Evolution of Australian Birds

Patricia Macwhirter B.V.Sc. (Hons), M.A., F.A.C.V.Sc.
Highbury Veterinary Clinic
128 Highbury Road
Burwood, Vic, 3125

When we go out to dinner after the conference tonight, look to west, just above Sydney Harbour, beyond the sunset and the smog and you should see the stars Altair and Antares, parts of the constellations Aquila and Scorpio. From where I come from in Victoria, the Bunurong Aborigines perceived these stars to represent their creator spirits, Bunjil, the eagle and Pallyan, the bat. It is perhaps from this rich region of the night sky that the 'big bang' singularity event occurred some 13.7 billion years ago. According to Stephen Hawking (2001), within a second of this event, the big bang produced protons, neutrons, photons, electrons, neutrinos and their antiparticles, which, as the universe expanded and cooled combined to form the nuclei of helium, hydrogen and other light elements. Several hundred thousand years later the temperature dropped to a few thousand degrees, a level at which electrons slowed down to a point where light nuclei could capture them to form atoms. By some three billion years after the big bang, energy and matter had decoupled, the universe became transparent and clusters of matter began to form quasars, stars, proto-galaxies and globular clusters. It is to this time, more than 10 billion years ago, that the globular cluster M4 or the Cat's Eye Cluster, which lies near the star Pallyan/Antares and has been dated.

Several lines of evidence suggest that by five billion years ago stars had begun to synthetise heavier nuclei and new galaxies formed in which stars, including the sun we now see overhead, and associated solar systems emerged. In this context, the planet earth formed from a spinning disc of gas, dust and a core of molten rock. In early times it was constantly bombarded by meteors and on its surface volcanos erupted as the crust solidified into massive tectonic plates. Tiny zincron crystals found in sedimentary rocks from Mount Narrayer in Western Australia dating from 4.2 billion years ago, tell of these fiery times when volcanos and comets came together and temperatures fell enough to produce the key elements of life: hydrogen, carbon, nitrogen and sulphur, along with an atmosphere and liquid oceans. Carbon chemistry could begin to work its apparent 'magic' in a primeval chemical broth and give birth to ribonucleic and, later, deoxyribonucleic acids, the central chemicals in replication of life forms. A strong case can be made for natural physical and chemical processes, random variation and selection pressure being driving forces behind the emergence and evolutionary development of both geological and life forms.

Sometime around 4.0 - 3.8 billion years ago the common ancestor of life on Earth emerged, perhaps similar to present day prokaryotic bacteria, organisms that are still found in abundance, both free living and as pathogens. Subsequent selection pressures favoured the emergence of new chlorophyll containing, oxygen producing prokaryotes, the cyanobacteria, such as those that still live as Stromatolites in Shark Bay in Western Australia. These bacteria are thought to have profoundly altered the earth's environment by gradually increasing the oxygen in the atmosphere.

By about 1.4 billion years ago, probably from the union of two prokaryotes, the size of micro-organisms increased and ameoboid-like, ‘eukaryotic’ cells came to have internal organelles encased in membranes, including nuclei to house nucleic acids and oxygen utilising mitochondria as minute power houses to fuel respiration. These basic features are ones that have been retained by present day pathogens, such as *Histomonas* sp, the agent causing Black Head in Gallinaceous birds, as well as being the building blocks for more complex life forms.

The longest ever Ice Age lasting from one billion to 600 million years ago (mya) caused major extinctions of this early biota, the first of half a dozen such major extinction events that have occurred since life began on earth. As the cold times ended, water mobilised from the depths of ocean basins brought with it phosphate, a previously rare element needed for skeletal development and the first truly multi-cellar organisms. The Edicara Fauna of the Flinders Ranges (670 mya) and lamp shells (brachiopods), which are still found in waters off eastern Australia, date from these times. Sexual reproduction, also emerged. The haploid nuclei that form the two ‘eyes’ of Giardia protozoans are thought to be a relict form that date back to early forms of sexual reproduction.

