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# *Gondwana Alive* Corridors: Extending Gondwana Research to Incorporate Stemming the Sixth Extinction

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**Abstract**

In this volume in honour of John Rogers we propose a new way of looking at Gondwana and we urge our colleagues everywhere to join us in this venture. The *Gondwana Alive* Corridors provide a way of celebrating the unique geological, biological and cultural heritage of the Gondwana continents, and they offer a focus for the holistic management of that heritage. Here we explore a set of 15 prototype corridors from around Gondwana which together weave a tapestry of our prodigiously diverse planet. This Earth-history tapestry traces geological time from the oldest crust to the youngest ice sheets and from the earliest known life to the current activities of our human family. The corridors, in proliferating number, offer a science-based strategy towards stemming the Sixth Extinction.

**Key words:** *Gondwana Alive* Corridors, Sixth Extinction, biodiversity, consilience, Earth System Science.

## Introduction

Traditionally, Gondwana research has dwelt on the formation, lifespan and breakup of the southern supercontinent. Here we urge researchers to expand their focus, particularly over the next few years, to include the subsequent history and destiny of the Gondwana fragments through to today and beyond. Where are they now, where are they going? How have they influenced the post-breakup geological and biological history of Planet Earth? For example, the mingling of Gondwana stock at the docking of India with Asia has greatly affected the flow of life in that continent.

We ask our colleagues to extend their research 'out of Gondwana' into tracking the diaspora of Gondwana stems and in doing so to better understand the global stage as the springboard into the Sixth Extinction.

This volume is in honour of John Rogers. His lifetime research into understanding Gondwana processes is something that many of us have admired and we feel that he would highly endorse this new extended vision of Gondwana Research. We know that John himself would love to journey along the Gondwana corridors outlined in this paper. In celebrating John's vast contribution, we propose a way to trace out a new Gondwana path. With our geological and palaeontological eyes trained to seek backwards, our fraternity is bringing into focus the five earlier extinctions that are so well preserved in Gondwana sequences. Let us now look forward, too, and seek to understand the present and to apply our Gondwana knowledge into forecasting the course of this Sixth Extinction. How can we contribute towards stemming this rampant tide?

The *Gondwana Alive* (*GA*) Corridor Project was first presented at the 11th International Gondwana Conference held in Christchurch, New Zealand (25–30 August, 2002). These conferences have run for more than 30 years and provide a forum for the meeting of Gondwana minds and for Gondwana links to be strengthened and revitalised. The 11th conference, ably convened by Professor Bryan Storey, focussed on *Correlations and Connections*, and therefore provided an opportune time to launch the Corridors of Gondwana, a concept that aims to link Gondwana's deep-time connections with its present-day progeny. The corridor concept aims to re-connect Gondwana stems to their evolved biodiversity on contemporary Gondwana fragments now dispersed throughout the world; a biodiversity, born from a united Gondwana, but now threatened with collapse. We believe that there is an urgent need for new ferment and a reunited Gondwana spirit to contribute to the survival of wilderness and biological splendour beyond the fast-spreading Sixth

Extinction—through lessons learned from Gondwana experiences across previous bottlenecks of life.

The idea of bridging 'Earth Systems' across Gondwana met with an enthusiastic reception at Gondwana-11. This endorsement gave us the confidence to proceed with the project. Here we spell out its beginnings and its principal aims. It is hoped that it will evolve into a life of its own: firstly in the form of a key theme at Gondwana-12 to be held in 2005 in Thailand; and secondly as an official project ratified under the International Union of Sciences. We are at an important Gondwana crossroad. Taking the route that will preserve what we still have of our most youthful Gondwana shoots requires forethought and well co-ordinated projects, based on exciting but new scientific concepts that encapsulate robust contracts with global society and its environment.

### *Core themes and holistic management*

*GA* Corridors comprise two essential elements: core themes, and holistic management. Each of the 15 prototype corridors (Fig. 1) proposed and described here has a defined core theme. For one or more reasons, each corridor as a strip of territory is unique or unsurpassed globally from an earth science, evolutionary-biology or cultural history perspective. Each tells a story of the history of our world that cannot be told so well elsewhere. This is the reason for its recognition.

The second, and no less significant element, is implementing fast-track holistic interdisciplinary management along the corridor. We simply cannot conduct affairs globally along the well-tried traditional procedures, since it is precisely in this mode that we are destroying life on our planet. If we are to decelerate, convincingly, the Sixth Extinction within the decade—and we must—it is imperative that we think a quantum bigger than we are normally accustomed to.

An imperative part of thinking bigger is an awareness of where and how we as humans fit in the history of our Earth. We need to feel a oneness with our Earth and with nature; we are all latent biophiliacs (Wilson, 1992, 1994,

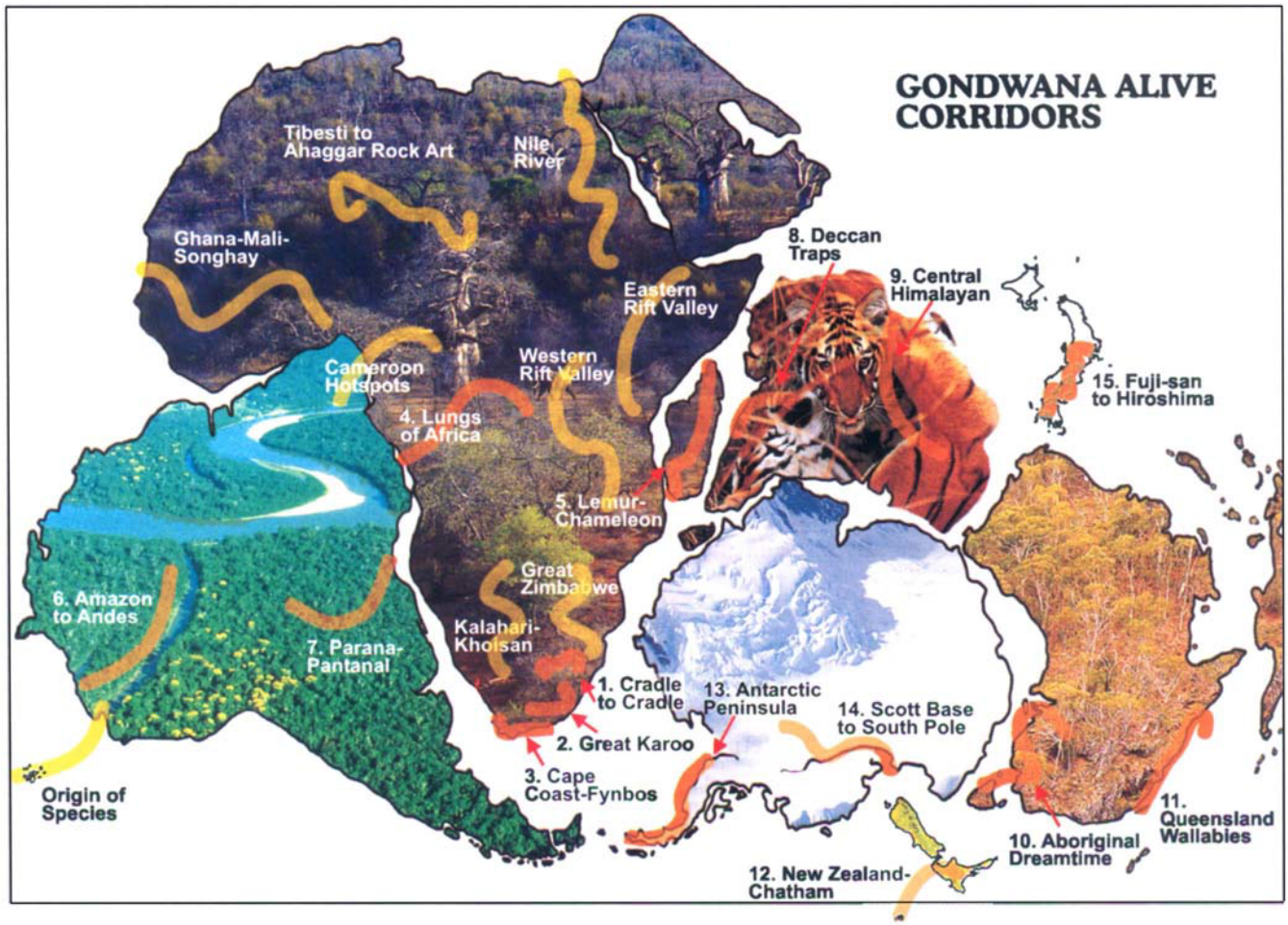


Fig. 1. *Gondwana Alive* Corridors: showing the 15 prototype corridors (orange, numbered) described in the text; and nine additional potential corridors (yellow, not numbered) through Africa and extending from the Galapagos Islands across to South America (see also Anderson and de Wit, 2003).

1998). If we understand and visualize our deep evolutionary roots, from the earliest appearance of life, through successive radiations of new life forms, the vertebrates, the mammals (Fig. 2), the primates (Fig. 3), the hominids, and finally *Homo sapiens sapiens* (Fig. 4), then we might hope to forge the international synergy necessary to halting the decimation of our planet's prodigious biodiversity.

### *A Gondwana-wide girdle/network of corridors*

We visualize, over time, an unbroken girdle–or, more precisely, network–of corridors spreading across the family of Gondwana continents and across the intervening oceans.

(a) On average, a corridor might extend ~1,000 km in length and have a width of ~50 km.

(b) Each corridor would be an autonomous unit, yet be an integrated part of the whole girdle or web.

(c) Each can be visualized as a belt of territory incorporating a series of critical nodes (World Heritage Sites; Biosphere Reserves; national, provincial or private parks; geological, biological or cultural hotspots)–a string of pearls.

(d) All persons living along a corridor take pride of curatorship and proprietorship and are partners in the holistic management thereof.

(e) All plant and animal species, and all biological communities, along the corridor are respected as having an equal right to optimal existence.

There follows in this paper a selection of proposed (but by no means exhaustive) prototype corridors (Fig. 1) for which research, GIS mapping and management plans could begin with a minimum of delay. The paper is one of a pair (see Anderson and de Wit, 2003) planned to appear more or less concurrently in mid-2003. While the present contribution has a fuller focus on the corridors and their management, the other has more emphasis on biodiversity, radiation and extinction.

### *Twin launching at Gondwana 11 and WSSD*

In late August to early September 2002, two global events coincided, the 11th International Gondwana

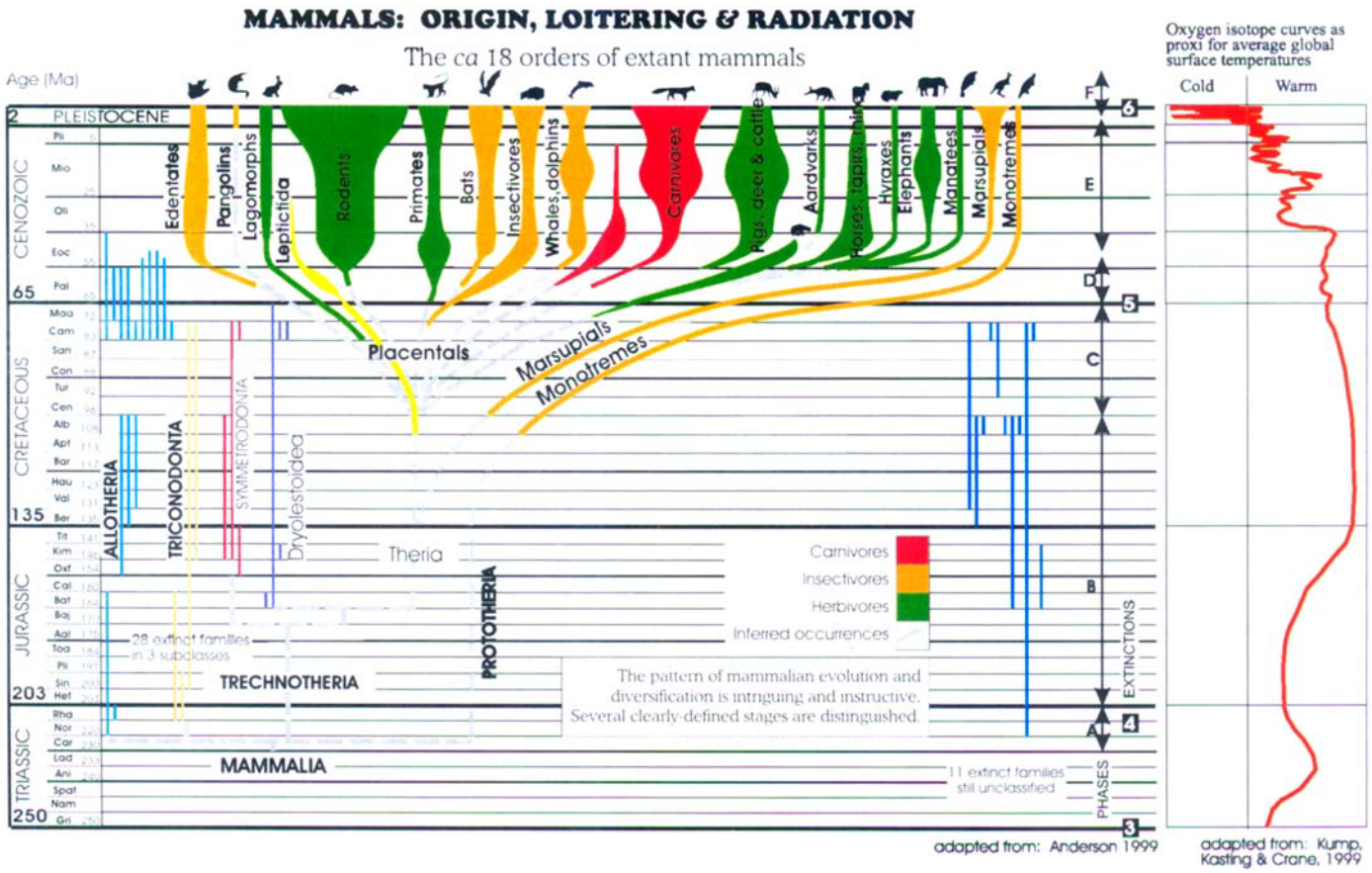


Fig. 2. Mammals: origin, loitering and radiation. This figure forms a triptych with figures 3 and 4; together they provide a picture of the adaptive radiation---at successive levels of resolution—of the mammals, primates and *Homo sapiens sapiens*. In each case, the phylogenetic tree of the group is plotted against a graph showing mean global temperature. It is clearly seen that our history as warm-blooded animals, over 100 Ma since the mid-Cretaceous, has been closely tied to a general trend of global cooling. Sources as indicated on figure.

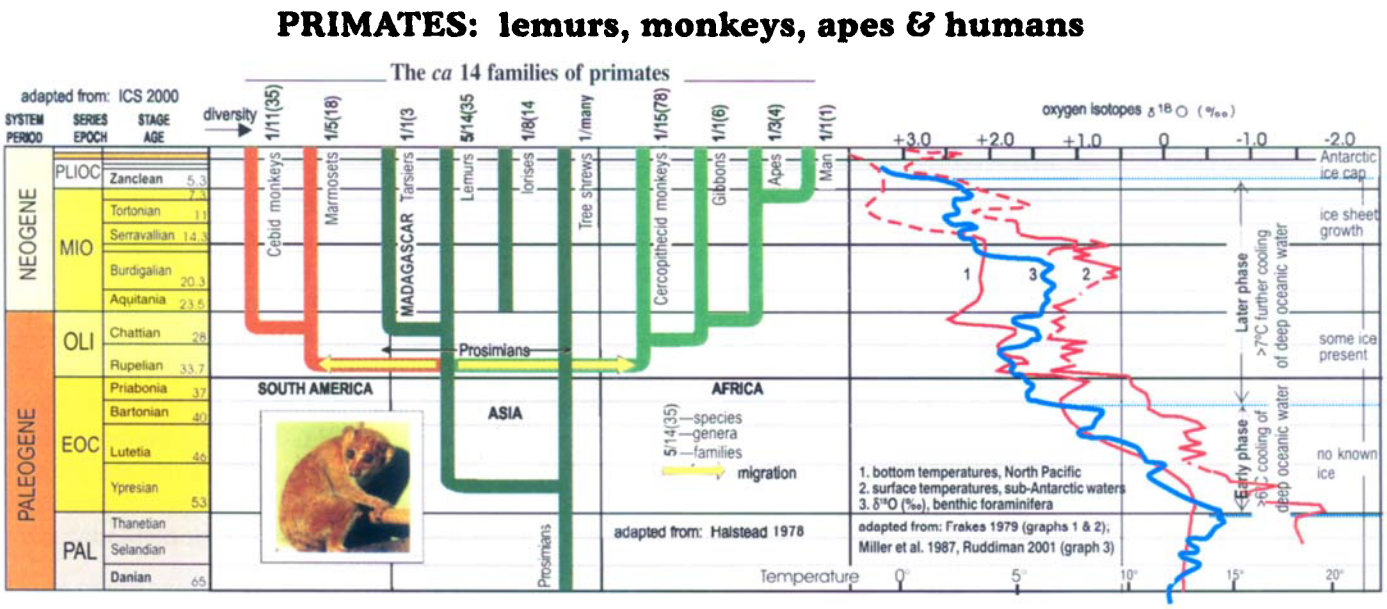


Fig. 3. Primates: lemurs, monkeys, apes and humans. The hominid (man) and pongid (ape) families diverged from a common ancestor at around 7 Ma in the tropical forests of Africa. Sources as indicated on figure.

Symposium (Christchurch, New Zealand) and the World Summit on Sustainable Development (WSSD; Johannesburg, South Africa). The *GA* Corridors concept was launched simultaneously at these two events–fittingly symbolic at opposite sides of the globe–by the current authors.

While there was a widespread feeling of despondency by scientists and conservationists after the World Summit, we feel buoyed. Admittedly the 128-clause Jo'burg plan of Implementation (http:/nrdc.org/international/summi.asp.), negotiated by politicians and signed by the leaders of some 200 nations, offers far too little far too sluggishly in the face of the Sixth Extinction, yet it is now on paper. The 128 strategies, revolving around Water, Energy, Health, Agriculture and Biodiversity (WEHAB), are nowhere signed into law and call for insufficient shifts over the next decade or so, yet they offer a springboard for action. The challenge is out. The call for innovation is loud and it is clear. It is the peak season for Gondwana scientists.

### *Biodiversity Hotspots; a 'silver bullet' strategy*

One of the most powerful strategies thus far conceived—and adopted—towards slowing the destruction of nature globally, is the Biodiversity Hotspot concept. It was created by Myers (1988) and taken up as the main thrust of Conservation International (CI) over the last few years. Indeed, CI sees it as a 'silver bullet' strategy for tackling the problems engulfing all of life. What has made the concept such a success? Aside from its indisputable potential, this would appear to rest largely in the precise nature of the two major criteria employed in defining the hotspots: plant endemism and human impact (threat).

A hotspot is defined as including >1,500 endemic plant species (or 0.5% of the global total) and having already lost >70% of the original natural vegetation to human activities (Conservation International, 2000). There are 25 such hotspots—ranging greatly in size from New Caledonia (at 18,576 sq. km) to the Mediterranean Basin (at 2,362,000 sq. km). Collectively they include an area of just 1.4% of the Earth's land surface yet contain the 'sole remaining habitats of 44% of all plant species (and 35% of all vertebrate species)'. A frightening 88% overall of the original habitat in these 25 areas has already been lost.

'Plant endemism was chosen as the primary criterion for hotspot status' since plants, as habitat and food, 'support most other forms of life and are relatively well studied'. A key consideration behind hotspots is that many experts believe that the 'extinction spasms' predicted as imminent—or already begun—will occur largely within their borders (Conservation International, 2000).

The hotspot concept as it currently stands takes into account only the continental biotas. The oceanic realm, as clearly stressed by many researchers (e.g., Schiermeier, 2002), is no less under threat and is equally urgently in need of such dedicated global attention.

### *Gondwana Alive Corridors; a 'guilt-edged' strategy*

If concentrating conservation within biodiversity hotspots is already seen as a 'silver bullet' strategy in stemming the Sixth Extinction, then might *Gondwana Alive*

Corridors not become a 'guilt-edged' strategy? While the hotspots might be pre-eminent in preserving the habitat of 44% of plant species and the rich spectrum of associated life, we visualize the corridors as holding the potential to motivate all of humanity to preserve all habitats and all life. They could be the thread to bind us together, offering decent well-being for all humanity, and the cherished co-existence of all other species.

