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EARTH' S GEOLOGICAL HISTORY
A CONTECTUAL FRAMEWORK FOR ASSESSMENT OF WORLD HERITAGE FOSSIL SITE NOMINATIONS

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This paper considers the contextual framework for placing fossil sites on the World Heritage register. It was requested by the IUCN, The World Conservation Union.

PURPOSE

The brief provided by IUCN was as follows (quote):

> *To provide a contextual framework on earth's geological history. This will be provided in the form of an overview discussion paper which will serve to assist in evaluations of natural World Heritage properties with regards to Criterion (a)(i) [q.v. below]*

OUTPUTS

The discussion was to address three issues (quote):

(1) *what are the key events in our understanding of the history of life on earth*
2) *which fossil deposits have made major contributions to this understanding.*
3*) whether the existing sites on the World Heritage list adequately represent these various stages of earth's history.*

INTRODUCTION

1.1 Heritage

The World Heritage Convention adopted by the UNESCO General Conference in 1972 came into force in 1975. It has as its aim the protection of natural and cultural heritage deemed to be of outstanding universal value. By definition, universal value is of value to all people irrespective of political or geographic boundaries.

Palaeontological heritage is a subset of heritage that embodies both natural and historical components which has received only indirect recognition. It falls within Criterion (a)(i) as being "outstanding examples representing major stages in earth history including the record of life (author's emphasis), significant on-going geological processes in the development of landforms or significant geomorphic or physiographic features."

1.2 Fossils

Palaeontological heritage is based on fossils, literally something dug up (fodere Latin to dig). In today's vernacular, fossils are any evidence of ancient life be it a mummified carcass, bones, shells, tracks, trails, carbonised impressions, moulds, casts or even the preservation of organically derived compounds.

Fossils form the evidence used in reconstructing the history of life on earth. It is a history of ancestor/descendant relationships, an ever branching tree of life. The fossil record is biased; there are more fossil sites known from the recent part of earth history than the earlier; some environments and times favour the accumulation and preservation of fossils more than others. The fossil record represents only a tiny fraction of all the organisms that have lived on earth.

All fossil sites form part of the history of life on earth, however there are a smaller number that have played a significant role in reconstructing this history. There is a subset among the significant sites that are outstanding for their species diversity and excellence of preservation. Choosing from among these a representative sample of World Heritage significance is one of the problems I will address.
Clearly selecting too many reduces World Heritage value. Selecting a small number leads to the problem of representativeness. I will therefore argue for selection based on a theme. I believe the overarching theme is evolution. I will argue that this is best represented by a collection of sites representing samples of communities that existed during different periods in earth history. Combinations of these sites then allows for the development of subsidiary themes, eg. evolution of the fishes, rise of the mammals etc., themes which together embody an evolutionary interpretation of the history of life on earth.

This history spans some 3.5 billion years. Selecting which periods to represent from this vast span of time poses a further problem. Undoubtedly the evolution of life forms is influenced by and influences the changes in the physical world (eg. the oxygen catastrophe, continental fragmentation and fusion, oceanic circulation etc.) However neither the fossil record nor the geological record is uniformly distributed in time and space and furthermore biological processes operate on different time scales to geological processes. It is therefore not simply a matter of matching biological change to geological change. Sediments and fossils from the last 500 million years are the best preserved and of the greatest diversity and therefore have tended to be the major (although by no means the only) focus of attention. I will therefore argue that for all the above reasons choice of fossil site should be dictated by major faunal composition rather than geological event, notwithstanding that the two are often interrelated.

1.3 Palaeontology and the Fossil Record

A brief comment on palaeontology and geology is relevant here.
Acceptance of the fossil record as evidence of past life on Earth was not universally agreed until the early nineteenth century and even then to many people fossils were nothing but evidence of failed creations on the path to perfection and man. However the extinction of these life forms required explanation. For many scientists in Victorian England extinction was directly attributable to the Biblical Flood, a catastrophe that eliminated the less fit and such fossil remains were accordingly considered ante-diluvean.

Fossils then were accepted as evidence of past events, be they creations or extinctions. Fossils were not regarded as samples of ever changing (ie. evolving) communities. However, it was noted that fossils were generally found in sedimentary rocks and these rocks were of increasing interest to 19th century geologists. Sedimentary rocks are deposited in layers or strata. The principles of stratigraphy had been enunciated by Steno in the 18th century. Geologists reasoned that if these sedimentary layers that cover the surface of the Earth could be organised as a single geological column, a pancake stack from youngest at the top to oldest at the base, they would provide a record of Earth history.
It also became evident that if the processes of erosion and deposition observable today were modifying landscapes in the same manner and perhaps rate in past eras, then the evidence of these processes left in the sedimentary record attested to a much older Earth than the 4004 BC proposed by Bishop Ussher (1581-1656). Indeed by the time of publication of Lyell's Principles of Geology (1830) its age was estimated to be of the order of millions of years, radiometric dating has now extended these estimates to 4.8 billion years. As well as extending the known chronology of the Earth, radiometric dating techniques have led to a current estimate of the span of life on Earth from millions to currently 3.5 billion.
In reality the sedimentary record is disjunct.

The Earth's crust remains m a constant state of change, sediments have been uplifted, eroded, consumed, regenerated, melted and transformed. The history of the Earth's surface then is preserved only as scattered remnants. Placing these remnants in a time/stratigraphic order was one of the great contributions of 19th century geology. The ordering was made possible when it was realised that the strata contained distinctive suites or assemblages of fossils. Similar fossil assemblages were indicative of similar age strata. A stratigraphy based on fossil assemblages enabled earth scientists to place strata, first in Britain then in Europe and today all over the world in a sequence or order from youngest to oldest. They devised names for these stages in Earth history, names reflecting either the geographic regions in which the strata were defined e.g. Cambrian from Cambria (Latin for Wales), Jurassic from Jura Mountains of France and Switzerland, or the nature of the rocks e.g. Cretaceous for the chalky nature of those sediments, Carboniferous for the coal-bearing sediments. Each stage is represented by a type section(s) and today many are listed as Geological Heritage.

