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Australian Natural History

SUMMER 1990–91 VOLUME 23 NUMBER 7

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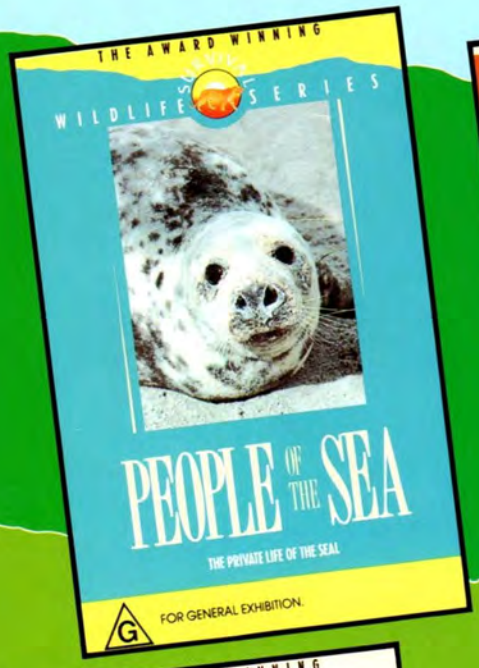

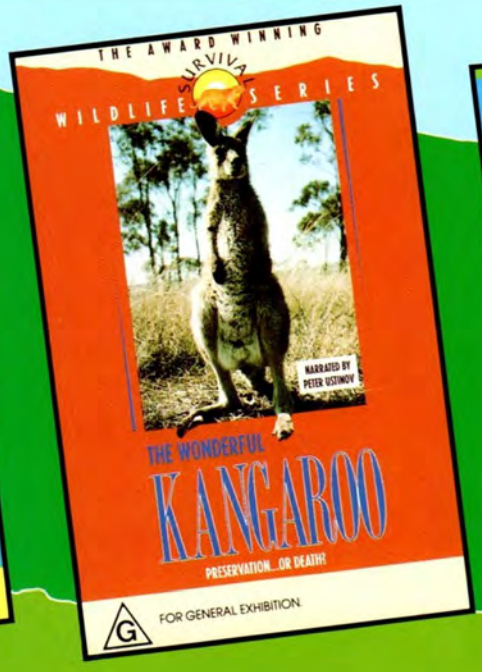

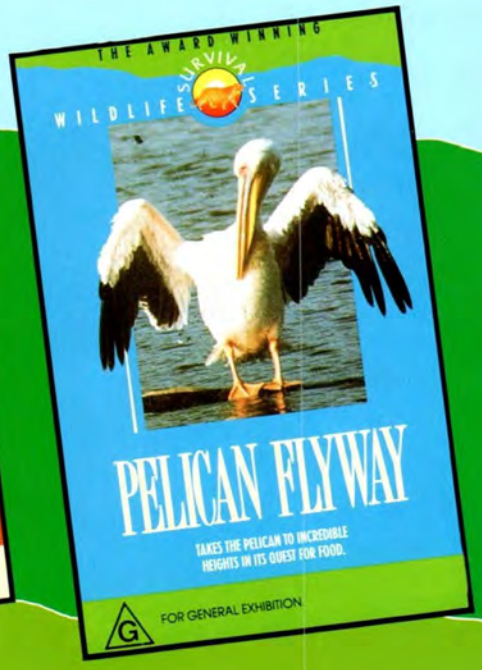

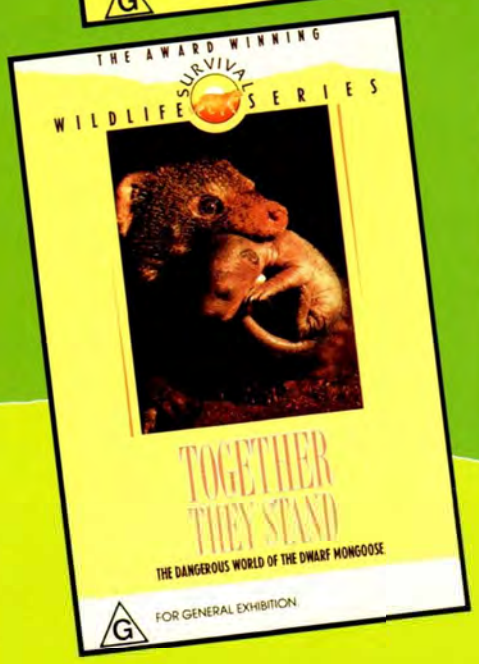

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ANH
Australian Natural History

Summer 1990–91
Volume 23 Number 7
Published by
The Australian Museum Trust
6-8 College Street,
Sydney, NSW 2000
Phone: (02) 339 8111
Trust President: Robyn Williams
Museum Director: Desmond Griffin
EDITOR
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SCIENTIFIC EDITOR
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ART DIRECTION
Run Run Run Design Pty Ltd
EDITORIAL ASSISTANT
Jennifer Saunders
TYPESETTING
Excel Imaging Pty Ltd
PRINTING
Dai Nippon Printing Co., Tokyo, Japan
ADVERTISING
Wendy Symonds
Lisa Rawlinson
(02) 339 8234
SUBSCRIPTIONS
Annual subscription (4 issues)
Within Australia $A30
Other Countries $A42
Two-year subscription (8 issues)
Within Australia $A58
Other countries $A78
New subscriptions can be made by credit card on the ANH toll-free hotline 008-028558 or use the form in the back of the magazine. If it has been removed, send cheque or money order to the address above, made payable to the 'Australian Museum' in Australian currency.

Australian Natural History is printed on archival quality paper suitable for library collections.

Published 1990
ISSN-0004-9840

Australian Natural History is audited by the Audit Bureau of circulations.

Australian Natural History is proud winner of the 1987, 88, 89 & 90 Whitley Awards for Best Periodical.

Front Cover

Scientists Gordon Grigg, Mike Augee and Lyn Beard (pictured) spent over two years tracking Echidnas in the high country to discover just how they survive the freezing winters. The answer has important implications for the study of hibernation. Photo: Gordon Grigg.

E D I T O R I A L

EXPORTING OUR EXPERTS

BY FIONA DOIG
EDITOR

ONE OF THE BEST EXPORT ITEMS TO come out of Australia yields the country virtually no financial gain. In fact, it is costing us money. The importer, on the other hand, reaps all the benefits. What ridiculous kind of product could that be? Our experts. Those people who have the capacity to solve some of our major environmental problems, bring us closer to an understanding of our natural history and develop our resources more effectively.

Why are we exporting these products, which cost so much to produce, for no gain?

A student entering any field of the natural sciences has to be *dedicated* to the subject. That person must put up with shoddy conditions, lack of incentive and poor prospects—at least in this country.

When I see an advertisement for a PhD in nuclear physics with several years experience offering a salary less than a fresh economics graduate, I question the imbalance.

I have met many scientists on occasional sojourns back to the 'land of milk and honey' telling tales of the great job prospects in other countries. . .and moaning the abysmal lack of professional work in their own.

But this is not the worst of what appears to be a general trend. Not only are we losing trained people, fewer and fewer students are reaching the higher levels of education. Fears that Australia will face a huge shortage of post-graduate scientists have been confirmed in a recent study by Flinders University. This research found that there was, for example, a net loss of mathematicians from Australia to other countries every year and that only about 60 PhDs in physics are graduating annually. In 1989, 270 positions for such people were advertised in one daily newspaper alone. I imagine the stakes for the natural sciences would not be dissimilar.

Concern within the CSIRO about finding qualified staff in the future was so great it triggered the implementation of a union–management action plan to take their argument for a 19 per cent pay increase before the Australian Industrial Relations Commission.

Job and pay structure needs to be improved if young academics are to be encouraged to pursue a career in scientific research. Universities aren't even able to compete with the CSIRO. Not only are salaries appallingly low and poorly structured, a distinct deterioration of working conditions has occurred over the last few years, with greater pressure on staff to increase teaching hours and administrative duties. Many senior research scientists find they must spend an inordinate amount of time chasing up funding for their research projects—they are literally being forced to become entrepreneurs, leaving less and less time for research.

Job insecurity is a major stumbling block. Many scientists I work with exist from grant to grant, with periods of employment ranging from a few months to a few years. Add to this scenario the ever-increasing annual budgetary cutbacks with which research institutions like museums are struggling and you have the recipe for mass emigration of scientists.

On the flip side of the educational coin, science teachers are leaving schools in droves. This shortage is so severe that primary school teachers are being put through crash 13-week courses to teach science in high schools. What kind of science education can they provide future generations of scientists?

All of this is occurring at a time when the Federal Government and unions are emphasising the importance of a brain-led economic recovery—but what has been done to achieve this?

At least this ideal has recognised the fundamental error we have been making in relying heavily on primary produce for our export income, rather than using our collective intelligence. Just compare Australia's economic structure with that of other, relatively stable, nations. Switzerland, for example, lives off not the fat of the land but the power of the brain, as does Japan.

These countries advance in technology while we stay behind and mind the sheep. Our infrastructure is not unlike that of many developing nations.

Much is said of a lack of economic comprehension among scientists, but little is said of scientific literacy amongst economists or politicians who ultimately make decisions that affect this country's future. An emphasis on research that leads to solving global problems will certainly reap vast benefits for the nation that comes up with viable alternatives, for example, to fossil fuel-based energy.

Economic support of science is vital so that we can put Australia's scientific credibility back on track. ■

IN THIS ISSUE

BY GEORGINA HICKEY
SCIENTIFIC EDITOR

THE STEREOTYPE IMAGE OF AN Echidna is that of a primitive, egg-laying holdover from the earliest days of mammalian evolution. You can imagine the surprise, then, when Gordon Grigg (pictured) and his colleagues found Echidnas in the Snowy Mountains hibernating over winter—a mechanism previously reserved for only birds and 'higher' placental mammals. This exciting discovery has led the authors of the article on page 528 to reconsider, among other things, the traditional concepts of hibernation.

Australia's extinct Thylacine is also put under scrutiny, but from a phylogenetic viewpoint. Dan Faith uses the Thylacine to explain methods of evolutionary biologists intent on elucidating the relationships between animals. In this new age of technological advancement, the systematist is faced with the problem of deciding how much weight should be given to different structural or morphological evidence and that derived from molecular studies (see page 546).

John Brackenbury, the author of the recent "Insects in Flight" article (ANH vol. 23, no. 5, 1990), offers more of his superb photographs, starting on page 562, to illustrate the array of ingenious design principles that can be gleaned from the study of insects. Other articles in this issue deal with the evolution of haemoglobin and opalised Australian fossil marine reptiles. Mike Archer, after recently attending a US conference on the interrelationships of mammals, writes about some of the key players—the Platypus and her three direct ancestors. Also, Ralph Molnar and Glen Ingram discuss evolution at the level of the gene; Tim Low looks at some of the products of the early acclimatisation societies; and Robyn Williams delights us with the strange eating habits of Frank Buckland.

Last but not least, ANH has been awarded the Royal Zoological Society of NSW'S 1990 Whitley Award for Best Periodical. And earlier in 1990, we ran equal first in the Media & Education category of the Australian Heritage Awards.

Articles

LETTERS

Comments, criticisms and congratulations from concerned correspondents. Readers are invited to air their views.

JOHN GILL

Antarctic species, like these Emperor Penguins, are directly dependent on the ocean.

Antarctic Park

Perhaps ANH is playing devil's advocate in publishing Phillip Law's objections to the idea of an Antarctic World Wilderness Park. His arguments ("The Last Word", ANH vol. 23, no. 4, 1990) are based on outdated concepts of wilderness and conservation.

Dr Law is a respected pioneer; I admire his Antarctic work of the 1950s. But the gulf between pioneering vision and environmental sense is illustrated by his ideas on rubbish disposal. Most of the rubbish that now lends such an air of dereliction to Antarctic stations is the result of bureaucratic policies and demonstrably gross and wasteful overdevelopment. To hide this junk permanently in Antarctica, where the taxpayer cannot see it, would add deceit to environmental insult. Like most easy solutions, it would be wrong.

But there are far more serious problems with Dr Law's arguments. He accepts an uncertain fate for 'threatened parts' of the continent simply because they are relatively small. Antarctica, he states, is not at risk because "99 per cent of it *will always remain a wilderness*, no matter what...". This argument is refuted, I believe, by one crucial fact: that the threatened, accessible, coastal, partly ice-free areas contain virtually all the wildlife breeding sites. Penguins, petrels and seals would compete with industry for the same one per cent of the continent. The remaining 99 per cent is scarcely relevant to the conservation issue. Even the "vast geographical scale" of the coastline does nothing to invalidate my concern because nobody can say where the limits to exploitation, once begun, would finally be drawn.

Those who have experienced the Antarctic hinterland know the soulless desolation of a landscape devoid of plant and animal life. Yet one would be forgiven for thinking that Dr Law sees Antarctic wildlife as a mere side-issue. Wildlife conservation measures that he mentions (such as specially protected areas) are barely adequate against modern expeditions and would be mocked by any Antarctic industry.

He finds the treatment of the Antarctic conservation "one-sided and characterised by emotion, ignorance and exaggeration". In the same literary breath he trivialises the likely consequences of a major Antarctic oil spill, comparing it, quite illogically, with a spill in Bass Strait.

Antarctica's cold, species-poor ecosystem is largely isolated by the oceanic convergence—principles of biological resilience and environmental regeneration that apply in lower latitudes, and even in Arctic zones, apply less readily here. Every Antarctic species depends directly and completely on the ocean. Numbers within some species are strikingly small. Standing at Auster Rookery, (about 50 kilometres east of Mawson Station) for example, one can see—and actually count—roughly one twentieth of the world's entire Emperor Penguin (*Aptenodytes forsteri*) population. Adaptive mechanisms are extreme. There is a fine line between breeding success and disaster. And to cap it all, our understanding of the lower end of the food chain (recklessly exploited by Russian and Japanese fleets) is very sketchy indeed. Antarctic biological literature abounds with examples of serious wildlife disruption by mere scientific bases.

How many Treaty Nation policy-makers (the weight of whose opinion so impresses Dr Law) understand Antarctica as a landscape, let alone as an ecosystem of unique beauty and fragility?

Dr Law's arguments really amount to a dogmatic and rather unscientific advocacy for the acceptance of very uncertain odds on Antarctica's future integrity.

—John Gill
Medical Offer,
Mawson Station 1988
Prince Charles Mountains
1989 Antarctica

Fire Management Paradox

Although I personally agree with much of Dr Flannery's argument concerning wilderness and Aboriginal fire regimes ("The Last Word", ANH vol. 23, no. 2, 1989), the scientific basis of the debate is still far from proven. I wish to illustrate this with the problem of fire management in the south-western Tasmanian wilderness.

It is now widely accepted that south-western Tasmania has had a long history of human occupation and that the use of fire by the Tasmanian Aborigines contributed to vegetation patterning of this region. Regrettably, however, we don't know how they burnt the lowlands while avoiding the elimination of fire-sensitive rainforest and alpine communities. For some this question may seem academic yet it is the crux of the fire management issue in this region as the primary goal of fire management is to avoid destroying fire sensitive refugial communities.

If the Aborigines intentionally burnt the lowlands then presumably they produced sharpened vegetation boundaries that also acted as fire boundaries and thus protected fire-sensitive vegetation. This is certainly the case in the Top End of the Northern Territory, where vegetation boundaries typically coincide with environmental discontinuities as well as differences in fuel

mass and moisture content.

The creation of 'wilderness' following the eradication of the Aborigines in this region 150 years ago may have resulted in the expansion of the scrub ecotone between the forests and treeless plains. This wedge of inflammable shrub species would have fundamentally changed fire patterns such that fires are now more likely to run into and ignite the surrounding forests. If this argument is correct then we can never return to an Aboriginal fire regime as vegetation and fire patterns have changed.

Unfortunately there is an urgent need for fire management because the 'wilderness' is now repopulated by bushwalkers—potential sources of ignition with far less ecological savvy than the Aborigines. Clearly tourists must be educated about their responsibility not to start bushfires. However, wildfires will continue to occur in the south-west. I believe that only some of these should be fought

FIONA DOIG

Bushwalkers need to be educated about fire management.

in order to protect specific places of value from fire damage. Similarly, some areas of country should be intentionally burnt to maintain particular wildlife habitat mosaics. Such management burns should occur where there is no risk of these fires destroying sensitive vegetation.

Whatever course of action is taken, one thing is certain: there is a need for constant scientific monitoring and study of natural areas to ensure that we don't destroy one of the scarcest resources on Earth—ecosystems unmodified by civilisation.

—D.M.J.S. Bowman
Conservation Commission of the Northern Territory, Darwin, NT

ANTHONY FARR

Energy used by life on Earth originates from the sun.

Dynamically Speaking

Ralph Molnar and Glen Ingram ("The organisation of life: from entropy to evolution", ANH vol. 23, no. 4, 1990) appear to believe a conflict exists between the second law of thermodynamics and neo-Darwinian evolutionary theory. They imply that the course of evolution represents a net reduction in entropy. This idea stems from the mistaken assumption that the Earth's biosphere constitutes a closed system in thermodynamic terms. Nothing could be further from the truth.

Virtually all life on Earth obtains the energy it requires from sunlight, either directly as with plants or indirectly as do animals. Sunlight is produced by the sun from the conversion of hydrogen to helium at the rate of four hundred million tons (4×10 grams) per second. The cost of this energy release is an increase in the sun's entropy.

Since the energy used by living things originates from the sun, the decrease in entropy represented by the growth, reproduction and hence evolution of complex organisms is only possible because of the corresponding increase in entropy that the sun has undergone. To go a little further, the loss of energy as waste heat at every biological transformation means that the net entropy of the system is increasing over time even if we ignore the sunlight that is radiated directly to space without impinging on Earth at all. There is no 'free lunch', and the second law of thermodynamics holds true for the evolution of life on Earth, just as it does for individual organisms.

Some other difficulties arise from the puzzling assertions and generalisations scattered throughout the article, which are presented without visible support or justification. Some examples include:

"Thermodynamics is the realm of the dead". The laws of thermodynamics apply to all matter, living and non-living. The very process of living is intimately related to heat flow.

"Organisms are only tenuously related to the environment". Conventional biology holds the view that organisms are inextricably related to their environment. The wildlife that died in the Alaskan oil-spill disaster died because the addition of oil to their environment made it too hostile for them to survive. Is this seriously being disputed?

"Developmental constraints lead to long-term stability in species such as Horseshoe crabs". What evidence is there that this stability is due to developmental constraints? Another point of view might be that any species that is still around after 150 million years must be fairly well adapted to it's environment and is therefore under no pressure to change.

"Organisms adopt a lifestyle suited to their anatomy". This statement leaves us with one of two possibilities. The first is that there is a lifestyle suited to every imaginable anatomy—somewhere an eighty ton elephant with the legs of a small budgerigar can make a good living. Alternatively, there is some guiding influence that has the foresight to ensure that only those anatomies which have an associated lifestyle can appear—in which case we are appealing to religion and have no need to construct a rigorous scientific argument at all. Neither of these alternatives commends itself to me.

It makes very little sense to state "the role of the genes is not clear" and then to state categorically in the next line that they play no part in developmental programs (a view completely discredited by the well established developmental effects of point mutations in the fly *Drosophila melanogaster*).

Finally it is unsatisfactory to state that "adaptation arises in an unspecified fashion from the thermodynamics of the genes and development". Adaptation of organisms to their environment is already competently explained by natural selection in the Neo-Darwinian theories so lightly discarded here. It is critical to the credibility of any rival theory that it can explain the facts as they are currently observed. Recognition of this requirement might have restrained Molnar and Ingram from expressing the uncritical enthusiasm so evident in their closing paragraph. As far as I can see, that enthusiasm is misguided.

—William Russell
Cammeray, NSW

Mr Russell is quite right in implying that no conflict exists between thermodynamics and evolution. As he points out, there is no apparent conflict between irreversible *thermodynamics—that applicable to open systems—and evolution. But there* is *a conflict between equilibrium thermodynamics and evolution, which is the crux of the column. Living organisms are not in equilibrium with their environment—when they are no longer living, hence my hyperbolic comment that (equilibrium) thermodynamics is the realm of the dead. Studies in irreversible thermodynamics indicate that the complexity and organisation characteristic of many organisms not only are not in conflict with the second law of thermodynamics, but in fact may be expected to appear spontaneously, without recourse to some supernatural creative force.*

The distinction between

equilibrium and irreversible thermodynamics is crucial, for almost all our understanding and ability to predict refers to equilibrium thermodynamics. This distinction has been well-known overseas for at least a decade and a half, but still seems poorly understood by Australians. This column aims to bring such matters to the interested reader.

I feel that Mr Russell read the column but missed the point. It is true that there is no conflict between thermodynamics and evolution; acknowledging this is not enough. There is more to thermodynamics than simply consistency with the second law. It is the absence of any clear understanding of the relationships of thermodynamics to evolutionary processes that prompted this column. Too often we have been content merely to state that thermodynamics and evolution are not contradictory and neglect to pursue an understanding of their relationship.

Mr Russell's remaining comments refer to my description of Brooks and Wiley's views. The comment that organisms are tenuously related to their environment should be taken in terms of environmental causation of organismal form. I doubt that Brooks and Wiley would seriously dispute the effects of pollution and other environmental influences on an organism's survival. Regarding long-term stability and developmental constraint, I agree. This is also the case with adoption of a lifestyle suiting the anatomy. I think Brooks and Wiley have in mind some 'influence' analogous to principles in physics, such as that of least action. These rules enable the prediction of which one of several conceivable outcomes of a mechanical interaction is the most likely. I think the implication is that non-equilibrium thermodynamics determines that certain anatomies are possible and others are not.

It is not contradictory to state that the role of genes is not clear (true) and that they play little part in the development process. This must be considered to the effect that the part genes play in development is much less than their other roles. To be sure they do play a role in development as well is attested by recent work on, for example, homeobox genes.

I agree with Brooks and Wiley's suggestion that to say adaptation arises in some unspecified fashion from developmental thermodynamics is unsatisfactory. However, many prominent evolutionary biologists—Steven Jay Gould, for example—regard the explanation of adaptation by natural selection as totally unsatisfactory. Adaptation is a controversial subject. Indeed it is the aim of this column to bring such matters to ANH readers.

—Ralph Molnar
Queensland Museum

Seeing Red

As usual the poster from ANH vol. 23, no. 4, 1990 is another excellent production and hangs in the hallway for all to view.

I wonder if you would kindly unpuzzle me. The poster is labelled Scarlet Banksia, *Banksia speciosa*, but as our first visitor commented, there's not a trace of scarlet in the painting. Yet on page 305, with the caption "The Scarlet Banksia (*Banksia coccinea*)" is one that *is* scarlet or at least red.

My wife and I have seen *B. coccinea* in Western Australia and know well that its flower, leaves etc. are quite different from *B. speciosa* but how do both, especially the latter, have the common name "scarlet"? I greatly look forward to being enlightened.

—Harry Dodson
Rosny Point, Tas.

The common name for Banksia speciosa *is the 'Showy Banksia', not the 'Scarlet Banksia'. As thorough as we are on ANH, sometimes errors do occur!*

—Ed.

The real Scarlet Banksia, *Banksia coccinea*.

Whale Shark Tales

I read with interest Geoff Taylor's "The Whale Shark" (ANH vol. 23, no. 4, 1990). The good news is that Whale Sharks are regular visitors to the Coral Sea (east and north-east of Cairns) each year. They appear in the deep channel between the outer Barrier Reef and the Queensland Plateau around the time of the full moon in November.

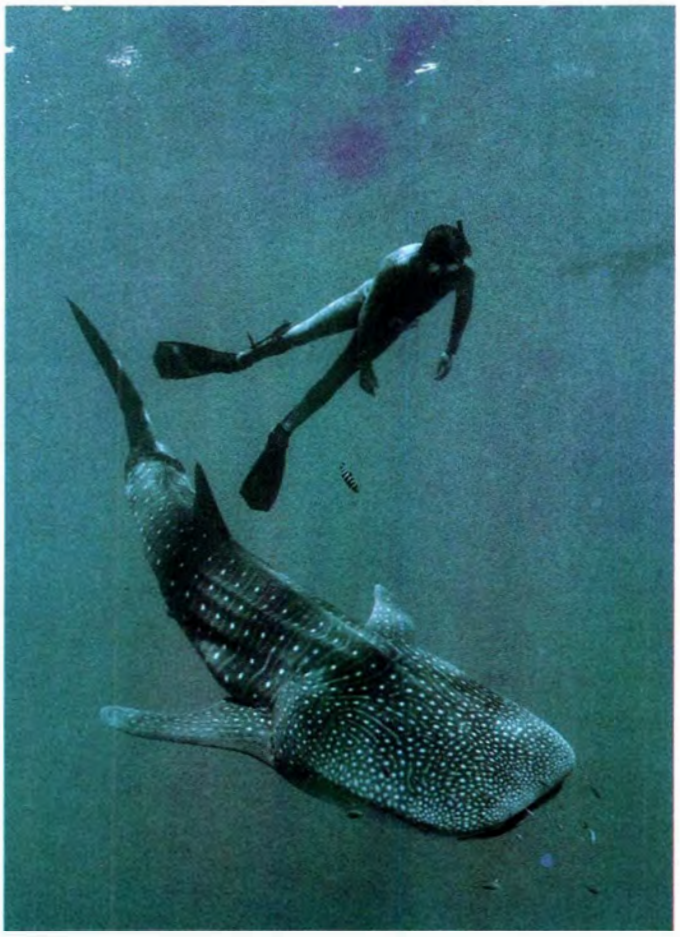
Whale Sharks have been reported as congregating in this area at the same time as large aggregations of spawning Yellowfin and Bigeye Tuna. The Japanese first reported this in the mid 1960s and tuna research by the Queensland Department of Primary Industries has confirmed their observations.

In the absence of detailed data, I have proposed that an oceanographic event occurs in this restricted area of the Coral Sea (at least in October and November) that is associated with possible nutrient upwelling, peak spawning activity of deepwater lantern-fish (family Myctophidae) and peak spawning of Yellowfin and Bigeye Tuna.

As to 'who eats who', we can eliminate Whale Sharks eating adult tuna and vice versa. However, other scenarios—of young tuna feeding on eggs or larvae of lantern-fish and Whale Sharks feeding on any of the above—are all possible and understandably advantageous to some of the participants.

It is quite likely that Whale Sharks act as fish aggregating devices—when the Japanese handline vessels locate the Whale Sharks up to one kilometre away on sonar, there is invariably a large aggregation of tuna around them.

Whale Sharks are regarded as welcome visitors by Japanese and Australian fish-



PATRICK BAKER

Whale Sharks are regular visitors to the Coral Sea.

ermen alike. I have been on a Japanese handline vessel that sidled up to three Whale Sharks basking on the surface in crystal-clear water. Tuna fishing was dispensed with while a few kilometres of colour film were devoted to these beautiful creatures.

The Whale Sharks appear in this area, remote from the Barrier Reef, prior to and during the coral spawning event. Whether Whale Sharks occur in numbers closer to the reef at this time is unknown.

A great magazine, keep it up.

—Geoff Macpherson
Cairns, Qld

Suggestion Box

Just a quick note to express my appreciation of the recent ANH issues—the photography is exceptional! I have long felt that this publication is a better medium for increasing the awareness of Australians about their environment and geographic region than *Geo* or *Australian Geographic*.

I would like to see some useful follow-up articles or critical comments about researchers' attitudes about endangered species management in Australia and perhaps theprogress towards farming Australian macropods. I recall some useful commentaries by Gordon Grigg on this topic in earlier issues.

From my perspective as a veterinarian with some experience in wildlife disease investigation and management (both in wild populations and in captivity), I feel the need for debate on the rationale for captive breeding programs, habitat preservation, feral and predator control and reintroduction programs etc. These issues need to be discussed more publicly. There are too many examples of endangered animal species. Is it too little too late? It smacks too much of *Homo sapiens*' attitude of feeling OK because we can use our technology to have one species 'hang on' in a zoo or small reserve, while all about is laid waste!

Finally, please check ANH vol. 23, no. 4, 1990, for some photographic inversions. The lower radiograph accompanying Peter Vaughan's letter (page 269) looks as though it would correspond to the line drawing only if it were reversed (based on positions of the 'blue' permanent teeth). The other is in "A tale of three species: the stilt, the shrimp and the scientist" (page 325), where the satellite images appear to be reversed. Otherwise, keep up the very good work!

—David L. Oberdorf
Trevallyn, Tas.

You are correct. The radiograph is backwards and the satellite lake images are correct when rotated 180° (as if you cut the photos off the page and turned the entire section upside-down). Unfortunately, although we specified these changes to be made on the proofs, they were not and the error remained in the final print.

—Ed.

Liar-bird?

I wish to correct a statement I made in my review of the video "Kingdom of the Lyrebird" (ANH vol. 23, no. 5 1990). Unfortunately I got my facts wrong in regard to the moult of the Lyrebird's tail when I commented that the "feathers are lost and replaced gradually over a number of months".

L.H. Smith, who extensively studied the growth and replacement of the tail, found that there is complete tail moult every spring (August-December), the feathers being shed over a period of 1–3 weeks (mostly within ten days).

This is unusual in songbirds, in which the loss and replacement of the tail feathers are gradual. Nonetheless, the statement in the video that the Lyrebird sheds its entire tail is correct. It is doing exactly what it should be doing—and not what mistaken ornithologists would have it do.

—Walter E. Boles
Division of Vertebrate Zoology (Birds)
Australian Museum

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QUIPS, QUOTES & CURIOS

COMPILED BY GEORGINA HICKEY
SCIENTIFIC EDITOR

STEPHEN DUPONT/SYDNEY FREELANCE

Good news for weary transmeridian travellers.

Shedding Light on Jet Lag

Human brains may have made aeroplanes but planes can scramble brains—via the curse of jet lag. However, a natural cure for this 20th-century nuisance is now at hand. Global circumnavigators who find themselves staring at the ceiling at three o'clock in the morning are being advised by scientists to spend a couple of days at the beach to reset their internal clocks.

Charles Czeisler, Richard Kronauer and colleagues from the Center for Circadian and Sleep Disorders Medicine in Boston have found that humans are far more sensitive to changes in light than previously thought (*Science* 244: 1328–1332; 1989). Until recently it was believed that, unlike other animals, social contacts rather than the light–dark cycle synchronised the human circadian system to the 24-hour day. Now experimental evidence shows that the human circadian pacemaker—our internal clock—can be reset, either backwards or forwards, by scheduled exposure to light.

In a series of laboratory experiments in which subjects underwent several 'resetting trials' where light–dark schedules were variously altered, the researchers showed that, following a six-hour phase-advance shift, for example, the human body after nine days is still not fully realigned with the new sleep–wake schedule. But, with properly timed exposure to bright light, ordinary indoor room light, and darkness, physiological adaptation to the new light regime can be completed within two to three days. The researchers suggest this may explain why transmeridian travellers who spend more time outdoors show quicker adaptation to new time zones than those who stay indoors, illuminating the potential role of bright (outdoor) light exposure in the phase-resetting process. The results also have implications for treatment of disorders such as shift-work dyssomnia, disrupted sleep in the elderly and other sleep disorders.

Czeisler *et al.* believe that light probably exerts its primary action directly on the human circadian pacemaker via the retina and hypothalamus. Sleep–wake patterns, body temperatures, hormone secretion and various other physiological functions are all affected.

The researchers have found that, to reset the human internal clock, two cycles of exposure to light are needed to crush the amplitude of the circadian cycles (making them irregular and less pronounced) and a third to reset the pacemaker to the new light–dark phases. As Kronauer explains (cited in *Science* 244: 1256–1257; 1989), if you are travelling from New York to Sydney, which is 14 hours ahead, and immediately go to work, it will take ten days to fully adjust. Under normal internal lighting your internal clock will be reset by only about an hour a day. But if you spend six to eight hours of the first day in bright sunshine, this should do the work of two cycles of bright light exposure, crushing your internal circadian cycle. Another day outside should reset your clock and bring you back in tune with Australian local time.

—S.H.

When the Pitcher Pays

Australia has two native species of those extraordinary botanical curiosities, the carnivorous pitcher plants. The best known is the Tropical Pitcher Plant (*Nepenthes mirabilis*) of the family Nepenthaceae, found on Cape York Peninsula, northern Queensland. The family is widespread in South-East Asia and eastern Africa. The other Australian pitcher plant, the Albany Pitcher Plant (*Cephalotus follicularis*), is the only species of the family Cephalotaceae and is restricted to the south-western corner of Western Australia. These two species are not closely related and have evolved their strikingly similar carnivorous habits separately. They are a classic example of the phenomenon biologists call convergent evolution.

The pitcher plants are found in swamps and on poor soils, and supplement the nutrients from their roots and leaves with nutrients supplied to them from insects caught in specialised leaves that function as pitfall traps. These leaves are shaped like a pitcher (hence the common name), have smooth internal walls and are half-filled with a clear fluid that the plant produces. Just inside the gaping mouth of the pitcher are nectar-secreting glands, which attract foraging insects. These hapless individuals fall into the fluid and drown because they cannot scale the smooth internal walls of the pitcher. The pitcher fluid contains chemicals that hasten the decay of the insects. The plant takes up nutrients from the fluid through the pitcher walls.

Insects are well known as the quintessential opportunists, and some species have turned the tables on the Tropical Pitcher Plant. They have developed the ability to live in the pitcher fluid unharmed and feast on the prey of the pitcher plant! These insects are termed commensals, in that they take food from the plant without adversely affecting it. The larvae of various species of flies, including mosquitoes and sandflies, have been found in the Tropical Pitcher Plant.

Until recently nothing was known of the commensal insect fauna of the Albany Pitcher Plant. The plant itself

has a patchy distribution, colonies being found in swamps and beside watercourses adjacent to the south-western coast of Western Australia, from Mt Manypeaks to Augusta. On examining the contents of pitchers for the first time I could see many insect remains, most commonly ants of the genus *Iridomyrmex* but also flies and beetles. Sure enough, soon a small, white fly larva (maggot) wriggled from underneath a decomposing beetle. Up to 25 larvae in all stages of growth can be found in one pitcher—all lively and eating the insect cadavers around them with impunity. They are about seven millimetres long when fully grown, cigar-shaped and breathe air. Most of the body of the maggots remains submerged, however they are equipped with two air holes (spiracles) on their posterior end. The spiracles are surrounded by water-repelling hairs and the larvae breathe by periodically thrusting the spiracles above the pitcher fluid surface whilst they are still eating at the other end.

The discovery of commensal fly larvae in the Albany Pitcher Plant was exciting enough, but the story has another curious twist that was revealed when the larvae finally completed metamorphosis and emerged as adults. They turned out to be wingless flies that mimic ants! Although there are some other wingless flies known, they are by no means common. Many flies that have reduced wings are known from subantarctic islands (perhaps an adaptation to the windy conditions?) and some families of flies have evolved into external parasites of bats and as a consequence have lost their wings altogether. The wingless pitcher plant fly has no wings at all and has even lost the halteres, small sense organs that flies use for balance in flight.

As an improbable coincidence, these wingless adult flies were first collected in September 1987 by David McAlpine (Australian Museum) while sweeping vegetation adjacent to a creek near Pemberton. He recognised the flies as taxonomic novelties and described them as a new genus and species (*Badisis ambulans*) in the family Micropezidae. Although there was no hint at the time of their bizarre life history, he noted that they were mimics of the ant *Iridomyrmex* (*conifer* species group), which is the most common prey of the pitcher plant!

There are many unanswered questions about this fly and its relationship with the pitcher plant. How does it get out of the pitcher, which is specifically designed to guard against insect escape? Why does the adult fly mimic the main prey item of the pitcher plant? Are the larvae only found in pitcher plants or do they have more catholic tastes? The evidence relating to this last question favours *Badisis* being restricted to pitcher plants. I have now found the fly larvae in all four pitcher plant localities I've visited, and have also found a healthy population of pitcher plants, with *Badisis* larvae inside, at the location where David McAlpine first collected the adult flies. If indeed the fly is restricted to breeding in pitchers, how does it move between the isolated pockets of suitable swampy country where the pitcher plant occurs? It can't fly there!

Sadly, even though the Albany Pitcher Plant is very restricted in distribution, much of its habitat is in prime farmland and many of the swamps have been drained, making them unsuitable for the plant. Of course, when the plant dies out so does its strange wingless inhabitant. However, many pitcher plant populations are preserved in the D'Entrecasteaux and Walpole–Nornalup National Parks. Let's hope that enough remain, allowing us to find meaningful answers to the puzzles of this pitcher plant fly.

—David Yeates
WA Dept Agriculture

M & I MORCOMBE

JIRI LOCHMAN/LOCHMAN TRANSPARENCIES

The Albany Pitcher Plant is home to the larvae of a recently described species of wingless fly that mimics the plant's most common prey—*Iridomyrmex* ants, this one falling victim to the plant. Inset: the commensal wingless fly larva, *Badisis ambulans*.

