The Non-steady State of the Inner Shelf and Shoreline: Coastal Change on the Time Scale of Decades to Millennia[1]

November 9-12, 1999
University of Hawaii, Honolulu, Hawaii

A conference held as part of
International Geological Correlation Programme, Project 437:
Coastal Environmental Change During Sea-Level Highstands: A Global Synthesis With Implications For Management of Future Coastal Change

ORGANIZING COMMITTEE:
Charles H. Fletcher, III (Chip), Conference Chairman
Colin V. Murray-Wallace, Leader IGCP Project #437 (1999 - 2004)
Orson van de Plassche, Leader IGCP Project #247 (1988-1993)

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Acknowledgements and Introductory Statements

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4) **University of Hawaii Department of Geology and Geophysics**

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MEETING PROGRAM

Tuesday, November 9, 1999

7:30am – Continental Breakfast
8:00am – Welcome, Blessing and Introductory Remarks,
8:15am – IGCP #437 Dr. Colin Murray-Wallace, Project Leader

Scientific Session #1

8:30am – **Richard Peltier**, Global Glacial Isostasy and Coastal Evolution (45 min.)

9:15am – Poster Viewing (30 min.)

9:45am – Research Briefings, Principal Investigators (10 min. ea.)

9:50 – 10:00 **H. Yamano, H. Kayanne and N. Yonekura**, Internal structure and late Holocene evolution of Kabira Reef, Ishigaki Island, Southwest Japan

10:00 – 10:10 **P.D. Nunn**, Illuminating sea-level fall around AD 1220-1510 (730-440 cal yr BP) in the Pacific Islands: implications for environmental change and cultural transformation.

10:10 – 10:20 **B.M. Richmond, C.H. Fletcher, R.A. Mullane,** Pacific Island beach systems: examples from Hawaii and Micronesia.

10:20 – 10:30 **D.M. Kennedy and C.D. Woodroffe**, Holocene reef growth on high-latitude south Pacific reefs

10:30 – 10:40 **P. Larcombe, A. Kirsch, T. Harvey and R. M. Carter,** Cyclone sedimentation in the central Great Barrier Reef Province during the Holocene sea-level highstand.

10:40 – 10:50 **I. Goodwin and E.E. Grossman**, Coastal evolution and sea-level changes in Samoa since the Mid Holocene.

10:50 – 11:00 **Y. Ota, K. Sasaki, A. Omura,** Holocene sea level and tectonic history at Kikai Island, the northern Ryukyu Islands, as deduced from drilling survey through coral reef terraces.

Break – Poster Viewing (20 min.)

11:20 – 11:30 **N.-A. Mörner, D. Rossetti, P. de Toledo,** Sea level changes in NE Brazil, regional eustasy and local tectonics.

11:30 – 11:40 **R.J. Angulo, F.I. Isla, E.J. Schnack and M. C. de Souza**, A review of Holocene sea-level curves from the southwest Atlantic Ocean

11:40 – 11:50 **R.J. Angulo and M.C. de Souza**, Relative variation curves in sea-level during the last 7000 years in Brazil: A review

11:50 – 12:00 **S.D. Pereira, H.A.F. Chaves, R. Rodrigues, and L.G. Coelho**, Relative Sea-level change influence in a mangrove of Sepetiba Bay–RJ (Brasil), in the last 6000 years.

12:00 – 12:10 **R. Baitelli, L.E.S.B. Almeida, E.E. Toldo, Jr., C.E. Barros, L.R. Martins and J.L. Nicolodi** Retreat of the Rio Grande Do Sul Coastal Zone, Brasil.

12:10 – 1:30 Lunch available at Campus Center (not hosted)

Scientific Session #2

1:30pm – **Colin Woodroffe**, Morphodynamic response of shorelines to interglacials (45 min.)

2:15pm – Poster Viewing (30 min.)

2:45pm – Research Briefings, Principal Investigators (10 min. ea.)

2:50 – 3:00 **E.A. Felton**, Coarse gravel facies associated with rocky shorelines: significance for evaluating claims of tsunami and hurricane deposition.

3:00 – 3:10 **B.H. Keating and C.E. Helsley**, The Mahana, Kaluakapo, and Manele Ancient Shorelines, Lanai, Hawaii.

3:10 – 3:20 **R. Noormets, E.A. Felton and K.A.W. Crook**, Megaclasts on a shoreline reef terrace near Sharks Cove, Oahu's North Shore, Hawaii: Preliminary results.

3:20 – 3:30 **R.J. Turner**, The evolution of beachrock morphology and its influence on beach morphodynamics.

3:30 – 3:40 **H. Regnauld and R. Louboutin**, Variability of beach profiles and meso-scale evolution of dune morphology: a linked approach (Brittany, France).

3:40 – 3:50 **E. Isoun, C. Fletcher, N. Frazer, J. Harney, and J. Gradie**, Passive airborne multi-spectral remote sensing application to nearshore, ocean-floor mapping and geology.

Break – Poster Viewing (20 min.)

4:10 – 4:20 **D.A. Cacchione, B. Richmond, C. Fletcher, G. Tate, and J. Ferreira**, Sand Transport in a Reef Channel off Kailua, Oahu, Hawaii.

4:20 – 4:30 **J. N. Harney and C. H. Fletcher**, The carbonate factory: 5000 years of sand production, flux and storage on a windward fringing reef (Kailua, Oahu, Hawaii).

4:30 – 4:40 **C.T. Blay**, Compositional analysis of Hawaiian beach sediment: an indicator of source, process and coastal change.

4:40 – 4:50 **M.A. Hampton, M.E. Torresan, F.L. Wong, C..S. Frazee J.H. Barry, M.C. Ericksen**, Possible sand resources on the reef front around Oahu.

4:50 – 5:00 **C. J. Murray, Y-J. Chien and M. A. Hampton**, An exploration model for sand resources, Kailua Bay.

5:00 – 5:10 **E.E. Grossman and C.H. Fletcher**, Holocene reef development in Kailua, windward Oahu, Hawaii shaped by wave forcing, Late Pleistocene antecedent topography and concomitant island uplift.

7:30 – 9:30pm **Community Workshop, Coastal Change – Future Directions and New Ideas**

Wednesday, November 10, 1999

Field Trip – Hanauma Bay
8:00am – 11:30pm

Buses will pick up conferees in front of the Conference Center at 8:00 am
Please dress in beach wear with sun screen, towel, sun hat, swimming clothes (snorkel gear if desired), lunch will be provided.

Scientific Session #3

1:00pm – **Kelvin Berryman**, The many faces of tectonics and its role in shaping Late Quaternary shorelines (45 min.)

1:45pm – Poster Viewing (30 min.)

2:15pm – Research Briefings, Principal Investigators (10 min. ea.)

2:20 – 2:30 **N.-A., Mörner, Y. Ota, C. Firth,** INQUA's contribution to sea-level research: the new commission and it's new program

2:30 – 2:40 **C. Goldfinger and L.C. McNeill**, Holocene sea-level change as a result of elastic and anelastic deformation along the central Cascadia Subduction Margin, USA.

2:40 – 2:50 **N. Litchfield**, Late Quaternary sea-levels and shore platforms on a tectonically rising coastline, New Zealand

2:50 – 3:00 **A.H. Sallenger, J. Brock, M. Hampton, W. Krabill, R. Swift, D. Eslinger and B. Richmond,** El Niño induced coastal change: implications for the decadal scale evolution of coastal morphology.

3:00 – 3:10 **C. Hapke and B. Richmond**, Short-term episodic response of seacliffs to tectonic and climatic events: rates, failure style and spatial variability, Santa Cruz, California.

3:10 – 3:20 **C. Storlazzi, M. Field, J. Tait, and R. Anima**, The influence of tectonics and sea- level fluctuations on sediment distribution and modes of littoral transport along the rocky inner shelf of central California.

3:20 – 3:30 **G.M. Kaminsky, H.M. Jol, P.J. Cowell, P. Ruggerio, G. Gelfenbaum,** Measuring and modeling coastal progradation, catastrophic shoreline retreat and shoreface translation along the coast of Washington State, USA.

3:30 – 3:40 **J.B. Rooney and C.H. Fletcher,** decadal to century scale sand movement of a Hawaiian shoreline.

Break – Poster Viewing (20 min.)

4:00 – 4:10 **C. Chagué-Goff, J. R. Goff, J. Zachariasen, K.R. Berryman, C. J. Hollis, S.. Dawson, D.C. Mildenhall, A.G. Beu, M. J. McSaveney, B.V. Alloway, D.L. Garnett, H.M. Waldron, E.C. Vye, U. Cochran and C. Stewart**, A record of environmental changes (subsidence earthquakes, tsunami) in northern Hawke's Bay, New Zealand.

4:10 – 4:20 **A.C. Hinton and M.J. McSaveney**, Schmidt hammer and weathering rind studies of a modern and uplifted beach sequence, Turakirae Head, New Zealand.

4:20 – 4:30 **K. Schwarzer and Kerstin Schrottke**, Shoreline displacement along the Southern Baltic Sea coastline due to sea-level changes and human impact.

4:30 – 4:40 **K, Balakrishna, B.R. Manjunatha, R. Shankar and T.R. Mahalingam**, Heavy metal enrichments in an 'Endangered' coast, south west coast of India: A baseline study.

4:40 – 4:50 **M.E. Torresan, M.A. Hampton, and J.V. Gardner**, Geophysical and geological monitoring of Hawaiian Ocean disposal sites.

4:50 – 5:00 **R.T. Patterson, J.-P. Guilbault, R.E. Thomson, A. Dallimore, A. Kumar, M. Hay, T. Schell and A. Chang**, Oxygen Level Control on foraminiferal distribution in Effingham Inlet, Vancouver Island, British Columbia: Implications for Assessing long-term variability in pelagic fish abundance and paleoceanographic conditions.

Thursday, November 11, 1999

Scientific Session #4

8:00am – **Richard Fairbanks**, Quaternary sea-level cycles amplified by tropical sea-surface temperature changes. (45 min.)

8:45am – Poster Viewing (30 min.)

9:15am – Research Briefings, Principal Investigators (10 min. ea.)

9:20 – 9:30 **I. Shennan**, Global meltwater discharge and the deglacial sea-level record from Scotland.

9:30 – 9:40 **D.E. Smith and C.R. Firth,** The Mid-Holocene rise in sea-levels off Northwest Europe

9:40 – 9:50 **A.B. Rodriguez and J.B. Anderson**, Position of the Middle Wisconsin shoreline on the Texas inner continental shelf.

9:50– 10:00 **E.R. Thieler, W.C. Schwab, P.T. Gayes, O.H. Pilkey, Jr., W.J. Cleary, and K.M. Scanlon**, Paleoshorelines on the U.S. Atlantic and Gulf Continental Shelf: Evidence for sea-level stillstands and rapid rises during deglaciation.

10:00– 10:10 **J.V. Barrie and K.W. Conway**, Rapid sea-level changes and coastal evolution on the Pacific margin of Canada

10:10 – 10:20 **S. Dawson,** Late Holocene relative sea-level highstand in northern Scotland: Climatological inferences.

10:20 – 10:30 **E. Farabegoli and G. Onorevoli**, Modeling the Holocenic evolution of northwestern Adriatic Sea - southern Po Plain (Italy).

Break – Poster Viewing (20 min.)

10: 50 – 11:00 **T. Boski, D. Moura, S. Camacho, D. Duarte, D. B. Scott, C. Veiga-Pires, P. Pedro, and P. Santana**, Postglacial sea-level rise in south Portugal as recorded in Guadiana Estuary.

11:00 – 11:10 **J. Grindrod, P. Moss and S. van der Kaars**, The Palynology of mangrove response to Late-Quaternary sea-level Change.

11:10 – 11:20 **B.P. Horton and I. Shennan**, Modelling Holocene depositional regimes in the western North Sea at 1000 year time intervals.

11:20 – 11:30 **J. Xueshen**, Division of Late Quaternary marine beds and in Bohai Gulf.

11:30 – 11:40 **J.S. Tribble, G.H. Garrison, J.S. Athens, C.B. Allen, C.G. Skilbeck and E. Frankel,** Evidence for Early-Mid Holocene sea-level on Oahu, Hawai'i from coastal pond sediments.

11:40 – 11:50 **N.-A. Mörner,** From the past via the present to the future: Facts and fiction in sea-level estimates.

11:50 – 1:30 Lunch for Conferees at Campus Center (not hosted)

Scientific Session #5

1:30pm – **Paul Hearty**, Warm interglaciations, abrupt environmental change, and "The Antarctic "Wild Card" (45 min.)

2:15pm – Poster Viewing (30 min.)

2:45pm – Research Briefings, Principal Investigators (10 min. ea.)

2:50 – 3:00 **J.B. Anderson**, Antarctica's contribution to eustasy during the past glacial/interglacial cycle.

3:00 – 3:10 **O. van de Plassche**, Century-scale sea-level changes in Long Island Sound since AD 500; Correlation with North Atlantic climate-ocean changes.

3:10 – 3:20 **E.J. Schnack, U.R. Colado and F.O. De Francesco**, El Niño, storm surges and sea-level change in the development of the Rio De La Plata coastal plain, Argentina.

3:20 – 3:30 **J.A.G. Cooper**, The role of extreme floods in estuary-coastal behaviour: Contrasts between small river- and tide-dominated systems

3:30 – 3:40 **Z.Q. Chen, J.F. Donoghue and R.W. Hoenstine**, Sea-level-climate-coupled Late Quaternary history of the northeastern Gulf of Mexico coast and inner shelf, northwest Florida.

3:40 – 3:50 **G. Skilbeck, E. Frankel, A. Cramp, P. Purser, and J. Tribble**, A record of coastal change preserved in high-stand littoral lakes from a stable passive margin (central eastern coast of Australia).

Break – Poster Viewing (20 min.)

4:10– 4:20 **O.K. Mason**, Coastal re-organization north of Bering Strait during the Early Medieval Glacial Episode, AD 750-1150.

4:20 – 4:30 **P.D. Nunn**, Temporal hiatuses in Holocene sea-level records from the Southwest Pacific.

4:30 – 4:40 **A.B. Rodriguez, and J.B. Anderson**, Response of Gulf of Mexico coastal systems to Holocene sea-level rise and implications for the future of our coasts.

Waikiki Dinner at the Halekulani Hotel - bus pick-up at the conference site at 5:45pm

Friday, November 11, 1999

Scientific Session #6

8:00am – **Larry Edwards, K. Cutler, H. Cheng, J. Adkins, F. W. Taylor, C. D. Gallup and R. Speed,** Sea-level and deep ocean temperature history over the last 200,000 yr (45 min.)

8:45am – Poster Viewing (30 min.)

9:15am – Research Briefings, Principal Investigators (10 min. ea.)

9:20 – 9:30	**J.F. Wehmiller, L.L. York, M.S. Harris, D.E. Krantz**, Timescales for evolution of emergent and inner shelf Quaternary units, U. S. Atlantic Coastal Plain: Insights and enigmas from radiocarbon, U-series, paleomagnetic and aminostratigraphic results.
9:30 – 9:40	**C.V. Murray-Wallace, B.P. Brooke, J.H. Cann, A.P. Belperio, and R.P. Bourman**, Whole-rock Aminostratigraphy of the Coorong Coastal Plain, South Australia: A one million year record of sea-level highstands.
9:40 – 9:50	**A. Molodkov and N. Bolikhovskaya**, Eustatic sea-level and climate changes over the last 600 ka as derived from mollusc-based ESR-chronostratigraphy and pollen evidence in the Eurasian North.
9:50 – 10:00	**T.E. Törnqvist, J. Wallinga, A.S. Murray, H. de Wolf, P. Cleveringa and W. de Gans**, Evolution of the Rhine-Meuse coastal plain (west-central Netherlands) during the last Quaternary glacio-eustatic cycles.
10:00 – 10:10	**D.B. Scott and R.R. Stea**, Late Quaternary relative sea-level variations in the North Atlantic: Comparison of mid-Holocene highstands to the last interglacial (isotope stage 5e) highstands.
10:10 – 10:20	**S.R. Riggs**, Coupled inner shelf-shoreline sediment responses to small-scale Holocene sea-level fluctuations: North Carolina coastal zone.
10:20 – 10:30	**M. Umitsu, S. Sinsakul, S. Tiyapairach and N. Chaimanee**, Late Holocene evolution of the Central Plain, Thailand.

Break – Poster Viewing (20 min.)

10:50 – 11:00	**J. van der Molen and B. van Dijck**, Holocene tidal and wave-driven sand transport in the southern North Sea and the evolution of the Dutch coast.
11:00 - 11:10	**L. J. Kaszubowski**, Contemporary evolutional trends of the central Polish coast.
11:10 – 11:20	**J.C. Kraft, G. Rapp, Jr., J.A. Gifford and S.E. Aschenbrenner**, Mid-late Holocene epoch variance in coastal depositional morphologies in the N.W. Peloponnese, Greece.
11:20 – 11:30	**C. Baeteman**, Factors controlling the formation of intercalated peat beds in the Holocene sequence of the coastal lowlands of the southern North Sea.
11:30 – 11:40	**G. Mastronuzzi and P. Sansò**, Sea-level changes and coastal dune development in Apulia (Southern Italy).
11:40 – 11:50	**Y. Wan–rong**, Characteristics in formation and diagenesis of Cenozoic reefs in South China Sea.
11:50 – 12:00	**C.E. Sherman, C.H. Fletcher and K.H. Rubin**, Accretion and diagenesis of Pleistocene reefal carbonates from a nearshore submarine terrace, Oahu, Hawaii.

End Morning Session

12:00 – 1:30 **Lunch for Conferees at Campus Center** (not hosted)

1:30 – 4:00 Afternoon Business meeting of IGCP#437

abstract titles

Keynote Papers

Session Papers

Antarctica's contribution to eustasy during the past glacial/interglacial cycle

John B. Anderson

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Knowledge of Antarctica's contribution to eustasy during the past glacial/interglacial cycle has recently improved as a result of onshore and marine geological surveys. Marine geological studies have yielded compelling evidence that all three components of the Antarctic cryosphere, the East Antarctic Ice Sheet (EAIS), West Antarctic Ice Sheet (WAIS), and Antarctic Peninsula ice sheet, advanced across the continental shelf during the last glacial cycle. There is also new evidence to suggest that the EAIS retreated from the continental shelf prior to 24,000 yrs BP, possibly during Oxygen Isotope Stage 3. The WAIS retreated from the shelf after the LGM (Oxygen Isotope Stage 2). Retreat of the Antarctic Peninsula ice sheet from the shelf was complete by the mid-Holocene.

Marine geological surveys conducted during the past five years have focused on the individual drainage systems of the West Antarctic Ice sheet. These studies have shown that the retreat of the WAIS was diachronous around the continent, with different glacial drainage systems behaving more or less independently during recession. Some drainage systems, such as those of the western Ross Sea, retreated slowly and continuously from the shelf, whereas other segments, such as the Pine Island Bay drainage system, retreated rapidly. Collapse of some WAIS drainage systems, such as the Pine Island Bay system, could have caused eustatic rises of several decimeters over a few centuries. There were still significant volumes of ice left on the Antarctic continental shelf after 9000 years to have contributed to the observed sea-level rise of the late Holocene. There is some evidence for rapid phases of retreat during this time interval.

The complex retreat history of the Antarctic Ice Sheets indicates an episodic nature to sea-level rise with potentially rapid phases of retreat that could have significantly altered coastal systems. There is no evidence for widespread deglacial episodes that would have caused the kinds of meter-scale rapid rises invoked by some researchers.

Relative variation curves in sea-level during the last 7000 years in Brazil: A review

Rodolfo José Angulo and Maria Cristina de Souza

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In the last three decades hundreds of paleosea-level indicators from the Brazilian coast were dated and several paleosea-level curves, for the last 7,000 years, were published for different sectors of the coastline (Figs. **1** and **2**). These curves present significant differences and contradictions, which are: i) the existence or not of 3-4 m oscillations between 4100-3800 years B.P. and between 3000-2700 years B.P. (Suguio et al. 1985, Angulo & Lessa 1997, Martin et al. 1998, Lessa & Angulo 1998); ii) the existence or not of a sea-level rise in the last two thousand years along the coast of Rio Grande do Sul State, and (Tomazelli & Villwock 1989 apud Tomazelli 1990, Tomazelli 1990, Angulo & Giannini 1996); iii) the maximum altitude attained by the post-glacial marine transgression on the State of Paraná (Martin et al. 1988, Angulo 1992, Angulo & Suguio 1995).

There are still other aspects that have not yet been discussed, such as (a) when did the sea reach a level similar to the current one for the first time during the Holocene, and (b) what was the maximum altitude of the post-glacial marine transgression (PMT) in the country? Previous studies suggested different times when sea-level eventually reached the present mean sea-level after the PMT, and that would span between 7100 and 6600 years B.P. Holoceno (Suguio et al. 1985). It is also proposed that the maximum sea-level at the end of the PMT would have occurred around 5100 years B.P., and that it would have reached altitudes that vary from 4.8 ± 0.5 m to less than 2.5 m. These differences in age and elevation are explained by the shifting of a geoidal depression now located close to Cananéia, São Paulo State (Martin et al. 1985).

A critical analysis o the literature suggests that elevations of sea-level maximum higher than 4 m are probably overestimated. This is mainly due to the fact that there are more than one hundred vermets samples dated in the Brazilian coast, and only three indicate paleo-sea-levels higher than 4 m (**Fig. 3**). The majority of the samples were obtained on cliffs exposed to strong wave action, in which case the ecological zone of the vermets can be displaced 1 m upwards (Laborel 1986). In two places, "in situ" oyster shells would suggest a sea-level maximum of 4,8 m. However, Delibrias & Laborel (1969) consider that this elevation would also be overestimated since the reference level used was the mean sea-level instead of the ecological zone of the oysters which in some situations can be 3 m higher than that level. It would then be necessary to know the characteristics of the place where the oysters were collected to define the precise paleo-sea-level. Finally, higher than 4 m estimates of the sea-level maximum come from shell fragments found on paleo-beach deposits or the elevation of the paleo-beaches terraces. In these cases it is well known that wave run-up can form sedimentary deposits several meters above mean sea-level.

The analysis of the data used to produce the curves reveal that, besides the scarcity of the data, the considered margins of error are frequently extremely small for the type of indicator used. Thus, the curves are not too precise due to the quality of the data utilized in their construction. As for the time when sea-level first reached the present one, the published data indicate only that this happened about 7000 years A.P. The data are not sufficiently precise for an adequate identification of the proposed regional differences. For example, wood fragments deposited in clay-sandy sediments attributed to mangroves, which would more likely indicate a lowest possible paleo-sea-level, is used to determine mean sea-level with a margin of error of only 0.3 m to 0.4 m.

Considering the maximum sea-level altitude after the PMT, the published data, in most cases, does not allow for a determination with an accuracy of less than 1 meter. Moreover, they do not have enough precision to identify possible significant differences in altitude at several sections of the Brazilian coast as previously proposed. The data only indicate altitudes around 2.5 to 4.0 m in the period between 5000 and 5400 years B.P.

References

Angulo, R.J., 1992. *Geologia da Planície Costeira do Estado do Paraná*. Unpublished Ph.D. Thesis, Geoscience Institute, University of São Paulo, Brazil, 334 p.

Angulo, R. J. and Giannini, P. C. F., 1996. Variação do nível relativo do mar nos últimos dois mil anos na região sul do Brasil: uma discussão. *Boletim Paranaense de Geociências Curitiba*. 44:67-75.

Angulo, R.J. and Lessa, G.C., 1997. The Brazilian sea-level curves: a critical review with emphasis on the curves from Paranaguá and Cananéia regions. *Mar. Geol.*, 140:141-166.

Angulo, R.J. and Suguio, K., 1995. Re-evaluation of the Holocene sea-level maxima for the state of Paraná, Brazil. *Paleogeog., Paleoclim., Paleontology*, 113:385-393.

Delibirias, C. and Laborel, J. 1969. Recent variations of the sea-level along the Brazilian coast. *Quaternaria*, 14:45-49.

Laborel J. 1986. Vermetid gastropods as sea-level indicators. In: Van de Plassche, O. ed. *Sea-level research: a manual for the collection and evaluation of data*. Norwich. Geo Books. p.281-310.

Lessa, G.C. and Angulo, R.J., 1998. Oscillations or not oscillations: that is the question - Reply. *Mar. Geol.*, 150:189-196.

Martin, L.; Bittencourt, A. C. da S. P.; Dominguez, J. M. L.; Flexor, J. M.; Suguio, K. 1998. Oscillations or not oscillations, that is the question: Comment on Angulo, R. J. and Lessa, G. C. The Brazilian sea-level curves: a critical review with emphasis on the curves from the Paranaguá and Cananéia regions. *Mar. Geol.*, 140:141-166. Marine Geology. Amsterdam. 150:179-187.

Martin, L; Flexor, J.M.; Blitzkow, D. and Suguio, K. 1985. Geoid change indications along the brazilian coast during the last 7,000 years. In: *Int. Coral Reef Congress*, 5. Tahiti, 1985. Proc... Tahiti, v.3. p.85-90.

Martin, L.; Suguio, K.; Flexor, J.M. and Azevedo, A.E.G.. 1988. Mapa Geológico do Quaternário Costeiro dos Estados do Paraná e Santa Catarina. Série Geológica DNPM, no. 28, 40 p.

Suguio, K; Martin, L.; Bittencourt, A.C.S.P., Domingues, J.M.L.; Flexor, J.M. and Azevedo, A.E.G., 1985. Flutuações do nível relativo do mar durante o Quaternário Superior ao longo do litoral brasileiro e suas implicações na sedimentação costeira. *Rev. Bras. Geoc.*, 15:273-286.

Tomazelli, L. J. 1990. *Contribuição ao estudo dos sistemas deposicionais holocênicos do nordeste da província costeira do Rio Grande do Sul, com ênfase no sistema eólico*. Unpublished Ph.D. Thesis, Geoscience Institute, Federal University of Rio Grande do Sul, Porto Alegre, Brazil, 270p.

Fig.1 Location map

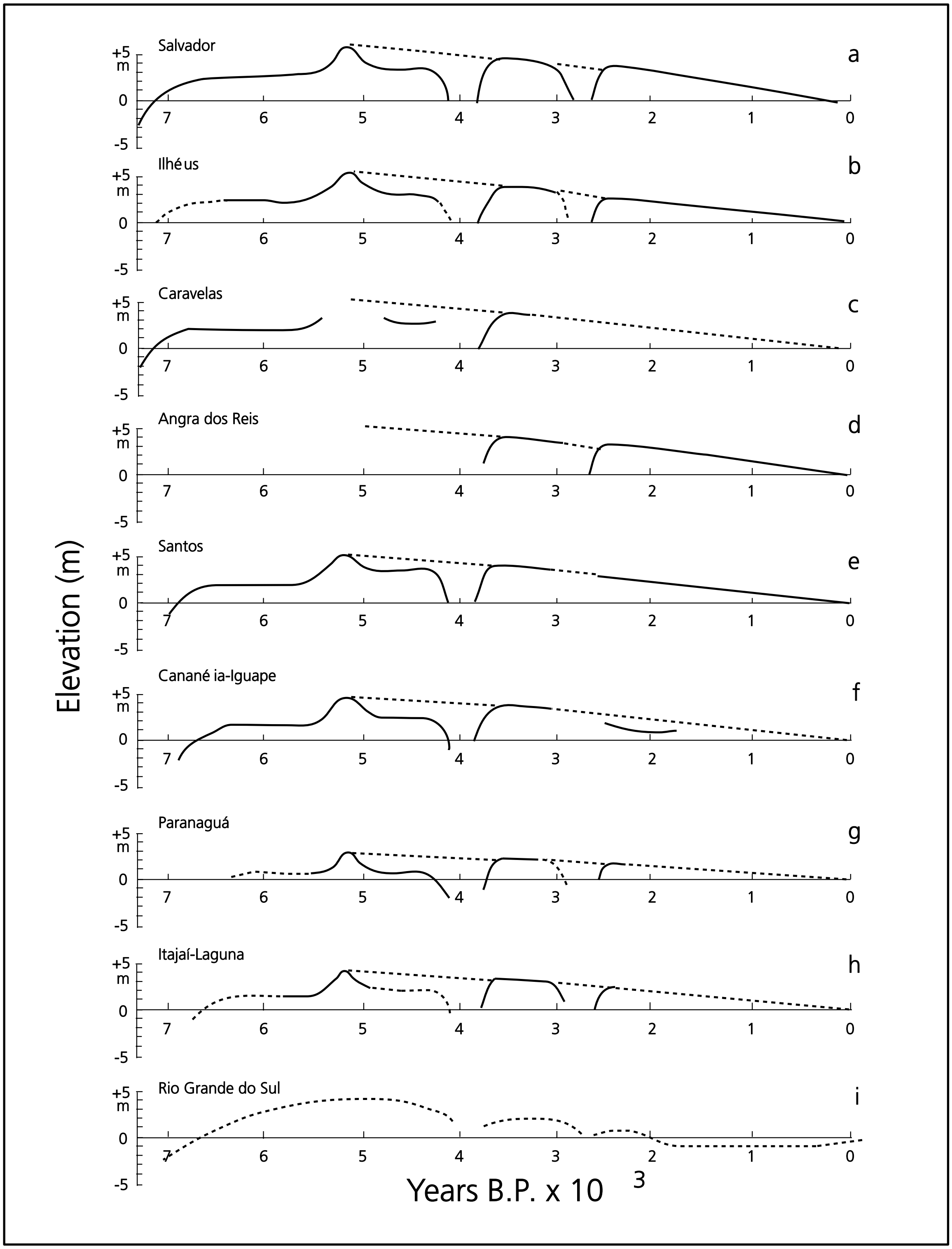

Fig. 2 The Brazilian sea-level curves for the last 7000 years (after Suguio et al., 1985 and Villwock and Tomazelli, 1989, in Tomazelli, 1990). See **Figure 1** for location.

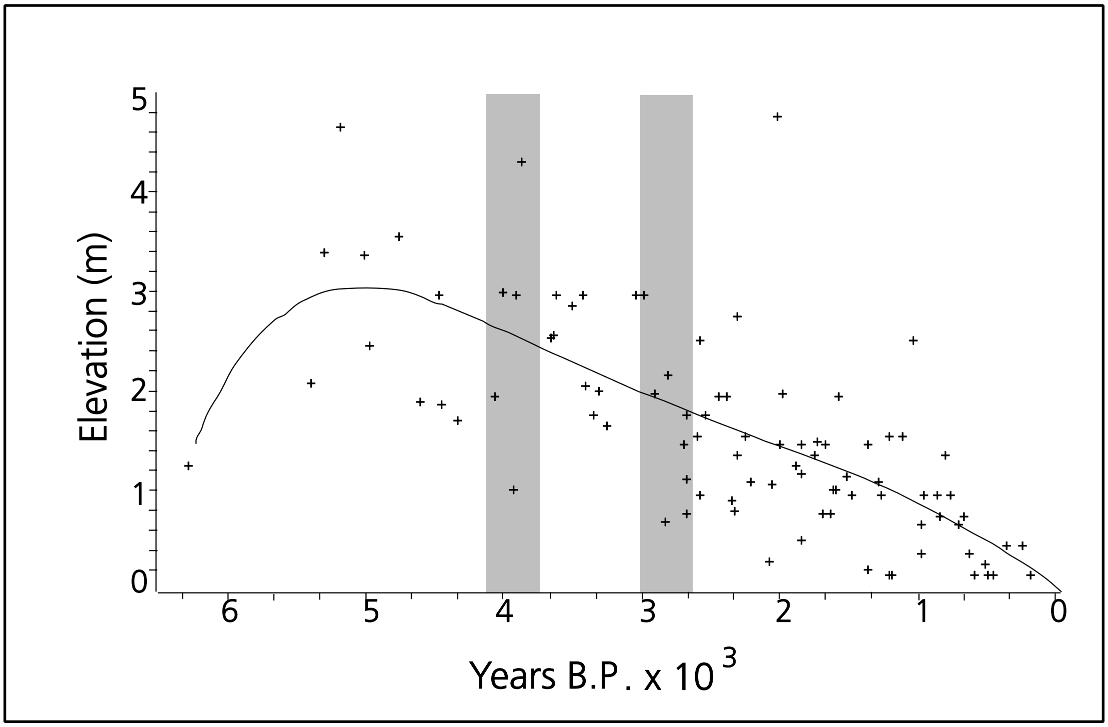

Fig. 3 Elevation of the published paleo-sea-level indicators in Brazil derived from vermetid radiocarbon dates. Shaded areas indicate the time for the proposed secondary oscillations proposed by other authors (see Suguio et al. 1985). The line is a 4th order polynomial best fit. (Angulo & Lessa 1997)

A review of Holocene sea-level curves from the southwest Atlantic Ocean

R. Angulo[1], F. I. Isla[2] , E. J. Schnack[3] and M. C. de Souza[1]

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Upper Pleistocene marine terraces from northern Argentina and southern Brazil suggest that the southwestern coast of the Atlantic Ocean has been approximately stable since the last interglacial (Sangamonian).

Different sea-level curves have been proposed showing a fluctuation for the last 7,000 years. From the comparison of these curves, some questions arise:

a) Which was the maximum height of the Holocene transgression?

b) When did the maximum sea-level stand occur?

c) Were there fluctuations below present mean sea-level (MSL)?

a) Height of maximum MSL

Many authors have proposed different maxima for the MSL (Suguio et al., 1985; Martin et al.,1988; Isla, 1989; Cavalotto et al., 1993; Aguirre and Whatley, 1995; Angulo and Lessa, 1997). A critical analysis of the literature suggests that elevations of maximum sea-level higher than 4 m are probably overestimated. In southern Brazil some maxima are based on *in situ* vermetids and oyster shells. Values based upon vermetids probably are overestimated because the majority of the samples were obtained on cliffs exposed to strong wave action, in which case the ecological zone of the vermets can be displaced 1 m upwards (Laborel, 1986). Maximum levels based on oyster shells can be overestimated because the reference level used was the mean sea-level instead of the ecological zone of the oysters which in some situations can be 3 m higher than that level.

Most estimations of these maxima in northern Argentina and some of southern Brazil are based on reworked mollusk shells and therefore indicating the level reached during storms. Extra-tropical storm surges originating in the South Atlantic are frequent and are a strong morphodynamic factor on the whole coast. Because it is reasonable to assume they have been acting during the last few thousand years, dating on storm deposits should be avoided in order to estimate MSL. Furthermore, a cleanup process of the existing database is necessary to provide safer data for MSL estimation and construction of sea-level curves. In addition, further examination of chronological evidence should prove useful in order to understand the slight differences in the age of the maximum sea-level stand.

The Brazilian sea-level curve composed from radiocarbon-dated vermetids (**Fig. 1**) is significantly lower that other curves based on different materials (mollusk shells, wood fragments, peats, carbonate algae, corals). Out of more than one hundred vermetid samples only three indicate paleo sea-levels higher than 4 m and this are probably over estimated. On the other hand, trying to discard those datings related to storm ridges and considering only those datings belonging to estuarine environments (estuaries and coastal lagoons), a MSL curve "out of storms" for northern Argentina has been proposed (**Fig. 1**; Isla and Espinosa, 1998).

b) Age of maximum MSL

In the last 10 years, it has been clear that the so-called "mid-Holocene transgression" (MHT) was older in northern Argentina than in southern Brazil (*see* Isla, 1989). The maxima for the brazilian MHT was 5000 to 5400 years B. P.; instead in Argentina it was older than 6000 years B.P.

Comparing the vermetid Brazilian curve with the Argentine MSL curve "out of storms" there is still a lag about 500-1000 years (*see* **Fig. 1**); Argentine data older than Brazilian. Buenos Aires sediments and soils are dominated by a high content in calcium carbonate (caliche). Surface water and groundwater have a higher content in CO_3^- and $HC0_3^-$ (pH is usually between 7.8 to 9). Mollusk shells are therefore subject to incorporate much reworked carbon. There is no reservoir effect carried out, but some preliminary radiocarbon dates performed on shells on living *Tagelus plebeius* from the Quequén Grande estuary indicate an age of 230 years (Figini, 1997).

