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Lecture 2: Geological setting

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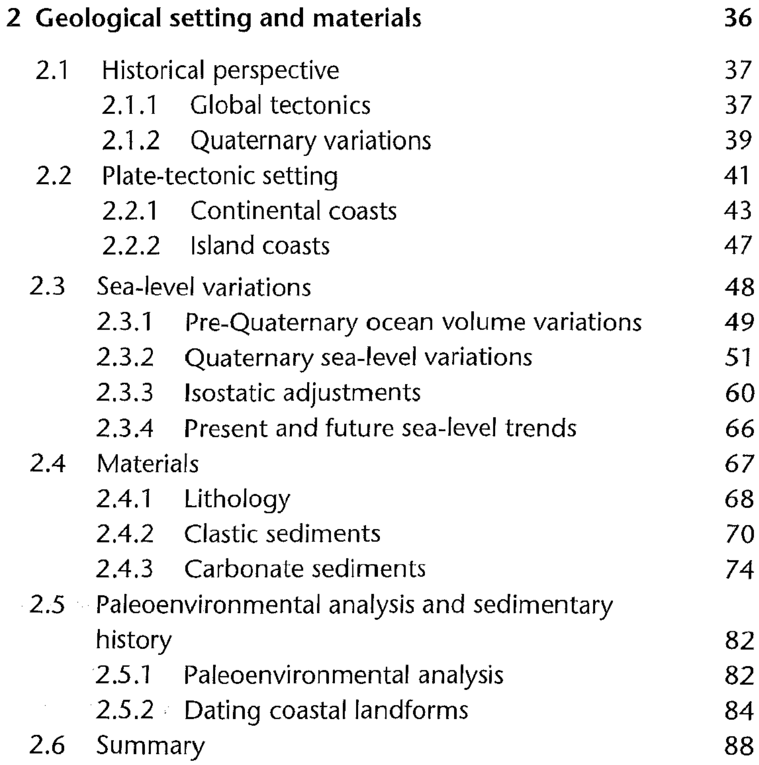
Colin Woodroffe (2002) “Coasts: Form, Process and Evolution”, Outline of Chapter 2:



2 Geological setting and materials 36

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)

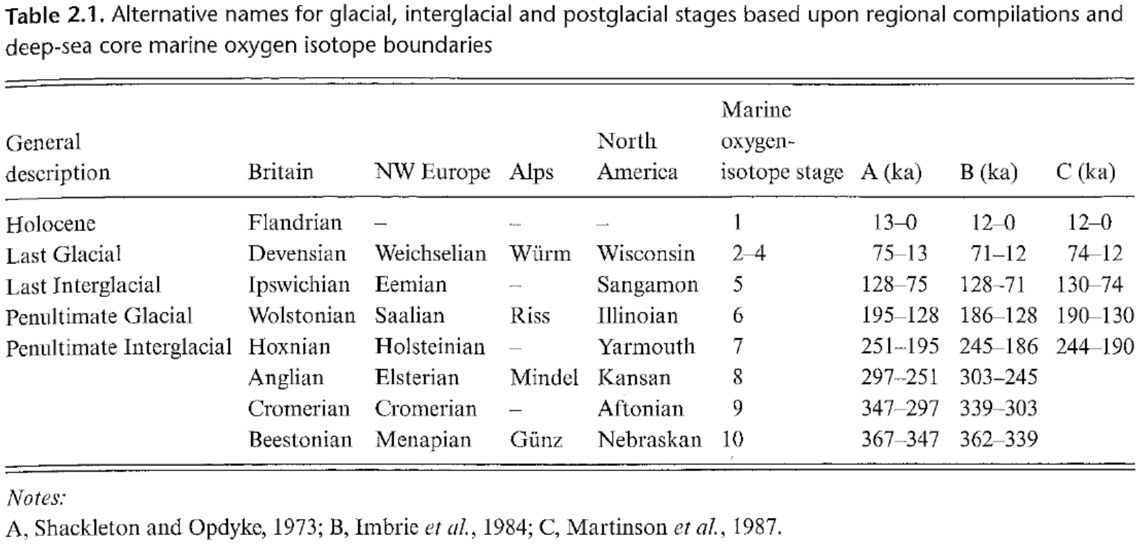
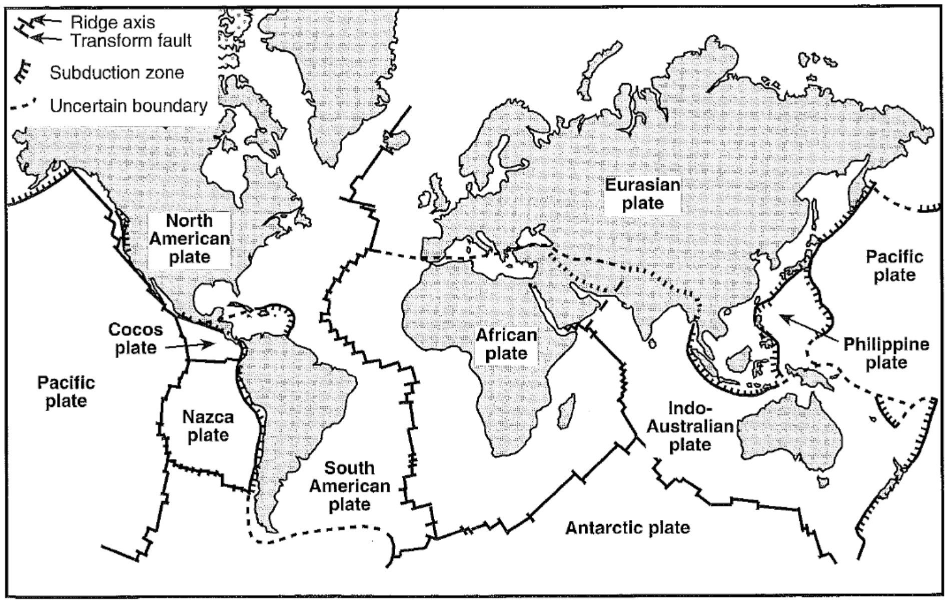