Thus the fossil record (Fig. 1.) came to be viewed not as evidence of events, the catastrophism of the early 19th century, but rather as evidence of evolutionary change and extinction yielding continual species replacement through time. The role of palaeontologists became one of reconstructing the patterns of change.

Figure 1. A generalised interpretation of the fossil record depicting parallel evolutionary change in the plant and animal kingdoms.

PERIOD			EVOLUTION OF ORGANISMS	
CRYPTOZOIC	Proterozoic	1000	Mass extinction of algae SEVERE GLACIATION	EDIACARA FAUNA (worldwide) First eucaryotes, first multicellular animals BITTER SPRINGS BIOTA (Australia)
		1500	BECK SPRING (USA) ?Eucaryotes	Diverse microbiotas and widespread stromatolites
		2000	GUNFLINT CHERT BIOTA (USA / Canada) First widespread red beds (Buildup of Oxygen) Banded iron formation	
		2500	GLACIATION	
	Archaen	3000		
		3500	FIG TREE MICROBIOTA (South Africa) - First cells (procaryotes) ONVERWACHT C^{12} enrichment First photosynthesis WARRAWOONA MICROBIOTA (Australia) ?First stromatolites	
		4000	Oldest sedimentary rocks (Greenland)	
		4500	Oldest rock dated on earth (Australia)	

Millions of years ago
FORMATION OF THE EARTH

PHANEROZOIC

PERIOD		PLANT EVOLUTION	ANIMAL EVOLUTION
Quaternary	Epoch		Appearance of *Homo sapiens*
	Recent	Increase of herbaceous plants	Repeated glaciation leads to mass extinction
2.5	Pleistocene	Repeated glaciation leads to mass extinction	First *Homo*
Tertiary	Pliocene	Decline of forests, spread of grasslands	Appearance of hominids
	Miocene		Appearance of first apes
	Oligocene		All modern genera of mammals present
	Eocene		In seas, bony fish abound
65	Paleocene	Explosive radiation of flowering plants	Rise of mammals First placental mammals
Cretaceous 135		First flowering plants	Dinosaurs extinct Modern birds
Jurassic 195		Forests of gymnosperms and ferns over most of the earth	First birds Age of dinosaurs
Triassic 240		Gymnosperms dominant	Explosive radiation of dinosaurs First dinosaurs First mammals Complex arthropods dominant in seas First beetles
Permian 285		Widespread extinction Decline of nonseed plants	Widespread extinction Appearance of therapsids, mammal like reptiles Increase of reptiles and insects Decline of amphibians
Carboniferous - Pennsylvanian - Mississippian 375		Gymnosperms appear Widespread forests of giant club moss trees, horsetails and tree-fern create vast coal deposits	Early reptiles First winged insects Increase of amphibians
Devonian 420		First seed plants Development of vascular plants: club mosses and ferns	Amphibians diversify into many forms First land vertebrates- amphibians
Silurian 450		First vascular plant First land plant	Golden age of fishes First land invertebrates- land scorpions
Ordovician 520			First vertebrates- fishes Increase of marine invertebrates
Cambrian 570		Algae dominant	Trilobites dominant Explosive evolution of marine life

Millions of years ago

1.4 Evolution - Reconstructing the pattern of life on Earth

The vast majority of organisms that ever lived is now extinct. About I million of an estimated 30 or even 100 million species currently living is described. The 100,000 fossil species described is a mere fraction of the total species that have ever lived. As a result the fossil record is a very fragmentary and biased record of life on Earth, but it is the only actual record of the pattern of organic change. To apply a simple analogy, reconstructing this pattern is akin to reconstructing a family tree from photographic albums. Such albums generally contain snapshots of events, personalities or occasionally a sequence of events. The fossil record is similarly capricious: 'snapshots' at irregular intervals, sometimes a group all of one species, sometimes of the community, sometimes of the individual. Some fossils are of poor quality but may record important events, some are of excellent quality but lack a community context, occasionally important sequences are captured, some times and places well represented some missing altogether, some so altered and weathered as to be of marginal value.
Reconstructing the events that shaped any branch of the family tree necessitates the use of other historical evidence. For the fossil record the encapsulating sediments provide this evidence, they represent an extrordinary account of past environments, their geographic distribution and relative age. All this information is used to build an historical account of life on Earth.

However like any history, it is an account of a one-way process in time. History cannot be rerun, the test of any account can only be its consistency with newly discovered evidence. But all good histories are not simply inventories of events, they are interpretations of events, interpretations almost inevitably biased by the viewpoint of the writer. So it is with the history of life on Earth. Today it is told from the bias of the single most important unifying concept in biology that of Evolution by Natural Selection.

This theory was first advanced in a convincing manner by Charles Darwin in his book "On the Origin of Species by Natural Selection or The Preservation of Favoured Races in the Struggle for Life" (1859). The theory has now withstood 130 years of test and attempted refutation and continues to serve as the primary tool for explaining the story of life. Similarly the geological principles first enunciated by Lyell and Hutton continue to provide the chronological and palaeoenvironmental framework in which to place this history. Illustrating this history with a few well chosen fossil sites is the basis of this exercise.

SELECTION CRITERIA

2.1 Choosing sites for historical context

What criteria should be used to make a selection of sites from the fossil record which best represent this history in a way that is of universal value? Should selection be made on quality of preservation; on event; on diversity of species; on geography (i.e. should all continents have equal representation); on the best chronological sequence (every geological period) or only those snapshots most important to reconstruction of events (e.g. rise of the mammals); or of universal appeal (eg. dinosaurs)?

Ideally the selection should include all sites for which there is published research, preserving the evidence for future scholars to ponder in the light of current and future interpretations. But, as with evolution, there are constraints and it is necessary to work within these. In this case we have been asked to make a selection. Therefore, a judgement must be made as to which sites/fossils are of greatest value in communicating the story of Evolution by Natural Selection and its corollary, community change through time. In other words the choice should be based on looking at changing diversity and environments through time.
Precambrian communities are restricted to the marine realm. Phanerozoic communities will encompass marine, freshwater and terrestrial realms. The divisions here are endless, choice must involve additional criteria. Nonetheless as a guiding principle well-preserved communities of high species diversity (fossil Lagerstatten) should be ranked higher than fossil accumulations with low species diversity.
[For a footnote on fossil Lagerstatten see end of file.]

