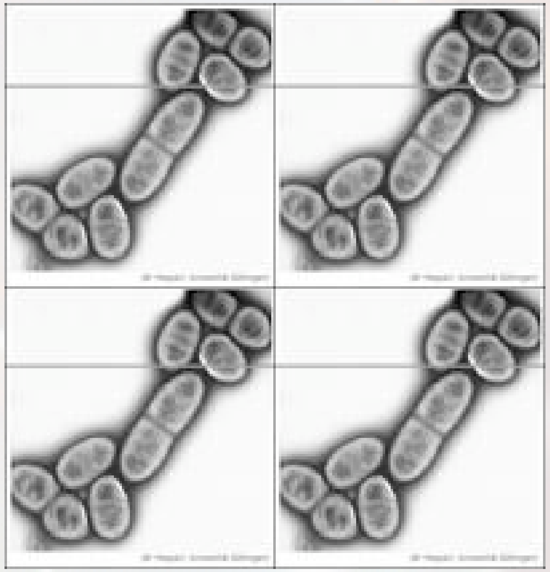

Wir sind nicht allein
Forscher glauben an Leben im All


FACTS
FACTS
DAS SCHWEIZER NACHRICHTENMAGAZIN
Schweiz wohin?
Die Pläne
der Chefs von
SP und SVP
Wir sind nicht
allein
Forscher glauben an Leben im All

BUT

Are we surrounded by



or

?

Thesis

Life is widespread in the universe,
but complex life is rare!

Thesis

So, we surrounded by

but not

RARE EARTH

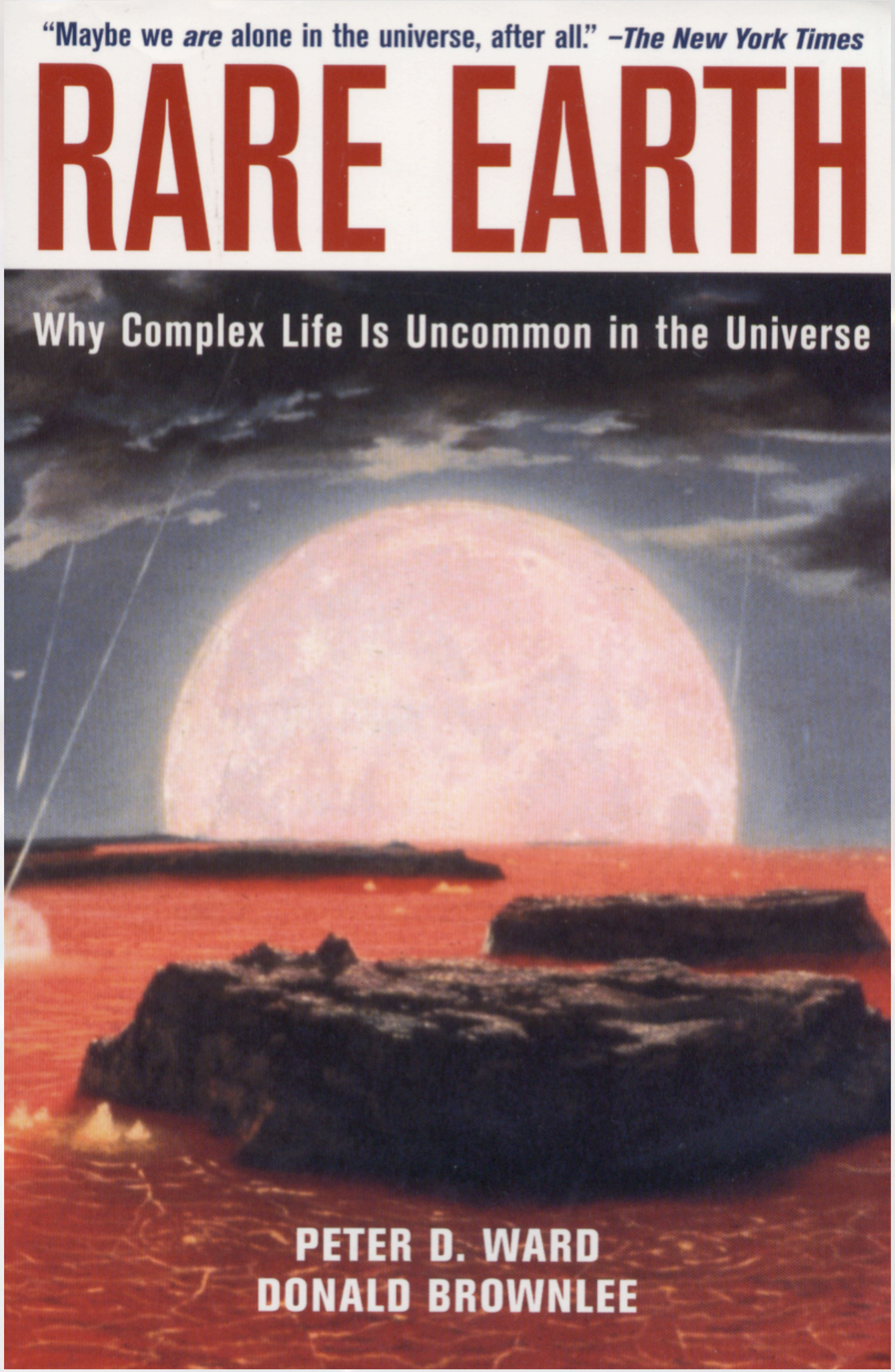
Why Complex Life is Uncommon in the Universe

Ralf
Klessen

after a book by
Peter D. Ward
Donald Brownlee

Rare Earth

and maybe this is good so …


"Maybe we are alone in the universe, after all." –The New York Times
RARE EARTH
Why Complex Life Is Uncommon in the Universe
PETER D. WARD
DONALD BROWNLEE

Content

- Why life may be widespread in the universe
- Habitable zones in the universe
- Life’s first appearance on Earth
- How to build animals
- Enigma of the Cambrian explosion
- Mass extinctions and rare Earth hypothesis
- Importance of plate tectonics
- Moon, Jupiter, and life on Earth

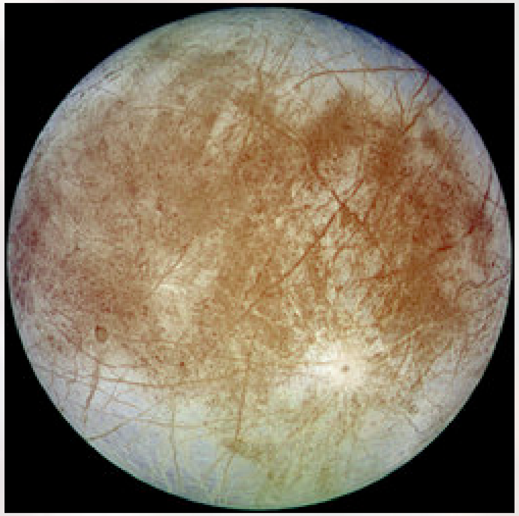
Life is common

- There is life everywhere on Earth!
  - ocean (shore, deep sea, volcanic vents)
  - land surface (largest diversity)
  - ice (Antarctica, Greenland)
  - in soil and rock
  - in boiling water