At the dawn of the Phanerozoic Era (about 545 mya) Sydney lay submerged beneath Australia’s coastal waters, near where the present day Philippines lie. Trilobites and graptolites dominated the seas and one very large continent, Gondwana, which then included Africa, South America, Australia and Antarctica, straddled the equator. Thanks to countless generations of cyanobacteria, the earth’s atmosphere and oceans had become rich in oxygen, which animals could use for respiration and, in turn, produce carbon dioxide on which most plant life relied. The cycle had begun which ultimately produced the flora and fauna of our present continents, including birds that fly and humans, like you and I, who could look at them and puzzle “Why?”

Rifts

During the Cambrian and Silurian eras (570-400 mya), Gondwana drifted slowly south under the influence of convection currents from the still molten metallic mass of the earth’s interior and came to rest near the South Pole. Australia became a peninsula whose extensive coastline straddled the Tropic of Capricorn. As part of the largest land mass and with one of the longest coastlines in the world it is not surprising that the Australian peninsula was a place where sea creatures came to breathe air and venture ashore. More than 400 mya a small crocodile-shaped amphibious creature placed footprints on a sandy shore in western Victoria, while early lungfish gulped air in coastal rivers. Most of Europe still lay beneath the sea. For the next 175 million years amphibians called labyrinthodonts dominated a land vegetated with primitive psilophytes, lycopods and horsetails.

By the Carboniferous Period, 350 mya, the continent of Laurasia, which included Europe and parts of North America emerged from the sea, moved south and coalesced with Gondwana to become a single land mass, Pangaea. The collision zone, formed 300 mya is still evident in the folding, faulting and granite outcrops of hills that run from the Carolinas, Georgia and westwards. Flora and fauna between the two landmasses intermingled, enabling a vastly increased pool of natural variation. With new selection pressures at work, the amniotes, vertebrates who were able to produce eggs in which embryos could develop independent of an aquatic environment, emerged. Reptiles were the first to appear.

When the next wave of global extinctions occurred 245 mya, large amphibians over most of Pangaea were wiped out while descendants of the small reptiles survived and evolved to fill a wide range of ecological niches. These included the progenitors of turtles, lizards and snakes as well as the archosaurs which in the warm. humid climate of the Mesozoic Era gave rise to the crocodile family, the pterosaurs, the dinosaurs and birds. It has been argued that birds should rightly be a subgroup within Reptilia rather than given equal rank with Mammalia and Reptilia.

When and where did feathered reptiles first appear?

Cases have been made for birds closest relatives being the therapods (small, bipedal, carnivorous dinosaurs including thecodonts), the crocodile family or an early, extinct archosaur lineage that is neither crocodilian nor dinosaur. Bird bones are particularly fragile and do not preserve well, so it is not surprising there are gaps in the fossil record. Phylogenetic analysis and fossils with possible pro-avian features emerging from both Asia and North America have not resolved the debate as to whether birds are embedded in the highest node of dinosaur evolution, as supported by Larry Martin (2002) or had a progenitor in a small, arboreal, basal archosaur of the Triassic Age, a proposition supported by Paul Sereno (2002).

About 140 million years ago the earth's convection currents carried the Australian peninsula of Pangaea to its furthest point south, near the Antarctic Circle. Walk southwest from this hotel and you could cross Antarctica and proto- India and could then turn north to reach those parts of Pangaea that would one day become the Americas. North West Africa remained connected with South America but water encircled Africa's eastern and southern coast. Proto-Europe and proto-Asia lay beyond the east-west orientated Tethys Sea. It was on the north shore of this sea, 140 million years ago, that *Archeopteryx* lived, the earliest feathered reptiles to be found in the fossil record to date. Significantly, basic dinosaur features (a postero-ventrally facing glenoid, open pelvic acetabulum and a supra-acetabular shelf) are absent while *Archeopteryx* skeletons show a curious mix of traits including a primitive pelvis with an elongated digitigrade foot. Major avian features of the wrist, ankle & stiffened tail are also absent and so would have been absent in any common ancestor. Differences in form, implantation and replacement of the teeth in *Archeopteryx* also suggest that the common ancestor might not have been a thecodont.