This leads to the first recommendation.
RECOMMENDATION 1
Choose sites that contain well-preserved fossil accumulations of high species diversity which in combination best document the story of community and environmental change through time.

2.2 The elements of "Universal Value"

Selection criteria must, by definition, include 'universal value'.

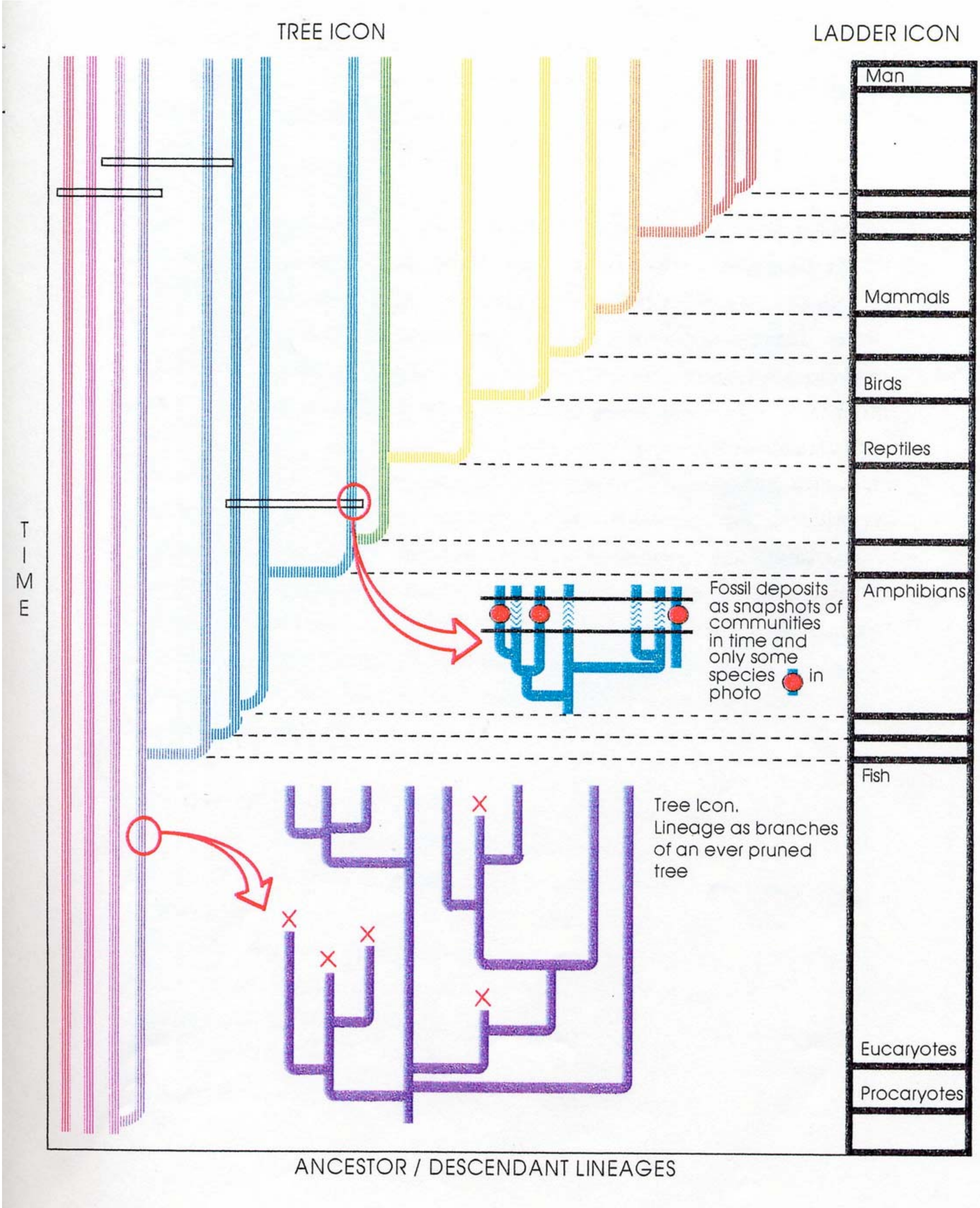
It could be argued that scientific value is universal value, alternatively universal value may include values of aesthetic or emotional appeal, values ostensibly eschewed by many scientists. Scientists strive for objective observation, their views are influenced by the constraints of a different culture and hence thought less subjective. Science, however, is as embedded in society as most other human endeavours and palaeontology is no exception. Indeed, it may be argued that it is one area of science in which iconography is pivotal. For instance, Stephen Jay Gould in the Preface to The Book of Life (1993) entitled ‘Reconstructing (and Deconstructing) the Past' wrote "Iconography, in my view, provides the best domain for grasping this interplay of social and intellectual factors in the growth of knowledge - and the iconography of ancient beasts opens a revealing window upon ourselves, while providing a series of images for creatures of the distant past."

Gould goes on to argue that the very way in which the history of life on Earth is illustrated belies our dispassionate objectivity. Most texts and popular accounts of life on earth trace a path from single cells to man, a subliminal ladder of progress. Such images have more impact in shaping perceptions of the past than a thousand intellectual writings. Gould draws upon the current phase of dinomania to drive home his point. Dinosaurs once depicted as giant lumbering primitive reptiles too heavy to support their own weight on land, were usually drawn buoyed up in primaeval swamps. In the old pictorial parades of life they were replaced by large-brained active mammals in a more advanced world. Today dinosaurs have been given new vigour and dynamicism and box office respect in keeping with their perceived man-like dominance of the terrestrial realm of the Mesozoic. In changing their image the movie makers have changed perceptions of history. The dinosaur extinction is no longer due to their 'primitive' nature, their lower rung on the ladder of progress, but rather

the chance impact of an extra-terrestrial body, a fate that could befall any life at any time.
Hollywood has, perhaps unwittingly, grasped the evolutionary nettle. In the public mind, dinosaurs are now dignified with their own branch of an evolutionary tree (a "clade"), they are no longer on a ladder of evolutionary progress to humankind. This form of imagery is important in changing peoples' perspective of the place of the human primate in the history of life. The selection and interpretation of sites should take such imagery (tree of life) into account, it plays an important role in communicating evolutionary concepts. This is particularly so for the higher vertebrates, a group to which all humans can relate.
Accordingly it may be appropriate to have a number of sites combined to tell a particular portion of the story eg. the recently listed Australian Fossil Mammal Site comprising two separate localties and two time frames attempts to fulfil this role. Such sites then become representative of independent branches on the evolutionary tree, not rungs on a ladder of progress (Fig. 2.).