hydrothermal vent, thriving with life

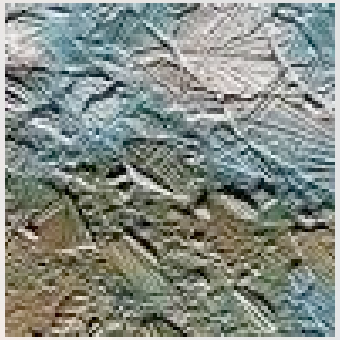
Life is common

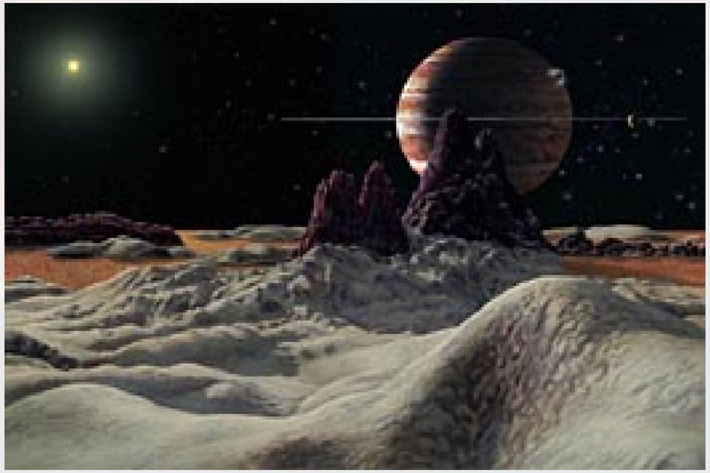
- There is life everywhere on Earth!
- But what about different places in the universe?
  - planets: Mars?
  - moons: Europa? Io?
  - exoplanets?
  - ? ? ?

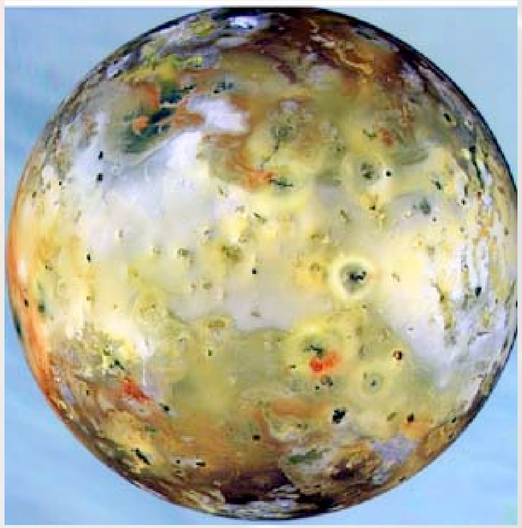


Europa

surface details







Io

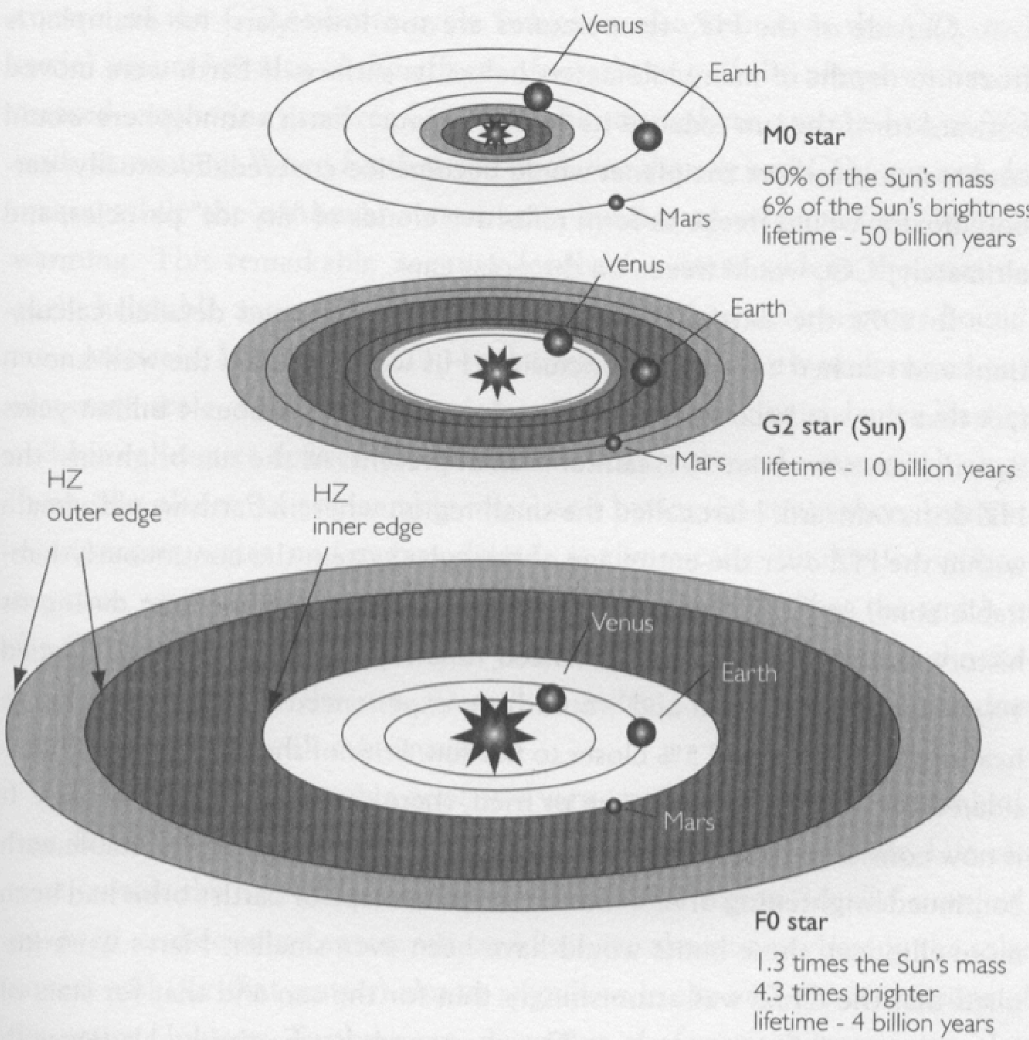


Figure 2.1 *Estimates of the habitable zones (HZ) around stars that are slightly less and slightly more massive than the Sun (based on results of Kasting, Whitmore, and Reynolds, 1993). Two estimates of the cold outer edge of the HZ are based on the temperature where* CO_2 *(dry ice) begins to condense in the atmosphere (inner limit) and the theory that Mars was in the Sun's HZ early in its history (the outer limit). The hot inner edge of the HZ is estimated both in terms of the belief that any oceans on Venus boiled away at least a billion years ago and in terms of estimates of the atmospheric conditions required to produce runaway greenhouse heating.*

Building Habitable Earth

- Requirements
  - “habitable zone” around long-lived star
  - right size to keep atmosphere
  - heavy elements
  - water/oceans (but not too much)
  - plate tectonics
  - right tilt (seasons)

