Figure 1: A modern Oil Painting of a 300m+ high Australian Open-Cast Mine (thank you Inkscape)

Figure 2: The opportunity to engage in the Dance of Life

The Story of Coal

Researched & Written by Alex Kemp

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Overview

This exploration will be more in the nature of skipping a stone across the surface of the lake rather than a deep dive. It is an attempt to understand the miracle of how on this earth seams of coal 330 metres (almost 1100 feet) thick could exist within Australian coal mines.

Life on Earth

(when Theia met Gaia)

The story of coal begins with the appearance of life on Earth.

Figure 3: Theia colliding with the proto-Earth [YouTube (NASA)]

The Earth + Moon Gemini-pair (wiki) (NASA Super-Computer Simulation on YT) are reckoned as forming at 4½ Ga[1] (just 40 m years after the formation of the proto-Earth itself) and, although life is thought to have begun at 4 Ga, those were single-celled organisms living within a reducing atmosphere[2] (notice how my talk is immediately of twinned-processes). Since the modern atmosphere is clearly oxidising & not reducing, a mechanism is needed to explain the switch. That mechanism is thought to be encapsulated by the pre-Cambrian fossil[3] record of shallow-water Stromatolites (wiki) (created by cyanobacteria (wiki); see next page).

The earliest undisputed life on earth at 3.0 Ga is thought to be microbial mats of anaerobic[4] bacteria (causing a "Purple[5] Earth" [wiki] due to the use of '*Retinal (wiki)*' to convert sunlight into energy rather than '*Chlorophyll (wiki)*', which latter gives rise to a "Green Earth"). *Retinal* is a fairly simple carbon-based molecule which plays a vital role in metabolising light-energy within both anaerobic bacteria and (although not directly connected) also in modern aerobic life. In the former it plays a role within the cell membrane in photosynthesis of light (it goes *13-cis-retinal* in light & cycles back to *all-trans-retinal* in the dark). In the latter it is a crucial part of the Vitamin-A

1 *Ga == 'gigaannum' == "Billion Years Ago" == 1,000,000,000 years == 10^9 years*
2 *Reduction == gain of electrons; Oxidation == loss of electrons*
3 *Note: all early fossils provoke the argument that "they may be non-biological".*
4 *Aerobic == "oxygen-rich"; Anaerobic == A-Aerobic == "not aerobic"*
5 *In Emin parlance, Purple is "the scorch-mark of Silver", worn by the earliest students*

metabolic path (in which oxidation plays a part, and beta-carotene can feature, and thus carrots[6]) and is also crucial for the ability of mammalian eyes to detect light (it is *11-cis-retinal* in the dark & goes *all-trans-retinal* when capturing a photon).

Figure 4: Stromatolites (wiki); Hamelin Pool Marine Nature Reserve, Shark Bay, Western Australia

The emergence at about 3 Ga of cyanobacteria[7], which use water as a reducing agent and produce oxygen as a by-product, led to the *Oxygen Holocaust (wiki)* at 2.4 Ga as the atmosphere & oceans switched from anaerobic (no oxygen, reducing) to become aerobic (oxidising). Cyanobacteria are Blue-Green. Marine cyanobacteria still exist in the modern age & are thought to be responsible for 20% of the oxygen in the Earth's current atmosphere. That switch from anaerobic to aerobic caused an 80% loss of anaerobic life, and also led to the establishment in the Stratosphere of the Ozone Layer, which filters out the most damaging UV light. Without Ozone there can be zero modern life on land nor in the ocean top-surface. There was iron dissolved in all oceans at that time. Whilst the iron in the oceans was *"ferrous oxide"* it was soluble, but at the point of the *Oxygen Holocaust* it switched from ferrous to *"ferric oxide"*, which is insoluble, and thus banded iron oxide deposits (BIF: "*Banded Iron Formations (wiki)*", see below) were made across all seabeds in the then-oceans (which allows the *Oxygen Holocaust* to be dated).

6 *The carrot reference is to Churchill's deception during WW2 in declaring that John_Cunningham (wiki) had such a good kill-rate due to excellent eyesight helped by consumption of carrots, rather than possession of early radar-detection equipment in his plane*

7 *The evidence for oxygen-producing bacteria at 3 Ga is almost entirely indirect rather than direct, yet is accepted as conclusive*

Figure 5: BIF: Banded Iron Formation (wiki); Dales Gorge, Fortescue Falls, Australia

The first paragraph above states that *"life began at 4 Ga"*, but that is true only for the oceans. Water is essential for life, and the best that could be hoped for on land by a thin-membraned single-cell bacteria was a shallow rock pool, which then probably regularly dried out. Next was the issue of travel. Until the creation of spores, legs, wings or whatever, the best that bacteria could hope for was wind & waves. It therefore should offer little surprise that the fossil record suggests that all land was bare of life for 4 billion years apart from the odd, wind-blown specks of algal scum.

So, at Earth's beginning whilst very little life was happening on land & not a lot was happening in the seas, world-wide *"Plate Tectonics"* were beginning to ramp up, and the weather continued to be rampant.