On the other hand, surface water and groundwater on the southern Brazilian coastal zone have not such CO_3^- and $HC0_3^-$ content (pH is usually between 4.0 to 7.2). This reservoir-effect difference could explain the lag on the timing of maximum MSL between both regions.

c) Fluctuations below present MSL

Although two lower-than-present sea-level stands were proposed in Brazil about 4100-3800 years B.P. and between 3000-2700 years B.P. (Suguio *et al*. 1985 and Martin *et al*. 1998). According to Angulo and Lessa (1997) and Lessa and Angulo (1998) dates do not support the existence of such oscillations. No evidence has been found in this sense in Argentina..

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References

Aguirre, M.L. y Whatley, R. C., 1995. Late Quaternary marginal marine deposits and palaeoenvironments from northeastern Buenos Aires Province: a review. *Quaternary Science Reviews* 14, 223-254.

Angulo, R.J. and Lessa, G.C., 1997. The Brazilian sea-level curves: a critical review with emphasis on the curves from Paranaguá and Cananéia regions. *Mar. Geol*., 140:141-166.

Cavalotto, J.L., Parker, G. and Violante, R.A., 1995. Relative sea-level changes in the Río de la Plata during the Holocene. In Ortlieb, L. (ed.) *Late Quaternary coastal records of rapid change: application to present and future conditions*. 2nd. Annual Meeting, Abstracts, 19-20. Antofagasta, Chile, November 12-18.

Figini, A.J., 1997. *Comparación de edades C-14 en muestras de origen marino y terrestre. Efecto Reservorio.* Unpublised report, LATYR, UNLP, La Plata, Argentina, 6 pp.

Isla, F.I., 1989. The Southern Hemisphere sea-level fluctuation. *Quat. Sc. Reviews*, 8:359-368.

Isla, F.I. y Espinosa, M. A., 1998. Modelo sedimentario de colmatación de pequeños estuarios dominados por limos, Provincia de Buenos Aires. *VII Reunión Argentina de Sedimentología*, Salta, AAS, 12 al 16 de octubre de 1998, Actas, 24-36.

Laborel, J., 1986. Vermetid gastropods as sea-level indicators. In Van de Plassche, O. (de.) Sea-level research: a manual for the collection and evaluation of data. *Geobooks*, Norwich, 281-310.

Lessa, G.C. and Angulo, R.J., 1998. Oscillations or not oscillations: that is the question- Reply, *Mar. Geol*., 150:189-196.

Martin, L., Bittencourt, A.C., Domingues, J.M.L., Flexor, J.M. and Suguio, K., 1998. The Brazilian sea-level curves: a critical review with emphasis on the curves from the Paranaguá and Cananéia regions. *Mar. Geol*.: 150:179-187.

Suguio, K., Martin, L., Bittencourt, A.C., Domingues, J.M.L., Flexor, J.M. and Azevedo, A.E.G., 1985. Fluctuacoes do nivel relativo do mar durante o Quaternário Superior ao longo do litoral brasileiro e suas implicacoes na sedimentacao costeira. *Rev. Bras. Geoc*., 15:273-286.

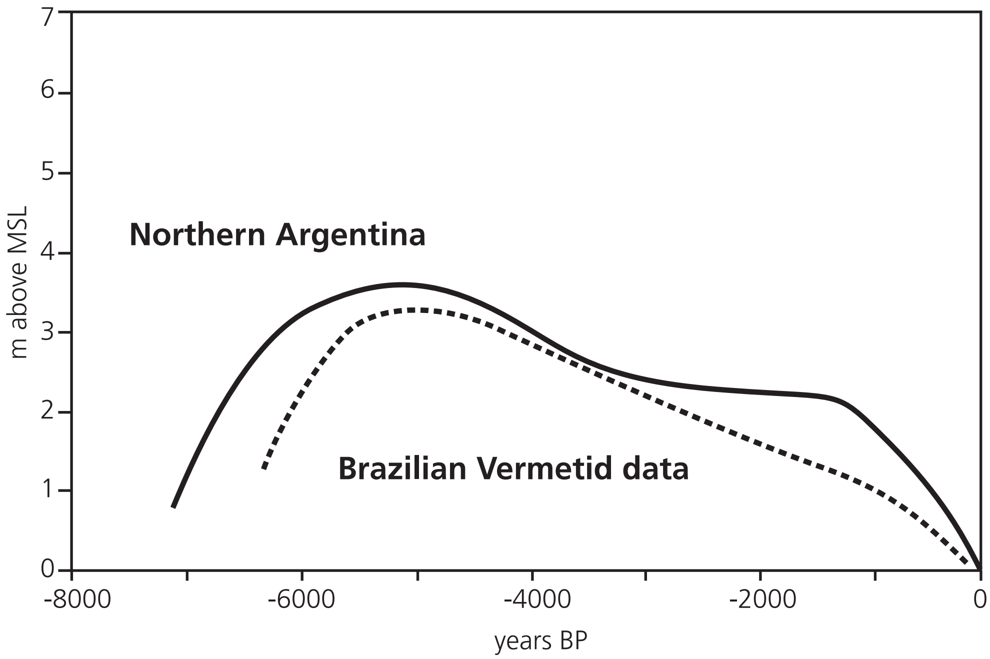

Fig. 1 Comparison between the vermeti brazilian curve and the argentine MSL curve out of storms (After Angulo and Lessa, 1997; Isla and Espinosa, 1998).

Factors controlling the formation of intercalated peat beds in the Holocene sequence of the coastal lowlands of the southern North Sea

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Introduction

Peat beds intercalated in tidal mud deposits are very typical in the Holocene sequence of coastal lowlands along the southern North Sea. Although their formation is usually attributed to sea-level fluctuations, their formation remains questionable. Despite the uncertain origin of their formation, intercalated peat beds are very often regarded as stratigraphical units or indicators of sea-level tendencies.

In order to reveal the factors controlling the formation of the intercalated peat beds, detailed stratigraphical and sedimentological work (on the basis of a dense boring grid), supported by ^{14}C datings, was carried out in the landward portion of the Belgian coastal plain, in particular in a major palaeovalley (containing a complete sequence of Holocene deposits) and its tributaries where it is assumed that maximum preservation of the various facies occurs. It is most likely that the palaeovalley was formed by river action during the Weichselian sea-level fall and lowstand. The presence of basal peat on top of the Pleistocene deposits, in particular in the deeper parts of the palaeovalley, indicates that the morphology of the valley already existed before the sea-level started to rise in the Holocene. The stratigraphical and chronological results of the landward portion were compared with the central and seaward portion of the plain.

Discussion

The palaeovalley fills show a high variability of the sedimentary succession. Differences of the encountered facies (mud, sand, peat and gyttja) are expressed across and along each palaeovalley fill itself, between the different palaeovalleys, and between the various sub-regions. However, intercalated peat beds are completely absent in the period prior to ca. 7300 cal BP because sea-level rise was too rapid (ca. 7m/ka), so that the active sedimentation surface of the flats did not silt up until supratidal levels lasting a sufficient long period, thus enabling a freshwater lens to form in the subsoil, with consequent initiation of a freshwater marsh. For that period, only vegetation horizons are occurring. As from 7300 cal BP. on, intertidal and supratidal flats, freshwater swamps and freshwater-filled depressions existed next to each other, even over very short distances, resulting in a rapid alternation of mud, peat and gyttja in the vertical sedimentary sequence.

Intercalated peat beds originate when the active sedimentary surface builds up high enough that it is permanently situated above the level of the highest astronomical tide (HAT) resulting in the formation of a freshwater marsh in which peat can accumulate provided that the sediment surface remains saturated throughout its formation. However, the initiation of peat in a freshwater marsh requires the installation of a freshwater lens in the subsurface for a sufficiently long duration, otherwise only humic vegetation horizons will be allowed to exist due to the dense salt-marsh vegetation introducing a lot of organic matter into near-surface deposits.

Unlike autochtonous peat, gyttja is formed by plant remnants which have been physically moved from a somewhat distant source, most likely the vegetation lining influent rivulets. The formation of gyttja must be attributed to ponding and sluggish drainage in the topographic depressions where water is backed up in the drainage channels of the palaeovalleys. The latter had no significant slope and acted as a drain for the outcropping Pleistocene hinterland. Gyttja formation also denotes inadequate sediment supply, so that the sedimentary surface could not accrete upwards in pace with the water level. Consequently, the initiation of peat on gyttja implies a lowering of the water level with respect to the sedimentary surface, most likely caused by an improvement of the drainage. This is in contrast with the initiation of peat on the salt marsh where vertical accretion of sediment is the determining factor. Consequently, changes between gyttja and peat reflect temporary changes in the local hydrology within the drainage channels in the palaeovalleys.

The comparison of the facies changes and their chronology within the palaeovalleys and between the different areas clearly demonstrates that a general synchroneity or regular distribution pattern does not exist at particular levels throughout the entire area, at least not until ca. 5500 cal BP, and not until a level of about 0 m (period and elevation at which the plain was almost completely filled). Throughout the whole period before 5500 cal BP, the area was characterised by a variety of facies ranging from tidal-channel sand, intertidal mud and sand, peat and gyttja; all occurring next to each other.

The observed facies changes and their chronology suggest that the changes are directly related to the position of the active sedimentary surface with respect to the level of the water. The sedimentary surface is determined by the sediment supply which, in turn, is governed by the sediment source, while the water level depends on the tidal and groundwater level, both of which are induced by the level of the sea.

The tidal flat is dissected by a very extensive network of tidal channels and creeks (in the supratidal zone) acting as local sediment sources. When a substantial amount of sediment is supplied to the tidal flat under conditions where a rapid relative rise in sea-level exists, it rapidly silts up until high-water level. Consequently, the frequency of tidal inundation decreases and a part of the drainage network serving that particular area becomes redundant and silts up. Eventually the area becomes out of the reach of tidal inundation and the salt marsh encroaches the mudflat, followed by peat accumulation if sufficient time is available for the formation of a freshwater lens in the subsoil. However, at the same time, intertidal deposition continues in an adjoining part of the peat area until it, in turn, will emerge above high-water level and will experience the same evolution.

But the rapid relative sea-level rise steadily creates more accommodation space (i.e. an increasing tidal prism) for the channels which experience a headward growth together with a rise of the water level. Those areas where peat was forming, have been deprived of sediment accumulation for a few hundred years, resulting in their active sedimentary surface being lower in relation to the surface of the tidal flat flanking the channel. Consequently, these areas are in a location that is extremely prone to being flooded when the channel shifts its position.

The latter is probably not caused by the mechanism of lateral channel migration whereby erosion takes place in the outer bend of the channel and deposition in the inner bend because lateral migration is limited when storage capacity is continuously created. The geometry of the sand deposits as depicted in the cross-sections, and the lack of erosional features lead us to assume that crevasse splays as well as meander cut-offs caused the shifts in the position of the channels. These mechanisms were initiated by the water level steadily rising, and by the high aggradation in the channel which considerably reduced the storage capacity for sediment in the channel itself. The high aggradation in the channel or in a segment of it resulted from a decrease in the size of the tidal prism of a part of the channel network due to surface elevation of its surrounding flats. The necessary storage capacity for the channel to compensate the surpassing sediment supply was however available in the lower-lying surroundings of the channel (segment) where peat was forming. Such crevasse splay deposits are almost instantaneously filling the lower-lying surrounding areas of a channel.

The drowning of the freshwater marsh due to the shift in channel position did not occur gradually. The water level rose above the surface rather suddenly, thus preventing a salt marsh from initiating and accreting upwards in pace with the water level. On the other hand, sediment import was sufficient to maintain the intertidal flats.

The imbalance between relative sea-level rise and sediment supply leading to the formation of gyttja in the landward part of the palaeovalleys resulted from the silting up of the tidal flat in more downstream areas preventing the sediment source from reaching the area, or simply because the channel and creek network had not yet reached the area. Moreover, it is most probable that a higher water level was enhanced by the blockage of run-off from the Pleistocene hinterland by the formation of peat itself in the more downstream parts of the drainage channels. The accumulation of organic matter was most probably enhanced by fluvial processes, although with less activity. Moreover, formation of gyttja was greatly affected by the rising hydraulic base level, because the very rapid relative sea-level rise at the beginning of the Holocene was causing a change in stream slope and drainage characteristics in the landward palaeovalleys.

Peat accumulation on gyttja could start as soon as the superfluous water was evacuated. This was caused by the approach of a tidal channel by landward migration and/or shift (while accumulating), resulting in the blockage disappearing, and consequently, better drainage.

The mechanisms of meander cut-offs and crevasse splays resulting in the take-over of drainage of one channel system by another, or the change to a quite different course, can result in the abandonment of a channel, or a segment of it, which is then filled within a relatively short period (months to years). If sediment import is sufficient to balance the relative sea-level rise, such areas escape from the subtidal into the intertidal environment, evolving into salt marsh, and eventually into freshwater marsh with peat accumulation.

From the discussion above, it follows that the alternation of mud, peat and gyttja, and the occurrence of the different sedimentary environments next to each other at the same time and even over very short distances, is solely determined by sedimentological control. The change of one environment into another, laterally as well as vertically, is strictly related to the distal or proximate position of the channels and creeks, even on a small scale. The occurrence of the various environments next to each other resulted from the position of the active sedimentary surface with respect to the water level which was controlled by the distal or proximate position of a particular site to a channel segment, i.e. to the local sediment supply. A proximate position brought the active sedimentary surface within the reach of the daily tidal flooding enabling the surface to rise until it reaches supratidal level. A distal position provided the opportunity for peat to initiate and accumulate on the supratidal flat, while a deprivation of sediment drowned the surface thus allowing gyttja accumulation.

The shift of the channels alternately serving and abandoning a particular part of the flat continues as long as new accommodation space is steadily being created by the rapid relative sea-level rise, so that the entire channel network can continue to migrate landwards and upwards. It is self-evident that sediment supply must outrun the creation of accommodation place, otherwise silting up would not occur in the channels, nor would the flats silt up each time to the supratidal level.

With a decreasing rate of relative sea-level rise as from about 5500 cal BP, the creation of new accommodation space progressively reduces, and the vertical sediment accretion in the channel and on the flats slows down. This results in a reduction in the frequency of channel shifting and explains why the periods of peat growth lasted longer, and why the lateral extension became more and more generalised as the filling of the tidal basin proceeded.

This purely sedimentological mechanism, acting only under conditions of a rapid relative sea-level rise and a general landward migration of the channel network, is at the origin of the alternation of peat beds, gyttja and tidal sediments. It also explains why the intercalated peat beds are not synchronous and do not exhibit a regular pattern in terms of level and spatial distribution.

Thus, a single peat bed should not to be used as marker bed in the stratigraphy, nor as stratigraphic unit. Nor does the alternation of mud and peat reflect positive or negative sea-level tendencies, since sea-level fluctuations play no part in their formation.

Conclusion

The study of the Holocene sequence of a main palaeovalley and its tributaries has shown the complexity of the fill and facies distribution, laterally as well as vertically. The filling of the palaeovalley and the ultimate formation of the coastal plain were controlled by a decelerated relative sea-level rise, the palaeotopography and accommodation space, sediment supply and the configuration of the tidal flat, especially the distal and proximate position of the tidal channel in relation to a particular site. The position of the channels and creeks significantly determined the development of the different depositional environments during the fill. Changes in the rate of relative sea-level rise seems to be the only regional factor. All other controlling factors act locally and their identification requires an integration of local site-based studies in the context of the large-scale coastal behaviour of the entire tidal basin. It should be mentioned that possible crustal movements throughout the Holocene have not been considered and must still be investigated within this context.

The infill of the palaeovalleys did not occur continuously, nor gradually, but in successive steps. Changes between different depositional environments mutually, and between peat growth and tidal deposition occurred rapidly, and this also applies to the spatial distribution and the vertical succession. The changes and the successive steps were not synchronous, not even over short distances, but depended on the local factors mentioned above. The facies sequence is much more sensitive to change in sediment supply than is generally assumed. The facies changes, in particular between mud and peat, is determined by sedimentological control under the conditions of a rapid relative sea-level rise and a landward migration of the channel network associated with a surpassing sediment supply. Periods of peat growth lasted longer and the lateral extension became more and more widespread as deceleration of the relative sea-level rise continued and the filling of the tidal basin proceeded, associated with the progradation of the shoreface.

Because of the irregular pattern of peat growth in time and space resulting from the combined action of the local factors which govern their formation, peat beds should no longer be used to differentiate stratigraphical units in the coastal sedimentary sequence.

Retreat of the Rio Grande Do Sul Coastal Zone, Brazil

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Introduction

In this work retreat and progradation refer to a change in shoreline position, whereas erosion and accretion refer to volumetric changes in the subaerial beach (Wood et al. 1988, Oertel et al. 1989, In: Pilkey & Thieler 1992). As used in this paper, erosion refers to any form of shoreline retreat, consistent with common usage (Pilkey and Thieler, 1992).

On all types of sandy or unconsolidate coasts, beach erosion can be considered to be controlled by a dynamic equilibrium involving three major components, amount and type of sediment supply, physical energy along the coast and rate of sea-level change (Davis, 1997).

When dealing with shorelines and beaches, it is crucial to distinguish between erosion and the erosion problem. Many kilometers of undeveloped U.S. shoreline are eroding and, as a rule, such locations are not considered to be a social problem. It is only when human activity interferes with or gets in the way of shoreline erosion that is becomes a problem (Pilkey & Thieler, 1992).

This paper reports on changes in shoreline position in the state of the Rio Grande do Sul, where the rapid erosion is well documented, the accretional areas is not known and the processes responsible for these conditions are not well understood, by comparing the beach line determined by GPS survey in 1997 with the beach line determined from aerial photos taken in 1975.

Physical Setting

TThe study area is a sandy coastline composed mainly of unconsolidate Quaternary sediments (Villwock, 1986). The coastal plain of Rio Grande do Sul covers a large area of 33,000km^2, consists mostly of sandy deposits interrupted by small streams, has elevations up to 6m, and contains an great number of ponds and lakes and two large lagoons. This coastal plain extends from a headland of granite rocks at Cabo Polonio in Uruguay to the basalts of the Serra Geral Formation at Torres beach.

The Rio Grande do Sul coastal line is a 630km long beach, which runs roughly NE-SW (**Fig. 1**). The continuity of the beach is interrupt by four inlets, which represent a shallow embayment that receives freshwater and high suspended sediment concentration, mostly from the Lagoa dos Patos Lagoon (Hartman, 1988), whose a mean discharge is 4,800m^3/s. The supply of sandy sediments to the coast is not important because the rivers deposit their sediment load into the estuaries and lagoons. Hard structures have been built at three locations, Chui inlet (South limit), Lagoa dos Patos inlet, Mampituba inlet (North limit), in an effort to fix three inlets.

The coastal line trends ESSE, has a mean tidal amplitude of 0.45m, and is exposed to a dominant wave approach from the passage of frontal systems and from passing extratropical cyclones. Prevailing winds are northeast along virtually the entire coast. These wind conditions are particularly persistent during summer. In the summer and autumn the storms frequency are of east and Southeast, and in the Winter the storms frequency are from the South and Southeast, (Tozzi & Calliari, 1997). Except for the passage of cold fronts, the coast experiences medium to high wave energy conditions; mean annual significant wave height is 1.50m and the mean wave period is 9 seconds (Wainer, 1963; Motta, 1969; Almeida et al., 1997). Swell and sea conditions occur along all coast with periods up to 9 and 5 seconds respectively, swell is from SE and the sea is from the E.

Storm surges have been recorded at numerous locations in the study area over the past few decades during the passage of cold fronts. Almeida et al. (1997), observed a storm event at Tramandai beach, which produced a maximum water level of 1.5m in April 07, 1997.

The subaerial beach at the North littoral, between Torres beach and Quintao beach (**Fig. 1**), has a smooth slope between 1:30 and 1:40 and an average width of 60m, which immediately flattens (to about 1:60) in the subtidal zone. The sediments across the beach and the surf zone consist mostly of well-sorted fine sand (mean size 0.2mm), as analyzed by Martins (1967), Alvarez et al. (1983), Tomazelli & Villwock (1992), Toldo et al. (1993), Weschenfelder et al. (1997). From the Conceicao lighthouse southward, Calliari & Klein (1993), report fine quartz sand with gravel and bioclastic sand. Siegle (1996), also noted the dominance of fine sand in this area as well as some medium sand and heavy minerals in sections of the beach between the Conceicao lighthouse to the Hermenegildo beach (Martins da Silva 1976, Villwock 1978, Tomazelli 1978).

The coast between the Imbe and Tramandai beaches is characterized by intermediate to dissipative states (Toldo et al., 1993), from Conceicao lighthouse to Sao Jose do Norte the beaches are also intermediate to dissipative with a more reflective stage during periods of low wave heights (Alvarez et al. 1981, Barleta & Calliari, 1997). The coast between Cassino beach and Chui beach, has different morphodynamic states: intermediate to dissipative North of the Albardao lighthouse, and intermediate-reflective at South of this lighthouse (Calliari & Klein 1993, Tozzi 1995).

Methods

Measurements the position of the coastal line were made from 26 to 28 November 1997, between Torres beach and Chui beach using two GPS, GARMIN model GPS 100 Personal Surveyors, with an accuracy of 10m for the navigator mode and 3m for the static mode. The GPS was installed in a vehicle that was driven approximately 20m of distance from the water line with a medium speed of 50km/h, and an other GPS, in the static mode, was positioned at places previously established on the coast about 100km apart, in order to cover the readings and to increase the precision of data. The sampling rate for both of the GPS instruments was 5 seconds, which allowed post-processing to show the coastline position with an accuracy of 3m. In this work, the space of 18km between the Mostardas lighthouse and Barra da Lagoa do Peixe, was not measured (**Fig. 2**).

The beach line established by GPS in 1997, was compared with the beach line reproduced from the army chart collection make in 1978 year at a scale 1:50,000, based on aerophotogrametric study in 1975 year. Changes in beach line were established on a scale 1:1,300,000 using the IDRISI software.

Results and Discussion

The Rio Grande do Sul State includes 630km of open coast with Quaternary deposits that are almost exclusively unconsolidated and the shoreline ranges from severely eroding to prograding (Fig. 2).

Shoreline comparisons between 1975 and 1997 show both the retreating and progradating areas along the coast between Torres beach and Chui beach. There are 528km of eroding beaches, 50km of prograding beaches and 52km of beach without significant variations. The coast near the hard structures built close to Chui inlet and Lagoa dos Patos inlet has a balance between sediment supply and removal with variations of the coast line smaller that 20m between 1975 and 1997. This work does not consider, however, the shoreline between Torres and Mampituba inlet nor the 18km near the Lagoa do Peixe inlet. As shown by **Figure 2** the majority of Rio Grande do Sul coast is retreating at a high rate. The landward translation of the coastline exceeds 100m in 378km whereas nowhere has shoreline progradation exceeded 40m during the past 22 years (**Fig. 2**). Evidences of beach erosion in the Rio Grande do Sul coastal zone have been documented by Alvarez et al. (1981, 1983), Barletta & Calliari (1997), Calliari & Klein (1993), Calliari et al. (1996), Siegle (1996), Toldo et al. (1993), Tomazelli & Villwock (1989, 1992), Tomazelli et al. (1996) and Tozzi & Calliari (1997).

These trends of eroding beaches are an example of the complex interaction between the rates of sea-level change, wave processes and storm impacts, to understand the historical shoreline evolution along the Rio Grande do Sul coast. The variations rates of sea-level for this area are in the order of +0,62mm/year as established from the tide gauge of Punta del Este - Uruguay Republic (Fig. 1), from 1901, Laborde (*in*: Isla, 1997). Toldo (1989), in geological and hydrodynamic studies of the Lagoa dos Patos, inferred a recent elevation of the medium water level in +1m for the last 300 years, using growth rates of spits.

Four other factors – wave refraction, storms, bulkheads and human activity, need to be considered qualitatively even through their magnitudes are not known. The first factor was analyzed by Siegle (1996), who observed that occurrence of energy concentration induced by wave refraction in the places with high erosion rates (> 80m), between Conceicao lighthouse and the Chui beach. The second factor are the effects caused by catastrophic storms, generated during the passage of cold fronts which raise the medium level of the sea up to 1.5m on the coast (Almeida et al., 1997). Waves associated with extratropical storms cause the most visible and obvious shoreline erosion, but often storm-caused erosion is substantially repaired by pos-storm onshore and longshore sediment transport in the Rio Grande do Sul coast. Calliari et al. (1996), Tozzi & Calliari (1997), describe the shoreline retreat under storm conditions in the Rio Grande do Sul coast. The third and fourth process are the influence of bulkheads about the front dunes, and the impacts of population occupation, mainly at the North area between Torres and Pinhal beach (Fig. 1), where population in the Summer reaches more than 2 million. As discussed by Willians et al. (1997), the vast majority of coastal areas around the world which are under increasing stress from natural processes in recent years received the effect of population grow.

These four processes, responsible for short and long period of erosion, demonstrate the complexity of its interactions when trying to explain coastal erosion in Rio Grande do Sul and rank them in relative importance. Besides these processes, the presence of accretional areas, in the absence of new sand from the mainland is also a problem. The existence of these accretional and erosional areas shows that the rates of shoreline erosion along Rio Grande do Sul coast cannot be viewed independently of the large-scale processes of erosion, deposition and sediment redistribution that occur along the whole coast especially in the shoreface, as observed by List et al. (1997), in studies from 100 years of historical bathymetric data of the Louisiana barrier island coast, and McBride & Byrnes (1997), when analyzing the importance of the coastal sediment budget on the coastal change. List (1997), concluded that historical shoreface map comparisons have led to results that were not anticipated from an examination of shoreline changes alone, and also that longshore transport seems to play a major role in the rapid erosion. This longshore transport occurs both along the shoreline through well-documented littoral processes along the Louisiana coast, and also apparently at shoreface depths by processes that are poorly understood.

Regardless of its causes the results of this study are important for the management of the coastal zone in Rio Grande do Sul. Coastal restoration programs can utilize this information to: identify areas in greatest need for protection and restoration, help determine the type of coastal protection needed, and evaluate project performance (hard or soft structures) by comparing post-project rates of shoreline change with long-term historical trends, i.e., have a well established baseline control data set (McBride and Byrnes, 1997).

Final Comments

There are some generalizations that can be made along with their respective rationales, about this study that has documented the accretional areas and erosion problem about many kilometers of Rio Grande do Sul shoreline.

The Rio Grande do Sul State shoreline is experiencing severe eroding conditions. Over the period of 22 years, the primary factors driving erosion along of coastal zone are the combined effects of wave energy, sea-level change and sediment supply with recent and local impact from human intervention.

Coastal erosion contributes to improved understanding of the historical shoreline evolution along the Rio Grande do Sul State as well as the accretional areas. These conditions suggests that for the understanding of the coastal sedimentary dynamics is necessary to understand the large-scale process of erosion, deposition and sediment redistribution on shoreline and on shoreface.

The data obtained from of the methodology used in this wok provides a mechanism for estimating the coastal sediment budget, that in beginning constituted in the most influential factor affecting the Rio Grande do Sul coastal change.

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References

Almeida, L.E.S.B.; Rosauro, N.M.L.; & Toldo Jr., E.E., 1997. Análise Preliminar das Mares na Barra do Rio Tramandai, RS. XII Simposio Brasileiro de Recursos Hidricos, Vitoria, ES, Resumos, p. 560-566.

Alvarez, J.A; Gre, J.C.R.; & Toldo Jr., E.E. 1981. Estudos da Praia a Nordeste do Molhe de Rio Grande, *Pesquisas*, 14: 131-147.

Alvarez, J.A; Gre, J.C.R; & Toldo Jr., E.E. 1983. Estudos Oceanográficos e sedimentologicos preliminares da praia de Tramandai-RS. *Pesquisas*, 15: 66-85.

Barletta, R.C., & Calliari, L.J., 1997. Caracterizacao Morfodinâmica de Praias Compreendidas entre o Farol da Conceicao e Sao Jose do Norte, RS. Resumos, p. 24-26, Anais da Semana Nacional de Oceanografia, UNIVALI, Itajai, SC, Brasil.

Calliari, L.J., & Klein, A.H.F., 1993. Caracteristicas Morfodinâmicas e Sedimentologicas das Praias Oceânicas entre Rio Grande e Chui, RS. *Pesquisas* 20(1), 48-56, UFRGS, Porto Alegre, RS, Brasil.

Calliari, L.J.; Tozzi, H.A.M.; & Klein, A.H.F., 1996. Erosao associada a mares meteorologicas na costa sul-riograndense (COMEMIR/OSNLR), Anais, 34o Congresso Brasileiro de Geologia, Salvador. SBG. 4:682-684.

Davis, Jr., R.A., 1997. Regional Coastal Morphodynamics Along the United States Gulf of Mexico. *Journal of Coastal Research*, 13(3), 595-604.

Hartman, C; & Sano, E.E. 1988. Contribuicao ao estudo da hidrodinâmica e evolucao das massas de água na Laguna dos Patos, atraves de imagens MSS/Landsat, no periodo de 1979 a 1983. *Revista Brasileira de Geofisica*, 4:215-228.

Isla, F.I., 1997. Boletin Informativo Regional no 12. OSNLR Universidad Nacional de Mar del Plata, Argentina.

List, J.H.; Jaffe, B.E; Sallenger, A H., Jr., & Hansen, M.E., 1997. Bathymetric Comparisons Adjacents to the Louisiana Barrier Islands: Processes of Large-scale Change. *Journal of Coastal Research*, 13(3):670-678.

McBride, R.A. & Byrnes, M.R. 1997. Regional Variations in Shore Response along Barrier Island System of the Mississipi River Delta Plain: Historical Change and Future Prediction. *Journal of Coastal Research*, 13(3):628-655.

Martins da Silva, M.A., 1976. Mineralogia das Areias de Praia entre Rio Grande e Chui, Rio Grande do Sul. Curso de Pos-Graduacao em Geociencias, UFRGS. Dissertacao de Mestrado. 93p.

Martins, L.R. 1967. Aspectos texturais e deposicionais dos sedimentos praiais e eolicos da planicie costeira do Rio Grande do Sul. Publicacao Especial da Escola de Geologia, UFRGS, Porto Alegre, 13:1-102.

Motta, V. F. 1969. Relatorio Diagnostico Sobre a Melhoria e o Aprofundamento do Acesso pela Barra do Rio Grande. Relatorio Tecnico. Porto Alegre, Instituto de Pesquisas Hidraulicas, UFRGS. 144p.

Pilkey, O. H. Jr., & Thieler, E. R. 1992. Erosion of the United States Shoreline. Quaternary Coasts of the United States: Marine and Lacustrine Systems. IGCP Project #274, SEPM, Special Publicaton 48.

Siegle, E., 1996. Distribuicao dos Sedimentos Litorâneos entre o Farol da Conceicao e Farol do Chui, RS, e Fatores Condicionantes. Curso de Graduacao em Oceanologia, Fundacao Universidade do Rio Grande. Trabalho de Graduacao, 91p.

Toldo Jr., E.E. 1989. Os Efeitos do Transporte Sedimentar sobre a Distribuicao dos Tamanhos de Grao e Morfodinâmica Lagunar. Porto Alegre. 143 p. Dissertacao de Mestrado em Geociencias, Instituto de Geociencias, Universidade Federal do Rio Grande do Sul.

Toldo Jr, E.E.; Dillenburg, S.R.; Almeida, L.E.S.B.; Tabajara, J.L.; Martins, R.R.; & Cunha, L.O.B.P.1993. Parâmetros Morfodinâmicos da Praia de Imbe, RS. Pesquisas, 20(1):27-32, UFRGS, Porto Alegre, RS, Brasil.

Tomazelli, L.J., 1978. Minerais Pesados da Plataforma Continental do Rio Grande do Sul. Acta Geologica Leopoldensia, 5(2):103-160.

Tomazelli, L.J., 1990. Contribuicao ao estudo dos sistemas deposicionais holocenicos do nordeste da provincia costeira do Rio Grande do Sul - com enfase no sistema eolico. Porto Alegre. 270 p. Tese de Doutorado em Geociencias, Instituto de Geociencias, Universidade Federal do Rio Grande do Sul.

Tomazelli, L.J., & Viilwock, J.A., 1989. Processos Erosivos na Costa do Rio Grande do Sul, Brasil: Evidencias de uma Provável Tendencia Contemporânea de Elevacao do Nivel Relativo do Mar. Resumos, II Congresso da Associacao Brasileira de Estudos do Quaternário, Rio de Janeiro, ABEQUA, p. 16.

Tomazelli, L.J. & Villwock, J.A. 1992. Consideracões Sobre o Ambiente Praial e a deriva litorânea de sedimentos ao Longo do Litoral Norte do Rio Grande do Sul. Pesquisas, 19(1):3-12.

Tomazelli, L.J.; Villwock, J.A.; Dillenburg, S.R.; Bachi, F.A.; & Dehnhardt, B.A., 1996. Erosao Costeira no Rio Grande do Sul, Anais, 34o Congresso Brasileiro de Geologia, Salvador, BA. SBG. 4:685-687.

Tozzi, H.A.M.; & Calliari, L.J., 1997. Influencias das Tempestades Extratropicais sobre o estoque de Sedimentos das Praias entre Rio Grande e Chui, RS. Resumos, p. 85-87, Anais da Semana Nacional de Oceanografia, UNIVALI, Itajai, SC, Brasil.

Tozzi, H.A.M., 1995. Morfodinâmica da Praia do Cassino, Rio Grande, RS. Curso de Graduacao em Oceanologia, Fundacao Universidade do Rio Grande. Trabalho de Graduacao, 52p.

Villwock, J.A.; Tomazelli, L.J.; Hofmeister, T.; Juchem, P.L.; Dehnhardt, E.A.; & Loss, E.L., 1978. Análise Textural e Mineralogica das Areias Negras da Costa do Rio Grande do Sul. Anais, XXX Congresso Brasileiro de Geologia, Recife, PE, 2:913-926.

Villwock, J.A.; Tomazelli, L.J.; Loss, E.L.; Dehnhardt, E.A.; Horn Fo, N.O.; Bachi, F.A., & Dehnhardt, B.A. 1986. Geology of the Rio Grande do Sul Coastal Province. In: RABASSA, J., (ed.), Quaternary of South America and Antarctic Peninsula. Rotterdam: A.A. Balkema Publishers, 4, 11p.

Wainer, I.J., 1963. Análise e Previsao das Alturas de Onda em Tramandai. Relatorio Tecnico. Porto Alegre, Instituto de Pesquisas Hidraulicas, UFRGS.

Weschenfelder, J. 1996. Variabilidade Morfodinâmica das Praias Oceânicas entre Imbe e Arroio do Sal, Estado do Rio Grande do Sul, Brasil. Dissertacao de Mestrado em Geociencias, Instituto de Geociencias, Universidade Federal do Rio Grande do Sul, 132 p.

Williams, S.J.; Stone, G.W., & Burruss, A.E., 1997. A perspective on the Louisiana Wetland loss and coastal erosion problem. Jounal of Coastal Research, 13(3):593-594.

Fig. 1 Study area showing the principal locations.

