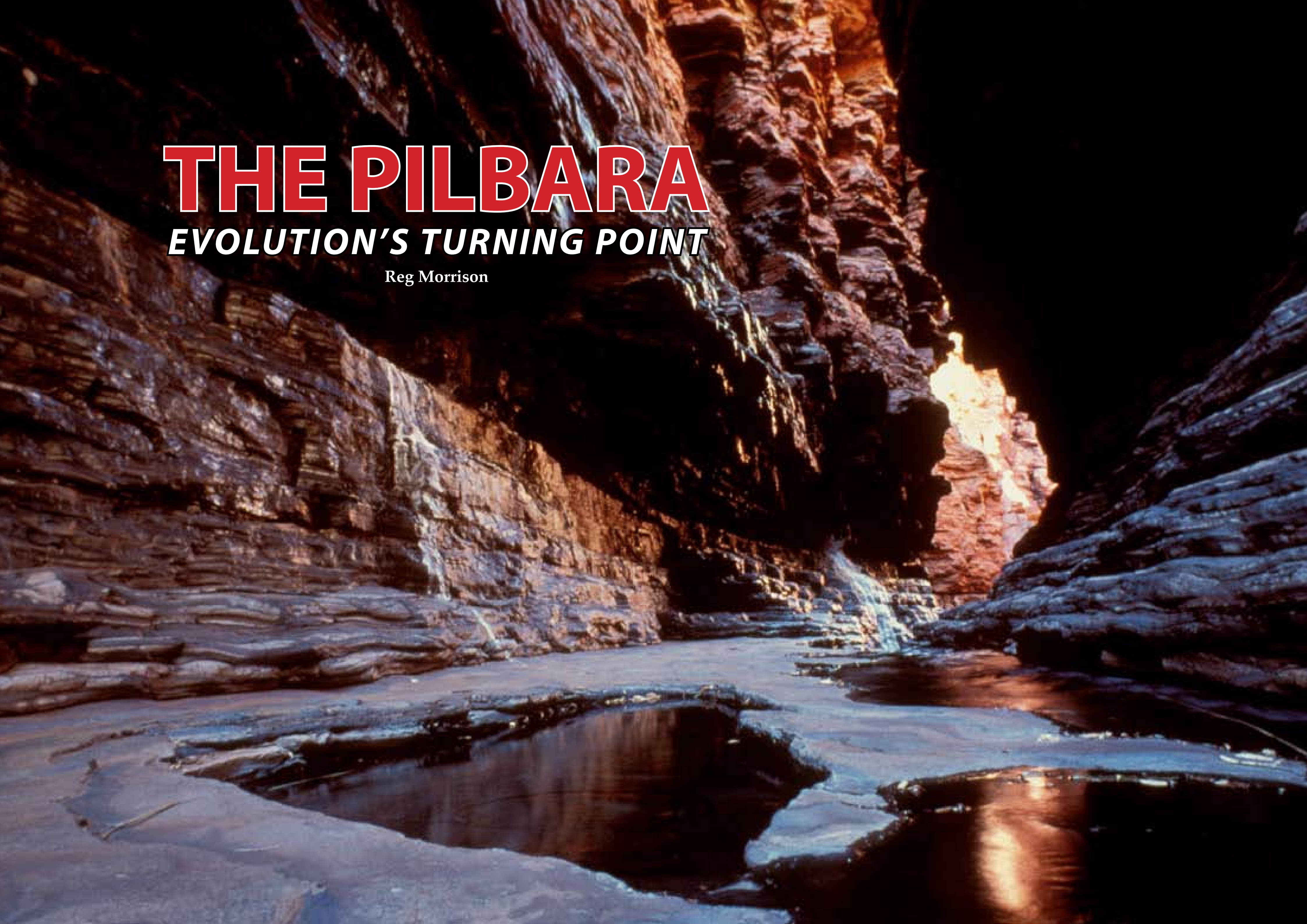
# THE PILBARA

## *EVOLUTION'S TURNING POINT*

**Reg Morrison**



Banded iron, Hamersley Ranges, Pilbara, WA.

# Evolution's turning point

The massive deposits of iron ore upon which Australia's economy so heavily depends hold vastly greater significance for us, and for our species, than mere money can begin to define.

Most humans now spend their lives in the shadow of steel-reinforced office towers, factories, apartment blocks and shopping malls, and use steel motor vehicles and rail systems to move about their sprawling conurbations. And in turn, these cultural baubles depend upon the integrity of vast electricity grids to link them together and enliven them.

Bedazzled as we are by our glittering technology it is easy to forget that we owe our existence to an iron-based catastrophe. If marine bacteria had not rusted the seas with their oxygen waste, and the sedimentary fallout had not formed the Hamersley Ranges, our species—like most of the others that we see about us—could not have evolved.

Casino, Hobart, TAS.

