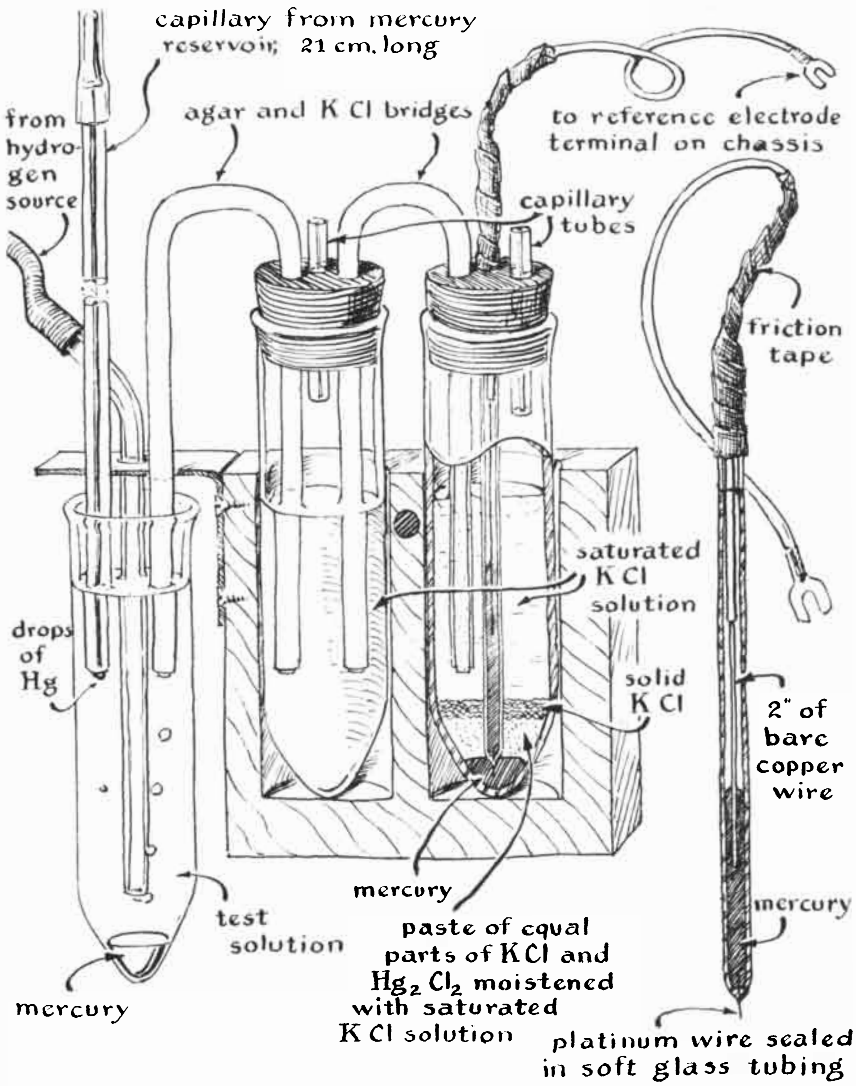




Polarograph designed for home construction

platinum electrodes. The electrodes can consist of No. 36 platinum wire one centimeter long, sealed in the end of a quarter-inch glass tube and equipped with a copper lead, as shown at the right in the accompanying drawing [*page* 252]. Three platinum electrodes are required: one for the saturated-calomel electrode, another for an electrolysis cell employing a mercury anode and the third for connecting the negative lead of the metering circuit to the mercury reservoir.

"The saturated-calomel electrode and agar–potassium chloride bridges that couple it to the electrolysis cell consist of 40-milliliter centrifuge tubes and U loops of quarter-inch glass tubing, with chemicals and associated hardware as shown. The mercury, calomel paste, solid potassium chloride and saturated potassium chloride solution are prepared and placed in sequence in one of the centrifuge tubes. The relative proportions are not critical and can be judged from the illustration. Some care must be exercised, however, in preparing the agar–potassium chloride bridges, which protect the saturated-calomel electrode from contamination by the test solutions. To prepare the bridges, soak four grams of agar in a small beaker containing 100 milliliters of distilled water, preferably overnight. Then place the small beaker in a larger one of boiling water and heat until the agar is fully dissolved. Add 30 grams of potassium chloride and, with the beaker still in the boiling water, stir until dissolved. If necessary, add just enough water to dissolve the salt completely. Then invert the U tubes, fit the ends with short sleeves of rubber tubing,



Details of electrolysis cell for polarograph

clamp and fill with the agar solution as shown in the accompanying drawing [*top of page 254*]. The agar solution must completely fill the bridge tubes and flexible sleeves, or air bubbles may be trapped when the tubes are inverted in the solutions. In spite of the best care, the agar eventually becomes contaminated, producing erratic results. To replace it, disassemble the apparatus, put the bridges in boiling water to melt the agar, rinse them thoroughly and refill.

"All mercury except that in the saturated-calomel electrode and the reservoir should be stored in narrow-mouthed polyethylene containers with screw caps. Work in a well-ventilated room without rugs or other fabric floor covering, so that mercury spilled accidentally can be cleaned up. Should mercury be spilled, collect as much as possible with a scoop made of sheet copper. The inner surface of the scoop should be amalgamated with mercury before use. The microscopic droplets remaining are recovered by sprinkling the area with finely divided zinc or copper moistened with a 10 per cent solution of hydrochloric acid. It is essential always to have these materials ready for action. Don't let mercury run down the drain! Even a seemingly small amount can poison the air in a small closed room. When a sizable amount of used mercury has been collected, it should be cleaned as described in the *Handbook of Chemistry and Physics*, but do *not* heat the material as recommended in the handbook. The polarograph requires two pounds of mercury of the grade used by dentists. [Most of the required components and chemicals can be bought locally from druggists and dealers in scientific supplies. Parts specially selected for the

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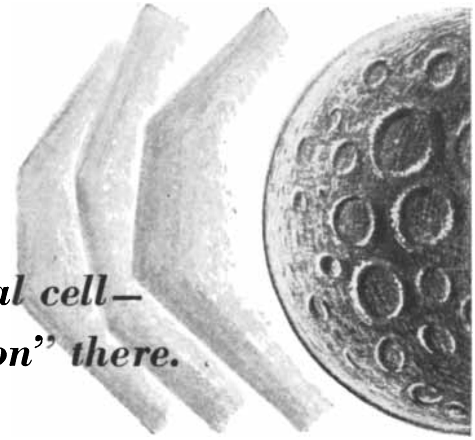

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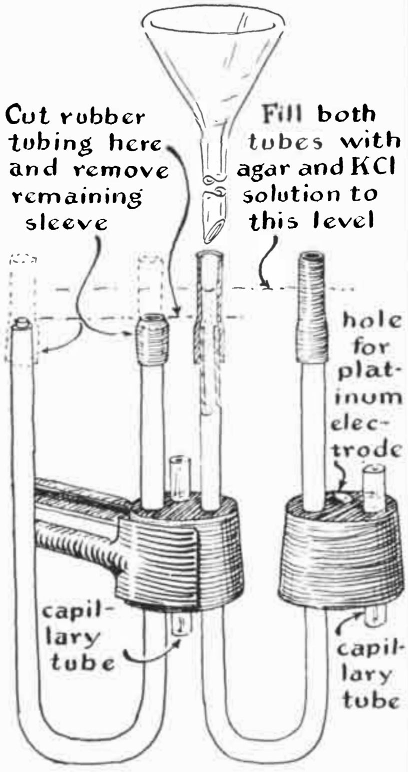
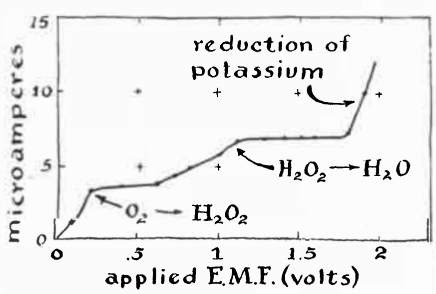


Salt bridges clamped for charging

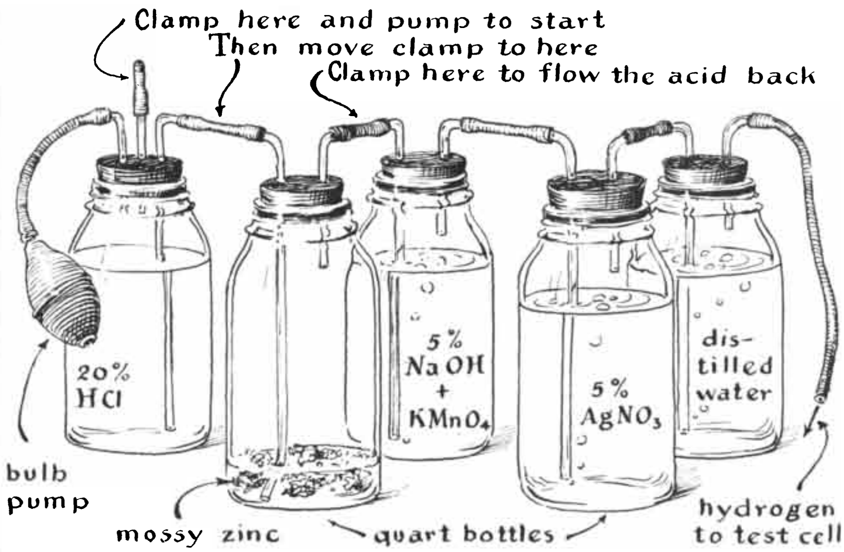
construction of Epstein's design can be ordered individually or in kit form from Henry Prescott, Main Street, Northfield, Mass.]

"Set up the completed apparatus as shown and fill the reservoir (filter funnel) about half-full of mercury. Switch the stopcock to feed the capillary with mercury and adjust the rate of flow by increasing or decreasing the height of the reservoir so that a pinhead-sized drop forms and falls every three or four seconds. Close the stopcock and return the mercury to the reservoir.

"An interesting experiment for checking the apparatus and acquiring experience with the procedure is based on the detection of dissolved oxygen. The supporting electrolyte consists of dilute potassium chloride that has been shaken several minutes to assure that it contains



Polarographic wave of dissolved oxygen

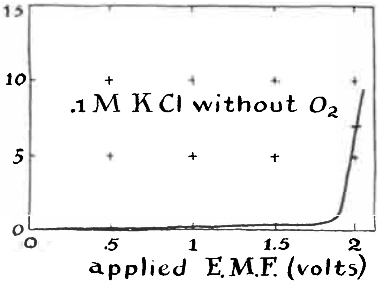


Hydrogen generator with scrubbing train

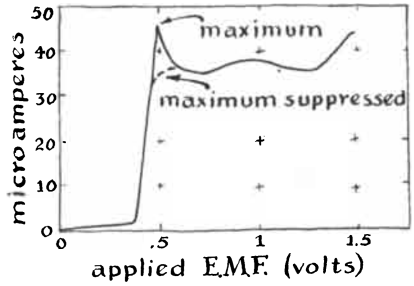
an appreciable amount of dissolved air. Incidentally, the supporting electrolyte constitutes the bulk of the dissolved material in all test solutions. Its concentration, particularly if the substance under analysis is ionic, must be at least 35 times that of the substance under analysis and usually even more. When the ions of the supporting electrolyte outnumber those of the specimen by a ratio of this magnitude, the rate of migration of the ions under analysis through the electrolysis cell is negligible.

"The extreme sensitivity of the polarograph restricts the experimenter's choice of test materials to reagent grade chemicals. Distilled water must be used not only for making up test solutions but also for rinsing the apparatus between tests and preparing it for storage. Normally the strength of solutions is expressed in terms of molarity. One mole of a substance is equal in grams to the sum of the atomic weights represented in the formula of the substance. The atomic weight of potassium, for example, is 39.1 and that of chlorine 35.5. The sum of the atomic weights constituting potassium chloride, a compound consisting of one atom each of potassium and chlorine, is accordingly 74.6. One mole of potassium chloride therefore weighs 74.6 grams. Cadmium chloride contains one atom of cadmium (atomic weight, 112.4) and two of chlorine (atomic weight, 2×35.5). The sum is 183.4, and one mole of cadmium chloride weighs 183.4 grams. A one-molar solution (1M) of potassium chloride contains one mole, or 74.6 grams, of potassium chloride per liter of solvent. Similarly, a .001M solution of cadmium chloride contains .1834 gram of cadmium chloride per liter.