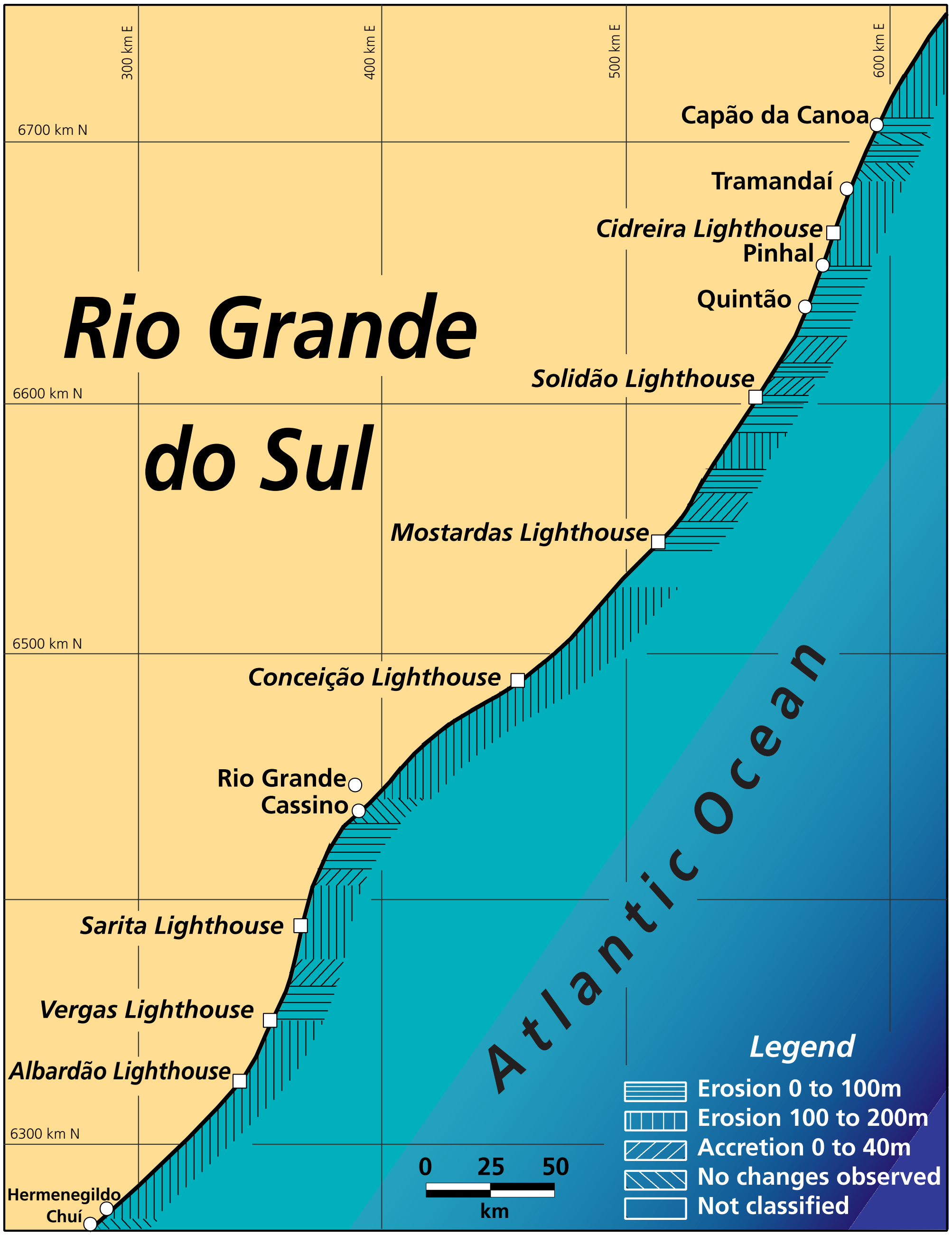

Fig. 2 Map of the Rio Grande do Sul coast showing the general pattern and values of erosion and accretion areas.

Heavy metal enrichments in an 'Endangered' coast, south west coast of India: A baseline study

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Rivers are the channelised routes through which continental materials like weathered products and anthropogenic materials are transported to the coast. Removal of both suspended and dissolved materials takes place during the mixing of river water with sea water due to gradients in pH, salinity and other physico-chemical parameters like dissolved oxygen, Eh, turbidity and humic acids. About 92% of the river-borne sediments (13.5 billion tons/yr) are trapped in estuaries and connected drainage basins like lagoons, tidal flats, marshes and adjacent continental shelves due to flocculation, agglutination and fecal pelletisation processes. This is the prime reason for the accumulation of contaminants like heavy metals, radionuclides, and organic contaminants in densely populated and industrialised coastal belts of the world.

Nearshore regions serve as a sink or filter for continental detritus, but they are not a permanent sink for base metals. Due to the rapid accumulation of organic matter in these sediments, diagenetic processes result in the depletion of dissolved oxygen producing anoxic conditions, under which redox sensitive metals are easily remobilised from the sedimentary column and added through the pore water to the overlying water. Remobilised metals may again undergo adsorption and precipitation and thus be incorporated into the particulate phase under oxic conditions. The direction of bottom currents influences the transport of remobilised elements either landward or seaward. In general, because of the seaward decrease of terrigenous influx and the existence of oxic conditions in the open ocean, base metals are enriched in open ocean sediments when compared to nearshore sediments.

As two thirds of the world population lives in and around coastal areas, it is imperative to monitor pollution in the aquatic system. Baseline data for the various organic and inorganic constituents in the environment (air, water and land) and their periodic monitoring are needed to evaluate the impact of industries on the environment. Baseline studies will not only help in evaluating the impact from upcoming industries on the environment but also in understanding natural processes operating in the area.

India's vast coastline is densely populated and characterised by a number of industries like chemical and fertiliser plants, oil refineries, nuclear power plants, ports etc. The study area forms a part of Karnataka State which has a coastline of about 300 km along the south west coast of India, bordered by the Western Ghats on the east and the Arabian Sea on the west. This coastline is punctuated by a number of natural as well as man-made features; man-made features include ports / harbours, fertiliser plant, etc. A number of industries have recently come up and few others are in the process of being set up in the coastal zone like the Mangalore Chemicals and Fertilisers, Mangalore Refineries and Petrochemicals, Cogentrix thermal power plant, Nuclear Power Plant, Naval Base etc.Therefore coastal environment of Karnataka is presently sitting under an industrial hotspot .

Keeping this in background, the present study is taken up in this area along a small tropical river-estuary-coastal system (Kali river; lat 14° 54'N, long 74° 29'E and 14° 48'N, 74° 01'E) draining into the Arabian Sea. This study acts as a baseline data which investigates the anthropogenic contribution of trace metals in the river-estuary and coastal sediments.

In this study, enrichment factor and geoaccumulation index have been used to assess heavy metal pollution in the area of investigation for Mn, Fe, Co, Ni, Pb, Zn, Cu and Mo. Enrichment factor ($EF = Metal/Al_{(sample)} / Metal/Al_{(average\ shale)}$) has been calculated for these elements both in suspended and river-bed sediments that were collected during pre-monsoon, monsoon and post-monsoon seasons. The composition of global average shale has been taken as the background value as no similar data are available for the study area. The average composition of normal shallow water shale used in this study represents the crustal composition and is based on the average of 277 shale samples. Geoaccumulation index (I_{geo}) is another measure of quantifying metal accumulation in polluted sediments. Because it is a simple measure of knowing the level of heavy metal pollution in aquatic environments, it is widely used.

Geoaccumulation index is expressed as:

$$I_{geo} = \log_2 (An/Bn \times 1.5)$$

where: An = concentration of element A in a sample
Bn = background value (i.e. average shale) of element A, and
1.5 = factor that takes care of possible variations in background data due to lithologic effects

Geoaccumulation index can be classified into seven grades, of which I_{geo} 6 indicates a 100-fold enrichment of an element above the background. It is distinct from EF because of the factor of 1.5 provided in the equation which takes care of possible variations in the background data due to lithologic effects. In addition, EF does not take into account the nature and genesis of the matrix which plays a crucial role in metal contamination.

Manganese and Pb show EFs of >2 in different seasons for SPM and bottom sediments from the riverine and estuarine environments. The occurrence of Mn deposits in the catchment must have contributed to the high enrichment of Mn. The I_{geo} for Mn is uniformly zero in all the environments of the Kali system proving that there is no anthropogenic factor behind Mn enrichment. Lead is enriched in the estuarine and coastal ocean SPM of post-monsoon and monsoon seasons and in the estuarine bottom sediments of the pre-monsoon season. The I_{geo} for Pb in pre-monsoon estuarine sediments is also 2. The principal source of Pb could be the atmosphere which reacts with particulates leading to the enrichment of Pb in SPM and bottom sediments.

Iron in the monsoon season is mainly enriched in the riverine SPM; but the EF gradually decreases in the estuary and the coastal ocean. A similar pattern is observed for bottom sediments. Iron in the riverine sediments has an EF of 2. This is supplemented by the high I_{geo} values observed for the sediments. Due to the predominance of chemical weathering in the catchment, the rocks are transformed into laterites which are rich in Fe and Al. With passage of time, they are eroded and transported as particulate load or as bed-load in the Kali river. Cobalt shows an EF of about 2 in the riverine and estuarine bottom sediments whereas enrichment in SPM is uniform in all the three environments. Cobalt shows an I_{geo} of 2 for riverine sediments of the monsoon and post-monsoon seasons whereas Ni shows an I_{geo} of 2 in the pre-monsoon season. This higher-than-normal enrichment could mainly be due to natural processes as Co and Ni are known to be associated with Fe and Mn dioxide phases during chemical weathering.

Copper, Zn and Mo show moderate to minimal enrichment in the riverine, estuarine and coastal environments in the three seasons. Their I_{geo} values do not exceed 1 which is well within the safe limits from the point of view of pollution.

This study has suggested that there is no pollution of SPM and bottom sediments in the area investigated due to anthropogenic activities as of date of sample collection. However, the enrichment in Mn, Pb, Fe and Co in SPM and bottom sediments could be due to natural materials / processes.

Rapid sea-level changes and coastal evolution on the Pacific margin of Canada

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Glaciation reached its maximum extent sometime after 21,000 ^{14}C yr B.P. off the northern Pacific margin of Canada with ice moving into Dixon entrance from southeastern Alaska and the British Columbia mainland, joined by local ice from the northern Queen Charlotte Islands. Glacial retreat began sometime after 15,000 ^{14}C yr B.P. and ice had completely left the marine areas by 13,500 to 13,300 ^{14}C yr B.P. A core obtained at the present day water depth of 37 m contains cold water foraminifera (*Cassidulina reniforme*) in ice proximal laminated fine-grained sediments which date to 14,570 ^{14}C yr B.P. (Barrie and Conway, 1999). Another core taken from a nearshore sand deposit has been dated to between 12,710 and 12,880 ^{14}C yr B.P. in 77 m of water. The indication is that a rapid regression occurred on the continental shelf between approximately 14,600 and 12,500 ^{14}C yr B.P., contemporary with deglaciation, due almost entirely to rapid isostatic rebound. Sea level had reached a maximum lowering of over 150 m and remained low until approximately 12,400 ^{14}C yr B.P., after which a rapid transgression occurred (Josenhans et al., 1997). As the sea transgressed the continental shelf west of the British Columbia mainland, sea-level reached a maximum of 200 m above present in Kitimat trough on the mainland at 10,500 ^{14}C yr B.P. (Clague, 1985). Contemporaneous shelf tilt existed across the northern Pacific margin of Canada ranging from 200 m of submergence at the fjord head near Kitimat on the British Columbia mainland to greater than 100 m of emergence on the western edge of the Queen Charlotte Islands at approximately 10,500 ^{14}C yr B.P. This regressive/transgressive cycle lasted only 5,200 to 5,500 ^{14}C years, a result of the development and collapse of a glacioisostatic forebulge.

Sediment supply, wave and tidal current energy were the primary factors that controlled coastal response to these late Quaternary relative sea-level changes. Plate tectonics, on the other hand, played a secondary role in coastal evolution. During deglacial regression of the shelf and transgression of mainland British Columbia sediment supply was abundant. This resulted in extensive glacial outwash and glaciomarine deposition except where wave and current energies where high, such as Dixon Entrance and the western coast of the Queen Charlotte Islands. In these areas early intrusion of the high energy Pacific waters resulted in the transfer of sediment to the selfbreak. During the early Holocene transgression of the shelf, sediment supply was primarily restricted to the erosion of the previously deposited deglacial deposits, resulting in the formation of drown wave-cut terraces and spit platforms as sea-level rose in steps. The rapid rate of sea-level rise (5 cm/yr) was such to also drown and preserve fetch-protected paleolacustrine and estuarine environments. Sediment supply was reduced as sea-levels increased, except for the northeastern coastline of the Queen Charlotte Islands where glacial and outwash deposits still form much of the coastline. Here, Holocene sea-level changes still impact the coastal zone and transfer sediment offshore. As much as 12 m of coastal erosion occurred during the recent El Niño, when sea - levels reached 40 cm above normal during the peak in February 1988.

References

Barrie, J.V. and Conway, K.W. 1999. Late Quaternary glaciation and postglacial stratigraphy of the northern Pacific magin of Canada. *Quaternary Research*, 51, 113-123.

Clague, J.J. 1985. Deglaciation of the Prince Rupert - Kitimat area, British Columbia. *Canadian Journal of Earth Sciences*, 22, 256-265.

Josenhans, H.W., Fedje, D., Pienitz, R., and Southon, J. 1997. Early humans and rapidly changing Holocene sea-levels in the Queen Charlotte Islands-Hecate Strait, British Columbia, Canada. *Science*, 277, 71-74.

The many faces of tectonics and its role in shaping Late Quaternary shorelines

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Introduction

For as long as civilisations have occupied the coastal environment, the combination of climate, weather, volcanism and tectonics has left a lasting impression. Greek and Roman civilisations documented the occurrence of earthquakes and volcanic eruptions and their effects on coastal landforms. Combining the written record with a modern understanding of physical processes provides a powerful tool in documenting a long time series of geomorphic cause and response (e.g. Vita-Finzi, 1986; Pirazzoli et al., 1989). Separation of land and sea processes (tectonics versus eustacy) has, and continues to be, a significant challenge at many temporal and spatial scales.

Historical Perspective

For a century and a half there have been "modern" reports of the effects of earthquake on coastal areas including both site specific case studies as well as with global perspectives. Charles Darwin was an eyewitness to the effects of the 20 Feb, 1835 earthquake centred on Concepción in central Chile. In Concepción most of the damage was due to a large tsunami, but there was about 0.6-1.0 m of coastal uplift. Darwin (1851, p. 300) noted that:

> "[on] the island of Santa Maria [~50 km from Concepción]....the elevation [co-seismic uplift] was greater; on one part Captain Fitzroy found beds of putrid mussel-shells still adhering to the rocks ten feet [~3 m] above the high-water…..the inhabitants had formerly dived at low-water spring tides for these shells…..The elevation of this province is particularly interesting from its having been the theatre of several other violent earthquakes, and from the vast number of sea-shells scattered over the land up to a height of certainly 600 [feet] and I believe 1,000 feet [200-300 m]."

Other historical examples of coastal uplift and subsidence at the time of great subduction earthquakes or upper plate faults in collision zones have been repeated many times since Darwin's classic description from Chile, especially in the circum-Pacific region, and the Mediterranean, and have also been widely interpreted from the geological record.

Darwin also described the classical coral reef island sequence of high tropical islands with fringing reefs, barrier reef island, and finally atolls, from observations made during the expedition of the Beagle (Darwin, 1842). The crustal processes behind this sequence are now understood in terms of cooling and sinking of lithosphere along hot-spot tracks (Menard, 1986) or lithospheric flexure around active oceanic volcanoes (e.g. McNutt & Menard, 1978).

By the late 1800's Seuss (1888) had described distinct differences in the coastal geomorphology between dynamic Pacific-type coasts and passive Atlantic-type coasts, and in this sense he pioneered coastal classification systems that embraced tectonic processes as a key determinant of coastal landforms and process.

Plate Tectonic Framework

The advent of plate tectonic theory and its verification from the 1960's (e.g. Le Pichon, 1968, Isacks et al., 1968) provided a quantitative, broad, framework for coastal classification, building on the early insights of Seuss. Inman & Nordstrom (1971) discussed first order coastal evolution in relation to plate tectonic models, and proposed a three-fold classification (**Table 1**).

Dating

Establishment of radiocarbon dating from the early 1950's was a turning point in moving coastal geomorphology from a qualitative and descriptive science to an incresingly quantitative and integrated process-oriented science, integrated with global and regional climate and large-scale tectonic models based on plate tectonics. Further advances in Quaternary dating methods, the understanding of astrophysical controls on global sea-level fluctuations, and the variation in timing and elevation of those global eustatic levels allows the use of successive interglacial shorelines, and the c. 6.5 ka age of the Holocene transgression shoreline to be used as approximate datums for vertical deformation. At high latitude sites the effects of uplift due to ice melt, followed by peripheral forebulge collapse leads to very complex, first-order, relative sea-level curves. At many mid-high latitude sites along continental margins the postglacial sea-level would appear not to have reached a culmination, but rather has continued to rise at a slow rate from the deceleration at 6-7 ka (e.g. Bloom, 1977).

Holocene Records and Eustacy

The common aspects of relative sea-level curves in mid-latitude locations is a rapid rise in sea-level from 15-7 kyr, a decrease in the rate of rise to a culmination between 6-7 kyr in mid-latitudes, but rather variable thereafter as regional hydro-isostatic processes take effect. Ota et al (1988) found a tendency for the age of the culmination of postglacial accumulations in estuaries was rather older at sites where there was a higher average uplift rate. The culmination of postglacial sea-level rise also marks the change from a rising to falling trend of relative sea-level as tectonic processes driving land uplift are no longer swamped by very rapid sea-level rise.

Thus at one level of investigation we find that in tectonically active areas that sea-level rise was the dominant factor in coastal geomorphology even in tectonically active areas until about 6-7 ka BP. After that time tectonic uplift (and subsidence) has dominated over sea-level fluctuations when tectonic movements have resulted in net movement of 5 m or greater in the past 6-7 kyr. Where the net movement is less than several metres then a great number of processes and measurement considerations are required to intepret the signal. The compilation of these Holocene sea-level curves revealed appreciable differences in space and time, and the notion of a world-wide eustatic sea-level, with resolution of a metre or less, was obviously a flawed notion. Three papers in the 1970's (Walcott, 1972; Chappell, 1974; Clark et al., 1978) provided the crucial insights into eustacy as a regional phenomonon, and extended the beginnings made by early work of Daly (1925), and Bloom (1967). Daly and Bloom had noted that if the ocean floor deforms under the load of water from postglacial sea-level rise, then that deformation must be considered before deriving eustatic signals from past markers of sea-level. Clark et al (1978) was the first of many numerical models of isostatic adjustment to load depending on location, geophysical parameters of earth structure, and time constants of the processes.

At a more detailed level of investigation where the relative shift of Holocene shorelines is less than a few metres, a large number of factors require consideration. These include:

- The possibility of very infrequent but large earthquakes in areas where there is no historical seismicity.
- Determining how elevated deposits relate to modern equivalents and present-day mean sea-level.
- Hydro-isostatic effects. On wide continental shelves the load of sea water in the prism from c. 125 water depth to the shore may result in peripheral bulge at, and inland of, the coast.
- Climatic and tidal changes through time. Changes in dominant wind directions in the period since the culmination of the postglacial sea-level rise has the potential for changing the mean level of the sea surface. Similarly where estuaries or bays have evolved quickly since the culmination of the postglacial sea-level rise there may have been significant changes in tidal ranges, and hence there is uncertainty in relating elevations of fossil sea-level markers to present-day equivalents.
- Sediment loading in basins on the continental shelf may result in peripheral uplift in a similar fashion to hydro-isostacy effects, although the spatial and temporal distribution of the deformation may be different.

Future Challenges

There are substantial challenges in future coastal studies worldwide. In most localities there is a requirement for more detailed mapping and improved dating of stratigraphies of coastal deposits and of landforms, particularly those that are beyond the range of radiocarbon dating. Increasing confidence with luminescence techniques along with dating schemes using radionuclides such as Be^{10}, and Al^{26}, integrated with isotope studies, paleontology, and geochemistry, offer exciting opportunities. With dating and rate estimates comes the opportunity to differentiate and isolate the governing parameters in coastal evolution in space and time. The advent of real-time monitoring of deformation with GPS allows research to look within one earthquake cycle. Differentiation of crustal processes within earthquake cycles from relative sea-level movements due to climate change are significant issues for future management of the coastal zone. The identification of low rates of coastal uplift in regions that have not experienced large earthquakes in the historical period suggest there may be non-seismic tectonic processes such as hydro-isostacy, and deformation in response to sediment loading, at work on the coastline. Their identification, and determination of their length and time scales, separate from possible climatic signals, also represent significant challenges.

References

Bloom. A.L. 1967. Pleistocene shorelines: a new test of isostacy. Geological Society of America Bulletin 78: 1477-1493.

Bloom, A.L. 1977. Atlas of sea-level curves. Cornell University, New York. (International Geological Correlation Programme 61).

Chappell, J.M.A., Geology of coral terraces on Huon Peninsula, New Guinea. *Geological Society of America bulletin 85*, 553-570. 1974.

Clark, J.A.; Farrell, W.E.; Peltier, W.R. 1978. Global changes in post-glacial sea-level: a numerical calculation. Quaternary Research 9: 265-287.

Daly, R.A. 1925. Pleistocene changes of level. *American Journal of Science 6:* 246-250.

Darwin, C.A. 1851. *Geological observations on coral reefs, volcanic islands and on south America; being the geology of the voyage of the Beagle, under the command of Captain Fitzroy, R.N. during the years 1832 to 1836.* London.

Darwin, C.A. 1842. *The structure and distribution of coral reefs.* Smith Elder & Co. London.

Davies, J.L. 1972. Geographical variation in coastal development. Oliver & Boyd. Edinburugh.

Inman, D.L.; Nordstrom, C.E. 1971. On the tectonic and morphologic classification of coasts. Journal of Geology 79: 1-21.

Isacks, B.; Oliver, J.; Sykes, L.R. 1968. Seismology and the new global tectonics.. Journal of Geophysical Research 73: 5855-5899.

Le Pichon, X. 1968. Sea-floor spreading and continental drift. Journal of Geophysical Research 73: 3661-3697.

McNutt, M.; Menard, H.W. 1978. Lithosphere flexure and uplifted atolls. Journal of Geophysical Research 83: 1206-1212.

Menard, H.W. 1986. *Islands.* Scientific American Library. Freeman & Co. New York.

Ota, Y., K.R. Berryman, A.G. Hull, T. Miyauchi, and N. Iso. 1988. Age and height distribution of Holocene transgressive deposits in eastern North Island, New Zealand, Paleogeography, Paleoclimatology, Paleoecology 68: 135-151.

Pirazzoli, P.A.; Montaggioni, L.F.; Saliège, J.F.; Segonzac, G.; Thommeret, Y.; Vergnaud-Grazzini, C. 1989. Crustal block movement from Holocene shorleines: Rhodes Island (Greece). Tectonophysics 170: 89-114.

Suess, E. 1888. The face of the Earth. Vienna (in German – translated 1906, Oxford).

Vita-Finzi, C. 1986. *Recent Earth Movements.* Academic Press. London.

Walcott, R.I. 1972. Past sea-levels, eustacy, and deformation of the earth. Quaternary Research 2: 1-14.

Table 1
Coastal Classification Based on Plate Tectonics

Primary Class	Secondary Class	Description	Type Examples
Collision	continental collision	where a continental margin is located along the zone of convergence	Alaska, Chile, New Zealand
	island arc collision	where no continental margin is located along the zone of convergence	Tonga, Vanuatu, Marianas
Trailing Edge	neo-trailing edge	where a new zone of spreading is separating a landmass	Red Sea, Gulf of California
	Afro-trailing edge	where the coast on the other side of the continent is also trailing	east Africa, west Africa, Greenland
	Amero-trailing edge	where the coast on the other side of the continent is collisional	Argentina, Brazil, eastern USA & Canada
Marginal Sea		where the coast is on the margins of a backarc basin	Korea, China facing Japan Sea

Classification based on original concept of Inman & Nordstrom (1971), modified by Davies (1972)

Compositional analysis of Hawaiian beach sediment: an indicator of source, process and coastal change

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Introduction

Beach sediment composition and texture reflects the source of the sedimentary material and the sedimentary processes involved in its production. Samples from sandy beaches around the Big Island of Hawaii, the Island of Kauai and islands of Midway Atoll were systematically collected, impregnated in blue-dyed epoxy resin and thin-sectioned for quantitative examination utilizing a standard polarizing petrographic microscope. Gamma-ray emission measurements, utilizing a GRS-500 Differential Spectrometer/Scintillometer, also were obtained at most sample localities in order to assess the character and abundance of potassium-bearing volcanic lithic fragments. A total of 62 Big Island beach, dune and offshore samples from 42 discrete beaches were analyzed. On Kauai 210 localities on more than 80 beaches were measured and sampled; 130 beach and dune samples were examined petrographically. From Midway Atoll, 5 beach samples were examined from Sand Island and Eastern Island.

Big Island

In general the beach sediments of the Big Island reflect strongly its geologic youthfulness. The windward eastern coasts are dominated by volcanic constituents (**Fig. 1**). The beaches of Pololu and Waipio valleys along the North Kohala Coast, and various beaches of the Hamakua Coast, are composed mainly of highly altered, crystalline basalt and moderate amounts of olivine derived from the fluvial erosion of the oldest volcanic elements exposed on the island. Black sand beaches rimming the relatively young Kilauea lavas of the Puna Coast display a wide range of compositions with abundant volcanic glass, olivine and altered crystalline volcanics; much of that material has been produced directly from molten lavas pouring into the sea. At Mahana (Green Sand) Beach olivine, derived locally from specific picritic lava flows and tuff cones, ranges up to greater than 90% of the beach sediment. The relatively low energy, leeward Kona beaches are dominated by carbonate constituents; although, locally relatively young lava flows have contributed extensive amounts of volcanic (i.e., black) sand. The carbonate (i.e., white) sand beaches are composed mainly of stony, aragonitic coral and calcitic coralline algal fragments with additional significant amounts of molluscan, foram and echinoid fragments. Beaches along the Kona Coasts south of Kailua are composed dominantly of coral (>60%) with coralline algae being much less abundant (<20%), whereas those north of Kailua display relatively less coral (<45%) and more coralline algae (>30%); molluscan fragments also seem to increase in abundance northward (**Fig. 2**).

Kauai

Beaches of Kauai reflect the island's relative geologic maturity, with its complex suite of volcanic materials, high degree of weathering and erosion and extensive, prominent coralgal fringing reefs. Nearly 50% of the island's 111 mile (179 km) perimeter is occupied by sandy beaches, most of which are dominated by biogenic carbonate constituents; only one significantly large volcanic sand beach exists on the island (i.e., Waimea Beach at the mouth of Waimea Canyon). Coastal deposits associated with the older shield volcanics of the Waimea Canyon Basalt occupy the 41 miles (66 km) of the western portion of the island from Hanalei Bay to Na Pali Coast and Mana Coastal Plain; they display an average of nearly 40% total volcanic rock fragment (VRF) grains, including >15% olivine (**Fig. 3**). Beaches associated with the post-erosional Koloa Volcanics around the eastern 70 miles (113 km) average <10% VRF and <1% olivine; significant exceptions occur at three isolated localities where point sources of olivine-rich volcanics exist (Hanapepe Bay, Kipu Kai and Kilauea cinder cone). The beach sediments of Kauai are dominated by reef-building constituents which average 72.5% of the carbonate fraction and, surprisingly, show relatively little variation around the island, regardless of proximity to the prominent fringing coralgal reefs (**Fig. 4**). Coralline algal fragments are consistently the most abundant constituent (average of nearly 40%) with coral being second (average <25%) and reef-cemented-sediment intraclasts comprising about 10% of the carbonate fraction. Non-reefal constituents include foraminifers (12%), molluscs (6.5%) and echinoid fragments (5.5%).

Midway

Midway beach samples are the whitest of all the samples examined in this study. VRFs are completely absent from the deposits. Overall the few samples analyzed are dominated by coralline algal fragments (average of >40%) with coral (23%) and cemented sediment intraclasts (5.5%) comprising the reefal material (composite average of 70%) (**Fig. 5**). Foraminifers and Halimeda are abundant non-reefal constituents (average of 17% and 4.5%, respectively). Interestingly, the three samples from beaches that face the outer portion of the atoll display much greater amounts of coralline algae (average of nearly 50%) and lesser amounts of foraminifers (13%) than do the two samples from beaches that face the lagoon (average of 30% coralline algae and 23% foraminifers). Coral composition does not seem to vary much between the outer and inner beaches (average around 23%).

Implications

1. The significant variability of Hawaii's beach sediments, from beach to beach on a given island and from island to island, reflects the complex geologic history of the archipelago, both in terms of its mountain/island volcanic complex and the production of biogenic marine carbonates.

2. The dominance of volcanic (i.e., black) sand beaches along the Big Island's windward coast is indicative of the abundant source of volcanics and lack of reef development along that high energy coast. The abundance of coral fragments in leeward Kona beaches reflects the rapidly growing reefs dominated by corals trying to keep up with island subsidence; the more northerly Kona beaches and reefal structures display greater amounts of coralline algae owing to the greater relative stability and reef maturity in that area.

3. The variable character of Kauai's beaches is related mainly to the composition, structure and related geomorphology of the mountain/island, and to the irregularities of the drowned shoreline that resulted from the Holocene rise in sea-level. The predominance of carbonate constituents reflects, in part, the greater resistance of carbonate material to weathering and abrasion, compared to less resistant volcanic materials. Kauai's prominent fringing reefs, with broad shallow platforms, are today composed mainly of coralline algae owing to the island's relative stability and maturity.

4. The sediment of most beaches on both the Big Island and Kauai appear to have been derived locally, confined to relatively small beach cells and not distributed great distances along the highly irregular (indented) shorelines. Movement of beach sediment appears to be mainly on and off shore in response to changing wave-generated energy conditions. The extensive Mana Coastal Plain coastline of Kauai is a notable exception, however.

5. The abundance of coralline algal fragments in Midway Atoll beaches demonstrates that reef development continues to be dominated by the growth and binding capability of stony red algae. Scleractinian coral production appears much less important in terms of reef structure and growth. Foraminifera display great abundance in lagoonal facing beaches and may comprise a significant proportion of the atoll's carbonate complex.

6. Obviously, the composition of Hawaii's coastal sediments is indicative of the variety of materials available (i.e., the source) and the sediment producing processes of erosion, transport and deposition. A clear understanding of such variables is essential for dealing with the various aspects of coastal change.

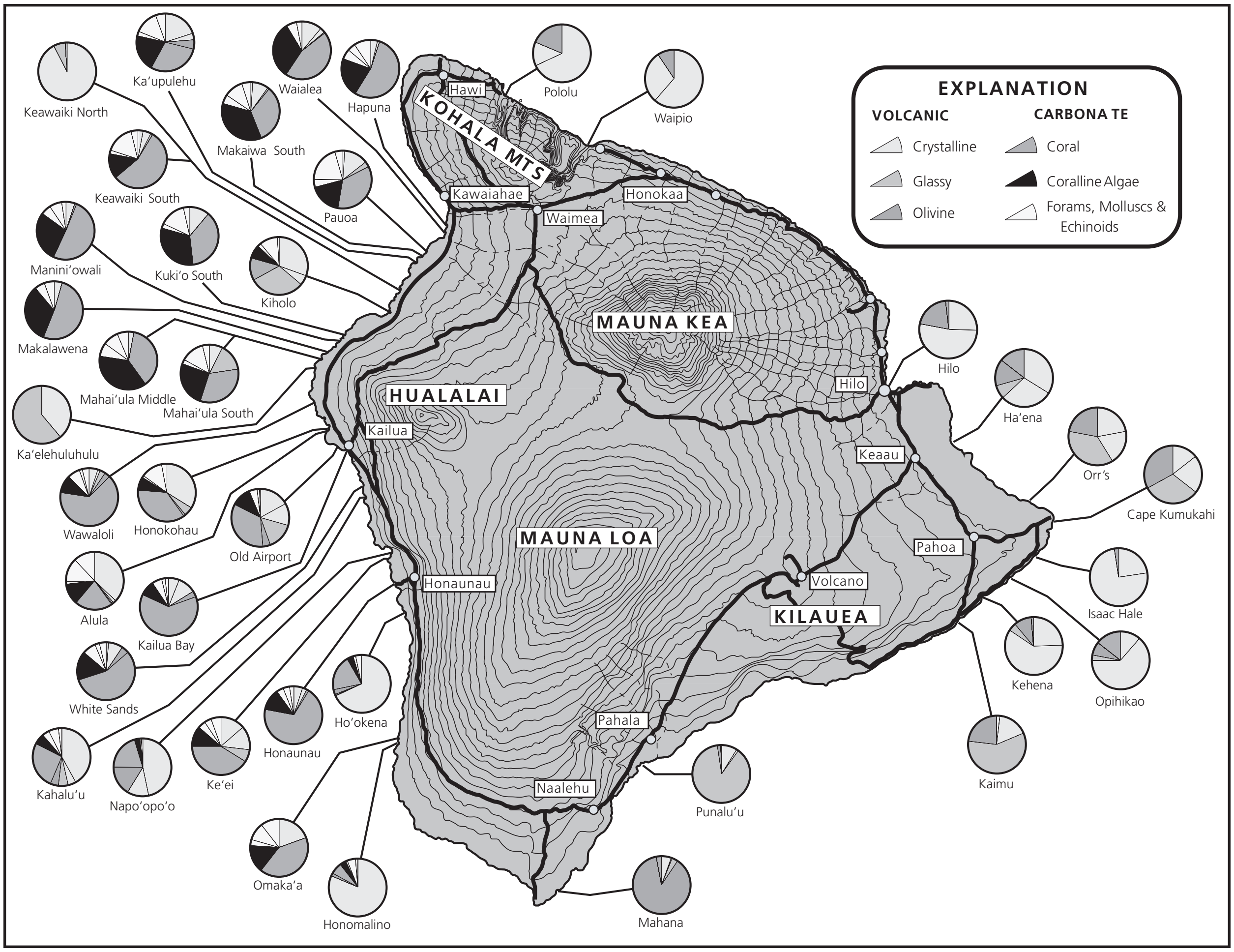

Fig. 1 Pie diagrams displaying the composition of beaches around the Big Island of Hawaii. Note the predominance of volcanic constituents along the eastern, windward portions of the island. Along the western, leeward coast carbonate constituents become abundant. Coral is the main carbonate constituent; however, coralline algae increases in abundance to the north where reefs apparently are more mature.

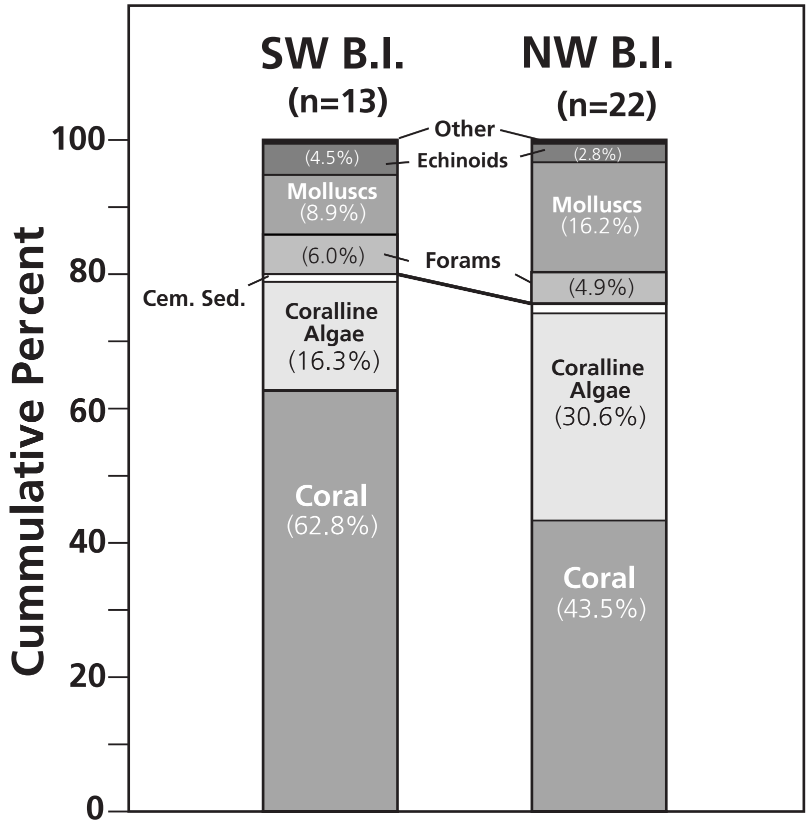

Fig. 2 Histograms of carbonate constituents of beaches along the leeward portion of the Big Island, south and north of Kailua, showing the predominance of coral clasts but also the increase in coralline algae and molluscan fragments northward.