Feasting on Feathers

Grebes are known from lakes and marshes on all continents except Antarctica. The Great Crested Grebe (*Podiceps cristatus*) is the largest of the three species of grebes found in Australia. It sports a regal chestnut and black collar and two black ear tufts, which are displayed during courtship. The plumage is particularly soft and dense, so much so that in Europe the desire to trim ladies' hats with 'grebe fur' seriously threatened the species' existence. Today the bird is protected.

Grebes, however, have been putting their own feathers to extra use long before the 'grebe furriers' came along: they are unique in their habit of eating their own feathers. Feathers can be clearly seen in the pellets that the birds regularly (about every second day) eject from their mouths and by which the entire stomach content is removed. They do not actively pluck their feathers, but only ingest those that have already moulted.

Four main hypotheses have been suggested to explain this peculiar feather-eating habit. Feathers may protect the stomach wall from sharp fish remains; they may form a pad around sharp fish bones so damage to the oesophagus does not result when the bony pellets are ejected; they may be necessary in the formation of a 'pyloric plug' to filter sharp fish debris or even smaller particles such as parasites and so prevent them from entering the intestine; or they may simply contribute substance to the stomach contents, enabling the formation of pellets that can be ejected.

To elucidate the feather-eating habit, Dutch scientists Theunis Piersma and Mennobart van Eerden examined the stomach contents and degree of moulting of over 400 non-breeding Great Crested Grebes that had accidentally drowned in gill nets in Lake IJsselmeer, The Netherlands (*Ibis* 131: 477–486; 1989). They discovered that flank feathers were actively ingested over other feather types (scapular, breast, belly, head etc.). Flank feathers are the longest soft feather and show a regular curvature—features that may help to efficiently wrap up the stomach contents.

Also discovered was a correlation between fish species and amount of feathers ingested. Birds that consumed mainly smelt ingested more feathers than those that had consumed other fish species, such as pikeperch and perch. The main difference between smelt and other fish, the authors explain, is their digestibility. Smelt is digested completely, leaving behind only two small otoliths or earbones; pikeperch and perch, on the other hand, are not nearly as digestible, with scales and many bony remains being left behind.

This inverse relationship between bony fish remains and number of feathers ingested discounts the first three possible functions of feather-eating and lends support for the fourth. That is, feathers, in the absence of indigestible matter, contribute substance to the stomach contents for the formation of ejectable pellets.

But why form pellets in the first place? Why is there a need for regular emptying of the stomach? Comparison of stomachs and oesophagi of 16 species of fish-eating waterbirds showed that those species that produced pellets harboured a much lower number of parasites than those that didn't form pellets. This suggests that regular emptying of the stomach reduces the chance of gastric parasites building up to dangerous levels in the upper alimentary tract.

Grebes are also unique in that they continue to moult their flank feathers during mid-winter. It seems that the benefits derived from having a continual supply of feathers for ingestion outweigh the costs involved in the production of new feathers to replace those moulted.

—G.H.

Great Crested Grebes are unique in their habit of eating their own feathers.

AUSTRALIAN PICTURE LIBRARY

Scare Tactics

I have always been rather fond of huntsman spiders, especially those large, hairy members of the genus *Isopeda* that roam around the living room walls or pop out unexpectedly from the dashboard of the car—rather intimidating to some but they are good value as insect killers. Many are crevice dwellers living under loose bark, their flattened bodies sometimes as thin as cardboard. One of the latter, *Delena*, can be found massed together in colonies of many hundreds, hairy leg to hairy leg. Other huntsman spiders have less flattened bodies and are as often found on foliage as on bark. Some of the most interesting belong to the genus *Olios*. Seen from above these spiders are a uniform brown or grey colour, but turn one over and a different picture emerges. The legs are banded and the abdomen has a shield-shaped pattern of strongly contrasting colours (hence the common name of shield or badge huntsman spiders). *Olios patellatus* from south-eastern Australia and Tasmania is most spectacular with an orange and black abdominal ventral pattern and blue, black and orange banded legs. The common species around Sydney have rather more staid patterns of white on black for *Olios pictus*, and with an added patch of orange for *O. diana*.

The Sydney huntsman spider *Olios diana* has a brightly coloured ventral surface, which it displays when under threat by predators.

M.H. GREGG

Bright colour patterns are usually associated with either mating or defensive behaviour. Because the *Olios* colour patterns are unique to each species, one might suspect a role in mate recognition, except that huntsman spiders are not renowned for foreplay let alone elaborate mating display. A warning defensive function seems more likely but how might these spiders use their hidden ventral colours?

An answer to this question was provided for me by the family cat. Blackitt (the cat) had somehow flushed out a female *Olios* (probably *O. pictus*) from our overgrown shrubbery onto the grass. The spider darted off across the lawn with the cat and myself in hot pursuit. As the cat neared the spider, the latter underwent an astonishing transformation—by disappearing. In its place flashed a vivid back and white mask. This was visible only for an instant before vanishing in its turn to reveal the spider running at an angle to its former path into the safety of some ferns.

This sudden change in appearance certainly startled both me and the cat—testimony to its effectiveness as a defensive scare tactic. The spider apparently achieved its disconcerting effect by propping suddenly and raising the underside of its abdomen to flash its black and white pattern before righting itself and racing on. If cornered, *Olios* will rear up like a funnel-web spider, fangs at the ready and banded legs spread wide—a formidable 'last resort' threat display. Such tactics, very effective against people and pussies, are also used effectively against more genuine predators such as lizards, frogs, birds and small mammals.

—Mike Gray
Australian Museum

Tunnel of Love

The Mountain Pygmy-possum (*Burramys parvus*) is one of Australia's most threatened small marsupials. It is the only mammal restricted to alpine and subalpine areas of Australia, where it lives in rock screes in Mountain Plum-pine (*Podocarpus lawrencei*) heathland. The entire habitat available to the species is a mere 12 square kilometres. It probably stockpiles seeds, fruits and insects during summer for the colder winter months, when it lives under the snow. The species has been the subject of intense study since 1966 when it was first discovered in a Mt Hotham ski lodge. Before then it was known only from fossil remains.

The number of breeding Mountain Pygmy-possum females is estimated to be 1,800 in two or more isolated populations in the New South Wales and Victorian highlands. About 40 per cent of the total estimated population occurs on Mt Hotham between Mt Higginbotham and Mt Loch in Victoria. Here adult female Mountain Pygmy-possums live sedentary lives in high-altitude areas that provide good food and shelter, while adult males move to and from these areas, generally from lower slopes, via natural rock screes.

Redevelopment of the Mt Hotham Ski Resort had the effect of inhibiting the dispersal of males to and from the females' territory further up the slopes. Adult males were remaining at female breeding areas during the non-breeding winter season and the number of females surviving winter had seriously declined.

In October 1985, therefore, a funnel-shaped, 60-metre-long corridor of basalt rocks leading to two adjacent rock-filled tunnels was constructed beneath the Alpine Way at Mt Hotham, following the design of Ian Mansergh and David Scotts from the Arthur Rylah Institute of Environmental Research in Melbourne. The idea was in order to provide a suitable habitat corridor for the Mountain Pygmy-possum. Sure enough, within two weeks of installation of the 'tunnel of love', Mountain Pygmy-possums were recorded using the tunnel and, within a relatively short period of time, the composition of the disturbed population returned to that found in undisturbed areas. Adult males dispersed downslope at the end of the breeding season, most juveniles dispersed during the non-breeding season and female survival returned to that found elsewhere on the mountain (*J. Wildl. Manage.* 53: 701–707; 1989). It appears that segregation of the sexes in the non-breeding season is an integral part of the social organisation of Mountain Pygmy-possums, at least at Mt Hotham. Mansergh and Scotts found that females become very aggressive when carrying young and that they probably apply a great deal of social pressure on males to leave at the end of the breeding season.

Roadsigns are used to warn motorists that Mountain Pygmy-possums cross at night to mate.

IAN MANSERGH

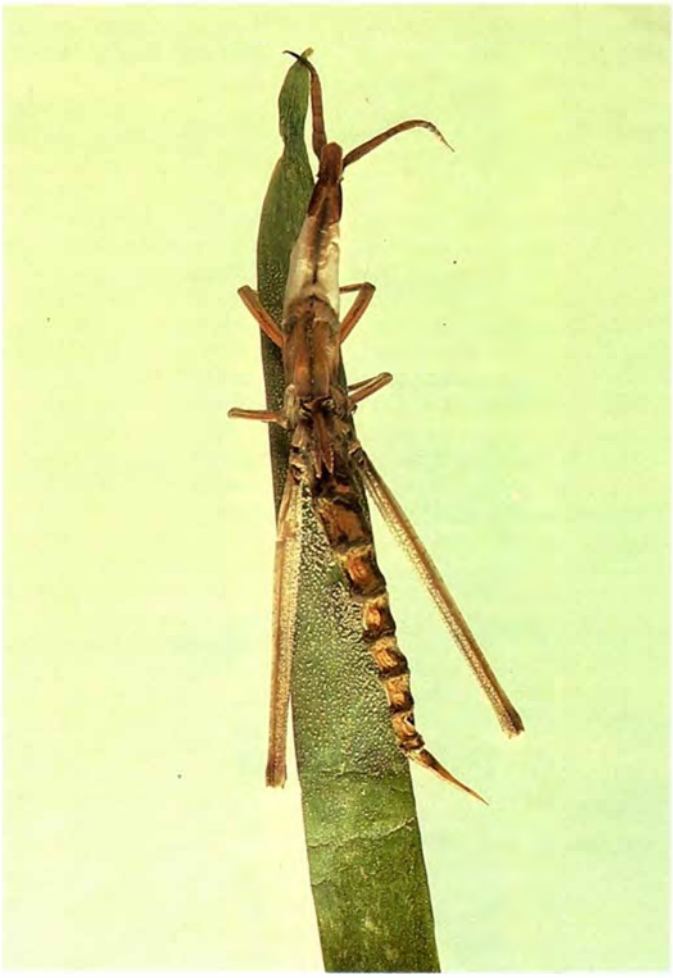
Tunnels under roads have been used previously to conserve wildlife, such as in the United Kingdom, United States and Netherlands for badgers, big game and amphibians respectively, but Mansergh and Scotts believe that the speed with which the Mt Hotham tunnels were used by Mountain Pygmy-possums and the apparent reversion to a natural population structure have no parallels elsewhere.

—S.H.

Australian Fungal Aid

With grasshoppers raising havoc throughout range and crop lands of the western United States, American scientists have come to Australia for assistance. Help may be near at hand following the collection, isolation and American release of a naturally occurring pathogen of grasshoppers found along Kangaroo Creek, near Wongwibinda, New South Wales. With the assistance of CSIRO scientists Dr Richard Milner and Mr George Lutton, the fungal pathogen *Entomophaga grylli* was collected and imported into the United States by scientists from the United States Department of Agriculture (USDA). CSIRO and USDA scientists have a long history of assisting one another, particularly in the area of biological control of pests. Parasites, predators and pathogens of important pest species have long been the focus of joint research and exchange programs (see ANH vol 23, no. 6, 1990).

Entomophaga grylli is an obligate pathogen of grasshoppers. When grasshoppers come into contact with *E. grylli*, the fungus infects its would-be host by directly penetrating the body wall through a combination of enzymatic and mechanical actions. Once infected, grasshoppers have little hope of recovery as the fungus proliferates throughout its body in the form of amoeba-like cells called protoplasts. Within approximately one week of contact, grasshoppers will be found dead clinging in the top of the grass canopy. Four to six hours after the grasshoppers die, the fungus grows to the outside surface of its old host where it produces millions of spores called conidia. These conidia are forcibly ejected into the local environment to ensure contact with susceptible grasshoppers. If proper environmental conditions exist, the disease will spread within the grasshopper population. Although the exact mechanisms are still not fully understood, fungal pathogens of many different insects cause their hosts to climb to elevated positions within their normal habitat just prior to death. They also control the time of day when mortality occurs. In the case of *E. grylli*, grasshoppers only die in late afternoon and early evening. This timing allows the pathogen to synchronise sporulation, conidial germination and secondary host infection with moderate night-time temperatures and dew formation. Since the pathogen requires free moisture for disease transmission to occur, insect pathologists believe that the climbing behaviour of dying grasshoppers and their synchronisation with optimal environmental conditions for fungal development are adaptive characteristics that aid the pathogen by increasing the efficiency of conidial production, dispersal and ultimately host infection.



RICHARD MILNER/CSIRO

A grasshopper (*Acrida conica*) infected with the fungus *Entomophaga grylli* has crawled to the top of a grass stem and millions of spores (conidia), seen here as the white powder on the stem, have been ejected into the environment.

Due to the speed with which this pathogen infects and kills grasshoppers (it may cycle three to four times in a single generation of its host grasshoppers), it can rapidly induce a major epidemic in the field causing significant declines in grasshopper numbers. Near the end of the summer season, the fungus develops an environmentally resistant 'resting spore' that allows the pathogen to spend the winter months in the soil in a dormant condition. Each spring, these resting spores germinate just in time to infect newly hatched grasshoppers and the struggle for life between the pathogen and its host insects begins again.

Although *E. grylli* may be killing off grasshoppers in some parts of Australia, grasshoppers are still major pests in other areas of the country where the pathogen does not exist in high enough numbers, or environmental conditions are not appropriate for disease transmission to occur. However, many factors cause grasshopper outbreaks and this pathogen is only one factor helping to limit their numbers. Nevertheless, American scientists are particularly interested in *E. grylli* because it infects a wide range of grasshoppers while having no adverse effect on other beneficial insects, such as Honeybees and other pollinators.

Following extensive scientific evaluation, *E. grylli* was determined to be an effective biological control agent of grasshoppers and safe for United States field release. Following its release in late July 1989 in western North Dakota, *E. grylli* infected several different species of grasshoppers. Although the pathogen was introduced into the field late in the grasshopper season and environmental conditions at the time were quite dry (similar to conditions found in Australia), the pathogen was still effectively transmitted to pest grasshoppers. Over the month of August, *E. grylli* reached moderate infection levels (about 15 per cent) in the release site, killing thousands of grasshoppers in the process. Disease transmission was short-lived, however, as the pathogen began producing resting spores rather than the infective conidia, which are primarily responsible for spreading this disease within a season.

Although the overall reduction in grasshopper numbers was small in 1989, it appears that *E. grylli* is established in the North Dakota release site and, hopefully, larger impacts will be realised in future years. USDA scientists are interested to see if the fungus will be able to withstand the harsh North Dakota winters and, if so, to determine if the resting spores will germinate at appropriate times to infect grasshoppers soon after they hatch.

If *E. grylli* is found to be an effective biological control agent of grasshoppers in the current test sites, introductions will be made in other parts of the western United States where grasshoppers are now causing economic damage. In addition, scientists investigating the African locust plagues have already shown interest in the possible use of *E. grylli*. It is currently unknown, however, if the Australian isolates of *E. grylli* will infect these pests or if the conditions in the locust problem areas are appropriate for the use of this fungus.

—Raymond I. Carruthers
& Mark E. Ramos
USDA Agricultural
Research Service
New York

The Value of Rotten Eggs

Scientists in Israel believe there may be a method in the apparent madness of birds that incubate eggs containing dead embryos. Prolonged incubation of dead eggs has been reported in a number of bird species. According to Daniel Afik and David Ward from Ben Gurion University of the Negev, dead eggs may act as heat buffers for subsequently laid, live eggs (*Auk* 106: 726–728; 1989).

Afik and Ward monitored a pair of Hoopoes (*Upupa epops*) nesting in a disused building in the Negev Desert. The nest, built between the ceiling and roof of the building, was completely enclosed except for a small hole through which the parents entered. A normal clutch size for Israeli Hoopoes is five to six but over the summer study period the pair laid 32 eggs, representing six consecutive clutches.

Because the birds were unable to use convective cooling in the enclosed nest, it was assumed that the birds would have difficulty in controlling egg temperature above 40° C, the normal body temperature for birds. So the researchers compared the difference between the temperature of the nest and the surrounding space within the ceiling, as well as the heating and cooling rates of the nest, when it contained all eggs (live and dead) and when it contained only live eggs.

For ceiling temperature over 40° C, Afik and Ward found that when the nest contained only live eggs it had a temperature above 40° C for 100 per cent of the time; when the nest contained dead and live eggs the temperature was above 40° C for only 81 per cent of the time.

Apparently dead eggs reduce heating and cooling rates of the nest, and increase the absolute difference between nest and ceiling temperatures. When dead eggs are in a nest, the amount of time that nest temperature remains above what is considered to be the limit of a bird's ability to control nest temperature is reduced significantly.

—S.H.

Why do some Hoopoes incubate dead eggs? (Illustration by W. T. Cooper in *Kingfishers & Related Birds Vol. IV.*)

LANSDOWNE LTD ED, WELDON YOUNG PROD.

Mussel Monitor

Mussels are being used to monitor water pollution levels. The Mussel Monitor, designed by Dutch researchers, is comprised of eight mussels glued to stainless steel plates and fitted with electronic devices that monitor closure of the shells (*New Sci.* 16 December 1989: 18).

Mussel shells are open most of the time for filter feeding but close in response to changes in their immediate environment, such as a drop in oxygen level or an influx of noxious chemicals. In the Mussel Monitor, a small computer checks shell movements and data are transmitted by radio to a control station on shore. Closure of six of the eight mussels over a given time activates an alarm.

Because their growth and reproduction are very sensitive to pollution, mussels are often used to monitor water quality. The Mussel Monitor is particularly valuable because it can continually monitor water quality, tests showing that the device still works after more than ten weeks.

One prototype of the device is being used at the outlet of a Dutch chemical plant, another is monitoring the amounts of chloride released from the cleaning of a power plant's cooling system, and a third is monitoring water quality in the River Rhine.

—S.H.

KATHIE ATKINSON

Mussels' sensitivity to water pollution makes them ideal organisms to monitor water quality. Shown here is an Australian species, *Velesunio ambiguus*.

Dr Suzanne Hand, Biological Science, University of NSW, is a regular contributor to QQC.

Bats Turn Over a New Leaf

One of the fascinating areas of animal–plant relationships is the way animals have adapted to an all-plant or, more particularly, all-leaf diet. The catch is there is only a limited amount of nutritive value to be extracted directly from the leaf. Most of the leaf is cell wall material, cellulose, hemicellulose and lignin. Strangely, no 'higher' animal produces a cellulose-digesting enzyme. They depend on micro-organisms in the gut to break down the material and extract useful energy from the fermentation products. This takes time. Thus there is always a trade-off between getting the most value from the food and the weight the herbivore can carry around in its gut; that is, between efficiency and rate of passage. There are no flying ruminants apart from the cow that jumped over the moon. The only bird with fermentative digestion, the South American Hoatzin or Stinkbird, is so bizarre that it proves the rule (see ANH vol. 23, no. 6, 1990).

So it was of some interest to find Australian animals that side-step this evolutionary problem in a neat, if wasteful, way. They chew up leaves, swallow the liquid fraction that contains almost all the easily accessible nutrients, and then simply spit out a pellet of leaf fibre rather than try to process it in the gut. The animal I've observed doing this is the Black Flying-fox (*Pteropus alecto; Aust. Wildl. Res.* 16: 203–206; 1989). These bats are normally fruit or flower eating but, from April to September in the tropics, they visit Siris or Rattlepod trees (*Albizia lebbeck*) in order to chew through a quota of leaves. Similar observations have been made at Palm Cove, Queensland, by Mr Greg Richards (CSIRO Division of Wildlife and Ecology) for the closely related Spectacled Flying-fox (*P. conspicillatus*) and tree (*A. procera*). The bat behaviour is a lot less exuberant when they are feeding on fruit, and the leaves probably represent a stand-by food supply. It seems likely it is the protein, which is usually deficient in their diet and which happens to be more available in *Albizia*, that is the main attraction. Most tropical trees are well protected by deterrent chemical features. Certainly, these two species of *Albizia* appear to be the only trees used in this way.

I strongly believe that the Siris tree can be of major value, in several ways, to the pastoral industry (see ANH vol. 23, no. 4, 1990). It is nice to know that my opinion of its food value is endorsed by the flying-foxes.

—J. Brian Lowry
CSIRO Division of Tropical and Animal Production

KATHIE ATKINSON

In its quest for protein-rich food, the Black Flying-fox bites off more than it can chew.

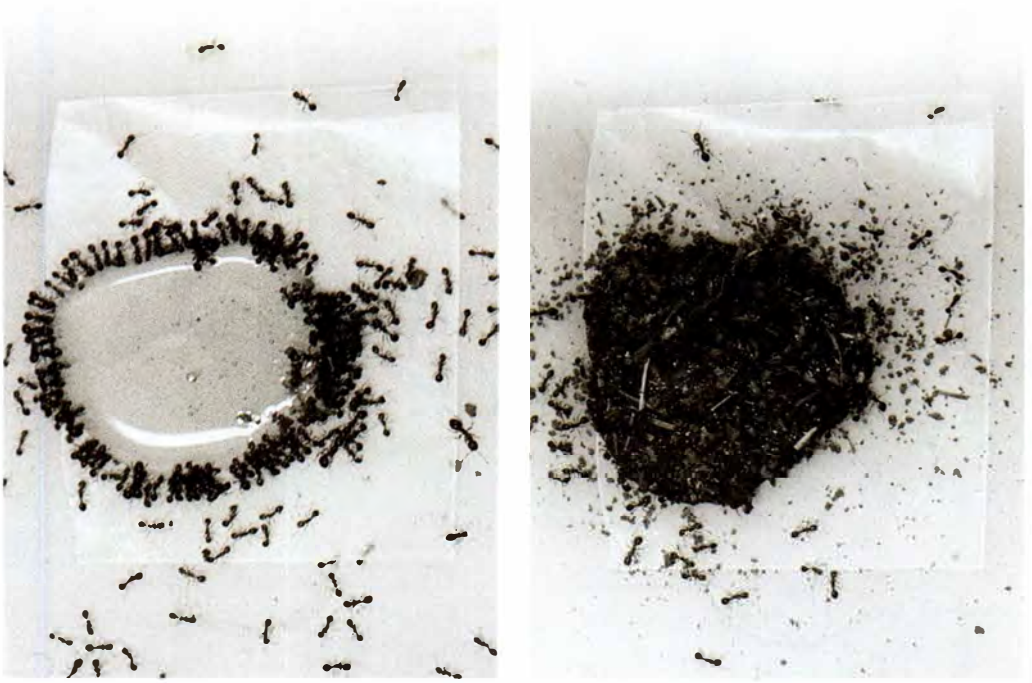
Fire Ants Blot and Run

Researchers from Tulane University in New Orleans have recently reported the use of tools by the Imported Fire Ant, *Solenopsis invicta* (*Anim. Behav.* 38: 550–552; 1989). The ants used objects to soak up honey in order to carry it back to their nest.

John Barber and colleagues recorded the behaviour of fire ants, which were being maintained in their laboratory during the course of an unrelated research project. During a period of more than a year, three separate ant colonies were kept. Food consisted of a millilitre of honey placed about 15 centimetres from the ant colony. For each colony of ants, the honey was disposed of in one of two ways. If they had been starved for ten days before the honey was provided, the ants would rapidly locate the food, inform others and the food would be eaten on the spot. However, if the colony had been previously well fed, the ants would locate the honey and direct others to it but would not immediately eat it. Rather, they would go back to the nest and return with grains of sand, pieces of dead grass etc. The ants would place these in the honey and later remove them and take them back to the nest. This 'blotting' activity would start around the periphery of the spot and work inwards until the honey was entirely covered. The debris with absorbed honey was subsequently transported to the nest. The time for complete removal ranged from 48 hours to ten days, depending on the amount of food previously eaten.

To date, the use of tools for food transportation has been reported in six species of ants, although Barber and colleagues believe this behaviour may be far more common than previously assumed.

—S.H.



COURTESY JOHN T. BARBER

Imported Fire Ants use debris to blot up honey for transportation back to the nest. Shown here is a spot of honey after 30 minutes (left) and 18 hours (right).

"There can have been few other natural history specimens that received so many detailed descriptions in Australian newspapers and journals in the 19th century."

ON THE TRAIL OF A BUNYIP

BY JULIAN HOLLAND
MACLEAY MUSEUM, UNIVERSITY OF SYDNEY

"THE BUN-YIP—THE PUBLIC ARE RE-spectfully informed that by the kindness of His Honor the Speaker, the cranium of the supposed Bun-Yip, recently discovered in the vicinity of Melbourne, may be inspected at the Australian Museum upon Wednesday and Thursday next, from ten to three o'clock."

In these sober terms, the public of Sydney was invited to visit the Museum in July 1847 to see the remains of a possible Bunyip. The story of this remarkable skull began nearly a year before.

In the 50 years or so of inland exploration and settlement, many strange creatures had been discovered and, from some of the Aboriginal tribesmen, stories of even stranger creatures had been gathered. Dwelling in the deeper waterholes of some of the inland rivers were supposedly fearsome creatures that devoured Aboriginal children. Occasionally white settlers and travellers reported seeing some unknown animal in the rivers, but never had a specimen of a Bunyip been obtained to substantiate the stories. So the discovery of a strange skull on the Lower Murrumbidgee in 1846 attracted great public and scientific interest.

The skull was found in October 1846 or a little earlier on the property of Atholl T. Fletcher, a squatter, in the vicinity of what is now Balranald, New South Wales. The skull was without lower jaw and no other bones were found. There was a hole in the top of the domed cranium with signs of Dingo tooth marks. The remains of membranes and ligaments attached to the skull—and even blood stains—indicated that the skull was recent.

Some time later Fletcher took the skull to Melbourne where it was reported to be the following January. Fletcher lent it to Edward Curr, a notable local figure who had been the manager of the Van Dieman's Land Company in Tasmania for several years. He forwarded the skull to his friend Ronald Gunn in Launceston. Gunn, an energetic botanist and editor of the *Tasmanian Journal of Natural Science*, sought the opinion of Dr James Grant. The skull of "an apparently new form", was that of a young animal, reported Grant, probably even foetal. He concluded that the skull, which was 11 inches (28 centimetres) long, was possibly that of a young camel, certainly that of a large herbivorous animal. Although this contrasted with the renowned carnivorous diet of the Bunyip, the skull continued to excite attention.

Several Bunyip stories appeared in Melbourne newspapers and a long letter in the *Sydney Morning Herald* announced the discovery of the skull, and provided an illustration and description of it under the heading "The Apocryphal Animal of the Interior of New South Wales." The author, William Hilton Hovell, had seen the skull during a three-month exploration of the Murrumbidgee–Murray area, from which he had just returned.

All the publicity had quite an effect on the inhabitants of the Lower Murrumbidgee district and further mysterious sightings were reported in the *Sydney Morning Herald*: "...almost everyone became immediately aware that he had heard 'strange sounds' from the lagoons at night, or had seen 'something black' in the water, which if not a whale, was 'very like a whale'; and some who read this will smile at the remembrance of the high state of excitement they were thrown into by the appearance (on the surface of the Murrumbidgee) of a sleeping turtle, which being rather larger than usual, and appearing in a peculiar manner, was taken for the crown of the bunyip's head!...Such errors of judgment and false conclusions arose solely from the *reported existence* of a bunyip."

In mid 1847 Edward Curr sent the skull to the Speaker of the Legislative Council, Charles Nicholson, in Sydney. Nicholson, later Sir Charles, was one of the most cultivated men in the colony. He was a doctor of medicine trained in Edinburgh whose collection of antiquities later became the Nicholson Museum at the University of Sydney. Nicholson passed the skull over to be examined by William Sharp Macleay, the leading naturalist in Sydney.

Macleay wrote an article describing the skull in detail and compared it with "another and still more extraordinary skull in my possession". Although mammalian, the peculiar shape of the skull gave the notion of a bird such as the Emu or Ostrich. Like Dr Grant in Launceston, he concluded from the teeth that the animal was "quite young, if not a foetus". While some characteristics of the skull were suggestive of certain members of the camel tribe, in particular the Peruvian Llama, the teeth and bones were overall more like those of the horse. The molars were exactly those of a young foal and the animal was grass-eating.

Whereas the Murrumbidgee skull had widely separated eyes, the skull in Macleay's possession had the opposite peculiarity—it was a cyclops! It was from the foetus of a mare that had been found floating in the Hawkesbury River in 1841. (The skull and mounted skin are still preserved in the Macleay Museum at

Illustration of the skull found on the Lower Murrumbidgee in 1846. (From Ronald C. Gunn's 'On the "Bunyip" of Australia Felix', *Tas. J. Nat. Sci.* vol. III, no. II, plate 3; 1849.)

MALCOLM RICKETTS

The skull and mounted skin of the 'Hawkesbury River Cyclops' found in 1841, now housed in the Macleay Museum.

the University of Sydney.) In Macleay's opinion, both skulls were in some respects identical to those of foals and inother respects unlike any known mammals. It was therefore likely that both specimens represented freaks of nature and the Murrumbidgee skull was not a new species. Even if it did represent a new species, Macleay concluded: "I do not imagine that, even then, it can be identical with the so-called Bunyip, of which so many unintelligible accounts have been given in the Sydney papers; for the Bunyip is said to be a solitary aquatic animal, whereas this skull must have belonged to a solipede, which if full grown, would have delighted in grass, dry land and the society of its own species."

Macleay's article appeared in the *Sydney Morning Herald* on Wednesday 7 July, the first of the two days of showings at the Australian Museum. It may be supposed that the inhabitants of Sydney went in considerable numbers to the Museum, then located in the Court House in Darlinghurst, to see the curious skull, but there are no records to confirm this.

Later in July, William Hovell's original letter on the "apocryphal animal" was published in the London *Athenaeum*. It was the common practice of the time to send unusual specimens 'home' to England to be pronounced upon by authorities such as Richard Owen of the Hunterian Museum, the leading anatomist and palaeontologist in Britain for much of the 19th century.

Some of the more scientifically minded in Sydney were fearful of the impression the skull would make in London. A veterinary surgeon, John Stewart, wrote to the *Australian Medical Journal*, urging the editor to protest against "such an ostentatious display of our ignorance and credulity. Before it is two days in London it will be recognised as the head of a foal that has had hydrocephalus and been born dead." The editor assured his readers that such an "*os*tentatious display" (*os* being Latin for bone) was not likely to take place as it had been determined to keep the skull in the Museum. In December Richard Owen, who had refrained from publishing any comments on the skull while it seemed likely to be sent to England, wrote to the *Athenaeum*. On the basis of the illustrations in Hovell's letter, Owen had formed the view that the rude figures of the Bunyip represented the misshapen skull of a new-born calf or foal.

Despite such a thorough scientific dismissal of the evidence for the existence of Bunyips, reports of sightings continued to appear, even into this century, but the Murrumbidgee skull is the closest anyone has ever got to tangible evidence. Some evidence!

Two mysteries remain. What became of the skull? If it was retained in the Australian Museum, there is no record of it. Gilbert Whitley, for many years curator of fishes at the Museum and the author of numerous historical articles on Australian natural history, asserted that the skull was not there in 1940. Possibly, despite the comment of the editor of the *Australian Medical Journal*, it was not long retained in the Museum. From the tone of the original newspaper advertisement, it seems that it was not intended to remain permanently in the Museum. Perhaps it was returned to Edward Curr or Atholl Fletcher. At all events there can have been few other natural history specimens that received so many detailed descriptions in Australian newspapers and journals in the 19th century. The skull is hardly necessary.

And the other mystery? Why do people persist in believing things for which there is no evidence? Whole books could be written on that subject. ■

Mr Julian Holland is Research Assistant and Curator of Technology at the Macleay Museum, University of Sydney. He is a specialist in historical scientific instruments and has recently published a catalogue of the microscopy collection at the Macleay Museum.

"A favourite way to prepare it is mashed with honey and crushed Munyeroo seeds."

THE 'UNDERGROUND PUMPKIN'

BY ANTAL SOOS, ANNE KERLE & PETER LATZ
CONSERVATION COMMISSION OF THE NORTHERN TERRITORY

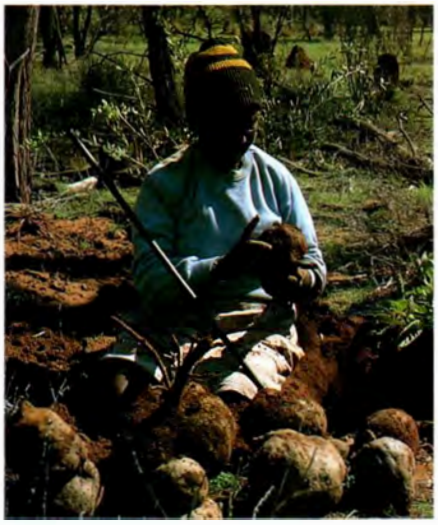
THE 'UNDERGROUND PUMPKIN' (*Ipomoea polpha*) is a native sweet potato familiar to the Anmatjirra Aborigines from Ti Tree, 200 kilometres north of Alice Springs. The plant was first recognised as a new species in 1979 when it was shown to Peter Latz by a health worker. The existence of sweet potatoes in this area of the Northern Territory had previously been reported but it had been assumed that the reference was to *Ipomoea costata*, a widespread species with woody stems and small tubers. By contrast, *I. polpha* produces spectacularly large and numerous tubers that average about one kilogram in weight. Some as large as a man's head and weighing 2.6 kilograms have been found.

Ipomoea polpha is a perennial plant with creeping stems that may grow to four metres in length. The stems die back in autumn and, if conditions are favourable, will regrow in the spring. The showy reddish purple, funnel-shaped flowers appear in summer.

With the assistance of Aboriginal people we now know that it is indeed a rare plant. The species is currently known from only one locality in the Northern Territory, but five stands of a closely related species occur in Queensland. Little is known about the Queensland populations except that they are being reduced by clearing, especially in grazing areas because the leaves are toxic to stock. The taxonomic status of these Queensland and Northern Territory *Ipomoea* plants is still being resolved.

The population of 'underground pumpkin' plants in the Northern Territory locality is actually more extensive than at first thought. About 11,000 mature plants occur within one small catchment. The catchment is gently sloping and ponding readily occurs. The plants apparently require moist soil conditions such as are produced by this type of catchment for successful germination and seedling survival.

The plants prefer to grow in mature mulga woodland where there is a well-developed canopy and a good accumulation of leaf litter. Other plants found in association with the 'underground pumpkin' include the Native Currant (*Canthium latifolium*), the Pencil Yam (*Vigna lanceolata*), Munyeroo (*Portulaca oleracea*), Emu bushes (*Eremophila* species) and the grasses *Digitaria coenicola* and *Enteropogon acicularis*.



ANTAL SOOS

Kitty Napurula examines a tuber dug from an *Ipomoea polpha* plant.

Ipomoea polpha was a favoured and reliable food for the Anmatjirra people, its large edible tubers being collected at any time of the year. The flavour is similar to commercial sweet potato and the nutritional value is also equivalent. Unfortunately it becomes rather rubbery when cooked. The Anmatjirra people no longer rely on this food source but it is still eaten, especially on 'picnics'. A favourite way to prepare it is mashed with honey and crushed Munyeroo seeds.

The traditional method of digging tubers with digging sticks is still used. Two women can dig ten kilograms of tubers in two hours and they do not damage the tubers when digging. Only a few are ever removed at a time, allowing the plants to survive. If the tubers are being transported long distances they are often strung onto a long runner of Snake Vine (*Tinospora smilacina*), which is then twisted into a circle.

This sweet potato features strongly in the mythology of the Anmatjirra people. They believe that it only grows on their land. Even if seeds are taken away, germination will not occur. When one of the owners of the *antjulkinha* (sweet potato) dreaming died, the people believed that the ensuing drought was connected to that death, the owner having taken away the rain to stop the sweet potatoes from growing. People are also forbidden to collect wood from the mulga woodland where the sweet potatoes grow. This ties in closely with the need to retain the canopy and litter cover for the species to survive.

Several tribal groups in the Northern Territory have their own word for *I. polpha* so it is possible that its distribution was once more widespread. However, there is also evidence that the tuber was once traded and that neighbouring people were involved in sweet potato ceremonies. It is therefore difficult to assess its past distribution.

In addition to its cultural value, *Ipomoea polpha* may have considerable economic potential. Nursery trials have shown that the plants can be readily propagated. They produce a lot of tubers in a short time and can grow in poor soils. Aborigines have expressed an interest in its cultivation for community use and its tubers may be suitable for marketing. There is also a potential for gene exchange with commercial varieties of sweet potato to enhance the commercial cultivars.

Information about the ecology of the plant suggests that, without careful management, the future of the species in the Northern Territory may not be secure. Protection from wildfire is vital since fire removes the mature mulga association that is essential for seedling regeneration and promotes the encroachment of wire grass and spinifex, resulting in reduced germination. A fire control program including development of fire breaks has been initiated by the Conservation Commission of the Northern Territory. Permanent plots have been established so that the vigour of the *Ipomoea polpha* population can be monitored. ■

Suggested Reading

Latz, P.K., Soos, A. & Kerle, J.A. (in press). The status and ecology of the native sweet potato *Ipomoea polpha* in the Northern Territory. *Aust. Rangel. J.*

Messrs Antal Soos and Peter Latz are Technical Officer and Plant Ecologist respectively in the Wildlife Research Section of the Conservation Commission of the Northern Territory. Dr Anne Kerle is a Consultant Biologist in Alice Springs.