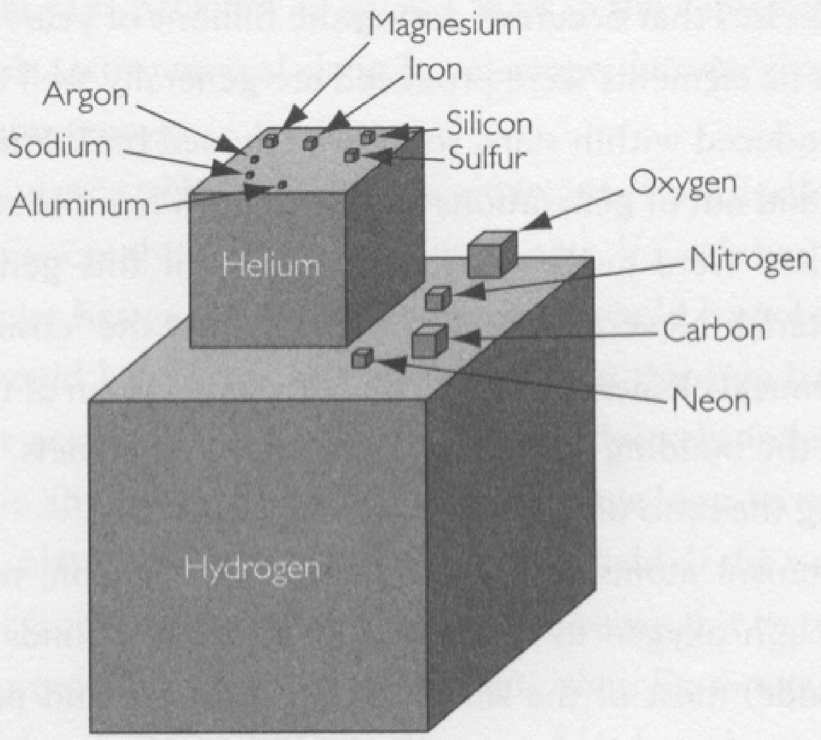
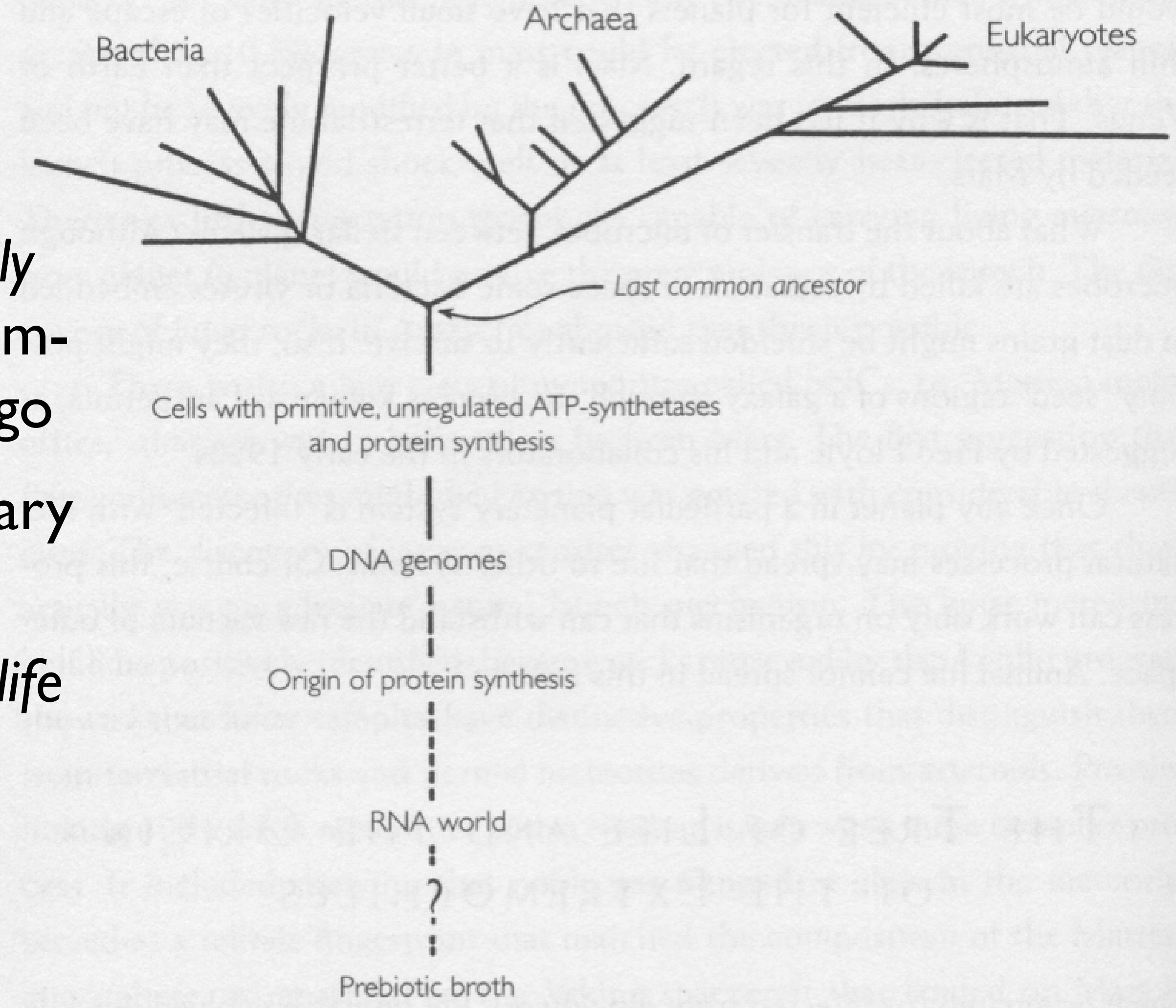


Figure 3.1 *The relative proportions (by number) of the most abundant elements in the Sun. Hydrogen and helium and the elements resting directly on top of the hydrogen cube dominate the composition of stars and Jovian planets. The terrestrial planets could not efficiently incorporate these elements and are composed largely of oxygen and the elements resting on the helium cube.*

First Appearance of Life on Earth

- Earth age: *4.6 Ga*
- Recipe for life: RNA/DNA
- life started *immediately* after end of heavy bombardment: ~ *3.6 Ga* ago
- importance of planetary cross-talk !?
- enigma of the *tree of life*