*Buffer zones and satellite nodes*

A corridor would consist, as already noted, of a relatively narrow winding strip of territory (1,000 × 50 km on average) with a total area of some 50,000 sq. km. Though the corridor has a distinct border as drawn on a map, it is not exclusive. It is surrounded by a buffer zone and satellite nodes, and when a full network is in place these buffer zones between corridors could meet. The

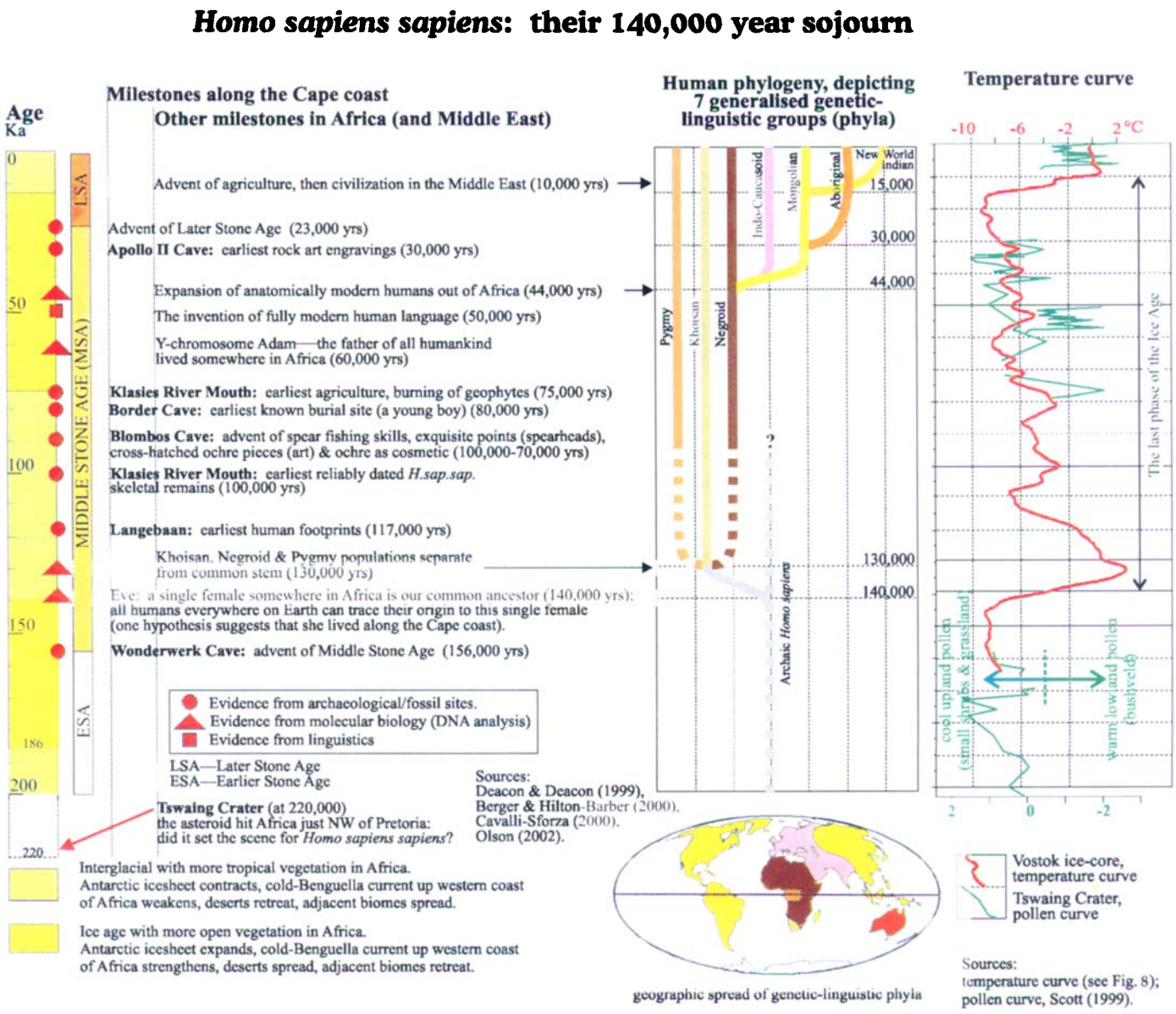


Fig. 4. *Homo sapiens sapiens*: milestones, phylogeny and colonization, plotted against global atmospheric temperature. Our history, as one closely related 'family' of 6,000 million persons, can be traced back to a single individual female ('Mitochondrial Eve') living somewhere in eastern or southern Africa ~140,000 years ago. Our emergence from archaic *Homo sapiens* (Fig. 8) appears to tie closely with the rapid warming event at ~140,000 years; just as the advent of agriculture in the Middle East at ~10,000 years somehow ties with the next major step in warming. It must be emphasized that the location and date of all milestones is inevitably subject to change with continuing exploration and research; as is the tree of human genetic-linguistic lineages. The picture shown here is our syntheses of current data, based primarily on the references cited on figure.

corridor has gravity: all persons living along it or in its general vicinity feel kinship, as for a football team, an Olympic athletic squad or a national flag. It is an educational corridor, an ecotourist flight-path, a scientific laboratory and a workbench for holistic management.

*Earth's autobiography*

Each corridor tells a part of the story of the life of our planet, together they offer a full autobiography of our Earth. Each corridor is a chapter, the set of corridors is the book of Earth's life. The selection of abridged chapters that follow offer a précis of Earth's autobiography.

## 1. Africa: Cradle To Cradle Corridor (CCC)

*Core theme and key references*

Celebrating 3.5 billion years of life on Earth; from the origin of life to the origin of humans (Fig. 5). Viljoen and Viljoen (1969), Tankard et al. (1982), Anhaeusser (1983), Schopf (1983), Hart et al. (1990, 1991), Evans et al. (1997), Lowe and Byerly (1999), Viljoen and Reimold, (1999), Eales (2001), Gibson and Reimold (2001), Frimmel and Minter (2002), Westal et al. (2002).

*Uniqueness*

South Africa is without question a world geological hotspot and the former Transvaal (Mpumalanga, Gauteng and surrounds) is the core of this hotspot. The Cradle to Cradle Corridor tracks a walk through more than two thirds of Earth history far more comprehensive than is possible elsewhere, and concludes with rare insights into the hominid story. It literally sees us through from The Cradle of Life to The Cradle of Humanity.

Four fundamental steps have been recognized in the history of life: the origin of life itself (unicellular prokaryotes with naked nuclei), the origin of higher organisms (unicellular eukaryotes with enclosed nuclei), the Cambrian explosion of macroscopic multicellular life, and the origin of the human mind (Wilson, 1992). Excluding the Cambrian explosion, three of these steps are covered supremely well in the *Cradle to Cradle* story.

The following geological milestones may be plotted as nodes along the CCC (Fig. 5).

### *Barberton Greenstone Belt: 3,570–3,060 Ma*

(a) Constitutes by far the largest, best preserved stretch of the world's oldest known landscape (see further on).

(b) Preserves the world's oldest fossil bacteria (3,472 Ma), found in cherts deposited around hydrothermal springs.

(c) Most famous as the world's type locality for Komatiites, very high temperature lavas with large skeletal olivine crystals—spinitex textures.

(d) Contains the earliest meteorite impact debris on Earth.

(e) Includes the oldest known gold deposits (~3,060 Ma).

(f) The entire belt became covered by Transvaal Supergroup rocks—and still later by Dwyka glacials as evidenced by U-shaped glacial valleys in the Barberton Mountain Land—and was therefore geologically protected until ~180 Ma following breaking up of Gondwana. River erosion then caused back-cutting along the eastern margin of southern Africa to form the present-day Drakensberg Escarpment, and exposure of this magnificent Archaean treasure.

### *Archaean granitic crust: 3,700–2,700 Ma*

(a) Especially significant is the Swaziland Ancient Gneiss Complex (3,700–3,000 Ma) with the oldest recorded rocks of Africa.

(b) Site of intrusion of numerous granitoid bodies in several stages of emplacement in an environment similar to that of the Andes volcanic mountain chain in South America today.

### *Witwatersrand Supergroup: 3,000–2,714 Ma (300 Ma span)*

(a) This oval, 350 × 150 km, remnant of a vast basin with a 7,000 m thick accumulation of fluvial to shallow marine sediments, is by far the world's greatest goldfield. It has yielded ~40% of the gold ever mined in the world (Frimmel and Minter, 2002).

(b) The extensive gold-bearing layers ('reefs'), unique in kind, consist of minute grains of gold, encapsulated in pyrite grains, that comprise part of the matrix of pebble beds and conglomerates formed in braided rivers flowing into the Witwatersrand basin. Gold nuggets also occur.

(b) By ~2,800 Ma, the first photosynthetic bacteria made their appearance globally; but pyrite and uraninite grains in the Witwatersrand sediments are witness of a toxic reducing (oxygen-starved) atmosphere. The oldest signs of oil deposits (in the form of small amounts of kerogens) occur in association with detrital gold flakes, suggesting a close relationship between mineralisation and the evolution of early life forms.

### *Ventersdorp Supergroup: 2,714 Ma*

(a) Huge volumes of lava in the form of hundreds of individual flows with interlayered sediments extruded over a short period of time; an ancient equivalent of continental flood basalts, like those of Ethiopia and the Deccan traps of India, and the Drakensberg Mountains of Lesotho.

### *Transvaal Supergroup: 2,714–2,050 Ma (664 Ma span)*

(a) Spanning two thirds of a billion years across the Archaean-Proterozoic boundary (at 2,500 Ma), this largely shallow marine intracratonic sequence of sediments forms the backbone of the spectacular topography of this corridor: the dipping quartzitic and carbonate ranges of the Transvaal Drakensberg and of the Magaliesberg range west of Pretoria.

(b) It was precisely during the span of the Transvaal Supergroup that oxygen levels of Earth's atmosphere first rose above 1%. By 2,000 Ma a large fraction of existing organisms were generating oxygen through photosynthesis, but this element was mostly absorbed by ferrous oxide and not liberated into the seas or atmosphere. Instead, ferric oxides, red oxides of iron in the form of haematite and rust, insoluble in water, settled out on the sea floors in the form of vast iron-ore deposits, the like of which the world has never seen since. The world literally 'rusted'. The great thicknesses of banded ironstones of the Penge (2,400 Ma) and Timeball Hill (2,300 Ma) formations attest elegantly to this. The latter formation is associated with the first known major global glaciation. (Holland, 1990; Wilson, 1992; Evans et al., 1997; Eriksson et al., 2001.)

(c) The Malmani Subgroup dolomites, in particular, span the Archaean-Proterozoic boundary and immediately predate the Penge Formation. They were deposited in a shallow, clear water sea inhabited for much of its history by algal colonies; the organo-sedimentary domed structures called stromatolites formed by growth and metabolic activity of unicellular prokaryotic micro-organisms, principally cyanophytes (blue-green algae). These stromatolites of the Transvaal Supergroup dolomites, which cover large areas of northern and northwestern South Africa, are the most extensive in the world.

(d) The Quaternary hominid-bearing limestone cave deposits (see below) occur within this dolomite formation.

### *Bushveld Igneous Complex (BIC): 2,060–2,055 Ma*

(a) The BIC, one of the great geological wonders of the world, 'represents the greatest mineral deposit event that has ever occurred on Earth' (Coetzee, 1976). It is by far the largest known intrusion of its kind globally—covering ~60,000 sq. km.

(b) Contains the world's largest known resources (~95%) of the platinum group elements (platinum, palladium, iridium etc.), as well as huge stores of chromium and vanadium.

### *Vredefort Dome: 2,023 Ma*

(a) Vredefort is the world's oldest and largest known impact structure; caused by a meteorite ~10–15 km in diameter. The evidence, in the form of impact breccias, pseudotachylites and shatter cones, is abundantly preserved.

(b) The original impact structure would have been 250–300 km in diameter. In effect, the Vredefort dome is interpreted as the eroded root of the central uplift of the far larger, complex Vredefort impact structure. The full crater would have encompassed the entire extent of the erosional remnant of the Witwatersrand (Supergroup) basin (Gibson and Reimold, 2001).

(c) This is the only place in the world where one can walk 36 km through the full crust of a continent, from its upturned surface (impact rim) to the crust-mantle boundary (MOHO) uplifted and exposed in the centre of the structure.

(d) At 65 Ma a massive bolide 5–10 km in diameter slammed into the Yucatan Peninsula (today's Mexico) causing the Fifth Extinction, including the demise of the dinosaurs, and terminating the Mesozoic era. The Chicxulub structure resulting from this impact is 180 km across. The Vredefort bolide was almost twice the size of Chicxulub and left a crater twice the diameter. Its effect on the history of life must have been profound, and in its wake possibly stimulated a radiation of photosynthesising unicellular plants including the revolutionary eukaryotes (first known as fossils by 1,800 Ma, but clearly arising earlier).

### *Waterberg Group: 1,900–1,700 Ma (200 Ma span)*

(a) At around 1,800 Ma, two profoundly significant phenomena, surely closely related, are recorded in Earth history. The earliest subaerially deposited sedimentary 'red-bed' ('rust'-stained) sequences appear, providing the first evidence for substantial amounts of oxygen in the atmosphere. More or less simultaneously appeared the first eukaryotes—'higher organisms', still unicellular at this stage, with membranes enclosing their DNA. These were alga-like forms, 'forerunners of the dominant photosynthesisers of the modern seas' (Wilson, 1992).

(b) The Waterberg Group, deposited in a number of substantial terrestrial basins in the Kaapvaal Craton, provides a classic example of such a red-bed sequence. In the central Waterberg region up to 5,000 m of 'rust' pigmented (haematite-coated) sediments, largely sandstones and conglomerates, occur (Callaghan, 1993). Here and in adjacent regions, the red sandstones form spectacular cliffs, a scenic mecca for rock climbers.

(c) The sandstones of the Makgabeng Plateau are believed to represent one of the oldest known desert landscapes on Earth, and the muddy roll-up structures in clastic interdune beds are thought to represent the oldest indications of terrestrial life in history (Eriksson et al., 2000).

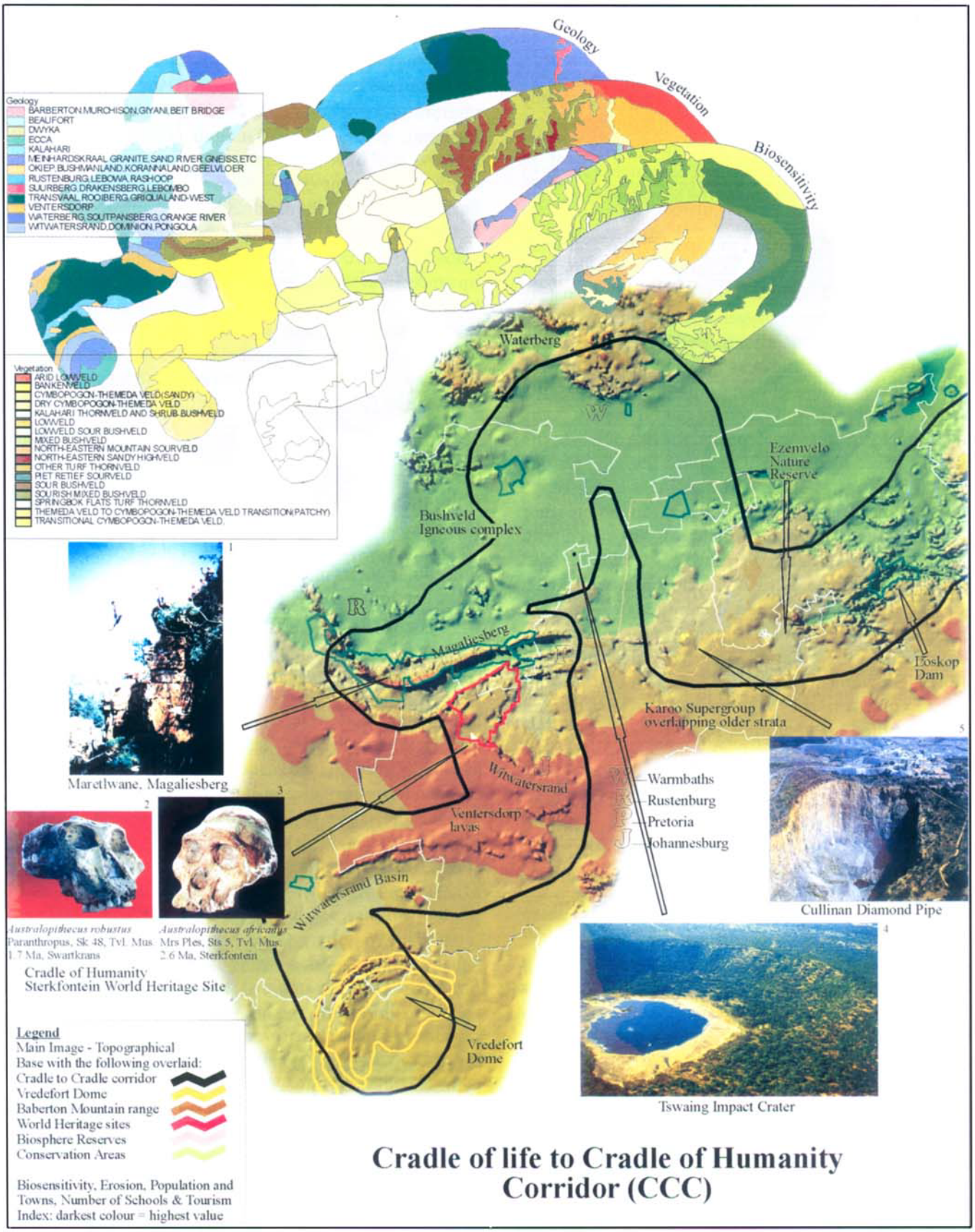


Fig. 5. The Cradle of Life to Cradle of Humanity Corridor (CCC): towards a GIS (Geoinformation Science) perspective. Photo credits indicated on figure.

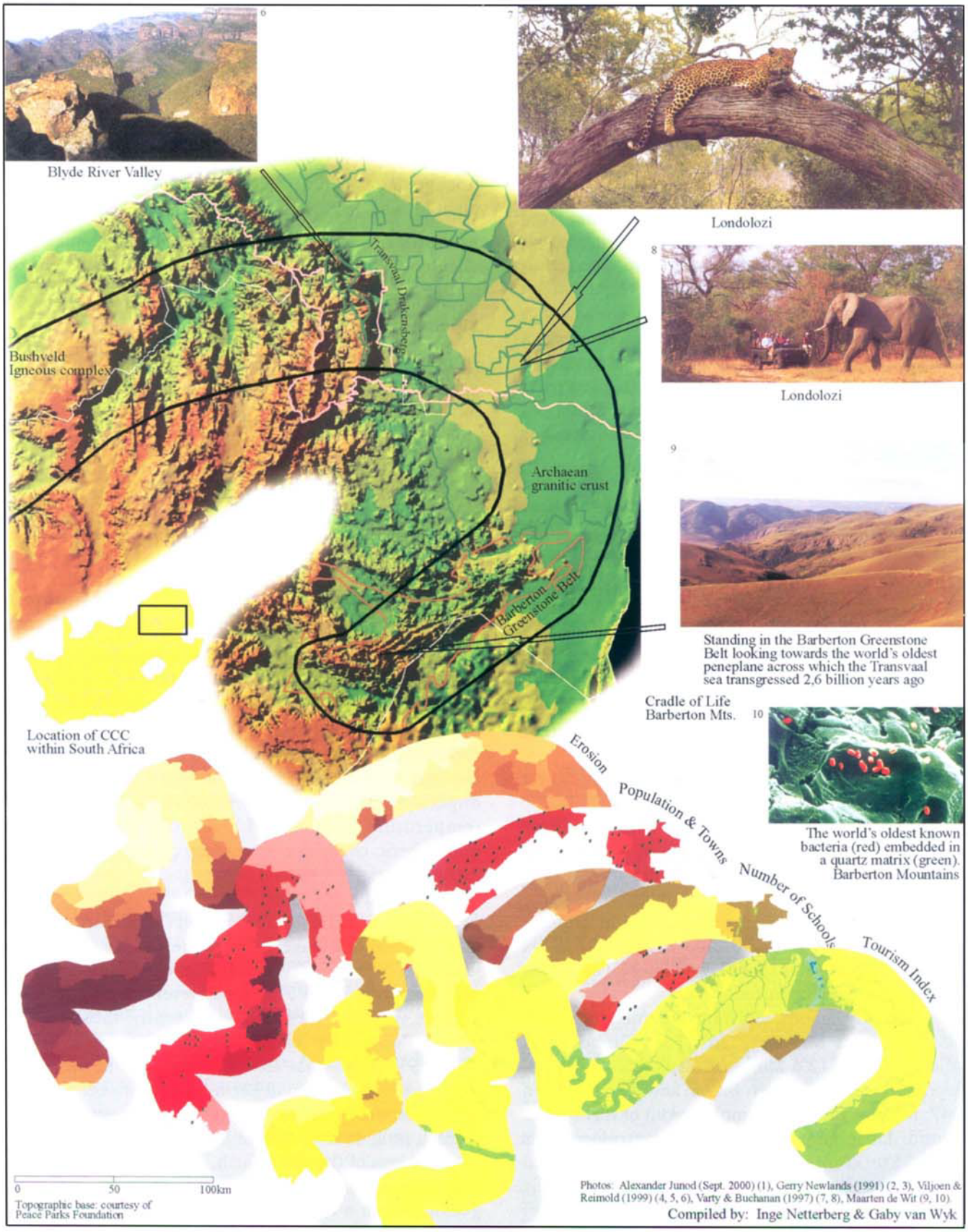
6
Blyde River Valley
7
Londolozi
8
Londolozi
9
Standing in the Barberton Greenstone Belt looking towards the world's oldest peneplane across which the Transvaal sea transgressed 2,6 billion years ago
Cradle of Life
Barberton Mts.
10
The world's oldest known bacteria (red) embedded in a quartz matrix (green). Barberton Mountains
Transvaal Drakensberg
Bushveld Igneous complex
Archaean granitic crust
Barberton Greenstone Belt
Location of CCC within South Africa
Erosion
Population & Towns
Number of Schools
Tourism Index
0 50 100km
Topographic base: courtesy of Peace Parks Foundation
Photos: Alexander Junod (Sept. 2000) (1), Gerry Newlands (1991) (2, 3), Viljoen & Reimold (1999) (4, 5, 6), Varty & Buchanan (1997) (7, 8), Maarten de Wit (9, 10)
Compiled by: Inge Netterberg & Gaby van Wyk

Fig. 5. *Contd.*

### *Cullinan Kimberlite pipe: 1,200 Ma*

(a) The Premier Mine at Cullinan (opened in 1902 east of Pretoria) is renowned for the number of large diamonds it has produced; the 3,106 carat Cullinan Diamond is the largest gem diamond ever found.

