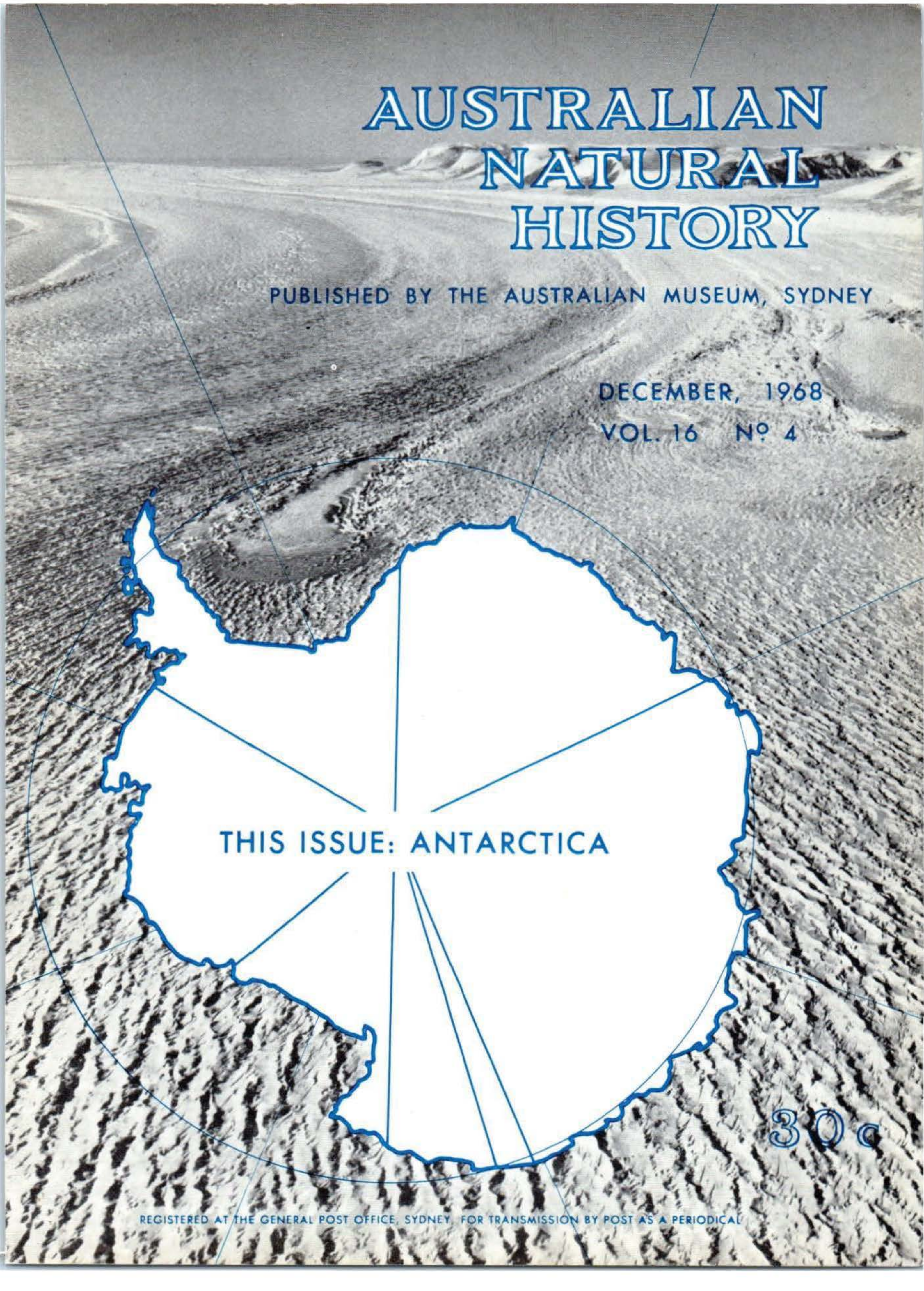

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This issue is devoted to Antarctica and its natural history. It contains sixteen extra pages.

CONTENTS

● **FRONT COVER: Behind the outline map of Antarctica is an Australian National Antarctic Research Expedition photo of an Antarctic glacier. BACK COVER: The Gentoo Penguin (*Pygoscelis papua*), generally called "Johnny" by sailors who visit the Antarctic. It is found in the southern oceans and breeds on the islands, and has been recorded once from Tasmania. The white fillet on the head distinguishes the Gentoo from all other similar penguins. (Photo: Ederic Slater.)**

Antarctica—Nature's Unique Scientific Laboratory

By PHILLIP LAW
Vice-President, Victoria Institute of Colleges, Melbourne, and formerly Director of the Antarctic Division, Department of External Affairs

THE motivation for Antarctic activities has varied over the years since the continent was first sighted in 1820. In the beginning the incentive was commercial gain and the expeditions were largely organized and financed by sealing and whaling enterprises.

Next came the era of exploration, in which national aspirations for colonial conquest played an important part. Before the exploration of Antarctica was completed —in fact, before little more than the fringe of the continent had been mapped—the advent of the International Geophysical Year in 1957 made scientific discovery a major motivating factor in Antarctic work.

The signing of the Antarctic Treaty in November, 1959, pushed into the background the 50-year-old international competition arising from territorial claims, and the contest changed to one in which twelve nations vied with each other to demonstrate their scientific and logistic competence in a hostile environment.

At present, then, the urge for expeditionary activity is almost completely scientific. So far, no resources of immediate commercial significance have been discovered. The whale stocks have diminished to a point where whaling is scarcely profitable any more and, although there are great numbers of seals, their wide dispersal makes it unprofitable to hunt them. No ore bodies have been discovered, let alone any of sufficient size to justify establishing a mining industry.

Expanding scientific interest

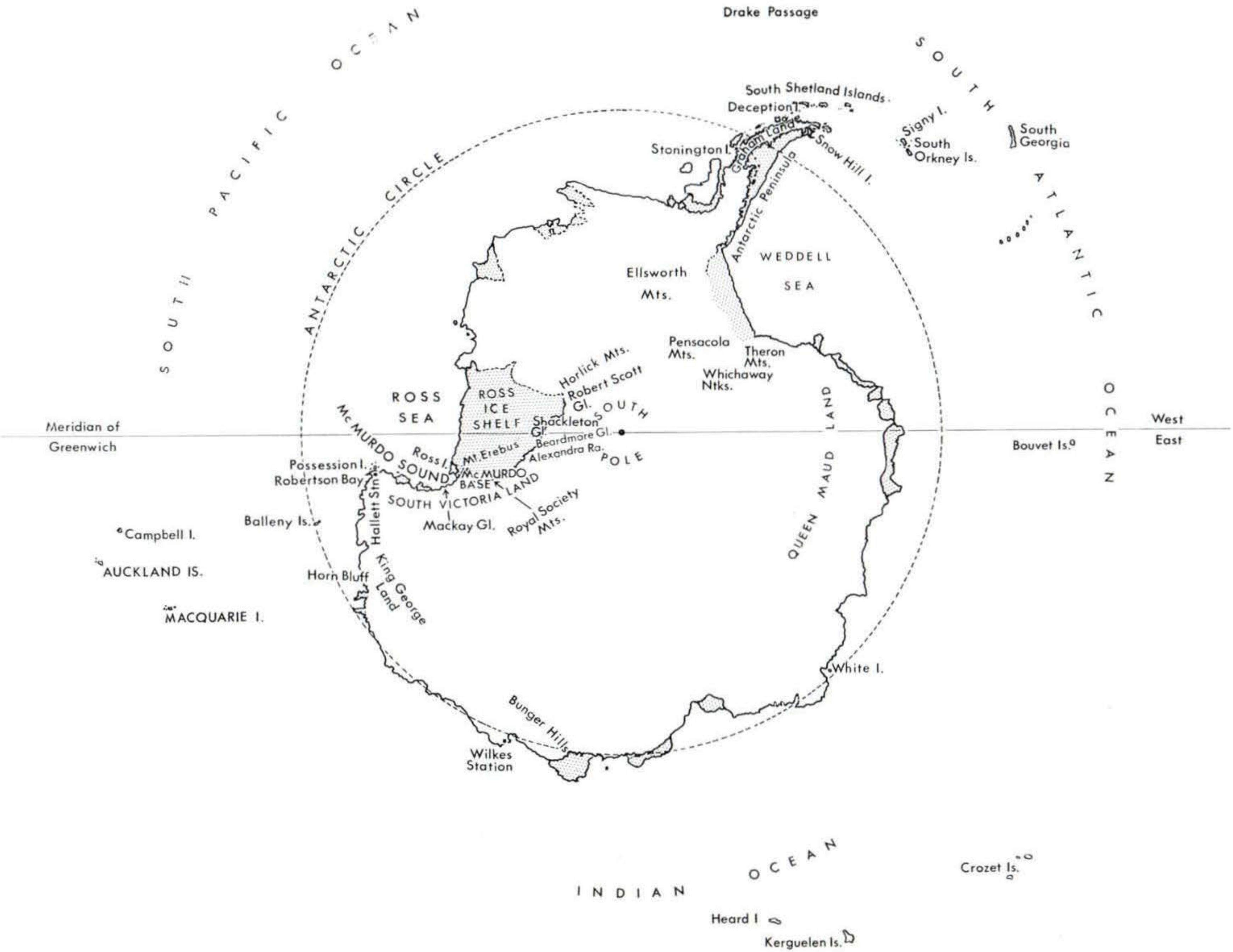
But, scientifically, Antarctica is a treasure house of riches. In an age when scientific research has been extended to the second and third order of difficulty, here is a region in which much cream, at a level of primary simplicity, remains to be skimmed off. Antarctica offers unusual and valuable dividends in most disciplines and scientific interest in the region has continued to expand and develop.

Why is this? The reasons for the unique nature of the research opportunities are largely geographical. The distribution of land and ocean in the Southern Hemisphere is quite different from that in the Northern Hemisphere. Instead of large continents extending towards the north with narrowing belts of oceans between and an oceanic basin at the Pole, there are in the Southern Hemisphere wide wastes of ocean sweeping uninterrupted around the world and washing on the shores of a great polar continent.

This distribution and the comparative symmetry of Antarctica result in a much simpler system of winds in the Southern than in the Northern Hemisphere and encourage meteorologists to attack broad problems of atmospheric circulation.

The Antarctic Convergence—that narrow region encircling the globe at about 50° to 55° S. latitude, where the cold Antarctic ocean water plunges below the warmer temperate water—is a very real boundary influencing the distribution of planktonic species, fish, mammals, and birds. Oceanographically, the southern regions of the Indian, Pacific and Atlantic Oceans are of the greatest interest.

The Antarctic Continent itself is unique. It is the coldest, highest, driest, most sterile region on earth. In area $5\frac{1}{4}$ million square miles, it is covered almost entirely with an ice sheet the average depth of which is about 1 mile. Other Antarctic characteristics are the unequal distribution of night and day, the convergence towards the magnetic pole of lines of force of the earth's magnetic field, the isolation of the continent, and the absence upon it of land-based animals.



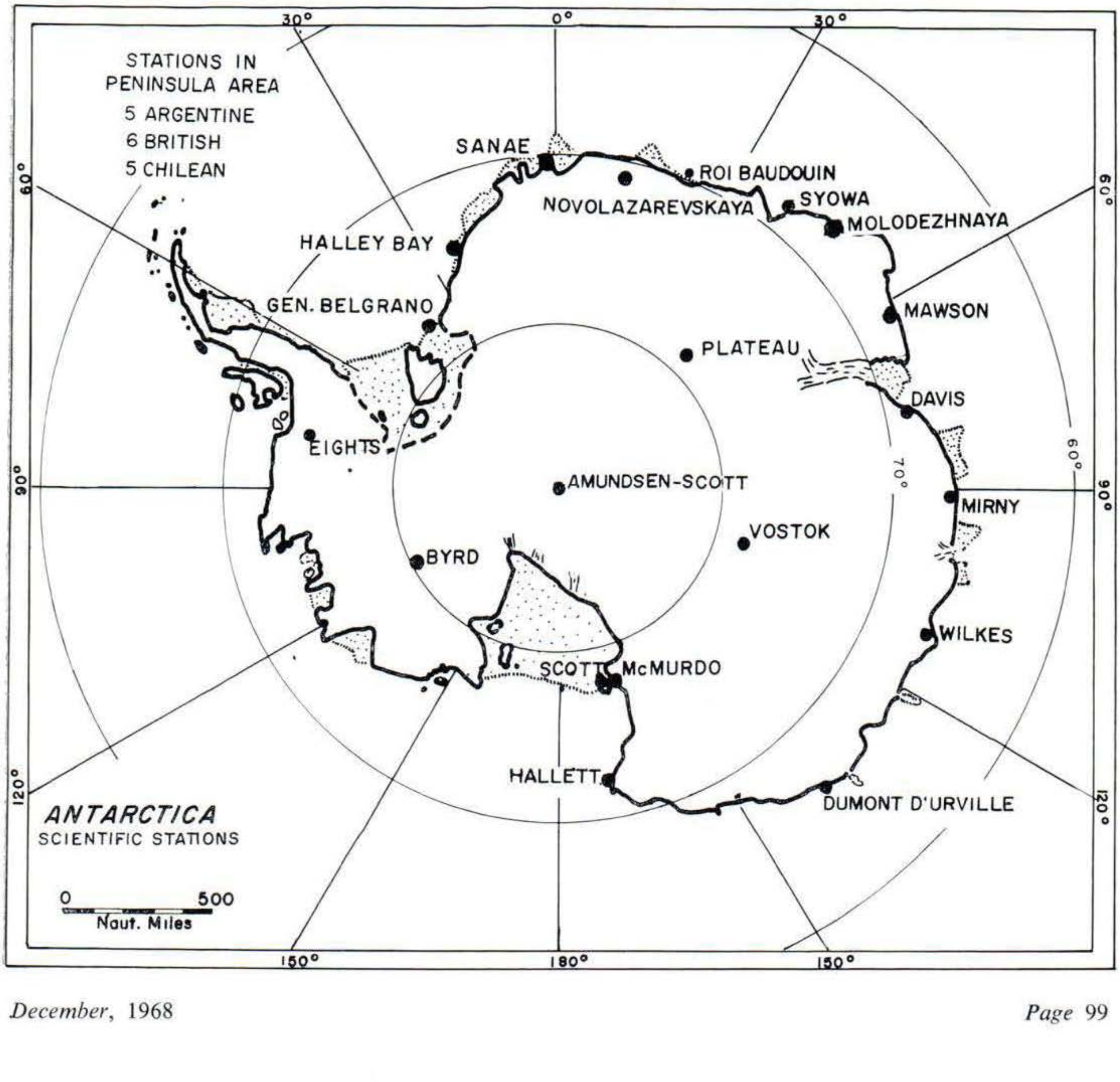
Antarctica and surrounding islands. Map by Elvie Brown and Beverley Crew, Australian Museum.

Difficulties obstruct research

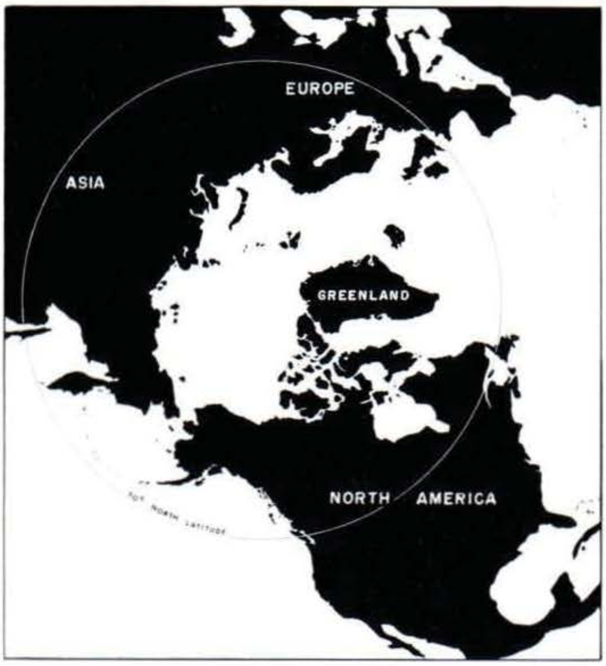
The prosecution of research in this interesting region is obstructed by numerous difficulties. Climatic conditions are severe, with intense cold and, in many places, hurricane-force winds; lines of communication between Antarctic research stations and established centres of population on other continents are long and fraught with hazards; and the isolation of personnel at stations during the long, dark Antarctic winter raises psychological problems. Antarctic research is thus a highly specialized business, and only long experience and meticulous attention to detail in the design of equipment can produce results commensurate with the expense of mounting expeditions.

In 1967 there were ten nations active in Antarctica: U.S.A., U.S.S.R., Britain, France, Japan, New Zealand, South Africa, Chile, Argentina, and Australia. Two other nations active during the International Geophysical Year—Norway and Belgium—have temporarily withdrawn. The scientific stations operating in 1967 are shown in the map on this page. The remarkably uniform distribution of stations is not fortuitous but the result of International Geophysical Year planning. The international co-operation developed during that period has been extended and firmly established.

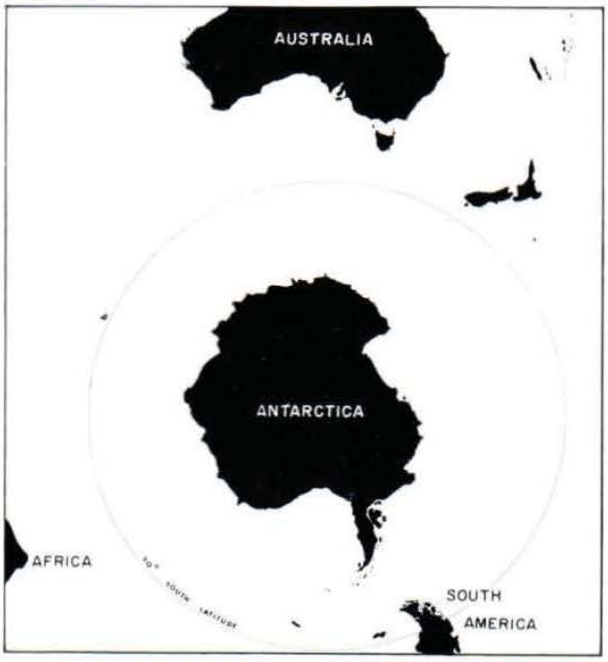
One of the special committees of the International Council of Scientific Unions is the Scientific Committee on Antarctic Research (SCAR). Twelve delegates, one from each of the nations listed above, meet together, with their advisers, once



every 2 years to arrange for adequate exchange of information, to propose future programmes, and to facilitate international collaboration and assistance.



These maps show how different is the distribution of land and ocean in the Southern Hemisphere to that in the Northern Hemisphere.



Much cartography yet to be done

All major features of Antarctica have now been mapped in general outline and there are few areas of its surface that have not been sighted. Much detailed cartography of rock exposures and mountains remains to be done, a lot more work is needed on the contours of the ice surface of the plateau, and some difficult ice coasts require interpretation before they can be accurately portrayed on charts; but the overall picture is well established.

Such mapping has been a pre-requisite for many scientific studies, notably geology, biology, and glaciology, and for this reason it was granted high priority. Also, the national prestige to be derived from discovering and naming new features encouraged all the Antarctic nations to push on vigorously with exploration.

