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Lecture 2: Geological setting

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Chapter 2. Geological Setting and Materials, 2.1. Historical Perspective

Geological setting and materials = geologically prescribed boundary conditions for morphodynamic model (i.e., independent variables). Morphodynamics can’t (easily) feed back to change geologic setting or materials.

-- 1800s: Cases of past vertical movement of land and sea recognized (e.g., Lyell, Darwin)
-- Early 1900s: Four main ice advances identified in Quaternary (Penck & Bruckner)
-- 1960s: Acceptance of plate tectonics (e.g., Dietz, Hess)

Table 2.1. Alternative names for glacial, interglacial and postglacial stages based upon regional compilations and deep-sea core marine oxygen isotope boundaries

<table>
<thead>
<tr>
<th>General description</th>
<th>Britain</th>
<th>NW Europe</th>
<th>Alps</th>
<th>North America</th>
<th>Marine oxygen-isotope stage</th>
<th>A (ka)</th>
<th>B (ka)</th>
<th>C (ka)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holocene</td>
<td>Flandrian</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>1</td>
<td>13–0</td>
<td>12–0</td>
<td>12–0</td>
</tr>
<tr>
<td>Last Glacial</td>
<td>Devensian</td>
<td>Weichselian</td>
<td>Würm</td>
<td>Wisconsin</td>
<td>2.4</td>
<td>75–13</td>
<td>71–12</td>
<td>74–12</td>
</tr>
<tr>
<td>Last Interglacial</td>
<td>Ipswichian</td>
<td>Eemian</td>
<td>–</td>
<td>Sangamon</td>
<td>5</td>
<td>128–75</td>
<td>128–71</td>
<td>130–74</td>
</tr>
<tr>
<td>Penultimate Glacial</td>
<td>Wolstonian</td>
<td>Saalian</td>
<td>Riss</td>
<td>Illinian</td>
<td>6</td>
<td>195–128</td>
<td>186–128</td>
<td>190–130</td>
</tr>
<tr>
<td>Penultimate Interglacial</td>
<td>Hoxnian</td>
<td>Holsteinian</td>
<td>–</td>
<td>Yarmouth</td>
<td>7</td>
<td>251–195</td>
<td>245–186</td>
<td>244–190</td>
</tr>
<tr>
<td>Anglian</td>
<td>Elsterian</td>
<td>Mindel</td>
<td>Kansan</td>
<td>8</td>
<td>297–251</td>
<td>303–245</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cromerian</td>
<td>Cromerian</td>
<td>–</td>
<td>Aftonian</td>
<td>9</td>
<td>347–297</td>
<td>339–303</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes:
2.2. Plate-Tectonic Setting

- Why does oceanic crust have ocean above it?

- Why doesn’t Iceland have ocean above it?

Figure 2.2. Schematic cross-section of oceanic plate showing nature of collision at plate margins. Note mirror-image pattern of polarity reversals, indicated by black and white shading, with distance from mid-ocean ridge.

Plate boundaries (lots of earthquakes) – Types:
- Spreading centers (mid-ocean ridges)
- Ocean-continent collision coasts (ocean trench)
- Ocean-ocean collision coasts (island arcs)
- Continent-continent collision (v. large mountains)
- Transverse plate boundaries (lateral faults)
2.2.1. Continental Coasts

Collision coasts (leading edge coasts, active margins) – steep, rocky but poorly lithified, emergent, uplifted terraces, rapidly down-cutting rivers, narrow shelves, active canyons, sediment moves off shelf. Volcanos with granitic composition. e.g., Pacific ocean coasts

Trailing-edge coasts (passive margins) – low gradient, broad continental shelf, coastal plain sediments, sediment caught on shelf in sedimentary basins. e.g., Atlantic ocean coasts.

Marginal sea coasts – sheltered but floored by oceanic crust. e.g., U.S. Gulf coast, South China Sea

Tectonically complex continental coasts – e.g., Mediterranean

Which classic coast type is most sensitive to sea-level fluctuations?

