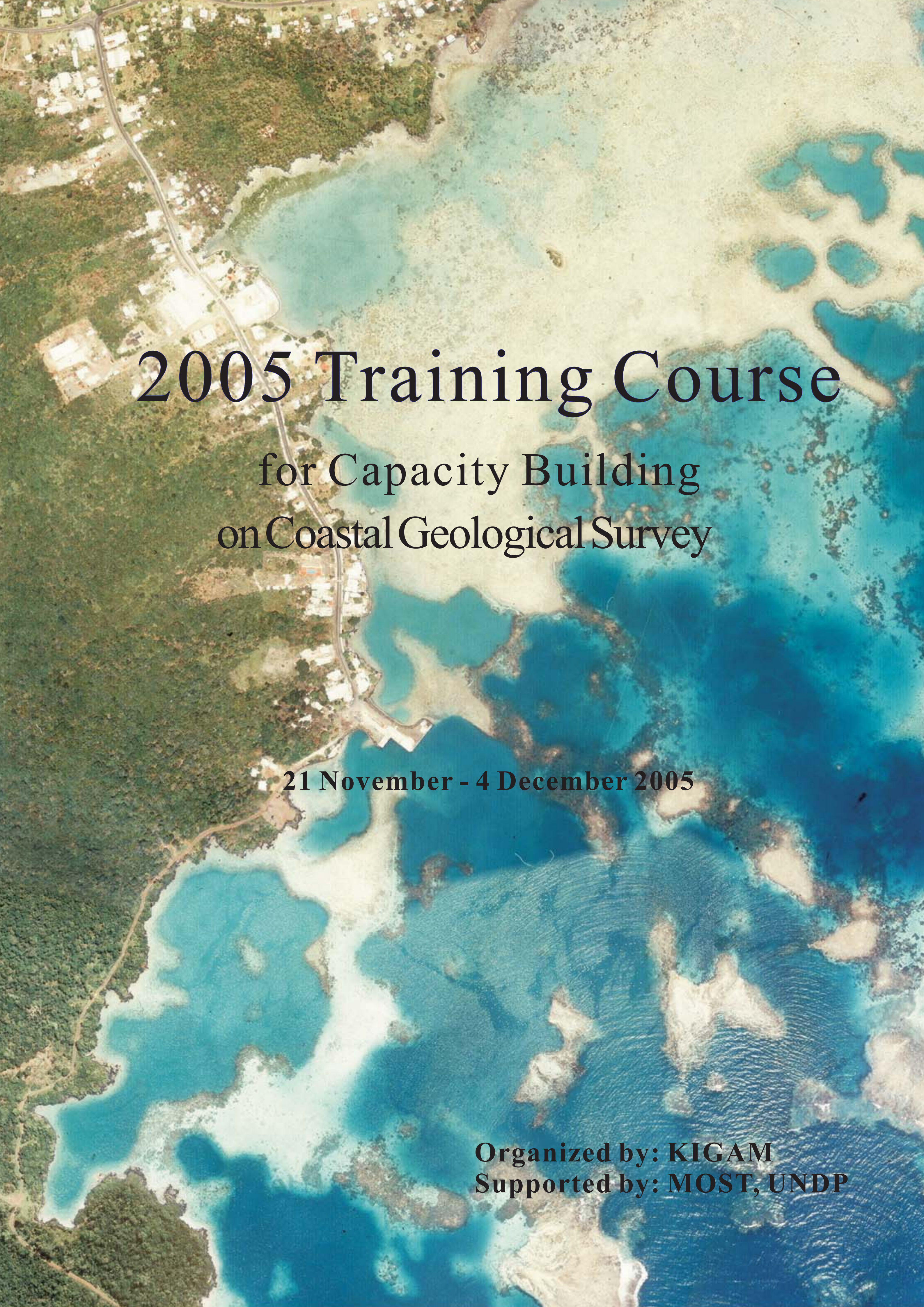


2005 Training Course

for Capacity Building on Coastal Geological Survey

21 November - 4 December 2005

Organized by: KIGAM
Supported by: MOST, UNDP

Training Course

for Capacity Building
on Coastal Geological Survey

2005

21 November - 4 December 2005

Organized by:
Korea Institute of Geoscience and Mineral Resources (KIGAM)

Supported by:
Ministry of Science and Technology (MOST)
United Nations Development Programme (UNDP)

11/19 (Sat) 05:35 Apia to Nadi Arrival: 11/20 (Sun) 06:30 *by Air Pacific*

11/21 (Mon) 10:00 Nadi to Incheon Arrival: 17:35 *by KAL*

19:10 Incheon to Daejeon Arrival: 22:00 *by airport bus*

11/22 (Tue) 10:00 Tour for the facility of KIGAM

11:00-12:00 Meeting with president of KIGAM

13:30-14:30 Korean language lesson (by Ms. Ji Young Lim)

14:30-17:30 Introduction to training session (by Dr. Se Won Chang)

11/23 (Wed) 09:30-12:00 Coastal geomorphology (by Dr. Seong-Pil Kim)

13:30-14:30 Korean language lesson (by Ms. Ji Young Lim)

14:30-17:30 Coastal geomorphology (by Dr. Seong-Pil Kim)

11/24 (Thu) 09:30-12:00 Coastal geomorphology (by Dr. Seong-Pil Kim)

13:30-14:30 Korean language lesson (by Ms. Ji Young Lim)

14:30-16:00 Current state of Korean IODP (by Dr. Young Joo Lee)

16:00-17:30 Global climate change (by Dr. Seung Il Nam)

11/25 (Fri) 09:30-12:00 Coastal geology (by Dr. Se Won Chang)

13:30-14:30 Korean language lesson (by Ms. Ji Young Lim)

14:30-17:30 Coastal geology (by Dr. Se Won Chang)

11/26 (Sat) 09:30 – 11/27 (Sun) 17:30

Excursion to drilling site (Pung-do) (by Dr. Seong Pil Kim)

11/28 (Mon) 09:30-12:00 Sediment size analysis (Theory) (by Dr. Jeong Hae Chang)

13:30-14:30 Korean language lesson (by Ms. Ji Young Lim)

14:30-17:30 Sediment size analysis (Theory) (by Dr. Jeong Hae Chang)

11/29 (Tue) 09:30-12:00 Sediment size analysis (Experiment) (by Dr. J.H. Chang)

13:30-14:30 Korean language lesson (by Ms. Ji Young Lim)

14:30-17:30 Sediment size analysis (Experiment) (by Dr. J.H. Chang)

11/30 (Wed) 13:30 – 18:00

Symposium for capacity building on coastal geological survey

12/1 (Thu) 09:30 – 12/2(Fri) 12:00

Field excursion (beach at Kochang-gun) (by Dr. S.W. Chang & others)

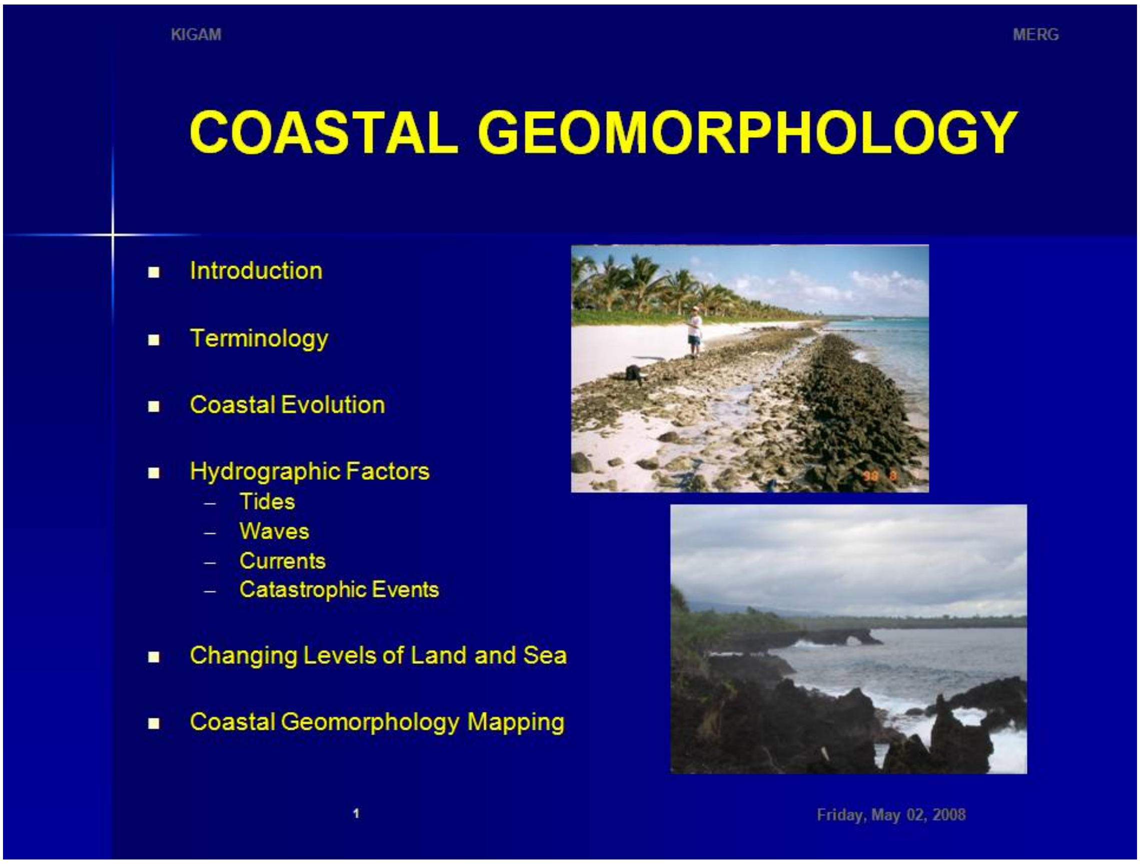
12/3 (Sat) Cultural excursion in Seoul

12/4 (Sun) 19:30 Incheon to Nadi Arrival: 12/5 (Mon) 08:40 *by KAL*

12/6 (Tue) 23:00 Nadi to Apia Arrival: 12/6 (Tue) 01:05 *by Air Pacific*

* The representatives from SMD and SOPAC will be together with the trainees from the 28th of November.

1. Coastal geomorphology



COASTAL GEOMORPHOLOGY

- Introduction
- Terminology
- Coastal Evolution
- Hydrographic Factors
  - Tides
  - Waves
  - Currents
  - Catastrophic Events
- Changing Levels of Land and Sea
- Coastal Geomorphology Mapping

- A study of
  coastal landforms,
  their evolution,
  the governing processes,
  and the present changes

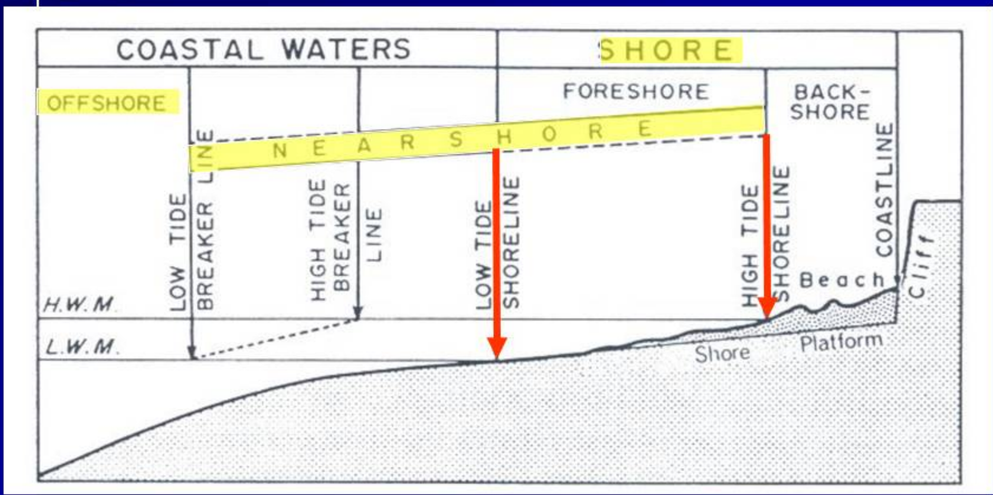
COASTAL GEOMORPHOLOGY

- Introduction
- Terminology
- Coastal Evolution
- Hydrographic Factors
  - Tides
  - Waves
  - Currents
  - Catastrophic Events
- Changing Levels of Land and Sea
- Coastal Geomorphology Mapping

- **Shore**: the zone between the water's edge at low tide and the landward limit of effective wave action
- **Shoreline:** the water's edge, migrating to and fro with the tide
- **Near shore zone**: the zone between the shoreline and the wave-breaking line (surf and swash zones included)
- **Offshore zone**: outside the near shore zone to an arbitrary limit in deep water
  (cf.) offshore, onshore, longshore

KIGAM MERG

COASTAL GEOMORPHOLOGY



4 Friday, May 02, 2008

KIGAM MERG

COASTAL GEOMORPHOLOGY

- Introduction
- Terminology
- Coastal Evolution
- Hydrographic Factors
  - Tides
  - Waves
  - Currents
  - Catastrophic Events
- Changing Levels of Land and Sea
- Coastal Geomorphology Mapping

- **beach**: an accumulation of loose sediment, such as sand, gravel, or boulders, sometimes confined to the backshore but often extending across the foreshore as well
- **shingle**: beach gravels, esp. where the stones are well-rounded
- **barrier**: a bank of beach material which lies offshore and is exposed at high tide
- **bar**: a bank submerged for at least part of the tidal cycle
- **spit**: a beach that diverges from the coast, often terminating in one or more landward projections, known as recurves

5 Friday, May 02, 2008

KIGAM MERG

COASTAL GEOMORPHOLOGY

6 Friday, May 02, 2008

KIGAM MERG

COASTAL GEOMORPHOLOGY

7 Friday, May 02, 2008

KIGAM MERG

COASTAL GEOMORPHOLOGY

8 Friday, May 02, 2008

KIGAM MERG

COASTAL GEOMORPHOLOGY

9 Friday, May 02, 2008

KIGAM MERG

COASTAL GEOMORPHOLOGY

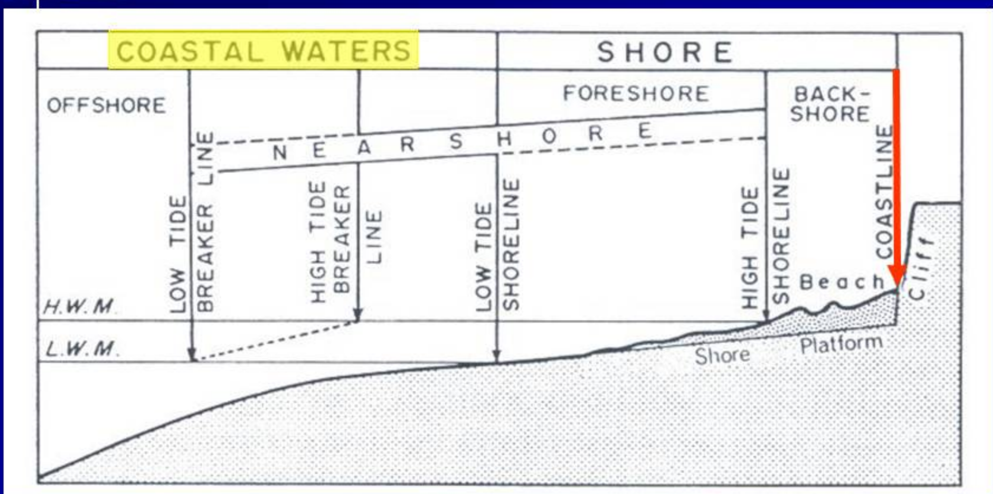
- Introduction
- Terminology
- Coastal Evolution
- Hydrographic Factors
  - Tides
  - Waves
  - Currents
  - Catastrophic Events
- Changing Levels of Land and Sea
- Coastal Geomorphology Mapping

- **coast**: a zone of varying width, including the shore and extending to the landward limit of penetration of marine influences (including the crest of a cliff, the head of a tidal estuary, or the solid ground lying behind coastal dunes, lagoons, and swamps)
- **coastline**: the land margin in the backshore zone
- **coastal waters**: the sea area adjoining the coast, comprising the nearshore and offshore zones

10 Friday, May 02, 2008

KIGAM MERG

COASTAL GEOMORPHOLOGY



11 Friday, May 02, 2008

COASTAL GEOMORPHOLOGY

COASTAL GEOMORPHOLOGY

- Introduction
- Terminology
- Coastal Evolution
- Hydrographic Factors
  - Tides
  - Waves
  - Currents
  - Catastrophic Events
- Changing Levels of Land and Sea
- Coastal Geomorphology Mapping

- **Controlling factors governing geomorphological processes**
  - **Geology**: structure and lithology of rock formations, sediment sources
  - **Climate:** weathering through physical, chemical, and biological processes
  - **Regional variations**: humid tropic, cold, arid
  - **Biology**: strongly influenced by climate (e.g. corals and associated reef building organisms, mangrove swamps, salt marshes in the temperate zone)
  - **Wind**
  - **Tide**
  - **Other oceanographic factors (e.g. salinity)**

COASTAL GEOMORPHOLOGY

Old Weathered Volcanic Basement

Recent Volcanic Lava Field

KIGAM MERG

COASTAL GEOMORPHOLOGY

- Introduction
- Terminology
- Coastal Evolution
- Hydrographic Factors
  - Tides
  - Waves
  - Currents
  - Catastrophic Events
- Changing Levels of Land and Sea
- Coastal Geomorphology Mapping

- **Viewpoints on coastal evolution**

- action-reaction of energy, materials and landforms
- past conditions (relict coastal landforms & sea-level changes)
- time scales: long-term (>10^4 yr), medium (10^2~10^4 yr), short-term (<10^2 yr) evolution
- human activities: direct or indirect effects

→ Understanding of the factors and processes at work in the coastal geomorphic system and to modify coastal changes are needed (patterns of change, the sources of sediment, the paths of sediment flow and the quantities involved over given periods of time)!

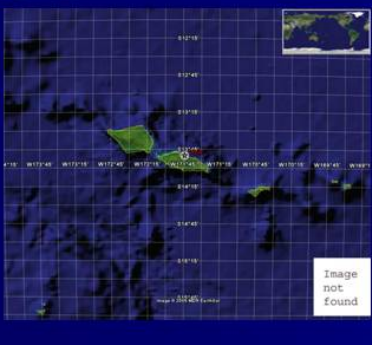
COASTAL GEOMORPHOLOGY

- Introduction
- Terminology
- Coastal Evolution
- Hydrographic Factors
  - Tides
  - Waves
  - Currents
  - Catastrophic Events
- Changing Levels of Land and Sea
- Coastal Geomorphology Mapping

- **New Technologies**

- remote sensing imagery (color or multi-spectral aerial photography, various satellite imagery)
- submersibles, underwater camera, diving and onboard drilling
- age dating based on radiometric, paleontological and archeological methods
- wave, current and tide measurement using various in-situ or remote sensing instruments
- laboratory modeling and virtual reality
- permanent shore stations with integrated and wireless-network sensors

COASTAL GEOMORPHOLOGY



KIGAM MERG

COASTAL GEOMORPHOLOGY

- Introduction
- Terminology
- Coastal Evolution
- Hydrographic Factors
  - Tides
  - Waves
  - Currents
  - Catastrophic Events
- Changing Levels of Land and Sea
- Coastal Geomorphology Mapping

- **Issues (Topics) in Researches**
  - Long-term, periodic or continued observation, investigation, survey or measurement and their correlation to coastal processes
  - Completely quantitative and *a priori* model advocation vs. empirical approaches and *a posteriori* solution

18 Friday, May 02, 2008

KIGAM MERG

COASTAL GEOMORPHOLOGY

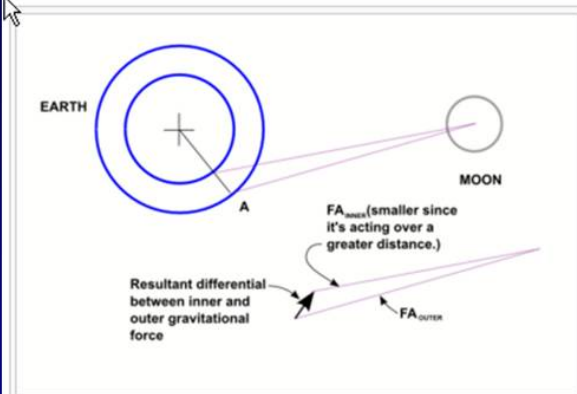
- Introduction
- Terminology
- Coastal Evolution
- Hydrographic Factors
  - Tides
  - Waves
  - Currents
  - Catastrophic Events
- Changing Levels of Land and Sea
- Coastal Geomorphology Mapping

- **Tides**
  - **Movements of the oceans mostly set up by the gravitational effects of the sun and the moon in relation to the earth**
  - **Regular changes in the level of the sea along the coast**
  - **Currents (tidal currents) generated when it ebbs and floods**
  - **Oscillatory characters determined partly by the size and shape of the basin**
  - **When combined with earth's rotation they circulate around a number of nodal (*amphidromatic*) points and their effects are most strongly marked in shallow and relatively enclosed ocean areas**

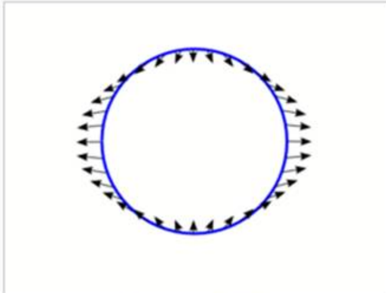
19 Friday, May 02, 2008

COASTAL GEOMORPHOLOGY

Tide-generating Forces



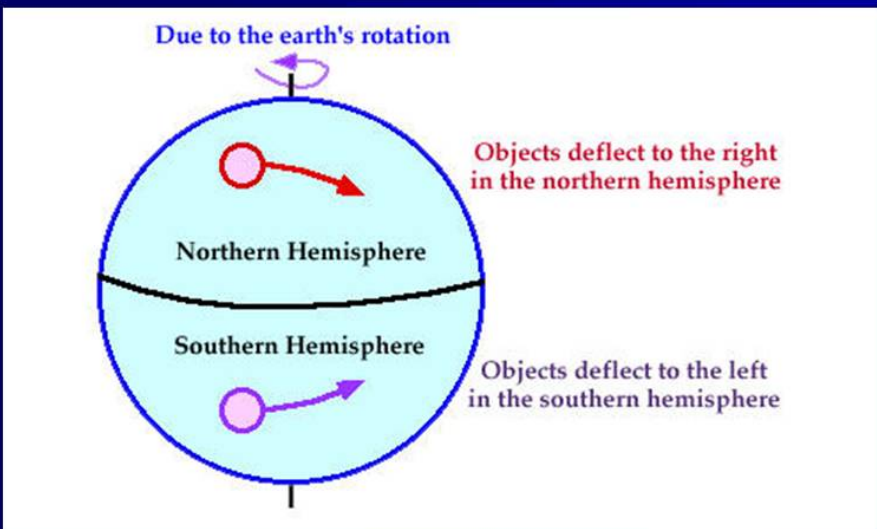
The Moon exerts its gravitational pull differently on different parts of the earth. The farther the Moon, the weaker its pull. Imagine a shell of the outer Earth, this diagram shows the Moon's gravity differential over the thickness of the shell.



The Moon's gravity differential field at the surface of the earth is known as the **Tidal Generating Force**. This is the primary mechanism that drives tidal action and explains two bulges, accounting for two high tides per day. Other forces, such as the Earth and Moon revolving around each other, and the Sun's gravity also add to tidal action.

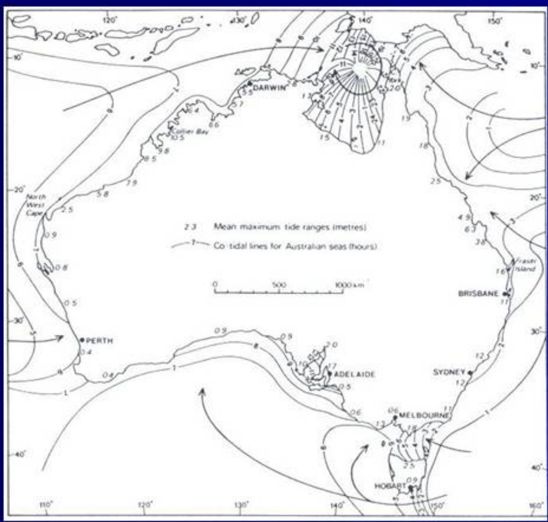
COASTAL GEOMORPHOLOGY

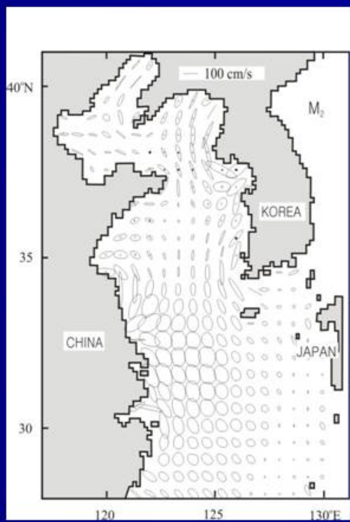
Coriolis Force



COASTAL GEOMORPHOLOGY

Distribution of Tidal Ranges and Amphidromatic Points

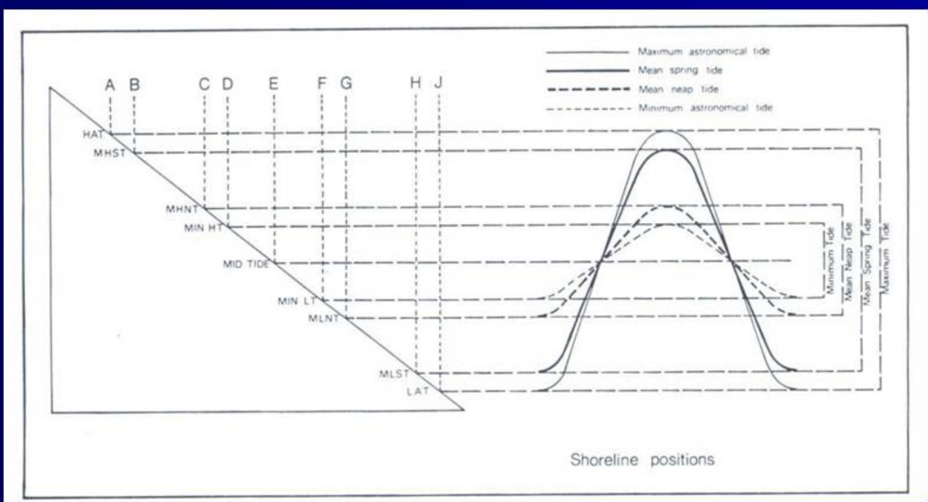




KIGAM MERG

COASTAL GEOMORPHOLOGY

Tidal Range



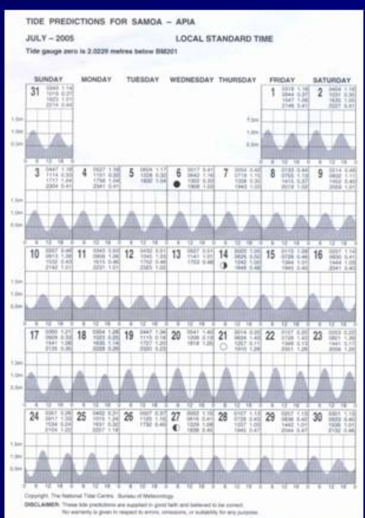
COASTAL GEOMORPHOLOGY

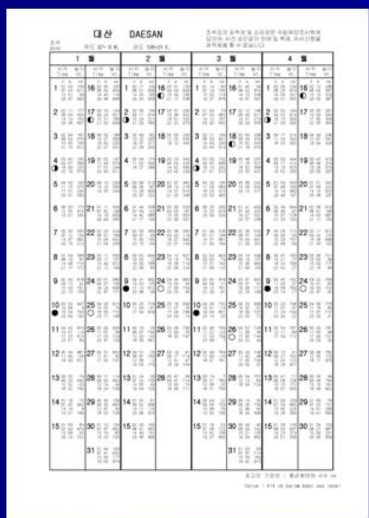
- Introduction
- Terminology
- Coastal Evolution
- Hydrographic Factors
  - Tides
  - Waves
  - Currents
  - Catastrophic Events
- Changing Levels of Land and Sea
- Coastal Geomorphology Mapping

- Periods: spring/neap, 27.5 days, apogean/perigean, 18.6 years
- Accurate determination requires more than 18.6 years tidal observations
- A reasonable estimate: 1 or 2 years' observations
- Meteorologic effects on tides
  - A fall of 1 mbar rises the ocean level about 1 cm
  - storm surges (wind-deriven)
  - "king tides" (high tide augmented by meteorological effects)
- Seasonal variations in temp. and salinity of the oceans inducing volume or density changes
- Local variations (e.g. configuration of the coast, the effect of outflow from rivers, breakwaters and jetties built at harbour entrances

COASTAL GEOMORPHOLOGY

Tide Prediction Table





KIGAM MERG

COASTAL GEOMORPHOLOGY

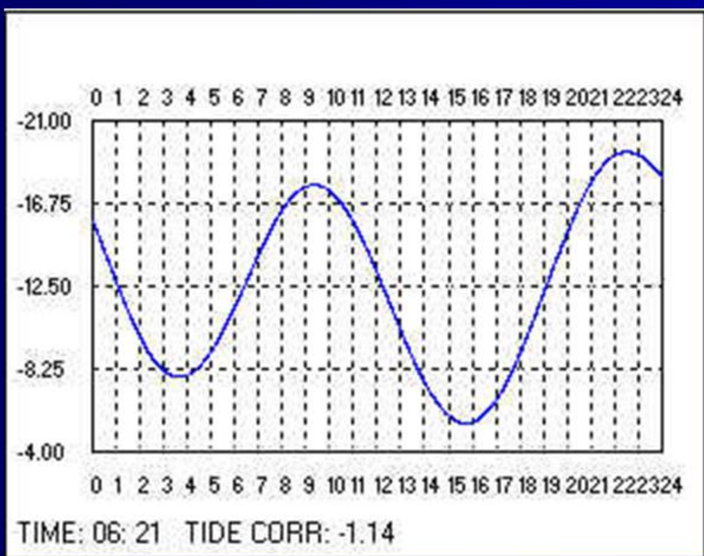
- Introduction
- Terminology
- Coastal Evolution
- Hydrographic Factors
  - Tides
  - Waves
  - Currents
  - Catastrophic Events
- Changing Levels of Land and Sea
- Coastal Geomorphology Mapping

- Tide ranges
  - Microtidal range (0~2 m): Samoa
  - Mesotidal range (2~4 m)
  - Macrotidal range (> 4 m)
    - W. Sea of Korea is a typical case
    - More than 20 m tide range was reported in N. Canada
  - "tidal bore"
  - Contrasts in tide range result in different characters of coastal geomorphology
  - large (macro tidal) range case
  - small (micro tidal) range case

26 Friday, May 02, 2008

KIGAM MERG

COASTAL GEOMORPHOLOGY



27 Friday, May 02, 2008

KIGAM MERG

COASTAL GEOMORPHOLOGY

Bay of Fundi – High Tide

Bay of Fundi – Low Tide

28 Friday, May 02, 2008

KIGAM MERG

COASTAL GEOMORPHOLOGY

Tidal Bore

29 Friday, May 02, 2008

KIGAM MERG

COASTAL GEOMORPHOLOGY

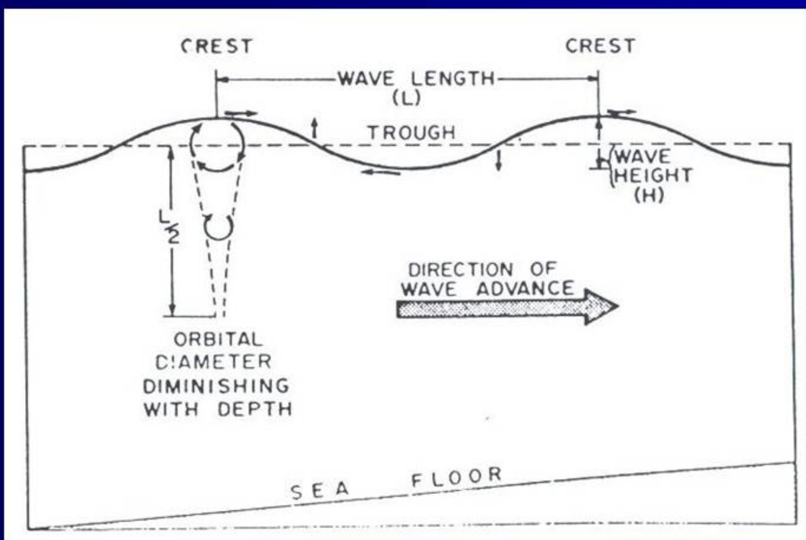
- Introduction
- Terminology
- Coastal Evolution
- Hydrographic Factors
  - Tides
  - **Waves**
  - Currents
  - Catastrophic Events
- Changing Levels of Land and Sea
- Coastal Geomorphology Mapping

- Superficial undulations of the water surface produced by winds blowing over the sea and thus inducing pressure contrast between windward and leeward sides
- Orbital movements of water which become very small (4% of the surface orbital diameter) at the water depth (d) of half of the wave length (L)
- Wave height (H) is the vertical distance between adjacent crests and troughs.
- Wave steepness is conventionally the ratio between the height and the length (Ho/Lo).
- Wave dimensions are determined by wind velocity, fetch, and the duration of the wind. N.B. fetch: the extent of open water across which the wind is blowing

30 Friday, May 02, 2008

KIGAM MERG

COASTAL GEOMORPHOLOGY



31 Friday, May 02, 2008

COASTAL GEOMORPHOLOGY

- Introduction
- Terminology
- Coastal Evolution
- Hydrographic Factors
  - Tides
  - **Waves**
  - Currents
  - Catastrophic Events
- Changing Levels of Land and Sea
- Coastal Geomorphology Mapping

- **In coastal waters (with limited fetch), H ∝ (wind velocity, C) and (wave period, T) ∝ √C**
- **In deep waters,**

  $C_o^2 = gL_o/2\pi$ or $C_o = gT/2\pi = 1.56T$ (m/sec),

  $\therefore L_o = 1.56T2$,

  where g = ca. 980.62 cm/sec^2

  N.B. '$_O$' denotes the still-water depth (d) is greater than half of the wave length
- **As waves move into shallower waters, where $d < L/2$,**

  $C_s^2 = gL/2\pi * \tanh(2\pi d/L)$
- **Wave height decreases as d/L falls below 0.5, but increases again when d/L is less than 0.06.**

COASTAL GEOMORPHOLOGY

- Introduction
- Terminology
- Coastal Evolution
- Hydrographic Factors
  - Tides
  - **Waves**
  - Currents
  - Catastrophic Events
- Changing Levels of Land and Sea
- Coastal Geomorphology Mapping

- Significant Wave
  - 'typical' wave length and height are difficult to describe. → the concept of **'significant wave'** was adopted.
  - '**significant wave**' is based on the calculation of the mean wave length ($L_{⅓}$) and the mean wave height ($H_{⅓}$) of the highest one-third of all waves over a period of 20 minutes.
  - This concept is useful and used frequently to compare the conditions of coastal waters at different times, or on different coastal sectors!

KIGAM MERG

COASTAL GEOMORPHOLOGY

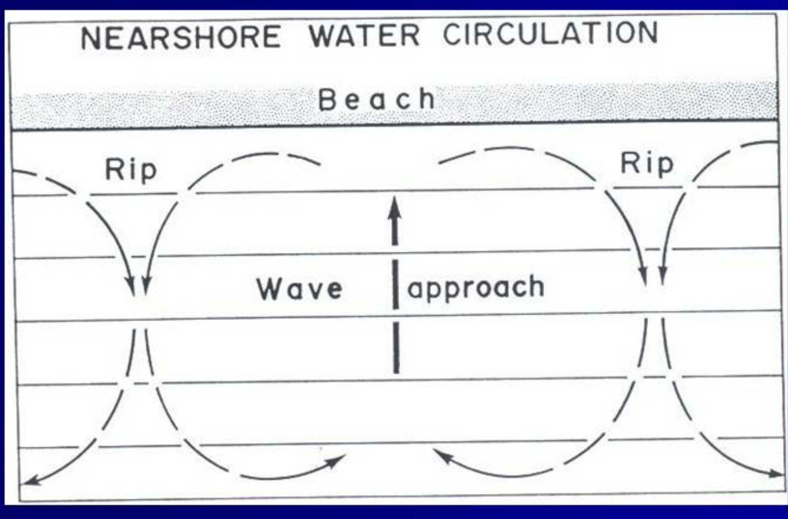
- Introduction
- Terminology
- Coastal Evolution
- Hydrographic Factors
  - Tides
  - **Waves**
  - Currents
  - Catastrophic Events
- Changing Levels of Land and Sea
- Coastal Geomorphology Mapping

- Nearshore water circulation pattern
  - waves → **breakers** → **swashes** → **backwash** (**sheet flow** near the sea bed) or in **rip currents** (usually localized)
  - rip currents: up to 30 m in width and 8 km/hr in speed
  - beach drifting and longshore drifting
  - ocean swell
  - edge waves and beach cusps

34 Friday, May 02, 2008

KIGAM MERG

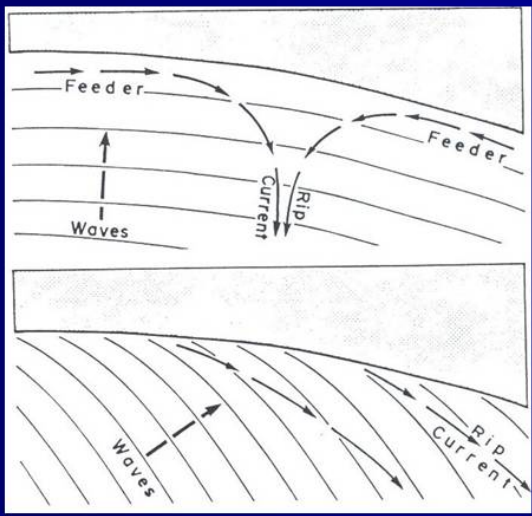
COASTAL GEOMORPHOLOGY



35 Friday, May 02, 2008

KIGAM MERG

COASTAL GEOMORPHOLOGY



36 Friday, May 02, 2008

KIGAM MERG

COASTAL GEOMORPHOLOGY

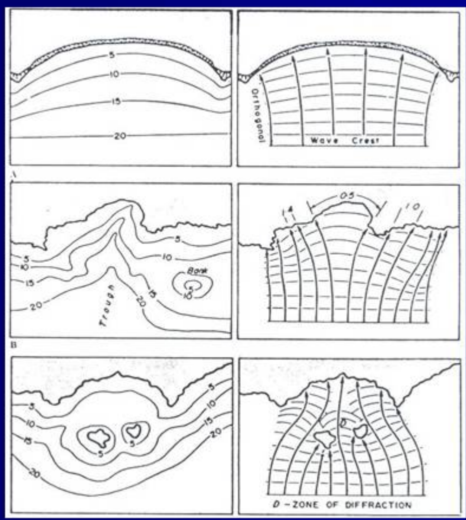
- Introduction
- Terminology
- Coastal Evolution
- Hydrographic Factors
  - Tides
  - **Waves**
  - Currents
  - Catastrophic Events
- Changing Levels of Land and Sea
- Coastal Geomorphology Mapping

- Wave refraction and their patterns
  - traceable from vertical aerial photographs or satellite imagery
  - also can be described graphically using computer programs
  - $H \propto 1/\sqrt{(\text{the relative spacing of adjacent orthogonals})}$
  - refraction coefficient (R) = $\sqrt{(So/S)}$, where So is the distance between a pair of orthogonals in deep water and S their spacing on arrival at the shoreline.

37 Friday, May 02, 2008

COASTAL GEOMORPHOLOGY

Wave Refraction



COASTAL GEOMORPHOLOGY

- Introduction
- Terminology
- Coastal Evolution
- Hydrographic Factors
  - Tides
  - **Waves**
  - Currents
  - Catastrophic Events
- Changing Levels of Land and Sea
- Coastal Geomorphology Mapping

However, the distinction should be made in terms of **normal prevailing wave regimes**, for occasionally drastic modification by strong wave action could be caused mostly during abnormal meteorologic conditions (e.g. cyclones).

COASTAL GEOMORPHOLOGY

- Introduction
- Terminology
- Coastal Evolution
- Hydrographic Factors
  - Tides
  - Waves
  - **Currents**
  - Catastrophic Events
- Changing Levels of Land and Sea
- Coastal Geomorphology Mapping

- Drifts of water in response to
  - prevailing wind patterns
  - density variations in the oceans resulting from differences in the salinity and temperature of water masses.
- True ocean currents are slow movements of water, and are not important in coastal geomorphology, except where they bring in warmer or colder water, which affects ecological conditions near the coast and thereby influences the world distribution of such landforms as coral reefs and mangrove swamps.
- The global oceanic current system

COASTAL GEOMORPHOLOGY

- Introduction
- Terminology
- Coastal Evolution
- Hydrographic Factors
  - Tides
  - Waves
  - **Currents**
  - Catastrophic Events
- Changing Levels of Land and Sea
- Coastal Geomorphology Mapping

- The effects of currents in transporting sediment (**Hjulström diagram**)

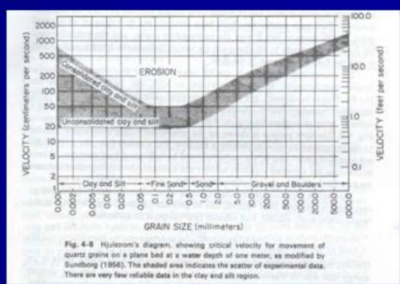


Fig. 4-8 Hjulstrom's diagram, showing critical velocity for movement of quartz grains on a plane bed at a water depth of one meter, as modified by Sundborg (1956). The shaded area indicates the scatter of experimental data. There are very few reliable data in the clay and silt region.

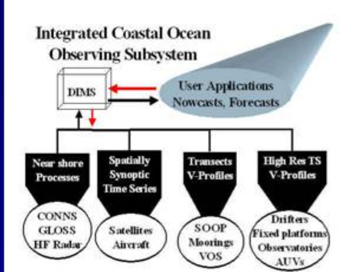
COASTAL GEOMORPHOLOGY

- Introduction
- Terminology
- Coastal Evolution
- Hydrographic Factors
  - Tides
  - Waves
  - **Currents**
  - Catastrophic Events
- Changing Levels of Land and Sea
- Coastal Geomorphology Mapping

- Currents are generally more effective in shaping sea floor topography than in developing coastal configuration, and the early view that long, gently-curving beaches on oceanic coasts were produced by currents sweeping along the shore has given place to the modern view that these outlines are determined by refracted wave patterns.
- Current trace and measurement
  - fluorescence or a colored dye
  - sea bed drifters
  - floats (e.g. COOP, GOOS)

KIGAM MERG

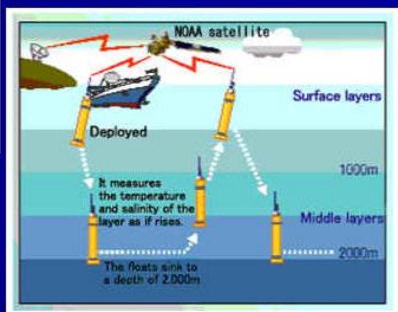
COASTAL GEOMORPHOLOGY



- Coastal Observing Network for the Near Shore (CONNS)
  - GLOSS
  - HF Radar
  - Near-shore measurements
- Fixed Platforms, Moorings, Drifters, AUVs
- Remote Sensing
- SOOP & VOS
  - e.g., CPR

COOP

GOOS

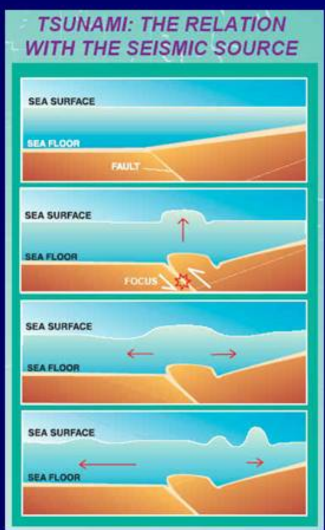


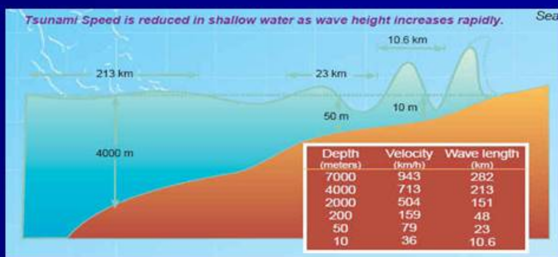
COASTAL GEOMORPHOLOGY

- Introduction
- Terminology
- Coastal Evolution
- Hydrographic Factors
  - Tides
  - Waves
  - Currents
  - **Catastrophic Events**
- Changing Levels of Land and Sea
- Coastal Geomorphology Mapping

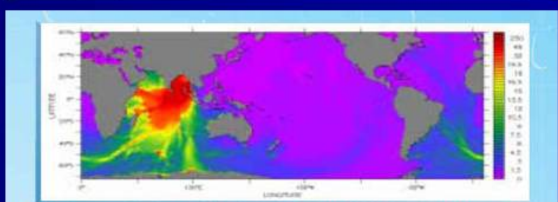
- **tsunami**: waves several hundred kilometers long, with periods of up to half an hour, proceeding at velocities of up to 800 km/hr across the deep oceans
- Origins of tsunami
  - earthquakes (e.g. 2005 SW Asia)
  - explosive volcanic eruptions
  - (submarine) landslides or rockfalls
  - tropical cyclones
- Characteristics of tsunami: tsunamis are not necessarily 'damp down' by distance. The magnitude of waves received depends partly on offshore topography, the waves being higher where the offshore zone is gently shelving, and partly on the orientation of a coast in relation to the source of the disturbance.

COASTAL GEOMORPHOLOGY



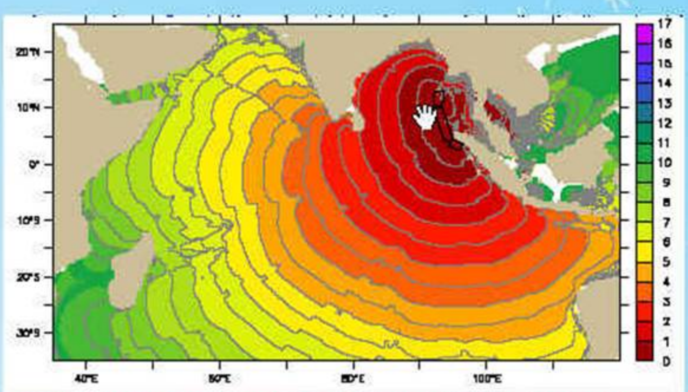


Depth (meters)	Velocity (km/h)	Wave length (km)
7000	943	282
4000	713	213
2000	504	151
200	159	48
50	79	23
10	36	10.6



Maximum calculated global wave heights (cm) from the December 26, 2004 Indian Ocean tsunami. Waves were recorded on sea level gauges in Antarctica, and along the coasts of South and North America and Canada in both the Pacific and Atlantic Oceans (NOAA PMEL).

COASTAL GEOMORPHOLOGY



Calculated tsunami travel times for the December 26, 2004 earthquake off western Sumatra. Each concentric curve represents 30 minutes of tsunami travel time. Destructive tsunami hit Indonesia in 15 minutes, Sri Lanka in two hours, and Kenya nine hours after the earthquake (NOAA PMEL).

COASTAL GEOMORPHOLOGY

Banda Ache (Before)

Banda Ache (After)

KIGAM MERG

COASTAL GEOMORPHOLOGY

- Introduction
- Terminology
- Coastal Evolution
- Hydrographic Factors
  - Tides
  - Waves
  - Currents
  - Catastrophic Events
- **Changing Levels of Land and Sea**
- Coastal Geomorphology Mapping

- **Types of coastlines**
  - Emerged coastlines
    - stranded beach deposits
    - marine shell beds
    - platforms backed by steep cliff-like slopes, etc.
  - Submerged coastlines
    - drowned mouths of river valleys
    - submerged dune topography
    - former coastlines marked by breaks of slope on the sea floor
    - freshwater peat and relict of land vegetation obtained from boring in coastal plains and deltas, etc.

48 Friday, May 02, 2008

KIGAM MERG

COASTAL GEOMORPHOLOGY

- Introduction
- Terminology
- Coastal Evolution
- Hydrographic Factors
  - Tides
  - Waves
  - Currents
  - Catastrophic Events
- **Changing Levels of Land and Sea**
- Coastal Geomorphology Mapping

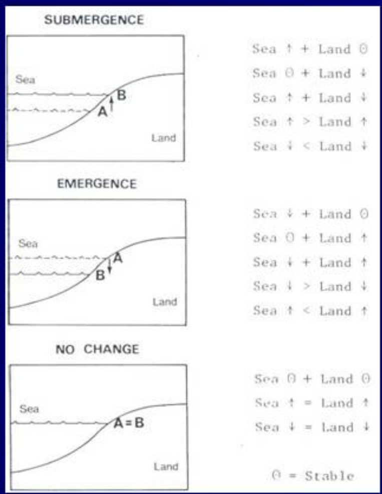
- **Factors to change the level**
  - Tectonic movements
    - Epeirogenic movements: broad-scale elevations or depressions with warping along a hinge line
    - Orogenic movements: folding, faulting, warping, and tilting
    - Isostatic movements: elastic or gravitational depression or uplift due to ice, lava, sedimentary deposits, etc.

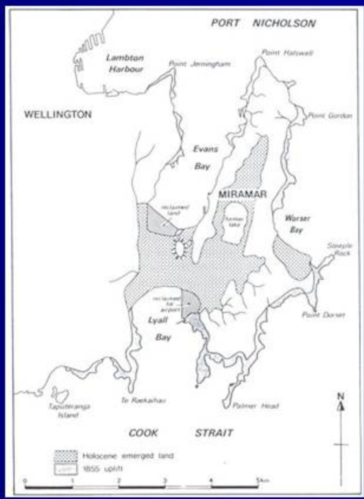
      N.B. Neotectonic coasts

      Divergent/Convergent margins
  - Eustatic movements: movements of sea level induced by
    - Absolute change of sea water amount
    - Temperature variation (+/-2m/℃)
    - Glacio-eustatic oscillation
    - Tectono-eustatic variation
    - Hydro-isostatic change
    - Transverse gradient

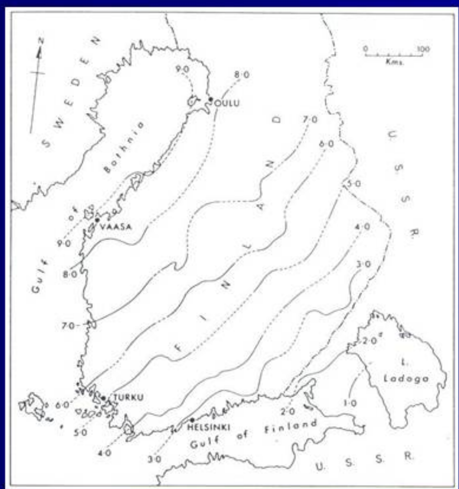
49 Friday, May 02, 2008

COASTAL GEOMORPHOLOGY

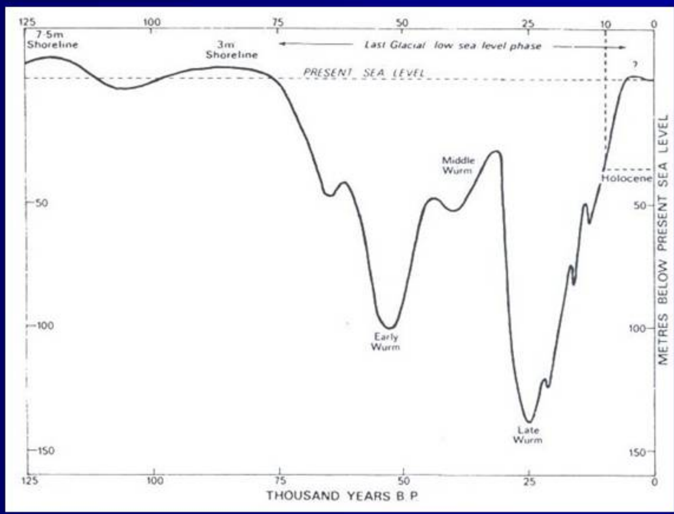




COASTAL GEOMORPHOLOGY



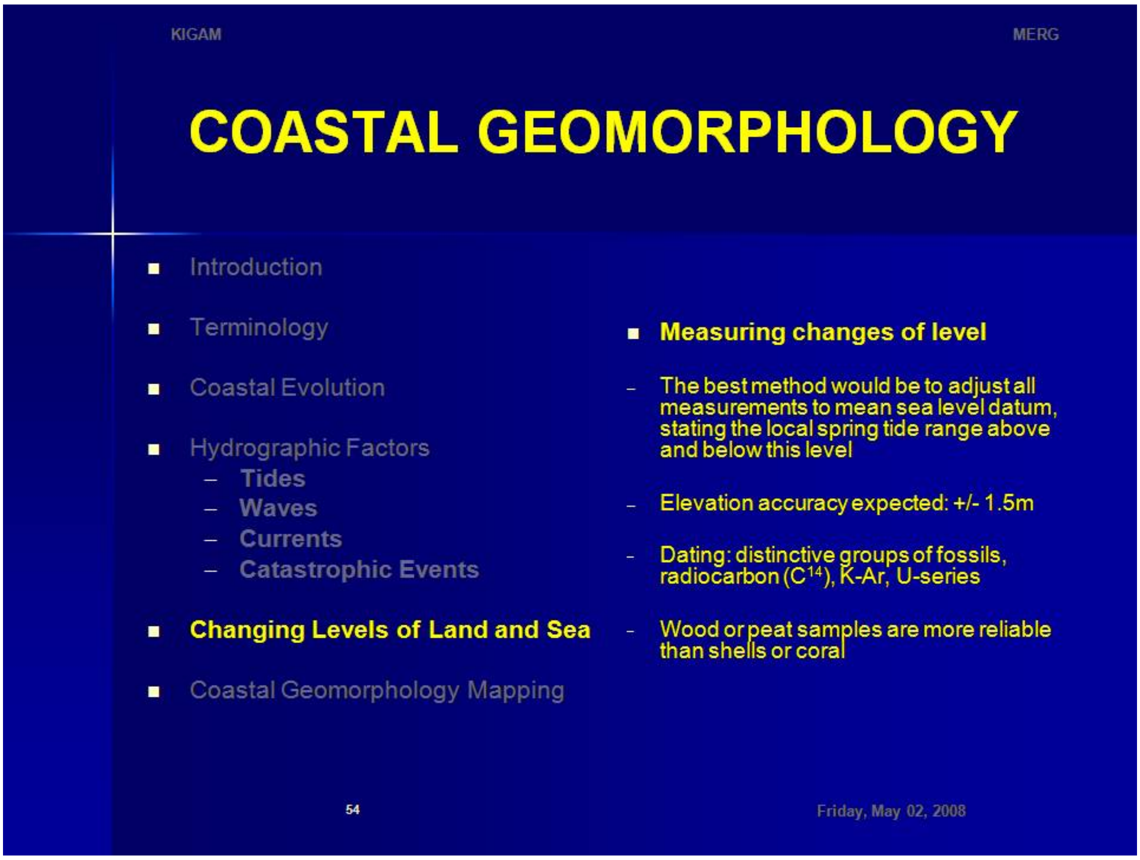
COASTAL GEOMORPHOLOGY

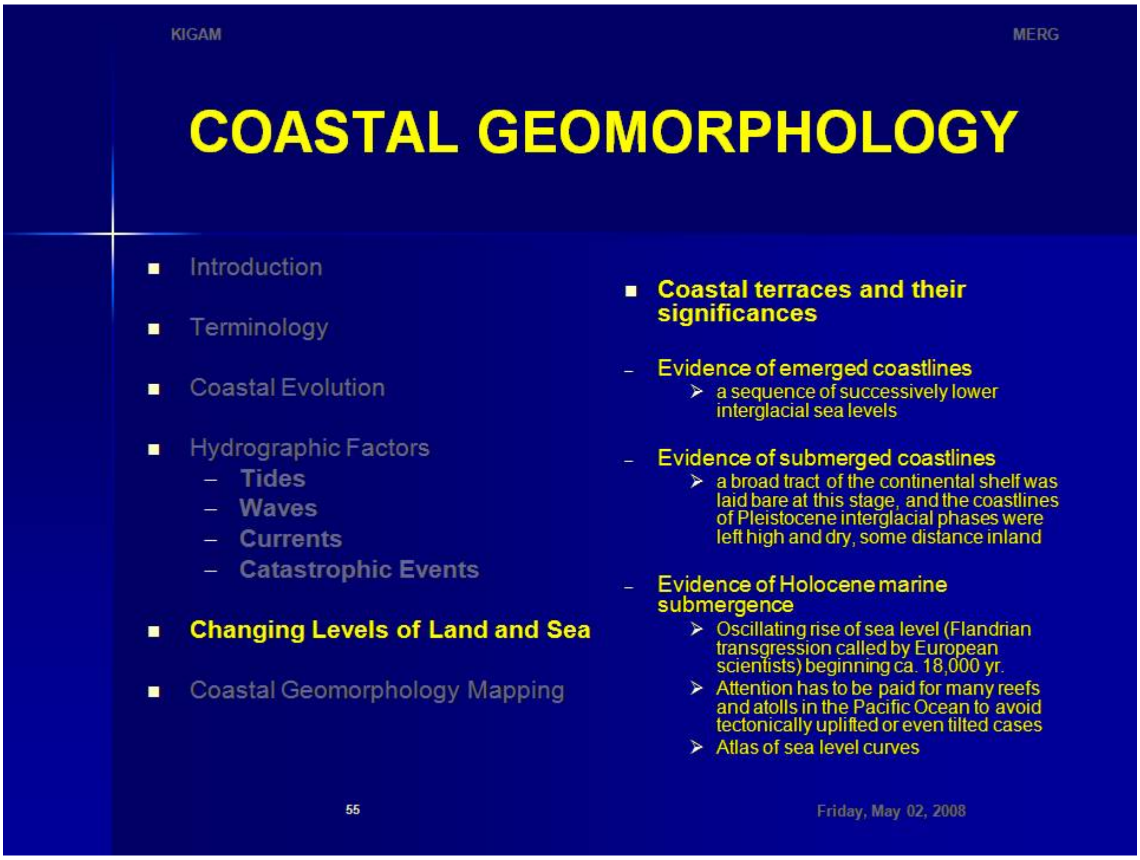


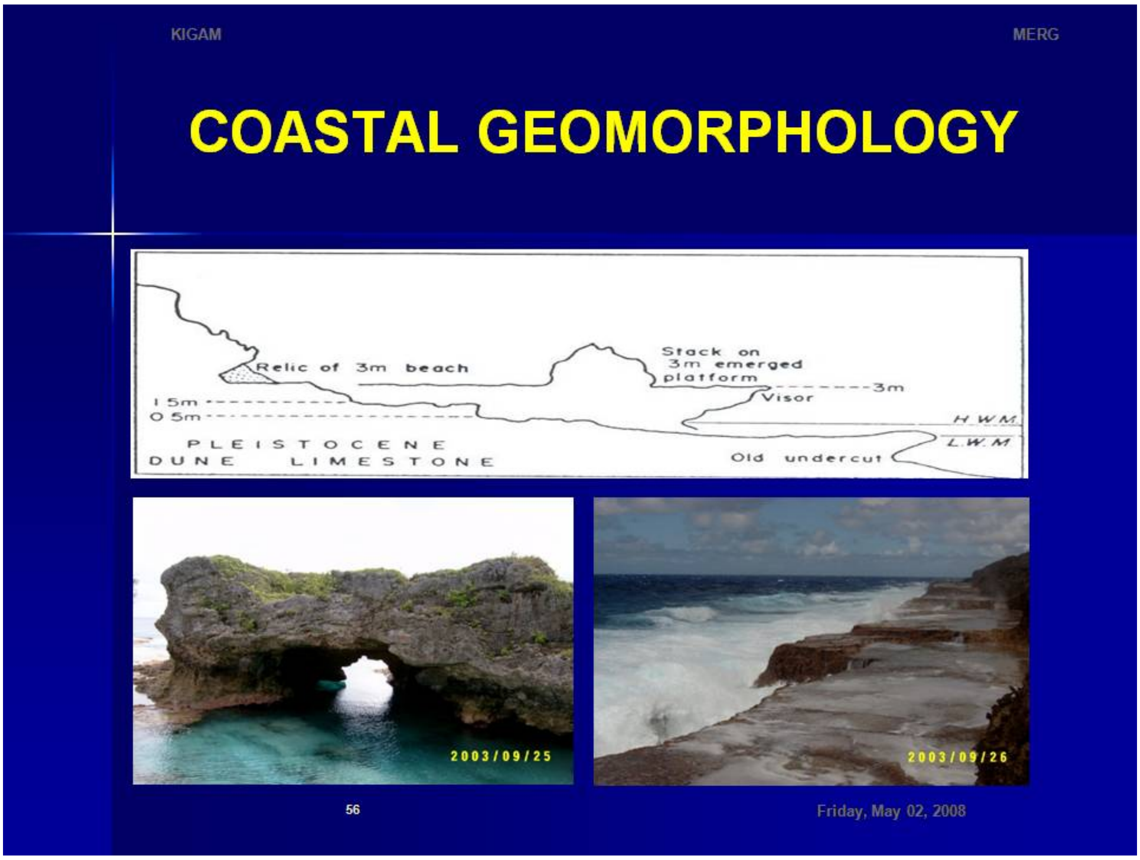
COASTAL GEOMORPHOLOGY

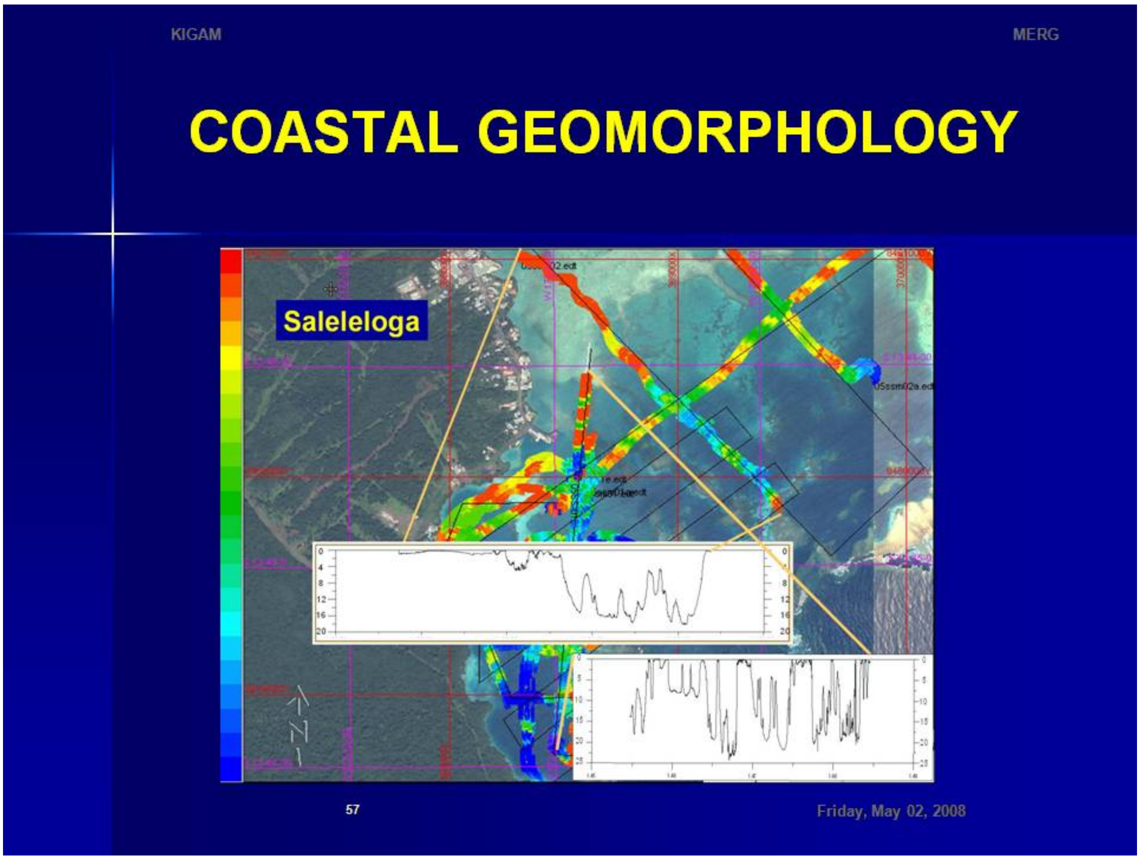
- Introduction
- Terminology
- Coastal Evolution
- Hydrographic Factors
  - Tides
  - Waves
  - Currents
  - Catastrophic Events
- **Changing Levels of Land and Sea**
- Coastal Geomorphology Mapping