possible evolutionary sequences

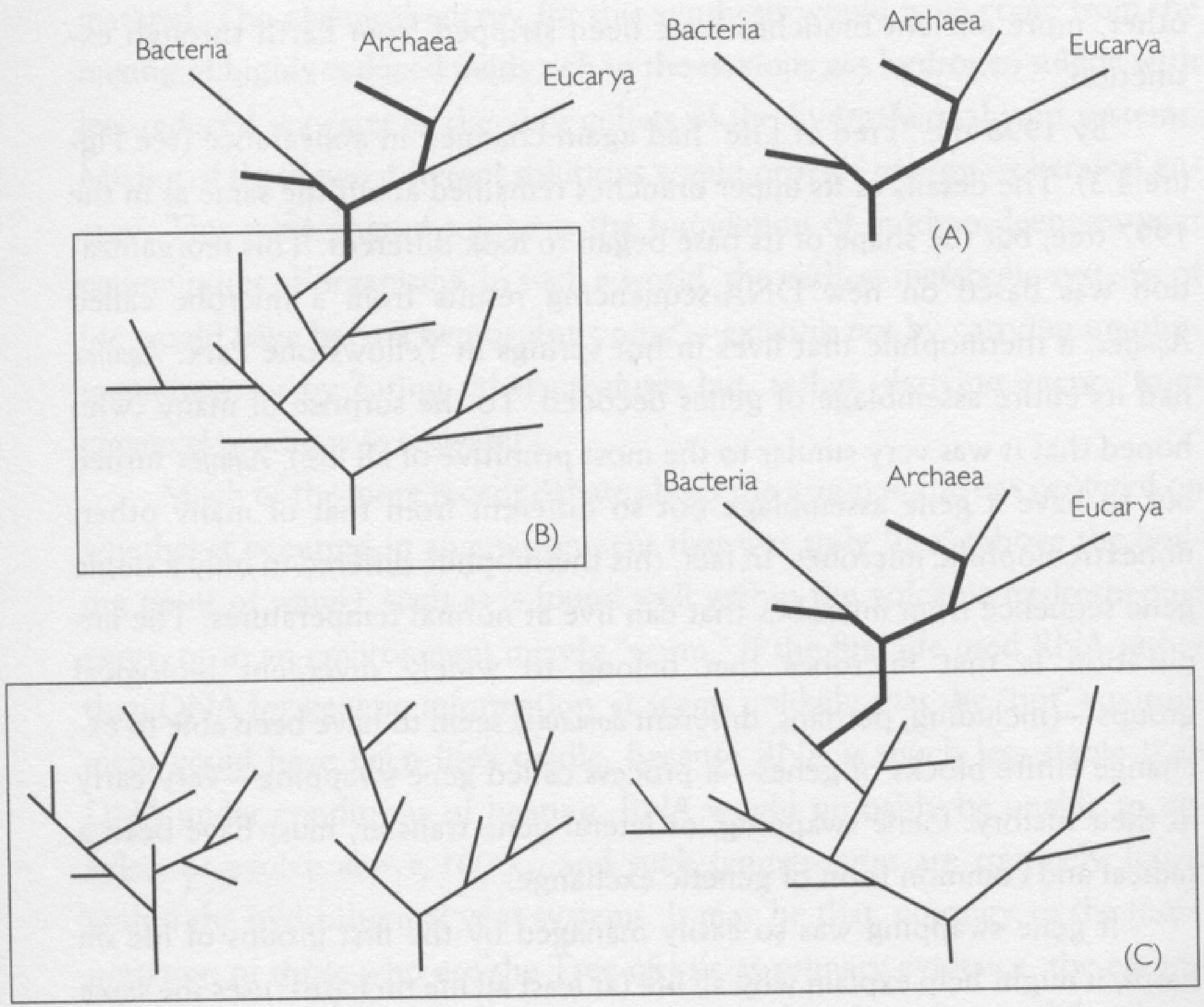


Figure 4.2 *Three alternatives for the evolution of life on Earth and its "Tree of Life." In (A), the three domains of life are seen to originate from a single common ancestor. This is the widely accepted "Tree" found in most texts today. In (B), the tree seen in (A) sits atop an older and currently unrecognized series of branches. In this interpretation, DNA life as we know it had a long prehistory with no preserved record. In (C), life is composed of several distinct types that independently evolved on the early Earth, with only one (DNA life) surviving.*

How to Build an Animal

- What is the origin of complexity?
- prokaryotes (archaeans & bacteria) vs. eukaryotes

Eukaryotes:
- DNA is contained in nucleus
- have other enclosed bodies in cell (mitochondria: energy, chloroplasts: photosynthesis)
- sexual reproduction
- flexible cell walls, which enable them engulf other cells through phagocytosis
- internal scaffolding system which controlls location of internal organelles: cytoskeleton (also helps at DNA replication)
- cells can be very large (on average eukaryotic cells are10.000 greater than prokaryotic cells)
- more DNA (~1.000 larger than for prokaryotes)

How to Build an Animal

- What is the origin of complexity?
- prokaryotes (archaeans & bacteria) vs. eukaryotes
- oxygen revolution

Oxygenation of atmosphere:

- 3.6 Ga ago: stromatolites ("stone mattresses) came in large quantities (probably from hydrothermal or deep-earth environment) and produced 6×10^{14} kg of iron oxide (as seen in banded-iron formations)
- eventually reservoir of dissolved iron was used up --> sea and atmosphere became saturated with free oxygen
- oxygen revolution ~ 2.5Ga ago
- most of all living creatures on Earth died (as many of Earth's most primitive organisms are incapable of dealing with free oxygen)
- some "old species" survived in airless habitats (ocean bottoms, rock, etc.)

How to Build an Animal

- What is the origin of complexity?
- prokaryotes (archaeans & bacteria) vs. eukaryotes
- oxygen revolution
- evolution of eukaryotic form and function

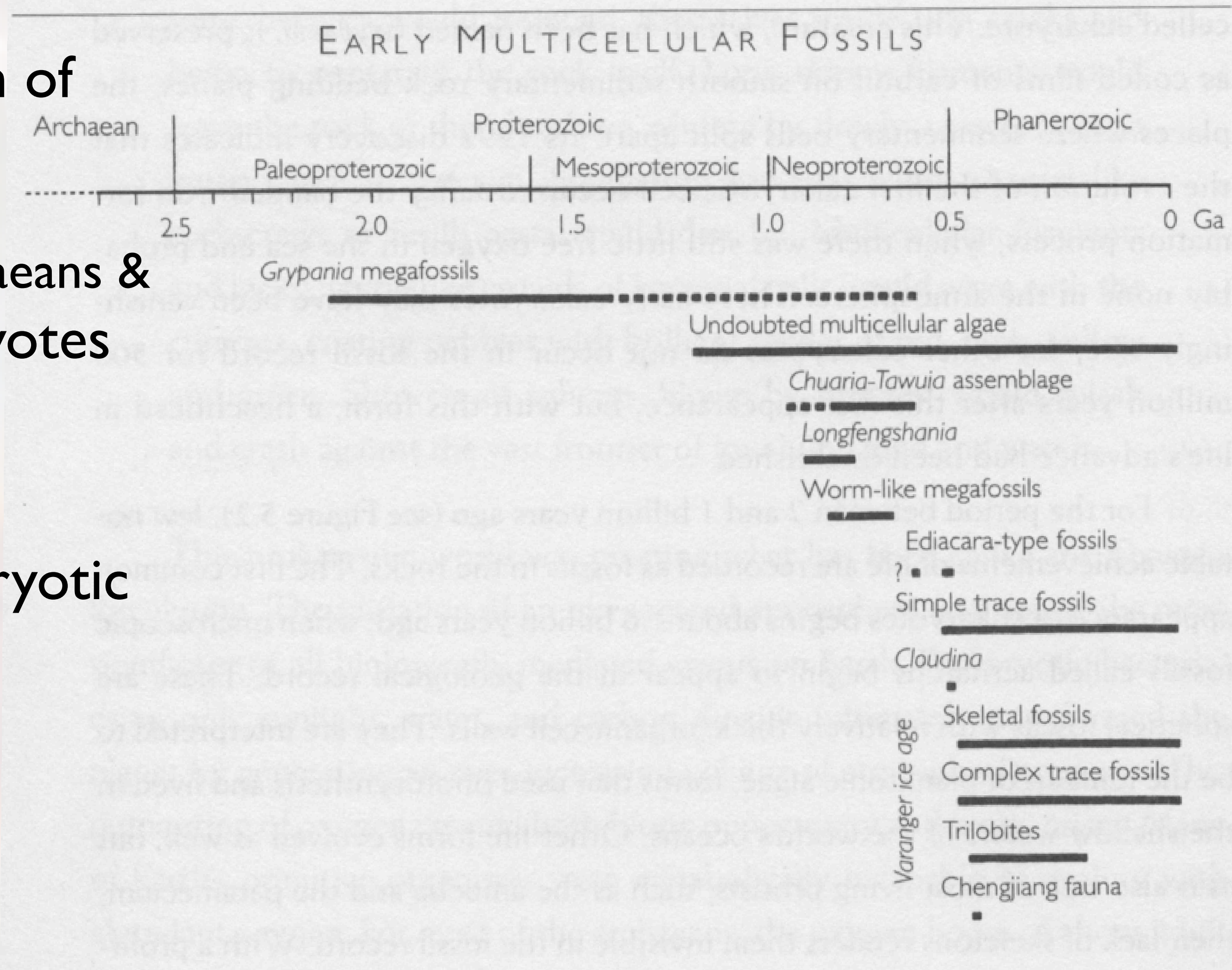


Figure 5.2 *Early multicellular fossils. Broken bars indicate uncertain time ranges.*

Cambrian Explosion

- About 550 to 600 Ma ago, the number of animal phyla *exploded* "Cambrian explosion"
- What is the trigger?