RECOMMENDATION 2
The 'events' to be represented in the history of life should, where possible, encompass the iconography of a tree of life not a ladder of progress.

Figure 2. A diagrammatic representation of the tree icon of evolutionary change compared with the ladder icon. In the tree icon (left) evolutionary lineages are depicted as branches of a tree. These branches may represent species, families, orders, classes, depending on the classificatory level used. In this diagram family lineages are composed ever dividing branches, (see inset) some pruned = extinction x, some divide = speciation. Fossil assemblages are snapshots of communities (horizontal bars) that include only some species from some families (see inset).
The ladder icon (right) depicts evolutionary change in terms of first appearance and dominance of particular groups eg. vertebrate classes. It implies position on rungs of a ladder, it implies direction and purpose, not chance and nescessity.


TREE ICON
LADDER ICON
Man
Mammals
Birds
Reptiles
Amphibians
Fish
Eucaryotes
Procaryotes
TIME
Fossil deposits as snapshots of communities in time and only some species in photo
Tree Icon. Lineage as branches of an ever pruned tree
ANCESTOR / DESCENDANT LINEAGES

2.3 How to select from among appropriate sites?

Clearly if the aim is to depict history, a time perspective is needed, from the earliest evidence to the present. It is also necessary to pick from among the paths of life those views with the highest resolution and the greatest information content. The most obvious place to begin is with fossil Lagerstatten.

The ecological and evolutionary significance of fossil Lagerstatten has been reviewed in a series of symposium papers edited by Whittington and Conway Morris (1985). The great importance of many of these deposits lies in their preservation of evidence of soft tissue anatomy in addition to mineralised elements such as bone or shell. This is attributable to the two principal factors of stagnation and obrution (smothering).

Seilacher et al. (1985) have discussed the environmental settings for fossil Lagerstatten and used these as a tool to prospect for them. This is important in that it highlights the possibility of an expanding suite of such spectacular sites spanning much of the fossil record. It implies that unlike living biomes which are finite, observable and mapable, any fossil deposit can be eclipsed by further discoveries. In other words the album can always be expanded by searching other archives and accordingly the story modified or elaborated.

This is a critical factor in decision making. At one extreme if all sites are included the value of any individual one is decreased. At the other extreme if too restrictive, a choice excludes further additions of equal or greater quality, the List becomes unrepresentative and is similarly devalued. The choice at any instant is going to be governed by the tension between these extremes and modulated by resource constraints.
The financial constraint includes not only the cost of additional sites but also the curation, study and display of the fossils. Indeed these are essential elements for the List to realise its value. If resources become very limiting

it may even be desirable to trade-off some sites in order to acquire others of greater value. This is a luxury that is not available with living biotas for what is lost or given away is lost forever.

Sites can only realise their 'universal value' if they are adequately studied, conserved and displayed. This poses a problem for sites where important collections have been scattered around the world. World Heritage is the most prestigious value any site can attain. Retaining this ranking in the face of further discoveries elsewhere is always a potential problem. Clearly if correctly chosen, provided adequate resources and promoted, any nominated site should be hard to eclipse. Some sites will always remain important for their historical importance (eg. Burgess Shale). Further discoveries elsewhere might then be added to form a serial listing. Conversely, if a large number of sites are listed, one which failed to realise its universal value in a specified period may run the risk of being supplanted or deleted and its ranking reduced.

RECOMMENDATION 3

> *Choose fossil Lagerstatten and make provision for expanding the List or substituting sites/fossils to better tell any chapter of the story.*

KEYEVENTS

3.1 'Key Events' in the history of life on earth: which to choose?

Selection of sites to illustrate the 'key events' of the history of life is the nub of the problem.

The origin of prokaryotes, the evolution of eukaryotes, the appearance of metazoa, the Cambrian explosion, the conquest of the land and the air, the extinctions of the terminal Permian and Cretaceous are 'key events' in the history of life. But are they 'events'? In human terms events are happenings, measured from the perspective of human life times. In evolutionary terms many of the aforementioned 'events' span millions or tens of millions of years. They are 'events' only in the sense of our inability on current evidence to resolve them more finely.

Another way of viewing events in the history of life is from the perspective of lineage splitting ("cladogenesis"). These events are the ones which have truly shaped the branches of the tree of life. These are the processes of macro-evolution. Eldredge and Gould (1972) went so far as to suggest that all major morphological evolution is associated with rapid and localised speciation (lineage splitting) events. Arguing that these are the processes which best account for the disjunct nature of the fossil record. Small peripherally isolated populations are the ones that change most rapidly and generally escape detection in the fossil record yet these are the 'events' which structure the pattern of life on earth. The appearance of new forms in the fossil record are thus stratigraphically sudden arisings from large relatively stable populations. The fossil record therefore appears disjunct, punctuated by sudden species appearances and disappearances, followed by long periods of relative stability ("stasis") where species morphologies drift slowly through time. Following pathways of descent requires selection of snapshots not only along a branch but from a number of branches of any particular group: the reptiles, the birds, the mammals, the fish, the amphibians, the psilophytes, the angiosperms, etc.

The recently proclaimed World Heritage Australian Fossil Mammal Site illustrates this point.
It currently consists of two separate fossil Lagerstatten, Riversleigh in northwestern Queensland and the Naracoorte Caves in southeastern South Australia. They are united in that they provide snapshots, time slices through the branches of Australian marsupial evolution at ~25mya and ~ 200ka respectively. Further snapshots are required to view the branch at other times eg. ~50mya. This approach goes beyond simply selecting any fossil Lagerstatten, as it is aimed at a story, in this case the evolution of Australian marsupials. The story nonetheless is still embedded in the history of each community and the changes associated with the re-arrangements of continents and climates.