You can learn a lot about the history of Macquarie Street just by looking at the pavement.

Macquarie Street's Sydney Hospital hasn't always enjoyed such an established and conservative title.

Last century, the site was occupied by a hospital which was named after the preferred liquor of the day, namely, Rum.

In 1810, three Sydney businessmen built the city a magnificent hospital in exchange for the coveted monopoly over the city's Rum trade.

This became the Rum Hospital, and stood complete until 1876, when the central block was demolished to build the present Sydney Hospital.

Further down the street you'll find the site where the Female School of Industry once stood.

In 1826, before anybody had even heard of 'Feminism,' the colony ran short of servants.

Accordingly, the ladies of the colony set up the Female School of Industry in order to teach their lesser sisters "every branch of household work." The site is more appropriately occupied now by the Mitchell Library.

The fact is, Macquarie Street is more than just another city street.

It is Sydney's, if not Australia's, most interesting thoroughfare.

In an effort to pay tribute to this, Caltex, in association with the NSW Public Works Department, has laid twenty commemorative footpath plaques along Macquarie Street, each marking a historical site.

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"The enormous costs imposed by these weeds, both economic and ecological, show up the folly of the acclimatiser's ideals."

ACCLIMATISING EDIBLES

BY TIM LOW
NATURE WRITER

DURING THE 19TH CENTURY THERE was a strong push to 'enrich' Australia's forests and fields with animals and plants from overseas. Colonial acclimatisation societies brought in deer, foxes, hares, sparrows, starlings and trout, and even talked of releasing African game into the outback and llamas into the Alps.

Foodplants were of major interest to the acclimatisers. Baron Ferdinand von Mueller, Victorian Government botanist and a leading acclimatiser, advocated establishing wild carrots, celery, cabbages and asparagus along the seashores, strawberries in the mountains, and pumpkins in the deserts.

Explorers sometimes planted crop seeds during their treks, usually in improbable places. Captain Charles Sturt scattered wheat, mustard and barley seed near the Darling River, Ludwig Leichhardt buried peach and plum stones in central Queensland, and botanist Charles Fraser planted banana trees near where Perth now stands.

Although most plant introductions failed, a few fruits and vegetables did become established in the wild, either from deliberate attempts or as escapees from cultivation. Wild forms of celery, beetroot, carrot, parsley, lemon, passionfruit, guava and many other foodplants can be found growing self-sown in paddocks and disturbed bushland. A few of these feral plants became important colonial foods.

The Pie Melon (*Citrullus lanatus*), also known as Bastard, Bitter and Camel Melon, is the wild form of Watermelon and Honeydew Melon. A creeper originally from Africa, it produces greenish yellow fruits up to 15 centimetres long. Von Mueller in 1885 indicated "the desirability of naturalising it in the interior deserts" and indeed, it is now found in the outback regions of all mainland States where it grows in sandy soils and on floodplains. It was widely used in colonial cookery and is still made into jam by country people today.

Melbourne journalist Donald MacDonald described this melon in the Riverina in 1887: "Along the banks of the watercourses, that not long since were merely dry depressions in the land, wild melons are springing up and spreading so rapidly as to give the place the appearance of a garden. The taste for these melons is hard to acquire, no doubt. Ancient shepherds and boundary-riders, who have lived for a quarter of a century on the plains, pretend to like the fruit, but their palates have been ruined by an everlasting diet of mutton and dyspeptic damper, and they have long since forgotten the flavour of a genuine melon."

In the Channel Country of south-western Queensland, Pie Melons were harvested by tribal Aborigines and sold to white settlers. Alice Duncan-Kemp of Mooraberrie Homestead told of the

Wild Pie Melons were gathered by colonists and fed to their pigs, or cooked with tomatoes to make puddings. The fruits have dark brownish seeds and the leaves are rough on the underside only; the related but poisonous Colocynth (*Citrullus colocynthis*) has yellowish seeds but the leaves are rough on both surfaces.

PHOTOS: TIM LOW

"gins" bringing in "big green sugar melons", as well as Emu, Brolga and Inland Dotterel eggs, to exchange for silver money. Aboriginal children in the Northern Territory use the long bristly stems as skipping ropes.

Another widely naturalised foodplant in Australia is Watercress (*Rorippa naturtium-aquaticum*). This spicy herb of creeks and soaks was widely spread about by colonists. The *Queensland Agricultural Journal* at the turn of the century even ran an article advising that it would "thrive well and yield good crops if sown amongst weeds on a creek bank or on the edge of a waterhole or swamp".

Cress of some kind, possibly Watercress, was planted in the wilds of Tasmania by two of Australia's 18th century navigators—Captain Bligh and D'Entrecasteaux. Cress was also sown in southern Queensland by Leichhardt on his second expedition, in an incident alluded to most unfavourably in Patrick White's novel *Voss*, based on the explorer's life.

The Blackberry Bramble (*Rubus fruticosus*) was another beneficiary of acclimatisation. Baron von Mueller declared that it deserved "to be naturalised on the rivulets of any ranges", and he reputedly spread the seeds in forest glades during his many botanical expeditions. Early this century hundreds of tonnes of the wild fruits were sent to Sydney jam factories.

The Blackberry spread very successfully in the wild—too successfully. By the late 19th century Victorian farmers were complaining that it was choking out paddocks, creek banks and forests, and providing refuge for destructive rabbits. It is now recognised as Victoria's worst weed: more than 663,000 hectares of the State are ensnared in its spiky canes. Many thousands of dollars are spent each year on control.

The example of the Blackberry shows up the dangers of the acclimatiser's ideas. It is not an isolated case. The Artichoke Thistle (*Cynara cardunculus*), ancestor of the Artichoke, has become an invasive weed of black soil plains in southern Australia. Migrants from southern Europe sometimes cook up the delicious but spiky buds. The Gherkin (*Cucumis anguria*) is a pest of northern Queensland cane fields, Fennel (*Foeniculum vulgare*) is a weed of temperate cities and farms, and the Rosella (*Hibiscus sabdariffa*), the source of Rosella jam, is an environmental weed of river flats at Kakadu.

The enormous costs imposed by these weeds, both economic and ecological, show up the folly of the acclimatiser's ideals. Von Mueller's charming vision of Australia as a great garden, stocked with wild fruits and vegetables, could never have come about. Ecosystems cannot be tinkered with in this way. Fortunately, the modern concept of wilderness has taken hold in Australia, the dangers posed by exotic species are well known, and the acclimatiser's dreams can be dismissed today as gentlemanly foolishness. ■

Watercress can be identified by its tiny white flowers with four petals, sausage-shaped pods one to two centimetres long, and pinnate leaves with a peppery taste. This plant was sprouting in a soak beside the path that runs south of Bondi Beach, Sydney.

Wild Blackberries are ideal for pies and jams. A decoction of the leaves, mixed with other herbs, was prescribed by colonial herbalists to treat sore throats, spongy gums and pimples.

Suggested Reading

MacDonald, D., 1887. ***Gum boughs and wattle bloom, gathered on Australian hills and plains.*** Cassell: London.

Mueller, F. von, 1885. ***Select extra-tropical plants: readily eligible for industrial culture or naturalization, with indications of their native countries and some of their uses.*** Government Printer: Melbourne.

Rolls, E., 1969. ***They all ran wild.*** Angus & Robertson: Sydney.

Tim Low B.Sc. is a full-time nature writer. He is the author of four wild food books, his latest being Bush Tucker *and* Bush Medicine, *which include articles reprinted from his ANH column.*

"Frank Buckland could not countenance a species new to himself or science without trying to put it in his mouth."

THE ZOO TUCKER MAN

BY ROBYN WILLIAMS
ABC RADIO SCIENCE SHOW

THAT OUTRAGEOUS AND HILARIOUS film by Peter Greenaway, "The Cook The Thief His Wife and Her Lover", satirised a world obsessed with consuming things, including food. They began with posh cuisine and ended up eating people!

Imagine, though, the equivalent in natural history, a fellow of hefty, bearded aspect similar to Michael Gambon's uproarious Thief, but who collected specimens not only to classify but to have them for dinner. This was the remarkable Dr Frank Buckland, Inspector of Fisheries in Victorian Britain. He was born in the Tom Quad of Christ Church College, Oxford, in 1826 and died 54 years later having devoured more beasts of land, sea and air than practically anyone before or since.

"Buckland", wrote Charles Darwin, "though very good humoured and good-natured seemed to me a vulgar and almost coarse man. He was incited more by a craving for notoriety, which sometimes made him act like a buffoon, than by a love of science."

But, love science he did; indeed, Frank Buckland produced a number of authoritative papers and articles, including "Natural history of British fishes". He lectured on the same stage as T.H. Huxley at the South Kensington Museum, wrote a regular column about nature for the *Field, Land and Water* periodical and published four series of jottings called "Curiosities of natural history".

This was at a time, remember, when the public, both in Britain and Australia, was obsessed with plants and animals and collecting their remains or representations of them. It was 'the heyday of natural history', and this is the apt title of Lynn Barber's delightful book (Jonathan Cape, 1980) in which Buckland, amongst many others, is celebrated.

He was of genteel circumstances, educated at Winchester and Oxford, where he studied classics, chemistry and geology. Then he enrolled as a medical student at St George's Hospital in London, where he derived especial delight in cutting up dead bodies. Buckland took his surgeon's interests to the dinner table where, a medical colleague recounted: "to a lover of Natural History it was a pleasant sight to see him at dinner with a chicken before him—to watch the scrupulous delicacy with which he removed the leg out of the socket, or examined, after very careful picking, the numerous troublesome little bones which constitute the pinion, and finally to hang over him as he performed a Post Prandium examination of the head—and then to see how, undeterred by foolish prejudices, he devoured the brain."

Frank Buckland (1826–1880). From Lynn Barber's *The heyday of natural history, 1980.*

Buckland learned the practice of eating specimens from his father, William Buckland, Canon of Christ Church Cathedral, Oxford, later Dean of Westminster. Buckland senior was also a renowned geologist. When Frank was four the family got hold of an aging crocodile. After riding about on it with his brothers, they exhausted the beast and it died. The family promptly cooked it, and so the pattern was set. Thereafter Frank managed to swallow "squirrel pie, mice in batter, hedgehogs, frogs and garden snails."

"A roast field mouse" he proclaimed "is a splendid *bonne bouche* for a hungry boy. It eats like a lark!" But earwigs "taste horribly bitter". However, "it is not known what excellent eating young rats are". At Oxford, records Lynn Barber "he feasted on panther, sent down from the Surrey Zoological Gardens. 'It had, however, been buried a couple of days', he noted 'but I got them to dig it up and send me some. It was not very good'."

So Frank Buckland's zoophagy was launched. He could not countenance a species new to himself or science without trying to put it in his mouth. Jackdaws, rooks, bison, elephant trunk soup, porpoise ("which tasted like broiled lampwick"), giraffe (like veal), boa-constrictor, boiled toucan, armadillo ("strong and rank"), red monkey, wild cat. He gave dinners where, like his father, he served "horse's tongue, alligator, puppies, mice, tortoise and ostrich".

In his never-ending search for fresh and novel creatures with which to decorate his menu Buckland was enraptured by the discovery of Australia's new animal cornucopia. And so there was Emu and 'Kangaroo Steamer'. Each dinner was conducted with formal hilarity and the exotic fauna was accompanied by vegetation of appropriate obscurity.

Buckland's contributions were significant beyond his promotion of zoophagy and it would be amiss to portray him as a daft eccentric. He established the Economic Fish Museum in South Kensington, and was succeeded as Inspector of Fisheries by no less a figure than T.H. Huxley himself.

Lynn Barber (whose book I recommend as a wonderful catalogue of characters and practices from a time when natural history ruled) quotes this obituary from the field of Buckland's achievements: "His great merit as a writer was his power of rendering natural history attractive to the multitude; this he did to perfection. . .Whilst other writers of popular natural history simply compile, Buckland described from his own quaint and singular points of view. His descriptions were therefore vivid, and, if not always consistent, were eminently readable, and doubtless have served their own good turn by attracting many to the study of nature and natural objects." ■

As Executive Producer of the ABC Radio Science Show, Robyn Williams has the opportunity to study many interesting people in science.

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"After a patient search the source of the signal was located. But was she alive? Telemetry pulses still suggested near-ambient temperature. Perhaps the animal was alive and in torpor?"

ECHIDNAS IN THE HIGH COUNTRY

BY GORDON GRIGG, LYN BEARD & MIKE AUGEE

DEPARTMENT OF ZOOLOGY
UNIVERSITY OF QUEENSLAND
SCHOOL OF BIOLOGICAL SCIENCE
UNIVERSITY OF NEW SOUTH WALES

OF ALL AUSTRALIA'S 150 OR SO native mammals, only the Short-beaked Echidnas (*Tachyglossus aculeatus)* have a distribution that can be said to be Australia-wide. They are found in deserts, wet and dry sclerophyll forests, rainforests and heathlands. They are even seen in the high country of the Australian Alps.

This remarkable range of habitats does not fit well with the usual stereotype of Echidnas as primitive, egg-laying holdovers from the earliest days of mammalian evolution. One would expect a living fossil to survive only in an isolated habitat to which it was specifically adapted. To

Gordon Grigg locates the antenna wire, which provides a clue to the position of the recording box used to track Echidnas in the high country. Above: tell-tale signs of an Echidna– fresh tracks in the snow.

LYN BEARD

be widespread and even common in such a diversity of habitats must require a great range of physiological and behavioural skills. We wondered if their secret was advanced adaptation or primitive plasticity.

In the traditional manner of comparative zoologists, we decided to approach a general question by looking at an extreme. The Australian Alps, above the snowline, provide an extreme habitat, and we knew that Echidnas could be found there. Cross-country ski enthusiasts told us of seeing Echidnas out and about in the middle of winter, poking about in the snow, and there was even a reliable report of one within a few metres of the summit of Mt Kosciusko. Such observations might be considered a bit unusual for a fox or a possum, but they begged further investigation for an animal often accused of 'primitive thermoregulation', 'heterothermy' and 'incomplete homeothermy'.

Of course one explanation for such sightings could be that the individual Echidnas were outside their normal winter range, perhaps stranded at higher altitudes to which they had wandered during the warmer months. Alternatively Echidnas might live there year round, spending the winter under the snow and emerging from time to time, a pattern reminiscent of mammalian hibernators. But they couldn't do that! One of us (M. Augee) had frequently stated that Echidnas are *not* hibernators. It was there in black-and-white, in scientific journals. That conclusion had been reached because captive Echidnas would only enter torpor reluctantly. In early studies carried out at Sydney University by H. Wardlaw in 1915, most Echidnas that did enter torpor died. Besides, the mating season is usually stated to be in July–August (mid winter), a most inconvenient time to be in hibernation! There were a few anecdotal reports of Echidnas found in a lethargic state in the wild during winter (one reported to have been dug out by earth-moving equipment), but no field data where actual body temperatures had been measured. We felt that the only convincing data would be that collected in the field; and the only way to collect such data would be by radiotracking (see box).

So we applied to the Australian Research Council for funds to solve the puzzle. In preparing this application we found very little in the literature about the biology of Echidnas in the field. The lack of field studies is probably related to the difficulty of relocating Echidnas and the impossibility of trapping them. The obvious technique to use was telemetry, employing modern, implantable, long-lived, temperature-sensitive transmitters that are small enough to be easily tolerated by an animal the size of an Echidna.

But first to find some Echidnas in the alpine habitat. We put out the word amongst the staff of Kosciusko National Park (KNP) that we particularly wanted animals from the highest ridges, as well as a 'control' group lower down in the Waste Point or Jindabyne area below the snowline. Meanwhile the grant had been obtained and laboratory work began at Sydney University, with Grigg and Beard perfecting the techniques of implanting transmitters within the peritoneal (body) cavity. Whenever possible we went to KNP in the hope of finding Echidnas ourselves.

As luck would have it, the very first animal that turned up in KNP was in a perfect spot for the study. Early in 1987 John Whittaker, while delivering ski-trail poles to Prussian Plain at 1,720 metres elevation on the crest of Ramshead Range south-west of Perisher, captured a tan-coloured female weighing about three kilograms. We implanted a transmitter and released her at the exact site of capture. The weather was warm as she crawled out of the opened sack and took a couple of hesitant steps onto the snowgrass. After sniffing the air she hastily burrowed into the soft earth. Although designated E10 (Echidna number ten), this was the first animal released in the Kosciusko study area.

Over the next few weeks we plotted the position and monitored the body temperature of E10 as she moved about Prussian Plain. We were pleased that she remained there and did not head down into one of the valleys. By now we also

GORDON GRIGG

Transmitters are implanted intraperitoneally under sterile conditions, as approved by the university's Animal Care Committee. Inset: the transmitters are coated with a physiologically inert wax.

Using a stopwatch or digital processor, Lyn Beard reads off the pulse intervals between signals recorded on cassette tape from the transmittered animals every few hours for the past couple of weeks.

Body Temperature by Radiotelemetry

By surgically implanting a small temperature-sensitive radio transmitter into the body cavity of an animal it is relatively easy to keep tabs on them for months, or even a couple of years, relocating them whenever required and recording body temperature without causing them any disturbance. This provides biologists with a powerful technique for learning about the behaviour and physiology of free-ranging animals.

The transmitters we use measure 20 × 8 × 7 millimetres. Powered by a three-volt lithium battery, they are waterproofed with a physiologically inert wax. Once powered up, pulses of 15 milliseconds duration are sent every second at 30° C, slowing down as temperature falls. The pulses are detected using a specially designed radio receiver. By careful calibration prior to implantation and careful timing of pulses once the animal is released, body temperatures can be monitored with an accuracy of ±0.2° C.

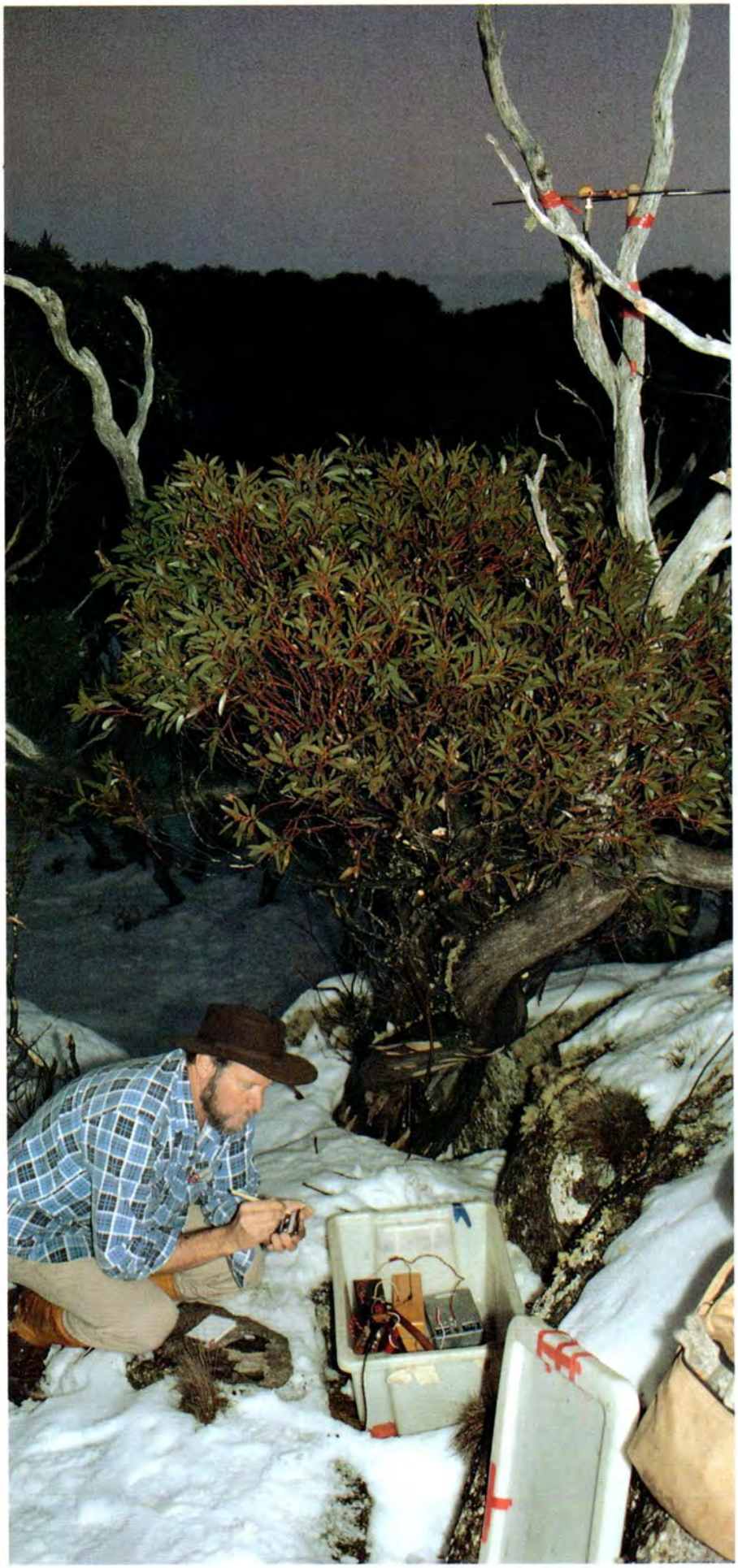
Each transmitter has a unique frequency that can be tuned in with the receiver. With a directional hand-held antenna connected to the receiver, an animal can be located by following the direction of greatest signal strength. The range is typically one kilometre, but often two to three kilometres.

To record body temperature when we could not be in the field, we devised a battery-operated system in which a programmable timer turned on the receiver and a tape-recorder at predetermined intervals. In this way we could sample temperatures hourly, eight-hourly, or whenever we wished, thereby covering intervals between field trips and obtaining a more or less continuous record of changes in body temperature for months at a time, changing the tape every two to three weeks as required. Using a scanner plugged into the receiver, the same 'box' could be made to record more than one individual's body temperature plus ambient temperature.

—L.A. Beard & G.C. Grigg

TOM GORRINGE

LYN BEARD



LYN BEARD

had two other Echidnas with transmitters (E11 and E13) at Waste Point on the shore of Lake Jindabyne (altitude 1,000 metres) and another (E15) at Rennix Gap (1,580 metres). We also came by a female (E12) from Dead Horse Gap, another high-altitude location, and released her onto Prussian Plain after implanting a transmitter. Now we had three animals above and two below the normal snowline, and were ready to establish the summer patterns of behaviour and body temperature before the weather turned cold.

IT WAS ALREADY KNOWN FROM STUDIES OF Echidnas in captivity that body temperatures vary on a daily basis, and we soon found this to be true in our summer field study. Most mammals have a small daily variation of a degree or so, being warmer when active and cooler when at rest. We found the Echidnas in KNP to vary daily by 6–8° C. The pattern set by E10 on Prussian Plain in those early weeks turned out to be typical. She was active all day, foraging for small black ants by digging along the edge of fallen timber and under clumps of snowgrass, with a body temperature of 32–34° C regardless of the weather. Soon after daylight had faded she would hole up for the night in a suitable retreat: a hollow log, under a rock, in a disused burrow or, as we observed several times, under a convenient clump of snowgrass. Shortly thereafter, as the lengthening times between pulses from the radio transmitter deep within her showed, body temperature began to fall, quite slowly, as she rested for the night. In these latitudes Echidnas tend to be late risers, avoiding the chill of early morning, so the minimal body temperatures at this time of year were measured between 9 and 10 am and were typically 25–27° C. When E10 emerged and became active again, body temperature rose rapidly; sometimes associated with basking in the sun but more certainly associated with heat produced from muscular activity. Sometimes, when Prussian Plain was swept with wind and rain, she would stay in her retreat and cool further for a day or two before re-emerging to forage and warm up, body temperature always returning to 32–34° C.

This was the typical pattern during the summer months for all our animals at KNP, and the field data agreed pretty much with conclusions from captive animals, going back to the pioneering work of Prof. C.J. Martin in Melbourne in 1902, that body temperature in Echidnas is highly variable for mammals. To us, following the animals about in their natural habitat, it looked to be a very sensible,

'Servicing' a recording box consisted of changing or turning the cassette tape, which recorded the 'beeps' from the receiver, and delivering fresh batteries. The antenna was placed as high as possible nearby, in this case taped to a dead tree on top of a rocky outcrop.

energy-saving pattern, rather than one suggestive of 'poor thermoregulatory abilities' associated with a 'primitive' animal.

We quickly realised how much more data we could obtain (and how much extra sleep we might get!) if we had an automatic sampling system that could gather data overnight. So we invented and deployed a couple of weatherproof systems to record body and ambient temperatures at pre-set times during the night onto cassette tape (see box). It was not until the first apparent 'disaster' in the study that the full potential of these 'boxes' (the system was enclosed in a large polypropylene box) was realised.

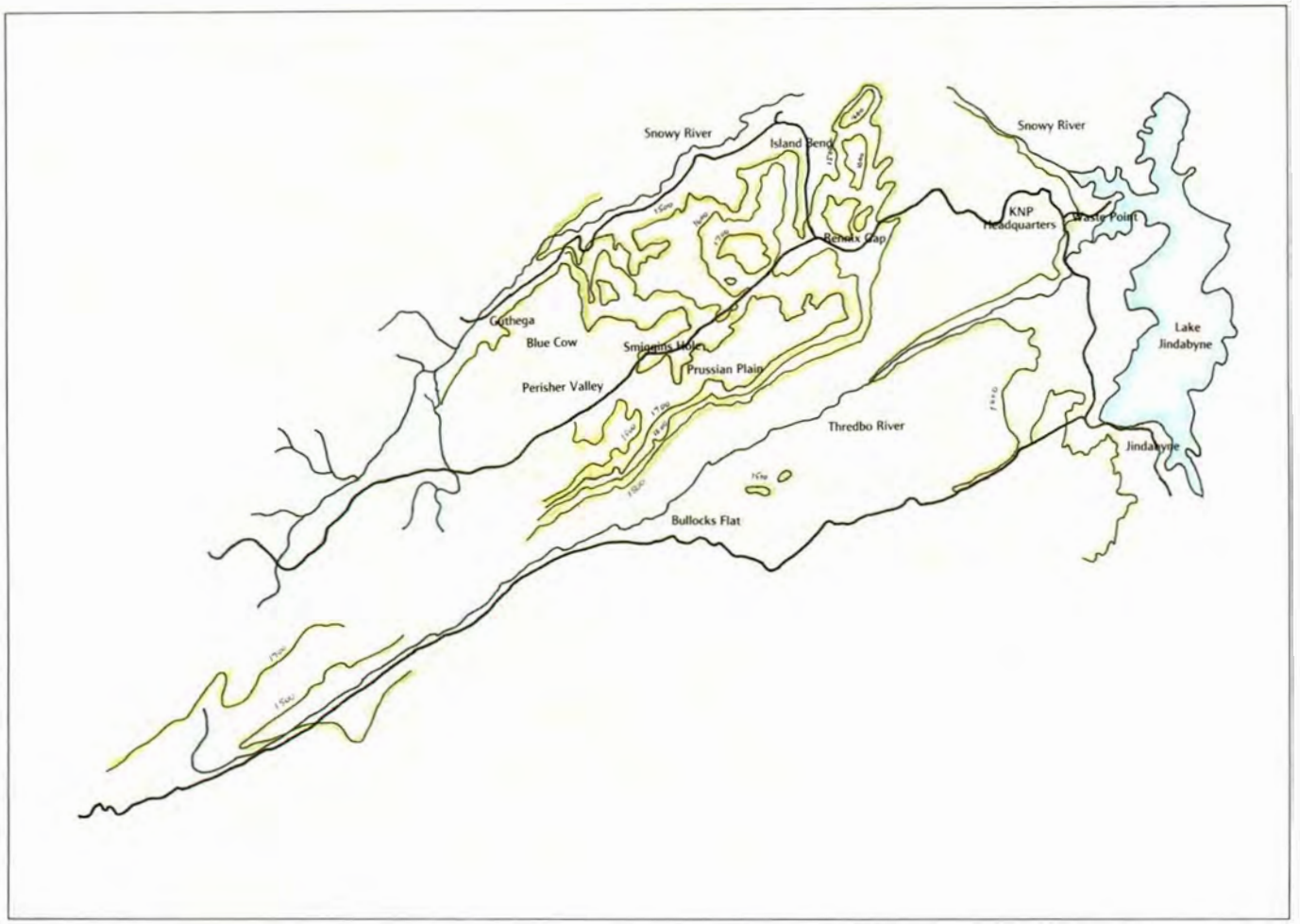
At Easter we returned, expecting to turn on the receiver in the vicinity of the last position of an animal and to hear the usual 'beep...beep...beep' on the appropriate frequency and at the usual rate. Echidnas seemed to have well-established home ranges and were always in the same general area. But when we got together at lunch time Mike Augee, who had gone up to Prussian Plain to locate E10, was pessimistic. He had picked up the signal as expected but it was coming in slowly, with a full 4.5 seconds between beats. That equated to 9.3° C, which was close to ambient temperature, and Mike's gloomy conclusion was that the animal was dead. However, he had not been able to locate the carcass as the long interval between signals made it hard to get a fix. It did seem to be off Prussian Plain, amongst dense snow gum saplings on the steep southern escarpment overlooking the Bullock's Flat ski-tube terminal far below. We discussed the possibilities, including predation (a fox perhaps?) and death from exposure. The first snow had not yet fallen but it had been very cold in the mountains. Maybe the Echidnas in the high country really *were* only strays, at the edge of survival, and this one had just not made the grade.

With still a few hours left until nightfall, Grigg set off to Prussian Plain to find E10. It was a quick trip over now familiar terrain to a rock cairn at the southern edge of the plain, overlooking the Thredbo River. After a patient search and a lot of scrambling through thick undergrowth on the precipitous slope, the source of the signal was located under a rock at the base of a large sun-bleached stump. It was typical for an Echidna retreat and there seemed to be every likelihood that E10 had entered there of her own free will. But was she still alive? Telemetry pulses still suggested near-ambient temperature. Perhaps the animal was alive and in torpor?

Here was an exciting problem, but we were committed to leave for Sydney the next day. We needed some way to keep

Gordon Grigg and Mike Augee fix the whip antenna high in a tree so the recording box may still pick up the Echidna's signal if it moves unexpectedly from its hibernation site nearby.

LYN BEARD



CATHY MCGAHEY

Lyn Beard follows a signal from a hibernating Echidna, which was found in a cavity formed between roots of a snow gum under a granite boulder.

GORDON GRIGG

track of the animal's body temperature until we could return. The solution was obvious—set up a 'box' to take readings not hourly or half-hourly, as we had been doing to make overnight records, but every eight hours to spin out the cassette tape for a couple of weeks until our return.

So we climbed again to Prussian Plain early the following morning carrying all the necessary equipment. The sky was blue but it had been damp and cold overnight. On reaching the crest we hurriedly checked the signal. It was more rapid! The animal was now warm! It took only 15.1 seconds for 10 beats, compared to the 45 seconds the previous afternoon. Far from being dead, she had now warmed up. The Echidna story was also hotting up! Periodic and rapid warm-ups from torpor are characteristic of hibernating mammals. Were Echidnas hibernators too? While it was not a sure bet, the odds were changing. We needed more data. We set up the 'box' to record the body temperature every eight hours for the next 15 days and secured the lid down with a large rock (gales are the norm on the Ramshead Range at this time of year).

Fifteen days later in early May we returned and went straight to Prussian Plain. Yes, she was torpid again, and she had moved. But she had moved to the northern side of the ridge out of range of the carefully placed recording box

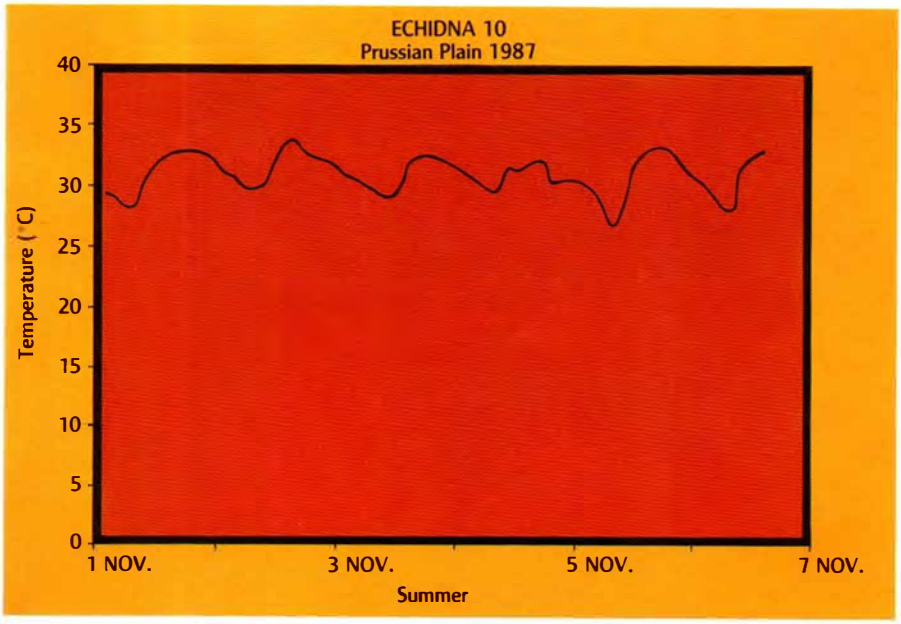
GORDON GRIGG

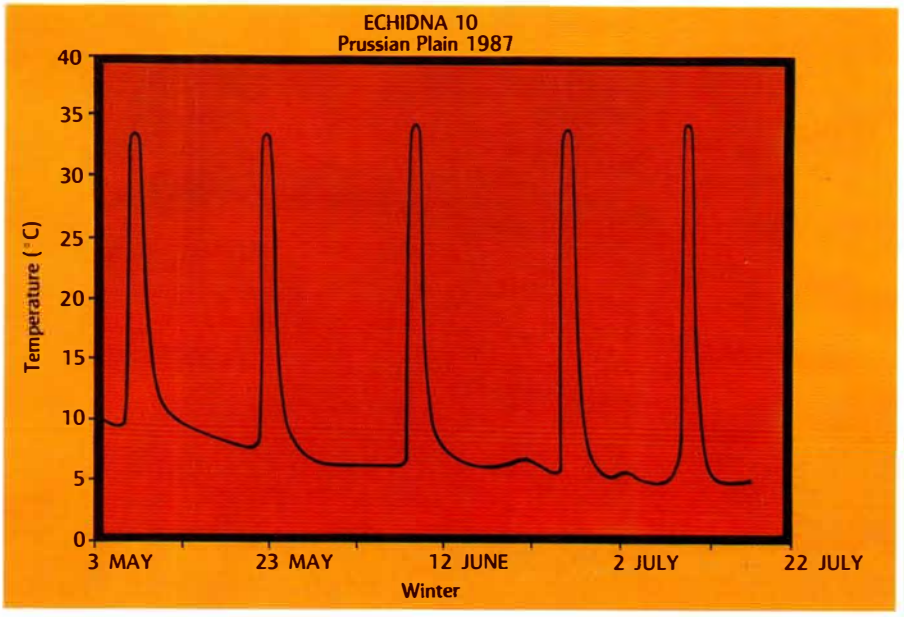
An Echidna (E10) dug up from hibernation is so slow in its movements and so cold that survival seems unlikely.

(Murphy's Law applies especially to field studies!).

Our two other high-country Echidnas, E12 and E15, were also torpid, and so was one of the Echidnas in the 'control' group well below the snowline beside Lake Jindabyne. Torpor was beginning to look like a normal event for Echidnas. Only E13 was still active. The four torpid Echidnas stayed put, with low body temperatures, for the four days of this field trip. We had only two recording boxes, so we left one at the new location of E10 and left the second to record data from another torpid animal. This time we were rewarded for the effort.

On the next trip we listened eagerly to the first tape. It had successfully recorded data every eight hours for two weeks and, most excitingly, it contained in beautiful detail a striking, rapid warm-up over about 12 hours to a 'normal' operating temperature (about 32° C) followed by a slower, steady decline almost to ambient temperature (in this case 10° C). This pattern was to be repeated again and again, every couple of weeks, by *every* monitored Echidna—just what would be expected of a ground squirrel or marmot. Echidnas are hibernators!





IAN FAULKNER

Contrasting patterns in body temperature during summer and winter shown by an Echidna (E10) on Prussian Plain. Note the different time scales. In summer, cyclic changes in body temperature correlate with periods of activity (by day) and rest (at night). In winter the animal entered hibernation in a burrow, its long periods of torpor being interrupted by spontaneous arousals during which body temperatures rose briefly into the low 30s before falling again to near ambient temperature. This pattern of hibernation is the same as that seen in traditional placental hibernators.

A young Echidna discovered in a burrow in a sphagnum bog on Prussian Plain. At 1,720 metres elevation, this is the highest recorded birth of an Echidna and it confirms their ability to cope with the rigours of the alpine climate.

GORDON GRIGG

Hibernation, Torpor, Lethargy or Just Plain Sleep?