Table 2.1. Alternative names for glacial, interglacial and postglacial stages based upon regional compilations and deep-sea core marine oxygen isotope boundaries

General description	Britain	NW Europe	Alps	North America	Marine oxygen-isotope stage	A (ka)	B (ka)	C (ka)
Holocene	Flandrian	–	–	–	1	13–0	12–0	12–0
Last Glacial	Devensian	Weichselian	Würm	Wisconsin	2–4	75–13	71–12	74–12
Last Interglacial	Ipswichian	Eemian	–	Sangamon	5	128–75	128–71	130–74
Penultimate Glacial	Wolstonian	Saalian	Riss	Illinoian	6	195–128	186–128	190–130
Penultimate Interglacial	Hoxnian	Holsteinian	–	Yarmouth	7	251–195	245–186	244–190
	Anglian	Elsterian	Mindel	Kansan	8	297–251	303–245	
	Cromerian	Cromerian	–	Aftonian	9	347–297	339–303	
	Beestonian	Menapian	Günz	Nebraskan	10	367–347	362–339	

Notes:
A, Shackleton and Opdyke, 1973; B, Imbrie *et al.*, 1984; C, Martinson *et al.*, 1987.

2.2. Plate-Tectonic Setting



(Woodroffe Fig. 2.1)

-- Why does oceanic crust have ocean above it?

-- Why doesn’t Iceland have ocean above it?

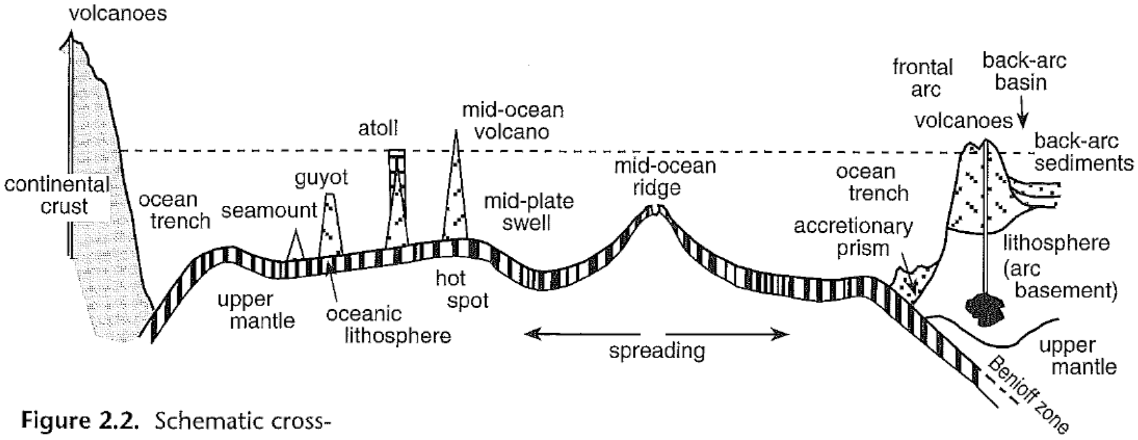


Figure 2.2. Schematic cross-section of oceanic plate showing nature of collision at plate margins. Note mirror-image pattern of polarity reversals, indicated by black and white shading, with distance from mid-ocean ridge.