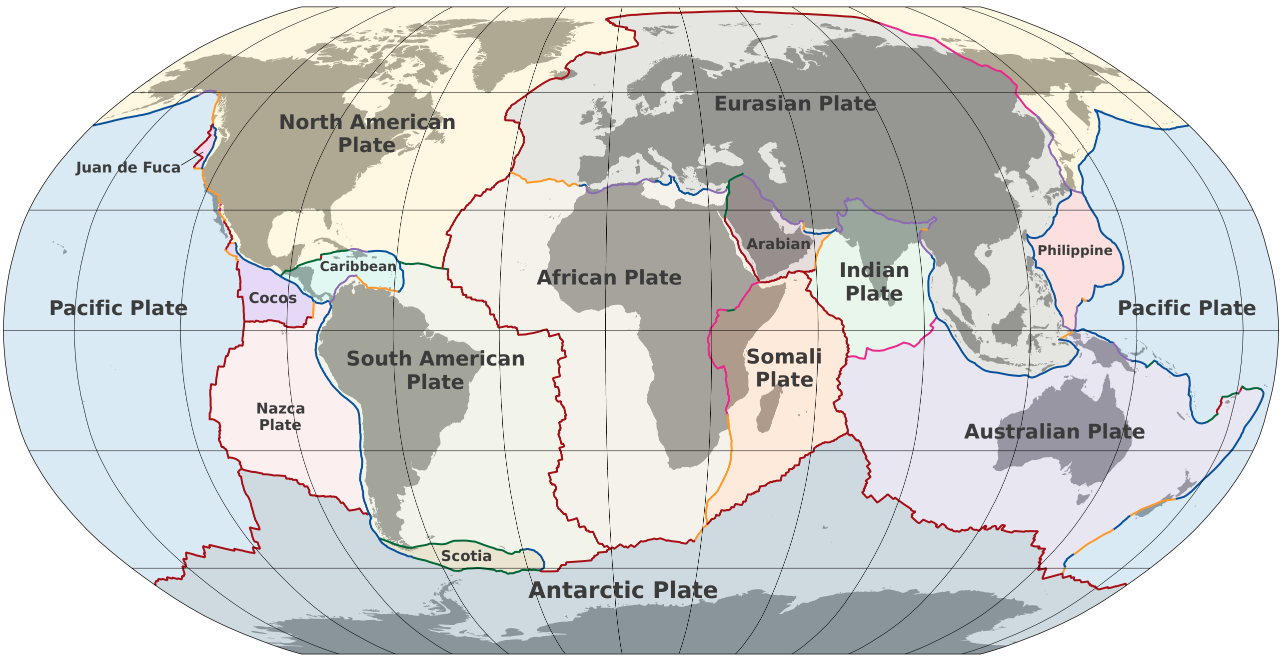

Figure 6: Map of Earth's Principal Tectonic Plates (wiki)

Evidence exists at 3.2 Ga for the beginning of Plate Tectonics (wiki). 'Vaalbara (wiki)' & 'Ur (wiki)' are both hypothesised as the 1st supercontinent, though without common agreement for either. By 2.5 Ga Plate Subduction (wiki) begins and that leads to basalt-remelting and thus to 'Cratons (wiki)'[8], which are permanent structures at the heart of continental Plates. Seismic tomography[9] has revealed, incidentally, remnants of *Theia* (see YouTube video), but more directly common properties for cratons: the latter is usually >2 Ga old, often >3 Ga and a few at 4 Ga (the

8 *The name 'Craton' derives from the Greek word (κράτος kratos) for 'Strength'; there are >50 named cratons.*

9 *CT for the planet: detailed investigation of seismic waves produced by earthquakes*

oceans are just 180 Ma). Non-cratonic lithosphere is typically 100 km thick, but cratons have more than twice that depth. They are usually lighter than the mantle or surrounding rocks & thus are buoyant, and are also stronger than other rocks due to low moisture content & re-melting. A further fun-fact is that diamonds originate in the roots of cratons (which then incidentally reveal their craton age).

As far as weather is concerned, we today exist within an inter-glacial in the middle of the Quaternary Glaciation (wiki). To try to put that into context, at 3.2 Ga, when modern-style plate subduction is believed to have begun, the oceanic temperature has been estimated at up to 85°C (just 15° below boiling point). At 2.9 Ga the sea surface was frozen for the first time.