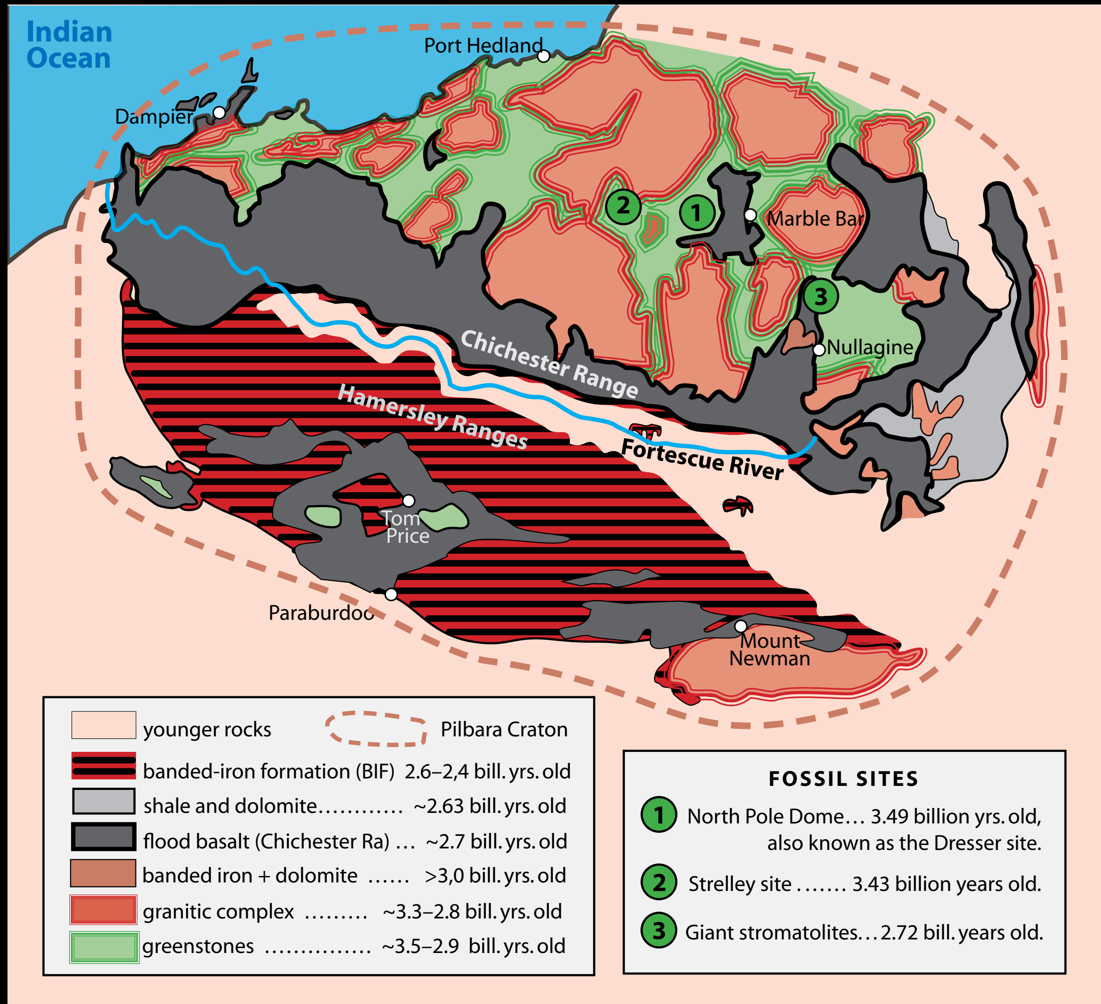
Sydney, NSW.

# Geology of the Pilbara

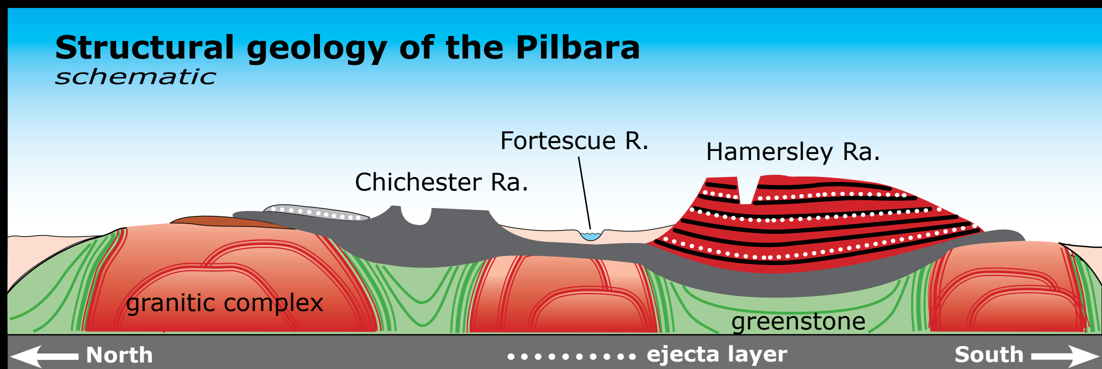
The Pilbara first appeared as a landmass more than 3.6 billion years ago with an accumulation of lighter mantle material that was nevertheless rich in magnesium and iron. Collectively known as greenstones these basement rocks were then repeatedly intruded by plumes of magma and remelted crust. These silica rich intrusions form the broad granitic plains that characterise the northern Pilbara. The region gradually became cratonised (coherent and permanent) about 2.9 billion years ago.

With Earth's interior molten and fractionating and its crust continually bombarded by comets and asteroids the young planet was meanwhile racked by volcanic activity. Many of the eruptions occurred below sea level where the molten lava would freeze on contact with the seawater to form globular structures known as lava pillows (see page 5).