At its simplest, hibernation is a vague notion that some animals survive harsh winter conditions by retreating to a den, burrow or nest, not to be seen until spring. Hibernation has often been termed 'winter sleep', in which case awakening should simply be a matter of putting the central nervous system on full alert, a process taking seconds or perhaps minutes. And yet, if you dig up a marmot in winter in the Canadian Rockies, it will take hours to become active, and that arousal will involve a gradual warming with heat produced from the animal's own metabolism until the nervous system is functioning at a normal level. If you dig up a nearby lizard, it will not become active until you apply external heat.

Obviously different vertebrates that remain inactive over winter do so in quite different states. A terminology, with the precision demanded by science, capable of making such distinctions is needed. 'Torpor' is a state in which body temperature is lowered almost to the temperature of the surroundings and functions such as heart beat, breathing and metabolism proceed at rates well below those observed in active animals. 'Hibernation' is used by most zoologists to refer to winter torpor with the additional proviso that the hibernator is capable of completely arousing itself at regular intervals to normal body temperature using its own metabolic resources. This definition therefore excludes all ectotherms and is restricted to birds and mammals. Some small desert birds and mammals show a similar response to summer conditions, in which case the term 'aestivation' is used. What about bears? They are often considered hibernators because they retreat to dens in winter in northern latitudes. In the '50s Raymond Hock, from the Arctic Aeromedical Laboratory in Alaska, measured the body temperatures of a couple of bears in winter in the field and found their body temperatures to be only about 5° C below summer active body temperatures. I have always considered this man, who "made deep rectal insertions" with a thermometer into bears in their dens, to be one of the great field biologists of our time. Needless to say the bears woke up rather quickly and these field measurements have not been repeated since. Most zoologists are content to consider that bears, like skunks and a few members of the order Carnivora, exhibit 'carnivorean lethargy'.

Hibernation involves complex seasonal cycles. Few mammalian hibernators are able to enter torpor during the summer active period. The reproductive season appears to require physiological conditions that preclude torpor. Many bats, however, can enter torpor at any time of the year. There are therefore a number of variations in the way different species utilise torpor. This has led to continuing adjustment of the terms used above and a search for a more quantitative definition of hibernation. Since mitochondrial membranes (which produce energy for many cell functions) of most endotherms cannot function at temperatures below 18° C, with the exception of those of hibernators, it is possible to define hibernators as those endotherms capable of lowering the minimal temperature of membrane function below 15° C. By this definition bears are not hibernators but Echidnas are.

—**M.L. Augee**

Hibernation: Primitive or Advanced?

Australian biologists are a bit touchy about the word 'primitive'. It is often applied to our native species, such as marsupials and especially monotremes. That implies they are second-class animals, isolated on a geographic ark and doomed to be out-competed by 'advanced' mammals from the 'real' world over the seas. The problem is that 'primitive' carries two meanings that are not necessarily compatible. It carried in biology the meaning of 'ancestral' in the case of phylogeny and 'old' in terms of the fossil record. It also of course means lacking in complexity, which has implications of being inefficient and old-fashioned. To get around this, a new word 'plesiomorphic' has been coined to carry the meaning 'ancestral' only.

Hibernation was originally considered primitive. Small mammals were said to 'abandon homeothermy' and revert during winter to a reptilian metabolism. Mammalian hibernation was considered to be a remnant of reptilian physiology held in a few mammals. In other words, it was then held to be a 'plesiomorphic' character state. In recent times, however, hibernation has come to be considered a very advanced ability, involving seasonal adjustment of function and even structure in the case of some membranes. Since hibernators are found in at least four separate orders, if hibernation is an advanced state it would have to have evolved separately at least four times. In evolutionary terms this would be an example of four-fold convergence. And now we have evidence that Echidnas hibernate. That should shift the balance toward the older view, since monotremes are the closest living mammals to the Mesozoic stem. Otherwise we are faced with five-fold convergence of a quite complicated character state, and that stretches the concept a bit too far. Obviously more information is needed about the basis of hibernation in the Echidna, and it could be that evolutionary terms and concepts that fit structural characters so well cannot be applied to functional states.

—**M.L. Augee**

THE STRATEGY OF HIBERNATING AND conserving energy during the period of the year when food may be in short supply or when environmental conditions are harsh makes sense in one of the coldest areas of Australia. However, there remains the problem that Echidnas are supposed to breed in July or early August. At first it looked as though they were indeed going to hibernate through the breeding season, and some did, but with a further year of monitoring we confirmed that most of them aroused in time for mating and breeding. The other animal being studied on Prussian Plain, E12, in fact hatched a living young in a burrow dug in a clump of sedge and sphagnum, providing strong evidence that the high-country Echidnas really live in that habitat and are not simply occasional visitors that become 'lost'.

To what extent hibernation in Echidnas is homologous to that of eutherian (placental) hibernators is still uncertain. The pattern is the same, but we do not know whether it is supported by the same physiology. If monotreme and eutherian hibernation are homologous, then this is a bit hard to reconcile with the current idea that hibernation is an advanced state derived in only a few mammals. Perhaps monotreme hibernation is based on physiological mechanisms present in ancestors common to all mammals, in which case further studies of thermoregulation in Echidnas might shed light on the development of endothermy and homeothermy in metatherian (marsupial) and eutherian mammals. Either way, the discovery of hibernation in Echidnas poses some questions for the old debate on whether hibernation is a primitive or advanced character state (see box). It also poses interesting questions about Echidnas themselves. How widespread is the occurrence of torpor, and is the ability to become torpid used under completely different circumstances in other areas?

The discovery of hibernation in Echidnas, like the recent discovery of electrosensitivity in monotremes (see ANH vol. 23, no. 4, 1990), indicates there is still much to be discovered about these fascinating beasts. All of which serves to reinforce Mike Augee's oft-quoted maxim "Never underestimate an Echidna!". ■

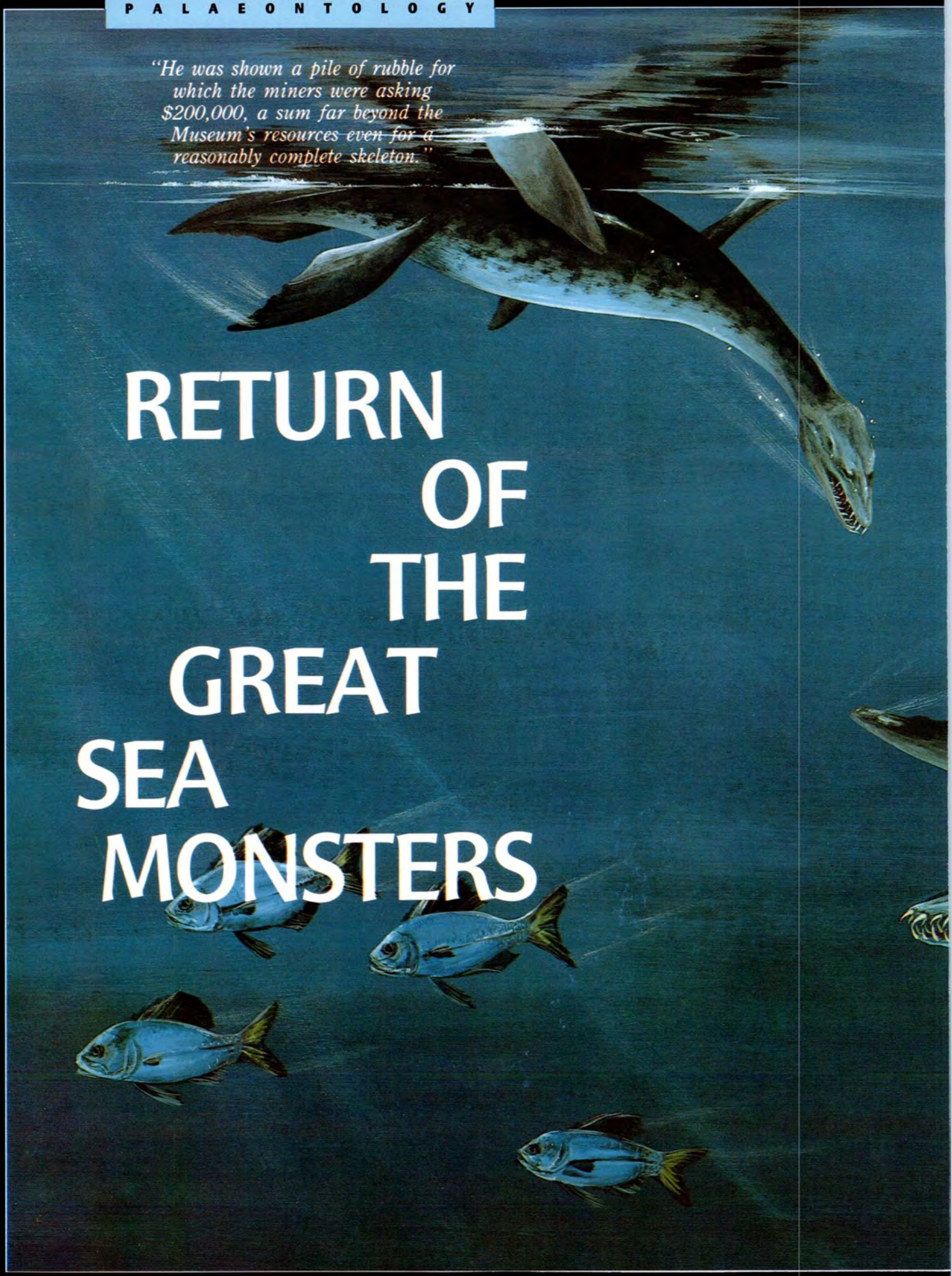
Suggested Reading

Grigg, G.C., Beard, L.A. & Augee, M.L., 1989. Hibernation in a monotreme, the Echidna (*Tachyglossus aculeatus*). *Comp. Biochem. Physiol.* 92A: 609–612.

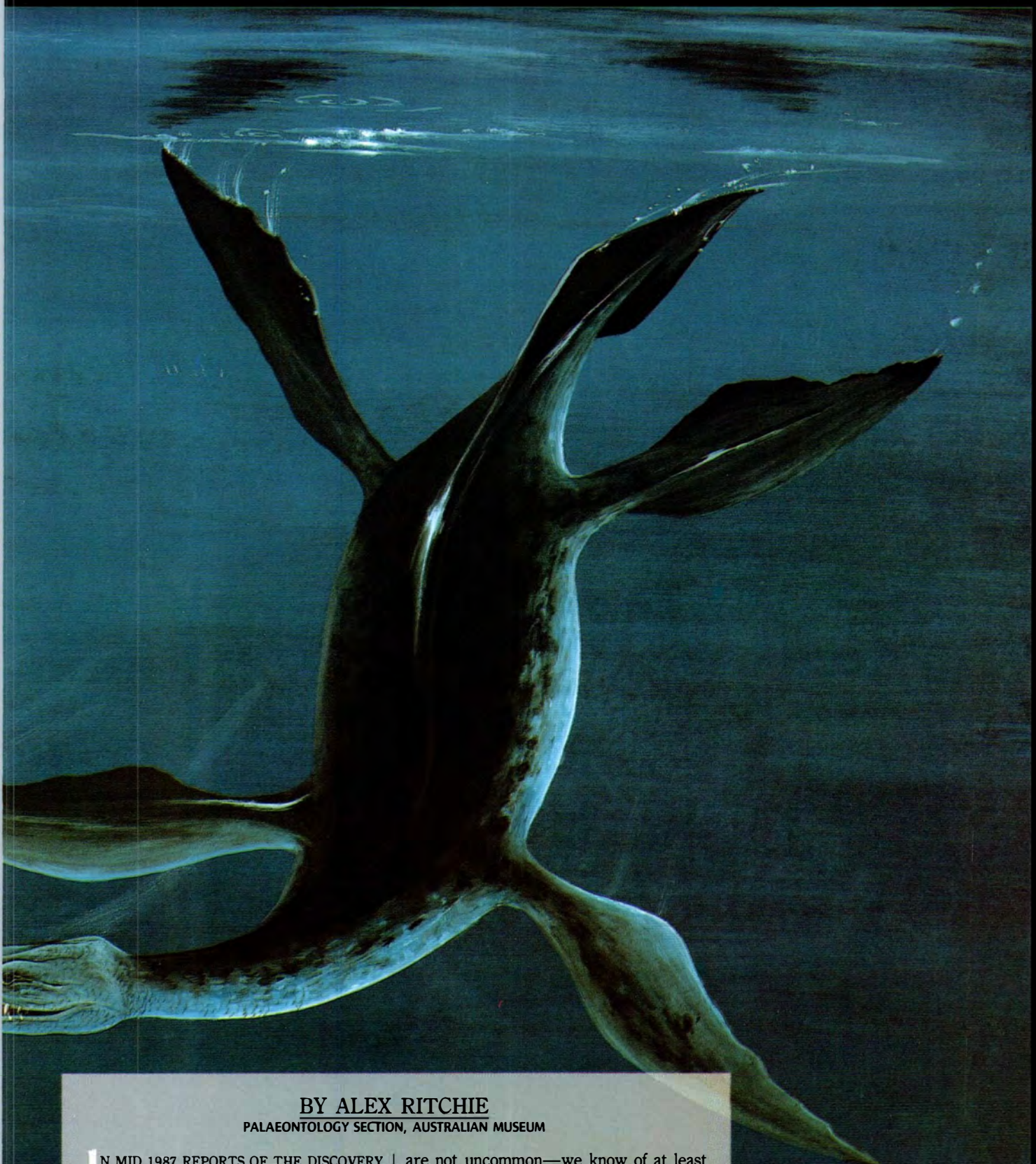
Prof. Gordon Grigg is Head of Zoology at the University of Queensland. His research interests include the physiology and ecology of Australian vertebrates, particularly Echidnas, crocodiles and kangaroos. Mrs Lyn Beard, Senior Scientific Officer, is his research assistant. Dr Mike Augee lectures in biology at the University of New South Wales. He has been studying the physiology of Echidnas since 1966.

"He was shown a pile of rubble for which the miners were asking $200,000, a sum far beyond the Museum's resources even for a reasonably complete skeleton."

RETURN OF THE GREAT SEA MONSTERS



JEANETTE MUIRHEAD



BY ALEX RITCHIE
PALAEONTOLOGY SECTION, AUSTRALIAN MUSEUM

IN MID 1987 REPORTS OF THE DISCOVERY of an opalised skeleton of a plesiosaur, an extinct marine reptile, reached us in the Australian Museum. The specimen had been dug out of an opal mine at Coober Pedy, South Australia. Such finds are not uncommon—we know of at least ten similar finds discovered over the last 20 years and there have almost certainly been others of which we scientists are unaware. We had been closely involved in one such find, in 1976, of a plesiosaur

Plesiosaurs and pliosaurs are long-extinct marine reptiles that lived during the Age of Dinosaurs. They flourished in shallow seas covering much of inland Australia in early Cretaceous times, 100–120 million years ago. They were fast-moving predators and probably swam by 'flying' underwater, not unlike modern penguins.

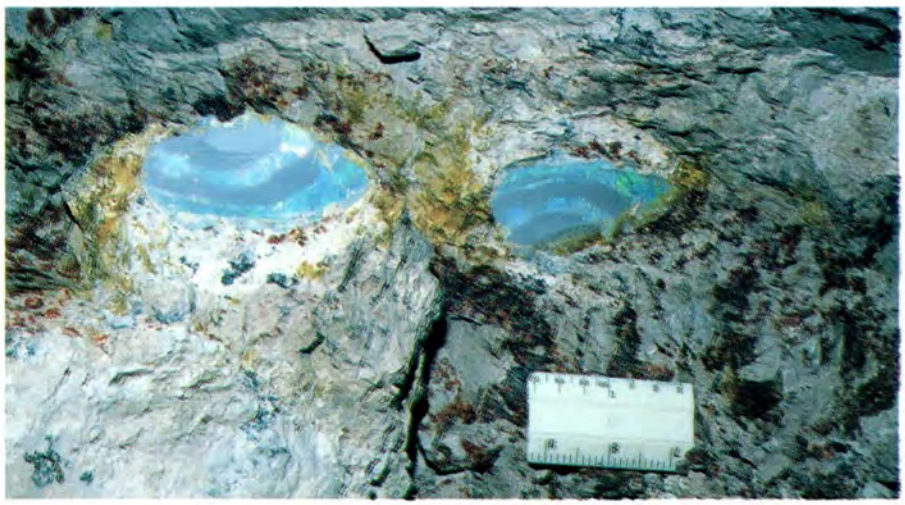
NEVILLE PLEDGE

Parts of the new Coober Pedy pliosaur in the condition they arrived in the Australian Museum and before preparation.

skeleton at White Cliffs, western New South Wales (of which more later). Unfortunately most opalised skeletons are incomplete, usually because they have been dug out by opal miners without scientific advice or assistance.

For two decades I have been interested in opalised fossils. On several occasions I have reported in ANH the fascinating—and frustrating—stories behind such finds (see ANH vol. 19, no. 12, 1979; vol. 21, no. 9, 1985; vol. 22, no. 8, 1988). For those who have followed the earlier discoveries, and for those who are new to the subject, a review of recent Australian discoveries and developments may be of interest.

On hearing of the latest find at Coober Pedy I immediately phoned Neville Pledge, my counterpart in the South Australian Museum. He confirmed that he had heard the report and was going to Coober Pedy to investigate. He later described how, when he visited the mine to inspect the specimen, he was shown a pile of rubble for which the miners were asking $200,000, a sum far beyond the Museum's resources even for a reasonably complete skeleton.



ALEX RITCHIE

Cross-section through a pliosaur femur replaced by precious opal, just after its discovery underground in Bob Foster's mine in the Sheepyard Opal Field, 70 kilometres west of Lightning Ridge, northern New South Wales.

ROBERT JONES

Alex Ritchie excavating a layer containing numerous opalised dinosaur bones in Bob Foster's mine, Sheepyard Opal Field, near Lightning Ridge in northern New South Wales.

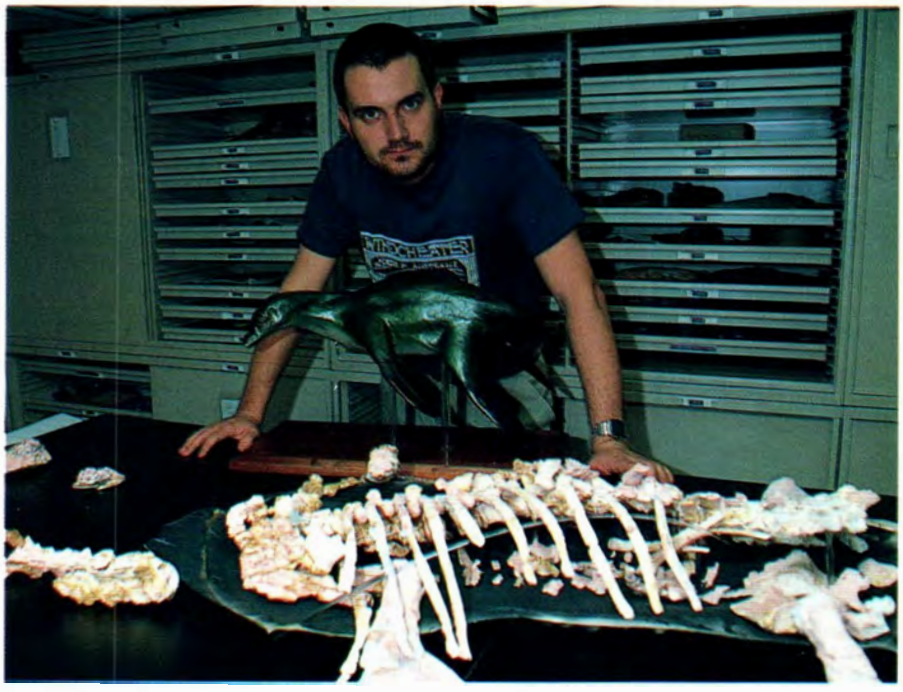
We thought nothing more about it until mid 1988 when Zoltan Berta, a Sydney opal dealer, sought our advice on an opalised skeleton that his firm, Berta Opals, was considering purchasing as a possible display item. It turned out to be the same Coober Pedy plesiosaur. Accompanied by Robert Jones, the Australian Museum's Palaeontology Collection Manager, I went to Berta Opals' office to inspect it. At first glance our hearts sank. The specimen had been brought to Sydney in a large steel box half full of pinkish sandstone blocks and innumerable smaller fragments. Most of them were bundled into plastic bags with no special packing or protection. None of the blocks was larger than fist-size. Some of the bags contained hundreds of miscellaneous opal chips.

We were introduced to Mr Joe Vida, the miner who had found it. He described how his tunnelling machine had cut into and exposed part of the skeleton in the wall of the opal mine. He and his partners had then dug the rest of it out with a pick. He assured us they had collected all of it but we had our doubts. We examined the rubble, in dismay, and knew just how Neville must have felt when he visited Coober Pedy the year before.

However, as we sorted through it, we gradually realised that we might still be able to salvage something from the wreckage. Some blocks contained parts of four or five evenly spaced ribs, others enclosed several vertebrae in line. Clearly the animal had been complete and still articulated when it was buried on a sandy sea-bottom over 100 million years ago. It was either a plesiosaur or a pliosaur, closely related marine reptiles, not unlike the legendary 'Loch Ness Monster', that swam in the seas over central Australia while dinosaurs roamed the land.

In our report to Berta Opals we recommended that, despite its condition, it *might* provide a reasonable display item but only if prepared by experts. It would still be a gamble because several crucial parts, such as the all-important skull, appeared to be missing. In the circumstances we questioned whether it was worth the $200,000 asked, mainly because of the haphazard way it had been excavated, collected and shipped, with bits rubbing freely against one another. (There is a lesson here for any other opal miner who finds such specimens: call in expert advice at the earliest possible opportunity. It will save money for you and valuable specimens for science.)

On reflection the board of Berta Opals decided against its purchase. Instead Mr Sid Londish, a prominent Sydney businessman and chairman of Comrealty, a large property development company, decided to buy it. On the basis of our report he had been able to buy it for considerably less than the original asking price, but still far more than any Australian museum could outlay. At that time Comrealty's planned developments in-



ANTHONY FARR/AUSTRALIAN MUSEUM

Paul Willis with the Coober Pedy pliosaur skeleton, which he prepared and reconstructed from hundreds of fragments in 450 hours of painstaking work.

cluded a large hotel and tourist complex in the Kings Cross area of Sydney. An opalised skeleton of an ancient sea monster would make a fine tourist attraction.

Having seen many fine fossil specimens ruined by well-meaning amateurs, we wanted to control the whole process and so we put a proposal to Comrealty. The Museum had the equipment and expertise, and we knew where we could find a student to prepare the skeleton under our supervision. Paul Willis, who is currently studying fossil crocodiles from Queensland at the University of New South Wales, has had a long-time fascination with dinosaurs. A plesiosaur was the next best thing to a dinosaur. Comrealty agreed with our suggestion and in September 1988 employed Paul to prepare their specimen in the Australian Museum's laboratory. To an impecunious student such employment was a godsend as well as invaluable experience.

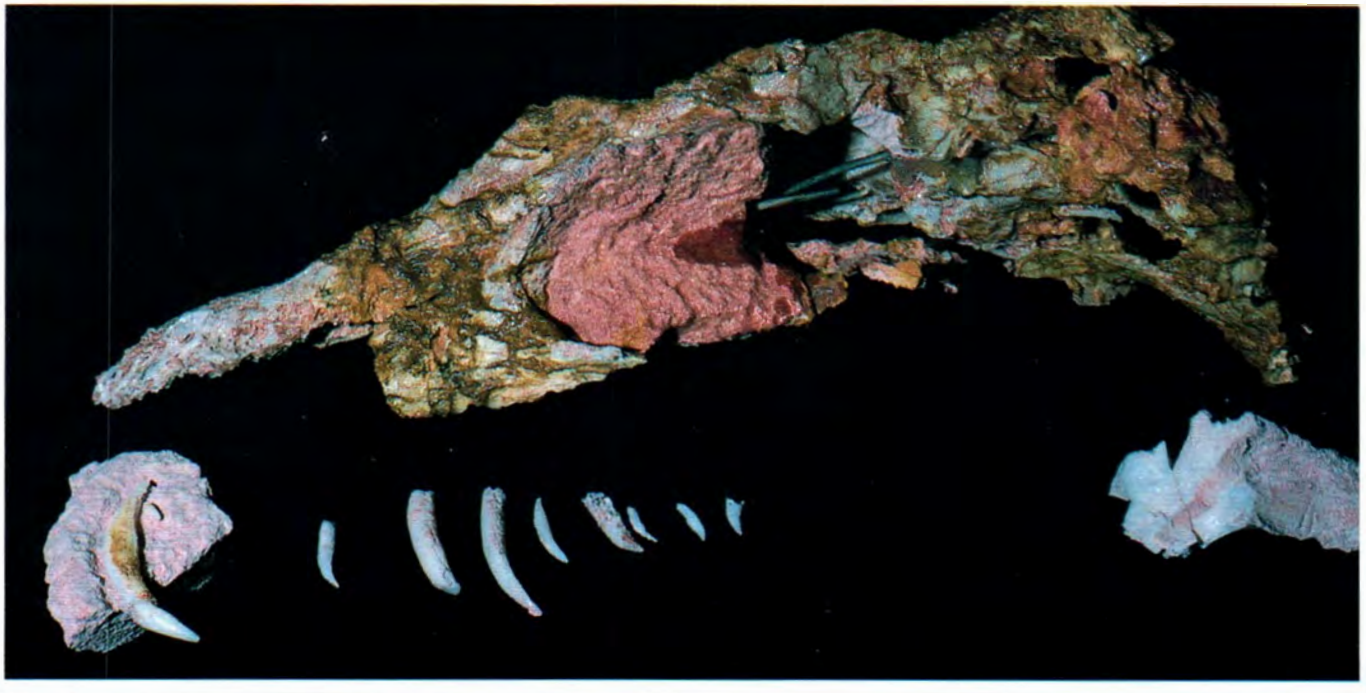
PAUL'S FIRST TASK WAS TO REMOVE THE rock from the opalised bones to find out how much was preserved. The thickest parts of rock were trimmed by an air-powered percussion tool. Closer to the bones Paul switched to more delicate means, an air-abrasive tool, a miniature sand blaster, using powders of different hardness. As the bones slowly emerged the magnitude of the problem became clearer. The larger blocks, with several bones still in association, provided the key as the backbone was extracted and reassembled.

The rib cage was especially tricky, with one side spread out and the other side more compressed. The miners had identified, cleaned up and partly reassembled the main limb bones (humerus and femur) but appear to have missed most of the smaller paddle bones (the phalanges). Although Paul searched carefully, only a few of the paddle bones were recovered.

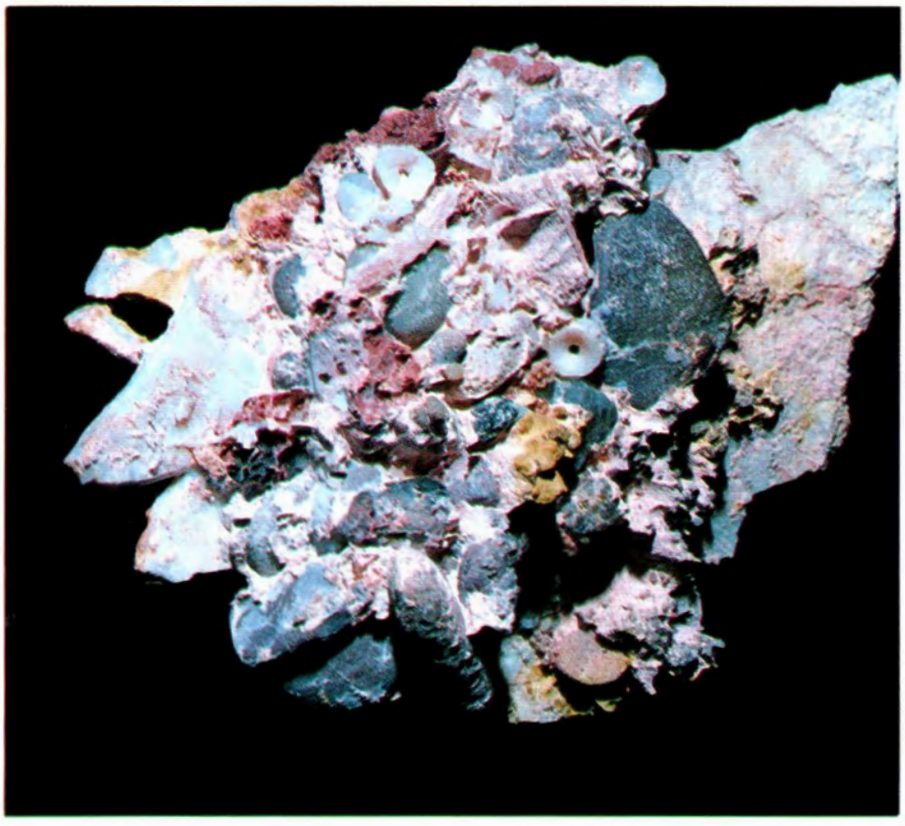
Although we had seen no trace of the skull, Paul gradually recovered parts of it as he systematically worked through the material. First the rear of the skull and braincase emerged, then most of the snout and two smaller pieces that fitted on to them. To our amazement most of the delicate triangular skull was present. Under the circumstances it was remarkably well preserved. None of the teeth remained attached to the skull itself but ten small, needle-sharp teeth were discovered lying loose in the rock surrounding the bones. They ranged in length from four to 45 millimetres. Only part of the rear of the lower jaw was found.

An even bigger surprise awaited us inside the rib cage—two clusters of smoothly rounded pebbles. The pebbles were of many different types of rock, as if they had been picked at random from a stony beach. They were quite out of place in the fine-grained sandstone matrix. The answer soon became clear; both lots of pebbles were still attached to parts of the pelvis and sections of the small ventral ribs characteristic of plesiosaurs and pliosaurs (and some other extinct rep-

The skull of the Coober Pedy pliosaur, extracted from four separate pieces of rock, resembles that of *Peyerus*, a pliosaur found in Cretaceous rocks of South Africa. Several loose teeth of various sizes were discovered in the sandstone around the bones.



ALEX RITCHIE

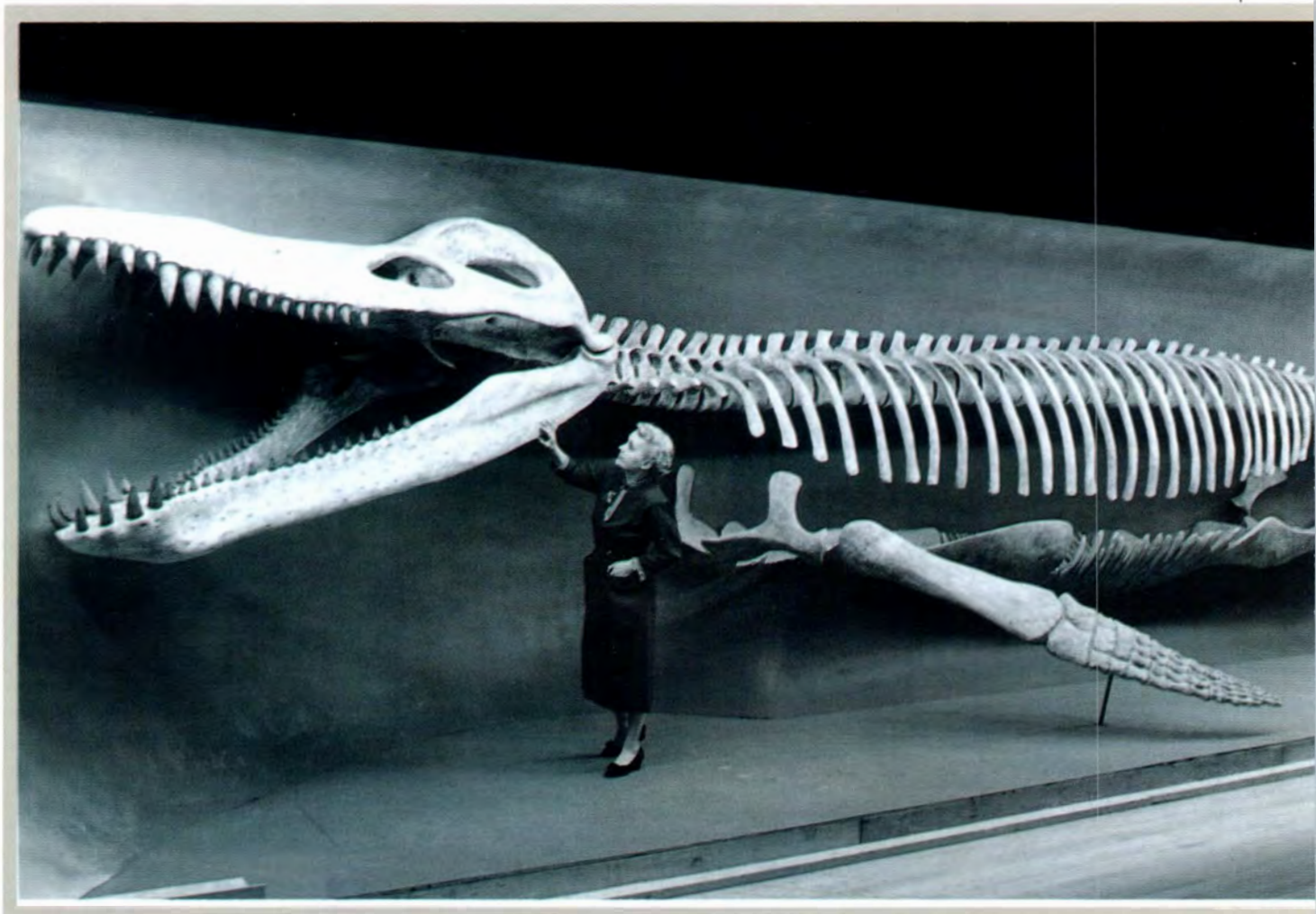


ALEX RITCHIE

tiles). The pebbles were gizzard stones, selected by the animal and swallowed either to help grind up its food or as a kind of ballast, or perhaps both. But the real surprise came as Paul cleaned up the patch of smaller pebbles. Nestling amongst them, complete and unabraded, were a dozen small fish vertebrae, also opalised. Paul, who had nicknamed his charge 'Eric', decided that the fish forming the remains of its last meal should be called 'Wanda', from the film of the same name. (Rather appropriately Paul was living in Wanda Crescent at the time!)

It took Paul about 450 hours of delicate, painstaking work to extract and reconstruct 'Eric'. As it was gradually reassembled it became clear that it was much more complete than we had anticipated, or had dared to hope. It was also clear that 'Eric' was *not* a plesiosaur, as we had originally thought, but a pliosaur.

A cluster of gastroliths (gizzard stones) attached to ventral ribs (not visible) and part of the pelvis of the Coober Pedy pliosaur. Lying among the rounded pebbles are about 12 small vertebrae of a bony fish. These vertebrae, the remains of 'Eric's' last meal, are also opalised, just like the pliosaur bones that enclose them.

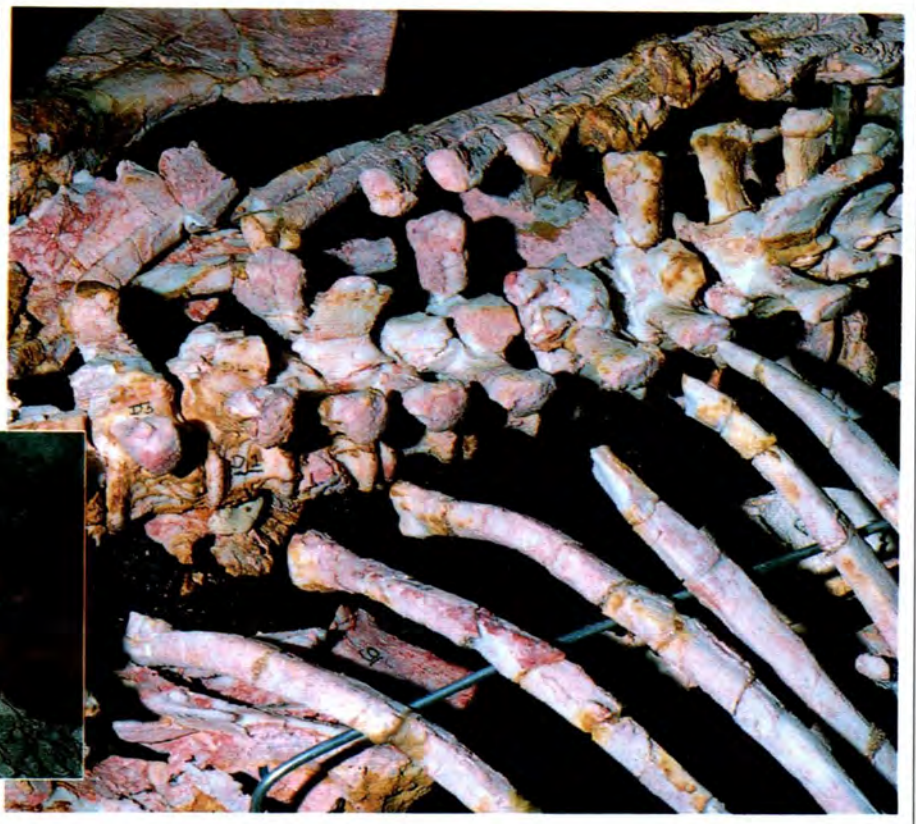


HARVARD UNIVERSITY

***Kronosaurus queenslandicus*, the world's largest known ancient sea monster, comes from Australia. It was discovered in 1931 near Richmond, northern Queensland by W. Schevill of Harvard University. This spectacular 13-metre-long pliosaur skeleton is seen here just before it went on display in 1958 in the Museum of Comparative Zoology, Harvard.**

Plesiosaurs and pliosaurs are closely related, but plesiosaurs have long, slender, flexible necks and relatively tiny skulls while pliosaurs generally have much larger skulls and shorter necks.