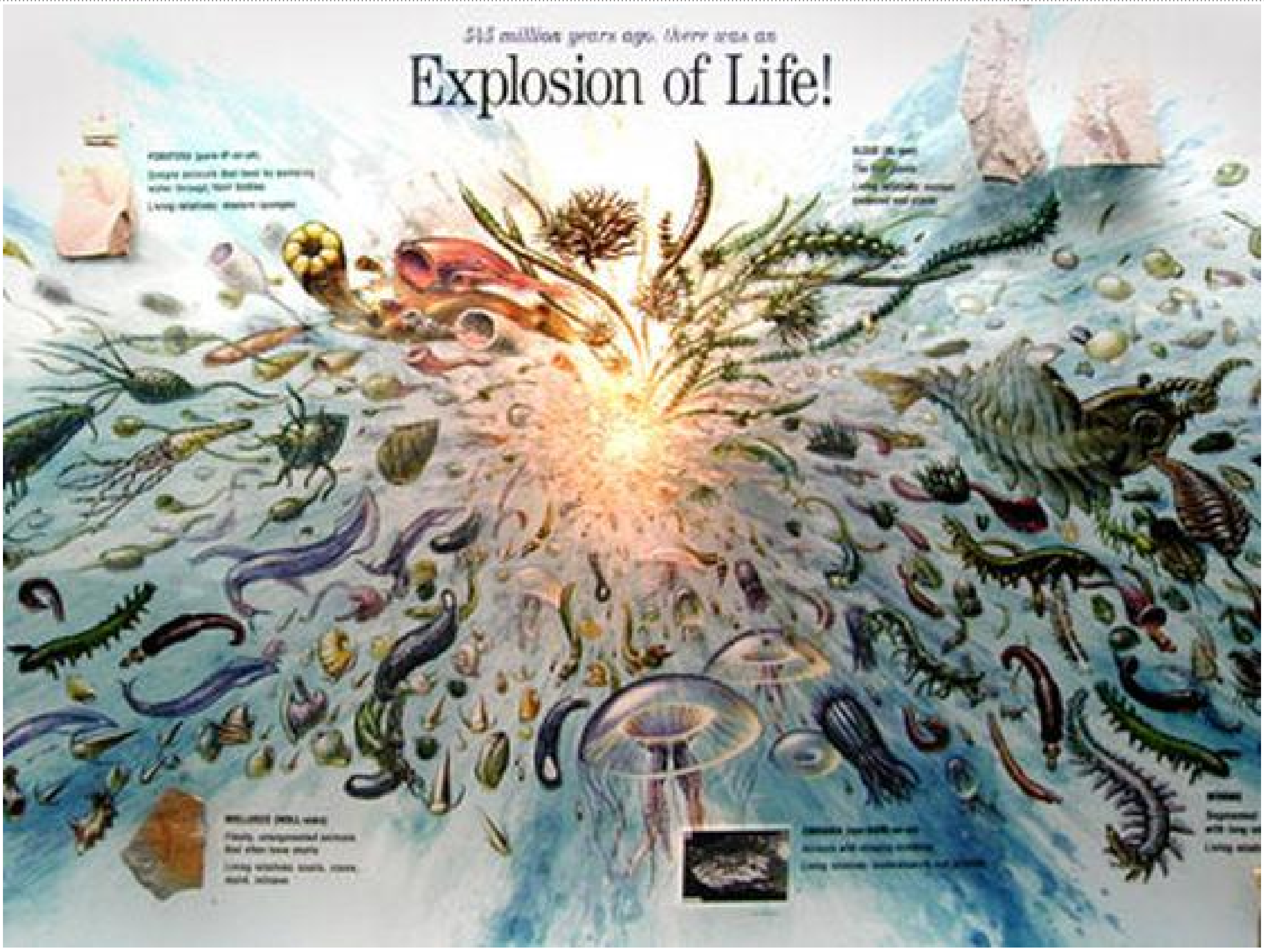

Figure 7: Cambrian Explosion of Life at Nexus NewsFeed

The situation described above is utterly transformed by the Cambrian Explosion of Life (wiki) within the seas, an event which began at about 538 Ma[10]. Before the Cambrian (wiki), early life on Earth is considered to be entirely single-celled, soft-bodied and living only within the seas; that means very few fossils (the early part Cambrian era is famous for the first abundance of fossils, although an abundance of animals appearing with hard chalk-shells may play a part in that). Now contrast the picture just painted with our modern age and indeed with yourself. We are the exact opposite of “single-celled”, and it therefore becomes clear that at some point between 3.0 Ga & 538 Ma living cells stopped being only unitary; some became cooperative families, whether as multicellular organizations such as cyanobacteria or slime molds (where it is a colony of identical cells), or as true complex multicellular organisms where each organism body contains a multitude of interconnected parts within the skin.

10 *Ma == ‘megaannum’ == “Million Years Ago” == 1,000,000 years == 10^6 years*

Sketching the Framework of a Miracle

I believe that the appearance of life, as briefly sketched in the previous paragraph, is actually more far-reaching & astonishing than most folks grasp. Consider the following:–

1. *3.0 Ga: 1st Appearance of an Animate Cell.*
   Stones only move if an external force affects them. A living cell moves if it decides to, and that fact is perfectly astonishing. The day when it occurred for the very first time must have rent the universe with wonder from top to bottom. Now something other than inanimate things existed & could observe the world. There was now more than just one thing in the world.

2. *2.4 Ga: Colonies of Bacteria form Cooperative Families.*
   The classic example is of cyanobacteria forming Stromatolites (colonies of identical cells glueing together sand-grains into circular pillars as homes – see Figure 1). Together they changed an entire world from Purple to Green. Jaw-dropping. Twice. And a bit frightening (80% of original anaerobic life was annihilated).

3. *2.2 Ga: Anaerobic Archaea unite in Symbiosis with Aerobic Proteobacteria.*
   As we all live within a world that was created from the union of two early proto-planets it should not really be a surprise that early single-celled life goes & mimics that identical process amongst themselves, creating eukaryotes (cells with nuclei). I do love, however, the way that the Wiki calls the anaerobes *"Asgard archaea"*, since that seems to call to the story within the *Book of Enoch* of Angels taking wives from amongst the women of the Earth.

   One example of the end-result of this symbiosis is Mitochondria (wiki), and it is worth pointing out that:–

   i. mitochondria have their own unique DNA
   ii. which DNA comes from the female line only
   iii. sexual reproduction is estimated to date from 2.0 Ga.

   The nucleus of Eukaryotes (wiki) contains all the cell DNA, with the notable exception of some mitochondria, which retain at least some unique genes locally.

4. *The symbiotes from (3) then go on to live within animals, fungi & plants.*
   That process is called '*endosymbiosis*'. One brilliant sentence quoted in the Wiki is: *"Life did not take over the globe by combat, but by networking"* (by cooperation). We will meet this again with both trees & mammals. However, it did not stop there.

5. *1.6 Ga The symbiotes from (3) can then undergo another merger, eg with cyanobacteria to create Chloroplasts.*
   This is yet another *endosymbiotic* structure, and one that lives within all plants & algae; it is the core feature that allows them to photosynthesise sunlight by means of *Chlorophyll*. This mechanism of '*symbiogenesis (wiki)*' was first suggested in the 19th Century and was finally substantiated with microbiological evidence in 1967.

Symbiogenesis:

here is one framework for this whole astonishing dance:–

Figure 8: Symbiogenesis at thoughtco.com (Getty Images)

a) An anaerobic archaea[11] develops a nucleus[12], becoming an *eukaryotic (wiki)* cell
b) An aerobic proteobacteria (wiki)[13] is engulfed by an anaerobic eukaryotic cell
c) Rather than being consumed, the two become symbiotes; specifically, the bacteria becomes endosymbiont†
   (in an era when the increasing oxygen in the atmosphere is poisonous for the Archaea, the ability of the Proteobacteria to feed on oxygen & supply energy to the cell is a positive benefit)
d) The endosymbiont† bacteria becomes an *organelle*[14]
   †'Endosymbiont' represents "an entire organism living inside another organism". That is, to point to an important example, exactly how every mammal digests it's food. Whilst recent estimates vary wildly, the human gut microbiome of bacteria, archaea and eukarya is reckoned to contain both more cells than the human host & a vastly more diverse genome. In every way, we are actually more bug than human[15].
e) The sequence of (a) + (b) is now reckoned always to have happened sequentially within the same moment where *Mitochondria* are concerned, and the sequence of (b), (c) + (d) is reckoned to have re-occurred many times (including acquiring multi-endosymbionts, with an example here at (5) with the creation of *Chloroplasts*).

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11 *Archaea are single-cell life that originated during the Archean Eon. They lack cell nuclei and have one single membrane enclosing the whole cell. This structure causes them to be termed 'Prokaryotes'*
12 *A cell nucleus is home to the cell DNA, the location for the cell genome (genes) & the centre from which cell mitosis will occur*
13 *Proteobacteria are prokaryotes; the significant feature is that these bacteria are aerobic*
14 *The movement from 'Endosymbiont' to 'Organelle' is achieved by a transfer of most of the symbiont genes to the host cell genome (and thus to the nucleus, meaning a closer marriage).*
15 *Oh, OK, it's probably an overstatement. But, the fact that we, like every mammal, are host to a huge range of other endosymbiont life, both within & upon our skin, is undeniable (see "Demodex folliculorum" (wiki)). I believe that a perfectly reasonable statement is that almost no human has ever managed to grasp the full range of what 'being human' actually means.*

Tectonics Dance

life is not the only entity holding hands & dancing (or is it?)