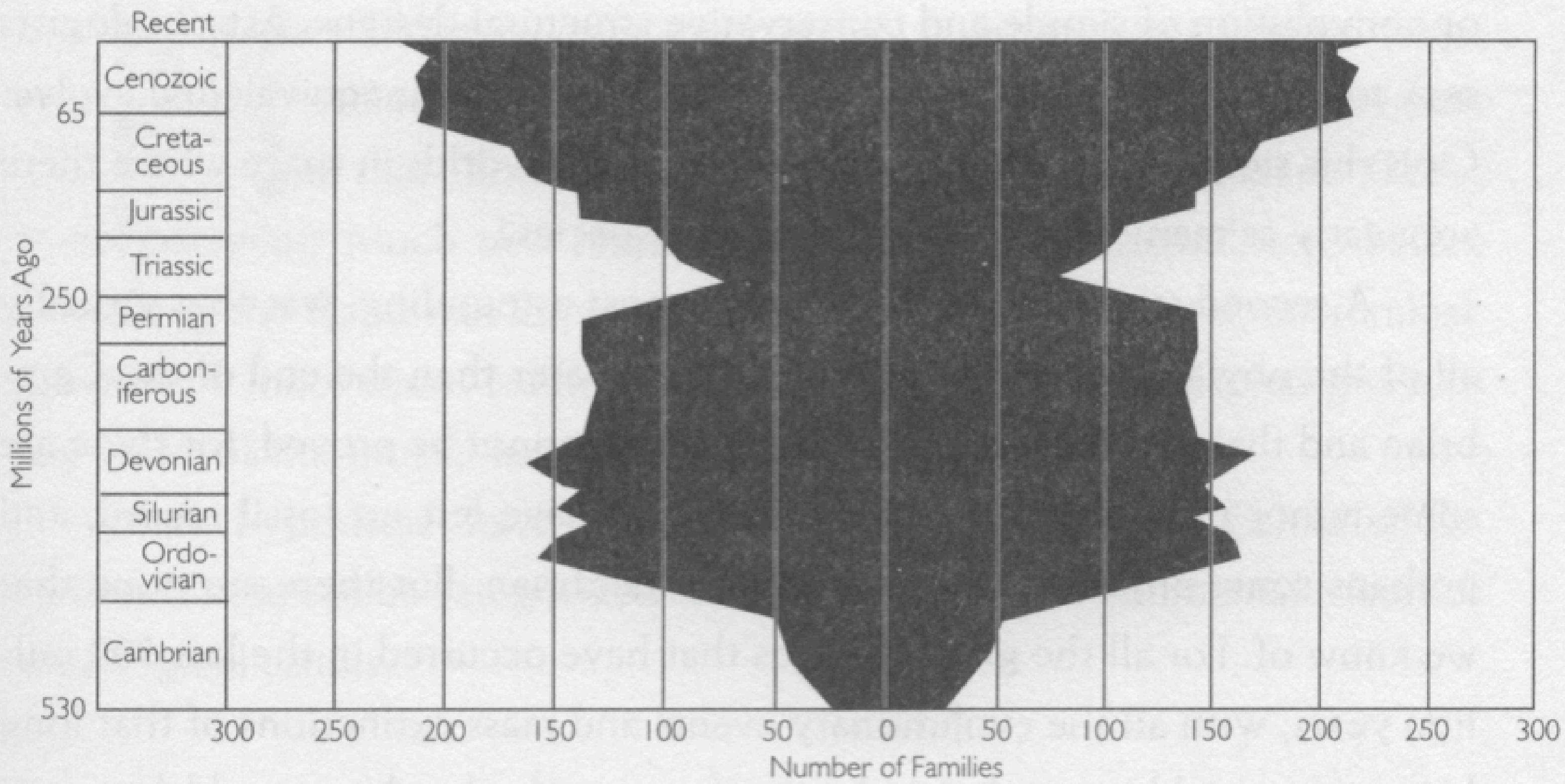


Figure 7.2 *Fluctuations in the number of families, and hence in the level of diversity, of well-skeletonized invertebrates living on the world's continental shelves during the past 530 million years are plotted by geological epoch in this graph. Time proceeds upward.*

Cambrian Explosion

- About 550 to 600 Ma ago, the number of animal phyla *exploded* "Cambrian explosion"
- What is the trigger?

Possible triggers:
- oxygen level reaches critical threshold value?
- nutrients became available in large quantities?
- temperatures became moderate again following the Precambrian "Snowball Earth" events?
- inertial interchange event (continental drift with profound influence on climate -- change of ocean currents, release of greenhouse gases, formation of ice caps, etc...)

Possible triggers:
- first occurance of (fossilable) skeletons (shells, bones, etc.)

Cambrian Explosion

- About 550 to 600 Ma ago, the number of animal phyla *exploded* "Cambrian explosion"
- What is the trigger?
- Cambrian explosion / cessation?

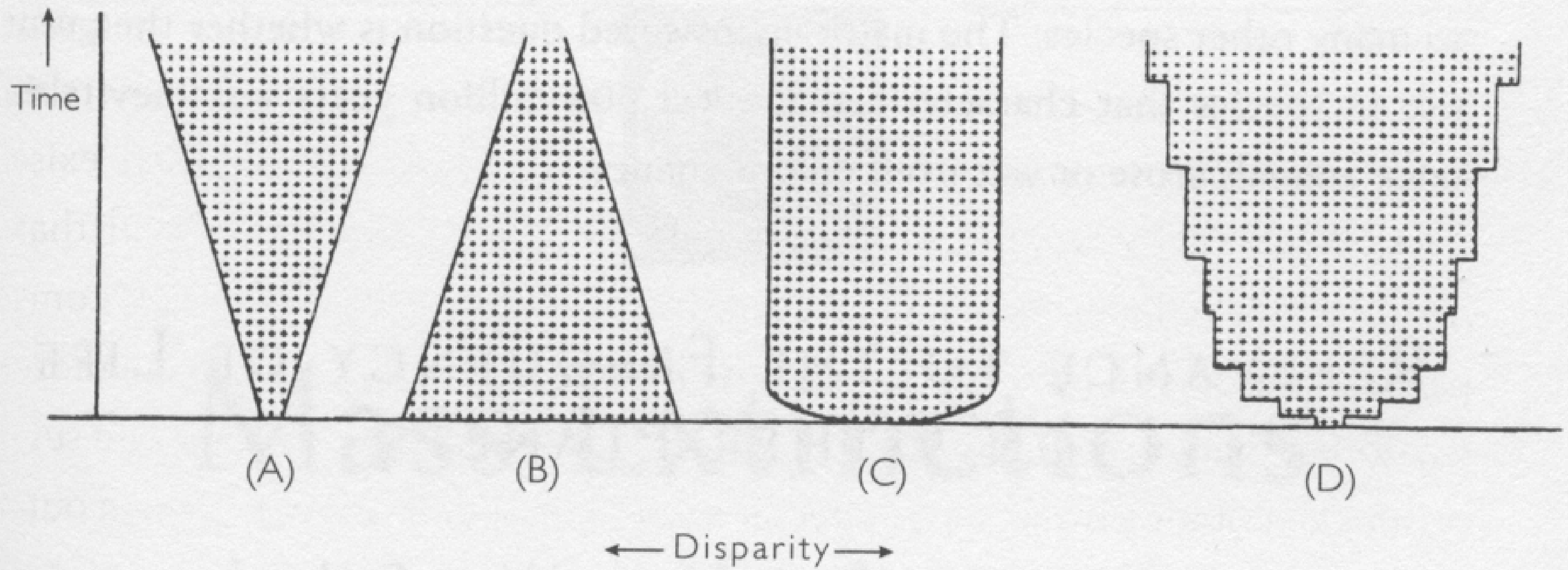


Figure 7.3 *Various interpretations of the history of life and its disparity. (A) The traditional view, whereby disparity steadily increases through geological time. (B) The view presented by S.J. Gould, whereby maximum disparity occurred in the Cambrian. (C) The view that disparity increased very rapidly in the Cambrian and thereafter stayed much the same. (D) The view that disparity increased rapidly in the Cambrian and since then has generally increased, though at varying rates. (From Simon Conway Morris.)*

Mass Extinctions

- Mass extinction have the potential to end life on any planet.
- On Earth, ~ 15 such episodes during past 500 Ma, 5 of which eliminated more than half of all species inhabiting our planet.