'Eric's' flippers were unusually long and powerful, and its short stubby tail ended in a series of about six fused and



ALEX RITCHIE

Part of the rib cage and backbone of the 1976 White Cliffs plesiosaur (below) with some ribs polished to show the opal and of the new Coober Pedy pliosaur (right) after reconstruction by Paul Willis. These two specimens represent the finest opalised marine reptiles found in Australia.

Other New Sea Monster Finds

The last couple of years have seen a remarkable chain of discoveries of extinct reptiles in Australia, especially in Queensland. In mid 1989 the Queensland Museum recovered a two-metre-long skull of the giant pliosaur *Kronosaurus* from a property in north-central Queensland. *Kronosaurus*, which reached a length of about 14 metres, is one of the largest known extinct marine reptiles.

Two months later, in October 1989, another property owner in the same area, near Richmond, discovered a fossil skull of another, smaller pliosaur weathering out of a creek bank. It was reported to the Queensland Museum whose team returned to the area to excavate the new specimen. It turned out to be a virtually complete pliosaur skeleton, five metres long, and one of the finest specimens of its kind found anywhere in the world.

Less than two months later, fired by his success, the same grazier went fossil prospecting again. On a low hill on his property, several kilometres from the first discovery, he found a second skeleton. This time it wasn't a marine reptile but a much rarer find—a dinosaur skeleton. With help from four students—Paul Willis, John Scanlon and Huw Barton from the University of New South Wales, and Juliet Hugenholz from Queensland University—the Queensland Museum extracted the specimen in January 1990. It was a small, three-metre-long ankylosaur (*Minmi*), unquestionably the most complete Australian dinosaur skeleton yet found (see ANH vol. 23, no. 6, 1990).

Although elated by their participation in this historic find, the three Sydney students were taken aback to find that the specimen they had come so far to help excavate had only taken three days to extract. They asked the Queensland Museum team to recommend other likely sites and were directed to a nearby property where, they were assured, they would certainly find some bone fragments.

Shortly after reaching the site and starting to prospect in the creek banks, Paul and his companions noticed a lump of limestone with bone weathering out. Digging around it they rolled it into the creek bed only to find, to their amazement, that it was the back half of a beautifully preserved, almost uncrushed, icthyosaur skull. Ichthyosaurs were dolphin-like marine reptiles that swam in the same seas as plesiosaurs and pliosaurs. With their trophy carefully wrapped up and cushioned, the three students drove back to Sydney in triumph.

With perfect timing Paul, John and Huw arrived back in Sydney shortly before our major exhibition 'Dinosaurs Alive' opened. 'Dinosaurs Alive' was based mainly on large, moving, stomping, roaring, robotic models of dinosaurs on loan from the National Science Centre in Canberra. To supplement the Disneyish aspect of the moving models I had been desperately seeking other items such as skulls, skeletons, models and trackways to increase the scientific and educational content of our display. We quickly slipped the ichthyosaur skull into a bath of dilute acid to clean it up. In the display we had a section for 'New Australian Finds' and the ichthyosaur skull provided a showpiece item.

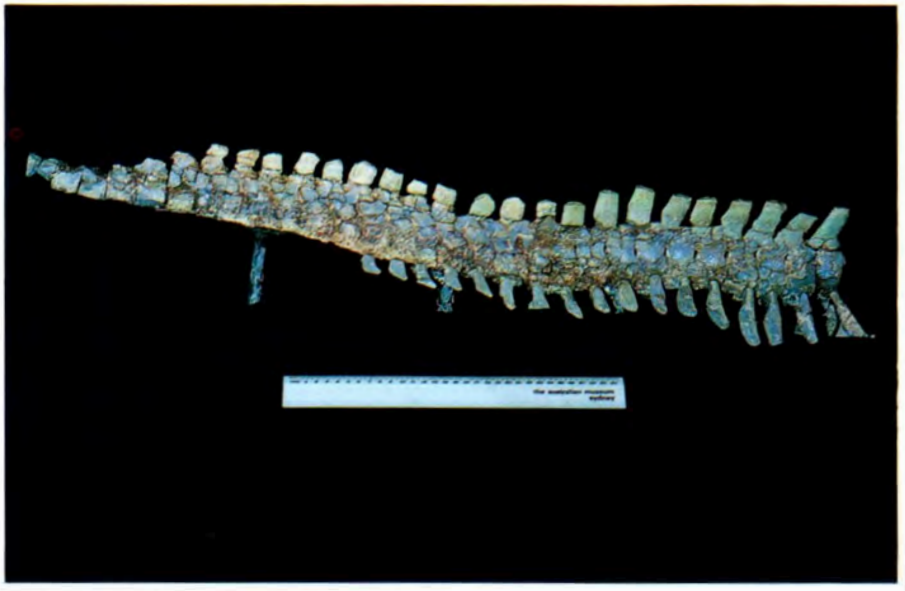
Two days after 'Dinosaurs Alive' opened, one of the security guards noticed a young man staring at the ichthyosaur skull for a very long time. When approached the visitor asked to speak to a Museum palaeontologist and I was sent for. He informed me that his name was Ken Delaney and that his family had owned the property where it was found until the previous year. "I've got a more complete skull than that one," Ken said, pointing to the specimen found by the three students. "You can have it if you like, it's probably better off in a museum!"

At the time of writing, arrangements are being made to have Ken Delaney's specimen shipped down to Sydney from Townsville but, even from his photographs, it is clear that it is a very fine specimen. The skull is about 1.5 metres long, lacking only about 50 centimetres of the snout, with the lower jaws still attached and all the teeth still in place.

Plans are also being made to return to northern Queensland to search for the missing front half of the ichthyosaur skull find. Maybe there will be an interesting sequel to this remarkable chain of discoveries in the saga of the 'Return of the Great Sea Monsters'.

ALEX RITCHIE

Hauling the White Cliffs plesiosaur specimen to the surface in July 1976.



ALEX RITCHIE

Neck of the White Cliffs plesiosaur after cleaning and reconstruction by its discoverer, opal miner Ken Harris.

somewhat flattened vertebrae, suggesting that the tail may have been slightly flattened and used for propulsion or as a rudder. In the shallow seas covering central Australia in early Cretaceous times (110–120 million years ago) fast-swimming, fish-eating predators such as 'Eric' were the reptilian counterparts of today's marine mammals and mobility in water must have been a major asset.

Until studies of the specimen are complete we are uncertain if it represents a new genus or species, but preliminary investigation by Dr Ralph Molnar of the Queensland Museum has revealed that, in several unusual features of its skull, the new Coober Pedy specimen resembles a known pliosaur called *Peyerus* from Lower Cretaceous rocks of South Africa.

MR SID LONDISH AND COMREALTY, owners of the Coober Pedy pliosaur, have generously allowed us to display this remarkable specimen in the Australian Museum while discussions about its eventual fate proceed. There can be no

doubt that such opalised skeletons form a unique part of Australia's natural heritage and deserve to be recognised as such. Without Mr Sid Londish's involvement and support it is likely that this specimen, like so many others before it, would have been broken up or shipped out of the country to some overseas museum and Australia would be the poorer.

By a strange coincidence another opalised skeleton went on public display in Sydney at about the same time that 'Eric' arrived at the Museum. It was the plesiosaur skeleton that Robert Jones and I had helped excavate at White Cliffs in 1976. Its owner, opal miner Ken Harris, has now leased it to Fantos Ltd, a large new Japanese-owned duty free store in George Street, Sydney, a stone's throw from Circular Quay. The White Cliffs plesiosaur was installed, under our supervision, in a large display case in a setting resembling an underground opal mine at White Cliffs. At least it is now in Sydney and thus more readily accessible to all visitors, Australian or overseas.

Our long-term hope is that, one day, both of these fabulous specimens will be acquired by, and permanently installed in, the Australian Museum. The White Cliffs plesiosaur and the Coober Pedy pliosaur form a beautifully complementary pair. Displayed together they would provide a breathtaking, unique exhibit of two Australian national treasures that deserve to be seen by the widest possible audience, in perpetuity. ■

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Dr Alex Ritchie is palaeontologist and senior research scientist at the Australian Museum. He has been there since 1968. His main research is on early fossil fish but he is also involved in the search for Australian dinosaurs and other fossil reptiles.

TASMANIAN MUSEUM

"Many workers have regarded the mystery as resolved. Nevertheless the case of the Thylacine has continued to be a tempting context for exploration of new kinds of data."

SEARCH FOR THE THYLACINE'S SISTER

CHARLES KNIGHT

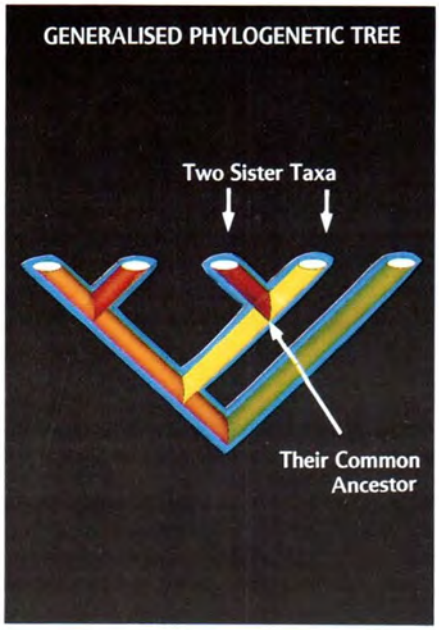
BY DANIEL P. FAITH
CSIRO DIVISION OF WILDLIFE AND ECOLOGY

THE DIVERSITY OF AUSTRALIAN MARSUpials includes not only our familiar Koala, kangaroos and possums, but also species that, for one reason or another, are less well known. Sadly, the endangered status of some of these species, or even their outright extinction, may mean that we never become familiar with some quite remarkable animals.

D. WATTS/NPIAW

One of the most fascinating of all marsupials is almost certainly extinct. Imagine a large carnivorous marsupial, resembling a Wolf on one hand, but also having stripes like a Tiger. This animal, the Thylacine (*Thylacinus cynocephalus*), presents us with some mysteries that would challenge any detective. Their disappearance is intriguing because they were, at one time, not only found in Tasmania but also on mainland Australia.

Thylacines were considered sheep killers in Tasmania and a Government bounty was paid between 1888 and 1909 for skins presented. Such direct, deliberate human intervention led to the extinction of the Thylacine within the first half of this century, which has made it all the more difficult to trace its evolutionary relationships with other marsupials. Top: Reconstruction of the early Miocene borhyaenid *Prothylacynus patagonicus*. Borhyaenids, the South American group of carnivorous marsupials, were thought to be the Thylacine's closest relative at the beginning of the century, a theory challenged since. Bottom: After weighing up all the evidence, the Thylacine seems to be most closely related to dasyurids, such as this Eastern Quoll (*Dasyurus viverrinus*).



One dramatic bit of evidence for this is the rock paintings of Thylacines in Kakadu National Park, Northern Territory. While Thylacines apparently disappeared about 3,000 years ago from the mainland, they persisted in Tasmania at least until 1936, when the last known wild individual died after capture. Much detective work since has failed to find a living specimen.

Another kind of detective work on the Thylacine has also been going on for much of the past century, and has produced some tantalising results. This research concerns the mystery of the evolutionary or phylogenetic relationships of this unusual species to other marsupials. Phylogenetic relationships are those that record patterns of common ancestry of different species (or, more generally, different 'taxa'). These relationships, in tracing the formation and evolutionary history of related taxa, can be represented by branching patterns, or tree diagrams, in which the taxa of interest form the tips of the branches. A phylogenetic tree identifies a hierarchy of pairs of taxa ('sisters') that share a common ancestor.

The position of the Thylacine in such a tree, relative to other marsupials, can shed some light on what the Thylacine must have been like. Clues to the relative position of the Thylacine on such a tree are found in the observed similarities between the Thylacine and other taxa. These similarities are based on morphology or other shared features that represent evolutionary novelties among marsupials. Because these available clues are not unanimous in the story they seem to tell, the task of unravelling this mystery has been a difficult one. In fact, the case of the Thylacine has been so challenging that it provides insights into the problems that all systematists face in accumulating evidence about phylogenetic patterns.

THE EARLY IDEAS ON THYLACINE RELATIONSHIPS have been well summarised by Professor Michael Archer of the University of New South Wales. Surprisingly, the story begins with South American marsupials rather than Australian ones. At the beginning of this century, B.A. Bensley noted striking similarities between the Thylacine and an extinct South American group of carnivorous marsupials, the borhyaenids. The similarities were particularly marked in the morphology or appearance of the teeth. Later workers noted additional similarities in skeletal features. Based on this evidence, the conclusion seemed inescapable that the Thylacine must have shared a recent common ancestor with the borhyaenids. In its origins at least, the Thylacine was apparently not a fair-dinkum Aussie at all, but rather had its sisters among the South American forms (see tree A).

This early work set the stage for some interesting counter-arguments over the next decades. The great evolutionist, George Gaylord Simpson, argued in 1941 that the Thylacine and the borhyaenids were not close relatives. His arguments highlighted one of the key weaknesses in using observations on shared features, such as the teeth characters, as evidence of common ancestry. Suppose that the observed features, rather than being inherited from a common ancestor, had evolved independently in Thylacines and borhyaenids. Such independent evolution of the same derived feature is called convergence. Convergent derivation of these shared features implies that the two species need not be closely related at all. Thus, Bensley's argument was turned on its head by Simpson (and later other workers) in proposing that the observed similarities between the Thylacine and borhyaenids were not evidence for recent common ancestry.

The counter-proposal growing out of

Cladistics

In cladistics, different features may provide evidence for different phylogenetic trees. In the figure here are two possible trees for four taxa (a, b, c and d). The table lists the taxa having each feature X, Y or Z. Tree I is supported by feature X, but not by feature Y. Feature X implies a single evolutionary acquisition of the derived feature, while feature Y implies two evolutionary events (or 'steps'). The reverse is true for tree II. Feature Z is compatible with either of the trees, but would not support a tree in which those taxa with that feature were found in different parts. If the observed features for these taxa included many features shared by taxa a and b, such as feature X (relative to features like feature Y), then tree I is favoured over tree II by the principle of parsimony.

	FEATURE PRESENT ?		
TAXON	X	Y	Z
a	YES	YES	NO
b	YES	NO	NO
c	NO	NO	YES
d	NO	YES	NO

IAN FAULKNER

this work was that the Thylacine had as its sister-group the Australian dasyurids—a group of insectivorous and carnivorous marsupials, including the Tasmanian Devil, quolls and others. This hypothesis has gained some strong support only in the last decade when new sets of anatomical features were examined in detail. Frederick Szalay, from the City University of New York, found a number of aspects of the morphology of the tarsal (foot) bones that were shared by the Thylacine and other Australian marsupials, but were absent from borhyaenids. Here, then, was a pattern contrary to that based on teeth and other skeletal features that had linked the Thylacine to borhyaenids.

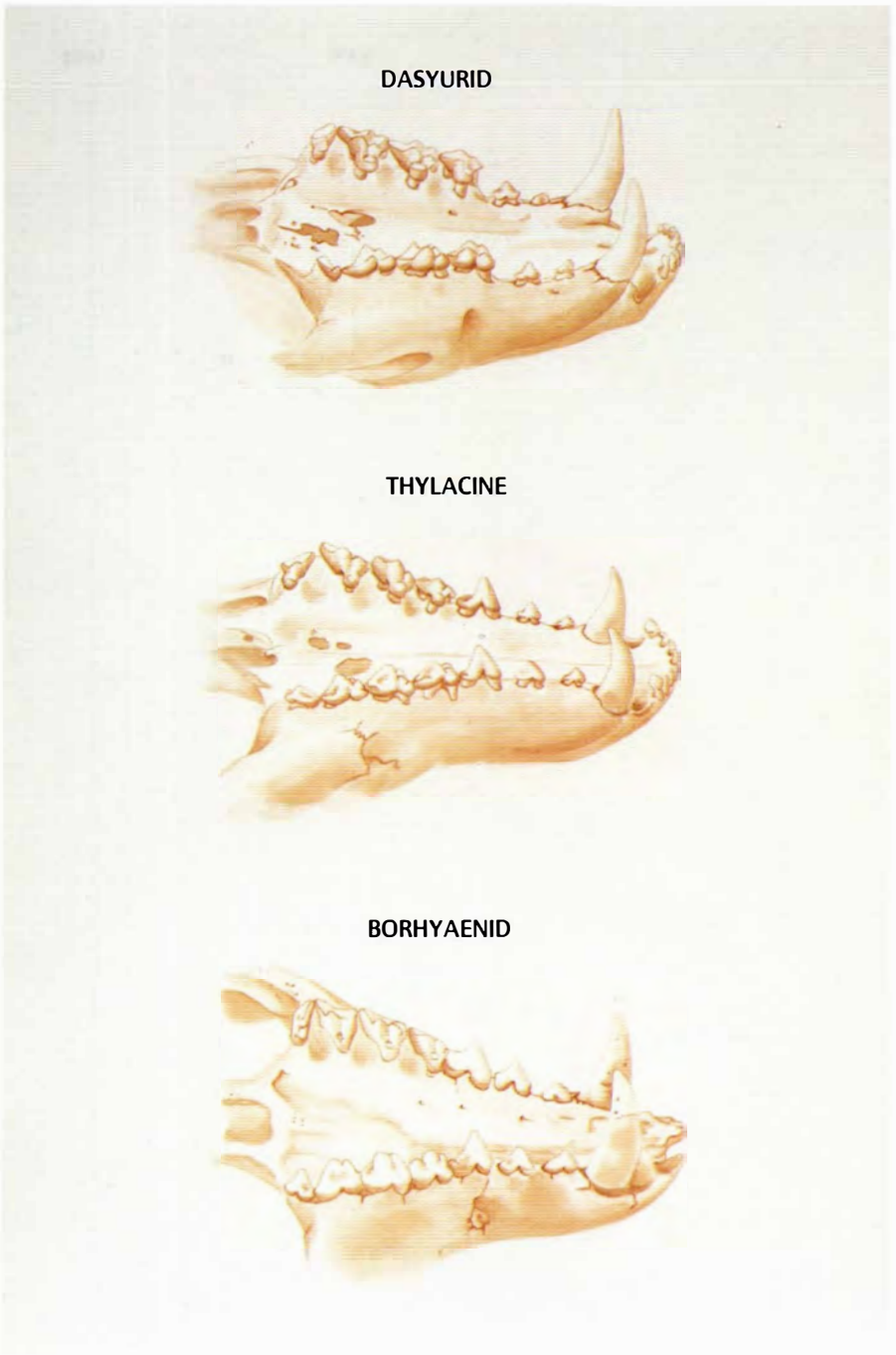
This new work was important in encouraging the evaluation of other features. But how should all these clues, represented by different features, be weighed up to draw a conclusion about phylogenetic relationships? What do systematists do when different sets of features (as for the teeth and the tarsus) yield contradictory evidence? Szalay and Archer and others have turned to a formalised procedure to explore all of this conflicting evidence.

BECAUSE THE DIFFERENT HYPOTHESES about phylogenetic relationships can be represented by different tree diagrams, a formalised method must somehow distinguish among all the possible trees in light of the best available evidence at the time. The methods of cladistics (from the Greek word *klados*, meaning branch) use evidence from many characters and choose the tree that implies the smallest amount of convergence and reversal (change of a feature back to a primitive form). This criterion turns out to be identical to choosing the tree that implies the smallest number of changes in features, and is sometimes referred to as the 'principle of parsimony'.

What is the rationale for this approach? Because we can never know for certain the historical events that determine a phylogeny, workers using cladistics take the view that the best hypothesis will be the one that best reflects our expectations about how a phylogeny can account for the shared features among taxa—namely through their inheritance from a common ancestor. By counting the number of changes in features implied by a particular tree, we measure the degree to which the tree accounts for inherited shared features (see box for further explanation).

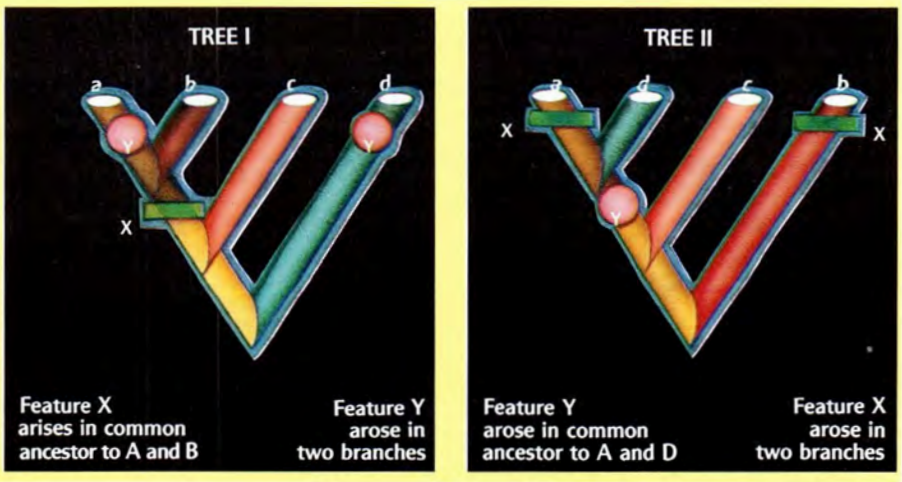
Archer used cladistic methods in 1982 to pull together all the evidence available at that time relating to the Thylacine. Based on all of the dental and skeletal features, including those for the tarsus, the most informative tree (in accounting for shared features) turned out to be the one in which the Thylacine and borhyaenids were sisters (see tree A).

However, some additional evidence of



LYNNE ALBERTSON

Comparison of the upper teeth rows of an Australian dasyurid (top), the Thylacine (middle) and a South American borhyaenid (bottom), showing the similarity between the specialised dentition of the Thylacine and boryhaenids.



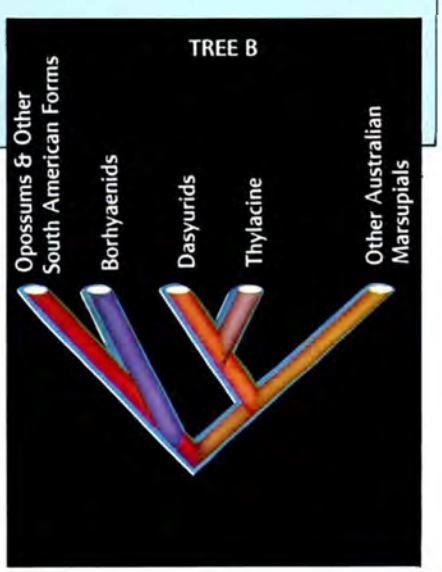
IAN FAULKNER

A mummified Thylacine, dated at 4,500 years old, collected from a cave on the Nullarbor in 1966. It is possible to extract small amounts of the protein albumin and even DNA from dried museum specimens for comparison with other marsupials.

quite a different kind also became available in 1982, using a relatively new technique for assessing relationships based on principles of immunological reactions. If versions of the same protein from two different species are compared, the more similar they are (in their exact make-up of amino acids), the greater the immunological response when antisera specifically designed to react to one of them are instead combined with the other protein. While this technique does not produce direct evidence of shared features, it does indicate the relative degree of overall similarity between the proteins of the two species. Presumably, the more similar the two proteins, the more closely related are the two taxa, because the proteins consequently have had less time to diverge through gradual evolutionary change.

The problem in applying this technique to the Thylacine, of course, was that no living material was available from which to extract protein samples. However, Vincent Sarich from the University of California at Berkeley and his colleagues, in the true spirit of detectives, were able to extract small amounts of the protein albumin from the dried skins of museum specimens, for comparison with albumin samples from other marsupials. While these comparisons were limited by the absence of material from borhyaenids, the surprisingly high similarity of the Thylacine to dasyurids suggested such a recent common ancestor for the two that a tree like tree B could be considered more likely than tree A. Consequently, Archer (in agreement with Sarich and col-

GEORGE KENDRICK/WA MUSEUM



IAN FAULKNER

leagues) concluded that it was more likely that the Thylacine was most closely related to dasyurids.

Many workers since have regarded the mystery as resolved, and have proposed classifications of marsupials based on the sister-relations of the Thylacine and dasyurids. Nevertheless the case of the Thylacine has continued to be a tempting context for exploration of new kinds of data. One reason might be that the indirect methods based on immunological reactions have been criticised in the past, and so it has remained somewhat unsatisfactory that more direct data, particularly on molecules, hasn't been available. Further, recalling Archer's cladistic analyses, the direct data available (that of skeletal features) implied quite a lot of convergence with borhyaenids if the Thylacine was to be considered more closely related to dasyurids. More direct observations on different kinds of features have thus been welcomed.

Given this state of affairs, then, it was naturally tempting to try to use one of the most exciting direct forms of molecular evidence—the comparison of features of the DNA of different taxa. Information on the details of DNA structure had al-

ANTHONY FARR/AUSTRALIAN MUSEUM

Pickled bag of treasure? This Thylacine foetus held in the Australian Museum's spirit collection may hold more clues to the Thylacine's ancestry.

AUSTRALIAN MUSEUM

One of the last photos of a live Thylacine, from the Australian Museum archives.

ready been used successfully in solving phylogenetic problems, particularly in the past decade. But for the Thylacine a serious problem was apparent: how can such data be obtained for an extinct species?

THE ANSWER TO THIS BECAME CLEAR IN 1989 with publication of a report in the British journal *Nature* by Richard Thomas and others at the University of California, Berkeley. Recent breakthroughs in DNA technology were used to extract an exceedingly small amount of DNA available from the museum specimens and then produce many new copies of the DNA in order to observe features of the sequence of nucleotides that make up the DNA. Their success in obtaining a DNA sample was all the more impressive because the museum specimens were prone to contamination by human DNA through handling.

By cladistically analysing the sequence positions of the nucleotides for each of five marsupial taxa (Opossum, Thylacine, dasyurids, bandicoots and possums), a tree like that of tree B, with dasyurids as the sister-group to the Thylacine, was favoured. Thomas and his collaborators considered that their data provided conclusive evidence for Thylacine relationships. However, this new evidence of Thylacine relationships has recently prompted some close attention to our fundamental ideas about how we should evaluate evidence from different sets of features. How should we decide whether the evidence from a given character data set is particularly convincing? I recently performed a simple computer-based experiment as one means of evaluating the DNA data on Thylacines.

Recalling that the 'success' of a cladistic tree is measured by the degree to which the total number of evolutionary changes in features is minimised, I wondered whether purely random data might have a reasonable chance of producing a tree as good as that of Thomas *et al.* Suppose that the set of nucleotides at each site had simply been dealt out, like playing cards, at random to each taxon. This would create a 'randomised data set' that could be analysed cladistically. Comparison of the original cladistic analysis with corresponding analyses on many such randomised data sets can form the basis for a significance test akin to that commonly used by statisticians to evaluate patterns. The statistician prescribes a maximum acceptable value on the observed proportion of random sets producing a pattern as good as that for the original data. If the proportion is greater than this maximum value, the original pattern is regarded as not significantly different from that which could be produced by chance. Normally, this maximum proportion is 0.05, or five out of every 100 data sets.

When this sort of comparison was applied to the cladistic analyses of Thomas

et al.'s data and 99 randomised data sets, the random sets were found to produce a tree at least as good as that for the original data approximately one in ten times. This proportion is about double that normally accepted by statisticians. Consequently, the cladistic tree produced from these DNA data cannot be regarded as significantly different from that which could be produced from random data! This result, presented in detail in a report in the same journal, casts some doubt on the finality of the evidence from this DNA data.

So the mystery concerning the identity of the phylogenetic sister of the Thylacine remains a demanding challenge to all kinds of data, and provides lessons in how data should be evaluated. While the mounting evidence points to the dasyurids as the Thylacine's sister-taxon, acceptance of this pattern means that we must in turn accept a remarkable amount of morphological convergence between the Thylacine and borhyaenids. Understanding this potential for convergence is fundamental to our understanding of the Thylacine's evolution and ecology. Indeed, if we return to the mystery of the Thylacine's disappearance from the mainland, convergence truly may have had the last word. According to Archer, the Thylacine's convergent similarity with a late arrival to Australia, the Dingo, may well have contributed to the Thylacine's decline, because such similarities may have placed the two species in intense competition. ■

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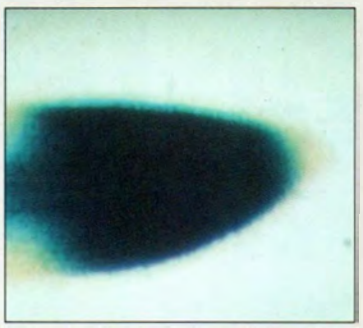
Dr Daniel P. Faith is a senior research scientist at CSIRO's Division of Wildlife and Ecology in Canberra. His research interests involve mathematical aspects of a variety of problems in ecology and evolution.

"In haemoglobin, evolution developed a successful molecular strategy to transport oxygen during one of the earliest periods of life on the planet. This gene has been retained, across billions of years, in what are now some of the most diverse life forms on Earth."

HAEMOGLOBIN IN PLANTS

WHEN CONSERVATISM RULES



BY KAREN McGHEE
CSIRO DIVISION OF PLANT INDUSTRY

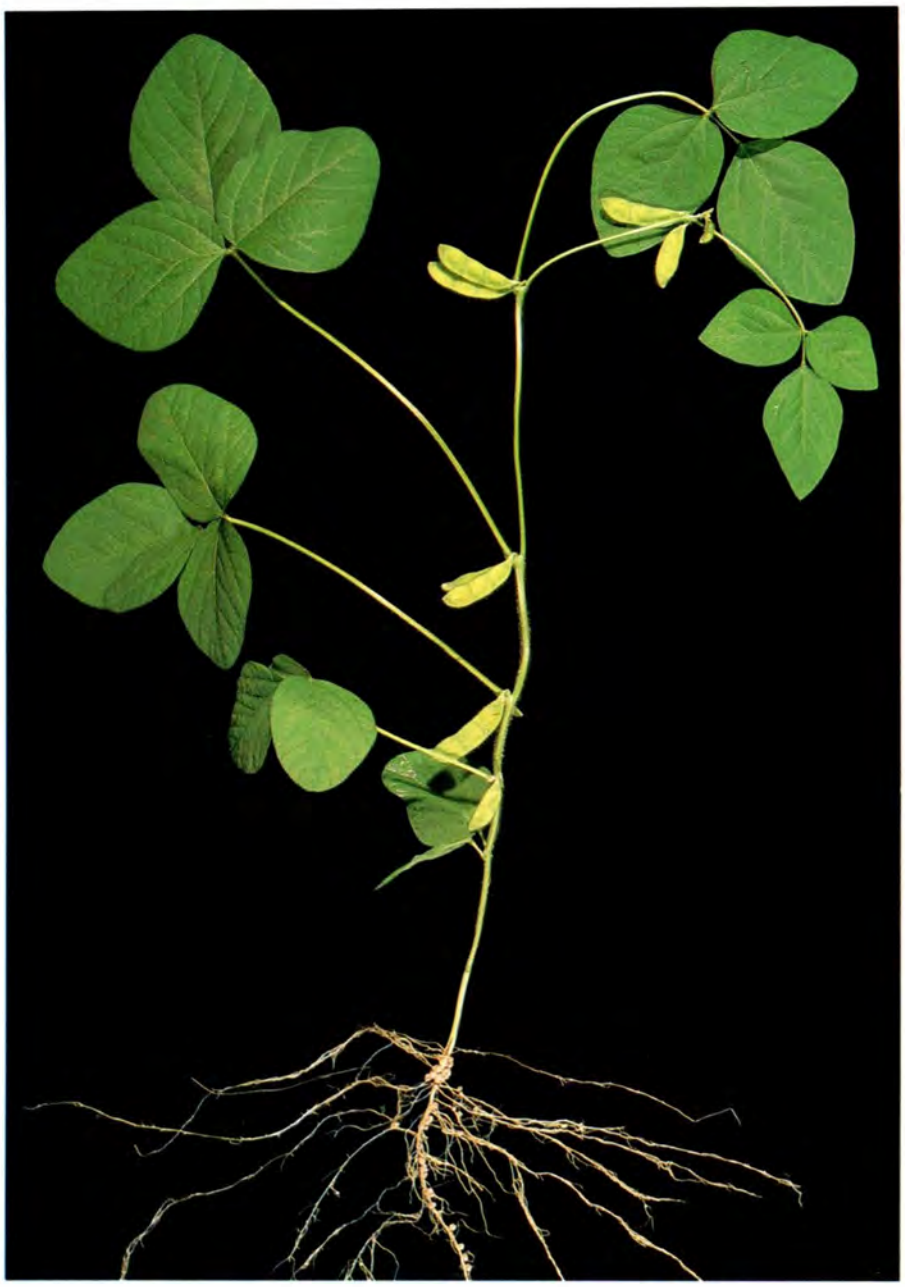
THE GENETIC PERSPECTIVE OF LIFE now rapidly emerging from the world's molecular biology laboratories is revealing evolution to be a force of extraordinary conservatism. Comparative morphology and physiology have long depicted evolution as frugal, but the 'new biology' is providing a more potent meaning to the words 'when you're on a good thing stick to it'. Across extraordinary distances against the rigours of time, evolution appears to have been unrelenting in the preservation of successful molecular and genetic strategies: even the most diverse forms of life, it seems, rely upon the same basic components.

Some of the most exciting recent Australian research to contribute to this view of evolution centres on haemoglobin, the oxygen-carrying protein found widely throughout the animal kingdom, notably in the blood of mammals. Investigations by a team of molecular biologists led by Dr Liz Dennis, at CSIRO's Division of Plant Industry in Canberra, have been instrumental in changing the scientific outlook on haemoglobin. The Division's work in the area suggests that this protein, once considered a key characteristic of animals, is also widespread in the plant kingdom. And the picture of haemoglobin that is developing internationally puts the origin of the gene responsible for the protein back billions of years.

STUART CRAIG

Haemoglobin has been found to occur in the nodules of *Parasponia*, a non-legume, nitrogen-fixing tree genus native to New Guinean and Indonesian rainforests (right). Using genetic engineering techniques a 'reporter' gene attached to *Parasponia* haemoglobin gene promoters (control 'switches') is engineered into tobacco. Expression of the reporter gene (shown in blue) is concentrated in the root tips of the transgenic tobacco plant (top).

JULIE FAULKNER



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JULIE FAULKNER

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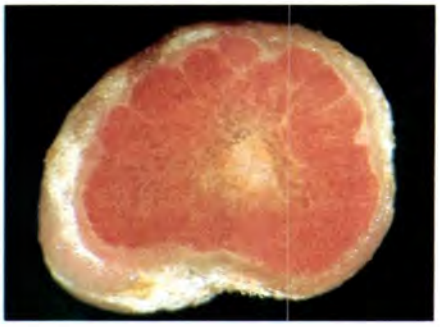

STUART CRAIG

This series of photos shows the nodules on a soybean—a nitrogen-fixing legume: the whole plant, a cluster of nodules just below the stem, and a close-up of and cross-section through one of the nodules. The haemoglobin molecule incorporates iron, giving mammalian blood its characteristic red colour and the pink–red tinge seen here in the nodules.

FOR DECADES IT WAS THOUGHT THE OCcurrence of haemoglobin in the plant kingdom was an anomaly associated only with the mechanism of nitrogen fixation. By forming symbiotic relationships with bacteria such as *Rhizobium* and *Frankia*, a small number of diverse plant groups have gained the ability to manufacture their own nitrogen. These plants develop organs known as nodules on their roots to house the bacteria that fix nitrogen as a metabolic by-product.

Plant haemoglobin was first discovered about 50 years ago in the nodules of legumes, the largest group of nitrogen-fixing plants. Its role in legumes is to deliver a constant low-level concentration of oxygen needed by enzymes involved in the nitrogen-fixing process. Haemoglobin's development in these plants was seen by some as an example of 'convergent evolution' with animal haemoglobin. Others saw it as a possible case of 'horizontal gene transfer', the haemoglobin gene passing into legumes through a close association with bacteria or an insect.