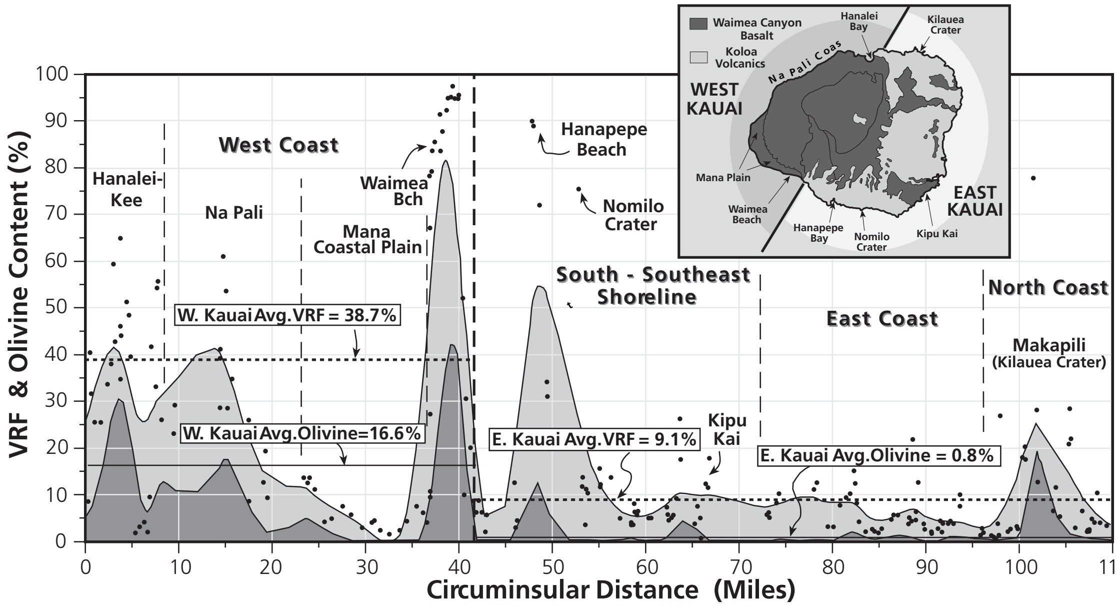

Fig. 3 Circuminsular plot of the volume of volcanic lithic materials in beaches around the Island of Kauai. The plot starts at the eastern side of Hanalei Bay and wraps around the island. Data points for total volcanic rock fragments (VRFs) (including olivine) are displayed. Data-distance smoothing curves are displayed for both total VRFs (light shading) and olivine (dark shading). The variability of VRFs and olivine within beach sediments around the island reflects the composition of the island's volcanic rocks.

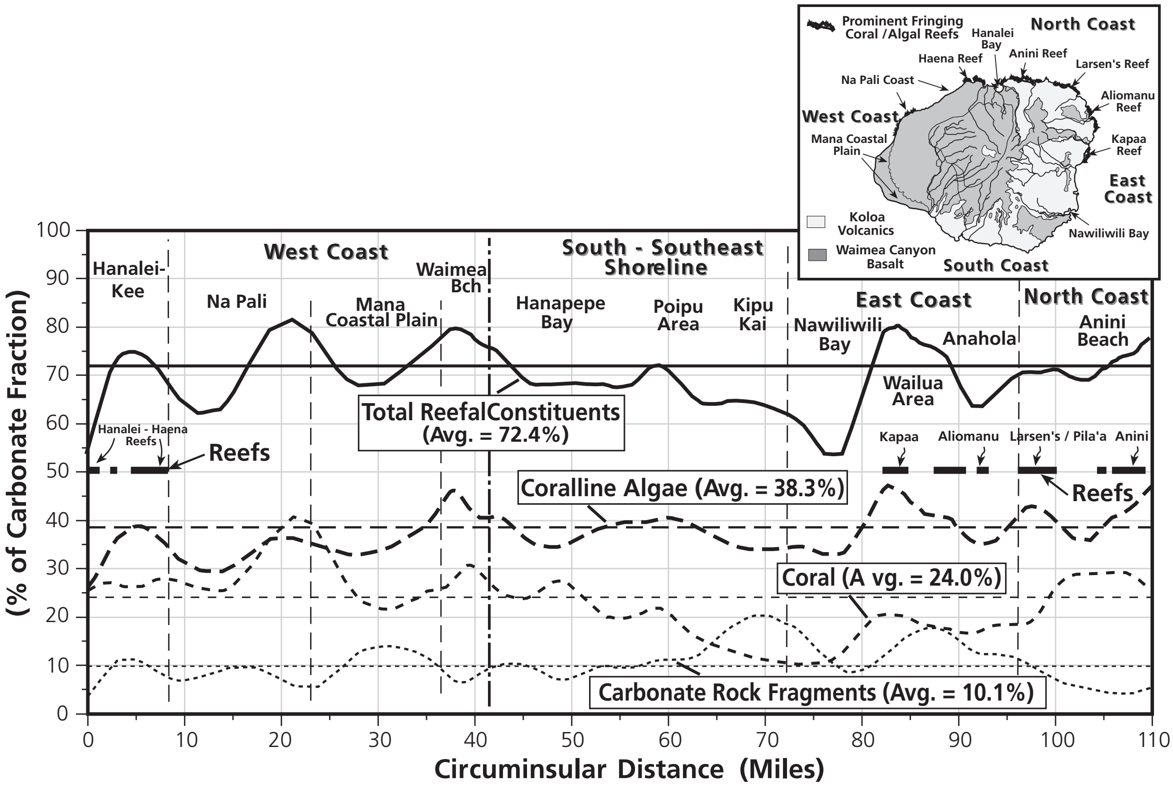

Fig. 4 Circuminsular plot of reefal carbonate constituents of Kauai's beach sediments. Note the location of the prominent fringing coralgal reefs. The distribution of these carbonate grains does not appear to reflect the location of reef structures. Coralline algae is most abundant, indicative of the predominance of stony red algae in Kauai's reefs.

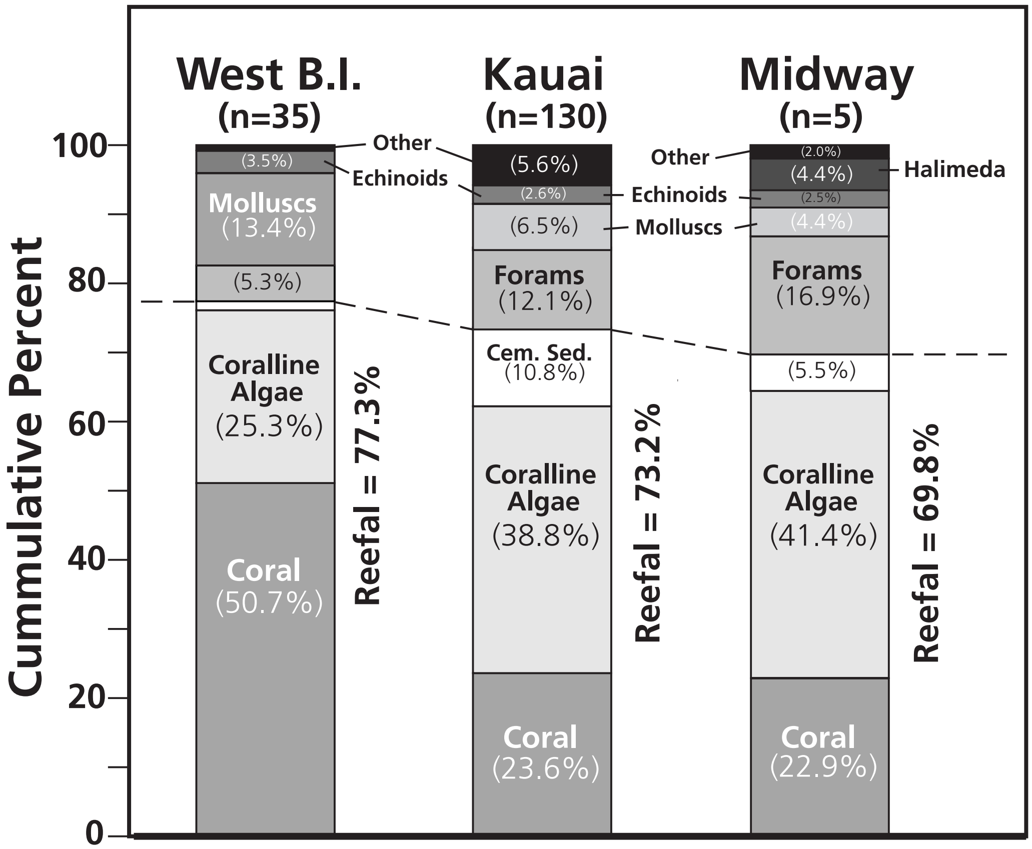

Fig. 5 Comparative histograms of carbonate constituents of beaches for the western portion of the Big Island, Island of Kauai and islands of Midway Atoll. Note the increase of coralline algae, cemented-sediment intraclasts and foraminifers in Kauai and Midway beach sediments, most probably indicative of the greater stability and maturity of their coralgal reefs.

Postglacial sea-level rise in south Portugal as recorded in Guadiana Estuary

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The Guadiana River Estuary is located in the terminal part of a deeply incised river valley, which accumulated several tens of meters of sediments during the Holocenic transgression. Five cored boreholes (see **Fig.1** for localisation) that reached the pre-Holocenic substratum were drilled recently in order to recognize the architecture of sedimentary facies and to quantify the accumulation of organic carbon trapped in sediments during the valley infilling by marine waters. It was assumed that due to structural constraints imposed by Palaeozoic and Mezozoic substratum, the main estuarine channel did not change its position significantly. Consequently borehole locations were chosen in order to represent different sedimentary environments in the estuary: proximity to the main channel (CM1 and CM3), external sea facing (CM4) and lagoonal (CM2 and CM5) environments. In all five boreholes the Holocene was found to overlay Pleistocene fluvial gravels at depth of 39.2m in CM1, 10m in CM2, 31m in CM3, 19.2m in CM4 and 50.8m in CM5. These depths reflect the pre-Holocenic topography of Guadiana Valley: the basal gravels correspond respectively to Pleistocene terrace levels, in boreholes CM1, CM3 and CM4, to shallow Jurassic platform in CM2 and to the bottom of Beliche River (Guadiana tributary) valley in CM5.

From **Table 1** which resumes results of datings so far done, it appears that the entire Holocenic sedimentary history is recorded within the deeper portions of Pleistocene river valleys (CM5 and CM1 boreholes), where the initial most rapid part of transgression, resulted in the deposition of monotonous clay sequence reported in the works of Dabrio *et al.* (1995) and Goy *et al*. (1996) from Tinto–Odiel Estuary in Spain. This type of sedimentation, i.e. from the upper intertidal regime, prevailed until present day in the confined areas of CM2 and CM5 boreholes. In the areas of CM1 and CM3 the basal clay portion is followed by the succession of meander bar sequences and on top by a lateral bar sequence.

In the area of CM4 which is the most sea exposed, the basal clay sequence is thin or almost lacking (yet to be checked by datings), due to the elevation of Pleistocene surface. The coarse/medium sand sequence represents depositional environment of coastal bars and in the top 3m, dunes.

The microfaunistic analyses of CM1 and CM3 yielded to the identification of two species associations, with a very distinct Shannon's index. This one abruptly changed from 0.03 to 2.28 at 8430 BP in CM1 and from 0.00 to 2.97 at 9470 BP in CM3. These associations testify the evolution from saltmarsh environment to a medium intertidal environment, between 8430±380 BP and 9470±250 BP.

The species association dominated by *A. beccarii* and *H. germanica*, did not undergo alteration along borehole CM2 sedimentary columm.

The major marine influence was recorded in CM4 through a high plancktonic/benthic foramineferous ratio, which begins to increase significantly around 6250±250 BP.

References

Borrego, J.; Morales, J. A. & Pendon, J. G. (1993) Holocene filling of an estuarine lagoon along the mesotidal coast of Huelva: The Piedras Tiver mouth, southwestern Spain. Journal of Coast. Res. 9, 242-254.

Goy, J. L. ; Zazo, C.; Somoza, L.; Dabrio,C.J. Lario , J.; Borja, F.; Sierro, F. J. & Flores, J. A. (1996) Global and regional factors controlling changes of coastlines in South Iberia (Spain) during Holocene. Quaternary Science Reviews, 15, 773 –780.

Table 1 Summary of sediment datings from 4 boreholes in Guadiana estuary.

Borehole	Sample depth(cm)	Age BP(yr.)	$\delta^{13}C$(‰)	Material	Method
CM1	824	5020±310	1.1	shells	radiometric
CM1	1530	4600±40	-26.9	organic matter	AMS
CM1	1712	6210±220	-25.9	peat	radiometric
CM1	1860	6205±40	2.08	shells	AMS
CM1	2127	7590±100	20	shells	radiometric
CM1	2850	8430±380		shells	radiometric
CM2	200	3080±100	-27.3	organic matter	radiometric
CM2	715	5950±190	0.4	shells	radiometric
CM2	854	10130±200	-5.98	shells	radiometric
CM3	459	3300±160	-0.6	shells	radiometric
CM3	960	6710±120	1.6	shells	radiometric
CM3	1452	7080±200	0.7	shells	radiometric
CM3	2690	9470±250	-22.9	wood	radiometric
CM4	700	6200±340	1.6	shells	radiometric
CM4	975	5640±90	-0.31	shells	radiometric
CM4	1575	6250±250	1.4	shells	radiometric
CM4	2834	16980±100	-28.5	organic matter	AMS

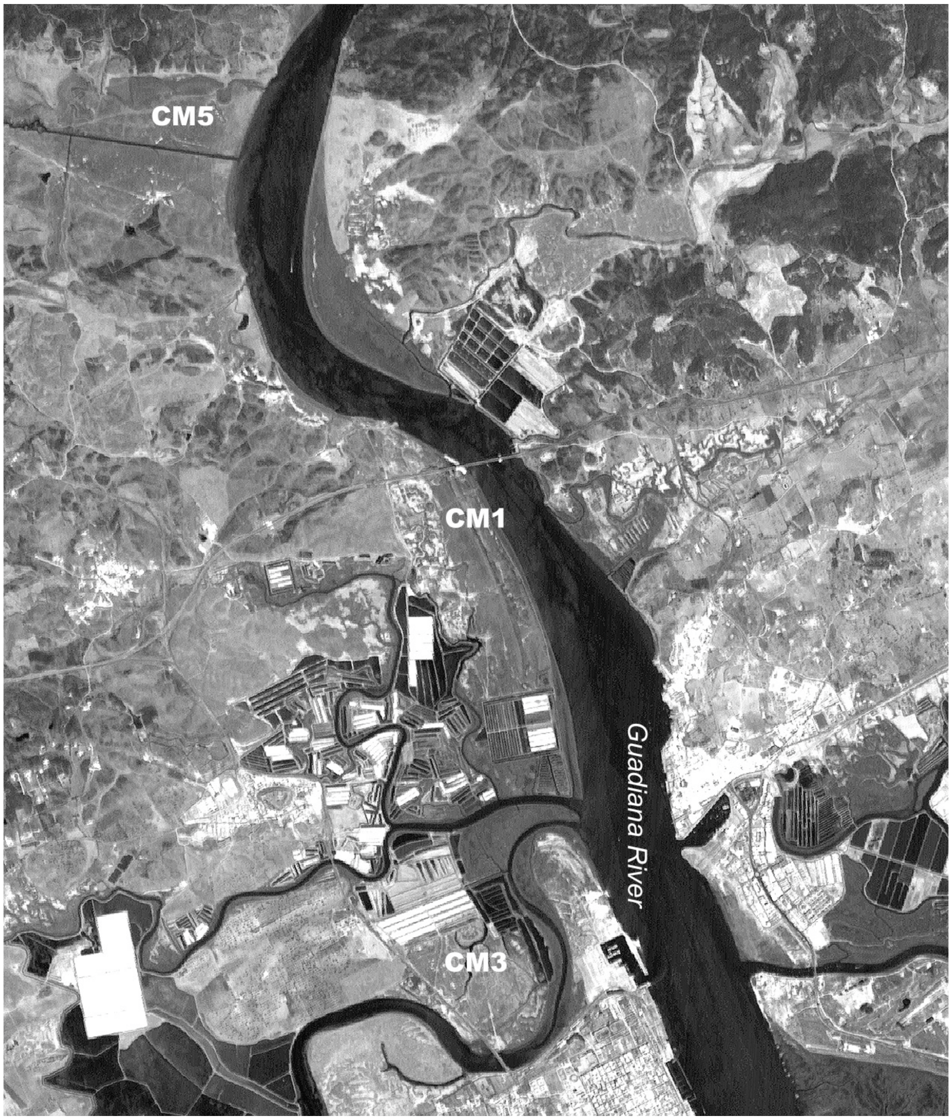

Fig. 1 Geographical localication of the five cored boreholes.

Sand transport in a reef channel off Kailua, Oahu, Hawaii

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Loss of beach sand along the coast of Kailua, Oahu, Hawaii, over the past decade has concerned state, county and local officials and residents. Studies of the causes and rates of this sand loss were undertaken jointly by researchers at the University of Hawaii and U.S. Geological Survey commencing in 1995. One aspect of these studies was determining the role that a well-defined channel through the fringing reef had in the transport of sand. This presentation discusses this transport pathway, and describes data collected during deployments of a newly developed, instrumented bottom tripod. The deployments were successfully completed during the Sept.-Nov., 1996 (56 days), and May-Sept., 1997 (137 days), and June-July, 1998 (53 days). The channel meanders from about 5-m depth to about 25-m depth across the reef complex. Its average width is about 100 m; its walls extend about 3 to 8 m above the channel floor. The floor of the channel is mantled by medium-sized carbonate sand that has been formed into large symmetric ripples. Diver observations, video images and data from a sonic bed elevation sensor showed that during all deployments the sand ripples had wavelengths (L) of 0.75-1.0 m and heights (H) of 6-12 cm. Divers and video images also documented that sand grains on the ripples often were placed into motion by oscillatory bottom currents. The tripod current measurements and video recordings from the 1997 and 1998 deployments showed that grain motion was correlated closely with bottom wave speeds.

The measurement system was designed and constructed to provide continuous self-contained operation on the sea floor for periods up to 3-4 months. The present suite of sensors on the tripod obtain near-bottom measurements of current, waves, suspended-sediment concentrations, temperature, conductivity, and bed elevation. The sampling scheme is controlled by a microcomputer-based logging system that is programmed prior to deployment. Typically, rapid bursts of discrete samples are obtained and recorded on a fixed schedule (e.g., 1,024 samples at 1 Hz collected each hour), although other sampling programs can be easily implemented. The tripod also contains a video camera and light for recording sequences of bottom images at preset intervals. A mounting attachment for an Acoustic Doppler Current Profiler (ADCP) is also available on the frame.

Seaward low-frequency bottom currents and sand transport were determined from the data during the first deployment. These data were obtained during periods of low to moderate Trade Wind activity. The video images were difficult to interpret because of rapid biofouling of the glass lense cover. In marked contrast, during the second deployment over a period of five days in mid-July, 1997, when the Trade Winds were considerably more intense, sand ripples at the tripod site were observed to migrate onshore in the video images. Ripple migration speeds were estimated to be about 0.5 L/day from the video and bed elevation data. Estimates of onshore sand transport during this period were calculated from a simple model that relates ripple migration to sediment transport rate. For this particular period, the rate was 4.7 g/cm/s. A survey of the bottom at the tripod location by divers indicated that the well-formed ripples were long-crested, approximately normal to the channel walls, and extended across the entire channel width. Assuming that the estimated transport rate was representative across the entire channel at this depth, the total transport of sand was computed to be 4.0 x 103 kg/day. At other times the transport would vary proportionately with the ripple migration rate.

Reef channels can be significant transport pathways for sand deposited on local beaches protected by a reef complex. The rates and direction of transport through these channels are related to several factors including local and regional wind patterns, circulation and tides within the reef complex, wave conditions, sediment characteristics, and channel geometry. We will discuss the interplay of these processes to explain the quantitative information on sand loss (or gain) obtained from the tripod observations off Kailua, and discuss the role that these channels might have in other settings.

A record of environmental changes (subsidence earthquakes, tsunami) in northern Hawke's Bay, New Zealand

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Introduction

Whakaki and Te Paeroa Lagoons are part of an extensive wetland, lagoon and sand dune system, which forms a coastal plain a few km east of Wairoa, northern Hawke's Bay, New Zealand (**Fig. 1**). The coastal plain is backed by steeply dissected hills, up to 600 m in altitude, which are composed of late Tertiary siltstone and sandstone. A study by Ota et al. (1989) suggests that the freshwater lagoons formed circa 4000 years ago, and that it could probably be attributed to the stabilisation of sea-level and the closure of an estuary as the result of continued growth of a sandy barrier separating the lagoon from the open sea. This study also infers that tectonic subsidence has occurred during the Holocene in the Wairoa region.

The purpose of the present study was to establish a record of environmental changes with particular reference to coseismic events and tsunami in the sedimentary sequence. Coastal sediment sequences were collected around Te Paeroa Lagoon in October 1998 (cores TP1, TP2 and TP3) using soil and peat augers. Further cores were collected around Te Paeroa Lagoon and east of Whakaki Lagoon in February 1999 (cores C1 to C8) (see Figure 1 for core locations). Two cores were also collected in Whakamahi Lagoon in October 1998 (Figure 1). Heights of the sampling sites were determined by levelling from a benchmark (HH61; **Fig. 1**) along State Highway 2. Cores were examined using sedimentological, geochemical (Instrumental Neutron Activation Analysis – INAA), palynological (pollen, dinoflagellates) and paleontological (foraminifera, diatoms, macrofossils) analyses, and geochronological control was obtained using tephrochronology and radiocarbon dating. In this paper, we present the results of a reconnaissance study based on the analysis of cores TP1, TP2 and TP3.

Preliminary results and discussion

The stratigraphy of cores TP1, TP2 and TP3 is shown in **Figure 2**. Core sequences were aligned relative to their height below mean sea-level (bmsl). The 5 m thick sequence in core TP1 consists of a basal green grey mud layer overlain by a 20 cm thick gravel layer at about 3.4-3.6 m bmsl. The continuity of the overlying mud sequence is interrupted by the Whakatane ash. The top metre of the sequence consists of sandy, silty and peaty layers intercalated with the Taupo and the Kahoroa tephras. In core TP2, the continuity of the grey mud layer is interrupted by a thin sand layer at about 3.4 m bmsl. The top 2.30 m of the sequence consists of sand, clay, organic-rich mud, peat and tephra (Whakatane, Waimihia and possibly Taupo tephras). Stratigraphy of core TP3 is similar, with a thick mud sequence interrupted by two thin sand layers at circa 3 m bmsl. The top 2.20 m of the sequence consists of sand, silt, peat and tephra (Whakatane, possibly Waimihia, and Kahoroa tephras).

The radiocarbon age of samples of organic material taken from the three cores (**Fig. 2**) suggests that the sedimentary sequences were deposited within the last 6500 years. It also appears that the layer of gravel thinning landwards to sand was deposited circa 6300 years BP.

Diatom analysis indicates that shallow brackish estuarine deposition has dominated at the TP1 site over much of the time represented by the core. Greatest marine influence is evident in the coarse sediment layer a 3.4-3.6 m bmsl. Marine influence decreases in the upper part of the core and totally freshwater conditions are evident in the uppermost 50 cm, associated with tephras and peat.

Pollen analysis supports the inferences drawn for diatom analysis, indicating that the sequence represents a coastal estuarine to lagoonal freshwater environment, which is periodically invaded by marine dinoflagellate-bearing water. Foraminifera are almost absent from the sequence above 3.4 m bmsl, whereas the foraminiferal faunas from the lower part of the sequence reflect varying marine influence. The assemblage present in the coarse layer is typical of lower intertidal to shallow depths.

The geochemistry of the sediments reflects the change in stratigraphy, with distinct signatures for the tephra layers (Na, Fe, Cr), organic-rich and peat layers (As, Br) and the coarse sandy layer at 3.4-3.6 m bmsl.

The diatom assemblages present in the lower part of cores TP2 and TP3 also suggest a progression from an intertidal to a fully marine environment, confirming the marine origin for the thin sand layers occurring in both cores, at 3.4 m and 3.05 m bmsl, respectively. The marine and brackish influence is also shown by the occurrence of dinoflagellates at site TP2, whereas foraminifera are absent from the upper 1.2 m of the sequence, reflecting the strong freshwater influence.

The transition from intertidal to marine environment may or may not be associated with tectonic subsidence. As yet, there is no macroscopic evidence in the cores of coseismic vertical displacement associated with past subduction zone earthquakes. Further study is underway to refine the record over the last 6000 years and to try to identify the influence of coseismic subsidence on the depositional environment.

Conclusions

This paper presents the preliminary results of a multidisciplinary study, which aimed to establish a record of the environmental changes in northern Hawke's Bay, New Zealand. This study confirms the occurrence of a short-lived marine inundation in a shallow intertidal environment, at about 6300 years BP, which has resulted in the deposition of a gravel layer that thins landwards to sand. Bearing in mind the unique nature of the deposit, we feel confident that this is a catastrophic saltwater inundation (CSI). However, further research is needed to ascertain its cause and origin.

Acknowledgements

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References

Ota, Y., Berryman, K.R., Brown, L.J. and Kashima, K. 1989. Holocene sediments and vertical tectonic downwarping near Wairoa, northern Hawke's Bay, New Zealand. *New Zealand Journal of Geology and Geophysics*, 32, 333-341.

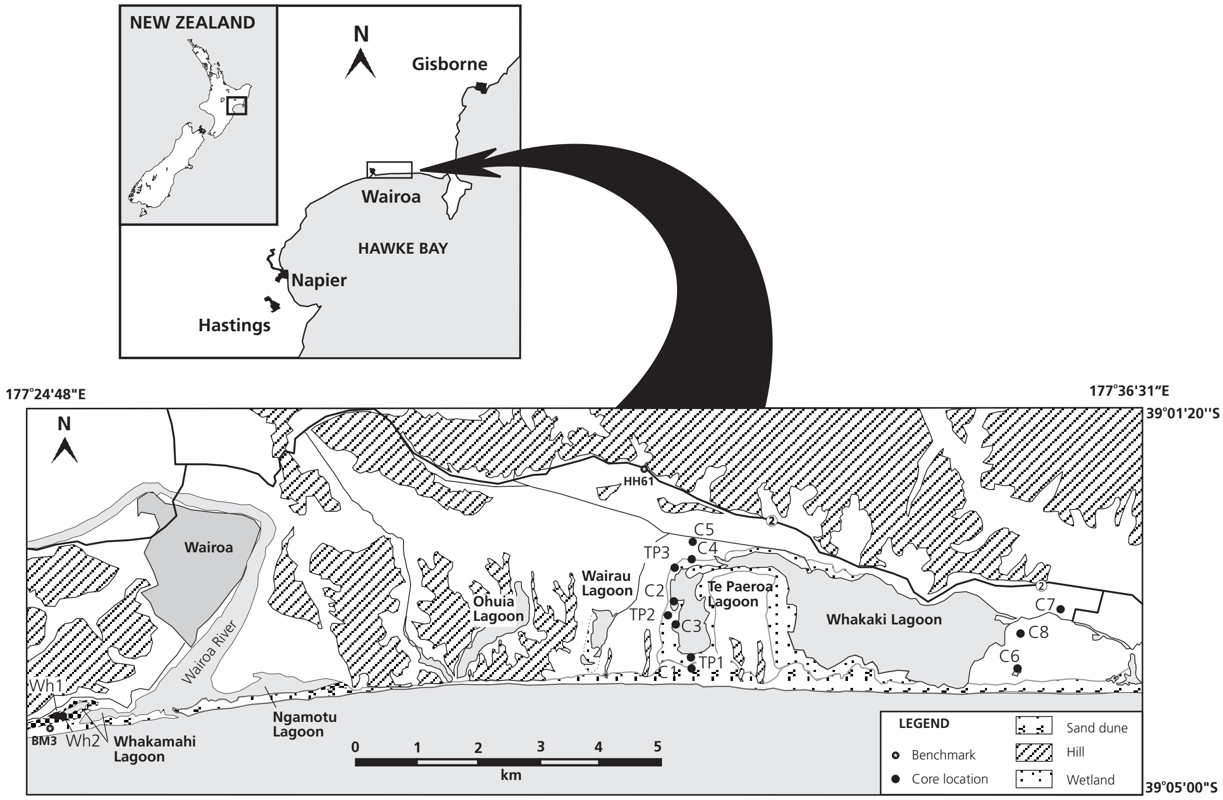

Fig. 1 Location map, showing the various morphological features in the Wairoa region, and the sampling locations.

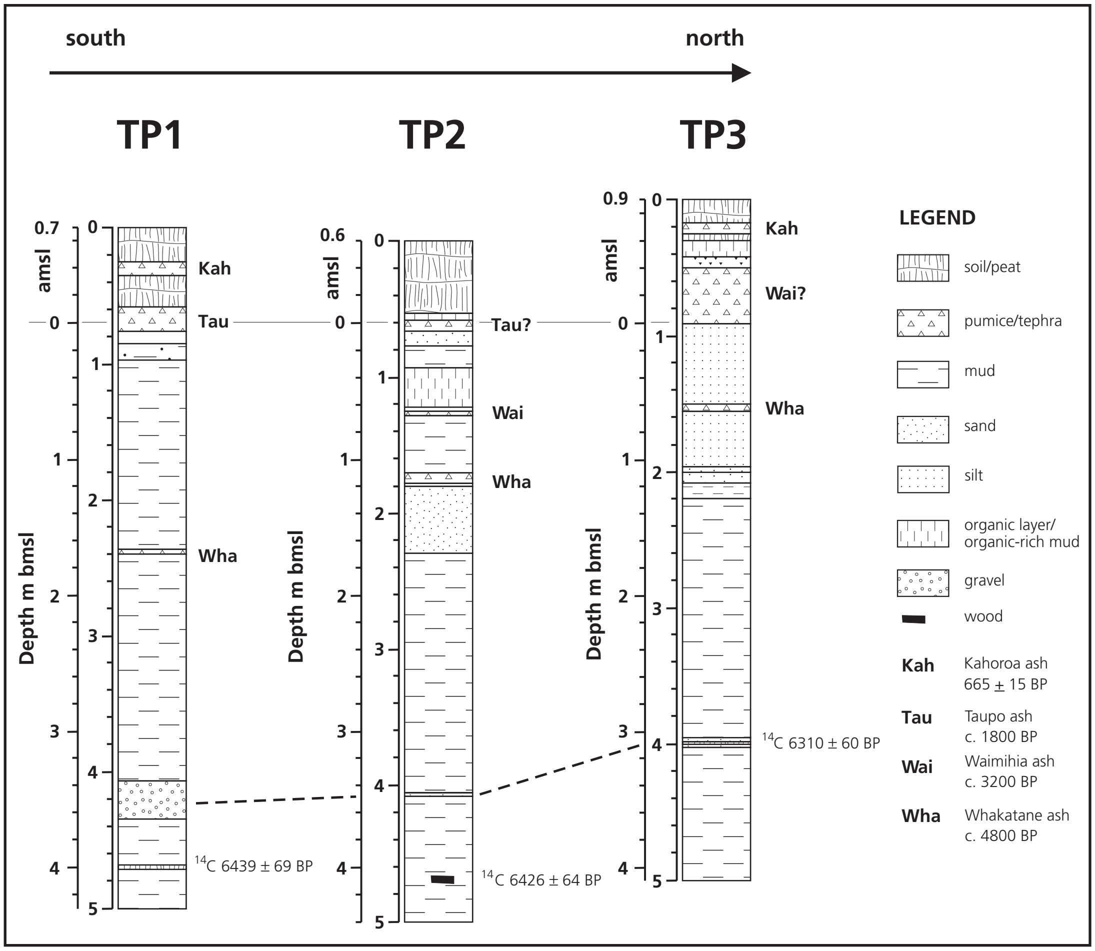

Fig. 2 Stratigraphy of cores TP1, TP2 and TP3. See **Figure 1** for core locations.

Sea-level-climate-coupled Late Quaternary history of the northeastern Gulf of Mexico coast and inner shelf, northwest Florida

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The late Quaternary is a time unique in Earth's history, characterized by major fluctuations in climate and sea-level, and the rise of *Homo sapiens*. The climatic, hydrologic and geomorphologic changes that have taken place during the Quaternary – especially since the beginning of the last deglaciation approximately 20,000 years ago – have significantly altered the North American landscape. This is especially true in the Southeastern United States where intensive change in relative sea-level has brought drastic change to the coastal zone.

The late Quaternary sea-level history of the inner continental margin and estuaries of the northeastern Gulf of Mexico is recorded in its near-surface geology and geochemistry. Portions of the record are found in a diversity of locations: in the now-buried paleokarst features of the continental shelf; in the chronology of development of the paleofluvial system beneath the present-day inner continental shelf; in the geochemical history of the sediments of one of the region's largest estuaries, the Ocklockonee River estuary (**Fig. 2**); and in the relict geomorphological features and pollen chronology from the Ochlockonee watershed. Using geochronology, pollen analysis and broad geochemical indicators – indices such as the degree of pyritization (DOP), total organic carbon (TOC), S/C, (Mo+Cu)/Zn, etc. – a detailed sea-level and climate-coupled late Quaternary history of this part of the NE Gulf of Mexico coast has been delineated.

Through examination of more than 800 km of high-resolution seismic data and sedimentologic data from a suite of vibracores in the northeastern Gulf of Mexico, multiple generations of paleofluvial systems on the coast and inner shelf have been revealed. Four regional seismic stratigraphic units have been discerned in the seismic records, tracing distinctive seismic reflectors in the study area: the St. Marks Formation (Miocene), post-St. Marks clastic sediment, a mid-Holocene clastic unit, and a late Holocene transgressive sediment sheet. A Wisconsinan paleochannel system and karst topography are the most striking and important morphologic features of the Quaternary subaerial erosion surfaces of the inner shelf. The Wisconsinan erosion surface is superposed on a late Neogene subaerial erosion surface which developed on top of the St. Marks Formation, creating a major regional seismic reflector. The Wisconsinian seismic reflector in places overlaps with the older regional seismic reflectors.

With the waning of the last glaciation, regional climate gradually entered a warmer and wetter mode approximately 9,000 yr BP. The annual precipitation at that time is estimated to have been as great as 30% wetter than the present day. The outcomes of the pluvial conditions were the rapid infilling of the Wisconsinan paleofluvial systems in this region, the development of the paleo-Ochlockonee River delta, Delta I, in the present-day Dog Island Shoal area, and widespread karstification both onshore and offshore. Approximately 4,500 yr BP, climate is inferred to have begun a shift to a relatively drier and perhaps warmer condition. The paleo-Ochlockonee River delta apparently migrated northeastwards to a new location, Delta II, in the area of the present-day Ochlockonee Shoal. Between 4,500 to 1,500 yr BP, the regional climate underwent a series of dry swings, encouraging the widespread development of karst features. Since the onset of the pluvial episode, with rapid sea-level rise, the lower reaches of the regional rivers and their distributaries have been subjected to drowning and rapid retreat. As a consequence, fluvial-mediated intensive dissolution and karstification have swept across the broad coastal terrain, including much of the present-day inner shelf. At approximately 1,500 yr BP, regional climate entered the modern climate mode. With further rise of sea-level, and diminishment of regional precipitation levels, the Ochlockonee River delta retreated northwestward to the present-day upper Ochlockonee River estuary, forming Delta III. With additional westward retreat during prehistoric time, the modern bay-head delta, Delta IV, began to develop. Figures **1**, **2** and **3** detail the inferred late Quaternary sea-level-climate-coupled history in the study area.

