The Search for Intelligent Life in the Universe
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Oxygenation and the Late Permian Extinction

Oxygen generated by aerobic photosynthesis eliminated methane and initiated global cooling.
O$_2$, CH$_4$ Levels

Huang et al. (2018)

20.95%

20.83%
Seismic (Body) Waves

- P waves – Compressional or longitudinal (sound) waves, can travel through fluid, solid and gaseous materials. P means primary, because they travel faster and arrive sooner.

- S waves – Shear or transverse (analogous to waves on a taut rope), can only travel through solid materials. S means secondary, because they travel less quickly.

When a wave hits an interface between two materials of different densities, it can be reflected and/or refracted (bent). Gradual and continuous density changes cause gradual and continuous refraction.
P- and S-Wave Propagation

geophysics.ou.edu/solid_earth

P-wave shadow zone: 104° – 140°
Plate Tectonics

Earth’s crust is divided into plates. Plates move because they float on the semi-liquid asthenosphere, a region 100–250 km below the surface at the top of the upper mantle. Energy source is heat conduction from interior.

Ritter, Michael E.: The Physical Environment: an Introduction to Physical Geography

USGS, Wikipedia
Fossil Evidence for Continental Drift

200 Myrs ago

- Fossil evidence of the Triassic land reptile Lystrosaurus.
- Fossil remains of Cynognathus, a Triassic land reptile approximately 3m long.
- Fossil remains of the freshwater reptile Mesosaurus.
- Fossils of the fern Glossopteris, found in all of the southern continents, show that they were once joined.
“Well, looking back I suppose it’s been going on for quite some time, but I only noticed we were drifting apart during the last 50 million years...”
620 Myrs ago
In 25 million years...

San Andreas fault line
San Francisco
Los Angeles
Baja California

The Gulf of California widens into a narrow seaway.

In 50 million years...

Los Angeles
San Francisco

Los Angeles becomes a northern suburb of San Francisco.

In 250 million years...

Alaska
Los Angeles
San Francisco

What is now California forms the westernmost mountain range of North America, and Los Angeles is tucked up next to Alaska.

Source: Christopher R. Scotese

"I've heard of continental drift, but this is ridiculous."
Earthquakes

- Earthquakes caused by slipping of faults when rock cracks.
- Total energy of earthquakes measured by the Richter Scale.

\[ E(MT) \approx 30^{M-6} \]

- Global earthquake frequency, as a function of magnitude \( M \), is well-reproduced by the Gutenberg-Richter formula:

\[ N(\geq M) \approx 10^{8-M} \text{ per year} \]

- There are about 1 million earthquakes per year with \( M \geq 2 \).
- \( M \leq 10 \) because rock has a limited strength, \( M_{max} = 9.5 \).
- The total annual energy of all earthquakes is 50,000 MT.
- The total annual energy of all impactors on the Earth is 1 MT, averaged over the last 100,000,000 years.
- Most earthquake energy is harmlessly dissipated into the Earth, in contrast to impacts that focus the energy.
- During the last century, there were 1 million recorded earthquake fatalities, or about 10,000 per year. This is much less than the number of coal-related deaths from mining accidents, black lung, and other diseases.
### The Richter Scale

<table>
<thead>
<tr>
<th>Magnitude</th>
<th>Seismic Energy (TNT weight)</th>
<th>Frequency down to M</th>
<th>Example (approximate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>32 kg</td>
<td></td>
<td>Construction site blast</td>
</tr>
<tr>
<td>2.0</td>
<td>1 ton</td>
<td>8000 per day</td>
<td>Large quarry blast, large WWII bomb</td>
</tr>
<tr>
<td>3.0</td>
<td>30 tons</td>
<td>1000 per day</td>
<td>Small nuclear weapon</td>
</tr>
<tr>
<td>4.0</td>
<td>1 kton</td>
<td>50,000 per year</td>
<td>Average tornado</td>
</tr>
<tr>
<td>4.5</td>
<td>6 kton</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.0</td>
<td>30 kton</td>
<td>6200 per year</td>
<td></td>
</tr>
<tr>
<td><strong>Slight damage to well-constructed buildings</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.0</td>
<td>1 MT</td>
<td>800 per year</td>
<td>Double Spring Flat, NV, 1991</td>
</tr>
<tr>
<td>6.5</td>
<td>6 MT</td>
<td></td>
<td>Northridge, CA, 1991</td>
</tr>
<tr>
<td><strong>Major earthquake</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.0</td>
<td>30 MT</td>
<td>120 per year</td>
<td>Largest nuclear weapon</td>
</tr>
<tr>
<td>7.5</td>
<td>180 MT</td>
<td></td>
<td>Landers, CA, 1992</td>
</tr>
<tr>
<td><strong>Great earthquake</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.0</td>
<td>1 GT</td>
<td>18 per year</td>
<td>San Francisco, C, 1906</td>
</tr>
<tr>
<td>8.5</td>
<td>6 GT</td>
<td></td>
<td>Anchorage, AK, 1961</td>
</tr>
<tr>
<td>9.0</td>
<td>30 GT</td>
<td>1 per year</td>
<td>Chile, 1960</td>
</tr>
<tr>
<td>10.0</td>
<td>1 TT</td>
<td>Unknown</td>
<td>Fault almost circling Earth</td>
</tr>
<tr>
<td>12.0</td>
<td>1 PT</td>
<td></td>
<td>Earth's total solar energy per year</td>
</tr>
</tbody>
</table>