Feathers, modified scales, are the key difference between birds and (other) reptiles but the earliest birds did not fly and the evolutionary steps between ectothermic reptiles and the wide diversity of endothermic, flighted and non-flighted avian species of today has been the subject of much speculation. Critical bio-geographical events over the 140 million year period since the first appearance in the fossil record of reptiles with feathers have included
the gradual break up of Pangaea and Gondwana due to tectonic plate movement, the emergence of flowering plants and the expansion of winged insects, major extinctions that marked the end of the Cretaceous Era, possibly due to a meteor crash near present day Central America 65 mya, *'la grande coupure'* - the separation of South America and greater Australia from Antarctica with resultant circumpolar currents, global cooling and increased winds, ongoing sea level changes, fluctuating climates and the emergence and global expansion of mammalian species, especially pinnepeds, felids, canids and humans.

Australia's earliest currently known bird fossils date back to Early Cretaceous Times, about 120 mya when dragon flies, bracken ferns and cycads dominated the landscape and the earliest flowering plants were just appearing. At least five feathers have been recovered from the fossil bed of an ancient wetland near Koonwarra, Gippsland, beside a forest of ancient Gingko trees with leaf types similar to those of the Rajmahl series in India and the Tico flora of Patagonia. The vegetation pointed to links Australia shared with India and Patagonia when the three were joined as part of Pangaea and lay near the Arctic Circle. After detailed studies, Rogers (1987) concluded that one of the feathers could be distinguished from all modern orders of Aves. Apart from material from Koonwarra, to date the other avian remains from the Mesozoic of Australia is a tibiotarsus from west Queensland, *Nanantius eos.* This fossil appears to be related to the enantiornithines, an early subclass of birds with a global distribution including Mongolia, Mexico and Argentina. Occurrences outside Australia are all from the Late Cretaceous so, to date, the Australian fossil is the oldest known member. *Nanatius* was about the size of a European blackbird (*Turdus merula*), which would also have been consistent for a bird from which the Koonwarra feathers moulted. Avian bones have recently been found from the Koonwarra Swamp material and work is currently being undertaken to determine whether they are likely to have been of enantiornithine origin.

With tectonic plate movement, a rift valley formed between Gondwana and proto-New Zealand which, some 80 mya, gradually flooded to become the Tasman Sea. To date the avian fossil record of New Zealand only dates back to 65 mya and early finds are dominated by sea birds but this may reflect poor preservation and lack of systematic searching rather than the true position.

The great crash of 65 mya. Given the global distribution of enantiornithine and more than a dozen other genera of land and sea based Mesozoic bird fossils, it would seem that a variety of primitive birds were widespread at the time of the great Central American meteor crash of 65 mya. It is likely that birds and bird-like reptiles living near the impact would have had little chance of surviving the initial explosion and fires and the ensuing long dark winter. Those living at a distance, for example southern South America, Antarctica and Australia (which at that time were still conjoined as Gondwana) may have escaped the worst of the global disaster and provided populations from which ecological niches in the northern hemisphere could be repopulated. The ability to fly or swim would have aided dispersal. Fossil evidence and distribution of endemic bird families suggest that Western Gondwana might have been the origin of many bird species of today. Vickers-Rich (1996) notes that flightless land birds, penguin-like birds using their wings as flippers and loon-like marine birds using their feet as paddles were amongst primitive avifauna of the southern regions of Early Tertiary times. Warheit (2001) in his comprehensive list of fossil sea birds lists bony-toothed pelicaniformes from both North Hemisphere sites and, later, New Zealand.

La grande coupure. The next critical biogeographical event for evolving avifauna was *la grande coupure* - the great cut, so coined by the Swiss palaeontologist Hans Stehlin. Beginning 60 mya Australia began to unzip itself from Antarctica as tectonic plate movement slowly drew the continent northwards. Fossils of giant penguin-like birds have been found near Adelaide that date to these times. By 40 mya, about the same time that India crashed into southern Asia, the Antarctic Circumpolar current flooded between Southern Tasmania and Antarctica. This caused global cooling and strengthened coastal and trade winds. When the Drake Passage between South America and Antarctica opened 35 mya the effect was magnified, polar ice caps expanded, winds strengthened, temperatures dropped further and global cold water currents carried rich marine food sources northwards. It was from this time that the dramatic expansion and diversification of flighted bird families occurred.