(b) Kimberlite, an unusual ultrabasic igneous rock, occurs as small volcanic pipes, dykes and sills; they originate at depths of over 120 km in the Earth's upper mantle. The ages of diamonds found in these Kimberlite pipes vary from 3,200 to 80 Ma (a swarm of such pipes, from 140–80 Ma, are plentiful across the surface of southern Africa).

(c) Diamonds are formed at high pressure; only within the roots of Archaean cratons (as in southern Africa's Kaapvaal Craton) where temperatures at these depths are low enough for diamonds to be preserved. (In most parts of the Earth temperatures at such depths are too high.) Kimberlites intruding beyond the craton boundaries rarely contain diamonds.

(d) The carbon of diamonds originated at surface and derived from ancient bacteria whose organic carbon was converted into diamond during deep burial at high pressures and temperatures.

### *Karoo Supergroup: 325–175 Ma (150 Ma span)*

The Karoo Basin contains the richest known terrestrial vertebrate and plant deposits through the Permian, Triassic and into the Jurassic (for discussion see under Great Karoo Corridor).

### *Hominid-bearing limestone cave deposits: 3.5–1.0 Ma*

(a) The Sterkfontein World Heritage Site is the richest of all fossil hominid sites in Africa.

(b) Of ~600 hominid individuals (crania and/or postcrania from 7.0–0.5 Ma) recovered from ~20 localities across Africa, almost half derive from the several cave deposits of this World Heritage Site (Anderson, 1999).

(c) At least three hominid species, *Australopithecus africanus, A. robustus* and *Homo habilis,* from six distinct cave-deposit sites spanning an interval of 2.5 Ma (~3.5–1.0 Ma), are recognized.

(d) Particularly famous, individually named specimens include: Mrs (now Mr) Ples, Little Foot, Orpheus and Eurydice. Mrs Ples (2.6 Ma, *Australopithecus africanus,* Sterkfontein) found by Robert Broom and John Robinson in 1947, remains the most complete skull of this species yet found. Little Foot (?3.5 Ma, cf. *Australopithecus afarensis,* Sterkfontein), found by Ron Clarke and colleagues through the late 1990s, is the only virtually complete ape-man (skull and skeleton) individual yet found. Orpheus (male jaw) and Eurydice (female skull with jaw) (2.0 Ma, *Australopithecus robustus,* Drimolen), found by André Keyser in 1994, are the most complete male-female pair of specimens of this species from a particular site and horizon yet found (Keyser, 2000).

(e) The earliest evidence of the controlled use of fire, at around 1.5 Ma, has been described from bone beds at Swartkrans. This is 'a technological advance of immense significance, giving early hominids a measure of protection from predators badly needed when sheltering in caves at night' (Brain, 1993).

### *Tswaing Impact Crater: 220,000 BP*

(a) Tswaing is one of the best-preserved youngest craters on Earth: only one other example, Meteor Crater (~50,000 BP) in Arizona, is as accessible and well preserved.

(b) The crater of 1.13 km diameter was formed by a stone meteorite of 30–50 m diameter travelling at between 40,000 and 260,000 km/h (Reimold et al., 1999).

(c) Only some 160 terrestrial impact structures are known globally: four of these occur in South Africa.

(d) The 1988 core from a borehole sunk through 90 m of crater sediments has provided an unrivalled palaeoclimatic-environmental record of the past 220,000 years for Southern Hemisphere mid-latitudes (Partridge, 1999; Partridge and Maud, 2000) (see Fig. 4).

### *Barberton Mountain Land: the world's oldest well-preserved landscape and fossilized life forms*

Does the Earth operate in the same way today as it did when it was young, in Archaean times, at 4,000–2,500 Ma?

Geologists have been arguing about this for decades, because great scientific rewards are at stake: Earth's oldest rocks hold the only direct clues to the origin of life and the environment in which it subsequently evolved; the origin of Earth's greatest mineral deposits; Earth's surface temperature at 4,000 Ma; its magnetic field; its atmospheric chemistry; its extensive bombardment by extraterrestrial comets and meteorites; the origin of plate tectonics, and much more.

Why is it so difficult to reconstruct what Earth looked like in its youthful stages? One of the reasons is that very little has been preserved from that far back in time. Archaean rocks cover 7% of the present-day continental surface, yet these rocks represent nearly 45% of Earth history. Rocks older than 3,000 Ma are scarcer still: less than 0.5% of the total area of all continents' preserved records of the first third of Earth's evolution. On Earth no rocks older than 4,100 Ma have yet been discovered. Thus there is little direct evidence from which to reconstruct the workings of the early Earth, and none from the first 500 Ma since its formation at almost 4,600 Ma, except by guessing from a few kilograms of old moon rocks that have been returned to Earth by astronauts, and a bunch of local meteorite fragments.

Geologists are literally in the dark searching for Archaean clues. No wonder therefore that the Barberton Mountain Land is THE mecca for geologists that study the early evolution of Earth. Barberton is one of only a handful of places around the planet with the world's oldest rocks (established within a 1,000 Ma of the formation of our planet). And the Barberton Mountain Land is by far the best preserved of them all. This is why geoscientists come to Barberton from all over the world: it is here that they gain understanding of the beginnings of life and the hostile environments in which it survived to eventually give rise to life as we know it 3,000 Ma later (that can be studied some 500 km away in Sterkfontein at the other end of this *Gondwana Alive* Corridor).

The oldest rocks in Barberton have been dated at around 3,570 Ma. The rock-forming processes here came to a halt some 500 Ma later, with the formation of the oldest known gold deposits, around 3,060 Ma, concentrated particularly around the town of Barberton. The world's oldest fossil bacteria have now been found in Barberton rocks—as old as 3,472 Ma (Westal et al., 2002). Many other rock treasures are found only in these early days of Earth's existence: such as the famous volcanic rocks called Komatiites (named after their type locality along the Komati River), and the evidence in these rocks that at the time of their eruptions Earth already had a magnetic field similar to that of today.

Walking across the Barberton Mountain Land with its stunning vistas and landscapes, you find evidence for this early dawn of life all around you, providing an awe-inspiring insight into the environments where life on Earth may have started and has been nurtured ever since. It offers a unique experience to peer back along the path of organic evolution to its very beginnings.

### *On Pre-Barberton life*

Earlier signs of life on Earth have come from older (3.8 Ga) rocks in Greenland, but this is based purely on chemical grounds (e.g., by proxy evidence) from rocks that are poorly preserved and highly altered by metamorphism. The best direct evidence is from the fossils in Barberton and similar-age fossils in rocks of the Pilbara region of northwestern Australia. In fact, evidence from magnetic measurements indicate that these Australian rocks were once connected to the Barberton area; thus the world's oldest fossils of these two areas may have been part of the same earliest preserved ecosystem (Zegers et al., 1998).

## 2. Africa: Great Karoo Corridor (GKC)

*Core theme and key references*

Through the egg timer's waist at the Permo-Triassic boundary; extinction and radiation (Figs. 6, 7). Rubidge (1995), MacRae (1999), Anderson (1999), Gould (2000), Anderson and Anderson (2003 a,b).

*Uniqueness*

This corridor links perfectly, both geographically and temporally, with the Cradle-to-Cradle and Cape Coast-Fynbos Corridors. It also is a place of prime global heritage. During that critical interval of time when the single supercontinent Pangaea was most tightly packed, when global temperatures were sharply on the rise (Fig. 6), when the mammals evolved from the reptiles (Fig. 2) and the stem-angiosperms from the gymnosperms, the Karoo Basin lay deep within the heartland of Gondwana. It preserves this critical transition in the history of terrestrial life, spanning the Third Extinction and the extraordinary radiation of new life that followed, more fully than anywhere else.

### *Climate: from Ice House to Hot House World*

The ~150 Ma span (325–175 Ma) covered by the Great Karoo Corridor (Fig. 6) includes a sharply increasing temperature trend following the end of the late Palaeozoic glaciation around 300 Ma. In marked contrast to the radiation of angiosperms and mammals (Figs. 2, 3) through the Tertiary during a major trend of cooling, the radiation of gymnosperms and of the early reptiles through to both dinosaurs and mammals tracked this prolonged period of warming.

### *Plants: from glossopterids to stem-angiosperms*

Three plant-bearing horizons in the Karoo sequence are particularly rich and of prime interest.

*Middle Ecca Coal Measures (Early Permian)*

A wide suite of unique gymnospermous fruit found attached to *Glossopteris* leaves, overwhelmingly dominant throughout the Gondwana Permian, were first found and described in these strata from 1946–1962. Similar finds have since been made on all former Gondwana continents. In recent years, the glossopterids have assumed top significance: it seems highly probable that they gave rise to several new orders of gymnosperm that appeared in the Triassic radiation, from which ultimately arose the flowering plants (White, 1986; Anderson, 1999).

*Estcourt Fm. (Late Permian)*

This formation provides an unparalleled opportunity for studying ecosystems just prior to the end-Permian extinction. It is singular in yielding excellently preserved plant and insect assemblages with a diverse tetrapod fauna in closely adjacent horizons. No other formation around

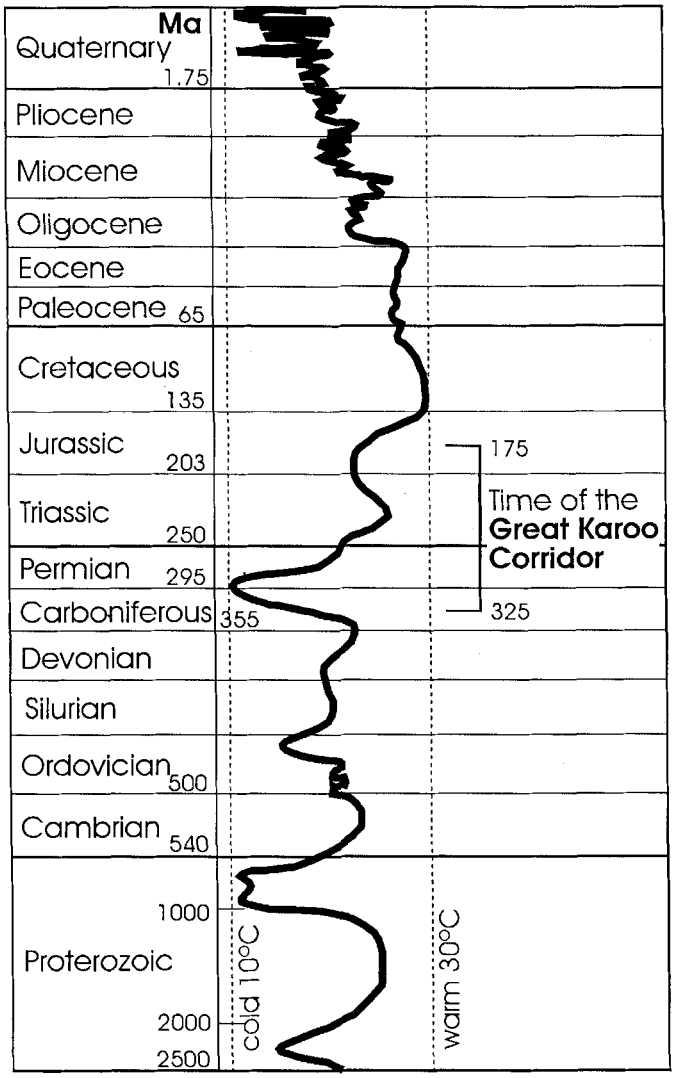


Fig. 6. Average global temperature through 2,500 Ma of Earth history: showing the ~150 Ma duration of Karoo sedimentation and volcanic activity. Temperature curve adapted from Kump et al. (1999).

Gondwana or elsewhere can compete. The Estcourt flora is still dominated by a diversity of glossopterids, but of a different range of families.

*Molteno Fm. (Late Triassic)*

An extraordinary radiation of new life occurred in the wake of the Third Extinction (end Permian). From the plant (and insect) perspective, this is nowhere better seen than in the Molteno (Anderson and Anderson, 1995, 2003 a,b; Anderson et al., 1996). Extensive collections from 100 sites show a diversity (from species to class) arguably greater than in any other known fossil flora. It appears to represent the heyday of diversity of the gymnosperms. And of particularly great interest, it was in the rich ecosystems of this heyday that the earliest dinosaurs and mammals (Fig. 2) seemingly made their debut.

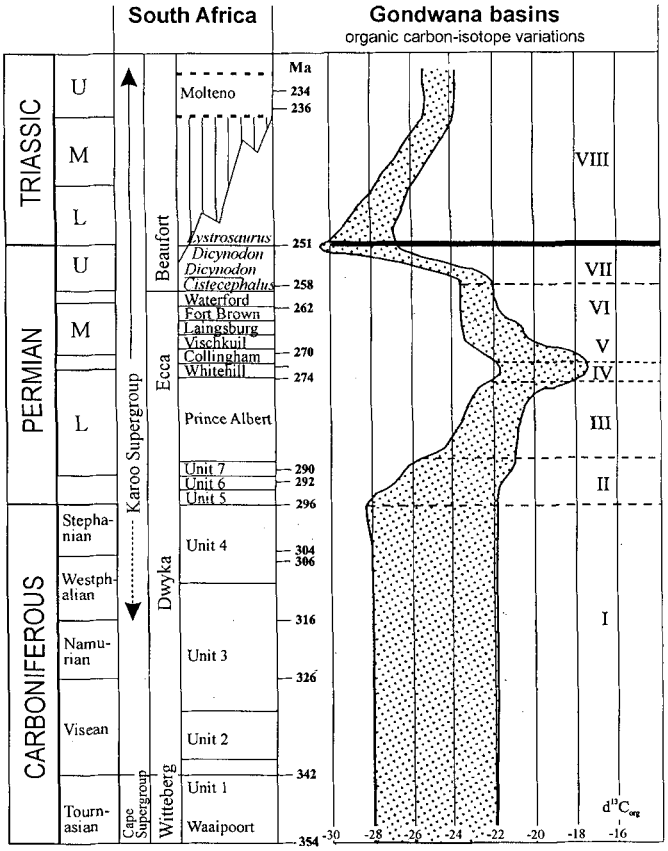


Fig. 7. General organic carbon-isotope variations during the late Palaeozoic: as recorded in terrestial sediments of Gondwana basins. Adapted from de Wit et al. (2002).

### *Insects: towards the modern spectrum of orders*

The Estcourt Fm. (Late Permian) and Molteno Fm. (Late Triassic) have also yielded particularly good insect faunas. Both have been well sampled and studied and show especially clearly the contrasting spectrum of insects flourishing before and after the end-Permian extinction (Anderson, 2003b). The Estcourt fauna (240 specimens, 11 localities) includes 67 species (57 genera, 15 orders): it is strongly dominated in diversity and abundance by the Homoptera (bugs). The Molteno fauna (2,056 specimens, 43 localities) includes 333 species (117 genera, 18 orders): now the beetles make up almost half the total diversity, much as in today's insect world, while the cockroaches compromise half the total abundance but show little diversity.

### *Vertebrates: from reptiles to mammals and dinosaurs*

The Beaufort Group, with eight assemblage zones through some 35 Ma, straddles the Permo-Triassic boundary. This mecca for vertebrate palaeontologists offers by far the fullest picture worldwide of tetrapod evolution for this time.

Sampling of this sequence (4,580 m thick), with a huge outcrop (~1,100 by 400 km), has been increasingly intensive since the pioneering road-builder, Andrew Geddes Bain, made his first discovery in 1838. The observed biodiversity, from amphibians (Temnospondyli) to primitive reptiles (Captorhinida) to the forerunners of the dinosaurs (Thecodontia) and to the mammal-like reptiles (Therapsida), runs now at ~250 species in 158 genera and 50 families (Rubidge, 1995; Anderson, 1999).

Moreover, capping the plant-rich Molteno Fm. and capped by the massive Jurassic lavas, are the Eliot and Clarens formations outcropping around the mountainous country of Lesotho. These span the Triassic-Jurassic boundary and include some of the world's earliest dinosaurs and mammals.

### *The Third Extinction across the Permian -Triassic boundary*

Throughout Gondwana, stratigraphic transitions from the Permian to the Triassic, around 251 Ma, record extensive global collapse and recovery of biodiversity. Extinctions in marine and terrestrial life across the boundary were abrupt, at >90% and 70% of species respectively (Erwin, 1993; Retallack, 1995). Yet there is circumstantial evidence that environmental stresses on ecosystems preceded this global crisis by at least several million years and there is substantial evidence that in the wake of the extinction, maximum biosphere recovery was delayed until at least the Middle Triassic (~245 Ma). Such observations suggest a sustained and complex feedback mechanism during the build-up and dissipation of this global ecological crisis (Fig. 7), rather than a sudden reaction to an abrupt single event as in the rapid outpourings of the Siberian flood basalts or a cometary impact. It is important to be able to resolve different palaeo-ecodynamic forces so that resulting patterns of biotic recovery and origination following extinction events can be analysed and simulated with confidence.

Chemical stratigraphy, using $^{13}C/^{12}C$ ratios (expressed as $\delta^{13}C$) of both marine and terrestrial carbonates and organic matter, has documented severe changes in the global carbon cycle across the Permo-Triassic (P-T) boundary. These studies have identified a large and sharp negative $\delta^{13}C$ spike that straddles the P-T boundary in marine sequences. High-precision radiometric analysis of volcanogenic zircons in tuffs across the boundary has dated the approximate peak of a negative excursion in a marine sequence of a northern Gondwana fragment (now southern China) at 251.4±0.3 Ma. This peak is closely linked with the major P-T extinction peak and appears to be in response to a catastrophic addition of light-carbon to the oceans in less than 170,000 years (Bowring et al., 1998).

In numerous marine sections along the southern platform margin of the palaeo-Tethys ocean, a number of complex spikes have been recorded. In some sections a peak minimum occurs in the early Triassic, yet elsewhere along the same Tethyan margin a minimum occurs in the late Permian. Moreover, these relatively rapid excursions are often superimposed on a gradual late Permian decline in $\delta^{13}C$, documented in both terrestrial and marine sections.

In a coupled atmosphere-ocean system, the carbon budget of the atmosphere is much smaller but more dynamic than that of the oceans, so that small oceanic perturbations are amplified significantly. $\delta^{13}C$ stratigraphy of terrestrial sequences should, therefore, provide a more sensitive response and increased insights into the nature of these chemical excursions.

Organic materials across the palynologically defined P-T boundary from terrestrial basins in the interior of the Gondwana Supercontinent show large to very large (5–15‰) multiple negative spikes of $\delta^{13}C$, separated in places by sharp reversals of up to 20‰ (de Wit et al., 2002). Large oscillations of $\delta^{13}C_{org}$ between –36‰ and –15‰ from mean values of ~24±2‰ in India, ~26 ± 2‰ in Madagascar and ~23±2‰ in South Africa occur before and after the P-T transition. The mean values are within the range of modern C3 plants (~ -25‰). The negative $\delta^{13}C_{org}$ spikes of terrestrial plant remains therefore complement the similar spikes recorded globally in marine carbonates across the P-T boundary. Models of carbon fluxes in a coupled atmosphere-ocean system indicate that the sharp declines in terrestrial and marine $\delta^{13}C$ can be best explained by episodic release of methane from clathrates (~ -60‰) either directly into the atmosphere or via the oceans. This provided feedbacks to drive rapid, but punctuated, increase in atmospheric $CO_2/CH_4$ (and lower $O_2$), and in turn to extreme global warming in the early Triassic (de Wit et al., 2002).