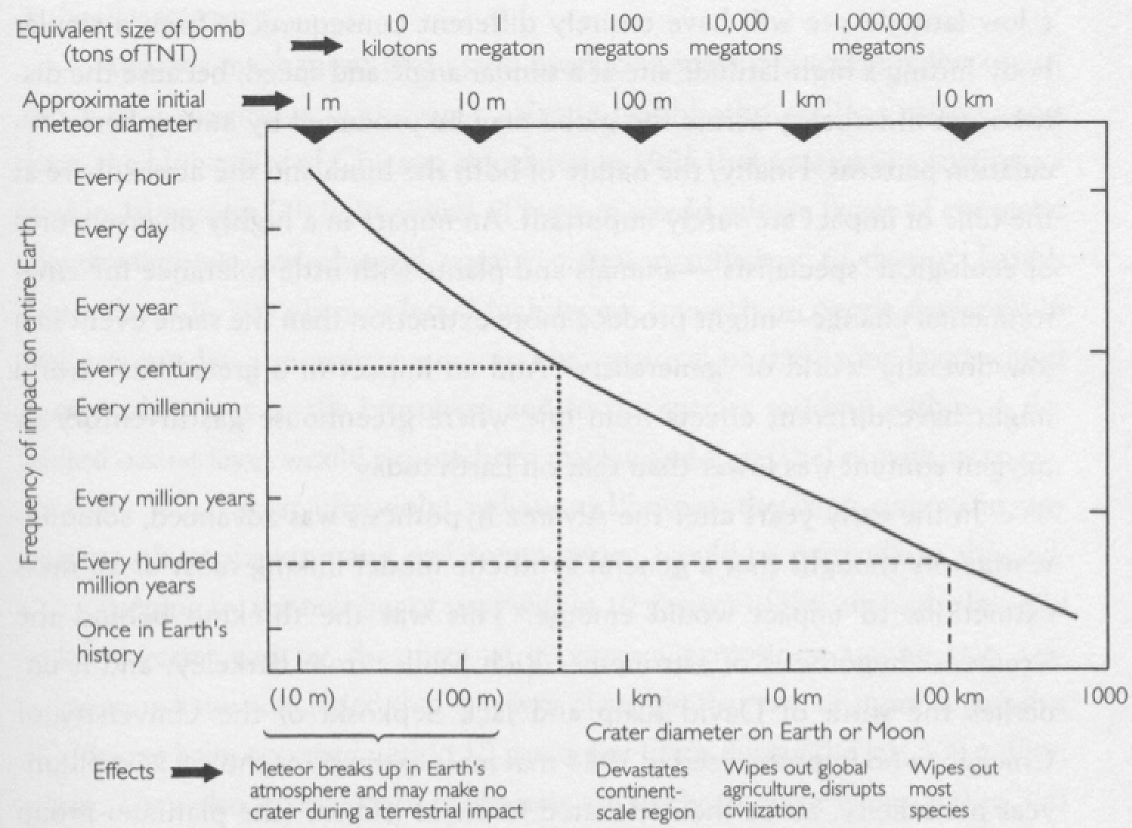


Figure 8.1 *The rate of meteor impacts at the top of Earth's atmosphere as a function of meteor size. Bottom scale gives crater size for typical impact velocity of about 15 kilometers per second. Top scale gives meteorite size and energy in terms of tons of TNT. Dotted line shows the scale of the Siberian meteoritic explosion of 1908. Dashed line shows the scale of the impact 65 million years ago that wiped out dinosaurs and other species. (After Hartmann and Impey, 1994; 1993 data from E. Shoemaker, C. Chapman, D. Morrison, G. Neukum, and others.)*

Mass Extinctions

- Effects of mass extinction

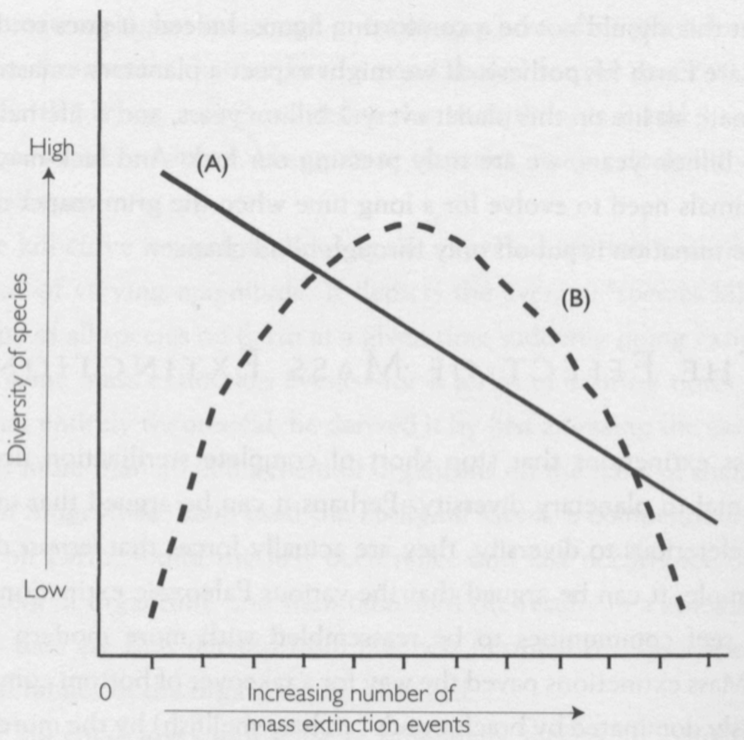


Figure 8.2 *Two models of how mass extinction affects diversity. (A) Increasing number of mass extinction events leads to ever lower diversity. (B) There is some critical number of mass extinction events that causes lower diversity.*

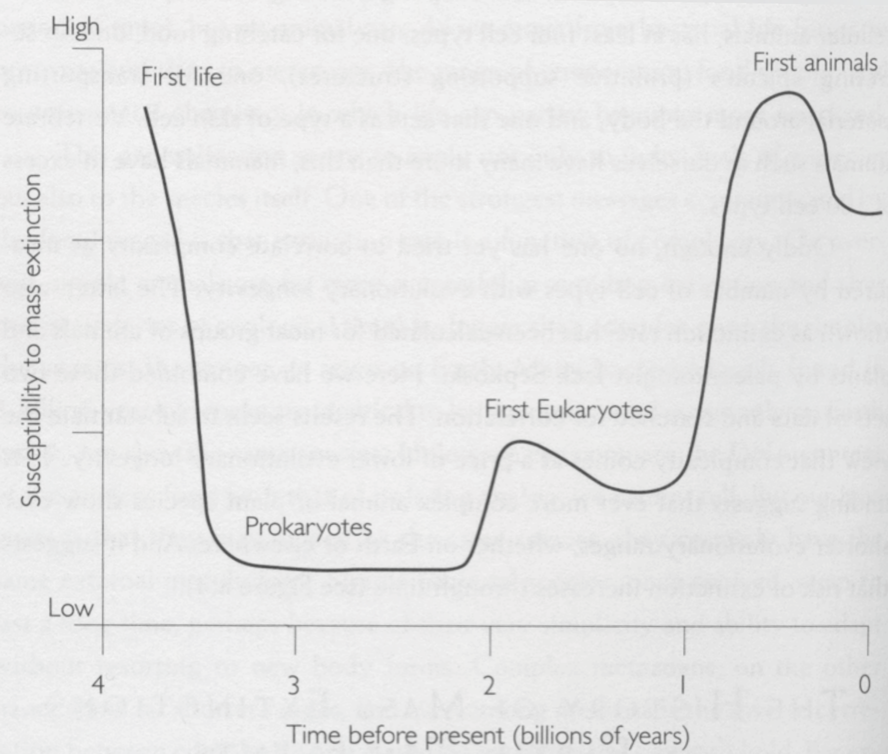


Figure 8.4 *Hypothesized curve of extinction "risk," or susceptibility, through time. Extinction risk is highest soon after a new evolutionary type appears and then lessens as diversification occurs. Diversification is insurance against extinction.*