- **Measuring changes of level**
  - The best method would be to adjust all measurements to mean sea level datum, stating the local spring tide range above and below this level
  - Elevation accuracy expected: +/- 1.5m
  - Dating: distinctive groups of fossils, radiocarbon (C^{14}), K-Ar, U-series
  - Wood or peat samples are more reliable than shells or coral


KIGAM
MERG
COASTAL GEOMORPHOLOGY
Introduction
Terminology
Coastal Evolution
Hydrographic Factors
– Tides
– Waves
– Currents
– Catastrophic Events
Changing Levels of Land and Sea
Coastal Geomorphology Mapping
Measuring changes of level
– The best method would be to adjust all measurements to mean sea level datum, stating the local spring tide range above and below this level
– Elevation accuracy expected: +/- 1.5m
– Dating: distinctive groups of fossils, radiocarbon (C^{14}), K-Ar, U-series
– Wood or peat samples are more reliable than shells or coral
54
Friday, May 02, 2008

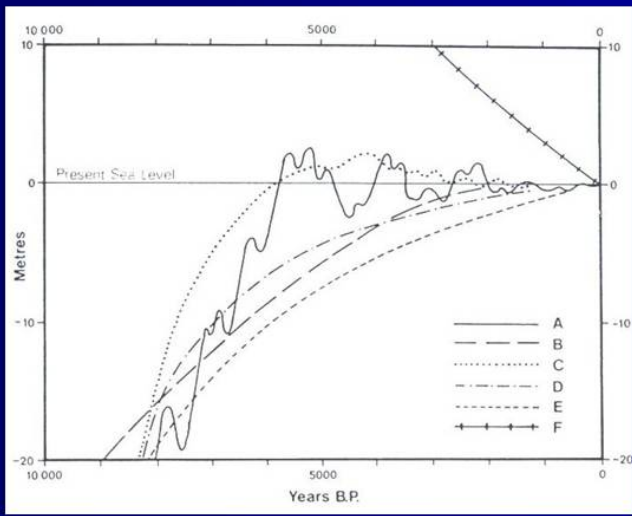

KIGAM
MERG
COASTAL GEOMORPHOLOGY
Introduction
Terminology
Coastal Evolution
Hydrographic Factors
– Tides
– Waves
– Currents
– Catastrophic Events
Changing Levels of Land and Sea
Coastal Geomorphology Mapping
Coastal terraces and their significances
– Evidence of emerged coastlines
➢ a sequence of successively lower interglacial sea levels
– Evidence of submerged coastlines
➢ a broad tract of the continental shelf was laid bare at this stage, and the coastlines of Pleistocene interglacial phases were left high and dry, some distance inland
– Evidence of Holocene marine submergence
➢ Oscillating rise of sea level (Flandrian transgression called by European scientists) beginning ca. 18,000 yr.
➢ Attention has to be paid for many reefs and atolls in the Pacific Ocean to avoid tectonically uplifted or even tilted cases
➢ Atlas of sea level curves
55
Friday, May 02, 2008


KIGAM
MERG
COASTAL GEOMORPHOLOGY
Relic of 3m beach
Stack on
3m emerged
platform
3m
1.5m
0.5m
Visor
H.W.M.
L.W.M.
PLEISTOCENE
DUNE LIMESTONE
Old undercut
2003/09/25
2003/09/26
56
Friday, May 02, 2008


KIGAM
MERG
COASTAL GEOMORPHOLOGY
Saleleloga
57
Friday, May 02, 2008

KIGAM MERG

COASTAL GEOMORPHOLOGY



58 Friday, May 02, 2008

KIGAM MERG

COASTAL GEOMORPHOLOGY

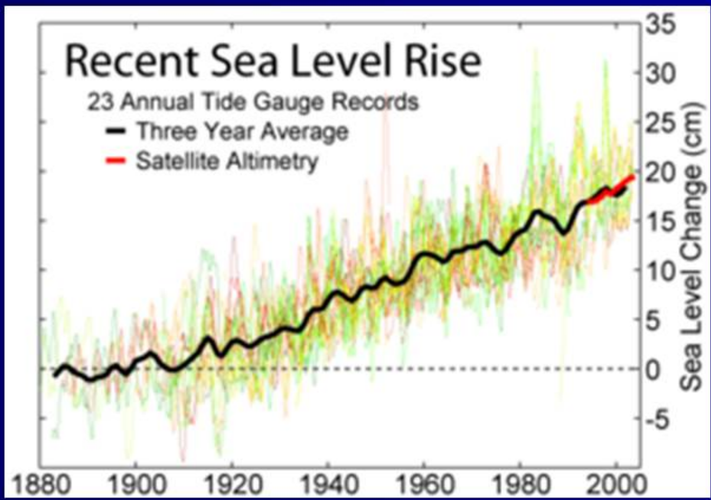
- Introduction
- Terminology
- Coastal Evolution
- Hydrographic Factors
  - Tides
  - Waves
  - Currents
  - Catastrophic Events
- **Changing Levels of Land and Sea**
- Coastal Geomorphology Mapping

- Changes of level at the present time
  - Tide gauge records show emerging, submerging and apparently stable coastal stations.
  - A number of geomorphological effects have been attributed to the rise in sea level over the past century.
  - Renewal of coral growth on planed-off reef surfaces
  - The onset of erosion on most sandy shores
  - The prevalence of erosion on the seaward margins of many marshlands

59 Friday, May 02, 2008

KIGAM MERG

COASTAL GEOMORPHOLOGY

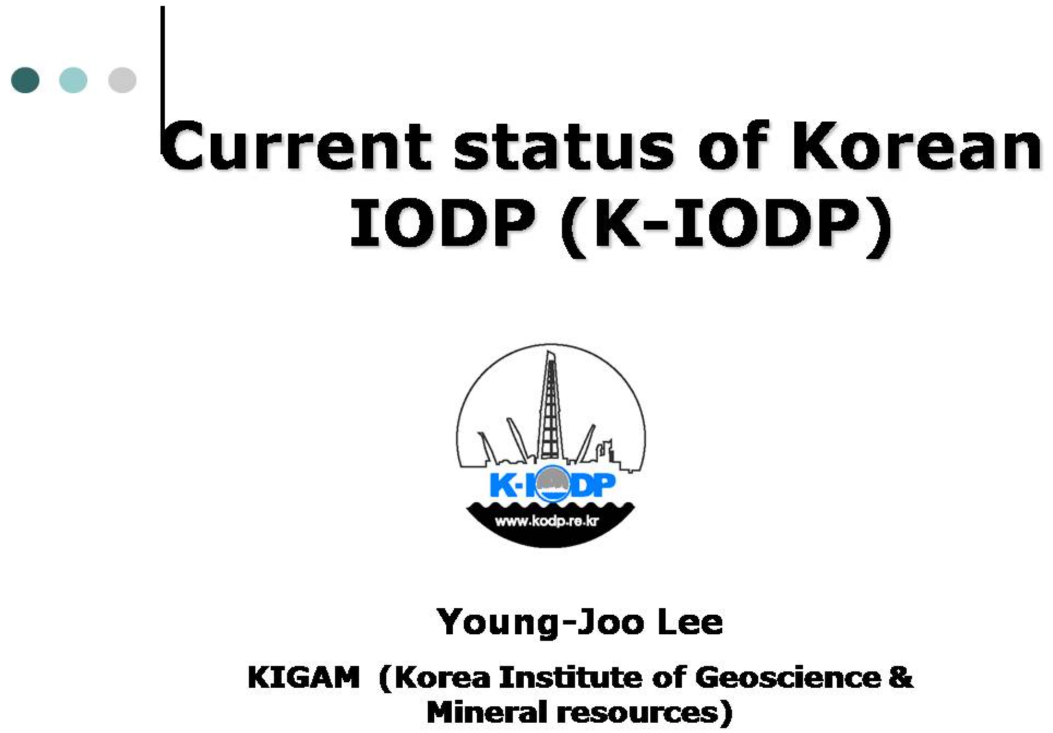


KIGAM MERG

COASTAL GEOMORPHOLOGY

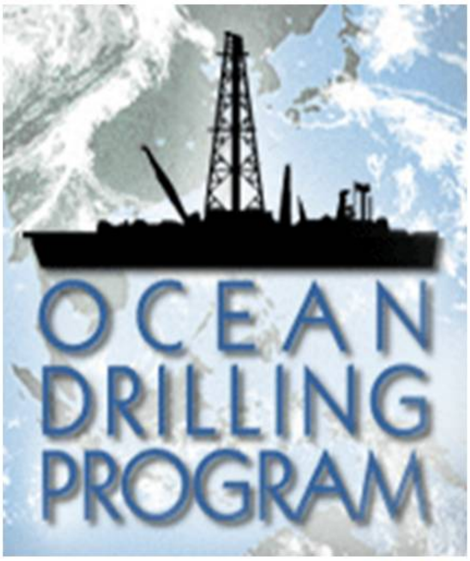
- Introduction
- Terminology
- Coastal Evolution
- Hydrographic Factors
  - Tides
  - Waves
  - Currents
  - Catastrophic Events
- Changing Levels of Land and Sea
- **Coastal Geomorphology Mapping**
- **Coastal Geomorphology Units**
  - Cliffed Coasts
  - Beaches, Spits, and Barriers
  - Coastal Dunes
  - Estuaries and Lagoons
  - Deltas
  - Coral Reefs and Atolls
- **Classification of Coastal Landforms**

2. Current state of Korean IODP (K-IODP)



Outline

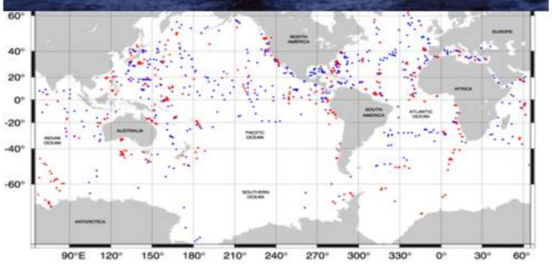
- Introduction of IODP
- Korean IODP
  - Background
  - Organization and Functions
  - Recent Activities
    - Shipboard Scientists
    - Researches related to ODP/IODP
    - Drilling Proposals
    - Managing K-IODP office
  - Future Plans



한국지질자원연구원
KIGAM

Scientific Ocean Drilling Project

- **DSDP**
  - 1968 ~ 1983
  - Glomar Challenger
  - US, Germany, France, UK, Russi
  - 624 Site (Leg 1-100)
- **ODP**
  - 1985 ~ 2003
  - JOIDES Resolution
  - 22 Countries
  - 653 Site (Leg 101-210)
- **Scientific Achievements**
  - Operation of Plate Tectonics
  - Discovery of Gas hydrate
  - Subsurface deep biosphere
  - Extreme Climate change
  - Large Igneous Plutons



DSDP Legs 1–96, Sites 1–624 (•) and ODP Legs 100–210, Sites 625–1277 (•)

KIGAM

IODP (Integrated Ocean Drilling Program)

- Begin Oct, 2003
- Chikyu, J/R, MSPs
- Earth, Oceans and Life (120M/yr)
- Nature, Science promote IODP

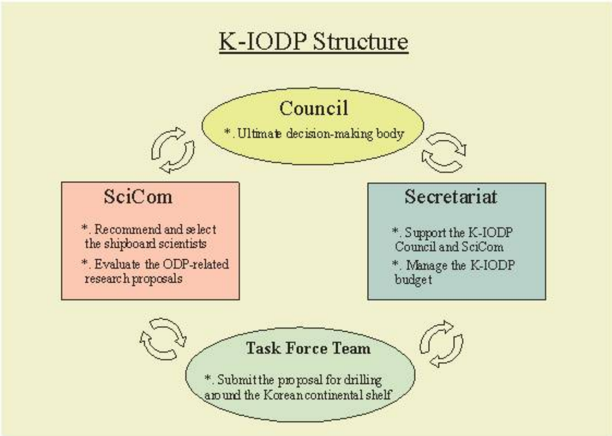
Background

- 1996 : Korea formed a consortium with Canada and Australia and joined the ODP as an 1/12 member
- 1997 : PacRim consortium (Australia-Canada-Taiwan-Korea) was established
- 1998 : First shipboard scientist from KODP
- 2004 : K-IODP, funded by MOMAF
- 2006 : Join IODP as Asian Consortium

한국지질자원연구원
KIGAM

K-IODP

- **MOMAF**
- **Budget**
  - 2004-2010 : 7.7 M
- **KIGAM**
- **Participating**
  - **KORDI**
  - **10+ universities**
  - **KNOC**
  - **KBSI**
  - **Private companies**



한국지질자원연구원 KIGAM

Council

- **Mission**
  - **Decision making**
  - **Selection of SciCom board**
  - **Revision/amendment of K-IODP articles**
- **Members**
  - **Representative from government funding agency**
  - **Presidents of KIGAM and KORDI**
  - **Chairpersons of scientific organizations (KSG, KSO, etc)**

Contact: Dr.Tai-Sup Lee, tslee@kigam.re.kr (KIGAM)

한국지질자원연구원 KIGAM

SciCom

- **Mission**
  - **Selection of shipboard scientists, panel members, etc**
  - **Evaluation of IODP related researches**
  - **Deliberation on K-IODP articles, structure, etc.**
- **17 board members**
  - **7 (universities), 4 (KIGAM), 4 (KORDI), 1 (KNOC), 1 (KBSI)**

Contact: Dr. Soo Chul Park, scpark@cnu.ac.kr

한국지질자원연구원 KIGAM

Secretariat

- **Main Duty**
  - **Supporting the K-IODP Council and SciCom**
  - **Managing the K-IODP National office**
    - Workshops, seminars
    - Public relations
      Promotion of K-IODP
      Newsletters
      Education and outreach programs
      Homepage (www.kodp.re.kr)

Contact:

Dr. Ho Young Lee, hylee@kigam.re.kr
Dr.Young-Joo Lee, yjl@kigam.re.kr

한국지질자원연구원 KIGAM

Task Force Team

- **Mission**
  - **Preparation of Drilling Proposals**
  - **National Science Plan**
- **Members**
  - **Task dependant**
  - **IODP #604 full proposal**
    - 3 (universities), 3 (KIGAM), 2 (KORDI)

Contact: Dr. Gwang H. Lee, gwanglee@pknu.ac.kr

한국지질자원연구원 KIGAM

K-IODP Activities

- **Shipboard Scientists**
- **Researches using DSDP, ODP, IODP samples/data**
- **Proposals for IODP drilling in Korean Waters**
- **Managing K-IODP National Office**

한국지질자원연구원 KIGAM

Opportunities for Shipboard Scientists & Researches Using DSDP/ODP Samples

www.kodp.re.kr

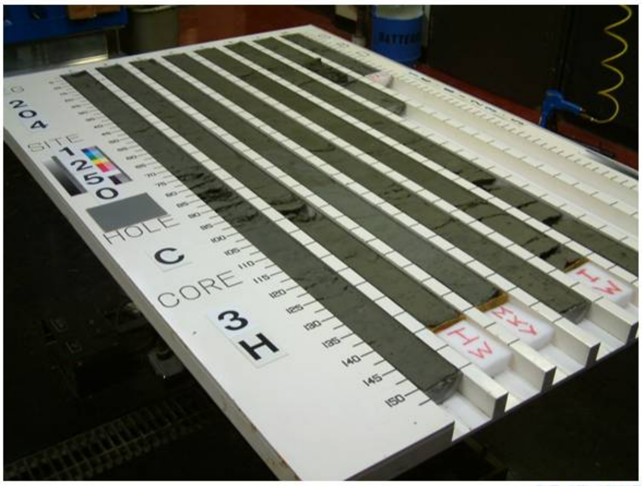
- **Open to:**
  - University scientists including graduate students
  - Scientists in research institutions (KIGAM, KORDI, NORI, etc)
  - Scientists from private sectors
- **Applications/proposals are evaluated by SciCom**

Shipboard Scientists 2005

- Public advertisement
- Exp. 310 Tahiti Sea Level (Dr. Woo, Kangwon National Univ.)
- Exp. 311 Cascadia Margin Gas Hydrate (Mr. Ji-Hoon Kim)
- Exp. 313 Superfast spreading crust (Dr. Sung-Hyun Park)

Researches on Samples/Data

- ODP Legs 127, 128, 193, 204, and 208
  - KIGAM
  - KORDI, KBSI
  - Universities



한국지질자원연구원 KIGAM

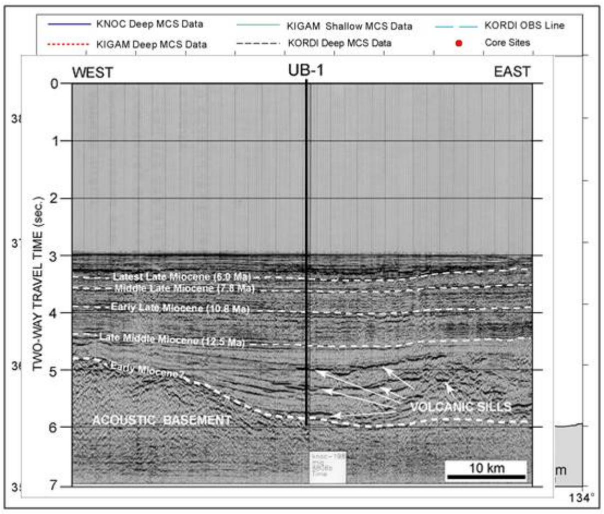
IODP Meetings

- Council Meetings
  - Nagaski, June 2005
- Panel meetings
- IODP Workshops

한국지질자원연구원 KIGAM

IODP #604 full
Climatic and Tectonic Evolution of Eastern Asia: Evidence from the Ulleung Basin, Southwestern East Sea/Japan Sea

- Strengthening of monsoonal conditions
- East Sea circulation & gateway development
- Evolution of the Ulleung Basin
- Back-arc volcanism in ocean-continent subduction settings



한국지질자원연구원 KIGAM

Seminars & Workshops

- **Workshops**
  - **InterRidge 2004**
  - **J-K ST Forum 2005**
  - **K-IODP Workshop**
    - Dec. 10, PKNU 2004
    - Sept. 2, KIGAM 2005
- **Seminars**
  - **IODP related**
  - **Universities**
- **Domestic committee Meetings**
  - **Council & SciCom**

한국지질자원연구원 KIGAM

Promotion of K-IODP

- **Promotional Materials**
  - **Brochures & Newsletters**
    - Institutions, Organizations
    - Universities
    - Academic Societies
- **Academic Society Meetings**
  - **KSO, GSK**
    - IODP session
    - Special Booth for K-IODP

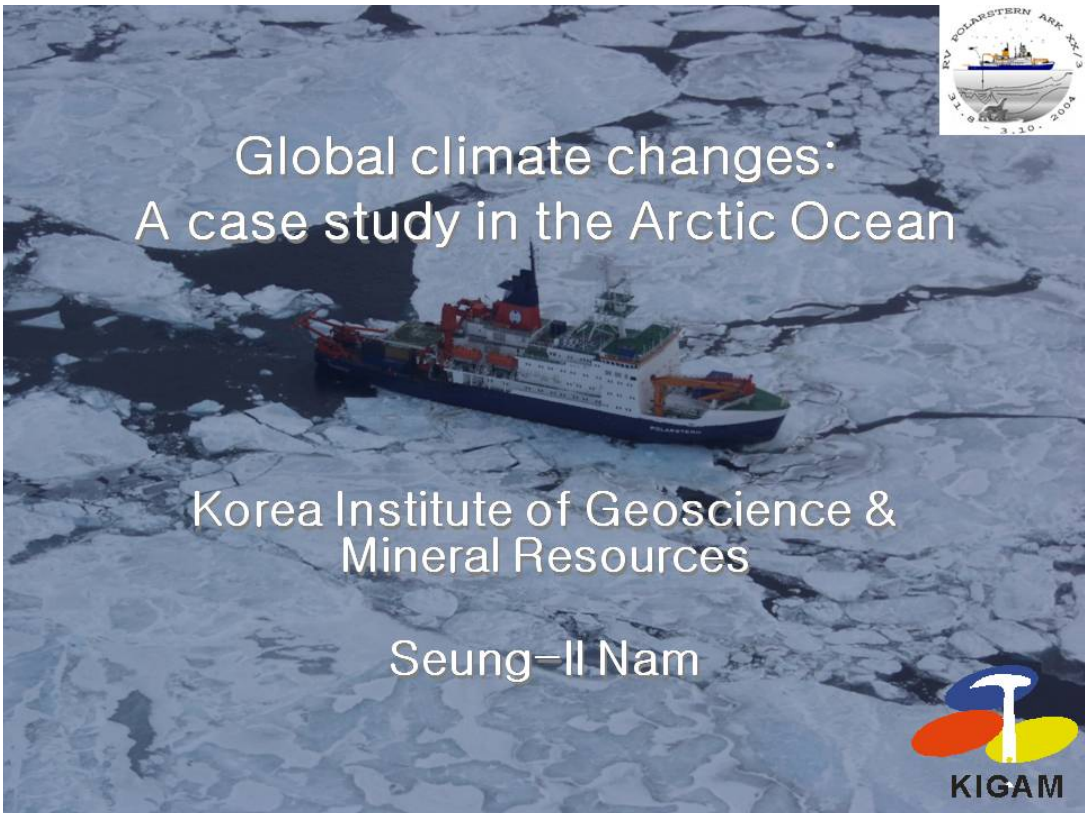
한국지질자원연구원
KIGAM

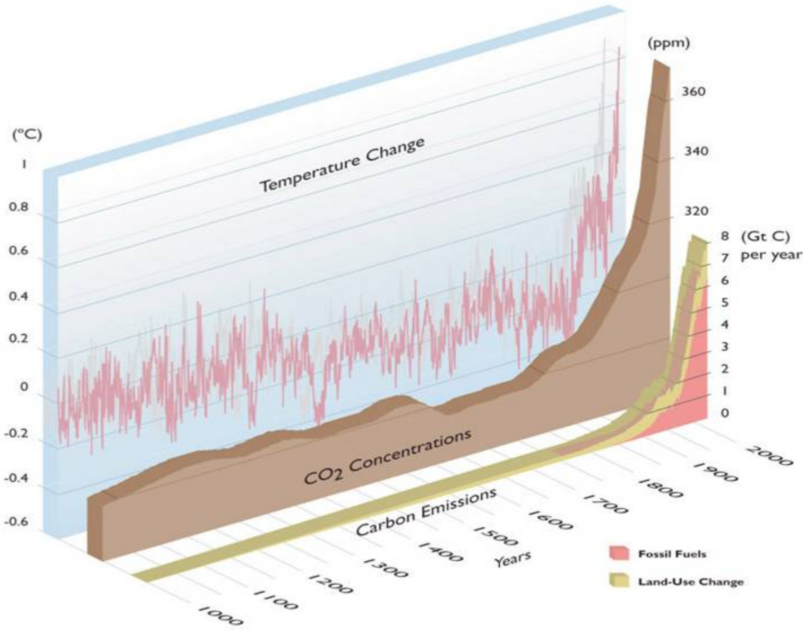
Plan for 2006

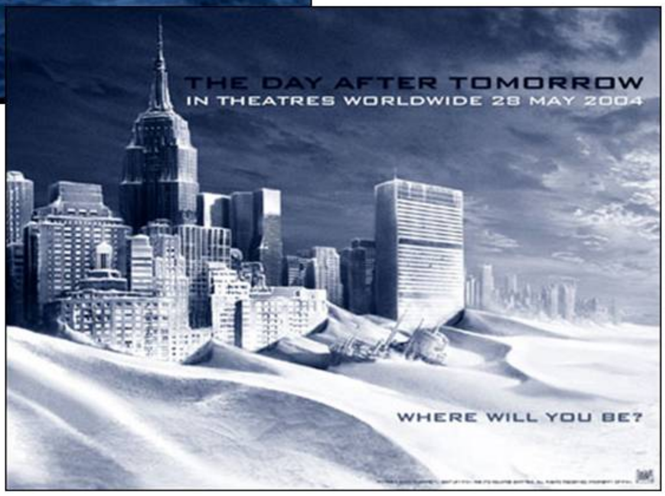
- **Interim Asian Consortium**
  - **Promote participation of Asian countries**
    - Australia, Taiwan, India
    - CCOP, SOPAC
    - ACORD
- **Researches using samples/data**
  - **ODP samples, IODP Exp 310, 311, 312**
- **IODP drilling in Korean Waters**
  - **Workshop for East Sea/Japan Sea Drilling**
    - 26-28th April, Niigata
    - 5 topics (PP, Tectonics, Backarc volcanism, GH, Biosphere)
  - **Joint Site Survey for IODP Drilling**
    - JAMSTEC, IFREE/KIGAM, SNU
    - Korean Peninsular-Ulleung Basin-Japan-Nankai Trough: 1,200 L-Km
- **IODP workshops**
  - **Domestic**
  - **International**
    - Kochi meeting; June 5~7
    - IGCP 476 Pusan: September 3~6
- **Promotion OF IODP, K-IODP**
  - **Academic Society Meetings**
    - Invite IODP experts
  - **University, Museum**

한국지질자원연구원
KIGAM

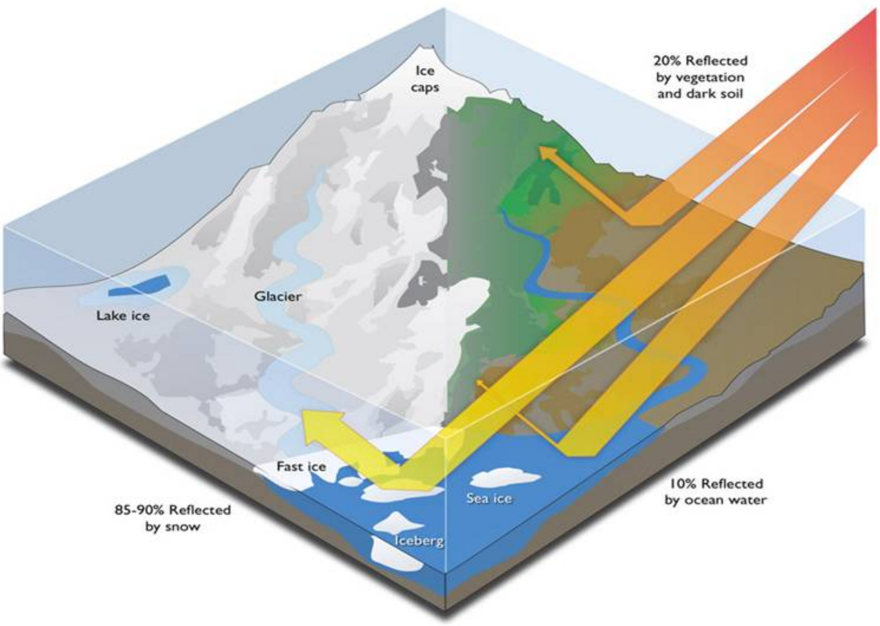
3. Global climate change



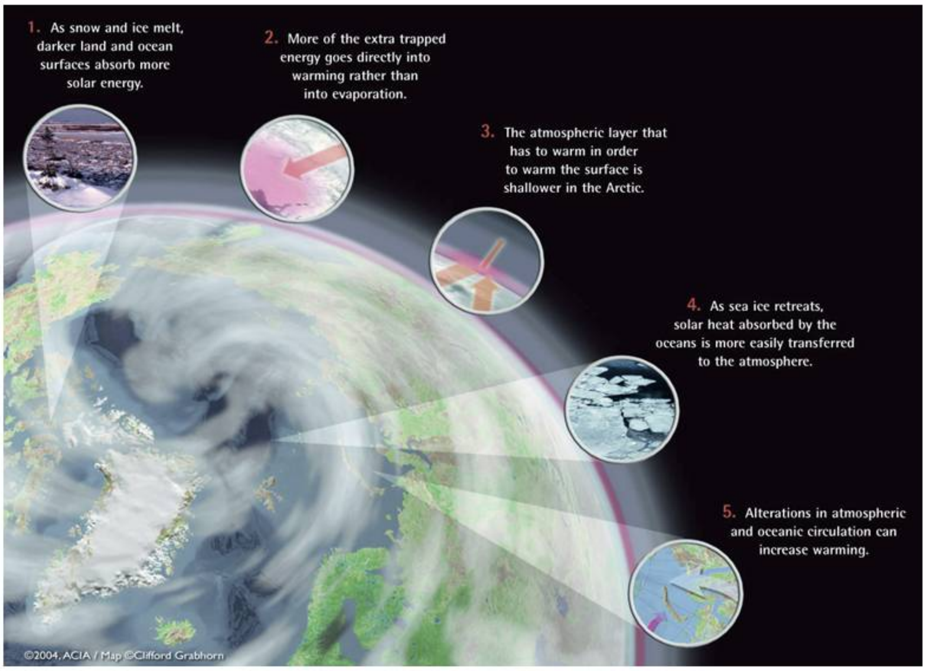




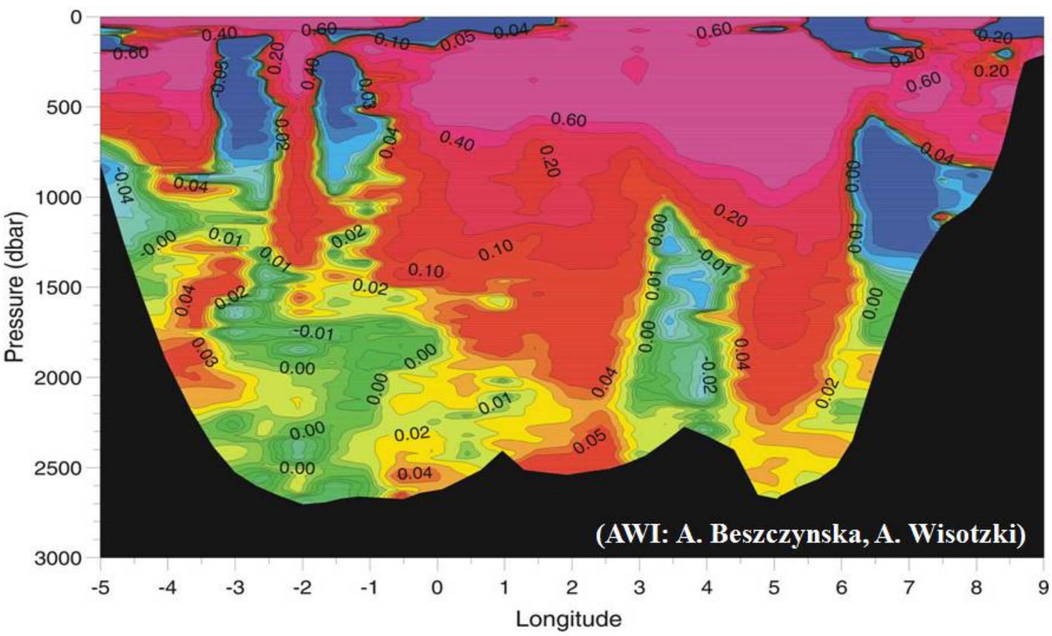
Changes in the Reflectivity of the land and ocean surface: Global warming



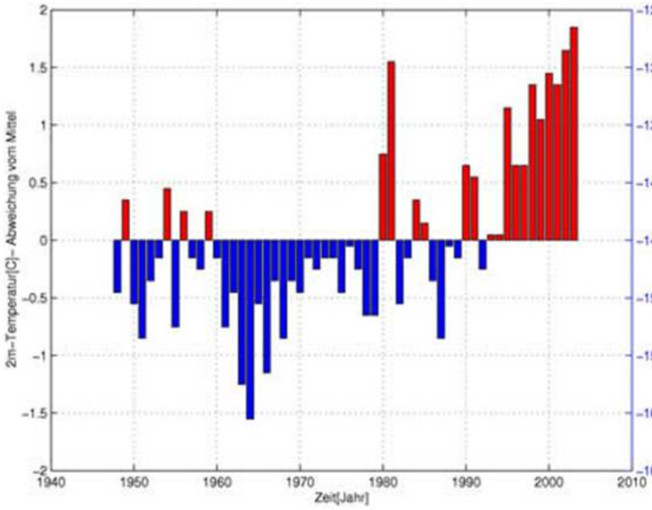
Why Does the Arctic Warm Faster than Lower Latitudes ?



Temperature difference in the Fram Strait between 2003 and 2004

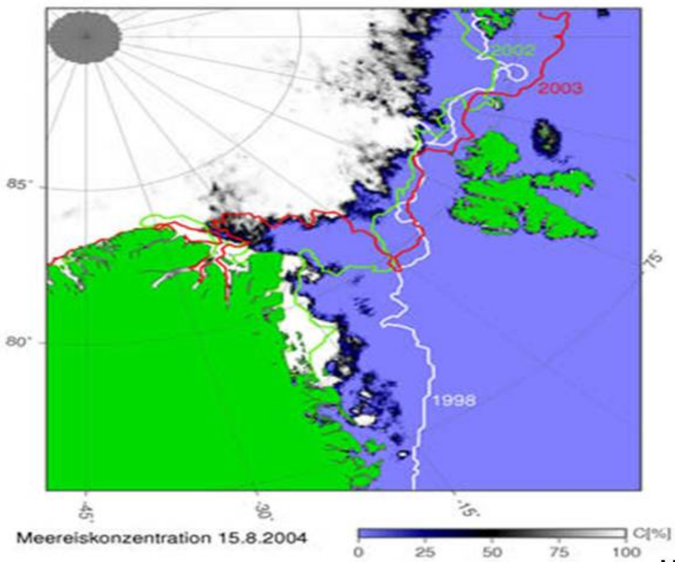


1948-2003년 동안 북위 70°N 에서의 온도변화

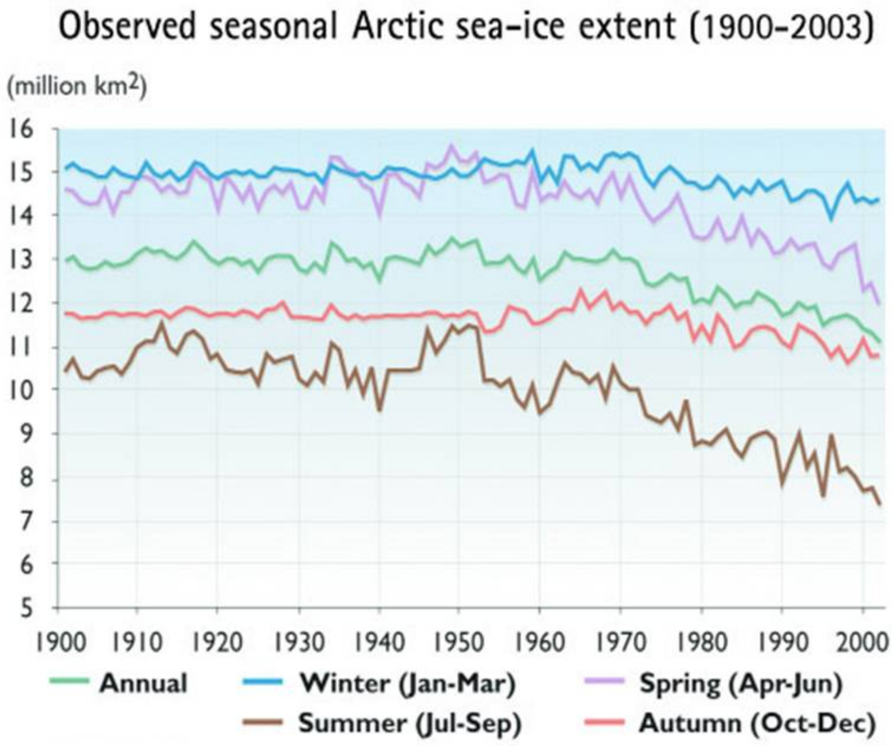


(NCAR/NCEP, AWI: C. Kōberle)

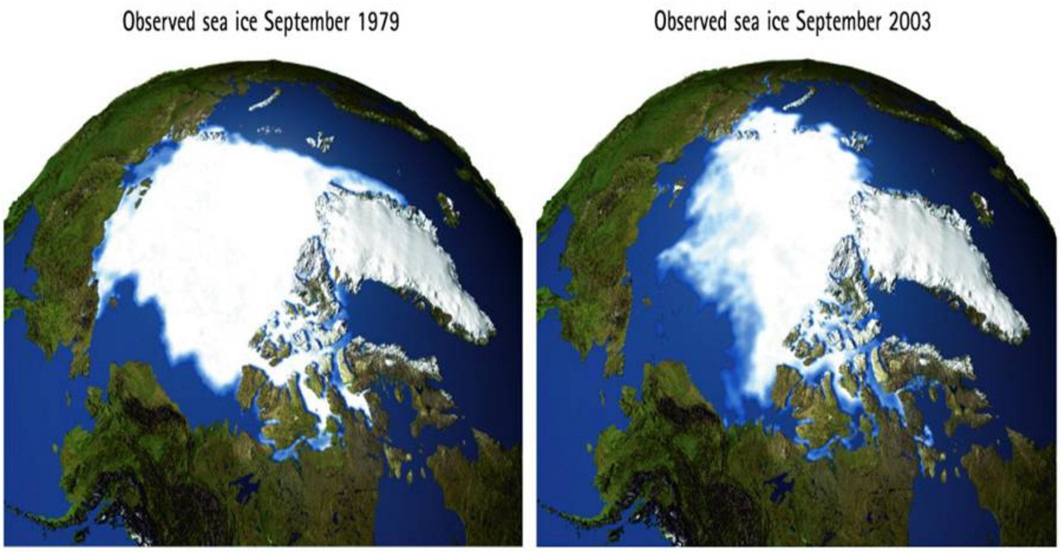
Changes in sea-ice coverage of the Arctic Ocean: (15 August 2004, 2003, 2002, 1998)



AWI: G. Spreen



Changes of sea-ice coverage in the Arctic Ocean



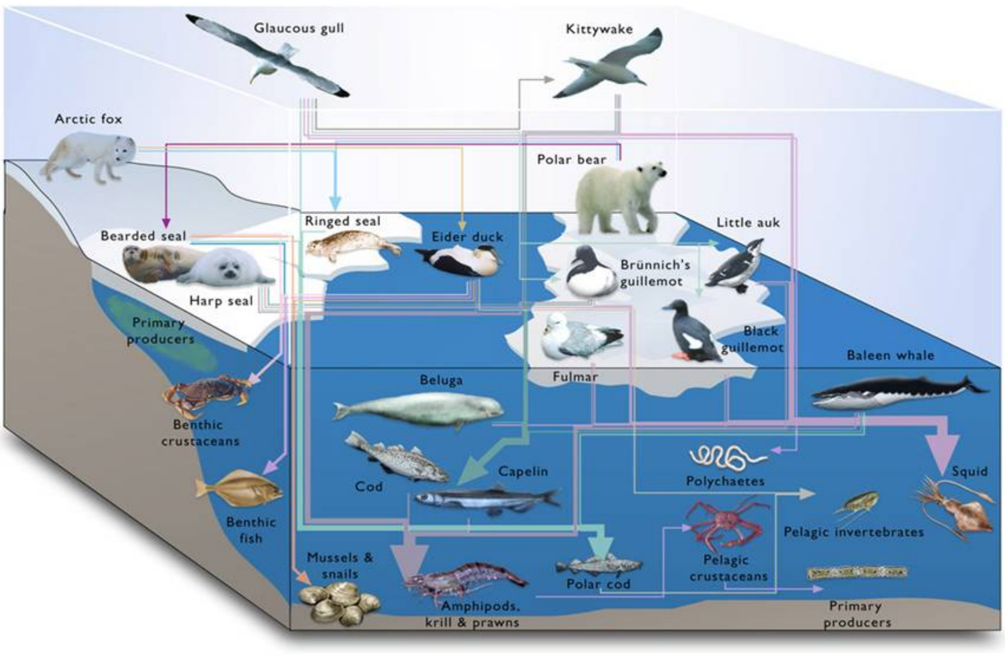
©NASA

The Arctic Ocean and its special importance to the global climate changes

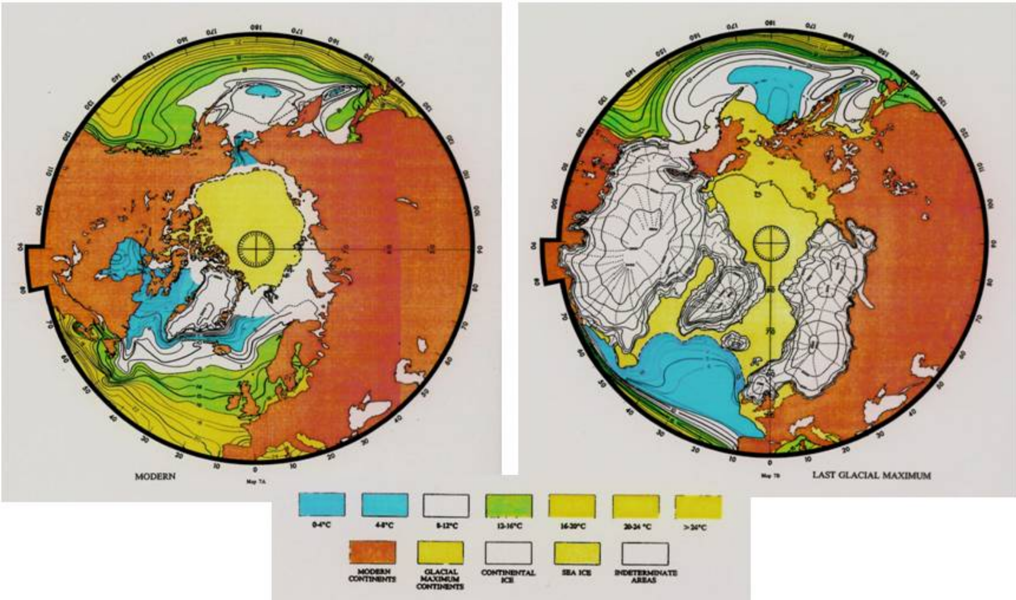
- The Arctic is now experiencing some of the most rapid and severe climate change on earth.

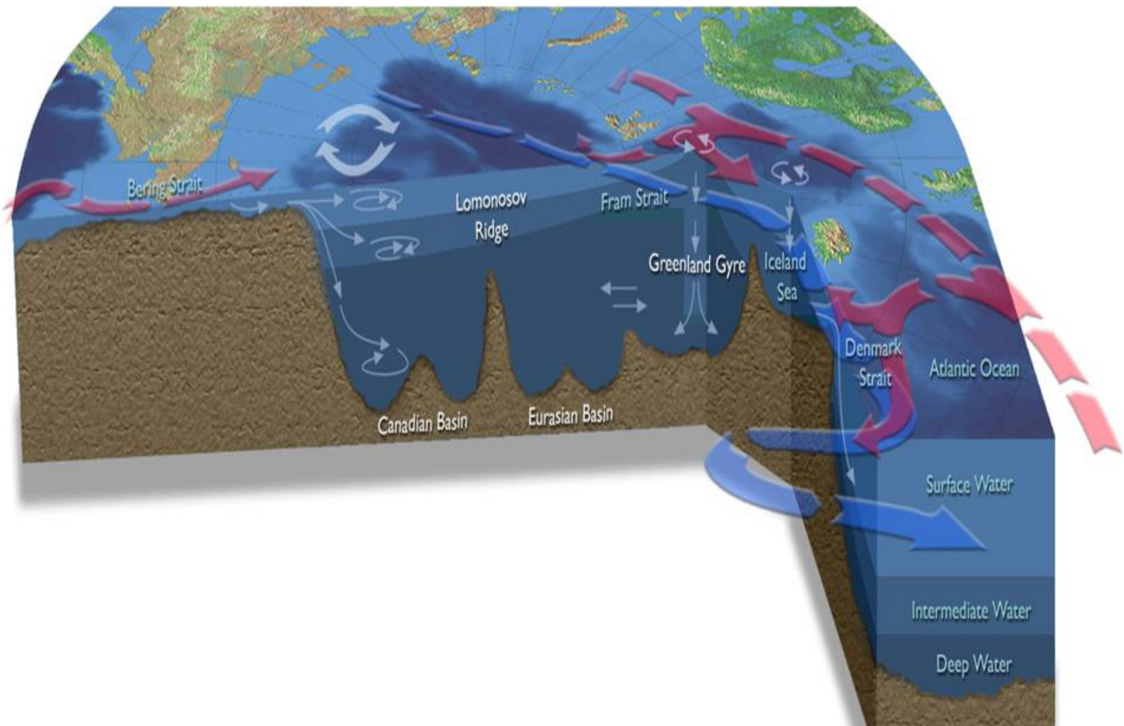
- Over the next 100 years, climate change is expected to accelerate, contributing to major physical, ecological, social, and economic changes, many of which have already begun.

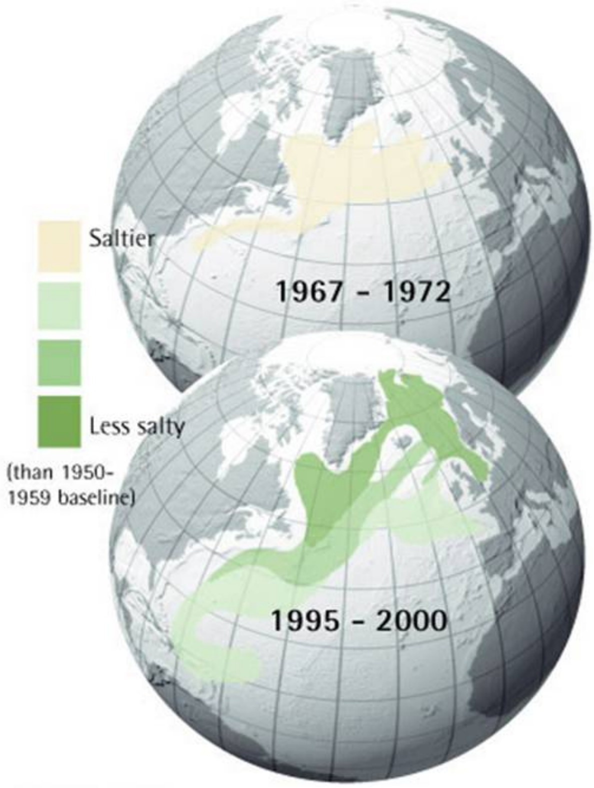
- Changes in arctic climate will also affect the rest of the world through increased global warming and rising sea levels.



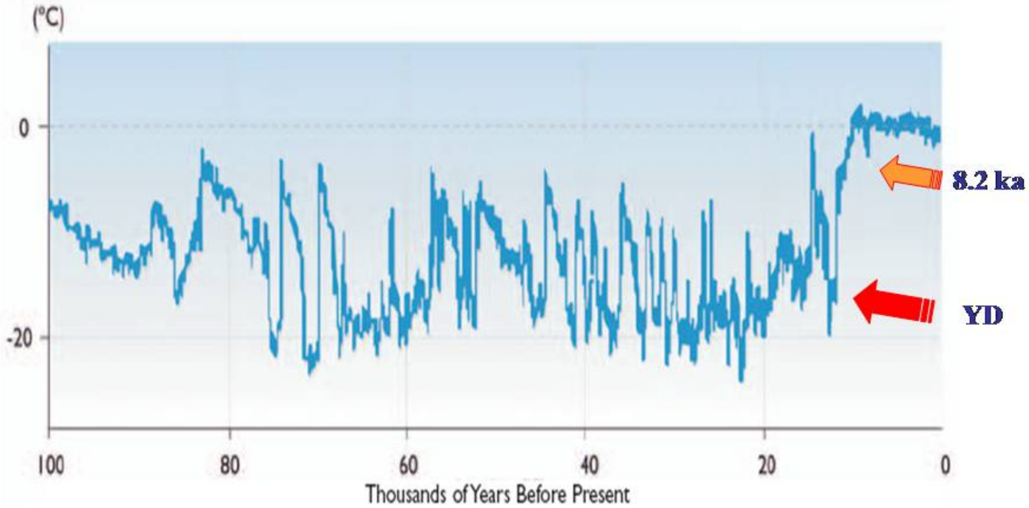
Climate Change of Northern Hemisphere during the Holocene and LGM







Temperature variation in Greenland during the 100 ka



Bathymetry and drill sites of ODP Leg 151 and 162

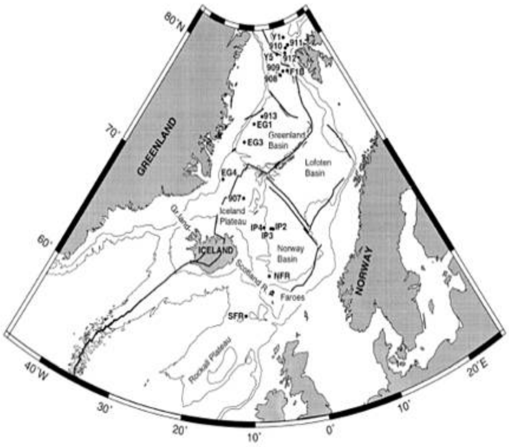


Figure 3. Simplified bathymetric map of the Norwegian-Greenland Sea with locations of proposed sites and drill sites of ODP Leg 151.

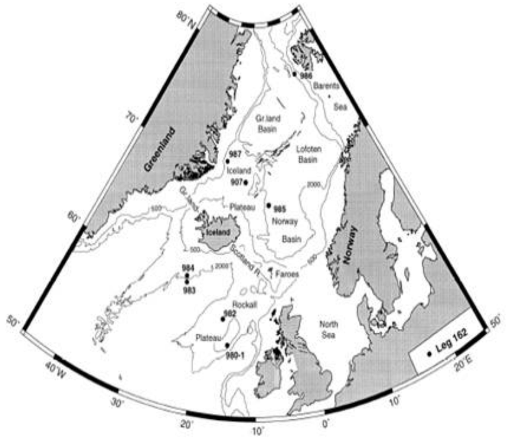
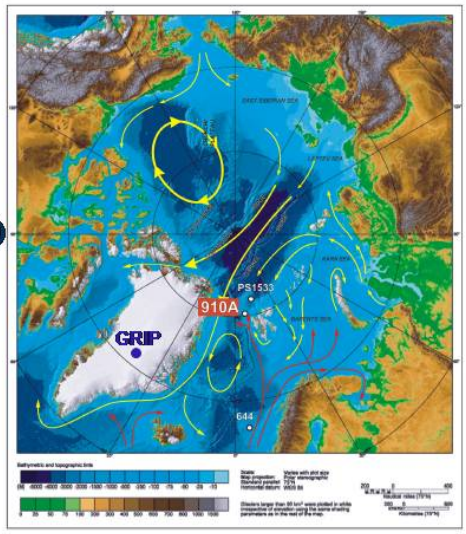


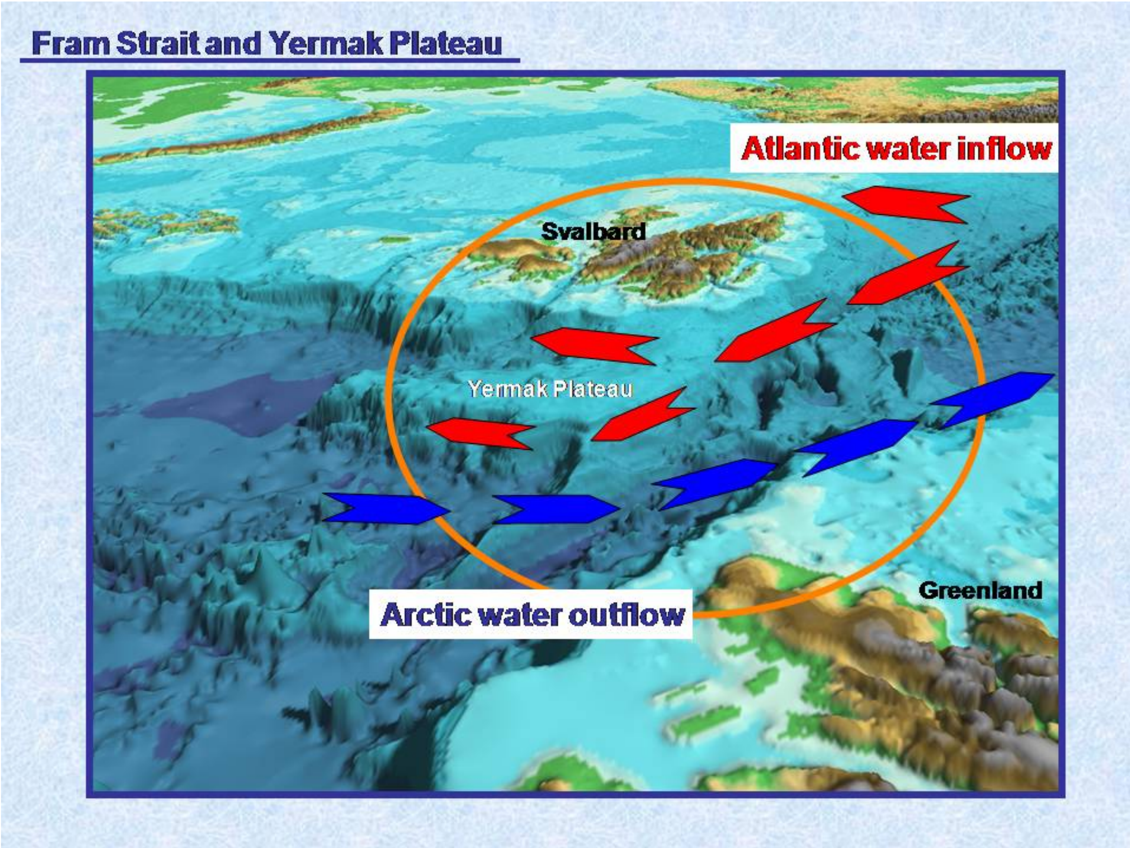
Figure 4. Simplified bathymetry of the northern North Atlantic, of the Greenland-Scotland Ridge, and of the adjacent Norwegian Greenland Sea, with drill sites of ODP Leg 162.