Selecting for phylogenetic stories works well for the Phanerozoic but is not, and may never be, applicable to the Precambrian (Cryptozoic). The dearth of fossils from this period being the result both of subduction and alteration of much of the early sedimentary record and its fossils, combined with the absence of mineralised tissues in early life forms. Indeed, so difficult is it to unravel those early pathways of Precambrian evolution that Gould has used the analogy of the stolon of life rather than that of a single branching trunk. Each fossil assemblage consists of a suite of bizarre individuals that bear few familial resemblances, each an evolutionary experiment currently without apparent antecedents or descendants. Each of these Precambrian snapshots is so rare in this vast span of earth history as to warrant special investigation, although clearly some are of greater historical significance (eg. Ediacara).

RECOMMENDATION 4

(i) separate Precambrian history from Phanerozoic history (the roots from the upper branches of the evolutionary tree respectively),
(ii) present Precambrian history as major events, such as the origin of life, multicellularity, etc. and
(iii) present Phanerozoic history in terms of communities and/or stages in the evolution of major groups .

The aforementioned division separates the List, into that part of history portraying 'events' and that dealing with the evolution of major groups or communities. Agreed that this is a somewhat artificial separation in what after all is a continuum of life forms, but it is a practical solution that recognises the reality of the record.

3.2 Precambrian Sites based on 'Events'

The Precambrian constitutes the first 4.25 billion years of Earth history or approximately 88% of total Earth time. For much of life as we know it today the Earth was an alien planet throughout almost half of this period. Lacking a protective blanket of ozone its surface was bombarded by UV radiation, its atmosphere a mixture of carbon dioxide, hydrogen sulphide and methane. As the surface cooled it formed a crust of plates each comprising a thick continental portion and a thinner oceanic segment. These plates have moved over the surface of the Earth in an episodic, discontinuous manner. The boundaries between these plates usually lie under the oceans and are places where upwelling molten rock from the mantle is added to the plates; or, places of subduction where crust is consumed back into the mantle. The consequence is that over a period of 4.25 billion years much of the record of erosion and sedimentation has been lost by subduction and recycling. The ability to resolve chains of events so far back in time is extremely limited, to resolve phylogenies of early life forms almost an impossiblity. For these reasons I believe that the best that can be done with snapshots from all but the very last part of this period is to use them as 'event' markers. They record evidence of the first cells, of oxygen producing bacteria, of eukaryotic cells and beginnings of sexual reproduction, etc., indeed so very rare are these fossil sites that all are worthy of informed discussion as potential Heritage by experts in that portion of the record.

RECOMMENDATION 5

All published Precambrian fossil sites should be reviewed by an expert panel to select those worthy of evaluation for Heritage listing. This may be best achieved through a panel drawn from the international palaeontological societies.

3.3 Phanerozoic Sites Based on Communities and/or Lineage

To focus the account on communities and lineages requires an appreciation of evolutionary rates and diversity within the selected clades. A selection of snapshots of a rapidly diversifying group carries more information than those of a lineage in stasis. Furthermore, the diversity changes at the higher taxonomic levels of family, order and class are not only more significant to the story but they are also the levels at which it is possible to be most confident (i.e. although each individual fossil is a representative of a species only, a fraction of species diversity is preserved; higher categories are therefore more inclusive). Thus to tell the story adequately within the constraints requires careful selection of sites and fossils in both time and space.

RECOMMENDATION 6
Phanerozoic sites should be chosen so as to be representative in time and space of both community structure and selected phylogenetic lineages.

Clearly Recommendation 6 could lead to a plethora of sites if lineages and histories are divided too finely. Keeping the focus on higher taxonomic levels offers some control. Fortunately, few sites are restricted to a single taxon. Careful selection may allow for portrayal of communities which also include groups that when combined with other sites portray evolution within a lineage, eg. The Gogo fish site could illustrate a Devonian reef community while at the same time combined with Canowindra and Miguasha depict the evolution of fishes.

There are cogent reasons for focussing on vertebrate lineages.
Popular accounts and displays of fossils concentrate, almost without exception, on the vertebrates. The reasons are probably manifold and complex, not the least being that humans belong to this important subphylum of chordates. Vertebrates undoubtedly have universal appeal and therefore warrant special attention. Vertebrates thus become the ideal vehicles for conveying evolutionary concepts and vertebrate sites should be selected accordingly, eg. to illustrate fish, amphibian, reptile, bird and mammal evolution.
Invertebrates gain attention in the great Cambrian explosion of diversity but then are often overlooked by biologists when teaching about the latter part of the history of life on earth. In terms of diversity and biomass and impact Invertebrates far outweigh the vertebrates. They are well represented in marine sediments, less so in fresh water and much rarer in terrestrial deposits. Their importance in biocorrelation, biogeography and palaeoenvironmental reconstruction greatly exceeds that of the vertebrates. They deserve a higher profile in the telling of the history of life in the Phanerozoic than they currently enjoy. However, to attempt to portray invertebrate lineages even at the level of class would lead to a plethora of sites. Invertebrates are best portrayed as members of communities. The choice of communities may be influenced as much by the vertebrates they contain as their representativeness in time and space.
There are a significant number of marine and euryhaline fossil Lagerstatten (e.g. the Burgess Shale and Mazon Creek) but there are fewer fresh water and terrestrial Lagerstatten (e.g. Messel Pit and Santana). Fossil Lagerstatten that include a high diversity of both invertebrates and vertebrates are of the greatest value.

RECOMMENDATION 7

> *Any fossil Lagerstatten chosen from the Phanerozoic should wherever possible be of high diversity and include significant invertebrate as well as vertebrate assemblages.*

I have already highlighted the need to present this record in a conceptual framework rather than simply as an inventory of species. In its purest form the record of life is the history of ancestor descendent relations, the tree of life. There are many other ways of presenting this record. Sites could be presented as containing fossils representative of evolutionary grades (eg. among the metazoa as diploblastic, triploblastic, segmented forms, appearance of paired appendages, jaws etc.), in terms of palaeogeography (eg. Gondwanan, Laurasian faunas, impact of land bridges etc.) or palaeoecology (eg. evolution of marine/terrestrial carnivores, herbivores, omnivores,etc.) or in terms of major origination and extinction events (eg. the Cambrian explosion, Permian and K/T extinctions etc.) and within the scientific community there are undoubtedly proponents of all these approaches and many others. The simplest, the most direct, the most all encompassing, the most unifying concept for presentation of the record of life remains that of phylogeny. Where phylogeny fails, or is at least greatly weakened, is in the Precambrian and here I have made a case for presenting the record in terms of 'events'.