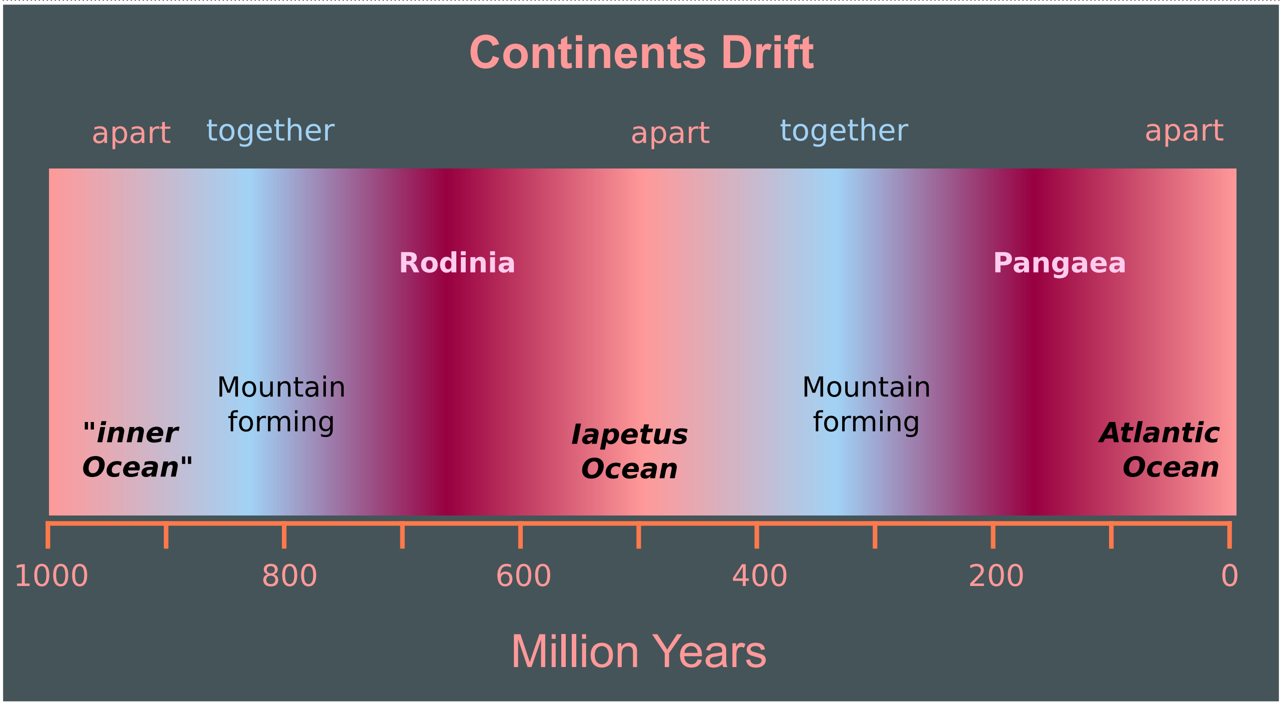

Figure 9: The Wilson cycle (plate tectonics) (wiki).

Whilst life is becoming complex, supercontinents are forming then breaking up in a cycle (or are they?).

It goes like this (disputed, naturally):–

I. 4.0 Ga: (unknown, but diamond ages suggest this)
1. >3 Ga: (possibly) Vaalbara (wiki) and/or UR (wiki)
II. >2 Ga: (possibly) Kenorland (wiki)
III. 1.8 Ga: Columbia / Nuna (wiki) forms
IV. ~1 Ga: Rodinia (wiki) forms
V. 0.6 Ga: Gondwana (wiki) forms (Pannotia (wiki) not fully accepted) (some think just one super-continent throughout the aeons until this time (which is the Ediacaran (wiki)))
VI. 0.3 Ga: Pangea (wiki)

Pangea is generally accepted as the most recent super-continent, but argument over all earlier super-continents continues.

There is a climate consideration about Pangea (and by reflection, *all* super-continents): it was a desert in the centre, and life could only have existed at the margins. The classic modern example to demonstrate this is Australia.

The Wilson cycle describes the cyclicity in plate tectonics by forming supercontinents (Rodinia, Pangaea) and its breakup in hundreds of millions of years. It is named after the Canadian geologist John Tuzo Wilson (1908-1993) (wiki).

Cambrian Period

the 1st Period of 12 in the Phanerozoic Eon (wiki)

(it goes: Cambrian, Ordovician, Silurian, Devonian, Carboniferous, Permian, Triassic, Jurassic, Cretaceous, Paleogene, Neogene, and Quaternary)
(there are four formally defined eons: the Hadean (wiki), Archean (wiki), Proterozoic (wiki), and Phanerozoic (wiki))

The Seas Explode with Life.

(or at least, now there are some fossils to show what happened)