Yermak Plateau : Northern Gateway connects the Arctic Ocean and Nordic Seas

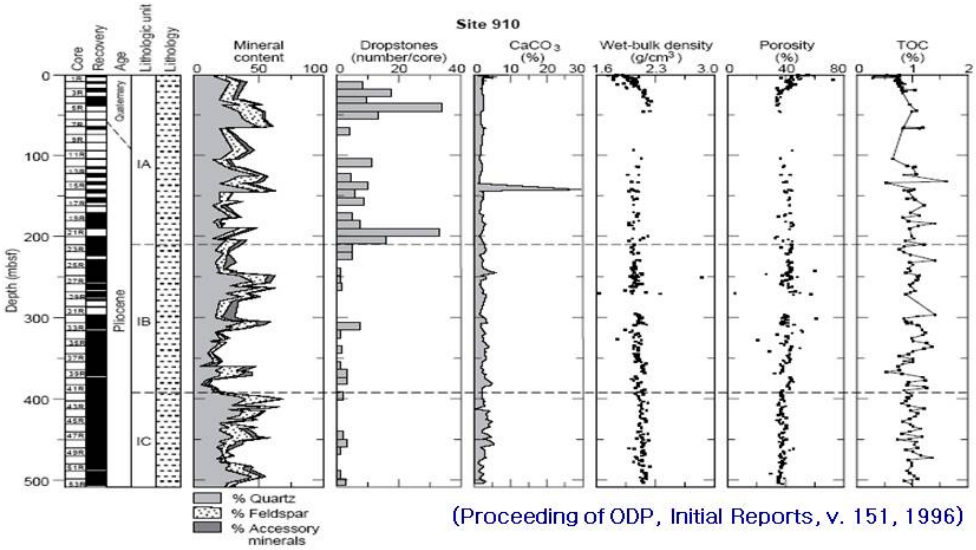
Hole 910A

- **at 556m water depth**
- **located close to the present ice edge, seasonally ice-free**
- **total depth drilled ca. 506 mbsf**
- **dominantly terrigenous sediment (silty clay) with minor biogenic origin**
- **the late Pliocene to Holocene**
- **first true Arctic records of Quaternary paleoceanographic changes**
- **oxygen & carbon isotopes measured on *N. pachyderma* sin. used to date the termination of over-consolidation near the stage 17/16 boundary at ~780 ka**



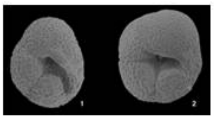


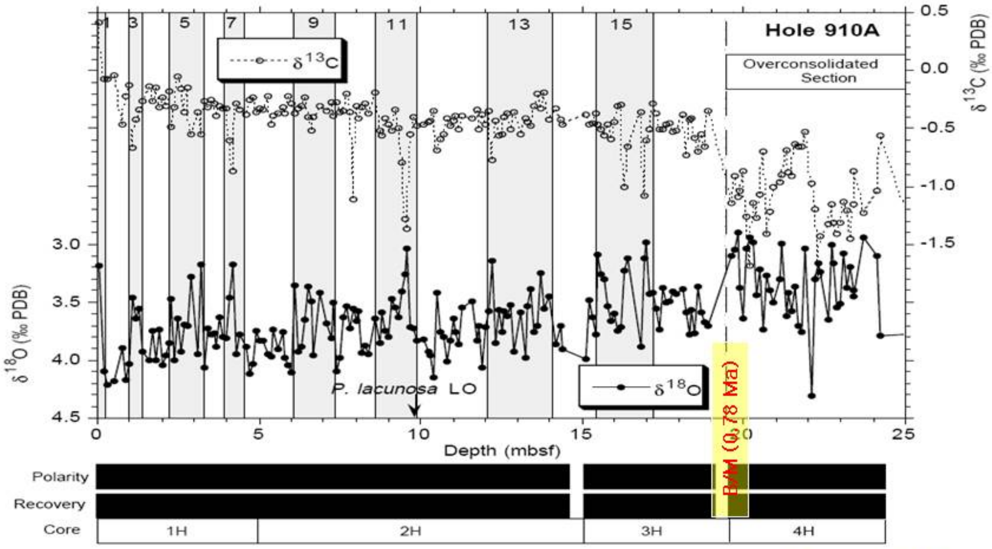
Multi-parameters for Site 910A



(Proceeding of ODP, Initial Reports, v. 151, 1996)

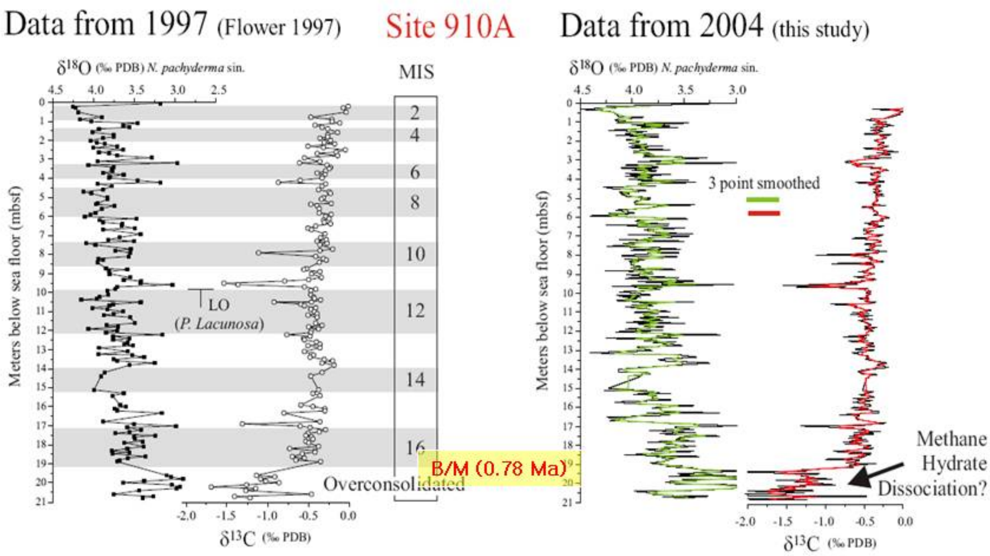
Hole 910A oxygen & carbon isotope records on *N. pachyderma* (sin.) vs. depth



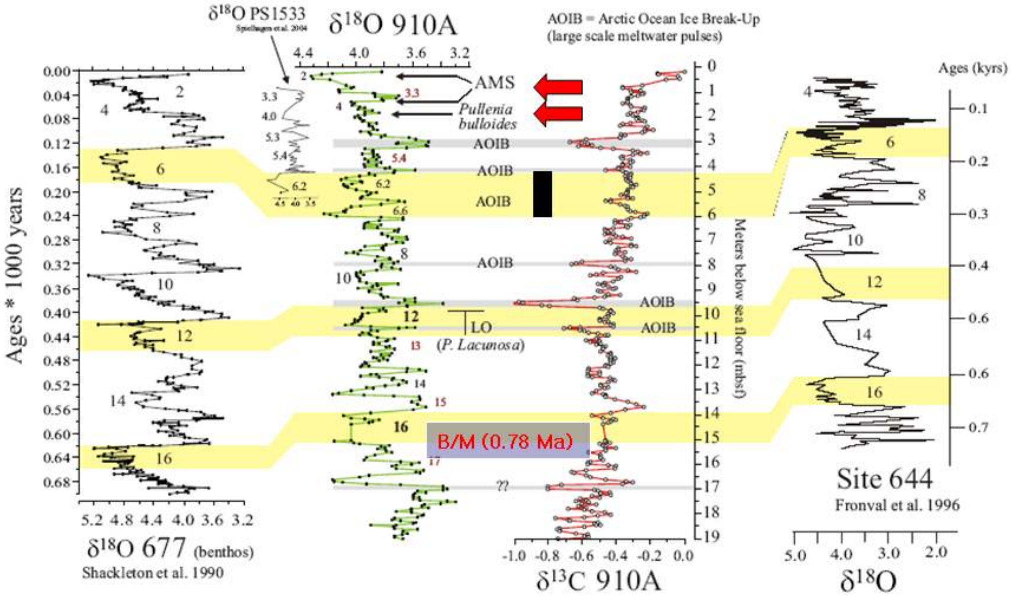


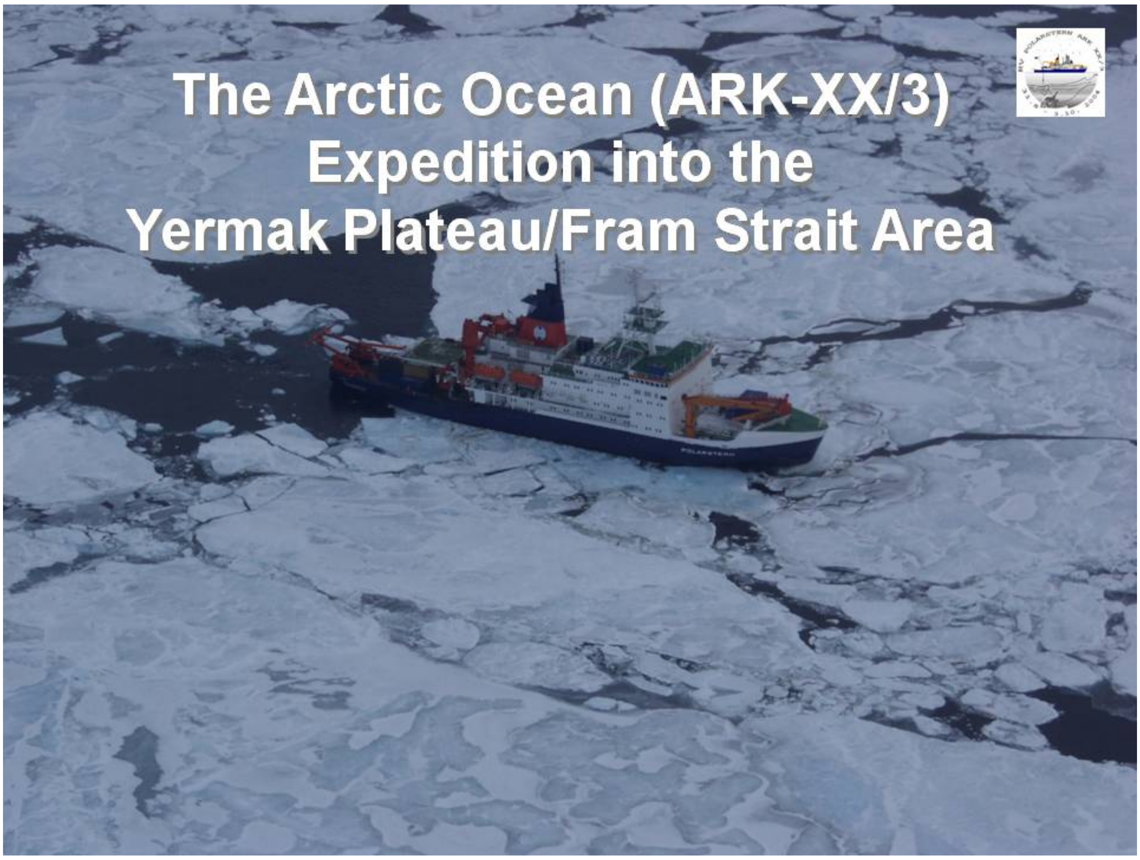
(Flower, 1997)

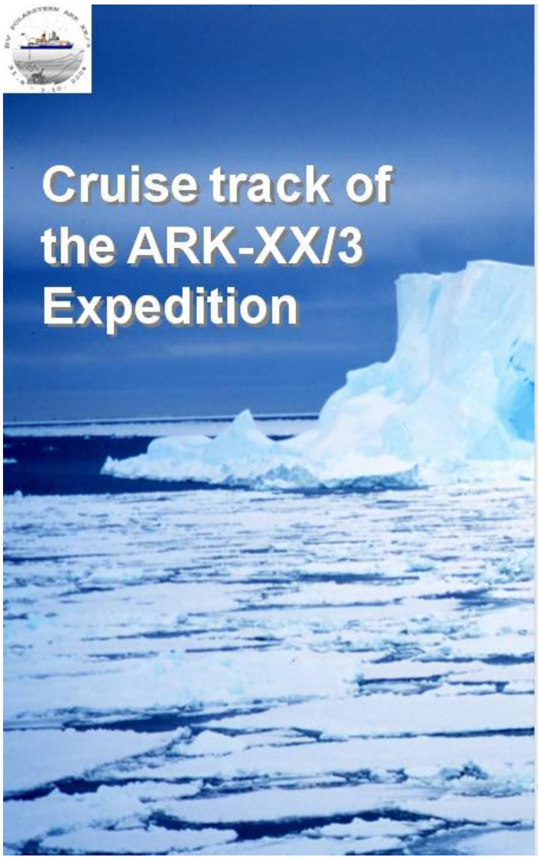
High-resolution stable oxygen & carbon isotope stratigraphy

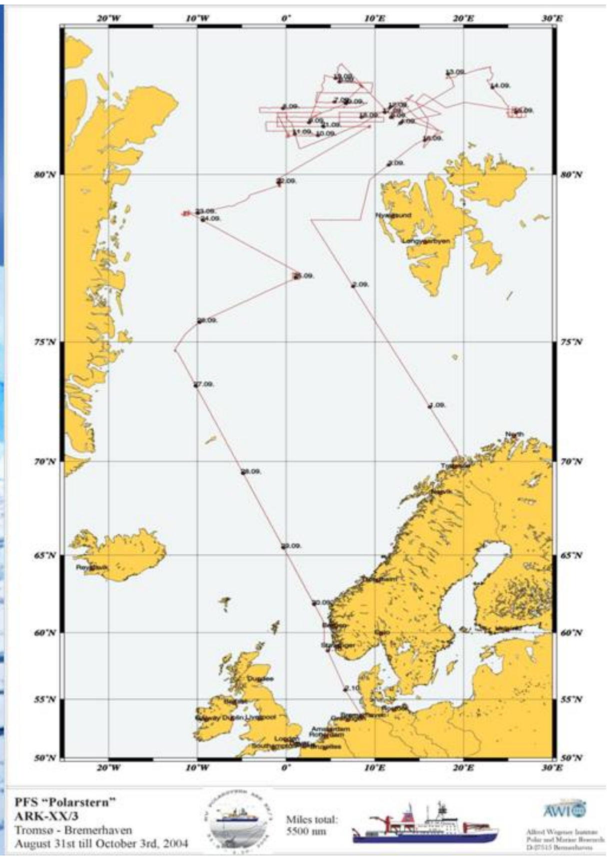


Revised Chronostratigraphy









IODP Proposal (645-Pre)

Received 30 March 2004

645-Pre

Above For Official Use Only

IODP Proposal Cover Sheet

☑ New ☐ Revised ☐ Addendum

Please fill out information in all gray boxes

Title:	Arctic Ocean – North Atlantic Gateway: Tectonic and Paleooceanographic evolution of the Fram Strait and Yermak Plateau area during Cenozoic Times		
Proponent(s):	Wilfried Jokat, Ruediger Stein, Seung-Il Nam, Jan-Inge Faleide, Jochen Knies, Jens Matthiessen, Morten Smelror		
Keywords: *(5 or less)*	Arctic Gateway, Tectonic, North Atlantic Paleoceanography	Area:	Fram Strait N-E Greenland

Contact Information:

Contact Person:	Wilfried Jokat		
Department:			
Organization:	Alfred Wegener Institute for Polar and Marine Research		
Address:	Columbusstrasse, D-27568 Bremerhaven, Germany		
Tel.:	+49-471-4831-1211	Fax:	+49-471-4831-1149
E-mail:	jokat@awi-bremerhaven.de		

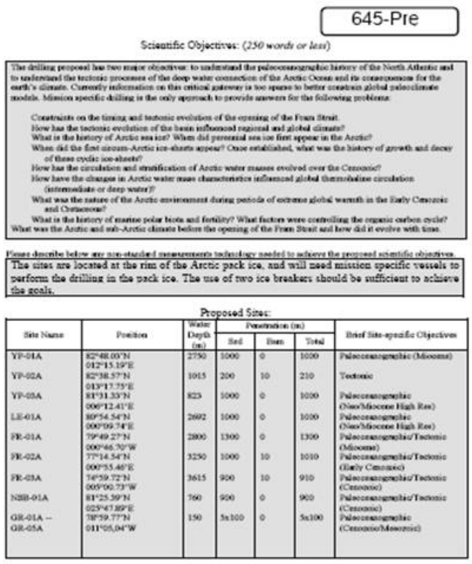
Permission to post abstract on iSAS Web site: ■ Yes

Abstract: *(400 words or less)*

The tectonic processes in the North Atlantic ocean and especially in the Fram Strait are believed to have played an important role for the Northern Hemisphere Glaciation.
Compared with the importance of this gateway for the earth's climate little details are known based on drilling results. XX sites are proposed to address this problem. The sites are distributed between 83°N and 74°N. The drill holes are chosen to
- provide high resolution information on the paleooceanographic environment during the critical time of the onset of major northern glaciations.
- provide direct information on the onset of the deep water circulation through the Fram Strait. Two locations are choosen at the northern Yermak Plateau and in the Lena Trough to drill drift sediments.
- provide information on the environment in the newly formed southern ocean basins, namely the Boreas and Greenland Basin, during the continuous/stepwise opening of the Fram Strait. These sites are important to understand if the onset of deep water circulation in the northern hemisphere depended only on the opening of the Fram Strait or if the existing ridges (Hovgaard Ridge and Greenland Fracture Zone) played also an important role to establish a new circulation system.
- address the Arctic and sub-Arctic environment prior to the opening of the Fram Strait. A site on the northern Svalbard margin and on the East Greenland shelf can provide this information. In the case of the East Greenland shelf several shallow holes are planned at the flanks of a salt dome. These units crop out at the sea floor.

The proposed program addresses a number of key questions raised in the IODP Initial Science Plan. Amongst scientific issues relating to "Environmental Change, Processes and Effects" are
- The role of the only deep water gateway in the Fram Strait for the long-term (55 Ma) climate history of the northern Atlantic, and its role in the transition from the Paleogene greenhouse to the Neogene icehouse.
- To better resolve the Neogene climate history of the North Atlantic Ocean at a sub-millennial scale resolution.

The proposed sites are located in dense to light ice conditions, and require the use of mission specific vessels. However, since most of the sites are located at the rim of the Arctic pack ice the use of two ice strengthened vessels should be sufficient for a successful drilling campaign.



645-Pre

Scientific Objectives: *(250 words or less)*

The drilling proposal has two major objectives: to understand the paleoceanographic history of the North Atlantic and to understand the tectonic processes of the deep water connection of the Arctic Ocean and its consequences for the earth's climate. Currently information on this critical gateway is too sparse to better constrain global paleoclimate models. Mission specific drilling is the only approach to provide answers for the following problems:

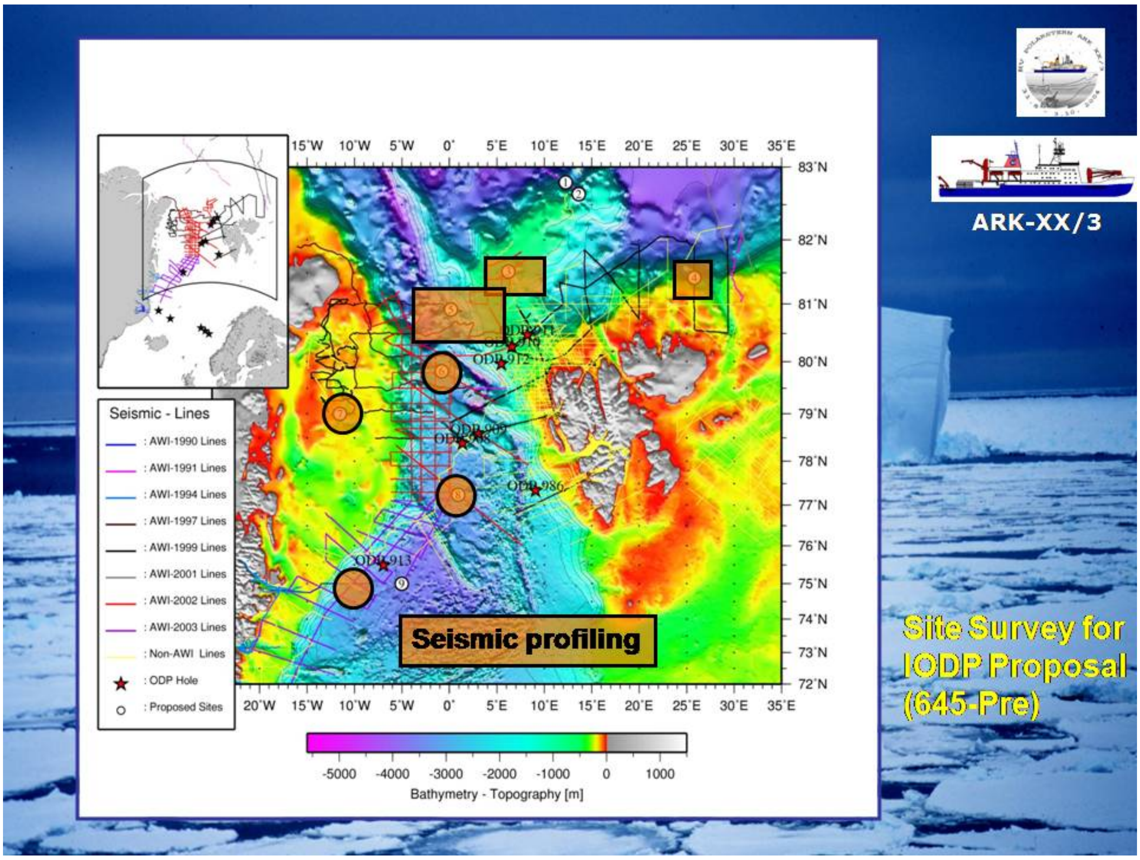
Constraints on the timing and tectonic evolution of the opening of the Fram Strait.
How has the tectonic evolution of the basin influenced regional and global climate?
What is the history of Arctic sea ice? When did perennial sea ice first appear in the Arctic?
When did the first circum-Arctic ice-sheets appear? Once established, what was the history of growth and decay of these cyclic ice-sheets?
How has the circulation and stratification of Arctic water masses evolved over the Cenozoic?
How have the changes in Arctic water mass characteristics influenced global thermohaline circulation (intermediate or deep water)?
What was the nature of the Arctic environment during periods of extreme global warmth in the Early Cenozoic and Cretaceous?
What is the history of marine polar biota and fertility? What factors were controlling the organic carbon cycle?
What was the Arctic and sub-Arctic climate before the opening of the Fram Strait and how did it evolve with time.

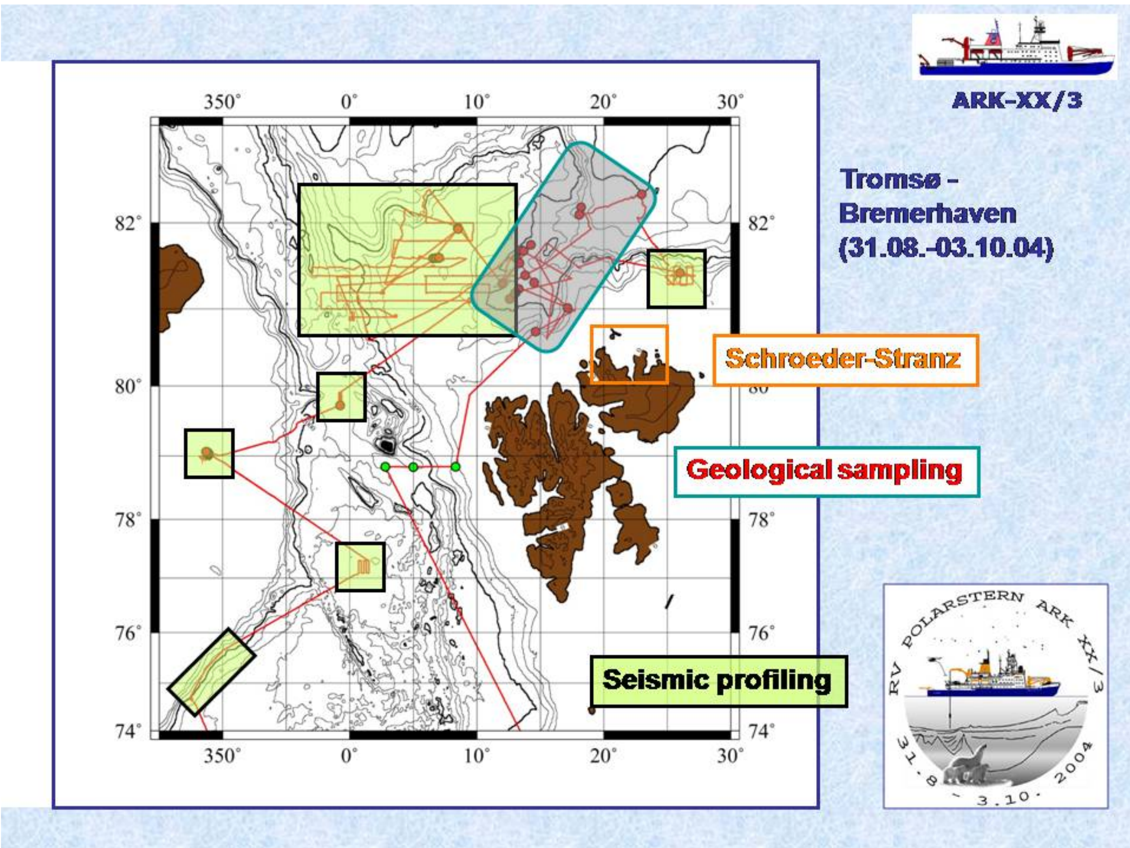
Please describe below any non-standard measurements technology needed to achieve the proposed scientific objectives.

The sites are located at the rim of the Arctic pack ice, and will need mission specific vessels to perform the drilling in the pack ice. The use of two ice breakers should be sufficient to achieve the goals.

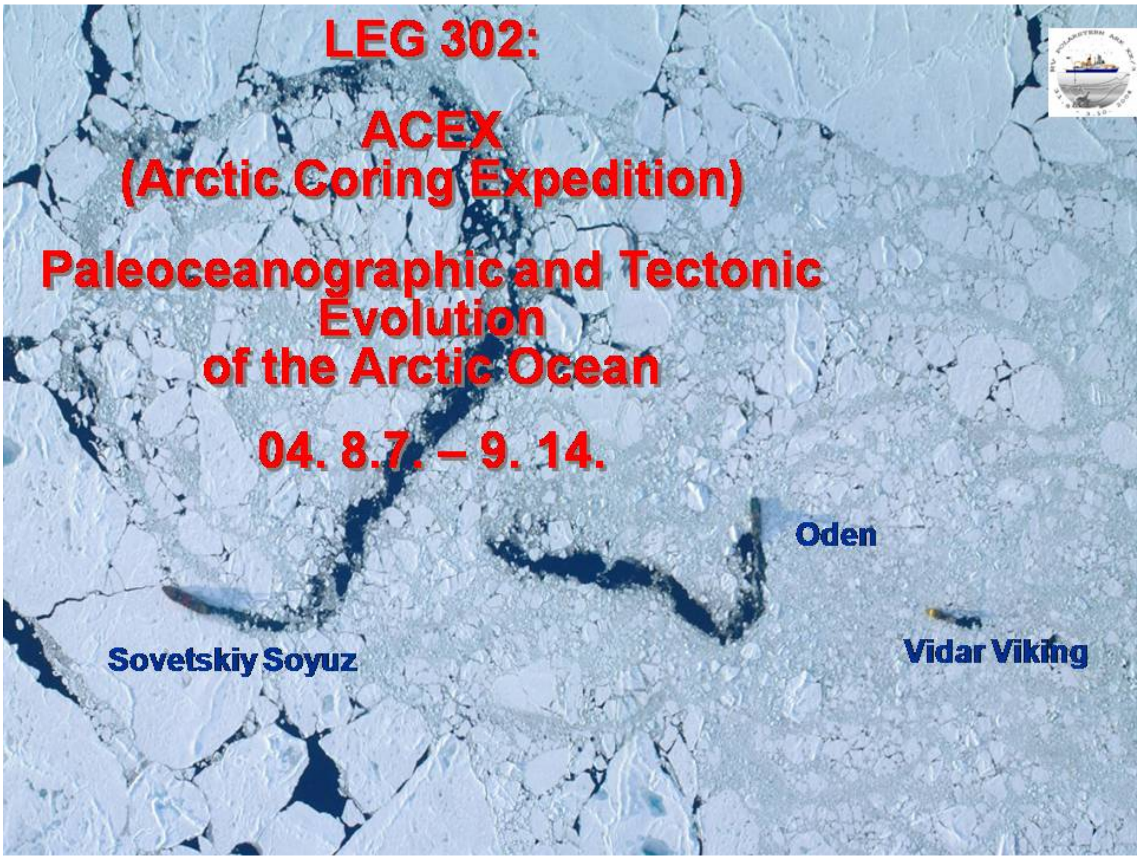
Proposed Sites:

Site Name	Position	Water Depth (m)	Penetration (m) Sed	Bsm	Total	Brief Site-specific Objectives
YP-01A	82°48.03'N 012°15.19'E	2750	1000	0	1000	Paleoceanographic (Miocene)
YP-02A	82°38.57'N 013°17.75'E	1015	200	10	210	Tectonic
YP-03A	81°31.33'N 006°12.41'E	823	1000	0	1000	Paleoceanographic (Neo/Miocene High Res)
LE-01A	80°54.54'N 000°09.74'E	2692	1000	0	1000	Paleoceanographic (Neo/Miocene High Res)
FR-01A	79°49.27'N 000°46.70'W	2800	1300	0	1300	Paleoceanographic/Tectonic (Miocene)
FR-02A	77°14.54'N 000°55.46'E	3250	1000	10	1010	Paleoceanographic/Tectonic (Early Cenozoic)
FR-03A	74°59.72'N 005°00.73'W	3615	900	10	910	Paleoceanographic/Tectonic (Cenozoic)
NSB-01A	81°25.39'N 025°47.89'E	760	900	0	900	Paleoceanographic/Tectonic (Cenozoic)
GR-01A – GR-05A	78°59.77'N 011°05,04'W	150	5x100	0	5x100	Paleoceanographic (Cenozoic/Mesozoic)


ARK-XX/3
Site Survey for IODP Proposal (645-Pre)
Seismic profiling
Seismic - Lines
: AWI-1990 Lines
: AWI-1991 Lines
: AWI-1994 Lines
: AWI-1997 Lines
: AWI-1999 Lines
: AWI-2001 Lines
: AWI-2002 Lines
: AWI-2003 Lines
: Non-AWI Lines
: ODP Hole
: Proposed Sites
ODP 913
ODP 986
ODP 909
ODP 912
Bathymetry - Topography [m]
-5000 -4000 -3000 -2000 -1000 0 1000


ARK-XX/3
Tromsø - Bremerhaven (31.08.-03.10.04)
Schroeder-Stranz
Geological sampling
Seismic profiling
RV POLARSTERN ARK XX/3
31.8.-3.10.2004


11.5 m
Core barrel
Kastenlot
-the dream of
marine geologists
30 cm
30 cm
Weight of 3.5 t


LEG 302:
ACEX
(Arctic Coring Expedition)
Paleoceanographic and Tectonic
Evolution
of the Arctic Ocean
04. 8.7. – 9. 14.
Oden
Sovetskiy Soyuz
Vidar Viking

LEG 302:

ACEX
(Arctic Coring Expedition)

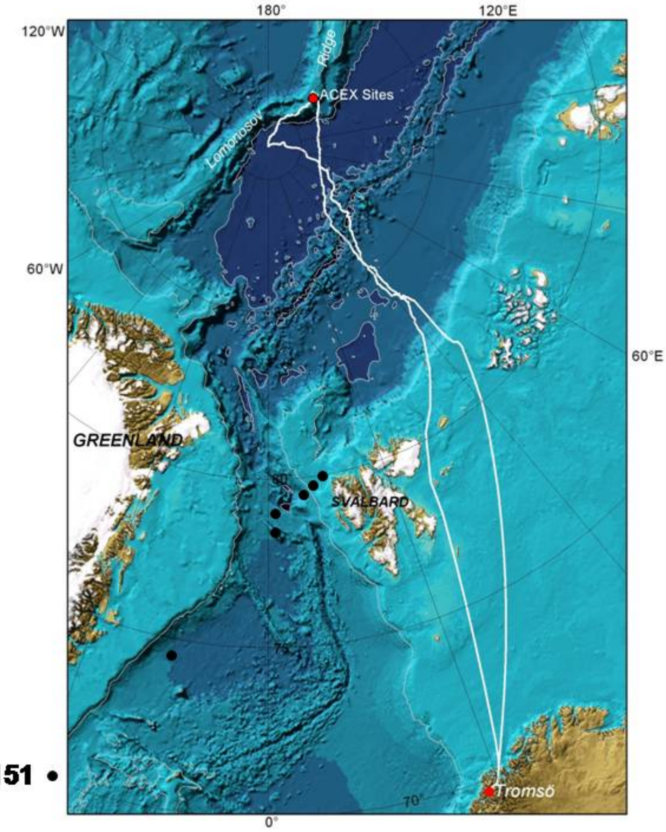
Paleoceanographic and
Tectonic Evolution
of the Arctic Ocean

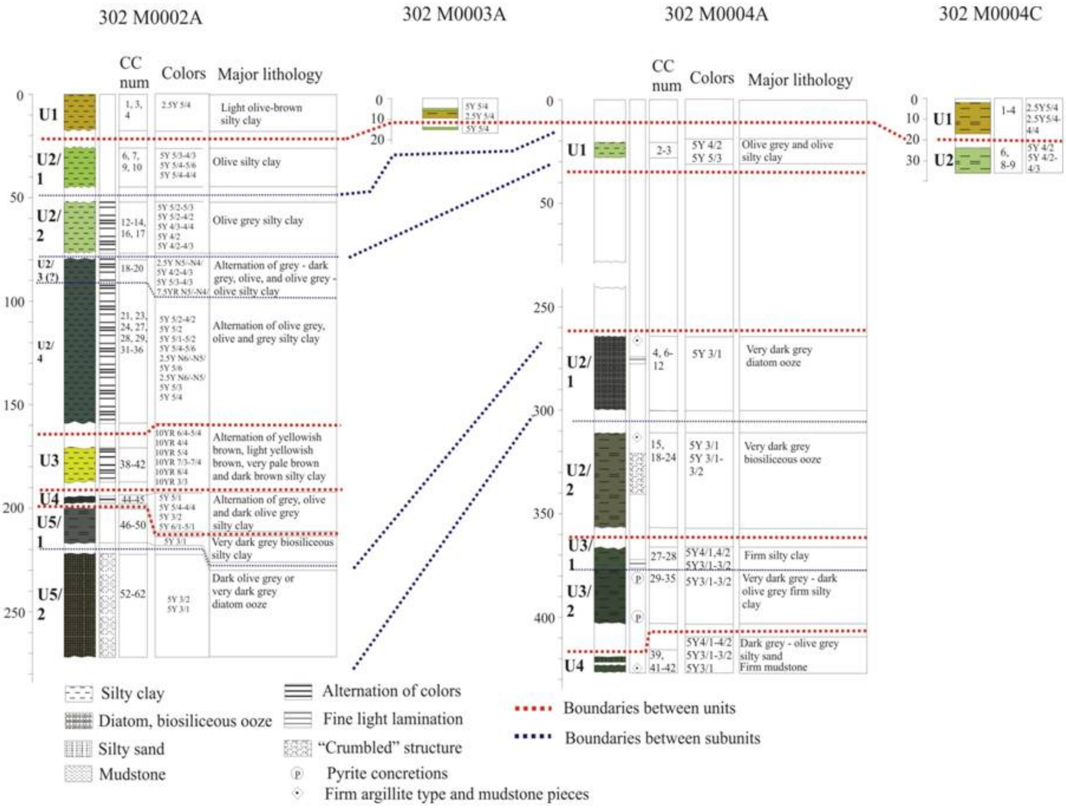
04. 8.7. – 9. 14.

Drilling on
Lomonosov Ridge

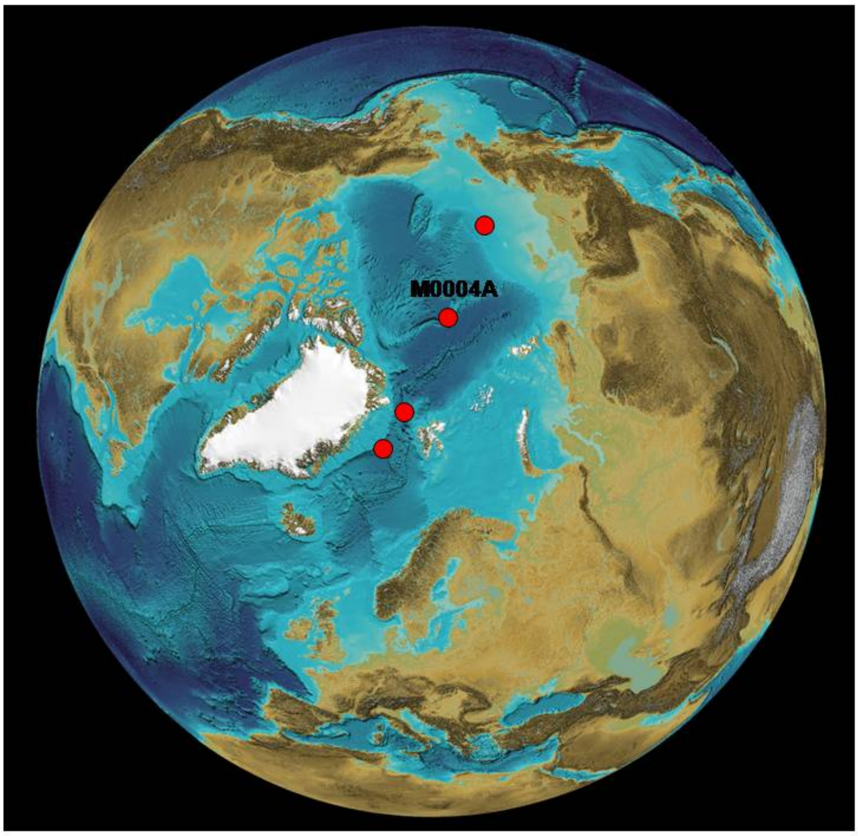
8. 15. – 9. 5.

LEG 151 •





New Era for Understanding Tectonic & Paleoclimate Evolution of the Arctic Ocean during the Cenozoic



4. Coastal geology

4-1. Coast

Cliffed Coast

The retreat of cliffed coasts take place mainly during storms, and is achieved largely by wave action: the hydraulic pressure of impact and withdrawal, and the abrasive action of water laden with rock fragments (sand and gravel) hurled repeatedly at the cliff base. The platform is often termed a wave-cut, or abrasion platform, but these genetic terms can be misleading and the purely descriptive term, shore platform, is preferred. The several kinds of cliffed coast with or without shore platform are illustrated (Fig. 1)

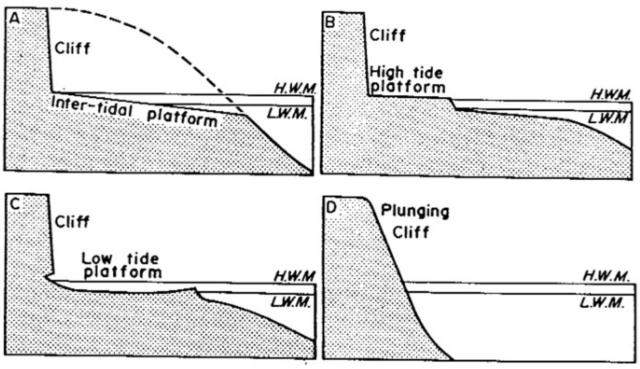


Fig. 1. Types of cliffed coast.

A. Cliffed coast with an inter-tidal shore platform
B. Cliffed coast with shore platform at about high tide level
C. Cliffed coast with shore platform at about low tide level
D. Plunging cliff, with no shore platform

1. The morphology of cliffs

Fig. 2. Arches in Niue.

Fig. 3. Chasm in Niue.

The features of cliffed coast are related to variations in lithology and structure, picked out by marine erosion. The more resistant part of coastal rock formations protrude as headlands, or persist as rocky stacks and islands offshore, whereas the weaker elements are cut back as coves and embayments. Resistance means the hardness of rocks or their durability including the physical and chemical effects. Solid and massive formations are generally eroded more slowly than formations that disintegrate readily, such as friable sandstones, or rocks with closely-spaced joints and bedding-planes, or rock formations shattered by faulting. Weathering and marine erosion penetrate these lines or weakness, excavating caves and coves, so that patterns of jointing and faulting influence the outline in plan of cliffed coast (Fig. 2 & 3).

Certain kinds of lithology yield characteristic cliff forms. On soft clay formations. Cliffs are subject to recurrent slumping, particularly after wet weather. Subsequent removal of slumped material by waves from the base of the cliff then rejuvenates the profile, preparing the way for further slope failure, so that the cliffs recede as the result of alternating marine and subaerial effects (Fig. 4 & 5). Recession of vertical cliffs by intermittent rock falls and basal rejuvenation provides a similar sequence (Fig. 6).

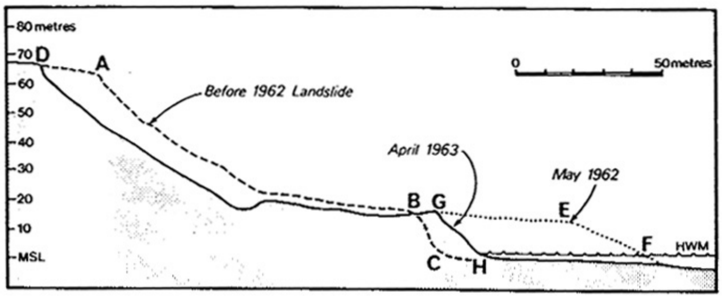


Fig. 4. The cliff crest recede from A to D by landslide, but the undercliff (BC) advanced as a lobe to EF, subsequently cut back to GH by marine erosion.

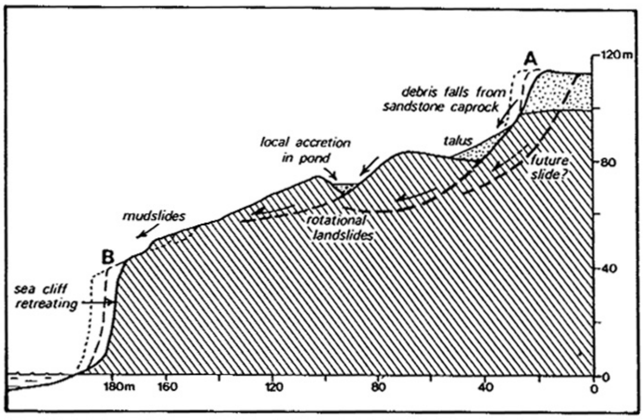


Fig. 5. The recession of the cliff crest (A) has been about the same as undercliff recession (B), but there has been complex variation in the intervening landslide topography.

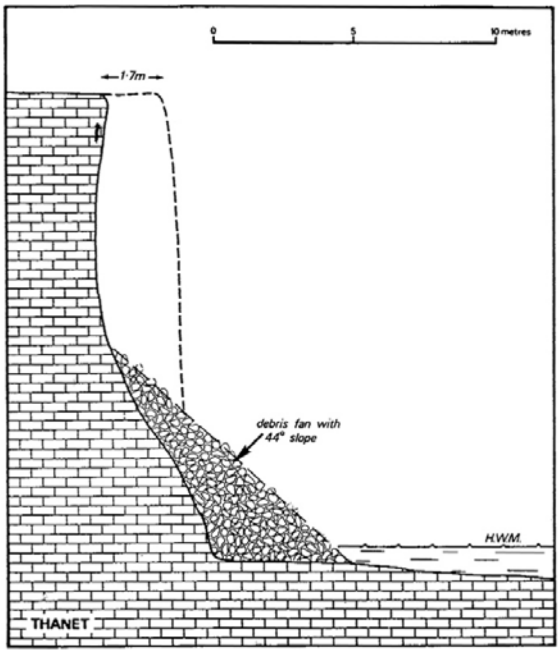


Fig. 6. Cliff recession has produced a basal debris fan, gradually reduced by solution and attrition and removed by wave action, until the cliff base is again exposed to wave attack. Undermining then produces further rock falls so that the cliff crest recede intermittently.

Where the dip of coastal rock formation is seaward, undercutting by marine erosion often leads to landslips and rock falls, the undercut rock sliding down bedding-planes into the sea, leaving the exhumed bedding-planes as a coastal slope.

Where relatively resistant coastal rock formations are backed by weak outcrops, penetration of the outer wall by marine erosion is followed by the excavation of coves and embayments.

Where the recession of cliffs cut in a relatively weak formation such as glacial drift or dune clacarenite uncovers outcrops of harder basement rock at or near sea level, the latter become persistent headlands as the weaker formation is cut back in bayments.

Cliffs exposed to powerful wave action are often shaped entirely by marine erosion. Where steep cliffs have been cut by marine erosion in horizontal stratified sedimentary rocks, and the huge waves that break against these during storms have cut out ledges along the bedding-planes at various levels up to 60m above high tide mark. They are the product of present-day storm wave erosion; they should not be confused with coastal terraces that bear ‘raised beach’ deposits indicative of emerged coastlines.

Cliffs on more sheltered sections of the coast, where strong wave action is intercepted by headlands, islands, or reefs offshore, or attenuated by a gentle offshore slope, may show features that have been formed by subaerial denudation as well as those shaped by marine attack. Cliffs in these situations often consist of a coastal slope shaped by rainwash and soil creep, the lower part of which is kept steep and fresh by wave attack.

The profiles of steep coasts on similar rock formations show intricate variations related to exposure to wave attack.

When marine erosion of a cliffed coast is halted (by accumulation of protective beaches or barriers, by coastal emergence, or by the construction of sea walls to prevent wave attack), subaerial processes become dominant and the sea cliff is 'degraded' to a coastal bluff of gentler inclination, comparable with escarpment and valley-side slopes inland, and determined by the geotechnical properties of the rock outcrops: usually between 8 and 10 on soft clays and steeper on more resistant formations. The active cliffs that we now see on the coast have assumed their present form only since the Holocene marine transgression brought the sea to its present general level within the last 6,000 years.

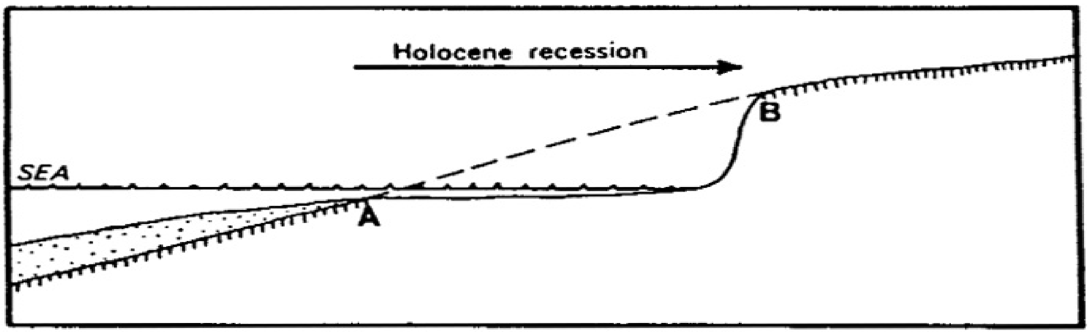


Fig. 7. An extent of cliff recession may be estimated from the weathered horizon A equivalent to the cliff-top weathering mantle B, since the Holocene sea attained its present level relative to the land.

2. Shore platforms

On the simplest form of cliffed coast, the cliffs are bordered by platforms extending across the shore zone and sloping gently, but not always uniformly, to pass beneath the sea. These platforms are evidently developed and widened as the cliffs recede, and shaped by the action of waves and other marine processes. They extend from high tide mark, at the base of the receding cliff, to a level below and beyond low tide mark, in the nearshore zone, and it is convenient, though not strictly accurate, to describe them as inter-tidal shore platforms (Fig. 1A). Such platforms are best developed where the coastal rock formations are homogeneous, without structural or lithological variations, but it is difficult to find ideal examples.

Much attention has been given to horizontal, or nearly horizontal, shore platforms found on many coasts, which truncate local geological structures and cannot be explained in terms of lithological control. These widespread occurrence on the islands and shores of the Pacific and Indian Oceans, and locally on the Atlantic coast fall into two main categories: those developed at, or slightly above, mean high tide level ('high tide shore platforms') (Fig. 1B), and those developed slightly above mean low tide level ('low tide shore platforms') (Fig. 1C).

High tide shore platforms have been interpreted in various ways. It has been suggested that they are essentially 'storm wave platforms' produced by waves driven across them during storms when the cliff at the rear is cut back; in calmer weather, wave action is limited to the outer edge, which gradually recedes, the width of the platform being a function of the relative rates of front and rear recession. But horizontal platforms truncating local geological structures cannot be explained in terms of storm wave attack, which appears to have a secondary and modifying influence on these features.

It has been suggested that shore platforms at or slightly above mean high tide level are the product of wave abrasion at an earlier phase when sea level was higher, the platforms merely being kept fresh by the surf that washes over them at high spring tides and during storms.

Low tide shore platforms may be defined as horizontal, or almost horizontal platforms exposed only for a relatively brief period when the sea falls below mean mid-tide level. They are best developed on certain limestone coast, where they are broad and almost flat, except for an inclined ramp towards the rear, leading up to the cliff base, which frequently has a notch overhung by a visor. There is sometimes a slightly higher rim at the outer edge formed by an encrustation of algae in a zone that is kept wet by wave splashing even at low tide (Fig. 8).

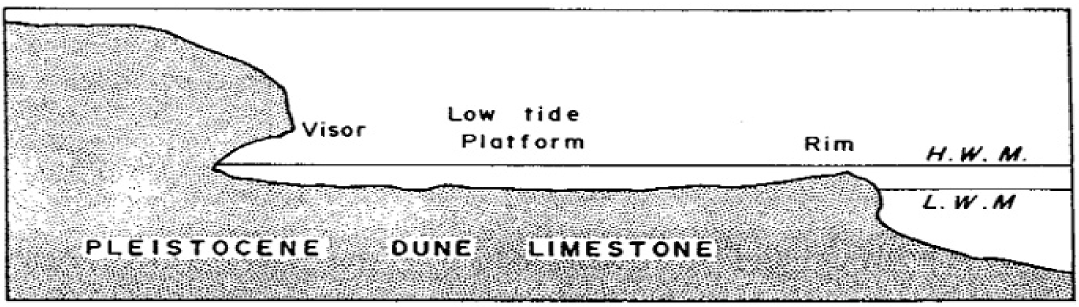


Fig. 8. Low tide shore platform, as developed on Pleistocene dune limestone (Aeolian calcarenite).

3. Plunging cliffs

Plunging cliffs (Fig. 1D) are cliffs that pass steeply beneath low tide level without any development of shore platforms. These have several possible explanations. Plunging cliffs can be produced by Holocene faulting, the cliff face being the exposed plane of the fault on the up-throw side, the down-thrown block having subsided beneath the sea. Tectonic subsidence of coasts may lead to the development of plunging cliffs, possibly with former shore platforms submerged beneath low tide level.

Beaches

Beaches are accumulations of sediment deposited by waves and currents in the shore zone. In terms of the Wentworth scale of particle diameters they are typically composed of sand or pebbles: granular beaches are uncommon, but silt beaches may occur on very sheltered coastlines.

Beach sediments composed of larger particles tend to develop steeper gradients, chiefly because of their greater permeability. Wave swash sweeps sediment forward on to a beach, and backwash to carry it back, but the greater permeability of gravel and coarse sand beaches diminishes the effects of backwash, leaving swash-piled sediment at relatively steep gradients. Fine sand beaches are more affected by back. Wash, and have gentler slopes, often of firmly-packed sand across which it may be possible to drive a car. Where the sands are well sorted, and composed of well-round and highly-polished sand grains, the beach may emit a squeaking noise when walked upon.

1. The Origin of Beach Sediments

The nature of beach sediments is clearly related to the nature of material supplied by rivers from the adjacent and foreshore, or brought in from offshore or alongshore sources. Gravel or shingle beaches are found where coastal rock formations yield debris of suitable size, such as fragments broken from thin resistant layers in stratified sedimentary rocks, or eroded out of conglomerates or gravel deposits, or derived from intricately-fissured igneous outcrops. Sandy beaches may be supplied with sand eroded from coastal arenaceous outcrops

Sand may be also be delivered to the shore by rivers, as on the coast of Southern California, where the beaches consist of sand fluvial origin that drifts southwards from river mouth, accumulating against the northern flanks of promontories, or lost onto the heads of the submarine canyons that run out from the southern ends of several material on this coast.

The large-scale sandy beaches forms part of a barrier system that seals off river mouths as coastal lagoons in which the fluvial sand supply is intercepted.

In general, sandy beaches are supplied partly by material eroded from adjacent part of the coast, partly by fluvial sediment, and partly by sand carried shoreward from the sea floor, the relative proportions being determined by conditions. In addition, quantities of sand may be blown from the land into the see, particularly on desert coasts, and thence delivered to the beach.

On steep and rock and coast, beaches of sand or gravel develop and persist in suitable niches, such as relatively shallow bay-heads, coves and inlets; many such beaches are locally derived, but some are interceptions of sediment carried alongshore, or washed in from the sea floor.

2. Beach profile

The profile below illustrates a meso-tidal beach more typical of the North Shore of Massachusetts, showing the components of a beach profile in descriptive terminology (Fig. 9). Most textbook illustrations of beach profiles show a single berm, a well-defined step, and little to no low tide terrace. Such profiles are more common in micro-tidal settings, and for introductory students are often difficult to reconcile with the beach morphology observed locally. The locations of most of these zones and their features may vary with tidal stage and beach state (erosional or accretional), they are not permanent either temporally or spatially, but migrate shoreward or seaward.

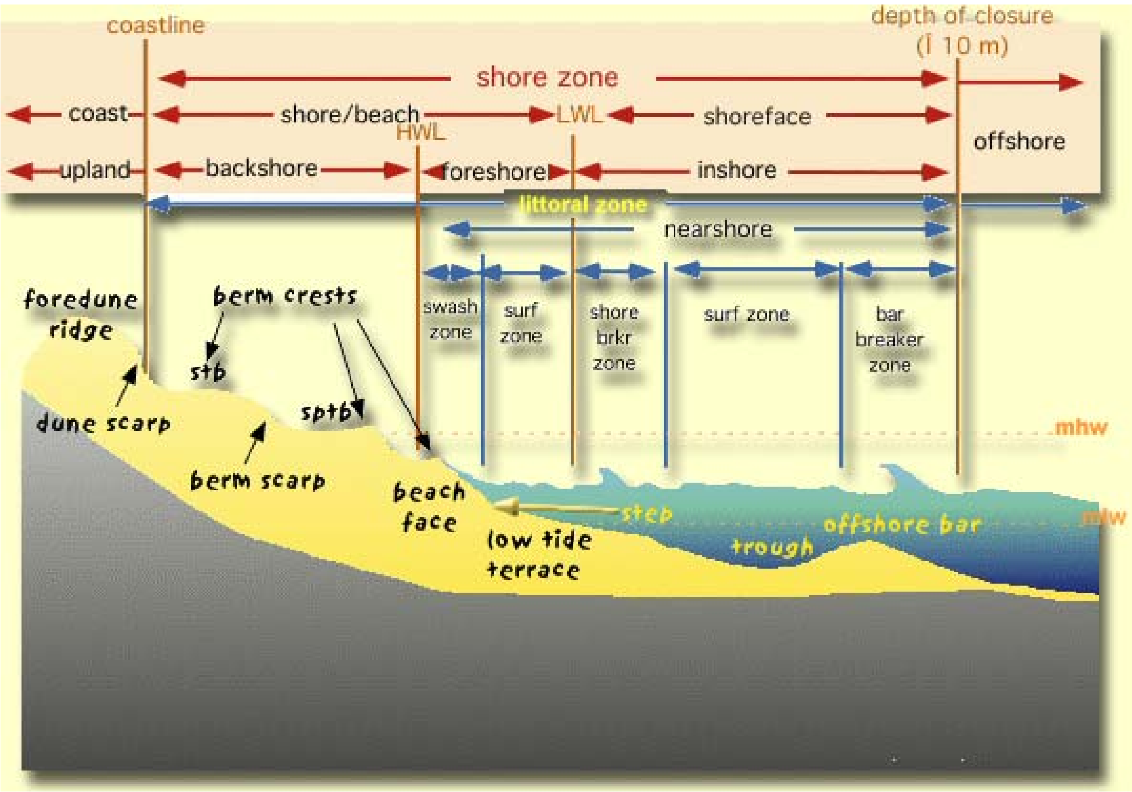


Fig. 9. Zones and features of the shore zone. Stb=storm berm, Sptb=spring tide berm, MHW=mean high water, MLW=mean low water.

Morphological Zone

The shore zone refers to the region of mobile sediment that is available to waves and currents for building of the beach. It contains the body of sediment that forms the slope extending from the fore-dune ridge or a bluff to the shelf. The seaward limit is defined by a change in slope where the sediment wedge meets the shelf and the depth of closure, the depth below which waves are incapable of moving sediment. As it would be expected, the shore zone may undergo radical changes as wave climate varies. The components of the shore zone are as follows.

A. Shore and beach: The strip of land in direct contact with the water between high and low water. The term beach applies if the region is composed of unconsolidated sediment. The width of the shore is determined by tidal range and slope.
B. Backshore: The region of a beach from the berm crest landward to a foredune ridge, vegetation line, seawall etc. Under typical conditions the berm area includes the supratidal area of a beach. The backshore is typically beyond the reach of ordinary waves and tides but is influenced by aeolian processes. Swash processes are important along the berm crest. The backshore becomes wider during the Summer and narrower during the Winter. In some instances along engineer coasts the backshore may be missing.
C. Foreshore: The sloping portion of the beach between the limits of high tide and low tide swash. It includes the intertidal (beach face and low tide terrace)--the entire area affect by swash and backwash. The Beach face is commonly separated by a plunge step, a small trough filled with coarse sand or shells from by the breaking of small plunging waves at the base of the beach face.
D. Shoreface/inshore: Area seaward of the foreshore to a point outside the breaker zone. Subtidal area below mean low water. This is the region where sediment motion is dominated by waves.
E. Offshore: Area extending from the breaker zone to the edge of the continental shelf.

Note: Sometime the term shoreface is loosely used to include the entire shore zone.

Beach Features

1) Berm

The dry, upper flat portion of the beach generally located at or above MHW (supratidal) is the berm. This is the area that you set your towels when you don't want to move them again when the tide rises. The berm is periodically overtopped during storms or extreme high tides.

- On sandy and shingle beaches berms build seaward through the multiple accretion of bars to the beach face. (See Fig. 11 below) Vertical accretion to the berm is accomplished by swash (Fig. 10), which is influenced by wave height. The berm height approximates 1.3 x the significant Ho. Therefore, all other factors being equal (e.g. grain size), berms on beaches facing the open ocean are higher than those on beaches in sheltered coves.

- A beach may have more than one berm or none at all (e.g. an eroded beach backed by a seawall).
- Some beaches, particularly mesotidal gravel beaches, may exhibit multiple berms (e.g. LHT berm, HHT berm, summer berm, winter berm, storm berm, etc). High-water berms are formed during storm surges or spring tides (HHT berm). The most ephemeral berm would be the low berm formed during neap tide (LHT berm).

- The berm crest is a linear feature that marks the seaward limit of the berm and shoreward limit of the beach face. The berm crest migrates seaward during periods of accretion and landward during periods of erosion.
    - o typically marked by an abrupt change in slope between the horizontal berm and sloping beach face.
    - o formed along the upper limit of normal wave swash.

Fig. 10. Singing Beach, Manchester by the Sea, MA. (late October 99). During high tide, waves breaking on the beach face over-top the berm. Vertical accretion occurs when water percolating down through porous sand leaves behind its load. The shallow uprush of water that carries the sediment is termed swash. The limit of swash during a tidal cycle is marked by a band of debris pushed shoreward by the leading edge of the swash.

Fig. 11. Goldthwaite/Devereau Beach, Marblehead, MA (July 03). This steep shingle beach typically contains multiple berms formed by the welding of gravel bars during various monthly levels of high tide. The highest ridge on the beach is formed during northeasters when large amounts of gravel are thrown on the beach. Also, gravel tossed onto residential lawns is bulldozed back to the beach ridge.

2) Beach face:

- The sloping portion of the beach dominated by wave swash and backwash.