3.4 Events

The following is a working list of the primary events of the Precambrian and early Cambrian.

(i) Evolution of the first cells.
(ii) Evolution of oxygen-producing bacteria (cyanobacteria) leading to banded iron formations and ultimately an oxygen rich atmosphere.
(iii) Evolution of eukaryotic cells and sexual reproduction.
(iv) Evolution of the first metazoans, the Ediacrans.
(v) The Cambrian explosion in body plans.

3.5 Lineages and Communities

The following is a working list of major vertebrate classes whose evolution could be traced. It is envisaged that much of this evolution be covered by a careful selection of sites, each of which also includes representatives of many invertebrate and plant groups comprising the palaeo-community. Interpretation would include all aspects of a site's history, but the initial selection would be influenced by the evolutionary stages of the vertebrate groups represented. This procedure would avoid duplication of sites included purely for the excellence of preservation of the fossils.

The major classes are:

- (i) Agnatha (jawless fishes).
- (ii) Chondrichthyes (cartilagenous fishes).
- (iii) Osteichthyes (bony fishes)
- (iv) Amphibia
- (v) eptilia
- (vi) Mammalia
- (vii) Aves (birds)

Important 'events' of the Phanerozoic are not excluded by this selection process. Each site would have its own stories to tell, e.g. rise of the fishes, conquest of the land and air, return to the sea, biogeographic interchange, Permian, K/T and Pleistocene extinctions, etc. The primary choice of sites, however, remains their window on phylogeny.

Any site proposed for World Heritage listing would then be assessed in terms of its diversity of forms, excellence of preservation, its place in geological time and its value to the sequence of one or more lineages.

EVALUATION

The current IUCN Site Evaluation Checklist comprises the following ten questions.

(1) Does the site provide fossils which cover an extended period of geological time? i.e. how wide is the geological window.

(2) Does the site provide specimens of a limited number of species or whole biotic assemblages? i.e. how rich is the species diversity?

(3) How unique is the site in yielding fossil specimens for that particular period of geological time? i.e. would this be the 'type locality' for study or are there similar areas that are alternatives?

(4) Are there comparable sites elsewhere that contribute to the understanding of the total 'story' of that point in time/space? i.e. is a single site nomination sufficient or should a serial nomination be considered?

(5) Is the site the only or main location where major scientific advances were (or are being) made that have made a substantial contribution to the understanding of life on earth?

(6) What are the prospects for ongoing discoveries at the site?

(7) How international is the level of interest in the site?

(8) Are there other features of natural value (e.g. scenery, landform, vegetation) associated with the site? i.e. does there exist within the adjacent area modern geological or biological processes that relate to the fossil resource?

(9) What is the state of preservation of specimens yielded from the site?
(10) Do the fossils yielded provide an understanding of the conservation status of contemporary taxa and/or communities? i.e. how relevant is the site in documenting the consequences to modern biota of gradual change through time?

Although all these questions (with the exception of 10 which applies largely to late Pleistocene/Holocene sites) are relevant in assessing the quality of any fossil site, the site must ultimately be evaluated in terms of the aims of World Heritage listing. Criterion (a)(i) Universal Value.
To be of universal value clearly some provision must be made for curation, study and display of any site and its fossils.

RECOMMENDATION 8
A condition for granting World Heritage status should include provision for curation, study and display of any site/fossils.

SITE LISTS

5.1 Fossil Sites of Potential World Heritage Value

This fossil site list is indicative only of the type of site which may be considered for world heritage nomination. The list covers, as far as possible, the entire chronology of life on earth, as well as all major groups of organisms.

The sites were selected for their representation both of the palaeo-communities of the respective time periods, as well as the different stages in the evolution of the major groups. Palaeo-anthropological sites have been deliberately omitted, as they are traditionally considered under archaeology rather than palaeontology. All Precambrian, ie. Proterozoic and most Vendian sites have been listed as they represent the totality of the fossil record known for that period of the earth's history. It is not intended that all be granted World Heritage status. Rather they are of great scientific importance and require special consideration when compiling a representative list.

Phanerozoic sites, on the other hand, represent the author's view of the most outstanding fossil localities for the respective time period. This list undoubtedly reflects a western bias in the scientific literature on fossils and fossil localities. The list provides a working model upon which to build. Sites may be added or substituted for others in order to better represent palaeo-communities at a particular time and/or the evolution of a particular group. Some existing World Heritage Sites (eg. Grand Canyon, Canadian Rocky Mountain Parks) already contain exceptional fossil deposits.

Participation of specialists in the different major groups and time periods is essential for the compilation of a truly representative list of sites.

RECOMMENDATION 9

Specialists in the major Phanerozoic groups and time periods should be consulted to refine and update the indicative list. This may be best achieved through a panel drawn from the international paleontological societies.

THE LIST

Precambrian (Cryptozoic)

Wan-awoona Microbiota, Warrawoona Group, Western Australia, Australia (≈ 3500 Mya)
Oldest Known Fossils. First photosynthesis?, first stromatolites.

Fig Tree Microbiota, Fig Tree Formation, South Africa (3350 Mya)
First definite cells preserved in the fossil record (prokaryotes).

Gunflint Chert, Minessota, U.S.A. & Ontario, Canada (1900 Mya)
Prokaryotic microfauna.

Beck Spring, U.S.A. (≈ 1200 Mya)
Preservation of a microfauna. Possible first Eukaryotes.

Bitter Springs, Northern Territory, Australia (900 Mya)
Well preserved prokaryotic microfauna.

VENDIAN

***Ediacara**, Flinders Ranges, South Australia, Australia. (□ 700 Mya)
Site of great scientific and historical importance. First record of Metazoans (multicellular organisms). Preservation of soft bodied organisms.
* The author's preferred Vendian site.

Punkerri Hills, Officer Basin, Australia
Ediacaran Metazoans.

Deep Well, Northern Territory, Australia
Ediacaran Metazoans.

