Why is this planet to be the Earth?

- The water vs. shore planet Earth
- How to make the continent
- The reason for operation of plate tectonics
- Water: its contribution to the Earth evolution

Y. Tatsumi (CPS/Kobe-U)
The Water Planet Earth
Water:
- covers \( \sim 70\% \) of the Earth’s surface
- weighs \( 1.4 \times 10^{18} \) ton
- has been playing key roles in the evolution of the Earth system
The Shore Planet Earth

Bi-modal height distribution:
- lowland → ocean
- highland → shore

Uni-modal height distribution:
- Apparently bi-modal, but actually uni-modal

Mass \( C \) ≠ Morpho.
## Continent vs. Ocean

<table>
<thead>
<tr>
<th></th>
<th>Continental Crust</th>
<th>Oceanic Crust</th>
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<tbody>
<tr>
<td>Height</td>
<td>850 m</td>
<td>-3800 m</td>
</tr>
<tr>
<td>Thickness</td>
<td>40 km</td>
<td>6 km</td>
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The Continental Crust is significantly thicker and higher than the Oceanic Crust. The Continental Crust is about 40 km thick and 850 m high, whereas the Oceanic Crust is only 6 km thick and -3800 m high.
# Continent vs. Ocean

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<tr>
<td><strong>Birth Place</strong></td>
<td>arc</td>
<td>MOR</td>
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**Arc primary magmas are mafic in composition.**
Ocean creates continent: Project IBM

An example of combined seismic and mogmatologic approach
Seismic imaging of IBM crust/mantle

Ubiquitous creation of **continental crust** with 6.5km/s $V_p$
Arc evolution: creating continental crust and anti-continent

**Crust-mantle transformation across the transparent Moho**
- discharging the ultramafic anti-continent to the mantle
- evolving arc crust from mafic to intermediate compositions
Subduction zones working as a factory

**Raw materials**
- Oceanic material: sediments + MORB
- Mantle wedge material

**Products**
- Magma/Volcanoes
- Volatiles
- Continental crust

**Wastes**
- Chemically modified sediment
- Chemically modified/fresh MORB
- Anti-continent
SubFac vs. HotspotFac

3 enriched reservoirs in the deep mantle vs.
3 wastes from SubFac
Chemical modification via dehydration

Aizawa et al. (1998)

Kogiso et al. (1997)
Isotopic evolution of sediment & MORB

Aizawa et al. (1998)

Dehydrated sediments → EMII

Dehydrated + fresh MORB → HIMU

Tatsumi & Kogiso (2005)
Fate of the anti-continent: density change

Thermally-equilibrated Anti-continent

MORB

PREM

Upper Mantle

Lower Mantle
Fate of the anti-continent: density change

Falling down headlong towards the CMB
Volume of accumulated anti-continent

- Existing continent: $7.4 \times 10^9 \text{ km}^3$
- CC Comp: 20% melting of IBC

\[ \Rightarrow \text{Accumulated A–C: } 2.9 \times 10^{10} \text{ km}^3 \]
\[ \sim 200\text{km layer above CMB} \]

- D” layer: Accretion of A–C?
Fate of the anti-continent: isotopic evolution

- EMI
- contribution of anti-continent

<table>
<thead>
<tr>
<th>87Sr/86Sr</th>
<th>206Pb/204Pb</th>
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<tr>
<td>0.700</td>
<td>14</td>
</tr>
<tr>
<td>0.704</td>
<td>16</td>
</tr>
<tr>
<td>0.708</td>
<td>18</td>
</tr>
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<td>0.712</td>
<td>20</td>
</tr>
<tr>
<td>0.716</td>
<td>22</td>
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Raw Materials

- Oceanic sediments & crust
- Mantle wedge peridotite

Products

- Magmas & volcanoes
- Continental crust

Waste Materials

- Anti-continent chemically modified sediments + crust

Subduction Factory

- Operating as a zero-emission factory

Mantle Plume Sources (EM1, EM2, HIMU)

Operation of SubFac: Consequence of plate tectonics
Why has plate tectonics been working solely on the Earth?