An earliest Triassic methane greenhouse is indeed evident from analyses of the mineralogy of deeply weathered palaeosols located just above the P-T boundary in Australia and Antarctica. The occurrence of minerals formed under reducing conditions in the palaeosols indicate soil oxygen consumption by the influx of atmospheric methane to form carbon dioxide, which in turn warmed the earliest Triassic, giving rise to a postapocalyptic greenhouse (Sheldon and Retallack, 2002).

The rapid increases in $\delta^{13}C$ reflect a punctuated increase in C3 biomass production related to globally elevated atmospheric $CO_2$, some of which may be due to mantle $CO_2$ ($\delta^{13}C$ ~ -6‰) related to the contemporaneous outpourings of the gigantic Siberian flood basalts.

While the carbon isotope stratigraphy across the P-T boundary cannot yet resolve details of complex feedback mechanisms, it has proved to be a powerful tool with which to track coupled climate change and extinctions. This approach has shown that it is unlikely that models of the end-Palaeozoic biodiversity collapse and ensuing Mesozoic recovery can be based on a singular perturbation at the P-T boundary and that detailed Gondwana stratigraphy clearly still has much to offer to our understanding of the ominously spreading Sixth Extinction.

## 3. Africa: Cape Coast-Fynbos Corridor (CFC)

*Core themes and key references*

A tale of biodiversity and the origin of humanity; (a) the origin and evolution of our subspecies (*Homo sapiens sapiens*) (Figs. 4, 8), (b) the history behind extreme biodiversity. Cowling et al. (1997), Deacon and Deacon (1999), Berger and Hilton-Barber (2000), Cavalli-Sforza (2000), Van Wyk and Smith (2001).

*Uniqueness*

With regard to superlatives and uniqueness globally, this corridor possibly comes a close second to our Cradle-to-Cradle flagship prototype. At a string of sites along the spectacular coastline is preserved the story of our human (*Homo sapiens sapiens*) emergence from around 140 to 70 thousand years ago (Fig. 4). The earliest known human footprints (at Langebaan, ~117,000 B.P.), the oldest reliably dated *H. sapiens sapiens* skeletal remains (Klasies River Mouth, ~100,000 B.P.), the most ancient work of art (Blombos cave, ~77,000 B.P.) and the first glimpses of agriculture (Klasies River again, ~75,000 B.P.) are all there to engage our wonder. And then there is the Cape Fold Belt and its clothing of Fynbos (~9,000 plant species, 69% endemism) with the interfingering Succulent Karoo (~5,000 species, 40% endemism). This isolated mountainous chain crossing the southern foot of Africa is home to one of the six plant kingdoms recognized on Earth. In biodiversity and endemism, it is seen as the equivalent of the entire Northern Hemisphere.

The logic/irony of the paired themes should not be missed. It is here that our global family may well have first emerged from archaic *Homo sapiens* stock (but see Olson, 2002) and it is here that the peak of angiosperm diversity appears to occur. The impact of the one on the other, the Sixth Extinction globally, is more poignantly expressed here than in any other corner of our world.

### *$CO_2$, temperature and human evolution*

At all levels of classification and temporal scale our hominid and human emergence seems inescapably and intimately linked to climate change. The great evolutionary radiation of the placental mammals (Fig. 2) through the late Cretaceous and Tertiary, the radiation of the primates (Fig. 3) through the mid to late Tertiary and the radiation of ethnic groups and languages within *Homo sapiens sapiens* (Fig. 4) through the last phase (140,000 years) of the Plio-Pleistocene Ice Age are expressions of repeated environmental stress, most evidently climate change.

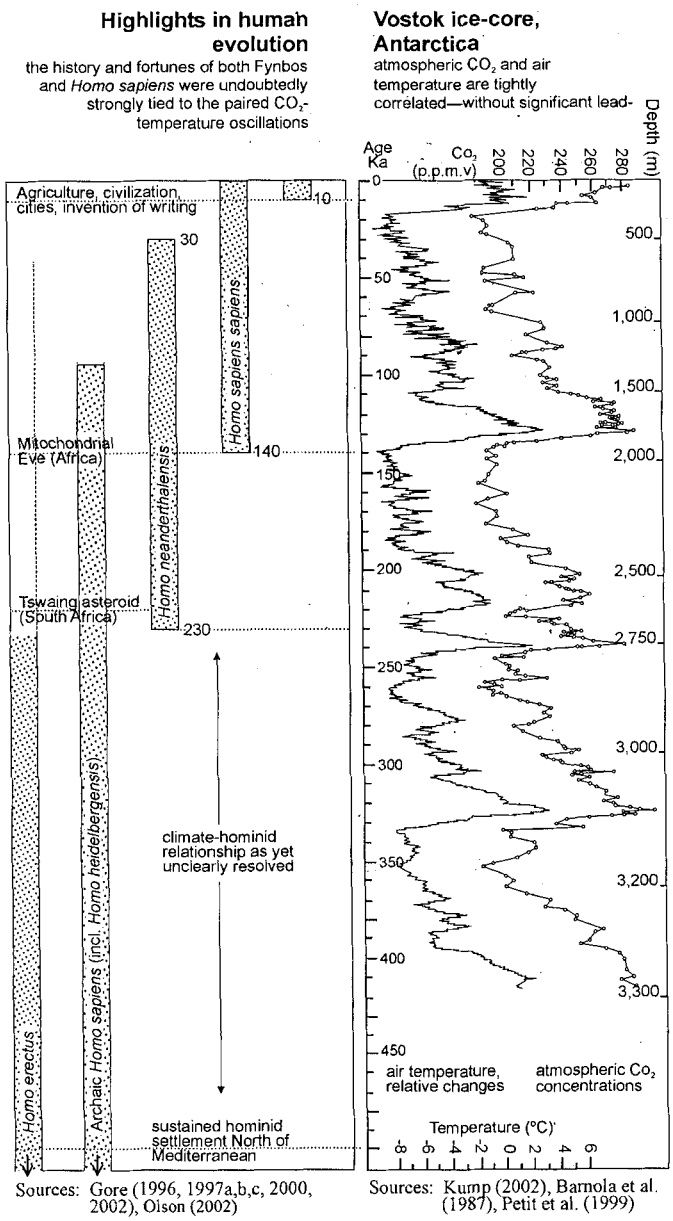


Fig. 8. Highlights in human evolution over the past 500 Ka, correlated against $CO_2$ and air temperature curves as recorded in the Vostok ice-core, Antarctica. Atmospheric $CO_2$ and air temperature are shown to be tightly correlated, without significant lead-lag; while the evolution of *Homo sapiens* appears to be strongly linked to the paired atmospheric-climatic oscillations. Sources as indicated on figure.

Under the later text on Antarctica, we emphasize the profound importance of the Vostok ice-core (see Fig. 15 for location) in demonstrating unmistakably the tightly correlated atmospheric $CO_2/CH_4$-climate (air temperature) relationship. Here we aim to show graphically (Fig. 8) the astonishingly close tie between $CO_2$, temperature and human evolution. *Homo neanderthalensis* first appears (in Europe) at ~230 Ka, *Homo sapiens sapiens* (in eastern or southern Africa) at ~140 Ka, and agriculture followed by civilization (in the Middle East) around 10 Ka (Gore, 1996; Berger and Hilton-Barber, 2000; Cavalli-Sforza, 2000; Olson, 2002). Each is closely correlated with successive major swings in global warming. Fundamental environmental shifts drive fundamental human change. There is a lesson in this.

### *The angiosperm heyday and hotspot*

South Africa with ~23,500 species of indigenous plants (~9% of the world's total) is home to unquestionably the greatest floral diversity outside the equatorial rainforest belt (Cowling et al., 1997; Anderson, 1999; Le Roux, 2002). With the existence of seven ecoregions (biomes) and around 70 ecozones (vegetation types), each of an entirely different floristic and vegetational character, the ecological diversity within the region contributes substantially to this unique world heritage.

If purely species richness per unit area is considered, then the tropical Andean headwaters of the Amazon is possibly today's angiosperm diversity hotspot. If percentage endemism were the criterion, then Madagascar seemingly claims top hotspot status. However, if all aspects of biodiversity, from taxonomic (including intraspecific variation), to endemism, to habitat and communities, are considered, then South Africa might well emerge as the hottest of all angiosperm hotspots. Both the Fynbos and Succulent Karoo occur in our Cape Coast-Fynbos Corridor and each is defined as one of the 25 biodiversity hotspots recognised globally (Mittermeier et al., 2000; Conservation International, 2000; Van Wyk and Smith, 2001).

## 4. Africa: Lungs of Africa Corridor (LAC)

*Core theme and key references*

Primates under threat; the diverging hominid (human) and pongid (ape) families and their subsequent fortunes (Figs. 3, 9). WCMC (1992), Cavalli-Sforza (2000), Quammen (2000, 2001a,b).

### *Womb of the hominid family*

It is from the equatorial forests of Africa (Fig. 9), stretching from Gabon to Rwanda, that our very first steps towards humanity were taken: the lungs of Africa were the womb of our hominid family. At ~7 Ma, a fork appeared in the primate family tree—the one branch leading to ourselves, who colonized the world, exploded to 6 billion individuals and set the Sixth Extinction alight; the other to the chimpanzees and gorillas who remained in their place of origin and are severely threatened by that extinction.

### *Pygmies and the human genome*

The declining pygmy population of the tropical forests of central Africa, together with the similarly declining

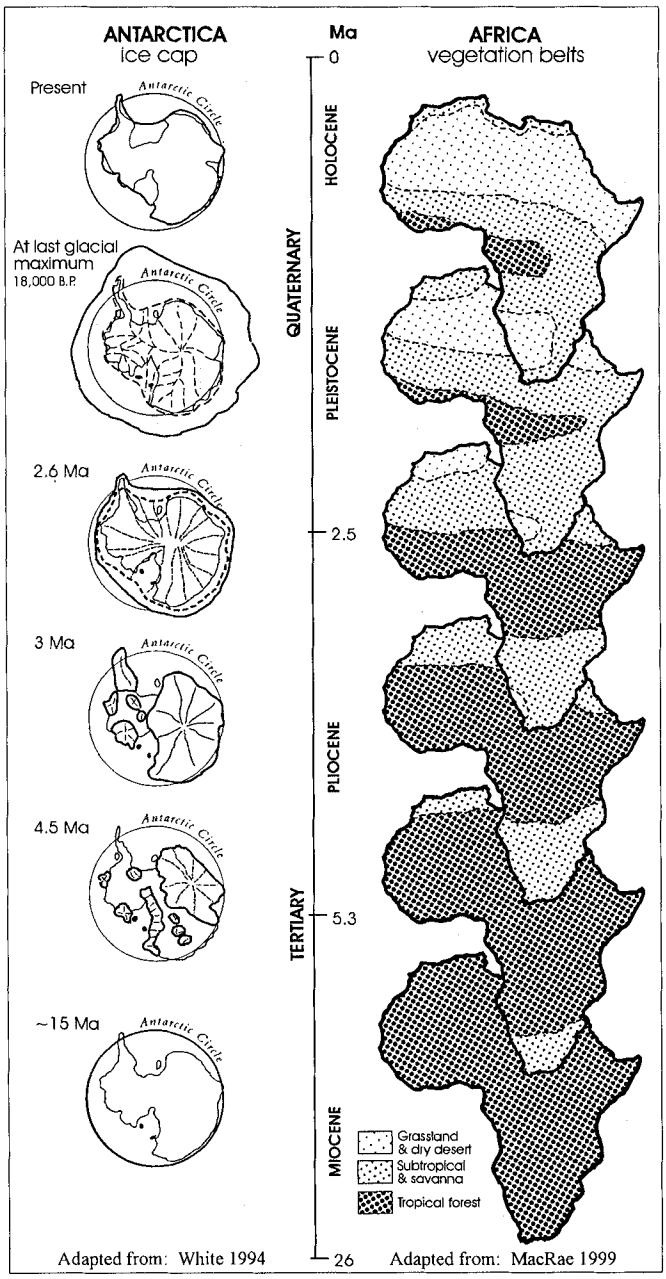


Fig. 9. The close correspondence between the growth of the Antarctic ice cap and the desertification of Africa through the past 15 Ma. Sources as indicated on figure.

Khoisan populations of the semi-arid areas of southern Africa, are of the greatest significance in understanding the ~140,000 year history of our global human family. This stems, in the first instance, from our rapidly increasing knowledge over the past few years of the human genome and of the phylogeny of our human family tree (Cavalli-Sforza, 2000; Olson, 2002). The Khoisan and the pygmy have the longest branches on that tree. Their lineages can be traced back the furthest in time (Fig. 4), to perhaps 130,000 years. They are the direct bearers genetically, linguistically, anthropologically, of our earliest history.

Very unfortunately, from a heritage-cultural point of view, both racial groups are being rapidly assimilated into the surrounding, expanding, African population. The original pygmy languages have all already become extinct. "The only possible traces of those languages are in their names for forest animals and plants" (Cavalli-Sforza, 2000). It is significant in this regard that a pygmy will recognize, by name, hundreds of tree species (in the same order as western botanists) and several hundred animal species.

In any attempt to understand the story of the human colonization of Africa from 'Mitochondrial Eve' through to our expansion out of Africa; and in any attempt to explore the origins and early evolution of language—surely the most important of all human inventions—the pygmy and Khoisan are our living encyclopedia, our human library. If we are to unfathom the symbiotic partnership between *Homo sapiens sapiens* and the diversity of other species, plant and animal, sharing the African landscape through our first 130,000 years before the advent and spread of agriculture, then it is to the few remaining clans of pygmy and Khoisan that we must turn. They could not be of more fundamental significance.

Should we complacently let matters simply ride on as usual over the next decade or two, then the conduit to a great part of our past will have been rusted closed forever.

### *Lungs and heart of Africa*

Africa is the one continent that stretches more or less symmetrically across the equator and consequently shows clear climatic and vegetational zonation to north and south. The tropical forest belt sits astride the equator at the heart of Africa. The LAC traverses across that heart.

Africa can be visualized as a bellows (Fig. 9) with the tropical forest comprising the lungs of the continent. For the past 10 million years in particular, the parallel growth of the Antarctic ice cap (see also Fig. 3) and the deserts of Africa can be traced. The close harmony between global climate and vegetation is blatantly evident. Africa has shifted in this interval from a continent more or less fully covered by forest to one covered largely by desert, semidesert and savanna.

Over the past 500 thousand years (Fig. 8) there has occurred a succession of major and minor expansions and contractions of the Antarctic ice sheet (not seen at the scale of mapping on Fig. 9), following global cooling and warming, and followed in close unison by the contraction-expansion pulses of the tropical forest. Since the dense equatorial forests, in their cycle of transpiration and respiration, are a major contributor to the balance of carbon and oxygen in the atmosphere, the lungs metaphor is entirely apt.

Perhaps the most direct evidence of major changes in the climate and vegetation of Africa within the span of our human family comes from the study of rock art. Such art is preserved extensively, for instance, through the mountainous central Sahara (see Fig. 1 for position of the proposed Tibesti to Ahaggar Rock Art Corridor). This remarkable outdoor gallery dates back as far as 12,000 B.P., and indicates, through the fauna represented, extensive forests in the wake of the last glacial maximum at ~18,000 B.P.

### *Mammalian diversity hotspot of the world*

In terms of mammalian species diversity, Zaïre (DRC) (with 415 species) ranks third globally (Table 1). Only Indonesia (515 species) and Mexico (439 species) rank higher—and each is just slightly smaller in area. Brazil (394 species) and China (394 species) rank joint fourth and fifth in mammal diversity, but are three to four times larger in area (WCMC, 1992).

However, if diversity at higher taxonomic levels and at different weight classes is taken into account, then the DRC probably ranks first. This is very likely a consequence

Table 1. Zaire (Democratic Republic of Congo, DRC) as mammalian diversity hotspot of Africa and the world: statistics supporting the claim. For Africa, a selection of countries is listed north to south to emphasize the general law that diversity increases towards the equator. For the world, the 15 countries that rank top in terms of mammalian diversity are listed.

| Africa | | Mammals | | Global | | Mammals | | Area |
|---|---|---|---|---|---|---|---|---|
| | | spp. | endemics (no.) | | | spp. | endemics (no.) | mill.sq. km |
| 1 | Algeria | 92 | 1 | 1 | Indonesia | 515 | 165 | 1.90 |
| 2 | Egypt | 102 | 4 | 2 | Mexico | 439 | 136 | 1.97 |
| 3 | Niger | 131 | 0 | **3** | **Zaire (DRC)** | **415** | **25** | **2.34** |
| 4 | Chad | 134 | 0 | 4 | Brazil | 394 | 68 | 8.51 |
| 5 | Sudan | 267 | 7 | 5 | China | 394 | 32 | 9.56 |
| 6 | Ethiopia | 255 | 26 | 6 | Colombia | 359 | 22 | |
| 7 | Nigeria | 274 | 2 | 7 | USA | 346 | 93 | |
| **8** | **Zaire (DRC)** | **415** | **25** | 8 | Peru | 344 | 46 | |
| 9 | Kenya | 309 | 10 | 9 | India | 317 | 38 | |
| 10 | Tanzania | 306 | 12 | 10 | Uganda | 315 | 4 | |
| 11 | Angola | 276 | 4 | 11 | Kenya | 309 | 10 | |
| 12 | Mozambique | 179 | 2 | 12 | Tanzania | 306 | 12 | |
| 13 | Zambia | 229 | 3 | 13 | Myanmar | 300 | 8 | |
| 14 | Botswana | 154 | 0 | 14 | Australia | 282 | 210 | |
| 15 | South Africa | 247 | 27 | 15 | USSR | 276 | 55 | |
| 16 | Madagascar | 105 | 67 | | | | | |

Source: WCMC (1992)

of the Sixth Extinction, during which the megafauna, other than in Africa, has been decimated by humankind (see text on Madagascar, Australia and New Zealand). At continental scale, Africa with 14 orders (see Fig. 2) and 59 families of mammal comes first in richness (South East Asia has 12 orders and 49 families; Central America has 12 orders and 40 families)

Indonesia and Mexico are special cases, each for a very different reason. Indonesia is a republic comprising an archipelago of 11 main islands and a plethora of 3,000 small islands. Mexico forms part of the corridor between North and South America: it is a nexus between two continents and two faunas, yet at order and family level it surely has significantly less diversity than the DRC.

## 5. Madagascar: Lemur-Chameleon Corridor (LCC)

*Core theme and key references*

Born on a microcontinent; island biogeography, vicariance, radiation and extinction (Fig. 10). Masters et al. (1995), Quammen (1996), De Wit (2003).

Madagascar, with old crust dating back to >3,200 Ma, is the world's fourth largest island after Greenland, New Guinea and Borneo and is the most isolated. Its natural history provides profound insights into key concepts of geologic and biologic evolution: the formation and breakup of supercontinents, ecosystem dynamics, vicariance and radiation, extinctions, sustainability of biodiversity. It is the most vulnerable of the world's 25 recognized biodiversity hotspots and has the highest levels of endemism. Over 9,700 extant plant and 770 vertebrate (including freshwater fish) species are endemic to the island.