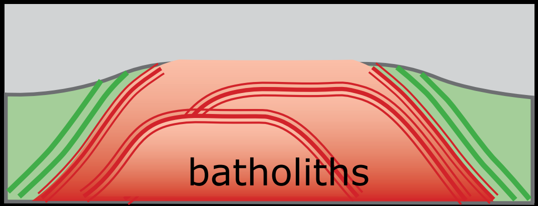
Finally, the region became blanketed by floods of free-flowing deep-source lava. The crumbling, iron-stained basalt that forms the rock-pile buttes and mesas of the Chichester Range is a remnant of this and would have been the source of much of the iron in the Hamersley Ranges.




Pyramid Hill, Chichester Range.



# Granites and greenstones

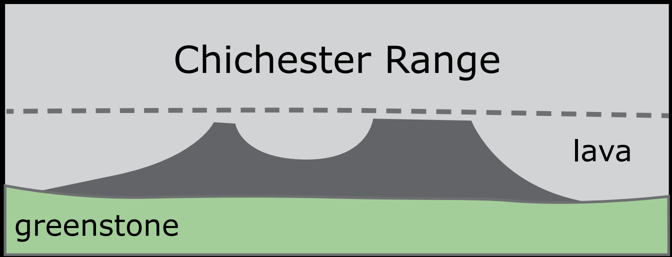



Recent Petroglyphs on granite, Gallery Hill, Abydos Station, Pilbara.

Ancient Petroglyphs on granite, Mt. Edgar Station, Pilbara.

The greenstones that form the foundations of the Pilbara craton are remnants of a primordial iron-rich crust that was intruded and reworked many times more than three billion years ago. The granitic complexes too, show signs of multiple intrusions between 3.3 and 2.8 billion years ago. Coarse-grained and siica-rich, the faces of the granite boulders nevertheless became a smooth and durable archive for the art of the continent's earliest human colonists. Although these engravings (petroglyphs) are not directly dateable with any degree of accuracy some of them are believed to be considerably more than 20,000 years old. At the most conservative estimate they represent the earliest examples of human art in the southern hemisphere and they may even be among the oldest traces of art in the world.

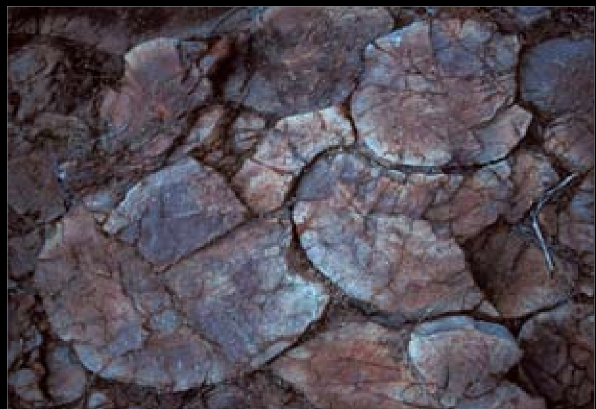
# Floods of lava




Flood basalt, Chichester Range.

Flood basalt at Python Pool, Chichester Range.

Remains of a lava flood, Chichester Range.



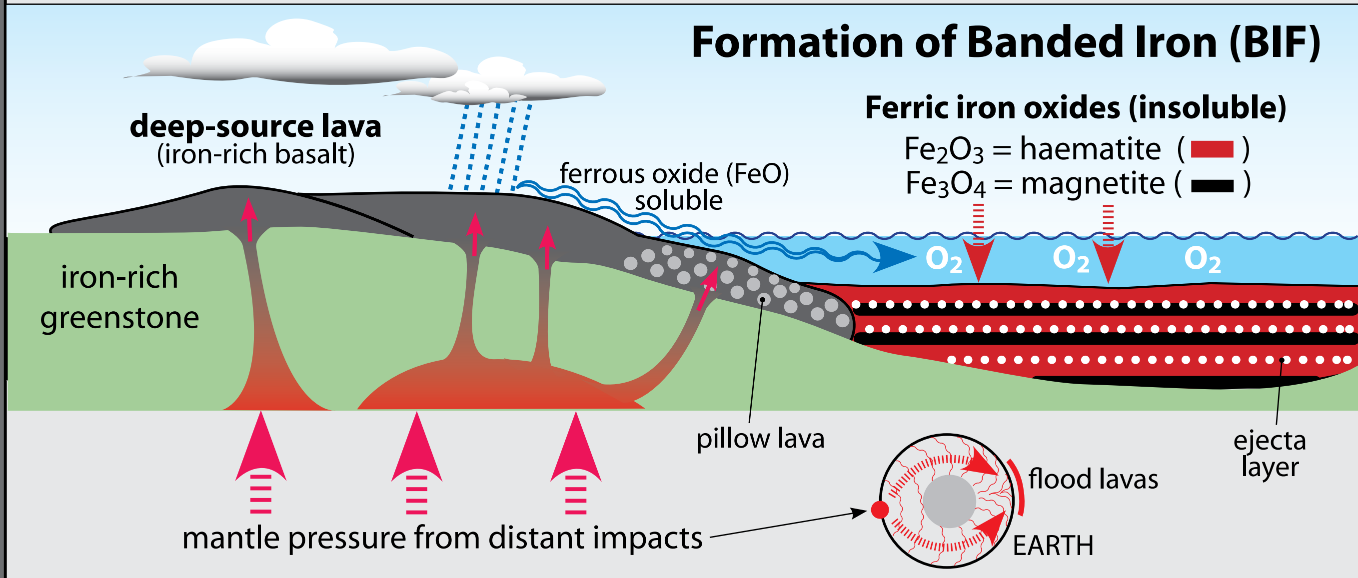
Submarine lava (lava pillows), Shaw River, Pilbara.