Mass Extinctions

- 15 events in past 500 Ma
- some more important ones:

- bombardment extinction
  4.6 - 3.6 Ga ago
- advent of oxygen
  2.5 - 2.2 Ga ago
- Snowball Earth events
  750 - 600 Ma ago
- Cambrian mass extinction
  560 - 600 Ma ago
- Ordovician & Devonian
  extinctions: 440 & 370 Ma
- Permo-Triassic event
  250 Ma ago
  (most devastating of all events: 50% of families and 90% of all species extinct)
- end-Triassic extinction
  202 Ma ago (50% of all genera)
- Createous/Tertiary boundary
  event, 65 Ma ago
  (dinosaurs)
- modern extinction
  (since end of last glacial period, Earth experiences one of the largest extinction rates ever)

Plate Tectonics

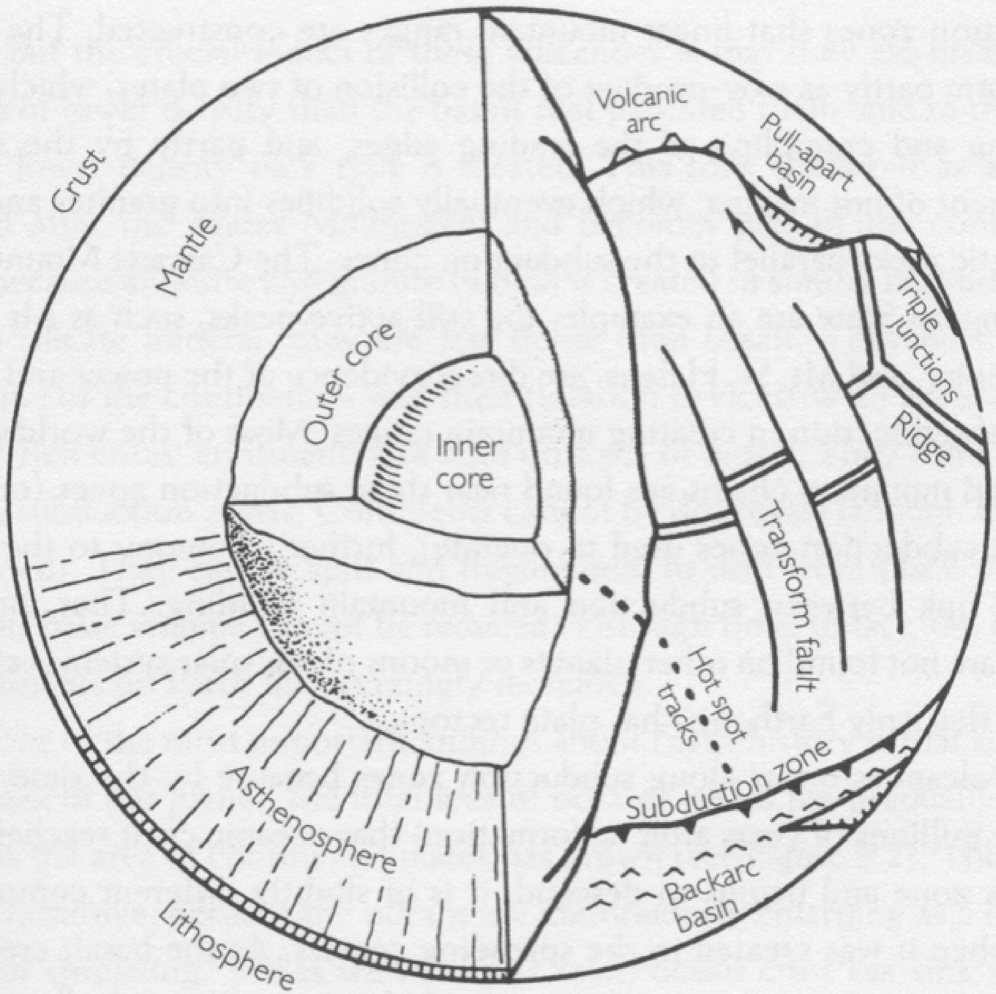


Figure 9.1 *Schematic diagram displaying the principal features of the lithosphere, the rigid plates 50–150 km thick that incessantly move about on Earth's surface, created along the 56,000 km of spreading-ridge systems and consumed along the 36,000 km of subduction zones.*