3) Offshore bar and trough:

- An offshore bar is an inshore(below mlw) linear deposit of sediment that forms a ridge that typically runs parallel to shore. The trough is the swale shoreward of the bar. Breakers will form in response to the shoaling caused by offshore bar, therefore the location of an offshore bar can be identified by noting breaker zones.
    - Offshore bars are generally composed of sand eroded from the beach face during storms
    - breaker zone: zone of convergent between onshore and offshore currents
    - In tidal regions there may be two sets of bars formed and high and low tide
    - Offshore bars act as filters, allowing only waves of a certain height to pass

4) Ridge and runnel (bar and trough):

- A ridge and shoreward trough formed by the landward migration of an offshore bar

- A breach in the ridge formed by water rushing seaward from the runnel is called the **runnel outlet**
- generally absent from gravel beaches

5) Low tide terrace:

- The flat lower portion of the beach exposed during low tide.
  - On microtidal beaches the low tide terrace is very narrow or lacking.
  - On mesotidal and macrotidal beaches the low tide terrace is very broad and is composed of finer sediment than that on the beach face. Typically the dominant region during low tide.
  - The low tide terrace is compose largely of fine grain material (sand, silt or clay) even on gravel beaches.

6) Beach step (plunge step):

- The beach step is the final breaking point of waves before they rush up as swash on to the beach face. Because this is a high energy environment sediment along the beach step is typically coarse grained. The beach step is best developed microtidal beaches.

7) Beach scarp:

- A scarp formed along the foreshore by beach erosion. During periods of erosion the berm crest is replaced by a landward migrating beach scarp. The berm become progressively narrower which the low tide terrace widens.

8) Cusps:

- A series of embayments separated by horns of coarser sediment located in the foreshore region. Horn spacing ranges from 1 to 60m. Cusps are thought to be formed by edgewaves, which move parallel to the shore.

9) Foredune ridge and foredune scarp

- The outermost portion and a dune backing a sandy beach. With the exception of erosional bluffs and artificial structures the foredune ridge marks the backshore limit of most sandy beaches.

Fig. 12. Singing Beach, Manchester by the Sea (Fall 93) taken close to low tide. The beach zones on this photo are quite clear. Before moving the cursor over the figure try to identify the berm, beach face, low tide terrace and the fitted riprap revetment that terminates the backshore.

Note: On the low tide terrace lies a bar (ridge) cut by numerous runnel outlets. Sand eroded during a storm is now migrating onshore. The dry sand on the berm is lighter in color that the wet sand along the beach face and low tide terrace. Shoreward of the bar lies light band between the low tide terrace and the beach face. This highly reflective band is water ponded in the trough (runnel), located along the step.

Beach zones based on wave action

1) nearshore zone:

- The entire area affected by wave bores, swash and backwash
    - includes the foreshore and inshore
    - **swash zone:** The area of wave swash (uprush of water) and backwash (back rush of water)--foreshore
    - **surf zone:** The zone landward of the breaking wave where there is the forward
    - translation of water called wave bores
    - **Breaker zone:** The zone of breaking waves

Note: Nearshore zones with multiple bars will have more than one breaker and surf zone. Waves that break on the outer bar will reform to break on the next inner bar. Each set of waves will be smaller than its predecessor.

3. Beach outlines in profile

The profile or cross-section of beach at any time is determined largely by wave conditions during the preceding period, and the effects of a severe storm may still be visible sever month later. In calm weather, low waves form “spilling: breakers with a constructive swash which moves sand or shingle on to a beach to build up a ridge or ‘berm’ parallel to the shoreline. In rough weather, higher and steeper waves from ‘plunging’ breakers, with collapsing crests which produce less swash, and a more destructive backwash which produce less swash, and a more destructive backwash which scours sediment away from the beach.

Beach profiles can also be modified by wind action, when sand blown along or across the beach, lowering some parts some parts and building up others: beach barchans may from, and migrate down-wind. Sand winnowed from the beach face by onshore wind is carried inland, whereas offshore winds sweep it into the sea. Runoff during heavy rains may also wash beach sand into the sea.

Beach profiles are modified by changes in the relative levels of land sea, Other things being equal, submergence leads to recession of the beach and emergence to progradation, but it is necessary to take account of other factors, including variations in the incidence of cut and full and the availability of beach sediment. A beach receiving abundant sediment may prograde even during a phase of submergence, while a beach that is losing sediment offshore or alongshore may be cut back even during a phase of emergence. Bruun (1962) suggested that if a beach profile has attained an equilibrium in relation to the processes at work on it, a relative rise of sea level will cause erosion of the upper beach and deposition in the nearshore zone in such a way as to displace the original in the profile landward. Schwartz (1967) has confirmed this, both from laboratory model experiments and from careful one neap low tide to the next spring low tide, during which there is a successive raising of the high-tide swash zone, which can be taken as simulating a short-term sea level rise. It was found that the beach profile was displaced landward, erosion in of the upper beach being compensated by nearshore deposition in such a way as to maintain the water depth adjacent to the shore (Fig. 13). By contrast, active emergence promotes shoreward drifting of sea floor sand on to is re-working drowned eskers in a shallowing sea, and around the emerging Caspian coast. This reverses the sequence shown in Fig. 13.

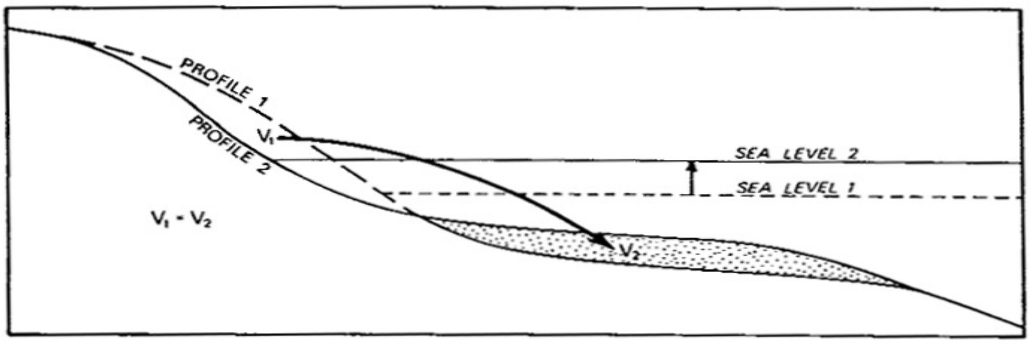


Fig. 13. Response of a beach profile to a sea level rise: the 'Brunn Rule'

Sand removed during storms is often retained as bars, awash at low tied, in the nearshore zone. These are concentrations of sand where the waves break, sand carried shore-wards by the waves meeting sand withdrawn from the beach by the back-wash. This effect has been reproduced in wave tanks, where it can be shown that size of 'break-point' and their distance dimensions from the shore for a given caliber of sediments are related to the dimensions of waves: bigger waves build larger bars farther offshore. In calm weather, when constructive swash is more effective, bare move closer to the shore, and become swash bars, flatter in profile.

The alternation of cut and fill on a shore receiving plenty of sand may produce a succession of parallel ridges. Once a berm survives a storm, a new one is built up in front of it as sand is supplied to the beach during a succeeding phase of calm weather. Prograded sandy beaches may show a series of parallel ridges, often surmounted by dunes.

Parallel sandy ridges can also be formed by the successive addition of spits growing parallel to the shoreline.

The profiles of shingle (gravel) beaches differ in some ways from those of sandy beaches. This is partly because storm waves can have a slightly different effect: in addition to scouring shingle away from the beach face, the breaking waves throw some of it forward to build a ridge higher up the beach. In this way, a storm phase leads to the steepening of the beach profile. Subsequently, in calm weather, shingle returns to the beach face, restoring a gentler profile. Ridges on prograded shingle beaches are the outcome of successive storms, each of which threw up a ridge of shingle parallel to the shoreline. It appears that shingle, and possibly also coarse sand, can be built into berms by storm wave action which is purely destructive on beaches of finer sand.

The height and spacing of parallel sand or shingle ridges are influenced by a number of factors, including the rate of supply of sand or shingle to the shore, the incidence of cut and fill, and changes in the relative levels of land and sea. A series of ridges showing an overall seaward descent in the levels of crests and swales may indicate progradation on an emerging coast, but the other factors must also be taken into account.

4. Beach rock

Beach rock is formed where a layer of beach sand becomes consolidated by secondary deposition of calcium carbonate at about the level of the water-table (Russell, 1962). The cementing material is precipitated from ground water in the zone between high and low tide level, which is subject to repeated wetting and drying as the water-table rises and falls with the tide, or during and after wet weather. Some believe that precipitation of calcium carbonate is aided or brought about by the action of micro-organisms, such as bacteria, which inhabit the beach close to the water-table. Often the cementing material is aragonite, probably derived from sea water, rather than calcite, derived from ground water (Stoddart and Cann, 1965). Where the cemented material is gravel rather than sand, the resulting formation may be termed a beach conglomerate (rounded gravels) or beach breccia (angular gravels). Cementation ca proceed rapidly, for artifacts such as bottles have been found incorporated in beach rock.

5. Spits

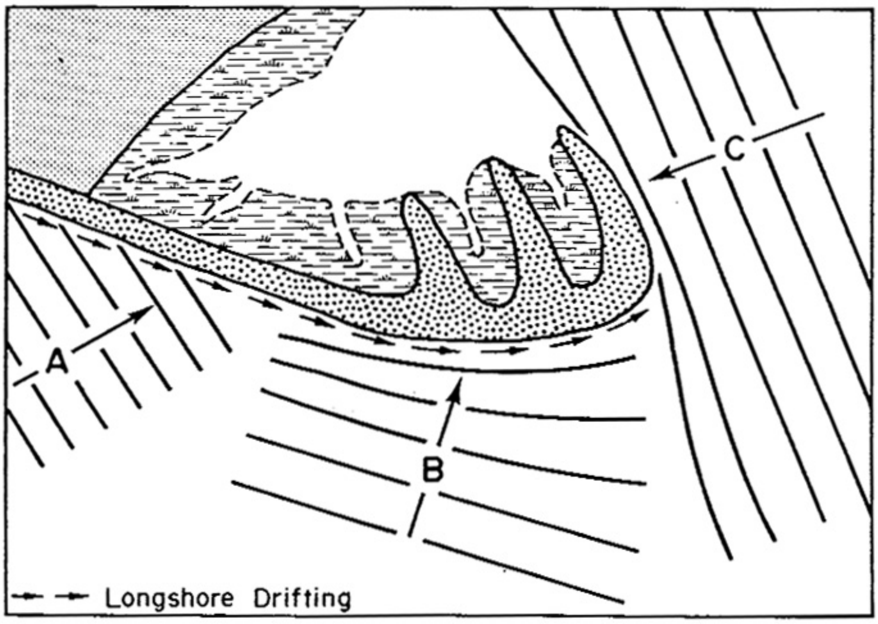


Fig. 14. The shaping of a recurved spit: waves from A, arriving at an angle to the shore, set up longshore drifting which supplies sediment to the spit; waves from B and C determine the orientation of its seaward margin and recurved laterals respectively.

Spits are depositional features built up above high tide level in such a way as to diverge from the coast, usually ending in one or more landward hooks or recurves (Schwartz, 1972). Gulliver (1899) ascribed spit growth to current action, but although currents may contribute sediment to them, they grow in the predominant direction of longshore sediment flow caused by waves, and their outlines are shaped largely by wave action. The recurves are formed either by the interplay of sets of waves arriving from different directions (Fig. 14), or by wave refraction around their distal ends.

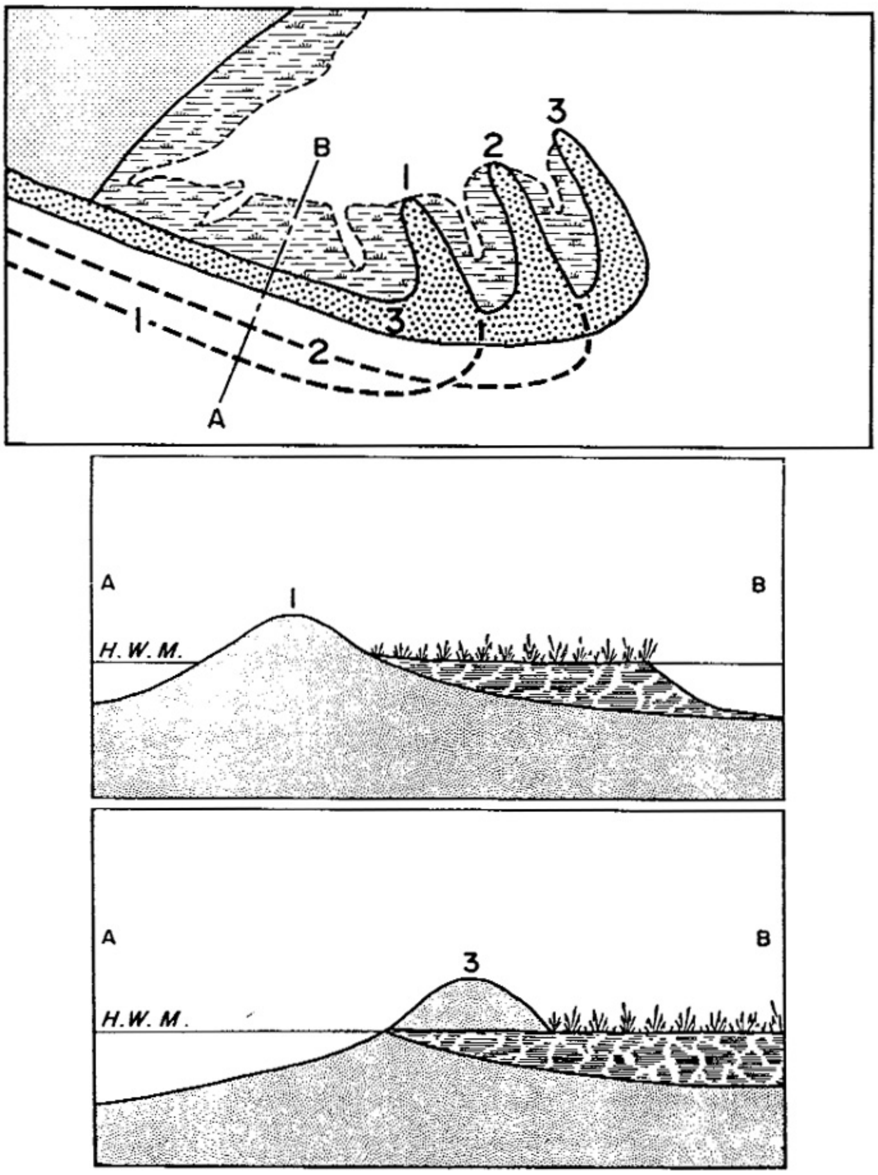


Fig. 15. Stages in the revolution of a recurved spit.

Spits built of sand and gravel derived from gracial drift deposits have been driven landward athwart the salt marshes in successive storm surges(e.g. 1953,1976,1978), so that salt marshes outcrop on the seaward side (Fig.15). Other spits have been widened by the addition of successive ridges on the seaward side, and stages in their evolution can be deduced from the pattern of beach ridges, as on the spit in Carrickfergus Bay, on the E coast of Tasmania(Fig. 16). Sand eroded from cliffs of glacial drift on the Cape Code peninsula has been built into a spit, prograded on the seaward, the fulcrum of this spit has migrated up the coast so that part of the formerly prograded sector has now been truncated by marine erosion.

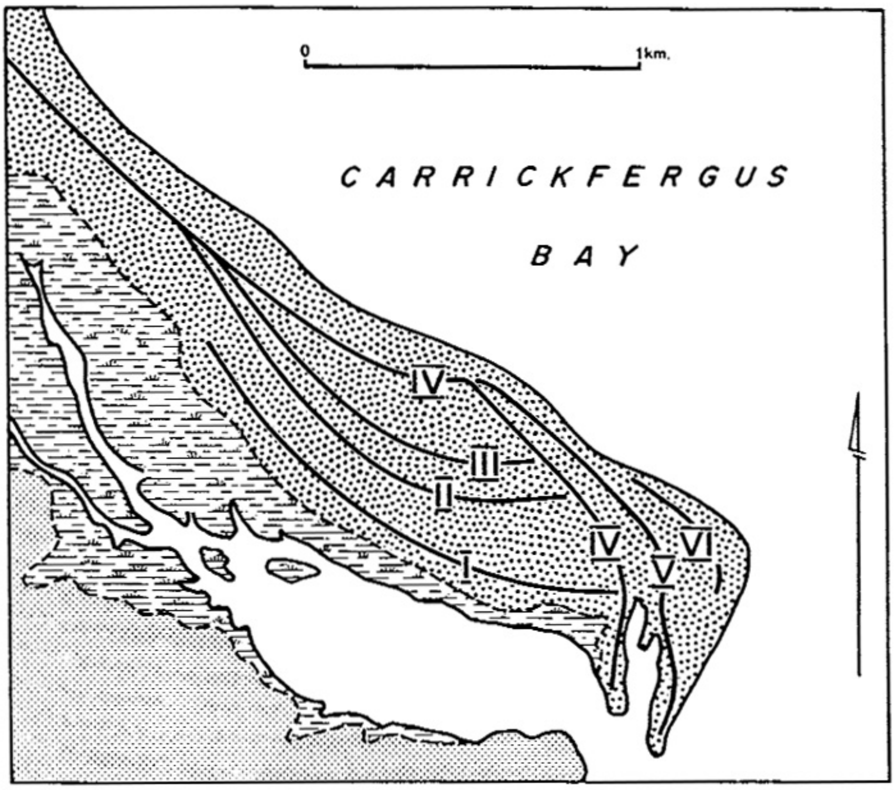


Fig. 16. The recurved spit in Carrickfergus Bay.

6. Barrier beaches and related forms

The deposition of beach material offshore, or across the mouths of inlets or embayments, in such a way as to form barriers extending above the normal level of highest tides and partly or wholly encosing lagoons, is a widely-distributed phenomenon which has received considerable attention in recent years. Barriers, thus defined, are distinct from bars, which are submerged fro at least part of the tidal cycle, and from reefs of biogenic origin, built by coral and associated organisms. They show a variety of forms. Barrier beaches are narrow strips of low-lying depositional land consisting entirely of beach sediment, without surmounting dunes or associated swamps. Many barriers do have these additional features, and some attain widths of several kilometers, with crests of dunes sometimes rising more than a hundred meters above sea level. The term bay barrier describes a feature built up across and embayment, and barrier island indicates a discrete segment, often recurved at both ends.

The two main modes of barrier origin are by the longshore growth of spits (Fig. 17) and by development of emergent bars as beaches offshore during a phase of sea level lowering, and by the partial submergence of a pre-existing coastal sand ridge during a phase of sea level rise. Many barriers have had a composite origin.

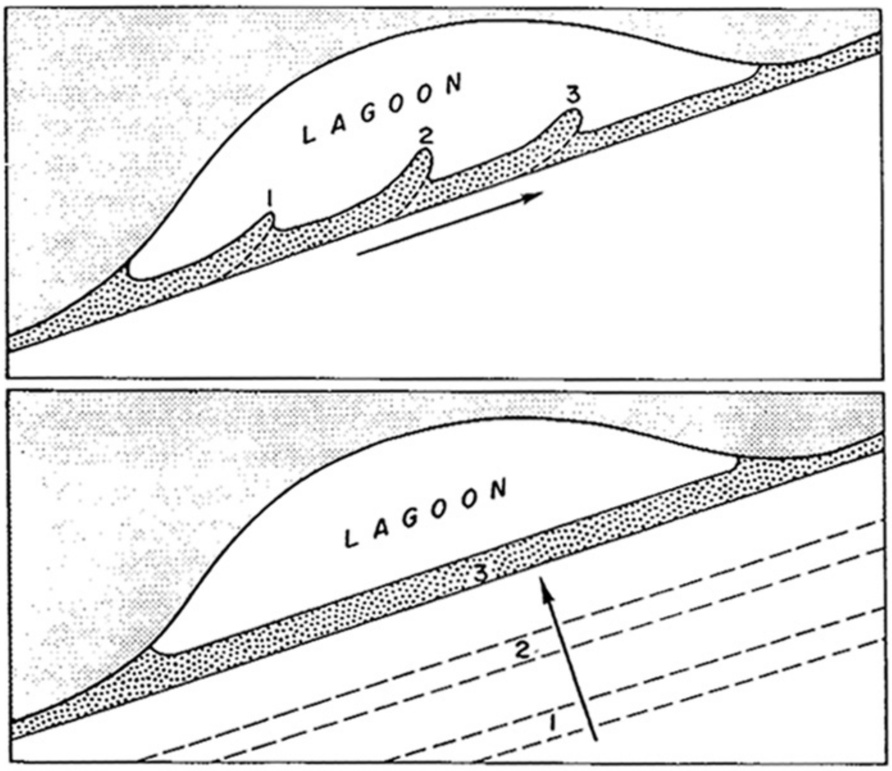


Fig. 17. Stages in the evolution of a barrier to enclose a lagoon; by prolongation of a spit (above) or by shoreward migration of a barrier that originated offshore (below).

7. Beach erosion

Beach erosion is in progress on many coasts. Sandy coastlines in many parts of the world have been retreating during the past century, and possibly for a longer period (Russel, 1967;Thom, 1974). Recession is in progress even on the shores of barriers that were previously prograded by deposition. It is quite difficult to find sectors of naturally prograding sandy beach, whereas receding sandy shorelines are extensive. Factors that have contributed to the modern prevalence of erosion on sandy coastlines include reductions in sediment yield from rivers, especially where dams have been built to impound reservoirs (e.g. S California); a diminution in sand supplies from the sea floor (Davies, 1974); the response to a possible rise in sea level relative to the land (Bruun, 1962); and the possibility of increased storminess in coastal water (Thorn, 1974).

The response to beach erosion has often been the construction, elaboration and extension of artificial structures designed to protect the coastline. Alternatively, eroded beaches (especially in resort areas) have been replenished artificially by pumping or dumping sand taken from the sea floor or from coastal or inland quarries on to the foreshore.

Beach systems are thus dynamic interactions between shore processes and coastal sedimentation (Komar, 1976). An understanding of these interactions is a necessary prelude to beach management.

Coastal Dunes

Coastal dunes are formed where sand deposited on the shore dries out and is blown to the back of the beach. Where the tide range is large, as on the Atlantic coast of Devon and Cornwall, sand blown from broad foreshores exposed at low tide is built up as dune topography extending inland from high tide mark. Dunes are similarly derived from broad inter-tidal foreshores. On coasts where the tide range is small, sand delivered to the beach by wave action may have provided the material for dune construction.

On arid zone coasts bordering the Sahara and in NW Australia desert dunes may adjoin and mix with dunes derived from beach sands. On some coasts wind-blown sand has been accumulating during and since Pleistocene times, producing extensive and complicated sequences of dune topography. Where the parent sands are calcareous, as on the W coast of Australia, the older dunes have been lithified by internal deposition of calcium carbonate from percolating water, forming dune limestone, an aeolian calcarenite which preserves the dune topography in solid rock, but where the parent sands are quartzose, as on Australia's SE coast, this kind of lithification has not taken place, and the dunes remain unconsolidated-either active and mobile, or retained by a vegetation cover.

Coastal dunes are best developed on coasts in the temperate and arid tropical zones: in the humid tropics they are of limited and local extent, sandy coastal topography consisting of low beach ridges with little transgressive dune development.

1. Foredunes

Foredunes are built up at the back of a beach or on the crest of a beach ridge of sand or shingle where dune grasses colonise and start to trap blown sand. They become higher and wider as accretion continues (Fig. 18).

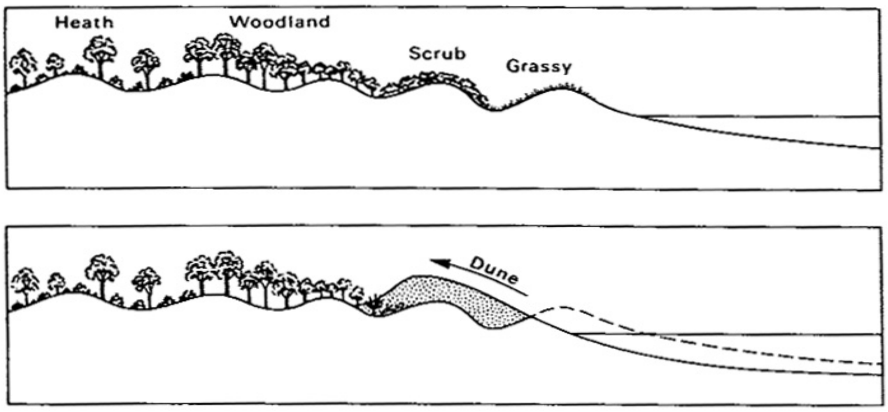


Fig. 18. Typical relationship of vegetation and prograded beach ridges, and more recent development of dunes moving landward behind the beach on Holocene outer barriers.

2. Parallel dunes

When the seaward margin of a foredune is timed back by waves during a storm, a crumbling cliff of sand is exposed (Fig 19C). Subsequently, during calmer weather, waves build up a new beach ridge in front of, and parallel to , the trimmed margin of the foredune, separated from it by a low-lying trough or swale(Fig 19D). Dune grasses tend to colonise the new beach ridge first, leaving the swale unvegetated, so that sand accretion is concentrated along the line of the beach ridge, and a new foredune is built up. Continued growth of the new foredune gradually cuts off the supply of sand to its predecessor, which becomes relatively stable, and the dune grasses are then invaded and replaced by scrub vegetation.

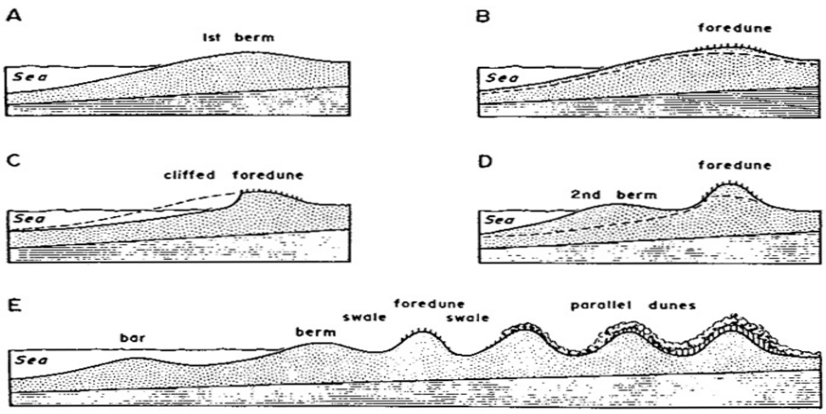


Fig. 19. Stages in the successive formation of coastal dunes parallel to an intermittently prograded coastline.

Many coastal dune systems do not show regular patterns of dunes parallel to the shoreline. Some show traces of a former parallel pattern that has been interrupted by the formation of blowouts and parabolic dunes, but out others are quire irregular, and have not necessarily originated from dunes built in parallel. The development of a large, coastal dune topography can result from a rapid supply of sand to the shore, without the separation of deposited successive foredunes by cut and fill alternations in the manner described above, or from the delivery of sand blown from the emerged sea floor during glacial phases of sand blown from the emerged sea floor during glacial phases of the Pleistocene period, when sea level was lower (Fig. 20).

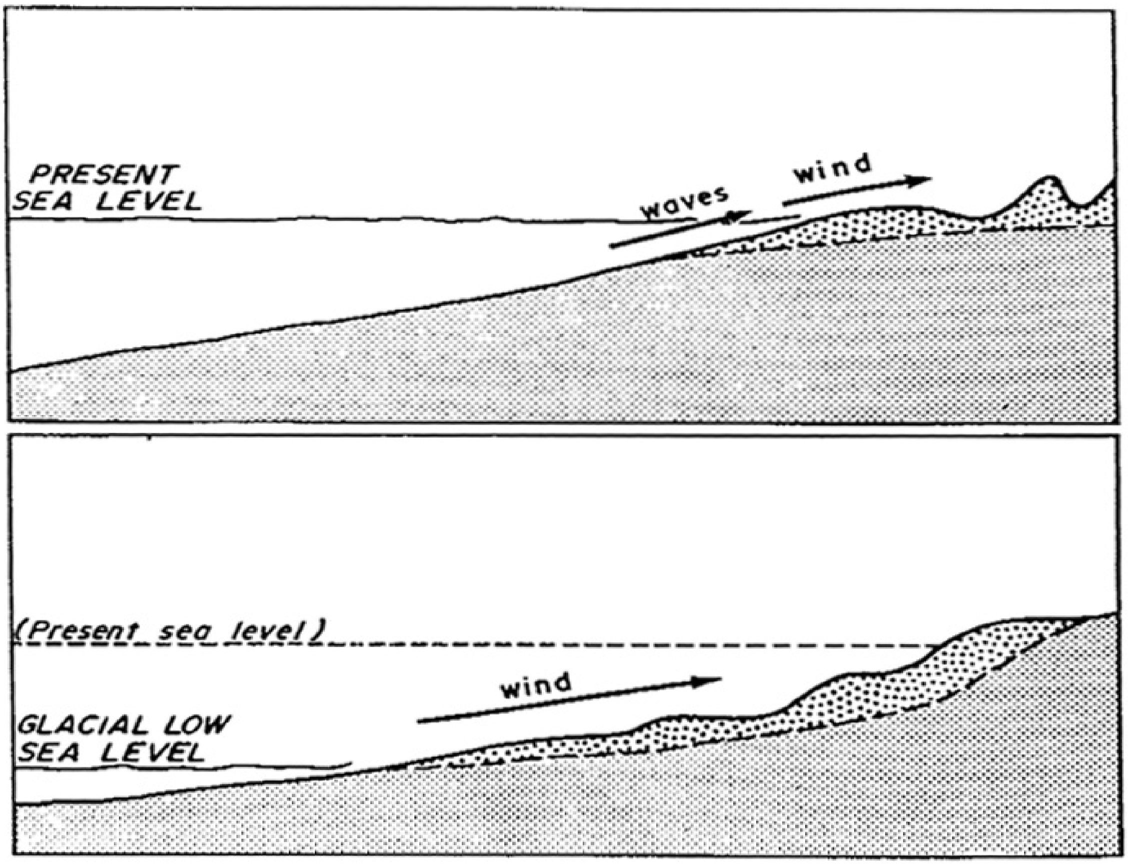


Fig. 20. Two possible mechanism of the delivery of sediment to a coast.

3. Blowouts and parabolic dunes

Blowouts develop where the vegetation cover of unconsolidated coastal dunes is destroyed or removed, so that sand is no longer held in position. They are often initiated by intensive and localized human activity. The evolution of blowouts is related to onshore winds and is most rapid on sections of the coast exposed to strong winds. A blowout that becomes enlarged begins to migrate through coastal dunes, with an advancing nose of loose sand (sloping at 30^{o}-33^{o}) and trailing arms of partly-fixed sparsely-vegetated sand; in this way it develops into a parabolic or U-dune. Dunes of this type are often found disrupting a pattern of parallel dunes (Fig. 21).

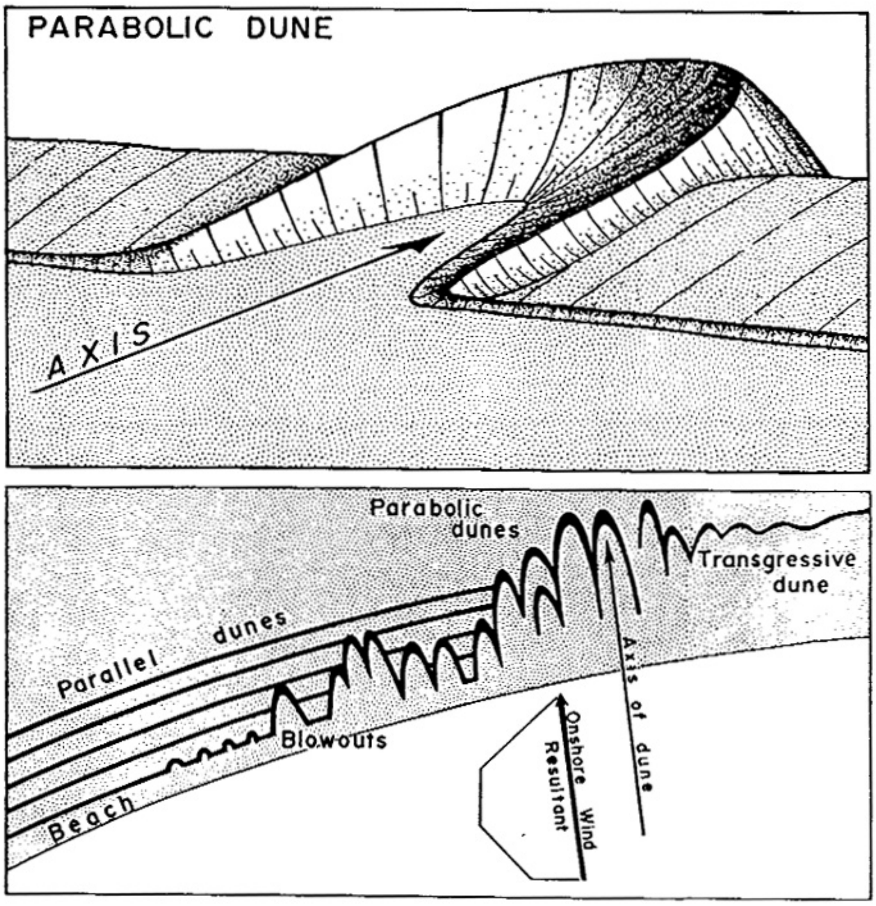
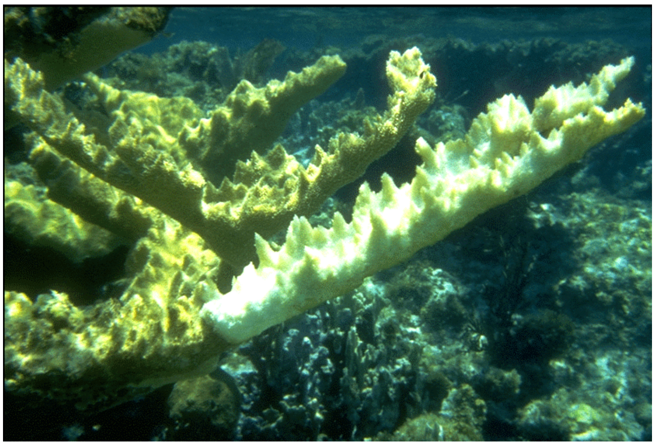


Fig. 21. Diagrams showing a parabolic dune (above), and blowouts and parabolic dunes interrupting parallel dunes (below), and showing a axis aligned with the onshore wind resultant.

Corals

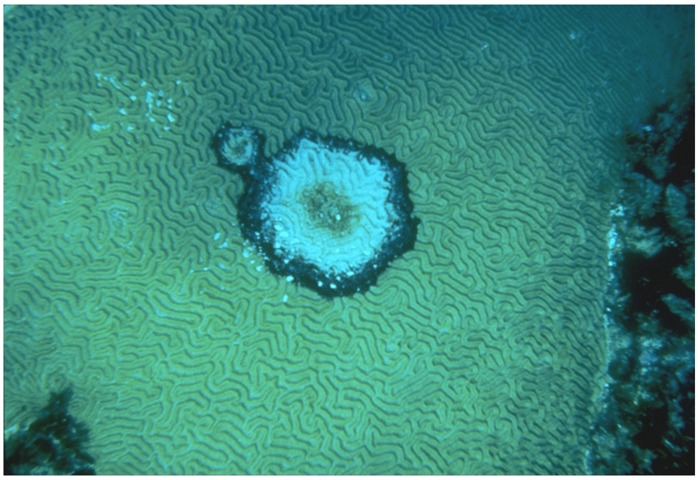
Florida's Reef Building Corals

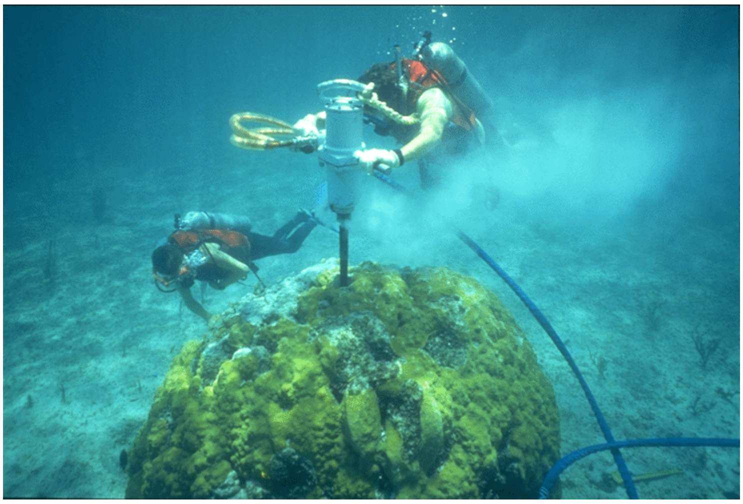
U. S. Geological Survey (USGS) divers taking a coral core sample with an underwater coring device. Hoses connected to a hydraulic pump in the boat drive the drill (yellow) made from a converted impact wrench. Garden hose provides sea water to lubricate drill bit and remove rock cuttings. This device was developed by the USGS and has been used since 1975 to take cores of rocks and reefs in the Florida Keys and elsewhere



Bleached elkhorn coral (white area) has lost its color due to environmental stress. Bleaching that continues for several weeks can be fatal to the coral.

Black-band disease on brain coral (Diploria strigosa).





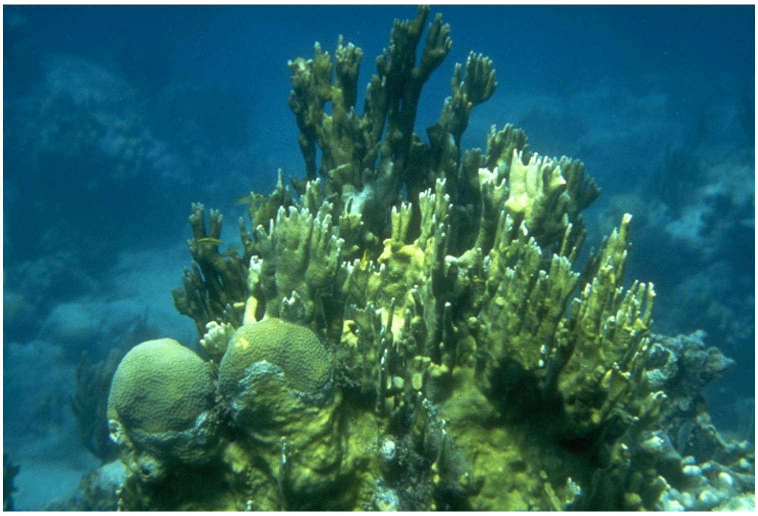
Core sampling of a large star coral in the Northern Bahamas. This coral is a major-reef building species and is also found in the Florida Keys.

Types of Coral

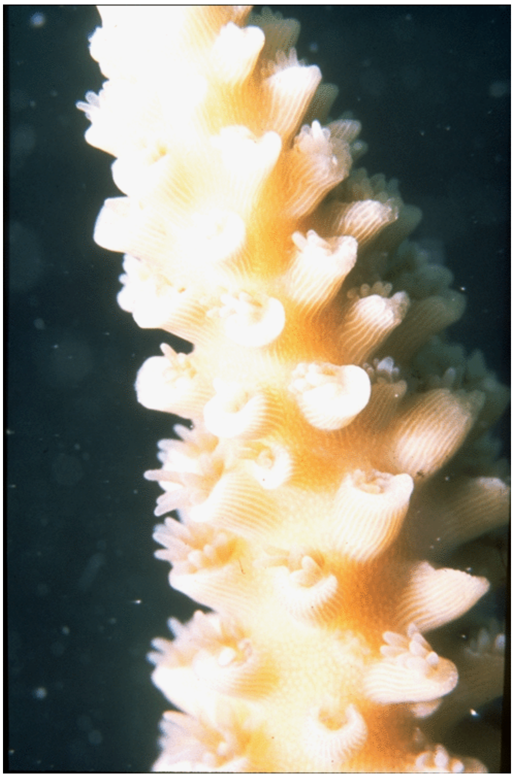
Sea whips and sea fans on a small reef in the Florida Keys.

How Pollution Affects Corals

Coral reef systems in South Florida thrive in clear, clean water. Coral reef systems generally form over porous limestones, which provide pathways for the movement of both toxic and nutrient-rich ground water. Small increases in the nutrient content of coastal waters, associated with stormwater runoff containing fertilizer and discharge of sewage into the limestone, may upset the fragile balance necessary to maintain the health of coral reefs. Coastal pollution studies will improve our ability to predict the processes by which pollutants affect the health of Florida's coral reef systems. The study of growth bands in cores taken from mounds such as the star coral allows researchers to study past coral growth in much the same way foresters study tree growth by counting and measuring tree rings.



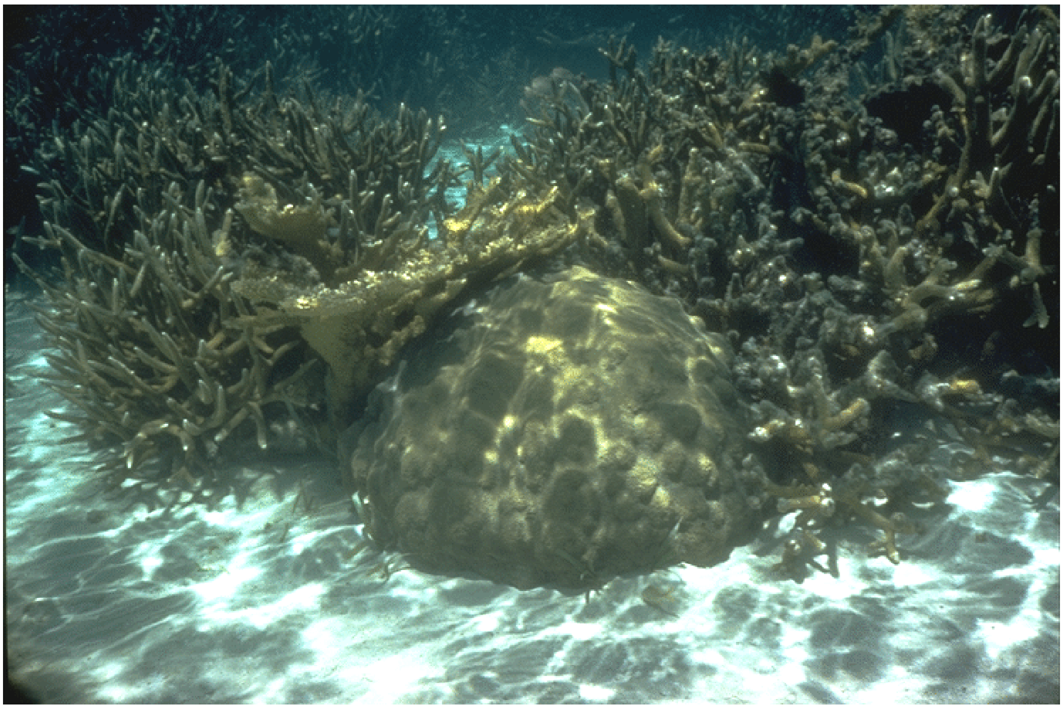
A healthy coral mound of pillar coral (Dendrogyra cylindrus), staghorn coral (Acropora cervicornis), and lettuce coral (Agaricia agaricites).



Here a healthy coral extends its polyps (finger-like fleshy 'tentacles') for feeding. Exposure to pollutants such as oil can cause the polyps to stay retracted in the coral's hard skeleton.

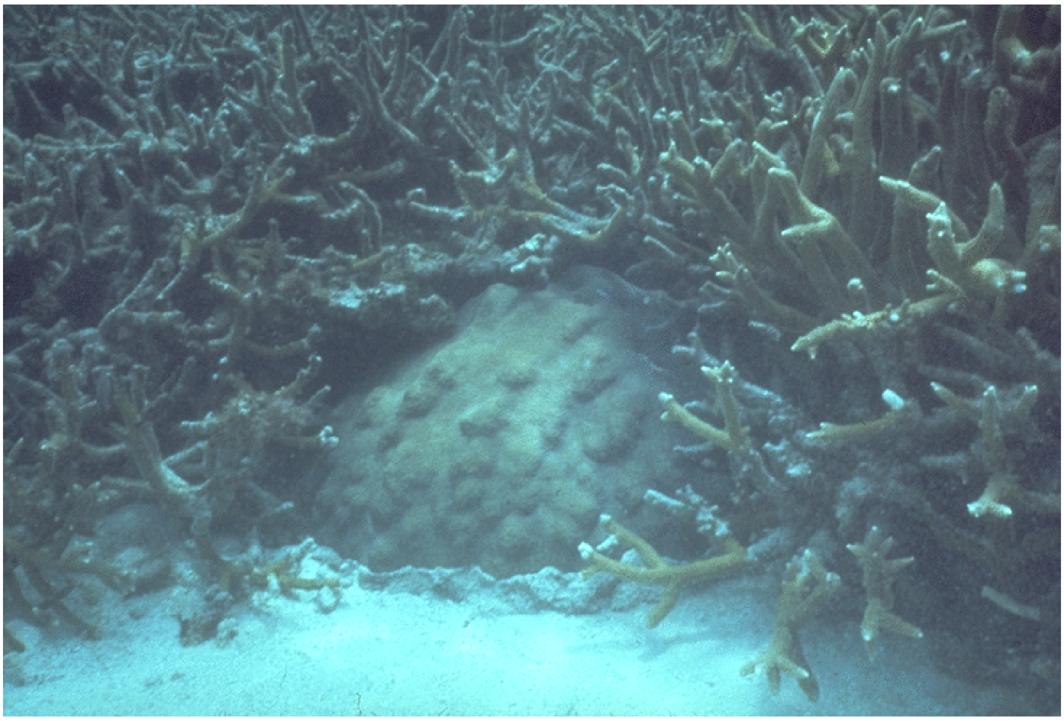
Life and Death of a Reef

1971 - Staghorn coral and the prominent elkhorn coral are encroaching on the star coral (center mound).

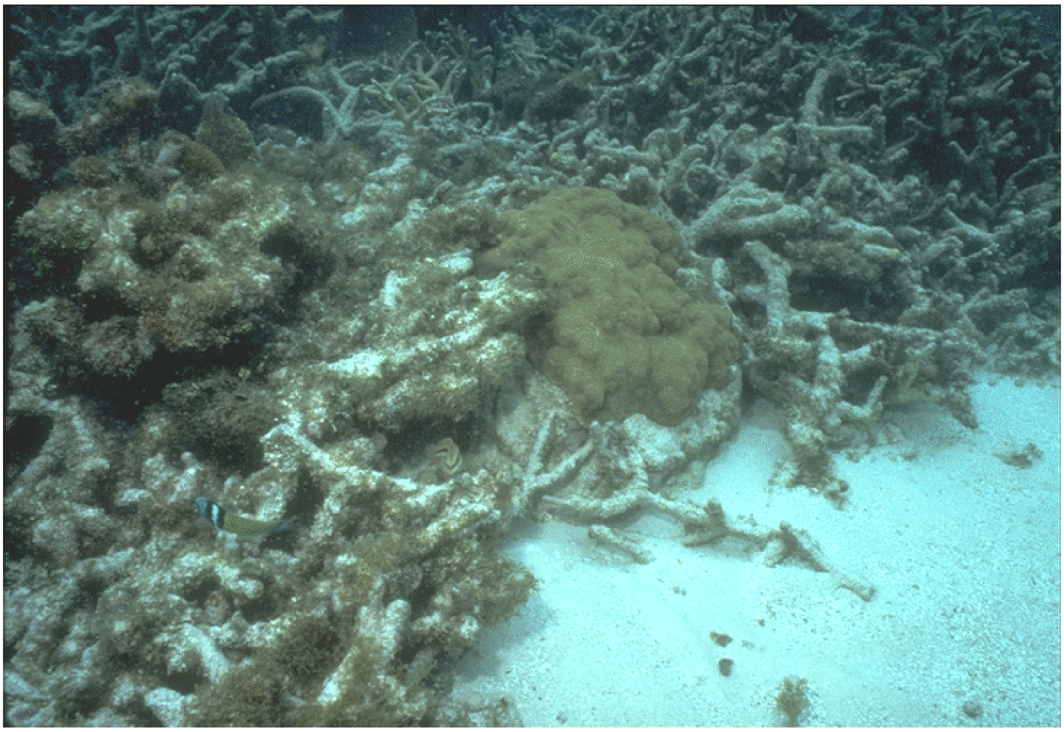


1976 - Diver's hand rests on elkhorn coral, which is now dead.

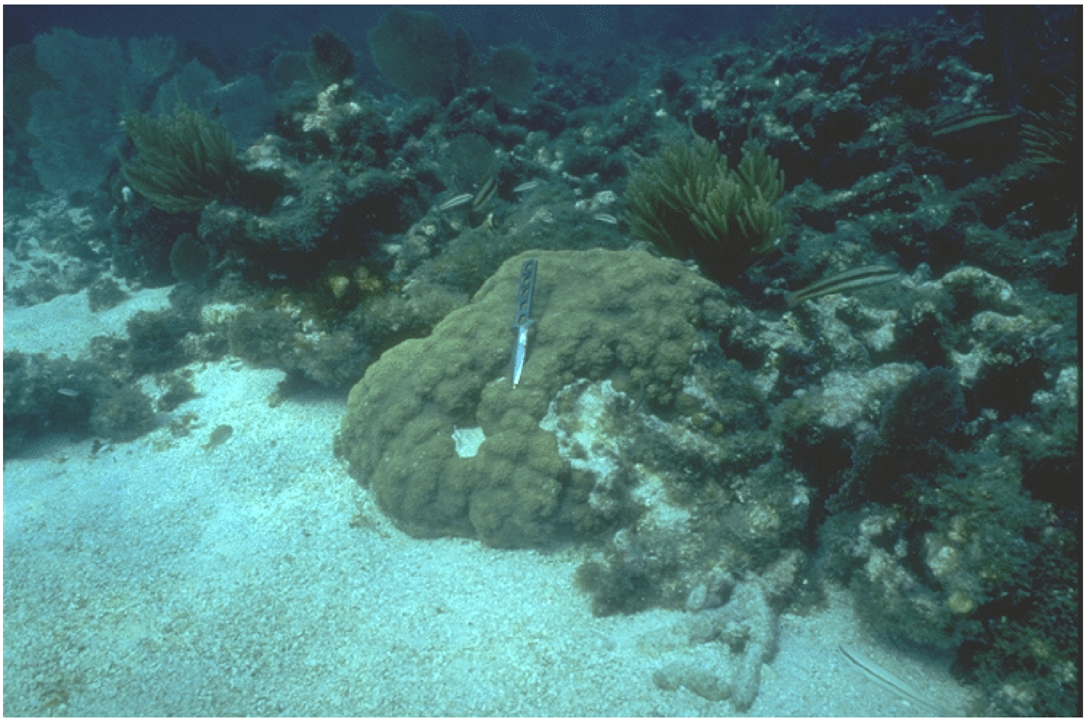
1978 - Most of the staghorn coral above and to the left of the head coral is dead. Note the skirt of dead coral around the base of the coral head.



1988 - Only a small patch of the staghorn coral (above and to the left of the head coral) remains alive. Notice the reduced size and lumpy nature of the star coral.



1992 - Much of the dead staghorn coral has been removed by parrot fish, which eat algae-covered coral. Only a small part of the star coral remains alive. (The holes in the knife are approximately 1 cm in diameter.)

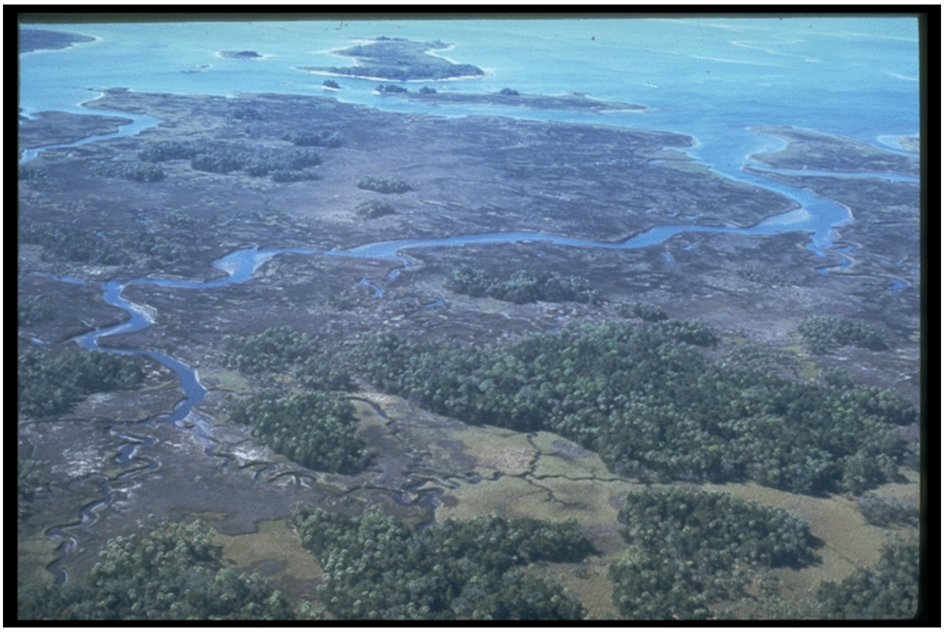


Wetlands

Marsh Characteristics

In an otherwise flooded embayment, sabal palm (Sabal palmetto) and red cedar (Juniperus siliciocola) form a hammock on a rocky limestone outcrop near Yankeetown, Florida.

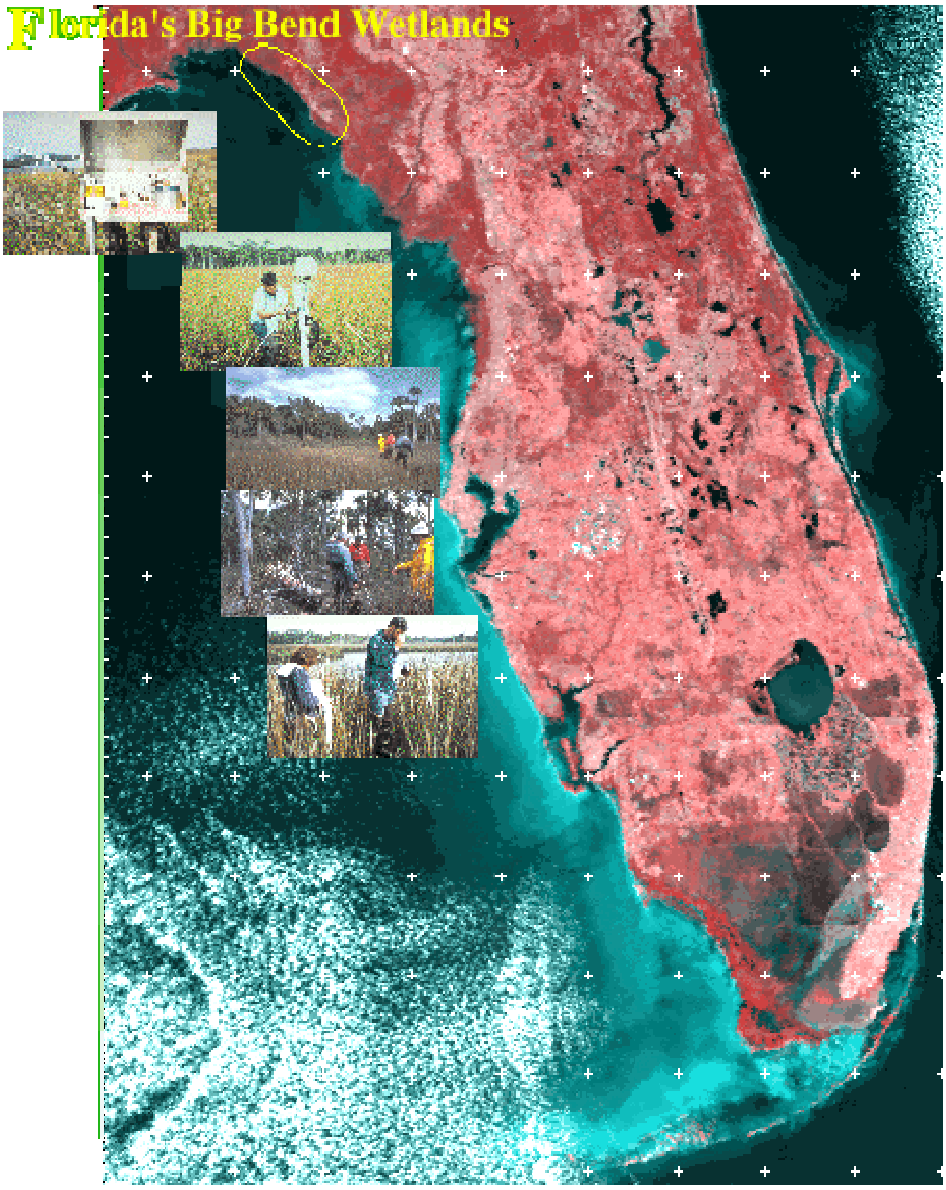
A coastal band of wetlands is a mosaic of marsh and hammock vegetation strongly influenced by the porous limestone bedrock. Hammocks have little tolerance for salt and grow where the limestone elevation is high. The marsh grows between the high and low tide lines where the limestone is low enough to be coated by a veneer of mud.



Hammocks of sabal palm and red cedar thrive on limestone high areas scattered throughout the wide marsh plain.

Wrack, a thick layer of marsh debris, is depostited against the tree line following a major storm. Although resilient to storm events, the marsh coast is sensitive to significant and long-term changes.

Gulf Coast Wetlands



The uneven surface of exposed limestone allows sediments to accumulate over time. The marsh will eventually fill in the pockets and break up the remainder of the surface rock.

White Pelicans (Pelecanus erythrorhynchos), a winter visitor to this area, gather on one of the marsh islands

Visible Changes in the Marsh

Oyster bars develop in estuarine environments, contributing to changes in tidal flow and the depostion of sediments. They also form a substrate used by other plant and animal species

Severe storms may knock down the trees and flood hammocks, leaving behind a thick layer of debris

Marsh sediments fill the pockets of exposed limestone, providing a foothold for colonization by salt-tolerant species such as the glassworts (Salicornia spp).

The shallow roots of the read cedar cling precariously to the exposed limestone surface beneath a coastal hammock.

Why Are Wetlands Important?

Tidal wetlands support a variety of fish, shellfish, birds, and wildlife; buffer storm surge on inland areas; and filter pollutants and nutrients from storm water runoffs into coastal waters. Natural rise in sea level and man-made stresses (influxes of people and development) can stress this environment and cause change and loss of the wetlands. Because of their economic, recreational, and environmental importance we need to understand how wetlands respond to these stresses.

A clump of sabal palm clings to the bank of a tidal creek near the Suwanee River in Florida.

Hurricanes

Coastal Changes & Damages: Florida Keys

Ragged Key

Two weeks before Hurricane Andrew

One week after Hurricane Andrew

Elliot Key

A storm surge (the rise in sea level above normal caused by the low-pressure center associated with hurricane) destroyed this home on Elliot Key. House debris can be seen to the left. The former support pilings, which have been knocked over by the forces associated with waves and currents, can be seen to the right.