The flood of deep-source lava that blanketed much of the Pilbara about 2.7 billion years ago now forms the flat-topped buttes and mesas of the Chichester Range. This and other deep-source floods of iron-rich lava seem to have provided much of the banded iron in the Hamersley Ranges. There is also fragmentary evidence to suggest that such Archaean lava floods may, in some cases, have been forced to the surface by the impact of gigantic asteroids elsewhere on the planet.

# WHEN ASTEROIDS STRIKE …

The impact of a large asteroid on the Earth's crust is similar to the impact of a water droplet on the surface of a pool (*left*). In the case of asteroids, however, the impact explosion would have hurled vast quantities of vapourised rock and other fine material into the atmosphere in a dustcloud large enough to encircle the planet. Wherever this material settled it left its unmistakable 'fingerprint'—microspheres of re-crystallised rock vapour, grains of fractured quartz and a trace of the heavy metal, iridium. (Iridium is common in comets and asteroids but rare in the Earth's crust.)

Four layers of impact ejecta have now been identified in the Pilbara with dates that range from 3.47 to 2.48 billion years ago. These four layers, plus two others, also appear in South Africa's Traansvaal region. The broad spread of this ejecta linked to clear evidence of associated tsunamis with wave amplitudes up to 200 metres indicate that these traumatic events were global in scale. Such asteroids, 20–50 kilometres in diameter were of a mass that would have enabled them to penetrate the Earth's thin crust. The shock waves would have travelled through the Earth's molten interior and generated eruptions of mantle material where the waves converged on the far side of the planet. This is a pattern that has recurred several times in the past, most recently, when a small asteroid plunged into the Gulf of Mexico 65 million years ago unleashing floods of lava in India, which was on the opposite side of the planet at that time.



# The pivot on which our biosphere turns

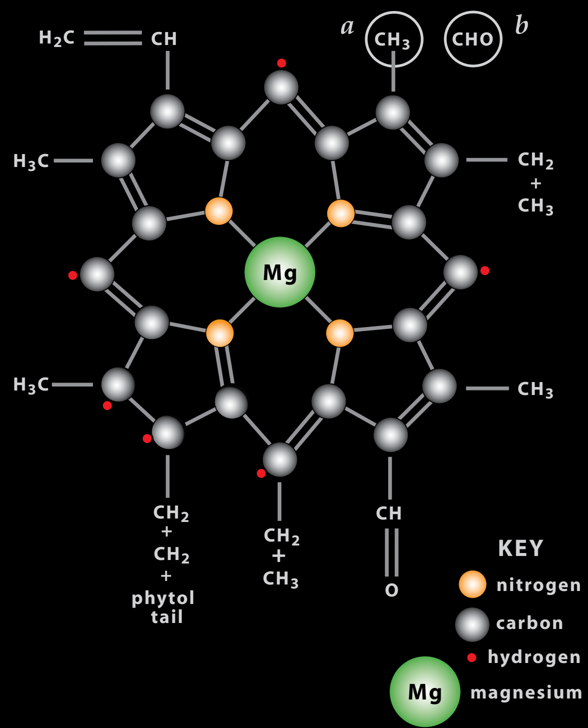
Whatever the origin of the iron embedded in the Hamersley Ranges, the primary agent of the biological revolution that followed its deposition was the molecule we know as chlorophyll. As a catalyst of photosynthesis bacterial cells equipped with chlorophyll were able to harvest hydrogen from their habitat much more easily than their competitors. Inevitably, these chlorophyll-mediated primary producers soon dominated the planet's biota and some even evolved the ability to harvest hydrogen from its most abundant source, water.

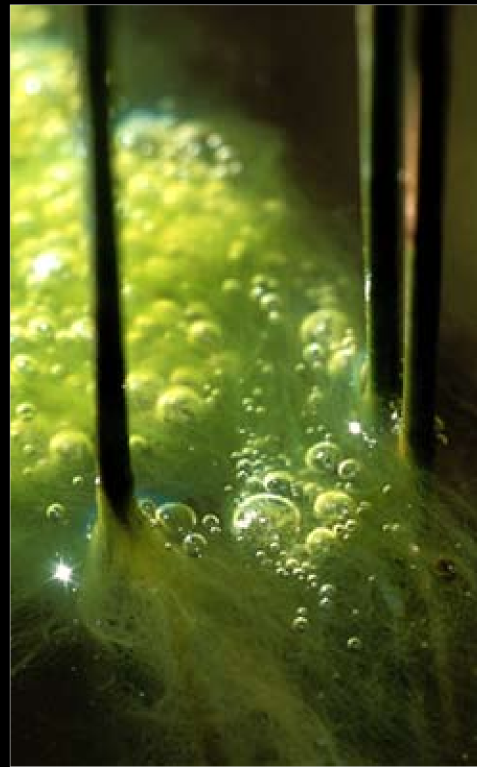
They achieved this feat via an improved catalyst, chlorophyll *a*, which, with its associated Photosystem II, yielded 18 times more energy than other metabolic processes. Inevitably, these cells thrived. But energy comes at a price. The more vigorous the metabolism, the more voluminous or dangerous the waste. By splitting water molecules and harvesting their hydrogen these new cells charged the biosphere with large quantities of oxygen. This dangerous pollutant would eventually collapse the biota, but it would also induce the bacterial tree of life to grow a third branch that could cope with it successfully. This was the eukarya.