Plate Tectonics

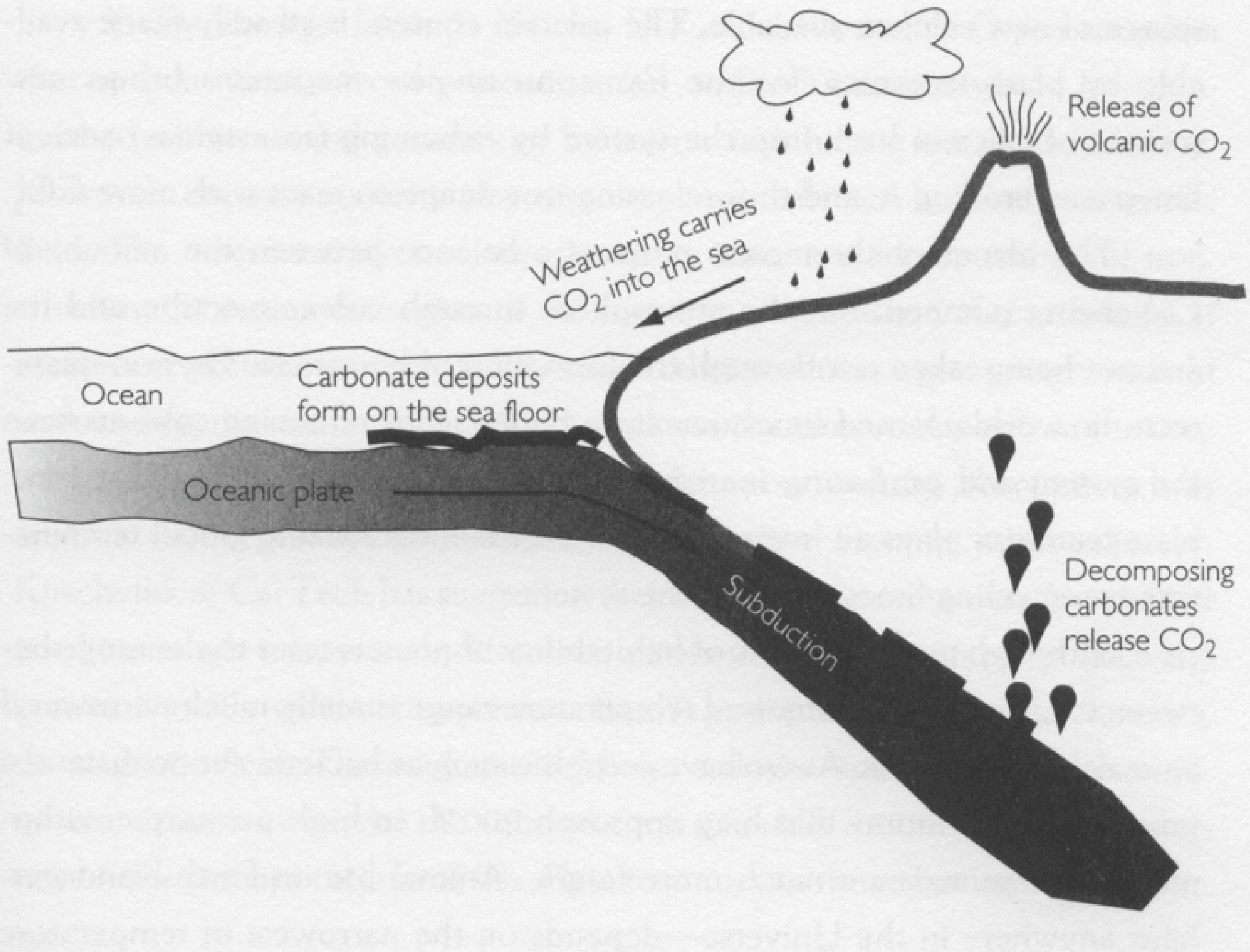


Figure 9.3 *The CO_2–rock weathering cycle. This remarkable cycle has controlled the amount of atmospheric carbon dioxide, a greenhouse gas, to regulate Earth's surface temperature for billions of years. Because this process requires both surface water and plate tectonics, it is not known to occur elsewhere.*

Jupiter and Moon

- Jupiter clears out comets and asteroids (current impact rate is small). Not too close, not too far.
- Large Moon stabilizes Earth's tilt (seasons not too severe). Is at right distance.

Detection of Life

- See current searches!

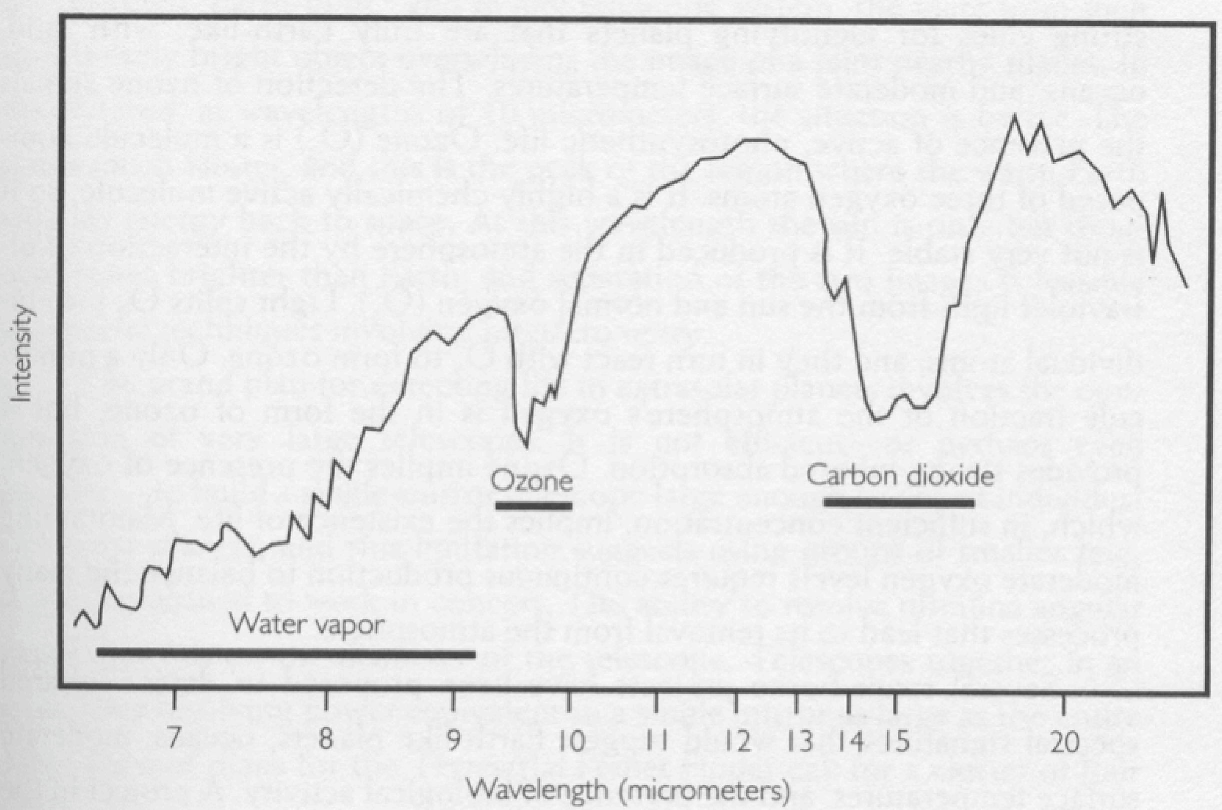


Figure 11.1 *The hypothetical infrared spectrum of an Earth-like planet with life. The abundances of water vapor, carbon dioxide, and ozone would be clues indicating that the planet was in the habitable zone of its star and that life was producing oxygen.*

Dead Zones in Universe

early universe	Most distant galaxies are too young to have enough metals for formation of Earth-size inner planets. Hazards include energetic quasar-like activity and frequent SN explosions.
globular clusters	GC's are too metal-poor to have inner planets as large as Earth. Solar-mass stars have evolved to giants that are too hot for life on inner planets. Stellar encounter perturb protoplanetary disk and outer planet orbits.
centers of galaxies	Energetic processes impede complex life.
edges of galaxies	Most stars are very metal-poor.

Dead Zones in Universe

planetary systems with hot Jupiters	Inward migration of giant planets may have driven possible inner planets into central star.
planetary systems with eccentric outer gas planets	Environment too unstable to higher life. Some planets may get lost to space.
future stars	Uranium, potassium, thorium are perhaps too rare to provide sufficient heat to drive plate tectonics.

Cosy place somewhere off-center in a L_* galaxy around a G-type single star?

Rare Earth Factors

right distance from star
- habitat for complex life.
- liquid water near surface.
- far enough to avoid tidal lock.

right mass of star
- long enough lifetime.
- no too much UV radiation from stars

stable planetary orbits
- long-term stability of environment.

right planetary mass
- retain atmosphere and ocean.
- enough heat for plate tectonics.
- solid/molten core.

Jupiter-like neighbor
- clear out comets and astroids.
- not too close not too far.

Mars
- small neighbor as possible life source

Rare Earth Factors

atmospheric properties
- maintaining adequate temperature, composition and pressure for plants & animals.

evolution of oxygen
- invention of photosynthesis.
- not too much, not too little.
- production at the right time.

right position in galaxy
- not in center, not in halo.

biological evolution
- successful evolutionary path to complex plants and animals.

right kind of galaxy
- enough heavy elements.
- not small, elliptical, or irregular.

wild cards...
- snowball Earth?
- Cambrian explosion?
- inertial interchange event?

Rare Earth Factors

plate tectonics
- CO_2 - silicate thermostat.
- build up land mass.
- enhance biodiversity.
- enable magnetic field.

large moon
- right distance.
- stabilizes tilt.

right tilt
- seasons are not too severe.

ocean
- not too much.
- not too little.

giant impacts
- few impacts.
- no global sterilizing impacts after initial period.

right amount of carbon
- enough for life.
- no run-away greenhouse effect.

Summary

- Simple life forms may be abundant in the universe.
- Complex life may be rare.
- Reference:
  "Rare Earth", by Peter D. Ward & Donald Brownlee (Copernicus Books, New York)