2.2.2. Island Coasts

Island arc – From collision of two oceanic plates – arcuate, frontal uplifted non-volcanic arc, uplifted terraces on frontal arc (with corals in tropics), volcanoes toward back of island arc, back arc basin with sedimentation behind volcanic arc. Trench on ocean side. Intermediate composition between basaltic and granitic.

Mid-plate islands – Originally of volcanic origin over hot spots. Basaltic composition. Often form chain tracing seafloor spreading over hot spot. Form coral atoll as they sink, followed by guyot. Often associated with seamounts in same chain. Large islands can depress cold ocean crust.

(Woodroffe Fig. 2.2)
2.3. Sea-level Variations, 2.3.1. Pre-Quaternary Ocean Volume Variations

Causes of Pre-Quaternary long-term eustatic (global) changes in sea level:
- Height of mid-ocean ridges;
- Volume of sediment in oceans;
- Water temperature; Juvenile water;
- Subduction of rock and/or water.

Local changes in relative sea level:
- Local/regional tectonics.

Low-stand vs. Transgressive vs. High-stand Systems Tracts

a) Terrigenous clastic

Lowstand systems tract
- exposed shelf
- incised valley
- lowstand wedge
- lowstand fan

Transgressive systems tract
- coastal plain
- estuarine
- starved

Highstand systems tract
- alluvial plain
- coastal and nearshore
- offshore marine

b) Carbonate

- kastified shelf
- narrow platform
- starved
- subtidal
- reefs
- slope sediments
- intertidal/supratidal
- reefs and shoals
- slope deposits

(Woodroffe Fig. 2.4)

(Woodroffe Fig. 2.5)
2.3.2. Quaternary Sea-Level Variations – Fossil shorelines on uplifting coast

Beach ridges from successive highstands are preserved on uplifting coast. Sequence of quartz and calcareous sandy ridges, inter-fingered with estuarine and lagoonal muds, run more than 300 km parallel to South Australia coast.

(Woodroffe Fig. 2.6)

2.3.2. Quaternary Sea-Level Variations – Terraces

Rapidly uplifting shorelines preserve past shorelines as wave-cut or reef terraces.

(a) Height of last interglacial (~100,000 yrs) shoreline terrace in meters
(b) Heights of reef terraces in Indonesia

(Figure 2.7. Late Quaternary shorelines in the Pacific. (a) Height at which Last Interglacial terrace is found around the Pacific (based on Ota and Kasukawa, 1991). At plate margins, the terrace is generally raised above the level at which it formed. Although vertical movements are less marked in mid plate, there is still variability. A Last Interglacial terrace is found well below sea level on the Big Island of Hawaii (isostatically submerging), at shallow depths on atolls (gradually submerging), and raised above sea level on Makatea islands (undergoing lithospheric flexure). (b) Coral terraces from the rapidly uplifting coast of Huon Peninsula (triangle on (a)), indicating the sequence of terraces with more terraces on those coasts which uplift more rapidly, i.e. Kanzania section (based on Aliston and Chappell, 1986). Section from Atauro (square on (a)) shown for comparison to illustrate sequence of higher terraces (based on Chappell and Veeh, 1978). LIG, Last Interglacial; SL, sea level.)
Table 2.2. Dated indicators of last glacial maximum lowstand sea level