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

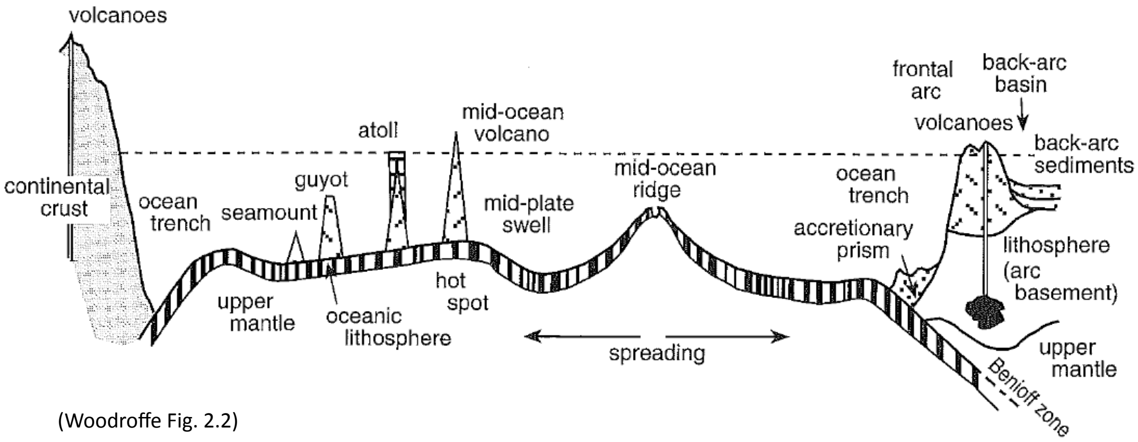
Tectonically complex continental coasts – e.g., Mediterranean

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.

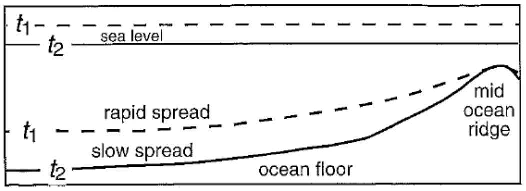


(Woodroffe Fig. 2.2)

2.3. Sea-level Variations, 2.3.1. Pre-Quaternary Ocean Volume Variations

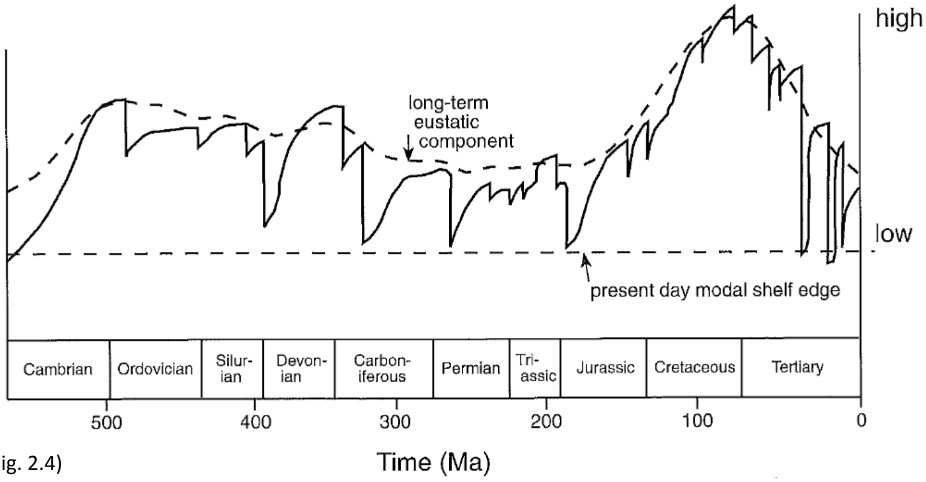
Causes of Pre-Quaternary long-term eustatic (global) changes in sea level:

- Height of mid-ocean ridges;
- Volume of sediment in oceans;
- Water temperature; Juvenile water;
- Subduction of rock and/or water.