Eukaryotes are composite cells founded on a symbiotic partnership between the two primary branches of primordial life, archaebacteria and eubacteria. Since each cell of our bodies is just such a bacterial composite, we too, are eukaryotic organisms—and a byproduct of the global pollution created by oxygen. Even more remarkable, we now depend on oxygen with every breath we take, thanks to chlorophyll's molecular twin: haemoglobin.

In this fashion chlorophyll supplies the pivot on which almost all of the surface biota now turns, and this is what drives and regulates the chaotic weather systems that envelop our oxygen-charged, water-blue planet.

## CHLOROPHYLL



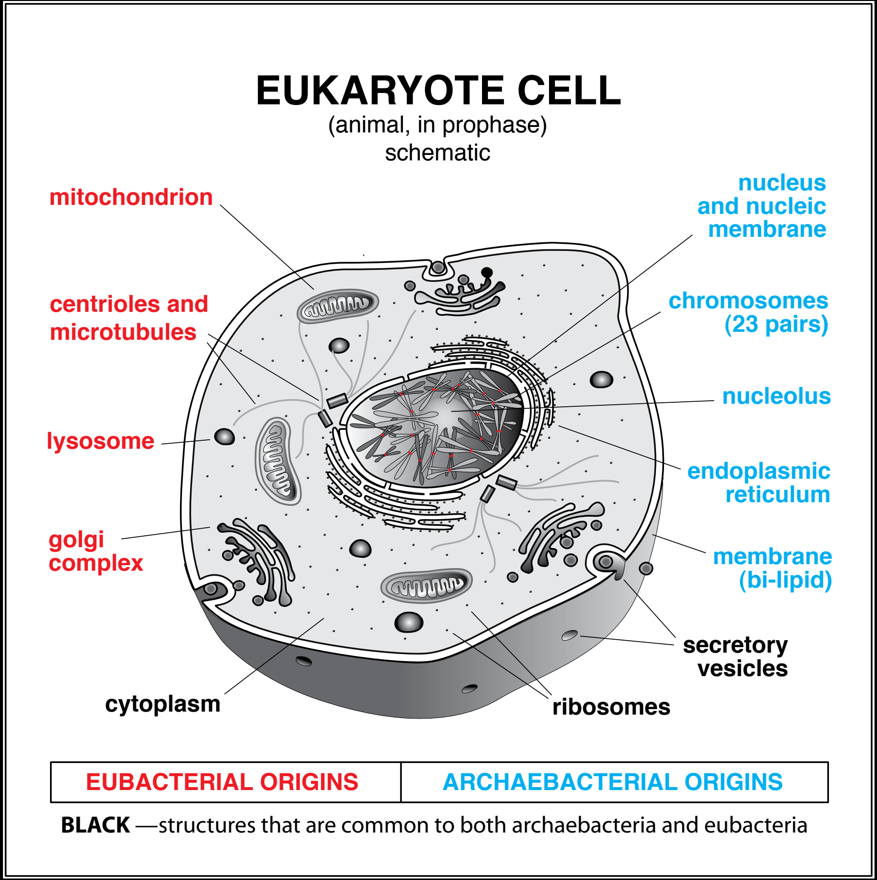



*This mat of cyanobacterial filaments completely covers a small freshwater spring at the edge of a beach south of Sydney. Such chlorophyll-loaded bacteria have, over time, charged the atmosphere with so much of their highly reactive waste gas, oxygen, that an oxygen-breathing animal kingdom evolved to tap this massive energy resource. The balance between $O_2$ discharged by plant photosynthesis and $CO_2$ discharged by animal respiration now helps to fine tune the temperature of the entire planet and continuously regulate both the biosphere and its biota.*

# The tree of life grows a third branch

Signs that chlorophyll was about to trigger an oxygen crisis first appeared when coastal seas regularly became stained a rusty red due to clouds of iron oxide. Half a billion years of photosynthesis by bacteria had saturated the waters with their oxygen waste, and the rust-red stains of ferric oxide were a warning that a pollution backlash had begun. It would last almost a billion years, tear the biota to shreds, and launch life in a wholly new direction.

The earliest evidence of this showed up during molecular analyses of seabed sediments laid down about 2.7 billion years ago in northern Australia. The sediments contained traces of cells with doubled outer walls. It suggests that these bacteria were upgrading their defences to keep oxygen out. This relatively minor structural adjustment represents a biological watershed of monumental significance in the drama of the evolutionary narrative, for these robust new cells were the forerunners of the double-walled eukaryotes that would give rise to all plants and animals and would lead eventually to the evolution of our own species.




During the next billion years these proto-eukaryotes would gradually acquire most of the internal structures that characterise their modern descendants (left). Many of these membrane-bound structures, known as organelles, are relics of bacteria that set up house inside their archaebacterial hosts and offered goods or services in return for nutrient and the added security from oxygen that their hosts doubled walls supplied.