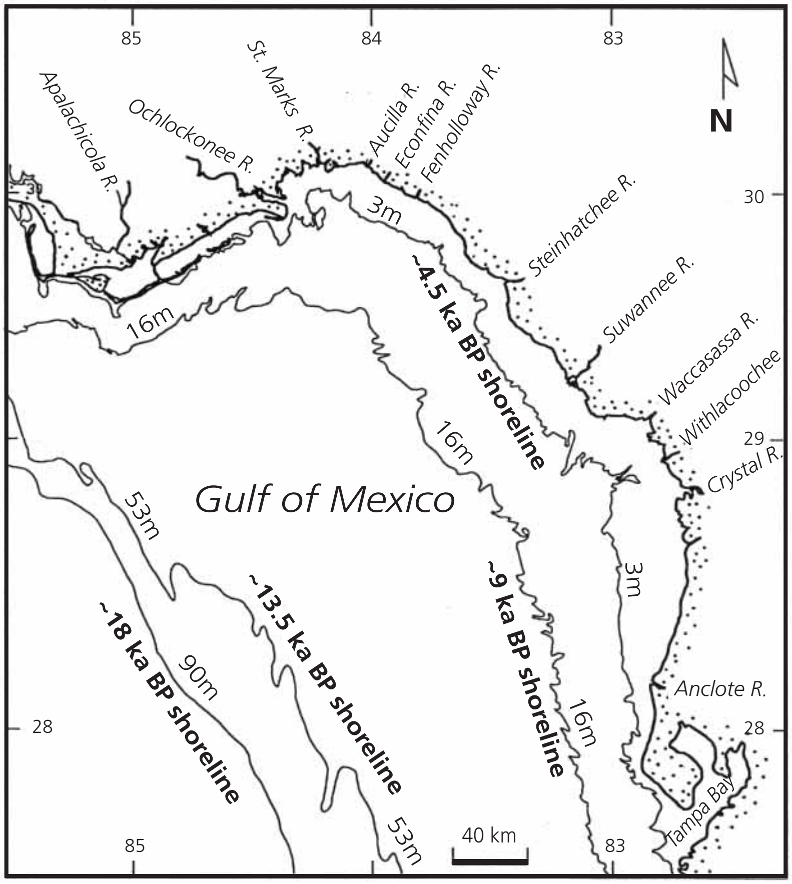

Fig. 1 A reconstruction of late Quaternary shoreline migration in response to sea-level rise in the northeastern Gulf of Mexico. Sea level positions are based on Frazier (1974).

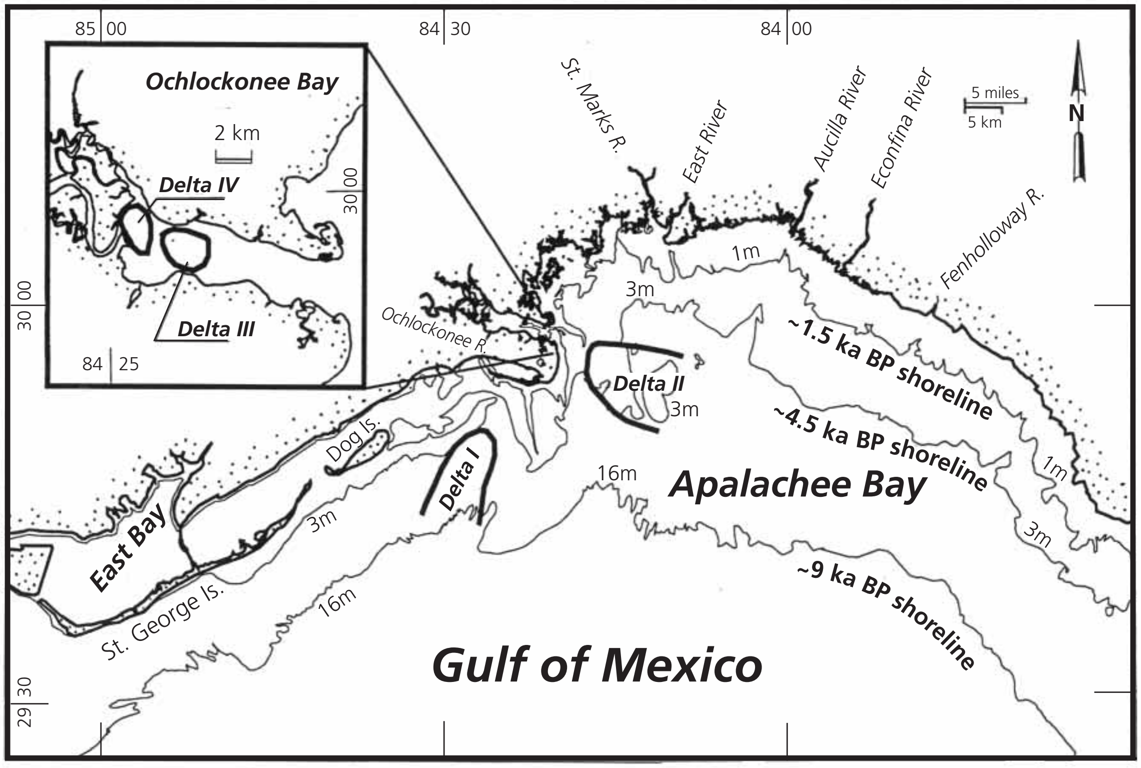

Fig. 2 A reconstruction of Holocene shoreline evolution and inferred history of the paleo-Ochlockonee River delta in response to sea-level rise in the study area. Sea-level data is based on Frazier (1974). The paleo-deltas were located and identified using seismic data from this study.

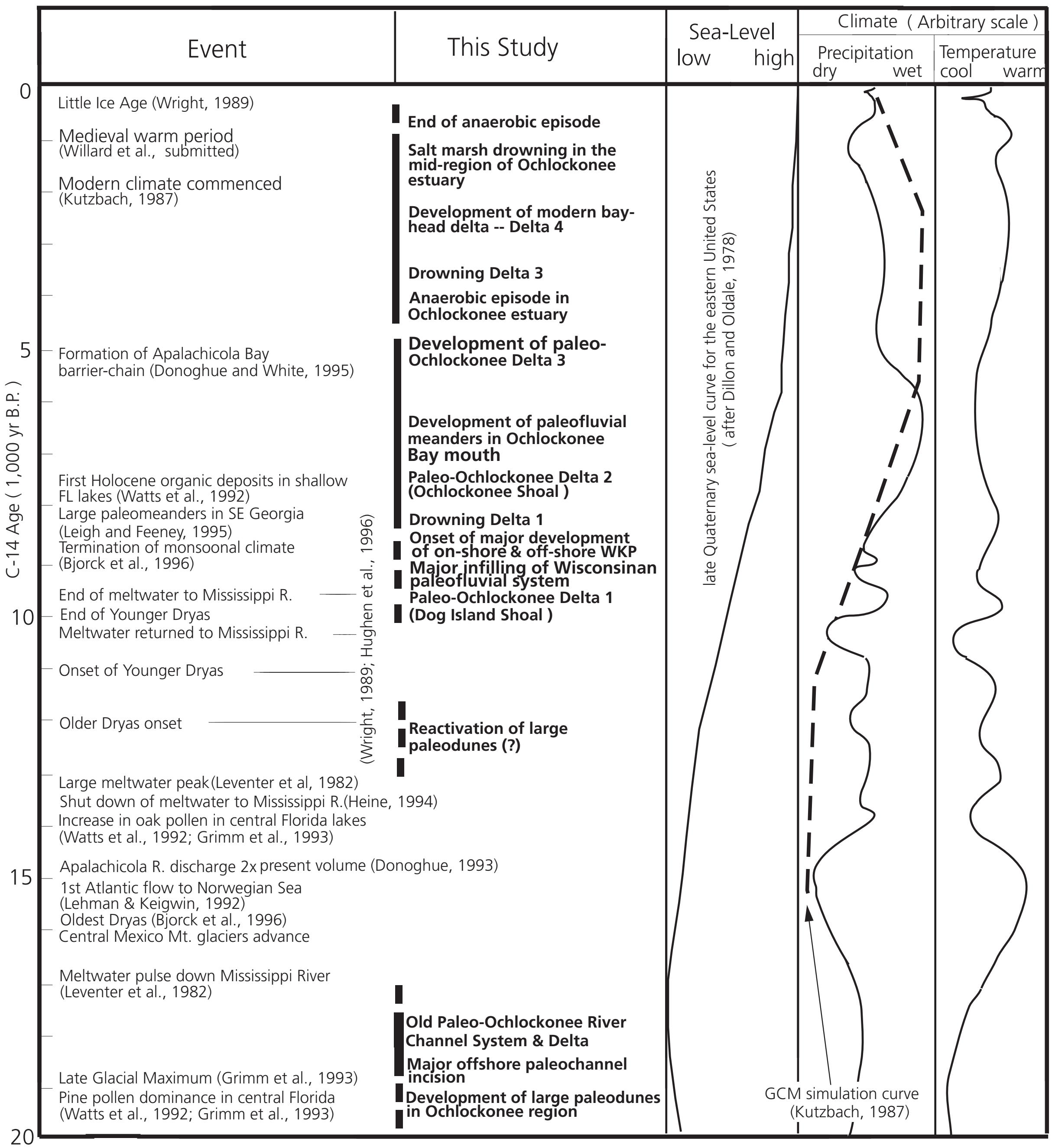

Fig. 3 Summary of the major late Quaternary sea-level, paleoclimate and paleoenvironmental events for the northeastern Gulf of Mexico coast, Northwest Florida. Events marked with bars and described in bold font are based on the present study. The scales for temperature and precipitation are arbitrary and are relative to present-day conditions. Temperature and precipitation curves are based on palynologic and geologic studies as cited in the left column.

The role of extreme floods in estuary-coastal behaviour: Contrasts between small river- and tide-dominated systems

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Introduction

Episodic events have the potential to surpass critical erosion thresholds and introduce large volumes of sediment onto the inner shelf at estuary mouths. These periodic influxes of sediment may influence behaviour of the adjacent coast and estuary for several decades, however, the long term influence of such events may be either part of a progressive cycle of infilling, or perturbations around a long term equilibrium state. Case studies of the impacts of such events from the South African coast illustrate the contrasting nature of (i) flood-induced erosion-deposition patterns and (ii) coastal morphological response at the mouths of estuaries of different types. Estuary types are here differentiated mainly on the basis of whether an estuary retains sufficient tidal prism for its inlet to be maintained by tidal currents or whether its prism is so small that it is necessary for fluvial discharge to maintain it against wave action (Cooper et al., 1999). By reference to case studies of both types of system, some generic insights are presented regarding the role of episodic floods and their significance in producing temporally non-linear coastal behaviour.

River-Dominated estuaries

The large-catchment rivers of South Africa are frequently characterised by sediment-filled valleys although the strong offshore wave climate and rapid coastal sediment dispersal prevent the widespread development of deltaic plains under present sea-level conditions. In the estuaries of these rivers, high sedimentation rates, steep hinterland gradients, shallow channels and laterally confined valleys preclude the development of large tidal prisms and it is high river discharge volumes that are necessary to overcome cross-shore and alongshore wave transport at the coast and maintain tidal inlets.

Observations during a regional flood in 1987 with a predicted recurrence interval of c.1:150 years enabled rare insights into the impacts of such events on these systems. In the Mgeni estuary, north of Durban, the cohesive mud and gravel bed of the estuary, together with an entire mangrove-fringed central island were eroded (Cooper et al., 1989, Cooper 1993a). In addition, the 800m-long sand barrier and small flood-tidal delta were totally eroded. This estuarine sediment and additional sediment from the catchment were deposited immediately offshore of the former inlet as a submerged delta. The post-flood estuary channel was up to 7m deep and for a short time acquired a large tidal prism. Within a few months the barrier had reformed by wave action and the estuarine channel was infilled by continuing downstream transfer of fine sand. The reformed barrier was up to 50 m wider than the pre-existing barrier and continued to accrete by a further 100 m over the following 3 years as flood-deposited sand was reworked landward. A similar pattern was observed in the Mvoti estuary, some 70 km to the north (Cooper, 1993b).

Comparison with historical changes documented by air photography since 1931, suggests that a similar pattern of coastal advance followed by retreat was effected by a severe flood in 1917 and that the retreat phase lasted from the 1930s until 1987 and was associated with alongshore dispersal of sediment accumulated after the last major flood. This phase of dispersal culminated in 1986 with overwashing of the barrier and destruction of a portion of the back-barrier mangrove swamp.

Tide-dominated estuaries

In estuaries with large tidal prism, the tidal inlet is maintained by tidal flows independent of freshwater discharge. Such systems exhibit a typical tripartite division into sandy fluvial delta in the upper reaches, deep, muddy middle reaches and a sandy barrier-associated environments including a flood-tidal delta. In interflood periods these systems exhibit progressive upstream growth of the flood-tidal delta due to inequalities in the tidal flow and to enhanced wave-induced sediment suspension on the flood tide. Observations during the 1987 flood in Natal (Cooper 1989, 1993c) and following a 1985 flood in the eastern Cape (Reddering & Esterhuysen, 1987) revealed that floods produce differential erosion of the sandy facies in the lower reaches of the estuary. The upper reaches of the system may experience an increase in sedimentation at the downstream end of the fluvial delta, but the deep middle reaches exhibit little change. The barriers and flood-tidal deltas may be entirely eroded. In such systems, the barrier-eroded sediment is deposited immediately offshore and is reworked landward by wave action in the months after the flood. Since the barriers are short and headland-bounded, their eroded sediment is transported into position rapidly and little coarse-grained sediment loss appears to take place from the embayment margins. The recovery of the barrier to its pre-flood morphology is typically accomplished within a few months.

Discussion

Both river-dominated and tide-dominated estuaries exhibit an instantaneous response to river floods which in each case results in the formation of an offshore delta. The differences in behaviour between the two types of system lie largely in the volume of sediment deposited within the delta. River-dominated systems undergo much more erosion of the channel and deposit greater volumes of sediment in the ephemeral delta, than do tide-dominated systems where erosion is minimised by a large estuary volume. The barrier response in river-dominated systems follows a pattern of total erosion, followed by sustained accretion over a period of several years until the submerged delta sediment is re- incorporated into the emergent barrier. After this phase barrier erosion begins as sediment supply is diminished and this has continued in the historical period for timescales of over 50 years (1931-1985). In tide- dominated systems, the eroded sediment of the barrier is not augmented by additional estuarine and river-derived sediment but is transported offshore and stored temporarily. Consequently, the time period required for complete reconstruction of the barrier is comparatively short (< 1 year) and the barrier does not advance significantly seaward following a flood phase.

The magnitude of flood required to produce a significant morphological impact in a river–dominated system is likely to be much greater than in a tide-dominated system of similar magnitude. This is as a result of the more cohesive estuary bed that characterises a river-dominated system. Less severe floods are capable of eroding the uncohesive sandy sediments associated with the barrier of tide-dominated estuaries and these appear to contribute to the maintenance of an equilibrium inlet condition that fluctuates on a time scale of <10 years. River-dominated systems are only affected by major flood events with a recurrence interval of 50-100 years and their post-flood recovery may take equally long.

References

Cooper, J.A.G., Mason, T.R., Reddering, J.S.V. & Illenberger, W.I. 1989. Geomorphological effects of catastrophic fluvial flooding on a small subtropical estuary. Earth Surface Processes and Landforms, 15: 25-41.

Cooper, J.A.G., 1990. Ephemeral stream-mouth bars at flood-breach river mouths: comparison with ebb-tidal deltas at barrier inlets. Marine Geology, 95: 57-70.

Cooper, J.A.G. 1993a. Sedimentation in a river-dominated estuary. Sedimentology. 40: 979-1017

Cooper, J.A.G. 1993b. Sedimentary processes in the river-dominated Mvoti estuary, South Africa. Geomorphology 9: 271-300.

Cooper, J.A.G. 1993c. Sedimentation in the cliff-bound Mtamvuna estuary, South Africa. Marine Geology, 112: 237-256.

Cooper, J.A.G., Wright, C.I., Mason, T.R. 1999. Geomorphology and sedimentology of South African estuaries. In Allanson, B.R. & Baird, D. (eds.) Estuaries of Southern Africa. Cambridge University Press. 5-25.

Reddering, J.S.V. & Esterhuysen, K. 1987. The effects of river floods on small estuary mouths: a case study from East London. S. Afr. Jour. Geol. 90:448-457.

Late Holocene relative sea-level highstand in northern Scotland: Climatological inferences

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The northern coastline of mainland Scotland, which lies on the periphery of the Scottish glacio-isostatic uplift centre, is devoid of an established relative sea-level history. Analyses of sites located across the coastline of mainland Britain, range from open coast estuarine sites to shingle barrier and dune-fringed areas, allow a detailed reconstruction of relative sea-level changes to be determined. In particular, the majority of the sea-level index points are dated to the late Holocene (last 4000 years), typically a period with an acknowledged paucity of data throughout Scotland.

Four sites reflect relative sea-level rise and fall between c.4500-c.2500 BP (5300-1900 cal BP) and the deposition of extensive clastic sands and silts. Within the lower Wick River valley the transgression is dated between c. 4400-c. 2300 BP (5200-2500 cal BP) and reached 2m OD. At Loch Erriboll, c.4200-c.3600 BP (5000-3650 cal BP) and attained 2.4m OD. At Sandwood Loch, on the NW coastline, the transgression encompasses c.4000-c.3600 BP (4800-3700 cal BP) and reached 2.05m OD, whilst in Strath Halladale deposition of extensive sands has been dated to c.3700-c.2600 BP (4200-2400 cal BP) reaching a maximum altitude of 2.08m OD. The registration of this mid-Holocene transgression across northern Scotland is compared with evidence elsewhere of a renewed period of sea surface change and imply a possible diachroneity over a period of c.700 years.

Encompassed within the transgressive events above are a series of oscillations recorded at the study sites and occur at c.3300-c. 3100 BP (3600-3250 cal BP) at Strath Halladale and between c. 2900-2600 BP (3200-2700 cal BP) and between c. 2500-2200 BP (2750-2150 cal BP) at Sandwood Loch. The final period of relative sea-level change is dated from c.2200 BP (2350 cal BP) at Strath Halladale and from c.900-1200 BP (800-1150 cal BP) within the lower Wick River valley.

The identification of fluctuations in relative sea-level at increasingly higher altitudes on the periphery of the isostatic uplift centre above 0m OD contrasts with the presumed negative altitudes and general assumption that the relative sea-level record in this area would be represented by a relative fall from the mid- Holocene maximum. The detailed fluctuations identified thus reflect the position of the area, where fluctuating sea surface levels in the late Holocene exert more influence on the patterns of change than the declining isostatic uplift.

The smaller magnitude sea-level variations after c. 5000 cal BP occur after the large magnitude changes due to ice melt and ocean volume increases of the early and middle Holocene. These smaller changes may reflect the redistribution of water masses and may be the result of changes in Gulf Stream strength. The late Holocene relative sea-level record identified for northern Scotland is compared with climate parameters, in particular the se surface temperature record (SST) from the Sargasso Sea, the GISP 2 ice core records which detail the Medieval Warmth Period as well as the reconstruction of SST since 5000 cal BP. Although dating resolution remains a problem, the broad phases of warming recognised in the longer-term series of oxygen isotope studies, glacial advance and retreat phases, SST records and ocean circulation parameters are consistent with the relative sea-level record from northern Scotland.

Sea-level and deep ocean temperature history over the last 200,000 Years

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Since the development of high precision mass spectrometric thorium-230 dating techniques over a decade ago (Edwards et al., 1987), the scientific community has worked toward constructing a high resolution absolute-dated late Quaternary sea-level curve. Such a curve is critical for understanding climate change and a variety of coastal processes. The thorium-230 technique provided the ability to date corals (younger than about 500,000 years) precisely, thus overcoming a major hurdle. However, as work on the sea-level curve progressed, two other obstacles hindered progress: (1) the potential for diagenetic alteration of corals, shifting thorium-230 ages to inaccurate values and (2) our limited ability to actually recover corals that grew during certain time intervals. As a community, we are slowly overcoming the latter problem by a combination of well-planned drilling expeditions, and well-chosen field sites. The first problem has also largely been solved by the development of high precision mass spectrometric protactinium-231 measurement capabilities (Pickett et al., 1994) and their application to the dating of carbonates (Edwards et al., 1997). High precision protactinium-231 dating gives us a second high-resolution chronometer, which we can use as a key check of the accuracy of thorium-230 ages. If a coral has not been altered, it will record identical thorium-230 and protactinium-231 ages.

By applying both chronometers, we have constructed a high resolution absolute-dated sea-level curve that covers most of the past 135,000 years (the last interglacial-glacial-interglacial cycle) and some portions of the time interval between 200,000 and 135,000 years (the cycle before last). The new curve confirms some well-established characteristics of the sea-level curve, and also resolves some discrepancies. Sea level dropped rapidly between marine oxygen isotope stages 5e to 5d, 5c to 5b, 5a to 4 and 3 to 2. The most rapid drop took place between stages 5a and 4, when sea-level dropped at an average rate of about 10 meters/thousand years over nearly 6,000 years.Thus, almost 45% of glacial maximum ice volume was accommodated in less than 6,000 years. Each of the periods of rapid drop corresponds to a time of low northern latitude summer insolation, indicating that low insolation is necessary for significant net ice accumulation. Conventional wisdom suggests that it takes a long time for the earth to go from interglacial to maximum glacial conditions. Our data indicates that, at times glacial accumulation can be very rapid. Thus, we argue that the interglacial to maximum glacial transition takes a long time because the intervals amenable to rapid glacial buildup (unusually low insolation) are brief.

Our sea-level curve includes the times of relatively high sea-level, corresponding to oxygen isotope sub-stages 7.1, 6.5, the 6/5e transition (Termination II), 5e, 5c, 5a, and 1. All times (with the exception of the timing of Termination II) correspond to times of high northern hemisphere summer insolation, indicating that insolation is an important factor influencing sea-level. Termination II largely preceeds a large rise in northern hemisphere summer insolation. Thus, the relationship between insolation and sea-level rise is fundamentally different for Terminations II and I. Possible triggers for Termination II include (1) some kind of indirect forcing ultimately resulting from northern hemisphere summer insolation change, (2) southern hemisphere insolation change, with some kind of ocean or atmosphere link to the northern hemisphere glaciers, or (3) other factors related to some kind of inherent instability of the climate system.

By correlating our sea-level curve with benthic deep sea oxygen isotope records, we have separated the ice volume and temperature contributions to marine oxygen isotope variations at a Pacific and an Atlantic site. Both sites record significant deep sea warming during Termination I (about 2 degrees in the Pacific and 4 degrees in the Atlantic, consistent with earlier work) and significant cooling subsequent to 5e. These data are consistent with southern ocean warming of about 2 degrees during Termination I, and a Termination I switch from southern source waters to North Atlantic Deep Water at the Atlantic site. We also observe that cooling subsequent to 5e was smaller than Termination I warming at both sites. This temperature residual is linearly correlated with sea-level between stages 5c and 2.

References

Edwards, R.L., Chen, J.H. and Wasserburg, G.J. 1987. U-238, U-234, Th-230, Th-232 systematics and the precise measurement of time over the past 500,000 years. Earth Planet. Sci. Lett., 81, 175-192.

Edwards, R.L., Cheng, H., Murrell, M.T., and Goldstein, S.J. 1997. Protactinium-231 dating of carbonates by thermal ionization mass spectroscopy: implications for the causes of Quaternary climate change. Science 276, 782-786.

Pickett, D.A., Murrell, M.T., and Williams, R.W. 1994. Determination of femtogram quantities of protactinium in geologic samples by thermal ionization masss spectrometry. Anal. Chem. 66, 1044-1049.

Quaternary sea-level cycles amplified by tropical sea-surface temperature changes

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Isotopic measurements of Northern Hemisphere and Southern Hemisphere polar ice cores indicate synchronous temperature oscillations (synchronous within the error of age-dating the ice cores) at the Earth's precessional and obliquity frequencies. The phasing of the polar temperature cycles is consistent with the Northern Hemisphere radiation curves computed by Milankovitch. How the Southern Hemisphere's climate synchronizes with the Northern Hemisphere's climate signal is one of the great unanswered questions in Quaternary studies. Constrained by the invariant tropical sea surface temperature estimates of the CLIMAP Project, researchers have focused on those inter-hemispheric climate links or mechanisms that propagate from the Northern Hemisphere to the Southern Hemisphere, yet bypass the tropical region. Therefore, most efforts concentrate on the combined changes in the thermohaline circulation and variations in atmospheric CO_2. To date, data and models of these two mechanisms have not provided a credible explanation for symmetrical inter-hemispheric climate changes.

However, sea-surface temperature estimates from tropical corals indicate that tropical sea-surface temperatures change by 5ºC in the Quaternary. Substantially cooler tropical sea-surface temperatures dictate a dramatic drop in the water vapor content of the atmosphere, the Earth's dominate greenhouse gas. Changes in the global water vapor content, mediated by changes in the tropical sea-surface temperature, must therefore be the dominant climate amplifier of the Earth's astronomical seasons.

Quaternary sea level records from coral reefs offer a means to refine our understanding of the water vapor amplifier paradigm. ^{230}Th/^{234}U-dated sea level records obtained from coral reefs incorporate the records of the rates of polar ice melting, i.e. sea level record, and tropical sea surface temperature change. The fact that the same coral specimens may be ^{230}Th/^{234}U-dated to compute rates of sea level change and also measured for paleo-temperature, allows for the first time, a direct assessment of the absolute timing of tropical sea surface temperature change and polar ice sheet melting rates.

The results of two offshore drilling expeditions, one to Barbados in the western tropical Atlantic and one to Kiritimati Atoll in the central equatorial Pacific, provide high-resolution ^{230}Th/^{234}U-dated tropical temperature records directly tied to sea-level. The Barbados record is based on the reef-crest coral *Acropora palamta,* which provides a high-resolution sea-level record and paleo-temperature record for the western Atlantic. The Kiritimati Pacific sea-surface temperature record is based on the reef-crest species *Acropora hyacynthis*. *Acropora* is arguably the best calibrated paleo-temperature proxy based on Weber's (1973) δ^{18}O versus temperature calibration using 835 specimens from 28 localities and Reynaud-Vaganay et al. (1999) calibration of *Acropora* under controlled culture experiments.

Data from stratified MOCNESS plankton tows, HONJO sediment traps, and analysis of the transfer-function paleotemperature assumptions, provide an explanation for the discrepancy between foraminiferal statistically-based tropical temperature estimates and those from geochemical analyses of *Acropora*. In addition, Quaternary reef sediments accumulate at rates exceeding 600cm/kyr compared to 3 to 5 cm/kyr typical for nearby deep sea cores. Attenuation of the δ^{18}O signal in deep sea cores accounts for the differences observed between coral reef δ^{18}O time-series and those derived from planktonic foraminifera.

Modeling the Holocenic evolution of northwestern Adriatic Sea - southern Po Plain (Italy)

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The Po Plain (named after the Po River) is a triangle-shaped alluvial area, about 600 km height and 300 km wide, bounded by two converging A-type mountain chains (the Alps to the N, the Apennines to the S) and the Adriatic Sea to the E. The Po Delta extends over 50 km into the Adriatic Sea.

The Po plain and the Adriatic marine bottom feature a very low topographic gradient (0.3-0.5 %), whereas the Adriatic slope extends along the Pescara (Italy) - Split (Croatia) alignment, over 350 km south of the Po Delta.

About 1.3 m.y. b.p. this area was a deep marine, strongly subsiding (1.5 m/kyr) basin (Po Gulf), bounded by two narrow belts of alluvial and shallow marine sediments. The peri-apenninic shallow marine facies (Imola Yellow Sands) was connected via a complex delta slope to a few hundred meter deep marine environment. The growth of four main detachment thrust-faults below the Po Plain-Adriatic Sea controlled the external shape and the maximum thickness (about 1000 m) of the deltaic wedge, whereas the eustatic oscillations modeled its internal architecture.

South of the Po River, the deltaic wedge is overlaid by a early Pleistocene (900-800 kyr) - Holocene sequence, 200 to 1.000 m thick, composed of 12-14 alluvial/shallow marine quasi-tabular levels. Seismic profiles reveal tectonically controlled onlap structures and rare delta foreset into the oldest levels (14-6). The uppermost 5-6 levels (100-400 m thick) contain the most important water reservoir in Italy. A 20-40 m thick stiff clay layer divides the Würm sequences from the older ones, at the depth of 150-180 m.

Since the Po Plain and the Adriatic bottom surface featured a very low topographic gradient over about 250 kyr, the highstand phases allowed tens to hundreds kilometers-wide transgressions, reaching the toe of Apennines alluvial fans. During the Würm-glaciation acme, the Adriatic coastline and the Po Delta were located along the Pescara-Split alignment. Because of the extremely flat topographic surface, the Flandrian transgression produced a fast (35 m/yr) north-western shift of the shoreline. A 2-3 meters thin sandy-peaty lens crops at a depth of about 40 m, along the median axis of Adriatic Sea, 65 km seawards of the Ravenna coastline: it corresponds to a 9-8 kyr old Po Delta prograding sequence, during a short regressive phase. Less than 3 kyr later (6.0-5.5 kyr ago), the maximum flood shoreline advanced about 150 km northwards and 100 km westwards, tens of km landwards of the present shoreline; the Po delta divided two wide gulfs: the Venice Gulf in the N and the Ravenna Gulf in the S.

The start of a mainly atlantic-type humid climate (6-5.5 yr ago) lead to a huge increase of fluvial sediment yield and a subsequent rapid progradation of the Po Delta. Particularly after the Bronze age, the Po Delta acted as a large scale barrier, which stopped the NW longshore sediment drifting, increasing the progradation rate of the southern sector. A well mapped system of marshes, lagoons, coastal barriers and dunes points out the historical coastline progradation (i.e. the Ravenna roman-age harbour was located 6 km landwards of the present coast line, at a depth of about 6 m below present surface).

Three evidences suggest the role of tectonic subsidence in determining the holocenic large scale geomorphology of the southern Po Plain:

- The maximum flooding surface corresponds approximatively to the culmination of the Ferrara Folds in the N, and to the Cervia thrust-fault in the S.
- Locally, the surface of Flandrian transgression displays a slighty wavy geometry, according to tectonic folds.
- A large number of proto- and historical swamps and lagoon lied on the major Pleistocene sinclines.

In order to estimate the critical ranges of the major parameters (tectonics, euxtatic sea-level changes, fluvial and marine hydraulics, etc.) controlling landscape evolution during the last 10 kyr, we used a bi-dimensional basin-fill modeling software (Waltham and Hardy, 1995). Back-analysis of sedimentary evolution was performed along three 100 km long sections, traced South of the Po Delta.

Using an eustatic curve like the one proposed by Fairbridge (1962) and five constraints listed below, the model reproduced topography and sedimentary architecture fitting well with the actual ones:

- Initial (10kyr ago) planar topographic surface sloping 0.47% to NE.
- Planar normal fault producing a constant subsidence rate of 2m/kyr (i. e. extension rate = 0.57m/kyr).
- Holocenic sediments granulometric curve: coarse 10%, medium 55%, fine 35%.
- Sediment transport distance (from the coastline): coarse to 0.30 km; medium to 3 km, fine to 10 km.
- Sediment flux increasing in time, from 10 to 220m^2/yr just S of the Po Delta, and from 10 to 130 m^2/yr about 50 km in the S (around Ravenna).

Usually, the simulations reproduce well the location and the thickness of the offshore "relict" clastic Po delta. Moreover, we tested the Milliman (1992) eustatic curve, integrated with the Fairbridge e.c. for the last 5 kyr. Using a planar normal fault, but lower tectonic subsidence (0.4 m/kyr) and sediment-flux (20 to 65 m^2/yr), we modeled a sedimentary wedge partly similar in shape and architecture but thinner (20 vs. 30m) to the actual one. A more realistic model was obtained using a listric normal fault producing a differential tectonic subsidence ≈1 m/yr offshore vs. 2m/yr along the present coastline. Anyway, using the Milliman e.c. it resulted impossible to reproduce the observed offshore "relict" clastic Po delta.

Coarse gravel facies associated with rocky shorelines: significance for evaluating claims of tsunami and hurricane deposition

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Tsunami and/or hurricane deposition has been claimed for several deposits of very coarse coastal gravels located well above modern high tide level (Bourrouilh-Le Jan and Talandier 1985; Moore and Moore 1988; Bryant, Young et al. 1992; Jones and Hunter 1992; Fryer and Fletcher 1995; Young et al. 1996; Nott 1997; Hearty, 1997). A common feature of these deposits is their association with rocky shorelines. Rocky shoreline environments are poorly studied from a geological perspective (see Johnson 1992), and the characteristics of their associated sedimentary facies have not been described.

A study of modern rocky shorelines in Hawaii and Australia has shown that their associated sedimentary facies consist of coarse gravel of large pebble size and greater. Facies and large-scale shoreline morphologies (headlands, embayments, cliffs and platforms) are independent of rock type: shorelines studied were composed of carbonate lithofacies (not a modern coral reef), sandstone and basalt.

Gravel is derived primarily from wave attack on supratidal and subtidal cliffs. The maximum and average clast sizes of material supplied to the depositional system are a function of the structure (jointing and bedding) of the eroding rock. Clast and megaclast sizes of coarse boulder and block grades are common.

Very coarse gravel facies (boulders and blocks *sensu* (Blair and McPherson 1999) are associated with both supratidal and subtidal platforms on headlands. Similar very coarse boulder and block facies occur on subtidal platforms in embayments without beaches, backed by rocky cliffs. Facies are:

- Clast cluster;
- Isolated megaclast;
- Clast carpet
- Breccia wedge

Clast cluster

This consists of a group of several boulder-sized clasts which mutually support each other. Individual clusters may have an overall dip to landwards or seawards, but no consistent orientation has been observed in groups of clusters on the same platform.

Isolated megaclast

The size of isolated megaclasts is often larger than the mean clast sizes of any associated cluster or carpet; block size clasts are common. Where clast orientation can be determined, orientation is non-uniform.

Clast carpet

This facies is present only on subtidal platforms, where it is best developed at the foot of a subaerial cliff. It consists of a close-to loosely-packed layer with a maximum thickness of only a few clasts; it is commonly only one or two clasts thick. There is no consistent preferred orientation of clasts.

Breccia wedge

Located adjacent to the supratidal or subtidal cliff, this detritus is derived from cliff collapse, and is characterized by angular clasts. Clast size varies, but a high proportion of cobble and boulder material is present. Around the base of wedges on supratidal platforms, some removal of finer material and orientation of clasts in a seaward-dipping direction has been observed.

A stepped cliff-platform morphology is common on rocky coastlines. This morphology is best developed on on coastal headlands, where several platform levels (both supratidal and subtidal) may be present. The coarse gravel facies observed in this study are similar on all platforms (although not all may be present on any platform). Clast clusters and isolated megaclasts in particular are commonly found on the same platform. This implies that the same or similar transport processes have operated on both the subtidal and supratidal platforms, up to several metres above sea-level.

In interpreting coarse gravel deposits of rocky shorelines, the possibility needs to be considered that deposits presently in a supratidal location may represent former subtidal deposits. In addition, modification of even very coarse gravels after original deposition is highly likely, as subsequent wave events re-work the deposits. The degree of modification may include re-deposition, reorientation or clast shape and fabric changes due to the action of subsequent waves. Thus few deposits of hurricanes or tsunami are likely to preserve an unequivocal record of a particular transportation process or links to a specific event.

References

Blair, T. C. and McPherson, J. G. 1999. Grain-size and textural classification of coarse sedimentary particles. Journal of Sedimentary Research 69 (1): 6-19.