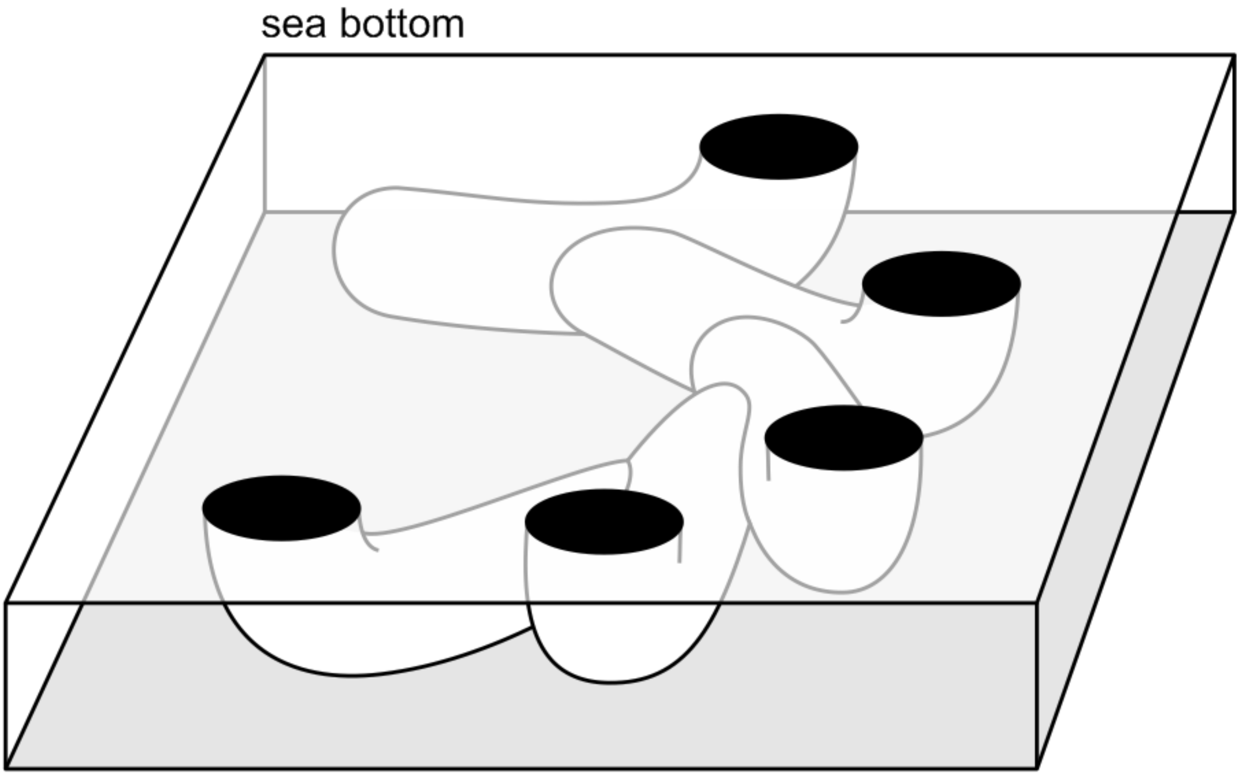

Figure 10: A 3D Illustration of Trace Fossils of Treptichnus Pedum (wiki)

The Ediacaran Period (wiki) ended at 541 Ma and the Cambrian Period (wiki) began. Land above sea-level at that time was dry & lifeless apart perhaps from some microbial soil crust. A little biofilm on land is unlikely to ever produce any coal, and that means that the astonishing 162m-thick 800 Ma Gondwana coal seams in India can only ever have originated within a life-rich sea. Even the beginning of the Cambrian at 538 Ma is linked with the 1st appearance of the trace fossil Treptichnus pedum (wiki) (above) (the animal itself was soft-bodied & left no fossil, but it burrowed immediately below the soil surface & those burrows left a fossilised trace of it's existence). There are a good number of trace fossils on/in land during the Cambrian. And that was that for life on or in the land throughout the Cambrian Period (wiki).

Ordovician Period

the 2nd Period of 12 in the Phanerozoic Eon

(it goes: Cambrian, Ordovician, Silurian, Devonian, Carboniferous, Permian, Triassic, Jurassic, Cretaceous, Paleogene, Neogene, and Quaternary)

The Pale / Green Horse

Figure 11: "Death on the Pale Horse" by Gustave Dore (wiki)

The Cambrian Period (wiki) ended at 485 Ma and the Ordovician Period (wiki) began. The first ever appearance of land-plants occurred at the middle of this period at about 466 Ma with plants that could produce spores (the plants themselves were too soft to produce fossils, but the spores had shells hard enough to both resist dessication during life and then across the aeons to fossilise & be discovered in our time). A million years before this appearance (and there is some argument as to whether the two are connected) were extensive bombardments by Chondrite meteorites (wiki). The southern continents were gathered together in the super-continent “Gondwana”, and it was positioned over the South Pole (that fact is soon to become important).

The final event of the entire period was the world’s first Mass Extinction Event (wiki) (the 2nd largest of all 5, as long as the *Oxygen Holocaust* at 2.4 Ga is ignored). The Ordovician began with intense greenhouse conditions causing hot weather and sea-surface conditions. The Earth began to cool & became temperate at the middle Ordovician, and glaciers & ice-caps on land appeared in the late Ordovician. Indeed, that time is considered to be the coldest ice-age in the last 600 million years of Earth’s history. It is considered that the expansion of terrestrial plants is largely responsible for this ice-age (presumably due to their removal of CO^2) and thus for the first pulse of the extinction, whilst the second phase that immediately followed was worldwide anoxic (low oxygen) conditions + toxic sulfide production. These extinction events were at 444 Ma & mark the end of the Ordovician Period (wiki) & the beginning of the Silurian Period (wiki).

Silurian Period

the 3rd Period of 12 in the Phanerozoic Eon

(it goes: Cambrian, Ordovician, Silurian, Devonian, Carboniferous, Permian, Triassic, Jurassic, Cretaceous, Paleogene, Neogene, and Quaternary)

The Silurian Period (wiki) began at 444 Ma and ran until 419 Ma when the Devonian Period (wiki) began, itself ending at the beginning of the Carboniferous Period (wiki) at 359 Ma. The Silurian saw the first fossil records of vascular[16] plants on land. These were the first life that became independent of needing a film of water across all cells. The material that the ducts were constructed from is called 'xylem', and that name is derived from the Greek word for wood. And so, finally, one of the most important plant-building material appears within this story of life, because xylem is constructed from Lignin (wiki) (that name is derived from the Latin word for wood - are you spotting a theme here?).