Australia, which claims a large sector of Antarctica and which entered the International Geophysical Year with a long and proud tradition of Antarctic exploration and research, has produced cartographic results that stand comparison with those of any other Antarctic nation. In Antarctic meteorology, geology, biology, geophysics, and physiology Australian scientists have shown the energy and adaptability that characterize their work in other fields. They have participated in a most rewarding and exciting era, during which a virtually unknown continent has been opened up and investigated with a concentrated intensity never before applied to any single region.

Now that the attention of scientists has been directed to the rich harvests to be gleaned from Antarctic research, it can be expected that activity will continue at an undiminished level until, at some time in the future, the discovery of exploitable wealth opens the way for still yet another phase of Antarctic development—the colonization of the region.

[*The maps on pages* 99 *and* 100 *were prepared by the Antarctic Division, Depart- of Supply*.]

Typical mountain scenery in Antarctica, with Arena Valley in the foreground and peaks flanking Ferrar Glacier in the background. This area is part of the region in which the author of this article worked. [Photo: U.S. Navy Air Force.]

Mineral Resources and Geology

By C. T. McELROY
Director, Geological Survey of New South Wales, Department of Mines

MANY nations are carrying out research projects in Antarctica, and valuable work is being done by the Australian National Antarctic Research Expedition. Australians have also been supported from time to time by the United States Antarctic Research Programme. In the austral summer of 1964–65 and again in 1966–67, two small parties from the University of Sydney, the University of New South Wales, and the Geological Survey of New South Wales undertook geological work in Antarctica. In the first season, D. Anderson, B. Hobbs, C. McElroy, and P. Williams carried out structural and stratigraphic studies in the area west of McMurdo Sound, and in the second season, J. Bryan, C. McElroy, and G. Rose made detailed structural studies in Arena Valley, a small part of the previously examined area.

Much of this article is based on the findings of these journeys, and it is especially desired to record the debt of gratitude owed to the National Science Foundation and the United States Navy Air Force for the support received. Published literature has been freely drawn upon and the reader is referred to the works of Harrington (1965) and Warren (1965) for fuller accounts of certain sections of the geology and for morphological aspects not considered here.

Mineral resources

Dr A. P. Crary, Chief Scientist, Office of Antarctic Programmes, National Science Foundation of America, recently gave an address at McMurdo Base to a group of visiting scientists and politicians. In the course of this address, he was asked the inevitable question as to the potential for economic development of Antarctic mineral resources. He replied to the effect that if the most profitable mining operation in the world today were transplanted to Antarctica, it would no longer be a paying proposition. Quite simply, this is a function of transporation difficulties to, within, and from Antarctica, together with the problems of working year-round in the unpredictable Antarctic weather conditions. Nevertheless, it is possible to envisage that an exceptionally rich deposit of a valuable metal or precious stones might prove to be workable. At the present time, however, although there are traces of a number of metals in scattered localities, there are no significant finds of minerals to foster the hope that a reserve against the depletion of the world's mineral resources exists in Antarctica.

It might be said that one has read of "thick coal seams in Antarctica". Unfortunately, most of the coal examined to date has proved to be very inferior in quality, thin, and of limited lateral extent. Commonly it has been affected (baked, in fact) by the occurrence nearby of masses of dolerite, which, while in the molten state, intruded the coal-bearing sediments, sometimes with violent displacement, as shown in the photo on this page.

Clearly, deposits of the fuels, coal, oil or natural gas, would be most useful on the spot, providing discovery does not come too late, as already a small nuclear power plant at McMurdo is both supplying electricity and desalinating sea-water for domestic use at the base.

Geology

Although significant advances have been made in geological knowledge in Antarctica, the proportion of the continent that has been examined in the detail desired by most geologists is small indeed. Nevertheless, a basic assessment of the geological history has been built up from the rock sequences so far investigated. Brief comments follow on the nature of these sequences. For convenience, these will be grouped into seven units, which will be discussed in turn, commencing far back in geological time.

Unit 1

Oldest of all, is a *Basement Complex* of older Precambrian age; the age of these rocks, based on potassium/argon and rubidium/strontium methods, is placed at a minimum of some 2,000 million years. There are now to hand quite a number of age determinations in the range 1,000 to 2,000 million years for this complex. The

Sandstones (almost white) and shales (thin dark bands) in the lower section and in patches, much disrupted by intruding dolerite (dark grey and black, at top and in centre). The width of the photographed area is 80 feet. [Photo: Author.]

Sandstones of the Beacon Group, Arena Valley. The peak on the right is East Beacon Mountain, over 8,000 feet above sea-level. Note the extensive intrusion of dolerite sills (dark grey layers near top and at right, middle ground). The floor of the valley is 4,000 feet above sea-level. [Photo: Author.]

complex includes highly metamorphosed sediments, schists, gneisses, and ancient, much altered basic volcanic and intrusive rocks, with veins of aplite and pegmatite in places. The rocks are highly folded and the relationships between the various units are mostly obscure.

Unit 2

Overlying the Basement Complex is a substantially younger unit, probably not much older than 600 or 800 million years, that is, of younger Precambrian and Cambrian age. This has been called the Ross Supergroup and it comprises folded quartzites, greywackes, limestones, marbles, and argillites (impure, silty, somewhat metamorphosed sediments). These rocks contain Cambrian trilobites and other invertebrates, but of special interest is the occurrence in places of the sponge-like Cambrian fossil *Archaeocyathus*, a widely distributed diagnostic fossil, which is best developed in rocks of similar age in South Australia and Central Australia. In recent years, the same fossil has been discovered in far western New South Wales.

Unit 3

All the foregoing rocks, from older Precambrian to Cambrian, have been intruded by granite, granodiorite, and gneiss, most of which are of early Palaeozoic age, that is, around 500 million years. The units so far mentioned, 1, 2, and 3, may together be considered as a nucleus that formed an older Antarctica, which suffered folding, uplift, and subsequent erosion. Over large areas the surface was planed almost flat by the agents of weathering—presumably water, wind, and possibly ice. Onto this peneplain, as it is called, was deposited the fourth unit in the sequence.

Unit 4

The *Beacon Group* is a flat-lying unit having a total thickness of at least 8,000 feet, although the remnants of the sequence at any one locality aggregate less than 5,000 feet. The most important rock type of the group is medium to coarse-grained sandstone, which occurs in layers hundreds of feet thick. In places, successive layers form sheer cliffs over 1,000 feet in height. The photo on this page illustrates this feature.

It might be noted that the rocks are the same type as the Hawkesbury sandstone of the Sydney district, although the Antarctic rocks pictured are in fact much older. It is now established that the age of the Beacon Group extends at least from the Lower Devonian to the Jurassic Period, that is, from about 400 to 150 million years ago. It may be older, but no fossils older than Lower Devonian have yet been found.

Among the more interesting aspects of the fossil record are fish remains of Middle or Upper Devonian age. Many of these primitive fish had small polygonal plates, instead of "conventional" scales to protect their bodies. Different species had characteristic ornamentation, as is illustrated in a specimen (see photo) collected from Aztec Mountain near the Beacon Valley. It is also of interest that fossil spores and pollens of similar age have in the last few months been identified from fine sandstones a few feet above the fish-plate horizon in the same locality.

In addition, there are enormous numbers of "trace-fossils" or "problematica", representing tracks and trails or burrowings of ancient organisms, but the precise origin of these is not known. Some of these are shown in the photos on the next page.

Great interest has often been expressed in the record of coal in Antarctica, and especially the association of the fossil leaves *Glossopteris* and *Gangamopteris* and other plants which are so prominent in the Permian

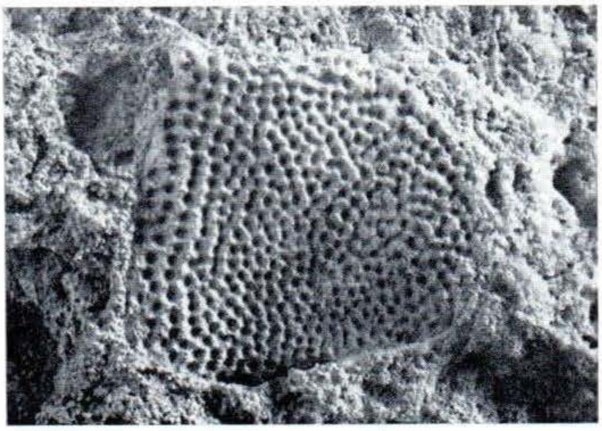


Plate from the "armour" of a fossil fish, about 350 million years old, of Devonian age, collected from Aztec Mountain in January, 1967. The width of the plate is about 1·5 cm (about three-fifths of an inch). [Photo: J. M. Hamilton.]

Coal Measures of Australia, India, South America, and South Africa. Economic aspects of the coal have been referred to above, but here we might pause to reflect upon the fact that the fossil record of abundant plant life in parts of Antarctica, where now nothing grows, points to a milder climate in the past—in this case, some 200 million years ago. There are also spores and pollens of Triassic age, 180 million years old, identical to those in rocks from the Sydney district.

Other evidence, including that deduced from geophysical studies, suggests that Antarctica lay at various latitudes nearer the equator at different stages of its history. The extensions of this evidence and the distribution of the *Glossopteris-Gangamopteris* flora, together with many other arguments, have led many geologists to believe that the southern continents and India were once united in a great land mass to which the name Gondwanaland has been applied. At the same time, it must be pointed out that many other geologists have raised objections to the concept of "continental drift" and have been at pains to point out that there are many differences in the rock associations and geological histories of the Gondwanaland components. The subject remains an absorbing controversy with interest currently at a high level.

Other rocks of the Beacon Group include red, green, and grey shales and siltstones; fine conglomerates are well developed in the upper part of the sequence in the Beacon Valley area.

Another coarser conglomeratic horizon in places occurs between rocks of Devonian age and rocks of Permian age. It appears that this may be a record of active erosion, which was taking place during or just after the Carboniferous Period, as there are no known sedimentary rocks of this age in Antarctica.

Rocks composed of debris formerly carried by glaciers, termed tillites, are found in some localities in the upper part of the Beacon Group. However, it is believed that most of the group was deposited under shallow marine conditions, although positive evidence is not to hand. The coal-bearing section was almost certainly deposited under freshwater conditions.

Although the Beacon Group is essentially flat-lying, in places great blocks, whole mountains in fact, have been displaced hundreds of feet vertically, the movement going hand-in-hand with the invasion of massive sills of dolerite. Some such sills and other wall-like intrusions of dolerite may be seen in the photo on the previous page. Furthermore, in Arena Valley there are many hundreds of feet of folded and tilted sediments sandwiched between flat-lying units. It is believed that these structures, unique, as far as is known, in

Antarctica, resulted from gravitational slumping at the time of deposition of the sediments. The movement and subsequent deformation were possibly triggered-off by slight earth flexures at the time.

Unit 5

The great invading sheets (sills), wall-like masses (dykes), plugs and irregular bodies of dolerite to which reference has been made have been called the Ferrar Dolerite. These are of Jurassic age, and, together with associated volcanic rocks, may be regarded as the fifth unit in our discussion. The volcanic rocks comprise basalts, which were poured out over the land surface of the time, and other rocks formed of fragments deposited after ejection from volcanic vents.

It is of interest that there is almost no visible evidence of changes in either dolerite or sandstone at the junction between the two, and it must be remembered that vast masses of molten rock were involved, which makes the lack of metamorphic effects remarkable. However, the state of preservation of spores and pollens in the sedimentary rocks and the rank of the coals appears to have been substantially affected by this activity.

Unit 6

In Graham Land, the peninsula of Antarctica that stretches towards the southern tip of South America, occur extensive deposits of Jurassic and Cretaceous shales, limestones, and coarse sandstones with beds of both freshwater and marine origin. The latter include molluscs, brachiopods, annelids, and ammonites. There are associated volcanic rocks, but more widespread are granites and gabbros which invaded large areas, replacing rocks of the Jurassic and Cretaceous sequence. These rocks are very similar to some of the granitic suites of the South American Andes.

Unit 7

The last unit we discuss takes us from some 80 or 90 million years ago, in the Tertiary Period, up to the present day. The rocks include calcarious sands, conglomerates, silts, and greensands. They are characterized by a rich fossil flora and fauna, and in places there are penguin remains dating back millions of years.

These two photos show trace-fossils from rocks of the Beacon Group, Devonian age. The markings represent tracks, trails, and burrowings of ancient organisms of uncertain type.
[Photos: Author.]

Among the most recent sediments, perhaps less than 1 or 2 million years old, are deposits, many of them of marine origin, which are now situated at heights ranging from a few tens of feet to nearly 2,000 feet above present sea-level. It is clear that in the near geologic past there was an uplift of the land relative to sea-level, and one can but speculate on the true origin of this movement.

Was the rise due to the unloading of enormous thicknesses of ice in the past, the land rising as a ship rises as it is unloaded? Was it uplift occasioned by forces having their origin deep within the mantle of the earth?

Perhaps equally as exciting is the evidence, not only of volcanic activity in the near past, but at the present day. Until very recently it was thought that magnificent Mt Erebus, rising pure-white from McMurdo Sound to a height of over 13,000 feet, was the only active volcano in Antarctica. However, two more volcanic centres have now been found and doubtless others will be discovered as exploration proceeds.

Earlier it was mentioned that extensive gaps in our knowledge of Antarctic geology exist. However, a start has been made to fill some of these gaps.

Particularly appropriate to Antarctica are the words of one of the earliest Antarctic workers, Professor Sir Edgeworth David. Writing in the early thirties on the incompleteness of knowledge of Australian geology, David referred to the " . . . tale which will surely never all be told. Yet just therein lies its charm, for it is full of the old, but for us ever-new, ever-changing, yet not wholly elusive, mystery and wonder of the world around us. To attain to absolute truth we neither aspire nor desire, content, however faint and weary, to be still pursuing, for in the pursuit itself we find an exceeding great reward".

METEORITE DISCOVERIES

During the period 1911–1914 the Australasian Antarctic Expedition, under the leadership of Sir Douglas Mawson, was carrying out its work in the Antarctic.

On 5th December, 1912, the Western Sledging Party set out from the main base at Cape Denison. About 20 miles from the base they were travelling over an entirely snow-covered surface with no rock exposures whatever to break the monotony, when to their surprise a small black object, weighing about 2¼ pounds, was noticed lying in a slight depression in the snow. This proved to be a stony meteorite of the chondrite type. There was no way of determining the date of fall, but the fact that it was found at all in such an environment is truly remarkable. When it fell it would have penetrated some distance into the snow and would undoubtedly have been quickly covered. It probably reappeared on the surface a number of times when phenomenal wind velocities removed the snow covering. If, however, a succession of calm sunny days had ensued some melting of snow would have occurred and the meteorite would have sunk beneath the surface once more. A succession of high wind velocities and infrequent calm sunny days in the period preceding the arrival of the sledging party were probably the main factors leading to this extremely interesting chance discovery.

The meteorite was named the Adelie Land, and the main mass is in the Australian Museum collection.

During the current period of intensive activity in the Antarctic two more meteorites have been found.

In January, 1961, two Russian geologists found two portions of an iron meteorite weighing 22 pounds and 4½ pounds on a rocky surface in the Humboldt Mountains south of Lazarev Station. It has been named the Lazarev.

Almost exactly a year later a party from the United States Geological Survey found a rarer type of meteorite, a pallasite, consisting of iron and the silicate mineral olivine, on the surface of a glacier in the Horlick Mountains. Like the Lazarev, this had broken into two pieces, weighing 50 pounds and 20 pounds, which were found about 300 yards apart close to some prominent rocky slopes. This meteorite has been named the Horlick Mountains Meteorite.—*R. O. Chalmers.*

Hallett Station on Sea Bee Hook is shared by New Zealand and United States scientists. According to carbon-dating techniques, Sea Bee Hook has been an Adelie Penguin rookery for some 5,000 years. About 300,000 penguins now breed on the spit's higher mounds which show up as grey guano deposits. The lower and darker areas are wet from snow meltwater and support a vigorous bloom of algae in the austral summer. Lichens and mosses occur on the lower scree slopes at the foot of the steep cliffs in the background. [Photo: U.S. Navy.]

PLANT LIFE

By GEORGE A. LLANO

Programme Director, Antarctic Biology, National Science Foundation, Washington, D.C., U.S.A.

ANTARCTICA ranks fifth in size among the earth's continents, with a land surface of 5·3 million square miles, or about twice the area of Australia. Like Australia, Antarctica is an island-continent, completely isolated by broad reaches of the Atlantic, Indian, and Pacific Oceans. It has been known by many names, and, until Tasman reached the Australian coast, Antarctica was called *terra Australis incognita*. The name White Continent is perhaps the most appropriate, since scientists considered it to be a "cold desert" with a landscape that has been likened to that on the moon. Biologically, the principal difference between the White Continent and all other major continents is the primitive nature of the vegetation and complete absence of indigenous vertebrate animals. As is well known, none of the millions of oceanic birds or seals which visit Antarctica during the breeding season remain on the continent once the young are ready to fend for themselves. Consequently, Antarctica has no resident vertebrate animals, which is a most extraordinary record for a major land mass.

Antarctica is almost circular, with its centre at about the geographic South Pole, from which it extends outward and northward to about 66° 30′ S. latitude. The shape of Antarctica accounts, in part, for the peripheral distribution of its organisms, both plants and animals, and makes the coastal regions a major zone of life. The shoreline of the continent is readily

Wright Valley, the largest of the valley complexes in the Dry Valley region of McMurdo Sound. This view westward shows the barrenness of the area and the relation of the valley to the vast polar ice-cap in the background. The light snowfall brings out the polygonal features and other ground relief. [Photo: U.S. Navy.]

accessible as a breeding area for migratory seals and oceanic flightless and flying birds which, from time immemorial, have come to Antarctica during the austral summer. The coasts constitute a major area of ice-free and snow-free land, and exhibit deviations of temperature to a lesser degree, on an annual basis, than the interior. In winter, blizzards carry great quantities of snow from the interior to the coasts; and, with the annual formation of sea and pack ice, the continent appears to more than double in area in winter by gaining a "phantom" or secondary coastline which disproportionately exaggerates the overall continental dimensions. The repeated build-up and break-up of the sea and pack ice is a phenomenon unique to Antarctica which has earned it the additional sobriquet of the "pulsating continent".

Because the South Polar region is a major land area in contrast to the Arctic sea basin at the North Pole, the perennial snowfall accumulates as vast ice-fields which effectively cover all but 10 per cent of the continent. The Antarctic ice-cap contains about 95 per cent of the earth's permanent supply of ice or, in terms of a liquid, about 10 per cent of the globe's water budget. The mass of frozen water is estimated at about seven million cubic miles of ice, which gives Antarctica an average elevation of about 7,500 feet, the highest of all the continents. Maximum depth of the polar ice-sheet is in excess of 10,000 feet, and the compacted snow at the base of the ice-sheet could have fallen on the continent 50,000 years ago. The relief of the land where it rises clear of ice and snow provides some of the most spectacular mountain scenery in the world. In terms of the earth's past history, the contrasting ice and mountain landscape appears as a frozen vista from the Pleistocene, when the Ice Age dominated even the Temperate Zones.