Bourrouilh-Le Jan, F. and Talandier, J. 1985. Sedimentation et fracturation de haute energie en milieu recifal: tsunamis, ouragans et cyclones et leurs effets sur la sedimentologie et la geomorphologie d'un atoll: motu et hoa, a Rangiroa, Tuamotu, Pacifique SE. (Major high-energy events in a reef environment: Tsunamis, Hurricanes and tropical cyclones and their efects on the sedimentology and geomorphology of an atoll: Rangiroa, Tuamotu, SE Pacific). Marine Geology 67: 263-333.

Bryant, E. A., Young, R. W. et al. 1992. Evidence of tsunami sedimentation on the southeastern coast of Australia. Journal of Geology 100: 753-765.

Fryer, G. J. and Fletcher, C. H., III 1995. Kapapa and South Mokulua: evidence for prehistoric tsunamis on windward Oahu? (Abstract). Tsunami Deposits: Geologic Warnings of Future Inundation, Seattle, Washington, May 22-23, 1995.

Hearty, P. J. 1997. Boulder Deposits from Large Waves during the last Interglaciation on North Eleuthera Island, Bahamas. Quaternary Research, 48, 326-338.

Johnson, M. E. 1992. Studies on rocky shores: a brief history and annotated bibliography. Journal of Coastal Research 8: 797-812.

Jones, B. and Hunter, I. G. 1992. Very Large Boulders on the Coast of Grand Cayman: the Effects of Giant Waves on Rocky Coastlines. Journal of Coastal Research 8: 763-744.

Moore, G. W. and Moore, J. G. 1988. Large scale bedforms in boulder gravel produced by giant waves in Hawaii. Geological Society of America Special Paper 229: 101-110.

Nott, J. 1997. Extremely high-energy wave deposits inside the Great Barrier Reef, Australia: determining the cause - tsunami or tropical cyclone. Marine Geology 141: 193-207.

Young, R. W., Bryant, E. A. et al. 1996. Catastrophic wave (tsunami?) transport of boulders in southern New South Wales, Australia. Zeitschrift fur Geomorphologie N. F. 40: 191-207.

Holocene sea-level change as a result of elastic and anelastic deformation along the central Cascadia Subduction Margin, USA

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Geological and geophysical investigations of the Cascadia subduction zone during the fifteen years have increased public awareness of regional earthquake hazards from a subduction zone previously thought to be aseismic (Ando & Balazs 1979). Evidence for repeated abrupt subsidence in the last few thousand years is found in coastal bays and estuaries in the form of buried marsh surfaces and drowned forests (e.g., Atwater 1987, 1992; Darienzo & Peterson 1990; Atwater et al. 1995; Nelson et al. 1995; Yamaguchi et al. 1997). These deposits are widely interpreted as the result of coseismic subsidence during subduction zone earthquakes (e.g., Atwater 1987, 1992; Darienzo & Peterson 1990; Atwater et al. 1995; Nelson et al. 1995; Yamaguchi et al. 1997). A non-tectonic origin may be responsible for some of these events, but most are linked with other evidence of earthquakes such as tsunami deposits and paired marsh burials and forest drownings, similar to the effects on coastal area! s from the 1964 Alaskan earthquake.

The chronology, distribution, and amount of subsidence for individual locations and events have been used to estimate recurrence intervals and magnitudes. However, a significant component of subsidence recorded at these sites could be attributed to localized permanent crustal deformation (Goldfinger et al. 1992a; Nelson 1992; Goldfinger 1994; McCaffrey & Goldfinger 1995; Nelson & Personius 1996; McCrory 1996; Clague 1997).

Geophysical data of the offshore Cascadia forearc reveal many Quaternary upper-plate faults and folds. Most active structures are within the accretionary wedge, but significant deformation is also found on the continental shelf and along the coast. Several faults and synclines project into adjacent coastal bays where deformation of Pleistocene marine terraces is observed. Rapidly buried marsh deposits and drowned forests in these coastal lowlands may thus record both elastic strain release on the subduction zone and localized upper-plate deformation. Movement on upper-plate structures may be triggered by a subduction zone earthquake, as observed in the Nankai and Alaskan forearcs, or they may deform independently.

Coastal response to elastic loading during the seismic cycles can be observed over hundreds of years. Permanent deformation of the coastal region, can be observed over many time scales. On the shortest scale of a few hundred years, coastal retreat and advance appears to be linked to the elastic response of the upper plate to interplate coupling. The signal may also reflect shorter wavelength elastic and anelastic signals from individual upper-plate structures.

The combined signals produce both broad regional subsidence and uplift, and more localized vertical motions both with and without crustal faulting. Coastal erosion patterns along the Oregon margin appear to reflect these short-term deformation signals (Komar and Shih, 1993).

The location and existence of coastal bays may in part be a reflection of an anelastic component of motion on crustal structures. Presently, the resolution of ice-rebound models in not sufficient to determine whether coastal folding is required to preserve the buried marshes of Cascadia, or whether Holocene sea-level rise alone is sufficient to account for their preservation.

Recent GPS measurements confirm surface motions associated with the plate-locking signal, though the vertical component is at present still poorly resolved. Variability of this signal may illuminate the relative importance of elastic and anelastic deformation in the next few years.

Over longer time scales, several hundred thousand years, marine terraces are uplifted in a process probably representative of a small residual component of anelastic deformation during each seismic cycle. Alternatively, the uplift may be due to deep-seated underplating along the plate boundary. Over even longer time scales, (and coarser measurement scales), uplift of the coastal range has resulted in steepening of the coast range uplift, and deepening of shelf sedimentary basins, with little net movement of the coastline since middle Miocene time. This signal suggests that the coastline itself is a hinge-line, and probably reflects long-term plate interaction onto which the shorter-term signals are superimposed.

Coastal evolution and sea-level changes in Samoa since the Mid-Holocene

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Previous research on relative sea-level history in Samoa has yielded contradictory views. However, a recent reconnaissance survey of the Samoan coastline together with detailed studies of the coastal evolution at Maninoa and Mavaega, on the south coast of Upolu and at Taga, on the south coast of Savaii, indicate a consistent pattern of Holocene sea-level change. A submerged, principally, volcaniclastic beachrock barrier berm, located approximately 50 m offshore at Maninoa indicates that sea-level was lower than present at 4,000 yr BP. Similar submerged features were observed offshore at Safotu on the north coast of Savaii. Between 3000 yr BP and 1200 yr BP sea-level was up to 1.2 to 1.5 m above present along the south coast of Upolu. In addition, a raised beach, elevated wave-cut notch and sea cave in cliffs at Taga on the south coast of Savaii, indicates that sea-level was 1.2 m above present during the Late Holocene, possibly coincident with the south coast of Upolu. Between 3000 yr BP and 1200 yr BP, relative sea-level rose, according to the succession from submerging barrier beaches to estuarine formation.

Subsequent to 1200 yr BP, coastal progradation occurred along the Upolu coast forming a coastal plain with progressive carbonate sand deposition partially infilling estuaries and lagoons formed during the prior relative sea-level transgression. In places, the coastal plain is mantled by alluvial sediments which have been deposited subsequent to the transgression, and probably in association with anthropogenic activities. The coastal progradation accompanied a relative sea-level regression. The modern barrier reef crest offshore from the south coast of Upolu yield dates between 900 to 1100 yr BP which indicates that the reef crest has been planed and eroded since then. During the sea-level regression, the landward of two beachrock layers, commonly observed along the Samoan coast, was formed between 440 to 350 yr BP. It is probable that larger than present volumes of carbonate sand were produced by the reef crest erosion, which was transported across the shoaling reef lagoon and deposited on the beachface. The beach progradation occurred at a time when global climate was near its peak cooling in the last millennium, and a prolonged period of strong El Niño events occurred (Quinn et al., 1987). In the last 100 years, a second beachrock layer was formed to seaward, with a slightly higher elevation and steeper seaward dip than the inland layer. The profile of the seaward beachrock layer indicates that the beach sand bedding, had been deposited during a period of higher wave energy, and carbonate cementation had taken place under a sea-level ~0.2 m higher than that for the inland beachrock layer. The increased wave energy and higher sea-level may be associated with regional sea-level rise and/or oceanographic conditions associated with a dominance of La Niña events.

Recent papers by Nunn (1991, 1995, and 1998) and Dickinson and Green (1998) have argued respectively, for and against the occurrence of a mid-late Holocene sea-level high-stand in Samoa, and whether long-term volcano-isostatic subsidence has occurred. Local-scale Holocene volcanics (inflation, local flexure, subsidence, faulting?) may have played a role influencing the signature of relative sea-level changes, but inter-island and island wide patterns of similar submergence and emergence histories suggest that there is a regional pattern of higher than present sea-level around ~3000 to 1200 yr B.P. and subsequent fall. This is consistent with the theoretical visco-elastic earth response to the post-glacial sea-level rise. The timing of the onset of the recent relative sea-level rise is not known. However, the minimum estimate for the onset of relative sea-level rise along the south coast of Upolu is after 350 yr B.P. Widespread erosion of beach sands and exposure of underlying beachrock layers around the islands, and progressive coastal retreat is evident along both Upolu and Savaii Island shorelines, during the last few decades. The coastal retreat is associated with cyclone and major storm events, and possibly with global sea-level rise.

References

Dickinson, W. R. and Green, R. C., 1998. Geoarcheological context of Holocene subsidence at the ferry berth lapita site, Mulifanua, Upolu, Samoa. Geoarcheology 13 (3), 239-263.

Nunn, P. D., 1991. Sea level changes during the last 8000 years in Fiji, Tonga and Western Samoa: Implications for future coastline development. In Workshop on Coastal Processes in the South Pacific Island Nations, Lae, Papua New Guinea, 1-8 October 1987. SOPAC Technical Bulletin 7:79-90.

Nunn, P. D., 1995. Holocene sea-level changes in the south and west Pacific. Journal of Coastal Research Special Issue No. 17: Holocene Cycles: Climate, Sea Levels, and Sedimentation, 311-319.

Nunn, P. D., 1998. Sea-level changes over the past 1,000 years in the Pacific. Journal of Coastal Research 14(1), 23-30.

Quinn, W. H., Neal, V. T. and Antunez de Mayolo, S. E., 1987, El Niño occurrences over the past four and a half centuries, Jour. Geophys. Res. 92, C13, 14,449-14,461.

The palynology of mangrove response to Late-Quaternary sea-level change

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Mangrove forests are a common feature of low energy tropical coasts. Palynological data from continental shelf and deep sea cores in the north Australian region indicate substantial shifts in mangrove abundance coinciding with late Quaternary changes in relative sea-level.

The continental shelf study site encompasses a section of the mid to outer shelf in the Great Barrier Reef Province, northeast Queensland. Thirteen sediment cores were taken at ocean depths from 40 to 70 metres. Core locations were selected at former river or tidal channel margins, as identified by ship-board Precision Depth Recorder. Pollen and radiocarbon results indicate extensive mangrove development inside the Great Barrier Reef Lagoon during the Last Glacial Marine Transgression, particularly for the period 10,050 to 7200 years ago.

Three long Quaternary records from deep sea locations are examined. These derive from the Coral Sea in northeastern Australia (ODP 820), the Banda Sea (SHI-9014) and Lombok Ridge (G6-4) in Indonesia.

Pollen and radiocarbon results for the upper section of ODP 820 indicate very strong mangrove representation during the last marine transgression, consistent with results from the adjacent continental shelf study, with an attenuation of mangrove since around 7 000 years ago. Pollen and oxygen isotope data from all deep sea records indicate recuring phases of mangrove expansion during previous Quaternary transgressions, and reduction of mangroves during regressive phases and rarer periods of relative sea-level stability.

Comparison with terrestrial pollen records suggests that the most recent episode of flourishing mangrove in northeast Queensland cannot be linked directly to a phase of humid climate, as has been suggested in studies elsewhere. More probably, the expansion and decline of mangrove communities at a broad regional scale, is linked to the physiographic nature of transgressive and regressive shorelines. In this interpretation marine transgressions provide flooding river estuaries and enhanced potential for mangrove growth. By contrast, river floodplain surfaces lie beyond tidal reach during regressions and still stands, thus limiting the potential for mangrove habitat in estuaries.

These results provide insights for the ecological management of tropical, muddy coastlines, particularly in the likelihood of predicted sea-level rise.

Holocene reef development in Kailua, windward Oahu, Hawaii shaped by wave forcing, Late-Pleistocene antecedent topography and concomitant island uplift

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Drill cores and benthic surveys of the bay-filling, fringing reef of Kailua, Oahu, Hawaii show that it is comprised of modern, Holocene, and Pleistocene-age reef and nearshore carbonate lithofacies. Large-scale morphologic variations across the 10 km^2 reef, including karst features, spur and groove physiography, platform depth, forereef slope, and a paleostream channel cut through the reef, indicate unique constructional and erosional histories within the bay that commenced prior to the Holocene. We identify lagoon, beach, back reef, reef crest, and reef front facies in core samples that reflect distinct depositional environments owing to at least two, possibly three, interglacial sea-level fluctuations. Extensive mineralogic alteration of reef bioclasts by meteoric diagenesis evident in XRD and petrologic analyses, implies that much of Kailua's reef is pre-glacial in age having been subaerially exposed. A late Pleistocene age for these fossil outcrops is consistent with Th–U ages of reef corals comprising much of the insular carbonate shelf surrounding Oahu ranging 80–210 kyr B.P. Calibrated ^{14}C AMS ages of cored Kailua corals show that Holocene reef accretion in the bay is >3–4 m thick in isolated localities, and that initial postglacial flooding of the bay occurred prior to 6800 yr B.P. The most prodigious modern coral growth in Kailua occurs as 100% living cover of mixed fingering *Porites compressa*, massive *P. lobata* and platy *Montipora verrucosa* at the central fore reef in water depths of 15 to 22 m.

The paucity of Holocene reefs on Oahu (except wave-protected Hanauma Bay) has been attributed to high annual and episodic wave energy. The modest modern–Holocene reef growth found in Kailua, however, indicates that Kailua is a transitional environment for postglacial reef growth, lying along a gradient in wave forcing between high-energy, swell-dominated north coasts void of Holocene growth and low-energy or wave-protected settings, such as Hanauma Bay and south Molokai. In addition, the occurrence, composition, and morphology of modern reef structures in Kailua can be related to environments that experience wave energy dissipation due to wave shadowing and diffraction owing to antecedent topography. Our model of postglacial sea-level rise, island tectonics, antecedent topography, and wave forcing in the main Hawaiian Islands suggests that limited accommodation space has existed for Holocene reef accretion on Oahu during the Holocene. This model helps to explain the scarcity of Holocene reefs on Oahu and the more luxuriant modern, and potentially thicker Holocene growth on Maui and Hawaii islands in comparable wave-energy settings. Oahu reefs, due to the convergence of a shallow antecedent basement, high wave energy, and concomitant uplift, currently exist within a geologic window of vulnerability to human impacts.

Possible sand resources on the reef front around Oahu

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Large sediment deposits on the reef front around Oahu are a possible resource for replenishing eroded beaches. We have collected closely spaced, high-resolution subbottom profiles that clearly depict the deposits in three areas: Kailua Bay off the windward coast, Makua to Kahe Point off the leeward coast, and Camp Erdman to Waimea off the north coast. Most of the sediment is in water depths between 20 and 100 m. Typically, the deposits rest on drowned terraces, formed during ancient low-stands of sea-level, and they extend seaward from the mouth of sinuous channels that traverse the modern reef platform.

The Kailua Bay deposit comprises 53 million m^3 of sediment, reaching a maximum thickness of 40 m. Sediment samples (surface pipe dredge and 2-m vibracore) are composed mostly of tan to light gray reef-derived carbonate grains, and textures range from sandy mud to sandy gravel. Significant amounts of the sediment are of similar grain size and color to sand on nearby Lanikai and Kailua beaches, although most samples also contain finer grained sediment. The gray color, deemed undesirable for beach replenishment, is confined almost exclusively to coralline algae grains, whereas other taxa are white, tan, or orange.

We mapped several contiguous deposits off the leeward coast. They contain a total of 107 million m^3 of sediment with a maximum measured thickness of 23 m. Although most of the deposits issue from reef-platform channels, at least one apparently is sourced by sediment that washes over a long, uninterrupted reach of the platform edge. In places, the sediment is confined to a deep terrace, 70 to 80 m below present sea-level, and seems to be relict from a previous sea-level lowstand. Elsewhere, this deposit is overlain by younger sediment that extends up to shallower terraces and the modern reef platform, suggesting that deposition is presently active.

Off the north coast, deposits issue from at least three channels, and more than 255-million m^3 of sediment of 21-m maximum measured thickness occurs within the mapped area. Terraces typically are less well developed compared to the other mapped areas, and the deposits tend to rest on a relatively rough surface of the reef front. Several long reef-front ridges interrupt these deposits, so the sediment cover is discontinuous.

The reef-front deposits are within reach of modern offshore mining technology. We have not yet collected sediment samples from the leeward and north coast deposits, but previous investigations, mostly near the mouth of reef-platform channels, report a variety of sediment textures and colors. Some or most of the sediment might need to be processed to remove fine grains and perhaps those of undesirable color in order to produce ideal beach-replenishment sand.

Short-term episodic response of seacliffs to tectonic and climatic events: rates, failure style and spatial variability, Santa Cruz, California

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Documenting shoreline and coastal cliff erosion rates typically involves using historical photography and maps to delineate the change in the position of the feature in question. Although this method yields an historical change rate, it provides little or no information on the episodic nature and processes of retreat. Many researchers have noted that coastal cliff retreat is highly episodic. It has been suggested that for the California coast, more erosion occurs over a time scale of several years, during periods of severe storm or tectonic activity, than occurs during decades of "normal" weather or tectonic quiescence (Griggs and Scholar, 1997; Griggs, 1994; Plant and Griggs, 1990; Griggs and Johnson, 1979 and 1983; Kuhn and Shepard, 1979).

This study is intended to provide insight into the processes of coastal cliff retreat in the short-term through the analysis of modes of failure, spatial variability of failures, and temporal variations in rates. The study area is a section of the northern Monterey Bay coast near Santa Cruz, California that has been identified as an "erosion hotspot" (Moore et al., 1999; Griggs and Savoy, 1985), with episodic retreat threatening homes and community infrastructure(s). Most previous studies have focused on calculating the long-term average erosion rates in this area. However, the methods used did not provide the data resolution necessary to conduct detailed analyses of the processes responsible for retreat of the seacliffs, with the exception of Griggs (1994) who documented the episodic nature of cliff retreat at 3 points along seacliffs to the west of the study area.

The short-term framework begins with aerial photography from October 18, 1989 (1:12000, black and white), which was taken immediately following the magnitude 7.1 Loma Prieta earthquake. This earthquake was the largest earthquake this century in the Santa Cruz Mountains. The more recent photography (1:7500, color) was taken with the USGS CAMS (see Hapke and Richmond, 1999) on 3 dates during the winter of 1998, capturing the response of the coast to the severe storm events associated with the 1997-98 El Niño.

For each data set, the top edge of the cliff is digitized in stereo at very high resolution (0.2 m/pixel). At each location where the cliff has failed, the position and characteristics (amount of retreat, style of failure, linear extent of failure) are documented. The style of failure is determined by both the nature of the failure scar and the deposit on the beach below. The failure signature is then recorded for each data set by displaying the cliff position of the previous date and demarcating the areas of failure. These failure signatures represent, in most cases (but not all as discussed below), retreat of the cliff as defined as the landward movement of the cliff edge. Cliff retreat is thus defined because in studies utilizing aerial photography, the landward movement of the cliff edge is the feature used to measure long- and short-term change. For the 1989 data set, the areas of failure do not represent retreat with which to compare the position of the cliff edge, as no earlier date of photography was processed for use in this short-term study. A plot of the failure signatures reveals the spatial distribution, plan form (e.g. arcuate vs. linear) of the failure scar, and the amount of cliff retreat.

Along this portion of the northern Monterey Bay coastline, the 20-30 m high seacliffs are composed of the Pliocene Purisima formation, a massively bedded, well consolidated silt to sandstone (Dupre, 1975). An unconsolidated layer of terrace deposits, the top of which defines the retreating edge of the cliff, caps the Purisima. Three styles of cliff failure are described in this area using stereo photography, oblique aerial video, and ground observation: 1) debris fall, involving only terrace deposits, 2) rock fall, involving only Purisima, and 3) complex failures, which involve some combination of rock fall and debris falls. It is important to note that cliff retreat, again defined as the landward movement of the top edge of the cliff, only occurs when terrace deposits are involved in failure. Although the geologic characteristics of the Purisima are generally considered when describing cliff retreat in this area, erosion of the terrace deposits is the dominant process leading to cliff retreat. During the Loma Prieta earthquake, 264 m of the 1 km stretch of coast in this study failed as a result of violent ground shaking. Debris falls of terrace deposits were by far the most common type of failure (77%), as compared with rock falls (15%) or complex failures (8%). The mean retreat from the earthquake alone was 4.2 m (maximum retreat was 7.2 m).

The retreat of the cliff on a decadal scale is in response to some continual combination of terrestrial and marine processes. The period from October 1989 to January 1998 was relatively quiet both tectonically and climatically, except for 1996 when Santa Cruz received excessively high rainfall. During this decade, 192 m of the study area experienced failure events. The style of failure was nearly equally distributed between debris falls (47%) and complex failures (53%). No rock-fall-only occurrences were identified, and the mean retreat of the cliff was 2.4 m, almost half of the instantaneous retreat that occurred during the earthquake. The decadal retreat rate (0.26 m/yr, based on the 9 year time period) is slightly higher than the long-term average erosion rate given as 0.15 m (Moore et al., 1999), and as 0.21 by Benumof and Willis (in prep). During the first major storms of the 1997-98 El Niño, which brought heavy rains and large waves to this section of coast, 84 m of the cliff failed, and the processes of debris falls, rock falls, and complex failures contributed equally (33%). Retreat amounts are larger where complex failures occurred, and all of the failures during this 2 week period (Jan. 27 – Feb. 9) occur at or adjacent to areas of previous failures. In the period from Feb. 9 to March 6, storm intensity decreased somewhat, and during this time 79 m of the section failed, again at or adjacent to areas of previous failure. In this late-El Niño period, the only process of erosion was in the form of debris falls.

Overall, the plot of the failure signatures reveals a clustering of failure episodes, implying some intrinsic spatial relationship between failures; the failures seem to be concentrated in 3 distinct areas. In several locations, the failure signature for a given year is seaward of the previous one; this is a function of failures that do not involve the retreat of the top edge of the terrace deposits. In other words, if the failure results in retreat of the cliff edge, then the failure signature will be landward of the previous signature in that area. However, if the failure occurs only within the Purisima or involves failure of terrace deposits seaward of the top edge of the cliff, the failure signature may lie seaward of the previous failure. Both the linear extent of the failure signatures and the magnitude of the landward retreat of the cliff as a result of the Loma Prieta earthquake indicate that large-scale tectonic events have a very significant impact on cliff retreat on a short time scale.

The widespread removal of the terrace deposits during the earthquake may ultimately contribute to block erosion of the Purisima by increasing the surface area available for direct infiltration of rain and run-off. Increased fluid pressure during ensuing periods of high rainfall may enhance conditions for failure along existing planes of weakness (joints and fractures). Loss of the front several meters of the cliff in the form of rock falls may, in turn, encourage debris falls within the terrace deposits by creating steeper, thus more unstable slopes in the overlying unconsolidated deposits.

Large-scale climatic events such as the 1997-98 El Niño, produce somewhat accelerated cliff failure and retreat; however, the effects are not dramatic when compared to the gradual decay of the cliffs from exposure to waves and rainfall over a decade time span. Although episodic failure did occur during the 1997-98 El Niño, this stretch of coast did not experience widespread failure. Storms bringing large waves and high rainfall over the duration of several days are not atypical in the decadal scale along the central California coast. The slightly accelerated response of seacliffs during the 1997-98 El Niño suggests that seacliffs do have an increased, although not dramatic, response to events of this magnitude.

References

Benumof, Benjamin, and Willis, Cope, in prep, Seacliff Erosion Rates, Cliff Material Properties, And Physical Processes Along the Central California Coast.

Dupre, W.R., 1975, Maps showing geology and liquefaction potential of Quaternary Deposits in Santa Cruz County, California, U.S.: USGS Misc. Field Studies Map MF-648, scale 1:62500.

Griggs, Gary B. and Johnson, R.E., 1979, Coastal Erosion, Santa Cruz County: California Geology, v. 32/4, p. 67-76.

Griggs, Gary B. and Johnson, R.E., 1983, Impact of 1983 Storms on the coastline of Northern Monterey Bay, Santa Cruz County: California Geology, v. 36/8, p. 163-174.

Griggs, Gary B. and Savoy, Lauret (eds.), 1985, Living with the California Coast, Duke University Press, 393 pp.

Griggs, Gary B., 1994, California's Coastal Hazards: Journal of Coastal Research Special Issue No. 12: Coastal Hazards, pp. 1-15.

Griggs, Gary B, and Scholar, Deirdre C. Coastal Erosion Caused by Earthquake-Induced Slope Failures: Shore and Beach, 65:4, pp. 2-7.

Hapke, Cheryl J. and Richmond, Bruce M., 1999, The Development of a Coastal Aerial Mapping System (CAMS) and Its Application to the Study of Coastal Morhpodynamics: Coastal Sediments '99, v.3, pp. 2398-2413.

Kuhn, Gerald G. and Shepard, Francis P., 1979, Accelerated Beach-Cliff Erosion Related To Unusual Storms in Southern California: California Geology, pp.58-59.

Moore, L.J., Benumof, B.E., and Griggs, G. B, 1999, Coastal Erosion Hazards in Santa Cruz and San Diego Counties, California: Coastal Erosion Mapping and Management, JCR Special Issue No. 28, p. 121-139.

Plant, Nathaniel and Griggs, Gary B., 1990, Coastal Landslides Caused by the October 17, 1989 Earthquake, Santa Cruz County, CA: California Geology, v. 43, p. 75-84.

The carbonate factory: 5000 years of sand production, flux and storage on a windward fringing reef (Kailua, Oahu, Hawaii)

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The carbonate reef system of windward Kailua Bay (Oahu, Hawaii) is a complex assemblage of various ages and accumulation histories that provides a new opportunity for mapping and describing windward reef structure and zonation. The shoreface is dominated by a broad (4 km^2), shallow fringing reef 5–20 m in depth bisected by a sinuous, sand-filled paleostream channel ~200 m wide. The inner reef platform lies in 5–8 m water depth and is composed largely of "karstified" fossil reef outcrops with 25–50% living coral cover. The outer reef platform extends seaward to 20 m depth as spur and groove topography with 50–100% living coral cover. Along the reef margin 3 km offshore, the fore-reef slopes steeply seaward (in some places as talus and elsewhere as living coral cover) to abut a sand field at –25 m. The scleractinian coral genera *Porites*, *Montipora*, and *Pocillopora* characterize the reef platform, and their distribution, abundance, and morphology varies with depth and hydrodynamic energy. Coralline (red) algae (e.g. *Porolithon onkodes*) are prolific inhabitants of the benthic community at all depths.

Beach and submarine sediments are >90% biogenic carbonate produced by two processes: mechanical, chemical, and biological destruction of reef framework limestone (coralline algae and coral) into rubble, sand, and silt; and direct sedimentation upon the death of organisms such as *Halimeda*, molluscs, and foraminifera. Carbonate sediments are dominantly fossil-aged: of 20 accelerator-radiocarbon ages on bulk sand and skeletal constituents, only one dates post-1950; twelve ages are 500–1000 calendar years before present (cal yr BP); five are 2000–5000 cal yr B.P. (Harney et al. in review). This indicates long residence times for carbonate grains, such that the entire period of relative sea-level inundation (~5000 yr) is represented in the sediment.

Carbonate dynamics in this system are controlled by physiographic setting (e.g. depth, substrate type, and hydrodynamics), structure and function of the carbonate-producing community, and changing environmental regimes (e.g. Holocene sea-level fluctuations). Our comprehensive model of sediment production in various habitats of Kailua Bay quantifies the modern processes of gross carbonate framework construction (by corals and coralline algae), the subsequent degradation of consolidated reefal substrates into loose sediment, and the direct addition of carbonate sediment through the biologic activities of *Halimeda* (a calcareous green alga), molluscs, and benthic foraminifera. Using field data collected in various physiographic regions of Kailua Bay, we estimate that carbonate sediments are produced at a rate of ~4000 m^3y^{-1}. Thus, during the 5000 years that Kailua Bay has been wholly inundated by post-glacial sea-level (Grossman and Fletcher 1998, Fletcher and Jones 1996), ~20 million m^3 of carbonate sediment has been produced in the system. We compare this cumulative production volume to that which is currently stored in submarine and subaerial reservoirs of the bay and coastal plain (a combined estimate of 14 million m^3). By these calculations, nearly one-third of the sediments produced since 5000 yr B.P. in our model are unaccounted for. This imbalance may represent sediment loss due to dissolution, abrasion, and/or transport offshore, or it may arise from the inaccuracy of some model parameters.

Warm interglaciations, abrupt environmental change, and the Antarctic "Wild Card"

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Research on shoreline deposits in Bermuda, the Bahamas, and Hawaiian Islands provides insight into the nature of environmental change during warm and/or prolonged interglaciations. Of particular interest is the shoreline geology associated with marine isotope stages (MIS) 5e and 11, which are the warmest interglaciations of the past half-million years. The geology of both interglaciations reveals "catastrophic" events (both in human and natural contexts) caused by abrupt sea-level changes. Significant draw down of some of the world's great ice sheets, including Greenland (GIS), West Antarctica (WAIS), and East Antarctica (EAIS) appears to underlie these global disruptions. Ultimately, these findings suggest that current predictions of sea-level and climate change by "greenhouse" warming may be wholly inadequate to describe the threat that lies ahead.

MIS 5e

As recorded in reef and intertidal sequences on Bermuda and the Bahamas, sea-level lay between +2 and +3 m for most of the last interglaciation, MIS 5e. After 10 kyr of apparent stability, as documented by stratigraphy and thermal ionization mass spectrometry (TIMS) dates on growth-position corals, sea-level rose to between +6 (Neumann and Hearty, 1996) and +9 m late in the period. Because of tectonic uplift due to lithospheric flexure in Oahu, Hawaii, the same early and late sea-level peaks are recorded approximately 3 m higher, yielding an uplift rate of ~0.025 m/kyr. After a brief pause (100's years) at this maximum, terminal position, sea-level began a descent toward its "mid-glacial" position at the onset of MIS 5d. This unsettled transitional period, centered around 118 kyr, was characterized climatic instability.

In the Bahamas, vast areas of the carbonate platform were reshaped by high winds and by the impact of massive waves that formed km-scale chevron shaped ridges and runup deposits over 800 km of the Atlantic (northeast) margin of the Bahama Banks (Hearty et al., 1998). Thousand-ton boulders were catapulted onto and over 20 m-high coastal ridges (Hearty, 1997). While tsunamis could be the mechanism behind these giant waves, most of the independent global records identifying radical environmental change at the close of MIS 5e favor a climatic mechanism for these events.

MIS 11

Consistent with vertical rates of ~0.025 m/kyr on Oahu, the "uplift corrected" terrace positions of MIS 11 yield sea-level records parallel with those from tectonically stable Bermuda and the Bahamas. The earliest paleosea-level of MIS 11, indicated by a shallowing-upward sequence at +2 m, is exposed in the rocks of Eleuthera, Bahamas, and in the eastern cays of Bermuda. Shore deposits at the base of a section on west Oahu indicate a probable equivalent stillstand. A subsequent rise to +7.5 m in the Bahamas (+13.5 m in uplifted Oahu) deposited a second shallowing-upward sequence on a broad terrace carved in the older shore sediments. After a period of apparent stability at +7.5 m, sea-level jumped again to over +20 m, eroding narrow benches in Eleuthera, Bahamas, and filling high caves with marine sediments in Government Quarry, Bermuda (Hearty et al., 1999). A marine terrace at "70 feet" (+21.3 m) was documented at the same locality by Land et al. in 1967, but unfortunately was destroyed shortly thereafter by quarry expansion. In Oahu, slightly altered corals from an extensive marine terrace at +26 to +30 m at Waianae and Kaena, respectively, yield maximal TIMS ages around 530 kyr. Given the documentation of a +20 m sea-level in Bermuda and the Bahamas, only 8 to 10 m of Oahu's +28 m MIS 11 shore elevation can be attributed to uplift, thereby yielding a vertical rate (~0.020 ±0.005 m/kyr) in accordance with that of MIS 5e.

The most chemically reliable TIMS age of 420 ±30 kyr was obtained from flowstone directly overlying beach sediments in the Bermuda cave (Hearty et al., 1999). Calibration of whole-rock A/I ratios from those beach sediments is provided by the 420 kyr date, which allows a reasonable AAR correlation of numerous sites based on the similarity of A/I ratios. Thus, the parallel stratigraphy, chronologies, and sea-level histories from these remote sites, together with abundant corroboration from land records and deep sea data (amply discussed in Poore et al., 1999), support a MIS 11 age for these dramatic sea-level events.

The Antarctic "Wild Card"

What was the nature and underlying cause for punctuated sea-level rise during both warm interglacials, MIS 5e and 11? The preservation of unique geologic details at several localities provides some answers to this question.

Numerous scientists have suggested that the collapse of the WAIS was the cause of the rapid rise sea-level at the end of MIS 5e, and glaciological mechanisms for this collapse have been offered. The immediate result was rapid and presumably unpredictable sea-level change. In addition, there appear to be numerous spin off effects of ice collapse that lead to high-energy oceanic changes, and abrupt climatic shifts. Adkins et al. (1997) identified a "rapid shift in oceanic conditions in the western North Atlantic" about 118,000 yr ago. They attribute the shift to an increase in southern source waters, a marked reorganization of the oceanic circulation patterns, and the initiation of a "climatic deterioration" over a ~400-yr period. This deterioration is further documented in pollen data from Europe which indicates major environmental vegetation shifts from temperate to coniferous forests, or to grassland communities over a short interval of time. Extinction events, such as that of the "Senegalese Fauna" in the Mediterranean, are also a likely effect of the climate shift at the end of MIS 5e. Perhaps generated by steeper climate gradients in the North Atlantic, storms associated with high winds and giant waves vastly altered the geomorphology of the Bahama Islands.

During MIS 11, parallel stratigraphic successions in Eleuthera, Bahamas, and Oahu (uplift corrected) reveal a "stepping up" of sea-level to quasi-stable positions at +2 m, +7.5 m, and +20 m. A core from ODP Site 982 (Rockall Plateau, North Atlantic, Stanton-Frazee et al., 1999) shows very high ice rafted debris (IRD) during Termination V, but contains no IRD during the early 23 kyr of MIS 11. It thus appears that the GIS was the first ice sheet to suffer a major deglaciation in MIS 11. Melting of the GIS would account for the early rise of sea-level from +2 to a relatively stable +7.5 m level. Collapse of the unstable, marine-based WAIS presumably followed later in the interglaciation, perhaps initiated by destruction of protective ice shelves. The collapse of the WAIS in turn, must have triggered the drawdown of the adjacent EAIS ice basins, elevating global sea-level to +20 m by the end of MIS 11. A total increase in ocean volume of 20 m *can only be accommodated* by the melting, collapse, and drawdown of the world's major ice sheets, and evidence of these changes is found in the rocks of Bermuda, Bahamas, Hawaii, Alaska, and Britain (and certainly other localities to be identified). The importance of the coastal record in preserving evidence of detailed sea-level changes during past interglaciations, and the use of traditional geological techniques to interpret these changes, cannot be overstressed.

Widespread global change is evident during MIS 11 in deep sea records. Oppo et al. (1990) characterized MIS 11 as "the most extreme interglacial of the past 500,000 years", noting the greatest flux of North Atlantic deep water to the Southern Ocean and the furthest poleward shift of the polar front. North Atlantic winter SST's were the warmest in the past million years, while pollen and loess records indicate unrivaled interglacial biomass production and aggressive soil weathering conditions in mid latitudes, reflecting the warmest and most humid climate of the past half-million years. Extinction of the Short-Tailed Albatross in the North Atlantic, and that of numerous other low-island inhabitants occurred at the end of MIS 11.