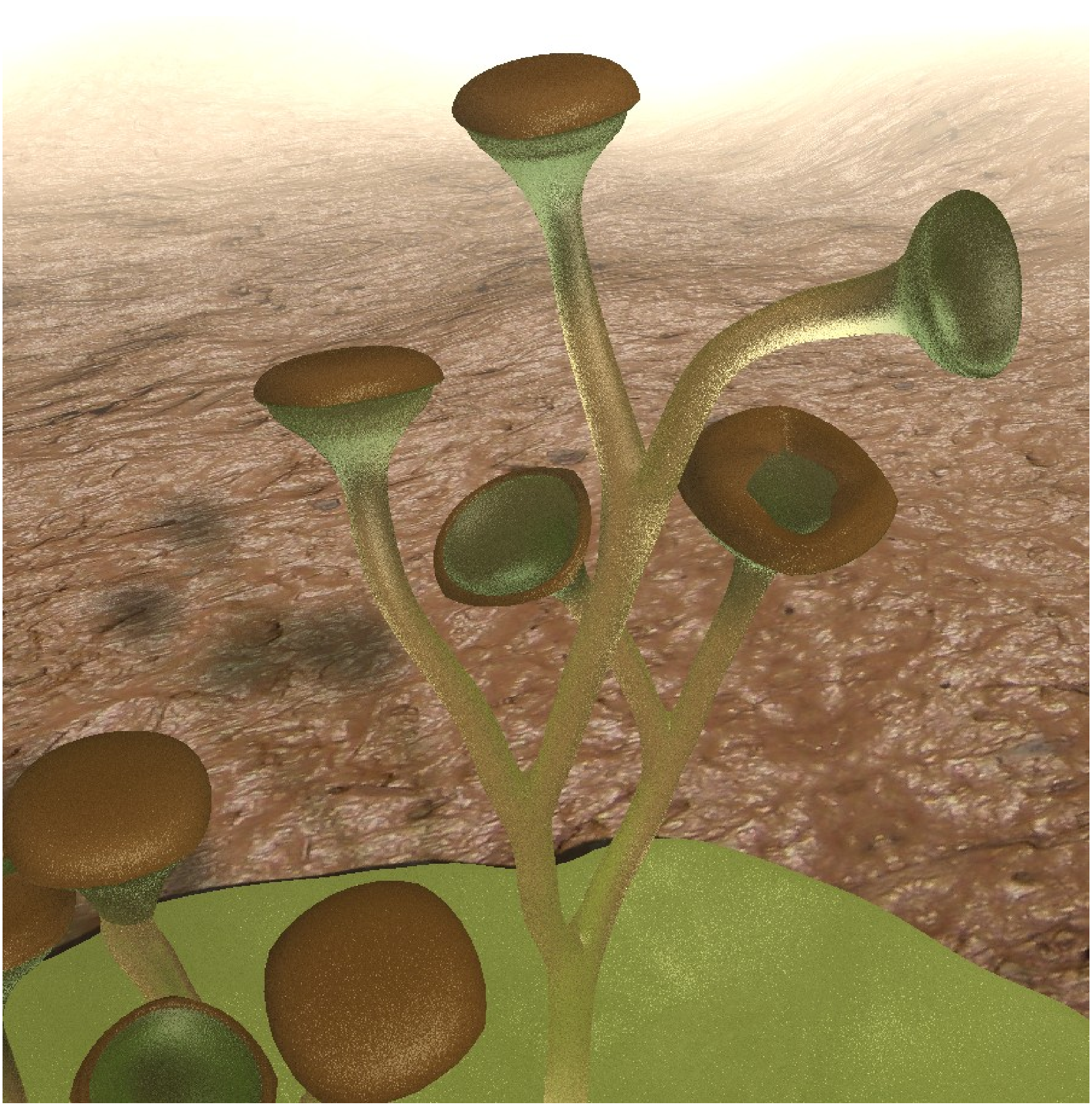

Figure 12: Cooksonia pertoni (vascular plant, Silurian) (wiki).

The ducts within vascular plants allow transport of water & nutrients throughout the plant. *Lignin* is a complex organic polymer that is durable, structural & hydrophobic, which latter helps the plant to

16 *Vascular: the name comes from the Latin word for 'duct'*

Figure 13: Woods: (LtoR: Pine, Spruce, Larch, Juniper, Aspen, Hornbeam, Birch, Alder, Beech, Oak, Elm, Cherry, Pear, Maple, Lime & Ash (wiki))

both transport water & resist drying out. *Lignin* also appears within red algae, suggesting a common ancestor for both red algae & vascular plants. *Lignin* has become in our time the 2nd most common organic polymer on the planet (the 1st is cellulose) (*lignin* composes 30% of current non-fossil organic carbon, and 20 to 35% of the dry mass of wood). It is the component within newspaper that causes it to turn yellow as it ages, and the self-same component needs to be extracted from wood-pulp in order to manufacture fine-paper (which is then used to print quality books, etc).

Chemically, *lignin* is a polymer made by cross-linking phenolic precursors. These precursors are termed 'monolignols' (alcohols), and there are 3 main ones which get termed 'H', 'G' & 'S'. Now, even if I knew *lignin* chemistry deeply (which I do not) I would not try to specify it for you, since it has a high level of diversity, and a molecular mass in excess of 10,000, and few have the time for that (for comparison, methane == CH^4 == mole 16.043). What is important at this level of exploration is to realise that *lignin* character/nature derives from (1): the balance of the precursors used, and (2): the degree of interlinking. To keep it simple (KISS) the main precursors are S+G; gymnosperms (softwoods, grasses) are mostly G, angiosperms (hardwoods) are both G & S, whilst palms are mostly S.

It almost seems that Nature was experimenting across the period of the Silurian + Devonian with differing *lignin* chemistry until it got a balance that it liked. At the beginning the ducts were not very strong and the plants were in consequence not very high. Land vegetation within the fossil record remained only a few centimetres high at the beginning of the Devonian. A 400 Ma fossil of a plant with woody tissue was reported in 2019. Wood is one key to height for plants but there are others. The development of roots, stems & leaves are found in the Devonian and, by Middle Devonian, actual trees had appeared and thus the 1st forests.

The complex of things required to support a forest is large and — in my observation — little spoken of, but let's try to enumerate some of it:–

Soil

1. This is merely the first in a long list of miracles. It may take hundreds, thousands, or even billions of years to produce. It occurs by the action of wind, wave, stream, ice and/or rock upon rocks (plants also create their own soil), and one key feature is the mean diameter of the eventual grains. Here are classifications for the same mineral at different diameters:–
   stones: > 2.000 mm
   sand: 0.050 mm – 2.000 mm
   silt: 0.002 mm – 0.050 mm
   clay: < 0.002 mm
2. The physical & chemical properties can depend upon the soil grain size. In the case of clay, it will even depend on whether the clay retains a marine environment, or whether the salt has been washed out. One key feature to understand is that the surface area of clay is huge when compared to other grain sizes. That means — as just one example — that it will hold large volumes of water and dry-out slowly.
3. It would be a mistake to concentrate only upon physical aspects. The house is obviously important, but so is the life that occurs within it. I think that the best example here is that it is very clear that one prime reason for the success of modern mammals lies in their dung[17], in that soil needs a steady supply of dung to feed the microscopic life that enable plants to exchange both nutrients & moisture, and also that the same (or similar) microscopic life is required by those mammals to be able to digest their food, which itself is supplied directly or indirectly by the plants. Try to get the point here, that there is a vast cooperation between multiple lifeforms, both below & above the soil surface, and it is perhaps hardly surprising that it took billions of years to put it all in place.

Addendum:

To try to underline the last phrase in the last sentence above, understand that both *Mammoths* & *Elephants* possibly had/have an inferior microbiome[18] compared to cows. That is suggested in the way that elephants are barely able to digest the vast weights of leaves that they eat (they need to eat a lot because they get so little out of each mouthful). That then further suggests that both mammals & bugs have had upgrades that are complementary and

17 *"what's brown & sounds like a bell?"*

18 *from Ancient Greek μικρός (mikrós) 'small', and βιος (bíos) 'life'*

connected. Last, that must surely also apply to the interaction between plants & bugs, but were they always perfectly in step? *Lignin* can be remarkably durable. As the planet evolved a version of *lignin* in the Late Devonian that could endure and was stable enough to support tall trees, had the planet also evolved life that could eat it when it died? 330m thick coal seams in Australia suggest that the answer is "*not until later*".