About six years ago, Dr Cyril Appleby and Dr Mike Trinick, also at the Division of Plant Industry, found haemoglobin in the nodules of species from the non-legume, nitrogen-fixing elm tree genus *Parasponia*, which has a restricted distribution in New Guinean and Indonesian rainforests. Soon after, haemoglobin was also found in the nodules of other nitrogen-fixing, non-legume tree species, in particular the Australian native genus *Casuarina*. These discoveries put serious strains on the validity of, what were at the time, the two most popular theories on plant haemoglobin evolution. And in recent years the techniques of the molecular age of biology have provided almost indisputable evidence for another theory, one of 'linear descent' of the haemoglobin gene in the plant and animal kingdoms from a common ancestor.

The initial breakthrough came with the analysis of the haemoglobin molecules from legumes and mammals. Both were shown to be extraordinarily similar. In particular, some of the most critical amino acids in the haemoglobin structure—those involved in folding the protein and forming the molecular pocket that transports oxygen—were found to be identical.

The next development appeared with the isolation and comparison of the structure of the genes responsible for the production of the haemoglobin protein in

legumes and mammals. All proteins are produced in living organisms according to coded genetic instructions carried on the double-stranded DNA molecule. There are about 100,000 different genes in the average plant or animal: each is responsible for the production of a different protein. Plant and animal DNA is generally confined to the nuclei of cells. In a cell, the instructions from a gene are copied by a single-stranded molecule known as messenger RNA and carried from the nucleus to the cell's 'protein factories'—the ribosomes, located in the cell's cytoplasm. The ribosomes then 'read and translate' the messenger RNA, laying down amino acids, according to the coded instructions, to produce a protein.

The similarities between the legume and animal haemoglobin genes were striking, suggesting an even closer relationship than was indicated by the match between the proteins. According to a widely supported theory, plant and animal genes are built up from separate functional components as if they were Lego constructions. The component sections of the chemical code are known as exons, and the sites where they join are introns. There are three introns in the legume haemoglobin gene and two in the animal haemoglobin gene. The first and third introns in the legume gene are in exactly the same position as the introns in the animal gene. And the central intron of the legume gene is located where protein chemists had predicted (from the structure of the animal haemoglobin molecule) that a third intron would have been expected in the animal gene. Presumably this intron had been there once but had disappeared through the course of evolution of the animal haemoglobin gene.

These similarities could not be explained by mere coincidence: the hypothesis of linear descent was looking more and more acceptable. The theory gained more weight with the isolation and analysis of other plant haemoglobin genes, initially from *Parasponia* spp. and later from *Casuarina* spp. Again, the composition of the exons and the positions of the introns of these genes had an extraordinary affinity with those from legumes and animals.

Nitrogen fixation has a widely scattered phylogenetic distribution throughout the plant kingdom. Yet, it was obvious that the haemoglobin gene confirmed a degree of commonality between the otherwise diverse plant groups that have the ability to fix nitrogen. The question is, were all plants once nodulating (that is, producing nodules) with nitrogen-fixing capabilities, the mechanism and the haemoglobin gene surviving today as relics in only a few species throughout

JULIE FAULKNER

The nitrogen-fixing Australian native tree, *Casuarina*. Haemoglobin is found in its nodules and to a lesser degree in its roots.

A section by section comparison of the biochemical structure of legume, non-legume and mammalian haemoglobin reveals remarkable similarities, shown in green.

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                    10        20        30        40        50
Trema Hb            SSSEVDKVFTEEQEALVVKSWAVMKKNSAELGLKFFLKIFEIAPSAKNLFSYLKD
Parasponia Hb       SSSEVNKVFTEEQEALVVKAWAVMKKNSAELGLQFFLKIFEIAPSAKNLFSYLKD
Casuarina Hb        +++++++ALTEKQEALLKQSWEVLKQNIPAHSLRLFALIIEAAPESKYVFSFLKD
Soybean Lb          +++++++VAFTEKQDALVSSSFEAFKANIPQYSVVFYTSILEKAPAAKDLFSFLAN
Sperm whale Mb      +++++++VLSEGEWQLVLHVWAKVEADVAGHGQDILIRLFKSHPETLEKFDRFKH

                    60        70        80        90        100
Trema Hb            +SPI+PLEQNPKLKPHAMTVFVMTCESAVQLRKAGKVTVRESNLKRLGAIHFKNG
Parasponia Hb       +SPV+PLEQNPKLKPHATTVFVMTCESAVQLRKAGKVTVKESDLKRIGAIHFKTG
Casuarina Hb        +SNE+IPENNPKLKAHAAVIFKTICESATELRQKGHAVWDNNTLKRLGSIHLKNK
Soybean Lb          +GVD+P++TNPKLTGHAEKLFALVRDSAGQLKASGTVVADAA++++LGSVHAQKA
Sperm whale Mb      LKTEAEMKASEDLKKHGVTVLTALGAILKKKGH+++++HEAE+LKPLAQSHATKH

                    110       120       130       140       150       160
Trema Hb            VVNE+HFEVTRFALLETIKEAVPEMWSPEMKNAWGEAYDQLVAAIKSEMKPSST++
Parasponia Hb       VVNE+HFEVTRFALLETIKEAVPEMWSPEMKNAWGVAYDQLVAAIKFEMKPSST++
Casuarina Hb        ITDP+HFEVMKGALLGTIKEAIKENWSDEMGQAWTEAYNQLVATIKAEMKE++++
Soybean Lb          VTDP+QFVVVKEALLKTIKAAVGDKWSDELSRAWEVAYDELAAAIKKA++++++++
Sperm whale Mb      KIPIKYLEFISEAIIHVLHSRHPGDFGADAQGAMNKALELFRKDIAAKYKELGYQG
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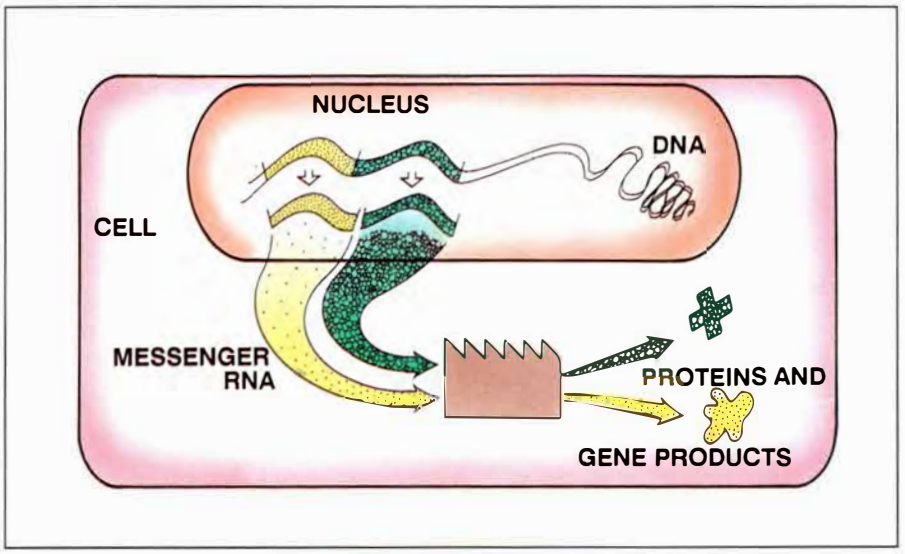


GARRY BROWN

Genes are segments of DNA. There are about 100,000 different genes in a typical plant or animal cell, each a set of coded instructions for the production of a different protein. The instructions are picked up by messenger RNA and carried to the cell's 'protein factories' (ribosomes) where the instructions are translated and the corresponding proteins produced.

JULIE FAULKNER

Dr Liz Dennis, from the CSIRO Division of Plant Industry, identifies the DNA code for the haemoglobin gene found in the elm tree genus *Trema*.

several families? Or was the haemoglobin gene an integral and functional part of the genetic make-up of all plants and, in a few different groups, had helped facilitate the independent development of nitrogen fixation?

Researchers were steered towards the latter scenario by studies in evolutionary biology that indicated it was unlikely that nitrogen fixation was a primitive characteristic. Morphological evidence on the structure of nodules and the biology of the different nitrogen-fixing groups' symbiotic relationships with bacteria also supported the independent evolution of nitrogen fixation throughout the plant kingdom. And so the search for the plant haemoglobin gene widened to include non-nodulating plants—those without the ability to fix nitrogen. Dr Dennis' team started in the elm family, which had both nodulating and non-nodulating species. A functional haemoglobin gene was soon found in species of *Trema*, a genus closely related to *Parasponia* but which does not nodulate. This was followed by the discovery of a haemoglobin gene in species of the non-nodulating *Celtis*, another genus in the elm family. And there were indications that species of *Ulmus*, another non-nodulating related genus, also contained haemoglobin genes. It is on the basis of these discoveries that Dr Dennis and her colleagues at the Division of Plant Industry believe it possible that all plants have a haemoglobin gene. (The search to trace the gene through the plant kingdom is continuing.)

THE NEXT STEP WAS TO ISOLATE WHERE the haemoglobin gene was 'expressed' in non-nodulating plants. In most cases, every cell of a plant or animal will contain an organism's full complement of different genes. However, not every gene will have an active role to play in every cell of the organism; that is, they will not be 'expressed' in every cell or tissue. For example, in a mammal the genes that produce the proteins that make up a woolly coat would be expressed only in skin cells, not in the cells of the animal's eyes.

Dr Dennis' team checked the stems, roots and leaves of non-nodulating *Trema* species for this non-symbiotic plant haemoglobin (haemoglobin not associated with nitrogen fixation). The protein and messenger RNA from the gene was found only in the roots. The fact that the gene was expressed in one tissue type and not randomly throughout the plant suggested the protein had a specific role to play in these plants.

To determine more about the structure of the gene responsible for non-symbiotic plant haemoglobin, the analyses were taken further using genetic engineering techniques. Haemoglobin genes from non-nodulating *Trema* and nodulating *Parasponia* species were transferred separately into tobacco, the genetic engineers' model plant. Tobacco

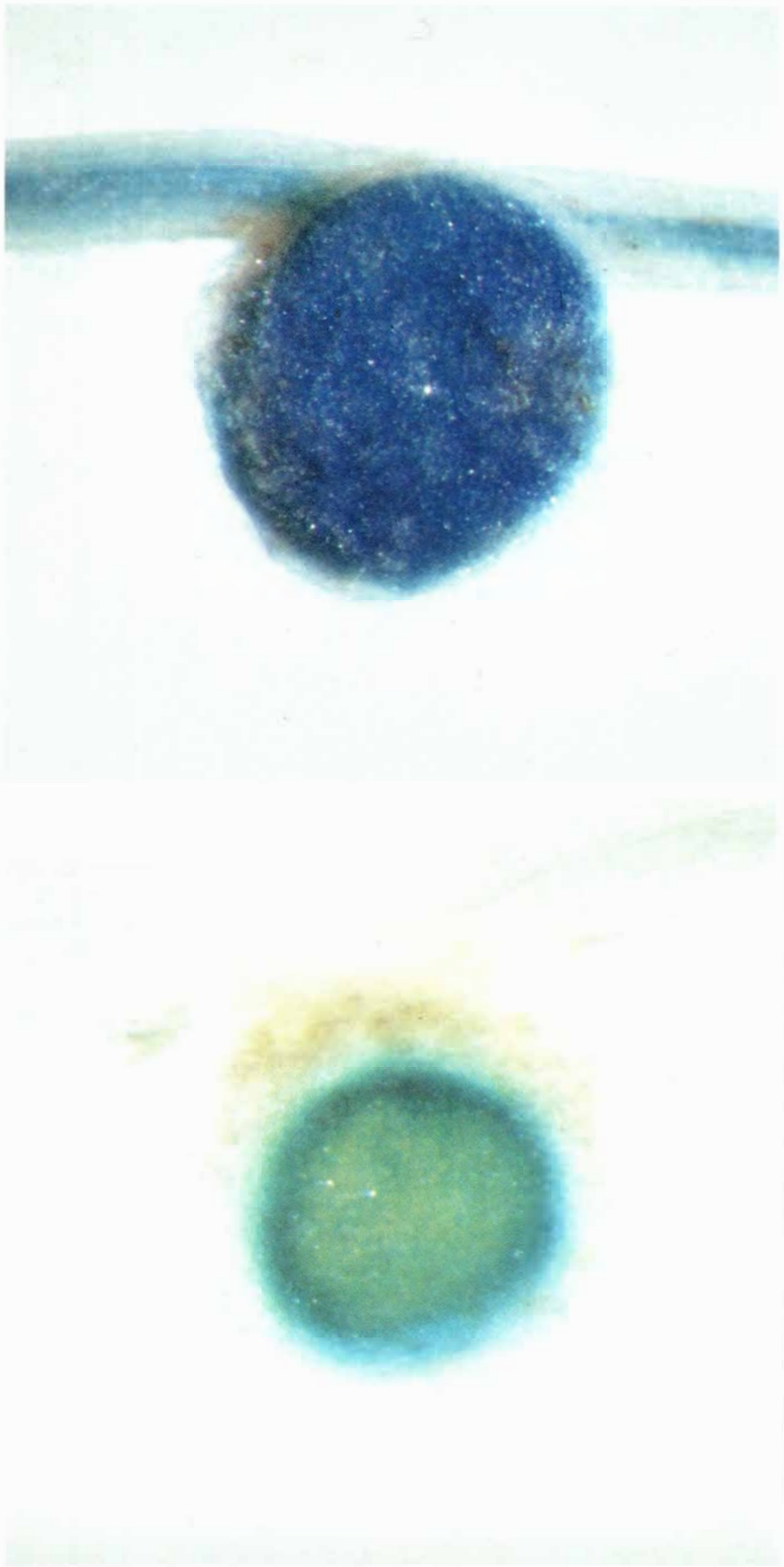
does not produce nodules and in both cases expression of the foreign genes appeared to be mainly confined to the roots of the transgenic tobacco plants.

The experiments continued with investigations concentrating on the mechanisms that dictate the expression of plant haemoglobin genes. When, where and to what extent a gene is expressed in an organism is directed by control 'switches', known as gene promoters. These are coded chemical sequences (a series of nucleotides) usually located upstream from the gene on the DNA molecule. Dr Dennis' researchers isolated the promoters controlling the *Parasponia* and *Trema* haemoglobin genes and in each case hooked them up to 'reporter' genes—benign laboratory genes that are readily traceable using microscopy techniques. These gene complexes were engineered into tobacco with the result that the reporter genes, whether under the control of either *Parasponia* or *Trema* promoters, were expressed in the roots of the transgenic tobacco. The tobacco plant appeared to be fully equipped with the necessary mechanisms to cope with the haemoglobin genes and their promoters that had developed in the elm family, both in nodulating and non-nodulating species. Possibly tobacco has its own haemoglobin gene, highly homologous to those inserted by genetic engineering.

The experiments continued in the nitrogen-fixing legume *Lotus*.When introduced into *Lotus*, both the *Parasponia* and *Trema* promoters directed expression mainly in the cells in the centre of the root nodules where the symbiotic bacteria are concentrated. There was also expression, to a much lesser degree, in the roots of *Lotus*. Obviously, the promoters that controlled expression of the haemoglobin gene in the roots of the non-nodulating *Trema* also contained the correct mechanisms to control expression in nodules.

The results from this series of experiments suggest the control of expression in the nodules of plants developed from an existing mechanism that regulated expression in plant roots *before* the evolution of nodulation. This was supported by a previous finding that, in *Parasponia*, its own haemoglobin gene is expressed to a large extent in its nodules and to a lesser extent in the plant's roots. It was beginning to appear that there were at least two components to the promoters of plant haemoglobin genes: one that directed expression in nodules and one that directed expression in the roots.

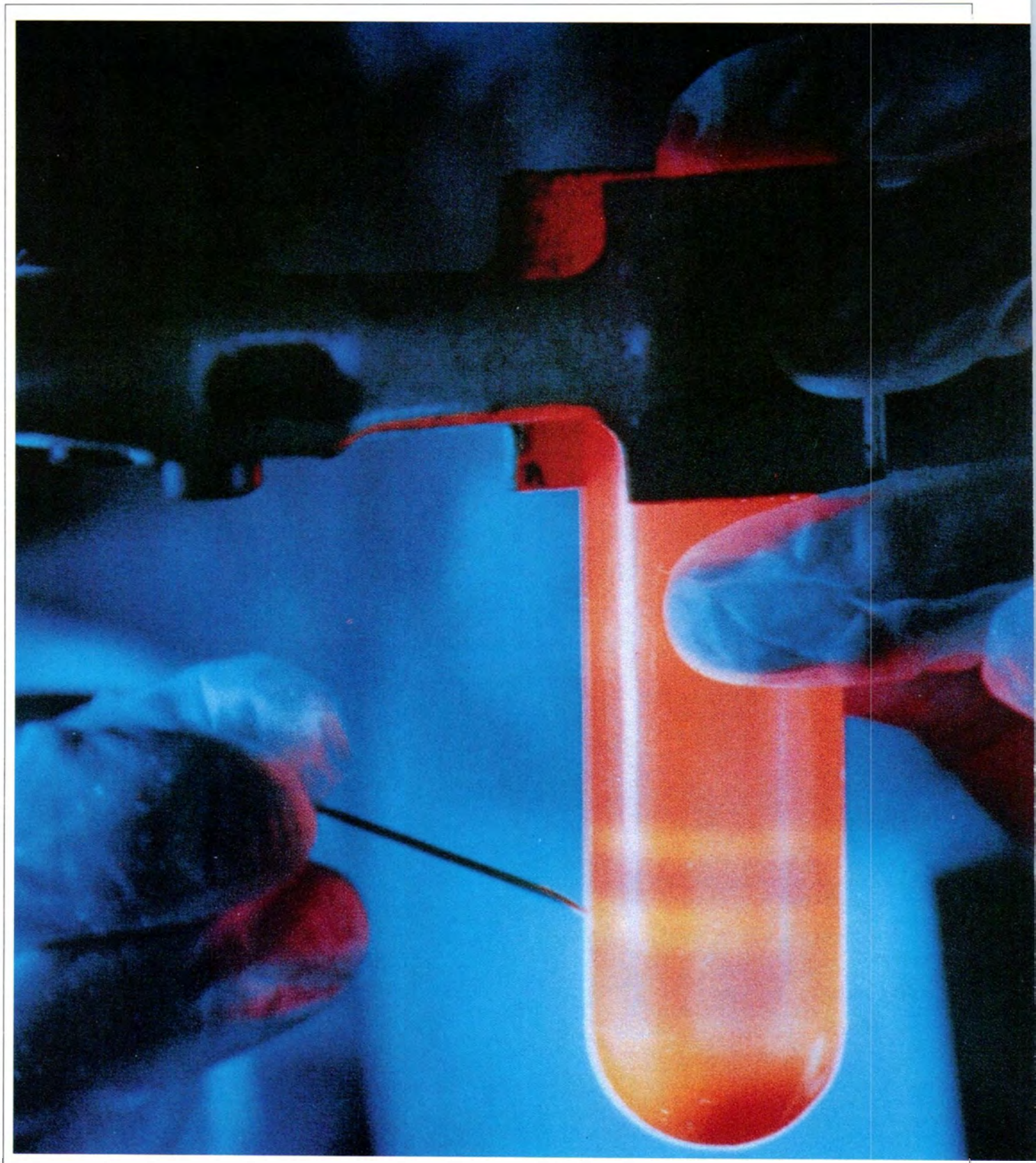
The preliminary results from other experiments by Dr Dennis' team indicate how these shifts in sites of expression may have come about. In *Lotus*, promoters from the non-nodulating *Trema* had directed the expression of a reporter gene in the centre of nodules. The removal, however, of an extremely small part of the regulatory sequence in the



STUART CRAIG

STUART CRAIG

A 'reporter' gene is attached to promoters ('switches') from the haemoglobin gene of a species of the non-nodulating genus *Trema* and engineered into a species of the nitrogen-fixing legume *Lotus* (top). The reporter gene, under the control of the *Trema* switches, shows up in the centre of the nodules (shown in blue). Repeating the experiment with *Parasponia* switches produces similar results (bottom).



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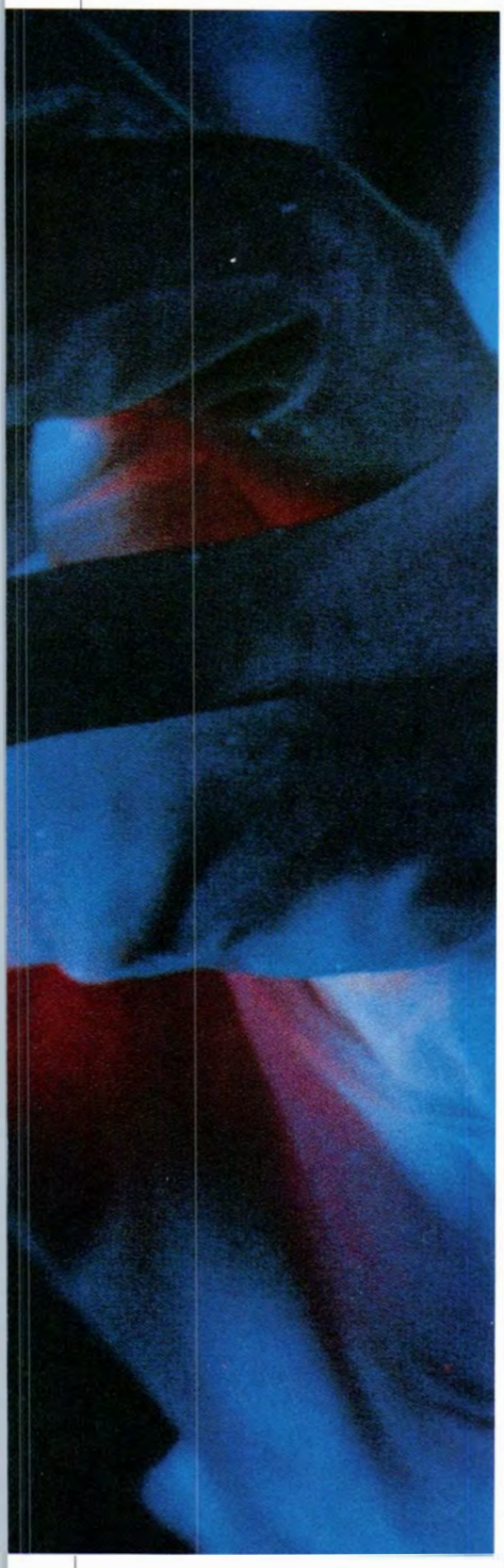
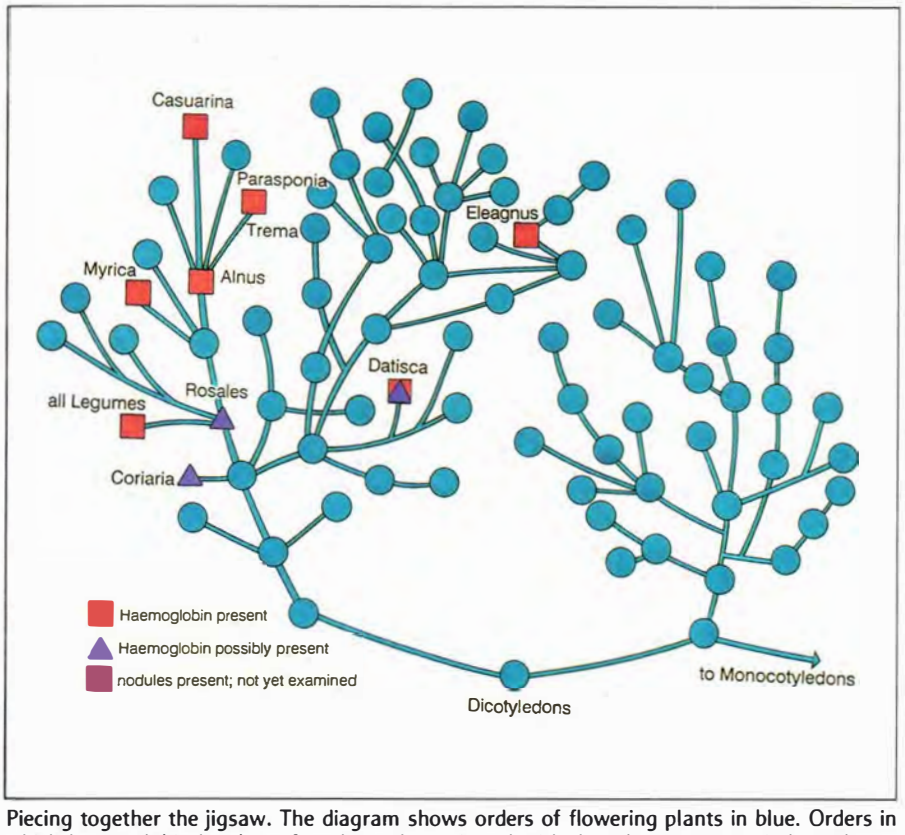
Isolating a cloned *Parasponia* haemoglobin gene: the DNA is bound to a dye that fluoresces under ultraviolet light making it easy to locate.

Trema promoters led to expression of the reporter gene in the outer edges of the *Lotus* nodule where no bacteria occur. Perhaps small natural changes in promoter sequences coincided with the development of nodulation and symbiotic relationships with nitrogen-fixing bacteria in different plant groups, facilitating the development of the nitrogen fixation mechanism.

IF NON-SYMBIOTIC HAEMOGLOBIN HAS been retained in plants, seemingly across vast distances in time, it must have some function. Until recently, it was thought the concentrations at which haemoglobin occurred in roots were too low for the protein to perform as an oxygen transporter as it does in nodules. It was suggested that it might function as an oxygen sensor, playing a role in some feedback mechanism that transmits information to other genes that respond to periods of low oxygenation, for example during waterlogging. However, it has recently been shown that the expression of haemoglobin in roots tends to be concentrated in particular cells—those that are





ANNE WARRENER

Piecing together the jigsaw. The diagram shows orders of flowering plants in blue. Orders in which haemoglobin has been found are shown in red with the relevant genera indicated.

growing and rapidly dividing at the root tips. So it is still possible that non-symbiotic haemoglobin acts as an oxygen carrier.

This could also explain new reports of haemoglobin in plant embryos. There have been accounts of the protein in the seed of the winged bean. And recently Dr Dennis' researchers found that haemoglobin genes engineered into tobacco also show expression in the developing embryos of the transgenic plants. Haemoglobin may ensure the sustained supply of oxygen needed by the rapidly dividing cells of plant embryos.

It now seems likely that the primitive condition in plants is that there is a haemoglobin gene in the genome, the protein it produces having one or more functions in specific plant tissues. Small changes in nucleotide sequences in haemoglobin gene promoters may have helped nitrogen fixation evolve in some plant groups.

The link between plant and animal haemoglobin genes remains a little less clear but the relationship may extend back to the 'primordial slime'. In a recent overseas development, haemoglobin was found in the bacterium *Vitreoscilla*. The structure of the haemoglobin gene in this organism displays a degree of similarity that relates it to both animal and plant haemoglobin genes. The discovery has sparked suggestions that the genes in both kingdoms originated in a common ancestor, perhaps a primitive archaebacterium, some 3.5 billion years ago. The implication is that, in haemoglobin, evolution developed a successful molecular strategy to transport oxygen during one of the earliest periods of life on the planet and has steadfastly conserved it. It appears that this gene has been retained, across billions of years, in what are now some of the most diverse life forms on Earth with only comparatively minor structural alterations arising in response to the developing needs of different organisms.

But the significance of this developing theory on the evolution of haemoglobin may run even deeper. The biochemical pathways that produce energy in living things are far more efficient in the presence of oxygen than in its absence: the transition from aerobic to anaerobic processes exposed vast reservoirs of energy and represented an enormous step in the evolution of life on Earth. Was haemoglobin, in a form very similar to that seen on Earth today, one of the vital developments that allowed life on the planet to evolve beyond the primordial slime, the gene responsible for the protein playing a role in selection ever since? ■

Suggested Reading

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Ms Karen McGhee is a science writer and communicator for the CSIRO Division of Plant Industry. Researchers from the CSIRO Division of Plant Industry involved in recent discoveries about plant haemoglobin include Cyril Appleby, Didier Bogusz, Stuart Craig, Liz Dennis, Jorg Landsmann, Danny Llewellyn and Jim Peacock.

"Insects have had millions of years to experiment with the art of folding and many of the patents they have developed could be applied, after suitable upward scaling, to engineering construction."

ORIGAMI IN THE INSECT WORLD

TEXT AND PHOTOGRAPHY BY JOHN BRACKENBURY

SUB-DEPARTMENT OF VETERINARY ANATOMY, UNIVERSITY OF CAMBRIDGE

ALTHOUGH AIRCRAFT WINGS ARE marvellous things for flying with, they pose serious problems when it comes to parking your plane on the ground. The same goes for insect wings: these delicate membranes can easily be broken and they must be stowed safely away when not in use. Inability to fold the wings close to the body would impose intolerable restrictions on the freedom of movement of an insect over the ground and it is not surprising that very few groups (and of these most notably the dragonflies) are without effective wing-

Many four-winged insects like the Green Lacewing (*Chrysopa viridis*) fold the wings roof-wise over the abdomen while at rest. During flight the front and hind wings move independently.

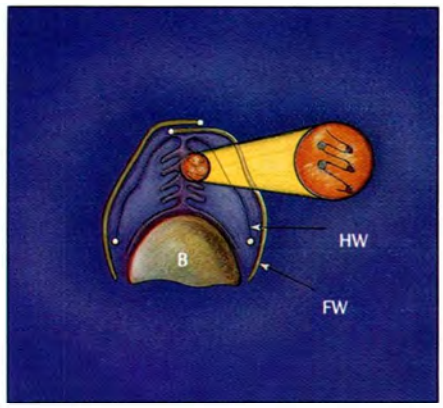
folding mechanisms. Dragonflies rest with their wings fully extended but they normally select a spot clear of immediate foliage that might damage the wings on take-off. By the end of the season it is not unusual to see individuals patrolling their territory but sporting one or two battered and torn wings. Of course having four wings helps since two or three fully intact wings can compensate for one or two that have been torn or completely broken.

Most insects, with their customary ingenuity, have devised a variety of wing-folding mechanisms, ranging from simply closing the wings flat or roof-wise over the back of the abdomen, to the extremely elaborate methods used by beetles to carefully fold and tuck the wings beneath their protective wing cases or elytra. Often this fastidious process is helped by the presence of special lines of flexibility or creases along which the wing folds more easily.

Wing closure is just one rather obvious facet of a much more general phenomenon recognisable among insects: the use of strategic folding patterns to assist movements of the various articulated appendages that characterise this class of animals. The biomechanical and indeed the ergonomic implications of surface-folding techniques in joint-bodied animals have not even begun to be examined in a coherent manner by biologists, but the widespread incidence of folding suggests that important design principles may be at work. You do not have to search far in the man-made world to find examples of such strategic folding: the crease in a pair of trousers, the arrangement of pages in a book or a newspaper, the opening and closing of an umbrella. These designs did not happen by accident, but have proved to be the best solutions to tricky folding problems, following centuries of trial and error. There is no reason why similar principles should not also be identifiable in insect body design.

ONE OF THESE DESIGN PRINCIPLES MUST surely be the fact, well known to engineers, that the introduction of a simple fold or pleat into a thin flexible membrane, like a sheet of paper or indeed an insect wing, can instantly create a structure that possesses unexpected strength and resistance to bending. The point can easily be demonstrated using a sheet of foolscap paper and a 500-gram weight (see diagram). While a flat sheet has no resistance whatever to loads applied either at its free edges or at right angles to its surface, the incorporation of a few parallel folds into the paper transforms it into a corrugated structure capable of load-bearing. There is no magic involved. What has happened is that, as a result of the creation of the pleats the stresses imposed by the load have now been taken up by tension in the plane of the paper. Although a sheet of paper cannot resist bending, it can have great tensile strength as you can easily testify by trying to stretch it between fingers and thumbs.

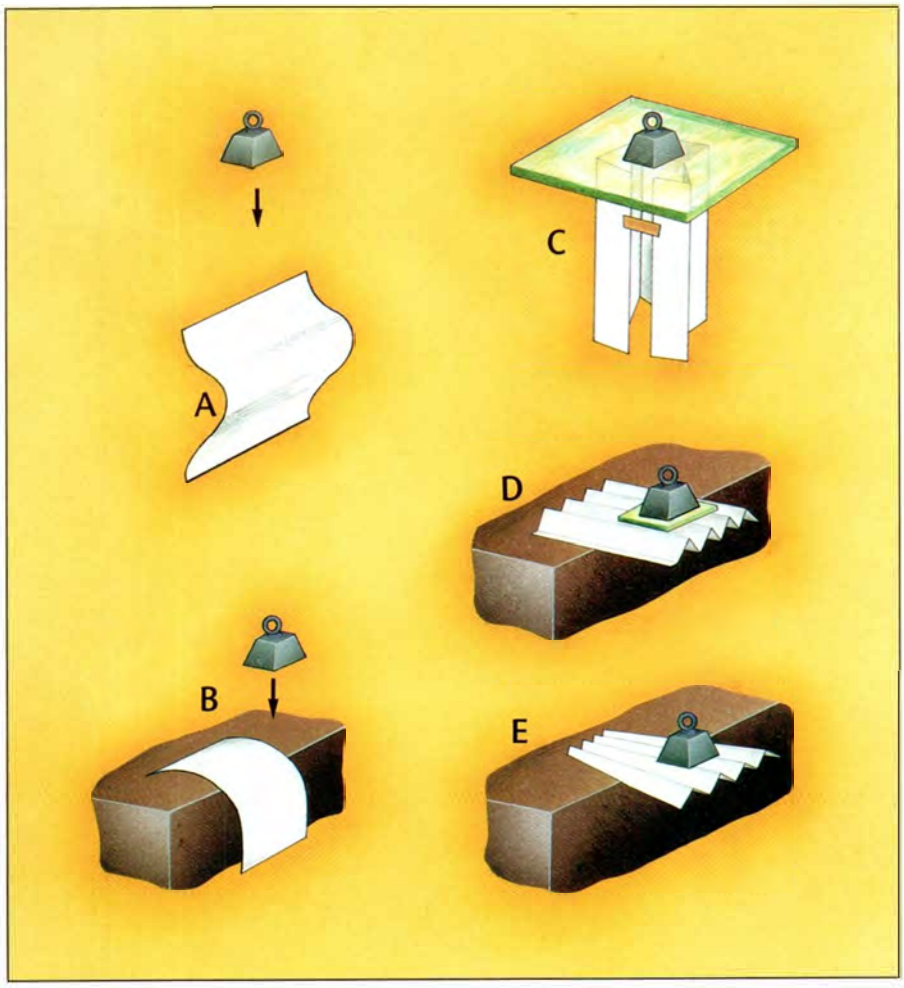
How can this analogy be applied, for example, to insect wings? The diagram shows that, if a system of parallel pleats is drawn together at one end to form a fan, the structure achieves even greater bending strength, and this principle can be seen at work in the expanded hind wing vanes of large insects such as grasshoppers, bush-crickets, cockroaches, stick-insects and mantids. The vane is constructed exactly along the lines of a lady's fan, with pleats radiating out from the base. The comparison is obvious from the moment the vane opens up at the beginning of flight, as can be seen in high-speed photographs of mantids unfolding their wings as they leap into the air. Incidentally, the fan-like opening and closing of the vane above the body, when it is raised into action and laid to rest respectively, also illustrates another advantage of pleat-like folding: the ability to pack away a large membrane with the least use of space (see diagram). But the main advantage must surely be in the fact that this delicate, lace-like membrane is thereby given the strength to resist ex-



IAN FAULKNER

A cross-section of a grasshopper's body (B) reveals how the stiffer front wings (FW) roof over and protect the membranous hind wings (HW), the pleats of which are folded together like a closed fan. The summits of the pleats are occupied by the primary tubular veins, the troughs by smaller secondary veins.

A sheet of paper and a weight illustrate the structural properties of pleating. An unfolded sheet will buckle without resistance when a force is applied either parallel to or at right angles to its surface (A and B). The pleats confer the ability to bear weight like a column (C) or like a horizontal beam (D). In the latter case, pinching the folds together at the base to form a fan further increases the bearing strength (E).