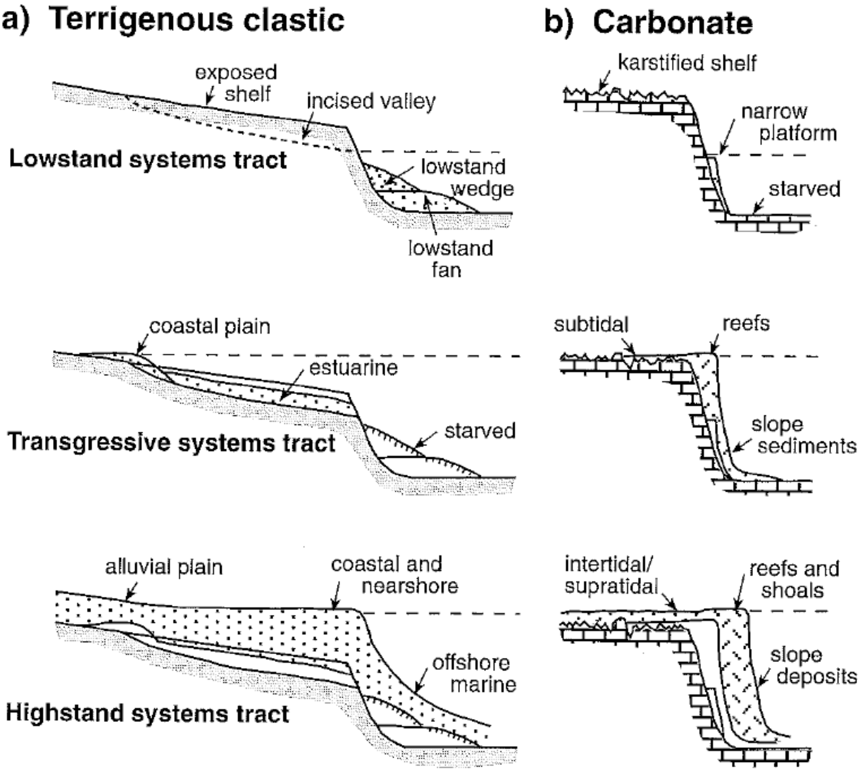
Local changes in relative sea level:

- Local/regional tectonics.



(Woodroffe Fig. 2.4)

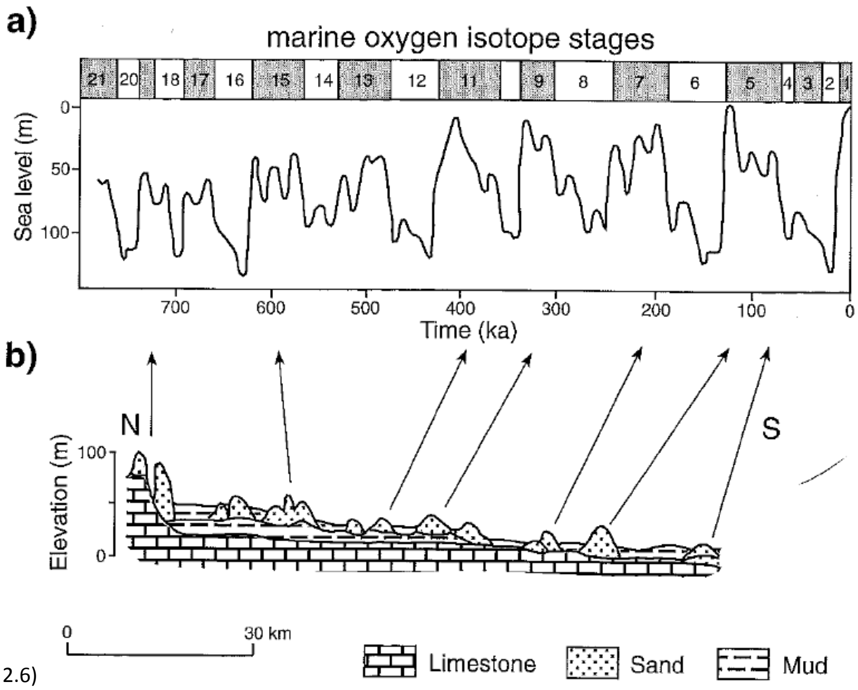
Low-stand vs. Transgressive vs. High-stand Systems Tracts



(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.