Laura Creek, Northern Territory, Australia
Ediacaran Metazoans.

Mt Skinner, Northern Territory, Australia
Ediacaran Metazoans.

Jervois Ranges, Georgina Basin, Australia
Ediacaran Metazoans.

Mato Grosso, Brazil
Ediacaran Metazoans.

Podolia, Ukraine
Ediacaran Metazoans.

Yenisey River, Igaraka, Turukhansk
Ediacaran Metazoans.

Irkutsk, Lake Baikal, ???
Ediacaran Metazoans.

Anabar and Oleneck, northern Siberia
Ediacaran Metazoans.

River Maya, China
Ediacaran Metazoans.

Longshan, China
Ediacaran Metazoans.

Yangtze Gorge, China
Ediacaran Metazoans.

Lake Tometrask, Sweden
Ediacaran Metazoans.

Leicester, England
Ediacaran Metazoans.

Mackenzie Mountains, Canada
Ediacaran Metazoans.

Southeast Newfoundland, Canada
Ediacaran Metazoans.

Palaeozoic

CAMBRIAN

Burgess Shale (Stephen Formation), Canada.
Exceptional preservation of a middle Cambrian (540-525 Mya) community including soft-bodied organisms. Unique for its diversity and excellent preservation.

ORDOVICIAN

Utica Shale, New York, U.S.A.
Famous for its preservation of soft body parts of Trilobites from the Late Ordovidan. The exceptional preservation includes appendages and detailed internal anatomy.

Mt Watt, Mfc Charlotte, Northern Territory, Australia.
Preservation of Ordovidan jawless fishes (Agnathans). Arandapsis sp oldest vertebrates (fish) in Southern Hemisphere

SILURIAN

Mississinewa Shale, Indiana, U.S.A.
Exceptional fossil Lagerstatte representing a Silurian marine community.

DEVONIAN

Gogo, the reef complex of the Fitzroy Ranges - Ganowindra fish sites, Australia.

Exceptional preservation of early and late Devonian vertebrates (fishes) which exhibit little compression and important anatomical details not preserved at other sites.

Rhynie Chert, Scotland, United Kingdom.

Well preserved early terrestrial community of vascular plants and arthropods.

CARBONIFEROUS

Mazon Creek, Illinois, U.S.A.

Exceptional fossil Lagerstatte including plants, insects, soft-bodied invertebrates and vertebrates, with both marine and terrestrial faunas represented.

PERMIAN

Geraldine Bonebed, Texas, U.S.A. **- Reef complex of the Guadalupe Mountains**

Exceptionnal fossil assemblage including amphibians, reptiles, sharks, fishes, ferns and conifers.

PERMIAN to TRIASSIC

The Karroo, Beaufort Beds, South Africa.

Exceptional fossiliferous sequence spanning from the Permian to the Triassic with a unique record of mammal-like reptiles (pelycosaurs, therapsids) and Early Triassic archosaurs.

Mesozoic

TRIASSIC

Isigualasco -Argentina
Exceptional mid Triassic record of early dinosaurs

South Wales, U.K. (??Late Triassic)
Extensive fissure fills containing the earliest pre- mammals.

Petrified Forest National Park (Chinle Fm.), Arizona, U.S.A. (Late Triassic)
Most extensive Late Triassic fossiliferous section in the world, with many different plant and vertebrate groups represented. Several different palaeoenvironments and palaeocommunities are indicated.

JURASSIC

Holzmaden, Germany
Exceptional preservation of marine organisms including the outline of soft bodied parts of vertebrates.

Dinosaur National Monument, Utah, U.S.A. (late Jurassic)
Outstanding dinosaur assemblage of great historical and scientific significance.

Solnhofen - Eichstatt, Bavaria, Germany (Late Jurassic)
One of the most outstanding world Mesozoic sites, historically, biologically and in terms of preservation of the fossils. All five kingdoms are represented, including most of the major animal phyla. Most famous for the earliest bird, *Archaeopteryx*.

CRETACEOUS

Santana Fossil Assemblage (Santana Fm.), Brazil (Early Cretaceous)
High diversity assemblage with many different plant, invertebrate and vertebrate groups represented. Fossils very complete and in an excellent state of preservation.

Koonwarra Fossil Beds (Korumburra Group), Victoria, Australia (Early Cretaceous)
Greatest floral and faunal (invertebrate) diversity of any Australian Mesozoic site.

Ukhaa Tolgod - Flaming Cliffs, Gobi Desert, Mongolia (Late Cretaceous)
Abundance, diversity, concentration and preservation of fossil terrestrial vertebrates (reptiles, birds, mammals) far exceed all other known Cretaceous sites.

LATE CRETACEOUS TO MIDDLE PALAEOGENE

Seymour Island (López de Bertodano, Sobral & La Meseta Fms), Antarctica
Extensive fossiliferous section spanning time of breakup of Gondwana. Plants, protists, invertebrates and vertebrates represented.

Cainozoic

PALAEOGENE

PALAEOCENE

Itaborai, Brazil

Riochican Fauna, largely mammals in limestone fissure fills including early primates, ungulates, litoptems, xenungulates and 14 species of marsupials

Tiupampa, Bolivia

The most important early Paleocene mammal site in South America.

The Banaca and Costa Blanca, Patagonia, Argentina.

Early marsupial mammal sites of great scientific importance as they provide a unique record of early marsupial mammals. This is critical in understanding the evolution of mammals in South America, Antarctica and Australia.

EOCENE

Messel, Germany.

Exceptionally diverse fossil Lagerstatte including aquatic and terrestrial fauna and flora of the Early Tertiary. Outstanding preservation of vertebrate remains. Unique window on the evolution and radiation of mammals. Important site for our understanding of evolution and Early Tertiary palaeoenvironments.

London Clay (London Clay Fm.), United Kingdom.

Unique, rich and diverse (over 350 species identified) flora from the Lower Eocene of Europe. Fossils include fruit, seeds, pollen, leaves and stems. Site of great palaeoenvironmental, palaeogeographic, phylogenetic and historical significance.

Monte Bolca, Verona, Italy.