Weatherwise, Antarctica is an extremely formidable region and is considered, without question, the coldest high-altitude desert on earth. The climate is characterized by its dry atmosphere, due to the high elevation and predominance of cold air masses over the continent, by its strong and persistent winds, by 5 months of continuous darkness, and by the lowest recorded temperatures on earth (to minus 126·9° F). Surface ozone values are about 25 per cent higher than in the middle latitudes of the Northern Hemisphere. There is some question whether this may not be one cause for the relative absence of airborne organisms since ozone is highly reactive, and toxic to surface cells. Precipitation is generally very low and almost always in the form of snow. The relative humidity is scarcely one-tenth that recorded in middle latitude regions. The high transparency of its atmosphere, due to the relative absence of pollutants or dust, favours the influx of solar radiation. The sunshine duration is greater in the Antarctic than in corresponding Arctic latitudes, although both polar regions receive more solar radiation in their summer months than the tropical regions.

One important effect of solar heating is seen in the significant differences in the radiation balance of rock and soil surfaces which promotes the development of micro-climates suitable for plant growth. As a result, the rock surface-air boundary layers in ice-free regions due to differential absorption of solar radiation create favourable and even excessively warm micro-environments. Plant growth in Antarctica, however, succeeds only when the combination of liquid water and plant nutrients, derived from nitrate-rich guano, is available. While these air-surface interface habitats are relatively warm and sheltered, the survival and distribution of plant and animal organisms under Antarctic environmental conditions require other characteristics; these are the ability to resist long periods of extreme dessication, persistent cold for the greater part of the polar year and the lack of solar energy for 5 out of 12 months.

Vascular flora

Two species of phanerogams—that is, plants with pistils and stamens—represent the totality of the vascular flora. By way of contrast, one may note that the vascular flora of north temperate Great Britain consists of 1,500 species; the dry hot lands of Egypt and Israel have, respectively, 1,800 and 2,500 species. The two flowering plants are *Colobanthus* and *Deschampsia*; the former is a plant of a kind commonly known as a pink, and the latter is a grass. Together, they occur in scattered, almost isolated sites along the Antarctic Peninsula and associated islands fronting the Drake Passage. *Deschampsia antarctica*, which is common to Patagonia and the Falklands, has been found as far south as Stonington Island, 68° 12′ S. on the western coast of the peninsula. Its range northward is shared with *Colobanthus crassifolius*, in a simple association growing over rock ledges or forming small patches of green over thin gravel soils. Neither plant does well in heavy moss mats and they are absent from steep slopes. Both genera are, however, found elsewhere on islands in the Southern Hemisphere. The question whether the species now established in the Antarctic Peninsula are of recent origin—that is, immigrants during the post-glacial recession—or represent survivors which managed to persist during the Pleistocene Ice Age, is difficult to answer. The fact remains that the broad oceans, the unfavourable direction of the winds around Antarctica, and the persistent low temperatures form an extraordinarily effective barrier to the distribution of seeds between the continents of the Southern Hemisphere and Antarctica.

Since the establishment of more or less permanent stations by man in the Antarctic Peninsula, three other flowering plants have been reported in the region—*Poa pratensis* and *Stellaria media* on the Peninsula and Signy Island, and *Poa annua* on Deception Island. These were undoubtedly introduced as weeds with fodder brought in to feed the domestic stock kept at some stations for food. Attempts to grow plants, both on the Peninsula and in the course of an experiment at Cape Hallett, have not proved very encouraging, and further point up the difficulty of cultivated plants propagating themselves naturally.

Lichens

Lichens appear to be the most numerous of indigenous plant life and some 350 species are listed in the scientific literature. They are widely distributed along the Antarctic coastline and are often the dominant plants on nunataks (peaks of mountains protruding through ice-sheets)

Yellow crustaceous lichen (*Xanthoria*) grows near bird rookeries, forming gay patches on the nitrogen-enriched rocks. [Photo: Author.]

in the interior. Lichens have been recorded within 4° of the geographical South Pole; nevertheless, they are often missing in much of the snow-free land. Of the three vegetational forms, the crustaceous, foliose, and fruiticose, the first is the one most commonly seen. Rock-encrusting lichens vary in size from the millimetre-size thallus filling the gas-formed pits in volcanic rock to broad, gay patches denoting the orange *Caloplaca* and yellow *Xanthoria*, which are the only bright colours in an otherwise drab rock landscape.

Of the fruiticose lichens, *Neuropogon* is, with the exception of one species, a truly Antarctic genus. In mass over rocks and ledges, it was mistaken for grass by the early explorers. The foliose genera—*Parmelia*, *Physcia*, and *Umbilicaria*—are often abundant in favoured areas, such as Wilkes Station and Cape Hallett. On the Peninsula these genera grow two to three times as large as they do elsewhere. Other lichen genera are *Alectoria*, *Ramalina*, and *Cornicularia*. The latter two are very rarely found on the continent south of the Antarctic Circle.

The favoured habitat of lichens is the warm rock-air interface, particularly when irrigated by meltwater, or on small stones in moist ground. In the Antarctic Peninsula, the Pyrenocarp lichens are truly amphibious forms, occupying freshwater puddles and the salt, littoral zone along the coast. While many lichens are quite tolerant to salt spray, the remarkable genus *Verrucaria* includes a submarine species which is found from high tide to a depth of several metres in the sea.

Algae

Algae are a conspicuous part of the Antarctic terrestrial vegetation and in species are almost as numerous as the lichens. The prevailing types are two, the greens and the blue-greens; the latter are an important element of the Antarctic algal flora. Algae occupy bare land or low rocky areas which are subject to flooding. They often form mats clogging coastal ponds which warm up during the austral summer; in the interior, the dried, flake-like sheets of *Hormidium* algae in low places often mark a former stand of meltwater. The ubiquitous *Prasiola crispa* has the widest distribution of any Antarctic land plant. This is largely due to the wide-ranging skuas, which rarely pass up the opportunity to bathe in freshwater, thus transporting the algae from the coast inland and almost to the Pole. All algae respond readily to nitrate and phosphate nutrients in bird guano, whether it be skua excreta in ponds or on the wet-land draining penguin rookeries.

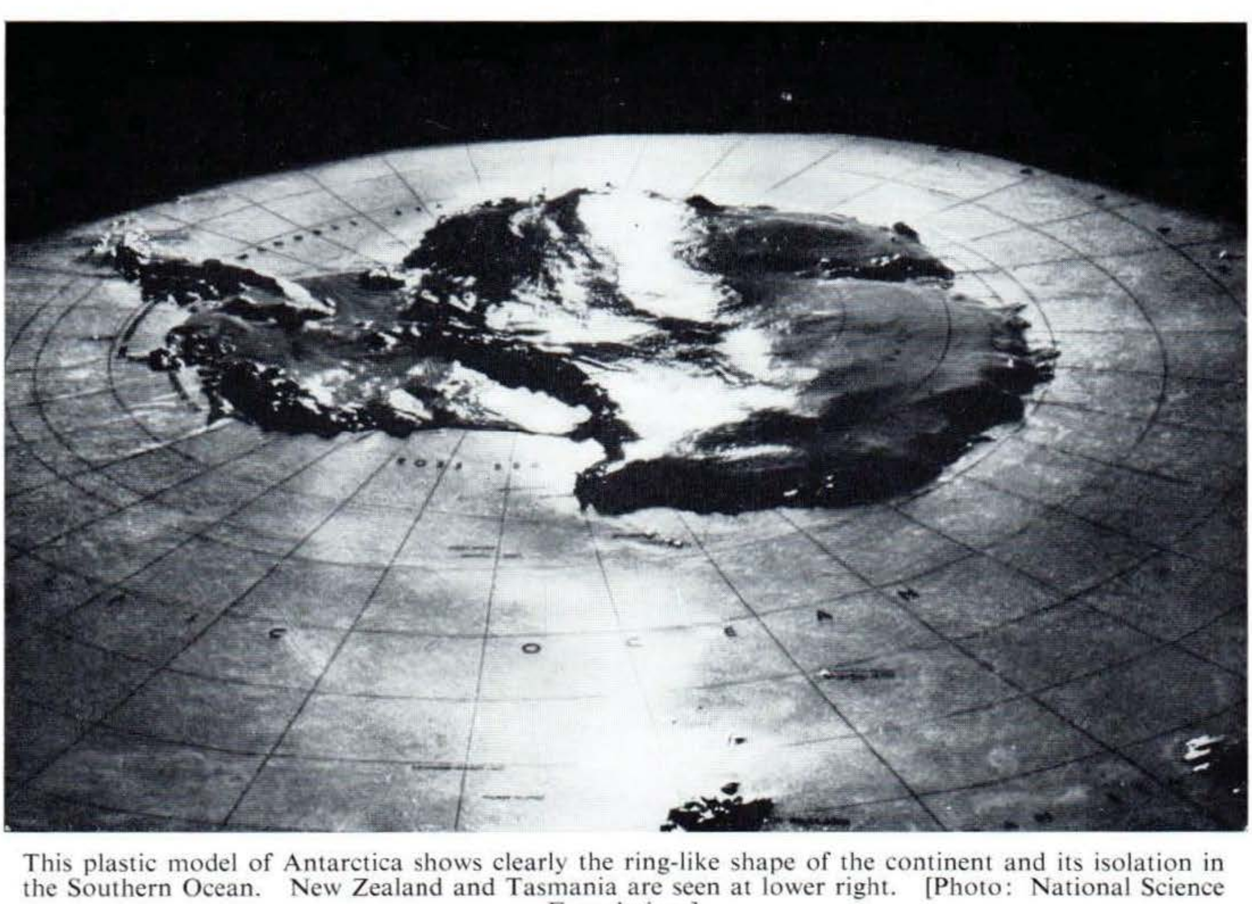
Snow and ice also provide a favourable habitat for algae, giving rise to the very colourful display of green and red snows. Elsewhere on earth, coloured snows are high-mountain phenomena; in Antarctica, however, these cryophytes are known from snowfields along the coast, but only north of the Antarctic Circle. With the exception of Wilkes Station, all occurrences of snow and ice algae displays are from the Antarctic Peninsula or off-shore islands. Indeed, in this region, many of the tabular tops of icebergs so characteristic of the Southern Ocean are frequently tinted pink.

Red snow is indicative of the presence of *Chlamydomonas antarcticus*. The conditions which favour the growth of this alga are a succession of days of sufficient warmth to thaw the snow's surface and a slight windborne dusting of bird guano from nearby rookeries. This vegetation develops rapidly, and is evident first as a tinge of pink turning rapidly to a deep red. With the rise in colour intensity, the warming effect becomes more evident as the red-stained snow deteriorates into ever-widening red puddles of slush. When the melted snow can no longer dam back the head of water, the snowfield collapses into a series of freshets usually flushing out to sea.

Mosses

About seventy-five species of mosses are known from Antarctica. The major portion and best development of the Antarctic moss flora are to be seen in the Peninsula region north of the Antarctic Circle. In this area, all moist ground is frequently occupied by carpets of moss, usually consisting of *Drepanocladius*, *Brachythecium*, and *Polia*. Beneath these carpets a layer of peat is well developed, sometimes to a depth of about 12 inches.

On better-drained ground of silt or gravel, the typical plant formation consists of a mixture of lichens, mosses, and the two vascular plants. Small moss tussocks also occur and in some cases are parasitized by lichens. Elsewhere on the continent *Ceratodon*, *Pottia*, and *Bryum* are the dominant genera of mosses. Along the coast where they are widely, if spottily, distributed, mosses form small mounds or stunted tussocks of sterile plants, usually jammed into warm nooks or crevices where carpet development is restricted to very



This plastic model of Antarctica shows clearly the ring-like shape of the continent and its isolation in the Southern Ocean. New Zealand and Tasmania are seen at lower right. [Photo: National Science Foundation.]

George Doumani, palaeontologist with an Ohio State University geological party in the Horlick Mountains, points to a large log of petrified wood found by the party. This indicates that Antarctica once had a milder climate. This investigation was part of a geological survey of the Horlick Mountains sponsored by the National Science Foundation as part of its U.S. Antarctic Research Programme. [Photo: National Science Foundation.]

small areas and there is rarely more than a token presence of peat formation. Mosses are found inland as well, but to a much more limited degree than lichens or algae. They fail, however, to reach the higher latitudes. At Cape Hallett, where the vegetation is a conspicuous feature, studies revealed that plants covered only about 15 per cent of the land area, algae comprising 12·8 per cent, mosses 2·4 per cent, and lichens 0·2 per cent. Antarctic mosses rarely produce sporophytes, apparently because of the rigorous environmental conditions, and reproduce mainly by vegetative means. Mosses occupy rock and soil habitats; one species, *Bryum korotkevicziae*, grows at a depth of 33–36 inches in the freshwater Lake Figurnoye, in the Bunger Hills. Interestingly enough, *Sphagna*, common in Arctic and Alpine zones, are absent from Antarctica.

The endemic moss *Sarconeurum glaciale* was first collected by Hooker during the 1839–1843 British expedition to the Antarctic Peninsula. It is now known to be widely distributed on the continent. According to reports of Soviet scientists, *S. glaciale*, as well as other mosses, occurs in "pure swards" at the Bunger Hills either on stone or fine earth substrate. The Bunger Hills are reported to be "extremely severe dry and cold, stony desert". Summer is said to be warmer and drier because the dark rock surfaces are warmed by the sun to a temperature of 30° C or more. The air temperature is 2° to 3° and sometimes 5° higher than the surrounding ice-covered land and may reach as high as 10° C during the day.

Liverworts

Only about half-a-dozen species of Hepaticae are described from Antarctica, and, until 1965, it was widely believed that these were restricted to the Peninsula. However, in 1958, a species of the genus *Cephaloziella* was collected by the author at Wilkes Station; other specimens have since been found at Hallett Station, and it is possible that this genus may be found elsewhere. An equally interesting find occurred in 1962 at Cape Spring, Danco Coast, where the Argentines discovered the genus *Marchantia*, not previously known to grow in Antarctica. Hepatics or liverworts are inconspicuous plants usually found mixed with mosses in fairly wet areas. They do not occupy a prominent role in Antarctic vegetation, although historically their presence is of great interest to plant geographers.

Ancient floras

While Antarctica today has only a sparse cryptogamic flora (plants which reproduce by spores or fragmentation and not by seeds) and nothing comparable to the tundra and taiga biomes which girdle the subarctic regions, the South Polar geologic history reveals that past climates favoured a variety of plant life. The evidence lies in coal seams, fossil wood fragments, spores, and leaf imprints that have been discovered since the first explorations. In west Antarctica the earliest known plants are of Jurassic age, while in east Antarctica plant remains range in age from the Devonian to the Triassic. In the Carboniferous of

This view is typical of the Chalikosystem habitat, which is characterized by the absence of vegetation. However even in these plantless areas mites and springtails may occur. The two entomologists are searching for Acarina and recording soil temperature variations. [Photo: National Science Foundation.]

Antarctica, forty-three plant species, predominantly *Glossopteris* flora, have been reported with close relationships largely to contemporary floras of India and South Africa and, to a lesser extent, to Australia and South America. The fossil occurrence and distribution of Mesozoic (180 million years ago) and Tertiary (60 million years ago) conifers, i.e., podocarps and araucarians, in west Antarctica show close floristic relationships with South America. These ancient floras are proof that this seventh continent was not always icebound. More than that, they suggest that the environment and the floras in the land masses of the Southern Hemisphere were contemporaneous. Indeed, Hooker, when reporting on the observations and studies of plants he saw while on his Antarctic voyage, identified Antarctica as the origin of much of the Southern Hemisphere flora. Fifty years later, two Swedish botanists, Florin and Skottsberg, published views in accord with those of Hooker. Florin's evidence is based on the "southern group of conifers", for whose origin he gives Antarctica.

Where woody plants, shrubs, grass, and herbs occur, even the layman is aware of changing vegetational patterns. Since these familiar plant forms are absent in Antarctica, one may think that the continent is without vegetational distinctions. However, one quite obvious vegetational change in the plant zones is revealed by the southern limit of *Deschampsia* and *Colobanthus*, which occurs at about the Antarctic Circle. Actually, the precise limit of Angiosperms, or seed plants, in Antarctica and the Southern Hemisphere is 68° 12′ S., 62° 02′ W. This is also the limit of the higher fungi and of the luxuriant carpet communities of bryophytes (non-flowering plants, including mosses and liverworts). Indeed, Holdgate identifies the Low Antarctic Province as the region of seed plants and of closed plant communities. The rest of Antarctica is referred to in Holdgate's terminology as the High Antarctic Province. This latter is an area of sparse vegetation, dominated by cryptogams. The High Antarctic Province may be further divided into maritime and continental regions. In the maritime region, the presence of bird excreta and salt spray are biotic factors which influence the distribution and growth of the plant cover found over bare ground. The continental region includes two types of habitats which Janetschek calls Chalikosystem and Bryosystem. The former is descriptive of the bare expanse of rock and soil which occurs widely in Antarctica, particularly inland, and appears to be without apparent plant or animal life. The Bryosystem is identified by mosses but includes lichens and algae which occur on flat areas; this vegetation is often inhabited by microfauna consisting of mites, or Acarina, and springtails, or *Collembolla*. Together, the arthropods and cryptogams of Antarctica form the most distinctive and diminutive fauna and flora of all the continents.

Killer Whales at the surface in the Antarctic, photographed by Herbert Ponting during Scott's last expedition. [Photo by courtesy of Paul Popper Ltd.]

WHALES

By J. L. BANNISTER
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NONE of the Cetacea (the whales, porpoises, and dolphins) are endemic to the Antarctic since none of the species recorded from that region are known to breed there. However, the "Antarctic zone" —the area between the convergence and the ice edge—is extremely important in the lives of many whales, particularly the large southern baleen whales, which rely almost entirely on the high productivity of its waters for food.

Almost nothing is known of the biology of the few dolphins or porpoises recorded from the region. Most of the whales are better known, mainly because their commercial importance has forced Governments to spend money on research and has provided specimens for scientists to study. Of the thirty or so cetaceans commonly known as whales (cetaceans more than about 12 feet long) eleven have been recorded from the Antarctic (as in the list below), but a few more may yet be found there. Representatives are present of both main divisions of the order—the Mysticetes or baleen whales (which feed on plankton or small fish strained from the water through horny baleen plates suspended from the upper jaw) and the Odontocetes or toothed whales (feeding mainly on squid or fish).

LIST OF THE BETTER KNOWN ANTARCTIC WHALES

Baleen whales (sub-order Mysticeti)

Eubalaena australis, the Southern Right Whale
Balaenoptera musculus, the Blue Whale
Balaenoptera physalus, the Fin Whale
Balaenoptera borealis, the Sei Whale
Balaenoptera acutorostrata, the Minke or Lesser Rorqual
Megaptera novaeangliae, the Humpback Whale

Toothed whales (sub-order Odontoceti)

Physeter catodon, the Sperm Whale
Orcinus orca, the Killer Whale
Globicephala melaena, the Pilot Whale
Hyperoodon planifrons, the Bottlenosed Whale
Berardius arnouxi (a beaked whale)

The baleen whales are, on the whole, very much larger than the toothed whales, and include the largest animal known to have lived, the now rare Blue Whale, for which the greatest recorded length is close to 100 feet and the greatest weight about 130 tons. The Blue Whale's close relatives—the Fin, Sei, and Minke—range in maximum size from 85 feet down to 33 feet. Together, these four species are known as the rorquals. All four also occur in the Northern Hemisphere, but as separate races, with northern individuals tending to be smaller than those from the south. Other Antarctic baleen whales are the Humpback (to about 50 feet) and Southern Right (to about 60 feet), both now rare, like the Blue Whale. Right Whales got their name because they were the "right" ones to catch when whaling was done by hand from open boats. They were "right" because they were slow, and thus relatively easy to kill, and because they floated when dead; their thick blubber gave large quantities of valuable oil, and they had long plates of baleen, ideal for skirt hoops, corsets, and umbrella spokes. The Humpback, though not large by Blue Whale standards, was fat and slow and had the unfortunate habit of swimming close to land on its migrations. To shore-based whalers it was an easy prize.