Humans first arrived on the island about 2,000 years ago and have wrought havoc since. The megafaunal 'extinction window' is currently estimated at between 1.5–0.5 Ka (Burney, 1999), linking their demise closely to overkill by human colonizers. At least 17 species of large mammals, birds and reptiles—including pigmy hippos, giant tortoises, elephant-birds and giant lemurs as big as gorillas—became extinct, apparently since the start of human influx. No indigenous terrestrial vertebrate with a body weight greater than 12 kg survived. And now in our

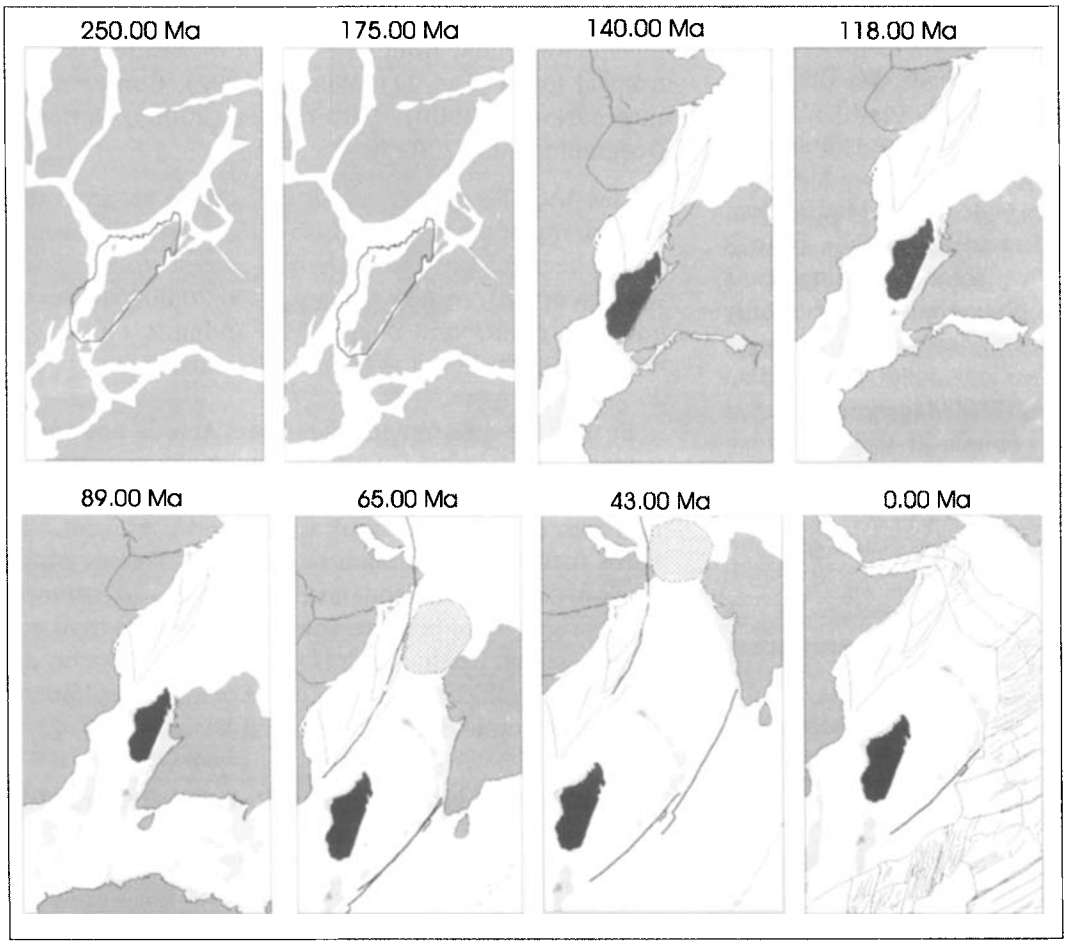


Fig. 10. Madagascar: micro-continental raft and home to a uniquely endemic fauna and flora. Adapted from De Wit (2003).

time there is massive destruction of habitat: about 65%, 34% and 10% of the island's primary tropical rainforests remained in 1950, 1985 and 2000 respectively.

### *Lemurs*

The biogeographical origins of the extant terrestrial and freshwater vertebrate fauna of Madagascar are one of the greatest unsolved questions of natural history. This relates particularly interestingly to the primates, our order (Fig. 3). With 35 living species of lemur in 14 genera and 5 families, Madagascar has proved a tantalising hotspot of vicariant radiation. Lemurs, extinct or extant, occur nowhere else in the world. Where did they originate? The island has been in its present isolated position for some 70 Ma (Fig. 10). The sister lemuriform groups, the lorises and bushbabies (galagos), occur in South East Asia, India and Africa (Fig. 3). The earliest known adapiformes (Table 2), the extinct ancestral stock common to the three lemuriform groups, date to 55 Ma in Asia and 37 Ma in Africa. New insights into evolutionary and biogeographic processes are sought to resolve the lemur enigma.

### *Chameleons*

Why do so many of the world's chameleons live in Madagascar? A vicariance view of Madagascar as an independent evolutionary hub was first suggested by Alfred Russell Wallace more than 100 years ago. The global chameleon fossil record goes back to 20 Ma, yet cladograms based on molecular and morphological evidence from 52 chameleon species suggest a Malagasy origin for chameleons with multiple 'out of Madagascar' radiations to Africa and other Indian Ocean islands (Raxworthy et al., 2002). Thus, some of Madagascar's indigenous inhabitants, like chameleons, successfully radiated and invaded neighbouring landmasses, although the mode of transportation across at least 500 km of Indian Ocean remains an enigma. Clearly Madagascar did act as an independent evolutionary source at least for some global biodiversity, but the cryptic role of global islands in the saga of extinctions and radiations remains to be unravelled.

Table 2. The 2 infra-orders of lemur-related primates: highlighting aspects of their evolution, phylogeny and biogeography.

| **Adapiformes** (lemur-like primates; stem-group for lemurs) |
|---|
| • A large radiation of primitive primates (possibly including the ancestors of living lemurs) chiefly in Eocene of North America and Eurasia; |
| • Earliest known fossil—55 Ma (Late Paleocene); |
| • Earliest dispersal—out of Asia where they flourished till Late Miocene (persisting in tropical forest refugia of S/SE Asia); |
| • Went extinct in Europe during major faunal turnover near Eocene/Oligocene boundary (absence of tropical forest refugia). |
| **Lemuriformes** |
| • Living lemurs—fossil and extinct forms confined to Madagascar; |
| • Lorises and bushbabies—sister groups of lemurs. |

Source: de Wit (2003)

### *Coelacanths*

Perhaps it is important here to note finally that Madagascar's coast is also home to the 'fossil fish', the coelacanths, now known from both sides of the Indian Ocean (http://www.saiab.ru.ac.za/coelacanth/s; also Erdmann et al., 1989). First discovered along the coast of South Africa some 70 years ago, and last seen in the fossil record ~80 Ma ago, they can be traced directly to a Carboniferous stem ~350 Ma ago, when Madagascar was first colonized by vertebrates after its long Precambrian history of deep crustal processes, and long before the opening of the Indian Ocean. The palaeodistribution patterns of coelacanths compared to their present distribution might provide simple models of vicariance and dispersal with complex food for thought.

## 6. South America: Amazon To Andes Corridor (AAC)

*Core theme and key references*

Observing biodiversity and the evapo-transpiration/precipitation flux; from core to rim of nature's largest tropical forest (Fig. 11). Wilson (1992), Conservation International (2000), Mittermeier (2000), National Geographic (May 2002).

The AAC (Fig. 11) descends in a gentle arc from the Andean rim of the Amazonian forest (in central Ecuador) to the heart of this largest tropical forest on Earth (in western Brazil). As home to a reputed 20,000 species of endemic plants and over 1,567 endemic terrestrial vertebrates, the Tropical Andes is the most diverse of the 25 global hotspots.

In that the Amazonian Wilderness Area is not under the same extreme level of human impact, it is not defined as one of the Conservation International 'hotspots'. It, however, is the largest tropical wilderness remaining on Earth (covering ~7 million sq. km.) and has very high levels of diversity and endemism. It is home, for instance, to more species of primate and freshwater fish than any other place on Earth. And it is the largest bellows on the planet: its significance in terms of the evapo-transpiration/carbon sink cycle cannot be overemphasized.

## 7. South America: Paraná-Pantanal Corridor (PPC)

*Core theme and key references*

Traversing 2 billion years through to the extant heart

of South America (from the neo-south Atlantic coast to the palaeo-south Pacific coast) (Fig. 11). Rösler et al. (2000), Schäffer and Prochnow (2002).

The PPC (Fig. 11) begins at the Atlantic coast, traverses westwards as far as the International Iguaçu Park (shared by Brazil, Argentina and Paraguay), then swings north-northwest along the Paraná and Paraguay Rivers to the unique pantanal at the very heart of South America. Incorporating the best remnants of one of the 25 biodiversity hotspots of the world, this corridor boasts many superlatives. Geologically and palaeontologically it spans the past 2 billion years, being richly fossiliferous and covering an enormous range of past environments and biological events. The rich spectrum of extant ecosystems are all heavily endangered. They include: mangroves (of the Atlantic coast), a rainforest even more diversified than that of the Amazon (Atlantic Forest Region), the *Araucaria angustifolia* ecosystem on the widespread plateau to the West of the Serra do Mar with a fauna including living-fossil marsupials, the semidesert *cerrado*, and the huge and unique lowland pantanal *matogrossense* with nothing similar elsewhere in the world.

At the start of this corridor along the Atlantic coast, rocks older than 2 billion years crop out to tell us part of the history of our planet during remote times (pre-Gondwanan period). The corridor then traces one of the best cross-sections through the Paraná sedimentary basin (Gondwanan period), with all the lithostratigraphic units outcropping along it; intrusive and extrusive activity around 600 Ma; multiple glaciation around 300 Ma (the last at ~280 Ma); positive epeirogeny and gradual aridity from 250 Ma; desertification during the Mesozoic; tectonics and extrusives related to the opening of the south Atlantic during fragmentation of Gondwana.


Fig. 11. South America: showing the Amazon to Andes (AAC) and Paraná-Pantanal (PPC) Corridors and a third (undescribed) Origin of Species Corridor (OSC). Biodiversity hotspots and Amazonia Wilderness based on Conservation International (2000).

Especially rich fossiliferous sequences occur, with wonderful documentation of the biological and environmental events from the first land plants of the Siluro-Devonian and the malvinokaffric marine fauna, to the latest Permian (Rösler et al., 2000) announcing the great Permo-Triassic extinction.

The Atlantic Forest presents an extraordinary dense ombrophilous vegetation. The PPC includes one of the few reasonably well-preserved remnants of this forest. According to Schäffer and Prochnow (2002), the Atlantic Forest is one of the most endangered regions of the world: yet still includes over 20,000 species of plants (50% endemic) and perhaps 1.6 million animal species (including insects). Among the animals are recorded 261 mammal species (73 endemic), 620 bird species (160 endemic) and 260 amphibian species (128 endemic).

The pantanal occupies an area of 133,000 sq. km. It is a natural corridor for migration and is essential for the reproduction of an incredibly large number of animals, including birds, crocodiles, mammals and fish. It is a miscellany of several different ecosystems. These pantanal lowlands represent the former Pacific coastal plain as it existed before the Andean cordillera uplift. Until today, many of the lakes and ponds of the pantanal are saline.

Available evidence points to the earliest human infiltration of the region at some 4,000 B.P. The original impact was mainly on the larger mammal fauna. Then came the Europeans at around 1500 A.D. to the Atlantic Forest Region, with the familiar refrain—first fragmenting the lives of the indigenous peoples, then colonizing the coastal plains and forested region in earnest. Nowadays, 120 million people live in this forest domain and its original extent has been reduced by a mortifying 92%.

## 8. India And Himalayan Region: Deccan Traps Corridor (DTC)

*Core theme and key references*

Archives of the Fifth Extinction; the Deccan Traps and Shiva Crater (Fig. 12). Tredoux et al. (1989), Chatterjee (1997), Zanda and Rotaru (2001).

Centred on the West-coast City of Mumbai, the massive, nonexplosive, continental flood basalt volcanism of the Deccan Traps cover over 800,000 sq. km, about the size of Texas. The lava floods erupted intermittently as India rode over the Réunion hotspot during its northward drift (Fig. 12). They show an age span, through radiometric dating, of 3 million years, from 67 to 64 Ma, with a main pulse close to the K-T boundary at 65 Ma. A succession of intertrappean beds (fluvial and lake deposits) yield abundant remains of plants, invertebrates and dinosaurs. Life clearly 'thrived during the recurrent Deccan eruptions' (Chatterjee, 1997).

What then was the agent of extinction at the K-T boundary causing the demise of the dinosaurs? This same region of India, remarkably, is 'ground zero' for both the Deccan volcanism and the oblong Shiva (impact) crater dated at ~65 Ma. The latter structure, the largest in the Phanerozoic world, is split in two along the Carlsberg (spreading) Ridge, with the southwestern half preserved in today's Seychelles region and the northeastern half in India.

The sharp K-T transition from the Cretaceous to the Tertiary left its mark as the fifth major global extinction event, particularly in the oceans (80% of the plankton species disappeared along with all the ammonites); on land all animals bigger than 25 kg, particularly the dinosaurs, also became extinct. Because the sediments at the K-T boundary contain shocked minerals, and chemical signatures (particularly the anomalously enriched Ir anomaly) indicative of meteorites (or the deepest bowels of Earth), a sudden influx of extraterrestrial material (or plume-induced material derived from the core-mantle boundary) is implicated with the catastrophic events recorded in the fossil record. Indeed the discovery, with geophysical tools, of the Chicxulub Crater in the Yucatan of Mexico buried beneath a thick blanket of Tertiary sediments, and the subsequent analyses of samples recovered from this crater by drilling, confirmed the K-T age (65 Ma) of this circular impact scar of some 200 km across.

This work showed beyond reasonable doubt that Earth was struck by a meteorite of about 10 km in diameter at the K-T boundary. What is not resolved, however, is the relative effects (and feedbacks) on the biosphere by the meteorite and the near-simultaneous outpourings of the deep-mantle-derived magmas that formed the Deccan Traps. To date, only few chemical measurements have been made on a global scale. One such study has clearly identified that possible extraterrestrial chemical signatures of, for example, Ir and its sister group elements (the PGE, or platinum group elements) are more distinct in the K-T boundary sediments of the Northern Hemisphere (where the Chicxulub Crater occurs), while those sediments of the Southern Hemisphere have clear 'deep earth' terrestrial signatures of these elements (Tredoux et al., 1989). Thus, further studies on the Deccan Traps (which formed when India was still in the Southern Hemisphere) are sure to enhance our understanding of the details of the Fifth Extinction.

## 9. India And Himalayan Region: Central Himalayan Corridor (CHC)

*Core theme and key references*

Closing the Gondwana-Asian divide; plate tectonics, continents in collision, mountain building, radiation (Fig. 12). Gansser (1964), Searle (1991, 2003).

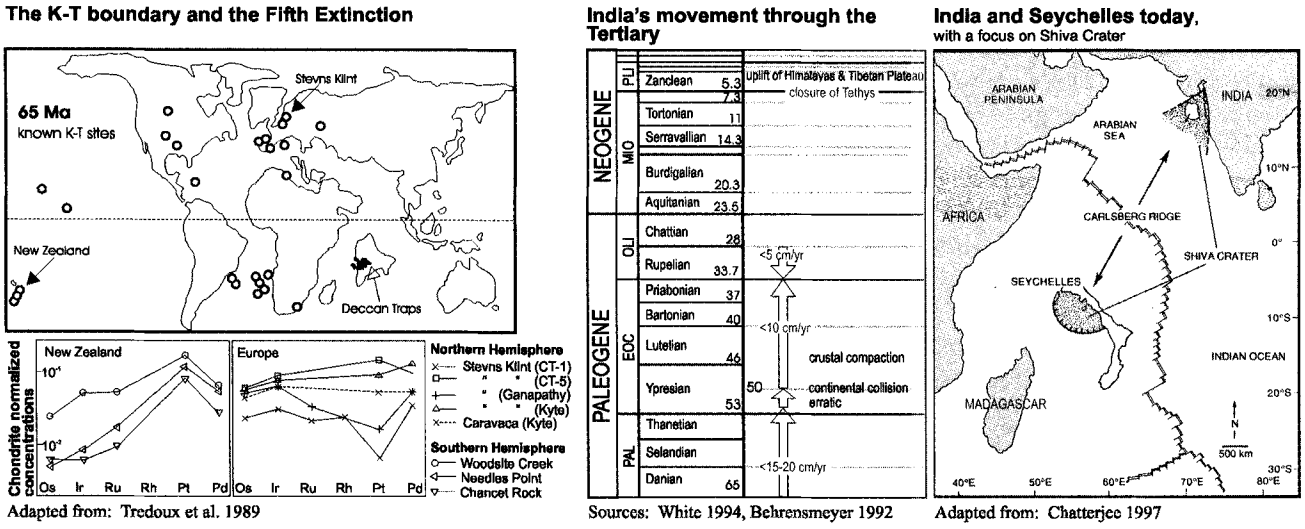


Fig. 12. India: from the K-T boundary and Fifth Extinction, through major northward Tertiary drift, to collision with Asia and the Himalayan uplift. Adapted and assembled from various sources as shown on figure.

The high crumpled Himalayas, including Everest and Kanchenjunga and K2 and Annapurna and Nanda Devi, the majestic playground of the mountaineers, are the most visible expression of what Gondwana and drifting continents are all about. As India drifted north and impacted into Asia, so this greatest of all ranges was moulded into being to become sculpted by time and the scalpel of the monsoons; and it provided a new route for Gondwana stock to enter and diversify into Asia. India was a veritable Noah's Ark transporting Gondwanan species to Asia.

'The Indian subcontinent reached the southern edge of Eurasia by the middle Eocene.... Although crustal compaction began 40–50 Ma, closure of the Tethys Sea and significant elevation of the Himalayas and the Tibetan (Qinghai-Xizang) plateau were a phenomenon of the late Neogene. Estimates of the rate and timing of uplift of the Himalayas and the Tibetan plateau during the Neogene and Quaternary vary, but it is generally agreed that global and regional climate tended to be cooler and drier as a result of the uplift' (Behrensmeyer et al., 1992)—since increased erosion in response to uplift acts as a $CO_2$ sink and therefore depletes the atmosphere of greenhouse gas (Ruddiman, 2001).

## 10. Australia And Polynasia: Aboriginal Dreamtime Corridor (ADC)

*Core theme and key references*

Tales of fatal colonization; hunter-gatherers, extinction (Fig. 13). White (1990, 1994) Flannery (1994), Gore (1997a, 2000), Diamond (1998), Parfit (2000).

When did *Homo sapiens sapiens* (modern humans) arrive in Australia, this great fragment of former Gondwana, and what was their effect on the unique marsupial megafauna that they encountered? Did one or more forms of archaic *Homo sapiens*, or even *Homo erectus*, arrive earlier? The answers remain elusive but highly intriguing and important.

At 140,000 B.P., a huge increase in carbon occurs in sea-bed sediments off the northern coast of Queensland. In cores from Lake George near Canberra, a detailed pollen sequence has been obtained from 700,000 B.P. (particularly 350,000 B.P.) through to the present. At 130,000 B.P., a sudden major increase in carbon particles occurs in these Lake George cores. Both the Queensland and Canberra carbon shifts indicate an increase in the frequency and severity of fires—and it has been suggested (controversially) that these point to the earliest appearance of hominids in Australia. The aboriginals were nomadic people without Bronze or Iron Age technology and no agriculture, but it is well known that they used fire extensively, particularly in hunting, and it had alarming effects on the natural vegetation.

The earliest stone tools, artworks and ochre crayons, in Australia (at Jinmium on the north coast) appear to date back to ~116,000 B.P. or even earlier (the dates, based on optically stimulated luminescence, have been strongly challenged and are considered unreliable). The earliest known skeletal material is that of the Mungo Lady (discovered 1968), dated in 1999 by three different methods, to 62,000 B.P. She had been burned on a funeral pyre, her bones smashed and buried in a hole at the front of a dune.

A rich suite of aboriginal sites (dated from 31,000 B.P. to present) occur down the sinuous sweep of the Dreamtime Corridor (Fig. 13), from the Willandra Lakes (NSW), to Kangaroo Island (S. Australia), to Cohuna and Keilor (Victoria), and across the Bass Strait to the Shannon and Florentine River Valleys (Tasmania). How do the peoples of these sites relate to those of the earlier sites? How is their impact reflected in the few known faunal sites (Fig. 13). What is the true history of the onset of the Sixth Extinction in Australia? The Aboriginal Dreamtime still dwells shrouded in the mists of the millennia.

## 11. Australia And Polynasia: Queensland Wallabies Corridor (QWC)

*Core theme and key references*

Chromosomes, genes and accelerated radiation. O'Neill et al. (1998), O'Neill et al. (2001), Fox (2002).

The rock hoppers of Queensland provide a highly informative example of the disparity between phenotypic expression and genotypic constitution (Fox, 2002). It is also a wonderful instance of the irresistible scientific reason for preserving what we have left of wilderness, undisturbed habitat, undomesticated nature. Along the coastal belt of Queensland, from Brisbane to the Cape York Peninsula, occur eight species of rock wallaby. They have overlapping habitat and spatial ranges, they all look identical, yet genetically they are recognised as eight species. Through painstaking DNA studies, the explanation seems to lie with retroviruses thoroughly shuffling the chromosomes of hybrid, yet fertile, individuals (O'Neill et al., 1998; O'Neill et al., 2001). It has been dubbed the Benny effect: Benny is the unlikely offspring of two distant species, a tall swamp wallaby and a tubby tammar wallaby, and it has a weirdly jumbled chromosome.