We can now begin to see a clear pattern from the *Cambrian* through to the *Carboniferous* of occupation of the land by life (*cheat sheet:* terrestrial plants are exceeding flat at the start & gradually get taller):–

Figure 14: Life on Land (one.org link)

Occupation of the Land by Life

A) Pre-Cambrian
B) 541 Ma Cambrian ("An Explosion of Life Within the Seas")
: at best, some microbial soil crust at the land margins
C) 485 Ma Ordovician
: arthropods[19] begin to spread to the land
D) 444 Ma Silurian
: mostly moss forests, and bacterial and algal mats
E) 419 Ma Devonian ("Age of Fishes")
: 419 Ma Early Devonian: vascular plants spread across the dry land, joined by fungal growth
: plants spread via spores
: most of the vegetation was like a low carpet
: a few very tall (8 metres, 26 ft) life is conjectured to be a fungal body
: stable soils develop around primitive rooted plants
: 400 Ma : wood-bearing plant fossil
: 393 Ma Middle Devonian: plant roots & leaves develop
: primitive land plants form forests which now are at shrub-height
: 382 Ma Late Devonian: seed-bearing plants
: 1st forests, with trees up to 9m tall (eg Cladoxylopsida + Eospermatopteris)
: tetrapods[20] begin to adapt to the land
: arthropods now established on land
: 375 Ma : Devonian marine extinction
: (4th largest of all 5) (carbon sequestration again is fingered as the reason)
F) (359 Ma Carboniferous)

Porous reef rocks from the Devonian Epoch (419-359 Ma) were perfect for holding the oil preserved by anoxic[21] oceans at the end of that age. The next age was the Carboniferous Epoch (359-299 Ma), which was the principal coal-creation era in the modern (Phanerozoic) Eon.

19 *Arthropods: these are invertebrates such as millipedes, spiders & insects*
20 *Tetrapods: these are four-limbed vertebrates*
21 *Anoxic: low oxygen conditions*

Fact Sheets

Terran Changes Timeline			
Time	*Eon*	*Period*	*Events*
15 Ka	Phanerozoic	Holocene	End of last glaciation; Holocene interglacial begins
2.58 Ma		Quaternary	Quaternary glaciation
50 Ma		Neogene	India collided with Eurasia (Himalayan mountains) & Australia collided with South-east Asia
66 Ma		Cretaceous – Paleogene	K-T event extinction (#5 of 5; 2nd largest of all 5); 75% or more of all species on Earth; all non-avian dinosaurs & large tetrapods; fungal life exploded
80 Ma		Cretaceous	N. America & Europe separated + Australia & Antarctica separated + India & Madagascar separated
140 Ma			South Atlantic ocean + Indian Ocean opened up + India separated from Antarctica and Australia
180 Ma		Early Jurassic	Gondwana began to breakup, forming central Atlantic Ocean (Africa/N. America) + Indian Ocean between Africa and Antarctica
201 Ma		Triassic –Jurassic boundary	End-Triassic extinction (#4 of 5; 3rd largest of all 5): flood basalt eruptions in the Central Atlantic Magmatic Province (CAMP) induced profound global warming + ocean acidification; dinosaurs to become dominant land-animal in Jurassic
252 Ma		Permian –Triassic boundary	End-Permian extinction (#3a of 5; the Great Dying; largest of all 5, ~80% of all species): flood basalt volcanic eruptions created the Siberian Traps, releasing huge amounts of carbon dioxide, elevating global temperatures and acidifying the oceans; catastrophic release of methane (from clathrates & other sources), destruction of ozone layer
255 Ma - 360 Ma		Permian, Carboniferous, Devonian	Karoo Ice Age
260 Ma		mid-Permian	Capitanian extinction (#3b of 5) (originally this got lumped in with the Great Dying; 5th largest of all 5): Emeishan volcanism caused an increase in atmospheric carbon dioxide that was both one of the largest and one of the most precipitous in the entire geological history of the Earth (for context, the end-Permian extinction involved CO^2 releases that rose 5x faster); volcanism also released high doses of toxic mercury.
273 Ma		early/mid-Permian	Olson's Extinction (#3c of 5) (originally called "Olson's Gap"; careful reviews confirmed it, but no accepted theory for the cause exists to date)
299 Ma		early Permian	Pangaea-supercontinent fully assembled as Gondwana + Euramerica + Angaran craton of Siberia combine (Cathaysia - N&S China) lay close to the east & together with other micro-continents later welded to the east margin of Pangaea
299 Ma - 359 Ma		Carboniferous	Name means "coal-bearing", due to the many coal-beds formed globally during this time
372 Ma		Devonian	Devonian extinction (#2 of 5; 4th largest of all 5)
400 Ma			Laurentian craton (USA) + Baltica craton + micro-continents form Euramerica
419 Ma			Fungal life common (and uncontroversial) on land; extensive colonisation of land by plants, leading to worldwide changes (including climate change) due to erosion & sedimentation-
419 Ma – 444 Ma		Silurian	
443 Ma		Ordovician	Ordovician extinction (#1 of 5 ; 2nd largest of all 5); came in 2 pulses: first was rapid switch from greenhouse to icehouse conditions during Andean/Hirnantian glaciation and affected life in Gondwana; second is immediately after end of glaciation due to worldwide anoxic (low oxygen) conditions + toxic sulphide production
420 Ma – 485 Ma			Andean glaciation
538 Ma		Cambrian	Beginning of the modern ages with an explosion of life within the seas & multiple fossils for the very first time