How did reptiles evolve into flighted birds?

If a species is to survive and multiply, evolutionary change needs to confer immediate advantage for the next generation. The paucity of the avian fossil record, particularly in Mesozoic Times, leaves many blanks but key events in the transition between reptiles (be they early archosaurs, thecodont or crocodilian) and birds must have included the development of feathers along with changes in thermoregulation, reproduction, nesting behaviour, respiration, renal function and musculo-skeletal structure. Efficient flapping flight appears to have occurred relatively late in the sequence. Birds leaped, ran, swam and glided long before they became masters of the air.

Feathers for thermoregulation, buoyancy and flight

In general, ectotherms are at an advantage in hot, sunny climates where food sources scarce but endotherms perform better when the climate is cooler, nights longer and food sources abundant. Winged insects pre-dated the emergence of birds by some180 million years. Such insects, along with aquatic creatures could have provided an abundant food source around the shores of the Tethys Sea where *Archeopteryx* lived, in the Gippsland wetland where the Koonwarra birds first moulted their feathers or in China or Texas where other early bird or pro-avian fossils have been found. The flat foot structure of early fossil birds suggest they leaped, waded, walked or ran on two legs rather than perched on small branches as their more curved footed descendants came to do. They perhaps leaped or hang-glided, using a long neck and bill, still with reptilian teeth, to catch prey, their forelimbs free for balance and other purposes. Insulation, balance and perhaps bouyancy, rather than flight, may have been the key initial benefits that feathers provided. *Hesperornis*, a toothed, loon-like Cretaceous marine bird from the northern hemisphere, for example, couldn't fly but used its large feet for swimming. When the great meteor crash of 65 mya occurred, the bird population of southern Gondwana, evolving near the Antarctic circle, had experienced long cold nights for at least 60 million of years. Being away from the site of the impact and having adapted to the cool, dark conditions for millions of years could have had some bearing why ancestral birds in this region (for example the progenitors of ratites, penguins and volant birds) appear to have survived and perhaps provided populations that dispersed elsewhere.

Reproduction and nesting behaviour

Birds' reptilian ancestors would probably have had two ovaries, laid large clutches of eggs simultaneously which were incubated in nests on the ground in moist conditions and gave rise to precocial young. Crocodiles, birds closest extant reptilian relations, still nest in this manner. For pro-avians, using body heat to shorten the incubation time, eventually including brood patches, could have been an advantage to reduce risk of predation and for survival of the young, particularly in cool climates, but would have also favoured birds having small enough clutches to incubate against the parent's bodies. Grebes, an ancient family that builds floating nests, might be a model for this type of incubation. Alternatively, a feathered, partially endothermic avian ancestor may have nested in burrows, as for example Little Penguins (another ancient avian family) still do today.

In either case, the ability of feathered pro-avians to use their own body heat to speed up the incubation process may have been advantageous in the short term in enabling birds to make use of nest sites in tree hollows, branches or bushes but this also required a change in egg structure to enable the embryos to survive in conditions with lower humidity. Laying small clutches of eggs individually rather than as a simultaneous clutch eliminated a need for two ovaries and pro-avian bodies could be streamlined to contain a single ovary and oviduct. By producing a more heavily calcified, less porous egg shell in a shell gland, bird eggs became less prone to desiccation and birds could exploit nesting sites above the ground. The emergence of medullary bone lay down of calcium in egg laying females would have assisted this process. Flight and the avian reproductive 'package' developed hand in hand. Reptilian characteristics are still seen in avian nesting behaviour, for example, standing and shielding eggs in cormorants and cockatiels.

While primitive birds would likely have hatched precocial young, altricial young could be produced from smaller eggs relative to the size of the adult bird. This could have been an advantage for many flighted birds and offset the greater parental care required to rear altricial young.