"To set up the introductory experiment, prepare a .1M hydrochloric acid supporting electrolyte containing dissolved air, place 35 milliliters in the electrolysis cell and open the stopcock. Readjust the height of the reservoir for the specified drop rate if necessary. Check the tip of the capillary tube and carefully remove any bubbles. Switch the meter to measure voltage and adjust the potentiometer for zero indication. Apply .1 volt to the cell and switch the meter



Wave of deoxygenated electrolyte

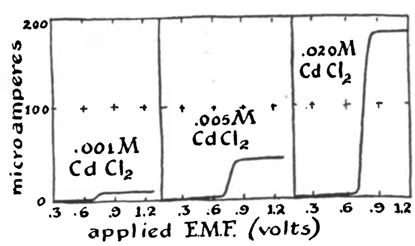


Wave illustrating "maximum" peak

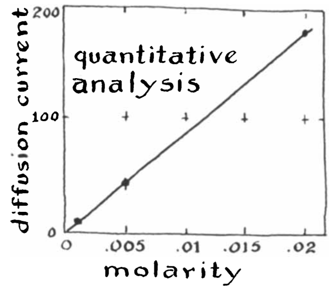
to indicate current. Record both current and voltage. Increase the voltage to .2 volt, read the current and continue the procedure in steps of tenths of a volt, tabulating both current and voltage to a maximum of 1.5 volts. When switched to indicate current, the meter will oscillate from minimum indication, as a new drop of mercury begins to form, to maximum, just before the drop falls. The fluctuation of the current is induced by the periodically expanding area of reaction at the cathode. Record the maximum current. Plot the tabulations with voltage as the abscissa and current as the ordinate. A sharp rise in the graph at about .1 volt indicates that dissolved oxygen was reduced to hydrogen peroxide. At 1.1 volts the hydrogen peroxide was reduced to water, as indicated by the polarographic waves in the accompanying graph [*bottom of page 254*].

"These polarographic waves from the reduction of oxygen are so pronounced that they interfere with the waves of most other substances. Hence oxygen must be removed from all solutions just before they are electrolyzed. This is accomplished by bubbling hydrogen or nitrogen through the electrolysis cell for five minutes. Connect a length of glass tubing to a source of hydrogen gas, immerse the tubing to within approximately one centimeter of the bottom of the electrolysis cell and pass a rapid but not violent stream of hydrogen through the electrolyte for five minutes. If compressed hydrogen is not available, one can put together a gas generator as shown in the accompanying drawing [*top of page 256*]. Test for oxygen removal by electrolyzing the solution. Tabulate the current and voltage and draw a corresponding graph. The residual current should persist to approximately 1.8 volts, the decomposition potential of potassium, as shown in the accompanying graph [*bottom left on page 256*]. This indicates that oxygen has been completely expelled from the solution by the stream of hydrogen.

"Before setting up the next experiment close the stopcock, lower the electrolysis cell and clean it. Rinse off the



Three cadmium chloride waves

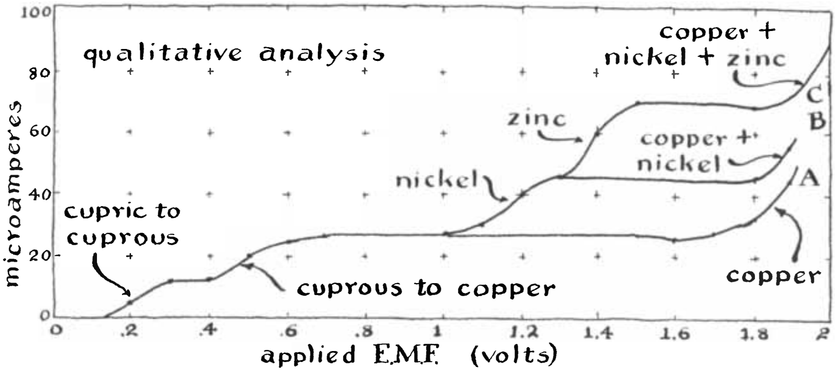


Concentration graphed against current

capillary, agar and hydrogen tubes. Always repeat this procedure between analyses. Never expose the agar tube to air for more than a few minutes or it will be damaged by drying. When you have finished working with the polarograph, immerse the dropping-mercury electrode in distilled water and the agar tube in a container of saturated potassium chloride. They can be so stored for long periods.

"Next, replace the electrolyte with 1M potassium chloride solution that is also made .004M with respect to lead nitrate. Add one drop of concentrated hydrochloric acid, flush out the oxygen with hydrogen and electrolyze in steps of tenths of a volt. The plotted results should resemble the solid curve of the accompanying polarographic wave [*bottom right on page 256*].

"This experiment demonstrates what has come to be known as a 'maximum,' an undesirable peak in the polarographic wave that appears at about .5 volt in this case. Such maxima, which frequently interfere with an analysis, have not been fully explained, but they must be eliminated. This is done by adding a 'maximum suppressor' to the solution. Many substances are effective as suppressors, including gelatin. Dissolve .5 gram of plain gelatin in 100 milliliters of distilled water. (Place a small beaker containing the gelatin solution in a larger beaker of hot water and boil until the gelatin dissolves; heating the small beaker directly over a flame would damage the gelatin.) Add one drop of the dilute gelatin to the lead nitrate solution. Store the remainder for future use; it will keep about three months if refrigerated. Electrolyze the lead nitrate solution again and plot the results. This wave should be identical with the first one except for the maximum, which will have vanished, as indicated by the broken curve. Remember this stratagem when maxima are encountered in future experiments, but never use more suppressor than absolutely necessary. Begin with a single drop and add one drop at a time



Waves of copper, nickel and zinc

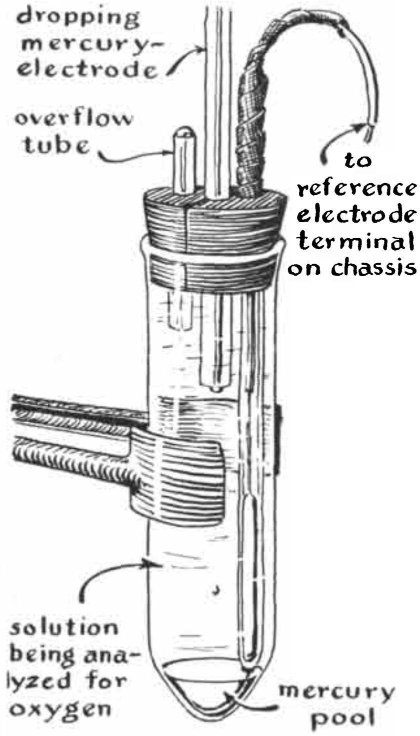
until the maximum peak disappears. Too much suppressor will reduce the limiting current and thus introduce error.

"To demonstrate how the polarograph measures concentration, prepare solutions of cadmium chloride in three strengths: .001M, .005M and .020M. Make up a supporting electrolyte of .1M potassium chloride and add one drop of gelatin. Drive out dissolved oxygen before each electrolysis. Apply voltage in steps of tenths of a volt from .3 to 1 volt. The plotted results should resemble the waves in the accompanying graph [*page* 258]. Plotting concentration against current results in a linear graph [*see preceding page*], which proves that the current increases in direct proportion to the concentration.

"To demonstrate the analysis of mixed substances, prepare a supporting electrolyte 1M with respect to both ammonium hydroxide and ammonium chloride and add one drop of gelatin. Then make up separate 100-milliliter solutions of 1M copper sulfate, nickel sulfate and zinc sulfate. Place about 20 milliliters of supporting electrolyte in the electrolysis cell, add two drops of copper solution, sweep out the oxygen and electrolyze between zero and two volts in steps of .1 volt, tabulating the results. Repeat after adding two drops of nickel sulfate and again after adding two drops of zinc solution. Having acquired experience with the method, the experimenter should be able to visualize the results while the analysis is in progress. A new wave appears for each added element as shown in the accompanying graph [*above*]. Observe the double wave for copper. It is a nice example of how the polarograph can be used in theoretical studies. The double wave is explained by the fact that cupric ion, which is characterized by a double positive charge (the atom of metallic copper has lost two electrons), is reduced in two stages. It first acquires a single electron and is thereby reduced to cuprous ion, which then acquires a second electron and is reduced to metallic copper.

"Although oxygen interferes with the polarographic analysis of most substances, its double wave can be used to determine the amount of gas present in solutions. For these experiments a reference electrode of mercury is most convenient. Remove and store the saturated-calomel electrode. (Remember to protect the exposed agar by immersing it in a saturated solution of potassium chloride.) The experiments to be made now involve biological materials. Use a 1 per cent solution (by weight) of sodium chloride as the supporting electrolyte. Place a small quantity of mercury in a clean centrifuge tube of 40-milliliter capacity and assemble the cell shown in the accompanying drawing [*page 262*]. For these experiments the electrolysis cell is filled completely and tightly stoppered, except for a breather tube of small bore. The oxygen content of solutions is proportional to the difference between current readings at .1 and 1 volt. The determination is only relative between solutions that differ in oxygen content. If the difference in current between .1 and 1 volt with solution A is higher, for example, than the difference in current with solution B, then A contains proportionately more oxygen than B. The absolute content of any given solution must be determined by chemical analysis. But experiments based on relative determinations alone can be fascinating.

"As an example, first electrolyze a cell of saline solution and plot the oxygen wave. Then add one milliliter of fresh chicken blood to the saline solution and make a second run. The second polarographic wave will indicate the amount of oxygen absorbed by the hemoglobin. The absorption will be found to differ when the blood of various animals is analyzed, a result that can be



Cell with mercury-pool anode

correlated with the differing structure of the red cells of the respective species.

"The analysis of a suspension of green algae can demonstrate the production of oxygen by photosynthesis. Fill the cell with a thick suspension of algae in 1 per cent saline solution. Let the material stand in darkness overnight and analyze for relative oxygen concentration. Then focus a strong light, such as the beam of a slide projector, on the electrolysis cell for an hour and repeat the analysis. Compare the results. Turn off the light and make a series of runs. The concentration of oxygen will diminish gradually as the algae consume oxygen in the process of respiration. Expose the suspension to light transmitted by a red, green and blue filter respectively. Observe the resulting influence of wavelength on the efficiency of the photosynthetic process.

"Having completed these experiments, you are on your own. Like the microscope, the polarograph opens the way to a broad field of investigation. In recent years the instrument, with appropriate modifications, has been applied to the analysis of solutions in disciplines as widely separated as medicine and metallurgy. Hospitals routinely subject biological materials to polarographic analysis, and research workers in nuclear physics use the procedure for the analysis of transuranium elements produced in microgram quantities by cyclotrons."