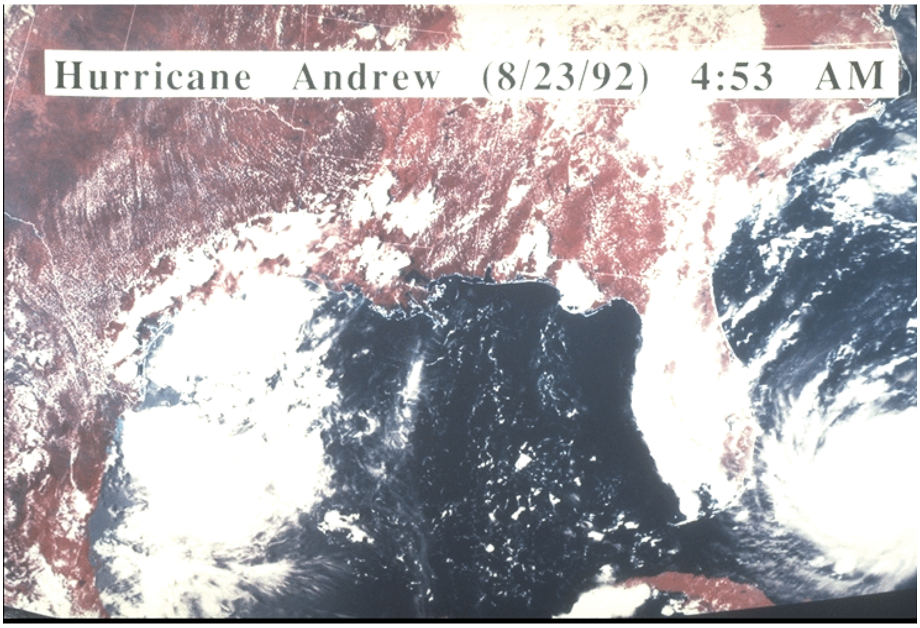
Soldier Key

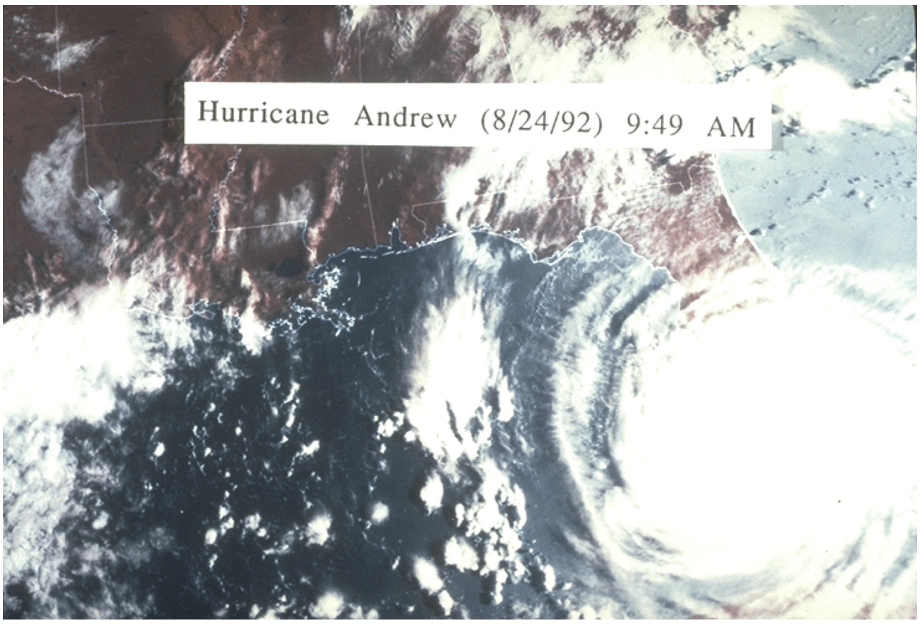
Two weeks before Hurricane Andrew

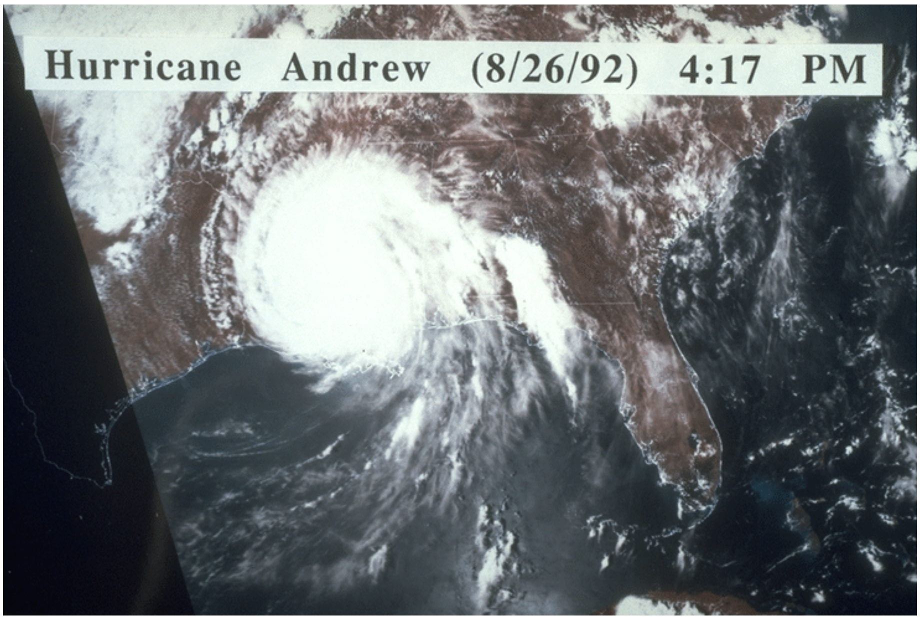
One week after Hurricane Andrew

Hurricane Andrew Effects

During August 1992, Hurricane Andrew severely impacted south Florida and Louisiana. At each landfall, the hurricane was classified as Category 4 with sustained winds between 131 and 155 mph. High onshore winds caused large waves and elevated sea level (storm surge) leading to extensive coastal changes.







Rosenstiel School of Marine and Atmospheric Sciences (RSMAS), University of Miami, satellite images of Hurricane Andrew.

Coastal Changes and Damages : Louisiana

Racoon Island

One month before Hurricane Andrew, the beach protects the marsh behind it from normal wave and storm conditions.

One week after Hurricane Andrew. Catastrophic events overpower the natural protection that beaches provide against erosion. The loose beach sand was washed away, exposing the marsh grass and vegetation to the waves.

Trinity Island

One month before Hurricane Andrew. Trinity Island hosts a number of fishing camps for Gulf of Mexico sport fisherman.

One week after Hurricane Andrew. Exposed to the full force of the wind, many fish camps were washed or blown away. Severe erosion of the beach uncovered old pier pilings long buried by the accumulation of beach sands.

Catastrophic Events

Studies of major hurricanes, other extreme storms, tsunamis, major floods, and pollution discharges (storm water runoff, oil and chemical spills) require both the ability to respond rapidly and a long-term commitment to the development of baseline data sets (information to which future data can be compared). We must understand the processes occurring during such events before we can assess the long term impacts which result. The products of these research efforts must be available and useful to concerned Federal and State agencies and to the public. Therefore, both data transfer and public education are vital components of the program.

More than 75% of the population of the United States lives within 50 miles of the Nation's oceans, Great Lakes, and major estuaries. Densely populated coastal areas are highly vulnerable to impacts of great storms.

Mapping Coastal Change Hazards

Introduction

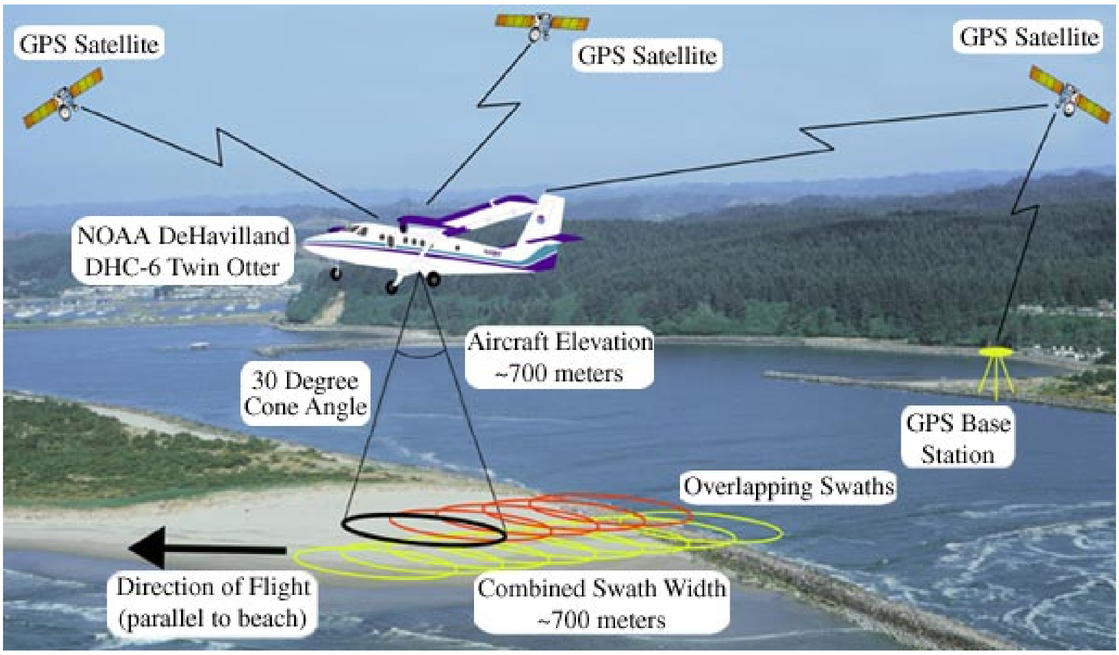
Coastal changes such as beach, dune and sea-cliff erosion, that occur during hurricanes and severe winter storms pose significant hazards to buildings and infrastructure that are built too close to vulnerable shorelines. Societal costs, in dollars spent and lives lost, can be staggering.


Northeasters


El Niño


Hurricanes

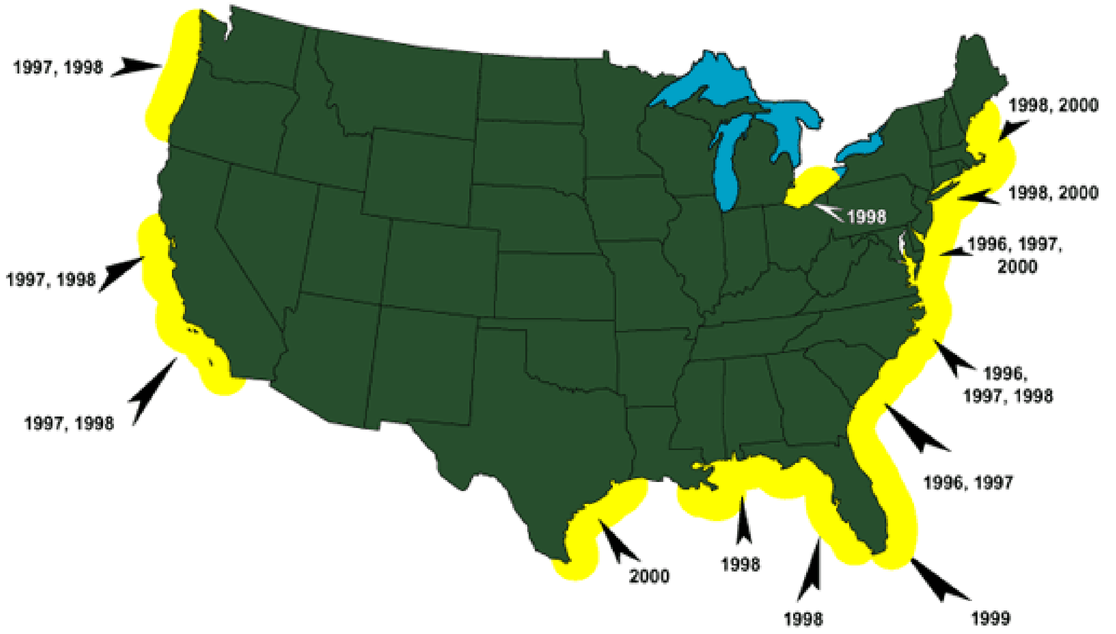
NASA's Airborne Topographic Mapper



Resource managers must be able to predict where and how much coastal change will occur in order to locate new construction landward of coastal change hazards. Developing this predictive capability requires quantifying how coasts respond to extreme storms.

With its rapidity of acquisition and very high data density, airborne lidar (**li**ght **d**etecting **a**nd **r**anging) is revolutionizing the quantification of storm-induced coastal change. Comparisons of before and after storm lidar surveys quantify patterns in erosion and accretion.

National Coastal Lidar Coverage:
USGS, NASA, NOAA, Texas Bureau of Economic Geology

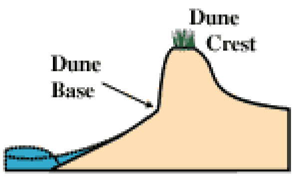


Note: Data gathered through 2000 available from NOAA's Coastal Services Center at: http://www.csc.noaa.gov/crs/tcm/index.html

Coastal Change Hazard Scale

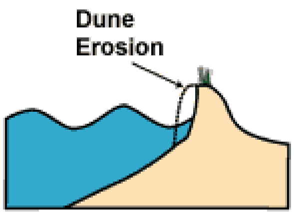
The impact of a storm on a barrier island is dependent not only on the magnitude of storm characteristics, such as storm surge and waves, but also on the elevation of the barrier island at landfall. By considering the magnitude of wave runup, the highest reach of the waves on the beach, relative to coastal elevation, a new scale has been developed that categorizes net erosion and accretion during storms.

Impact Level 1



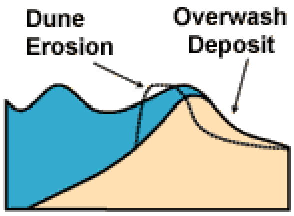
No Net Change to the System

Impact Level 2



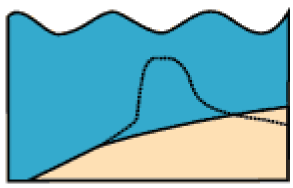
Net Dune Erosion

Impact Level 3



Net Onshore Transport, Order 100 meters

Impact Level 4



Net Onshore Transport, Order 1,000 meters

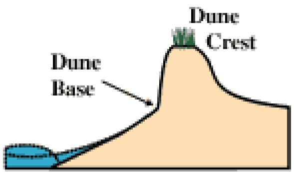
Classification of Storm-Induced Sedimentary Features and Responses

	Setting		
	Mainland Coast	**Barrier Island**	
		Ocean Level >= Lagoon Level	**Ocean Level < Lagoon Level**
Ocean Level < Dune or, if dune is not present, Berm Elevation	Erosion (and occasionally accretion due to berm migration) confined to the beach (**see Impact Level 1**)	If Dune is present, Dune Erosion (**see Impact Level 2**)	'Washout' and 'Ebb Flow' sedimentary features indicating flow from the lagoon to the ocean (latter stages for **Impact Level 4**)
Ocean Level >= Dune or, if dune is not present, Berm Elevation	Washover Terrace (**see Impact Level 3**)	Perched Fans and Sheetwash (**see Impact Level 3**) Channel Incision (**see Impact Level 4**)	?

Coastal Change Hazard Scale

Impact Level 1: Swash Regime

Impact Level 1

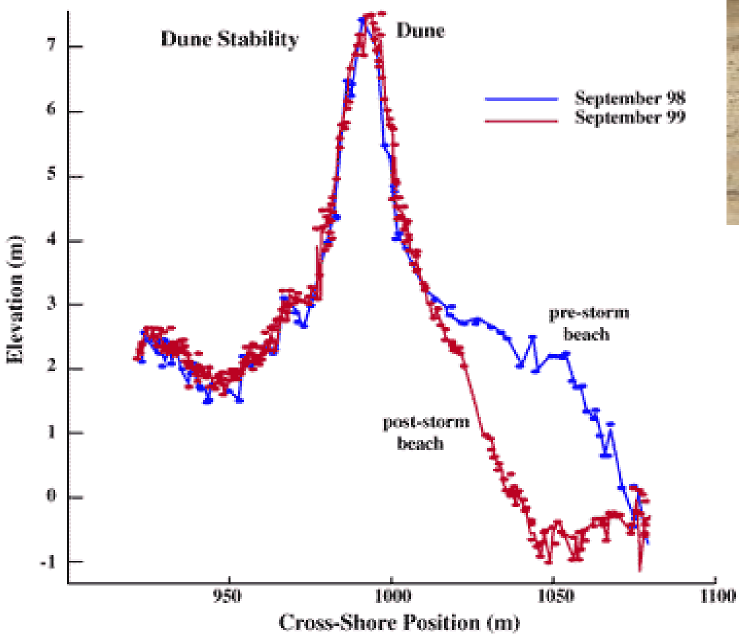


No Net Change to the System

Swash Regime:
During a storm, if wave runup is confined to the beach, the beach will typically erode and the sand will be stored offshore. However, over weeks to months following the storm, the sand naturally returns to the beach, restoring the beach to its original configuration.

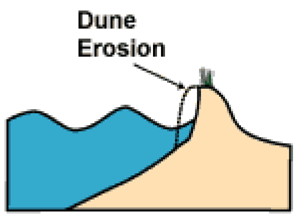
Minimal Impacts of the Swash Regime

During Hurricane Dennis, at this location, wave runup was confined to the beach. The beach eroded but the dune was untouched (see photo at right and compared cross-section below). Most of the eroded sand returned to the beach over weeks to months.



Impact Level 2: Collision Regime

Impact Level 2



Net Dune Erosion

Collision Regime:

If wave runup exceeds the elevation of the base of the dune, the runup will collide with the dune causing erosion and dune retreat. Unlike the temporary changes of Level 1, this change is considered a net, or (semi-) permanent, change to the dune.

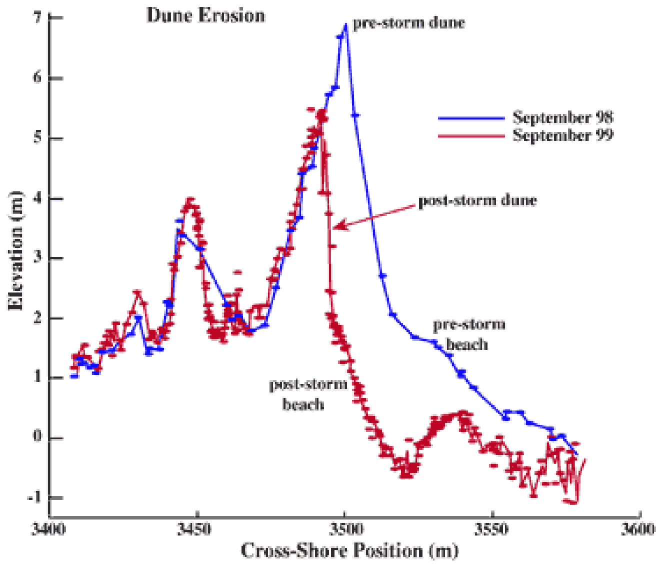
Before: July 1996, Hurricane Fran, Topsail Island, NC

After: September 1996, Hurricane Fran, Topsail Island, NC

Dune Erosion During the Collision Regime

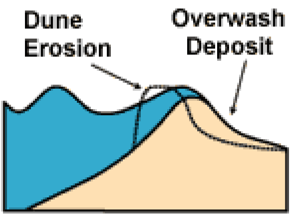
Above is a pair of before and after Hurricane Fran photographs show that the system was in Collision Regime, with significant dune retreat. At below is a result of dune retreat during Hurricane Dennis. A dune walkover, constructed of wood, was destroyed. The dune does not recover nearly as rapidly as the beach.

Below are cross-sections of lidar data showing dune retreat of 20 meters during Hurricane Dennis.



Impact Level 3: Overwash Regime

Impact Level 3



Net Onshore Transport, Order 100 meters

Overwash Regime:

If wave runup exceeds the elevation of the dune, or in the absence of a dune, the beach berm, the system will be overtopped, transporting sand landward. This is a net change contributing to the migration of the barrier island landward.

Impacts of the Overwash Regime

Below are overwash deposits near Rodanthe, North Carolina, after Hurricane Dennis. The sand was transported landward by wave runup overtopping the dune. In both photographs at right, wave runup overtopped the highest part of the system during a storm, resulting in net sand transport landward forming overwash fans.

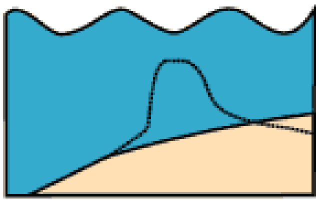
September 1999, Hurricane Dennis, Rodanthe, NC

Above: September 1999, Hurricane Dennis, Core Banks, NC

Below: February 1998, Northeaster, Assateague Island, VA

Impact Level 4: Inundation Regime

Impact Level 4



Net Onshore Transport, Order 1,000 meters.

Inundation Regime:

If the storm surge is high and the elevation of the barrier island is low, the barrier can become completely subaqueous. Sand is transported landward over the island an order of magnitude farther than typical overwash of Level 3.

Catastrophic Impacts of the Inundation Regime

During Hurricane Andrew, the Isle Dernieres in Louisiana were completely submerged. In places the beaches were entirely removed leaving only marsh remnants behind (see left photo pair below). Elsewhere, sand was transported landward on the order of a kilometer (see right pair below).

Before: July 1992, Hurricane Andrew, Isle Dernieres, LA

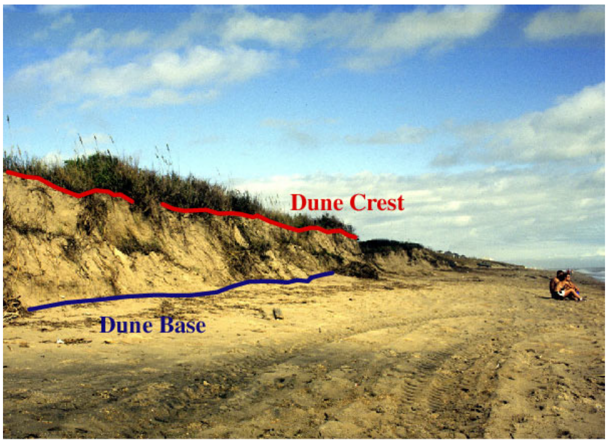
After: August 1992, Hurricane Andrew, Isle Dernieres, LA

Before: July 1992, Hurricane Andrew, Isle Dernieres, LA

After: August 1992, Hurricane Andrew, Isle Dernieres, LA

Elevations of the 'First Line of Defense' - South Atlantic U.S. Coast

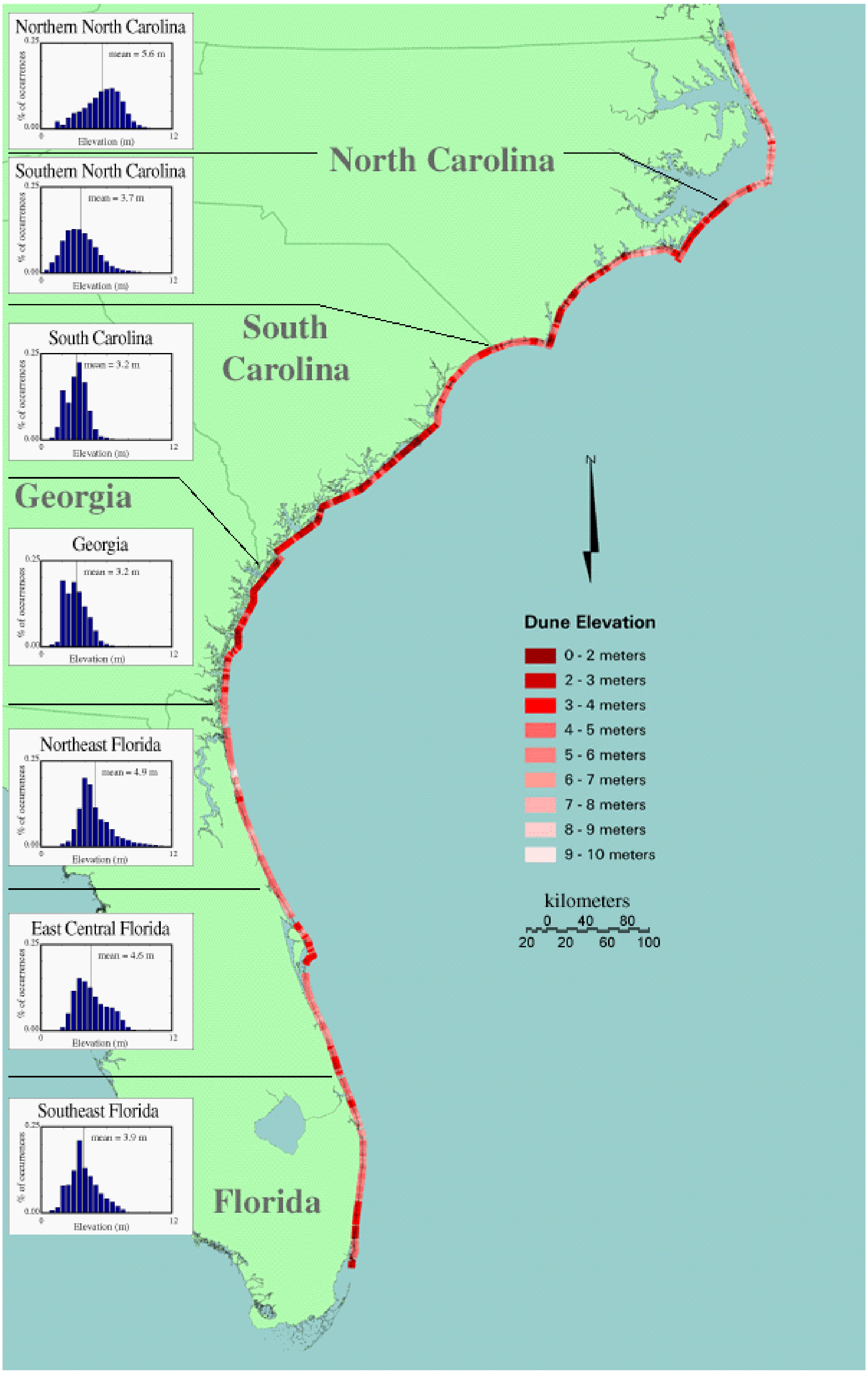
The map below illustrates the elevations of the 'first line of defense' of the beach system, either the first dune ridge or, in the absence of a dune, the beach berm. (For areas where dunes are absent and there are seawalls, or other shore-parallel coastal defense structures, the top of the structure becomes the 'first line of defense.')



The **dune crest** (or in its absence, the beach berm) is the 'first line of defense.

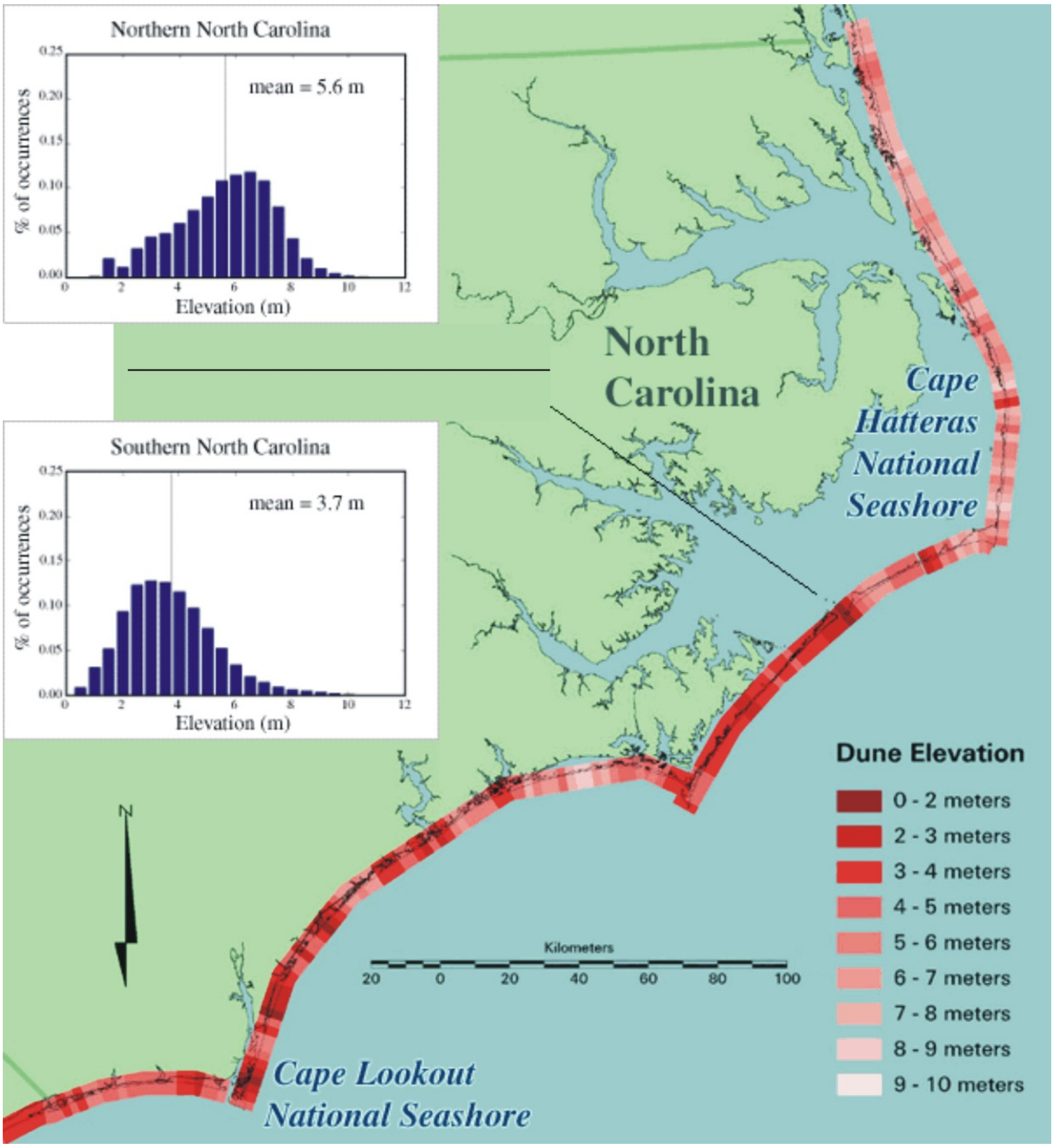
The map illustrates the relative vulnerability of the South Atlantic coast to change for a storm of the same wave runup elevation on the beach, hitting the coast at approximately mid-tide level. For example, darker red shades on the strip along the shoreline indicate low elevations and relatively high vulnerability to overwash and inundation. Lighter red shades indicate high, well-developed dunes and relatively low vulnerability to overtopping and to net coastal change. (See Hazards Scale for more background.)

Coastal 'First Line of Defense' Elevations



'First Line of Defense' - North Carolina

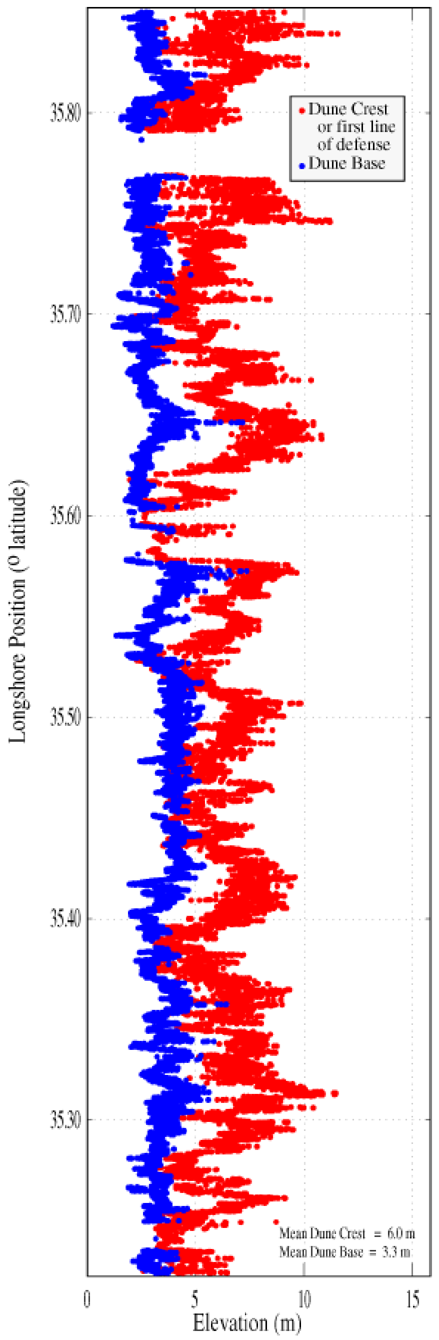
Below is a map of dune elevation for coastal North Carolina. On the left side of the map are histograms showing the distribution of these 'first line of defense' elevations, one for northern North Carolina and one for southern North Carolina.

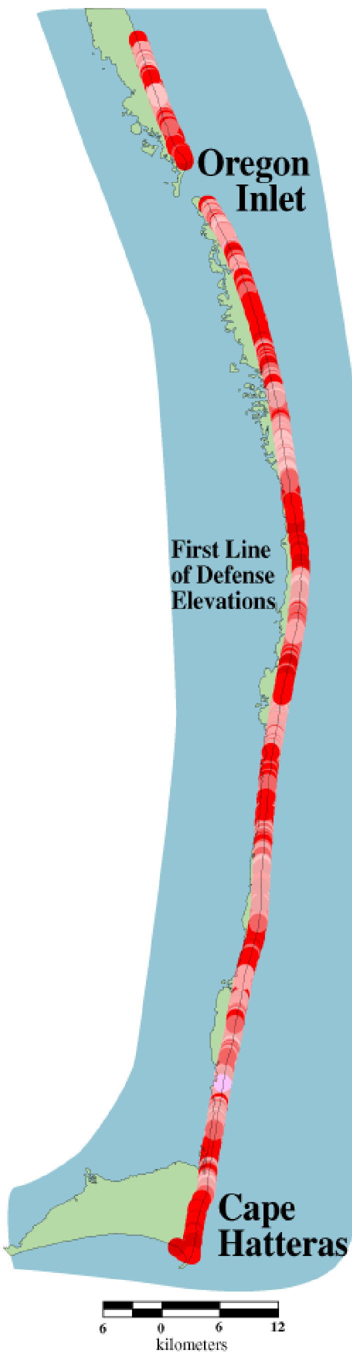


Below is additional detail for the Cape Hatteras National Seashore.

Storm Vulnerability at Cape Hatteras National Seashore

Below at left is a graph of the elevations of the dune crest and the dune base along Cape Hatteras National Seashore. The gap in data near the top of the graph corresponds with the position of Oregon Inlet. Note the spatial variability along the coast. Lower first line of defense elevations (red) are vulnerable to overwash and inundation regimes. Coasts with lower dune base elevations (blue) are vulnerable to the collision regime and dune retreat. The dune elevation map to the right of the graph covers the same stretch of the Cape Hatteras National Seashore and the vertical scale of dune elevation corresponds to the above map.





'First Line of Defense' - Determining Coastal Vulnerability

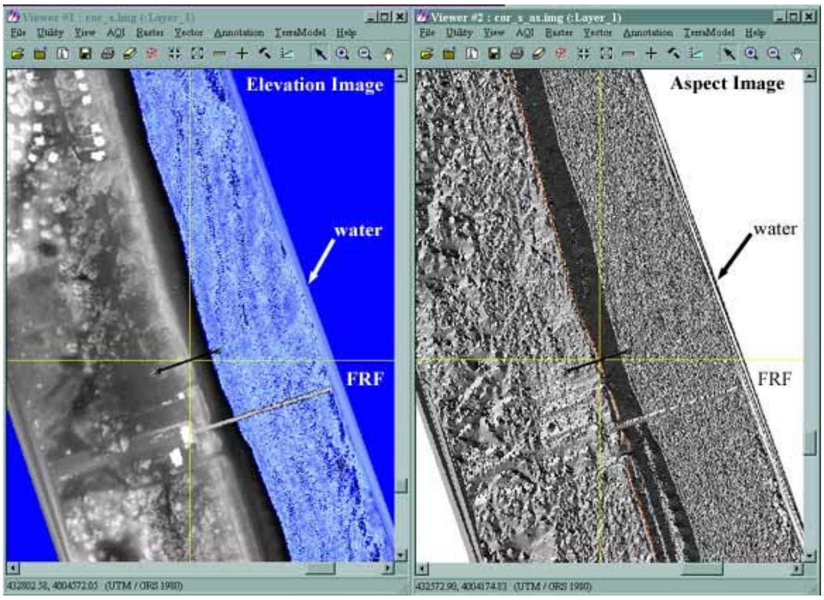
The vulnerability of a barrier island to storm overwash and inundation is determined, in part, by the elevation of the 'first line of defense', i.e. the foredune ridge, or if a dune is not present, the beach berm. The vulnerability of a barrier to the collision regime, and related dune erosion, is determined, in part, by the dune base elevation. These parameters are found from slope and aspect images of gridded lidar data.

The two photographs above were taken at the Army Corps of Engineers Field Research Facility (FRF) at Duck, North Carolina. The arrow in the oblique airphoto at left shows the location of the ground-level photo at right.

Dune Crest or First Line of Defense

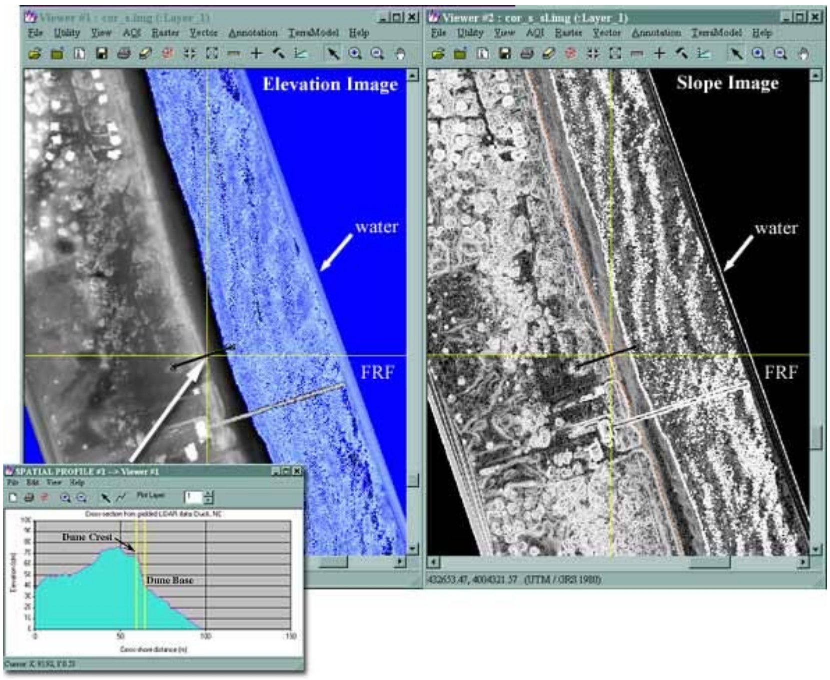
ELEVATION IMAGE: (below left) high elevations in white (houses); low elevations in black (beach); water is blue.

ASPECT IMAGE: (below right) direction of slope, where black slopes toward ocean, and gray slopes toward land. The contrast between the two highlights the dune crest.



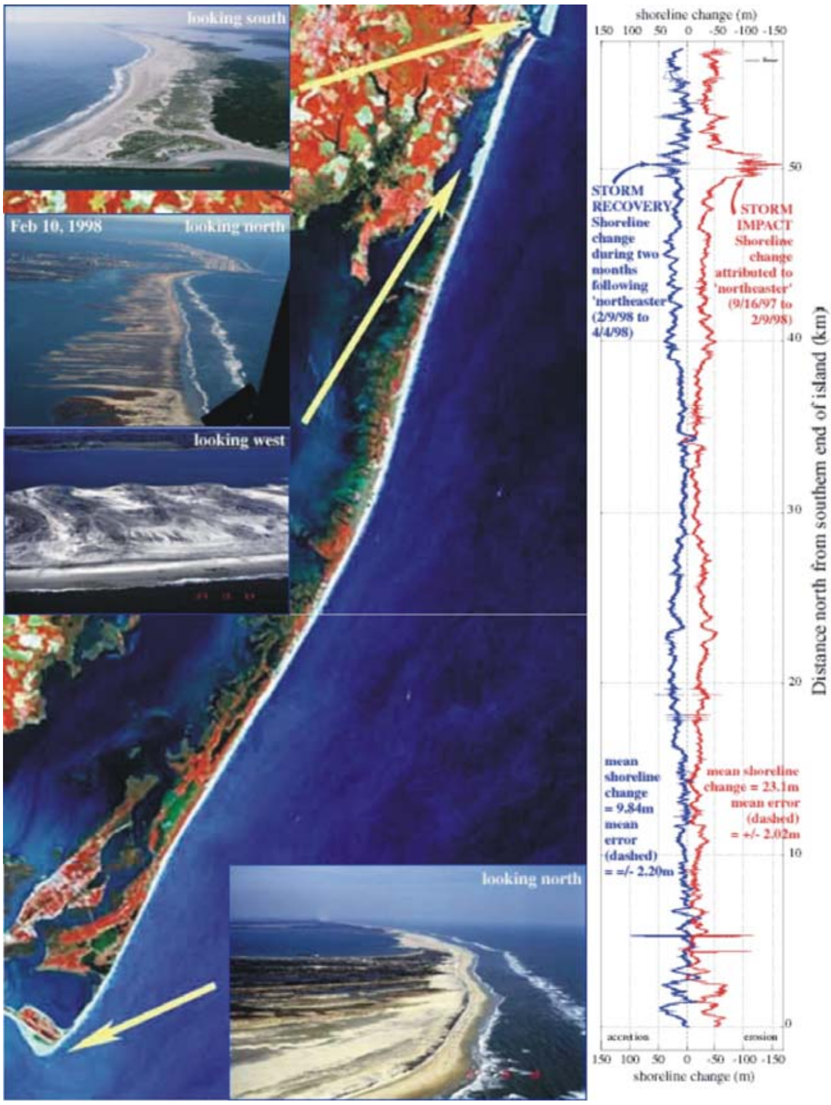
ELEVATION IMAGE: (below left) high elevations in white (houses); low elevations in black (beach); water is blue.

SLOPE IMAGE: (below right) magnitude of slope where black = flat slope (beach), and white = steep slope (seaward flank of dune). The contrast between the two highlights the dune base.



Major Northeaster, 1998: Assateague Island National Seashore

In February 1998, a major winter storm, or 'northeaster', severely impacted Assateague Island National Seashore. Offshore significant wave heights were approximately 7 meters. Impacts along the island were highly variable and suggested the occurrence of Impact Levels 2-4. Below left is an infrared satellite photograph of the Assateague Island National Seashore, including oblique aerial photographs from selected locations along the shore. Click on any of the photographs to view a larger, captioned version. To the right of the satellite image and the photographs is the lidar Storm Impact/Recovery graph. The graph has been aligned with the satellite image of the island for location reference. In places, the shoreline eroded over 80 meters (red line). However, the amount of change varied greatly along the coast. Within several months the shoreline had substantially recovered (blue line). A major research objective is to determine what causes this spatial variability along the coast.

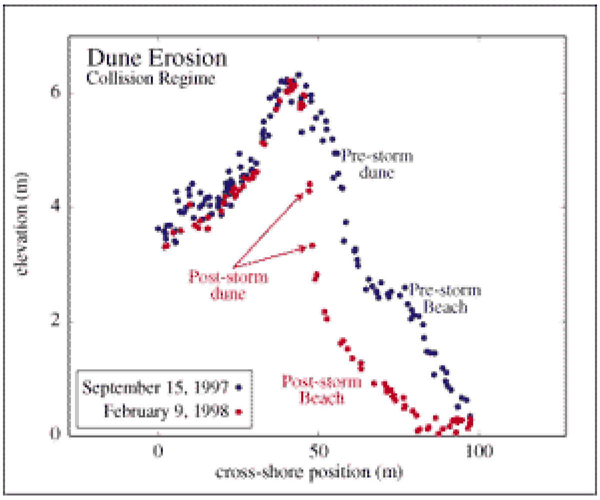


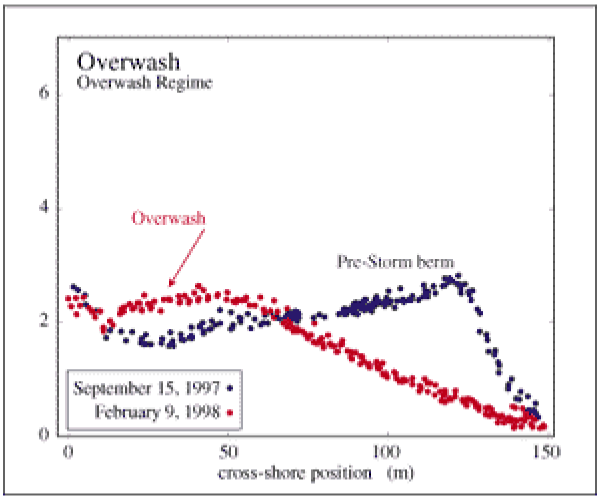
Major Northeaster, 1998: Assateague Island National Seashore - North End

Looking south from the northern tip of Assateague Island. There is severe long-term erosion related to the jetty (linear feature visible near bottom of photograph).

Major Northeaster, 1998: Assateague Island National Seashore - Lidar Cross-Sections

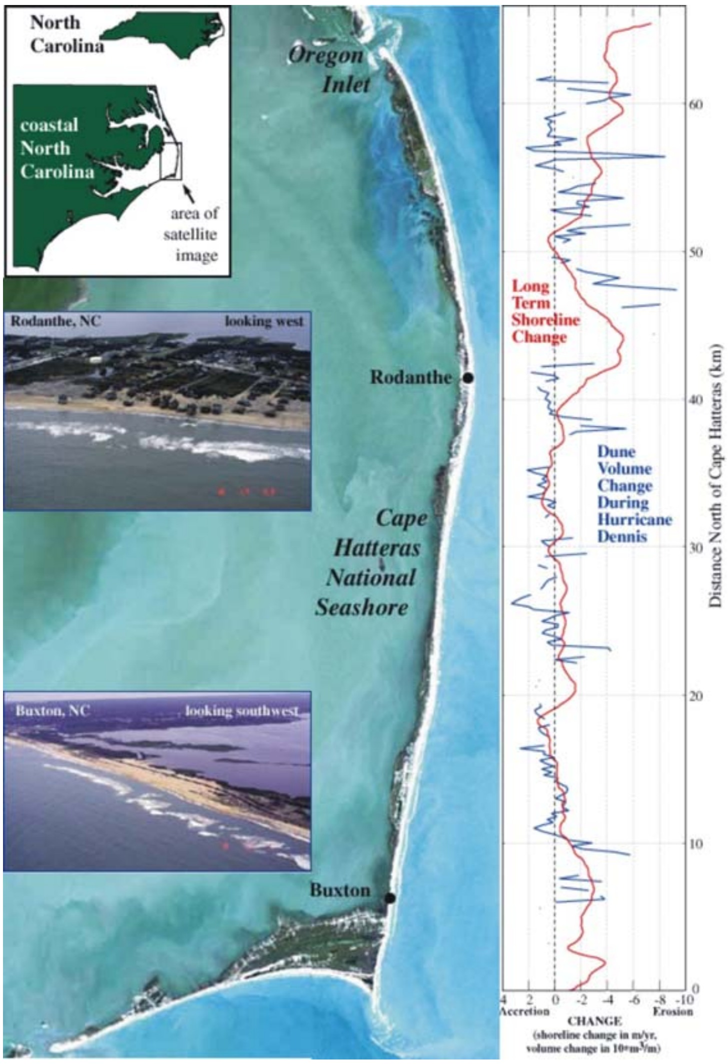
Example lidar cross-sections showing classic Collision Regime (Impact Level 2) and associated dune retreat (below left), and Overwash Regime (Impact Level 3) (below right).





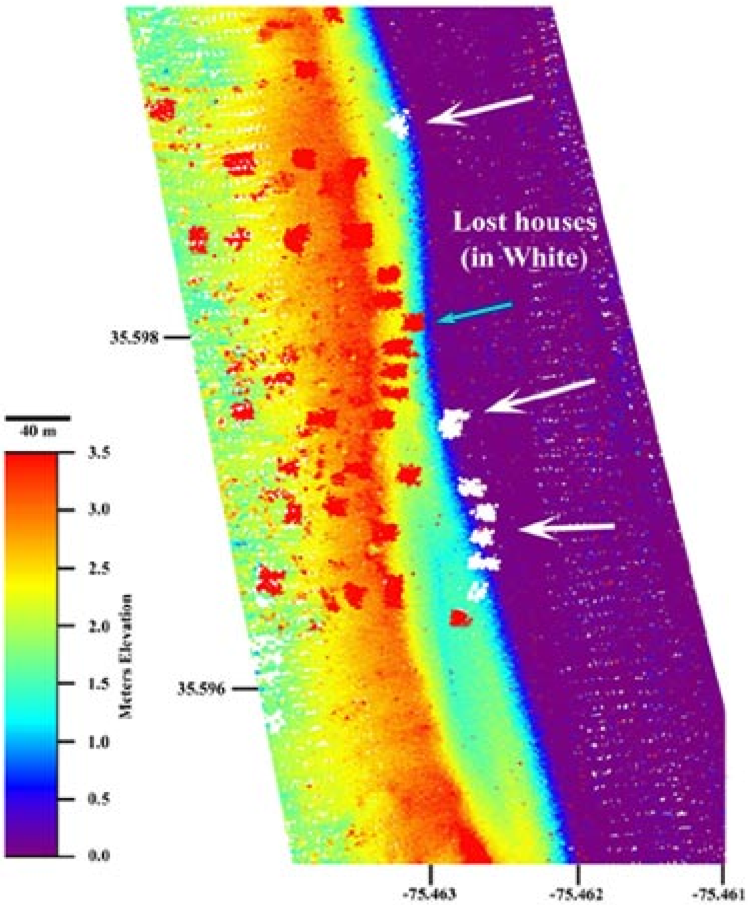
Hurricane Dennis, 1999: North Carolina Outer Banks

Hurricane Dennis meandered off the coast of the northern Outer Banks for nearly a week generating large waves that pounded the coast. The response of the coast was highly variable: some areas eroded extensively while others were virtually untouched. A major research objective is to quantify this spatial variability. Below left is a satellite photograph of the Cape Hatteras National Seashore, including oblique aerial photographs from the towns of Rodanthe and Buxton. Click on either of the photographs for more information about the impact of Hurricane Dennis at that location. To the right of the satellite image and the photographs is a graph of shoreline change. The graph has been aligned with the satellite image of the island for location reference. Dune erosion was highly variable along the coast with hot spots at about 10 kilometer intervals (blue lines). Also shown are the long term rates of shoreline change determined by the state of North Carolina (red line).



Hurricane Dennis, 1999: North Carolina Outer Banks - Rodanthe, NC

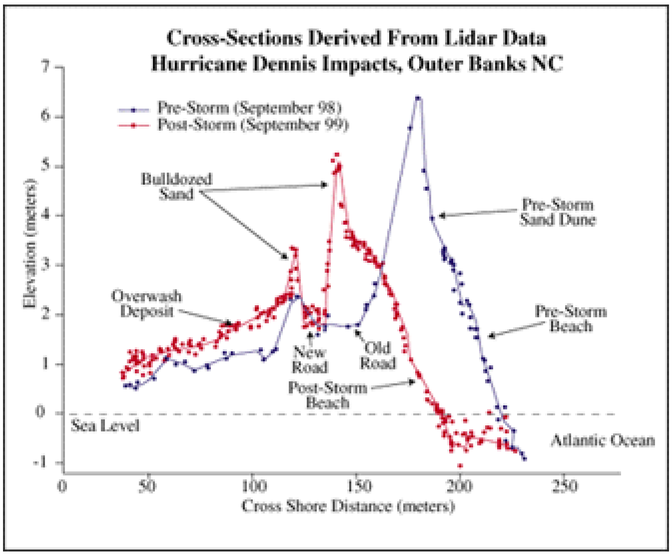
Below at left is a map of lidar-mapped topography near Rodanthe, NC, after Hurricane Dennis. The purple is water; hot colors indicate higher elevations (see scale). Note red rectangles which represent houses that survived the storm. The white rectangles are houses destroyed during the storm, found by comparing the pre- and post-storm lidar surveys. The photographs to the right of the lidar map both show the same house (blue arrow) viewed from the ground and from the air. The position of this house is also noted (blue arrow) on the lidar topographic map. Click on either of the photographs to view a larger version.



Hurricane Dennis, 1999: North Carolina Outer Banks - Buxton, NC

Below at left is a cross-section graph showing the pre- and post-storm configuration of the beach. During the storm, the dune was completely destroyed and sand was deposited landward by overwash. After the storm, bulldozers excavated a new road bed and pushed up a new protective dune.

To the right of the graph are two photographs showing where overwash destroyed NC Highway 12 during Hurricane Dennis. Asphalt for a new road was being laid several days after the storm as the photo was taken. Click on either of the photographs to view a larger version.

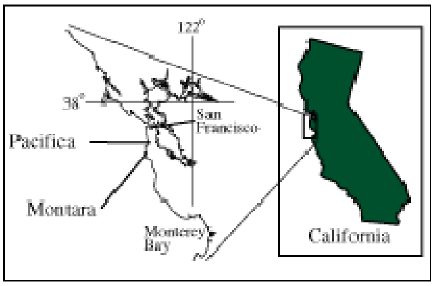


El Niño Storms, 1997-1998: Central California

Historically, the net longshore sand transport direction along the central California coast has been to the south driven by winter swell waves. In contrast, during the El Niño winter of 1997-98, sand was transported from south to north and accumulated on the south sides of headlands bordering pocket beaches (see examples from Montara State Beach). This redistribution of beach sand resulted in significant beach erosion at the south ends of pocket beaches where sea cliffs were preferentially exposed to wave attack and eroded as much as 14 meters (see examples from Pacifica).

Montara State Beach

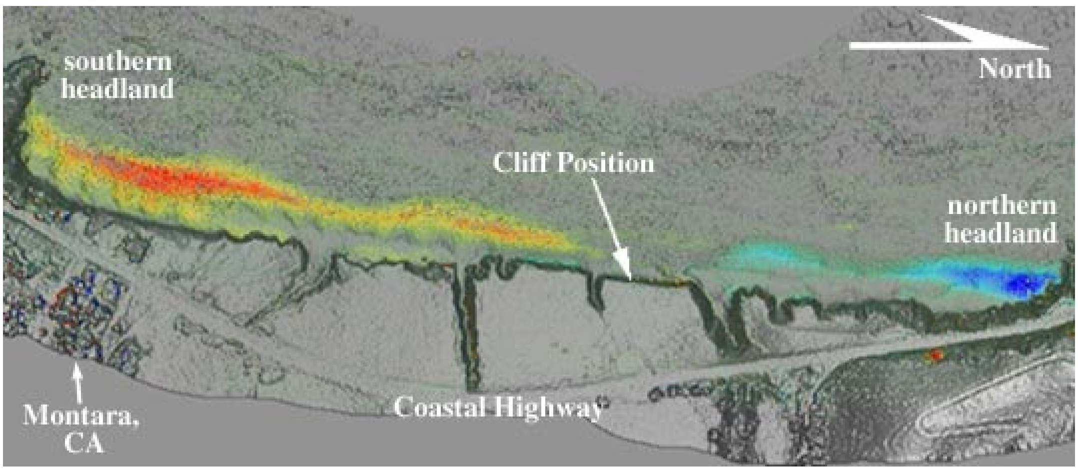
Left: Looking north along Montara Beach; note the headland in the distance. Photo taken from headland in the south. Click photo to view larger version.

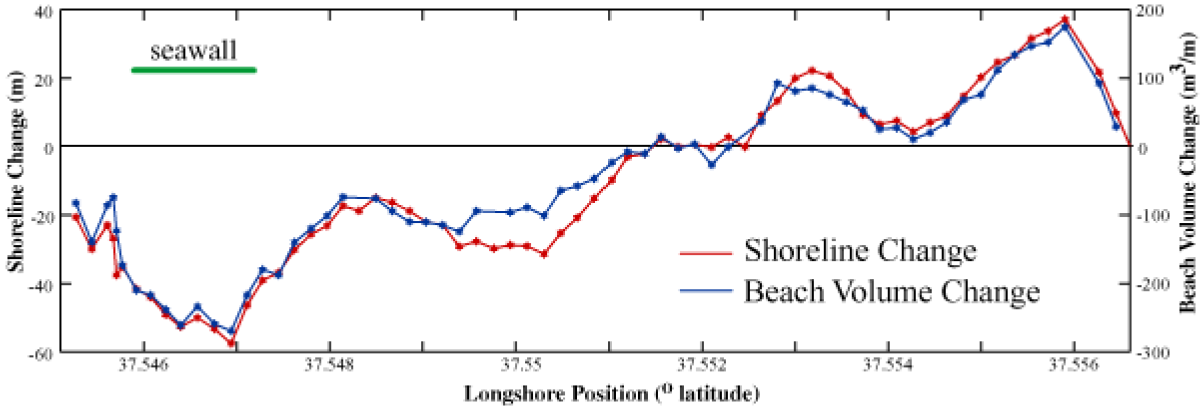


Above: Map of central California showing the locations of **Montara** and **Pacifica**.

Below is a shaded-relief map, derived from lidar data, of the Montara, California area. Shown in color are beach changes that occurred between October 1997 and April 1998, the El Niño winter. Vertical beach erosion is shown in red; vertical beach accretion is shown in blue. It can be seen that during this period of large storms, sand was transported from south to north along the beach.

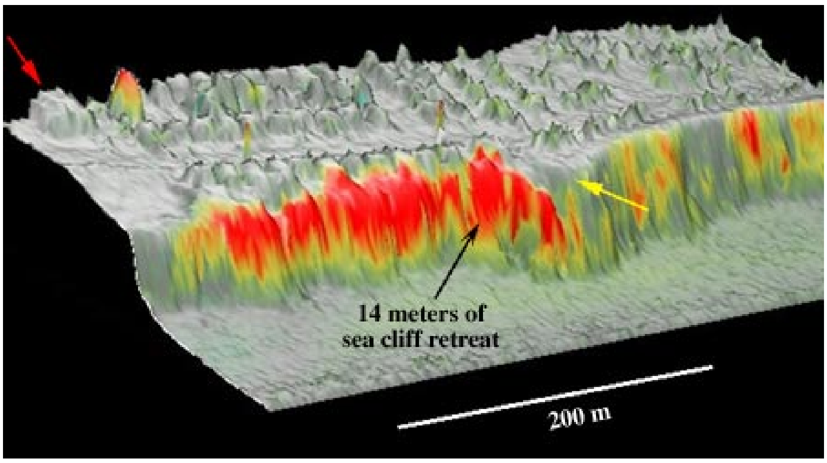
Beneath the shaded-relief map is a graph of shoreline change vs. beach volume change, aligned for comparison with the shaded-relief map. The shoreline along Montara State Beach eroded nearly 60 meters in the south, while accreting nearly 40 meters in the north, during the El Niño Winter.





Pacifica

Left: Looking north along Pacifica; photo taken from headland in the south. Click photo to view larger version.



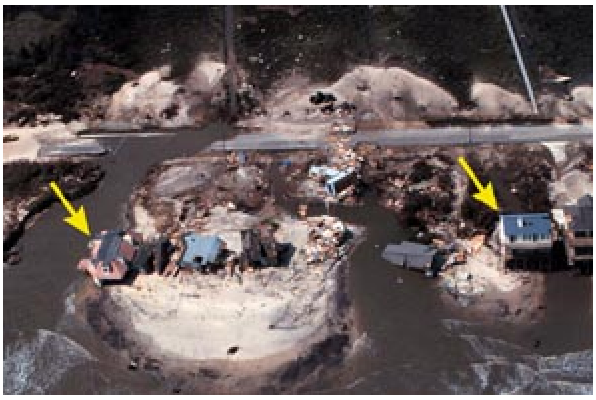
Left is an oblique airphoto of Pacifica. The cliffside photo above was taken from the subtle headland noted by the yellow arrow. Left beneath the airphoto is a three-dimensional view (derived from lidar data) of the Pacifica area. Draped on the 3-D plot are colors that indicate erosion (red) and accretion (blue). The maximum erosional area represents 14 meters of horizontal sea cliff retreat. The red arrow denotes the location of the same building in the airphoto and on the 3-D plot. The yellow arrow shows the location of the cliffside photo.