Plate tectonics: consequence of mantle convection
The Earth as an heat engine: Temperature of the Earth’s interior

The layered Earth
← Phase changes

Phase boundary
Depth of discontinuity
→ Temp. at the depth

Too small IC
→ little temp. grad.
The Earth as an heat engine:
Heat transfer in the solid mantle

Heat transfer:
thermal radiation, heat conduction and convection

Conduction or convection?

\[
Ra \equiv \frac{\rho_0 g \alpha (T_1 - T_0) b^3}{\mu \kappa}
\]

Ra \(>10^6\) for the mantle \(\gg\) critical Ra
The Earth as an heat engine: Heat transfer by mantle convection

Heat loss from the surface
\[ Q_{CHF} + Q_{OHF} = 46 \text{ TW} \]

Heat from the core
\[ Q_{C-M} = 8 \text{ TW} \]
\[ \Delta T, \kappa, d \text{ of D'' TBL} \]
- Latent heat: 2.9
- Gravitational work: 1.7
- Radioactive heating: 1.9 (K=300ppm)
- Core cooling: 1.5

Heat budget in the mantle
\[ Q_C = 46 - 8 - Q_R = 18 \text{ TW} \]
\[ \rightarrow \text{mantle convection} \]
The Earth as an heat engine:
Heat transfer by mantle convection

\[ Q_c = V \times \rho \times C_p \times \Delta T / \Delta t \]

- \( \rho = 4 \times 10^3 \)
- \( C_p = 10^3 \)
- \( \Delta T = 10^3 \)
- \( \Delta t = 5\text{cm/y for 2900km} \)
- \( V = \Phi SP \text{ Plume, 500km} \)

\[ Q_c = 10\text{TW} \sim 18\text{TW} \]
Mantle Convection vs. Plate Tectonics: P/T/T dependence of viscosity

\[ \eta = \eta_0 \exp \left( \frac{E + PV}{RT} \right) \]

T-dependent mantle viscosity

→ litho- & astheno-sphere

→ plate tectonics
Mantle Convection vs. Plate Tectonics: Stagnant Lid Convection

Plate is highly stagnant → Plate tectonics does not work
Mantle convection in the Venus and Mercury
Mantle Convection vs. Plate Tectonics: Strength of ‘rock’

Water reduces the strength of rock
→ The surface liquid water is critical in plate motion
Mantle Convection vs. Plate Tectonics: The role of fracture within the plate

Liquid water $\rightarrow$ Fracture $\rightarrow$ Plate Tectonics
The presence of water at the surface: the ultimate cause of being the Earth

- The origin of water
- The conditions suitable for the presence of liquid water
Why liquid water at the surface?
Origin of water

Carbonaceous chondrite:
A plausible source of the Earth and water

- Max. 17wr% H2O
- Deuterium/Hydrogen ratio identical to the Earth (ocean)
Why no liquid water at the surface?

Mars

- Earth/Venus: giant impact
- Mars: Planetesimal mass

Mars used to be a water planet by green house effect

- Dissipation of atmosphere
- Too small mass
Why no liquid water at the surface? Venus

- Severe heating by sunshine → higher-T for liq. water
- Simple but not true ← highly reflective atmosphere

Strong green house effect by CO$_2$-rich atmosphere

- Decomposition of H$_2$O into H and O by severe UVR and subsequent dissipation to the space
- No carbonate deposition in liq. water
Water in the Earth

Earth’s interior: → Huge reservoir of CHO
Why is this planet to be the Earth?

- The Earth is the only planet having both continent/ocean, i.e., high/lowlands
- This is caused by operation of plate tectonics
- Plate tectonics is triggered by both mantle convection and the presence of liquid water at the surface
- The distance from the Sun and the mass of the Earth are essential parameters in the presence of liquid water
- Distribution of CHO in the Earth’s interior is to be understood

Thanks...