Outstanding fossil assemblage (over 100,000 specimen collected) of great historical (first mention of the Bolca fossils in 1552) and scientific significance. Exceptional preservation of fishes, reptiles, insects, with some marine invertebrates and land plants. Preservation of skin, soft tissues and pigmentation.

Green River, National Monument U.S.A.
Oil shales with beautifully preserved articulated skeletons of fish, turtles, birds , mammals including eary bats, along with leaves and insects.

Baltic Seashore Amber, Germany, Poland, Russia.
Famous amber bearing deposits with abundant Insect inclusions perfectly preserved. Provides a unique record of insects, which are very seldomly preserved in other fossiliferous environments

EOCENE TO OUGOCENE

The Fayum (Jebel Qatrani Fm.), Egypt.
Most complete record of Palaeogene mammals for all Africa. The diverse fauna (40 genera, 75 species) which includes 2 hominoid genera is critical in understanding the evolution of many mammal groups on the continent, particularly hominids.

Big Badlands National Monument
(late Eocene, Chadron Fm. to early Oligocene Brule Fm.), South Dakota, U.S.A.
Site representing a transition from the Eocene forest fauna to the later plains fauna of North America. Important palaeodimatic and palaeoecological site. and for establishment of a biostratigraphy based on mammal ages.

OLIGOCENE

Florissant National Monument (Colorado) USA
An exceptionally rich deposit containing predominantly plants and insects along with fish birds and mammals buried in successive volcanic mudflows and ash falls. A view of North American flora and fauna during the Oligocene.

Northern Highland Amber, Domenican Republic (Oligocene)
Extensive Late Oligocene to Early Miocene amber bearing beds, with abundant insects perfectly preserved. Significant due to the rarity of such deposits and the quality of scientific information they provide.

John Day Fossil Beds National Monument.
Oligo - Miocene (Oregon) USA
40 million year record of plant and animal life in North America

W.H. Australian Fossil Mammal Sites, Riversleigh
Oligo-Miocene (NW Queensland) Australia. Serial nomination with Pleistocene deposits at Naracoorte Caves S.A. Remarkable for diversity, abundance and excellence of preservation of vertebrates in fresh water limestones.

MIOCENE

Agate Fosil Beds National Monument (Nebraska) USA
20 million year old Miocene mammals

Siwaliks India
Mammals including primates

PLIOCENE

Hagerman Fossil Beds National Monument (Idaho) USA
3.5 million year old deposit of great quality and diversity of flora and fauna, 110 species, 500 sites.

QUATERNARY

PLEISTOCENE

La Brea Tar Pits, California, U.S.A. (Late Pleistocene).

Excellent preservation in tar pits of complete vertebrate skeletons, but also abundant invertebrates including insects as well as many plants. Site of great palaeoecological, palaeoenvironmental significance.

Lake Callabonna, Fossil Reserve, South Australia (Pleistocene)

A huge necropolis of Australian megafauna, including giant kangaroos, large Diprotodons, dromornthid birds, literally thousands of skeletons of animals that mired in the ancient lake.

Australian Fossil Mammal Sites, Naracoorte Caves South Australia (Pleistocene).

Serial nomination with the 01igocene/ Miocene Riversleigh deposits in south west Queensland. The richest deposit of Pleistocene vertebrates known from Australia, remarkable for both diversity and excellence of preservation. Individual caves contain pitfall samples from different periods in the Pleistocene.

REPRESENTATIVENESS

6.1 Existing World Heritage Sites: how representative of fossil sites are they?

Palaeontological sites currently on the world heritage list include the Burgess Shale and Dinosaur Provincial Park(Canada), the Australian Fossil Mammal Sites (Riversleigh/Naracoorte), Olduvai Gorge (Tanzania) and the recently proclaimed Messel Fossil Pit (Germany). Of the above 5 nominations, only Dinosaur Provincial Park, the Australian Fossil Mammal Sites and Messel Pit are included on palaeontological grounds. The Burgess shale was inscribed on the W.H. List on palaeontological grounds in 1980 but was subsequently subsumed in to the Canadian Rocky Mountains Parks W.H. listing in 1984. Olduvai Gorge is of Anthropological value, rather than Palaeontological. Consequently, the sites currently present on the list **arc not representative** of the history of life on earth as they only provide information on 2 temporally very separate periods of earth's history.

Summary Recommendations

RECOMMENDATION 1
Choose sites that contain well-preserved fossil accumulations of high species diversity which in combination best document the story of community and environmental change through time.

RECOMMENDATION 2
The 'events ' to be represented in the history of life should, where possible, encompass the iconography of a tree of life not a ladder of progress.

RECOMMENDATION 3
Choose fossil Lagerstatten and make provision for expanding the List or substituting sites/fossils to better tell any chapter of the story.

RECOMMENDATION 4
Separate Precambrian history from Phanerozoic history (the roots from the upper branches of the evolutionary tree respectively),
Present Precambrian history as major events, such as the origin of life, multicellularity, etc. and
Present Phanerozoic history in terms of communities and/or stages in the evolution of major groups .

RECOMMENDATION 5
All published Precambrian fossil sites should be reviewed by an expert panel to select those worthy of evaluation for Heritage listing. This may be best achieved through a panel drawn from the international palaeontological societies.

RECOMMENDATION 6
Phanerozoic sites should be chosen so as to be representative in time and space of both community structure and selected phylogenetic lineages.

RECOMMENDATION 7
Any fossil Lagerstatten chosen from the Phanerozoic should wherever possible be of high diversity and include significant invertebrate as well as vertebrate assemblages.

RECOMMENDATION 8
A condition for granting World Heritage status should make provision for curation, study and display of any site/fossils.

RECOMMENDATION 9
Specialists in the major Phanerozoic groups and time periods should be consulted to refine and update the indicative list. This may be best achieved through a panel drawn from the international palaeontological societies.

Footnote: Fossil Lagerstatten: A term used by the German palaeontologist Adolf Seilacher to describe exceptionally rich fossil deposits. He divided such deposits into two categories: (i) Conservation Lagerstatten which are deposits yielding fossils of exceptional preservation which are not necessarily abundant; (ii) Concentration Lagerstatten yielding high numbers of fossils. The two categories are not necessarily mutually exclusive and some sites contain both high numbers and high quality of fossils.

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