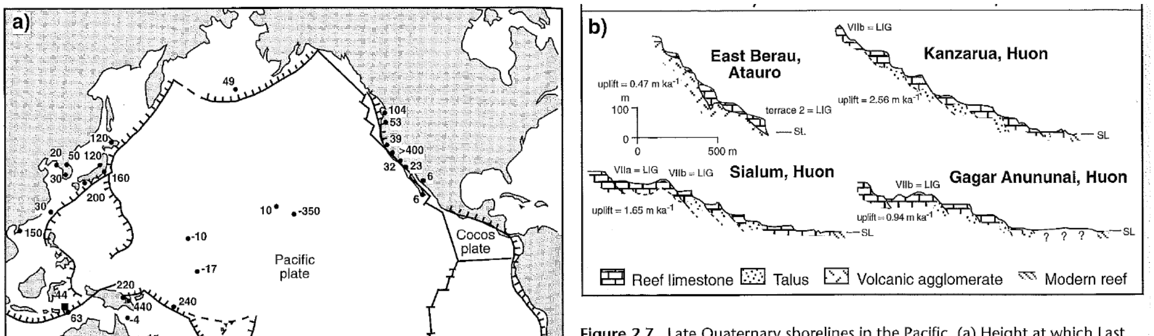


Figure 2.7. Late Quaternary shorelines in the Pacific. (a) Height at which Last Interglacial terrace is found around the Pacific (based on Ota and Kaizuka, 1991). At plate margins the terrace is generally raised above the level at which it formed. Although vertical movements are less marked in mid plate, 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. Kanzarua section (based on Aharon 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.

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

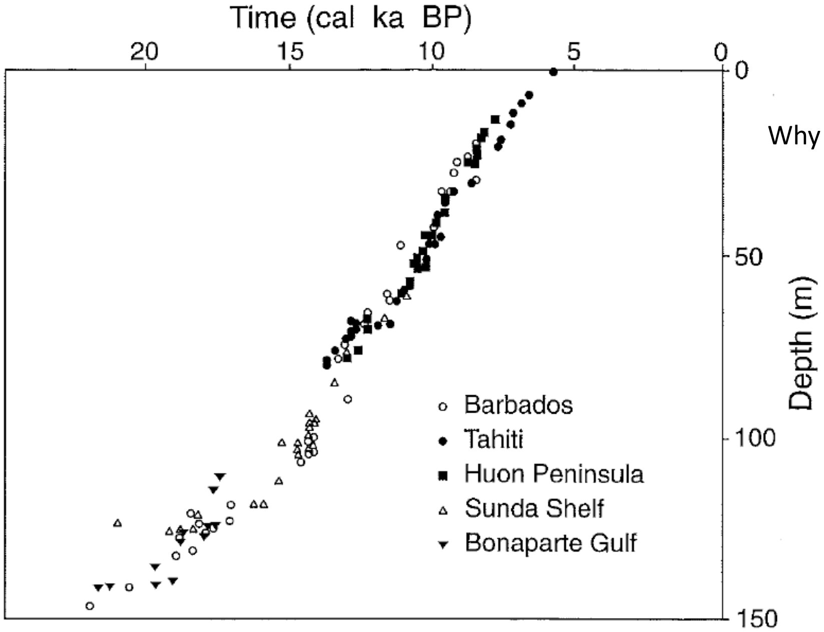
Table 2.2. Dated indicators of last glacial maximum lowstand sea level

Location	Material	Depth (m)	Ages (^{14}C years BP)	Reference
Mazatlan, Mexico	Shallow-water organisms	119	19300 ± 300	Curray, 1961
Timor Sea, Australia	Shallow-water shell, *Chlamys*	130	16910 ± 500	Van Andel and Veevers, 1967
Atlantic coast, United States	Shallow-water sediments and oyster shells	125	c.15000	Milliman and Emery, 1968
Arafura Sea, Australia	Beachrock	130–175	18700 ± 350	Jongsma, 1970
Great Barrier Reef, Australia	Shallow-water coral, *Galaxea*	160–175	17000 ± 1000[b]	Veeh and Veevers, 1970
Bonaparte Gulf, Australia	Microfossils in cores	121–129	18000–16000	Yokoyama *et al.*, 2001
Guinea–Sierra Leone	Algal rock	103–111	18750 ± 350	McMaster *et al.*, 1970
Barbados	Shallow-water coral, *Acropora palmata*	116–126[a]	c.17000	Fairbanks, 1989
Southeastern Australia	Shallow-water shells, *Pecten*	110–130	17320 ± 220	Ferland *et al.*, 1995
Mayotte Island, Indian Ocean	Coral, *Acropora*	152	18400 ± 500	Pirazzoli, 1996
Sardinia	*In-situ* vermetid gastropods	126–150	18860 ± 170	Pirazzoli, 1996

Notes:

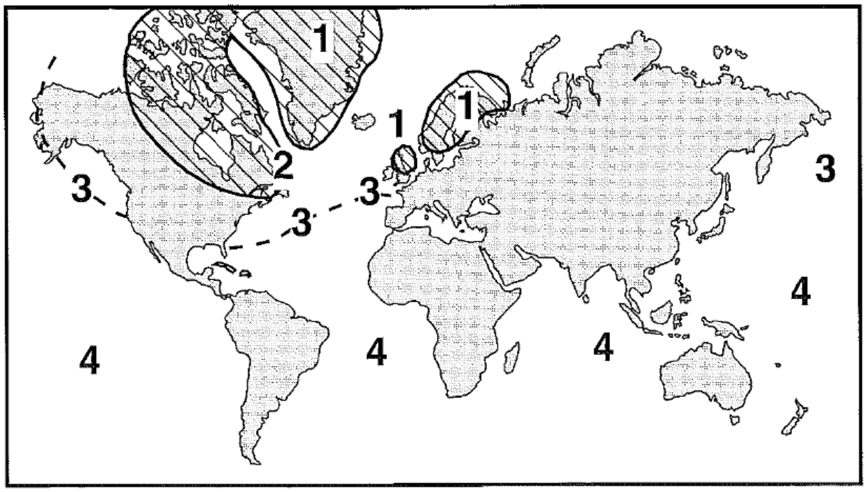
[a] uplift-corrected; [b] U-series disequilibrium age.

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



Why such good agreement?

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).



2.3.3. Isostatic Adjustments

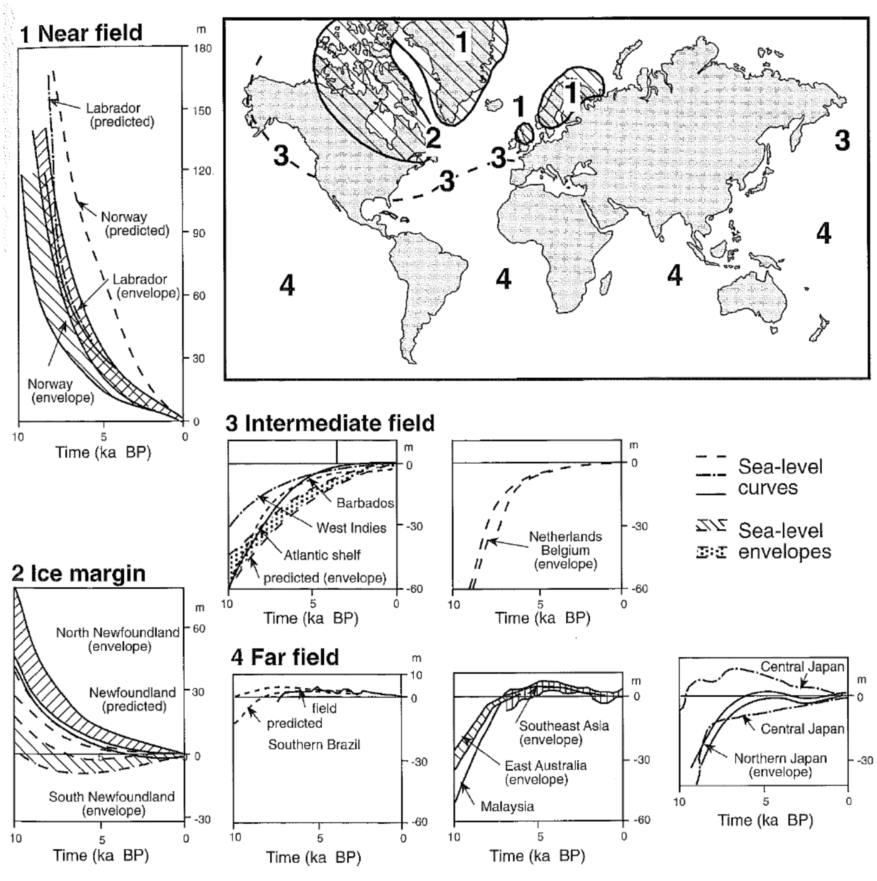
(Woodroffe Fig. 2.11)

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.

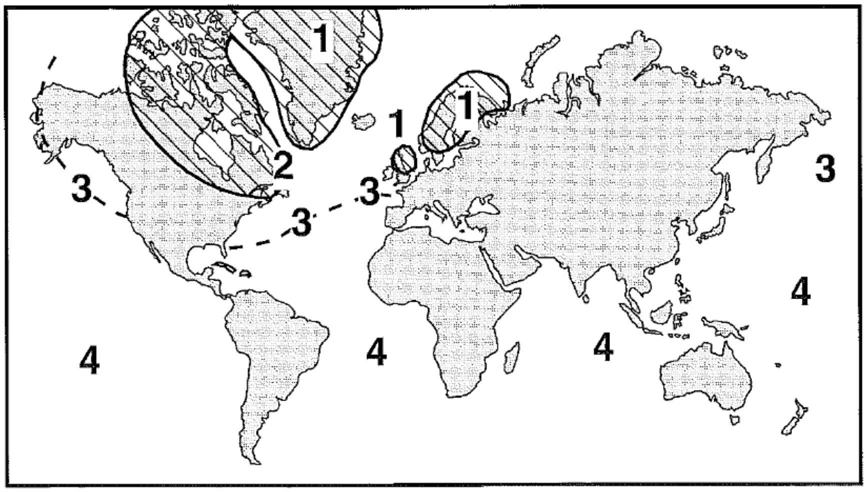
2) Ice Margin – Initial rapid uplift outpaced sea level rise. But recently sea level rise has outpaced uplift.