Coastal Change Photographs - Topsail Island, NC

Below are oblique aerial photographs taken on Topsail Island, North Carolina before and after Hurricane Fran in 1996. The yellow arrows point out the same buildings in both photos. Note the destroyed buildings, the overwash, and the damaged road in the post-storm photo on the right. Click on either photo to view a larger version.

Before: July, 1996

After: September, 1996



Below are oblique aerial photographs taken on Topsail Island, North Carolina before and after Hurricane Fran in 1996. The yellow arrow points out the same building in both photos. Note the prominent overwash and the damaged road in the post-storm photo on the right. Click on either photo to view a larger version.

Before: July, 1996

After: September, 1996

Sediment Grain Size Analysis

for

Training Course of Capacity Building on Coastal Geological Survey

(UNDP National Project 00044540, ROK/05/003)

November, 2005

J. H. Chang

KIGAM

I mainly referred to six books below, to prepare materials for this training course, Capacity Building on Coastal Geological Survey (UNDP National Project 00044540, ROK/05/003)

Allen, J. R. L., 1985, Principles of physical sedimentology, George Allen & Unwin, Boston, Sydney, 272pp.

Carver, R. E., ed., 1971, Procedures in sedimentary petrology, Wiley-Interscience, A division of John Wiley & Sons, Inc., New York, London, Sydeney, Toronto, 653pp.

Folk, R. L.,1968, Petrology of sedimentary rock. Austin, Tex.; Hemphill.

Lewis, D. W.,1984, Practical Sedimentology. Hutchinson Ross Publishing Co. Stroudsburg, Pennsylvania, 229pp.

Lindholm, Roy C., 1987, A practical Approach to Sedimentology, Allen & Unwin, Boston, Sydney, Wellington, 276pp

Syvitsky, J. P. M., ed., 1991, Principles, methods, and Application of particle size analysis, Cambridge University Press, Cambridge, New York, port Chester, Melbourne, Sydney, 368pp.

Chapter 1.

What do we study about individual sediment grain ?

1. Grain Morphology

Shape (form and sphericity)

Roundness

Surface features

2. Grain Mineralogy

(matter of grain density)

Light mineral

Heavy mineral

Clay mineral

Rock fragment

Bioclastics

3. Grain Size

Among the properties mentioned above, grain shape, density (mineralogy), and size are the most important factor to affect the settling velocity of the particles during size analysis by sedimentation method.

1. Grain Shape (Form and Sphericity)

Under the broad term "particle morphology" are included at least three concepts. These are (1) shape (form and sphericity), (2) roundness, (3) surface features. But the particle characteristics which affect the size measurement is density and shape. The grain shape, and density of sedimentary particles are casually linked by the action of weathering and transportation on the crystallographic properties of minerals and the conditions of their crystallization.

Geological meaning: Form and Sphericity are mainly the result of two factor: (1) internal anisotropism (the result of bedding, schistosity or cleavage in most cases, but directional hardness may possibly be important in case of quartz or kyanite), and (2) original shape of the particle (such as joint blocks, or platy quartz grains from schist. This is modified to some extent by abrasion.

Grain size analysis by settling techniques depends on knowing the relationship between falling velocity and size that is appropriate for the particle of interest. For the simplicity, we assumed a spheric particles falling through fluid for the settling equation, but all of the sediments particles are not spherical grains. Then for the mineral particles of the same density it is intuitively understood that larger particles will fall faster than smaller ones. In actuality, the shape of a particle affect its settling velocity.

1) Form is a measure of the relation between the three dimensions of an object, and thus particles may be classed quantitatively as compact (or equidimensional), elongated (or rodlike) and platy (or disclike), with several intermediate categories, by plotting the dimensions on a triangular graph (Sneed and Folk, 1958). A rod settles faster than a disk of the same volume.

2) Sphericity is a measure of quantitatively how nearly equal the axial dimensions of a particle are. True sphericity is the surface area of a grain divided into the surface of a sphere of the same volume - a rather impractical property to measure !

$$\text{True Sphericity (Wadell, 1935)} = \sqrt[3]{\frac{Vp}{Vcs}}$$

where Vp = volume of particle and Vcs = volume of circumscribing sphere (smallest sphere that would enclose the particle).

This formular can not exact indicates of the behavior of the particle during falling down because particles tend to settle with maximum projection area (the plan of long and intermediate axes) perpendicular to the direction of motion and hence resisting the movement of the particle. Then Sneed and Folk, 1958) suggested "Projection Sphericity, given by the formular as follow;

$$\text{Projection Sphericity, } \Psi_p = \sqrt[3]{\frac{IS}{L^2}}$$

where L= long axis, I = intermediate axis, and S = short axis.

In "Sphericity-Form diagram for particle shape" of Fig. 1-1 we can recognize the relationships between form and sphericity of particle.

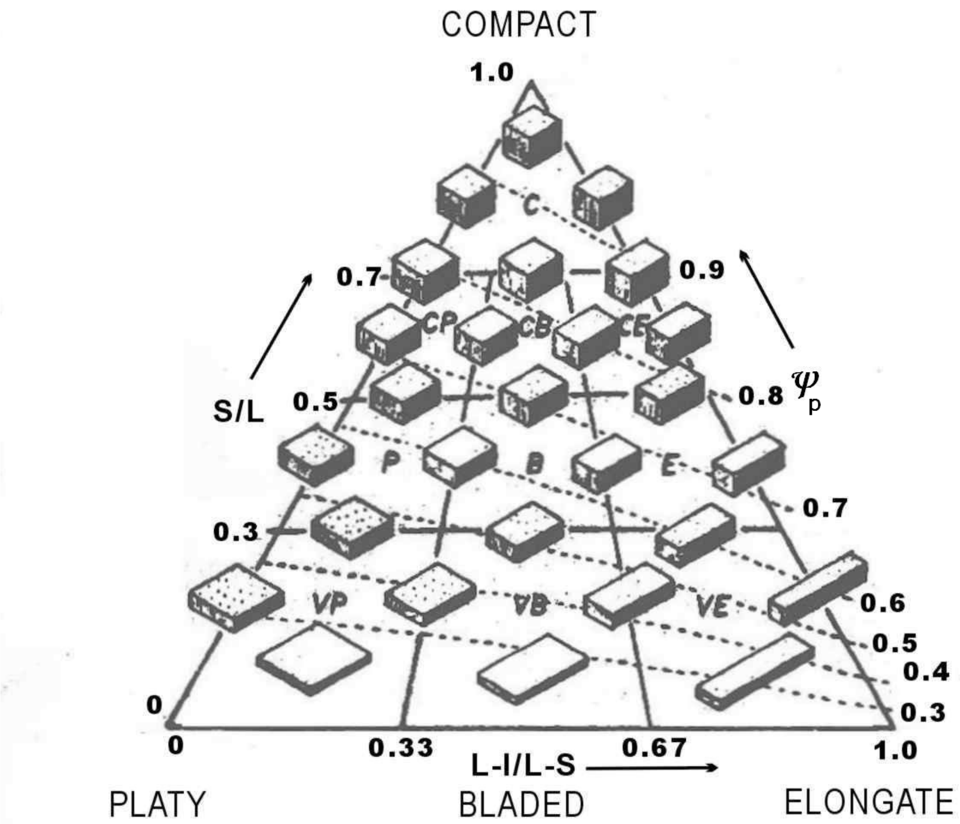


Fig. 1-1. Sphericity-Form diagram for particle shape after Sneed and Folk (1958). Shapes of particles falling at various points on the triangle are illustrated by a series of blocks with axis of the correct ratio; all blocks have the same volume. Independence of the concepts of sphericity and form may be demonstrated by following an isosphericity contour from the disklike extreme at the left to the rodlike extreme at the right. L=long axis, I=intermediate axis, S=short axis, ψ_p = projection sphericity (dotted line curves represent grains of the same effective settling sphericity, $\sqrt[3]{\frac{S^2}{LI}}$).

<Terminology>

Sieve diameter : is defined as the width of a sieve opening through which the particle will just pass.

Hydraulic diameter : the diameter of a quartz sphere with a settling velocity equal to that of the particle of interest

Sedimentation diameter : the diameter of a sphere of the same specific gravity and the same settling velocity, in the same fluid, as the particle of interest.

2. Density, or Mineralogy

The effect of particle density on grain size analysis is important for the dry sieving method for sand that directly involve measure of sample weight. For example, Heavy minerals tend to be found preferentially in the finer sieve classes (Rubey, 1933). Since sieving yields quasi-three-dimensional size, this causes a density-related bias in sieve size distributions, artificially shifting the population toward the finer sizes, although the effect is generally small.

The effect of density on settling is more complicated. When the density of the particle is known and is entered into the appropriate settling equation, the observed settling velocity may be used to calculate the sedimentation diameter of the particle. But a sediment sample is composed of mixture of particles of differing densities. This variability necessitates the assumption of a particular density for the bulk population. The value of quartz (2.65 g/cm^3) is generally chosen. Spheres of a given physical size whose densities are lower than quartz will have lower terminal velocities than a quartz sphere of equal size. This low velocity will then be converted into a hydraulic diameter less than the physical diameter of the spherical particle. Similarly, spherical particles denser than quartz will have hydraulic diameter greater than their physical size.

3. Grain size

The size distributions of detrital sediments have been most widely and intensively studied to provide data for interpreting geological history. It is a fundamental descriptive measure of sediment. It is also important in understanding the mechanisms operative during transportation and deposition, as well as the distance of sediment transport.

1) Grain-size classification

a) Size grades

Sediment particle size is measured in metric units. Size grades (grade = sizes intermediate between two defined points on size scale) based on a geometric scale in which class limits increase from a base of 1 mm by a factor of 2 or decrease by factor of 0.5. The size grades most commonly used by geologists were devised by J. A. Udden and modified by C. K. Wentforth (1922). It is commonly known as the "Udden-Wentforth Grade Scale" (Fig. 1-2).

b) ϕ notation

Krumbein (1934) devised the phi (ϕ) scale as a logarithmic transformation of the Wentworth scale (Fig. 1-2). He proposed that grain size should be expressed as phi (ϕ), which is the negative logarithm to the base 2 of the particle diameter in millimeters, and modern data are nearly always stated in ϕ terms because calculation of grain size parameters (e.g. mean size, standard deviation, and skewness) are much simplified.

$$\text{phi } (\phi) = -\log_2 D$$

where D is grain size in millimeters.

For example, the value of low boundary of very fine sand is 0.0625 mm and this will be notate as 4 ϕ as follows;

$$\text{phi } (\phi) = -\log_2 2^{-4} = (-)(-4)(-\log_2 2) = 4$$

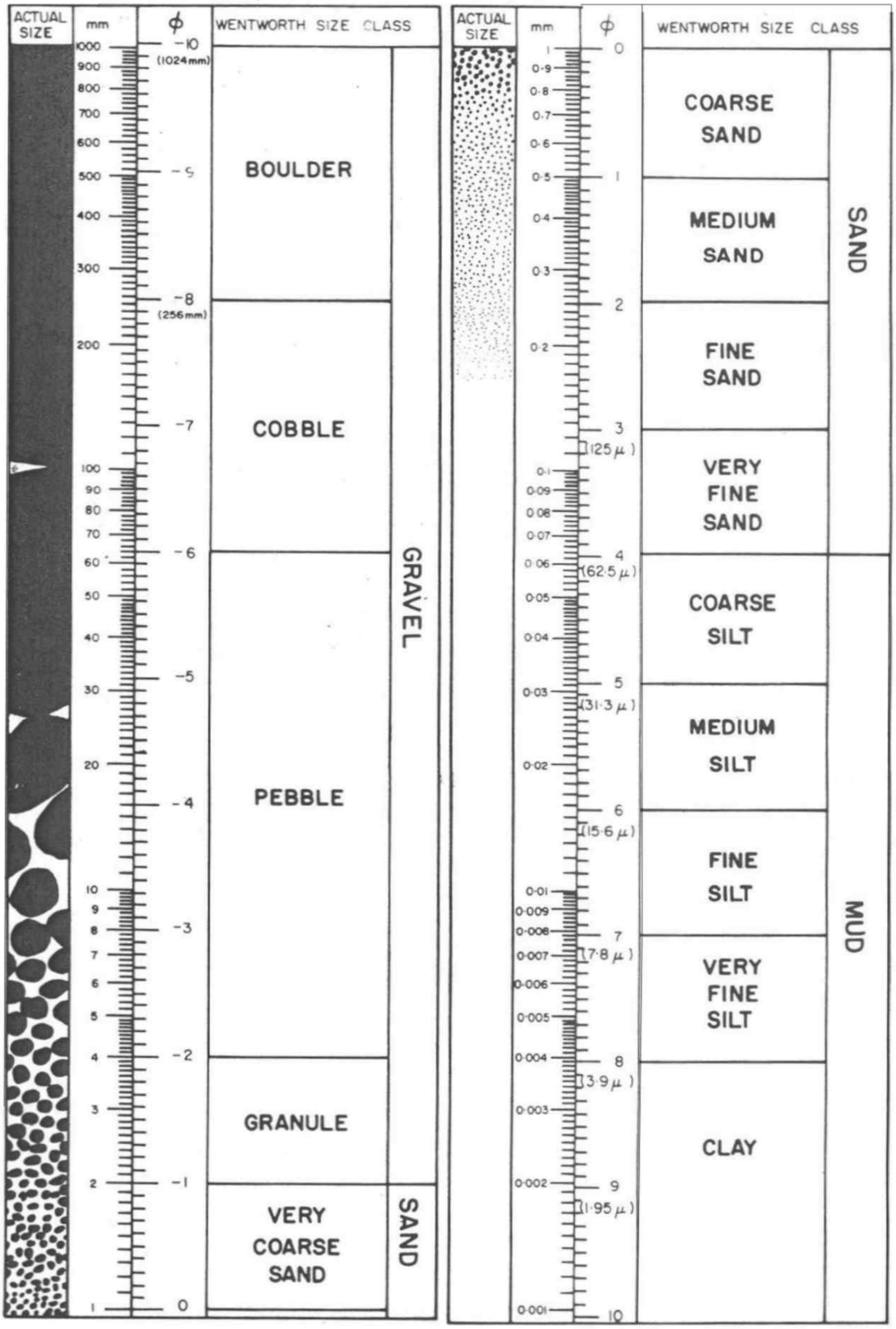


Fig. 1-2. Udden-Wentworth grain-size scale and ϕ / mm conversion chart.

c) Grain size nomenclature for sediments

With the results of grain size analysis, we can classified the sediments type in the base of classification system. One of most widely used is that proposed by Folk (1954, 1980) which utilizes two ternary diagrams, each with three end-member classes (Fig. 1-3; 1-4).

* Ternary diagram for gravel-bearing sediments

The proportion of gravel is in part of a function of the highest current velocity at the time of deposition, also together with the maximum grain size of the detritus that is available; hence even a minute amount of gravel is highly significant. For this reason the gravel content is given major emphasis, and is the first thing to determine in describing the sample.

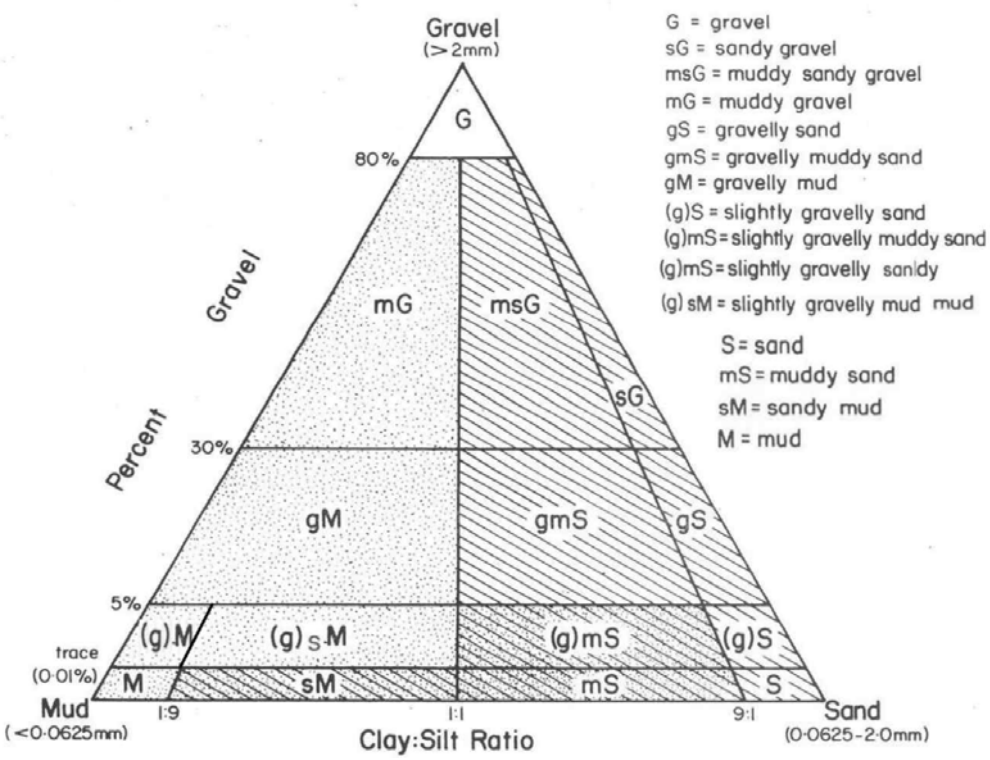


Fig. 1-3 Textural terminology for gravel-bearing detrital sediments. (After Folk, 1980)

To place a sample in one of fifteen major groups, only two properties need to be determined: (1) how much gravel (grain coarser than 2 mm, or -1 ϕ) it contains - boundaries at 80, 30, 5 percent, and a trace; and (2) the ratio of sand and mud (silt plus clay) with boundaries at 9:1, 1:1, and 1:9 (Fig. 1-3).

* Ternary diagram for gravel-free sediment

If the sample do not contain the gravels, then it is also plotted on a gravel-free ternary diagram (Fig. 1-4) according to the proportions of sand (2.0 - 0.0625 mm, or -1ϕ to 4ϕ), silt (0.0625 - 0.0039 mm, or 4ϕ to 8ϕ), and clay (less than 0.0039 mm, or finer than 8ϕ). The thee end-member is then 100% sand, 100% silt, and 100% clay, respectively.

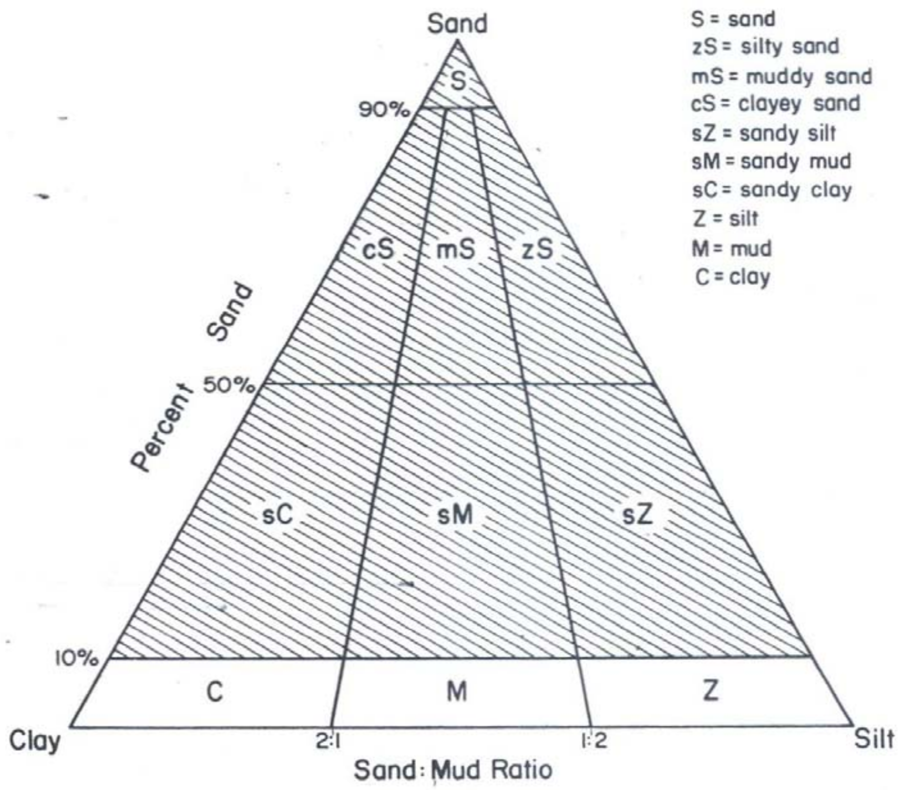


Fig. 1-4. Textural terminology for gravel-free detrital sediments. (After Folk, 1970)

The procedure for determining the sediment type is simple also. First determine the percentage of sand in the sample. Four categories are represented by tiers (horizontal line) on ternary diagram: more than 90%, 50 - 90%, 10 - 50%, and less than 10% sand. Next determine the ratio of silt to clay. Boundaries at 2 : 1 and 1 : 2 silt to clay subdivided each of the three lower tiers of the diagram into three classes, but the upper tiers consists of one class only, the sand class.

Chapter 2.

How Many methods?

This chapter introduces briefly (1) various methods of grain size analysis with some instrument, and (2) the theoretical back ground of "Sieving Method" and "Pipette Method" which we are going to practice during this training course.

1. The purpose of grain size analysis

The three objectives in determining the size distribution of a sediment are (1) description, (2) comparison, and (3) interpretation. The first is to add to the overall physical description of the sediment. The second is to compare the size distribution of the sediment with others. The third is to make interpretations concerning the sedimentological history of the sediments deposit.

Particle size is a fundamental property of sedimentary materials that may tell us much about their origin, then quantitative measurement of grain size is required for precise work.

2. Summary of Particle Size Analysis Techniques

Geological materials commonly contain a wide range of particle sizes from tens of millimeters down to clay of colloidal(<1μm) size. The sedimentologists have found several classic size analysis methods of counting, sieving, and settling and these methods are still in use though many new advanced methods, Laser diffraction and Photon correlation spectroscopy, which adopt new principles.

1) Principles of Methods and some Instruments

Counting

Direct measurement : For the gravels of very large diameter was counted and measured the size with caliper.

Image analyzing : Modern counting of particles uses image analyzer. The images are obtained traditionally with transmitted light microscopy or, for smaller particles, with scanning electron microscopy. Images analyzers are designed to sense the boundaries of particles, and once the outlines of all the particles are discriminated, the particle size and shape parameters may be obtained either through line scanning, pixel counting, or outline tracing. These parameters may include minimum or maximum grain diameters, or the circular area-equivalent diameter.

More advanced instrumental methods of particle counting are dominated by the electrical sensing zone particle counter, for example Coulter Counter.

Sieving

There is no new and special principle in sieving, but automated systems for set sieving, sonic, electromagnetic, and air-jet particle agitation have been added to the standard mechanical dry sieve shaking method.

Settling of suspensions

Most of the sedimentation analysis methods are based on the variation of density.

* *Direct sensing of density (The Hydrometer)* : This method directly determines the density changing using a hydrometer.

* *The pipette method* : Sedimentation methods dominated the analysis of fine particles, and among them the very classic "pipette method" was most commonly used. It is based on the variation of suspension density at a point as a function of time.

* *Optical attenuation method* : The so-called photoextinction method actually depends on the degree of attenuation of the light beam by a suspension of particles. The attenuation is caused by absorption and scattering, and scattering function is related to particle size.

* *X-ray attenuation method (The Sedigraph)* : The Sedigraph is a particle sizer that determines the concentration of particles remaining at decreasing sedimentation depth in a suspension-filled cell.

Laser diffraction

Methods based on the scattering of light by suspensions began to be implemented in the late 1970s. The original three manufacturers - Cilas Granulometer, Malvern Particle Sizer, and Leeds & Northrup Microtrac - have recently been joined by Fritsch, Coulter, and Horiba.

Photon correlation spectroscopy method

There are very few techniques that will yield data well into the submicron range. Photon correlation spectroscopy, which depends on the Brownian motion of suspended colloidal particles, is one. This method is not appropriate for larger particles.

2) Comparison of the methods

It is extremely difficult to specify the accuracy of a measurement of size distribution when the particles are of variable irregular shape and density. To a great extent the accuracy ("approach to the true value") is depend upon the definition of the size being determined - projected area size by image analyzer, intermediate diameter size by sieve, or quartz-equivalent spherical sedimentation diameter by pipette method.

A variety of techniques may be used to analyze the size of silt and clay fractions. The precision of "Pipette Method" is high - better than 0.1 ϕ unit - but the method is time-consuming. Most modern instrumental methods are more rapid in processing than the classic "Pipette Method" but we could not say which one is more accurate or not.

It should be realized that any method of size analysis is an indirect method of measurement. So different methods will yield different results, which can not be compared directly with one another. Anyway, for the small laboratory "Sieving Method for sand" and "Pipette Method for silt and clay" is convenient and economic.

Chapter 3.

What's their theoretical Back Ground?

1. Sieving Method
2. Pipette Method

1. Principle of Sieving Method for sand

Sieving is commonly used in determining the grain size distribution of sand. For the sieving method, there is not any complicate principles but one has to remember that the grain size measured by sieving is the “sieve diameter” of intermediate axis of particle, which is defined as the width of a sieve opening through which the particle will just pass. But the grain size determined by pipetting method is "hydraulic diameter" of the particle.

2. Theoretical back ground of Pipette method for silt and clay

Pipette analysis has a sound theoretical basis. It is based on calculations of the settling velocities for particles of different size (Stokes' Law) : the general invalid assumption is made that all particles are of the same shape and density (s.g.=2.65).

1) What is Stokes' Law ?

When a sphere falls down in a stagnant fluid we can calculate its present position If we know the settling velocity of the sphere. Settling velocities used in the sedimentation analysis of silt and clay are usually computed from the now-famous settling law developed by G. G. Stokes in 1851.

Stokes' law pertains to the terminal velocity of a sphere in a fluid and explained as follows;

VRF (the viscous resistance to fall of a sphere in a fluid) = $6\pi r\mu v$

where r = radius of the sphere in cm

μ = viscosity of the fluid in dyne-sec/cm^2

v = fall velocity in cm/sec

And ***NDF*** (the net downward force on a sphere in a fluid) = the force of gravity on the sphere minus the buoyant force of the fluid ;

$$\mathrm{NDF} = \frac{3}{4}(\pi r^3 d_s g) - \frac{3}{4}(\pi r^3 d_f g)$$

where r = radius of the sphere in cm,

d_s = density of the sphere in gm/cm^3,

d_f = density of the fluid in gm/cm^3,

g = acceleration due to gravity in cm/sec^2.

However, the terminal velocity is reached when VRF = NDF,

that is, when

$$6\pi r\mu v = \frac{3}{4}(\pi r^3 d_s g) - \frac{3}{4}(\pi r^3 d_f g)$$

or when

$$v = \frac{2(d_s - d_f)gr^2}{9\mu}$$

which is Stokes' law where v is now the terminal fall velocity of the sphere. According to Stoke's law, the terminal fall velocity of a smooth spherical particle settling along in an unbounded fluid is proportional to the density difference and to the square of the diameter, but inversely proportional to the fluid viscosity.

Stokes' law as used in sedimentation analysis at a particular temperature is commonly simplified to

$$v = CD^2$$

where C is a constant equaling

$$\frac{(d_s - d_f)g}{18\mu}$$

and d_s = 2.65 gm/cm^3(the density for quartz),

d_f = the density of distilled water at the particular temperature,

g = 980 cm/sec^2,

μ = the viscosity of distilled water at the particular temperature,

and D = the diameter of the sphere in cm.

Table 3-1. C values used in calculations involving Stokes' law

Temperature in degrees centigrade	Constant Value (C)
18	8,538
19	8,756,
20	8,975
21	9,198
22	9,421
23	9,648
24	9,876
25	10,107
26	10,340
27	10,575

Attention !!!

Stokes' law cannot be applied indiscriminately to all particles settling in a fluid. In the strictest theoretical sense, it is only valid under some conditions and limitation. Among them most important are as follows;

1) Particles must have reached terminal fall velocity. For particles within size range of applicability of Stokes' law, the terminal fall velocity is reached almost instantaneously. A sphere with a diameter of 50 microns, the terminal fall velocity is reached in about 0.003 second. For smaller particles, the time is even less.

2) Particle concentration must be less than 1% by volume. If particle concentration is high, the individual particles will interfere with one another during settling. A maximum of about 25 gm of sample can be used in a 1000-ml cylinder for a pipette analysis.

3) Particles must be greater than 0.5 microns (11 phi) in diameter. Very small particles are affected by the Brownian movement of the molecules of the fluid. It is why we take 11ϕ as lower limit of the size range for pipette analysis.

4) Particles must not be greater than 50 microns in diameter. Above this limit there is turbulence during settling. However Rubey (1933) shows that observed settling velocity differs little from the theoretically determined Stokes' value up to about 140 microns. Most investigators use Stokes' law up to the lower size limit of sand 62.5 microns, realizing that there may be a slight error in the 50 - 62.5 microns fraction.

3. Withdrawal depth of the sample calculated from Stokes' law

Subsamples of a specific volume are extracted from a suspension of mud at specified times and depths; the weight of each dried subsample is representative of the proportion of the total mud fraction remaining in suspension above that specified depth at that specified time. Thus each subsample measures the proportion of total mud that is finer than the size that will have settled to the specified depth in the specified time. This concept is illustrated in Fig. 3-1.

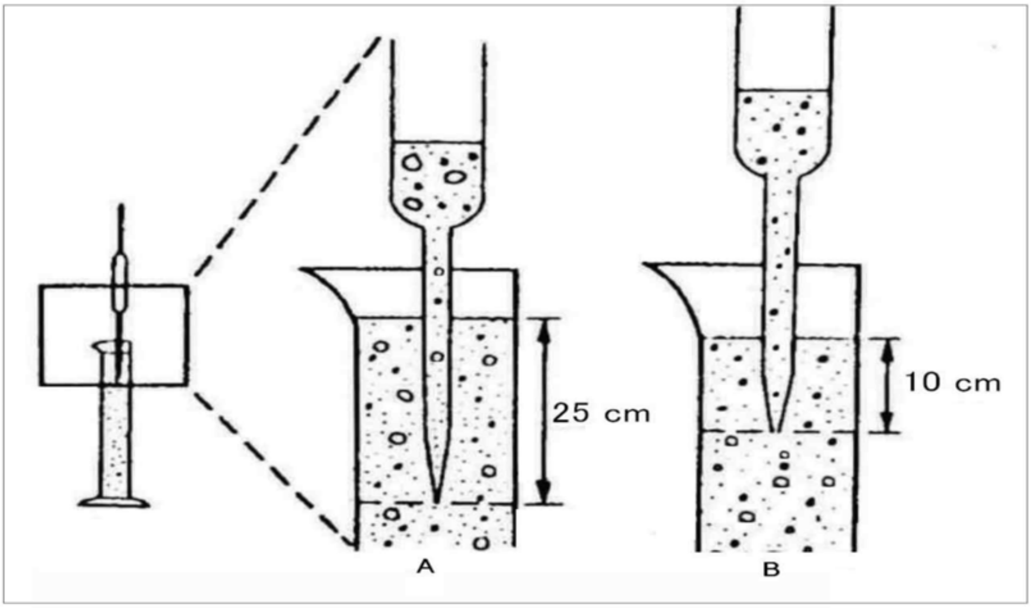


Figure 3-1. Withdrawals of sample by pipette. The first sample taken at 25 cm represents whole sample with all size range. The second after 2 minutes at 10 cm represents total amount of the sample finer than 5 ϕ.

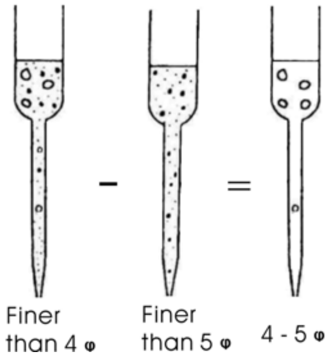
Depending on the values resulted from Stokes' law, one can calculate the depth and time of withdrawal of sample for particular particle diameter; for example 4ϕ, 5ϕ, 6ϕ, 7ϕ, 8ϕ, 9ϕ, and 10ϕ (see Table 3-2).

withdrawal number	1	2	3	4	5	6	7
Elapsed time for withdrawal of sample	**0 s**	2 m	8 m	32 m	2h 8 m	5h 58m	24 h
Grain size in ϕ Finer than	**4**	5	6	7	8	9	10
Withdrawal depth	**25 cm**	10 cm	10 cm	10 cm	10 cm	7 cm	7 cm

Table 3-2. Pipette withdrawal times calculated from Stoke's law for water at 20 ℃ and solid with a density of 2.65 (Krumbein & Pettijohn, 1961; McManus, 1988). s : second, m : minute, h : hour

The first 50-ml sample taken during a pipette analysis determines the total amount of silt and clay in 1000-ml cylinder. It is taken at such a time and depth (0 second at 25 cm) that no particular size fraction has completely settled past the sampling point. The subsequent samples, however, are taken at such a time and depth (2 minutes and 10 cm) that 4ϕ size fraction has settled past the sampling point (Fig. 3-2). In other word, the second sample will contain only particles with a sedimentation diameter finer 5.0 ϕ All the particles coarser particles will have settled past the 10 cm depth.

If we multiply the first sample weight by 20, it become total sample weight and subtract the weight of the second from the first, and multiply by 20, we can get total weight of the 4 -5 ϕ fraction.



4. Pipetting time table for 7 cylinders by one person.

In practice we have to analyze multiple samples in a time. Using the basic elapsed time table calculated from Stokes' law, we can make a economic pipetting time table as Table 3-3.

After many experiences in pipetting analysis, one person can deal 7 samples in one time with the interval of 5 minutes (Table 3-3)

Table 3-3. Withdrawal time table for 7 cylinders. From the 8th cylinder there is a time zone being piled one on another. W.=Withdrawal

W. Depth (No.) \ Cylinder No.	1	2	3	4	5	6	7	8
25 cm (1)	0 s	5 m	10 m	15 m	20 m	25 m	30 m	35 m
10 cm (2)	2 m	7 m	12 m	17 m	22 m	27 m	32 m	37 m
10 cm (3)	8 m	13 m	18 m	23 m	28 m	33 m	38 m	43 m
10 cm (4)	32 m	37 m	42 m	47 m	52 m	57 m	1h 2m	1h 7m
10 cm (5)	2h 8m	2h 13m	2h 18m	2h 23m	2h 28m	2h 33m	2h 38m	2h 43m
7 cm (6)	5h 58m	6h 3m	6h 8m	6h 13m	6h 18m	6h 23m	6h 28m	6h 33m
7 cm (7)	24 h	24h 5m	24h 10m	24h 15m	24h 20m	24h 25m	24h 30m	24h 35m

Attention !!

Hydraulic Diameter :

Sedimentation analysis actually determines the settling velocities of the particles with different sizes, shapes, and densities. In practice, these settling velocities are expressed in terms of the diameters of quartz spheres that will settle at the same velocity. These diameters are usually calculated using Stokes' law for silt and clay. The actual physical size or diameter of the particles is not determined, only the "hydraulic diameter" which is a function of particle size, shape, and density.

Flocculation and Dispersion of Mud and Clays

Grain-size analysis of fine-grained materials is not very satisfactory and there are a great many unsolved problems. For sizes finer than 6 or 7 Ø(0.016 to 0.008 mm) this analyses are often invalid. Below this size the analysis no longer measures true size of the particles, because the settling velocity is now affected greatly by the flaky shapes of the particles, degree of dispersion, electrical charges on the particles, etc. Two clay flakes of the same size but different compositions(e.g. kaloinite vs. monmorillonite) may settle at different rates because of these factors.

Clay flakes in pure distilled water are usually electrically charged. Most clays have a negatively-charged ionic lattice, which to attain electric neutrality must take up positively charged ions from the surrounding solution (usually H^+, Ca^{++} or others). This leaves the surrounding solution swarming with unsatisfied negative ions (OH^-, etc.) in the vicinity of the clay flakes. Thus when a clay flake with its surrounding "fog" of negative ions approaches clay flake, also with a negative fog of ions around it, the two flakes repel each other. This is the state we try to maintain, because if the flakes repel each other then they will not aggregate in to clumps, and we can then make a grain-size analysis on the individual grains.

To make this kind of state in the cylinder it is recommended to add a small amount of certain dispersing chemicals, called dispersant which prevent flocculation.

Some dispersants are the following: (1) a few drops of concentrated NH_4OH per liter of suspension; (2) 0.02N Na_2CO_3; (3) 0.01N sodium oxalate; (4) sodium hexametaphosphate. The latter (Calgon) is best for most purposes.

You must always know exactly how much dispersant in the water because it is an important factor in computation of the results.

Chapter 4.

Practice of Grain Size Analysis

1. Pretreatment of samples

2. Proper Weight of Subsample
   How much ?
   How ?
3. Equipments Needed for Size Analysis

1. Pretreatment of sample

The object of grain size is only mineral and lithic grains. In general, the sediments contain not only mineral grains but also other substances; carbonates (shell fragments), organic matters, soluble salt, etc. Also these substances interfere with dispersal of mud. Then, it is necessary to remove that substances from sediment subsample.

To carry out this pretreatment, lab hood facility is necessary.

1) Removal of Carbonates

Depending on the study purpose, for example mineralogical studies, this treatment procedure is not recommended.

* Place the subsample of sediment in 500-ml beaker and add 25 ml distilled water or deionized water. Then stir.
* Add 10 % of HCl slowly until effervescence stops.
* Put the beaker on the hot plate and heat to 60 - 80 ℃ and add HCl until effervescence stops.
* Add distilled water and wash by decantation. Repeat it 2 - 3 times.

2) Removal of Organic Matter.

This treatment will seldom remove all the organic matter, but is still very helpful in dispersing the sediment.

* Place the sample in 500-ml beaker and add H_2O_2 slowly. Stir it. Sometimes there is vigorous reaction in the beaker. Do not let the forth spill over.
* Add H_2O_2 until frothing stops
* If there is no more reaction at room temperature, put the beaker on hot plat and heat to 90℃ until there is no froths. Then let the beaker at room temperature.
* After cooling, decant the upper clean liquid of beaker and add distilled water. Wash the sediment by decantation. Repeat the decantation 2 - 3 times.

2. Taking a proper amount of representative subsamples

Samples must be large enough to give statistically meaningful results, hence must be "large" relative to the largest particle size present.

1) For Sand and Gravel sample

How Much ?

Mix sediments thoroughly and take the representative sample to be analyzed. The exact, or proper amount of specimen sample to be used depends on several factors : the size and sorting of sediment, the shape and roundness of the grain, the number of screens that will be used, the shaking time. Consequently exact weights cannot be specified. The general principle is that sieves should not be overloaded with sediment to avoid damaging the mesh. As a preliminary guide the following approximate weights are suggested as follows;

* fine gravel - 500 gm
* coarse sand - 200 gm
* medium sand - 100 gm
* fine sand - 25 - 50 gm

How ?

In the case of pure dry sand, if there is great amount of sample and you want to get exactly representative specimen, you can use very simple but effective method "Coning and Quartering Method"

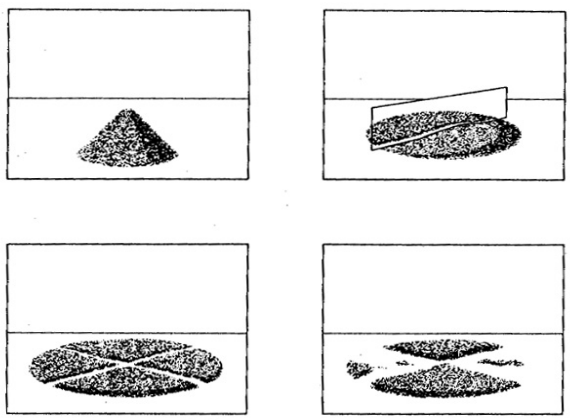


Fig. 4-1. Splitting sample by coning and quartering

Pour the bulk sample on a flat surface so as to form a cone (Fig. 4-1). Using a strait edge separate the cone first into half, and into quarters. Discard two of the alternate quarters and then mix the remaining two quaters in one. Repeat this method until the sample amount reach to proper weights.

Attention !!

The sand fraction obtained from the mixture sample must be used all for sieving.

2) For Gravel/sand/Mud Mixture or Mud sample

How Much ?

The amount of a representative subsample of mixture sediment should not be over the weight that the mud fraction will yield no more than maximum 25 gm, as already mentioned in chapter 3. Lewis (1984) shows a guide to subsample weight of mixture samples according to the sand/mud ratio (Fig.). For example, for the mixture sample of 1:1 sand/mud ratio, the subsample weight is about 40 gm.

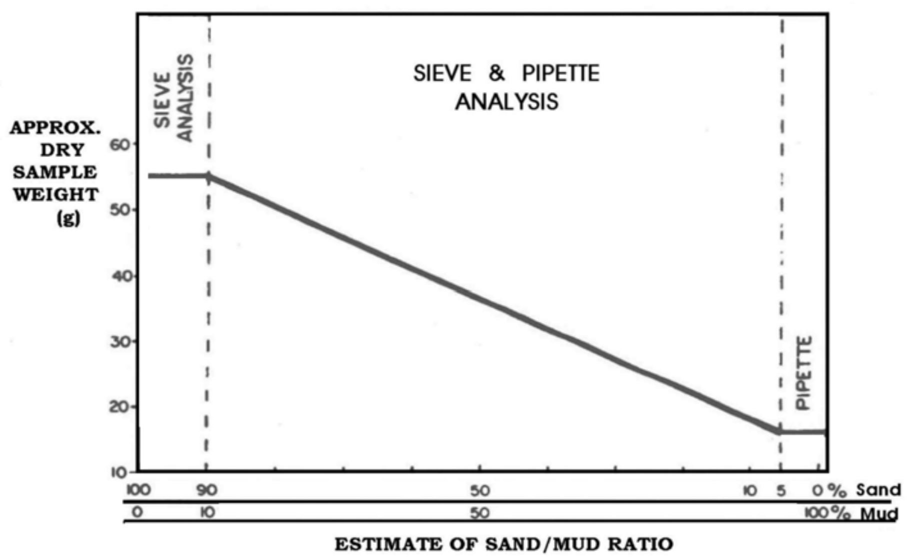


Fig. 4-2. Guide to subsample amount for the mixture sediment samples. If sample is wet, make allowance for water content. After Lewis (1984, p. 86).

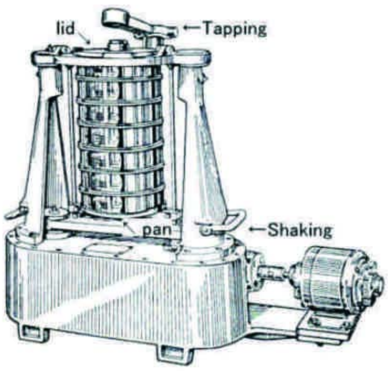
How ?

There is not any particular method to take the representative subsample from the mixture. Simply mix the bulk sample thoroughly using a spatular, and take proper amount by tablespoon. For most homogeneous sandy muddy sediments, a table spoon blindly dipped into the mixture is an adequate subsampling technique, as long as differential segregation has not occurred.

3. Equipment needed for size analysis

1) For dry sieving of sand

* Sieve shaker with sieve set (larger than 4 ϕ opening with 1 ϕ interval)



Ro-Tap Shaker

Shaker

2) For pipette analysis of mud






* 1000-ml graduated cylinders (plastic is more practical)

* 50-ml pippette

* Stirrer

* 4 ϕ sieve with funnel

* Hot plate

* Water bottle to rinse the pippette and sieve

* Digital clock   * distillation apparatus

3. For common use

* Dry oven

* Accurate balance

* beakers (500-ml, 100-ml)

* Brush for cleaning and sieving

* Data Sheet

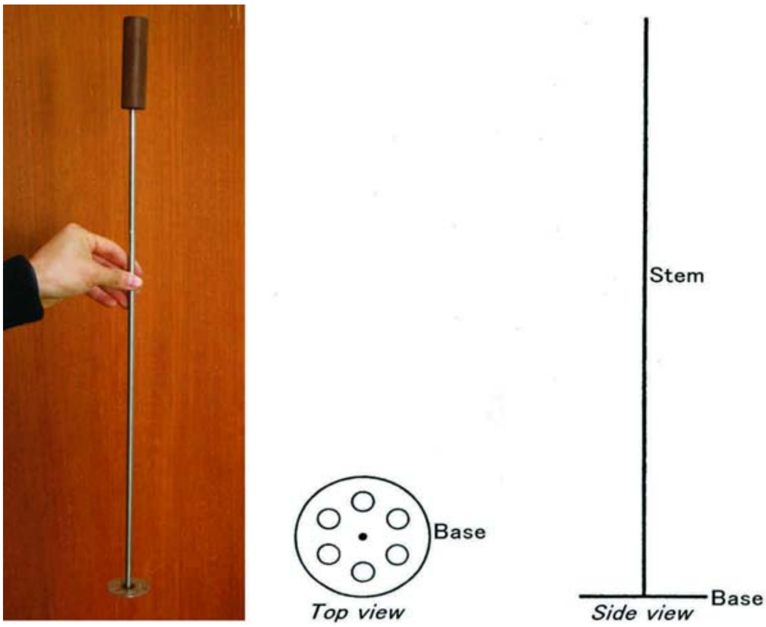
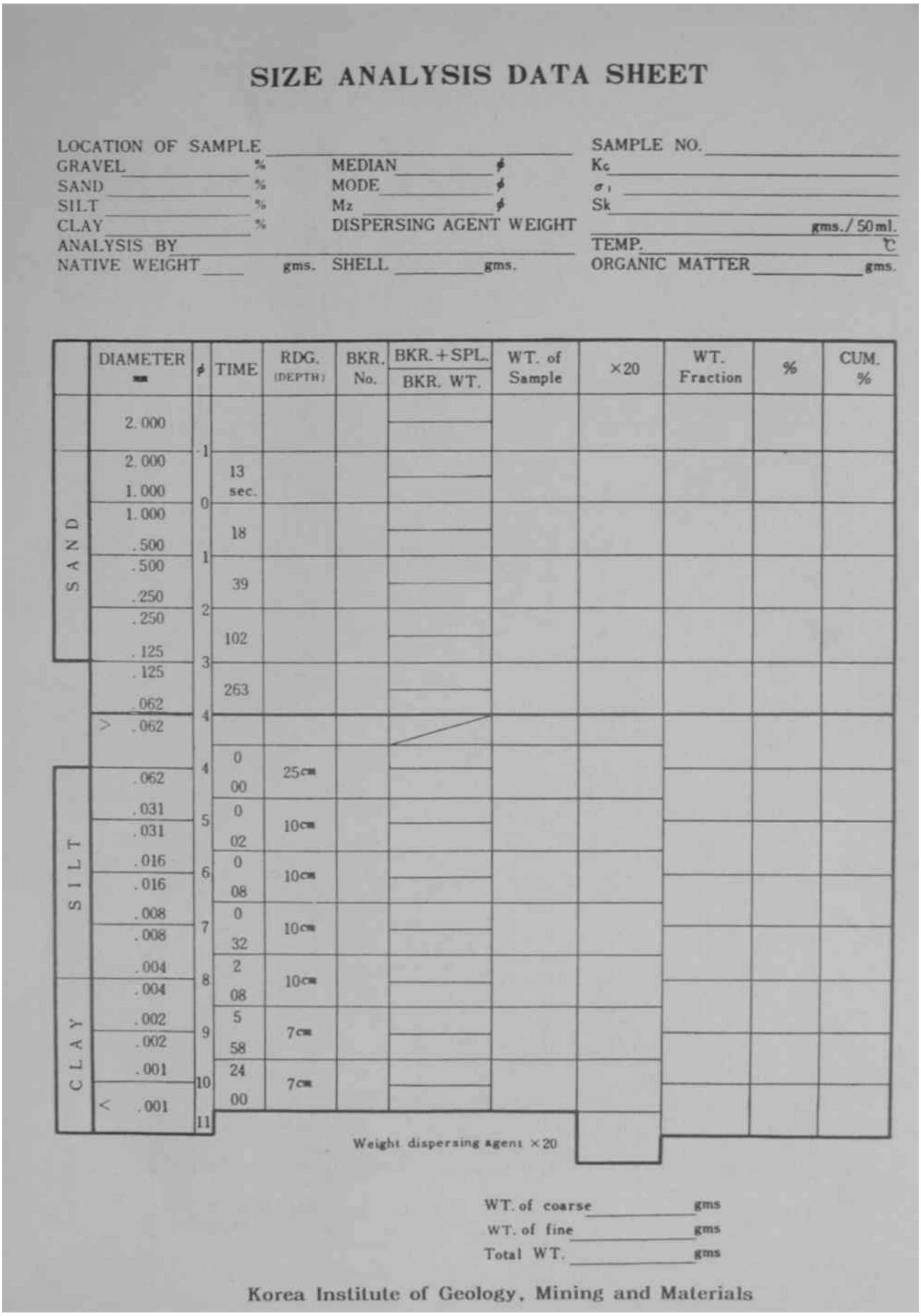


Fig. 4-3 . Stirring rod.

The stirring rod must be constructed to fit the particular 1000-ml graduated cylinders that are being used. The stem of the stirring rod is attached to the center of the base. The base can be made of metal or plastic and should have a diameter about 5 mm less than the inside diameter of the 1000-ml graduated cylinders. Circles represent holes cut in the base.



SIZE ANALYSIS DATA SHEET

LOCATION OF SAMPLE ______________ SAMPLE NO. ______________
GRAVEL ______ % MEDIAN ______ ϕ Kc ______________
SAND ______ % MODE ______ ϕ σ_1 ______________
SILT ______ % Mz ______ ϕ Sk ______________
CLAY ______ % DISPERSING AGENT WEIGHT ______ gms./50ml.
ANALYSIS BY ______________ TEMP. ______ ℃
NATIVE WEIGHT ______ gms. SHELL ______ gms. ORGANIC MATTER ______ gms.

	DIAMETER mm	ϕ	TIME	RDG. (DEPTH)	BKR. No.	BKR.+SPL. / BKR. WT.	WT. of Sample	×20	WT. Fraction	%	CUM. %
	2.000										
SAND	2.000 1.000	-1 0	13 sec.								
SAND	1.000 .500	0 1	18								
SAND	.500 .250	1 2	39								
SAND	.250 .125	2 3	102								
	.125 .062	3 4	263								
	> .062	4									
SILT	.062 .031	4 5	0 00	25cm							
SILT	.031 .016	5 6	0 02	10cm							
SILT	.016 .008	6 7	0 08	10cm							
SILT	.008 .004	7 8	0 32	10cm							
CLAY	.004 .002	8 9	2 08	10cm							
CLAY	.002 .001	9 10	5 58	7cm							
CLAY	< .001	10 11	24 00	7cm							

Weight dispersing agent ×20

WT. of coarse ______ gms
WT. of fine ______ gms
Total WT. ______ gms

Korea Institute of Geology, Mining and Materials

Fig. 4-4. Grain size analysis data sheet-front page

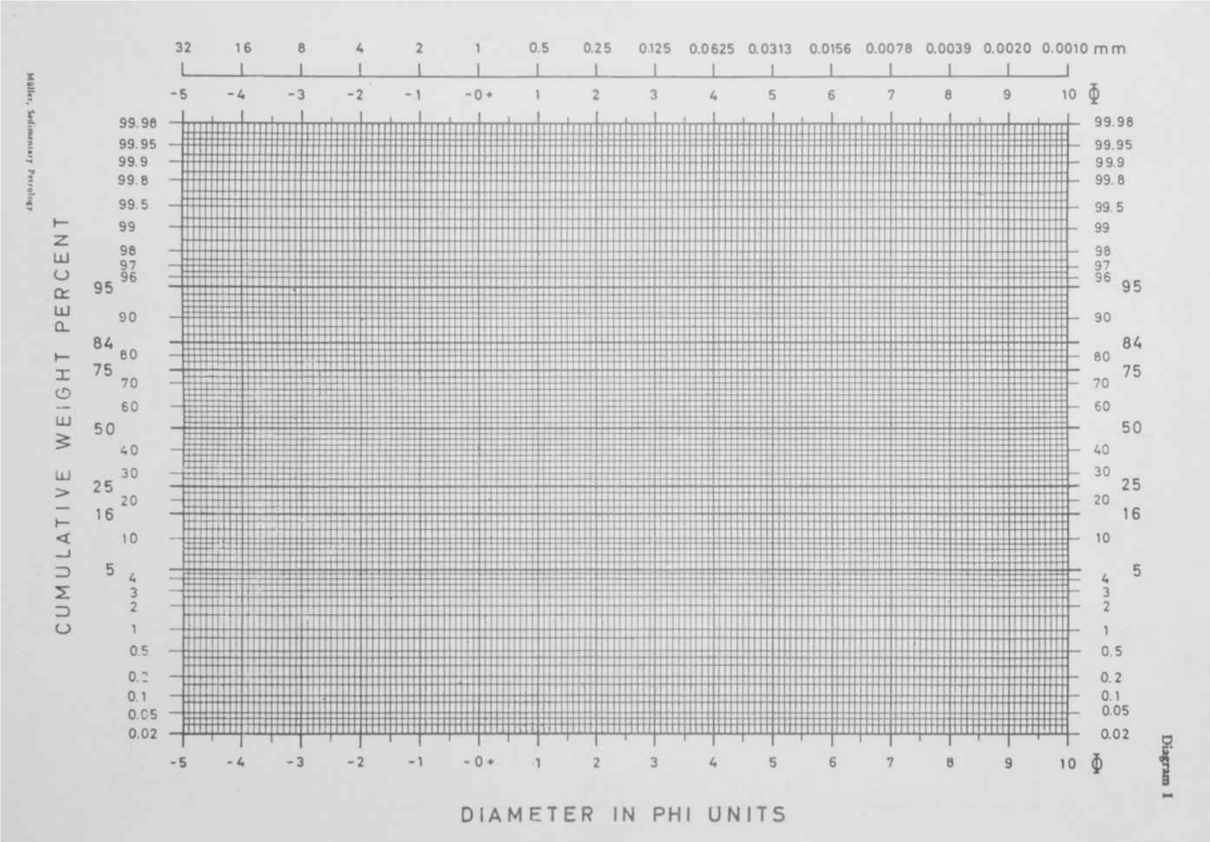


Fig. 4-5. Grain size analysis data sheet - back page. It is probability paper for plotting grain size distribution.

Chapter 5.

Detailed Steps of Grain Size Analysis

1. Sieving

2. Pipetting

In this chapter, the practical laboratory procedures of "Sieving method" and "Pipette method" will be referred.

In nature there are three type of sediments ; (1) sand and gravel, (2) mixture of gravel, sand and mud (silt and clay), and (3) mud (silt and mud). Only the pure sand and grave sediments can be analyzed directly, after some pretreatment, by sieving. But the others, after some pretreatment also, must be sieved first using 4ϕ sieve (230 mesh) for separating mud fraction from sand fraction (Fig.5-1). Then the sand fraction is analyzed by "Sieve Method" and mud fraction is analyzed by "Pipette Method".

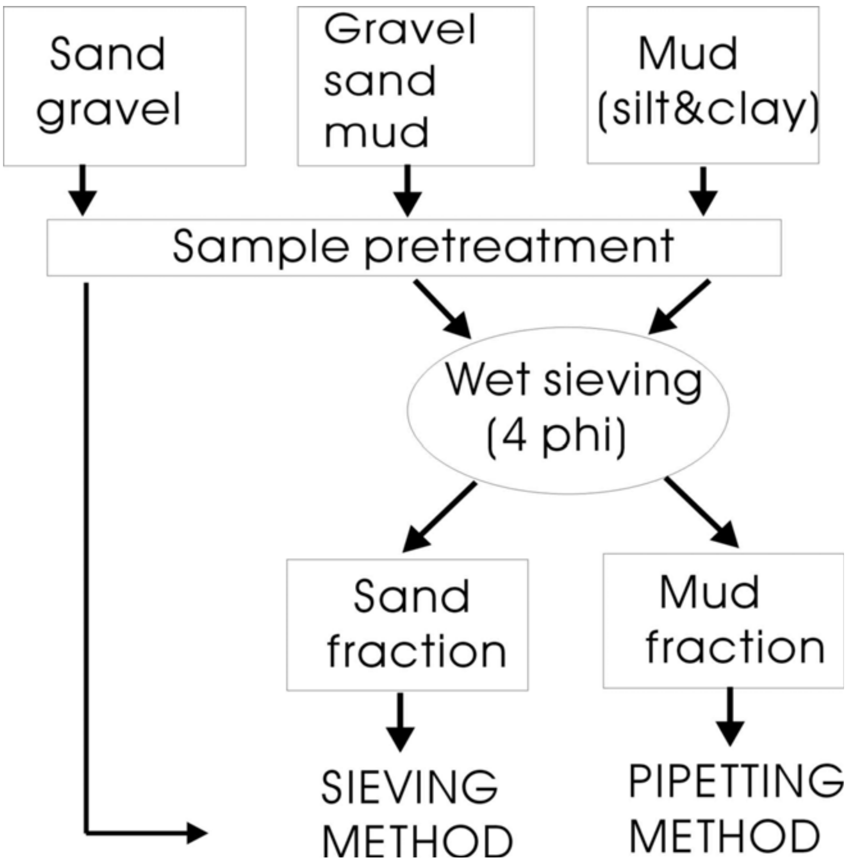


Fig. 5-1. Brief flow chart for sample preparation

1. Sieving Analysis of sand

<Step 1> Preparation

1) **cleaning sieves** : After each use all sieves should be carefully cleaned and stored. Occasionally, more thorough cleaning of the screens may be needed.

* Wash sieves in warm soapy water using the special sieve nylon and brass sieve brushes.
* If this treatment fails to remove most of the lodged particles, dip sieves in a boiling 5% solution of acetic acid and then use sieve brushes on sieve. Wash sieves thoroughly to remove the acid.

2) **Testing sieves** : Sieves may be checked for accuracy in several different ways.

* Use of Standard Samples : The use of calibrated glass sphere is recommended for checking and determining the effective sieve openings.
* Measurement of openings using microscope : Six nonoverlapping fields of view are selected. In each field measure at last 50 openings perpendicular to wire, with the openings being located in a diagonal direction across the field (Fig. 5-2).

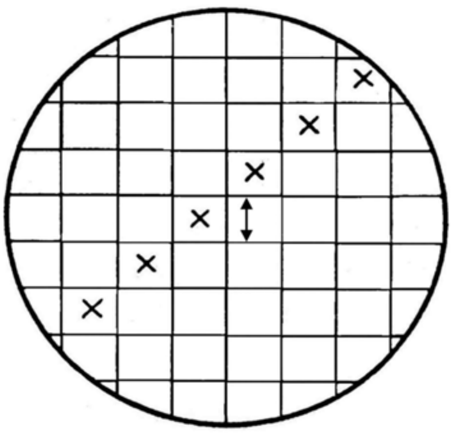


Fig. 5-2. Testing sieves by microscopic measurement of openings located along diagonals of openings.

The opening in three of the fields should be measured at right angles to those in the other three fields.

3) Determining the time of Shaking sieves : Most workers have accepted 10 minutes of shaking in a Ro-tap as an arbitrary standard, although some use 15 minutes. A long shaking time will result in more material passing through each screen; but because of inaccuracies in sieves, long shaking times result primarily in the near mesh-size particles passing through the too-large holes.

<Step 2> Drying samples

For efficient sieving the sample must be dried individual grains. According to Bartel (1960, in Muller, 1967, p.65) with a surface moisture as little as 1%, adhesion forces exist that can overcome the weight of grains smaller than 1 mm.