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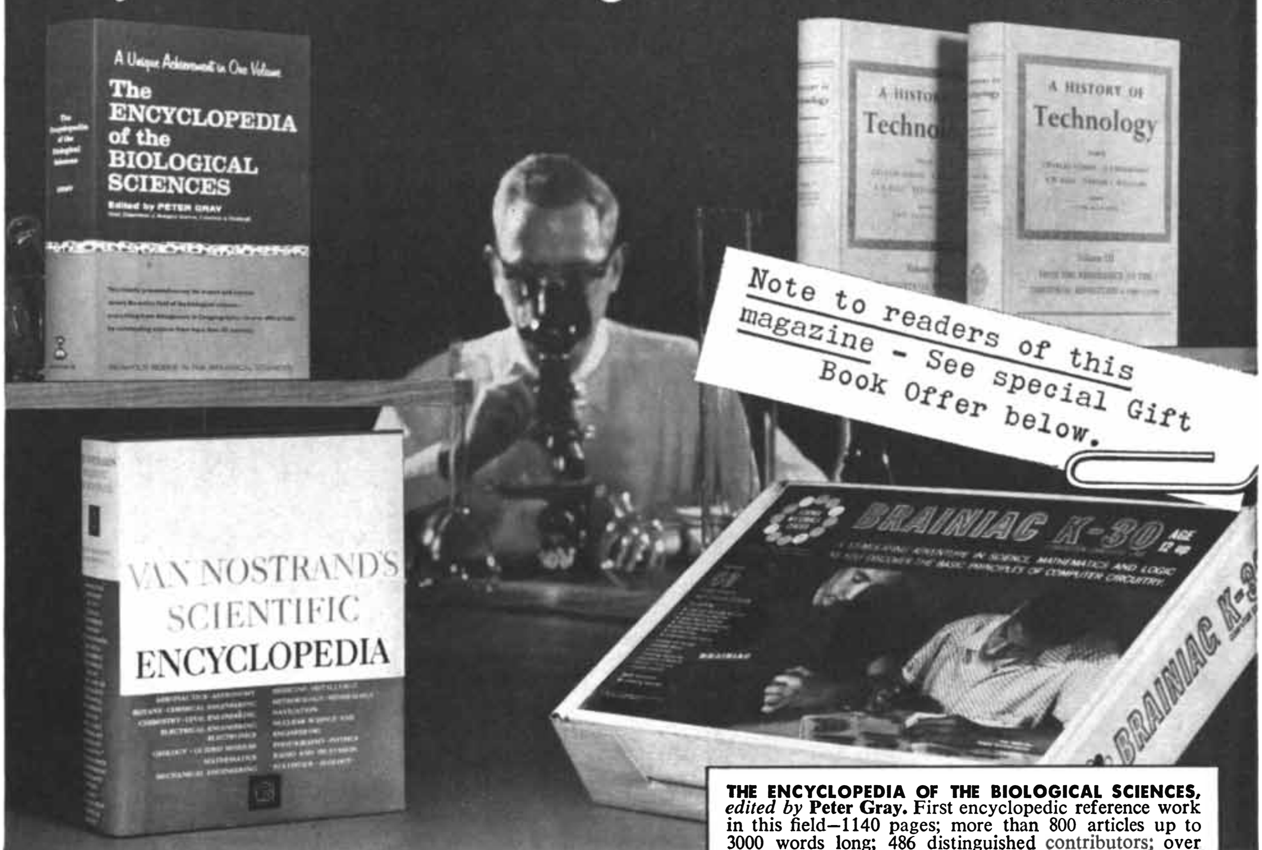

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by Sir Gavin de Beer

MANKIND EVOLVING: THE EVOLUTION OF THE HUMAN SPECIES, by Theodosius Dobzhansky. Yale University Press ($7.50).

Of all the natural sciences that can be brought to bear on the evolution of mankind, which is not quite the same thing as the evolution of man, genetics is among the most important and the author of this book is one of its foremost exponents. His book *Genetics and the Origin of Species* was epoch-making, and the present work is no less important. He begins by using a broad brush to sketch the scope of evolution, including that of man and his culture, and the theories advanced to explain it. Next follows an epitome of the general principles of genetics to which he has himself made such notable contributions, the relative importance of nature and nurture in determining the characters of an organism, the results of observations on identical twins, the integration of genetics and natural selection, the history of man's body as revealed by fossils, and his mental faculties and their antecedents. In a treatment of the problem of race, he shows among other things how the Indian caste system was an attempt to breed varieties of man genetically specialized to perform different functions and trades, whereas ancient China aimed at the converse process of a system of social mobility. The threats of increased mutation rates due to the effects of radiation, and of population increase due to lack of control, come in for careful appraisal; and although these dangers are squarely faced, and self-awareness is recognized as a blessing in giving man the power of imagination but as a curse in accompanying this gift with those of responsibility and freedom, the note on which he ends is not one of despair. Instead his discussion constantly provokes thought, which is obviously the first step along the way to the solution of these problems.

The significance of a hereditary link between the human race and the animal kingdom was already recognized by Darwin in the earliest notebook entries that he made in 1837, within a year of his return to England from the voyage of the *Beagle*. At that time he wrote: "If we choose to let conjecture run wild, then animals, our brethren in pain, disease, death, suffering and famine—our slaves in the most laborious works, our companions in our amusements—they may partake of our origin in one common ancestor—we may be all netted together." It is through genetics that we are all netted together in evolution, although at the time Darwin wrote these words knowledge of genetics amounted to less than nothing. The theory of blending inheritance, all that there then was to go on, is utterly false. It held that offspring struck an average between the characters of their parents and that variation was therefore halved after each generation. With the application of the experimental method to problems of heredity, first by Gregor Mendel and then by Thomas Hunt Morgan and his colleagues, the science of genetics has now been placed on an unassailable basis, and heredity has its particulate genes, just as physics and chemistry have their elemental particles, quanta and atoms. Realization of the implications of the principles of genetics remains, however, astonishingly poor among laymen.

It is still said, for instance, that a son is a chip of the old block. It may be that he resembles his father, but if he does, it is not because he is a detached bit of him, as is commonly imagined. Children are not the products of their parents at all. If they were, it would be impossible to understand why brothers or sisters are not identical; after all, their ancestry is identical. It would be necessary to suppose that all the differences between them were the result of new variations that had arisen during their own lives. Genetics has to account for differences no less than similarities; the problem is as simple—and as fundamental—as that. Children are the products of the germ plasm, the stream of hereditary factors that has flowed through the ancestors containing the genes, of which parents are nothing but the custodians who were themselves formed from the germ plasm of their antecedents. Children are the delayed brothers and sisters of their parents, and from the beginning of the evolution of man on earth it is literally and scientifically true that all men are brothers.

Because of the peculiar mechanism by which germ cells—eggs and sperm—are formed, no child can contain more than half of the genes carried by either parent. The mother is as likely as the father to transmit genes controlling characters that in some instances are shown by neither parent. Furthermore, the same mechanism of germ-cell formation sees to it that the complement of genes received by a child is not identical with that of either parent. There is plenty of room for the possibility that the chip may differ significantly from the old block, and this is what makes it difficult to support the view that the qualities of a useful legislator, say, are bound to appear in his children. For the same reason schemes to establish a sperm bank in which the most distinguished men would have accounts cannot avoid an element of chance. If you breed 10,000 peas or fruit flies, differing in characters controlled by genes that have been analyzed, the proportions in which the offspring will show those characters can be predicted with fair accuracy; when it comes to one child produced by one man and one woman, it is more difficult. Furthermore, as Professor Dobzhansky cogently asks, "Are we ready to agree what the ideal man ought to be?" Besides, there is something more, because there is another notion that is in need of repair. It is the view, still often expressed, that some characters are "innate" and others are "acquired." Nothing would seem to be more innate than that vertebrate animals should have two eyes in their heads. They have had them since the Silurian period, 350 million years ago. Yet if a fish embryo is made to develop in water to which a small quantity of a simple salt such as magnesium chloride has been added, it does not develop a pair of eyes at all but a single eye in the middle of its head like a Cyclops. This is one of the proofs that regardless of how long a time a line of ancestors may have possessed genes that control the development of structures, they cannot produce normal structures if the environment is abnormal. The reason for this is that the development of any character whatever is the result of interaction between the genes inside the organism and the factors of the environment outside it. Conversely, those people who set great store by the action of the environment must be reminded by this same simple experiment that 350 million years of normal environment has done nothing to "fix" the invariable and normal development of characters that one might think had been as irrevocably built in as a pair of eyes.

What all this adds up to is that every character that any plant or animal develops has its basis in the genes (without which it would not develop at all) and is to that extent "inherited"; but because the character is the result of interaction between the genes and the factors of the environment, it is also to that extent "acquired." There is no such thing as a character that owes its existence solely to heredity or solely to environment. All that is inherited by any offspring is a packet of genes with the capacity of reacting in various ways to the environment, and a few of these ways, within a certain latitude of tolerance in a normal environment, are what are regarded as normal. Some of the genes, possessed of what is called a high degree of penetrance, can overcome a wider range of variation in environmental factors than others and show their effects. This is at the base of the old controversy between "nature" and "nurture," opposed to which it is necessary to regard both nature and nurture as co-operating, without our being able to say in any one case exactly how much has been contributed by either.

The extent to which nurture undoubtedly can affect the end product of development is sometimes astonishing, and it is well illustrated by the history of Clarence, a fledgling sparrow less than one day old when it fell out of its nest and was rescued, nursed and reared by a human foster mother in her home. (The story is told by Clare Kipps in her book *Clarence: The Life of a Sparrow.*) Instead of developing into a hopping, chirruping, timid and characterless little bird, Clarence walked with alternate steps as no sparrow has ever been known to do, invented two new bird songs as a result of listening to its foster mother at the piano, developed a fetish for her hairpins, lay with pleasure on its back, played with playing cards carried in its beak, was quite fearless, scolded, bullied, "acted" and showed devoted affection. Clarence was a little person, with more character than many dogs. He lived more than 12 years. Another sparrow, Timmy, who came to live with Mrs. Kipps under other circumstances, also showed great character but was quite different from Clarence. This surely is one of the most awe-inspiring facts that have come to light, if what was never thought to be anything more than a stupid little creature weighing only a few grams is capable of such a degree of mental development and friendship. Could all sparrows, to say nothing of other passerine birds, become like Clarence and Timmy if they were brought up in similar environments? St. Francis of Assisi would surely have agreed, and Darwin would have rejoiced at being netted together with Clarence and Timmy.

There can be few matters affecting man as a social organism that do not depend for their solution on a scientific appreciation of the nature-nurture problem. Eugenics, as Professor Dobzhansky points out, is, as conceived by some of its exponents, in danger of being a travesty of science through overreaching itself by exaggerating the influence of heredity, and for the opposite reason psychoanalysis is in comparable danger from failure to recognize the part played by heredity. If Freud had appreciated the objectively based principles of genetics and the part heredity plays in psychology, if he had freed himself from his Lamarckian blinkers and the discredited theory of recapitulation, and if he had been less prone to make assumptions about birth traumas, sex drives and Oedipus complexes, there might be less controversy over what was started as a therapeutic technique and has come to be regarded as a pattern of life with ramifications extending into history, sociology and religion.

It is one of the worst injustices of history that Lamarck's name is not used to designate evolution, of which he was the first to put forward a general scheme. Instead "Lamarckism" is used to express concepts such as the supposed inheritance of acquired characters and of the effects of use and disuse of organs, ideas of which he was not the originator and which have been shown to be false.

From what has been said above of the relation between heredity and environment in the development of characters, it can readily be seen that the expression "inheritance of acquired characters" has as much meaning as the saying "Caesar and Pompey were very much alike, especially Pompey." It is not surprising that this folk belief should be so old and so persistent because, as the University of Pennsylvania botanist Conway Zirkle has aptly shown, it is based on two propositions each of which by itself is approximately correct. The first is that under the influence of the environment the body of an organism can be made to undergo changes, such as a thickening of the skin where it is subjected to friction or a strengthening of muscles that are in hard use. The second proposition is that like tends to beget like. But when the two propositions are combined into a sort of syllogism, the conclusion is fallacious that parents, after having been modified by the environment, beget offspring that show the same modification in the absence of the environmental factors that originally called it forth. Many people can say that "it stands to reason" that acquired characters should be inherited; but it happens not to stand to fact, as virtually countless experiments show.