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



(Woodroffe Fig. 2.11)

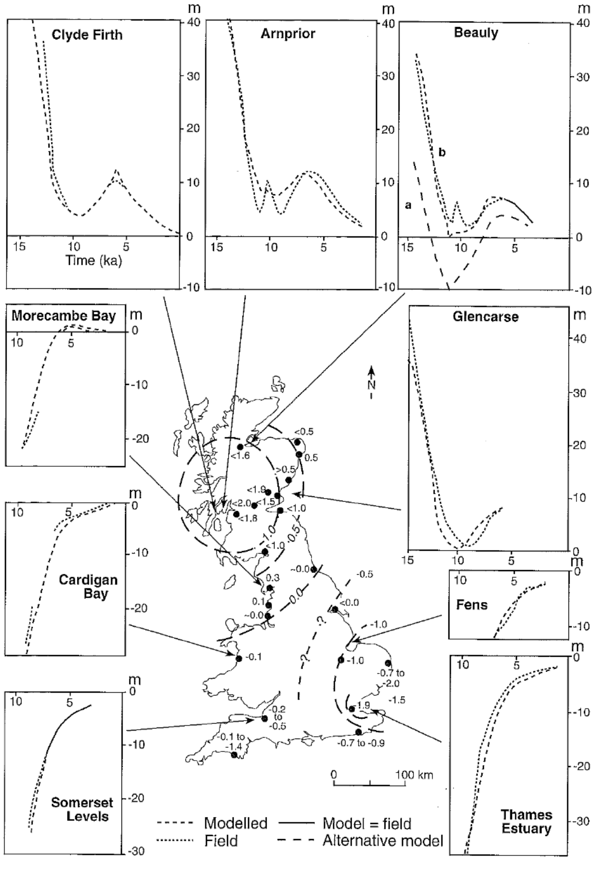


(Woodroffe Fig. 2.11)

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.



(Woodroffe Fig. 2.12)

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

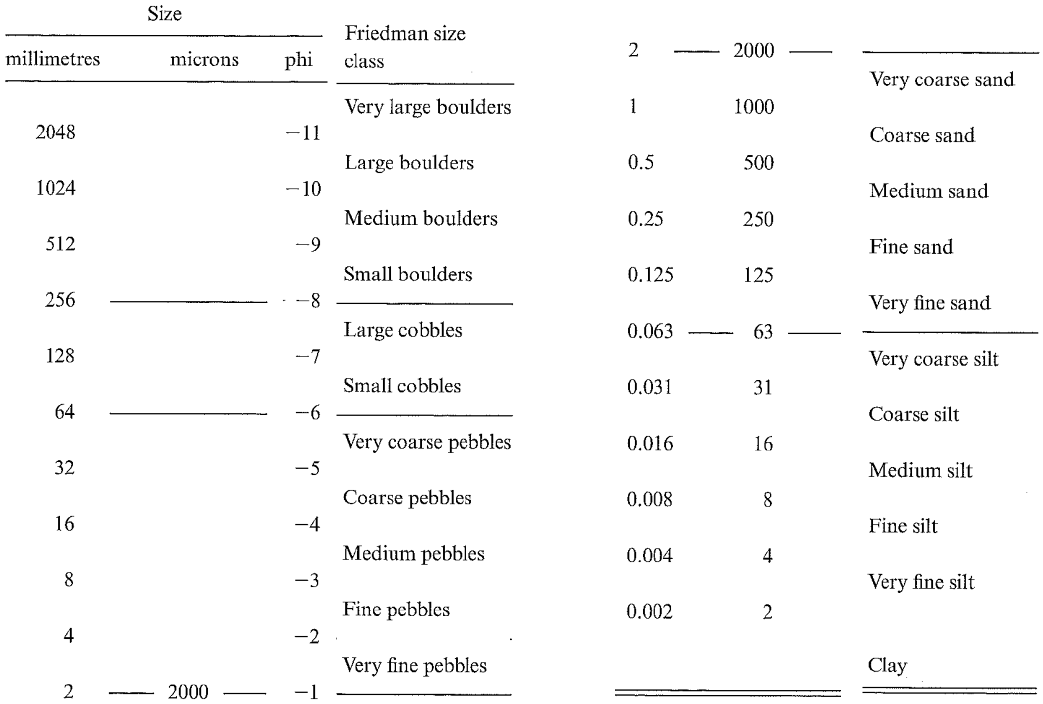
2.4.1. Lithology – density; consolidation; structural characteristics (fractures, joints, bedding, dip); state of weathering; igneous vs. metamorphic vs. sedimentary; solubility.