<table>
<thead>
<tr>
<th>Location</th>
<th>Material</th>
<th>Depth (m)</th>
<th>Ages ($^{14}$C years BP)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mazatlán, Mexico</td>
<td>Shallow-water organisms</td>
<td>119</td>
<td>19300 ± 300</td>
<td>Curray, 1961</td>
</tr>
<tr>
<td>Timor Sea, Australia</td>
<td>Shallow-water shell, <em>Chlamys</em></td>
<td>130</td>
<td>16910 ± 500</td>
<td>Van Andel and Veevers, 1967</td>
</tr>
<tr>
<td>Atlantic coast, United States</td>
<td>Shallow-water sediments and oyster shells</td>
<td>125</td>
<td>c.15000</td>
<td>Milliman and Emery, 1968</td>
</tr>
<tr>
<td>Arafura Sea, Australia</td>
<td>Beachrock</td>
<td>130–175</td>
<td>18700 ± 350</td>
<td>Jongsm, 1970</td>
</tr>
<tr>
<td>Great Barrier Reef, Australia</td>
<td>Shallow-water coral, <em>Galeaxea</em></td>
<td>160–175</td>
<td>17000 ± 1000$^b$</td>
<td>Veeh and Veevers, 1970</td>
</tr>
<tr>
<td>Bonaparte Gulf, Australia</td>
<td>Microfossils in cores</td>
<td>121–129</td>
<td>18000–16000</td>
<td>Yokoyama <em>et al.</em>, 2001</td>
</tr>
<tr>
<td>Guinea–Sierra Leone</td>
<td>Algal rock</td>
<td>103–111</td>
<td>18750 ± 350</td>
<td>McMaster <em>et al.</em>, 1970</td>
</tr>
<tr>
<td>Sardinia</td>
<td><em>In-situ</em> vermetid gastropods</td>
<td>126–150</td>
<td>18860 ± 170</td>
<td>Pirazzoli, 1996</td>
</tr>
</tbody>
</table>

*uplift-corrected; $^b$ U-series disequilibrium age.

**Why is there disagreement on exact date of last maximum lowstand?**

**Figure 2.10.** Record of postglacial sea-level rise (in calibrated years BP) from peak of last glacial until apparent cessation of ice melt around 6 ka (based on coral data from Barbados, Fairbanks, 1989; Bard *et al.*, 1990a; New Guinea, Chappell and Polach, 1991; Tahiti, Bard *et al.*, 1996; Montaggioni *et al.*, 1997; and mangrove sediments from the Sunda Shelf, Hanebuth *et al.*, 2000; and Joseph Bonaparte Gulf, Yokoyama *et al.*, 2001).
1) Near Field – Extreme isostatic rebound results in continual uplift (and continual sea-level fall) since ice melt. Uplift as much as 1 cm/year. But uplift rate decreasing with time.

2) Ice Margin – Initial rapid uplift outpaced sea level rise. But recently sea level rise has outpaced uplift.

3) Intermediate field – Presence of northern ice sheets uplifted this region due to a hinge effect on the underlying crust and mantle (“forebulge”). Relaxing of hinge accelerated sea level rise after ice melted.

4) Far Field – Sea level largely unaffected by glacial isostatic rebound. Global pattern present, but often overwhelmed by local tectonics including plate tectonics. Small sea level fall at equator due to movement of water north toward intermediate field.

2.3.3. Isostatic Adjustments

(Woodroffe Fig. 2.11)
Additional complexities:

-- Initial isostatic flexure response to water re-entering shelves (downwarp outer shelf, uplift shoreline) which is now viscously relaxing the other way – shorelines sinking again.

-- Non-linear response of entire ocean crust to glacial water volume cycle.

Around UK identify:

-- Near Field
-- Ice Margin
-- Intermediate Field
2.3.4. Present and Future Sea-Level Trends

Likely global trends (eustatic sea level rise):

-- Thermal expansion of the oceans with global warming (steric response).

-- Further melting from glaciers and grounded ice.

-- Transfer of ground water to the oceans.

-- Expected rise of 0.1 to 1 m by 2100 (1 mm to 1 cm/yr). (Biased by location of gages.)

Local trends (relative sea level, RSL):

-- Higher rates of RSL rise along U.S. East Coast due to Intermediate Field flexure.

-- Lower rates of RSL rise along the U.S. West Coast due to uplift.

-- Higher rates of RSL along the U.S. Gulf Coast due to withdrawal of oil and gas.