<Step 3> Set-up

1) Build up a nest of clean screens for subdivisions desired with the coarsest screen on top (1ϕ or 0.5ϕ interval; in general 1ϕ interval is enough). Half-height screens will allow a large number of screens to be used at one time. A lid should be put on the top and a pan at the bottom of the nest of sieves.

2) Pour dry sediment onto top of screen in nest. Make certain that all sediment passes the top screen (Fig. 5-3).

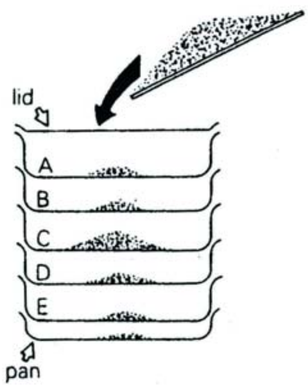


Fig. 5-3. Pouring sample onto screen

<Step 4> Shaking

Place the sieve set with sample in sieve shaker and shake for 10 minutes.

<Step 5> Weighing

1) Empty each sieve onto a large sheet of paper. The removal of sand is helped by striking the rim of the sieve with either the palm of the hand or the wooden handle of a screen rush along the general direction of the diagonals of the wire mesh and brushing the bottom of the sieve with a

sieve brush.

2) Weigh each fraction to the nearest 0.001 gm. If the sample is mostly composed of sand (more than 95%), weigh also directly the fines in the pan passing the bottom(1/16 mm or smaller). If not, add the fines to the cylinder.

<Step 6> Recording

Record all of the weight data of each screen on the data sheet as below (Fig. 5-4).

SIZE ANALYSIS DATA SHEET

LOCATION OF SAMPLE ______ SAMPLE NO. ______
GRAVEL ______ % MEDIAN ______ φ Kc ______
SAND ______ % MODE ______ φ σ ______
SILT ______ % Mz ______ φ Sk ______
CLAY ______ % DISPERSING AGENT WEIGHT 1.0 gms./50 ml.
ANALYSIS BY ______ TEMP. ______ ℃
NATIVE WEIGHT ______ gms. SHELL ______ gms. ORGANIC MATTER ______ gms.

	DIAMETER mm	φ	TIME	RDG. (DEPTH)	BKR. No.	BKR.+SPL. / BKR. WT.	WT. of Sample	×20	WT. Fraction	%	CUM. %
SAND	2.000	-1				107.060 / 105.803	1.257		1.257	3.27	3.27
SAND	2.000 – 1.000	0	13 sec.			107.680 / 105.813	1.867		1.867	4.85	8.12
SAND	1.000 – .500	1	18			109.155 / 104.925	4.230		4.230	10.99	19.11
SAND	.500 – .250	2	39			108.741 / 106.113	2.628		2.628	6.83	25.94
SAND	.250 – .125	3	102			106.560 / 105.433	1.127		1.127	2.93	28.87
	.125 – .062	4	263			106.601 / 105.677	0.924		0.924	2.40	31.27
	> .062										
SILT	.062	4	0 00	25cm							
SILT	.031 – .031	5	0 02	10cm							
SILT	.016 – .016	6	0 08	10cm							
SILT	.008 – .008	7	0 32	10cm							
SILT	.004 – .004	8	2 08	10cm							
CLAY	.002 – .002	9	5 58	7cm							
CLAY	.001	10	24 00	7cm							
CLAY	< .001	11									

Weight dispersing agent ×20

WT. of coarse 12.033 gms
WT. of fine ______ gms
Total WT. ______ gms

Korea Institute of Geology, Mining and Materials

Fig. 5-4. Example of data sheet for the sediment coarser than 4Φ

2. Pipetting Analysis of mud

<Step 1> Preparation

1) Place a funnel on the top of 1000-ml graduated cylinder.
2) Take take the 62 micron (230 mesh) screen that is reserved only for wet-sieving (Do not use a 4ϕ sieve from a set of dry sieves.), and dip in distilled water get the mesh thoroughly wet on both sides, otherwise the sludge will not run through easily
3) Put the sieve on the funnel.
4) Using water bottle, pour the pretreated subsample in the 500-ml beaker onto the screen of sieve, and rinse out every grain from the beaker.

<Step 2> Separating of mud fraction by brushing

1) Give the subsamples in the screen brushing back and forth while jetting the distilled water on it using water bottle, to wash the mud through the screen. Continue washing the sediment back and forth over the screen until the water runs through clear. The direction of brushing must be diagonal to the screen openings.
2) During the brushing, be careful not to damage the screen openings by wooden handle or metallic part of brush.
3) After completing the separation of mud, rinse out all of particles on the surface of funnel and cylinder.
4) Use as little water as possible, because you should end up with less than 950 ml for adding of 50 ml dispersant.
5) Pour all the sand fraction retained on the screen to a beaker using water bottle, and transfer into electrical to dry for "Dry Sieving Method".

<Step 3> Adding dispersant

1) Add 50 ml of 2% "Calgon" solution (commercial name of sodium hexametaphospate, $(NaPO_3)_6$, into cylinder. Record how much dispersant you used.
2) Fill the cylinder up to exactly 1,000 ml with distilled water.
3) Stir the material in the cylinder vigorously with stirrer, and let stand a day to check completeness of dispersion.

<Step 4> Arrange the cylinders, beakers, timepiece, and timetable.

1) Label each cylinders and beakers (sample no. & pipetting order)
2) Weigh to 0.001 gram seven 100-ml beakers and wright down on data sheet.
3) Arrange seven beakers in front of each cylinder
4) The 50-ml pipette stem should have previously been marked at 25, 10, 7 cm from the tip end). Prepare a timepiece and timetable.

<Step 5> Pipetting

1) If necessary, fill the cylinder up again to exactly 1,000 ml with distilled water.

2) stir the suspension of fine fraction in cylinder by stirrer for 1 minute in order to insure an even distribution of sediment throughout the cylinder. The last ten seconds of stirring should consist of smooth, long strokes with the stirrer traversing the entire length of the cylinder.
2) Withdrawn the stirrer from the cylinder 10-15 seconds before pipetting begins (The turbulence will be stop for the time), and put the stirrer into next cylinder.
3) Start to lower the pipette to the depth of 25 cm 2 - 3 seconds before, and at the starting time suck and withdraw the first pipette with sample smoothly.
4) An efficient procedure for this and subsequent withdrawals is to start to lower the pipette into the cylinder at the proper depth 2-3 seconds before the withdrawal time. At the exact withdrawal time, begin sucking the pipette until exactly 50 ml is in the pippette. This will take about 5 - 10 seconds. As the liquid reaches the 50-ml mark, close up the opening of pipette by

your tongue and remove the pippette from the cylinder. Let the pippette drain into the 100-ml beaker. Then, using water bottle of pure distilled water, rinse the inside of pipette, and drain the water into same beaker (as shown in below figures).

		
Pipetting	Draining	Rinsing

5) Then prepare for the second pippette withdrawal.

<Step 6> Drying

Hot Plate

1) When all withdrawals are completed, put the beakers onto hot plate first and evaporate half of the water rapidly.
2) Then put all of them in an electrical oven with the temperature of 90 - 120 ℃

<Step 7> Weighing

Balance

1) When they are dry up, remove the beakers from the oven and leave them to equilibrate with the room temperature for at least one and half hour.
2) Weigh them to 0.001 gram, recording the weight on data sheets where the weight of 100-ml beakers have already been recorded as Fig. 5-5.

SIZE ANALYSIS DATA SHEET

LOCATION OF SAMPLE ____________ SAMPLE NO. ____________
GRAVEL ______ % MEDIAN ______ φ Kc ______
SAND ______ % MODE ______ φ σ_1 ______
SILT ______ % Mz ______ φ Sk ______
CLAY ______ % DISPERSING AGENT WEIGHT 1.0 gms./50 ml.
ANALYSIS BY ______ TEMP. ______ ℃
NATIVE WEIGHT ______ gms. SHELL ______ gms. ORGANIC MATTER ______ gms.

	DIAMETER mm	φ	TIME	RDG. (DEPTH)	BKR. No.	BKR.+SPL. / BKR. WT.	WT. of Sample	×20	WT. Fraction	%	CUM. %
	2.000	-1				107.060 / 105.803	1.257		1.257	3.27	3.27
SAND	2.000 – 1.000	-1 – 0	13 sec.			107.680 / 105.813	1.867		1.867	4.85	8.12
SAND	1.000 – .500	0 – 1	18			109.155 / 104.925	4.230		4.230	10.99	19.11
SAND	.500 – .250	1 – 2	39			108.741 / 106.113	2.628		2.628	6.83	25.94
SAND	.250 – .125	2 – 3	102			106.560 / 105.433	1.127		1.127	2.93	28.87
	.125 – .062	3 – 4	263			106.601 / 105.677	0.924		0.924	2.40	31.27
	> .062	4									
SILT	.062 – .031	4	0 00	25cm		107.257 / 105.884	1.373	27.460	2.480	6.44	37.71
SILT	.031 – .016	5	0 02	10cm		104.528 / 103.279	1.249	24.980	4.420	11.48	49.19
SILT	.016 – .008	6	0 08	10cm		107.141 / 106.113	1.028	20.560	8.140	21.15	70.34
SILT	.008 – .004	7	0 32	10cm		105.046 / 104.425	0.621	12.420	5.660	14.70	85.04
CLAY	.004 – .002	8	2 08	10cm		107.148 / 106.810	0.338	6.760	3.520	9.14	94.18
CLAY	.002 – .001	9	5 58	7cm		106.150 / 105.988	0.162	3.240	1.660	4.31	98.49
CLAY	< .001	10 – 11	24 00	7cm		105.622 / 105.543	0.079	1.580	0.580	1.51	100.00
						Weight dispersing agent ×20		1.00			

WT. of coarse 12.033 gms
WT. of fine 26.460 gms
Total WT. 38.493 gms

Korea Institute of Geology, Mining and Materials

Fig. 5-5. Completed data sheet for sand and mud mixture sample

Chapter 6.

Data Processing & Interpretation

1. Calculation of Cumulative Weight Percentages
2. Calculation of Textural Parameters
3. Some Geological Interpretation

1. Calculation of Cumulative Weight Percentages

1) Computation of each size grade for sand

BKR.+SPL. / BKR. WT.	WT. of Sample	×20	WT. Fraction
107.060 / 105.803	1.257		1.257
107.680 / 105.813	1.867		1.867
109.155 / 104.925	4.230		4.230
108.741 / 106.113	2.628		2.628
106.560 / 105.433	1.127		1.127
106.601 / 105.677	0.924		0.924

Fig. 6-1. Weight data of each sand size grade

Simply subtract the weight of the cleaned, air-dried beaker from the weight of the beaker plus sample to get the sand weight on each screen (Fig. 6-1). Plus all of the weights of each grade. That is total weight of sand fraction (here 12.033 gm).

2) Computation of each size grade for mud

BKR.+SPL. / BKR. WT.	WT. of Sample	×20	WT. Fraction
107.257 / 105.884	1.373	27.460	2.480
104.528 / 103.279	1.249	24.980	4.420
107.141 / 106.113	1.028	20.560	8.140
105.046 / 104.425	0.621	12.420	5.660
107.148 / 106.810	0.338	6.760	3.520
106.150 / 105.988	0.162	3.240	1.660
105.622 / 105.543	0.079	1.580	0.580
Weight dispersing agent ×20		1.00	

Fig. 6-2. Weight data of each size grade for mud

* subtract the weight of the beaker from the weight of the beaker plus sample to get the weight of each withdrawal.

* Then multiply the weight of each withdrawal by 20 (here, 27.460 gm) (Fig. 6-2).

* Subtract the weight of dispersant (50 ml of 2% Calgon contains 1 gram of dispersant) from the first withdrawal weight becomes the total weight of mud in 1000-ml cylinder (here, 26.460 gm).

* And then subtract the weight of second withdrawal from the first one, this becomes the weight of 4-5 ∅ grade (here, 2.480 gm).

* Subtract the weight of third withdrawal from the second one, it becomes the weight of 5-6 ∅ grade(here, 4.420 gm).

* Continue same subtractions as above to 6th withdrawal

* For the 7th one, subtract the weight of dispersant (here, 1.580 - 1.000=0.580 gm).

3) Calculation of cumulative weight percentage.

WT. Fraction	%	CUM. %
1.257	3.27	3.27
1.867	4.85	8.12
4.230	10.99	19.11
2.628	6.83	25.94
1.127	2.93	28.87
0.924	2.40	31.27
2.480	6.44	37.71
4.420	11.48	49.19
8.140	21.15	70.34
5.660	14.70	85.04
3.520	9.14	94.18
1.660	4.31	98.49
0.580	1.51	100.00

Fig. 6-3

* merge together the result of weight computation of each size grade (Fig. 6-3).

* Now we can get the total weight of sample from the data sheet.

sand fraction(12.033 g) + mud fraction(26.460 g) = 38.493 g

* Caculate the weight percentage of each size grade.

* Cumulate the weight of each size grade from the coarse size grade.

* Then plot all the cumulative weight percentage data on the probability paper.

4) Graphing a cumulative curve

Results for gravel (if any), sand, and mud should be combined in a smooth, continuous cumulative curve (Fig. 6-4). Normally, the analysis stops at about 10∅ size parameters but the cumulative curve is extended in a straight line on ordinary arithmetic (squared) graph paper from the last date point (usually 10∅) to 14 ∅ at 100percent. This assumed that essentially all clay particles are larger than 14 ∅ (0.06micron), and that the clay mode is somewhere near 12 ∅ (0.24 micron). Grain size data may then be obtained from this extrapolated curve.

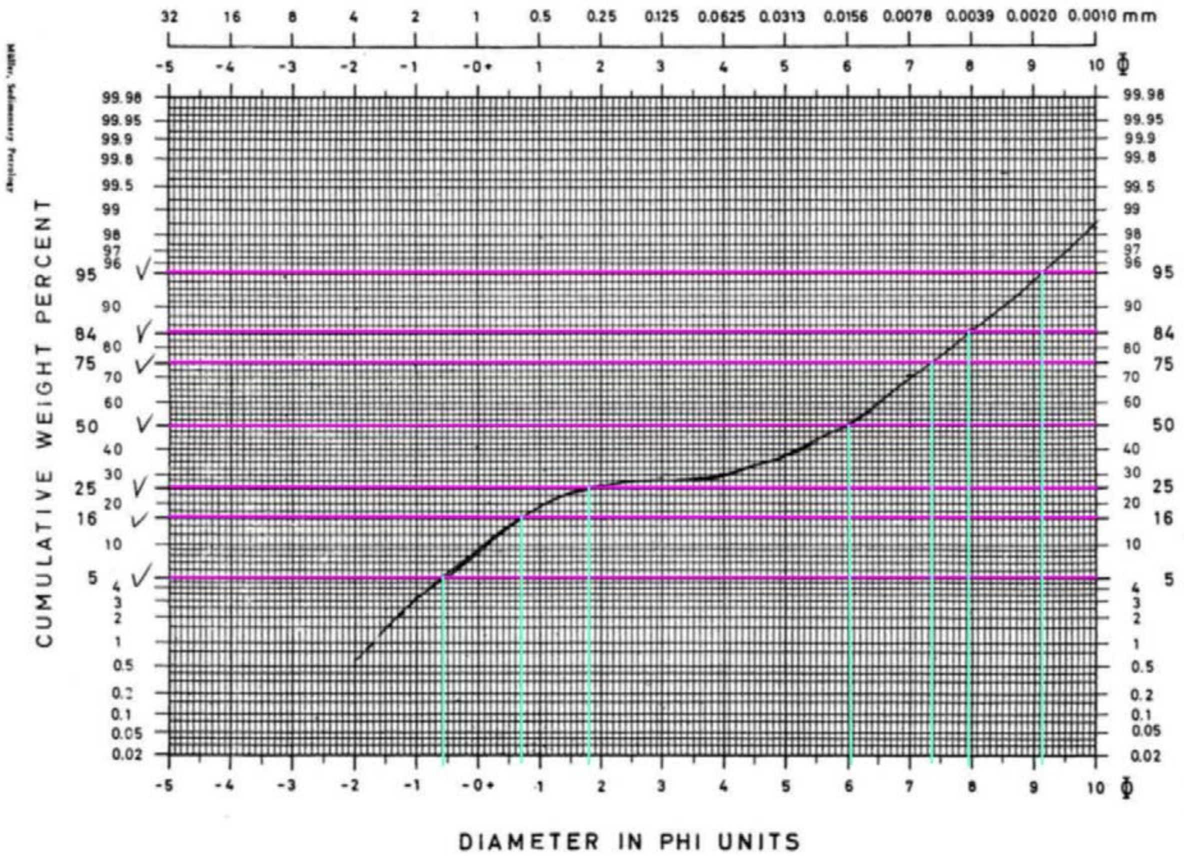
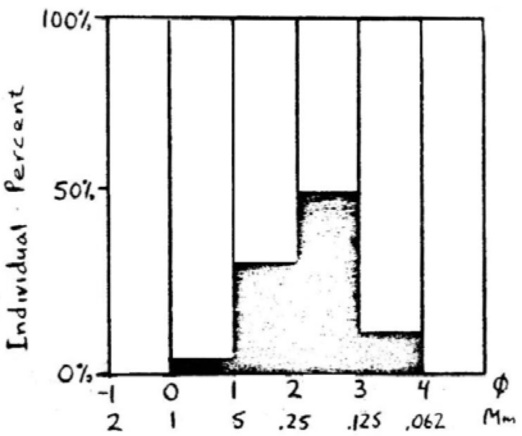


Fig. 6-4. An example of cumulative curve. Phi diameter value at 5%, 16%, 25%, 50%, 75%, 84%, and 95% on the cumulative curve

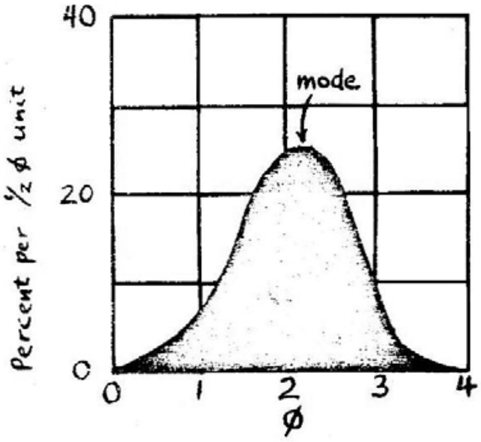
Attention !!

After Folk (1968)

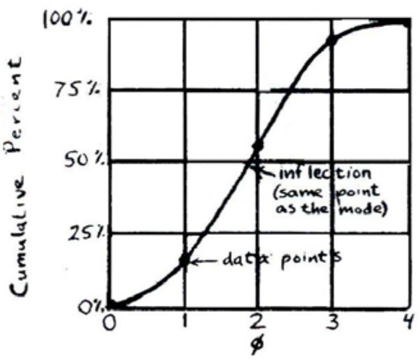
There are several graphic presentation methods to plot weight data obtained from grain size analysis; Histogram, Frequency Curve, Cumulative Curve with Arithmetic Ordinate, and Cumulative Curve with Probability Ordinate.



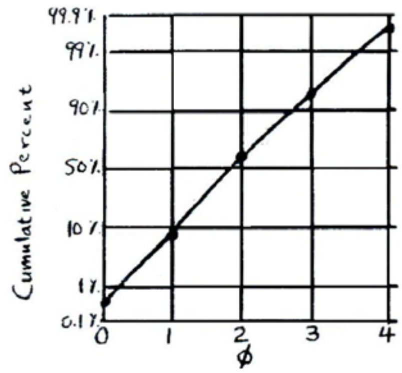
Histogram



Frequency Curve



Cumulative Curve with arithmetic ordinate



Cumulative Curve with probability ordinate

Each graphic presentation has its own merits, but Folk (1968) strongly suggested to use Cumulative Curve with Probability Ordinate. Most sediments tend to approach "normal probability curve" in their size frequency distribution - in other words, most of the particles are clustered about a given size, with les and less material on each side of this size. If the cumulative curve of a sediment following the normal, symmetrical probability distribution is plotted on probability paper, the result is a perfectly straight line whose position depends on the average particle size and whose slope depends on the sorting. This happens because the probability scale is very condensed in the middle of the scale (30 to 70%) and very much extended at the ends (under 10 or over 90%, thereby straitening out the S-shaped curve which would result if arithmetic ordinates were used. Thus it is very valuable for studying the departure of sediments from the normal probability law. Moreover, since the "tails" are straitened out and the sample tends to plot as a strait line, it is possible to read statistical parameters with much greater accuracy because of the ease of interpolation and extrapolation. ***Hence this is the curve that must be used for all determination of parameters.***

2. Calculation of Textural Parameters

Textural parameters, such as mean grain size, sorting, skewness, kurtosis, which are based on the shape of cumulative curves, are environment sensitive. They reflect the mode of transportation and the energy conditions of the transporting medium. And these kind of statistical parameter of grain size is very useful to compare sets of sediment samples quantitatively.

Folk(1968) suggested "Graphic Method" to calculate these parameters, which is very widely used now.

According to the Folk's method, the phi diameter values at 5%, 16%, 25%, 50%, 75%, 84%, and 95% on the cumulative curve must be taken to calculate the textural parameters (Fig. 6-4).

1) Graphic Mean (M_Z)

There are three way to show the average size, Mode, Median, and Folk's Graphic Mean. The best graphic measure for determining overall size is the Graphic Mean, given by the formula,

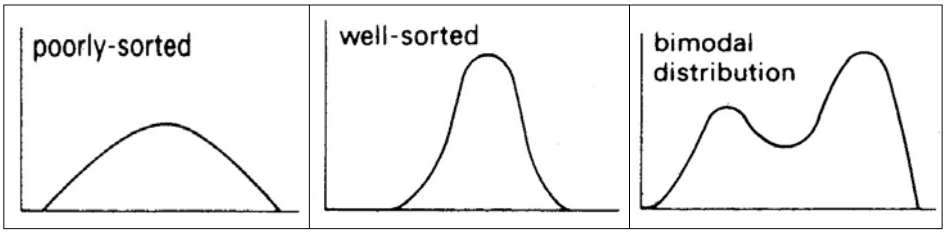
$$M_Z = \frac{\varnothing 16 + \varnothing 50 + \varnothing 84}{3}$$

Note : The unit of M_Z is $\varnothing$

It corresponds very closely to the mean as computed by the method of moments, yet is much easier to find. This formula is much superior to the median because it is based on three points and gives a better overall picture.

2) Inclusive Graphic Standard Deviation (δ_I)

Several measures are available for measuring the Deviation. Standard Deviation measures the sorting of uniformity of the particle size distribution



Folk's Inclusive Graphic Standard Deviation(δ_I) is a good measure of sorting and is computed as,

$$\delta_I = \frac{\varnothing 84 - \varnothing 16}{4} + \frac{\varnothing 95 - \varnothing 5}{6.6}$$

Note : The unit of δ_I is $\varnothing$

This formula includes 90% of the distribution and is the best overall measure of sorting.

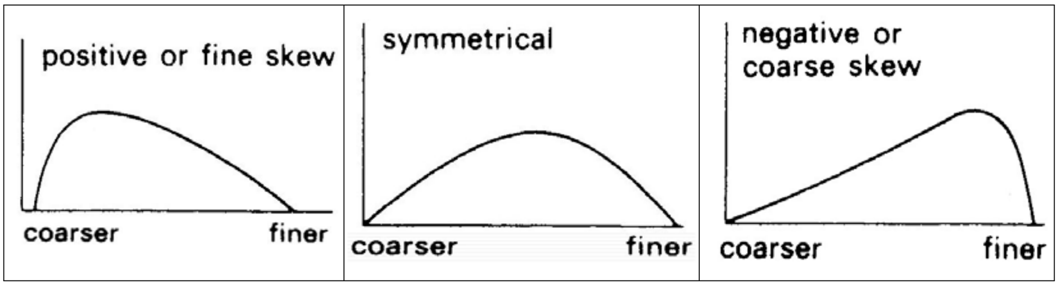
Measurement of sorting values for a large number of sediments has suggested the following verbal classification scale for sorting:

Table 6-1. Verbal classification scale of sorting. After Folk(1968)

Sorting Value (δ_I) in $\varnothing$	Verbal scale
under 0.35$\varnothing$	very well sorted
< 0.35 - 0.50$\varnothing$ ≦	well sorted
< 0.50 - 0.70$\varnothing$ ≦	moderately well sorted
< 0.70 - 1.00$\varnothing$ ≦	moderately sorted
< 1.00 - 2.00$\varnothing$ ≦	poorly sorted
< 2.00 - 4.00$\varnothing$ ≦	very poorly sorted
over 4.00$\varnothing$	extremely poorly sorted

3) Inclusive Graphic Skewness (Sk_I)

Skewness measures the asymmetry of the distribution. If there is more material in the coarse tail (coarse skewed), the skewness is referred to as being "negative" If there is more material in the fine tail (fine skewed), it is positive (see figures below).



Fine skewed Symmetrical Coarse skewed

Inclusive Graphic Skewness is given by the formula as below;

$$Sk_I = \frac{\varnothing 16 + \varnothing 84 - 2\varnothing 50}{2(\varnothing 84 - \varnothing 16)} + \frac{\varnothing 5 + \varnothing 95 - 2\varnothing 50}{2(\varnothing 95 - \varnothing 5)}$$

Note : Inclusive Graphic Skewness (Sk_I) has no unit.

The more the skewness value departs from 0.00 the greater the degree of asymmetry. The verbal limits on skewness are suggested as follows;

Table 6-2. Verbal classification scale of Skewness. After Folk(1968)

Skewness Value (Sk_I)	Verbal scale
+1.00 ~ +0.30	strongly fine-skewed
+0.30 ~ +0.10	fine-skewed
0.10 ~ -0.10	nearly-symmetrical
-0.10 ~ -0.30	coarse-skewed
- 0.30 ~ - 1.00	strongly coarse-skewed

4) Graphic Kurtosis (K_G)

Kurtosis measures the ratio between the sorting in the "tails" of the distribution and the sorting in the central portion of the distribution. If the central portion is better sorted than the tails, the frequency curve is said to be excessively peaked or leptokurtic.

Which would you say has the greater standard deviation? It is impossible to say.
The frequency curve on the right is more peaked at the center, which might lead us to believe that it has a lower standard deviation. It has fatter tails, which might lead us to believe that it has a higher standard deviation. If the effect of the peakedness exactly offsets that of the fat tails, the two curves will have the same standard deviation. The different shapes of the two curves illustrate kurtosis. The frequency curve on the right has a greater kurtosis than the one on the left.

[Greek kurtōsis, bulging, curvature, from kurtos, convex.]

In the normal probability curve, the phi diameter interval between ∅5 and ∅95 points should be exactly 2.44 times the phi diameter interval between ∅25 and ∅75 points. The kurtosis measure used here is the Graphic Kurtosis, K_G, (Folk, 1968) given by the formula,

$$K_G = \frac{\varnothing 95 - 5\varnothing}{2.44(\varnothing 75 - \varnothing 25)}$$

Note : Graphic Kurtosis (K_G) has no unit.

Table 6-3. Verbal classification scale of sorting. After Folk(1968).

Kurtosis Value	Verbal scale
under 0.67	very platykurtic
< 0.67 - 0.90 ≦	platykurtic
< 0.90 - 1.11 ≦	mesokurtic
< 1.11 - 1.50 ≦	leptokurtic
< 1.50 - 3.00 ≦	very leptokurtic
over 3.00	extremely leptokurtic

4. Some Geological Interpretations

Among the textural parameters of particle size distribution, Sorting of sands and depositional environment is correlatable, as shown in Table 6-4 (Friedman, 1962).

Table 6-4. Genetic Sorting Classification based on Standard Deviation

Verbal Scale of Sorting	Environment of Deposition	Sand Size
very well sorted	most coastal, barrier-bar, and lake-dune sands, many beach sands; many marine sand above wave-base; many lagoonal sands.	Medium to fine and very fine grained sands (mean size > 1.0 - 2.0∅)
well sorted	most beach sands; many or most marine sand above wave-base; many lagoonal sands; many island dune sands; some river sands.	
moderately well sorted	most river sands; many beach sands; many lagoonal sands from restricted lagoons; most continental shelf sands below wave base; most island dune sands.	
moderately sorted	many river sands; some lagoonal sands from restricted lagoons; some continental shelf sands below wave base; many glaciofluvial sands.	
poorly sorted	many glaciofluvial sands.	
very poorly sorted	many glaciofluvial sands.	
extremely poorly sorted	some glaciofluvial sands.	
moderately well sorted	many beach sands.	Coarse grained sands (mean size < 1.0 ∅)
moderately sorted	most river sands; many or most beach sands; most continental shelf sands.	
poorly sorted	many glaciofluvial sands.	
extremely poorly sorted	some glaciofluvial sands.	

Coastal Geology Mapping Protocols for the Atlantic and Gulf National Park Units

Canaveral National Seashore and Titusville, Florida
June 25-27, 2002
NPS-D-2269

National Park Service U.S. Department of the Interior Geologic Resources Division Geological Resources Inventory

U.S. Department of Interior Gale A. Norton, Secretary
National Park Service Fran Mainella, Director

GEOLOGIC RESOURCES INVENTORY

Coastal Mapping Protocols Workshop for Atlantic and Gulf National Parks
Canaveral National Seashore. Titusville, Florida
June 25-27, 2002

COVENERS

2002 Report NPS-D-2269
Edited by Kim Nelson and Rebecca Beavers
For additional materials from the *Mapping Protocols Workshop*, including notebook contents, MS power point presentations, and Coastal Park fact sheets, please visit www.nature.nps.gov/grd/geology/gri/coastal.

Rebecca Beavers, Ph.D.
Coastal Geologist, Geologic Resources Division
12795 West Alameda Pkwy, Lakewood, Colorado 80228
303-987-6945 rebecca_beavers@nps.gov

Tim Connors
Geologist, Geologic Resources Division
12795 West Alameda Pkwy, Lakewood, Colorado 80228
303-969-2093 tim_connors@nps.gov

Joe Gregson
Natural Resources GIS Coordinator, Natural Resources Information Division
1201 Oak Ridge Drive, Suite 200, Fort Collins, CO 80525
970-225-3559 joe_gregson@nps.gov

Bruce Heise
Geologic Resources Inventory Coordinator, Geologic Resources Division
12795 West Alameda Pkwy, Lakewood, Colorado 80228
303-969-2017 bruce_heise@nps.gov

EXECUTIVE SUMMARY

A comprehensive geologic resource inventory and mapping program is necessary for the effective management of our coastal national parks. At present, the National Park Service (NPS) recognizes 97 coastal units that encompass more than 7,300 miles of shoreline. In coastal areas, surficial and subsurface geology are complexly intertwined with park flora, fauna, water, air, and cultural resources. In addition, relative sea-level rise, geologic hazards, and anthropogenic modifications create an immediate need for detailed geologic mapping in coastal areas. *Presently, no mapping products or standards exist to meet this need.* The Geologic Resources Inventory (GRI), cooperatively administered by the NPS Inventory and Monitoring Program and the NPS Geologic Resources Division, took an important first step in meeting the geologic and surficial landform mapping requirements of NPS coastal park units. The GRI coordinated and funded a Coastal Mapping Protocols workshop on June 25-27, 2002 at Canaveral National Seashore (CANA) to address coastal park mapping needs and coastal management issues. This workshop brought together 38 federal, state, academic, and private industry employees including park managers, coastal geologists, resource specialists, information technology specialists and inventory & monitoring coordinators, to establish coastal mapping protocols for Atlantic and Gulf coastal parks in the National Park Service. Workshop participants discussed coastal park management issues and formulated a draft list of Coastal Landform Mapping (CLM) units that should be incorporated into coastal geology mapping products. GRI staff members will integrate the identified coastal mapping units into the NPS Geology-GIS Data Model, the documented standard for digital geologic maps within the NPS. Building upon this list of mapping units, an inventory of the significant geologic resources contained within each coastal unit will be identified during GRI scoping meetings. In addition, scooping meetings will determine individual park mapping priorities and needs. The GRI will attempt to provide coastal National Park units with bedrock geology, surficial geology and/or landform mapping products. Mapping products should include GIS digital coverages, hard copy geologic maps, and/or supplemental information regarding significant geologic features and processes found within each park unit. When possible, the GRI may also supply coastal parks with existing bathymetric, topographic, and benthic habitat mapping coverage. These maps will provide the geologic framework and base cartographic information necessary for park managers to effectively monitor coastal change and shoreline dynamics. GRI coordinators have outlined several inventory action items and more specific project tasks related to CLM that will be included in the FY2003 GRI work plan (Appendix 8).

The participants of the Coastal Mapping Protocols Workshop strongly encouraged a holistic ecosystem approach for the effective management of our federally protected coastal parks. To understand the broad range of multi-faceted issues commonly confronting coastal park managers, coastal landform maps should be integrated with biological and physical system components, including vegetation, species habitat, and oceanographic variables. Park infrastructure, boundary information, shoreline engineering, and cultural resources may also be integrated with the final geologic map products. GRI staff members will work with coordinators of other Natural Resource inventories and their partners to identify and initiate possible integrated data collection and mapping projects. Cooperative projects may allow significant cost savings for the inventories and higher quality data products for park managers. These additional mapping components will increase understanding of complex coastal environments, allowing park managers to make better-informed and more effective management decisions.

DEDICATION

This report is dedicated to the late DR. JAMES R. ALLEN, a coastal geomorphologist in the U.S. Geological Survey and U.S. National Park Service. Jim was an active participant in the Coastal Mapping Protocols meeting and also conducted beach surveys at Canaveral National Seashore the days prior to and following this workshop. His input, insight, and passionate disposition will be missed. Jim died on July 30, 2002. He often said that he had the best job in the world, being paid to be on beaches throughout the coastal national parks. Jim received his Ph.D. at Rutgers University in the early 1970s where he was supervised by Norbert Psuty. Early in his career, Jim taught at Northeastern University in Boston and at the University of Arkansas. In 1981 Jim returned to Boston, to serve as a coastal geomorphologist for the Northwest Region of the National Park Service. Later his unit was transferred to the USGS. Jim was an avid empirical researcher. He delighted in being in the field and deploying equipment to conduct measurements and build data records. Jim could often be found in the field beside an array of current meters, pressure transducers, laser surveying gear, reels of cable, data loggers, and a portable generator to power the mix of equipment. Once back in the lab, Jim would download the data and analyze a wide variety of measurements. His publications and reports are data-rich and based on well-conceived study. He provided us with knowledge of the physical functions of coastal systems within the parks through publications, professional presentations, and internal reports.

Jim applied coastal science to coastal management concerns, including resource management and decision-making. He valued the beaches and dunes in the parks and used his scientific acumen to help guide the parks in their stewardship of these vital national resources. Through his knowledge of geomorphic mapping and dynamic sedimentary environments, Jim was able to guide resource management decisions by discussing the important scales of variability for each park. The maintenance of naturally functioning ecosystems was facilitated by lengthy and numerous discussions with park staff that led to a better-educated core of park administrators. Jim's fieldwork extended from Acadia National Park in Maine to Padre Island National Seashore in Texas. Most recently, Jim was active in developing a shoreline monitoring program for the Northeast coastal parks, using knowledge gained from many years of research in Cape Cod National Seashore, Gateway National Recreation Area, and Fire Island National Seashore. He was among the first coastal scientists to begin using dynamic-GPS equipment to record and track shoreline changes, and he built a historical database in the parks that is setting the standard for GIS applications in the coastal parks.

Jim was active in the disciplines of geography and geology. He held an office in a disciplinary coastal specialty group and regularly presented at national and international meetings. Most uniquely, Jim was able to simultaneously communicate his love of coastal sediment dynamics to the park ranger, park superintendent, and university colleague on the same site visit. His enthusiasm was unparalleled. His cadre of friends and fellow geomorphologists was spread around the world. He will be missed by all of us who knew him as a friend and a colleague.

Rebecca Beavers, Ph.D.
National Park Service, Coastal Geomorphologist
September 2002

ACKNOWLEDGEMENTS

We would like to gratefully acknowledge the employees of Canaveral National Seashore for aiding in workshop planning and coordination, and for allowing participant use of park resources for educational and recreational purposes. Special thanks to Bob Newkirk (Superintendent), John Stiner (Chief of Natural Resources) and Donald Mock (Geologist) for the use of the Eldora House and the 'turtle watch' tour. In addition, many thanks to Randy Parkinson, of the Coastal Technology Corporation, for conducting a very informative field trip through Canaveral National Seashore.

COVER PAGE CREDITS

Geologic map of Florida highlighting Canaveral National Seashore park boundaries. This map illustrates that a surficial geologic map of coastal parks is not sufficient for solving complex coastal management issues. The homogenous geologic divisions do not adequately portray dynamic coastal environments and geological variability.

Data sources: Florida Geologic Survey and National Park Service (park boundary layer)
Cover design: Matt Schaefer, GIS Technician, NPS Geologic Resource Division.

TABLE OF CONTENTS

APPENDICES

INTRODUCTION

The NPS Geologic Resources Inventory Program (GRI) hosted a Coastal Mapping Protocols Workshop for Atlantic and Gulf National Park Units on June 25-27, 2002 at Canaveral National Seashore. Workshop participants included coastal geologists, park managers, natural resource specialists, information technology consultants, and inventory and monitoring coordinators (Appendix 2). The purpose of this workshop was to establish GRI mapping protocols for National Parks along the Atlantic and Gulf coasts. Workshop participants discussed coastal geologic mapping needs and formulated a list of specific mapping units for coastal parks. The major coastal map units chosen include Anthropogenic, Supratidal, Intertidal, Subtidal, and Coastal-Riverine features. This list of coastal map units will be revised as park-specific needs are identified during future individual coastal park GRI Scoping meetings. GRI staff will integrate the identified coastal mapping units into the NPS Geology-GIS Data Model, the documented standard for digital geologic maps within the NPS. Extremely complex features and processes characterize coastal environments. Workshop participants strongly recommended that biological and physical components should be integrated into coastal mapping products. These mapping units are related to landforms and include, but are not limited to, basic vegetation classes, identifiable species habitat, and geomorphic and oceanographic variables. In addition, mappable surface features such as cultural resources, park infrastructure and anthropogenic modifications may be integrated into coastal area maps for improved coastal zone monitoring and management. Through interagency partnerships, including but not limited to, the United States Geological Survey (USGS), National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA), state, academic, and private industry, the GRI will provide vital mapping products to coastal national parks as part of a comprehensive geologic resources inventory identified by the NPS Inventory and Monitoring Program. The GRI will provide each park with 1) a park specific bibliography of geologic literature and maps; 2) on-site evaluations of park geologic maps, resources, and issues; 3) a summary report with basic information on the park's geology, geologic hazards, issues, and existing data and studies; and 4) digital geologic mapping products with accompanying supporting information. The final mapping products will provide a baseline to aid in the understanding of geologic processes affecting coastal health and sustainability and in implementing an effective ecological monitoring program.

This report summarizes workshop proceedings and presents the final draft of coastal geology mapping units that will be utilized for mapping coastal landforms and features in Atlantic and Gulf coastal parks. In addition, this report may be used to assist coastal park managers to understand geologic mapping procedures. We have included a Federal contact list (Appendix 1), geologic resource inventory status (Appendix 7), and a coastal mapping unit checklist (p.20) to assist during future park-specific GRI scoping meetings.

COASTAL PARK MANAGERS AND GEOLOGIC RESOURCE MANAGEMENT

Many NPS coastal parks have a small number of employees who are required to fulfill a variety of functions including, but not limited to, administration, fire management, interpretive guidance, maintenance, law enforcement and public relations. In addition to these collateral duties, park managers (many with limited scientific backgrounds) are charged with the preservation and protection of coastal geologic resources within their care. It is critical that park managers are provided with the assistance necessary to make informed coastal management decisions. A detailed inventory of coastal geologic features and processes should be compiled within each coastal park. This process will require interagency, university, and private sector partnerships, and close communication among GRI and park staff, regional coordinators, and NPS coastal geology specialists. Also, the Geologic Resources Division, GRI staff, and other Natural Resource Program Center divisions will provide direct technical assistance to park staff for inventory and mapping needs. Coastal park managers should initiate and maintain communications and partnerships that will allow the pooling of resources, funding, and scientific expertise. In addition, GRI staff will host a geologic resource workshop for each park unit. These meetings are designed to assess the significant geologic resources and management needs of each coastal park Upon completion of a geologic resource inventory, it is vital that coastal park managers can access and interpret produced data to assist in coastal management decisions. Digital map layers will contain descriptive legends and associated graphics via clickable mapping units in ArcView GIS. This feature will provide readily accessible supplemental information on each geologic feature identified.

In addition, the GRI and the NPS coastal geology staff will provide technical support and map interpretation guidance when requested. The NPS Inventory and Monitoring Program will provide data management assistance and training, and the NPS GIS Program (Information Technology Center) can provide additional information concerning GIS resources including GIS training workshops. Combined, coordinated mapping efforts will establish relationships among park managers, GRI staff, NPS scientists, and non-NPS researchers that will continue to support critical decisions along NPS coastal areas.

MEETING SUMMARY

As the cover of this report demonstrates, standard geologic maps do not sufficiently illustrate the dynamic nature and geological variability of coastal environments. Presently, a mapping template does not exist that illustrates short and long-term changes in coastal features and processes, or the connections among geologic, biological and physical system components. Without this product, coastal park managers do not have the essential information necessary to make effective coastal management decisions.

The main purpose of the Coastal Mapping Protocols meeting was to bring together a small group of experts including geologists, coastal scientists, coastal park managers, information technology specialists, and inventory and monitoring coordinators to organize and design a comprehensive and beneficial mapping program for coastal National Park units in Atlantic and Gulf regions. Most importantly, coastal park managers identified specific coastal management concerns and geologic mapping needs. This information was then used to construct a new and innovative coastal mapping project for NPS coastal parks.

The first day of the workshop consisted of a field trip to Canaveral National Seashore (Appendix 4) to discuss site-specific mapping needs and procedures, and to investigate the geomorphology and ecology of the area.

Day two began with a welcome from Bob Newkirk, the Superintendent of Canaveral National Seashore and John Stiner, Chief of Resource Management at CANA. This was followed by an introduction and workshop agenda discussion by the NPS co-coveners, Rebecca Beavers, Tim Connors, Joe Gregson and Bruce Heise. The day progressed with presentations, including current mapping products and technologies, resource management concerns, inventories and monitoring of national parks, coastal vulnerability indexing (CVI), and NPS vital signs. These presentations sparked participant discussion and debate on coastal mapping protocols and procedures. This day ended with a social gathering at the Eldora House, and a midnight .turtle watch. hosted by John Stiner and Don Mock along Canaveral National Seashore.

On the final day of the workshop, the participants were divided into three working groups (marine, estuarine, and landform) during the morning breakout session. Each group discussed mapping needs and dilemmas, and formulated a list of specific mapping units (p.20) for their respective coastal area. In the afternoon, all participants reconvened to compile a workable list of geologic features for future mapping products. In addition, topics such as digital mapping processes, interagency cooperative agreements, costs, and final report content were discussed.

MOST IMPORTANT COASTAL MAPPING UNITS

The Geologic Resources Inventory will provide each coastal park unit with mapping products that define a park's geologic framework (i.e. bedrock geology) and/or geomorphic submerged and emergent features. When possible, available bathymetric, topographic and benthic habitat data will also be provided. This information will provide each park with the basic template to identify coastal change and shoreline dynamics.
This report includes known interagency and outside sources that may have access to or knowledge of existing mapping products. Additional sources should be identified to increase coastal mapping benefits to all partners.

1) Geologic Framework

Mapping needs
Coastal geologic mapping products should include surficial and bedrock geology. This geologic framework defines how the coast will evolve and will predispose some areas to more rapid change. Where feasible, Pleistocene and Holocene deposits should be differentiated and relict landforms should be assigned a consistent terminology. Surface and subsurface lithology should be included. In addition, regional geology should be discussed, using supplemental materials if necessary.

Example of Use
The geologic framework of older stratigraphic units often controls modern coastal dynamics and morphology. This is especially important on passive margins with limited sand supply such as is present over much of the Atlantic coast. Along Cape Hatteras National Seashore, more resistant units may influence sediment shoaling and shifts in shoreline position. For more information, please see Riggs, S., W.J.Cleary and S.W. Snyder, 1995. Influence of geologic framework on barrier shoreface morphology and dynamics. Marine Geology 126: 213-234.

Possible Sources
- National Park Service (NPS)'Geologic Resources Inventory (GRI)
- GEOINDEX and GEOREF databases
- U.S. Geological Survey (USGS)
- State Geological Surveys
- Ocean Drilling Project (ODP)
- Universities
- Private contractors

Mapping Considerations
Geologic mapping is time consuming and expensive. Although bedrock and surficial geologic maps are the base products of the GRI, to meet park needs in a cost-effective and productive manner, the National Park Service must form partnerships with other government agencies, universities, and private contractors.

Techniques
Currently, geologic framework protocols are not well defined for coastal areas, but it is critical information to predict coastal ecosystem evolution. The techniques used to map a region's geologic framework need to be refined through further studies. The shallow subsurface (~5-10m) may be mapped using shallow seismic or ground penetrating radar (if substrate is suitable) or hand augers.

2) Geologic Features (Geomorphology)

Mapping needs
Workshop participants compiled an extensive list of geomorphic features that should be included in the final geologic mapping products (p.21). Due to cost and time limitations, only the most significant of these features will be included in a coastal park map. Obviously, not all of the features listed will be found in all coastal parks. In addition, all landforms should be mapped with a consistent terminology so that the maps may be integrated on a regional or national scale. Supplemental information may include alternative terminology for landforms within a specific region. Submerged and emergent features should be represented on the same or linked coverages. Specific features for each park's map will be identified at the GRI scoping meetings. GRI staff will integrate the identified coastal mapping units into the NPS Geology-GIS Data Model, the documented standard for digital geologic maps within the NPS.

Example of Use
The North Carolina Geologic Survey is developing techniques for coastal landform mapping at Cape Hatteras National Seashore that may serve as a template for additional coastal units. This mapping is part of a coastal mapping cooperative spearheaded by USGS.

Possible Sources
- NPS - GRI
- USGS
- State Geologic Surveys
- Universities
- Private contractors

Mapping Considerations
Coastal geomorphologists will be needed to identify and differentiate many coastal geologic features. Because most parks do not employ geologists, parks must have outside expertise to accomplish this image interpretation and subsequent field verification. Where regional names exist for similar features, a uniform terminology should be applied and documented in the NPS Geology-GIS Data Model.

Techniques
Recent aerial imagery, high resolution digital elevation data, seabed imagery, and ground truthing in the field may be utilized for the mapping of geomorphic features.

IMPORTANT MAPPING UNITS

The GRI will attempt to obtain the following information for integration with coastal geomorphology and geologic framework map coverages. When accessible, the GRI will incorporate the best available bathymetric and topographic data, benthic habitat, shoreline engineering, and sediment characteristics into final mapping products. Where this information is not at a sufficient resolution, the GRI will seek to partner with other groups to acquire these data.

3) Bathymetry and Topography

Mapping needs
Maps should include seamless coverage of submerged to emergent features. It is critical that this link is made between NOAA bathymetric charts and USGS topographic maps. Joining these

coverages may require additional work along the shoreline, since many coverages use different datums. When feasible, all maps should be rectified to the same scale, with all maps produced at a scale of 1:24,000 or greater (1:12,000, etc.). An official definition of the shoreline will be required to produce standard mapping products.

Possible Sources

- USGS'Digital Topographic Map Layers (Inventory & Monitoring Base Cartography Inventory)
- National Oceanic and Atmospheric Administration (NOAA)'Bathymetric Maps
- NPS'GRI
- NPS'Inventory and Monitoring (I&M) Program
- NPS'Natural Resource Program Center (NRPC) NPS . GIS Program (Information Technology Center)

Mapping Considerations

The shoreline is difficult to define, and a consistent shoreline is difficult to measure. Most agencies use different datums for shoreline mapping. NOAA generally uses the Mean Lower Low Water (MLLW) mark as the datum for bathymetry charts, whereas USGS topographic maps extend to the Mean High Water (MHW) or Mean Sea Level (MSL) line. When these maps are joined, they will most likely not produce the same shoreline.

In shallow nearshore environments it is difficult to map slight elevation variations. Vegetation may be helpful for determining minor elevation differences. Interferometric sonar mapping appears to be most effective in shallow areas between 0-30m depth.

The frequency of coastal mapping is variable due to cost and time restrictions. Coastal areas should be mapped often (every 5-10 years?) because of short and long-term changes to topography and bathymetry caused by sediment transport and storm events. These changes begin approach the realm of monitoring, rather than inventory.

Inconsistent methodologies and mapping standards produce different levels of accuracy and resolution. Historic maps must often be utilized although they were created using out-dated technologies. Maps produced at different scales must be rectified at high resolution to be beneficial for coastal managers.

The National Academy of Sciences is currently defining coastal mapping standards for Federal, State and local governments. If these standards are approved, future mapping efforts will benefit from standardized digital information exchange between government agencies, and create more efficient and effective mapping and charting tools for our Nation's coasts. If national standards and data models are not available, the NPS will need to define and document its own coastal bathymetry/topography data model for consistent mapping and attribute data among NPS units.

Techniques

NOAA and the USGS have established a Bathy/Topo Java-based application that seamlessly merges bathymetric and topographic data from different sources using a Vertical Datum Transformation. NOAA has expressed interest in a collaborative partnership with the NPS to provide seamless coverage for coastal National Parks.

4) Sediment Characteristics - Grain Size, Composition, and Distribution

Mapping needs

Sediment characteristics including grain size, sorting and color descriptions should be integrated with coastal geology maps. Available information on sediment distribution, budget, and sources and sinks should be included in the mapping product. An understanding of a system.s sediment supply is critical for monitoring coastal areas and predicting shoreline change.

Possible Sources

- NPS'GRI
- NPS - Soil Resources Inventory (NRCS Soil Maps)
- NPS'Water Resource Inventories
- National Wetlands Inventory (NWI)
- USGS
- NOAA
- State agencies
- Ocean Drilling Project

Mapping Considerations

Sediment characteristics may change within small areas, making mapping difficult. Ground-truthing and laboratory analysis are time consuming and expensive. At a minimum, descriptions of sediment characteristics should be included in the legend of the coastal landform mapping discussed earlier.

Techniques

Field work during coastal landform mapping should include description of surface sediments and sediment cores (e.g., using hand augers or core drilling) to the extent that available resources allow. Side-scan sonar equipment can be used to define coarse or fine-grained sediments in submerged areas.

5) Benthic Habitat

Mapping needs

Important benthic habitats including coral reefs, shellfish beds, hardbottom, and submerged aquatic vegetation should be included in coastal landform maps. These features influence the hydrodynamic regimes within their localized areas, thereby determining sedimentation patterns. The location of these ecologically and economically vital resources must be known to determine the impacts that anthropogenic modifications may have on their survival. For example, heavy siltation caused by coastal development could suffocate shellfish beds, or excessive pollution may cause rapid die-off of coral reef populations. In addition, some aquatic vegetation such as eelgrass beds, are considered keystone species that promote increased biotic diversity and abundance in marine and estuarine environments. Coastal Park Managers must be aware of these resources and the effects that sediment transport may have on important ecological niches.

Possible Sources

- NPS'Natural Resource Inventories and I&M Networks
- NPS'NRPC
- NOAA
- NOAA's National Coastal Data Development Center (NCDDC). Coral Reef Information System (CoRis)
- NWI

Mapping Considerations

Many vitally important benthic habitats are small in size, and scattered throughout the coastal area. Although certain acoustic and optical technologies are useful in locating these features, ground truthing using SCUBA or underwater videography is most likely necessary to detail the scope of these habitats.

6) Shoreline Engineering

Mapping needs
Shoreline engineering structures may have a significant impact on sediment, hydrodynamics and shoreline geomorphology. All anthropogenic modifications to the shoreline should be mapped including, but not limited to: jetties, groins, seawalls, spoil deposits, riprap, and culverts.

Possible Sources

- NPS -Facilities Management
- NPS-GRI (Landform mapping)
- State governments
- US Army Corps of Engineers (USACE)
- Department of Transportation (DOT)

Mapping Considerations
Some park areas have been significantly altered by anthropogenic modifications for many centuries. For example, Native American middens are found throughout Canaveral National Seashore. Like middens, some features are difficult to locate and identify, especially dredge spoils, seawalls and rip rap when they are covered by sediment and vegetation. However these anthropogenic modifications must be identified in order to understand and predict shoreline change.

ADDITIONAL COASTAL MAPPING UNITS

The participants of the Mapping Protocols Workshop determined that a standard geologic map. Is not sufficient for highly dynamic coastal areas. Although the underlying geologic framework, surficial sediments, and geomorphology will provide the basis for understanding coastal geologic features, an integrative, holistic approach is necessary for effective coastal management due to the complex ecological interactions that govern coastal change. For a coastal *geology* map to be beneficial, it must integrate the biological and physical components of the coastal zone, which are closely related to associated landforms. The integration of landforms and associated ecosystem units into one comprehensive mapping product will aid park managers who are commonly confronted with multi-faceted coastal geology issues. To effectively resolve these issues, coastal managers require a broad understanding of the intricate links between sediment movement (erosion and accretion), grain size, biological habitats, hydrodynamic regimes, salinity, temperature, vegetative cover, tides and prevailing currents. When possible, the following mapping themes should be integrated with coastal landform mapping products. Due to funding and time restraints, the GRI will provide this information only when it may be readily acquired or derived during coastal landform mapping, but may provide additional technical assistance to park managers wishing to obtain this data. In addition, park managers may seek direct partnerships with other NPS divisions, government agencies and universities to acquire this information. We have included known interagency and outside sources that may have access to, or knowledge of existing mapping products. Additional sources should be identified to increase coastal mapping benefits.

1) Vegetation

Mapping needs
Vegetation found in coastal environments such as wetlands, marshes, dunes, mangroves and maritime forests should be incorporated with coastal geology maps for the following reasons:

- Vegetation, especially hydrophytes, strongly influences sediment deposition and hydrodynamic regimes.
- Vegetative associations may reveal slight differences in surface elevation and salinity.
- Vegetation aids dune and shoreline stability.

Example of use
Wetland environments have distinct vegetation zones created by changes in elevation, salinity and hydroperiod. Therefore, wetland vegetation may possibly be used to identify topographic and oceanographic variables and identify landform types.

Possible Sources
- NPS/USGS Vegetation Inventory
- NPS Biological Resources Management Division
- USGS - Biological Resources Division
- National Wetlands Inventory
- Bureau of Land Management (BLM)
- U.S. Fish and Wildlife Service (USFWS)
- Universities
- State Surveys

Mapping considerations
Most vegetation mapping programs utilize aerial and satellite technologies that only show vegetation associations, not specific species. Vegetation maps of submerged aquatic vegetation may require additional funding, because they are not funded by most vegetation mapping projects. Many technologies, such as Airborne Topographic Mapping (ATM) and Light Detection and Ranging (LIDAR) elevation data, have a difficult time resolving the extent of vegetation cover. However, new technologies such as Experimental Advanced Airborne Research Lidar (EAARL), will provide better resolution of vegetation cover. Cooperative data acquisition and mapping among the NPS/USGS Vegetation, NPS Geologic Resources, and NPS Soils inventories may be able to provide coastal parks with detailed data products to meet the management needs of coastal parks.

2) Threatened and Endangered Species Habitat

Mapping needs
Coastal resource inventories need to include threatened and endangered species distribution maps. Any anthropogenic modification to the coastal zone within, or adjacent, to park boundaries may have detrimental effects on protected species.

Example of Use
When sand replenishing on beaches is absolutely necessary within, or adjacent to, a park boundary, resulting changes in sediment load may have detrimental impacts on threatened and endangered species. Knowledge of preferred breeding grounds and seasonal trends in populations may influence the feasibility of shoreline engineering projects. Differences in grain size and sediment type may completely alter the quality and amount of habitat available for threatened and endangered species.

Possible Sources
- NPS Species Inventory
- NPS Biologic Resources Management Division
- NPS Vital Signs Monitoring Program

- Non-Profit Organizations
- Nature Conservancy

Mapping considerations
Many threatened and endangered species (especially marine organisms) are elusive and difficult to find, let alone map. Extant maps of threatened and endangered species are much more thorough for terrestrial species.

3) Oceanographic Variables

Mapping needs
Relative sea-level rise, temperature and salinity patterns, currents, tidal regimes, sediment budget, fresh/salt water interface within estuarine systems and upwellings are examples of oceanographic variables that are not well documented in most coastal park units.

Example of use
Dr. Greg Stone at Louisiana State University has used oceanographic instrumentation to measure physical processes near West Ship Island in Mississippi. These measurements were combined with beach profiles to document sediment dynamics near Fort Massachusetts. This fort is threatened by erosion, and available physical processes measurements were used to design a beach nourishment project in 2002 to protect the fort.

Possible Sources
- NPS/USGS . The Coastal Vulnerability Index (CVI) calculates the effects of relative sea level rise, tidal range, coastal slope, wave heights, shoreline erosion rates and geomorphology (relative erodibility) on the shoreline.
- NPS I&M Program . The I&M is funding acquisition of the 1:24,000 National Hydrography Dataset as part of its Water Resources inventories.
- NPS Vital Signs Monitoring Program
- NOAA

Mapping considerations
Salinity, water temperatures, currents and wave patterns may change daily, seasonally and/or yearly. Relative sea-level rise may be small (mm) and difficult to accurately measure. However, even the smallest sea-level rise may have a large impact on fragile estuarine and coastal environments. Although it is costly to maintain oceanographic instruments, a nationwide effort to develop a coastal observations system must be supported.

4) Park Boundaries

Mapping needs
Park boundaries must be determined to establish park jurisdiction and property rights. Offshore boundaries are extremely important to resolve legal issues such as mining rights, law enforcement, USACE dredging and disposal projects, etc. Coastal maps should incorporate areas outside of park boundaries. These areas should include external threats such as large developments and production plants. This is important when determining sediment transport (non-point source pollution, contaminated sediments, dredging and disposal impacts outside of park, etc.) The total area that should be included is an elastic boundary defined by system dynamics. The specific area included in each park map should be resolved during park scoping sessions. When possible, the map should include geologic and bathymetric data up to 5 miles offshore. Data collected outside

of park boundaries may be mapped at a lower resolution. Often, parks define this as their quadrangle of interest.

Example of use
The National Marine Fisheries Service notified Gulf Islands National Seashore (GUIS) of a U.S. Army Corps of Engineers (USACE) Preliminary Restoration Plan for the Fort McRee Dredged Material Disposal Area. USACE had proposed a variety of disposal scenarios that were located within congressionally authorized GUIS boundaries. In order to ensure protection of park resources and values within park boundaries, the NPS requested active participation in the Corps. planning process and monitoring activities. Without accurate knowledge of park boundaries, GUIS may not have been legally entitled to project intervention.

Possible Sources
- NPS . I&M Program
- NPS - GIS Program (Information Technology Center)
- Minerals Management Service (MMS) . Offshore boundaries
- BLM . Land boundaries
- USGS National Map

Mapping considerations
The Bureau of Land Management (BLM) maps to the Mean High Water (MHW) mark (what they refer to as the vegetation line), whereas the Minerals Management Service (MMS) determines offshore boundaries based on NOAA.s Mean Lower Low Water (MLLW) mark. Therefore, a large mapping gap exists between the MHW and MLLW lines. In addition, it is difficult to find a successful mapping methodology for the shallow nearshore zone (0-30m).

5) Cultural Resources and Park Infrastructure

Mapping Needs
Coastal Maps should integrate park infrastructure including, but not limited to, roads, restrooms, parking lots and visitor interpretation centers. Additional cultural resources such as archaeological sites, shipwrecks, quarries, and developed areas should also be accessible in integrated map coverages.