Emerging from this is one possible mechanism for the hugely accelerated rates of specific and generic differentiation required to explain geological intervals of

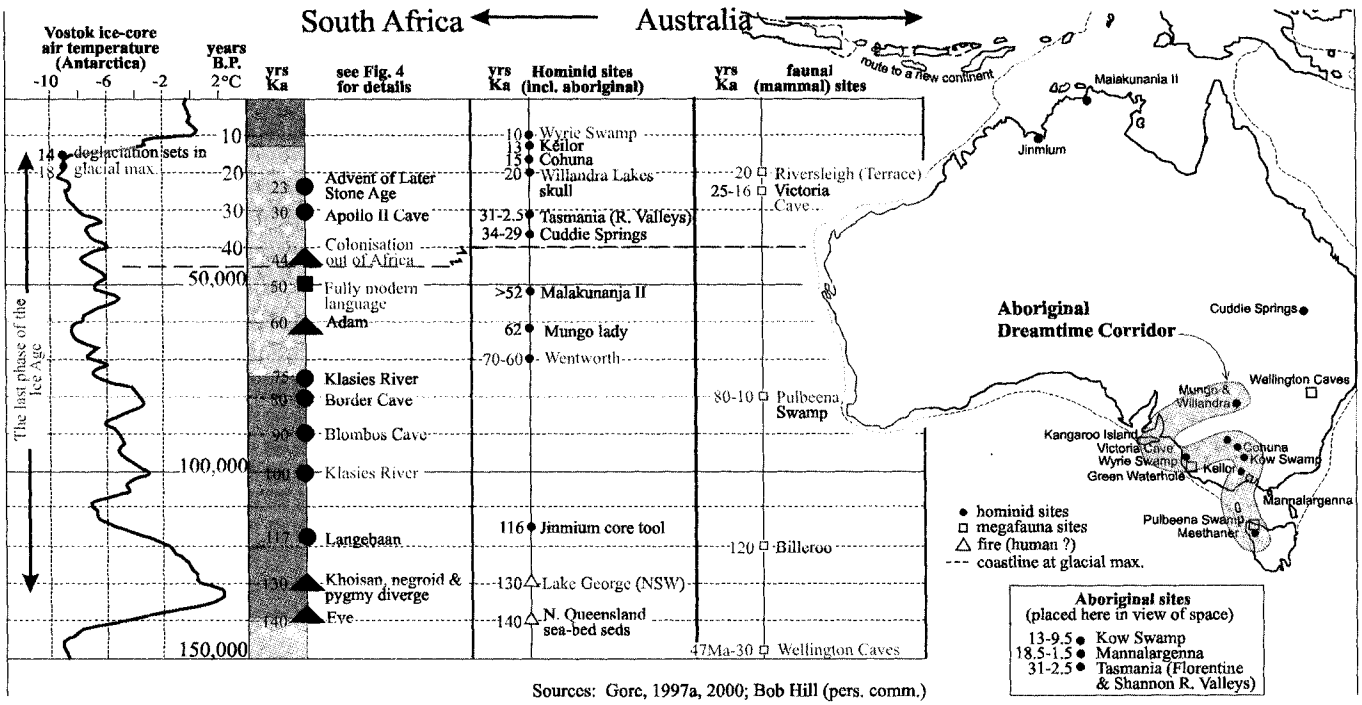


Fig. 13. Aboriginal Dreamtime Corridor (ADC): tracking human colonization of Australia from 150 Ka, as seen correlated against the Vostok ice-core temperature curve and comtemporary events in South Africa. Sources as indicated on figure.

explosive radiation—such as the Triassic Explosion (Anderson et al., 1996) following the end-Permian extinction. Atavism, Hox genes, stem cells, RNA interference, gene transfer, retroelements, inactive DNA, pre-programming, individually and in various combinations, provide a host of other hardly explored possibilities.

## 12. New Zealand: New Zealand–Chathams Corridor (NCC)

*Core theme and key references*

Riders of the last ark: the final frontier in the first wave of the Sixth Extinction (Fig. 14). Butler and Merton (1992) Department of Conservation (1996) Worthy and Holdaway (2002).

The Chatham Islands (Fig. 14) are one of those remote corners of the world beyond which there is serious oceanic space: open water all the way to South America. Positioned just east of the dateline, they strictly constitute New Zealand's westernmost territory with a Gondwanan heritage, or easternmost in a purely directional sense! Located some 850 km on the 44th parallel due east of Christchurch, New Zealand, they include two inhabited islands: Chatham Island (about 65 × 50 km) and Pitt Island (about 9 × 3 km). The population currently numbers less than 700. The Chathams include a number of smaller islets and rocks that are famous as breeding grounds and roosts for marine bird life, but also terrestrial birds such as the Black Robin. The Chathams, though remote, are a sensitive edge to the known world and they have been ravaged by successive waves of human engagement with nature's astonishingly rich but nevertheless very restricted bounty.

Historically, the Chathams are the home of a Polynesian people referred to as Moriori. As far as can be ascertained, they lived in isolation for at least 500 years prior to arrival of Europeans in 1791, and subsequent violent subjugation by New Zealand Maori in 1835. The Moriori were relatively nonaggressive hunter-gatherers who quickly succumbed to the warrior Maori culture, but it is important to note that the Moriori were almost certainly descended from a small group of Maori who made the original voyage of discovery to the Chathams and remained there. With time, the small genetic pool took on its own distinctiveness as Moriori. It is estimated that their population numbered about 2,000 in 1791. Sadly, the last full-blooded Moriori died in 1930: Tommy Solomon. It could be argued that this was an extinction event. Human hybridisation has ensured that there are people who identify themselves as Moriori or part-Moriori, and now there is an emerging renaissance of Moriori identity, language and culture.

Then there is the story of all the terrestrial plants and animals in the Chathams, as well as the marine life. This is well summarised in a small book published by

Canterbury University Press entitled *The Chatham Islands: heritage and conservation* (Department of Conservation, 1996). This essential reading is fascinating because it documents what there is on the land, in the sea, in the air ... and it does so in a historical context. But it is also disturbing because of its listing of species that have disappeared since the arrival of man. Is there no place that is safe from the excesses of humanity? Or is this normality?

The Chatham Islands are a sentinel outpost of Gondwana in the southwest Pacific, on the one hand facing the endless horizon, and on the other hand at the leading edge of terrestrial habitat. It represents the end point of the Chathams Corridor, that conduit of life stretching from Asia across Australia to New Zealand and a little beyond.

### *The Moa or te kura ('red bird'): extinct*

Incredibly, the first humans to settle New Zealand arrived only some 700 years ago. The islands were a strange untouched place where birds filled the roles of mammals. Armed only with limited Stone Age tools (no bows or spears) and with fire, those early Maori settlers eliminated over 60 endemic bird species—the widespread great red Moa amongst them. Some 500 years later James Cook and the Europeans arrived, bringing modern technology and a new wave of devastation. Close on 50% (41% endemic) of the islands' bird species have succumbed to this combined human onslaught (Worthy and Holdaway, 2002).

### *The Black Robin: back from the brink of extinction*

In the early 1980s, five individuals and just one single breeding pair of the Black Robin, living on one of the remote windswept Chatham Islands, were dramatically pulled back from the brink of extinction. Earlier attempts


Fig. 14. New Zealand-Chathams Corridor (NCC): highlighting the Sixth Extinction through the Moa (extinct) and Black Robin (rescued from the brink of extinction) at either end of the corridor. Base map provided by Hamish Campbell.

in the 1970s to rescue the species from extinction seemed to be heading for failure by 1980. Then a team of courageous conservationists managed the impossible. This is a fabulous story of perseverance and dedication towards stemming the Sixth Extinction, and one that can serve as an inspiration to inhabitants of Gondwana fragments. A pair of robins, Old Blue and Old Yellow, with the help of foster parents and determined, innovative scientists, saved the species: today there are over 100 birds, and the species future is once more secure. This is one of the most dramatic, daring and successful species recovery programmes anywhere in the world (Butler and Merton, 1992).

## 13. Antarctica: Antarctic Peninsula Corridor (APC)

*Core theme and key references*

Barometer of global warming; of algae, krill, penguins, seals, whales and melting ice shelves (Fig. 15). Joyner (1998), Smith (2001), National Geographic (2002), Trewby (2002).

The Antarctic Peninsula stretches sinuously northwards for some 1,500 km from the Lassiter Coast to Joinville Island (Fig. 15). It teems with wildlife running up through the food chain: from algae, growing initially in the ice, to the vast concentrations of krill, to the penguins, seals and whales. Is it a barometer of regional or of global warming? The Peninsula 'has warmed about four degrees in the past 50 years and in winter is a staggering ten degrees warmer. Winter sea ice at its northern reaches has been so reduced in recent years that the krill populations ... are in danger of crashing' (National Geographic, 2002). As krill support almost the entire Antarctic foodweb further up the chain, the consequences could be dire. Some 3,000 square miles of coastal ice shelves have disintegrated. The climate in the rest of Antarctica, by contrast, is changing very much more slowly. Whether of regional or global import, the climatic and biological patterns recorded along the Peninsula provide a vivid indication of what might await us.

On the far side of the South Pole, in the middle of the ice sheet of East Antarctica, was drilled the Vostok ice-core (Fig. 15). This core, together with the APC barometer, is of the most critical significance in the question of global warming.

### *The Vostok ice-core: archive of greenhouse gasses and recorder of sudden global climate and eco-changes of the past*

Arguably the most important graph produced during the last century is that depicting the coupled changes in global temperatures and carbon dioxide/methane concentrations of the atmosphere over the last 420,000 years. This graph was constructed using chemical concentrations of carbon dioxide, methane and oxygen isotopes analysed from fossil gas inclusions in a long (~4 km) continuous sequence of ice, cored and recovered by Russian engineers, and analysed by a consortium of Russian and French scientists. This sequence, known as the Vostok ice record, represents the 160,000-year (recovered by 1987) and now 420,000-year record of chemical change of Earth's atmosphere (Jouzel et al., 1987; Barnola et al., 1987; Chappellaz et al., 1990; Petit et al., 1999; see also Ruddiman, 2001; Kump, 2002). This groundbreaking work demonstrated for the first time beyond reasonable doubt that there is an intimate connection between natural global climate change and atmospheric $CO_2/CH_4$. Past increases in these gasses in our atmosphere occurred in tandem with average global warming, and visa verse decreases with global cooling. There is clearly a carbon-climate feedback. This Vostok record (and others from marine sequences) has now also taught us that the temporal variation sometimes occurred abruptly, giving cause to the real issues of concern today, namely the unpredictability of potentially catastrophic changes in global climate, and the complex response patterns of nonlinear ecodynamics. The message is clear: the Sixth Extinction may yet suddenly overtake us; it may well come at us unpredictably fast.

## 14. Antarctica: Scott Base To South Pole Corridor (SSC)

*Core theme and key references*

Of the human spirit and human endeavour (Fig. 15). Stump (1995), Solomon (2001), Trewby (2002).

Here we encounter human endeavour and human endurance at their limit and beyond their limit. And along the Transantarctic Mountains with their stark Gondwanan outcrops are seen sequences, paralleling those in each of the Gondwana continents, yielding fossils you could have collected around Sydney, along the Pranhita-Godavari Valley in India or inland of Rio de Janeiro.

Roald Amundsen, on 14 December 1911, reached the South Pole. He and his team were the first men to do so. Robert Falcon Scott's party of five arrived at the pole on 17 January 1912 after a two-and-a-half-month trek, to meet bitter disappointment at finding Amundsen's flag already there. They had lost the race. And they never made it home. Scott, Wilson and Bowers, the last survivors, finally succumbed, blizzard-bound in their tent, after a further two months on the return trek. But on their fatal return, they had collected 35 pounds of rock specimens,

with beautifully preserved *Glossopteris* leaves, from near Mt Buckley at the head of the Beardmore Glacier. These were discovered by a later expedition towards the end of 1912. The fossils lay with the bodies of Scott and his friends: they had jettisoned most of their equipment along route but not their geological treasures. These were the first fossilised plants of their kind found in Antarctica and were of great scientific value in establishing the icebound continent as a part of Gondwana.

### *Selected locations along the SSC* (Fig. 15)

*Ross Island*

Discovered by James Clark Ross in 1841, the island is dominated by the large and imposing Mt Erebus, an active alkalic volcano up to 2 million years old. It is part of the Cenozoic volcanic province formed on the edge of a West Antarctic rift system.

*Cape Evans*

Site of the winter hut of Robert Scott's 1910–13 British Antarctic Expedition located on the western side of Ross Island at the foot of Mt Erebus and named after Scott's second in command, Edward Evans.

*Ross Ice Shelf*

The largest floating ice shelf in the world is about the size of the State of Texas and bigger than France. It is up to 1,000 m thick at the point where it joins the land. Termed the Great Ice Barrier, by James Ross who sighted it in 1841, the seemingly impassable ice cliffs along the edge of the shelf awed early explorers.

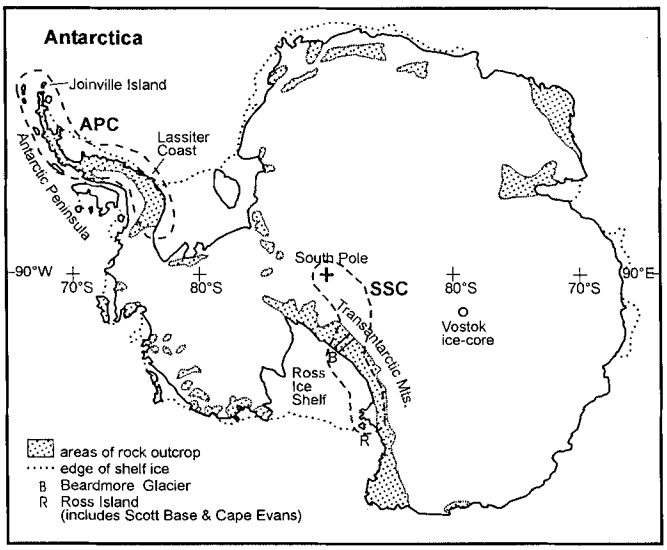


Fig. 15. Antarctica: showing the positions of the Antarctic Peninsula (APC) and Scott Base to South Pole (SSC) Corridors; and the fundamentally significant Vostok ice-core. Base map adapted from Taylor and Taylor (1989).

*Dry Valleys*

An ancient polar desert located at 78 degrees south, known for strong winds and extremes of cold and dryness. The region is dotted with large rocks, ventifacts, carved into strange sculptured shapes by winds, and several frozen saline lakes that contain rich populations of algae.

*Beardmore Glacier*

One of the largest known valley glaciers, 200 km long, descending 2,200 m from the polar plateau. It provided the route for Ernest Shackleton's 1908 attempt to reach the South Pole, and was followed by Scott's ill-fated expedition.

*Transantarctic Mountains*

A major divide separating the East and West Antarctic ice sheets. It preserves a record of active margin tectonics (of the amalgamation and separation of the ancient supercontinents Rodinia and Gondwana), a Permo-Carboniferous Gondwana glaciation, the widespread *Glossopteris* flora and Triassic coal beds, and the massive volcanic eruptions and sill complexes that pre-empted the breakup and final disintegrating of Gondwana leading to the present distribution of the Southern Hemisphere continents. The final stages of that process resulted in the West Antarctic rift system and the formation of the mountains themselves on the uplifted flanks of that system. The rocks are encrusted by algae, lichens, fungi, mosses and liverworts in the northern part of the transect.

## 15. Japan: Fuji-san To Hiroshima Corridor (FHC)

*Core theme and key references*

Geotectonism to homotectonism: from subduction-accretion orogens and island arcs to atomic bombs (Fig. 15). Leonard (1968), Yao et al. (1980), Isozaki (1997).

*Uniqueness*

The story of nature's prodigious and limitless energy, as released through geological processes in the Earth's crust during relentless subduction processes; and through the unhappy partnership of human scientific-technological ingenuity and political grandiloquence, is more eloquently told in southwestern Japan than in any other corner of our world. The drama unfolds at the following 12 nodes plotted along the FHC (Fig. 16).

Japan sits at the quadruple-junction of the Pacific and Philippine oceanic plates, and the Eurasian and North American continental plates. For close on 500 Ma, from

the Ordovician to the present time, it has built up as an accretionary island arc along the western margin of an active subduction zone (e.g. Isozaki, 1996). Relatively recent studies (Yao et al., 1980) of the exceptional Kiso River outcrops have provided the model for modern accretionary geology, and an effective tool for studying orogenic belts (Matsuda and Isozaki, 1991).

Earthquakes and volcanoes, often of disastrous proportions, are a part of life in Japan. No fewer than 100 major quakes of greater than magnitude 7 have struck in the past 110 years, and if those of lesser magnitude are counted, the number increases dramatically. The magnitude-6 earthquake that struck the Tokyo area in 1923 claimed as many as 140,000 lives (Graves, 1986). Volcanoes add to the natural hazards: close on 100 have been recorded in Japan through the Holocene (the past 10,000 years), of which 86 (405 recorded eruptions) have been active in the past 2,000 years. There can be no other densely populated country approximating this level of ever-menacing geotectonic activity.

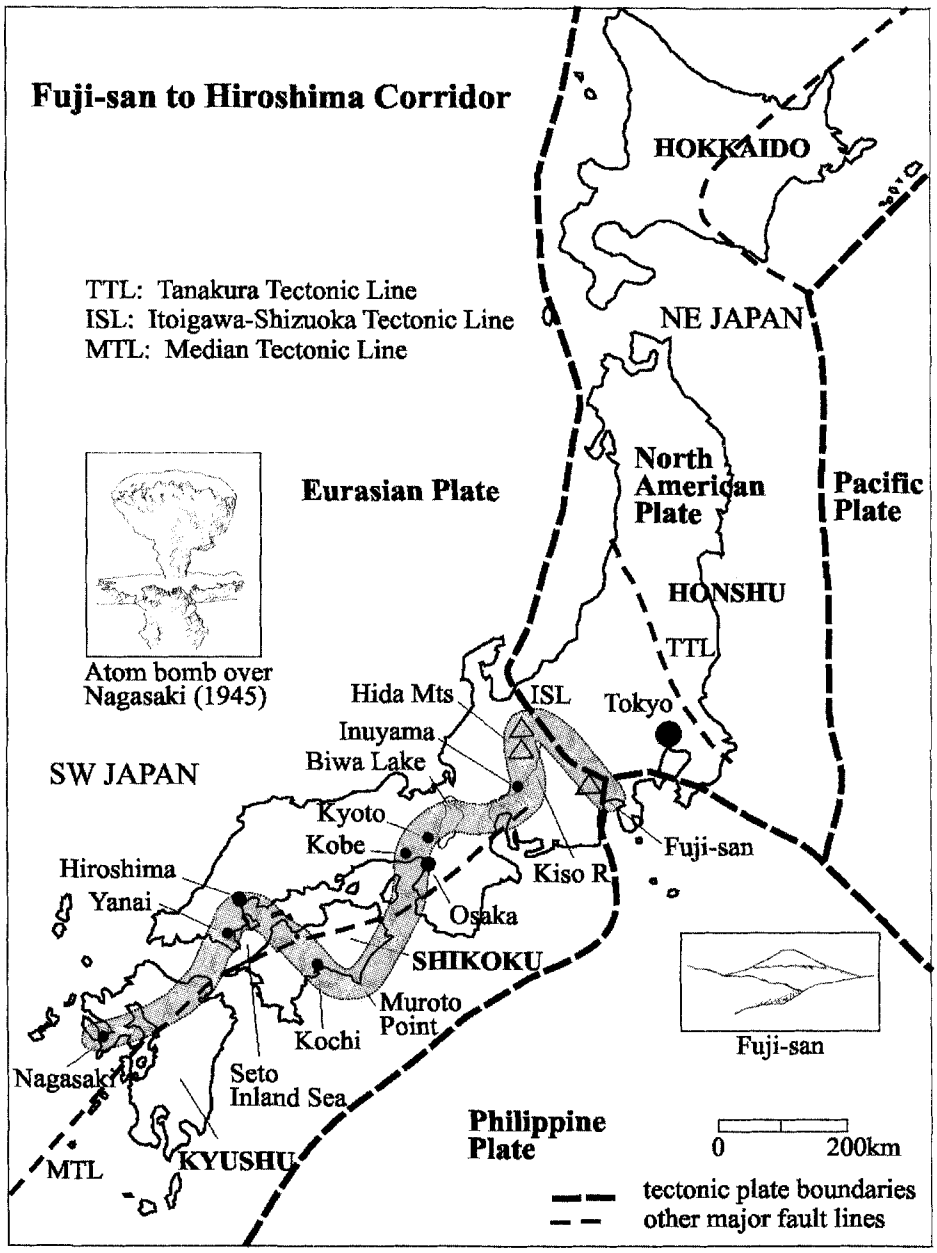


Fig. 16. Fuji-san to Hiroshima Corridor (FHC): showing the position of the corridor in southwestern Japan, with the various nodes and cities discussed in the text. Mt. Fuji apparently sits immediately to the west of the triple-junction of three tectonic plates (Isozaki and Maruyama, 1991). In the text we refer to the two closely adjacent triple-junctions as a quadruple-junction. From data supplied by M. Santosh (see acknowledgments).