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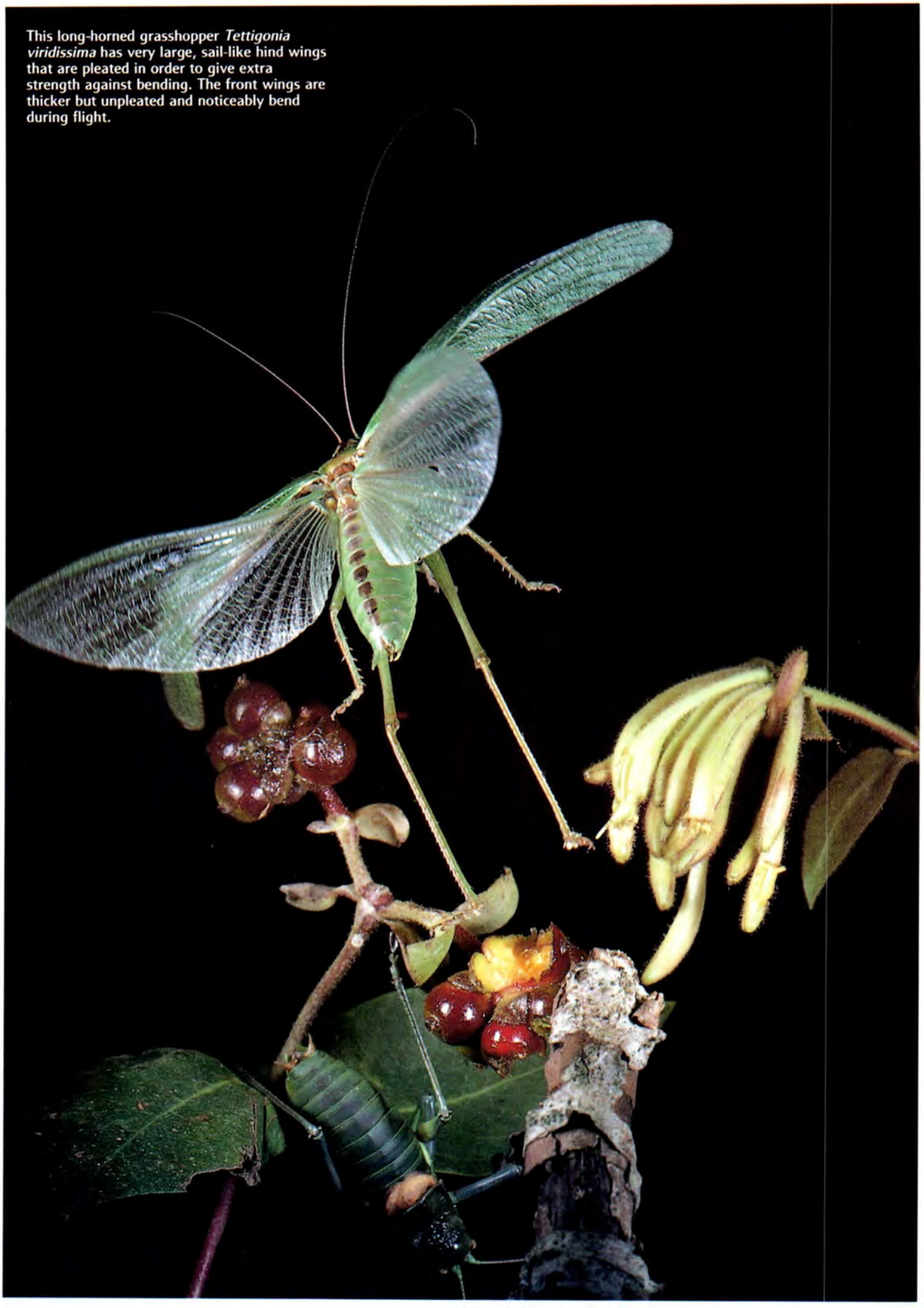
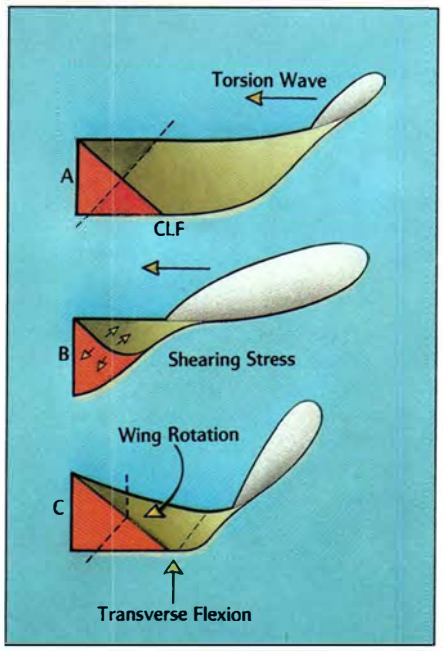
Inset: the soldier beetle *Cantharis* sp. in preparation for flight. The wing cases or elytra have been raised but the tips of wings have not yet unfolded from the position in which they were held at rest. Main photo: a fraction of a second later the wings are fully extended and the insect launches into flight.



This long-horned grasshopper *Tettigonia viridissima* has very large, sail-like hind wings that are pleated in order to give extra strength against bending. The front wings are thicker but unpleated and noticeably bend during flight.



IAN FAULKNER

This illustrates how a single oblique fold (the claval furrow CLF) near the base of the mantis front wing prevents a flexural wave from spreading to the base. In the top drawing the wave is progressing inwards from the tip of the wing and the dotted line shows that the wing section profile is flat; that is, the fold is not in operation. In this case, as shown in the middle drawing, the wave progresses without restriction to the base and creates dangerous shearing stresses. In the bottom drawing, the front part of the wing has rotated backwards around the claval furrow, creating a fold that now resists spread of the wave to the base and avoids injury to the wing attachment.

cessive bending and buckling under the forces generated by the air impacting upon the wing surface during flight.

It was Dr Robin Wootton of Exeter University who pointed out the full marvel of the design of these fan-like wings. As the fan extends its area during the downstroke, the rim of the trailing edge becomes pulled taut but the inner part of the wing remains pleated. Further extension then forces both the trailing edge and the veins that run along the crests of the pleats to bend downwards elastically. The pleats therefore become partially flattened to create a highly efficient cambered aerofoil. The effect is remarkably similar to the opening of an umbrella.

The forewing of a mantis or locust is not pleated in the same way as the hind but it does have a single large fold running obliquely across the basal region. This claval fold or furrow, as it is called, is present in almost all insect wings and therefore must be important in flight. High-speed photographs show that in the mantis the claval fold is flattened out during the downstroke, and it is only at the start of the upstroke that the curious function of the fold becomes apparent.

By normal standards the forewing is quite thick and heavy but it is also flexible like an elastic beam. At the start of the upstroke the base of the wing is pulled, causing the inner part of the wing to move upwards, but because of its inertia, the outer section of the wing continues its downward movement. The result is that the tip of the wing becomes strongly flexed downwards and a wave of flexion runs inwards towards the base. The wave gathers energy as it moves and the danger is that it will swamp the base and rupture the more delicate parts forming the broad attachment of the wing to the body. This is where the claval fold comes into play. Very rapidly the leading section of the wing is flipped backwards around the claval fold, instantly forming a corrugation that halts the progress of the wave. Instead of invading the base, the wave then expends itself by causing an even stronger downward deflection of the outer section of the wing (see diagram). Because the wing is flexible, this powerful deflection can be tolerated without harm to the wing fabric.

The start of the upstroke reveals the part played by the folds in the mantis wings. Downward flexure of the hind wing is seen in the tips, but is resisted by the inner part of the wing where pleating is stronger. Strong downward flexure occurs in the front wing but this is prevented from invading the wing attachments by the claval fold or furrow, which crosses the wing obliquely near its base.

This Water Boatman (*Notonecta glauca*) has just opened the wings after leaping into the air using the oar-like hind legs. Leaping allows the insect to keep the wings folded until the body is clear of the ground, thereby avoiding the risk of damage during take-off.

FORTUNATELY, AS FAR AS THE MANTIS IS concerned, the front wings are far less important in producing the lift that keeps the insect aloft than the hind wings, and strong flexure may not be a severe disadvantage to flight. But many insects have only one pair of serviceable wings and this includes the beetle family in which the front wings do not beat during flight but simply function as a protective case for the hind wings when at rest. As in most fully functional wings, the leading edge of the beetle hind wing is braced by a specially thickened sclerotised rod formed by the fusion of two or three longitudinal veins. This rod is the source of most of the bending strength of unpleated wings, acting rather like the spar at the edge of a sail. How curious, then, to find that the leading edge spar of the hind wings in beetles is interrupted by a flexure line.

The kink in the spar resulting from the presence of the flexure line must, one might assume, weaken it. The line crosses the outer section of the wing and its function is to allow the wing to be folded lengthwise when it is stowed away at the end of flight.

The main disadvantage of this fold is that it causes an additional delay in take-off at the start of flight since the insect must hesitate momentarily until the tip is unfolded and locked into line with the rest of the wing.

Interestingly in this context, many beetles (and many true bugs or hemipterans, which also have a kink in the leading edge spar) leap into the air during take-off, using the leg muscles to gain initial speed and acceleration. This allows them, as it were, to overcome the 'cold spot' in the engine while the wings become fully expanded.

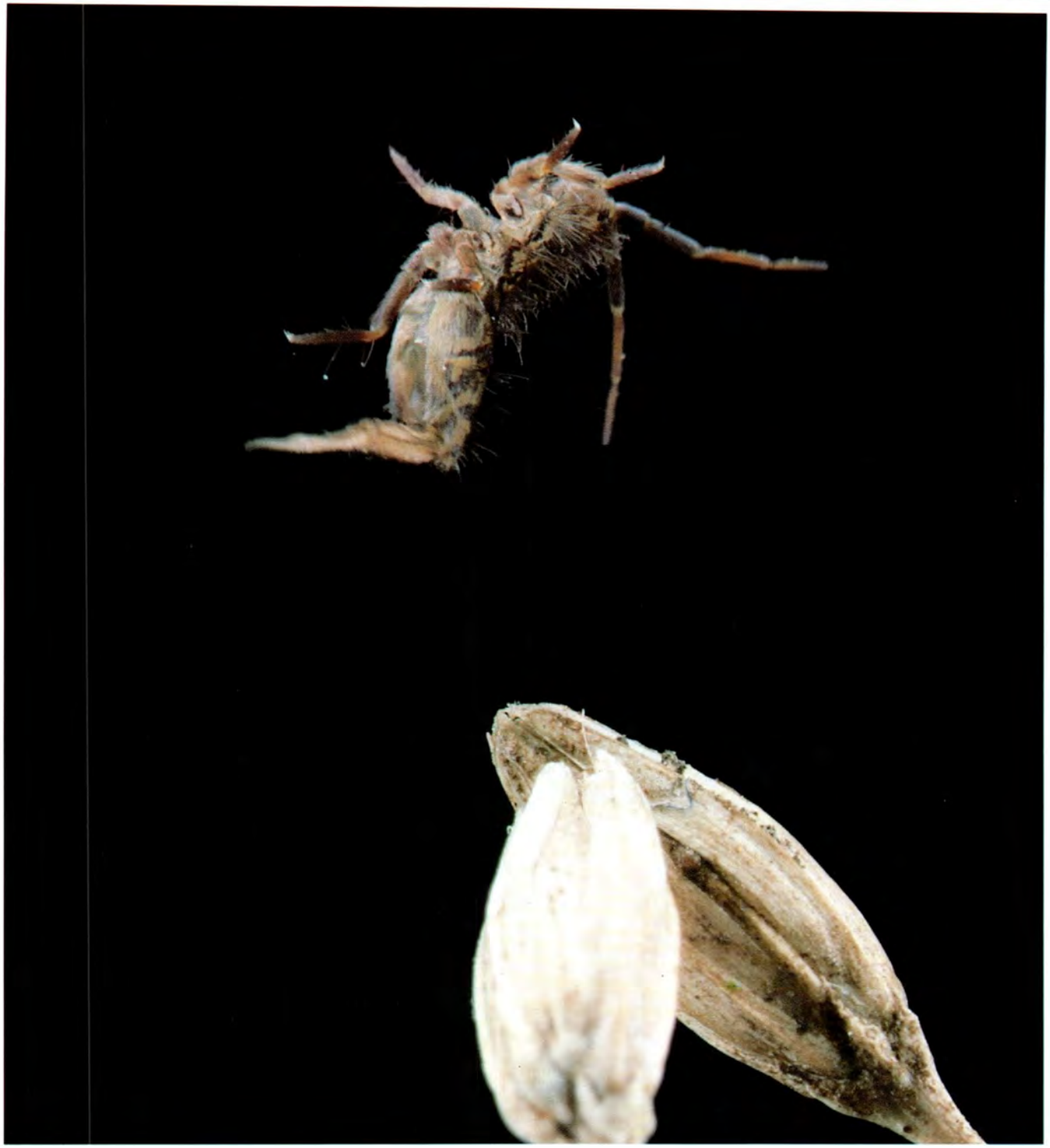
IAN FAULKNER

The mechanism of tail extension in the springtail is based on the sudden recoil of an elastic plate against which the tail is folded at rest. The tail has two stable positions: at rest and when fully extended, and it will click into either one or the other. In the drawing at top left the tail is stowed away in a groove on the underside of the abdomen. The base (B) of the tail is triangular in section and the apex of the triangle is connected by rods (R) to an elastic horseshoe-shaped plate (P), which surrounds the abdomen but is open at the bottom. At the beginning of tail extension pressure build-up inside the fluid within the body cavity begins to force the tail out of the groove (top centre). As the base of the tail rotates outwards, the connecting rods push against the jaws of the plate (P) forcing it to store energy. When the tail has swung out beyond a critical point the jaws of the horseshoe-shaped plate suddenly snap closed, forcing the tail out at high velocity (top right). Closure of the tail is simply the reverse process: a small muscle inside the abdomen draws the tail inwards to the mid-position and it then snaps into the groove. The mechanism can easily be reproduced on a model consisting of a piece of card folded into three plates, representing the tail base and the two connecting rods, connected to a piece of clock-spring metal bent into a horseshoe-shape. This is shown in the middle line of drawings. The bottom line of drawings shows how the spout of a paper milk carton snaps into the 'open' position once the plate (B) has been pulled out to the critical point shown in the middle drawing.

THE FINAL EXAMPLE OF WHAT MIGHT well be referred to as 'natural designer folding' in the insect world can be found in tiny, wingless insects called springtails or collembolans, ignobly relegated by taxonomists to the status of 'primitive arthropods'. How ironic, then, to find that the springing mechanism that gives these insects their name is based on an ingenious arrangement of folds between elastically stressed, sclerotised plates. The late Dr S.M. Manton of London University devoted a lifetime to the study of these and similar 'primitive' arthropods, and came to the conclusion that in many cases virtually the entire anatomy of the body has been evolved towards the efficient functioning of the springing organ: an extreme case of specialisation if there ever was one!

The tail is a remarkable organ representing the fused appendages of the fourth abdominal segment. Manton's prodigiously detailed morphological studies enabled her to identify the main structural components of the spring, but its true functional affinities are only now being recognised. Like the fetlock joint of a horse and the light-switch, the collembolan spring belongs to a category of mechanisms collectively labelled 'bistable devices'. The common feature of all these devices is that the moving part (switch lever, horse's foot or collembolan tail) can snap between two stable positions but cannot remain in between. Like the blade of a jack-knife, the collembolan tail is spring-loaded and has only two stable configurations: open or closed. When the tail is 'sprung' it is in the open position (see diagram). When it is drawn back into the groove on the underside of the abdomen it is in the closed position. Once the tail is released, it springs out of the groove, strikes the ground and propels the body into the air.

The tail gains its energy from the sudden buckling of a curved elastic plate to which the base of the tail is connected. With the benefit of Manton's anatomical description the main elements can be readily identified and it is a simple matter to twiddle the tail with a pair of watchmaker's forceps in order to demonstrate its bistable properties. But it is a much more difficult conceptual task to relate these movements to the folded nature of the tail articulation with the body. When I first began to ponder this problem in 'insect origami' I could find no obvious guidance from the various locomotory mechanisms found in other animals and I turned instead to the nearest man-made analogy. This was a classic example of late 20th-century 'applied origami': the humble paper milk carton. The spout of such a carton is made from a series of folded paper plates that can be made to buckle against one another so that the spout snaps either in (closed) or out (open). The principle is precisely the same as that controlling the inward and outward movements of the structures at-



Leaping in the tiny springtails (*Tomocerus* sp.) is brought about by the lightning-fast unfolding of the forked tail, which is normally stowed away in a groove on the underside of the abdomen. The force for tail unfolding is developed by an elastic, horseshoe-shaped plate against which the tail is folded under tension when at rest.

tached to the springtail's tail. This appears to be yet another unwitting example of art imitating nature.

There may well be lessons to be learnt here for modern design engineers. Insects have had millions of years to experiment with the art of folding and many of the patents they have developed could be applied, after suitable upward scaling, to engineering construction. In this brief survey alone we have identified entomological equivalents of the concertina-like fan, the mechanical switch, the jack-knife and the umbrella. An engineer with a keen eye towards future developments could do worse than spare an hour or two peering down a biological microscope. He might even spot (with a pinch of lateral thinking!) designs that had never even been thought of. Could the way in which a moth folds and extends its proboscis inspire a novel design for remote sensors carried on a future roving 'Moon buggy'? In an era of light-weight structure design who knows what doors could be opened by teasing ajar a mayfly's wings? ■

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EYE SPY

Spiny-tailed gecko (*Diplodactylus ciliaris*), Longreach, Queensland.

The eye. The multi-faceted orbs of some Tabanid flies (Marchflies) double up as beacons to display bands of vivid hues. Perhaps these represent 'colour coding' for species recognition. The eye may also be a potential giveaway, to be artfully concealed behind disruptive patterns. Either way, when you look into it, the eye is revealed as an organ most splendid and varied.

BY STEVE WILSON
FREELANCE NATURE PHOTOGRAPHER

Tabanid fly, Mount Nebo, Queensland.

Golden-tailed gecko (*Diplodactylus taenicauda*), Chinchilla, Queensland.

EYE SPY

Tabanid fly, Gibb River, Western Australia.

Long-headed Grasshopper (*Acrida conica*), Brisbane, Queensland.

Fish eye, Fitzgerald River National Park, Western Australia.

Red-eyed Tree frog (*Litoria chloris*).

Shovel-nosed ray (*Rhynchobatus djiddensis*).

"Out of Tharalkoo's eggs marched things from a duck's worst nightmare—miscegenetic monsters with a duck's bill and webbed feet but the fur and four feet of a Water Rat."

THARALKOO'S CHILD: AN UGLY DUCKLING STORY

BY MICHAEL ARCHER
SCHOOL OF BIOLOGICAL SCIENCE, UNIVERSITY OF NEW SOUTH WALES

LONG BEFORE EUROPEANS GAWKED IN disbelief at their first sight of a Platypus (*Ornithorhynchus anatinus*), long before they laughed at the supposed absurdity of the "Natives' belief that these creatures laid eggs", the Aborigines of the Wiradjurie Tribe of New South Wales had an intriguing answer to the 'big' question about this anomalous bag of biological bits: "*What* is a Platypus?" Their answer is an 'Ugly Duckling' Dreamtime legend far more intriguing than the declaration of fundamentalist creationists that God made these suckers, bills, spurs and all, on a sunny Tuesday, 6,000 years ago.

According to the Wiradjurie legend, an attractive girl duck named Tharalkoo failed to heed the warnings of family and friends about what might happen if she strayed too far from home. To cut a fascinating long story short, she was caught by Biggoon, a sex-crazed, far-sighted Water Rat. She feigned tolerance for her loony lover but constantly watched for a chance to escape. Finally, as the time of year came for ducks to lay eggs, she managed to beat a hasty retreat to duck city while the contented Biggoon snored in the noonday sun. Although enthusiastically welcomed back in time to join her friends' egg-laying frenzy, to their horror, out of Tharalkoo's eggs marched *things* from a duck's worst nightmare—miscegenetic monsters with a duck's bill and webbed feet but the fur and four feet of a Water Rat, the world's first Platypuses.

In June 1990, sitting belted into the seat next to me on her way to the American Museum of Natural History was the world's first flying fossil platypus, *Obdurodon dicksoni*, a vital part of the palaeontologist's answer to the 'big' question and a guest of honour at a conference where the interrelationships of mammals would be the focus of participants from all over the world. As the fossil platypus' chaperone, I had been invited to present our version of Tharalkoo's grandchild to this unique gathering of palaeontologists, molecular biologists and systematists.

My charge was already a very experienced traveller in space as well as time. Her first memories were of life in a turquoise pool in the dark, green rainforests of north-western Queensland 15 million years ago. Then, weary with life's course or perhaps stampeded by the ambitions of her peers, the dappled light of that young world went out for her until 1985 when a serendipitous blow from a sledge hammer jettisoned the rear half of her skull into the harsh light of Riversleigh's stark, spinifex-covered hills. Still half wrapped in her limestone shroud, this venerable flat-foot was given a seat of her own on the plane back to Sydney where Henk Godthelp (University of New South Wales) spent four weeks of skilled preparation removing the last of the rock that imprisoned her most remarkable head.

JEANETTE MUIRHEAD

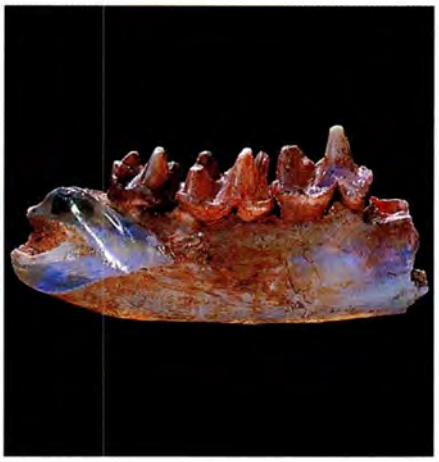
Reconstruction of the Riversleigh *Obdurodon* in its rainforest habitat of north-western Queensland (from a forthcoming book on Riversleigh to be published by Reed Books).

Unlike her modern descendant who underwent evolutionary change towards 'gummy-hood' (Platypuses lose their rudimentary teeth within a few months after birth and thereafter chew with horny pads) and many cranial specialisations, this Riversleigh platypus maintained a full set of well-developed choppers throughout her life and sported a much less-specialised skull.

That startling find at Riversleigh was number three in a series of discoveries illuminating the history of the modern Platypus. The first began with a tooth Mike Woodburne (University of California at Berkeley) and I found in the dull green 25 million-year-old clays of Lake Palankarinna, South Australia. It popped into view late at night as we sorted the day's screen washings—a bright but bizarre tooth begging to be rescued from a sea of fossil fish bones. At about the same time 375 kilometres to the south-east in similar-aged clays at Lake Namba, South Australia, Dick Tedford (American Museum of Natural History) and his crew of palaeontologists stared at a comparable tooth in their screen boxes and were just as puzzled. It took another two years of head-scratching before Mike and Dick produced a paper ascribing these two isolated teeth to the Platypus' family as the new genus and species, *Obdurodon insignis*.

Second to be discovered in the pageant of prehistoric platypuses was *Steropodon galmani*. A brilliant flash of fiery colour heralded the resurrection of the precious jaw of this 110-million-year-old monotreme from the opal fields of Lightning Ridge (see ANH vol. 21, no. 9, 1985). *Steropodon* has several claims to fame. It is Australia's first-known Mesozoic mammal and it is a contemporary of the dinosaurs. It was also one of the largest Mesozoic mammals known from anywhere in the world and it lived within the Antarctic Circle where, at the time, the annual average temperature was less than 5° C. And, after the Australian Museum raised $80,000 for the purchase of the collection of which it was a part, it became the world's most valuable Mesozoic mammal! When opal miners Dave and Alan Galman showed the jaw fragment to Alex Ritchie (Australian Museum), he immediately called our lab suspecting, as I was delighted to confirm over champagne, that it was this continent's first Mesozoic mammal—not to mention the world's oldest monotreme.

Although most of the details of the Platypus' family tree undoubtedly remain obscure, with only three glimpses available between its roots and its last-living branch, these three represent 200 per cent more than palaeontologists had 20 years ago. Further, they invite us to connect the different morphologies of the three through time, providing the vital fourth dimension that inseparably links ends to beginnings, thens to nows, *Steropodon* to *Obdurodon* and *Obdurodon*



JOHN FIELDS/AUSTRALIAN MUSEUM

The opalised jaw of *Steropodon galmani*, the 110-million-year-old monotreme from Lightning Ridge, New South Wales.

to *Ornithorhynchus*. And what do our glimpses of the chain of bills and flat-feet tell us about the comings and goings of platypuses?

The teeth of *Steropodon* and *Obdurodon* clearly indicate that monotremes were a mixed bag of primitive mammal and derived monotreme features—that is, classic missing links between more primitive mammals and the modern Platypus. Our tentative suggestion at the American Museum conference was that they might have descended from a group of South American dryolestoids, primitive Gondwanan mammals (recently described by José Bonaparte, Buenos Aires, Argentina) whose molar teeth exhibited a few distinctive features also found in our most primitive platypus teeth. While the magnificence of the Riversleigh princess certainly dazzled and enthralled the room-full of lovers of prehistoric biodiversity, the suggestion of possible dryolestoid relationships was received with much less enthusiasm. So, armed with this international community's wider experience to draw on, we will explore other possibilities and seek more data—such as the comparative enamel ultrastructure of our debutante's teeth—before presenting the final conclusion for publication as part of the book that will arise from this conference.

Looking upwards from the tree's roots, a lot more can be said with certainty. First, we have in this record a rather disquieting crystal ball because it is clear that, since 15 million years ago, in terms of specialisation (for example, loss of teeth, diminutive size and much more specialised snout), platypuses have been creeping dangerously far out on their evolutionary limb. If the last 3.5 billion years of biotic history teach us anything at all about the comings and goings of beasts, it is the gloomy fact that extinction rarely fails to overtake animals that become as specialised as the living Platypus. It's as if they give up their long-term capacity to adapt when they opt for short-term success as a specialist. Perhaps this lesson is one we should all take to heart.

Adding to this rather gloomy impression of a lineage in its dotage, teetering on the brink of phylogenetic suicide, is the radical decline in the distribution of platypuses. Following the loss of central and northern Australia's lush forests as Australia began to dry out ten million years ago, platypuses gradually became restricted to river systems along the eastern coast. In itself this might not be a worry but, with fewer and less widespread populations, local environmental disasters such as floods and pollution present an even greater threat to the survival of the Platypus.

It also seems ironic, considering the Wiradjurie attribution of Platypus fatherhood to Biggoon the Water Rat, that the arrival of Water Rats (*Hydromys chrysogaster*) into Australia, sometime this side of four million years ago, probably led to a further garotting of the already declining Platypuses. Water Rats are also Platypus-sized, aquatic mammalian carnivores and so the two are likely to compete when they overlap. Now wherever the Platypus struggles to persist, Water Rats are their constant companions. But Water Rats also persist in many river systems where Platypuses are no longer found, perhaps a silent testimony to ecological battles that prehistoric platypuses fought and lost.

On balance, the once vibrant light in the crystal ball provided by the platypuses' fossil record is clearly dimming. Without our role as administrators of the *coup de grace* to the Platypus' last strongholds via pollution, fertilisers washed into streams and increased flooding following forest clearance from watersheds, perhaps these enchanting remnants of the age of dinosaurs might not be stampeding quite as quickly towards life's last exit.

As palaeontologists, we must call the cards as we see them and in this case sound the warning bell. For conservationists the same evidence of decline and vulnerability should be a rallying cry to ensure that everything humanly possible is done to cherish and secure the last precious remnants of Tharalkoo's children. ■

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Professor Michael Archer lectures in biology at the University of New South Wales. Most of his non-teaching hours are devoted to the study of the fossil faunas of Riversleigh.

"There is more to genes than being just passive 'books' in the cell's archives."

THE DRIVE OF THE GENES

BY RALPH MOLNAR & GLEN INGRAM
VERTEBRATE FOSSILS, QUEENSLAND MUSEUM
VERTEBRATE ZOOLOGY, QUEENSLAND MUSEUM

DNA IS THE LIBRARY OF THE ORGANism; the repository of information used to create a new individual. It comes as genes that code for proteins, among other things, which in turn interact to construct a cat, mushroom, palm or human. If an essential gene is defective, the organism dies or fails to reproduce, and thus the gene 'responsible' also perishes. To spread, such a gene must enhance the prospects of survival and reproduction for 'its' organism. After all, genes are not directly exposed to natural selection and can only spread through the multiplication of their organism, can't they? Well, no. There is more to genes than being just passive 'books' in the cell's archives; just as organisms are actors in the environmental theatre, so genes act and react in the cell's nucleus. Not only can some genes spread regardless of whether they are harmful to 'their' organism, thus avoiding natural selection, but they can also be directly exposed to selection just as organisms are.

Genes are carried on chromosomes, and in sexual organisms chromosomes are paired (except for one, which codes for maleness). When eggs and sperm (that is, gametes) form, one chromosome from each pair goes into each of the two resulting cells. If the parent carries two forms of a gene, 50 per cent of the offspring will have one form and 50 per cent the other. Usually. . .but not always. Occasionally something happens to one of the chromosomes or to the gamete that inherits it, so that certain genes or chromosomes are consistently not passed on. Geneticists call this 'segregation distortion' or 'meiotic drive'.

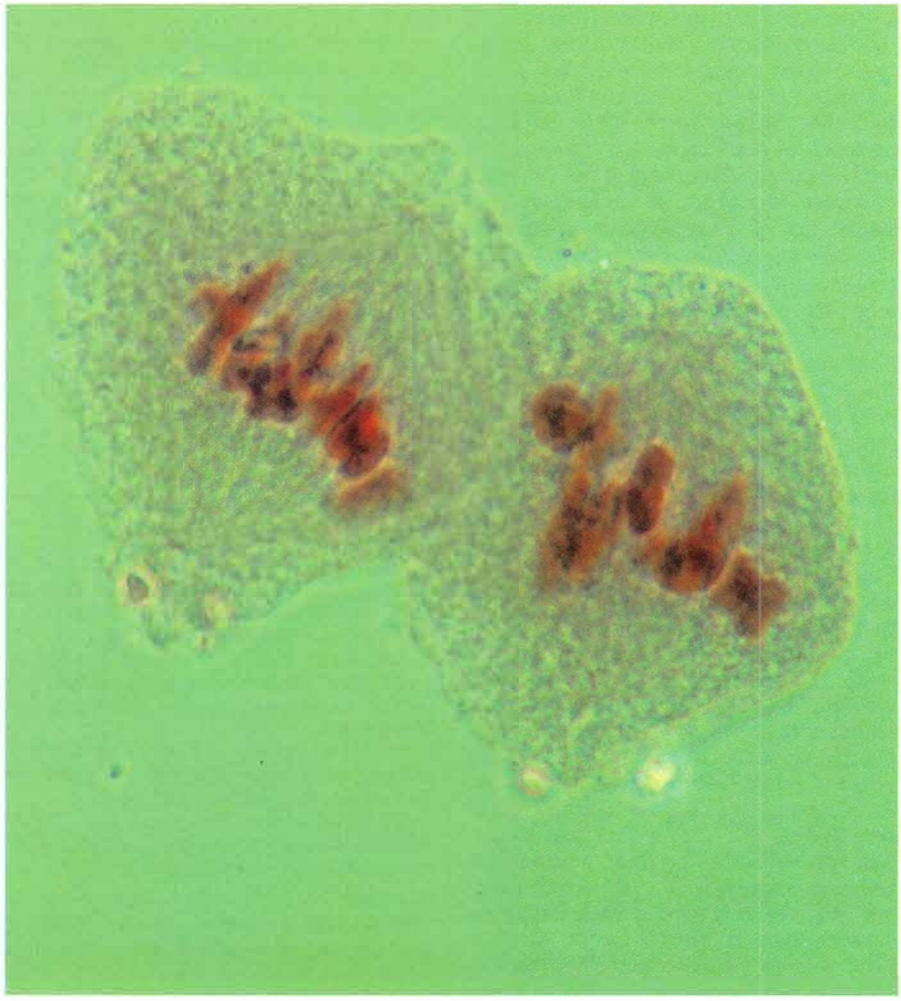
One instance of meiotic drive, discovered by L.C. Dunn of Yale University in the 1950s, concerns the homely mouse. The T gene of the House Mouse has a mutant form (t) that either kills or sterilises the individual inheriting it on both chromosomes. (The T gene is related to the formation of the vertebral column—especially in the tail, hence T gene.) Because the t form is harmful we might expect that natural selection would quickly remove it. But it isn't removed. Ninety-five per cent of the litter sired by a male carrying the t form will also carry that form. This is because, for some unknown reason(s) when the t mutant appears, the sperm carrying the normal version of the gene die. So only the t form is transmitted to offspring. Why this mutant affects only sperm and not eggs is not known.

By eliminating its 'competitor' (the normal form) during the formation of the sperm, the t version guarantees that it will remain common, regardless of its damaging effect on the individual carrying it. In this way the t mutant gets around the action of natural selection.

If this can happen with chromosomes, what about genes? Gabriel Dover, of the University of Cambridge, proposed a mechanism called 'molecular drive'. This he believes may be an important factor in evolution, because it "homogenises the genotype" (the total complement of genes carried by an individual). That is, it results in the replacement of all the variant forms (alleles) of a gene by only one or a few forms.

It is not really a single mechanism for, as Dover readily admits, at least five processes are involved. Among these are 'transposition' and 'gene conversion'. During transposition a gene generates a second copy of itself, which then migrates to a new location. If this new location

Meiosis acts to divide the chromosomes, and the genes carried on them, equally among the daughter cells (gametes). In meiotic drive this equal apportioning fails and certain chromosomes (and genes) are 'forced' on the offspring regardless of their value. The photo shows meiotic division during anaphase, the most distinguishing phase of meiosis.



MALCOLM RICKETTS

happens to be on another chromosome, the gene can eventually spread through all the chromosomes and become more common in the genome. This increases its chances of being inherited.

Sometime during the formation of gametes, the gene on one chromosome is replaced by a copy of the gene on the other. This 'gene conversion' can occur during cell division and, if it favours one form ('biased gene conversion'), sooner or later the favoured form will replace the others. It is as if the Sherlock Holmes stories in your library were to all become copies of *The hound of the Baskervilles.*

Molecular drive decreases the variation among the genes in an organism. Dover has suggested that this is how the diagnostic features of a species come to be possessed by all its members. He contends that molecular drive explains 'concerted evolution'. This is evolution in which the genes of individuals belonging to related species differ more than the corresponding genes of individuals belonging to the same species. Furthermore, molecular drive provides a mechanism of evolution that is neither 'at the whim' of the environment, as is selection, nor random, as is genetic drift (change in organisms by chance). Instead, it (and meiotic drive) could provide an internal mechanism directing evolution, of the kind suggested by Wiley and Brooks in their study of evolution and entropy (see ANH vol. 23, no. 4, 1990). Both meiotic drive and molecular drive are processes that 'force' the inheritance of certain genes (or chromosomes) regardless of their survival value.

Many organisms have large numbers of genes that seemingly do not contribute either to the development or the everyday 'running' (maintenance) of the organism. How did such genes originate? Could some genes code *only* for their own replication and do nothing for the organism? This is like a book that spells out in detail how to make another copy of itself. Ford Doolittle and Carmen Sapienza, at Dalhousie University in Nova Scotia (Canada), propose that there are such genes. They term the phenomenon 'parasitic DNA'.

An example is the F factor of the well-known colon bacillus *Escherichia coli.* The F factor is a double-stranded circular DNA molecule (a plasmid) including at least 30 genes. Some F plasmid genes induce a bacterium to grow a thread-like projection. When another bacterium is contacted, a process takes place by which a daughter F plasmid is placed in the other cell. Thus a set of genes that provides no (at least no obvious) benefit to the host organism can multiply and spread. In this instance the 'parasitic' DNA transfers itself from cell to cell; as originally proposed by Doolittle and Sapienza it would remain in the same cell but come to occupy more sites on the chromosomes. This is natural selection at the level of genes, where certain genes that can produce more often leave more copies of themselves than others.

But there is evidence that some DNA may multiply simply at random. William Loomis and Michael Gilpin from San Diego (California) have suggested that processes (like transposition) that duplicate genes will create considerable 'junk' or 'nonsense' DNA. Unlike parasitic DNA this DNA—like an unreadable book—doesn't code for its own replication, or for anything else; and it isn't harmful enough to the organism to be exposed to natural selection. Loomis and Gilpin ran computer simulations in which the 'genes' could be duplicated or dropped out at random. These produced proportions of coding to non-coding (akin to nonsense DNA) 'genes' similar to those actually found in organisms.

Gene conversion occurs in fungi; transposition is known in the fruitfly *Drosophila*, as well as in flowering plants; and nonsense DNA is known in many organisms. Despite their relative commonality, the significance of these factors in evolution is still debated.

But there is more to all this. Natural selection at the level of organisms is well known, and selection has also been proposed at higher levels, like extended family groups and even species. But we now know that selection, and random processes akin to the genetic drift that occurs among populations, also function at the lower levels—at the level of the genes. Therefore, just as organisms evolve in relation to their environment, so do genes evolve in relation to their environment—the nuclei of cells. All of these phenomena bear out the hierarchical interpretation of evolution and provide a framework for the understanding that, while we are clearly individuals, we are also—at the level of genes—communities. ■

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Dr Ralph Molnar is Curator of Palaeontology at the Queensland Museum. His research has been directed towards filling the vast gap in knowledge of Australian vertebrate history between the Devonian and Miocene. Dr Glen Ingram is interested in evolution and the philosophy of science. In 1987 he received a special commendation from the BBC Wildlife Nature Writing Awards.

QUESTIONS & ANSWERS

COMPILED BY JENNIFER SAUNDERS
EDITORIAL ASSISTANT

Bent Fish

Q. I've read somewhere that deep-sea fishes suffer from decompression when brought to the surface and this is why they often explode or distort. Yet the recent article in ANH (vol. 23, no. 5, 1990) mentions that the cells of these fishes are filled with fluid rather than air and so they do not have a problem with pressure. Could you please clarify this for me?