An example of the extent to which this fallacy is deep-seated can be seen in the Old Testament story of Jacob and Laban. When Jacob was working for Laban, it was agreed that Jacob could have any brown lambs that were born and any spotted and speckled goats born, whereas all white lambs and unspotted goats belonged to Laban. Jacob thereupon selected (he knew the importance of selection) the most healthy animals and subjected them to visual prenatal impressions by putting them in front of striped patterns of green leaves and white rods just before they conceived, with the result that they "brought forth cattle ringstraked, speckled, and spotted," which of course belonged to Jacob, whereas the weaker, untreated animals produced offspring that remained true to the specification of Laban's property. Another example is the ancient Greek myth of Phaeton driving his father Apollo's chariot with the sun across the sky. Being inexperienced, Phaeton drove the chariot much too near the earth in one place, with the result that the wretched inhabitants were scorched black and thereby became the ancestors of the Negro race. One wonders if Pauline theologians realize that the doctrine of original sin involves the inheritance of an acquired character, for only genes can be inherited and, by the nature of the case, neither Adam nor Eve when they first appeared on the scene possessed the character they are alleged to have transmitted to all their descendants. It is perhaps unkind to drive this last lesson home to its conclusion, but everything known about evolution shows it to be a process that takes place in populations numerous enough to ensure that interchange of genes is widespread and frequent enough to provide a sufficient supply of variation for natural selection to work on. It has been computed that the population of man's ancestors one million years ago was about 125,000 individuals. That was when man was emerging from his prehuman ancestors and no doubt was in many ways very brutal, so that mankind would have started with 125,000 doses of genes predisposing toward behavior that would now be regarded as sinful.

Great as the importance of genetics is in the pageant of evolution because of the part it has played in such continuity as there has been, there are three other actors of no less significance. The first is variation, concerning which Darwin wrote with simple truth that its causes were in his day completely unknown. It is one of the triumphs of genetics that this question can now be answered at a different level by saying that the causes of heritable variation are known; they are the mutation of genes due to fortuitous rearrangement of the contents of the genetic material, and the recombination of genes through sexual reproduction. This results in numbers of possible permutations of such astronomical magnitude that infinitely more variation is potentially possible than is ever realized.

The next actor is adaptation, sometimes called fitness. There is no such thing as adaptation in a vacuum. A plant or animal is adapted in varying degrees to a particular set of environmental conditions—a habitat or place that it is useful to call an ecological niche. The last actor is natural selection. At the time Professor Dobzhansky delivered the lectures that form the subject matter of this book, he had had no opportunity to become familiar with the contents of the manuscript notebooks in which Darwin recorded his thoughts and conclusions soon after his return from the voyage of the *Beagle;* it is only recently that Lady Barlow, Darwin's granddaughter, has provided an authentic version of these notebooks. As a result Professor Dobzhansky, like everyone else, has been slightly misled by the ambiguous

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phrasing of the passage in Darwin's autobiography, in which he wrote that it was on reading Thomas Malthus' *An Essay on the Principle of Population* he had at once been struck that favorable variations would tend to be preserved and unfavorable ones to be destroyed. This remark has been generally construed to mean that Darwin derived his theory of natural selection from Malthus. It has always been difficult to understand how Darwin could have been indebted for the key of evolution to Malthus, the Jeremiah who maintained that the social state of man was unimprovable. Darwin's notebooks show that he had thought out for himself the unlimited possibility of variation, the importance of niches in the economy of nature and the principle of natural selection before he ever opened Malthus' book. Darwin began to read Malthus on September 28, 1838, and what he got from it was the realization that natural selection exerts a pressure that forces those individuals who happen to have the requisite characters into the niches and leaves the others outside. Malthus knew nothing of, and did not want to know anything of, unlimited variation, ecological niches or natural selection; all that he supplied to Darwin was the argument, already known to Sir William Petty and Benjamin Franklin, that the reproductive rate unchecked outstrips food supply and that mortality must therefore be high. Nobody but Darwin integrated the facts of extinction, variation, geographical distribution, ecological niches and natural selection into a system that showed how natural selection exerts pressure resulting in adaptation. Professor Dobzhansky has interesting and profound things to say on the nature of creative thought, which, he thinks, may be a greater mystery to the creative poet or scientist than to his biographer.

Natural selection still operates in man and in some respects may become more rigorous, but for the most part its effects are nullified by the evolution of an ethical social system that is the one exclusive feature of man. The evolution of man has been characterized by a process known as pedomorphosis, in which adults resemble their ancestors when their ancestors were young. The principle is the exact opposite of recapitulation, in which it is assumed that the individual organism passes through all the stages of its evolutionary history as it develops from fertilized egg to adult. Pedomorphosis can be shown to have been operative in the evolution of the most successful biological groups, including insects and vertebrates other than man. Professor Dobzhansky agrees on the importance of pedomorphosis in the emergence of man, but he is concerned to know how it was achieved by natural selection. As I believe I was the first to generalize this subject a third of a century ago, I hope I may be allowed to suggest that the array of variants on which natural selection acts includes not only adult genetic variants but also variants along the time scale of development, some of which may be more juvenile and better adapted than others. The effect of slowing down the rate of bodily development is to allow for such features as more brain growth before the skull sutures close and to make the early postnatal stages so helpless that a prolonged period of parental care is necessary. During this time a character of "authority-acceptance" on the part of the children, as the University of Edinburgh geneticist C. H. Waddington has suggested, confers survival value, because without it the children would inevitably come to grief more than they do. The long period of childhood and parental care consolidated the family as a social unit that tended to become monogamous as woman became uninterruptedly receptive, and it provided a long period of overlap between generations during which experience could be taught. This process, which is not enforced by genetic inheritance, has to be repeated at the start of each generation and is the basis of what Professor Dobzhansky calls superorganic evolution and Sir Julian Huxley calls psychosocial evolution. It is responsible for the origin and maintenance of civilization and culture; man could not live without it. It is vastly more efficient than biological evolution as an instrument to bring about adaptation in man, and the speed with which it works is not only much faster but also is still accelerating. Yet it has not annulled the underlying genetic mechanism of evolution that still determines such matters as the response of the individual to the environment, even if it is the result of civilization.

Nobody would wish for a geneticist dictator even if his name were Plato, but it would do legislators no harm to appreciate the genetic effect of their policies. One cannot help wondering how many of them do, in any country. They might say that there are two cultures, humanities and science, and that there is no time to learn both. This would be no answer. There is only one culture, but most people are not even half-cultured. They should read Professor Dobzhansky's book; they will be sur-

prised how much of it they will understand, so clearly and sympathetically is it written.

Short Reviews

PHILOSOPHICAL IMPACT OF CONTEMPORARY PHYSICS, by Milič Čapek. D. Van Nostrand Company, Inc. ($7.50). A thoughtful, readable examination of the basic concepts of classical physics, the radical transformation of these concepts in the past half-century and the philosophical implications of this transformation. The author, trained both as a physicist and a philosopher and now professor of philosophy at Carleton College, gives a lucid account of the effect on classical concepts of space, time, matter, motion and causality of such major innovations as quantum and wave mechanics and relativity theory. His major thesis is that although the older Newtonian and Laplacian models of nature have been shown to be inadequate, we keep smuggling in the language and the images suited to these older models and then find ourselves drowning in a sea of paradoxes. As long as we insist on making pictorial models of all physical processes we must, he argues, expect to be overwhelmed by contradictions. Among the absurdities to which we are driven by clinging to outmoded models are the indeterminacy principle; time's arrow, which seems to move in both directions at once; the electron, which is here, there and nowhere all at once. The philosophical patchwork created to make sense of this nonsense merely adds to the confusion. We know that atoms are not held together, as was once thought, by hooks and eyes, but the modern theories of physics and chemistry are supported by pictorial images that are not much better. Čapek's pointed analysis of a series of questions that most contemporary philosophers have shirked is impressive, but when he proposes his own Bergsonian remedy for the disorder, he is less clear and less impressive. Nevertheless, this is an enjoyable book and a tonic to hard thinking.

REPORT ON THE LANDS OF THE ARID REGION OF THE UNITED STATES, by John Wesley Powell. Edited by Wallace Stegner. Harvard University Press ($5). A reprint of a famous report submitted in 1878 to the Secretary of the Interior by Major John Wesley Powell, at the time director of the U.S. Geographical and Geological Survey of the Rocky Mountain Region and already well known for his Western explorations and his conquest of the Green and Colorado rivers. Powell's report was a warning about the consequences of trying to impose on a dry country the habits formed in a wet one. The settlers pushing west had not the slightest notion of what to expect in the arid regions. Their agricultural expectation was that of people reared in areas of adequate rainfall. Eager to get to their 160-acre homesteads, they were bemused by myths and shibboleths about the "Garden of the World" and were deliberately deceived by railroad companies, land speculators and politicians. The West they dreamed of in their innocent way had been, as Stegner points out in his introduction, not so much settled as raided for its furs and its timber; this was to continue. Powell realized that few of the practices applicable to agricultural lands in well-watered areas could lead to anything but disaster when applied in Utah, Nebraska and the Dakotas. Farms would have to be laid out not to suit the convenience of surveyors but to meet water needs. Reservoirs would have to be built; irrigation projects would have to be started; anti-flood measures would have to be taken; large tracts would have to be subdivided in co-operative enterprises so that homesteaders of the arid lands would all have equal access to water. Some of Powell's recommendations were followed, but most of them were ignored and the consequences of their being ignored are felt to this day. In the past half-century many corrections of the earlier blunders were made. Yet between 1930 and 1950, as Stegner reminds us, when every other state of the Union showed substantial gains in population, Oklahoma, Nebraska and the Dakotas, all subhumid-to-arid Plains states, went down, demonstrating that adaptation to arid conditions is by no means completed. This reprint of a prophetic work makes engrossing reading; the only flaw is that the two maps, which are important to the study, have been reproduced without the original coloring, the result being that the explanation of the various markings and delineations on the maps makes no sense whatever.

THE TIDES AND KINDRED PHENOMENA IN THE SOLAR SYSTEM, by George Howard Darwin. W. H. Freeman and Company ($2.75). In 1897 Sir George Darwin, second son of Charles Darwin, delivered at the Lowell Institute in Boston a course of lectures on the tides. This book, first published in 1898, contains the substance of the lectures. Because they were designed for a general audience they contain little mathe-

matics and can be read by anyone able to follow a scientific popularization. They demonstrate once again that the greatest scientists, when they are prepared to make the effort, write the best science primers. Darwin, who is regarded as the founder of modern cosmogony and geophysics, performed an immense theoretical labor in studying the tides. Much of his work retains its validity, although the subject is now enjoying a rejuvenation with the application of new instruments, new techniques and high-speed computers. Darwin had never before undertaken a nontechnical exposition of his theories and he regarded the Lowell Lectures as a great challenge. He met the challenge superbly. This is a fascinating volume, of extraordinary clarity. He covers the subject from antiquity to the end of the 19th century; to cite only a single topic, his discussion of tide-generating forces is, to this day, without equal. An intellectual treat, in the finest tradition of 19th-century scientific writing, that will entertain and enlighten many readers. A paperback.

A HISTORY OF CHEMISTRY: VOL. II, by J. R. Partington. St. Martin's Press ($20). The second volume of a survey intended to be completed in four volumes; the third volume is in press and together with the second will cover the period from 1500 to about 1800. *A History of Chemistry* is an enlargement of Partington's *A Short History of Chemistry,* first published in 1937 and since then many times reprinted. The method of the *Short History* is followed here: separate chapters are devoted to major figures (e.g., Paracelsus, Francis Bacon, Van Helmont, Descartes, Boyle, Hooke, Boerhaave) and major schools and theories (e.g., iatrochemistry, atomism, the phlogiston theory); the lesser figures, schools and ideas are added to fill out the main scene. This is a work of true scholarship, possessing both the advantages and the disadvantages of such dedicated labors. It is not in general an easy book to read; it has thousands of footnotes and references; it parades a vast aggregate of details, the fruits of a lifetime of research. On the other hand, like Lynn Thorndike's *History of Magic and Experimental Science,* it is not only an incomparable reference source but also a treasure chest of obscure, curious, colorful information from which even the casual reader can derive enjoyment. The index is excellent; the illustrations are interesting but small in number. (Partington explains that a full complement of illustrations would have added unduly to the size and cost of the book.) One looks forward to further installments of this honorable and impressive contribution to the history of science.