Respiration

The fossil record is silent on the nature of the respiratory function in primitive birds but respiratory systems of birds differ significantly from reptiles in their extensive development of the air sacs, lack of a diaphragm, the presence of pneumatic bones and use of air capillaries rather than alveoli. These features generally make for lighter bodyweight and efficient respiration, both of which are cornerstones for leaping, running, swimming or flight. Ratites and penguins, both primitive Gondwanan avian families, have paleopulmonic parabronchi in which air flow is caudo-cranial and unidirectional linked with their air sacs. Storks, cormorants and cranes have this system as well as an additional network of parabronchi, the neopulmonic parabronchial net, in which air flow is bi-directional. Almost all other birds have well developed neopulmonic parabronchi. Birds' rigid skeletal systems appear to have functioned as a bellows-like apparatus in breathing and aided in streamlining and lightening birds' bodies for swimming or gliding long before birds took to the air in flapping flight.

Musculo-skeletal adaptations

The strong winds that followed *la grande coupure* may have been an added factor favouring birds that were good at gliding and, later, flapping flight. Cruise on Sydney Harbour and you'll see cormorants resting on the rocks with their wings stretched out, drying their feathers and enjoying the sun. Watching them it is easy to imagine how flighted birds' patagial membranes, stretching from the carpus to the shoulder and the elbow to the body wall, could have evolved. Birds generally have dorsoventral rather than lateral flattening of the body and, to assist flight, the centre of gravity needs to be below the extended arm rather than above it. Dinosaurs generally had deep slender bodies with arms ventrally situated to allow a wide excursion of the thigh when running but earlier archosaurs were not so specialised.

In avian ancestors rotation of the coracoid to the front of the chest and the scapula to the flat of the back left the glenoid in a dorsolateral position. This positioning of the scapula facilitates climbing as well as the formation of the wing and it is also seen in mammalian climbers, including primates. However in the avian model the scapula is strap-like, narrow and fixed compared with the broad triangular scapula of climbing animals. Flighted birds do not require strong muscles to raise their wings as 'lift' performs this function, but they require strong muscles for the down beat (superficial pectoral muscle), and muscles control of the patagial membrane to alter the angle of attack and the adjust curvature of the dorsal aerofoil surface of the wing.

In addition to the change in the centre of gravity and reduction and fixation of the scapula, skeletal refinements useful for flapping flight in birds include:

- pneumatic bones.
- replacement of teeth with lighter beaks
- fusion and strengthening of bones of the limbs, spine and synsacrum,
- enlargement of the ulna from which secondary wing feathers emerge,
- development of the alula from the second digit of the wing,
- development of uncinate processes on the ribs,
- shortening of the tail to become the pygostyle,
- fused clavicles forming the furcula,
- the enlargement of the coracoid,
- development of the keeled sternum,

- the triossesus foramen which enabled the tendon of the deep pectoral muscle to attach to the head of the humerus and control the angle of attack of the leading edge of the wing.

The seeds of some of these changes could be seen in *Archeopteryx* but the upsurge and explosion in diversity of birds capable of flapping flight did not occur until after 30 mya when pectoral girdle and sternum confirmation typical of modern carinates emerged and became widespread.

Australian and New Zealand Avifauna

To date the sum total of Australia's Mesozoic (pre-65 million years ago) bird fossils is a single fossil tibiotarsus from Queensland and the feather impressions and bones from the Koonwarra Swamp in Gippsland. These were discussed earlier and are both possibly of enantiorithine origin.

The Palaeogene (65-23 mya) record is also sparse and consists of dromornithid trackways in a closed temperate rainforest in Tasmania, along with large and small penguins from South Australia and Victoria. From the New Zealand fossil record there are diving birds, early penguins and a 60 million year old volant bird from Chatham Island.

The dromornithids or mihrungs, were large ground-dwelling birds known from tracks, gizzard stones, bony remains and egg shells, that diversified into at least eight species but declined and became extinct as grasslands expanded emu-like casuariids and later emus, became more abundant. Impressive giant penguins that were long necked and grew up to 135 cm tall became extinct, but the small fossil penguin species were quite similar to present day *Eudyptula* spp, the Little Penguins that delight visitors as they come onto the beach each evening at Phillip Island, near Melbourne.