—John Simms
Carlton, NSW

A. The article on deep-sea whalefishes dealt specifically with midwater fishes, that is, those fishes that live in the water column above the bottom. The deep-sea fishes that suffer from decompression are bottom fishes that have their swimbladder or airbladder expanded with decreasing pressure as they are brought to the surface. This expansion can be great enough to push the stomach out of the mouth, thus causing the distortion. This type of decompression can also affect fishes living in water as shallow as ten metres. Deep-sea midwater fishes have typically lost the swimbladder, or it has become filled with fat, and there is no air space to cause decompression problems.

—John Paxton
Australian Museum

Deep-sea fishes can be affected by decompression when suddenly brought to the surface.

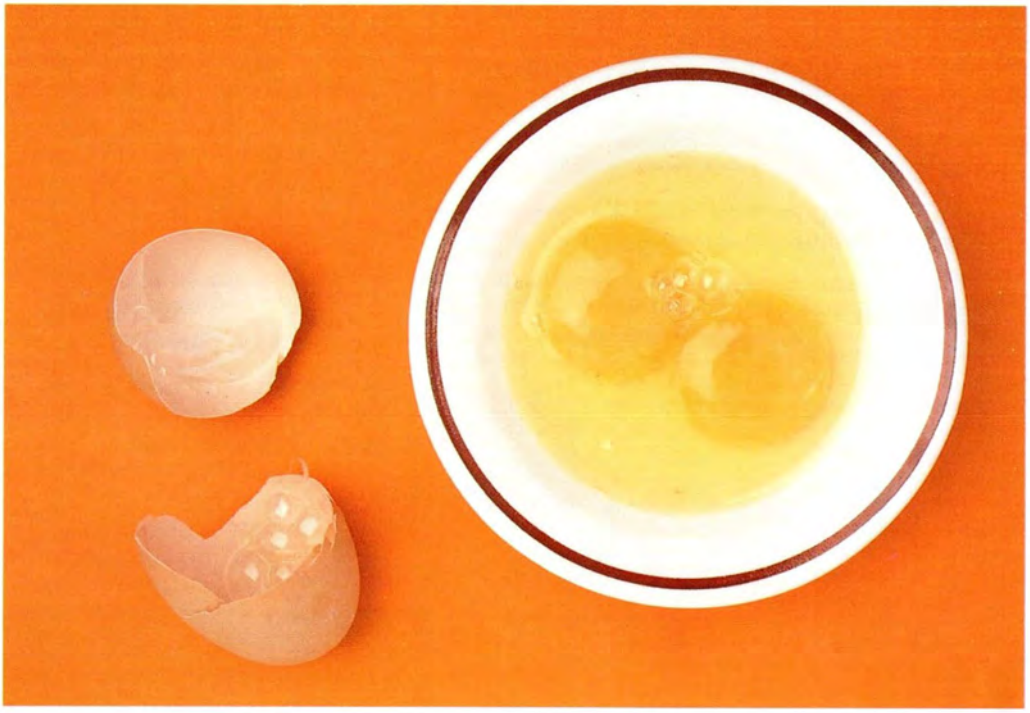
Double-yolkers

Q. Double-yolked chicken eggs are not that uncommon, but I have never heard of two chickens hatching from one egg. Why?

—Thomas Cobcroft
Ipswich, Qld

A. According to the CSIRO Division of Animal Production, the presence of a second yolk disrupts the normal development of the egg, making it inviable. This prevents the egg from reaching the hatching stage, except perhaps in very rare instances. In any case, commercial practice is to remove double-yolked eggs from the production line and not give them the opportunity to hatch, regardless of their viability. Double-yolked eggs are almost invariably the product of young hens and their frequency decreases with age: by a bird's twelfth week of laying usually only single-yolked eggs are produced.

—Walter Boles
Australian Museum



KAREN HANDLEY/AUSTRALIAN MUSEUM

Double-yolked eggs are rarely allowed to get to the hatching stage.

A Deadly Quandary

Q. Can you please resolve for me the correct zoological name for Australia's Fierce Snake, also known as the Inland or Western Taipan. Consensus suggests the name is *Oxyuranus microlepidotus* but Dr Cogger puts a strong case for *Parademansia microlepidota*. Also, can you suggest which are currently thought to be the world's deadliest snakes? If the African Black Mamba is not included, how would you rate this snake?

—Tony Hughes
Dingley, Vic.

A. As Dr Cogger stated in 1987, "groupings of species must always require an arbitrary decision about the boundaries of the group" (*Fauna of Australia 1B*, p. 269). The decision, therefore, to group *scutellatus* and *microlepidota* in the genus *Oxyuranus* or to consider them representatives of separate genera, *Oxyuranus* and *Parademansia*, must be a subjective one. Zoological nomenclature (the application of scientific names to animals) is designed, amongst other purposes, to reflect the evolutionary relationships of animals, and this is accomplished by the allocation of species to genera.

There is general agreement amongst scientists that the Taipan (*Oxyuranus scutellatus*) and the Fierce Snake (*O. microlepidotus*or *Parademansia microlepidota*) are more closely related to each other than to any other snake. They are similar in scalation, general biology and venom composition. There are, however, considerable differences in the skull, which some biologists consider more important than the above characteristics when deciding the degree of relationship between species. Venom yield, venom toxicity, fang length, head shape, colour pattern, habitat and geographical distribution also differ considerably between the two species.

The Fierce Snake superficially resembles the Western Brown Snake (*Pseudonaja nuchalis*)—which occurs within its geographical range—more closely than it does the Taipan. The geographical restriction of the Fierce Snake to ashy downs country in the Lake Eyre Basin of south-western Queensland and north-eastern

South Australia contrasts strongly with the coastal distribution of the Taipan, which extends from the Kimberleys of Western Australia to far north-eastern New South Wales.

Dr Cogger considers the lumping of the Fierce Snake and the Taipan into one genus masks these differences, which could be of medical, conservation and evolutionary significance. The consequences of this grouping would be even greater if a subspecies of the Taipan, *O. s. canni* (which occurs in Papua New Guinea) were elevated to specific rank as has been suggested. The grouping of these three species into one genus would disguise the much closer relationship of *canni* and *scutellatus*.

In short, if you think the differences between the Fierce Snake and the Taipan warrant their being placed in separate genera, then the correct scientific name of the former is *P. microlepidota*. If, however, you think they belong in the same genus, the correct name is *O. microlepidotus*.

In regards to the second query, the 'deadliness' of a species of venomous snake should be judged by a number of factors (venom toxicity, venom yield, fang length, temperament and frequency of bite). The most significant of these are venom toxicity and venom yield. The Fierce Snake has the highest toxicity of any snake venom measured (in terms of the quantity sufficient to kill a standardised sample of laboratory mice), although its average and maximum venom yields are considerably smaller than those of the Taipan, Tiger Snake, Death Adder, King and Indian Cobras and Eastern Diamondback Rattlesnake. The predicted lethality index proposed by J. Morrison, University of Queensland, and colleagues to combine toxicity and yield, places the Fierce Snake at the top of the list, followed by the Taipan, Tiger Snake and Death Adder (*Clin. Toxicol.* 21: 373–385; 1984).

If, however, fang length, temperament and frequency of bite were weighted equally with the first two factors, the sequence of deadliness would alter. For example, the Fierce Snake's fangs are shorter than those of the Taipan, Death Adder and Mulga Snake, its temperament has been described as 'placid', and it occurs in a very sparsely populated region of Australia so the actual and potential frequency of its bite is extremely low. In contrast to this, some species of viper in Africa and Asia are responsible for killing thousands of people each year.

The toxicity of the Black Mamba (*Dendroaspis polylepis*), according to P.A. Christensen in *Venomous animals and their venoms* (1968), lies between that of the Tiger Snake and Death Adder. It has a high venom yield and would make the list of the 'world's ten most deadly snakes' if you equate deadliness with Morrison's lethality index.

—**Liz Cameron**
Australian Museum

FRITHFOTO

Fierce Snake.

REVIEWS

COMPILED BY JENNIFER SAUNDERS
EDITORIAL ASSISTANT

A Run-down on Environmental Lifestyle Guides

How to be Green
By J. Button. Random Century Hutchinson, Sydney, 1989, 280pp. $14.95.

The Green Consumer Guide
By J. Elkington & J. Hailes. Penguin Books, Victoria, 1989, 326pp. $14.99.

The Green Buyer's Guide
By M. Gee. S. & W. Information Guides, Victoria, 1989, 263pp. $12.95.

It's Easy Being Green
By R. Gell & R. Beeby. McCulloch Publishing, Victoria, 1989, 131pp. $12.95.

The Green Cleaner
By B. Lord. S. & W. Books, Victoria, 1989, 82pp. $7.95.

Shop Safe
By M. Gore & C. Smeeton. Century Magazines, Sydney, 1990, 96pp. $3.95.

The Australian Non-buyer's Guide
By Australian Non-Buyer's Guide Collective, 2nd ed., 1990, 40pp. $6.00.

There is no shortage of advice on how to be environmentally responsible. The above books are just a few of the better, or better known, putative guides for the 'green way of life'.

It's easy being green is a good green primer. Although the authors had trouble keeping track of Australian peoples' water consumption and Australia's contribution to the greenhouse effect, they cover the issues and offer an easy-to-read guide with useful advice. Interestingly, this is also one of the few guides to propose specific native replacements for our high-maintenance, water-guzzling lawns.

Shop safe exemplifies a fundamental consumer concern—it's cheap, but is it a bargain? There are plenty of sound recommendations in this booklet but it is odd that few are concerned with shopping. There are also promotions of decidedly 'un-green' products such as photodegradable plastic bags and aerosol sprays. A potentially useful service is the Shop Safe Green Hotline but, at the time of writing, I was puzzled to hear recorded basketball scores. The main weakness of *Shop safe*, however, is that it is largely composed of nutritional information that is readily available elsewhere—such as on the sides of cereal packets.

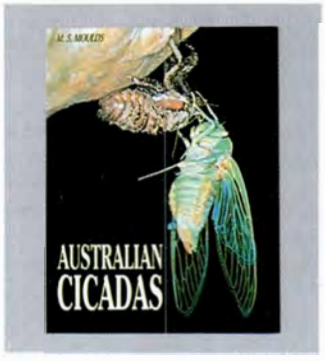
How to be green, *The green consumer guide* and *The green buyer's guide* are more comprehensive and have varying degrees of usefulness as both guides and references. All three provide the reader with comparable lists of contact organisations and suggestions for further reading. Each section in *How to be green* is divided into "The facts", "What needs to change", "What you can do" and "Who benefits". This structure clearly identifies the issues and appropriate actions required. The information would have been more accessible, however, if the book had an index like *The green buyer's guide* or, better still, a comprehensive index like *The green consumer guide*. The green guide of the darkest hue is *How to be green*. Whereas the other two guides allocate 'greenie points' (sometimes too freely) to supermarkets for changes to their operations (such as switching to photodegradable bags), Button argues against our centralised system of food production, processing and distribution. His book treats recycling and plastics well and, if you think you need it, there is a sizeable section on food and health in *How to be green*. Some however, may find the didacticism in this section a bit wearing. An inventory of the evils of alcohol, for instance, is probably less deservi[illegible] of a place in such a publication than are the whereabouts of producers of 'organically grown' wine (which can be found in the other two guides). The information in *The green consumer guide* and *The green buyer's guide* is in general well presented and preference for one or the other will partly be a matter of taste, but *The green consumer guide* seems to be more thoroughly researched.

If you're concerned about a household hoard of chemical cocktails in the guise of cleaners, pesticides, deodorisers etc., then *The green cleaner* is a good investment. While the other publications provide some recipes for substituting proprietary chemicals with biotic products and simple low toxic chemicals, *The green cleaner* is comprehensive in this regard.

For those who want to take consumer decision-making a step further, *The non-buyers' guide* is recommended. This work has been available for several years and it reveals which products (green or not) are made by companies also involved in rainforest destruction, arms manufacture, the nuclear fuel cycle, and so on. Handy cards to assist at the supermarket and updates are also provided.

All of these guides offer advice on how to reduce individual environmental impact, which is essential if we aspire after a sustainable society. Nevertheless such action will be little more than a salve for the conscience in the absence of achievements in the area of population control. While some authors try to provide a broader perspective, there is an implicit notion that pervades many green guides: "we can shop our way out of our environmental problems". The concept of the green citizen, who challenges the policies and structures that support the unsustainable activities of our species, should subsume that of the green consumer, not be peripheral to it.

—Alan Watterson
Australian Museum



Australian Cicadas
By Max Moulds. New South Wales University Press, Kensington, 1990. 217pp. $39.95.

Although Australia has one of the richest cicada faunas in the world, until now there has not been a reference book detailing it. Cicadas are immensely popular among school children, particulary in the eastern States where schoolboys might have a cicada in their pocket instead of the traditional frog. With the publication of this book, there is no reason why such childhood interest in these fascinating creatures should not blossom

into a more scientific adult study, as has happened so often with butterflies.

Max Moulds is probably Australia's best known insect collector and has the rare distinction of having species in nine orders named after him. Max is currently a Research Associate in the Entomology Department of the Australian Museum and has been interested in cicadas since he was a teenager.

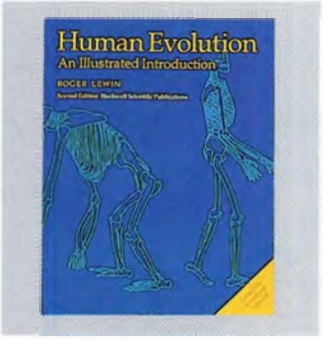
In this book, Max presents a review of all the information available on Australian cicadas. The text is divided into two parts. The first, the Introduction, includes nine chapters covering such topics as life history, sound production and reception, collection and preservation, structure and function, and classification. The second part of the book details the Australian cicada fauna. For each species a map of known localities and information on habitat, distribution, behaviour, morphological features of adults, song and life history is presented in a clear and concise fashion. A glossary, lists of abbreviations and reference works used, and a comprehensive index completes the publication.

Max's style is readable and easy to understand, even when dealing with highly complex subjects such as sound production. Particular attention has been paid to recording the common names applied to each species and this book will help to stabilise the plethora of names applied, frequently haphazardly, to cicada species. The 24 colour plates include photographs of the species described in the text and one plate shows the known nymphal exuviae.

Despite the obvious appeal to the popular market, there has been no compromise in the scientific content with much information new to science being presented in the appropriate scientific manner. The quality of production is first class, as exemplified by the apparent lack of errors and the clarity of the colour plates. It is a fitting tribute to the effort Max has invested in this project that *Australian cicadas* has been awarded a 1990 Whitley Book Award medal.

This book should sell well because of its subject matter alone, but it will also be the definitive reference work on this popular group of insects for years to come. This is not to say that there are no gaps in our knowledge of cicadas. Max frequently points out where more information is needed. It is expected, however, that this work will provide sufficient stimulus among insect workers of all levels of expertise to take a productive interest in these lively insects.

—**M.J. Fletcher**
Biol. & Chem. Research Inst.
NSW Agriculture & Fisheries



Human Evolution: An Illustrated Introduction
By Roger Lewin. Blackwell Scientific Publications, 2nd ed., Melbourne, 1989, 153 pp. $39.95.

There has long been the need for a clear, inexpensive introduction to human evolution, accessible alike to first-year university students, high-school students, and the interested general public. Too often we have textbooks of physical anthropology that cover too much ground too cursorily and with too much jargon. Roger Lewin's book, especially in its updated second edition, neatly fills this gap.

What makes Lewin so well qualified to write such a book is that he is a science journalist of a special kind: he has taken pains to adopt a 'hands-on' approach, having dug with Richard Leakey at Koobi Fora, sat at the scanning electron microscope with Alan Walker and examined computer printouts with Bernard Wood. His writing, moreover, has not been for the newspapers or the popular science magazines, but for one of the most widely respected professional journals, *Science*. This means he has acquired the knack of explaining certain kinds of science to other kinds of scientists, and so maintains a high standard of rigour without talking down to

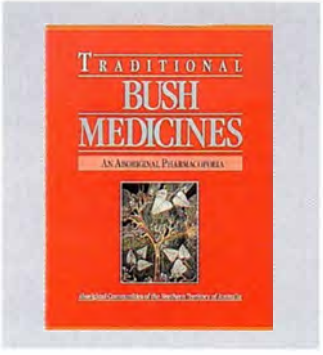
his readers. He also remains about as jargon-free as it is possible to be in such an enterprise.

The book begins with chapters on the history of evolutionary thought, evolutionary theory today, the concept of neoteny (misspelt "neotony"), and a little geological background, including the relatively new field of taphonomy (the study of burial and fossilisation processes). I would have liked to see a chapter on dating methods included here. Next is an introduction to systematics, with a discussion of phenetic and cladistic philosophies. It appears his sympathies seem to lie more with the non-cladists, and when he writes that "Classification should also reflect the very drastic ecological shift that has occurred in the hominid line compared with its ape cousins, they contend", it is with obvious approval. He does not bring out the subjectivity that this is bound to entail—what does it mean, for example, to recognise a family Pongidae, united as it is by primitive retentions alone? Or a genus *Australopithecus* full of robust and gracile species of admittedly diverse lineage affiliations? But there, my own prejudices are hanging out.

After a brief survey of the living Primates, especially as models for human evolution, and the fossil 'anthropoids', Lewin turns to the human fossil record. I mentioned earlier his non-cladistic stance (not exactly anti though; I don't think he has thought enough about it for that) and how it leads him into an unthinkingly 'trad' treatment of such fuzzy concepts as catch-call *Australopithecus*. This crops up again when he discusses *Homo erectus*, which he treats as just a segment on the ascending human lineage. He does cite the cladistic analyses of Andrews, Stringer and Wood, which suggest that the Asian *H. erectus* have their down-derived features that are not "on the way to modern humans", but dismisses them in a way that suggests he has really not quite understood their importance. "The counter to this cladistic analysis", he writes on page 102, "is that anatomical differences of this sort seen among *Homo erectus* as traditionally defined are precisely what would be expected in a geographically and temporally dispersed species". The second part of the statement is perfectly true but has no bearing on the first. After all this, I am bound to say that the treatment of the fossils is very thorough and gives a good feel of a dynamic field with lively debate and constant rethinking of paradigms. Theoretical discussion on the origin of modern humans, contrasting regional continuity ('candelabra') and replacement ('Noah's Ark') models' is followed by a recounting of the mitochondrial DNA evidence, which is unfortunately headed "Mitochondrial Eve" and so perpetuates a common misconception. The two final sections have overviews of the origin of cultural items, including language, art, dispersal to the Americas and Australasia, and the beginnings of settled life.

So this book has, in my opinion, some drawbacks but it is, after all, meant as an introduction; if it is read as such (and *not* as if it were the last word), it fills its chosen niche admirably. In fact, it has already been set as the textbook for a couple of courses at the Australian National University and has proved useful. If you want to find out about human evolution, this is certainly the place to start.

—Colin Groves
Australian National University



Traditional Bush Medicines: An Aboriginal Pharmacopoeia
By the Aboriginal Communities of the Northern Territory, Greenhouse Publications, Victoria, 1988, 265pp. $80.00.

Another book on the Aboriginal use of plants you ask? Well, yes it is. That in itself might cause one to ask how many of these kinds of books the market can support.

This book focuses on the use of plants as medicines, rather than on a broad range of plant uses or on plants as traditional sources of food. In fact, its subtitle *An Aboriginal pharmacopoeia* gives it the air of an authoritative, technical book. According to *The Macquarie dictionary* (1981), a pharmacopoeia is a book containing a list of medicinal drugs with their preparation, properties, uses etc. The book's preface mentions the importance of ritual, social obligations and seasonal factors as integral parts ensuring the efficacy of plant use by Aboriginal people, but then excludes the "esoteric power and mysticism of deeply held beliefs" from its analysis. Perhaps this book should not have been called an Aboriginal pharmacopoeia, for I can't imagine an Aboriginal project not including aspects that are part of the essence of Aboriginal plant use.

Traditional bush medicines, like most large-format books in this genre, is well presented—in fact it has so many well-produced photographs interspersed throughout the text that one might wonder how this affected the price of the book. Photographs show plant detail, habitat and occasionally people involved in gathering and manufacturing plants. One disturbing feature about the photographs is the anonymity of the Aboriginal people in them. This appears to be even more odd when, on page 9, a photograph showing a non-Aboriginal botanist with his back to the camera is named and an Aboriginal community adviser half facing the camera remains unnamed.

The layout of the text and the inclusion of line drawings showing fruit, flowers, leaves and an illustration of the typical form of the plant, make for easy identification. The description of the plants in the text, however, is of no use to a reader without background to formal descriptive jargon used in botanical identification (unless one were to continually refer to the glossary at the end of the book). If words like "phyllodes glabrous", "inflorescence densely villious" or "peduncles terete" leave you none the wiser, then you should focus on the bits of the description that say "flowers greeny-yellow", "bark dark grey, rough" or "seeds small, kidney-shaped". The amount of technical information within the text and the appendixes combined with the photographs give the impression of a coffee-table book designed for technicians.

A handy summary chart at the beginning of the book provides a quick reference and the glossary of botanical and pharmacological terms, plus the general glossary, can fill in the gaps any reader may have.

Traditional bush medicines was produced as a Northern Territory Health Department bicentennial project. It should be mentioned that this was not without some criticism being directed at both the product (that is, the book itself) and the processes involved in acquiring the information, the acknowledgment and recognition of Aboriginal expertise, and the high profile and control of the non-Aboriginal people involved in the project. A reader might argue it's not the place of the book reviewer to cover the controversy surrounding the original project and its end result, but the reviewer might respond by saying the book, isolated from its context and intent, is only part of its function. Its impact and usefulness can only be diminished if the Aboriginal people involved have been, or are seen to have been, excluded from the area where their expertise is undisputed.

—Anne Skates
Australian Museum

Aliens From Inner Space
The Fastest Claw in the West
BBC Wildlife Specials, distributed by Hoyts Polygram Video, 1988, Sydney, 24 minutes each. $29.95.

This videotape, from the famous BBC production, contains two stories on two totally unrelated animals. The first is titled *Aliens from inner space.* Anyone who has had the opportunity to observe a live cephalopod (cuttlefish, squid or octopus), either in captivity or in the sea, has never failed to be amazed at the beauty of this animal and its ability to change colour. This short program is a brief introduction to

this fascinating and unlikely (but true) relative of snails and mussels. Using superb photography the program shows the viewers the tremendous range and often ever-changing colour patterns in cephalopods, the fast and accurate strike actions of tentacles and arms in catching prey, the egg-caring behaviour of the octopus, and the hatchlings of octopus and squid. I particularly liked the sequence showing a large octopus escaping through a small hole—a phenomenon known to anyone who has ever tried to keep octopuses in an aquarium, but rarely observed. Regrettably, a small flaw does occur within one of the sequences on cuttlefish where a short segment showing a squid giving off ink is included.

Sepia latimanus, a giant cuttlefish growing to 50 centimetres in body length, is common in the coral reefs of the Indo-West Pacific region. The success of rearing them in aquaria provides opportunities not only for the public to view this fascinating creature but also for scientists like Roger Hanlon of the University of Texas to study it in captivity, as there are no cuttlefish on either coast of the Americas.

The ability of cephalopods to change colour rapidly is effected by minute organs call chromatophores. These consist of a sac-like cell filled with pigment granules surrounded by a series of nerve-controlled radial muscle fibres. The contractions and relaxations of the radial muscle fibres change the shape of the pigment-filled cell, thus changing the colour shown by the cell. The combination of three different pigments and varying degrees of expansion of the many pigment cells gives the animal 'infinite' colour patterns.

But what does this pattern of colour mean? Are these creatures signalling to one another? Although evidence exists that these colour patters, together with body surface textile patterns, are used in confusing prey and predators. Hanlon cautions that we are only beginning to understand the range of complexities of these patterns, and we are even further away from understanding what they mean and how they are used. "Alien from inner space"? You bet!

The second story is titled *The fastest claw in the west.* What has the speed of 10 metres per second and the impact of a .22 calibre bullet? A new weapon? No! Incredible as it may sound, it is the speed and power of a strike delivered by a mantis shrimp.

Mantis shrimp, so named because the front part of its body resembles that of a praying mantis, is an unusual member of the Crustacea. It is exclusively marine and predominantly found in the warm waters of the Indian and Pacific Oceans. It is carnivorous and hunts for prey by means of its characteristic raptorial claws (the modified second thoracic appendages).

This program shows how scientist Dr Roy Caldwell captures and studies this unusual and fascinating creature. Using superb photography it illustrates how the mantis shrimp hunts for its food, and defends and maintains its burrow. To study the animal's ability to learn, Caldwell used a plastic cube containing food with one glass-plated side. The mantis shrimp was shown to be capable of learning where to strike so it would smash the glass and hence reach its meal. To smash a thick-shelled snail it takes a mantis shrimp four or five strikes but, for a large snail, the mantis shrimp may work for an hour or more and deliver up to 500 strikes to reach the edible soft part.

With a strike speed of 36 kilometres per hour, the mantis shrimp can indeed live up to the program's title of the fastest claw!

This two-program videotape contains informative introductions to two fascinating marine animals. Its superb photography together with the clear narration of David Attenborough make it absorbing viewing.

Of course with the limitation of time the descriptions are sometimes overly simplistic. But perhaps this will whet the appetite of the viewers who want to know more about the subjects. The programs are educational and can be recommended to anyone who is interested in marine animals.

"Beautiful, fabulous", claims Roger Hanlon at the beginning of the tape, and I cannot help but echo this.

—C.C. Lu
Museum of Victoria

"At the risk of reducing archaeological reasoning to some sort of religious faith, it is clear that at some elemental level the identification of a specific tool rests solely on the perception of the observer."

WHEN IS A STONE A TOOL?

BY TOM H. LOY

RESEARCH SCHOOL OF SOCIAL SCIENCE & PACIFIC STUDIES
AUSTRALIAN NATIONAL UNIVERSITY

IN THE MIDDLE OF THE NIGHT, RAIN pouring down and the river rising by centimetres a minute, a gust of wind rips up one of the metal pegs holding down a corner of my tent's rain fly. There is not time to fetch the mallet before the fly is torn away by the wind so I quickly grab a nearby cobble, bang in the peg and go back to bed. I have just created a stone artefact.

How might some future archaeologist recognise my hammerstone as a tool? For that particular tool—one of a hundred cobbles along the river and used once for a job that involved 30 bangs on the peg—it would be difficult without some other clues. First, there would be some evidence that the patch of ground where I camped had been occupied; my hearthstones for example, or the remains of the wallaby I cooked and ate. Perhaps the pocket knife I lost might be found by a keen-eyed field worker.

At some point an experienced archaeologist would begin to look at less obvious evidence; the top of a rusted tent peg sticking out of the dirt, and eventually a hand-sized cobble that had impact pitting on one face. But would the archaeologist recognise that cobble as a tool? Perhaps he would merely look at the small pits, classify them as entirely natural and throw the cobble into the creek.

At the risk of reducing archaeological reasoning and analysis to some sort of religious faith, it is clear that at some elemental level the identification of a specific tool rests solely on the perception and thought processes of the observer. Museum curators are constantly entreated to verify dubious artefacts collected by people who have no training or experience in prehistory and whose sole criterion for giving an object the status of 'tool' is based on the fact that the rock 'fits the hand'.

To classify an object as an artefact or tool requires two lines of inquiry: what constitutes the set of things we call tools, and what things are not tools? To define tools, we must have some idea of the tasks that people in the past performed. They cut things, so some tools must have physical attributes that facilitate cutting. Similarly, they pounded things; so some must have physical attributes that facilitate pounding. The process of tool identification is one of subdivision and classification of attributes that suit specific tools to certain tasks.

Not all sharp-edged objects are cutting tools. On my first archaeological dig I found a leaf-shaped, thin, ragged-edge piece of quartzite near a fire hearth. I was convinced I had found an arrowhead (it fitted the imaginary arrow shaft, was pointy and certainly could cut). My professor patiently explained the process of heat spalling of rock; repeated freeze–thaw, or hot fires and cold rains can easily fracture a thin flake from the surface of a rounded cobble and it would look just like the one I had found.

"... stone tool function is a key to 99 per cent of human history..."

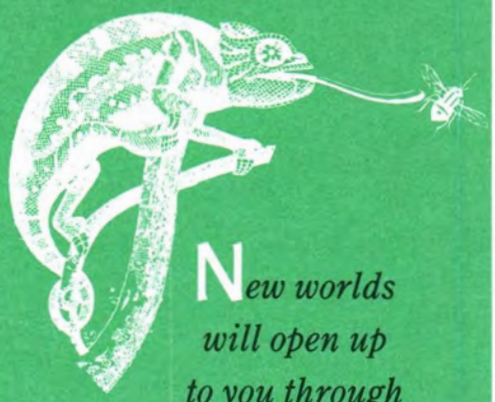
Rocks break in specific and predictable ways depending on the type and nature of the breaking force. Bashing one stone against another creates distinctive pitting but could be formed by natural or human forces; flaking rock using another stone (or bone, or antler, or hardwood) as a hammer leaves distinctive fracture marks and features on both the core (the original rock), the flake (the piece that was detached) and the hammer. So tool recognition and identification relies on an understanding of the physical results of the various steps in manufacture, and of the forces of nature that can produce things that might *look* like artefacts but that are clearly not tools.

Humans are purposive beings: actions are done to achieve specific results. The formation of an artefact or tool reflects a regularity of purpose and intention, and thus the tool reflects the regularity of both purpose and the regularity of the process of formation. Out of the set of all forms that might be suitable for use as a tool, only some will fit the mental image the maker had in mind. By identifying and combining the patterns inherent in the maker's choice of raw material, manufacturing technique, and the context of those patterns within the larger cultural and ecological setting, it is one of the aims of archaeology to reconstruct aspects of the intention and purposes of action that lie behind the fact of the tool.

But the examination of tools at this large, object-oriented scale is not always sufficient to discriminate between the 'tool' and the debris that results from its manufacture. And it is a truth that form does not always specify function. An arrowhead is defined partially by its form, but that form does not preclude its use as a knife, scraper, or strictly ceremonial object. Examination of objects at a smaller scale than we can see with the naked eye reveals the presence of the traces of the tool's use. The use history of the tool is evidenced by residues of blood, tissue, starch, resins, feathers and hair, for example; as well as the smearing, dragging, striations and edge damage that give testimony to the mode of use and number of times the tool had been used. A close look at my *ad hoc* hammerstone would reveal traces of metallic iron in addition to the less diagnostic patterns of pitting, size and shape.

The combination of shape, manufacturing technique and suitability for specific functions, when integrated with the identification of residues and other traces of use, can ultimately yield a definitive answer to the question: is this thing a tool? But is it worth the effort? Yes, because stone tool function is a key to 99 per cent of human history; and by employing science to understand how people thought through and solved problems in the past we are not only resolving an archaeological problem but also revealing our own thought processes. Our inquiries into the past expand our knowledge of human history and define more precisely our own minds and the nature of knowledge itself. Science and knowledge are peculiarly human—as renowned cosmologist Carl Sagan observed "*We* are the way the cosmos knows itself." ■

Dr Tom H. Loy is a visiting fellow in the Department of Prehistory, Research School of Social Sciences and Pacific Studies, Australian National University. The last ten years of his research has been directed towards blood residue analysis.



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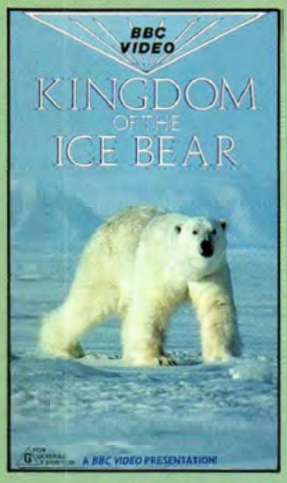

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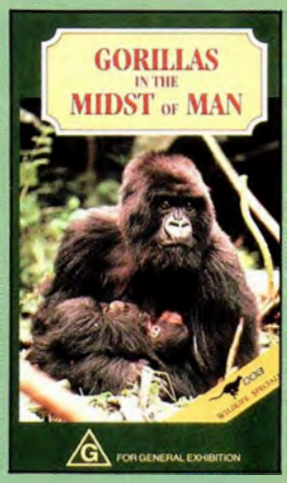

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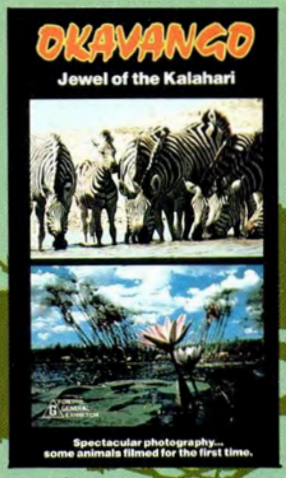

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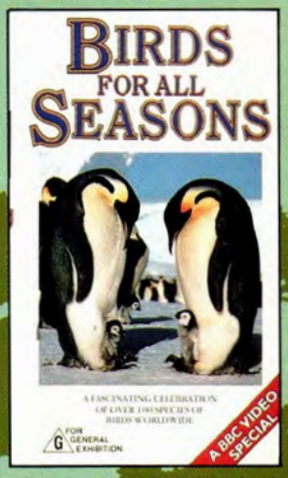

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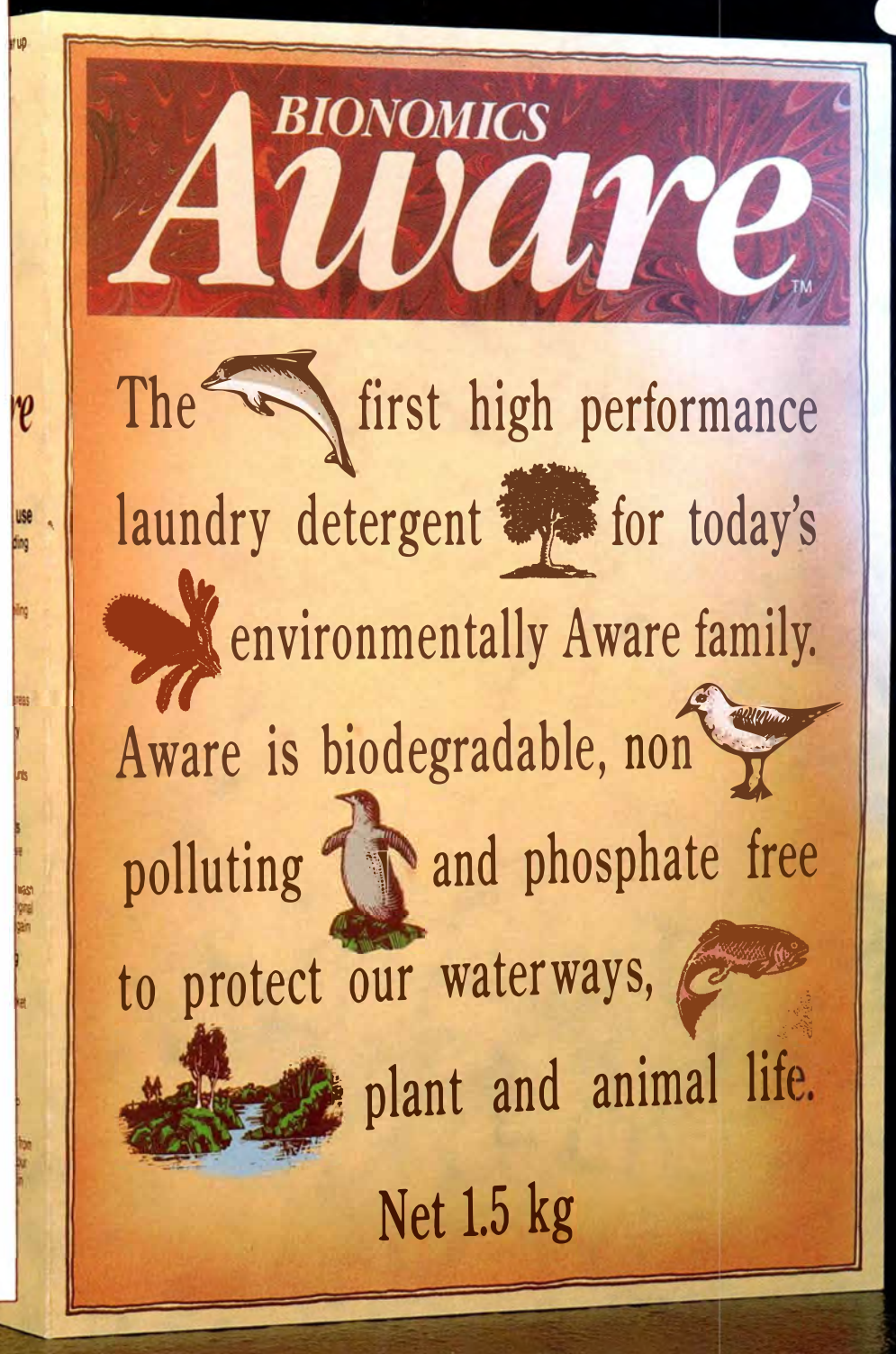

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