TRACTATUS LOGICO-PHILOSOPHICUS, by Ludwig Wittgenstein. Humanities Press ($4.50). The first edition of the English translation of this famous work appeared in 1922. Wittgenstein's compressed, complex and aphoristic expression made the task of translation very difficult, and he himself revised the text with the help of the brilliant young British logician Frank Ramsey. As a further aid to understanding Wittgenstein's nuances, the original German text was presented, page by page, opposite the translation. The complexities of the *Tractatus* are, as is well known, as formidable as its influence has been, but over four decades the ideas have become more familiar and other writings by Wittgenstein have appeared. For these and other reasons a new translation has been undertaken by D. F. Pears and B. F. McGuinness. The German text, still printed *en face,* has been carefully revised and an English index partly designed as a guide to the German terminology has been added. To those who have grown accustomed to Wittgenstein's unique literary quality the new version may seem a little disappointing and to have lost some of its bizarre charm. There is evidence, however, that great care has been taken to convey the author's meaning as clearly and plainly as possible. One is glad to have the new translation, but the old one is worth keeping.

THE RAILWAY REVOLUTION: GEORGE AND ROBERT STEPHENSON, by L. T. C. Rolt. St. Martin's Press ($6.50). Technological revolutions require many different hands, temperaments and skills. Inventors, engineers, mechanics, laborers and ditchdiggers, bridgebuilders, practical men and dreamers, road builders, men who were willing to risk their money and take other chances, bold and cautious men, organizers, politicians—all were needed to bring about the railway revolution. This is vividly brought out in Rolt's rich story of the Stephensons, father and son, who were the foremost pioneers in railroad building in Great Britain, who made the most efficient (although not the first) of the early locomotives and who planned, designed and built the Stockton and Darlington Railway, the first to carry passengers and goods by steam locomotion (September 2, 1825). Rolt's biographical history is distinguished not only for

its insightful portraits of the Stephensons and its clear grasp of the many complex technical problems that had to be overcome to make railroading a reality but also for its readable presentation of the dramatic vicissitudes and struggles attendant on the birth of the railway industry and of the relation of the railway revolution to contemporary social, economic and political circumstances. Illustrations.

NEW PERSPECTIVES IN PHYSICS, by Louis de Broglie. Basic Books, Inc. ($6). A collection of papers and lectures on various aspects of physics and on the history and philosophy of science written between 1950 and 1956. De Broglie belongs to the minority group of physicists today that is not enchanted with the Copenhagen school of thought but instead seeks to reinterpret wave mechanics, based on the substitution of "real" waves with singular regions for the usual continuous waves. One of the objectives is to "rejuvenate" quantum physics so that it will be able to describe the structure of different kinds of particles and to predict their properties; another is to relate quantum theory to relativistic physics in the Einsteinian sense—that is, to a general field theory. De Broglie is a lucid writer, whatever topic he is discussing, and this book makes both agreeable and stimulating reading.

COFFEE, by Frederick L. Wellman ($13); MUSHROOMS AND TRUFFLES, by Rolf Singer ($10.25). John Wiley & Sons, Inc.—Interscience Division. These two volumes in the publisher's "World Crop" series deal with the botany, cultivation and utilization of the crops named. The monograph on coffee is of particular interest because it presents legends and early history and because coffee is of such widespread importance in world commerce. Both volumes are fully illustrated, including a number of color plates for the study of mushrooms. Useful bibliographies.

CULTURE AND BEHAVIOR: THE COLLECTED ESSAYS OF CLYDE KLUCKHOHN, edited by Richard Kluckhohn. The Free Press of Glencoe ($6.75). This collection of essays by the late noted anthropologist serves to show the breadth of his interests and contributions to the discipline. It reprints, among others, papers on the concept of culture, conceptions of death among the Indians of the Southwest, Navajo ceremonial patterns, Navajo morals, ethical relativity, group tensions. The volume includes a complete bibliography of Kluckhohn's writings.

BIRD, by Lois and Louis Darling. Houghton Mifflin Company ($5). A simply written, well-illustrated account for the general reader of all phases of bird life. The authors sketch the history and evolution of birds (the 8,600 species alive today are only a small fraction of all that have lived, although estimates by leading authorities range wildly from 250,000 to 1.5 million) and discuss bird behavior (including instinct, display, learning, the reproductive cycle, social behavior and migration) and bird anatomy and physiology. The book includes helpful drawings by Mrs. Darling and a sound list of suggestions for further reading.

FORMAL METHODS, by Evert W. Beth. D. Reidel Publishing Co. (23.50 Dutch florins). This volume, which appears in the "Synthese Library," a series of monographs on the development of symbolic logic, offers an introduction to symbolic logic and to the study of effective operations in arithmetic and logic. The main purpose of the book is to explain as simply as possible the principles, foundations and methods of logic. Some skill in logical manipulations is presupposed but not previous study of logical theory.

THE DEVELOPMENT OF MATHEMATICS IN CHINA AND JAPAN, by Yoshio Mikami. Chelsea Publishing Company ($3.95). A reprint of the 1913 edition of this pioneer book, which, while by no means a systematic or comprehensive survey, is nevertheless filled with valuable information. Mikami knew personally a number of the leading Japanese mathematicians of the 19th century, and his account of their work, their personal eccentricities and their extraordinary ignorance about the state of mathematical knowledge in the West is an attractive feature. Another is the quaint style in which the work is written, recalling parodies of English prose passages as rendered by earnest Japanese students.

THE EDISON MOTION PICTURE MYTH, by Gordon Hendricks. University of California Press ($4). This interesting contribution to motion picture history, based on a careful examination of original sources, is intended to serve two purposes: to begin the task of "cleaning up the morass of well-embroidered legend with which the beginning of the American film is permeated" and "to afford some measure of belated credit"

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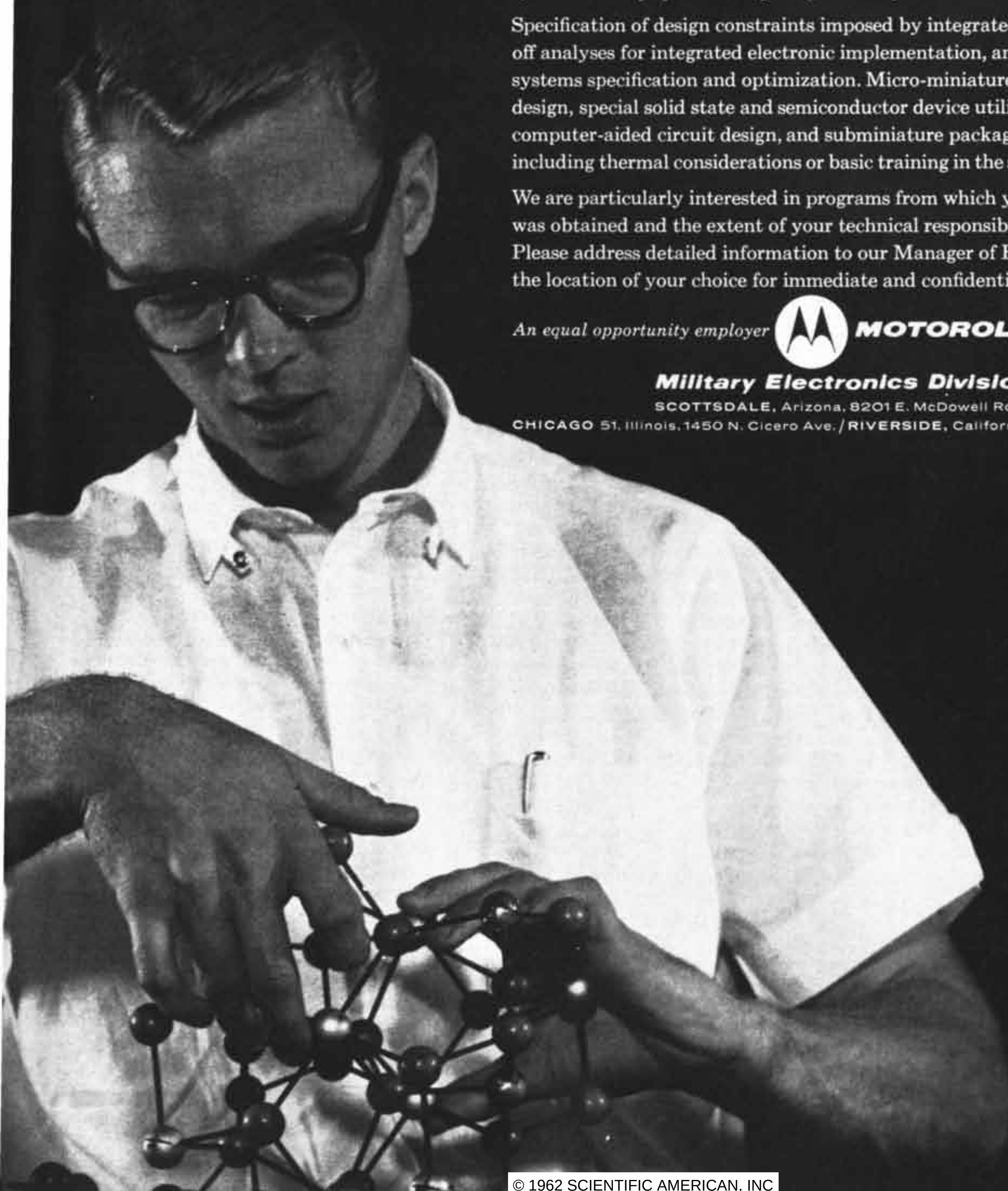


to the work done by W. K. L. Dickson, who worked in Edison's laboratory and was, as Hendricks maintains, responsible for advances usually attributed to Edison. Dickson himself, of course, based his work on the earlier work of other men, principally Étienne Jules Marey and William Friese-Greene. Photographs. A paperback.

HANDBOOK OF NORTH AMERICAN BIRDS. VOL. I: LOONS THROUGH FLAMINGOS, edited by Ralph S. Palmer. Yale University Press ($15). The first volume of a multivolume undertaking sponsored by the American Ornithologists' Union and the New York State Museum and Science Service, the purpose of which is to bring together up-to-date, complete accounts of all the birds found in North America north of Mexico, including Greenland and Bermuda. In addition to descriptions and the usual information about field identification, habitat, distribution, migration, reproduction, habits and food, the handbook contains such features as a simplified and more universal color standard (a color chart is included), distribution maps, data on banding and survival. Among the species considered are loons, grebes, albatrosses, petrels, shearwaters, fulmars, tropic birds, pelicans, gannets, boobies, cormorants, herons, bitterns, frigate birds, storks, ibises, spoonbills and flamingos. Many illustrations, some in color.

GRAVITY, by George Gamow. Anchor Books (95 cents). The well-known physicist and popularizer gives a clear summary of the classical and modern views of gravity. There are the usual whimsical Gamowisms that his fans love so dearly and a full set of his inimitable illustrations. The last two chapters on relativity and unsolved problems of gravity follow closely the author's article "Gravity," published in the March 1961 issue of SCIENTIFIC AMERICAN.

A PRIMER OF DUTCH SEVENTEENTH CENTURY OVERSEAS TRADE, by D. W. Davies. Martinus Nijhoff (15 Dutch guilders). A splendidly illustrated survey of the Dutch network of trade, which had remarkable ramifications in the 17th century, extending from Sweden, Russia and the Baltic ports to the Mediterranean, Indonesia, China and Japan, the Malay Peninsula, India, Ceylon and Burma, Arabia and Persia, Australia, Brazil. That this small country was at the height of its power a challenge to England, France and Spain, and that in the 17th century it was the greatest commercial power of Europe, is one of the amazing facts of history.

PLATO'S MENO, edited by R. S. Bluck. Cambridge University Press ($11.50). A newly edited edition, with an introduction and commentary, of one of Plato's famous dialogues, which deals with the nature and teachability of virtue, the relation between virtue, knowledge and true belief, learning as recollection and the pre-existence of the soul. The editor has taken into account the developments in scholarship during the past half-century and has based his text on a fresh examination of some of the most important manuscripts.