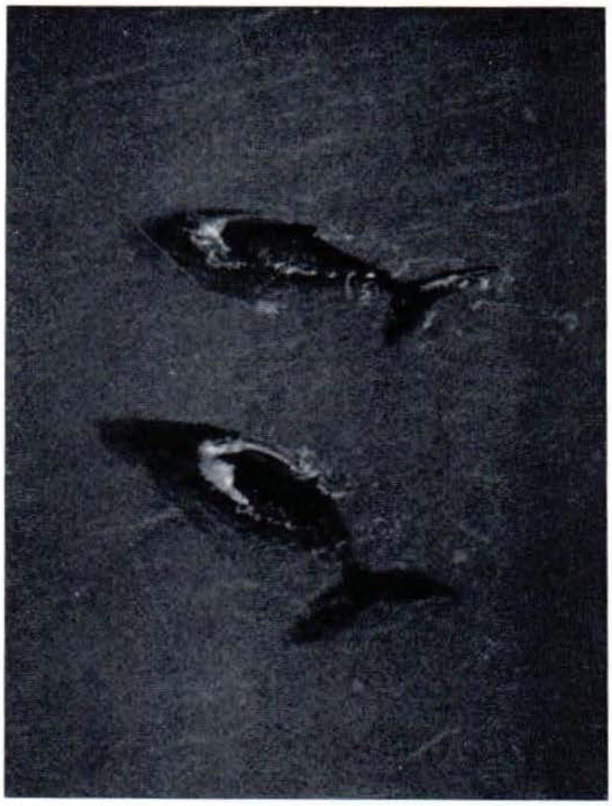
The best-known Antarctic toothed whale is probably the Killer, notorious as a voracious predator—an image heightened by its reported habit of overturning icefloes bearing penguins or seals. The Killer is probably important as a predator on other cetaceans, and is disliked by whalers because it will attack the carcasses of larger whales. But the largest Antarctic toothed whale, and indeed of the whole group, growing to around 60 feet, is the Sperm. In this polygamous species, only the males are recorded from the Antarctic zone, and in many other respects it is unusual. The Sperm Whale is one of the only two cetaceans with the blowhole to one side—on the left, towards the front of its massive head. Female Sperm Whales grow only to about two-thirds the size of the males, and keep to warmer waters with the calves and juveniles. Another gregarious species, the Pilot Whale, has not often been recorded from Antarctic waters but has occurred in schools around the coast of South Georgia. Pilot Whales are better known from more temperate waters and can grow to more than 25 feet. The only other relatively large cetaceans that certainly occur in the Antarctic, the Bottle-nosed Whale and

A Fin Whale on the flensing platform, Grytviken, 1960. The blubber is about to be removed. The whale is lying on its right-hand side. Note the ventral grooves, typical of the rorquals. [Photo: Author.]

Berardius arnouxi, are very little known, and then almost only from occasional strandings or captures. Both grow to about 30 feet. *Berardius* hasn't even got a common name; both have more common relatives in the Northern Hemisphere.

Distribution and movements

Nearly all the Antarctic baleen whales make long seasonal migrations. They feed extensively during the summer on the swarming "whale-food", known to whalers as "krill" (a euphausiid shrimp, *Euphausia superba*), and then move north to warm-water breeding grounds in winter. One species, the Humpback, has relatively well defined migration paths. Marking with stainless steel darts—fired into the back muscle and recovered when the carcass is processed—has shown that there are probably six separate Humpback stocks in the Southern Hemisphere, related to six different breeding grounds, one each off the east and west coasts of the southern continents. The different stocks seem to remain more or less distinct, so that most of those Humpbacks that, say, feed to the south of Western Australia in summer will return to their Western Australian breeding ground in winter. Blue and Fin Whales, on the other hand, are more oceanic than Humpbacks, and the exact locations of their breeding grounds are not known even yet. In the Antarctic these two species scatter more widely than Humpbacks; the basic pattern may be similar, but there is probably more interchange between different breeding groups. Even less is known of Sei Whale movements, and still much less of Minke, though both species seem to move north and south in the same way as their larger relatives. The Blue Whale tends to penetrate further south, into the coldest waters, than the others, though the Minke may go as far or even further. Sei Whales tend to occur less far south than Blue, Fin or Minke whales. Indeed, a very close relative of the Sei, Bryde's Whale, remains in warmer waters and never gets into the Antarctic at all. The Southern Right Whale may not be as migratory as the other baleen whales but, again, very little is known about it. It seems to go not quite as far south as Blue and Fin Whales, but has been fished near South Georgia and so qualifies as an Antarctic whale. Females come close to warmer coasts in winter to give birth.



Two Humpback Whales, nearing the end of their migration from the Antarctic, off Shark Bay, Western Australia. [Aerial photo: S. Fowler, CSIRO.]

Male Sperm Whales found in the Antarctic tend to be either lone and relatively old bulls, or younger adult males which may return to warmer waters later. There is recent evidence of this return in the presence of Antarctic diatoms on the skin of bulls caught at Australian and New Zealand land stations. However, the details of these movements are not known and there is no obvious separation of feeding and breeding behaviour, so Sperm Whale movements cannot easily be classed as "migrations" in the same sense as those of baleen whales. Nothing is known of the detailed movements of the other Antarctic toothed whales, though Killers seem to be widespread and have often been observed near the ice edge. *Berardius* (as well as Killers and Minke) has been recorded in open pools in the ice during winter. On that occasion the whales were probably trapped because their escape route to the north became frozen over.

King Edward Cove, South Georgia, where the first Antarctic land-based whaling station began operating in 1904. Humpback Whales were once caught in the open waters of Cumberland Bay, which opens to the sea in the left middle distance. [Photo: Author.]

Man's effect on stocks

The position today (summarized for baleen whales except Southern Right and Minke in the table at the end of the article) is that the Antarctic stocks of at least three species—the Blue, Southern Right, and Humpback—have been reduced to small remnants of their former size by over-hunting, while the stocks of Fin Whales are considerably reduced and Sei Whales may soon be in danger. The position of Sperm Whales is not so certain. The world catch of over 20,000 male Sperm Whales each year is probably near the limit that can be withstood by the stocks, though the Antarctic catches of about 4,000 to 5,000 per year should be mostly of males surplus to those needed to maintain breeding.

The main depletion of Antarctic baleen whales began in 1904 when the first land station opened at South Georgia. Before this the Southern Right Whale fishery, centred mainly on this species' coastal breeding grounds, had reduced the stocks to such a level that even today the numbers are still very low, though there are encouraging reports of increased sightings of Right Whales in the south Atlantic. "Modern" whaling, with fast steam catchers bearing harpoon guns that could fire explosive grenades, soon depleted the stocks of Humpback Whales near South Georgia, and attention turned to the Blues and Fins. From 1925 the introduction of the pelagic factory ship, independent of land and able to range over the whole area of the feeding grounds, allowed these species to be hunted much more extensively. In the 1930's, and again after the Second World War, an average of more than 30,000 whales were taken from the Antarctic each year, the Antarctic being responsible for about 60 per cent of the total world catch. Since 1946 the International Whaling Commission has regulated whaling by defining protected species, open or closed waters, size limits, the whaling period, and the maximum Antarctic catch, but the regulations have only been able to slow the rate of depletion. As one species has become depleted, attention has turned to another. Thus, from pre-war emphasis on Blue Whales, the industry turned to Fin, and now even the relatively small Sei Whale has become important. Sperm Whale catches have increased at the same time. Calculations based on biological evidence, data of catches and sightings, and modern methods of stock assessment have given the maximum

A small group of medium-sized Sperm Whales, seen from the air. [Photo: J. Bell, Cheynes Beach Whaling Co.]

numbers that could be taken each year from the stocks of the more important species, both at the present reduced levels of the stocks and at their optimum levels (see table). The difficulty today is not so much the lack or inadequacy of scientific evidence but the problems of economics and international politics.

In the Antarctic ecosystem whales are important as highly efficient "terminal concentrators" in the fairly simple food chains. In particular, the baleen whales are at the end of a simple chain which has only three steps, from phytoplankton (minute diatoms, algae, and other plant life) via the krill (*Euphausia superba*) to the whale itself. Sperm and other toothed whales are at the end of a more complex chain, from phytoplankton through zooplankton (including the krill) via fish and squid to the whale. In the case of the Killer Whale, penguins, seals, and even small whales are interposed in the chain. Man can make use of the efficiency of baleen whales by harvesting them as highly convenient parcels of fats and proteins. Indeed, it has been said that with one shot a harpoon gun can secure, from a large Antarctic baleen whale, up to 20 or more tons of oil and the equivalent, in protein, of a quarter of a million helpings of roast beef.

It is possible that with the great reduction, of 80 to 90 per cent, in the number of these "terminal concentrators" other Antarctic fauna may increase. There are signs that Sei Whales in one area and one species of penguin may be doing so already. People's thoughts now turn to the possibility of harvesting krill, rather than whales; modern technology may solve the problem but man will find it hard to be as efficient as the whales.

RECENT ESTIMATES OF THE CONDITION OF ANTARCTIC BALEEN WHALE STOCKS, BASED ON WORK CARRIED OUT FOR THE INTERNATIONAL WHALING COMMISSION BY ITS SCIENTIFIC COMMITTEES AND F.A.O.

Species	*Original stock size*	*Present stock size*	*Present sustainable yield*	*Maximum sustainable yield*	*Years to recover to optimum stock size*
Blue	more than 150,000	1,000–2,000	0–200	6,000	about 50
Fin	about 200,000	about 40,000	5,000	about 20,000	more than 10
Sei	more than 60,000	60,000	about 5,000	about 5,000	nil
Humpback*	22,000–27,000	600–1,300	less than 100	about 700	30–60

* Assessments for "Australia/Antarctic" stocks only.

COASTAL FISHES

By HUGH H. DeWITT
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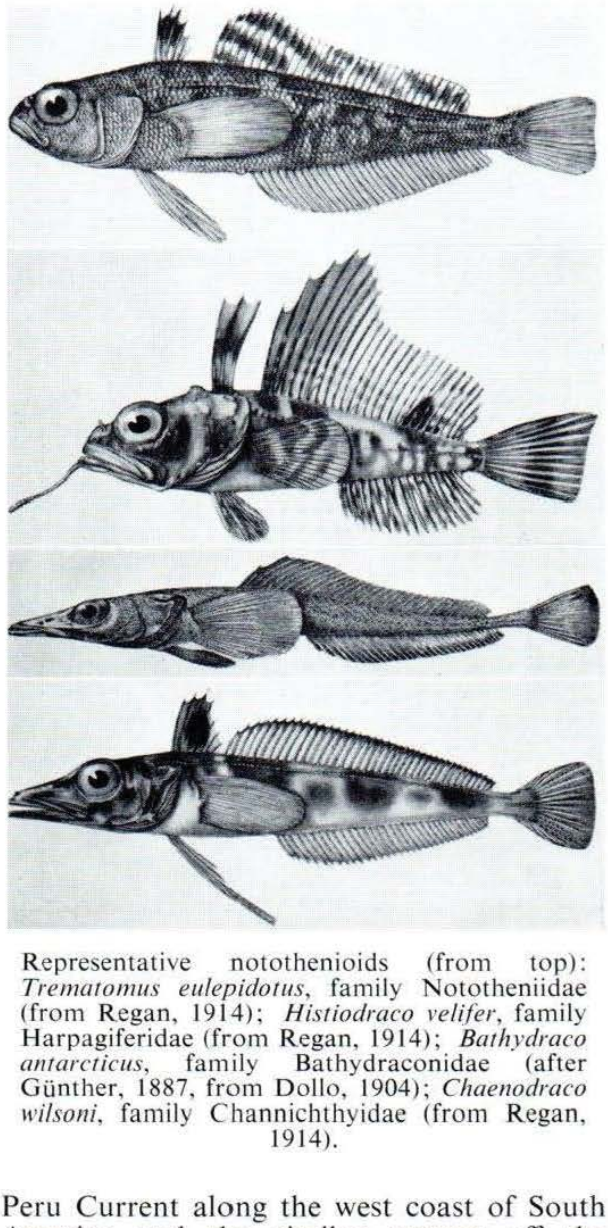
TWO features of the Antarctic Continent have contributed heavily toward creating in the waters which bathe its shores conditions suitable for the evolution of a peculiar and highly endemic fish fauna. The first is its geographic isolation. The closest land mass is South America, which lies 450 miles north of the Antarctic Peninsula. South Africa, Tasmania, and New Zealand are much more distant, with about 2,460, 1,320, and 1,260 miles, respectively, of open water between them and the continent. These distances compare favourably with those separating many of the isolated islands which dot the Pacific Ocean.

The second feature of importance is due to Antarctica's being nearly centred upon the South Geographic Pole. The low temperatures ordinarily associated with high latitudes have been pushed still lower by the development of a huge ice shield on the continental land mass. The limited solar radiation which reaches the ice shield is absorbed and reflected without creating any significant change in temperature. The continental mass prevents the oceans from distributing to the Polar region the heat they have absorbed in low latitudes. The waters surrounding Antarctica are therefore cold, rarely reaching zero degrees centigrade even during the summer, except for local areas, especially in the peninsular region. To the difficulty in traversing the oceanic barrier surrounding the continent is added the great change in temperature which must be endured for an animal to colonize Antarctic waters.

A third factor which may be important in maintaining the isolation of Antarctic continental waters is that the surface currents of the Southern Ocean at no place flow south from the northern land masses. On the contrary, north of about 65° S. latitude these waters, in their clockwise cycling about the continent, actually drift northward, eventually being split off when they are intercepted by land masses, to participate in northward-moving currents such as the Peru Current along the west coast of South America and the similar current off the west coast of Australia.



Representative notothenioids (from top): *Trematomus eulepidotus*, family Nototheniidae (from Regan, 1914); *Histiodraco velifer*, family Harpagiferidae (from Regan, 1914); *Bathydraco antarcticus*, family Bathydraconidae (after Günther, 1887, from Dollo, 1904); *Chaenodraco wilsoni*, family Channichthyidae (from Regan, 1914).

These factors of geography, temperature, and ocean current have been so effective in preventing fishes from passing to and from the Antarctic that, at the present time, about 90 per cent of the species found there have been discovered nowhere else. This endemism is reflected even at higher taxonomic levels: about 74 per cent of the genera are endemic, and three of the eight families found there contain only one or two species which inhabit more temperate waters.

Notothenioids

The fishes which are found living today near the Antarctic coasts can be divided into two groups with respect to the length of time they have probably inhabited these waters and in their relationships to fishes elsewhere in the world. The great majority of species belong to the suborder Notothenioidei, a group with rather uncertain relationships, which is confined primarily to the Antarctic and the members of which extend no further northward than the waters about the southern parts of South America and New Zealand and the rivers of south-eastern Australia, where the only freshwater species is found (*Pseudaphritis urvillii*, commonly known as Congolli). At various times ichthyologists have believed the notothenioids were related to the cod-like fishes, the blenny-like fishes, or the great order of perch-like fishes in which they have generally been placed. In appearance the notothenioids are rather elongate, generally with rather depressed heads. They have large eyes, long dorsal and anal fins, and fan-shaped pectoral fins with broad, nearly vertical bases. Characteristic is the placement of the pelvic fins, which are inserted below and anterior to the pectoral fins.

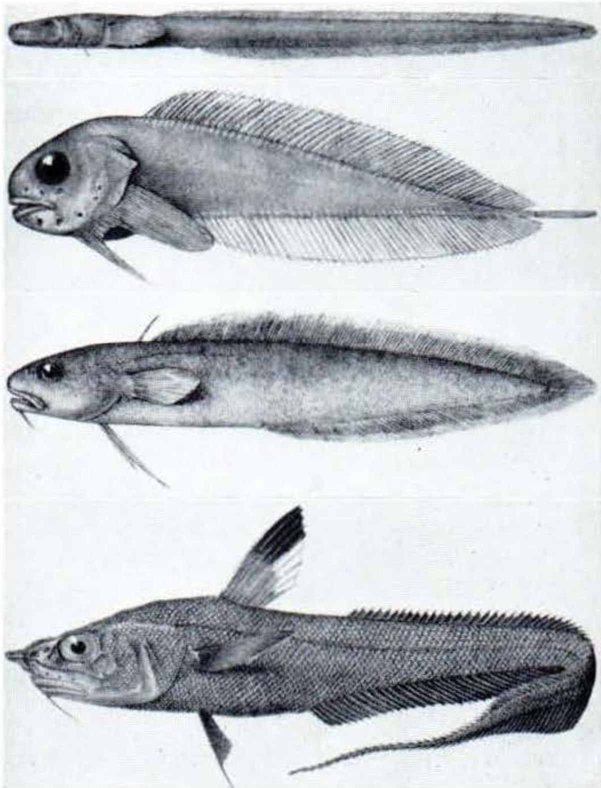
The notothenioids are the ancient endemic fishes of the Antarctic. Their isolated systematic position, their diversity, and their peculiar adaptations to life in Antarctic waters all indicate that they have inhabited the South Polar coastal waters for a long time, possibly for most of the Tertiary. They have evolved into four distinct families, each with a number of genera and species. Most are bottom-dwelling and probably omnivorous in their feeding habits. Nearly all of those which have been observed in aquariums were rather slow-moving, spending most of their time upon their spread pelvic fins and the lower edges of their broad pectoral fins. The ice fishes (family Channichthyidae) have become fish-eating, at least as adults, and some have left the bottom to become partly or wholly pelagic. In the family of Antarctic cods (family Nototheniidae), one species has become entirely pelagic, and is the only fish captured in abundance as an adult in the midwaters over the continental shelf. A second species probably has similar habits, but has been captured only rarely. Three other species have adapted themselves to living on and in the undersurface of the sea ice close to the continent, feeding upon the numerous amphipods and other small invertebrates which have become similarly adapted.

The larvae and juveniles of many species of all four families form an important element of the midwaters over the continental shelf where, because of the sudden drop in temperature from the deep open waters off-shore, the midwater fishes characteristic of the world ocean are absent. It would seem that the young notothenioids have entered a habitat over the continental shelf which has been almost entirely unoccupied. Although some of the juveniles show no special modifications for pelagic life, others definitely do. Larval ice fishes are unmistakable because of their hugely expanded pelvic fins, which probably aid them in their semi-drifting existence. Some of the juvenile deep dragonfishes (family Bathydraconidae) are very elongate and slender, and one species, *Prionodraco evansii*, has four rows of projecting spines along the body which may serve both for protection and as impediments to rapid sinking. Juvenile plunderfishes (family Harpagiferidae) have a globular head and body, with a short and stumpy tail behind, looking somewhat like a tadpole. The incorporation of the gelatinous material about the head and body probably serves to reduce the specific gravity of the young fishes, enabling them to maintain themselves more easily in the midwaters.