The other face of Japan is its pervasive serenity and natural beauty, a land of islands and seascapes, of enchanting peaks and green wooded slopes, of plentiful rainfall, of rivers, streams, lakes and waterfalls. A reverence for nature's bounty has always inextricably permeated the major religions of the country; first Shinto, then Buddhism from its first appearance here in the 6th century (Leonard, 1968).

### *Fuji-san*

At 3,776 m, Fuji-san, famed for the clean symmetry of its snow-capped cone, is the highest of Japan's 200 volcanoes, and the highest peak in the country. In its awesome latent power—it last erupted 300 years ago (in 1707)—and the elegant purity of form, it has long stood as the symbol of Japan. It is a place of veneration and pilgrimage, a truly dominating peak forming the backdrop to Tokyo. It features centrally in Japanese culture and consciousness. As a dream symbol of good fortune it appears very widely on Japanese crafts, including, significantly, their New Year's greeting cards. Hokusai, the famed and eccentric 18th century artist, produced numerous lyrical, romanticized views of the peak hinting at its monumentality and the transitoriness of human life (Sigurdsson, 2000).

Fuji-san, which has erupted at least 14 times since the first written records of the Heian era (800 A.D.), stands as a living reminder of the dramatic contrasts permeating the theme of the Fuji-san to Hiroshima Corridor.

### *Hida Mts*

This typically Japanese mountain belt, cutting across the centre of Honshú, is important both geologically and biologically. Its rich biodiversity reflects the clear altitudinal zonation of plant and animal communities. The eastern slope of the mountains is cut by the Itoigawa-Shizuoka Tectonic Line, an active and disastrous plate boundary fault, which divides the Japanese Islands into northeastern and southwestern sectors. Repeated island arc magmatic activity, ranging from Palaeozoic to recent, is extensively developed (Kano and Shimizu, 1992; Kano, 2001). Mt Tate-yama (3,015 m) and Mt Yari-ga-take (3,180 m) are particularly compelling from religious and mountain trekking points of view respectively.

### *Kiso River bed, Inuyama*

In the Inuyama area, about 30 km north of Nagoya City, the Kiso River flows southwestward cutting across the general structure of rocks of the Triassic-Jurassic accretionary Mino-Tanba belt. A beautifully exposed riverbed continues for more than 5 km and exhibits a more than ten-fold repetition of early Triassic to Middle Jurassic pelagic to near-trench sequences; each sequence being separated by bedding-parallel faults (Yao et al., 1980).

This Inuyama outcrop preserves a complete oceanic-plate stratigraphy as well as a beautiful clear Triassic/Jurassic boundary. It is important also from a historical geology perspective, since radiolarian biostratigraphy conducted at this outcrop (Yao et al., 1980), with that at the Hozukyo section in Kyoto (Isozaki and Matsuda, 1980), initiated the study of accretionary tectonics along the Japanese Islands (Matsuda and Isozaki, 1991; Isozaki, 1996). The studies born of this outcrop form the stem of accretionary geology, now established as an effective tool for studying orogenic belts. The complete Triassic-Jurassic section of this outcrop not only contributed to identifying the radiolarian extinction events at the T-J boundary (Hori and Carter, 2002); but also provided the principal data establishing the cause of the P-T boundary mass extinction to be due to global oceanic superanoxia (Isozaki, 1997).

In the Jurassic accretionary complex along the Japanese Islands, for nearly 1,000 km from the north of Tokyo to Kyushu island, occur, as already noted, fine sections of Permian and Triassic deep sea cherts (nowhere in Japan is the P-T boundary actually preserved and nowhere are Permian and Triassic sediments observed in the same outcrop). The geochemistry of these deep sea sediments has revealed that during the P-T transition, deep oceans globally became toxic to prevailing life. The oceans were starved of oxygen (superanoxic) and polluted by sulphur (Isozaki, 1997). This elegant Japanese work shows that the demise of many marine organisms during the Third Extinction (end-Permian) was due to large-scale chemical poisoning of major habitats. This is one of the few areas in the world where the record of these changes in the deep oceans is still preserved; and it should be read in conjunction with the complementary records of chemical changes in the atmosphere at that time, as recorded in the terrestrial sediments of the Karoo in southern Africa and other Gondwana-type deposits in Indian and Madagascan basins (de Wit et al., 2002).

Inuyama Castle, a national treasure, stands just above these supremely significant Kiso River outcrops. Traditional Japanese fishing with cormorants along with river cruises add further attraction to this part of the river.

### *Biwa-ko Lake and Kyoto*

Biwa-ko, Japan's largest lake, is an important water source to ~14 million people. It is a long-lived (5 Ma) palaeolake within the active mobile belt of central Japan. The preservation of this water resource, in quality and quantity, is a leading environmental issue for the Japanese people. At Otu city on the south coast of Biwa-ko, the

1st (1984) and 9th (2001) World Lake Conferences were held. No less than 1,000 plant and animal species have been recorded from the lake.

It is fitting that Kyoto (formally Heian-kyo), site of the Imperial capital for over 1,000 years (794 – 1868 B.P.), is the focal point today in the escalating debate over global warming. The Kyoto Accord signed here by 160 countries in 1997, calls for the industrial nations to reduce their greenhouse emissions to an average of 5.2% below 1990 levels between the years 2008 and 2012. In the context of the Sixth Extinction, it is far too small a commitment over far too long a period, yet it is a beginning.

In a quite different vein, Kyoto is the source of the world's first major novel and Japan's greatest literary classic: *The Tale of Genji*, a 630,000-word tale of courtly love written in 1020 by Lady Murasaki Shikibu, a lady-in-waiting to the Japanese empress. The golden era of Heian-kyo culture, an era of peace, tranquillity, poetry and art, lasting from 794 to 1156 (362 years), was rudely shattered by the coming of the Samurai, the fighting men of Japan. In the starkest contrast to the Heian Age, an interminable militaristic era of almost incessant feudal warfare followed (Leonard, 1968).

### *Kobe City*

It was early morning on 17 January 1995 when the Kobe earthquake (magnitude 7.2) struck. It left 6,400 people dead and 150,000 buildings destroyed. At heavily affected sites, the long period pulses were further amplified due to the basin margin effect and the thick Quaternary sediments. The Disaster Memorial Park at the Kobe port includes evidence of the liquifaction of landfill sediments used to extend the port since 1950 (Mitamura, 2001).

### *Osaka Basin*

The Osaka Basin on which the second largest Japanese city, Osaka, stands, includes the thick (>2,000 m) Plio-Pleistocene Osaka Group, capped by a thin (<100 m) later Quaternary formation. This mostly terrestrial sedimentary sequence, with 12 intercalated marine clay strata, provides a continuous stratigraphic and palaeoclimatic record through the past 3 million years. Pollen grains provide the best biostratigraphic tool. It is certainly the most fully studied sequence of this interval in Japan and possibly one of the best in the world (Itihara et al., 1987; Mitamura, 2001). The work is based on extensive field studies in hilly areas with good outcrops, as well as analyses of many borehole cores drilled in the 1960s for research into the cause of subsidence (shown to be due to the removal of groundwater) of Osaka City. The rather precise dating and correlation of tuff layers has made the very effective and detailed research of this group possible.

### *Muroto Coast*

The beautiful arcuate rocky coast of ~80 km from Muroto-misaki Point to Kochi is formed by spectacular outcrops of Cretaceous to Tertiary accretionary sequences (Taira et al., 1988) composed mostly of terrigenous sediments with minor oceanic interbeds. Fine syn- and postsedimentary deformational structures characteristic of an accretionary complex are extensively observed throughout.

### *North of Kochi (Kurosegawa Belt)*

The Kurosegawa terrane is an exotic sequence among other terranes in Japan, and is considered to be a Gondwana-derived fragment. It consists of fault-bound blocks of diverse lithologies and ages—from Ordovician (crystalline basement), to Siluro-Devonian (volcanoclastic sequence), and late Palaeozoic to early Mesozoic (accretionary complex)—observed in various outcrops (Hada et al., 2001).

### *Central Shikoku (Sambagawa Belt)*

This belt includes national and prefectural parks characterized by deep natural forest, rugged peaks (up to nearly 2,000 m) and steep valleys. An area of ~20 × 45 km provides excellent geology and superb outcrops of world type high-pressure metamorphic rocks with clear nappe structures.

### *Yanai City and Miya-jima Island*

The area surrounding Yanai city, ~30 km southwest of Hiroshima, provides particularly good exposures of the low-P/high-T Ryoke Metamorphic Belt. Hornfels, schist and gneisses, derived from a Jurassic clastic sedimentary sequence, occur extensively.

Miya-jima, ~10 km southwest of Hiroshima on the coast of the Seto-naikai Inland Sea, is one of 10 (as at end 2000) UNESCO World Heritage Sites in Japan. It offers a unique combination of natural and cultural heritage, with a focus on the Itsukushima Shrine, established in the 7th century. The island's forests have remained sacred and inviolable ever since.

### *Hiroshima*

At 08:15 on 6 August 1945, the first atomic bomb to be used in warfare was dropped by the USA on Hiroshima, a prosperous shipbuilding port on the delta of the Ota River in southwestern Honshu: 75,000 persons perished and the city was virtually obliterated. The detonation of a critical mass of Uranium 235 set off an atomic-fission chain reaction, releasing energy to cataclysmic effect.

### *Nagasaki*

On 9 August 1945, the second bomb dropped by the

USA on Japan almost completely destroyed Nagasaki, another port, some 300 km southwest of Hiroshima: 40,000 persons perished.

Hiroshima and Nagasaki changed the world as never before and never since. Humankind had domesticated the atom, they had in their hands a force capable of destroying all of life on Earth.

## On Fundamental Interdependence

The continuing selection and maintenance of the *Gondwana Alive* Corridors will require an integrated and holistic approach. Here we highlight three different expressions of the concept of fundamental interdependence that can serve as cornerstones for action along the corridors. No doubt all three thinkers would endorse the Corridor concept.

### *Holism: Jan Christian Smuts*

*'Things, ideas, plants, animals, persons: all these, like physical forces, have their fields, and but for their fields they would be unintelligible, and their activities would be impossible, and their relations barren and sterile.'* —Smuts (1925)

Holism, which undoubtedly will form a foundation of the new emergent paradigm of consciousness, is based on three factors manifesting in six genera of phenomena.

A definable entity, as the focus of observation, can be appreciated as a 'whole'. In the Aristotelian sense the properties and characteristics of the whole can be defined and appreciated, and its relationships to other entities can be identified. Such an entity can be: physical, as in a rock; generic, as in 'rock' generally; a general phenomenological description of behaviours, such as war, marketing, compassion; and metaphysical, such as mathematics, physics, aesthetics, spirituality.

However, the concept 'wholeness', as opposed to the concept of the whole, is both the physical reality and the conceptual understanding and appreciation of such an entity in its entire field of relationships. Such fields include: natural ecosystems with their observed interdependencies; human societal systems with their meaning-making functions; consciousness as a summation of all phenomena of existence.

Jan Smuts's concept of 'Holism' is the natural in-built drive of all entities and phenomena towards 'wholeness'. This, he declared, was the driving factor of evolution. From this factor, through the evolutionary process, emerged the following categories of wholeness: matter; life; mind; personality; suprapersonal systems such as states; and, ultimately, absolute values, both free and set free from subjective human experience.

The philosophy of 'Holism' thus provides us humans with the new conceptual tools to develop and implement a radically revised and sustainable system of ethics. This applies particularly to our relationship, including all our human behaviours, with our conditions of existence, including not only all the phenomena of Mother Nature, but also the natural laws dynamically governing and sustaining existence itself. 'Holism' takes human consciousness to a new horizon of responsibility and meaningfulness.

### *Gaia and Earth System Science: James Lovelock*

*'There is no longer any need to consider the evolution of the species separately from the evolution of their environment. The two processes are tightly coupled as a single indivisible process.'* —Lovelock (1991)

About 30 years ago, James Lovelock and Lynn Margulis formulated the Gaia hypothesis which suggests that life (the organic world) has a great influence on the evolution of (the inorganic) Earth, and that the biosphere serves as an active control system, providing homeostatic feedback loops in the stabilization of the global 'fluid envelope'. This idea shifted Earth sciences further towards integrating its disciplines, something that had started a few years earlier in response to the new Plate Tectonic paradigm. Lovelock later introduced the term 'geophysiology' as a transdisciplinary environment for studying planetary-scale problems from which a wide range of newly discovered properties would emerge. For practical purposes he advanced to consider Earth as if it were a living system (Lovelock, 1979).

Lovelock's Gaia theory rejects the apartheid of biology and geology. Instead it focuses on the evolution of an integrated biological and geological environment. Self regulation of important properties such as climate and the chemical make up of the atmosphere and oceans is a result of this evolutionary process. Lovelock views the world as a superorganism, and by tampering with one of its components, the others are sure to react. This view has led to a new way of thinking about Earth processes and evolution, and has heralded the new age of Earth Systems Science, a multidisciplinary exploration of how the Earth works. For the first time in the history of biological and geological sciences there exists now the foundation of a new approach that could help stem the Sixth Extinction.

The Gaia hypothesis holds that Earth's physical and biological process are linked to form a complex, self-regulating system, and that life has affected this system over time. Life, in other words, is an active participant in shaping the physical and chemical environment on which it depends. Recent measurements of increase in

anthropogenic $CO_2$ in Earth's atmosphere and the projected climate changes resulting from this, are consistent with this holistic Gaian view of Planet Earth.

### *Consilience (the unity of knowledge): Edward Wilson*

*'... the Ionian Enchantment ... means a belief in the unity of the sciences—a conviction, far deeper than a mere working proposition, that the world is orderly and can be explained by a small number of natural laws. Its roots go back to Thales of Miletus, in Ionia, in the sixth century B.C. ... The Enchantment, growing steadily more sophisticated, has dominated scientific thought ever since ... Its central tenet, as Einstein knew, is the unification of knowledge. When we have unified enough certain knowledge, we will understand who we are and why we are here.'* —Wilson (1998)

In his book *Consilience*, Wilson explores, with extraordinary cohesion, the natural sciences (physics, chemistry, biology), the social sciences, the arts, ethics and religion, the human mind, human nature and human culture, and he finds that they are all seamlessly interwoven. They are indivisibly bonded by a 'small number of natural laws'. They are one. Wilson's explorations are those not of a philosopher or a spiritual visionary but of a scientist, perhaps the greatest biological scientist of the 20th century.

Wilson brings sharp focus, for instance, to the causal webwork running from quantum physics to evolutionary biology to the science of the brain. He traces our gene-culture co-evolution within the overall context of 'consilience'. Our genes, our brain, our culture are each subject to measurement and mathematical analysis. Inevitably there are gaps in our knowledge, but we draw ever nearer to a *Unity of knowledge*, to *Consilience*.

*'We are drowning in information, while starving for wisdom,'* says Wilson.

The Corridors, we submit, offer a certain opportunity for the optimal application of information and wisdom.

## Women of Gondwana

Gondwana Research, like national and global affairs, has until now largely been the province of men—territorial men in their own divided fields. Now it is time that our whole global society in close embrace travels the road of Holism-Gaia-Consilience together. In the following pages, opening with the voice of women, we hope to offer a sense of this reality as can apply to driving the Corridors forward.

### *All Africa Women Geoscientists (AAWG)*

'In that men have ruled the world to date, it is they who have caused the Sixth Extinction—the escalating decimation of wilderness and biodiversity. Now, in the new millennium, as we steadily redress the gender imbalance—from politics to geology—women can play a leading role in stemming the extinction of the richness of life. Where men are instinctive fighters and hunters, women are nurturers and gatherers. So, as the influence of women grows in all human endeavour, they will inevitably become guardians of our planet. Women geoscientists in particular, in a spectrum of fields—geothermal energy, soils and agriculture, groundwater, palynology and climate change, geology and biodiversity (geochemistry), geological resources and poverty alleviation, geomedicine, geosites and geoheritage—can help guide us to sustainable development.

We, the women Earth scientists of Africa, commit to helping shift humanity from a malignant to a benign relationship with Mother Earth.' Cape Town, 21 October 2002 (signed by the 15 AAWG representatives included in figure 17).

### *All Africa Women for Peace (AAWP)*

'Africa is the womb of humankind. Every new step of our evolution through seven million years of hominid history has occurred in Africa; and from here we colonized the world. Africa is the only continent still harbouring a wide spectrum of primary ecosystems with an intact diversity of larger mammals. These have been decimated elsewhere in the escalating grip of the Sixth Extinction. Africa boasts the world's geodiversity hotspot and the largest, best preserved stretch of the Earth's oldest known crust including the earliest preserved signs of life (fossil bacteria aged 3.47 billion years). Africa was and is at the heart of Gondwana.

And yet the people of Africa are everywhere at war with one another, country against country, ethnic group against ethnic group, man against woman and against children, those in power against the rest; and, in consequence, they are everywhere at war against the very nature that spawned them and that is a part of their soul. We suffer poverty and famine and disease and illiteracy more overwhelming than anywhere else around the planet.

We, the women of Africa can no longer stand by and live with this wretched irony of being potential custodians of the world's supreme natural heritage, yet being in the deepest grip of human insolvency. We feel in close harmony with the Gondwana scientists in striving with every sinew, now, for a new balance with the prodigious glory of nature and for simultaneous peace, prosperity, dignity and well-being for our whole global human family. We are one!' Pretoria, 27 November 2002 (signed by the 17 AAWP representatives included in figure 17).

## Ecotourism and Education

Through ecotourism and education, to conservation and a reverence for our fragile planet, to peace and prosperity for all: this in essence is the process and the goal of the *GA* Corridors. In the following six short contributions, the sense of partnership in this endeavour is forged. *Nkomazi*, *Londolozi*, *Ezemvelo* and *Maretlwane* are privately owned wilderness (or game park) nodes along the Cradle of Life to Cradle of Humanity Corridor (Fig. 5). *Bergplaas* and *Khoinania* are similar nodes along the Great Karoo and Cape Corridors respectively (Fig. 1). These may be seen as the forerunners of continuous strings of such pearls.

*The Nkomazi Cradle of Life Museum™*

'Nkomazi sets about to tell the most exiting story ever told, a story of unimaginable time scale that reveals the birth and evolution of our planet, and life itself. It leads one on a remarkable journey of discovery from one wonder to the next, from the past to the present across billions of years of time to the recent (200 year) abuse of nature and finally to the current "Healing of the Earth" at Nkomazi. This is a fitting place to start the *Gondwana Alive* Corridors, since the concept was born to stem the Sixth Extinction, and Nkomazi is a textbook example.

There exists an opportunity to extend this journey over a unique corridor that runs through to the Cradle of Humankind in Sterkfontein. Such a corridor will track the Earth's history from a time when the forces of nature and the earliest forms of life created the conditions to form the Cradle of Life. These conditions paved the way for humans who literally appeared in the last seconds of geological time. This corridor incorporates an unparalleled sequence of geological formations from an area with a higher plant diversity than the famous Kruger National Park, tracking the golden thread of time from the 3.5 billion year goldfields of Barberton through the Bushveld Igneous Complex to the goldfields of Johannesburg, a journey from Cradle to Cradle, from Wilderness to Metropolis, symbolising the journey of life from single cell to modern man. This insight can teach us to live more wisely upon our planet's surface.' Fred Daniel, The Cradle of Life Museum™, Badplaas, 31 October 2002.

*Londolozi conservation development model*

'The Londolozi model was conceived in the early 1970s in an attempt to mitigate the government's disastrous political strategies. Land under wildlife was being expropriated to further the now failed homeland policy and biodiversity was in danger of being destroyed.