Example of Use
Erosional hot-spots, barrier island migration, and/or relative sea-level rise may influence relocation of park infrastructure and historic landmarks. Cape Hatteras National Seashore recently relocated the historic Cape Hatteras lighthouse due to natural barrier island migration, storm events and shoreline engineering. The integration of park infrastructure and important cultural resources with geologic maps is necessary to identify at-risk areas, and to make timely preparations and management decisions.

Possible Sources
- NPS GIS Program (National, Regional, and Park-based)
- NPS Facilities Management
- NPS Cultural Resources Programs
- NPS Submerged Resources Center
- NPS Base Cartography Inventory
- NPS Water Quality Inventory
- NPS I&M Program
- DOT

6) Miscellaneous Features

Mapping needs
Coastal mapping products should include cave and karst resources, natural springs, paleontological sites, flood-prone areas, and known mineral deposits.

Example of use
In January 1990, two visitors at Cape Hatteras National Seashore made a startling discovery. They found one of the most complete fossil walrus skulls found in the eastern United States. This fossil has shed light on past climate conditions, Gulf Stream current patterns, and our geological past.
Coastal park managers must be able to quantify the risk to these valuable resources from weathering and erosion. When located in coastal environments, fossils are easily exposed, and then lost, to wave action and storm events. Therefore, it is important for coastal managers to be familiar with a park's paleontological resources and to understand the threats confronting fossil preservation in coastal environments. Currently, park/regional GIS and I&M staff are GPS mapping paleontologic resources to assist park-monitoring efforts.

Possible Sources
. NPS . Known cave and karst resources, paleontological sites and mineral deposits, natural springs, shipwrecks
. NPS Vital Signs Monitoring Program
. NPS Geologic Resources Division (cave and karst, paleontology, disturbed lands, minerals oil and gas, etc.)
. MMS . Mineral deposits and claims
. NOAA . shipwrecks
. Federal Emergency Management Agency (FEMA) . Flood areas

Mapping considerations
Some sites may contain sensitive resources and location and attribute data that should only be accessible to park managers and NPS employees, whereas other sites may be for visitor use and enjoyment and should be made publicly available.

COASTAL GEOLOGY MAPPING FEATURES

The following is a list of coastal geology mapping features that may be incorporated into the NPS Geology-GIS Data Model and into final digital mapping products for each park unit. Not all of the features listed will be found within every coastal park. This checklist may be used as a reference for coastal park managers to compile a preliminary assessment of the geologic features found within their park boundaries to help facilitate the Geologic Resources Inventory. GRI scoping meetings are intended to assess the significant geologic features and processes located within National Park units. As of 2002, 78 parks have been scoped. 273 parks, including approximately 77 coastal units, with significant natural resources will ultimately be evaluated. Therefore, many managers of small or cultural coastal park units will be responsible for initiating the inventory and monitoring processes within their units. This will be successful if communication is established with national and regional coastal geology coordinators (Rebecca Beavers, (GRD) and Linda York (SER)), and interagency and university partnerships are formed. For assistance with coastal inventory and mapping projects, please see the list of federal contacts (Appendix 1).

The GRI will provide mapping products that include the geologic framework (both surficial and bedrock) and coastal landforms found within each park unit. When available, the GRI will also provide bathymetric and topographic data, sediment characteristics and benthic habitat maps to each park. Additional mapping units found in the following list may possibly be supplied by other NPS divisions or Natural Resource inventories (Water, Soil, Biological Resources, etc.), or from cooperative government agencies, universities and/or private consultants. GRI staff will work with coordinators of other Natural Resource inventories to identify and initiate possible integrated data collection and mapping projects. Cooperative projects may allow significant cost savings for the inventories and higher quality data products for park managers.

ANTHROPOGENIC FEATURES (Submerged to Emergent)

- Hazardous Materials
- Dredge Spoils
- Public (Non-Sensitive) and Sensitive Archeological Sites
- Middens
- Shipwrecks
- Shoreline Engineering Structures
- - Jetties
- - Groins
- - Seawalls
- - Piers
- - Rip Rap
- - Sand Tubes
- Propeller Scars
- Dredged Channels
- Borrow Sites
- Mosquito Ditches
- Impoundments
- Canals
- Artificial Levees
- Undifferentiated Mounds
- Undifferentiated Excavations
- Roads (Paved/Dirt)
- Railroads
- Docks/Marinas/Anchorages
- Dumps
- Culverts
- Dams
- Human Debris
- Artificial Reef
- Dune Walk-over
- Parking Lots
- Buildings
- Historic Structures (Lighthouses, Forts, Houses, etc.)

SUPRATIDAL ENVIRONMENTS

- Landslide Excavation & Deposits
- Vegetated/Unvegetated Beach Ridge

- Natural Debris
- Vegetated/Unvegetated Supratidal Flat
- Bluffs
- Dunes
- - Dune Ridge
- - Coppice
- - Complex (Discontinuous)
- - Isolated
- - Relict
- - Secondary
- - Active Blowout/Blowout Dune
- - Parabolic Dunes
- - Dune Swale
- - Deflation Troughs or Flats
- - Low Vegetated Ridge
- - Foredune
- - Vegetated/Unvegetated Dunes
- - Primary Dunes
- - Secondary Dunes

INTERTIDAL ENVIRONMENTS

Beach Environments

- Sediment Depth and Lithology
- Grainsize
- - Sand Beach
- - Mixed Sand and Gravel Beach
- - Gravel Beach
- - Boulder Beach
- Boulder Ramps
- Washover Fan/Overwash Deposits
- Spits
- Berm
- Ridges and Swales (Swash Bar)
- Beachrock

Marsh Environments

- High/Low Marsh
- Marsh/Wetland Levee
- Salt Pannes
- Salt Ponds
- Wetland Creek

INTERTIDAL/SUBTIDAL FLAT ENVIRONMENTS

- Bioherms (Oyster, Mussel, etc.)
- Channel Levee
- Algal Flat
- Eelgrass Flat
- Seaweed Flat

- Veneered Ramp
- Wind-Tidal Flat
- Tidal Flat
- Vegetated/Unvegetated Bottom
- Sediment Flat Type
- - Coarse-Grained Flat
- - Mud Flat

SUBTIDAL ENVIRONMENTS

- Tidal Channels
- Estuarine Channel
- - Estuarine Flood Channel
- - Estuarine Ebb Channel
- Inlet Channel
- Relic Inlet Channel
- Channel Slope
- Ebb-Tide Delta
- Flood-Tide Delta
- Coral Reefs
- Hard Bottom
- Soft Bottom

COASTAL-RIVERINE SYSTEMS

- Strandplain Beach
- Swamp Forest
- Upland Swamps
- Creeks-Rivers
- Riverine Cutbanks (Ledges)
- Wave-Cut Cliff
- Fluvial-Estuarine Channel
- Point or Lateral Bars
- Oxbow Lake
- Floodplain
- Crevasse Splay
- Alluvium

MISCELLANEOUS

- Spillover Lobe
- Geologic Hazards (Sinkholes, Slide Areas, etc.)
- Relict Reefs and Features (Pleistocene)
- Abandoned Channels
- Karstic features
- - Rillen-Karren
- - Poljes
- - Eolian Calcarenite
- - Sea Caves
- Mineral/Hydrocarbon Resources

- Sand Resources (areas of identified potential or exploited)
- Groundwater Seeps/Springs
- Geologic Framework
- - Structure (faults, folds, etc.)
- - Stratigraphy (delineated by structure contour and isopach maps; will show paleochannels)

BOUNDARIES

- Park Boundary
- Mean High Water and Mean Low Water Lines
- Shoreline
- Submarine Escarpments

SENSITIVE PARK SITES
- Caves
- Paleontological Resources
- Cultural Resources
- - Shipwrecks
- Mineral Deposits

Appendix 1 FEDERAL CONTACTS

AGENCY AND DIVISION Contact *Position*

Rebecca Beavers
Coastal Geologist
303-987-6945
rebecca_beavers@nps.gov
Assists coastal park managers with coastal erosion issues; coordinates current coastal mapping protocols program for the NPS; USGS Coastal and Marine liaison.

Pete Biggam
Soil Scientist
303-987-6948
pete_biggam@nps.gov
Coordinates soil surveys and soil research; will provide technical expertise and guidance in park soil inventories.

Julia Brunner
Policy and Regulatory Specialist
303-969-2012
Julia_F-Brunner@nps.gov
Provides National and park-specific policy and regulatory expertise in coastal management issues; can provide assistance with park boundary and NPS jurisdiction information.

Tim Connors
Geologist - GRI
303-969-2093
tim_connors@nps.gov
Provides information on existing park digital products; coordinates GRBIB; plans and conducts park scoping meetings.

Bruce Heise
Geologist - GRI
303-969-2017
bruce_heise@nps.gov
USGS and AAGS liaison; coordinates and conducts park scoping meetings; provides GRI administrative support.

Ron Kerbo
Cave Specialist
303-969-2097
ron_kerbo@nps.gov
Assists in cave and karst resource management,and protection; coordinates cave and karst research and cave cartographic projects; will assist in cave/karst projects and management planning documents; will provide cartographic information to parks.

Greg McDonald
Paleontologist
303-969-2821
greg_mcdonald@nps,gov

Assists in paleontologic resource inventory and protection; coordinates paleontology research programs; has proposed a standardized GPS paleontology mapping program that will automate database management; will assist parks with mapping paleontological resources.

National Park Service Geological Resources Division
WASO . Lakewood, CO

Dave Steensen
Geologist . Disturbed Lands
303-969-2014
dave_steensen@nps.gov
Will provide action plan to parks to assist in disturbed lands mapping; administers funding for disturbed lands inventories; developing standardized inventory template and guidance sheets for coastal parks.

Crista Carroll
Geographer
404-562-3113 X528
crista_carroll@nps.gov
GIS coordinator for National Parks within the Southeast Region; provides technical assistance with data acquisition and standards; arranges GIS training courses for park managers.

Larry West
Inventory and Monitoring Program Natural Resource Specialist
404-562-3113 x526
larry_west@nps.gov
Inventory and Monitoring Coordinator for the Southeast Region.

National Park Service Southeast Regional Office Atlanta, GA

Linda York
Coastal Geomorphologist
404-562-3113 x537
linda_york@nps.gov
Provides scientific expertise to assist in resolving coastal management issues; assists in pooling GIS technologies and technical expertise for small parks.

National Park Service Northeast Regional Office Boston, MA

Mary Foley
Chief Scientist
617-223-5024
mary_foley@nps.gov
Chief Scientist of the Boston Support Office of the Northeast Region.

AGENCY AND DIVISION Contact *Position*

Jim Tilmant
Fisheries Biologist
970-225-3547
jim_tilmant@nps.gov
Provides information on status of NPS coral reef mapping products; assists in coral reef protection and management; coordinates NPS coral reef research

Dean Tucker
Natural Resource Specialist
970-225-3516
dean_tucker@nps.gov
Provides Horizon reports (water quality assessments) to the NPS.

National Park Service Water Resources Division

Joel Wagner
Hydrologist
303-969-2955
joel_wagner@nps.gov
Coordinates wetland projects and information for the NPS; will assist in coordinating research and management of wetland resources; provides contact information for obtaining USFWS National Wetlands Inventory mapping products and data.

National Park Service Information Technology Center WASO. Lakewood, CO

Leslie Armstrong
GIS Coordinator
970-969-2965
leslie_armstrong@nps.gov
Coordinates GIS mapping products and NPS standards; organizes and conducts GIS training workshops for NPS park employees; coordinates data acquisition with outside sources; coordinates NPS data clearinghouse; has acquired 3-4 years of NPS coastal data for park distribution.

Joe Gregson
Natural Resources GIS coordinator
970-225-3559
joe_gregson@nps.gov
GIS and database technical support; assists in park scoping coordination.

National Park Service Natural Resource Information Division

Mike Story
Remote Sensing Specialist
303-969-2746
mike_story@nps.gov
Provides vegetation mapping products to parks; coordinates vegetation inventory, mapping and product distribution.

John Brock
Geologist
727-803-8747 x3088
jbrock@usgs.gov
Can provide technical expertise and research coordination with LIDAR; conducting numerous mapping projects with NPS and NASA.

John Haines
Coastal and Marine Program Manager
703-648-6422

Jhaines@usgs.gov
Program manager of USGS Coastal and Marine Geology.

United States Geological Survey

Asbury Sallenger
Geologist
727-803-8747 x3015
asallenger@usgs.gov
Administers National Shoreline Assessment Program.

Peter L. Grose
Estuarine Bathymetry – Special Projects
(301) 713-3000 x132
mapfinder@nooaa.gov
Provides DEMs of estuarine topography from more than 71 estuaries, many located in the Southeastern US.

National Oceanic And Atmospheric Association National Ocean Service

Bruce Parker
Chief, Coast Survey Development Lab
301-713-2801 x121
Bruce.Parker@noaa.gov
Development of Bathy/Topo mapping tool to provide seamless coverage between NOAA bathymetric maps and USGS topographic maps; suggests USGS-NOAA-NPS partnership to apply Bathy/Topo program to coastal National Park mapping products.

AGENCY AND DIVISION Contact *Position*

National Oceanic And Atmospheric Association
National Coastal Data Development Center

John Stinus
Director of NCDDC
228-688-3450
Joe.Stinus@noaa.gov
The NCDDC will connect coastal managers to available digital data information; major programs of focus include the following: coastal risk, harmful algal blooms, homeland security,marine invasive species, fish habitat, integrated sustained ocean observing system, and coral reefs.

National Oceanic And Atmospheric Association
Coastal Services Center
http://www.csc.noaa.gov/
843-740-1200

Leland F. Thormahlen
Chief, Mapping and Boundary Branch
303-275-7120
Leland.Thormahlen@mms.gov
May provide assistance to parks to map offshore boundaries and establish park jurisdiction.

Mineral Management Service

Robert Johnson
Cartographer, Mapping and Boundary Branch
303-275-7186
Robert.E.Johnson@mms.gov
May provide assistance to parks to map offshore boundaries and establish park jurisdiction.

Bureau Of Land Management

Daniel Mates
Cadastral Surveyor
Dan_Mates@co.blm.gov
BLM will resurvey land when requested; map shoreline at MHW mark (what they consider the vegetation line); would like to coordinate with NOAA definition of official MHW.

US Fish & Wildlife http://www.fws.gov/ *National Wetlands Inventory*
http://www.nwi.fws.gov/
US Army Corps Of Engineers
http://www.usace.army.mil/

Appendix 2 WORKSHOP PARTICIPANTS

LAST NAME FIRST NAME AGENCY AFFILIATION TITLE PHONE E-MAIL

Allen Jim federal USGS-BRD Geologist 617-223-5058 james_allen@usgs.gov
Armstrong Leslie federal NPS-ITC GIS 303-969-2964 leslie_armstrong@nps.gov
Beavers Rebecca federal NPS-GRD Geologist 303-987-6945 rebecca_beavers@nps.gov
Bilecki Michael federal NPS-FIIS Natural resources 631-289-4810 ext. 234 michael_bilecki@nps.gov
Brock John federal USGS-CMG Geologist 727-803-8747 ext. 3088 jbrock@usgs.gov
Bryant Richard federal NPS-TIMU Natural resources 904-221-7567 ext. 15 richard_bryant@nps.gov
Carroll Crista federal NPS-SER GIS 404-562-3113 ext.528 crista_carroll@nps.gov
Connors Tim federal NPS - GRD Geologist 303-969-2093 tim_connors@nps.gov
Conzelmann Paul federal NPS-SER Network coordinator 337-266-8839 paul_conzelmann@nps.gov
Daniels Carol federal NPS-SER CESU coordinator 305-361-4904 carol_daniels@nps.gov
Davis Gary federal NPS-WASO/CHIS Marine ecologist 202-208-3574 gary_davis@nps.gov
DeStoppelaire Georgia federal USGS-CMG Geologist 727-803-8747 gdestoppelaire@usgs.gov
DeVivo Joe federal NPS-SER Network coordinator 404-562-3113 ext. 739 joe_devivo@nps.gov
Duffy Mark federal NPS-ASIS GIS 410-641-1443 ext. 219 mark_duffy@nps.gov
Ebert Jim federal NPS-CAHA Natural Resources 252-473-2111 ext. 132 jim_ebert@nps.gov
Farrell Kathleen state AASG-NCGS Geologist 919-733-7353 ext. 23 kathleen.farrell@ncmail.net
Gregson Joe federal NPS, - NRID Physical scientist 970-225-3559 joe_gregson@nps.gov
Haines John federal USGS-Coastal and Marine Geology Geologist 703-648-6422 jhaines@usgs.gov
Harris Melanie federal USGS-CMG Geologist 727-803-8747 mharris@usgs.gov
Heise Bruce federal NPS - GRD Geologist 303-969-2017 bruce_heise@nps.gov
Hoffman Bill state AASG-NCGS Geologist 919-733-7353 ext.25 bill.hoffman@ncmail.net
Hoggard Riley federal NPS-GUIS Natural Resources 850-934-2617 riley_hoggard@nps.gov
Hutcherson Charlie academic FIT/Coastal Technology Corporation Coastal engineer 321-751-1135 chutcherson@coastaltechcorp.com
Kevill Cliff federal NPS-FOPU Park ranger 912-786-5787 cliff_kevill@nps.gov
Littman Sherri academic NPS-TIMU Geocorps GIP 904-641-7115 caribe.l@att.net
Mcmullen Ken federal NPS-PAIS Natural resources 361-949-8173 ken_mcmullen@nps.gov
Milstead Bryan federal NPS-NER Network coordinator 410-874-4603 bryan_milstead@nps.gov
Morrison Doug federal NPS-EVER Marine Biologist 305-852-0327 douglas_morrison@nps.gov
Nelson Kim consult NPS-GRD Geologist 303-969-2315 kim_nelson@partner.nps.gov
O'Neal Jerry federal NPS-SER Chief Scientist 404-562-3113 ext. 517 Jerry_oneal@nps.gov
Parkinson Randy consultant Coastal Technology Corporation Geologist 321-751-1135 rparkinson@coastaltechcorp.com
Patterson Matt federal NPS-SER Network coordinator 305-230-1144 ext. 3082 matt_patterson@nps.gov
Phillips Eleyne federal USGS-CMG Geologist 650-329-4921 ephillips@usgs.gov
Riggs Stan academic Eastern Carolina University Geologist 252-328-6015 riggss@mail.ecu.edu
Schaub Ron Consultant federal Dynamac Corp-NASA and Kennedy Space Center Remote Sensing Analyst 321-867-2112 ronald.schaub-1@ksc.nasa.gov
Stiner John federal NPS-CANA Natural Resources 321-267-1110 john_stiner@nps.gov
West Larry federal NPS-SER IM coordinator 404-562-3113 ext. 527 larry_west@nps.gov
York Linda federal NPS-SER Geologist 404-562-3113 ext. 537 linda_york@nps.gov

Appendix 3: Workshop Agenda

AGENDA
National Park Service Coastal Mapping Protocols Meeting
Canaveral National Seashore June 25-27

June 25 7:30 - 4:40 **Field Trip:** Canaveral National Seashore (Appendix 4)
June 26
8:00 **Welcome:** Bob Newkirk and John Stiner (NPS-CANA)
8:10 **Introductions & Purpose:** Bruce Heise, Rebecca Beavers
8:20 **Coastal Geology Overview of NPS Resources**: Rebecca Beavers
- Overview of Northeastern Coastal Park Geological Resources, Jim Allen, USGS-BRD
- Overview of Southeastern Coastal Park Geological Resources, Linda York, NPS-SER

8:50 Geologic Resource Inventory Program, Bruce Heise (NPS-GRD), Tim Connors (NPS-GRD), Joe Gregson (NPS-NRID)
9:30 Looking at Soil Resources as a Component in Coastal Resources Inventory, Ken McMullen, NPS-PAIS
9:45 GIS Program ***and*** Data Standards, Leslie Armstrong, NPS-ITC
10:00 Break
10:15 **Resource Managers Concerns**
Discussion leaders- Mike Bilecki (NPS-FIIS) and Cliff Kevill (NPS-FOPU)
11:15 Southeast Region NPS Inventory and Monitoring Program, Larry West, NPSSER
11:30-1:00 **Lunch**
1:00 Northeast Region Coastal & Barrier Network: Geomorphology Monitoring Program, Mark Duffy, NPS-ASIS
1:30 Vital Signs Monitoring and Marine Mapping Based on Airborne Remote Sensing, John Brock, USGS-CMG
2:00 Existing Coastal Map Products in Other Agencies, Linda York, NPS-SER
2:30-3:00 **Break and Posters**
3:00 NCGS/USGS/ECU Coastal Mapping of NPS units: Cape Hatteras National Seashore, Kathleen Farrell (NCGS) and Bill Hoffman (NCGS)
3:30 **Cape Lookout National Seashore Mapping**, Stan Riggs, ECU
4:00 Mapping Relative Coastal Vulnerability to Future Sea-Level Rise in the National Seashores, Rebecca Beavers, NPS-GRD
4:15 - 4:45 **Marching Orders/ Identify Working Groups**

June 27
8:00-11:30 **Breakout Sessions** to identify physical coastal features that can be captured on a map to assist park managers in making sound resource decisions.
11:30-1:00 **Lunch**
1:00 - 4:00 **Discussion**

1. Boundary Issues
2. Priorities
3. How to obtain raw data for map
4. Inventory report topics
5. NRBIB-GRBIB

Appendix 4: Field Trip Description

Field Trip to Canaveral National Seashore . June 25, 2002

A field trip to Canaveral National Seashore (CANA) was held on the first day of the Coastal Mapping Protocols Workshop. Dr. Randy Parkinson, a geologist with Coastal Technology Corporation, introduced 25 participants to the geomorphology and ecology of this area. The day was spent investigating the coastal areas of Canaveral, by traversing an east-to-west transect of the southern portion of the park. The four distinct geomorphic terrains in this region include 1) dune, 2) ridge and swale, 3) western, and 4) marsh. The *dune* terrain consists of recent, wave-dominated shorelines and aeolian dunes. The *ridge and swale* terrain is characterized by undulating topography resulting from a progradational beach ridge complex formed during a Pleistocene sea level high stand. The *western* terrain is typified by undistinguishable beach ridges and sinkhole depressions. Finally, the *marsh* terrain contains numerous circular marshes and lakes, resulting from underlying late-Cenozoic sub-surface karstic formations. Each of these unique areas is home to distinct ecosystems, demonstrating the vital relationship between geology and ecology. The field trip included stops at the following locations:

1. **Canaveral beach** (pavilion). The initial stop provided an overview of the modern coastal dune system and late Pleistocene ridge and swale geomorphic terrains. The dune system is narrow (1 primary ridge) and consists of classic clastic beach sediments, flora and fauna.

2. **Marsh impoundments**. A drive within the ridge and swale terrain provided a view of impounded wetlands, open water and hammock environments. Much of the hydrology in this geomorphic terrain has been altered by infrastructure and water managementstructures that alter water levels and hydroperiod.

3. **Riverbank** (near bridge). In addition to the unconsolidated late Pleistocene and Holocene sediments of the region, outcrops of coquina are exposed seaward of the modern coastal dune system and lie at or very near the surface at most locations. At Haulover channel, constructed earlier this century, exposures of coquina rock and residual soils are present along the margins of this anthropogenic feature. The age of this limestone is estimated at 120kbp, and it is thought to have formed within the coastal zone during a former sea level highstand. This location is at the boundary between the ridge and swale and western geomorphic terrains.

4. **Marsh**. In driving westward from the coquina outcrop, participants crossed the western terrain, a mesic floral environment established upon unconsolidated quartz sand and thin (<10 . 30 cm) residual organic-rich soil. Still further west, along the landward margin of the Refuge lies impounded marsh, the fourth and final geomorphic terrain. This area has been aggressively managed for mosquito and waterfowl for more than 5 decades and is highly deranged. Most of the salt- and fresh-water wetlands, hammock, or open water in this landscape is an artifact of surface water management.

Numerous discussions arose throughout the field trip concerning difficulties involved in mapping coastal areas. For example, what defines a natural landscape, and how do you recognize a disturbed landscape? Due to extensive anthropogenic manipulations (impoundments, dikes, dune building, middens, levees, etc.) there are few areas in Canaveral National Seashore left unaltered. In addition, this trip stressed the importance of combining surficial geology with the underlying geologic framework in order to effectively manage this coastal environment. It appears that most of the geomorphic features found within this vicinity result from the interactions between surficial sediment deposition, late-Quaternary sea level changes, and the dissolution of late-Cenozoic limestone. Currently, Canaveral National Seashore (CANA) is managed through multi-agency cooperation between the National Park Service (NPS), National Aeronautics and Space Administration (NASA) and the US Fish and Wildlife Service (FWS). Kennedy Space Center is located adjacent to the southern boundary of CANA. NASA owns the lower two-thirds of the lands that the NPS manages including various support facilities, camera sites, and observation towers that require restricted access for National security concerns. In addition, FWS manages water levels in lagoons and impoundments that provide extensive bird habitat on Merritt Island National Wildlife Refuge.

Appendix 5: Establishing a Geologic Baseline of Cape Canaveral.s Natural Landscape: Black Point Drive

2000 NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM
JOHN F. KENNEDY SPACE CENTER
UNIVERSITY OF CENTRAL FLORIDA
ESTABLISHING A GEOLOGIC BASELINE OF CAPE CANAVERAL.S NATURAL LANDSCAPE: BLACK POINT DRIVE

Randall W. Parkinson, Ph.D., P.G.[2]
Florida Institute of Technology, Melbourne, Florida 32901
KSC Colleague: Kelly Gorman, Division of Safety, Occupational Health & Environment

ABSTRACT

The goal of this project is to identify the process responsible for the formation of geomorphic features in the Black Point Drive area of Merritt Island National Wildlife Refuge/Kennedy Space Center (MINWR/KSC), northwest Cape Canaveral. This study confirms the principal landscape components (geomorphology) of Black Point Drive reflect interaction between surficial sediments deposited in association with late-Quaternary sea-level highstands and the chemical evolution of late-Cenozoic sub-surface limestone formations. The Black Point Drive landscape consists of an undulatory mesic terrain which dips westward into myriad circular and channel-like depression marshes and lakes. This geomorphic gradient may reflect: (1) spatial distinctions in the elevation, character or age of buried (pre-Miocene) limestone formations, (2) dissolution history of late-Quaternary coquina and/or (3) thickness of unconsolidated surface sediment. More detailed evaluation of subsurface data will be necessary before this uncertainty can be resolved.

1.0 INTRODUCTION

The origin of Merritt Island National Wildlife Refuge and Kennedy Space Center's (MINWF/KSC) unique ecosystems can be attributed in large part to the region's distinct geomorphology and associated geologic processes. The goal of this project is to identify the processes responsible for the formation of geomorphic features in the Black Point Drive area of MINWR/KSC, northwest Cape Canaveral (Figure 1). Without a basic knowledge of the origin and evolution of these features, any effort to manage the landscape or restore the function and value of an ecosystem becomes problematic. For example:

a. What did the *natural* landscape look like before human alteration?
b. What *natural* processes contributed to the formation of this landscape?
c. How do we recognize a *disturbed* landscape?
d. How is success quantified in a restoration or management program?

This project is designed to provide baseline geologic information useful to a land manager charged with maintaining functional ecosystems and restoring those altered by human activity. The decision to focus on Black Point Drive (Figure 1) was based upon (1) logistics and (2) prompt applicability. Much of the landscape in the area is accessible from numerous improved and [2]current address - Coastal Technology Corporation, 715 North Dr., Suite G, Melbourne, Florida 32936. unimproved roads, making field inspection of points of interest relatively easy. In addition, the information gathered during this project could immediately be applied to an ongoing investigation of wetland management practices funded by the US

Environmental Protection Agency (EPA). In due time, other quadrants could be investigated following the format developed herein.

1.1 Objectives

In order to successfully complete this project, 5 objectives were pursued:

a. (1) Review relevant literature, surveys, maps, and aerial photography, and (2) interview field scientists active in study area.
b. Establish (1) principal landscape components and (2) a practical field program capable of being completed within time allotted.
c. Conduct fieldwork on select landscape components complimented with data obtained from the (1) surface (i.e., historical photography, thematic maps) and (2) subsurface (i.e., drill logs, core borings).
d. Analyze data and construct summary documents as an initial step in understanding the geomorphology and geologic processes.
e. Test the utility of this study by applying the results to an ongoing *EPA Wetlands Initiative* currently underway within the MINWR and awarded to this NASA Summer Faculty Fellow (Randall W. Parkinson).

1.2 Operational Hypothesis

Prior to the initiation of this project, the following operational hypothesis was established: *The principal landscape components (geomorphology) of Black Point Drive reflect interaction between surficial sediments deposited in association with late-Quaternary sea-level highstands and the evolution of late-Cenozoic sub-surface karstic formations.* This interaction requires the presence of sub-surface limestone formations and should be most obvious in the western portion of MINWR/KSC, where the sandy late-Quaternary overburden is thinnest and where landscape features generally indicative of pervasive limestone dissolution are most apparent (Figure 1).

2.0 BACKGROUND

2.1 Description of Study Area

Surface. The geomorphology of MINWR/KSC has been previously described by Brooks (1972) and references cited therein. More recently, Clark (1987) proposed four surface aquifer terrains (Figure 1): (1) dune, (2) ridge2(2 As positive relief features in this terrain are no longer active aeolian dunes, Clark.s (1987) label has been changed from dune & swale to ridge & swale.) & swale, (3) western, and (4) marsh. The soils and sediments of this region have just been reviewed by Schmalzer and others (2000). The *dune* terrain is located along the eastern margin of Cape Canaveral. The terrain consists of recent, wave-dominated shorelines and aeolian dunes reaching elevations in excess of 10 m. Sediments consist of mid- to late-Holocene skeletal quartz sand; soil formation is minimal and classified as coastal by Schmalzer and others (2000). The *rigde & swale* terrain occupies most of the landscape east of the NASA Parkway. In this region, an undulatory topography is present and known to have formed as a progradational beach ridge complex during a late-Pleistocene sea-level high stand (110,000 yrbp, see Brooks 1972). Landscape elevation and local relief are diagnostic of this terrain and responsible for the presence of narrow, parallel bands of xeric, mesic, and hydric habitats. Distinct soil types also map as parallel bands corresponding to recent plant communities and generally consist of shelly quartz sand with varying amounts of organic matter (coastal, acid scrub, flatwood or hammock soils). Quartz-rich silt and clay, associated with fresh- and salt-water soils are encountered in the hydric habitats of the ridge &

swale terrain. The Black Point Drive area lies primarily in the *western* terrain, located landward of the NASA Parkway. It consists of subdued to indistinguishable beach ridges and sink hole depressions (Brooks 1972). The area now hosts flatwood, hardwood hammock and freshwater-wetland plant communities. Surface sediments consist of shelly quartz sand, locally organic rich or muddy. These correspond to flatwood, hammock or freshwater wetland soils (Schmalzer and others 2000). Thin and discontinuous coquina rock formations have also been described from this area. There is ample evidence of limestone dissolution, including the presence of a micritic cap rock, caliche crusts, and circular depressions (Figure 1). The depressions contain freshwater wetland or open water. The landward margin of MINWR/KSC consists of *marsh* terrain. Blackish-water wetlands are the principal plant community as the landscape is <1 m above sea level. Perhaps the most diagnostic feature of the marsh terrain is the presence of open water features, such as circular lakes and dissolution(?) channels. The area.s surface sediment consists of shelly quartz sand and silt, locally enriched in organic matter or mud, and grouped into the saltwater wetland soil class.

Subsurface. Based upon the work of Brown and others (1962) and Clark (1987), the subsurface stratigraphy of MINWR/KSC is known to consist of five geologic age groups: (1) Recent, (2) Pleistocene, (3) Pliocene, (4) Miocene, and (5) Eocene (Table 1 and Figure 2). The Quaternary (Recent and Pleistocene) consist of undifferentiated marine quartz sand deposited in association with sea-level high stands and intermittently subjected to the subaerial processes of weathering and erosion. Radio-isotopic analysis (Brooks 1972) yields the following ages for prominent geologic features along a regional west to east transect: 110,000 yrbp, mainland and Atlantic Coastal Ridge; western Merritt Island, 240,000 yrbp; eastern Merritt Island, 110,000 yrbp; Banana River, 20,000 to 45,000 yrbp; Cape Canaveral, 7,000 yrbp to Recent. Black Point Drive is located in western Merritt Island and therefore upon a 240,000 year old succession of inter-bedded clastic and biogenic sediments.

Table 1. Stratigraphic units of northwest Merritt Island. After Brown and others (1962).
Geologic Age Stratigraphic Unit Depth (m) Description
Recent Pleistocene & 0 - 15 Skeletal quartz sand;
Recent deposits locally organic-rich
Pleistocene or coquina
Pliocene Upper Miocene or 15 - 25 Greenish-gray, sandy
Pliocene deposits fossiliferous marl
Miocene Hawthorn 25 - 40 Phosphatic greenish-gray, Formation sandy marl or clay
Eocene Ocala Group 40 - ? White to cream, friable and porous coquina; soft, chalky marine limestones

The underlying Pliocene to late-Miocene consists of sandy silt, clay, and marl known locally as the confining layer because it separates the surface aquifer from the regional (Floridan) aquifer. This contact is encountered at ~15 m. These sediments were deposited upon the Hawthorn Formation, a fine-grained, phosphatic Miocene marine deposit. Eocene limestones are encountered ~40 m below sea level. Geologic cross-sections (see Figure 12 and 13 in Brown 1962) suggest the contact between Eocene and Miocene deposits is very irregular, while the overlying contacts between the younger geologic age groups are nearly horizontal.

2.2 Methods

Surface. This project was initiated by undertaking a survey of historical photography. Images depicting various portions of Black Point Drive were obtained for the following years: 1943, 1973, 1984, 1995, and 1999. Inspection of photography provided information on natural (i.e., landscape submergence) and anthropogenic (mining, impoundment construction) processes which were active during historical times. A field program was then designed to catalog (1) surface sediments and soils, (2) plant communities, (3) submergent and emergent terrains, and (4) presence or absence of limestone beds exposed by natural (i.e., erosion) or anthropogenic (i.e., ditching) means. All sites were accessed using existing improved and unimproved roads.

Subsurface. Investigation of the subsurface geology was undertaken using: (1) remediation and groundwater monitoring well reports (i.e., Clark 1987, Universal 1998), (2) core samples (i.e., Wilson Corners Groundwater Remediation Site, provided by HSA Engineers & Scientists), (3) outcrops, and (4) literature (i.e., Brown and others1962).

3.0 RESULTS

3.1 Surface

The Black Point Drive area of MINWR/KSC consists of a featureless sandy surface gently dipping westward from ~3 m above sea level to ~0.5 m at the boundary with the marsh terrain. Inspection of surficial sediments indicates the presence of a shelly organic-rich quartz sand. The poor preservation of shell material (i.e., corroded, chalky) suggests this component of the sediment is actively undergoing dissolution. High organic content is a result of *in situ* production of roots and above-ground litterfall; both of which are probably contributing to acidic surface-water conditions and the chemical weathering of biogenic sediment. Plant communities within the Black Point Drive area consist primarily of slash pine flatwood, hardwood hammock, and freshwater wetlands. Flatwood plant communities are the most extensive habitat, extending from the eastern boundary of the study area westward into hardwood hammock and freshwater wetland. Towards the marsh terrain, flatwood plant communities become increasingly isolated and occur as patches within freshwater wetlands. Inspection of a number of these patches revealed an apparent association with coquina rock at or very near (<1 m) the surface. Open water is present at a limited number of sites and is generally indicative of the presence of an inactive, shallow limestone quarry. Inspection of historical photographs suggests mining operations were activated during the construction of impoundment dikes (late 1950s and early 1960s) and after completion of unimproved roads and drainage ditches (pre-1943). All but one of the mines are located in the flatwood habitat, an observation consistent with the possible affinity of this plant community towards coquina outcrops. Along the western margin of Black Point Drive open water is widespread and associated with topographic depressions. These too represent alterations to the natural landscape as they formed by management induced water level elevation. In areas of submergence, the surface sediment layer is often sandy and subjected to wave-induced physical reworking. Organic-matter accumulation is minimal and restricted to a basin=s low-energy embayments or Aleeward@ margins.

3.2 Subsurface

Inspection of well logs and core borings obtained from the Black Point Drive area revealed the presence of a stratigraphic succession consistent with that first published by Brown and others (1962). Late-Quaternary sediments are present in the upper ~15 m of the succession. Sedimentology, stratigraphy, and a knowledge of sea-level history suggests these marine sands were deposited during a late-Pleistocene (110,000 yrbp) sea-level highstand and subjected thereafter to subaerial processes of weathering and erosion. As the area has not yet been submerged during the most recent interval of deglaciation and concomitant sea-level rise, sediment *deposition* has been minimal. The only processes to modify the stratigraphic succession of Black Point Drive over the past 15,000 yrs are: (1) *in situ* production of organic material and

(2) reduction of skeletal content through dissolution. In select (n~3) core borings obtained from the Wilsons Corner groundwater remediation site (Figure 1) a thin (<0.5 m), highly weathered (chalky) limestone layer was observed in the upper 2 m. The effects of sub-aerial exposure are minimal below ~5 m. The preservation of marine molluscs is phenomenal at depths of 5 to 15 m. Many of the shells still retain their delicate architecture and color; they could easily be mis-identified as modern sediments if the stratigraphic context and local sea-level history were not known. Clay-rich beds of Pliocene-Miocene time are generally encountered at -15 m and these are clearly delineated from the overlying sediments by texture, composition, and color.
No recent cores have penetrated pre-Pliocene or Miocene sediments and therefore no new data were collected. Drilling to depths >15 m may compromise the integrity of the confining layer and induce contamination of the regional aquifer. All data describing these older sediments were obtained from Brown and others (1962). According to these authors, sediments deposited during Miocene and older times are present beneath the MINWR/KSC at a depth of ~25 m. The first occurrence of limestone was encountered within Eocene beds (Ocala Group) at a depth of at least 40 m (Figure 2). The limestone surface is highly irregular (c.f. Figures 12 and 13, Brown and others 1962), suggesting weathering and erosion lowered elevations significantly. The extremely high permeability of these marine limestones is indicative of karstification via groundwater dissolution. The relief of this irregular contact is not translated in the overlying beds, suggesting the karstification processes ceased prior to their deposition.

4.0 DISCUSSION

4.1 Relevance to Operational Hypothesis

There is abundant geomorphic evidence in the *western* and *marsh* terrains of Black Point Drive to infer limestone dissolution and the subsequent formation of a karstic landscape. This type of weathering requires a humid climate and the presence of limestone bedrock in close proximity to the surface. East central Florida is subjected to humid climatic conditions, however the first appearance of contiguous limestone formation within the stratigraphic succession of MINWR/KSC is at a depth of ~40 m. This is inconsistent with the operational hypothesis of this investigation; a karstic imprint on the landscape requires the presence of much shallower limestone beds undergoing dissolution during late-Quaternary times. Numerous limestone outcrops are present within Black Point Drive and evidence of chemical weathering is abundant, including: micritic cap rock, caliche crust, and circular depressions. However, the coquina layers are relatively thin (<1 - 2 m) and it is difficult to envision how their dissolution could produce extensive circular or channel-like depressions with a diameter or length in excess of 1 km (Figure 1).

4.2 Management Implications

This investigation collected data applicable to understanding the paleo-environmental evolution of Black Point Drive and the surrounding area. The mainland coast, Merritt Island, and Cape Canaveral are geomorphic features that formed in association with the following late-Pleistocene sea-level highstands: (1) 240,000 yrbp, (2) 110,000 to 125,000 yrbp, (3) 20,000 to 45,000 yrbp, and (4) modern. During these times, skeletal quartz sand accumulated along at the coastline, in some cases prograding seaward as an undulatory beach ridge complex. During intervening lowstands, these deposits were subjected to chemical weathering and erosion. The presence of extensive dissolution features within ~5 m of the surface indicates weathering initially induced pervasive near-surface leaching and localized cementation at greater depths. Subsequent lowstands subjected lithified shell beds to dissolution and the formation of karstic features thereafter. These landforms are most abundant in the western region of Merritt Island, decreasing eastward towards the ridge & swale terrain. The processes responsible for the observed gradient in karstic landform distribution are unclear at present. The gradient may reflect: (1) spatial distinctions in the elevation, character or age of buried (pre-Miocene) limestone formations, (2) dissolution history of late-Quaternary coquina, and/or (3) thickness of unconsolidated surface sediment. More detailed evaluation of *subsurface* data will be necessary before this uncertainty can be resolved.

The recent acceleration in late-Holocene sea-level rise, complemented by elevated water level management strategies, has prompted the formation of extensive wetlands during historical times. In areas of higher elevation, slash pine flatwood and hardwood hammock habitats remain. If these conditions persist, the expansion of brackish-water wetlands and invasion of hydric plant communities into mesic terrains can be expected. From a technical point of view, sedimentation within MINWR/KSC has been minimal and restricted primarily to the *in situ* production of organic matter and accumulation of surface litter. *Destructional* processes are widespread. In submerged areas, the surface layer is being reworked by wave-induced circulation. Soils beneath mesic terrains are undergoing dissolution via downward percolation of acidic surface water. Hydrologic conditions created by the most recent sea-level highstand and managed water-level elevations have probably minimized the potential effects of karstification on the area=s landscape. The long-term (decades) prognosis of wetlands will be solely dependant upon biogenic processes. In contrast to wetland areas of the Gulf of Mexico or the more northern Atlantic coasts, fine-grained inorganic sediment is not a significant component of the sediment budget. Wetlands will persist or even expand into adjacent areas only if organic-matter production and accumulation can keep pace with rising water level. Managers must therefore work to understand the biogenic processes of sedimentation and the potential effects of water level management.

5.0 CONCLUDING REMARKS

The Black Point Drive area of MINWR/KSC consists of extensive flatwoods, hardwood hammock and wetland habitats that have colonized late-Quaternary skeletal quartz sands. These sediments were deposited during a preceding sea-level highstand and are currently undergoing localized physical reworking and pervasive chemical dissolution. Although there is abundant geomorphic evidence of karstification in the western portion of Merritt Island, the conditions responsible for the formation of these landforms remain enigmatic. These features may have formed via the chemical dissolution of near-surface coquina beds and/or buried Eocene limestone. The effects of Holocene sea-level rise and water-level management have probably reduced the potential for continued karstification and expanded the distribution of brackish- and fresh-water wetlands. The long-term prognosis of wetland persistence will be dependent solely upon the rate of biogenic sediment production and accumulation relative to the change in water-level elevation induced by natural and anthropogenic factors. Therefore, land managers must consider the effects of current water management strategies on organic-matter production and accumulation if wetland protection is one of their mandates.

6.0 ACKNOWLEDGMENTS

The following scientists are acknowledged for their assistance: Melissa Hensley, Ross Hinkle, Mark Provancha, and Paul Schmalzer. Support was also provided by my NASA Colleague, Kelly Gorman. Inspection of subsurface data was made possible by Jim Hayman and Darcie McGee (HSA Engineers & Scientists). Access to field sites and permitting was granted by the US Fish and Wildlife Service and in particular Gary Popotnik and Mark Epstien. Ron Brockmeyer, St. Johns River Water Management District, is acknowledged for his support.

7.0 REFERENCES

Brooks, H.K., 1972. Geology of Cape Canaveral, p. 35-44, *in* T.E. Garner (ed.), Space-age geology. Southeastern Geology Society. Tallahassee, Florida.

Brown, D.W., Kenner, W.E, Crooks, J.W., and Foster, J.B., 1962. Water resources of Brevard County, Florida. Report of Investigations no. 28. Florida Geological Survey. Tallahassee, Florida.104 pg.

Clark, E.E., Engineers-Scientists, Inc., 1987. KSC subsurface hydrology and groundwater survey. Volume IV. The areawide groundwater survey program. KSC-DF-3081. Unpublished report by Edward E. Clark Engineers-Scientists, Inc., Kennedy Space Center, Florida. Contract no. NAS10-11293. NASA, John F. Kennedy Space Center, Florida.

Schmalzer, P.A., Hensley, M.A., Mota, M., Hall, C.R., and Dunlevy, C.A., 2000. Soil, groundwater, surface water, and sediments of Kennedy Space Center, Florida: background chemical and physical characteristics. Unpublished Open File Report, NASA Environmental Program Office, Mail Code JJD, Kennedy Space Center, Florida. 44 pg.

Figure 1. Cape Canaveral.s principal geomorphic terrains: (1) dune, (2) ridge & swale, (3) western, and (4) marsh (after Clark 1987). Black Point Drive located north of Banana Creek and west of NASA Parkway. Wilson Corners located across road at north end of landing strip.

Figure 2 (below). Cross-section of coastal stratigraphy in Brevard County, Florida, constructed using wells shown in inset. Asterisks (*) denote Black Point Drive. Vertical scale in ft (50 ft ~ 15 m). After Brown and others (1962).

Appendix 6: Coastal National Park Units

Coastal NPS Units:
10 Alaska (8 Gulf of Alaska; 2 Bering Sea)
18 Northeast (18 Atlantic)
25 Southeast (14 Atlantic; 11 Gulf of Mexico)
9 Intermountain (1 Gulf of Mexico; 8 reservoir/lakeshore)
28 Pacific West (12 Pacific Coast; 10 Pacific Islands; 6 reservoir/lakeshore)
7 Midwest (7 Great Lakes)
97 TOTAL (76 marine; 21 lakeshores)
Alaska (10)
Aniakchak NMP
Bering Land Bridge NP
Cape Krusenstern NM
Glacier Bay NPP
Katmai NPP
Kenai Fjords NP
Klondike Gold Rush NHP
Lake Clark NPP
Sitka NHP
Wrangell-St. Elias NPP
North Atlantic (18)
Acadia NP, ME
Assateague Island NS, MD/VA
Boston Harbor Islands NRA, MA
Boston NHP, MA
Cape Cod NS, MA
Castle Clinton NM, NY
Colonial NHP (Jamestown, Cape Henry), VA
Fire Island NS, NY
Fort McHenry NMHS, MD
Gateway NRA, NY/NJ
George Washington Birthplace NM, VA
Governor.s Island NM, NY
New Bedford Whaling NHP, MA
Sagamore Hill NHS, NY
Saint Croix Island IHS, ME
Salem Maritime NHS, MA
Statue of Liberty NM, NY/NJ
Thomas Stone NHS, MD
Southeast Atlantic (14)
Biscayne NP, FL
Canaveral NS, FL
Cape Hatteras NS, NC
Cape Lookout NS, NC
Castillo de San Marcos NM, FL
Cumberland Island NS, GA
Fort Caroline NM, FL
Fort Frederica NM, GA
Fort Matanzas NM, FL
Fort Pulaski NM, GA

Fort Raleigh NHS, NC
Fort Sumter NM, SC
Timucuan EHP, FL
Wright Brothers NM, NC
Gulf of Mexico (12)
Big Cypress NP, FL
Buck Island Reef NM, VI
De Soto NM, FL
Dry Tortugas NP, FL
Everglades NP, FL
Gulf Islands NS, FL/MS
Jean Lafitte NHPP, LA
Padre Island NS, TX
Salt River Bay NHP&EP, VI
San Juan NHS, PR
The Virgin Islands Coral Reef NM, VI
Virgin Islands NP, VI
Pacific Coast (12)
Cabrillo NM, CA
Channel Islands NP, CA
Ebey.s Landing NHR, WA
Fort Clatsop NM, OR
Fort Point NHS, CA
Golden Gate NRA (Presidio, Alcatraz), CA
Olympic NP, WA
Point Reyes NS, CA
Redwood NP, CA
San Francisco Maritime NHP, CA
San Juan Island NHP, WA
Santa Monica Mountains NRA, CA
Pacific Islands (10)
Haleakala NP, HI
Hawaii Volcanoes NP, HI
Kalaupapa NHP, HI
Kaloko-Honokohau NHP, HI
NP of American Samoa, AS
Pu.uhonua O Honaunau NHP, HI
Pu.ukohola Heiau NHS, HI
War in the Pacific NHP, GU
USS *Arizona* Memorial, HI
Great Lakes (7)
Apostle Islands NL, WI
Indiana Dunes NL, IN
Isle Royale NP, MI
Perry.s Victory and IPM, OH
Pictured Rocks NL, MI
Sleeping Bear Dunes NL, MI
Voyageurs NP, MN

Reservoirs/ Large Lakes (14)
Amistad NRA, TX
Bighorn Canyon NRA, MT/WY
Chickasaw NRA, OK
Crater Lake NP, OR
Curecanti NRA, CO
Glen Canyon NRA, UT
Lake Chelan NRA, WA
Lake Mead NRA, AZ/NV
Lake Meridith NRA, TX
Lake Roosevelt NRA, WA
Ross Lake NRA, WA
Whiskeytown NRA, CA
Yellowstone NP, WY/MT/ID
Yosemite NP, CA

For updates or additional information please contact:
Rebecca Beavers rebecca_beavers@nps.gov (303) 987-6945
For more information on specific parks:
http://www.nps.gov/parks.html
(NPS Update . 10/16/01 by R. Beavers)

Appendix 7: Status of NSP Coastal and Lakeshore Areas for Geologic Resources Inventory (GRI) as of September 25, 2002

3 Type is "C" for coastal parks with tidal influence; .L" is for lakeshore parks.
4 Scoping Meeting Status and if applicable, date performed.

PARK NAME

State
Park Type 3
Scoping Meeting 4
Digital Mapping Status
Summary

Acadia NP ME C no preliminary Maine GS published both bedrock and surficial maps at 50,000 scale in late 1980's; Karen Anderson at ACAD has digital files for each coverage. Needs reviewed for conformity with GRI model Amistad NRA TX L no inactive No information available.

Aniakchak NM AK C no preliminary Surficial geology by USGS for Ugashik quad in MrSid format; projected to Alaska Albers projection.

Apostle Islands NL WI L no inactive digital files for quarries and sand spits only Assateague Island NS MD C no inactive No information available

Bering Land Bridge Npres AK C no inactive Know Patricia Heiser doing some mapping here

Big Cypress Npres FL C no inactive No information available.

Bighorn Canyon NRA MT L no inactive MT GS has worked with BICA staff to produce waysides on park's geology; files available from GRI. Contain good write-ups of stratigraphy and geologic processes in the park.

Biscayne NP FL C no inactive No information available.

Boston Harbor Islands NRA MA C no preliminary http://www.nps.gov/gis/park_gisdata/massachusetts/boha.htm has surficial geology metadata and other information

Buck Island Reef NM VI C no inactive No information available.

Cabrillo NM CA C no inactive No information available.

Canaveral NS FL C no inactive No information available.

Cape Cod NS MA C no inactive USGS has website for their activities here; need more details from them; http://woodshole.er.usgs.gov/epubs/oldale_geolcc/32index.html

Cape Hatteras NS NC C Yes 04-03-00 planned NC GS, USGS, ECU cooperative funded to produce geomorphic landform maps of CAHA, CALO, FORA, WRBR areas; Should try to contact Dare County, NC about digital FEMA maps for the area as well

Cape Krusenstern NM AK C no inactive No information available.

Cape Lookout NS NC C Yes 04-03-00 planned NC GS, USGS, ECU cooperative funded to produce geomorphic landform maps of CAHA, CALO, FORA, WRBR areas; Should try to contact Dare County, NC about digital FEMA maps for the area as well

Castillo de San Marcos NM FL C no inactive No information available.

Channel Islands NP CA C no preliminary http://www.nps.gov/gis/park_gisdata/california/chis.htm; lots of coastline stuff and geology for Santa Rosa Island

Chickasaw NRA OK L no inactive No information available

Colonial NHP VA C no preliminary needs reviewed for conformity to GRI model. Has geologic coverage at small scale (250,000); probably need larger scale maps for park resource management needs

Crater Lake NP OR L no in-progress GRI staff will work with USGS in FY-2001 on project completion

Cumberland Island NS GA C no inactive No information available

Curecanti NRA CO L Yes 08-26-98 complete available for download from: http://www3.nature.nps.gov/im/gis/ftp/ftparchive.cfm

Dry Tortugas NP FL C no inactive http://www.nps.gov/gis/park_gisdata/florida/drto.htm; but shorelines and bathymetry data

Ebey's Landing NH Reserve WA C Yes 09-12-02 inactive WA DNR has digital coverage of entire state digital at 100,000 scale; needs converted to GRI model

Everglades NP FL C no inactive http://www.nps.gov/gis/park_gisdata/florida/ever.htm; but only coastlines

Fire Island NS NY C no inactive No information available

Fort Caroline NMem FL C no inactive No information available.

Fort Clatsop NMem OR C no inactive No information available.

Fort Frederica NM GA C no inactive No information available.
Fort Matanzas NM FL C no inactive No information available.
Fort Point NHS CA C no inactive No information available.
Fort Pulaski NM GA C no inactive No information available.
Fort Sumter NM SC C no inactive need specifics from SC GS (Bill Clendenin)
Gateway NRA NY C no inactive No information available.
George Washington Birthplace NM VA C no planned No information available
Glacier Bay NP AK C no preliminary USGS has done significant mapping; apparently AKSO has digital geology from Dave Brew (USGS); check with Sara Wesser on this
Glen Canyon NRA UT L Yes 09-23-99 in-progress awaiting digital geology from UT GS; need report synthesized from UGA guidebook #28
Golden Gate NRA CA C no inactive No information available.
Gulf Islands NS FL MS C no inactive No information available.
Haleakala NP HI C no inactive http://volcanoes.usgs.gov/
Hawaii Volcanoes NP HI C no planned USGS has I-2685 (Maps showing development of the
Pu'u 'O'o-Kupaianaha Flow Field); not known if it's digital though; also consult http://volcanoes.usgs.gov/
Indiana Dunes NL IN L no inactive http://www.nps.gov/gis/park_gisdata/indiana/indu.htm; some landform cover stuff
Isle Royale NP MI L no preliminary NPS clearinghouse has files that need reviewed for conformity with GRI model
Jean Lafitte NHP & PRES LA C no inactive No information available.
Kalaupapa NHP HI C no inactive http://volcanoes.usgs.gov/
Kaloko-Honokohau NHP HI C no inactive coastline data exists digitally; also http://volcanoes.usgs.gov/
Katmai NP AK C no preliminary http://www.nps.gov/akso/gis/katm/katm_ptp.htm ; some for earthquake displacement. 3/1/02 also for Mt. Katmai - downloaded to z drive, gis, preliminary, alaska, katm
Kenai Fjords NP AK C no preliminary GRI staff have obtained digital geologic coverage from NPS clearinghouse; need to review for conformity with GRI model.
Klondike Gold Rush NHP AK C no inactive No information available.
Lake Clark NP AK C no planned GRI staff have obtained digital geologic coverage from NPS clearinghouse; need to review for conformity with GRI model. GRI staff will work on in FY-2001
Lake Mead NRA NV L Yes 02-12-02 in-progress USGS working on (2) 100,000 sheets that will cover most of park; need maps for southern portion though. Sue Beard has data at USGS in Flagstaff
Lake Meredith NRA TX L no inactive park has submitted TA requests to GRD to assist them with producing a digital geologic map for both ALFL and LAMR; no action taken on GRI half yet
Lake Roosevelt NRA WA L Yes 09-10-02 planned
LARO wants numerous surficial maps digitized for park management needs mapped by BOR; GRI staff wish to obtain maps from LARO to register and rectify, and will digitize in FY-2003
National Park of American Samoa HI C no inactive http//www.nps.gov/gis/park_gisdata/americansamoa/npsa.htm; has coastline and coral reefs; also NPSA GIS supplied GRI staff with TIF files of 1981 Coastal Atlas for American Samoa; could be georeferenced and digitized
Olympic NP WA C Yes 09-12-02 preliminary know of published USGS map I-994 at 1:125k; it's also digital but needs to be reviewed for GRI conformity
Padre Island NS TX C no inactive "Padre Island NS: A guide to the Geology, natural environments, and history of a Texas barrier island" is available; contains a paper map. Unknown if it is digital.
Pictured Rocks NL MI L no inactive know of work by William Blewett; have specific publications. Not known if digital
Point Reyes NS CA C no preliminary http://wrgis.wr.usgs.gov/open-file/of97-456/
Pu'uhonua o Honaunau NHP HI C no inactive No information available.
Puukohola Heiau NHS HI C no inactive No information available.
Redwood NP CA C no preliminary Needs reviewed for conformity to GRI model.
Sagamore Hill NHS NY C no inactive No information available.
San Juan Island NHP WA C Yes 09-12-02 inactive No information available.
Santa Monica Mountains NRA CA C no inactive Doug Morton of USGS doing work here ; need more details
Sitka NHP AK C no inactive No information available.
Sleeping Bear Dunes NL MI L no inactive work with USGS Bruce Jaffe for details of his work there
Thomas Stone NHS MD C no inactive No information available.
Timucuan Ecological & Hist Preserve FL C no inactive No information available.

Virgin Islands NP VI C no preliminary USGS mapped area; needs digitized though

Voyageurs NP MN L Yes 06-01-00 In-progress have obtained 24k all quads from MN GS and have converted to GRI model; awaiting help file completion and will upload to http://www3.nature.nps.gov/im/gis/ftp/ftparchive.cfm ASAP

War in the Pacific NHP GU C no inactive No information available.

Whiskeytown-Shasta-Trinity NRA CA L no planned USGS has several projects occurring; need to acquire digital geology from them

Wrangell-St Elias NP AK C no preliminary GRI staff have obtained digital geologic coverage from NPS clearinghouse; need to review for conformity with GRI model.

Yellowstone NP WY L no preliminary Good project for Anne Poole; GRI staff have obtained digital geologic coverage from NPS Clearinghouse; need to review for conformity with GRI model. USGS has also published OF

Yosemite NP CA L Yes 09-25-02 inactive No information available.

Appendix 8: Geologic Resources Inventory Tasks Related to Coastal Landform Mapping

As a result of the Coastal mapping Protocols Workshop for Atlantic and Gulf National Parks that is summarized in this report, GRI staff drafted initial lists of overall inventory action items and more specific project tasks to begin work on in FY2003. The bulleted lists will be planned in more detail and documented by GRI staff and cooperators.

GRI Coastal Landform Mapping (CLM) Action Items

- Develop and document base CLM data model/legend (from FL Workshop Report)
- Identify data sources and outline/document protocols for interpreting imagery/data into map themes
- Determine FY 2003 pilot projects and park project priorities
- Scope pilot parks if needed
- Begin base data acquisition, processing, and archiving
- Plan and initiate project(s) for imagery/data interpretation (coop./contract/in house)
- Plan and initiate field check/review and QA/QC of map(s)
- Complete development and documentation of inventory products
- Digital map(s) with metadata, legends, theme lists, sections, help files, etc.
- Updated GRBib
- GRI Report with annotated list of other coastal map/data needs and research projects

GRI Coastal Landform Mapping Project Tasks

- Acquire base data
- Recent aerial photography and/or high resolution satellite imagery
- High resolution elevation data (e.g., LIDAR)
- National Wetlands Inventory
- Topography and Bathymetry
- Available soil and vegetation data
- Base data processing and archiving
- Process/convert/rectify data as necessary to same GIS format and datum/projection
- Distribute data to cooperators and archive with I&M Program
- Imagery/Data Interpretation
- Develop/customize data attributes/legend and include in NPS Geology-GIS Data Model
- Interpret and digitize thematic CLM polygons and associated data
- Field check/review and QA/QC CLM map
- Validate theme polygons and correct map units as needed
- Complete formal QA/QC of map units as may be required
- Develop and complete CLM products
- Attribute and QA/QC digital map per NPS Geology-GIS Data Model
- Complete fully FGDC- and GRI-compliant metadata file(s)
- Document project tasks and write detailed unit descriptions and map summary/notes
- Develop theme list(s), GIS map legend(s), Help file(s), and report illustrations
- Complete GRI Report
- Update GRBib with citations from mapping and report projects.