Our cells' powerhouses, mitochondria, exemplify this. Driven by their own bacterial DNA these eubacterial relicts vacuum up any stray oxygen that enters the cell and build it into ATP (adenosine triphosphate), the universal energy molecule that fuels all eukaryote metabolism and enables our body cells to grow, repair and replicate themselves.

(For further reading see p.14)

## BANDED IRON

Around 3 billion years ago in a warm, shallow marine basin beside the embryonic landmasses that would eventually coalesce to form the Pilbara, seasonal blooms of photosynthetic bacteria began to charge the water with their life-threatening waste gas, oxygen. Soluble iron bonded with this oxygen and fell to the sea floor as insoluble rust. During the next billion years these iron oxides accumulated in layers to form what are known as banded iron formations (BIF). Most of the Hamersley iron deposits originated in this fashion.

# Earth's Mid-Life Crisis

***The Pilbara lay under northern stars when these giant stroma-tolites began to grow along its shorelines. The descendants of the bacteria that built them still build their high-rise cities in Shark Bay 800km to the south west …***

Stromatolites, Shark Bay, WA.

A giant tromatolite, Nullagine River, Pilbara.

Stromatolite domes, near Nullagine River, Pilbara.

These layered domes are massive deposits of limey waste left by mats of photosynthetic cyanobacteria that flourished along a Pilbara shoreline about 2.72 billion years ago. The overwhelming bacterial success implicit in these two-metre domes suggests that they also record the first appearance of bacterial chlorophyll. The oxygen discharged by the bacterial builders of these domes would have helped to rust the iron-rich seas and lay the foundations for the massive deposits of oxidised iron that now form the Hamersley Ranges. In a world that had been oxygen free until that time, this torrent of rust and the accumulation of free oxygen signalled the onset of a biological catastrophe. It was to be Earth's Mid-Life Crisis.

# Life’s point of no return

***Not only do the Hamersley Ranges commemorate the greatest biologically generated pollution event the world has ever known, they also signal the oxygenation of the biosphere and evolution’s point-of-no-return. Life could never begin again: oxygen would burn it up.***

Hamersley Ranges, Pilbara, WA.

This massive deposit of iron rust is the fallout from a rising tide of bacterial oxygen in a world that had been devoid of oxygen. It represented a biological catastrophe, for life itself was now under threat. By the time the last of the rust had settled and the seas had cleared, it is likely that up to 90% of the existing marine biota had succumbed to the oxygen pollution. It was a global-scale extinction event that had been wholly generated by life’s own overwhelming success. In this sense the Australia’s iron deposits have triple significance for us all: they are a memorial to life’s greatest crisis, they commemorate the evolutionary watershed that led indirectly to the evolution of our own species, and they embody an environmental warning that we ignore at our peril.

Hamersley Gorge, Hamersley Ranges, Pilbara, WA.

# The Price of Success

As one of the Earth's more reactive elements, oxygen threatened the survival of all pre-existing life forms. They had evolved no oxygen defences: their cell walls were thin and permeable and their free-floating DNA was exposed and vulnerable.

Only three options were open to them: take refuge where oxygen could not follow, significantly upgrade their individual defences, or join forces with other bacteria and pool the meagre resources that became jointly available to them via this symbiosis. Unfortunately, each of these strategies required the passage of considerable time to execute. Consequently, most species failed to escape extinction, and some estimates have set the loss as high as 90%. We will never know how accurate that figure is, but there is at least one tantalising clue to when it occurred. The evidence surfaces most clearly at the base of Hamersley Gorge where the Fortescue River winds it way out of the Hamersley Ranges on a thick bed of smooth grey dolomite.

Dolomite (calcium-magnesium carbonate) is an accumulation of biological debris from abundant life near the surface of the sea. Early life usually thrived in relatively shallow sunlit waters where photosynthetic bacteria could build their high-rise stromatolite cities and it usually shows signs of fragmentation by wave action, and often extreme fragmentation due to tsunamis. But the grey dolomite in Hamersley Gorge (*left*) is a smooth, semi-homogenous deposit that was laid down at great depth over a long period. This suggests that it may represent the prolonged fallout of bacterial debris from the upper layers of the water column—a collapse of primordial life triggered perhaps by rising levels of oxygen around 2.5 billion years ago. Significantly, a similar layer of smooth abyssal dolomite appears in African strata of the same age. It suggests that this widespread abyssal debris flags a marine extinction of global significance. It may yet prove to be the 'smoking gun' of the biological collapse that ended the dictatorship of primordial bacteria and turned evolution in our eukaryotic direction.

Abyssal dolomite, Hamersley Gorge, Hamersley Ranges.

# Creases in the Fabric of Time

As a source of economic wealth and a Mecca for international tourists, the Hamersley Ranges represent a crucial asset to the modern nation. Each year, tens of thousands of people wind their way through the breathtaking Hamersley gorges with camera shutters clicking, yet few are aware that they have journeyed to to the very heart of the evolutionary event that made their modern existence possible. If the Hamersley Ranges did not exist, neither would we.