Ice fishes

The ice fishes have become famous for a characteristic which is unique among vertebrates. All the species have virtually no red blood cells or haemoglobin. There is, in fact, no oxygen-carrying pigment in the blood of these fishes. In appearance, the blood is a slightly opaque, very pale greenish or yellowish white. The colour of the gills of a living or freshly-dead specimen is not red, as in other fishes, but a cream-white. The colourlessness of the blood probably accounts for their somewhat translucent aspect, especially in the tail region, and perhaps is responsible for their name. The lack of an oxygen-carrying pigment indicates that these fishes probably have reduced metabolic rates or that they are able to be active for only short periods. Certainly they appear to suffer from asphyxia more rapidly than do other Antarctic fishes, for when they are brought up in trawls they nearly always have their large mouths and gill-covers stretched open. At the present time there is no information about the metabolic rates of ice fishes, although research in blood chemistry and cellular respiration is in progress.

The respiratory rates of several species of Antarctic cods have been determined, and all of them show distinct cold adaptation, that is, their rates are higher than those of temperate species in waters of low temperature. Further, the respiratory rates of Antarctic cods reach a maximum at a temperature of about 2–3° C, and recent investigations have shown that the maximum lethal temperature is about 6° C. These fishes are therefore highly adapted to very low and unvarying temperatures.



Some secondary Antarctic fishes (from top): *Lycenchelys antarcticus*, family Zoarcidae (from Regan, 1913); *Paraliparis antarcticus*, family Liparidae (from Regan, 1914); *Muraenolepis microps*, family Muraenolepidae (from Regan, 1914); *Chalinura ferrieri*, family Macruridae (from Regan, 1913).

Second major group

The second major group of fishes consists of Antarctic representatives of families with worldwide distributions, such as the Zoarcidae (eel pouts), Liparidae (snail fishes), and Rajidae (rays). Of these, the Zoarcidae are the most important, having evolved into several genera and species peculiar to the Antarctic. The endemic genera appear to be related to the widespread genus *Lycodes*, which has many deep-water representatives. There is little doubt that most of the Zoarcidae reached the Antarctic via the Scotia Ridge, a large submarine mountain chain extending in an eastward-bending arc between South America and the Antarctic Peninsula. The same is probably true for the Liparidae, which are known from southern South America and South Georgia as well as the Antarctic continent, and is certainly true for the Rajidae, of which one species inhabits both the Patagonian Shelf off the east coast of South America and the shelf along the northwest coast of the Antarctic Peninsula. The Antarctic species of these last two families all belong to genera of worldwide distribution.

The members of this second group are more recent arrivals into the Antarctic and have become much less diversified than have the Notothenioidei. Evidence of their recent derivation from more temperate forms has come from physiological as well as systematic studies. The respiratory rate of a zoarcid from McMurdo Sound proved to be very low, showing no cold adaptation. Further, the respiratory rate rose with increasing temperatures up to a maximum of 4° C, higher than the temperature of maximum respiration recorded for the notothenioids, and the fish survived best in the laboratory at a temperature of 1–2° C, higher than that found in its normal habitat at the bottom of McMurdo Sound. The low respiratory rate and tolerance to higher temperatures indicate that the zoarcids have not yet become fully acclimated to the

Antarctic. Perhaps they are able to exist there because none of the notothenioids have evolved into elongate, eel-like forms with which they would have to compete. Unfortunately, even less is known about the Liparidae and Rajidae than is known about the Zoarcidae.

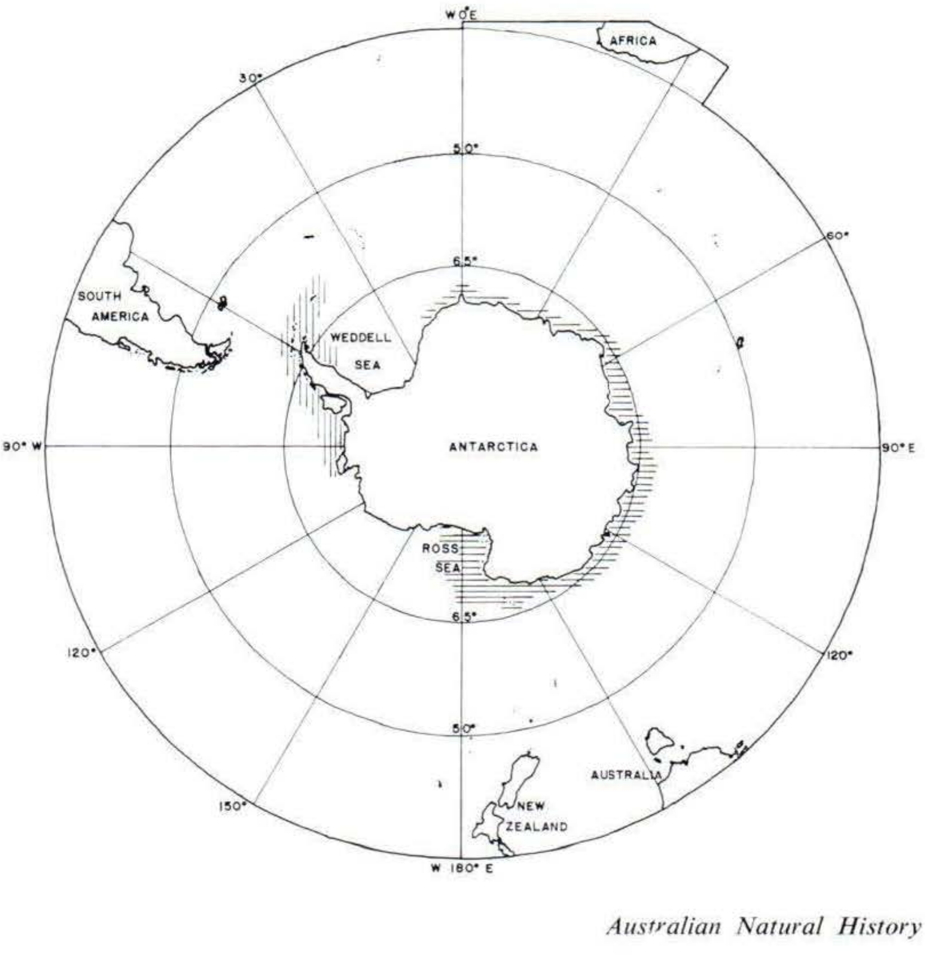
Other families

Two other families of fishes are encountered in Antarctic waters. One, the Muraenolepidae, comprising small fishes which have chin barbels and a pointed tail joined to the dorsal and anal fins, and which are related to the cod fishes, is found only in the Antarctic and subantarctic. There are only four species known, and it is not possible to tell whether they form a part of the older endemic element of the Antarctic fauna or whether they have more recently moved south. However, together with the notothenioids they add to the peculiar nature of the Antarctic fish fauna.

The second family is the Macruridae, a family of worldwide distribution in deep water. Several species of this family inhabit the deep waters of the Southern Ocean, and one or two have been captured from the upper part of the continental slope and the edge of the continental shelf. Apparently they are unable to withstand temperatures below —1° C, and occur only on the outer parts of the shelf where warmer water is able to penetrate a short distance to the south.

Two zoogeographic regions

Although some fishes have been found entirely about the Antarctic continent, others have more restricted distributions. It is possible to recognize two zoogeographic regions in the coastal waters on the basis of the restricted distributions of fishes. The smaller has been termed the West Antarctic District, and encompasses the region of the Antarctic Peninsula and nearby islands, including the South Orkney Islands. Its outstanding feature is the development of a number of species of the large genus *Notothenia*, a characteristic shared with South Georgia Island to the north. The larger region has been called the East Antarctic District, and encompasses most of the rest of the continental coast,



Antarctica and the Southern Ocean. The horizontal lines delimit the East Antarctic faunal district; the vertical lines delimit the West Antarctic faunal district.

from the Ross Sea on one side to the Weddell Sea on the other. This region is characterized by the development of the genus *Trematomus*, the absence of nearly all species of *Notothenia*, and the presence of a number of other endemic genera and species. The East District, with about fifty-two species, is significantly richer than the West District, which has about thirty-five species.

Why should the Antarctic, where water temperatures are so uniform, have two apparently different biological regions? Although the Eastern District has somewhat more severe conditions than the Western District, the differences are not great, being not more than 1 or 2 degrees, and in the winter temperatures are the same. A clue may be found in the depths of the continental shelves of the two regions. In the Western District, the continental shelf extends to depths of about 100 metres before dropping off more steeply into abyssal water. The outer edge of the continental shelf in the Eastern District is much deeper, averaging about 250 metres, and in some places being as deep as 500 metres or more. Often the slope of near-shore areas is very steep, dropping quickly to several hundred metres before encountering the more level shelf. Thus, fishes inhabiting relatively level shelf regions at 100 metres may not be able to exist at greater depths, and vice versa.

The relatively great depth of the continental shelf in the Eastern District may also be responsible for another peculiar distribution pattern. The greatest number of species is not found in shallow near-shore areas, as in most regions of the world, but rather at depths between 350 and 550 metres. This depth range coincides with the depth of much of the continental shelf. The absence of a littoral fauna and the relative paucity of shallow-water forms inhabiting depths less than 50 metres is probably due to the severe ice conditions at the shore line. The West Antarctic District also shows a depression for the depth of maximum diversity, but it is shallower, being between 200 and 350 metres. Further, the species maximum is less well marked and there are more species found in shallow water, perhaps implying somewhat less severe conditions.

Studies on blood chemistry

In this present period of intense activity in the Antarctic, a number of people have become interested in the coastal fishes, especially in regard to the physiology of cold adaptation and the activity of the Channichthyidae. Of particular interest will be the results of studies on blood chemistry and metabolic rates and pathways in the cold-adapted groups. Work on the ecology of under-ice communities, of which fishes are a prominent part, is also in progress. Investigations into life-histories, food habits, age and growth, and reproduction have also begun since the advent of well-supported Antarctic stations, where biologists are able to pursue their work in all seasons of the year. Yet because the Antarctic is remote and relatively inaccessible, our systematic knowledge of the animals which exist there is still incomplete. Much valuable work remains to be done in determining phylogenetic relationships, especially of the Notothenioidei, and in the description of new forms that continue to appear in our nets.

[*This article is a contribution from the Marine Science Institute of the University of South Florida. It is based, in part, on field work supported by a National Science Foundation Grant to the University of Southern California, Los Angeles.*]

GIANT PETREL BANDED

A white Giant Petrel (*Macronectes giganteus*) which was captured by surfers at Narrabeen, Sydney, and held by Taronga Zoo until fit for release was banded by the Curator of Birds at the Australian Museum, Mr H. J. de S. Disney, with CSIRO band number 130.13531 on 6th August, 1968. The Giant Petrel is a subantarctic bird and the usual form is dark brown. They breed on Macquarie Island, which is about 1,400 miles southeast of Melbourne, where it has been estimated 7 per cent of the population belong to the white phase. The bird from Narrabeen was unusual, as it was pure white; usually there are a few black feathers in the white plumage. The Sydney section of the Albatross Study Group have banded five of the white form when catching albatrosses out at sea near Malabar Heights, Sydney.

INSECTS AND THEIR RELATIVES

By J. LINSLEY GRESSITT
Chairman, Entomology Department, Bishop Museum, Honolulu, Hawaii

INSECTS and their relatives form an important segment of the terrestrial fauna of the Antarctic Continent. Although the marine environment of the fringes of the Antarctic Continent supports a very extensive fauna, the terrestrial environment is a much more rigorous one, since the temperature of the air (and consequently of the rocks, plants or other elements forming the habitable niches) falls far lower than that of the water (which cannot go below about —2° C). The temperatures of the environment of the free-living fauna may fall as low as —50° or —60° in winter.

With the adverse factors of the terrestrial environment, the number of species occurring is quite limited. There are about 150 species of arthropods known from the continent, including parasitic species and marine mites. They include the principal major groups of mites, Collembola (springtails), biting and sucking lice, a flea, and midges.

The principal environments of the arthropods include the vegetation, the undersides of rocks, soil, carcasses, nests of some kinds of birds (but not those of the southernmost birds), and the intertidal zone. Some mites are also marine, and, though not part of the terrestrial fauna, they belong to the principal group of free-living terrestrial mites.

Southernmost record

Arthropods (insects and their relatives) occur as far south as 85° 32′ S., by the Robert Scott Glacier, at the southern end of the Ross Ice Shelf. One species, the prostigmatic (trombidiform) mite *Nanorchestes antarcticus*, has been found there. This is the southernmost known record for animals, and the southernmost plant record is from just a little farther south in the same general area, at 86° 09′, in the Horlick Mountains, where lichens have been found. The next southernmost record for animals is for rotifers, at 85° 09′, on the Shackleton Glacier, and algae and bacteria were also found in that area. At just a little farther north, 84° 47′, five species of arthropods were found—three mites, *N. antarcticus*, *Protereunetes maudae*, and *Stereotydeus shoupi*, and two springtails, *Anurophorus subpolaris* and *Tullbergia mediantarctica*.

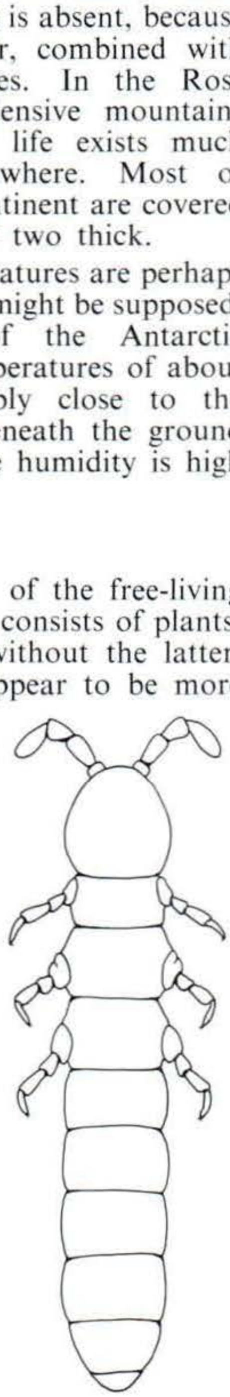
A worker collecting insects for the Bishop Museum, Honolulu, on Deception Island, a rich insect environment in the South Shetlands, in 1961. The collector, Thomas Leech, is in a moss field by a melting snow patch, and is using an aspirator, a common collecting tool.

Insects and mites are actually the dominant land animals of the Antarctic continent, since the vertebrates are all associated with the sea, though a partial exception might be made for the skua, which feeds at times on baby penguins, carrion or garbage. The arthropods occur in all habitable environments. The principal requirements for life are, of course, food, protection, sufficient humidity, and tolerable temperatures. All of these factors have severe limitations in Antarctica, and are not necessarily satisfied in all areas without permanent ice. The continent is essentially a cold desert environment, and the normal humidity of the air is generally too low, at least in more southern areas, to support life. In such areas the evaporation rate is too great, and life can only exist where snow-melt on warm days can provide sufficient moisture. Where temperatures are so low, and the air so dry, that snow sublimates directly on being heated by rocks warmed in the sun, life cannot exist. Thus there is a strip of area, in general landward of coastlines, where plants and animals cannot live, even where ice is absent, because of the dryness of the air, combined with constant low temperatures. In the Ross Ice Shelf area, with extensive mountains to the west and south, life exists much farther south than elsewhere. Most of the inland areas of the continent are covered with an ice-cap a mile or two thick.

The lower winter temperatures are perhaps not as great a deterrent as might be supposed. Experimentally, some of the Antarctic species have survived temperatures of about —50° C. This is probably close to the minimum temperatures beneath the ground surface in the areas where humidity is high enough to permit life.

Importance of plants

Since the primary food of the free-living (non-parasitic) arthropods consists of plants, the former cannot exist without the latter. Besides this, the plants appear to be more tolerant of the extreme conditions of humidity and temperature, because they are found a bit farther from the coasts, and occur in more exposed situations, such as on the surface of rock. In general, the insects are in cracks in rock and under loose rocks, particularly flat rocks lying on soil, where humidity is generally much higher than in the open air. These environments also provide the necessary protection, for the winds of Antarctica are generally strong to severe. Flat rocks on soil or fine gravel (more common than soil) seem to provide one of the most favourable niches. The rocks must be heavy enough, or so situated as not to be blown by strong gusts of wind, but not so thick that the heat of the sun will not penetrate sufficiently to warm the environment beneath. This provides a tolerable environment for the insect, and also favours more plant growth to provide food. Some arthropods, particularly the minute (and southernmost) mite *Nanorchestes antarcticus*, appear to occur where no plants are in evidence. However, there are often microscopic algae and fungi in soil and gravel or under rocks.



Anurophorus subpolaris, one of the two southernmost springtails, Queen Maud Mountains, near the south end of the Ross Ice Shelf.

Favourable environments

On the more northern fringes of the continent, types of favourable environments are more numerous. Bird nests, various types of debris, added types of plants (grass, herb, hepatics, larger fungi), seaweed, carrion, old bones, and human artefacts (like boards) provide added niches. Volcanic heat also provides favourable environments. Among the niches where highest populations have been found are the undersides of old dead penguins with algae growing on the feathers —even where the feathers and meat have been eroded off the upper side of the skeleton by windblown sand and snow. The population under one dead subadult penguin on Possession Island, off Hallett Station, approached 10,000 mites of two free-living species, each just over a quarter of a millimetre long as adults. High populations of certain springtails or mites are found in moss, among *Prasiola* algae, *Usnea* and *Ramalina* lichens, and bulky bird nests such as those of the gull *Larus dominicanus*. Grass, or debris such as accumulated moulted feathers, close to rookeries, and skua feather boluses, may harbour very

Oribatid mites *Alaskozetes antarcticus* on the underside of whalebone, Antarctic Peninsula, 1961.

high populations. The very dense populations on the Antarctic Peninsula often consist of the springtail *Cryptopygus antarcticus* or the wingless midge *Belgica antarctica*, although the oribatid mite *Alaskozetes antarcticus* may occur in great numbers. The minute prostigmatic mite *Tydeus tilbrooki* occurs in great numbers in several genera of fruticose lichens, or in mixtures of *Prasiola* algae with lichens. Snow with growth of algae, Red Snow (*Chlamydomonas*) and Green Snow (*Pandorina*), are niches for springtails (*Cryptopygus*) or the mites *Nanorchestes* and *Halozetes belgicae*. One *Cryptopygus* was even found in Green Snow on an iceberg.

Greatest known concentrations

The greatest known concentrations of numbers of species of arthropods in Antarctica are in the Antarctic Peninsula area, with the South Shetland Islands and the South Orkney Islands. Lesser concentrations are in North and South Victoria Land. It is interesting that eight free-living species have been found in Southern Victoria Land, and southward, much farther south than all the ice-free portions of East Antarctica (including the Australian and French territories, and the U.S.S.R., Japanese, South African, and Norwegian stations), whereas only six (one questionable) are known from East Antarctica (exclusive of Victoria Land). Twelve free-living species are known from North Victoria Land. Not only is there a high concentration of free-living species in Victoria Land, but the greatest concentration of endemic genera occurs there, with three endemic genera of springtails, as well as one of mites shared with Queen Maud Land. Only one endemic genus of free-living forms is known from East Antarctica, although the Antarctic flea, representing an endemic genus, is known only from the area. There is only one endemic genus (midge, *Belgica*) known from the Antarctic Peninsula area (including the South Shetlands).