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

Strength class	Description	Examples of rock types
1	Very strong rock: requires many blows with geological pick to break	Quartzite, dolerite, gabbro
2	Strong rock: requires single blow with geological pick to break handheld sample	Marble, dolomite, andesite, granite, gneiss
3	Moderately strong rock: firm blow with geological pick makes shallow indentation	Slate, shale, ignimbrite, sandstone, mudstone
4	Weak rock: surface can be cut or scratched by knife	Coal, schist, siltstone
5	Very weak rock: crumbles when hit with geological pick, can be cut with knife	Chalk, lignite, rocksalt

2.4.2. Clastic sediments – Properties: grain size; grain shape (round, rod, disc); angularity; color; mineralogy; alignment/stacking; porosity; surface texture of grains.

(Table 2.4)



Size millimetres	Size microns	Size phi	Friedman size class
			Very large boulders
2048		−11	
			Large boulders
1024		−10	
			Medium boulders
512		−9	
			Small boulders
256		−8	
			Large cobbles
128		−7	
			Small cobbles
64		−6	
			Very coarse pebbles
32		−5	
			Coarse pebbles
16		−4	
			Medium pebbles
8		−3	
			Fine pebbles
4		−2	
			Very fine pebbles
2	2000	−1	
			Very coarse sand
1	1000		
			Coarse sand
0.5	500		
			Medium sand
0.25	250		
			Fine sand
0.125	125		
			Very fine sand
0.063	63		
			Very coarse silt
0.031	31		
			Coarse silt
0.016	16		
			Medium silt
0.008	8		
			Fine silt
0.004	4		
			Very fine silt
0.002	2		
			Clay

How are grain size distributions described?

-- 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 –

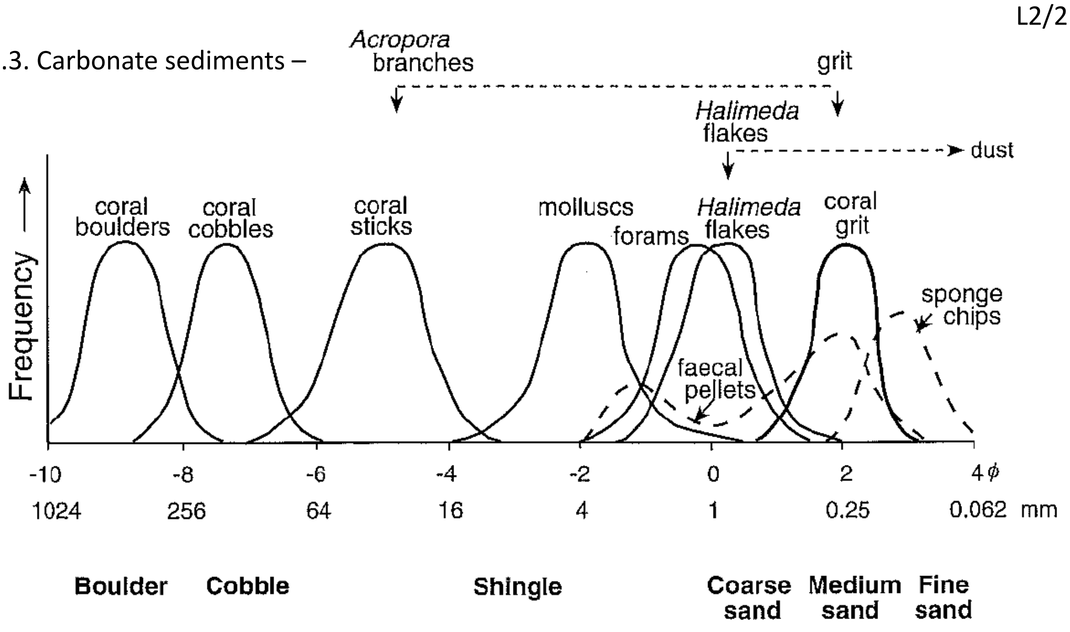


Figure 2.15. Reef sediments break down via a series of discrete size classes depending on the biological skeletal elements and the processes of breakdown which are operative (based on Folk and Robles, 1964; Scoffin, 1987).

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 (mulitple timescales depending on application).

Oxygen isotopes – Up to ~500,000 BP.