Alternatives were needed and through trial and error over several years it became apparent that by twinning hospitality and wildlife interpretation in a coherent manner, one could cause discerning travellers from around the world to visit a remote corner of South Africa—drawn by the magnet of Africa's wildlife. In so doing the visiting international traveller on 'safari' became the economic catalyst for the regional economy creating a variety of opportunities: jobs and careers for disadvantaged

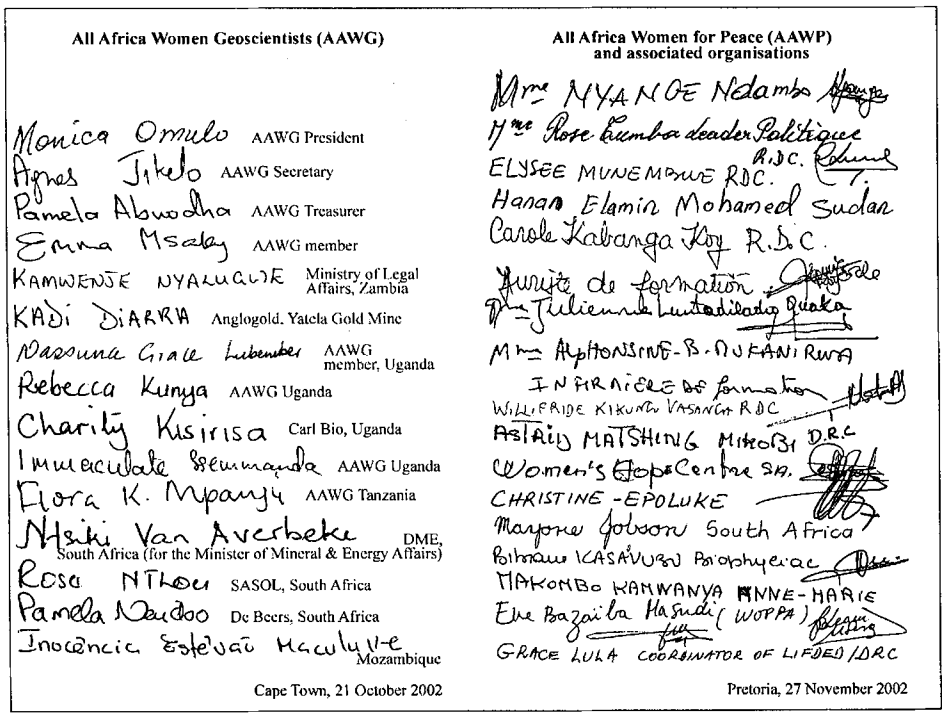


Fig. 17. Women of Africa: calling for a new era of commitment by all of humanity for all of humanity and for Mother Earth. The AAWG and AAWP declarations (see text) were signed in Cape Town (21 October 2002) and Pretoria (27 November 2002) as indicated.

communities living in abject poverty adjacent to the wildlife reserves; money which could be used for the restoration of land previously damaged by inappropriate farming activities; and foreign revenue for the country. This model would become a world leader in sustainable integrated ecotourism.

In 1990, Nelson Mandela endorsed the Londolozi model as a blueprint for future conservation development in South Africa. Ten years later, the South Africans, in partnership with their neighbours, led the world in the creation of vast transfrontier peace parks, restoring biodiversity and creating regional economic opportunity driven by the fundamentals of the original Londolozi model and others originated beyond South Africa.' Dave Varty, Founder Londolozi, Sandton, 5 December 2002.

*The Ezemvelo/Telperion Nature Reserve*

'The Ezemvelo Reserve, covering ~10,000 ha, belongs to the Oppenheimer family and is managed in a way that ensures that this unique area is maintained in pristine state for future generations to enjoy the beauty and splendour of varying habitats. The reserve, varying from undulating grasslands to rocky cliffs, is situated on the Bankenveld ecotone, the transition between the grassland and savanna biomes. Elements of each of these biomes are contained within the reserve, causing a rich biological diversity. The savanna area is more rocky and mountainous with the Wilge River sandstones forming beautiful rock formations. Game is both abundant and diverse, and over 200 species of birds have been identified. Visits by blue crane and crowned crane, Stanley's bustard, grey hornbill, black, martial and fish eagle are frequent. The rock art site at Ezemvelo has paintings from the Late White Era, as well as traces of the Bushman Era. The reserve maintains a special place in the heart of Strilli Oppenheimer who sees it as the ultimate paradise. Her efforts in maintaining it in as close to a natural state as possible are tireless. Management is from a holistic perspective and special attention is given to the usually overlooked creatures and plants that inhabit this unique and very special area. Ezemvelo will form an ideal node within the Cradle to Cradle Corridor.' Duncan MacFadyen, E. Oppenheimer and Son (PTY) LTD, Johannesburg, 10 December 2002.

*Maretlwane (Magaliesberg)*

'Towards the western end of the future Cradle to Cradle Corridor lies a small piece of mother earth, Maretlwane, in the Magaliesberg Mountains of South Africa. This has been donated to Pretoria Boys' High School by my wife and myself, as the present Chairman of the *Gondwana Alive* Society, for the development of a bushveld environmental school. It will seek to benefit from and identify all those aspects of biodiversity which are peculiar to the biosphere and the community to which it belongs. Only 20 km from the Cradle of Humankind at Sterkfontein, this node of learning will enrich the lives of all its pupils, black and white, by introducing into their lives an uninterrupted two-month contact with nature with all that mother earth and the mountains can teach them. For the first time in their education the emphasis will shift from academic, technological and sport achievement to listening and observing the message the Creator offers to the soul of each one of us: through silent meditation and contemplation to rediscover our true purpose in life as well as the serenity we so badly need in order to cope with the stress of modern times. Is it not more than coincidence that we humans have had bestowed upon us the gift of two ears, two eyes but only one mouth? Mountains, streams, plants, animals, the stars above us, do not pontificate yet they speak loudly if we only let them do so. Would that our educational leaders and our politicians understood this fact of life! *Soli deo Gloria.*' Adv. Francois Junod S.C., Founder Maretlwane, Pretoria, 6 December 2002.

*Bergplaas and the Nature College*

'Bergplaas, the highest inhabited farm in the district, lies imbedded in the high Karoo mountains. The eye can follow the dry open sweeps of landscapes, in between the hills and rugged mountains. It will encounter a dry semidesert soil, red koppies of the oddest shapes, shrubs and grasses of all sorts, and if the occasional rain hits the land, flowers in a great variety of colours will emerge miraculously.

I fell in love with this beautiful and powerful spot on Earth, where the winds howl, storms rage and the sun burns. Where eagles fly and at night the stones sing. I wanted to give it back to itself. Save it for the Earth. For that purpose I had to bring back the animals that belonged here and let the land restore itself from the grazing of cows and sheep. I bring people here to offer them healing within, in the context of the land and the animals. During courses and retreats the purity of the land itself brings new insights and peace. It is this mutuality in the relationship between man and the other life forms that is so important to me, as it indicates that we are participants in nature.

I founded the Nature College, to make people aware of the interconnectedness of life and to re-evaluate the role of man in nature. And where can we feel the interconnectedness better than here, linked up to the vast, dry, and astonishingly beautiful greater Karoo land.' Irene van Lippe-Biesterfeld, Princess of the Netherlands, Bergplaas, Central Karoo, 7 December 2002.

*Khoinania (Centre for Earth Restoration)*

'Situated in the heart of the Garden Route, on the western boundary of the Tsitsikamma National Park, Khoinania provides an ideal open air classroom for various environmental education programmes.

With comfortable accommodation for approximately 24 people, the centre is open during the "green season", May to November, to be used as a venue for such work. Over the years the team at Khoinania, under the auspices of the Garden Route Trust, have conducted experiential life skills and leadership training programmes for local youths, teachers and community leaders with the central objective of raising awareness about the vital importance of natural sustainability. We warmly welcome other organisations with similar aims and ethos to use the venue for workshops, seminars or retreats.

From December to April, Khoinania runs as a guest lodge, hosting visitors from all over the world who are drawn by the tranquillity of the place and the exquisite scenic beauty and fascinating biodiversity of this coastal area. Guided hikes through the indigenous forests, across hills of pristine *fynbos* and along this unusual coastline form an intrinsic part of our visitors' experience here.

We are honoured that Khoinania is to be a node within the *Gondwana Alive* biodiversity corridor network and fully support this admirable initiative.' Jenny Lawrence, Founder of the Garden Route Trust, Knysna, 27 November 2002.

## An Interactive *GA* Library

Geographic Information Systems (GIS), invented in Canada some 40 years ago, has now grown into a new science of storing and querying information about specific observations, measurements and analyses. These data are also directly linked to their precise origins, in the form of geographic locations. This is the foundation of the new global library of science. If we are to stem the Sixth Extinction in earnest, there can be no doubt that we must have access to reliable spatial and temporal information that can be updated in real time. GIS provides this opportunity, and all *GA* Corridor data should be tied together into a *GA* Corridor-GIS Network. Here we outline briefly how this has already begun for one of the corridors, and we hope that this will stimulate other corridor enthusiasts to follow suit.

### *GIS and the Cradle to Cradle Corridor (Fig. 5)*

Biodiversity is highly dependent on the quality, quantity and spatial cohesion of natural areas (van der Sluis and Chardon, 2001). Due to increasing demands on the natural environment, our natural landscape has become increasingly fragmented and this is detrimental to biodiversity.

To restore ecological cohesion, there has been a move in some parts of the world towards managing the environment as networks. This has proved successful in several European countries at local, regional and multinational levels. It is, however, not necessary to start from scratch, as many conservation areas already exist. The challenge is to link them through a series of corridors. The *GA* Corridors follow this concept of networks and aim to combat landscape fragmentation and loss of biodiversity. This development is, however, a complex issue owing to the necessity of understanding how the physical, ecological, social and economic systems (processes) involved, work. As all aspects of the environment are spatially fixed on, above, or below the surface of the earth, it is vital to study them in the context of their spatial properties. For any major project it is appropriate to model a prototype: in this case the Cradle to Cradle Corridor (CCC), with the core theme of 'celebrating 3.5 billion years of life on Earth'.

*Holism and areas of expertise*

The concept is a network of geologically, ecologically and culturally significant segments of landscape forming a distinctive whole, efficiently distributed on the basis of functional and spatial criteria, covering biotic, hydrological, soil and relief conditions (Mackovcin, 2000). The criteria for the selection of elements that form the corridors range far and wide, thus necessitating the input from numerous areas of expertise in order to follow a holistic bias.

*Selection criteria*

For the CCC protoproject to succeed, it must be as inclusive as possible. Yet, it is important not to lose track of the purpose of conservation and ecological networks in general, or of the core theme. To this goal, it is proposed that three types of sites be included and that separate selection criteria be developed for each. These include: core areas, secondary areas and supporting buffer areas.

Because of the theme of the CCC, the focus is on geological core areas specifically, and biodiversity, ecological and cultural core areas generally. The core focus areas alone, however, would not necessarily guarantee commercial success for the project. Therefore, secondary commercially viable areas should also be included. Supporting buffer areas, as for Biosphere Reserve buffers, will be identified.

In plotting the protoproject these criteria were applied (very broadly) to form a conceptual model—see graphical representation. The final corridor, however, may well appear fairly different.

*Processing*

Initially the primary source of data was the ENPAT (Environmental Potential Atlas), cadastral Landsat datasets of South Africa and a digital elevation model supplied by the Peace Parks Foundation. For the real project, more specific data may be captured and integrated as required. The data parallel the features mentioned within the criteria; the analysis models the relationships involved. Further research is necessary to refine the selection criteria and analysis.

*Maintenance and management*

Development of the project will be done with a number of secondary goals in mind. One of these is to provide systems that can be used afterwards for maintenance and management of different subprojects of the CCC at grassroots level. It is envisaged that the project will become an example of sustainable development in practice.

*Business opportunities and sustainability*

*'The integration of GIS, wireless technologies and the Internet is transforming how we experience and document exploration.'* (Fay, 2001).

Both the *Gondwana Alive* Project and its constituent subprojects need to be sustainable, indeed revenue-generating. This implies robust ground-level projects that feed the Project, in turn marketing the Corridors with their subprojects. Both local communities and external investors will need to be involved.

At this stage it is probable that the majority of revenue and projects will stem from tourism. Real tourism within the corridor could be augmented by a web-based (or similar technological development) armchair mapping application that allows the virtual tourist to plan a customised route along the various attractions of the corridor online. This can be a powerful marketing tool reaching across the globe. An irresistible and unmatched trek through geological time would start in the Barberton Mountains (Cradle of Life), pass through the ancient granites of the Kruger National Park and Londolozi, cross the escarpment formed by the Transvaal Supergroup including Blyde River valley into the Bushveld Igneous Complex, then pass the red Waterberg sandstones surrounding Loskopdam, pass the Cullinan Diamond Mine and Tswaing Crater to finally reach Sterkfontein (The Cradle of Humanity).

## Financing the Corridors

This is going to cost very big money. If we get it right, however, it will generate considerably bigger money and it will spread that money far and wide. Here are some ideas. We will need the input of everyone in all walks of life.

We hope to encourage the most resonant participation through a newly framed *Gondwana Alive* website. And we expect to elaborate on many aspects of the Corridors concept in our two forthcoming multi-authored *Gondwana Alive* books—*100 strategies* and *Biodiversity patterns* (Anderson, 2003, in prep. a, b)—planned for publication in 2003 and 2004.

### *Adopt a corridor*

(a) Billionaires, top corporations and foundations from Northern Hemisphere countries are approached to adopt particular corridors. Their name or names would be directly linked to all products, merchandise and advertising associated with that corridor.

(b) $10–100 million paid into a trust or foundation by the adoptee(s). The interest would be used for research, education and sustainable development projects in the corridor, with a direct outcomes-based focus on stemming the Sixth Extinction.

(c) 25% of the annual interest paid to a *Gondwana Alive*/PAST consortium to co-ordinate and fund fast-track scientific projects within the corridor.

(d) 25% paid to UNESCO (regional clusters or national commissions) to co-ordinate and fund cultural projects and activities.

(e) 25% paid to the Mandela Children's Fund to co-ordinate and fund education, health, sport and cultural activities for children and youth.

(f) 25% paid to The Natural Step to co-ordinate and fund sustainable business projects.

### *Adopt a school*

(a) Millionaires and smaller corporations particularly from Northern Hemisphere countries are approached to adopt specific schools within corridors. *Maretlwane* in the Magaliesberg would be an ideal pilot study.

(b) $100,000–$1 million paid into a trust or foundation by the adoptee(s).

(c) The interest to be used for eco-literate capacity building.

(d) The education faculties of the nearest universities would administer the interest and co-ordinate projects.

### *Sustainable business opportunities*

The opportunities here are limitless and might include: eco-cultural tourism; eco-crafts; small business enterprises; subscriptions/memberships; *GA* booklets, videos, tapes, GIS maps on each corridor; *GA* gigs, dance, theatre, art and architecture.

A proportion of the profits are fed straight back into the sustainable development projects within the corridor—

again with the specific focus on holistic management and stemming the Sixth Extinction.

### *Wealth of Nations to Wealth of Nature*

(a) The entire fund-raising mechanism is designed to redress the balance of wealth between the Northern and Southern countries. At present, perhaps 80–90% of all monetary and industrial wealth resides in the North, while 80–90% of all natural wealth—biodiversity and intact 'old' ecosystems (nondomesticated)—is preserved in the South.

(b) Massive torrents of money, investment and capacity could flow from North to South, to the great and lasting benefit of all, within the decade. Fast-track is the operative word.

(c) The best principles, already formulated by *'The Natural Step'*, UNESCO Biosphere Reserves and the science of environmental/resource economics, for instance, will permeate throughout.

### *Appropriate business and other partners in the GA Corridors venture.*

Here follows a selection of organisations with whom formalized partnerships have already been forged. Each is especially relevant in bringing the Corridor concept to effective reality.

*The Expanded OUZIT[1] Project*

'This is an integrated tourism development strategy aimed at establishing a comprehensive tourism and resource development zone in SADC[2]. It is expected to link 22 proposed SADC Transfrontier Conservation Areas (TFCAs) with Coastal Resort Hubs and other tourism products with a view to positioning the SADC Region as a premier ecotourism destination in the world. The project was officially adopted by SADC Ministers of Tourism as a Regional Project on 12 April 2001 and was formally launched at the World Summit on Sustainable Development in September 2002 by Sir Anerood Jugnauth, Prime Minister of Mauritius. Strategic partners of the Expanded OUZIT Project include: The Peace Parks Foundation, SADC, NEPAD[3], RETOSA[4], and the Development Bank of Southern Africa. The Expanded OUZIT Project endorses the *Gondwana Alive* Corridors initiative and will continue to engage in formal co-operation.' Ken Small, 28 October 2002.

[1]OUZIT—Okavango Upper Zambezi International Tourism. [2]SADC—Southern African Development Community; member states include all the countries of the southern half of Africa from the Democratic Republic of the Congo (DRC) to South Africa, as well as the Indian Ocean states of Seychelles and Mauritius. [3]NEPAD—New Partnership for Africa's Development. [4]RETOSA—Regional Tourism Organisation of Southern Africa.

*Peace Parks Foundation*

'The vision of the Peace Parks Foundation (PPF) is to develop a network of Transfrontier Conservation Areas (TFCAs) by unifying fragmented ecological habitats across international boundaries and promoting environmental and political stability in Africa. This vision converges with the purpose of the *Gondwana Alive* Corridors.' Craig Beech, 31 October 2002.

*University of Pretoria (Centre for Geoinformatics)*

This research and teaching centre is broadly active in the field of GIS, including the design and planning of ecological networks.

*Geospace International (GSI)*

GSI is an international company with headquarters in Australia, who acknowledge a responsibility towards fostering a healthy global environment and the harmonic co-existence between man and nature. Their specialist focus lies in GIS, remote sensing, database management and ecological networks.

*The Enviropaedia*

The Enviropaedia publish a directory of environmental organizations (private and public) in South Africa. Their aim is to facilitate co-operative synergy towards mass public participation in environmental sustainability.

*EcoPort RSA*

This ecology Portal is an Internet site whose unique vision and capacity is to become a free public-good encyclopedia of life on Earth. It is 'a global ecology knowledge processor, specifically designed to manage information in a holistic integrated manner, where interrelationships, interactions, associations and dynamic change can be accommodated and disseminated'. Roger Ellis, 2 December 2002.

*UNESCO Nairobi Office*

A digitized geological atlas, emphasizing geosites and geoheritage, for the 52 nations of Africa is nearing completion. 'In preparing this atlas, UNESCO has committed itself to the concept of Gondwana and Earth Corridors, stressing the indisputable urgency for the interconnected management of the cultural, biological and geological diversity of the continent.' Thomas Schlüter, 21 October 2002.

*The Global Classroom (GCR)*

'This is a US nonprofit organization committed to wilderness preservation through community involvement and education. Among GCR's achievements is establishing the Aula Global Biological Reserve in Costa Rica. Aula

Global is home to hundreds of bird and mammal species who use the canopy as their elevated highway. ... In a world burdened by an expanding system of human highways, let's make room for wildlife pathways. Let's remember to share this earth with them.' Colin Garland and Susan Cutting, 31 October 2002.

Below are listed a further selection of organizations with whom partnerships would be particularly appropriate. Similar relationships around Gondwana should be sought.

(a) Hewlett-Packard (sponsors of *A walk through time*).

(b) The Swedish Academy of Sciences (linked to environmental economics, The Nobel Foundation and The Natural Step).

(c) DBSA (Development Bank of South Africa).

(d) GEDA (Gauteng Economic Development Association).

(e) PAST (Palaeo-anthropological Scientific Trust; based in Johannesburg).

(f) De Beers and Anglo American (with ventures throughout Africa).

(g) Nedbank, Pick-'n-Pay, Old Mutual (South African companies presenting a green image).

## Summary and Conclusions

*'Thanks to science and technology, access to factual knowledge of all kinds is rising exponentially while dropping in unit cost. It is destined to become global and democratic. Soon it will be available everywhere on television and computer screens. What then? The answer is clear: synthesis. We are drowning in information, while starving for wisdom. The world henceforth will be run by synthesizers, people able to put together the right information at the right time, think critically about it, and make important choices wisely.'* —Wilson, 1998.

The success of the *Gondwana Alive* Corridor Project in stemming the Sixth Extinction will depend in the first instance on its stewardship by the Gondwana geoscientific and evolutionary biology fraternity and on their dedicated participation in extending the network. And then, however enticing scientifically and as an ecotourist catalyst, it will attain its ultimate goal only if all of humanity becomes holistically involved. Through an expanding reticulum of corridors we can readily imagine the entire human population, from schoolchildren to the elderly, celebrating nature in all its extraordinary complexity. Only when this dream and the reality converge will we legitimately find pride in our unique humanness and in our inevitable role as custodians of the Earth's biosphere.

We find Scott Base to South Pole (SSC) to be a fitting corridor to round off this initial set of 14 (strictly Gondwanan) described prototypes. In order to re-align history in the coming decade, we are going to have to mobilise all the extremes of human willpower and enterprise as witnessed in Antarctica, but on a global scale. The southern icecap and southern pole are the microcosm, our planet the macrocosm. Antarctica is the one continent free of nationalism. Since 1959 and the signing of a multinational treaty, it has been dedicated to scientific exploration and the free exchange of information.

In including the Fuji-san to Hiroshima Corridor (FHC) as a 15th prototype, we acknowledge the links between Gondwana and Laurasia in the geological past, and the oneness of the world today. As we discover along this corridor, parts of Japan are Gondwanan and parts are Laurasian.

Celebrating biodiversity to stem the Sixth Extinction!

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