It is not certain when, or even if nature will play her "Wild Card", but evidence of abrupt environmental changes during past warm interglaciations is compelling, and merits further investigation. The possibility of ice sheet melting, collapse, and drawdown should be seriously considered in future global warming scenarios.

References

Adkins, J. F., Boyle, E. A., Keigwin, L., and Cortijo, E., 1997. Variability of the North Atlantic thermohaline circulation during the last interglacial period. *Nature* , v. 390, p. 154-156.

Hearty, P. J., 1997. Boulder deposits from large waves during the last interglaciation at North Eleuthera, Bahamas. *Quaternary Research*, v. 48, no. 3, p. 325-337.

Hearty, P. J., Neumann, A. C., and Kaufman, D. S., 1998. Chevron ridges and runup deposits in the Bahamas from storms late in oxygen-isotope Substage 5e. *Quaternary Research*, v. 50, p. 309-322.

Hearty, P .J., Kindler, P., Cheng, H., and Edwards, R. L., 1999. A +20 m middle Pleistocene sea-level highstand (Bermuda and the Bahamas) due to partial collapse of Antarctic ice. *Geology*, v. 27, no. 4, p. 375-378.

Land, L. S., Mackenzie, F. T., and Gould, S .J., 1967. The Pleistocene history of Bermuda. *Geological Society of America Bulletin* , v. 78, p. 993-1006.

Neumann, A. C., and Hearty, P. J., 1996. Rapid sea-level changes at the close of the last interglacial (substage 5e) recorded in Bahamian island geology. *Geology ,* v. 24, p. 775-778.

Oppo, D. W., Fairbanks, R. G., and Gordon, A. L., 1990. Late Pleistocene Southern Ocean $\delta^{13}C$ variability. *Paleoceanography*, v. 5, p. 43-54.

Poore R. Z., Burckle, L., Droxler, A., and McNulty, W. E. (eds), 1999. *Marine Oxygen Isotope Stage 11 and Associated Terrestrial Records*. U.S. Department of the Interior. U. S. Geological Survey Open File Report 99-312.

Stanton-Frazee, C., Warnke, D. A., Venz, K., and Hodell, D. A., 1999. The stage 11 problem as seen at ODP Site 982. *In:* Poore R. Z., Burckle, L., and McNulty, W. E. (eds). *Marine Oxygen Isotope Stage 11 and Associated Terrestrial Records*. U.S. Department of the Interior. U. S. Geological Survey Open File Report 99-312, p. 75.

Schmidt hammer and weathering rind studies of a modern and uplifted beach sequence, Turakirae Head, New Zealand

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At Turakirae Head, at the southern end of the North Island of New Zealand, a series of uplifted beach ridge/platform sequences, associated with tectonic events, have been preserved over the last 7,000 years. The raised beaches have been dated by historical and radiometric methods. This paper presents evidence of Schmidt hammer measurements on the modern beach and adjacent raised beach from two sites. Comparative evidence of weathering rinds is presented from the same locations.

Schmidt hammer results show differences in rock strength between the underlying platform and the boulders resting on the platforms. This is reflected in the lithology; the platform being composed essentially of well-jointed mudstone, whereas the boulders are predominantly greywacke sandstone with considerably wider joint spacing. The platform versus boulder differences are significantly greater than the differences between the modern and raised beach results. A variety of types of weathering rinds were noted on the boulders, whereas flaking is predominant on the platforms. The depth of weathering was measured in each case. Comparison was made between the Schmidt hammer results and the depth of weathering rinds. A study of weathering-rind thickness on each of the raised beaches showed that it was not possible to determine the relative ages of the beaches by this method, because of surface spalling due to active salt weathering in the harsh coastal environment.

Further sedimentological studies are under way to determine the sources of the boulder material on the platforms at the two sites and the types of decomposition taking place.

Modelling Holocene depositional regimes in the western North Sea at 1000 year time intervals

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Geophysical model predictions of relative sea-level change and a model of continental shelf bathymetry combine to produce palaeogeographic reconstructions for the last 10000 years at 1000-year intervals. These reconstructions reveal the transgression of the North Sea continental shelf. The key stages include: a western embayment off northeast England as early as 10000 BP; the evolution of a large tidal embayment between eastern England and the Dogger Bank before 9000 BP with connection to the English Channel prior to 8000 BP; and Dogger Bank as an island at high tide by 7500 BP and totally submerged by 6000 BP. Analysis of core data shows that coastal and saltmarsh environments could adapt to rapid rates of sea-level rise and coastline retreat. After 6000 BP the major changes in palaeogeography occurred inland of the present coast of eastern England.

The palaeogeographic models provide the coastline positions and bathymetries for modelling tidal ranges. A nested hierarchy of models, from the scale of the North East Atlantic to the east coast of England, uses twenty-six tidal harmonics to reconstruct tidal regimes. Predictions consistently show tidal ranges smaller than present in the early Holocene, with only minor changes since 6000 BP. Recalibration of sea-level index points using the model results rather than present tidal range parameters increases the difference between observations and predictions of relative sea-levels from the glacio-hydro-isostatic models and reinforces the search for better ice sheet reconstructions.

Passive airborne multi-spectral remote sensing application to nearshore, ocean-floor mapping and geology

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Airborne digital multi-spectral images collected in four discrete narrow bands (488, 551, 557, 701nm; width of 10nm) provide high resolution mapping capabilities in near-shore marine environments. The digital database for this project consists of information for depths up to -35m in Kailua Bay; a typical fringing reef environment on windward Oahu, Hawaii. Subsequent physical modeling of the multi-spectral components is used to deconvolve the spectral effects of the atmosphere, water column and benthic substrates to obtain depth and bottom-type maps. Using high-resolution USGS bathymetry survey data collected at two sections of the bay for error assessment, the physical model achieves 80% accuracy in predicted depth. Spatial clustering of the bottom-type predictions are supported by extensive ground truthing and field knowledge as well as low error in depth predictions. Fifteen classes are mapped that reflect variations in ecology and sedimentary character of the ocean floor. The usefulness of this model lies its flexible application to this and other spectral data types collected in marine environments.

Measuring and modeling coastal progradation, catastrophic shoreline retreat, and shoreface translation along the coast of Washington State, USA

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A multi-disciplinary research program, the Southwest Washington Coastal Erosion Study, is investigating a regional coastal sedimentary system along the tectonically active margin of Pacific Northwest of the United States. The study area is known as the Columbia River littoral cell, a 165-km reach of coast that has accumulated Columbia river sand along four barrier-plain subcells separated by the large depositional estuaries of Willapa Bay and Grays Harbor. As a component of the study, the late Holocene and historical (post 1870's) evolution of barriers along the Southwest Washington coast is being investigated to determine the relationship between net progradation and sediment supply rates and the influence of intermittent earthquake-induced subsidence events that occur at approximately 500 year intervals.

Extensive ground penetrating radar (GPR) surveys have been conducted to map the near surface stratigraphy (upper 4–6 m) and morphological change of the prograded coastal barriers spanning time scales of years to millennia. High-resolution GPR topographically corrected with real time kinematic differential global positioning systems (RTK DGPS) has been used to obtain detailed images of the depositional history following the most recent subsidence events, which are typically marked in the subsurface by heavy mineral layers. Differences in the GPR reflection packages suggest changes in depositional processes, rates, and periods. High resolution GPR reflection data is allowing reconstruction of shoreline behaviour between timelines obtained from either historical records or various dating techniques (bulk and AMS ^{14}C, and optical). In particular, the high-resolution GPR profiles allow for comparison of coastal changes since the last earthquake-induced subsidence event of January, 1700 to those since the late 1800's, when the coast became subject to human intervention (e.g. jetties, dams, irrigation, dredging). A major objective of this research is to gain a better understanding of the time scale associated with morphological changes such as the post-subsidence rebound and morphological adjustment of the inner shelf and upper shoreface to an equilibrium condition.

Timelines and geometric parameters derived from GPR profiles, historical shoreline and bathymetric maps, and recent bathymetric surveys, are being used to conduct simulations of the evolutionary sequence of the coastal barriers and inner shelf. The observed cycles of episodic subsidence events and subsequent rebound and net progradation are simulated with the Shoreface Translation Model (STM), a mass-budget geometric profile model driven by sea-level change, littoral transport budgets, and morphological parameters. These simulations illustrate the interaction of the barriers and shoreface and help to determine the range of possibilities which could account for net seaward progradation, such as sediment supply from the Columbia River, and/or sediment supply from the lower shoreface. The exchange of sediment between the inner shelf and upper shoreface and the role of the lower shoreface in long-term nearshore morphology and shoreline dynamics is also being investigated with high resolution multibeam bathymetry and nearshore surveys.

The integration of data sets, and in particular, the combination of geophysical observations and simulations of morphologic change is enhancing both the quantification and conceptual understanding of coastal evolution over time scales (especially centuries) that have formerly been speculative due to a lack of data. Results of these efforts can be used to refine behaviour-oriented models and predictive capabilities of future coastal change.

Contemporary evolutional trends of the central Polish coast

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Introduction

The Polish coast is situated along the southern part of the Baltic Sea. The central Polish coast is here defined as extending from Darlówek to Karwia (**Fig. 1**). From the standpoint of hydrology, the Baltic Sea is an exceptionally diversified water basin. The reason for this phenomenon is the particular configuration of the shores, deeply indented fed to various degrees by fluvial waters, and differently situated in regard to the Atlantic Ocean (Mikulski, 1986).

The central Polish coast lies in a moderate, cool climatic zone. The regional climate is influenced by both the Atlantic Ocean and by the East European continent. The present outline of the central Polish coast is the result of a complex evolution of the Baltic Sea throughout the entire Holocene. During the last 8000 years, the Baltic basin had a permanent connection with the North Sea (Kaszabowski, 1988a, 1992). Global transgressions and regressions, which occurred during that period, left their mark on the Baltic Sea.

Contemporary Evolutional Trends

Spit shores predominate along the central Polish coast (**Fig. 2**). In this region, beaches are often wide, built of sandy sediments, and the adjacent sea floor has abundant in numerous underwater forms, mostly represented by bars. Scarce, high fluvioglacial-glaciogenic shores near Rozewie (sector 4,5; Fig. 2) have different dynamic features. The Rozewie cliff protruding far into the sea, while inert at present was very dynamic until recently. Between 1837-1875, the Cape Rozewie receded by 90 m, at an average rate of 2.35 m/yr (Szopowski, 1961). At the beginning of the 20th century, this section was protected. The Chlapowo cliffs are sandy gravel cliff debris, and in some places landslides of tills. In many places along the cliff profile, a distinct slide step is found, which is evidence of landslides triggered off by catastrophic storms at the end of the 19th and early 20th century (Subotowicz, 1984). Measurements between 1971-1975 (Subotowicz, 1984) indicate that the western section called Jastrzebia Góra cliff, recedes at the rate of 0.5m/yr (**Fig. 2**). Spit coasts in this area are the most developed Polish coasts of this type. They have a complex geological form, and are often 3-4 km wide. The central Polish coast has been receding southwards during the 1980's. The lowest erosion rate of 0.2 m/yr, is recorded in Karwia (sector 5, Fig. 2). Further westwards, in the region of Lubiatowo and Leba, the rate of the sea shore recession is high and amounts to 1 m/yr and 0.8 m/yr respectively (sector 6,7; **Fig. 2**).

The distinct erosion of spit shores is also pointed out by E. Zawadzka (1986). According to her, these shores are shifting southwards at the rate of 0.5-1.5 m/yr. However, some researchers (Mielczarski, 1972, 1978, 1989) claim that the Polish coast rests in relative dynamical equilibrium. This apparent effect is undoubtedly caused by general straightening of the shore line, and by the irregular character of coastal processes. Somewhat westwards from Gardno Lake (sector 8, Fig. 2), the glaciogenic-fluvioglacial coast between 1960-1978 has receded with a rate of O.2-1.8 m/yr (Miotk. and Bogaczewicz-Adamczak, 1986). The fluvioglacial-glaciogenic shores near Jaroslawiec, between 1842-1922 have receded with a rate of 0.55 m/yr (Subotowicz, 1984). According to P. Konarski (1978) between 19611971, cliff (sector 1O, Fig. 2) was receding at the rate of 1.4 m/yr, but between 1972-1977, the rate of erosion reached as much as 2 m/yr (Kaszubowski, 1992). The scientists who here examined this section (Konarski, 1978; Szot-Martychewicz, 1977) agree that erosion and geodynamical phenomena in this area have intensified after 1973.

References

Cieslak A., and Subotowicz W., 1987. Raport o stanie wiedzy o brzegu morskim w Polsce i jego ochronie (Report on the state of knowledge about the sea shore in Poland and its protection). Inzynieria Morska, no.2

Kaszubowski L., 1988. The Holocene transgression of the Baltic Sea on the middle sea coast in Poland. international Symposium on: Theoretical and applied aspects of coastal and shelf evolution, past and future. Extended Abstracts, Amsterdam

Kaszubowski L., 1992. Middle and Late Holocene Transgressions of the Baltic Sea on the Central Polish Coast. Journal of Coastal Research, Florida, Fort Lauderdale, USA 4. Konarski P., 1978. Rozwoj morfologiczny srodkowego wybrzeza w okresie lat 1961-1977 (Morphological development of the middle coast in the period 1961-1977). Pomorskie srodowisko przyrodniczejego ochrona i ksztaltowanie, vol.V, Slupsk

Mielczarski A., 1972. O aktualnych tendencjach zmian brzegowych na polskim wybrzezu Baltyku (On actual tendencies in shores changes at the Polish coast of the Baltic). Technika i Gospodarka Morska, no.3

Mielczarski A., 1978. Wzgledna stabilnosc poludniowego brzegu Baltyku - nowe argumenty (Relative stability of the southern Baltic shore - new arguments). Technika i Gospodarka Morska, no.10

Mielczarski A., 1989. Dynamika polskich brzegow morskich w ocenie raportu o stanie wiedzy o brzegach morskich (Dynamics of the Polish seashores appraised by the report on knowledge about seashores). Inzynieria Morska, no. l

Mikulski Z., 1986. Regionalizacja zlewiska Baltyku (Regionalization of the Baltic and its drainage area). In: B.Rosa (ed.), Peribalticum

Miotk G., and Bogaczewicz-Adamczak B., 1986. Marine transgressions on the basis of investigations of subfossil biogenic sediments in the Sarbska bar, Southern Baltic. Quaternary Studies in Poland, vol.7

Subotowicz W., 1984. Brzegi klifowe (CIiff shores). In: B.Augustowski (ed.), Pobrzeze Pomorskie, Ossolineum

Szopowski Z., 1961. Zarys historyczny zniszczen polskich morskich brzegow klifowych (Historical outline of destruction of Polish cliff seashores). Materialy do monografii polskiego brzegu morskiego, vol. l, Gdansk-Poznan

Szot-Martychewicz M., 1977. Proba oceny aktualnej syluacji na odcinkach klifowych srodkowego wybrzeza (Approach to appraisal of the actual situation on cliff sections of the middle coast) . Pomorskie srodowisko przyrodniczejego ochrona i ksztaltowanie, vol. V, Slupsk

Zawadzka E., 1986: Zmiany nadbrzeza wydmowego na wybranych odcinkach polskiego wybrzeza Baltyku (Changes of the dune coast on the chosen sections of the Polish coast of the Baltic). Kwartalnik Geologiczny, vol.30, Warszawa

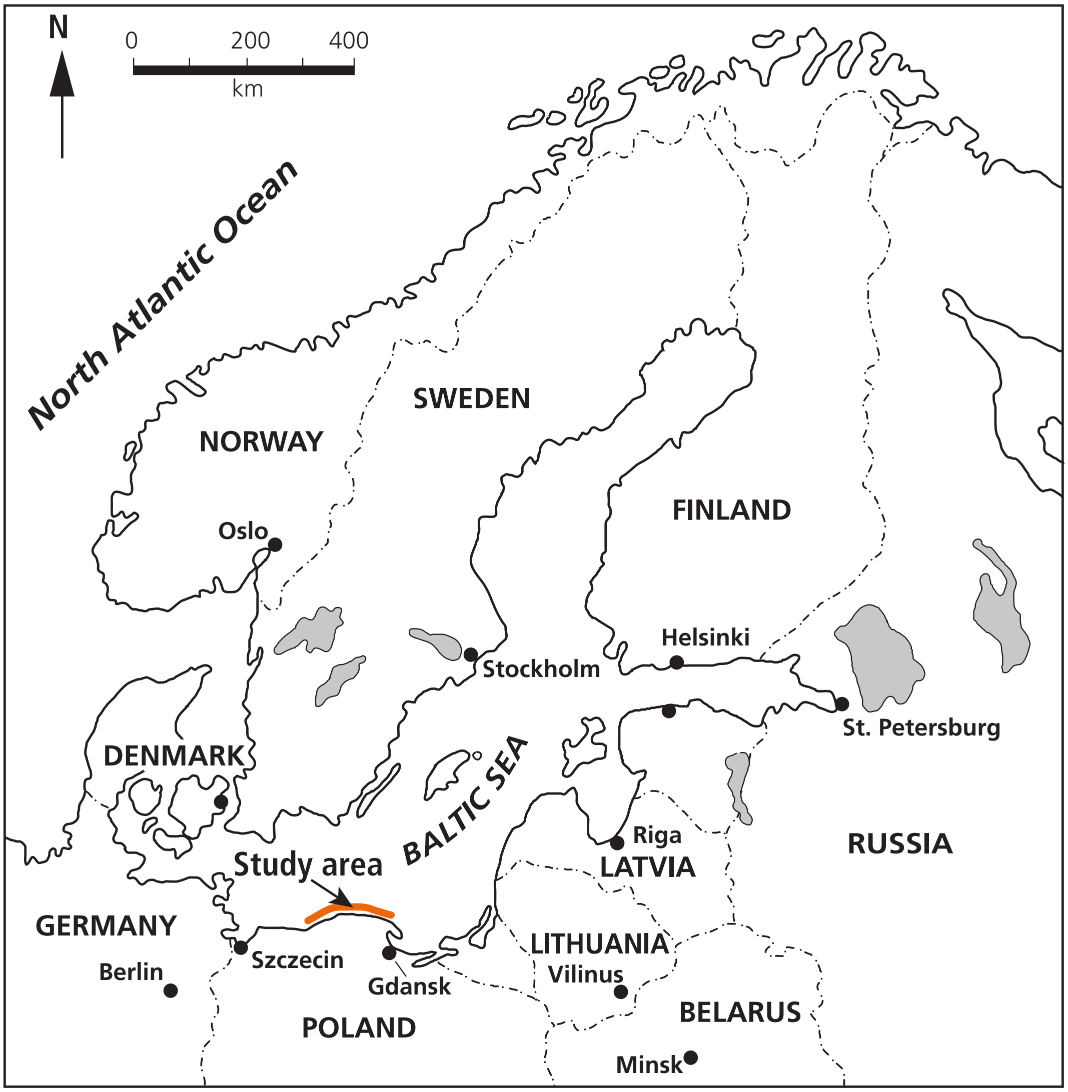

Fig. 1 Localization of the study area

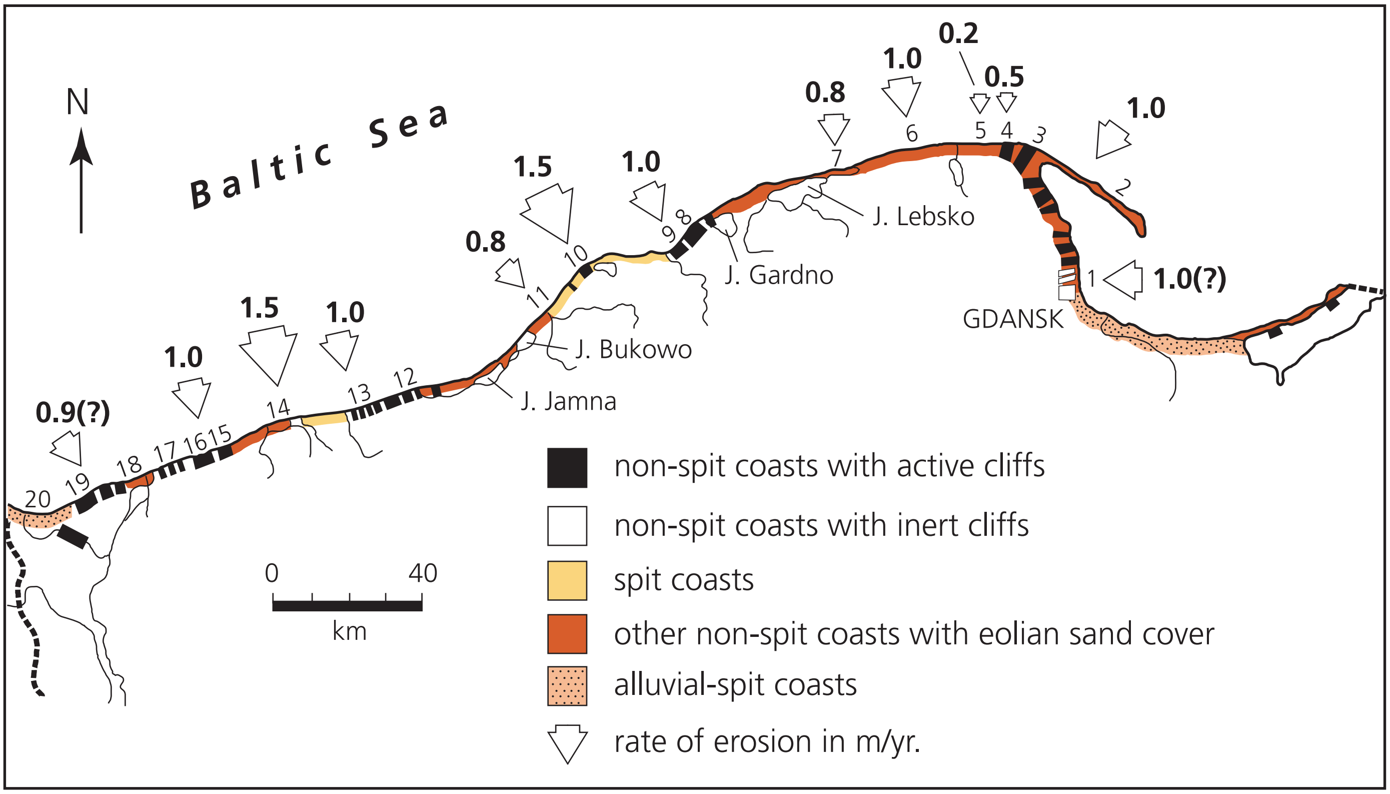

Fig. 2 Map of the Polish coastal erosion, simplified from (Cieslak and Subotowicz, 1987) and completed by the author in the coastal zone. Localities (5-10) central Polish Coast; (5) Karwia Spit; (6) Lubiatowo Spit; (7) Sarbsk Spit; (8) Debina Cliff; (9) Ustka Cliff; (10) Jaroslawiec Cape.

The Mahana, Kaluakapo, and Manele Ancient Shorelines, Lanai, Hawaii

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Harold Stearns described marine limestone at an elevation of 365 m on Lanai as evidence for the highest fossil shorelines in the state of Hawaii. He called this high stand of sea-level the Mahana Shoreline, a second shoreline at 190 m was given the name the Kaluakapo Shoreline, and a third shoreline at 170 m was given the name the Manele Bay Shoreline (Stearns, 1979). Moore and Moore (1984 and 1988) used the observations of Stearns that marine fossils were found at an elevation of 365 m., to suggest that giant tsunami waves ran up to an elevation of 365 m on the south coast of Lanai, despite the fact that Jim Moore (p. comm., 1997) never located marine deposits at this elevation. Several scientists (Moore & Moore, 1984 & 1988; Grigg and Jones, 1977; and Keating & Helsley, this paper) have searched for the Stearns type locality of the Mahana Shoreline and have not been able to locate fossil-bearing limestone. Instead, we observe abundant caliche vein-fillings in basalts (a precipitate formed in arid environments) at this elevation. Samples from these caliche exposures were collected and examined to determine if any fossils fragments might be present. The field studies described below clarify the nature of the Mahana, Kalauakapo and Manele Shorelines, provide no support for tsunami run-up to 365 m. elevation on southern Lanai island. These observations are significant, because the lack of marine deposits above 200 m., effectively halves the estimates of the elevation of the highest shorelines in the Hawaiian Islands, and halves the size of hypothesized "giant waves."

Field Observations

Puu Mahanalua, a volcanic cone, is accessed using a jeep trail to the summit. Panorama views of the Manele Bay area to the southwest and the Kaluakapo Crater to the southeast are obtained from this location, particularly the basin to the south, referred to as Kaluakapo Crater.

From Puu Mahanalua, access to Kaluakapo Crater is via jeep trail. Unfortunately the jeep road has been destroyed by erosion well-above the crater floor, thus it is necessary to proceed by foot, following the ridge line that intersects the eastern slope of Kaluakapo Crater. A series of rock descriptions were documented following this ridge line down to the elevation of 200 m (where a side trip into the interior of the crater is described), then traversing this ridge line within 200 m of the sea cliff, the route then detoured to the west descending the steep slope of the ridge west of Kaluakapo Crater to a gully-bottom eventually reaching the sea, east of the Manele Bay small-boat harbor.

Observations

In the vicinity of Puu Mahanalua and Kaluakapo Crater, at elevations from 365 to 200 m we found no deposits of fossiliferous limestone. The rocks were found to be thin bedded a'a lava flows, with weathering rinds. The slopes are covered with a'a lava flow fragments as would be expected from an area of extensive a'a flows on the arid leeward slopes of the Hawaiian islands (where rainfall is less than 25 cm/year). Caliches are commonly found as vein-fillings within the lava.

At an elevation of 190 m in the southwest portion of Kaluakapo Crater a boulder deposit was found associated with abundant corals. This platform is recognized as a remnant of a high-stand of the sea described by Stearns. Gravels exposed within gullies cut within the Kaluakapo basin floor at depths between 170 and 150 m are a mix of rock units derived from both sub aerial and marine settings.

Conclusions

Based on the field observations described here we conclude:

1) A Mahana high stand cannot be verified, we find no evidence for a high-level sea stand at any height above 200 meters.

2) The outcrops in the swale at 330 to 365 meters are not of marine origin but instead are fracture-filling caliches related to the faulting of the South rift zone of Lanai Volcano. There is abundant caliche in unoriented fractures below 200 meters both to the east of the so called crater, and in the vicinity of the resort.

3) Coral fragments are in situ up to about 190 meters and gray brown soils are also present in these areas. (This elevation corresponds to the Stearns' Kaluakapo Shoreline.)

4) Oxisols dominate the slopes between 438 to 200 m. elevation.

5) Evidence of the Stearns' (1979) Manele Shoreline (170 m) was observed indicating a period of high relative sea-level reached an elevation of at least 170 meters above present sea-level.

6) As to the giant wave hypothesis, no convincing evidence was found to invoking this hypothesis. The lack of marine deposits between 200 and 365 m. suggests that the sea-level responsible for fossil deposition is restricted to an elevation of less than 190 meters but higher than 180 meters since the small hill near the center of the crater lacks marine deposits on its summit.

7) We suggest the flat plain at 190 m elevation probably acted as a reentrant of the sea, at the Kaluakapo shoreline time. The presence of corals without accompanying shells may help to identify the facies, and depth of water these corals grew in. We interpret these deposits as evidence supporting Stearns contention that a period of long-standing sea-level was preserved at this site.

8) The presence of topographic highs at elevations of 190 m at Koala Gutch and at 140-150 m at Kapoho Gulch (3 km east) in southeastern Lanai leads us to suggest the topographic high grounds were carved by a high stand of sea-level. We speculate that the topographic highs at these elevations, provided a barrier to sediment transportation, trapping marine sediments and conglomerates, behind the topographic high. Following the lowering of sea-level, catchment basins for subaerially derived sediments and coarse debris have remained in place behind these topographic highs.

References

Athens, J. S., 1991, Archaeological Investigations at the Canoe Shed Complex of Hulopoe Bay, Lanai Site 85-40-98-85; Report tot he Lanai Co, Inc.: International Archaeological Research Institute.

Easton, W. H., 1965, New Pleistocene Shorelines in Hawaii: Geological Society of America, v. 61st Annual Meeting, p. 21 (abstract).

Grigg, R. W., and A. T. Jones, 1997, Uplift caused by lithospheric flexure in the Hawaiian Archipelago as revealed by elevated coral deposits: Marine geology, v. 141, p. 11-25.

Kaschko, M. W. a. A., J. S., 1987, Archaeology Inventory Survey of the Hulopoe Bay and Manele Bay Areas, Island of Lanai, Hawaii, pp. 1-161.: M& E Pacific, Inc.

Kascho, M. W., 1991, Archaeological Test Excavations and Site Mapping for the Manele Multi-family Residental Developement Area, Island of Lanai, Hawaii Report for M & E Pacific, Inc., pp 1-58.: International Archaeological Research Institute, Inc.

Keating, B. H. a. H., C. E., 1999, The Mahale and Manele Shorelines, Lanai, Hawaii: IGCP #437 Coastal Environmental Change during Sea-level highstands Conference, Honolulu, HI, v. Abstract volume, p. 1-4 (extended abstract).

Moore, G. W. a. M., J. G., 1988, Large scale bedforms in boulder gravel produced by giant waves in Hawaii: Geological Society of America, v. Special Paper 229, p. 101-110.

Moore, J. G. a. M., G. W., 1984, Deposit from a giant wave on the island of Lanai, Hawaii: Science, v. 226, p. 1312-1314.

Stearns, H. T., 1938, Ancient shorelines on the islands of Oahu and Maui, Hawaii: Geological Society of America Bull., v. 49, p. 615-628.

Stearns, H. T., 1978, Quaternary shorelines in the Hawaiian Islands: Bernice P. Bishop Mus. Bull., v. 237, p. 57.

Holocene reef growth on high-latitude south Pacific reefs

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Lord Howe Island (31° 30'S) in the Tasman Sea, and the atolls of Elizabeth (29° 59'S) and Middleton Reefs (29° 28'S) are the southernmost coral reefs in the Pacific occurring close to the latitudinal limits of reef development. They represent an island/seamount chain moving gradually north with the Australian plate into reef-forming seas and contain significant though contrasting accumulations of Holocene sediment.

On the western side of Lord Howe Island a discontinuous fringing reef 6 km long has developed. This reef encloses a shallow lagoon on average 2 m deep, extending up to 10 m in isolated depressions. Elizabeth Reef, 170 km to the north of Lord Howe Island, and Middleton Reef 30 km further north, are coral atolls over 20 km^2 in area. Islands are absent from the rim of these atolls. The reef forms an almost complete rim around each atoll with only one or two shallow channels occurring through the crest on the northern, leeward side.

Shallow rotary drilling and vibrocoring on these reefs suggests that their Holocene accretion histories were different. On Lord Howe detailed sampling has shown that reef and lagoon sedimentation was occurring by 6500 years BP, catching-up to sea-level. The maximum period of growth, however occurred between 5500 and 4000 years BP when the lagoon infilled, with a gravelly-mud, at an average rate of 5 mm/yr (maximum 10 mm/yr) but lagged behind sea-level. Sedimentation after 4000 years BP appears to be restricted as a result of infill of the available accommodation space, with the main sedimentation occurring as cemented rubble on the reef crest. On Elizabeth and Middleton Reef the crest appears to have caught-up to sea-level much earlier than Lord Howe between 6000 and 5000 years BP. The lagoonal sediments on Middleton Reef also differ from Lord Howe being dominated by sand.

The morphology of these reefs, especially Lord Howe Island, is determined primarily by a period of luxuriant growth in the mid-Holocene.

Mid-late Holocene epoch variance in coastal depositional morphologies in the N.W. Peloponnese, Greece

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The thirty km northerly coastal segment of the Gulf of Kiparrisia of the Ionian Sea in northwestern Peloponnese includes the delta of the Alpheios River, an adjacent barrier accretion plain and now drained broad shallow lagoons. About 8000 years before present (yr. BP.), this coastal zone was one of wave cut cliffs incised into uplifted Pliocene marine silts (marls) anchored to the NW by rocky Cape Katakolon (uplifted Pleistocene marine carbonates) and to the SE by the cliffs of the Samikon massif of Mesozoic limestone. Peak marine transgression occurred before 7500 yr. BP as evidenced by ^{14}C dates on lagoon fringing marsh organics that now lay seaward of the peak Holocene transgressive sea cliffs. The mid-Holocene wave incised cliffs most likely were reoccupied sea cliffs of previous sea-level highstands in Riss-Würm time (and maybe earlier). This uplifted coastal zone is thought to have risen at rates of 100 m
during the Quaternary Period.

Since the peak transgression of 8000 yr. BP, a broad lagoon-barrier accretion plain has prograded seaward with 3 distinctly separated barrier systems now extant and a forth barrier projected but not yet located. Coastal sedimentary environmental lithosomes including transgressive inner shelf marine sands, barrier accretion ridges, coastal lagoons (that varied from saline to brackish to fresh water), fringing marshes, foot-of-cliff colluvium, and the Alpheios River fluvial-deltaic sands and gravels are closely interrelated in 4 distinct progradational events. The first barrier-lagoons had formed by 7500 yr. BP in Mesolithic time. Dating of the 2nd, 3rd, and 4th prograding barrier-lagoons are relative only and the process of progradation may be continuing. These units are tentatively correlated with human impact/erosional events in the adjacent hinterlands at: 2nd barrier-lagoon system = circa 4500 yr. B.P. (Early Helladic); 3rd barrier- lagoon system = 3200-3400 yr. BP (early Mycenaean); and the 4th and perhaps still actively prograding barrier-lagoon system - from 2500 yr. BP to present. This more recent barrier system may be subdivided into 2-3 phases of progradation from Classical to present time. The dating of the latter 3 barrier lagoon systems may be correlated with the 3 distinct alluvial terraces inland along the Alpheios River and its tributaries (Hans-Jeorg, 1980).

With the rapid decrease in the rate of world sea-level rise starting about 7000 yr. BP (Or indeed the mid-Holocene highstand as posited by some), the coastal depositional landforms herein studied in part may have been impacted by fluctuating relative sea-levels. However, the availability of major supplies of coarse fraction sands (and lesser gravels) appears to be of greater import. Other workers have demonstrated major Holocene Epoch denudation events in the peninsulas of Greece and elsewhere in the Mediterranean; thus, we believe that people's impact has been of greater import in the evolution of the 4 mid-late Holocene coastal sedimentary/morphologic sequences in Elis, Greece than the alternative factors of eustacy, hydro-isostasy, tectonics or climatic change.

References

Streif, Hans-Jeorg, 1980, Geologic Map of Greece, 1:50,000. Pirgos Sheet. Athens: Institute of Geological and Mining Research.

Streif, Hans-Jeorg, 1982, Geological Map of Greece 1:50,000. Olympia Sheet. Athens. Institute of Geological and Mining Research.

Cyclone sedimentation in the central Great Barrier Reef Province during the Holocene sea-level highstand

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Introduction

Tropical cyclones are a common phenomenon in the Great Barrier Reef (GBR) region of NE Australia, and have been so throughout the Holocene sea-level highstand. Unfortunately, hydrodynamic data recorded on the shelf during cyclones are rare, and our understanding of the major mechanisms of cyclonic sediment transport is therefore relatively poor. We present data collected during Cyclone Joy from the inner shelf off Cairns, together with recent observations from the inner and middle continental shelf off Townsville, and discuss the range and likely causes of the sedimentary bedforms and deposits resulting from the passage of cyclones.

Cyclone Joy

In Dec. 1990 - Jan. 1991, Tropical Cyclone Joy produced off Cairns a 9-day period of along-shelf wind-driven currents, flowing to the NW (**Fig. 1**). This period included sustained current speeds of 60 cm/s and instantaneous speeds of up to 140 cm/s near the bed. Removal of the concurrent modelled weak tidal currents results in a calculated residual current speed of up to 130 cm/s.