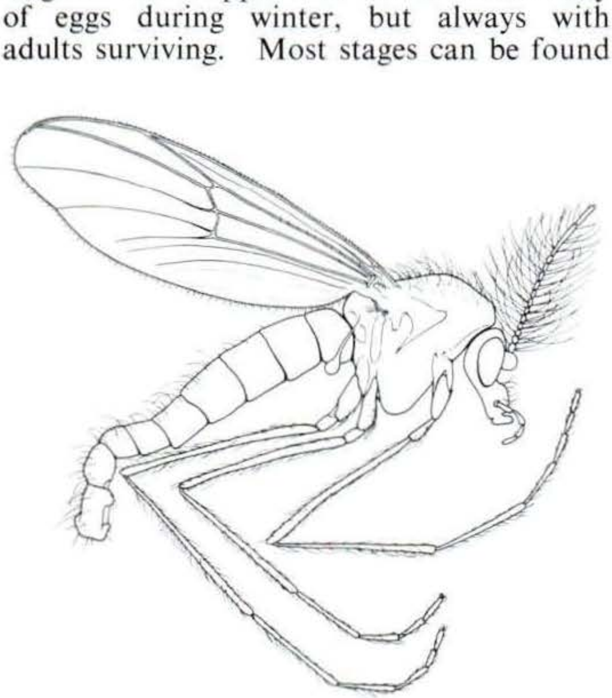
The groups of arthropods represented in the Antarctic terrestrial fauna include the five major groups of Acarina (mites and ticks), springtails, biting lice on birds, sucking lice on seals, the flea in petrel nests, and two species of midges, both in the South Shetland Islands, and the wingless midge also on the Antarctic Peninsula. There are about equal numbers of free-living and parasitic species on and around the continent. There are about 50 terrestrial

The springtail *Cryptopygus antarcticus*, with eggs, young, and moulted skins, Antarctic Peninsula.

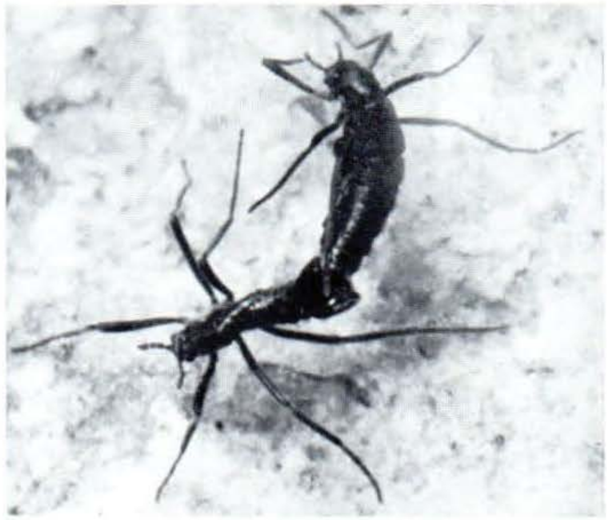
mites (of which a dozen or so are parasitic), 18 Collembola, 40 bird lice, 4 seal lice, 1 flea, and 2 midges—thus about 120 land species, plus nearly 30 known marine or intertidal mites. There are probably still a number of localized endemic free-living species to be discovered, as some parts of the continent known to support plants have not been investigated for insects.

The arthropods, occurring in great numbers in favourable environments, play an important role in the ecology of land life on the continent, limited as that is. The numbers of individuals of arthropods may reach population densities of up to 100,000 per square metre, although in more southern populated areas densities may usually be below 100 per square metre. The higher population densities may be hardly exceeded by those of the lower invertebrates—tardigrades, rotifers, nematodes, and protozoans. These lower groups have not been sufficiently studied, and may have more or fewer species on the continent than do arthropods.

Seasonal activity is variable and still poorly understood. There appear to be many overlapping generations, with perhaps each free-living species over-wintering in all stages. There appears to be lowest mortality of eggs during winter, but always with adults surviving. Most stages can be found



The winged midge *Parochlus steineni*, South Shetland Islands. This is the southernmost flying insect.



The wingless midge *Belgica antarctica*, Antarctic Peninsula. Female at right, male at left.

at the beginning of spring and the end of autumn (say November and February in the far south). Sudden onsets of colder weather may retard activity at any time in summer, as during blizzards, or during midnight hours when the sun is quite low in the sky. In the latter part of summer continued cold weather may terminate the growing season early, and even trap individuals in insufficiently protected environments for over-wintering. In the far southern areas it is difficult to find the hibernating insects, but this is perhaps largely because the snow-free summer environments may be ice (frozen snow)-covered in winter, till at least late October in the far south.

Zoogeographical relationships

The zoogeographical relationships of the Antarctic fauna are not very clear. This is because the primitive groups represented, particularly the free-living groups (which are of more zoogeographic significance, since the parasitic ones travel only with their hosts) are poorly known in general, and for the Southern Hemisphere in particular. Apparent relationships are with all the southern continents, but particularly with South America and New Zealand or Australia. Only two fossil insects are known—possibly water beetles—from the north end of the Antarctic Peninsula, plus an indeterminate neuropteroid type wing from the interior. Since their relatives are not known, they are of little help in working out the history of the fauna. In any case, it is obvious that Antarctica had an extensive temperate fauna in the late Tertiary. It is also certain that distribution of land life was more limited during Pleistocene ice ages than at present. Thus, probably a few species persisted through the ice age, and additional ones have been brought to the continent since the Pleistocene by winds and birds. Chances of repopulation by these methods are, of course, limited. For instance, normal surface winds blow outward from the centre of the continent. However, a number of non-Antarctic insects, mites and spiders have been trapped from the air on and around the continent.

The history of discovery of Antarctic arthropods is fairly brief. About one-third of the known species were discovered by the early expeditions of the "heroic period" of the end of the nineteenth century and the start of the twentieth century. Then less than one-third (mostly parasitic species) were discovered during the following five decades, and the balance of more than one-third came to light in the past decade, since the International Geophysical Year, mainly through the efforts of the United States Antarctic Research Programme, the British Antarctic Survey, the Australian National Antarctic Research Expeditions, and the New Zealand Antarctic Research Programme. The information on the fauna, both taxonomic and ecological, has been summarized, or presented for the first time, in *Entomology of Antarctica*, Antarctic Research Series volume 10 (American Geophysical Union, Washington, D.C.), 1967.

[*The photos in this article are by R. Leech; the drawings, were prepared under the direction of the author.*]

BOOK REVIEW

ANIMAL LOCOMOTION, by Sir James Gray. Weidenfeld and Nicolson. 458 pages. Many illustrations and diagrams. Bibliography and index. Price, $18.

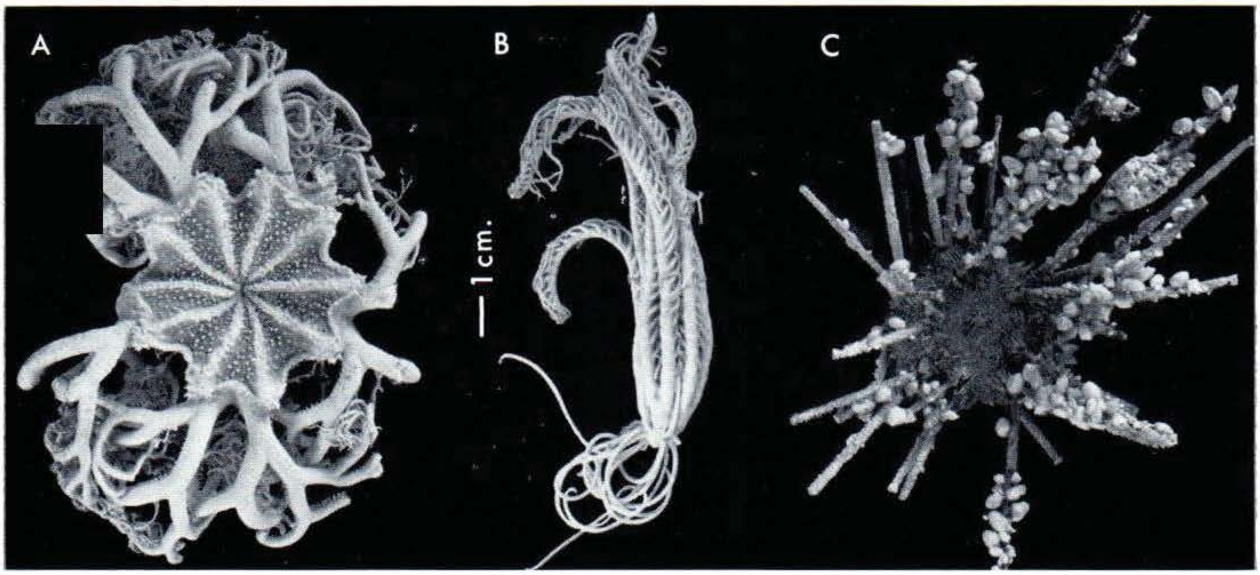
During his long career as Professor of Zoology at the University of Cambridge, Sir James Gray became not only the "Grand Old Man of British Zoology" but also the world authority on the locomotion of animals. More than thirty of his scientific papers were concerned with the topic. So also was his *How Animals Move*, first published in 1953.

It is certain that the insight and illumination which Sir James shed on the problems of animal locomotion by using comparatively simple techniques of analysis enthused a considerable number of undergraduates and junior colleagues to follow his lead. This resulted in the growth of a literature which has now become voluminous. Most of it is scattered through the learned journals and, therefore, in assembling much of it between two covers this present book performs a very useful service. *Animal Locomotion* is essentially a text which is a must for any specialist in the field, but it is also a book that may be read with profit and indeed pleasure by anyone interested generally in animals and/or functional anatomy.

The first and larger part of the book is devoted to the various problems (and their solutions) encountered by the different classes of vertebrates. That the vertebrates should occupy such a prominent position in the book is understandable, not only because they are the most studied but also because it is in them that one can see the very close correlation between their evolutionary history and the extraordinary adaptability of their limbs. This is not to say that invertebrate animals are disregarded. They are considered in six chapters in the second part of the book, but here the emphasis is more on mechanisms of the co-ordination of movement than on the dynamics of skeletal and muscle systems.

The book, as one expects from the publishers of the series "The World Naturalist", is attractively presented with clear print, many line drawings, and several interesting photographs. The bibliography is comprehensive and the index good.

—*J. R. Simons.*



Antarctic echinoderms: A, an ophiuroid with branching arms, *Gorgonocephalus chilensis;* B, a crinoid, *Notocrinus virilis;* C, a regular echinoid, *Ctenocidaris* species. [Photo: Smithsonian Institution.]

ECHINODERMS

By DAVID L. PAWSON
Supervisor, Division of Echinoderms, Smithsonian Institution, Washington, D.C., U.S.A.

MOST people are familiar with the starfish, which clings to rocks on our seashores. This animal is a representative of a very large group of animals called echinoderms ("spiny skins"), which includes the starfish (asteroids), brittle stars or serpent stars (ophiuroids), sea cucumbers (holothurians), sea urchins or sea eggs (echinoids), and sea lilies or feather stars (crinoids). A representative of each group from Antarctica is illustrated here.

Echinoderms are exclusively marine animals, and they are found in all seas, from the shore to the bottoms of the deepest trenches. Indeed, in very deep water, they can comprise up to 95 per cent of the total weight of animals (biomass) on the sea floor. They are generally restricted to the ocean floor, although a few are known to swim for varying periods of time. Echinoderms are unique in having a water vascular system—a system of fluid-filled tubes within the body that controls the function of special organs called tube feet, which the animal uses for locomotion. The body is generally enclosed in a rigid or flexible armour (test) of hard plates made up of calcium carbonate in the form of calcite, and many echinoderms have spines, lumps, and bumps on the body, also made of calcite. In most sea cucumbers, the plates of the body are reduced to form tiny microscopic particles, and thus the body wall is usually soft or leathery.

As a group, the echinoderms have a very respectable history, being known since the Cambrian era; they have therefore had a known time-span of at least 600 million years in which to develop into their present-day forms. Some echinoderms live attached to hard bottoms (for example, rocks) and feed on small organisms drifting in the surrounding water, while others are soft-bottom dwellers, deriving nutriment from the sea floor either by swallowing mud or by selectively picking up small organisms.

Our knowledge of Antarctic echinoderms stems from over 100 years of exploration in Antarctic and subantarctic seas. The echinoderms collected by several Australian, British, and other European expeditions have been described and discussed in large illustrated monographs, but nevertheless the job is nowhere near completion and there is still much to be learned about the echinoderms of the southern oceans.

Origin

There are very few clues as to the origin of the Antarctic fauna. Fossils, which are so useful in other parts of the world in determining origins and relationships of echinoderm faunas, are not common in Antarctic rocks, or at least few have been discovered. On Snow Hill Island, near the Antarctic Peninsula, a small collection of fossil echinoids was made by the Swedish South Polar Expedition 1901–1903. The specimens were from the Eocene and Cretaceous eras. They included representatives of two families and one subfamily that are no longer represented in Antarctic waters. It is possible that the Antarctic fauna at that time was quite different from what it is today—probably the water was warmer. If this is true, then the fauna of today is relatively "young". However, results afforded by various living groups of echinoderms are conflicting. On the one hand the echinoids of Antarctica appear to have evolved there from previously existing forms, and there is no evidence that echinoid species have migrated from elsewhere into Antarctica. On the other hand, the structure and relationships of the holothurian fauna indicate that the fauna was derived from the north and west, and we can seek and find relatives of Antarctic species in areas such as southern South America and the subantarctic islands.

Structure

All five groups of echinoderms are represented in Antarctic and subantarctic regions. The approximate number of species of each group known from depths of less than 1,000 metres (about 3,300 feet) in Antarctica proper is as follows: asteroids, 100; ophiuroids, 100; echinoids, 50; holothurians, 40; crinoids, 20.

The total number of species from Antarctica is thus approximately 310; this represents about 5 per cent of all known living species of echinoderms. This figure is surprisingly small, in view of the vastness of the Antarctic ocean, but it may tend to be misleading, for a characteristic of the echinoderm fauna of Antarctica is that several large groups of echinoderms are not represented in Antarctic seas or are very poorly represented. For example, among the sea urchins there are more than fifty families living today, and only six occur in Antarctic waters. The strange composition of the Antarctic fauna is undoubtedly a reflection of the very low temperature of the area.

Distribution and relationships

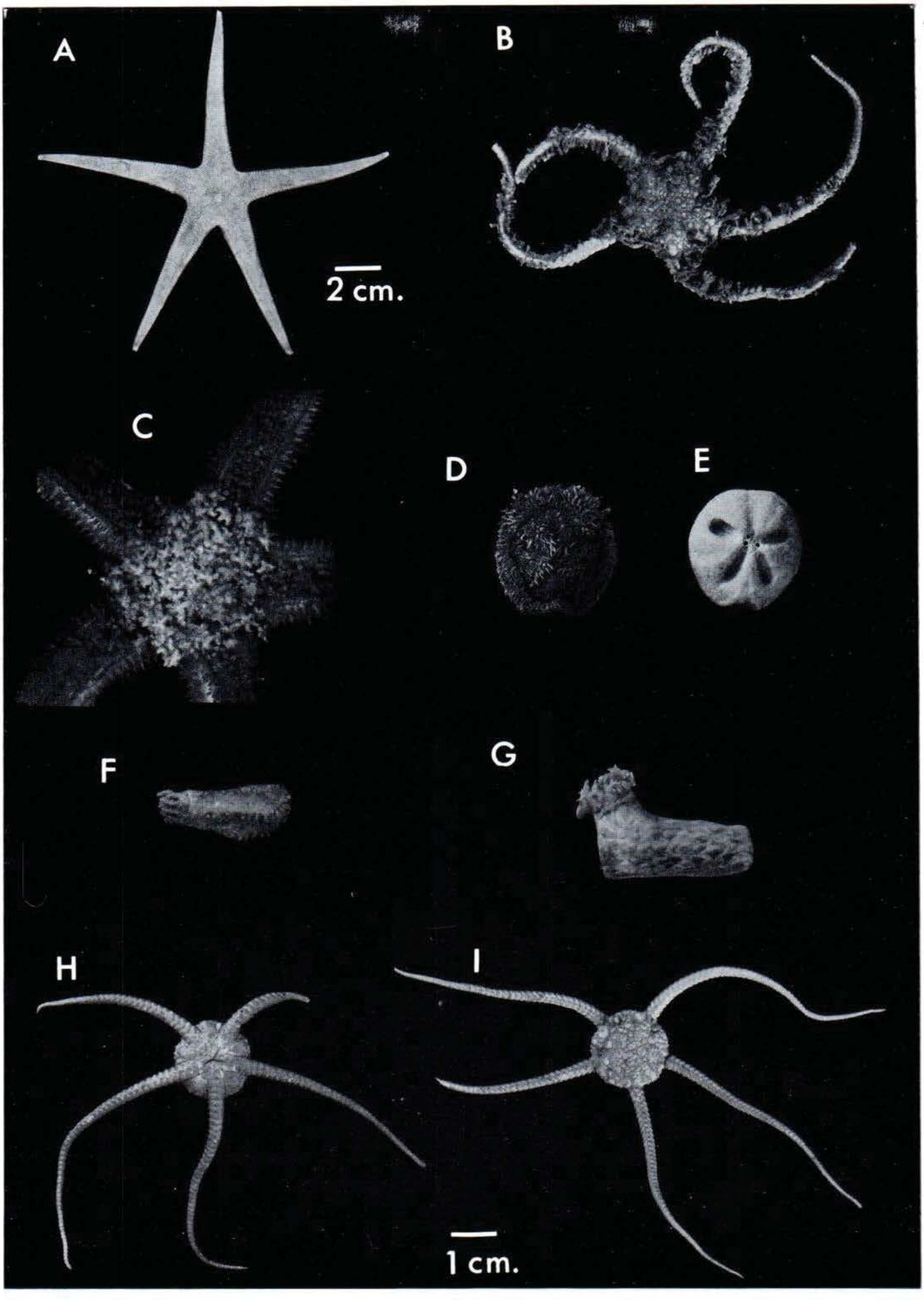
Analysis of the southern oceans echinoderms shows that there are four main patterns of distribution, when we consider the genus level of classification:

- Genera which are circumpolar in the Antarctic region only.
- Genera which are circumpolar in the Antarctic region only, but which also extend north to the Magellanic region of South America (a few also extend north towards Kerguelen Island).
- Genera with circumpolar or partly circumpolar distribution in the subantarctic region, but with no representatives in the Antarctic region (except perhaps South Georgia, which is an intermediate island).

(*Continued on page* 132)

OPPOSITE

Antarctic echinoderms: A, an asteroid, *Bathybiaster loripes*, dorsal view; B, an ophiuroid, *Ophiurolepis gelida*, parasitized by the sponge *Iophon radiatus;* C, a brooding asteroid, *Diplasterias brucei*, with young clustered around the mouth; D, an irregular echinoid, *Abatus* species, dorsal view; E, the same as D, but with spines removed to show four brooding chambers in which the young are carried; F, a holothurian, *Cucumaria* species, lateral view; G, a holothurian, *Psolus squamatus*, lateral view; H, an ophiuroid, *Ophiurolepis* species, ventral view; I, same as H, dorsal view. (The 1 centimetre scale applies to all specimens except A, which has a 2 centimetre scale. One centimetre equals about two-fifths of an inch.) [Photos: Figs A, C, by courtesy of Helen E. S. Clark; others, Smithsonian Institution.]


A
B
2 cm.
C
D
E
F
G
H
I
1 cm.

● Genera which occur in various southern land-masses, but are unknown elsewhere.