-- Other local effects: submergence due to water withdrawal, reduced rates of accretion due to sediment loss (damming, coastal erosion).

2.4. Materials

2.4.1. Lithology – density; consolidation; structural characteristics (fractures, joints, bedding, dip); state of weathering; igneous vs. metamorphic vs. sedimentary; solubility.

**Table 2.3. Rock mass strength classification (after Selby, 1985)**

<table>
<thead>
<tr>
<th>Strength class</th>
<th>Description</th>
<th>Examples of rock types</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Very strong rock: requires many blows with geological pick to break</td>
<td>Quartzite, dolerite, gabbro</td>
</tr>
<tr>
<td>2</td>
<td>Strong rock: requires single blow with geological pick to break handheld sample</td>
<td>Marble, dolomite, andesite, granite, gneiss</td>
</tr>
<tr>
<td>3</td>
<td>Moderately strong rock: firm blow with geological pick makes shallow indentation</td>
<td>Slate, shale, ignimbrite, sandstone, mudstone</td>
</tr>
<tr>
<td>4</td>
<td>Weak rock: surface can be cut or scratched by knife</td>
<td>Coal, schist, siltstone</td>
</tr>
<tr>
<td>5</td>
<td>Very weak rock: crumbles when hit with geological pick, can be cut with knife</td>
<td>Chalk, lignite, rocksalt</td>
</tr>
</tbody>
</table>
2.4.2. Clastic sediments – Properties: grain size; grain shape (round, rod, disc); angularity; color; mineralogy; alignment/stacking; porosity; surface texture of grains.

<table>
<thead>
<tr>
<th>Size</th>
<th>Friedman size class</th>
<th>2</th>
<th>2000</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>millimetres</td>
<td>microns</td>
<td>phi</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2048</td>
<td>-11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1024</td>
<td>-10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>512</td>
<td>-9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>256</td>
<td>-8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>128</td>
<td>-7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>64</td>
<td>-6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>-5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>-4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>-3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>-2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2000</td>
<td>-1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- median = d50, 50% of the weight or volume of the sediment is smaller and 50% of the sediment weight is larger (50% point on cumulative distribution curve)

- mode = most common size (peak on size distribution plot)

- mean = average size of particles by weight or volume. The mean is closer to the “tail” of the distribution than is the median.

- standard deviation = spread of distribution

- skewness = measure of asymmetry (presence of tail) (e.g., beach sand is negatively skewed – coarse tail, dune sand is positively skewed – fine tail)

- bimodal distributions = a mixture of two prominent sizes (e.g., coral rubble)
2.4.3. Carbonate sediments –

Acropora branches

Halimeda flakes

coral
grit

coral
boulders
coral
cobbles
coral
sticks

molluscs
forams

Thalassia
flakes

sponge
chips

Figure 2.15. Reef sediments break down via a series of discrete size classes depending on the biological skeletal elements and the processes of breakdown which are operative (based on Folk and Robles, 1964; Scoffin, 1987).

2.5.1. Paleoenvironmental Analysis

Grain size, sedimentary structures, ecological evidence

2.5.2. Dating Coastal Landforms

14C – formed from 14N from cosmic radiation (now bomb 14C is present), absorbed by living organisms, decays to 12C with time after death. Possible up to 40,000 BP.

Uranium Series – Corals incorporate U from seawater, but not Th. With time after death, U decays to Th, and Th collects in fossil coral. Possible up to 500,000 BP.

Thermoluminescence – Accumulation of electrons within minerals with time. Can work with sands. (But how do you know when TL set to zero?). Possible up to 500,000 BP.

Time horizons – Bomb contaminants (Cs, Pu), Other contaminants (Pb, ash layers, new or banned chemicals, changes in land use). Anthropogenic horizons 10s to 100s yrs.

Short-term radio-isotopes – 210Pb, 7Be (Months to decades).

Fossils – Pollen, diatoms, forams (multiple timescales depending on application).

Oxygen isotopes – Up to ~500,000 BP.