THEORY OF PROBABILITY, by Sir Harold Jeffreys. Oxford University Press ($13.45). In the third edition of this work Jeffreys has developed more fully his proof of the consistency of the postulates of the theory and has elaborated proofs of certain theorems. Jeffreys' work has from its first appearance in 1939 been regarded as one of the more thoughtful and original interpretations of probability. He now makes an effort to meet criticisms by proponents of other interpretations.

THE STRUCTURE AND DISTRIBUTION OF CORAL REEFS, by Charles Darwin. University of California Press ($1.95). First published in 1842, this book raised a scientific controversy that was not settled until recently, when drilling at Eniwetok and other oceanographic research confirmed Darwin's hypothesis that the mid-ocean reefs have grown up as underlying islands sank beneath the sea. It was a remarkable conjecture considering the scantiness of crucial facts available to him. The cause of the subsidence, as the geologist Henry W. Menard, Jr., points out in his foreword to this reprint of Darwin's scientific classic, is the "hotly debated question of the day." A paperback.

THE ART OF FALCONRY, by Frederick II of Hohenstaufen. Stanford University Press ($17.50). A reissue of a translated and edited version of *De Arte Venandi cum Avibus*, completed shortly before the year 1250 by Frederick II, Holy Roman Emperor, King of Sicily and Jerusalem. This is much more than a dissertation on hunting: it includes a long introduction dealing with the structure and habits of birds, and it is said to be the first zoological treatise written in the spirit of modern science. Many illustrations, translators' introduction, a chapter on manuscripts and editions of

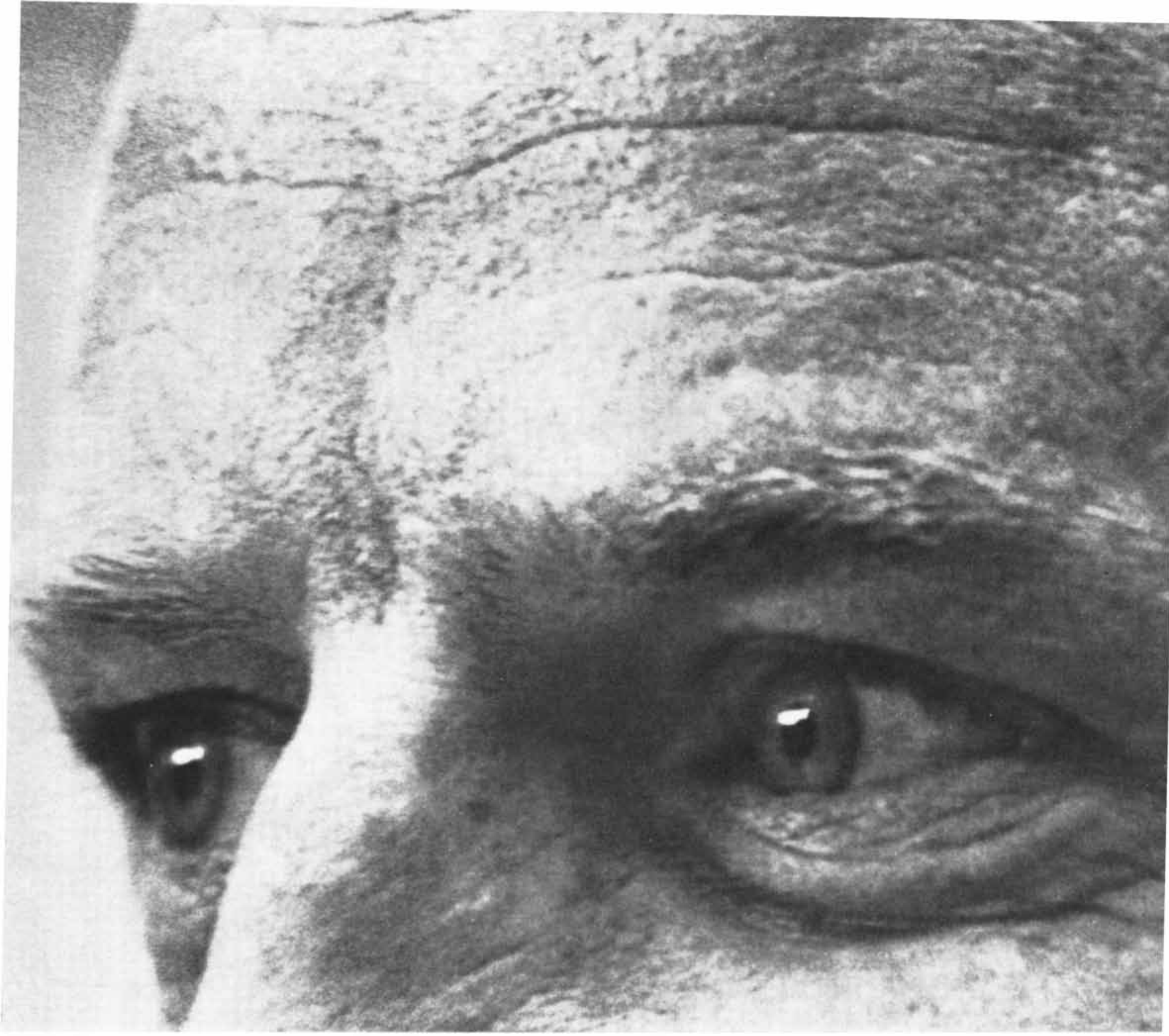
De Arte, a historical chapter on the Hohenstaufens, an annotated roster of birds familiar to Frederick II, an annotated bibliography of ancient, medieval and modern falconry and a glossary of falconry terms.

METHODS OF MATHEMATICAL PHYSICS. VOL. II: PARTIAL DIFFERENTIAL EQUATIONS, by R. Courant. John Wiley & Sons, Inc.—Interscience Division ($16). The second volume of Courant and Hilbert's well-known *Methods of Mathematical Physics* first appeared in the German edition of 1937. The book noticed here is, according to Courant, a completely new version in the English language of its German predecessor. It presents advances in knowledge in this field of mathematics over the past 25 years and Courant's own contributions to, and formulations of, these advances.

IRAN, by R. Ghirshman. Pelican Books ($1.95). An attractively illustrated survey, by a French archaeologist, explorer and historian who has spent many years in field research in Persia, of the prehistory and history of that country from the earliest times to the Islamic conquest. This is the kind of paperback that Pelican does better than any other publisher and at a remarkably low price, considering that among the many illustrations there are no fewer than 48 pages of fine plates.

THE AMERICAN COLLEGE: A PSYCHOLOGICAL AND SOCIAL INTERPRETATION OF THE HIGHER LEARNING, edited by Nevitt Sanford. John Wiley & Sons, Inc. ($10). This large volume of almost 1,100 pages, sponsored by the Society for the Psychological Study of Social Issues, contains essays on various aspects of the American college. Among other subjects, the essays deal with the entering student, academic procedures, student society and student culture, student performance in relation to educational objectives, interaction of students and educators, the effects of college education. A useful and timely evaluation of higher education by specialists in the social disciplines.

ETHICAL STUDIES, by F. H. Bradley. Oxford University Press ($1.85). A paperback of the well-known essay by the Oxford idealist metaphysician (best remembered for his book *Appearance and Reality*), which first appeared in 1876 and was still the subject of Bradley's attention almost half a century later, when he made many notes and changes. These he did not live to incor-



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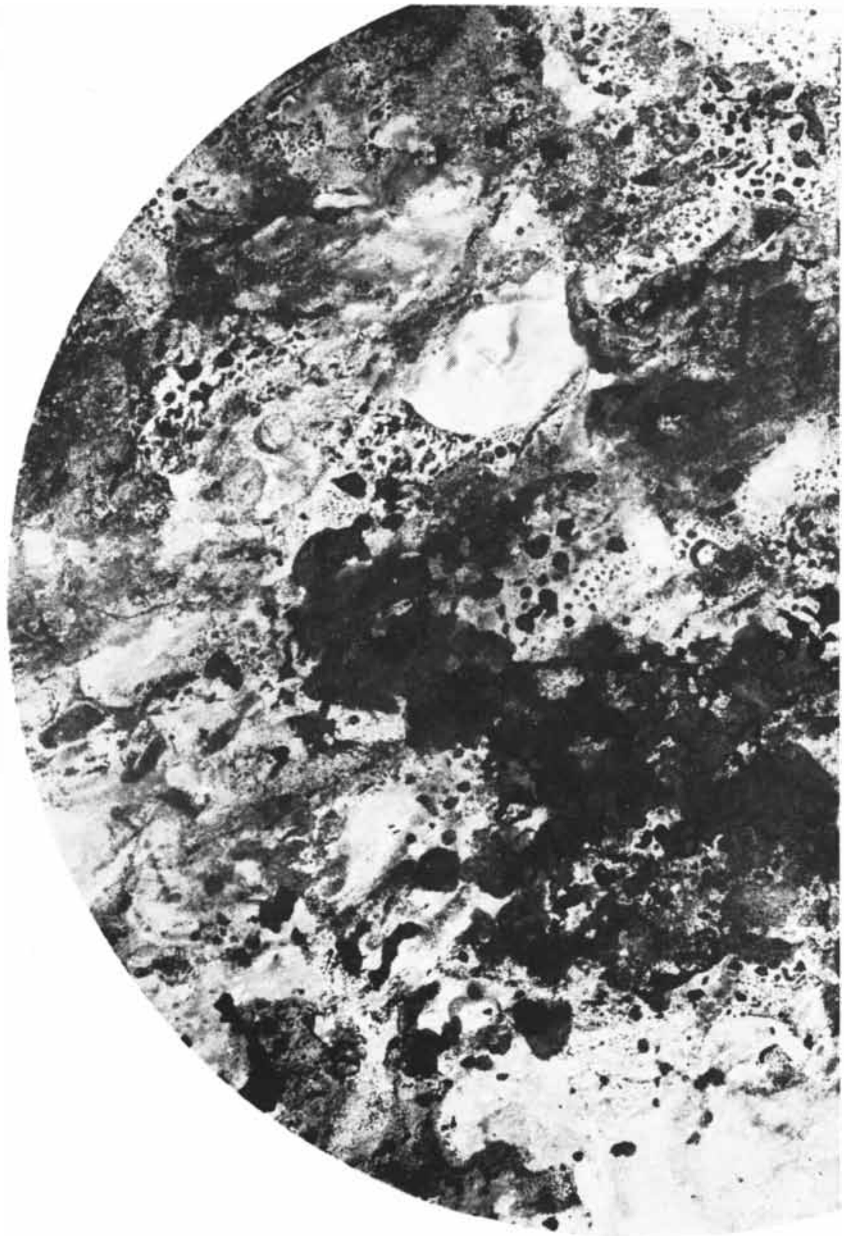


porate into the original work. Nevertheless, a second edition was published that contains the notes, and this is the volume now reissued in inexpensive format.

LIVING WITH THE ATOM, by Ritchie Calder. The University of Chicago Press ($5.95). This book, which grew out of two conferences held at the University of Chicago in 1960, discusses the peacetime uses of atomic energy and the many hazards of radioactivity attendant on these uses. Especial attention is devoted to the growing problem of the disposal of atomic garbage. As always, Calder writes sensibly and responsibly. Illustrations.