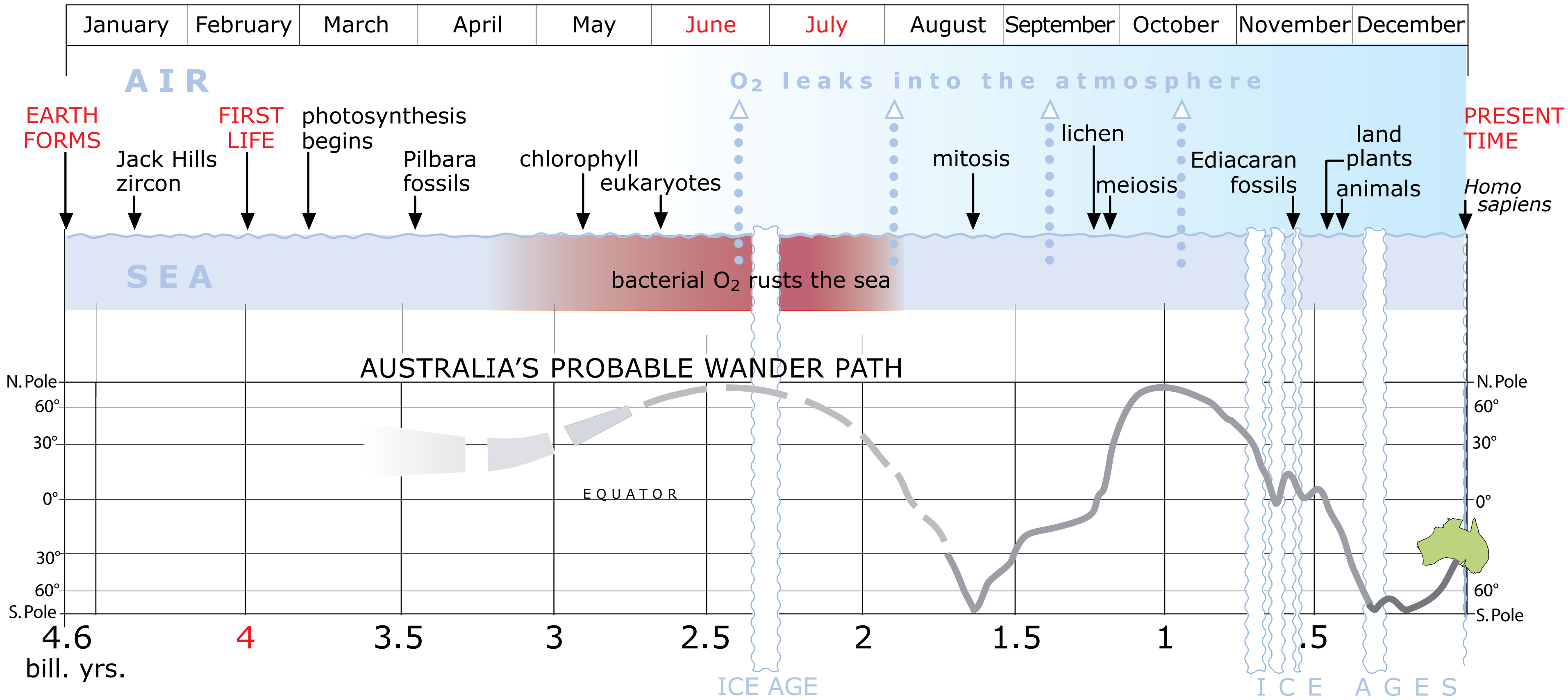
Waterfall, Hancock Gorge, Hamersley Ra.

Mount Frederick, Hamersley Ranges.

Weano Gorge, Hamersley Ranges.

# TIME SCALES

The span of time occupied by Australia's geological and biological record is incomprehensibly vast, so the 4.6 billion-year life of the planet has here been matched against a one-year calendar and divided into twelve individual 'months' in order to reduce this passage of time to proportions that we can readily grasp. According to this 12-month time scale the Earth was born at midnight on January 1, and the oxygenation of the biosphere began in 'May' with the bacterial evolution of chlorophyll. Evolution reached its point of no return in 'June' and 'July' when the Hamersley ore deposits appeared and oxygen began to leak into the atmosphere. It meant that life could never begin again, for oxygen would 'burn' it up. In fact, free oxygen was such a threat to the fragile hydrogen bonds that hold DNA together, that its wholesale release into the biosphere represents the most life-threatening event in the history of biological evolution. Meanwhile, drifting on tides of mantle convection at roughly the speed at which our fingernails grow, the Pilbara has since visited both poles, not once but twice, and it took almost all of that time for bacterial cells to learn to live with, and finally to harness, their own waste gas, oxygen. When oxygen reacts with organic matter during aerobic respiration, ten times more energy is liberated than was available for earlier anaerobic respiratory pathways. This source of power allowed multicellular corporations of cells to evolve and enabled them to develop a high degree of mobility. In short, it led to the evolution of large, energy hungry animals like us.