There are some exceptions to the categories above, but most genera display one of these distribution patterns. Several Antarctic echinoderms are shared with the Magellanic region, and that area is regarded as a portal of entry into the Antarctic region. No close relationship exists between the fauna of Antarctica and that of New Zealand, Australia, or South Africa. The southern oceans may be broadly divided into several faunal regions on the basis of echinoderms. These, broadly speaking, are the New Zealand-Australia region, southern Africa (which shares several species with Western Australia), the high Antarctic region, the subantarctic region (which includes all of the isolated subantarctic islands), and southern South America. Southern South America is unique in having a mixture of subantarctic and Antarctic faunas.

Breeding and brood protection

In the echinoderms the sexes are usually separate, males and females existing as such, unchanged, for their entire lives. However, many species are hermaphrodites, producing eggs and sperms at the same time, or at different times. Various kinds of development can take place in echinoderms, but two broad types are recognizable. Most warmer water species have a free-swimming stage called a larva. The fertilized egg develops into the minute larva, which swims and feeds in the plankton for several weeks, and then becomes transformed into a miniature adult which sinks to the sea floor. This type of development, egg-larva-juvenile, is termed *indirect*. The other type, in which the free-swimming larval stage is omitted, is termed *direct;* here the egg develops more or less directly into the juvenile.

It is an interesting fact that in the southern oceans the direct type of development is prevalent, and many Antarctic echinoderms have developed special mechanisms which enable them to protect their developing young—a phenomenon known as brood protection. The brooding habit is not restricted to Antarctic forms, but by far the greatest number of brooding echinoderms are found in Antarctic seas. Let us consider the brooding habit in each of the five main groups:

● Sea cucumbers: The young may simply be held on the external surface of the mother, in the tentacles or somewhere on the body wall, or they may be retained in specially developed pouches or pockets. Still another kind of brood protection is found in one species, where the eggs are retained inside the ovary of the mother and develop there into juveniles; presumably they are liberated to the outside by rupture of the body wall.

● Sea urchins: Several Antarctic species carry young either around the mouth or the anus, protected by spines; in some, the area around the mouth may be sunken to form a brood chamber. In the irregular echinoids (that is, those echinoids which are more or less elongate and flattened) brooding takes place in four sunken brood chambers on the upper surface of the body. The young are held in the chambers by means of short spines, which form a roof. It is believed that almost all of the Antarctic irregular echinoids brood their young in this way.

● Sea lilies: Most crinoids have a free-swimming larval stage, but several Antarctic species have developed special brood chambers on the arms in which the young develop, and the larval stage is suppressed.

● Starfish: In most of the brooding Antarctic asteroids the young are held on the underside of the body, around the mouth. The minute starfishes are often held together by a series of strands of tissue somewhat reminiscent of umbilical cords; however, it is believed that no nourishment passes through these strands. In a few other species the young are carried on the upper surface of the body.

● Brittle stars: In the brooding ophiuroids the eggs are discharged into special sacs inside the body called bursae. There they are held until they have developed into young brittle stars, when they are released to the exterior through the ten bursal slits, which open on the underside of the body. One can often see tiny arms projecting through the bursal slits when one is examining a fresh or preserved Antarctic brittle star.

Although there is a high incidence of brood protection in the Antarctic region, brood protection is nowhere near as common in the Arctic. A possible advantage of brood protection lies in the fact that there are no larvae to be exposed to the vagaries of ocean currents, and thus a high percentage of the young have a good chance of survival. In the case of echinoderms with indirect development, the presence of floating larvae helps to disperse a species but the chances of survival of any one embryo are relatively slim. It is for this reason, apparently, that species which develop indirectly produce great numbers of eggs, and consequently larvae, while direct developing or brood-protecting species produce far fewer eggs.

The question which has not yet been satisfactorily answered is: why is brood protection so much more common in Antarctic than in Arctic seas, and why has it arisen? The only physical factor which may possibly be responsible for the high incidence of brood protection in Antarctica is the low ambient temperature. Perhaps a biological factor is acting, too, for it has been shown that, in the case of at least one indirect developing Antarctic starfish, development of the larvae is timed to coincide with the summer bloom of the minute plants which constitute the phytoplankton and upon which the echinoderm larvae feed. During other times of the year in Antarctica the available food material is drastically reduced, and thus it may be more "convenient" to protect a brood rather than be tied to an annual bloom of phytoplankton. Low temperatures and annual blooms of phytoplankton are also typical of Arctic seas, and the discrepancy between the Antarctic and Arctic in the incidence of brood protection remains a mystery.

General biology

The study of the general biology of Antarctic echinoderms is still very much in its infancy, because of the obvious difficulties involved in conducting fieldwork in the area. However, some land-based research has been carried out in the Ross Sea area, and the technique of taking sea-floor photographs from ships is now providing very valuable information. A striking feature of the fauna (which the photographs show) is that in some areas echinoderms are dominant, and they form a thick carpet over the sea floor. It is not uncommon to pull up a dredge crammed with brittle stars or feather stars and little else. The Antarctic echinoderms have the usual complement of parasites, perhaps the most interesting being a sponge which grows all over the disc and arms of certain brittle stars. Many sea urchins are burdened by other animals, which live on their spines. These include various shellfish, worms, sponges, coral-like animals, and even other echinoderms, namely sea cucumbers.

Future research

Many details about the distribution of Antarctic species remain to be gathered. Until recently, sampling of the sea floor has been "spotty", but expeditions at present in progress and those planned for the near future should help to fill numerous gaps, and within the next few years we should have a far more meaningful picture of the patterns of distribution.

A great number of questions remain to be answered. How do essentially stationary Antarctic echinoderms (that is, those attached to rocks) which have no floating larvae achieve such a wide distribution? Why are some groups of echinoderms unable to tolerate Antarctic conditions while others apparently flourish there? What are the real advantages of brood protection, and why is it prevalent in Antarctica? How do the various echinoderms live? When do they breed? And so on.

With the aid of research based on the Antarctic continent, dredging, and sea-floor photography, it is hoped that some of the above questions may be answered. So far, some of the answers have been completely unexpected, and an eminent zoologist was recently prompted to say of these animals: "I . . . salute the echinoderms as a noble group especially designed to puzzle the zoologist".

The author (left) and Jack Littlepage, another American biologist, lower a trap through the sea ice at McMurdo Sound. A variety of fish and invertebrates were obtained in this manner. Mount Erebus is in the background. [Photo: U.S. Navy.]

BENTHIC INVERTEBRATES

By JOHN H. DEARBORN

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THE circumpolar seas south of the Antarctic Convergence abound with an astonishing variety of life. Some of the larger vertebrates which occur there, such as whales, seals, and penguins, are reasonably well known. Not so familiar are the drifting (planktonic) and bottom-dwelling (benthic) invertebrate animals, which are found in very large numbers. For example, one species of small pelagic crustacean, *Euphausia superba*, commonly known as krill, occurs in such numbers that literally tens of thousands of individuals may be eaten by a baleen whale at a single feeding. The numbers of benthic organisms in this region are no less impressive. At McMurdo Sound in the southwestern Ross Sea individuals of several genera of small gastropod molluscs such as *Margarella* and *Subonoba* may number in the thousands per square metre of bottom. In certain parts of McMurdo Sound the tanaidacean crustacean *Nototanais antarcticus* occurs in numbers exceeding 14,000 per square metre.

To the specialist, each group of Antarctic benthic invertebrates presents unique and challenging problems, yet there are some generalizations which can be made about the Antarctic fauna as a whole. Although there are exceptions to all of these general statements, the marine benthic invertebrate fauna seems to be characterized by great diversity, an abundance of sessile colonial suspension feeding organisms, many endemic forms, and many species with direct development.

Diversity

All major extant phyla of invertebrates and most minor phyla with marine members are represented in Antarctic seas. Foraminifera are abundant and are the best known of the Protozoa in the region. Sponges are very abundant, especially in depths between 50 and 400 metres. Siliceous sponges with long glassy spicules are most common and may reach considerable size. Individuals of the genus *Rossella*, for example, grow to a height of nearly 1 metre in the Ross Sea. Coelenterates are conspicuous, particularly stoloniferans such as *Clavularia*, gorgonaceans (horny corals), pennatulaceans (sea pens and sea pansies), and actiniarians (sea anemones). Nemertean worms are abundant as are the polychaetes or segmented marine worms with over 450 species knwon from Antarctic waters.

Certain groups of marine arthropods are very abundant in the Antarctic, but others are scarce or absent. Ostracods, copepods, mysids, cumaceans, and especially amphipods and isopods are very numerous. However, only eight or nine species of decapod crustaceans have been recorded from the Antarctic and these are all shrimps. Such common animals in temperate and tropical waters as crabs and lobsters are absent. The scavenging roles usually filled by crabs and lobsters in temperate seas are taken up in the Antarctic by amphipods and large isopods such as *Glyptonotus antarcticus*. The pycnogonids or sea spiders are most abundant in the Antarctic, with at least three times as many species there as in the Arctic.

The molluscs are not well represented in the Antarctic compared with other regions of the world, although all of the major types are present—amphineurans (chitons), gastropods (snails), bivalves (clams), scaphopods (tusk shells), and cephalopods (squids and octupuses). Only about 90 families averaging less than four species each are found, compared with about 160 families known from New Zealand. This is one of the few large phyla that are more abundant, in terms of number of species, in the Arctic than in the Antarctic.

Brachiopods (lamp shells) and bryozoans (moss animals) are abundant in southern seas, the latter group, together with sponges and coelenterates, forming a very substantial part of the thick mat of suspension feeding organisms which is so characteristic of many parts of the sea floor in this region.

One of the most colourful and obvious elements of the benthic fauna is the phylum Echinodermata. All groups of echinoderms are well represented—crinoids (sea lilies and feather stars), asteroids (sea stars), ophiuroids (brittle stars), echinoids (sea urchins), and holothuroids (sea cucumbers). There are 37 species of sea stars and 33 species of brittle stars or serpent stars known from the Ross Sea alone. There are, at present, about 270 species of echinoderms known from Antarctic seas, compared with about 60 species known from the polar Arctic.

Suspension feeders

The wealth of biological materials collected recently by various expeditions in the Antarctic and the evidence provided by recent underwater photographs taken mostly by American and New Zealand workers in the Ross and Weddell Seas confirm the fact that sessile, colonial, suspension feeding organisms dominate the benthic community in high southern latitudes. The most obvious of these are sponges, colonial coelenterates such as gorgonaceans, and bryozoans. They form an intricate mat of living animals which may reach a height of nearly 1 metre. Other benthic suspension feeders include many tube-dwelling polychaetes, bivalves, small crustaceans, brachiopods, and ascidians.

In using the term "suspension feeders" here I am referring to the general condition in which animals obtain particulate material from the water for food. Strictly speaking, suspension feeders like colonial coelenterates, certain polychaetes, bryozoans, brachiopods, and certain echinoderms, which simply remove particles from the water as it passes over their bodies, may be distinguished from filter feeders like sponges, many gastropods and bivalves, and many crustaceans, which actively pass water through parts of their bodies. The specialized structures used to filter the water usually retain particles according to size and shape. However, differences between filtering and non-filtering suspension feeders are not always well defined. The

Common benthic invertebrates at McMurdo Sound. Asteroids at left centre are *Odontaster validus* (one oral and two aboral views), at the top and right centre three specimens of *Diplasterias brucei*, and at lower right a *Perknaster fuscus antarcticus*. The isopod (lower left) is *Glyptonotus antarcticus*. The shrimp (bottom centre) is *Chorismus antarcticus*. An echinoid, *Sterechinus neumayeri*, is at left centre near the *Odontaster validus*, and the three ophiuroids in the centre are *Ophiurolepis* species. At the upper right is a pycnogonid, with shadows creating the appearance of an extra set of legs, and at top centre are two valves of the clam *Thracia meridionalis*. Bits of bryozoan colonies and a calcareous worm tube are also seen. [Photo: U.S. Navy.]

important point is that in Antarctic seas suspension feeders of one sort or another dominate.

Many other organisms live in or on top of the living mat. Some are small suspension feeders, others are carnivores or scavengers, and some are both. They frequently show modifications for their special existence of clinging to delicate branches of other animals. Many bivalves, for example, have extensive byssus threads by which they attach themselves. Certain crustaceans and brittle stars have spines or other projections which presumably aid in maintaining a favourable position in the mat.

Endemic forms

An important consideration about the distribution of the Antarctic benthos is that many groups are highly endemic—that is, many genera and species are confined to the Antarctic region and do not occur elsewhere. There are many examples that can be cited. Seven out of eight species of scleractinian corals known from the Antarctic shelf are restricted to the region. The polychaete fauna consists of more than 50 per cent endemic species. More than 70 per cent of the species of amphipods and isopods are apparently endemic. Among the molluscs, probably 80–85 per cent of the species of gastropods are restricted to high southern latitudes and at least 75 per cent of the bivalves are so limited. About 70 per cent of the echinoderm species and 30 per cent of the genera are confined to the Antarctic. Among specific groups of echinoderms—

A dense mat of sponges, bryozoans, and gorgonaceans on the sea floor at a depth of 110 metres east of Beaufort Island in the southwestern Ross Sea. A crinoid is seen at upper left, and part of a sea star in the top left corner. [Underwater photo by courtesy of the New Zealand Oceanographic Institute.]

for example, crinoids—the percentages are even higher. It is clear from these data that the invertebrate fauna of the Antarctic sea floor, in general, is very independent and restricted in its redistribution. Many of the forms that are not restricted to an Antarctic distribution are found in other parts of the world only in deep water.

Direct development

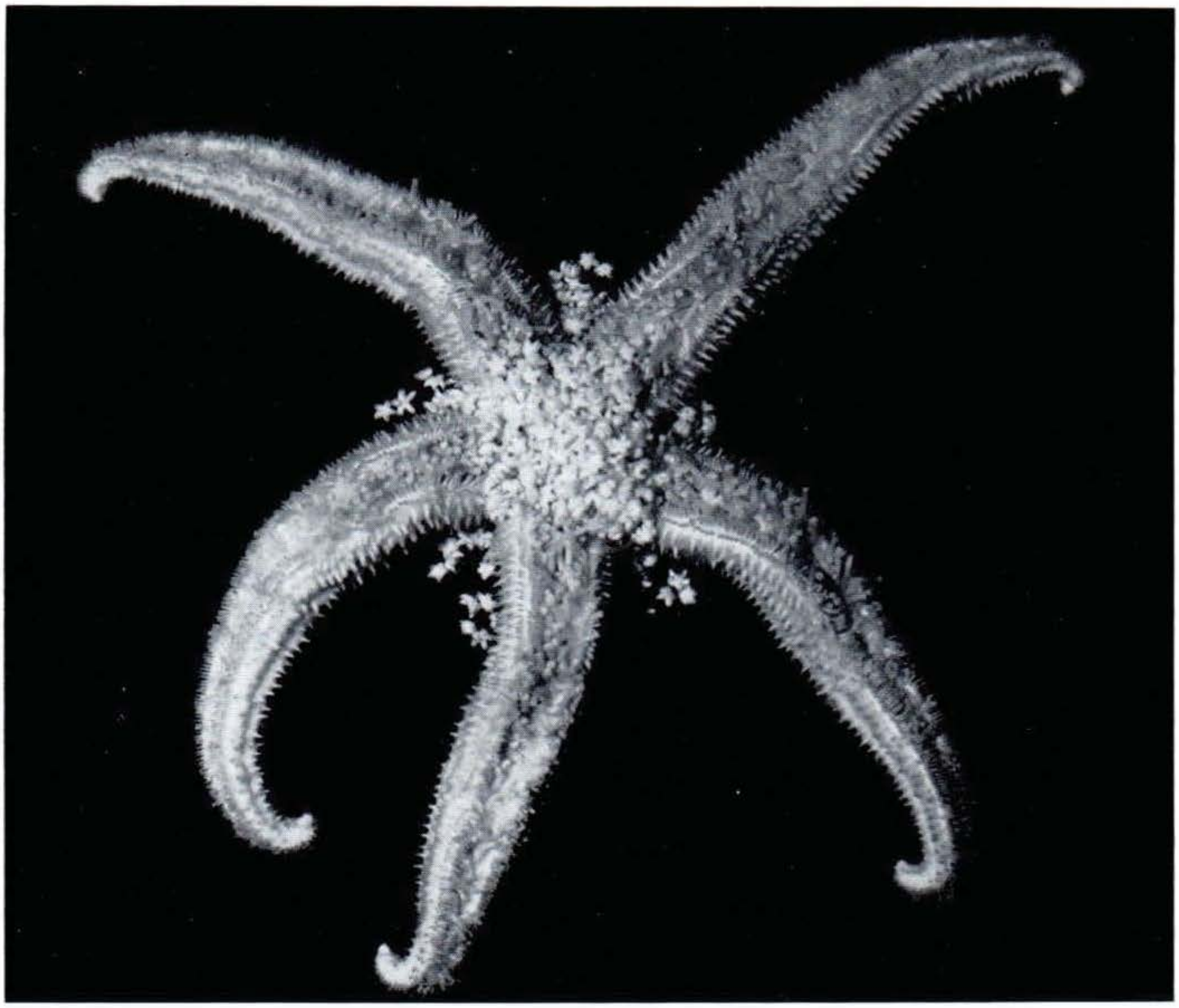
Many Antarctic invertebrates have reproductive habits in which eggs and larvae are protected during development. Large yolky eggs are usually produced. Many species are ovoviviparous, that is, the yolky eggs are retained and hatch within the female and the young are then released to the outside. Many other forms have special brood pouches for the protection of eggs and young. This habit of providing some form of protection for developing offspring is termed direct development as opposed to indirect development in which small eggs are released and the organisms pass through a series of free-swimming pelagic larval stages.

Direct development of some sort is especially common among Antarctic anemones, polychaetes, bivalves, asteroids, ophiuroids, and echinoids. The production of large yolky eggs and brood protection of eggs and young increase the chances of survival for each new individual. Many fewer eggs are produced by animals having direct development than by those having indirect development.

Some ecological considerations

The 12 million square miles of Antarctic ocean represent one of the richest biological areas in the world. Upwelling of water around the continent replenishes nutrients such as phosphates, nitrates, and silicates in the upper layers. In spring and summer rich blooms of phytoplankton provide food for myriads of animals. Some of the planktonic animals feed directly on the plants, but many others, like the large copepod *Euchaeta antarctica*, are carnivorous. The planktonic plants and animals and their remains, along with the suspended particulate remains of benthic forms, are utilized by those vast numbers of microphagous suspension feeders which dominate the benthos.

Water temperatures throughout the year are low and, especially in the highest latitudes, are very constant. At McMurdo



An oral view of a living female asteroid, *Diplasterias brucei*, with brooding young completely covering the mouth and basal portions of the arms. The specimen was collected at McMurdo Sound in December, 1959. [Photo: U.S. Navy.]

Sound water temperatures from the surface to the bottom vary throughout the year less than 2° C around a mean of minus 1·8° C.

The irregular topography of the bottom around the Antarctic Continent and the fact that sediments are carried north away from the continent by strong bottom currents mean that there are few large areas of level sea floor where soft substrates accumulate. However, many other kinds of materials, such as shells, gravel, rocks, and combinations of these, are common, and this variation in bottom type is reflected in the kinds of plants and animals that are found.