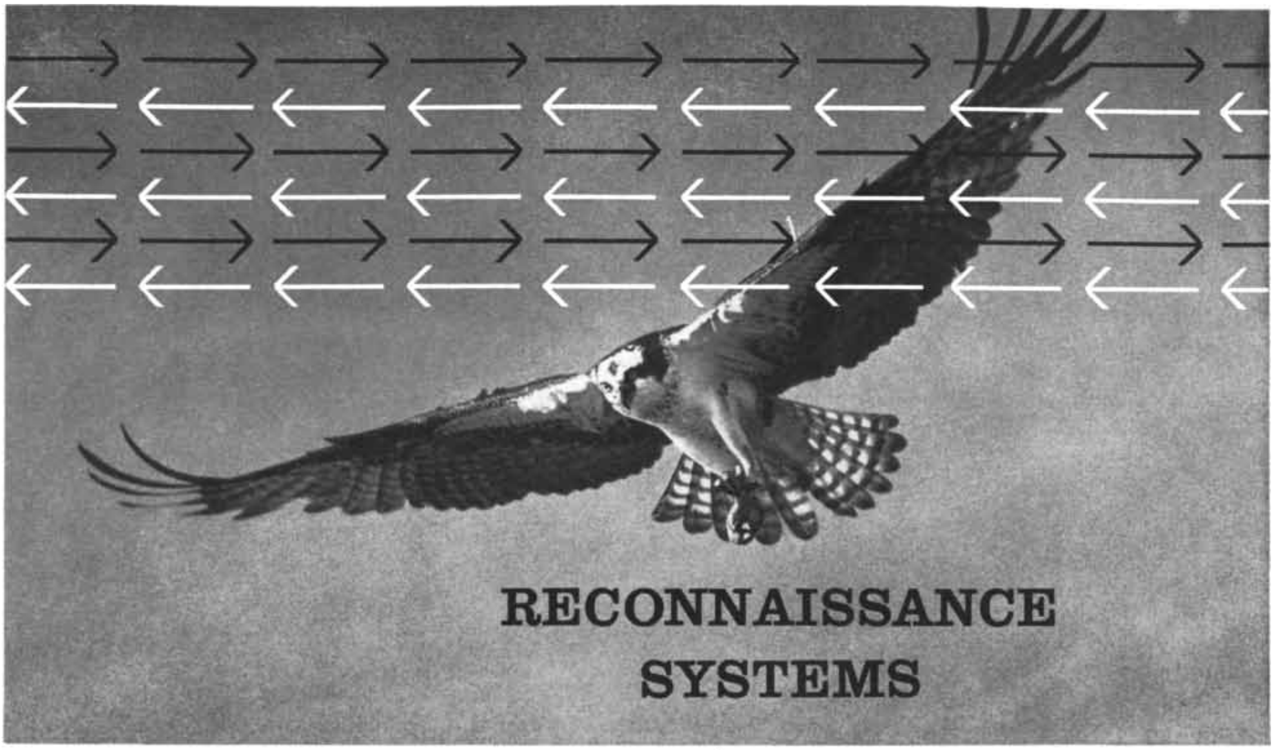
SCIENCE AND THE FUTURE OF MANKIND, edited by Hugo Boyko. W. Junk (35 Dutch guilders). The first publication of the World Academy of Art and Science, established in 1960 as an outgrowth of the 1956 International Conference on Science and Human Welfare, this volume collects a number of essays that deal with the problem of the beneficent uses of science and its application to political and economic problems, toward the end of promoting peace, economic well-being and "a higher level of culture than has yet been attained." Included are essays by Albert Einstein, J. Robert Oppenheimer, H. J. Muller, H. D. Lasswell, Bertrand Russell and others. There is also a foreword by Lord Boyd Orr.

SUMER: THE DAWN OF ART, by André Parrot. Golden Press, Inc. ($25). A fully illustrated study of the sculpture and engraving of the ancient Sumerians from the sixth millennium B.C. to about 1500 B.C. The reproductions are uneven, some of those in color particularly being overdramatized and quite poor. This is nevertheless a remarkable volume, the first of a new series, "The Arts of Mankind," edited by André Malraux and Georges Salles.

Notes

THE ORIGINS OF MODERN SCIENCE, 1300–1800, by Herbert Butterfield. Collier Books (95 cents). A soft-cover edition of Butterfield's study, which opened new lines of thought in the history of science.

ESSAYS ON THE FOUNDATIONS OF MATHEMATICS, edited by Y. Bar-Hillel, E. Poznanski, M. Bavin and A. Robinson. North Holland Publishing Co. ($11.20). Dedicated to the noted mathematician A. A. Fraenkel, this collection of essays deals with a variety of



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topics in axiomatic set theory, mathematical logic, foundations of arithmetic and analysis, and the philosophy of logic and mathematics. This is a collection for the specialist, but the general reader who happens to dip into the volume will find both accessible and intriguing the essay "Process and Existence in Mathematics," by Hao Wang of the University of Oxford.

SELECTED PAPERS OF A. H. STURTEVANT: GENETICS AND EVOLUTION, selected and edited by E. B. Lewis. W. H. Freeman & Co. ($7.50). A collection of technical papers by a member of the original Thomas Hunt Morgan group of *Drosophila* workers, who for more than half a century contributed to such genetic problems as sex-linkage, linkage and crossing over, the linear order of the genes, chromosome "maps," interference in crossing over and related matters.

HOW ANIMALS DEVELOP, by C. H. Waddington. Harper Torchbooks ($1.25). An inexpensive reissue of a short account of the science of embryology for students and the general reader.

GEOMETRY: AN INTRODUCTION, by H. G. Forder. Harper Torchbooks ($1.35). A soft-cover reprint of an able, readable introduction, from a modern point of view, to the main branches of the subject (excluding topology), consisting of chapters on Euclidean, projective, co-ordinate, algebraic, non-Euclidean, solid and differential geometry, on geometry of many dimensions and on the logical structure of geometries.

ACTION FOR MENTAL HEALTH, by the Joint Commission on Mental Illness and Health. Science Editions, Inc. ($1.95). A paper-backed edition of the report on the five-year study of mental health in the U.S. made by the Joint Commission on Mental Illness and Health.

COSMOLOGY, by H. Bondi. Cambridge University Press ($2.45). A soft-cover reissue of the second edition of a balanced and skillful survey of the theoretical problems and controversies of modern cosmology.

THE MOUNTAIN WORLD, edited by Malcolm Barnes. Rand McNally & Co. ($6.95). The 1961 volume in this series, known for its handsome photographs, contains, among others, papers on aerial photography, sundry expeditions in the Karakoram, the Swiss Andean expedition, mountaineering in Antarctica during the International Geophysical Year, and an essay on that curious mountainous creature the Yeti, which has probably given rise to the zany speculations about the Abominable Snowman.

THE LAWS OF NATURE, by R. E. Peierls. Charles Scribner's Sons ($1.45). A paper-backed edition of Peierls' able popular introduction to physics.

ATLAS OF THE UNIVERSE, by Br. Ernst and Tj. E. De Vries. Thomas Nelson & Sons ($9.95). An encyclopedia of astronomy written by nonspecialists for nonspecialists and subsequently edited by a professional astronomer (H. E. Butler of the Royal Observatory in Edinburgh). Bread-and-butter facts and ideas are given concisely and simply. Some of the illustrations are excellent.

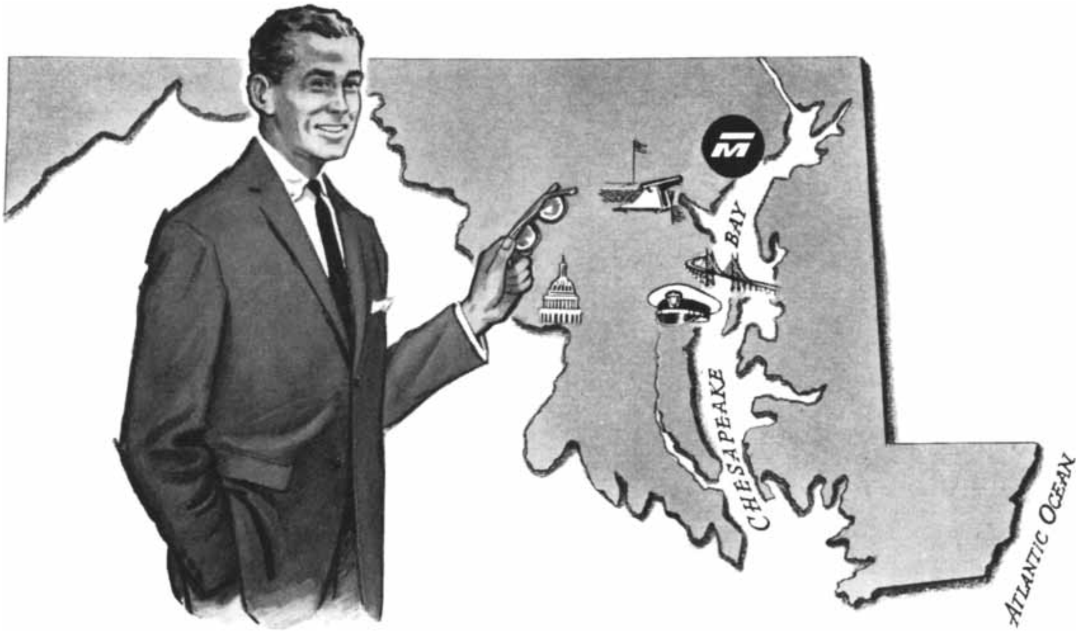
PASCAL'S PENSÉES, translated with an introduction by Martin Turnell. Harper & Row, Publishers ($6). This new translation of Pascal's beautiful and immensely influential collection of apothegms is based on the scholarly Lafuma edition of 1952. Critics in Britain, where this translation first appeared, have praised it highly for its felicitous English equivalents of Pascal's poetic utterances.

CIVILIZATION AND ITS DISCONTENTS, by Sigmund Freud. W. W. Norton and Co., Inc. ($3.75). A new translation by James Strachey of one of the last of Freud's books, which gives his gloomy and painfully prophetic views on the "irremediable antagonism between the demands of instinct and the restrictions of civilization."

STANDARD METHODS OF CHEMICAL ANALYSIS. VOL. I: THE ELEMENTS, edited by N. Howell Furman. D. Van Nostrand Company, Inc. ($25). Sixth edition of a source book of analytical information for general use in the chemical laboratory. This volume deals with the elements; two volumes in preparation are to cover industrial and natural products and instrumental analysis.

SIR THOMAS BROWNE, by Frank Livingstone Huntley. University of Michigan Press ($4.95). A not very inspiring but nonetheless erudite biographical and critical study of the noted English physician and scholar, who wrote so sublimely that under the spell of his incomparable style one is sometimes tempted to overlook the fact that he also had ideas.