# WARNING!

**The evolutionary narrative outlined in the preceding pages is science based and is therefore open to continual refinement as new data comes to hand. Based on findings from the frontiers of research it offers none of the comforting ‘certainties’ that characterise religions and other mystical belief systems. In short, this narrative incorporates several hypotheses that have not yet been exhaustively tested and the notion of probability is therefore implicit throughout this text whether stated or not.**

**FURTHER READING:**

“**Asteroid impact ejecta units overlain by iron-rich sediments in 3.5–2.4 Ga terrains, Pilbara and Kaapvaal cratons: Accidental or cause-effect relationships?**” Andrew Glikson, ANU. (2006)

“**Asteroid mega-impacts and Precambrian banded iron formations: 2.63 Ga and 2.56 Ga impact ejecta/fallout at the base of BIF/argillite units, Hamersley Basin, Pilbara Craton, Western Australia.**” Andrew Glikson and John Vickers (ANU). *Earth and Planetary Science,* Letters 254 pp.214–226. (2007)

“**Early Precambrian Asteroid Impact-Triggered Tsunami: Excavated Seabed, Debris Flows, Exotic Boulders, and Turbulence Features Associated with 3.47–2.47 Ga-Old Asteroid Impact Fallout Units, Pilbara Craton, Western Australia.**” Andrew Y. Glikson, ANU. (2004)

“**Field evidence of Eros-scale asteroids and impact forcing of Precambrian geodynamic episodes, Kaapvaal (South Africa) and Pilbara (Western Australia) Cratons.**” Andrew Y. Glikson, ANU. (2004)

**Greenhouse Warming by $CH_4$ in the Atmosphere of Early Earth.** Alexander A. Pavlov, James F. Kasting, Lisa L. Brown, Kathy A. Rages and Richard Freedman *Journal of Geophysical Research–Planets*, Vol. 105, No. E5, pp.11,981–11,990. (May 2000)

***Symbiosis in Cell Evolution***, Lynn Margulis. San Francisco: W.H. Freeman. (1981)

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## *THE DIARY of 'YOU'*

This illustrated High School science resource outlines the four-billion-year evolution of our species by presenting, in diary form, the evolutionary milestones that are embodied in the cell structures and chemical pathways that define our bodies today. The book is scheduled for release in 2008.*

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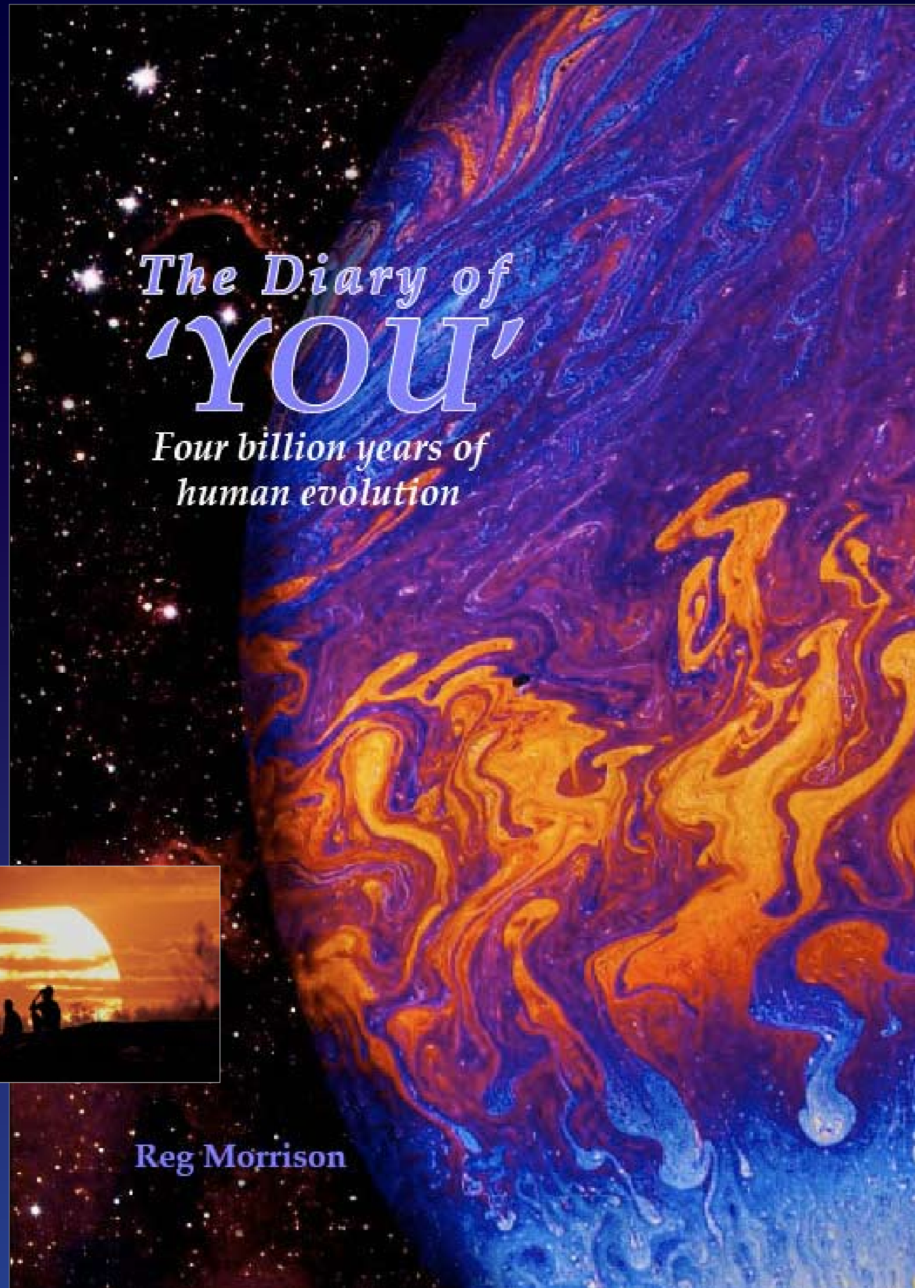


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