Terran Changes Timeline			
Time	*Eon*	*Period*	*Events*
538 Ma – 635 Ma	Proterozoic	Ediacaran	Multi-cell fauna began to appear for the first time; very few fossils exist
600 Ma			Gondwana fully assembled
573 Ma – 633 Ma			Pannotia (not fully accepted as a super-continent) (centred around the south pole; modern-day Africa was at it's centre)
633 Ma – 750 Ma		Cryogenian	Rodinia began to breakup
635 Ma – 720 Ma			Cryogenian (Snowball Earth)
542 Ma – 1.0 Ga		Cryogenian, Tonian	Gondwana-supercontinent began to assemble; (modern) South America, Africa, Arabia, Madagascar, India, Australia, and Antarctica
900 Ma – 1.26 Ga		Tonian, Stenian	Rodinia-supercontinent began to assemble
1.5 Ga		Calymmian	1st appearance of fungi; Columbia / Nuna supercontinent breakup
1.7 Ga		Statherian	1st appearance of multi-cellular life
1.8 Ga		Statherian, Orosirian	Columbia / Nuna supercontinent forms
2.0 Ga		Orosirian	1st appearance of sexual reproduction
2.4 Ga		Siderian	Oxygen Holocaust (1st mass extinction — 80% loss — classically restricted to Phanerozoic Eon): previous Eons were anaerobic, but cyanobacteria (blue-green) photosynthesis produced O^2; banded iron oxide deposits (ferrous iron is soluble but ferric iron is not); mitochondria hypothesised to date from this era as symbiosis between surviving archaea & aerobic bacteria which then went endosymbiont.
2.5 Ga		Siderian, Neoarchean	Huronian glaciation; reached a "Snowball Earth" & together with Oxygen Holocaust (see next) caused extinction of anaerobic microbial mats; the Earth thus changed from Purple to Blue-Green (from retinal to cyanobacteria); Plate subduction becomes active (and thus the formation of 'cratons' due to basalt remelting); oxygen begins to appear within atmosphere
2.9 Ga	Archaean	Mesoarchean	Pongola glaciation
3.0 Ga			Earliest undisputed fossils (single-celled life)
3.1 Ga			Ur as the proto-supercontinent hypothesised
3.2 Ga		Mesoarchean, Paleoarchean	Plate tectonics begins; Vaalbara supercontinent hypothesised
3.5 Ga		Paleoarchean	Earliest oxygen; photosynthesis begins?
3.8 Ga – 4.0 Ga		Eoarchean	Late Heavy Bombardment (LHB) likely stripped away any early atmosphere and/or oceans
4.54 Ga	Hadean	Hadean	Earth formed; 40m years later is the date suggested for collision between early Earth & Theia; thus origination of Earth's 'Gemini' nature, the Moon, and possibly also water (although the crust did not solidify until 100m years after formation)

Coal Seams & Locations			
Thick	*Age / Period*	*Location*	*Description*
330m	Black: Permian/Jurassic: 299/145 Ma Brown: Paleogene: 66/23 Ma	Gippsland Basin, Victoria, Australia	Many brown coal beds lie close to the surface and can be hundreds of metres thick
162m	(Gondwana) 800Ma	Singrauli, India	130–162m thick; also Jhingurda, India
30m	Carboniferous/Tertiary	Alpu, Turkey	Varies 10 to 30m for seam-A
24m	late Cretaceous to early Tertiary	Green River, Wyoming	4 sets of coalfields in Wyoming
20m	Early Permian: 293 Ma	Ordos Basin	No.6 seam, Heidaigou Mine, Ordos Basin, Inner Mongolia; seam is terrestrial rather than marine
8m	300 Ma	Warwickshire Thick	Warwickshire has a different concept of the meaning of ‘Thick’ to many other countries
6.7m	300 Ma	Pittsburgh, USA	Seams average about 8 feet … as much as 22 feet
4.3m	Early Permian	Georges Creek, Maryland	
2.4m	Carboniferous	South Staffordshire, UK	Both marine & some land-plants found as fossils within the coal
1.5m	Early Carboniferous	Burnley, UK	Most seams seldom exceeded 1.5 metres thickness; (sometimes) the thickness was only 0.5 metre
(varies)	Carboniferous (300 Ma)	South Yorkshire, UK	1.2 km total thickness, but individual seams vary a lot and are usually very thin

Snippets

Gondwana:

(also a region of central India)

… is the name given to the southern region of the super-continent of Pangaea by Austrian geologist Eduard Suess.

Alexander Du Toit, a South African geologist, in his 1937 book "Our Wandering Continents" documented geologic and palaeontological lines of evidence that linked the southern continents.

Pangaea:

(the last super-continent)

… was conceived of by Alfred Wegener, a German meteorologist, in 1912

Coal Seam Formation:

(https://energyeducation.ca/encyclopedia/Coal_seam)

Coal seams are formed from dead and decaying organic matter. Generally, this matter came from ancient peat bogs that died and fell into shallow, stagnant waters. As this material decayed, it became peat over time. As this peat was buried under sediment, the temperature increased and the pressure became greater. This compression and heating slowly turned the soft peat into harder lignite coal. With further burial and compression this brown lignite coal became sub-bituminous coal, then bituminous coal, and finally anthracite coal.[4] Regardless of the size or placement of the coal seam this formation pattern remains the same.

The size, location, and accessibility of coal seams can vary widely. Due to extreme pressures involved in the compression of the peat in the formation of coal, about 10 metres of peat will only form around 1 metre of coal. However, the thickness of the coal bands can vary significantly depending on the amount of peat that was initially buried. Coal seams have been found that are as small as 30 centimetres (or approximately a foot) all the way up to more than 30 metres wide.[2] Additionally, these seams can be buried either very deeply or fairly close to the surface. Most of the time the deeply buried seams are mined using deep mining techniques whereas ones close to the surface are obtained through strip mining.

In India, coal seams of >4.8m thickness are called "thick"

In China, coal seams are divided into thin coal seams (<1.3m), medium thick coal seams (1.3–3.5m), thick coal seams (3.5–8m), and extremely thick coal seams (>8m)

Bituminous coal and lignite seams (mined in 1945) of the United States and Alaska range from less than 2 feet in thickness to more than 50 feet, but the majority of the Nation's coal mines produce from seams 3 to 6 feet thick and the average of the country is 65 inches.

The adopted limit to call a coal seam thick in India is 4.8 m, which is on higher side of the range. Even after adoption of this higher limit, over 60% of the total coal reserve in the country belongs to thick seams. It is difficult to find any regular pattern of the coal seam thickness due to diverse depositional conditions of different coalfields. Some of the thick seams are nearly 30 m thick, while one exceptionally thick coal seam in Singrauli coalfield is 162 m thick.++

Burnley, UK: Regrettably the thin seams were a strong inducement to use child labour until the Act of 1842 prohibited the employment of children below the age of 10 in underground workings. Previously children of both sex were employed as 'drawers' or 'pushers' for hauling coal throughout the workings to the pit bottom. … Thus for a weekly wage of four shillings (20 pence) a seven year old boy, working eight hour shifts, pushed tubs of coal along one metre high roadways for distances of 135-180 metres in the Shell Coal at Vicarage Colliery (SD873334). Conditions were even worse at Burnt Hills Colliery (SD828286) where roadways in the Lower Mountain Coal were only 0.76 metre high.

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