MCGRAW-HILL YEARBOOK OF SCIENCE AND TECHNOLOGY, edited by W. H. Crouse and others. McGraw-Hill Book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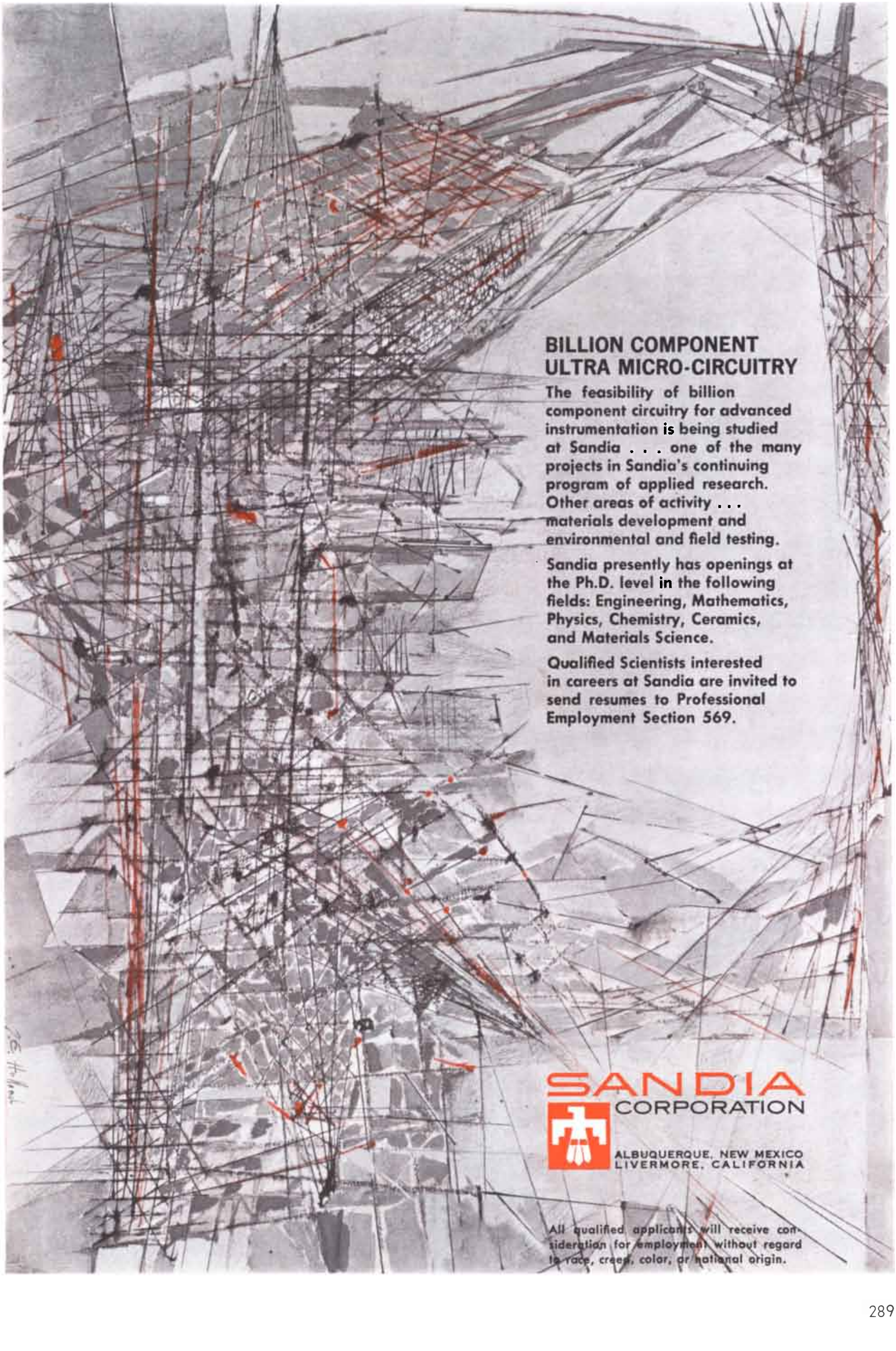
Co., Inc. ($17.50; $10.50 to owners of the *McGraw-Hill Encyclopedia of Science and Technology*). The first in a planned series of annual supplements to the *McGraw-Hill Encyclopedia of Science and Technology*, this volume contains some 300 articles concerned with scientific advances in 1961. Many photographs and drawings.

POETRY AND MATHEMATICS, by Scott Buchanan. J. B. Lippincott Co. ($1.75). A soft-cover reissue, with a new introduction by Buchanan, of an essay first published in 1929 that examines certain parallels of structure, form and conceptualization between poetry and mathematics. Buchanan may be inclined to strain the analogies, but he is successful in conveying the notion that the two activities in their different approaches to intellectual problems have much more in common than is usually supposed.

PROCEEDINGS OF THE FOURTH BERKELEY SYMPOSIUM ON MATHEMATICAL STATISTICS AND PROBABILITY, edited by Jerzy Neyman. University of California Press ($45). The proceedings of a symposium held at the Statistical Laboratory of the University of California in the summer of 1960. A first volume consists of contributions to the theory of statistics; a second volume, of contributions to probability theory; a third volume, of applications of these branches of mathematics to astronomy, meteorology and physics; and a fourth volume, of applications to biology and medicine.

A NEW DICTIONARY OF CHEMISTRY, edited by L. Mackenzie Miall. John Wiley & Sons, Inc.—Interscience Division ($13.75). The third edition of this dictionary has been fully revised. A work of moderate size, it is nevertheless a handy source of information on the meanings of many of the words used in chemistry and the related sciences, and it includes brief accounts of many chemical substances, chemical operations and men who have contributed to the progress of chemistry.

THE NEW CENTURY CLASSICAL HANDBOOK, edited by Catherine B. Avery. Appleton-Century-Crofts, Inc. ($15). An 1,162-page reference book with more than 6,000 entries, describing the great figures of classical Greece and Rome, the ideas and accomplishments, the places, myths and legends. This is a general handbook, humanist in orientation, with only sketchy coverage of such subjects as mathematics, the exact sciences, logic and philosophy.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INDEX OF

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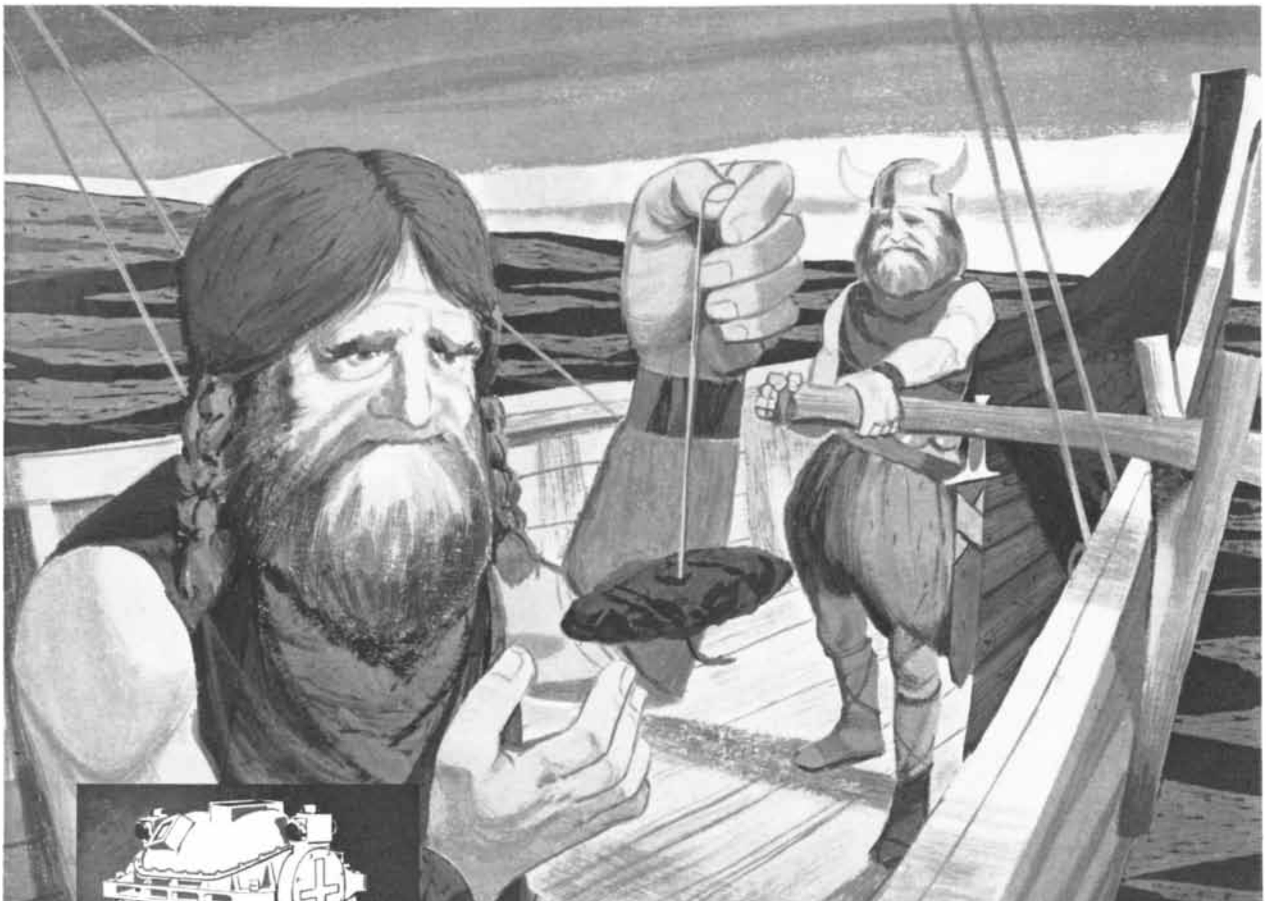

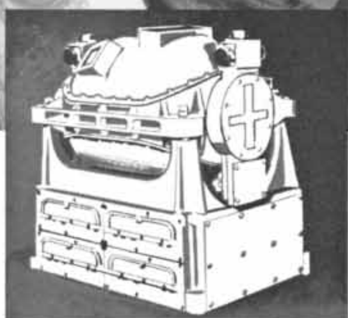

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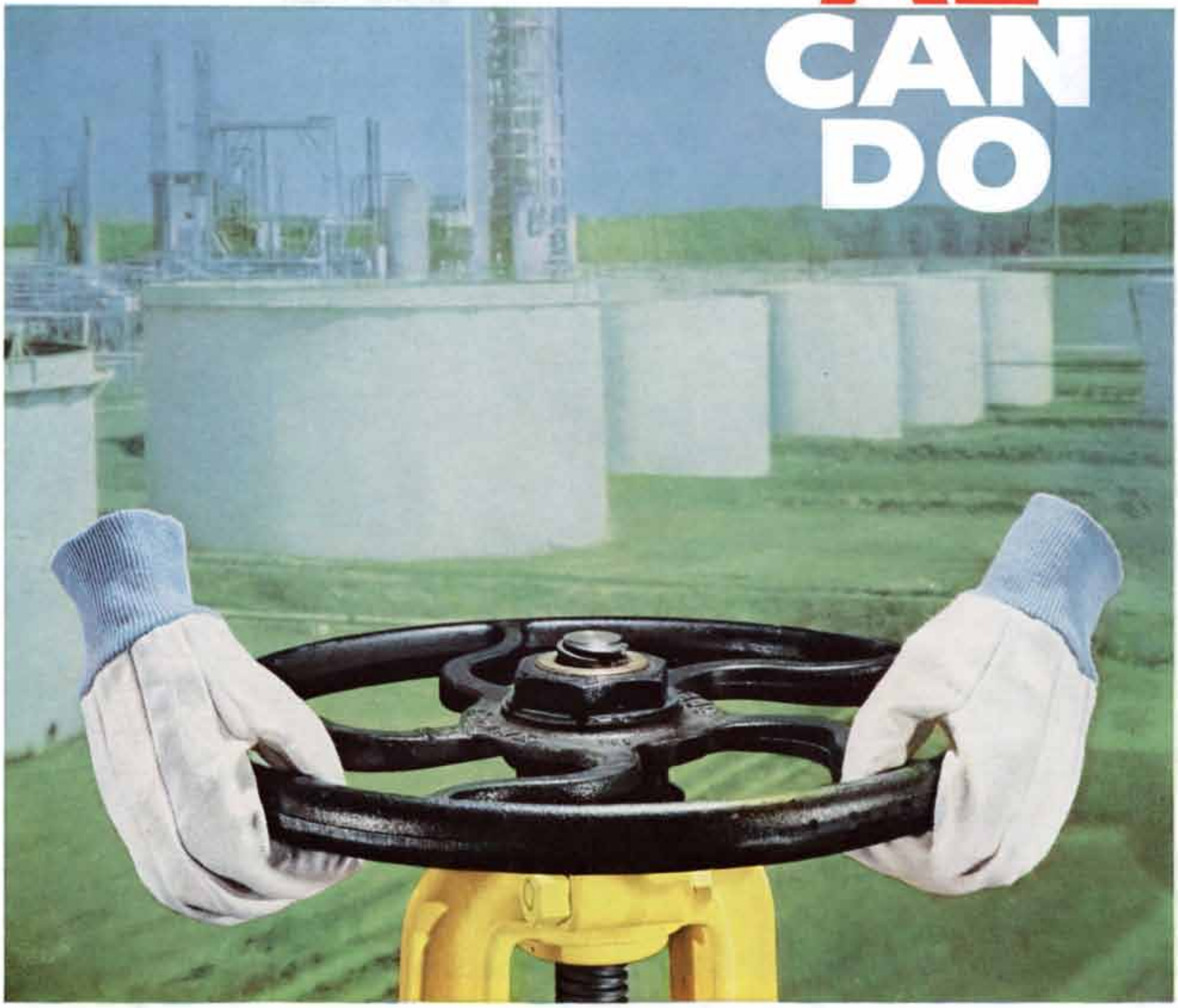

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