In the Miocene (23-5 mya) the Australian avian fossil record improves markedly, as do avian fossils from around the world, and diverse avifaunas emerge, particularly from sites in northern South Australia. These consist predominantly of waterbirds including ducks and related anseriforms, a variety of charadriiforms, including thick-knees (Burhinidae) and flamingos and flamingo-like palaelodids. The flamingos are particularly interesting as the species is no longer present in Australia, probably becoming extinct as the shallow permanent alkaline inland lakes dried up. Also represented, but rare, are pelicans, grebes, cormorants, raptors, rails, pigeons and passerines.

Only a few groups of birds have a good enough representation over time and have been studied sufficiently to allow reconstruction of their evolutionary pattern over the past 20 million years. Some groups, for example the stork, ibis and spoonbill, crane, heron, bustard and owls, are only represented in Australia by relatively recent fossil material similar to extant species. As fossil records elsewhere in the world are longer, this might suggest that these families of birds may have evolved elsewhere and only subsequently spread to Australia. Care needs to be taken, however, because bias and gaps in the fossil record are significant. In other groups the length of the Australian fossil record rivals that of elsewhere in the world.

Ratites
The oldest Australian record to date of this group dates from the Miocene in Western Queensland and is an intermediate form between Cassowaries and Emus. Cassowaries later came to dominate in the far north and New Guinea while emus rivalled the dromornithids in grasslands in the south. With rising sea levels at the close of the last Ice Age some 10,000 years ago, flora and fauna on Bass Strait Islands became stranded. Dwarf forms of emus evolved on Kangaroo and King Island and in Tasmania. These birds became extinct following white settlement.

The oldest records of New Zealand ratites, the kiwis and Moas, are less than 10 million years old. If ancestors for these flightless birds were isolated along with the islands when the Tasman Sea formed some 80-70 mya, the large gap in the fossil record is puzzling. While this may simply reflect a lack of fossil recovery, an alternative explanation could be that these groups derived from birds that flew or swam to New Zealand sometime after the split occurred. Moas became extinct following the arrival of Polynesians in New Zealand around 1000 years ago. Kiwis, the only flightless bird to remain at large on mainland New Zealand, have suffered dramatic falls in populations since European settlement.

Pelicans
Fossils of now extinct, ‘bony-toothed’ pelicans (Pelagornithidae) have been uncovered dating from soon after the end of the Cretaceous from a site in the North Atlantic, suggesting that this community survived the global extinction event. Later examples have been found in the Pacific Ocean and New Zealand. In Australia the oldest pelicans (without bony teeth) also date to the Miocene but evolutionary trends are difficult to assess because material is fragmentary.

Ducks, Geese and Swans
Australia has relatively few species of Anatidae when compared with the rest of the world. The fossil record dates back to the Miocene but species identified correspond to extant species. Species like the Magpie Goose and Freckled Duck have interesting archaic intermediate characteristics between swans and geese and swans and ducks respectively.

Hawks, Eagles and Falcons
The earliest fossil records of these families again date to the Miocene and there appear to have been a few more kinds of large accipitrids, including an Eagle that exceeded the size of current day Wedge-tailed Eagles. Otherwise the species recovered have been similar to present day species.

Waders
An abundance of fossil bones dating to the Oligo-Miocene period of a Burhinidae species distinct from, but related to, present day Beach Stone-Curlews has been uncovered. This rivals oldest records of the group from North America. Material from other wader families appear indistinguishable from extant species. A possibly pre-Quaternary partial skeleton similar to that of the extant Plains Wanderer, a species with affinities to both quail and waders has been uncovered in Victoria. A case for allying this group with avifauna of South America has been made.

Frogmouths, Owlet Nightjars and Swifts
The fossil record of frogmouths in Australia is restricted to the Quaternary(less than 1.85 mya), while a much longer record exists in Europe. Owlet Nightjars, on the other hand, are known from a primitive specimen preserved in volcanic caldera lake deposits in the Warrumbungle Mountains of New South Wales from around 15 mya. Records of swifts in Australia start in the Miocene or Late Oligocene, rivalling reports in Europe and Asia.