At McMurdo Sound, for example, most of the shoreline and bottom out to a depth of 15 to 20 metres is composed of rocks, cobble, gravels, and sand of volcanic origin. Scouring action of ice along the shoreline and frozen substrates in very shallow water effectively eliminate a permanent intertidal fauna. Between 20 and 50 or 60 metres the bottom usually consists of gravel or rocks covered with debris from diatoms, siliceous sponges, hydroids and bryozoans, some living sponges, and bivalve remains, mostly the empty valves of *Limatula hodgsoni* and *Thracia meridionalis*. In deeper water the bottom is covered with the thick mat of sponges, coelenterates, and bryozoans already discussed.

What of the invertebrate animals living on the bottom beneath permanent sea ice or extensive ice shelves such as the famous

Ross Ice Shelf? How far back from the leading edge of such ice barriers do bottom animals live? Are they the same kinds of organisms that occur on the sea floor over which there is no permanent ice cover? One recent study of specimens collected through cracks in the Ross Shelf near White Island and the mouth of the Koettlitz Glacier, south of McMurdo Sound, has shown that a variety of different types of invertebrates do indeed occur on the bottom as much as 28 kilometres back from the leading edge of the Ross Shelf. The absence from these collections of certain very common benthic organisms found regularly at McMurdo Sound outside the influence of a permanent ice cover, such as the bivalve *Limatula hodgsoni* and a sea star, *Odontaster validus*, suggests real differences in the composition of the two faunas. The difficulties of drilling or blasting through hundreds of feet of ice are obvious. Perhaps detailed studies of faunas under permanent ice will have to wait until appropriate submersible vehicles are available. One aspect is clear. Without any available light for photosynthesis to occur, all the living phytoplankton and plant debris, upon which all animals ultimately depend for food, would have to be transported under the ice by currents. The amount of nutrients and dissolved oxygen in the water would also be controlled largely by currents. Such a specialized environment poses new and fascinating questions to the marine ecologist.

Benthic invertebrates are important foods for certain vertebrates in the Antarctic. *Trematomus bernacchii*, the most common bottom fish at McMurdo Sound, feeds on representatives of at least nine invertebrate phyla. Prey organisms most heavily utilized by this sluggish, big-headed, rather stubby nototheniid fish are polychaete worms, gammarid amphipods, isopods, and gastropods. A close relative, *T. centronotus*, has very similar feeding habits, except that ostracods and gastropods are taken more frequently.

Benthic invertebrates are of less importance in the diets of Antarctic seals which tend to feed more on fish or pelagic invertebrates such as the shrimp-like krill or squids. (See "The Ross and Other Antarctic Seals", by Judith E. King, *Australian Natural History*, Vol. 16, No. 1, March, 1968, pages 31–32.) Weddell Seals, however, in addition to feeding on fish and certain planktonic crustaceans, also take benthic amphipods, isopods, shrimp, and cephalopods (especially small octopuses of the genus *Pareledone*).

Since 1958 probably more marine invertebrates have been collected in the Antarctic than in all previous years put together. This wealth of material has been obtained through the efforts of many nations, especially Argentina, Australia, Chile, France, Great Britain, Japan, New Zealand, the Soviet Union, and the United States. Research workers in these and other nations are now faced with the formidable task of identifying, describing, and reporting on these collections. The results of such systematic and zoogeographic studies should provide us with a firm knowledge of what organisms are present and how they are distributed. But this is not enough. We need to know the mechanisms by which animals are adapted to the uniformly cold environment. We need sufficient life-history information to test conclusively the generalizations about the Antarctic benthos discussed above. With the excellent shore laboratories and oceanographic vessels now available, biologists are able to investigate, using live specimens, basic problems in the physiology, behaviour, and ecology of Antarctic invertebrates. It is these sorts of studies, only recently made possible, that will provide answers to some of the most intriguing questions we now have about the animals of the sea floor.

LIFE IN PRIMAEVAL TIMES

By EDNA P. PLUMSTEAD
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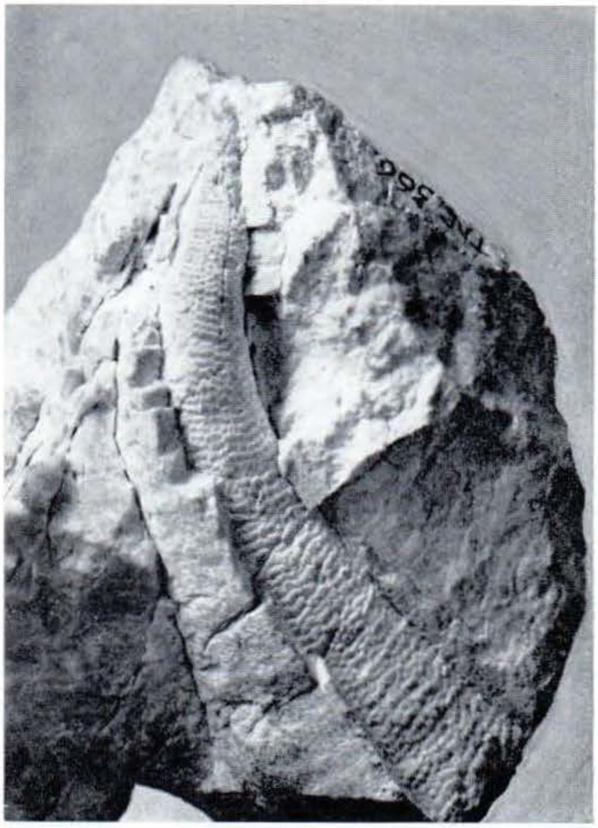
FOUR hundred years ago, in 1570, Ortelius published a map of the world. The outlines of Africa were fairly well known because of the route to India, and Magellan had circumnavigated South America 50 years before; the other two great southern continents, however, were still shrouded in mystery and fable, so that Ortelius placed a wavy line right across the southern portion and wrote beneath it, "Terra Australis nondum cognita" (the Southern Land not yet known), for he believed that it existed.

Two centuries later Captain Cook was engaged on his three famous voyages which played so great a role in southern exploration. He was the first to sail right round the world on latitude 60° S., and so demonstrated that Australia was a separate continent. It was on the second of his voyages that he sailed far enough south through the pack-ice to see unbroken ice rising in altitude. He counted ninety-seven "ice hills" but could see no land. This was Antarctica, and he described it as follows: "Countries condemned to everlasting rigidity by nature, never to yield to the warmth of the sun, for whose wild and desolate aspect I find no words".

In this century, explorers have discovered that the two continents of Australia and Antarctica, linked together by Ortelius in ignorance, must have been far more closely related and may actually have been connected in the past, for they shared the same climates and supported the same plant and animal life for an immense length of time. To Captain Cook such a statement would have seemed absurd. The pre-history of Antarctica is, however, written in its rocks in the form of remnants of plants and animals of different kinds and of many ages, which once lived in the now ice-bound and lifeless continent. These fossils, as they are called, have told us so much about the climates and the environments in which they lived and have revealed such close relationships with the past life of other southern continents that geologists, biologists, and geophysicists are now faced with a puzzle of enormous proportions but with fascinating implications.



Archaeocyathus, an extinct Cambrian marine invertebrate related to corals. This specimen came from Whichaway Nunatak moraine. [Photo: Jon Stephenson.]

The age references quoted are based partly on recent absolute ages determined by radiometric measurements but mainly by comparison with known sequences of plant and animal life in other parts of the world.

A glance at a map shows that Antarctica has two lobes separated at either end by two large indentations, the Ross Sea and the Weddell Sea, but connected in the centre by the covering ice-sheet. They have come to be called West and East Antarctica, respectively. The western portion is much smaller and has now been shown by seismic soundings to be an archipelago of large islands which both geographically and geologically resemble the fold mountain chains of the Andes, in South America, and of New Zealand. The rocks are either volcanic or marine and the oldest land fossils are Jurassic. East Antarctica, on the other hand, is a true continental shield of great size which lies completely within the Antarctic circle, and 95 per cent of it is under ice. Nowadays the central plateau is buried under so many thousands of feet of ice that it is heavily weighed down and no rocks can be seen, but in places around the rim of the saucer isolated mountains project. In particular, the western margin facing West Antarctica is a great wall of mountains broken frequently by wide glaciers

A twig of *Elatocladus*, a Jurassic coniferous ancestor of *Podocarpus*, collected in the Ross Sea area.

flowing from the plateau and intercepted from time to time by ice-fields.

The rocks have revealed that land life commenced in the Devonian period, as early as elsewhere in the world, that it was interrupted by an ice age, as in Australia, South Africa, South America, and India, and that it then with renewed vitality extended to the Jurassic, when it was apparently abruptly terminated by the onset of glacial conditions. No record of modern land plant or animal life has been preserved, nor does it exist today. No blade of grass nor tiny fern has ever been found in East Antarctica and the plant life is confined to patches of scaly lichens on some of the rocks and algae in some of the lakes. They lie dormant most of the time but in the short summer, if the ice melts, may form a patch of coloured weed on the water before the cold and darkness envelop the area once more.

Because of lack of space, the account which follows must be confined to this true continental area. The story of East Antarctica's rich life in former times has been built up during the past half-century by explorers from a number of different countries; the evidence has been pieced together from areas hundreds, and sometimes thousands, of miles apart, but it is now sufficient to form continuous chapter headings at least, and details are being filled in by each new field party.

The first and most dramatic record of fossil plants in East Antarctica is worth retelling. It was found by Edward Wilson, who served as both doctor and geologist on Captain Scott's tragic Polar journey in 1910. On their return from the Pole, weak from scarcity of food and fuel, the absence of vitamins, and the strain of man-hauling their sledges, and disappointed because Amundsen's Norwegian party had reached the South Pole ahead of them, Wilson found an outcrop of rock on the Beardmore Glacier, which contained seams of coal and shale bearing impressions of leaves resembling those of the gum trees of Australia. In his diary Wilson compared them to large beech leaves, for he had not seen eucalypts, but he recognized the great scientific importance of such large-leafed plants and coal at a latitude of 85° S. His enthusiasm restored, he collected 35 pounds of specimens to take back to Britain. Captain Scott himself shared the extra load, for they were very near the end of their physical endurance. Only a few days farther the party were caught in a blizzard and died in their tent. The precious fossils and diaries were found the following year by the rescue party, and the specimens can still be seen in the Natural History Museum in London. Professor Seward, of Cambridge, who described them, recognized the leaves as fragments of the tongue-shaped *Glossopteris*, a plant which is the commonest fossil in all Southern Hemisphere coal seams.

Part of a Triassic cycad frond (*Zamites*), from the Ross Sea area.

The second chapter was enacted by the Australian expedition in 1914–15, under the leadership of Sir Douglas Mawson. A small party consisting of Dr Madigan, McLean, and Correll found fossil leaves and coal at Horn Bluff on the coast of King George Land, longitude 150° E., a considerable distance from the Beardmore Glacier. From the description these leaves, too, were of *Glossopteris*, but unfortunately all the specimens were lost at sea.

In 1935 a party with the U.S.A.'s second Byrd expedition found similar plant fossils on Mount Weaver (86° 58′ S., 152° 30′ W.), only 210 miles from the Pole and the highest latitude from which fossil plants have been recovered, but unfortunately these were wrongly identified.

The Second World War intervened, and it was not until 1955–1958 that Sir Vivian Fuch's great concept of a Commonwealth Trans-Antarctic Expedition could become a reality. On this journey great advances in knowledge were made. One party under Sir Vivian took the previously unexplored route from the Weddell Sea. The geologist was Dr Jon Stephenson, now of Armidale University, New South Wales, who proved to be an expert fossil hunter and found in one mountain range, the Theron Mountains, four horizons of coal and three others containing fossil plants. In the Whichaway Mountains he likewise found excellent plant fossils, which have added considerably to our knowledge. In each case the plants proved to be of Permian age.

Meanwhile, on the Ross Sea side of the continent, parties of New Zealanders under the leadership of Sir Edmund Hillary were exploring, and they, too, had wonderful success, for they found plant fossils at twelve different sites which later proved to range in age from Devonian to Jurassic.

I had the great privilege of describing the plant fossils from both sides of the continent. Twenty-five genera and forty-six species of plants were found and an additional 20 too imperfectly preserved to be placed in genera. All showed close affinities with plants from other southern continents. The fossil woods were sent to Professor Kräusel, of Germany, who found two genera with southern relationships.

Two genera of Devonian fossils were found by H. J. Harrington's party; they proved to be closely related to those found in Devonian rocks of the Cape Fold Mountains of South Africa and also to some described long ago from eastern Australia by Feistmantel.

The Coal Measure or Permian plants far exceeded all others. From the combined Weddell Sea and Ross Sea areas twenty-two genera and forty-three species were described, of which seventeen were of the dominant genus *Glossopteris*. Only two species of the latter were new. As regards relationships, twenty-eight species were common with those of India, twenty-seven with those of Africa, two have been found only in Australia and Antarctica, and two in South America and Antarctica—but the majority are common to all these areas.

The woods all exhibited marked annual rings, a proof that distinct seasons existed. Northern Hemisphere coal-period fossil woods, other than those of India, show no growth rings. The specimens were collected by a number of geologists from six different areas.

Seven genera of Triassic age were found at four different sites by the New Zealanders Gunn and Warren. All are closely related to plants of this age in Africa, Brazil, Australia, and India. Finally, Gunn and Warren found also a small area at the head of the Mackay Glacier in which four genera of Jurassic plants were preserved. This was an amazing record for one expedition.

Soon afterwards the results of an American expedition to the Horlick Mountains were published. This area revealed one succession ranging from Devonian to Permian which yielded many fossils. Later exploration by Americans in the Pensacola and Ellsworth Mountains and by New Zealanders in Victoria Land have resulted in many new specimens of both Permian and Triassic age and have confirmed strongly the relationship of Antarctica with the other southern continents and India.

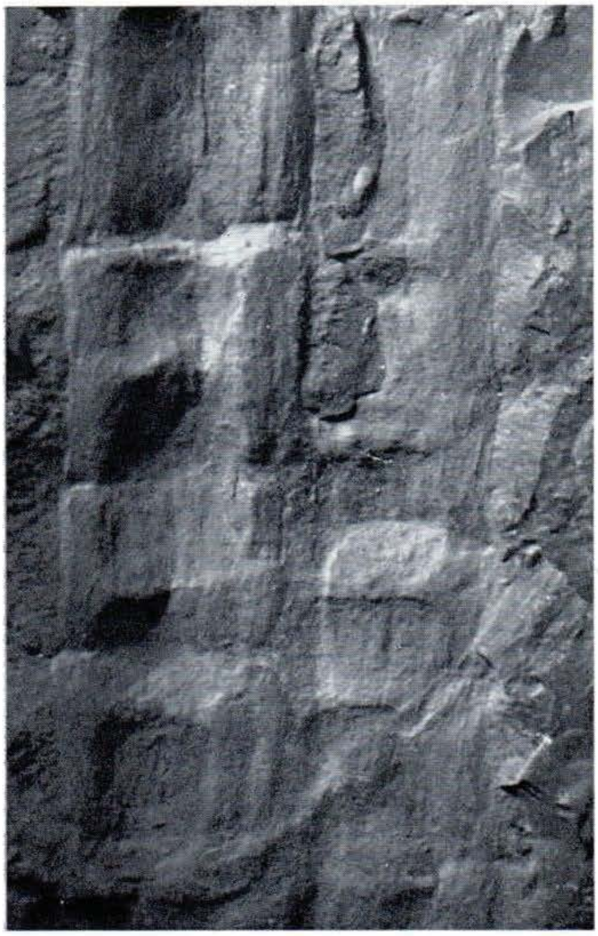
Today seventeen floral provinces are recognized throughout the world. They are of different sizes but are the areas in which plant life is closely related. They are separated from one another by barriers of climate, high mountain chains or wide oceans. In the late Palaeozoic Era only four such provinces can be recognized; three were in the Northern Hemisphere, but the largest was in the Southern Hemisphere and included all the southern continents, South America, Africa, and Australia and also, somewhat surprisingly, India. The association of plant life in these areas was so close that geologists conceived the idea of one great southern continent which they named Gondwanaland. It is now apparent that Antarctica, too, must be included.

Animal records are not nearly as numerous as those of plants. Marine invertebrates are known from a few horizons. Archaeocyathinae, which are long-extinct relations of corals, have been found in Cambrian limestones in South Victoria Land and also in fragments in the glacial moraines of a number of other areas. They must have been widespread, and Professor Dorothy Hill, of the University of Queensland, who described them, found a close relationship with those of the same age in South Australia.

Devonian invertebrate marine fossils have been found in the Horlick and the Ellsworth Mountains and are related to those found in South America and in the Cape. Remains of fresh-water Devonian fish have been recorded from several areas but are not well preserved.

Some freshwater invertebrates, known as *Leaia*, of Permian age have been collected in the Ohio Range of the Horlick Mountains by Doumani and Tasch. They were associated with *Glossopteris* flora and provide a useful age check as well as close

Glossopteris parallela from Antarctica, showing venation. ($\times 2$).



A Permian Coal Measure rhizome, *Vertebraria*, associated with *Glossopteris* in many areas. Locations: Whichaway Nunataks, Theron Mountains, Weddell Sea area. (×2).

comparison with similar shells in South America, South Africa, and New South Wales.

Freshwater conchostracans (crustaceans enfolded by a pair of shell-like extensions of the carapace) occur on Carapace Nunatak in association with Jurassic coniferous twigs, and also in Jurassic sediments intercalated with the Kirkpatrick basalts of Queen Alexandra Range.

Records of land animals are far more significant but are difficult to find; up to now only two are known, but are extremely important. On a specimen from the Theron Mountains on which six different plant species are preserved I found the impressions of parts of large insect wings superimposed on those of the leaves in three different places. This is still the only record of insect life in Antarctica. The second record is more spectacular, for it is the first land vertebrate found. It was discovered less than a year ago by geologists from Ohio State University (U.S.A.) on a ridge above the Beardmore Glacier, and has been described by Professor Colbert, of the American Museum of Natural History, who has worked extensively in South Africa and in other Gondwana countries. He was able to identify the fossil as part of the jawbone of a salamander-like amphibian closely related to a species which lived in South Africa and in other southern continents in the early Triassic period approximately 230 million years ago. The animal was normally between three and four feet in length, lived partly on the land and partly in freshwater, and could not have crossed the expanse of ocean which now separates these lands. It was, moreover, a warmth-loving animal, yet it was found only 325 miles from the South Pole.

In every portion of the southern floral province of Gondwanaland where a succession of distinct southern floras is found, the plants are associated with a steady development of vertebrate life, ranging from amphibia to reptiles to mammal-like reptiles. It was, therefore, natural to prophesy, as I did in 1962, that such vertebrate fossils would be found in Antarctica. Future efforts will no doubt be concentrated on finding more of them.

The records of land life in Antarctica present a challenge and provoke many questions. How can plant migration of complete floras have crossed the vast oceans which now separate them? How could the plants of the now steaming plains of India and of the now icebound Antarctic Continent have been so closely related in former ages? Shall we find the same succession of animal life hidden in the rocks? Why did the succession of plant life in Antarctica cease so abruptly?

Do all these contradictions suggest the existence of former land links or an actual movement of the present continents to former juxtaposition within the same climate zone? Has continental drift occurred and was Gondwanaland a reality?

The age of discovery is not past. The opportunity of searching for and finding the missing links in the evidence remains.

[*Photos in this article are by the author, except where stated otherwise.*]

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