Moundbuilders
Small megapodes were reported in Late Eocene deposits in France but the oldest Australian record of this group date to the late Tertiary. Currently megapodes are found only in Australasia, excluding New Zealand but including some of the Indonesian islands.

Pigeons
Earliest records of pigeons date from Early Miocene, with fossils identified from this time in both Central Australia and in France. Both dove and pigeon sized birds have been identified.

Parrots and Cockatoos
Earliest Australian record is that of a cockatoo dating to Late Oligocene or Early Miocene deposits in Riversleigh in Queensland. Interestingly older records exist for Europe with parrot fossils (*Paleopsittacus georgi*) being found in Eocene deposits in both Britain and France.

Passerines
Earliest Australian records again trace to the Riversleigh Oligo-Miocene sediments with species similar to the present day logrunners (Family Orthonychidae) and to lyrebirds (Family Menuridae) being identified. These records are as old as any in the world, although passerines from Oligo-Miocene material from France is of approximately the same age.

Origin of Australian Birds

Linking paleogeological data, fossil records and known current distributions of birds there are several routes by which various groups of birds may have arrived in Australia.
Ancient endemics
Dispersal via Gondwana
Dispersal from Eurasia
Oceanic dispersal
Human dispersal

Asia, North America and the Palaearctic each have only one endemic family of birds compared with thirty-one for South America, fifteen from Australia and six from Africa. This suggests that bird families are more likely to have evolved in Gondwana and dispersed north rather than the reverse. While the fossil record is sparse, the near simultaneous early records of such species as parrots, pigeons and passerines in Oligo-Miocene sediments in distantly separated France and Australia is intriguing and could suggest an earlier dispersal from a more central point. Paleogeological data suggests that north eastern South America retained contact with the western bulge of Africa, which indirectly retained contact with Europe some millions of years after Southern Africa had become separated from Gondwana. Likewise the southern tip of South America retained contact with Antarctica and, indirectly, Australia up until some 35 million years ago. Island and continent hopping along this chain could have provided a corridor via which early flighted birds could have dispersed. More research into the avian fossil records of South America and Africa could help to clarify the picture. It was only later, as Australia drifted north, that the distance between Australia and Asia diminished, and movement of birds, in either direction, along the Indomalaysian route to Australia was facilitated. This is perhaps reflected in the affinities that species of the so-called Torresian avifaunal region of northern Australia share with Indonesian and Asia compared with the more highly endemic birds of the Bassian avifaunal region of southern Australia or the Eyrean avifaunal region of arid central Australia.

Relevance of Evolution to Avian Veterinary Practice

Our universe has probably been around for some 13.7 billion years, birds for around 150 million, humans for less than a million. We are all part of an amazing, ongoing, interrelated creation in which time, energy and matter are intricately intertwined. This paper has only scratched the surface of this complex field, but features like avian anatomy, physiology and behaviour begin to make better sense when considered both in an evolutionary as well as a paleogeographic context.

Not surprisingly, avian diseases also show distributions that likely reflect the origins of avian species. Circovirus, for example, is widespread in psittaciformes on mainland Australia and also in Indonesia. Both pathogen and host species are likely have originated in Australasia, then perhaps became isolated on individual Indonesian islands with rising sea levels at the end of the last Ice Age, some 8,000 years ago. Circovirus was unreported in African or South American species until birds from these avifaunal regions were mixed with cockatoos from Indonesia in bird collections in North America. Following the movement of birds from aviculture collections globally, circovirus has now emerged in avicultural and, perhaps, wild bird populations in Africa and South America.

The circovirus puzzle is one which avian veterinarians, including some here today, have helped to unravel, yet our generation is contributing to the global spread of this disease. There are no prescriptive answers to these, or countless other, environmental problems confronting our generation. As leaders within our own spheres, in making complex decisions we need to link practice and theory, science and politics, the rational and the spiritual and act with a humble sense of respect for the past and responsibility future.

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