The Coastline

Along the central GBR coastline, the primary sedimentary records of cyclonic activity are chenier ridges, preserved in the south of northward-facing embayments, emplaced by rapid coastal progradation between cyclones. At Cocoa Creek, south of Townsville, the molluscan assemblages present in the youngest (most seaward) chenier ridge have been documented, together with those of nearby environments. The molluscan contents of the cheniers are strongly related to that of the modern low intertidal mudflats, indicating that the ridges form through onshore transport of shelly material through the mangrove fringe and across the mangrove muds, rather than shells being derived from the mangrove itself.

The Inner Shelf

The inner shelf (0-20 m depth) carries a shore-connected terrigenous sediment wedge, much of which is comprised of muddy sands and sandy muds, bioturbated to depths of 15-20 cm. Graded beds, representing the unmixing and redeposition of these mixed sediments by cyclones, are rarely preserved. However, in places, gravelly sediments occur, representing reworking of underlying Pleistocene material and/or local calcareous reefal sediments. Seawards of Paluma Shoals reefs, north of Townsville, these sediments are formed into a series of 1-2 m high features, with spacings of 120-300 m, slopes of up to 3 degrees, and linear shore-normal crestlines mostly of length 1.5 km but up to 3 km. The bedforms include a series of decimetre-scale interbeds of muddy and clean gravel. These features are interpreted as large 2-D starved gravel dunes. Calculated bed shear stresses for a range of hydrodynamic conditions indicate that significant bedload transport probably occurs only during cyclones, in response to wind-driven (coast-parallel) water flows. Between cyclones, these features are probably degraded only slightly, even during periods of swell waves created by SE trade winds.

The Middle Shelf

Offshore, the muddy terrigenous sediment wedge downlaps onto a sediment-starved middle shelf surface (20-40 m) which is covered by <2 m of poorly sorted, shelly, muddy sand, representing storm sedimentation over many thousands of years. During cyclones, erosion of the muddy shelly sand results in unmixing, with mud being transported long-shelf in suspension, leaving fields of mobile bedforms of bioclastic sand-ribbons up to about 15 cm thick on the middle shelf. Near reefs, where sediment supply is greater, large and very large sand dunes are activated. There is some input of mud to the middle shelf, primarily from riverine input (from shoreward) and by resuspension from the main reef tract (from seaward). A single storm-bed comprises up to 20 cm of graded bioclastic sand which is usually overlain by a post-storm mud drape up to 1-2 cm thick. As normal weather conditions return, the epibenthos rapidly recolonises the mud-draped substrate, and begin to bioturbate and homogenise the sand-mud storm layer.

Cyclones appear to be the primary agent (and regionally, the sole agent) for bedload transport of sands and gravels. On the middle shelf (and probably also the inner shelf) the long-term net transport direction is shelf-parallel, to the NW, consistent with that expected from cyclonic wind-patterns.

Comments & Working Hypotheses

Cyclones are a major causative factor in coastal change, but reconstructions of cyclonic activity and it's effects since the Holocene highstand remain difficult to assess for the GBR province. The record of cyclones is generally patchy, cryptic and liable to repeated reworking. The deposits are also are greatly variable in their nature and preservation potential across the shelf. Both at the coast and on the shelf, those deposits of cyclones which do become incorporated into the sedimentary sequence may be biased towards representing all or part of those sediments accumulated at the fastest rates (presumably, but not necessarily, by larger cyclones). The deposits of medium-scale events are likely to be reworked by subsequent larger events, and so the geological record may be sharply divided between the high-magnitude low-frequency depositional/energetic events and low-magnitude high-frequency inter-cyclone accumulation.

Further, radiocarbon dates indicate that many embayments on the GBR inner shelf have few preserved deposits corresponding to the peak highstand. Accumulation appears to concentrated mostly, but not exclusively, in the period around 4000-3000 years BP, during a phase of relative sea-level fall. All embayments appear to have had significant variations in rates of Holocene and highstand sediment accumulation, and of coastal progradation. This has clear implications for the preservation potential of cyclone deposits, which are likely to be overprinted in periods when sediment accumulation is slow or absent. Removing the sedimentary signals of sea-level, coastal geomorphological change and sediment supply from those of cyclones remains difficult.

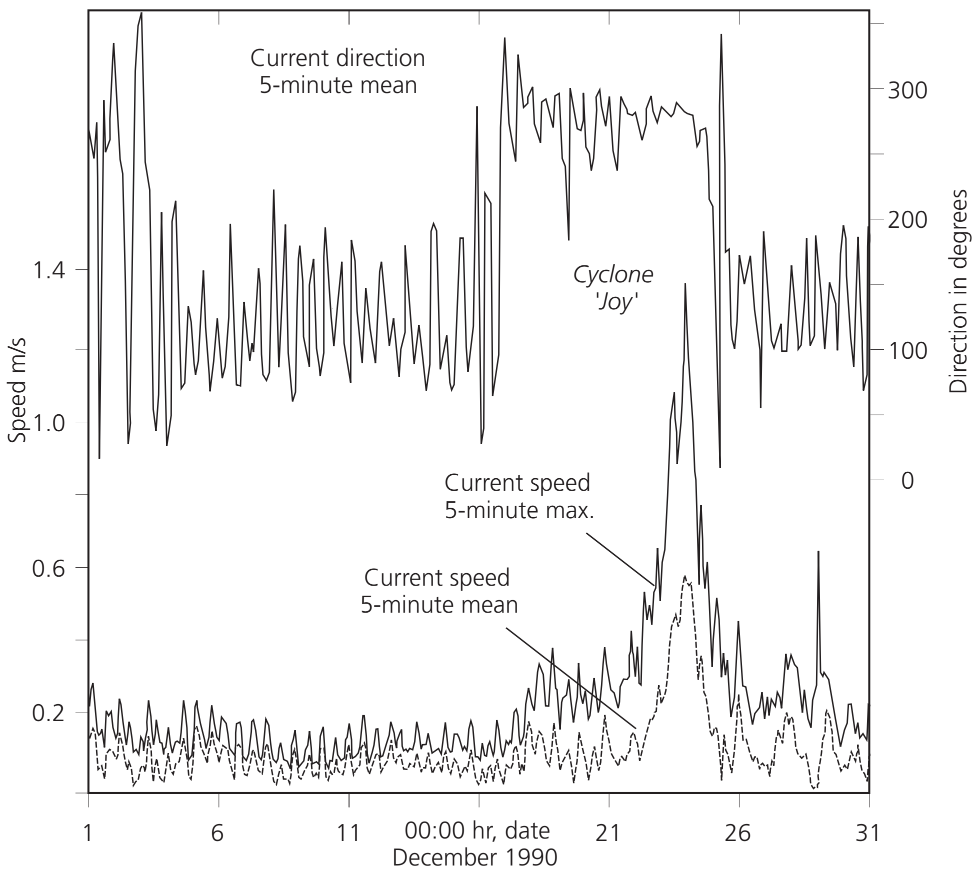

Fig. 1 Near-bed current speed and direction recorded in northern Trinity Bay, Cairns, in water depth of ~12 m, during the passage of Cyclone Joy, in late December 1990. Note that pre-cyclone current speeds rarely exceed 20 cm/s.

Late Quaternary sea-levels and shore platforms on a tectonically rising coastline, New Zealand

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The South Otago coastline, southeastern South Island, New Zealand, is tectonically rising, resulting in a flight of marine terraces and strandlines preserved up to 140m above present sea-level (**Fig. 1**). Uplift is controlled by reverse faults forming the leading edge of the continental collision plate boundary zone of South Island, New Zealand (**Fig. 1** inset).

Coastline morphology

The actively rising coastline stretches from near Dunedin city in the north, south to the mouth of the Clutha River (**Fig. 1**), the major source of sediment for the SE coast of the South Island. The shape of the coastline is sinuous with the convex middle section corresponding to the fastest rising segment.

Coastline morphology is strongly controlled by tectonics. The fastest rising segment is characteristically rocky, whereas slower rising and stable segments have flat shore platforms overlain by variable amounts of beach and dune sand. Furthermore, marine terraces are more numerous and closely spaced (both vertically and horizontally) on the fastest rising segment.

Marine terraces

Flights of up to eight marine terraces can be recognised along the coast, both Holocene and Pleistocene in age (see below). Exposures of the lowest terraces show shore platforms cut into Mesozoic bedrock, overlain by beach sands locally up to 5m thick. These are in turn overlain by variable thicknesses of bedded dune sands, alluvial deposits and loess. Raised beach sands are lacking in shells, and are generally well bedded on a centimetre scale. They range in grainsize from fine to granule. Stringers of coarser pebble layers also locally occur. Dune sand and alluvial deposits on the terraces thicken towards major river mouths, the latter reaching up to 20m near Clutha River mouth. Loess thickness is variable and may in fact have been substantially eroded off the higher terraces.

Tectonic uplift of marine terraces

One major feature of the South Otago coast is that it is disrupted by a shore-parallel Holocene-active reverse fault, the Akatore Fault (**Fig. 1**). The fault has both onshore and offshore traces and is upthrown on the SE side, resulting in the seaward, convex, rocky portion of the coast mentioned above.

Holocene Terraces

Two Holocene terraces are restricted to the Akatore block. The lowest, 3m above high sea-level (a.h.s.l.), is a well preserved rock bench overlain by small pockets of beach sands where cut into schist and a wide raised beach where cut into softer Cretaceous sediments. The upper (6m a.h.s.l) is represented by isolated rock bench remnants.

Uplift age of the 3m terrace is bracketed by two ^{14}C dates; a shell within the raised beach (1420 to 1310 yrs B.P.) and organic material overlying the raised beach sands (1065 to 975 yrs B.P.) (**Fig. 2**). Paleoseismological studies along the onshore Akatore Fault trace tightly constrain timing of two late Holocene uplift events at 1.1 and post 3.8ka. The 1.1ka event corresponds to the uplift age of the 3m terrace and hence the post 3.8ka uplift event is correlated to the uplift of the 6m terrace.

Sea level in New Zealand reached its present height at 7ka (Gibb 1986), stabilising at ~3.2ka (Thomas, 1998). A 1.9m transgression between 5 and 3.2ka (Thomas, 1998) is not high enough to have been the sole cause of cutting the 6m terrace. Therefore terrace heights indicate two 3m uplift events on the Akatore Fault post 3.8ka.

Pleistocene Terraces

Flights of higher terraces along the coastline also indicate differential uplift by their change in spacing and number across the Akatore Fault (Figs. **1**, **3**). The presence of terraces on both sides of the fault means that if terrace ages can be constrained, then the Quaternary sea-level curve can be used to measure values of absolute uplift of both the upthrown and "downthrown" sides of the fault.

The presence of loess covering all terraces except the (Holocene) 3 and 6m terraces indicates the higher terraces are all Pleistocene in age. Relatively slow long term regional uplift rates (maximum 1mm/yr, Berryman & Beanland, 1991) suggest the terraces are most likely to have been cut during interglacial highstands.

Optical and thermoluminescence dating of cover beds on the lowest Pleistocene terrace on both sides of the fault is currently in progress. Available luminescence dates indicate terrace cutting during the last interglacial period, most suggesting a 100ka or 80ka highstand age, rather than the 125ka highstand age previously assumed. There is disagreement between some of the dates however, and two OSL dates from 2 to 6m high terraces to the north, a region considered to be tectonically stable, also give 100ka highstand ages.

Possible models of terrace correlation and ages are presented, based on various interpretations of the luminescence ages and of post-125ka sea-levels. Failure to recognise an obvious 125ka highstand terrace in the area poses a serious problem. Implications of the preferred model(s) are (a) tectonic uplift rates have been variable through the late Pleistocene - Holocene, (b) localised terrace erosion has occurred, and (c) either (i) the entire coastline has undergone substantial regional uplift since 80ka, for which there is little independent evidence, or (ii) sea-level was actually much closer to, or higher than present at 80ka, as has been suggested by a number of workers recently (eg. Vacher & Hearty, 1989; Ludwig et al., 1996).

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References

Berryman, K. and Beanland, S., 1991. Variation in fault behaviour in different tectonic provinces of New Zealand. Journal of Structural Geology 13:177-189

Gibb, J.G., 1986. A New Zealand regional Holocene eustatic sea-level curve and its application to determination of vertical tectonic movements. In: Recent crustal movements of the Pacific Region. Royal Society of New Zealand Bulletin 24:377-395.

Ludwig, K.R., Muhs, D.R., Simmons, K.R., Halley R.B. and Shinn, E.A., 1996. Sea-level records at ~80 ka from tectonically stable platforms: Florida and Bermuda. Geology 24:211-214.

Thomas, D., 1998. Late Holocene radiocarbon ages from Blueskin Bay estuary: relevance to local eustatic sea-level during the last 7000 years. Geological Society of New Zealand, New Zealand Geophysical Society 1998 joint annual conference programme and abstracts. Geological Society of New Zealand Miscellaneous Publication 101A, p226..

Vacher, H.L. and Hearty, P., 1989. History of stage 5a sea-level in Bermuda: review with new evidence of a brief rise to present sea-level during substage 5a. Quaternary Science Reviews 8:159-168.

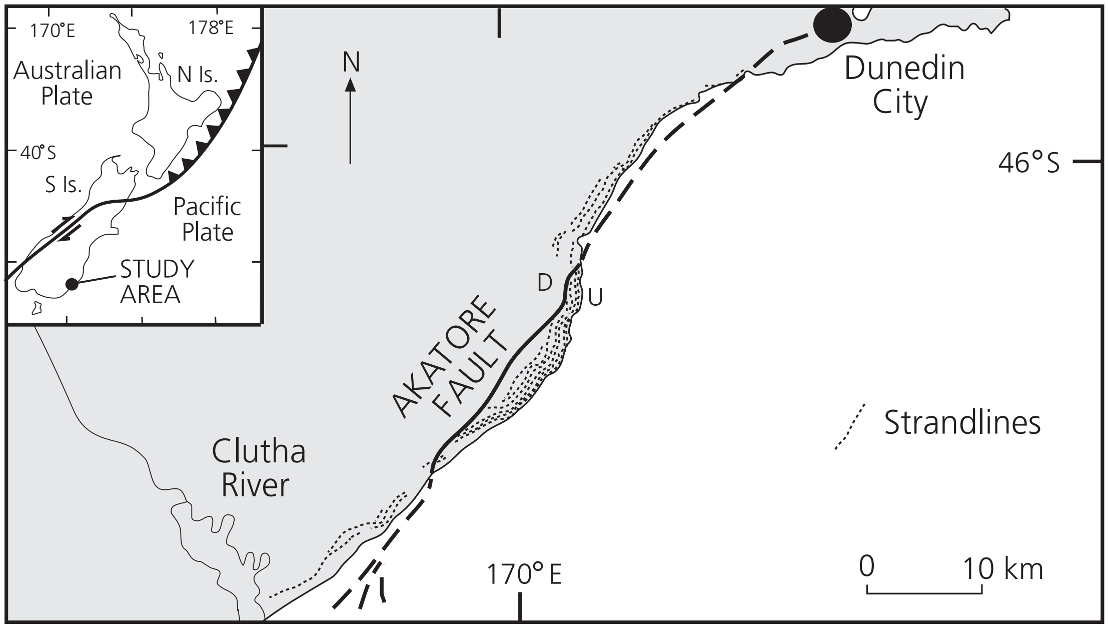

Fig. 1 Late Quaternary strandlines in the south Otago coastal area. Inset: New Zealand plate tectonic setting

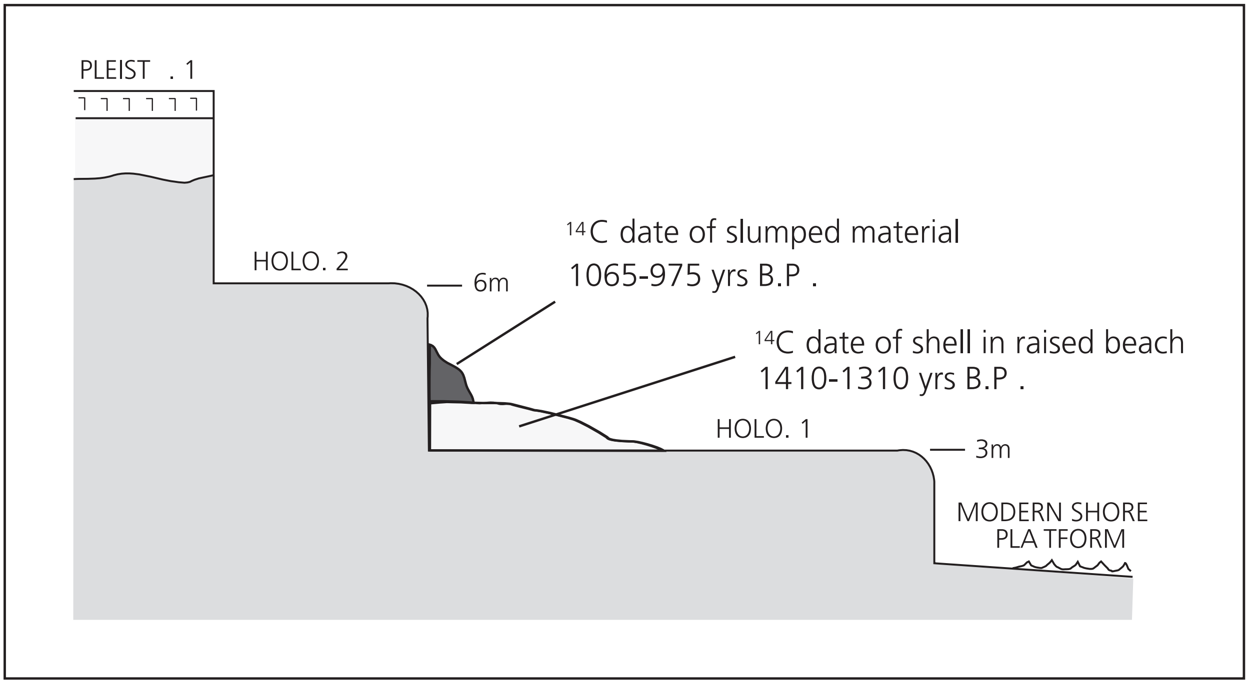

Fig. 2 Schematic section of Holocene marine terraces and radiocarbon dates on Akatore block

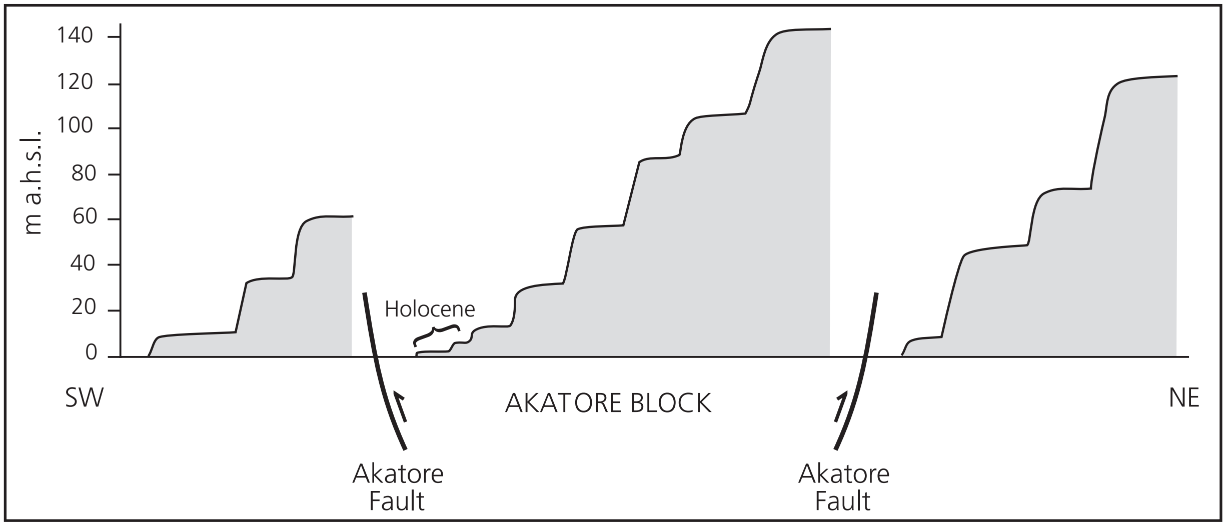

Fig. 3 Summary of marine terraces along the south Otago coast. All Pleistocene terrace heights include loess cover. Horizontal axis not to scale

Coastal re-organization north of Bering Strait during the Early Medieval Glacial Episode, AD 750-1150

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The sensitivity of arctic coasts to Global Change is postulated by many researchers. Tectonically stable, unglaciated NW Alaska coasts are an ideal laboratory to document eustatic sea-level and transient storm related changes. Barrier islands, deltas and spits along the Chukchi Sea yield data to reconstruct sea-level and climate for the last 6000 years. Calibrated ^{14}C ages (n=>275) constrain the record, derived from archaeological sites, storm and dune facies within beach ridges and salt marsh peats graded to sea-level. These data indicate a slow rate of sea-level rise of only 1.5m since 3500 cal BC, ca. 0.3 mm yr^{-1} suggesting that the Chukchi Sea is not sensitive to eustatic fluctuations (Jordan and Mason n.d.). Erosional truncations and dune growth occurred during cold climates (Mason and Jordan 1993), synchronously with worldwide glacial expansions (O'Brien et al. 1995), especially the Little Ice Age. This synchronicity, evident in 20th century newspapers from Nome (Mason et al. 1996), is a caution for the view that anthropogenic global change will heighten storminess along the Arctic Ocean.

Several depositional environments within dunes capping barrier islands, spit and forelands document coastal evolution along the northwest Alaska coast (following van de Plassche 1986 and Roep 1986, cf. Mason and Jordan 1993, Mason et al. 1997): (a) detrital grasses and storm-deposited driftwood and/or shell beds; (b) inter-stratified house floors and activity areas from prehistoric occupations, often (c) within buried soil horizons. These data are referenced to paleo-sea-level estimated from transgressed terrestrial and marsh peats within deltas, lagoon margins and exposed on modern beaches (Jordan and Mason n.d.). Field research, mostly on Seward Peninsula from 1986-1996, involved stratigraphic profiling of exposed cutbanks and shallow coring, using radiocarbon ages to establish the chronology; which is extended by dates from the literature. Roughly 15% of the ages relate to the time period in question. Beach ridges are mapped from aerial photographs (1:30,000), using the geomorphic criteria, e.g., the spacing and superposition of ridges, including unconformable or disconformable relationships, and blowout, thaw lake and soil development sequences. Pedogenic development within dunes, indicative of surface stability, also provides proxy data on coastal evolution.

Kotzebue Sound and Seward Peninsula are moderately seismogenically active, part of the Brooks Range province (Thenhaus et al., 1982). Seismic activity is sporadic in the Chukchi Sea, 6.4 magnitude quake occurred off Chukotka >300 km NW of Cape Espenberg (Fujita et al., 1991). No co-seismic elevation changes are reported, as evident in the consistent <10 m ASL elevation of 125,000 yr old shorelines from Isotope Stage 5e (Brigham-Grette and Hopkins 1995). The low coastal hills did not support glaciation during the late Pleistocene or Holocene; no isostatic factors need be considered.

The microtidal (<0.5m) north-facing Chukchi Sea is a 1000 km long embayment of the Arctic Ocean, located north of the Bering Strait, 65° N. latitude (Naidu and Gardner 1988). The south-facing Bering Sea is a compartment of the North Pacific. Although ice-covered from usually from late October to late June, Chukchi and Bering Sea coasts are wave-dominated and often subjected to Fall storm surges that reach several meters ASL (Wise et al. 1981). Due to combination of low tide range and abundant, mobile clastic material (both terrestrial and shelf), the coasts are sensitive proxies for atmospheric processes.

Fourteen of >20 northwest Alaska beach ridge complexes north of the Yukon River contain temporal data useful in establishing geomorphic history and storm frequency. Complexes vary in orientation and in number of ridges; cumulatively, at least 489 ridges can be enumerated, a mean of c. 33, within a range of 5 to 114. Higher numbers of ridges are preserved on many coasts due to a succession of lower intensity storms or during intervals with long recurrence intervals between storms. The highest number of ridges occurs at Cape Krusenstern, with at least 114 ridges preserved, not including composite ridges and lake-marginal ridges. Point Spencer contains >100 ridges but lacks any dating. Next-highest, Sisualik has c. 70 ridges while Cape Espenberg has 35 ridges which includes at least six composite dunes. Ridge addition reflects fetch and storm duration; circumstances also affected by the percentage of ice cover. Locations with multiple orientations have higher number of ridges, e.g., Cape Krusenstern. Predictably, the maximal number of ridges occurs in the middle stretches of the Chukchi Sea, not at the margins that are subject to variable (e.g. increased) ice conditions or limited fetch.

Of the total of 275 ^{14}C ages (cf. Mason and Ludwig 1990; Mason and Jordan 1993, Mason et al. 1997) that constrain the late Holocene depositional history of western and northwestern Alaska beach ridges, only 34.5% (n=95) were collected specifically with geological considerations. Archaeological samples comprise the overwhelming majority of the dates and provide only upper limiting ages, e.g., at the St. Lawrence Island cemetery and houses and the Cape Krusenstern houses employed by Mason and Ludwig (1990). All ages were dendro-calibrated to calendar years to adjust for ^{14}C variability following Stuiver et al. (1998), applying a 510±57 yr (Dumond, 1998) offset to shell ages, to account for the ingestion of older marine carbon. Ages are reported in two sigma ranges, using probability distribution to refine age determinations; cited as cal BC or cal AD. Approximately 35 ^{14}C ages bracket coastal changes in the late 1st millennium AD.

Nearly all beach ridge chronologies from the Yukon River delta to Point Barrow were subject to erosional truncation that produced disconformable ridges between cal AD 800-1150, due to a major shift in storm frequency and direction that caused substantial erosion and sediment re-mobilization along the Chukchi Sea (Mason and Jordan 1993, Mason et al. 1995, 1997). Storms produced substantial changes in the Little Ice Age, as well. At the south, the Yukon River witnessed a major avulsion and the creation of a new delta lobe after cal AD 700-1000 (Mason and Dupré 1998.) while several storm ridges were added to the south. Storm facies dated to the 1st millennium AD also occur on the Bering Sea shelf (Mason and Jordan 1993).

The fullest records of coastal evolution are from Capes Espenberg and Krusenstern on both north and south shores of Kotzebue Sound. Both north and south coasts experienced net erosion during the late 1st millennium AD. However, on the southern coast, Seward Peninsula from Wales to Espenberg, sand transported higher onto the back beach was incorporated into dunes by persistent high onshore winds during fall and winter. Within decades from cal AD 900-1100, high dunes had built along the entire northwest Seward Peninsula coast (Jordan 1990). Contemporaneously, storms cut inlet numerous channels through the Shishmaref barrier islands. Composite gravel ridges built along north-facing coasts at Point Barrow, Cape Krusenstern at Kotzebue and on Choris Peninsula (Mason and Jordan 1993) with archaeological stratigraphic evidence of powerful storms affecting north-facing coasts on St. Lawrence Island (Mason and Ludwig 1990) and southern Kotzebue Sound from Deering (Reanier et al. 1998) to Kotzebue. Soil development indicative of surface stabilization reflects decreased storm activity in the 13th century AD (Mason et al. 1997).

Cape Espenberg, the depositional sink for northern Seward Peninsula littoral cell, experienced 4 to 6 m of vertical dune growth landward of eroding beaches (cf. Psuty 1988) atop older, low dunes separated by wide swales, formed during AD 200-750 when storms were less frequent and of less magnitude. Two episodes of intense storms are recorded at Espenberg by shell beds (>1-1.5 m above MHW) dated to cal AD 750-950 and cal AD 1050-1150; but are separated by a non-stormy interval of dune stabilization and soil formation between cal AD 950-1050. Most dune building from cal AD 750-1150 reflects high onshore sand supply under the influence of North Pacific-derived storms that produced oblique waves that favored alongshore sand transport, unlike earlier stormy episodes in the Neoglacial, 1600-1200 cal BC (Mason and Jordan 1993) that produced little or no progradation due to mostly onshore waves.

South-facing Cape Krusenstern, opposite Cape Espenberg on Lisburne Peninsula, expanded partially by cannibalizing older ridges, as evident in the repeated southeastward displacement of clasts after major truncations (Mason and Ludwig, 1990). Storm erosion at Cape Krusenstern involved several responses. First, high intensity northwesterly storms truncated earlier ridges on its northwest margin between cal AD 750-950, and produced a high composite gravel ridge cal AD 1050-1200. The intervening century, cal AD 950-1050, witnessed the transport of sand, pebbles and cobbles, and the addition of several ridges to the southwest edge of the beach ridge complex. The poorly dated Sisualik spit, down drift about 50 km from Cape Krusenstern. probably also experienced a combination of erosion and southeastward progradation between cal AD 750-1150. A partially inverse relationship prevailed between the northern Seward and southern Lisburne Peninsulas. Differences in storm trajectories (variability in direction and duration) probably explain such responses; while northwesterly storms predominated between AD 700 and 900, recovery during fair weather periods allowed progradation to the southeast.

Comparisons with other regions shows numerous correlations with heightened storminess in northwest Alaska. The early Medieval period of coastal reorganization in northwest Alaska co-occurs with evidence of colder temperatures, hemispheric wide. Heightened storms co-occurs, and are perhaps correlative, with increased precipitation producing Brooks Range glacial expansion (Ellis and Calkin 1984) and wider Alaska tree-rings (Graumlich and King 1997), the development of a massive chenier ridge in north China (Wang and Ke 1989) and Yang-tze and Huang Ho flood records (Gong and Hameed 1991) as well as North Atlantic glacial expansions (Grove and Switsur 1994), and Greenland ice cores (Dansgaard et al. 1975, O'Brien et al. 1995).

References

Brigham-Grette, J., and Hopkins, D. M., 1995. Emergent marine record and paleoclimate of the last interglaciation along the northwestern Alaskan coast. *Quaternary Research* 43, 159-173.

Dansgaard, W., Johnsen, S. J., Reeh, N., Gundestrup, N., Clausen, H. B., and Hammer, C.U., 1975. Climatic changes,Norsemen and modern man. *Nature* 255, 24-28.

Dumond, D. E., 1998. The Hillside Site, St. Lawrence Island, Alaska: An examination of collections from the 1930s*.* *University of Oregon Anthropological Papers* 55.

Ellis, J. M. and Calkin, P. E., 1984. Chronology of Holocene glaciation, central Brooks Range, Alaska. *Geological Society of America Bulletin* 95, 897-912.

Fujita, K. Cook,D. B., Hasegawa, H., Forsyth, D. And Wetmiller, R., 1990. Seismicity and focal mechanisms of the arctic region and the North American plate boundary in Asia. *In:* Grantz, A., Johnson, L. and Sweeney, J. F. *The Geology of North America,* volume L: *The Arctic Ocean Region*, Boulder: Geological Society of America, pp. 79-100.

Gong, G. and Hameed, S., 1991. The variation of moisture conditions in China during the last 2000 years. *International Journal of Climatology* 11, 271-283.

Graumlich, L. and King, J. C., 1998. Late Holocene climatic variation in northwestern Alaska as reconstructed from tree rings. Abstracts, 25th Annual Meeting, Alaska Anthropological Association, p. 12.

Grove, J.M. and Switsur, R., 1994. Glacial geological evidence for the Medieval Warm Period. *Climatic Change* 26, 143-169.

Hopkins, D. M., 1967. Quaternary marine transgressions in Alaska. *In:* Hopkins, D.M., ed., *The Bering Land Bridge*: Menlo Park, Stanford University Press, p. 47-90.

Jordan, J. W., 1990. Late Holocene evolution of barrier islands in the southern Chukchi Sea, Alaska. Master's Thesis, Quaternary Sciences, University of Alaska, Fairbanks.

Jordan, J. W. and Mason, O. K., n.d. A 5000 yr record of intertidal peat stratigraphy and sea-level rise from northwest Alaska. *Quaternary International*, in press.

Mason, O. K., and Dupré, W.R., 1998. Was the Yukon delta uninhabitable until 3000 years ago? The interplay of Neoglacial storms, Yukon River and sea-level changes. Abstract, 26th Annual meeting, Alaska Anthropological Association, Fairbanks.

Mason, O. K. and Jordan, J. W., 1993. Heightened north pacific storminess and synchronous late Holocene erosion of northwest Alaska beach ridge complexes. *Quaternary Research* 40, 55-69.

Mason, O. K., Jordan, J. W., and Plug, L., 1995. Late Holocene storm and sea-level history in the Chukchi Sea. *Journal of Coastal Research*, Spec. Issue 17, 173-180.

Mason, O.K., Hopkins, D. M. and Plug, L., 1997. Chronology and paleoclimate of storm-induced erosion and episodic dune growth across Cape Espenberg spit, Alaska, U.S.A., *Journal of Coastal Research* 13(3), 770-797.

Mason, O. K. and Ludwig, S. L., 1990. Resurrecting beach ridge archaeology: Parallel depositional histories from St. Lawrence Island and Cape Krusenstern, Alaska. *Geoarchaeology* 5, 349-373.

Mason, O.K., Salmon, D. K. and Ludwig, S.L., 1996. The periodicity of storm surges in the Bering Sea region from 1898 to 1993, based on newspaper accounts. *Climatic Change* 34, 109-123.

Naidu, A. S. and Gardner, G., 1988. Marine geology. *In:* Hameedi, M. J. and Naidu, A.S. (eds.), *The Environment and Resources of the southeastern Chukchi Sea*, Outer Continental Shelf, Mineral Management Study 87-0113 pp. 11-28.

O'Brien, S.R., Mayewski, P. A., Meeker, L. D., Meese, D.A., Twickler, M.S., and Whitlow, S.I., 1995. Complexity of Holocene climate as reconstructed from a Greenland ice core. *Science* 270, 1962-1964.

Psuty, N.P., 1988. Sediment budget and dune/beach interaction. *Journal of Coastal Research*, Special Issue 3, 1-4.

Reanier, R. E., Sheehan, G. W., and Jensen, A. M., 1998. Report of 1997 Field Discoveries, City of Deering Village Safe Water Cultural Resources Project. Unpublished Report, Ukpeagvik Inupiat Corporation (UIC) Real Estate, Science Division, Barrow.

Roep, T.B. 1986. Sea-level markers in coastal barrier sands: examples from the North Sea coast. *In:* Van de Plassche, O. (ed.), *Sea Level Research: A Manual for the Collection and Evaluation of Data*, Norwich: Geo Books, pp. 97-128.

Stuiver, M., Reimer, P. J., Bard, E., Beck, J. W. Burr, G. S., Hughen, K. A., Kromer, B., McCormac, G., Van Der Plicht, J. and Spurk, M. 1998. IntCal98 radiocarbon age calibration, 24,000–0 cal bp. *Radiocarbon* 40(3), 1041-1084.

Thenhaus, P.C., Ziony, J.I., Diment, W.H., Hopper, M.G., Perkins, D.M., Hanson, S.L. and Aigermissen, S.T. 1982. Probabilistic estimates of maximum seismic horizontal ground motion on rock in Alaska and the adjacent Outer Continental Shelf. *In:* U.S. Geological Survey in Alaska: Accomplishments during 1980, U. *S. Geological Survey Circular* 844, pp. 5-8.

Wang Y., and Ke X. 1989. Cheniers on the east coastal plain of China. *Marine Geology* 90, 321-335.

Wise, J. L., Comiskey, A. L. and Becker, R. 1981. *Storm Surge Climatology and Forecasting in Alaska*. Arctic Environmental Information and Data Center, Anchorage.

Sea-level changes and coastal dune development in Apulia (Southern Italy)

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The coastal area of southern Apulia is marked by the occurrence of Holocene dune belts. A detailed study of these landforms has been carried out aiming to the reconstruction of Apulian coastal recent evolution. The morphological and stratigraphical data along with archaeological evidences and several radiocarbon determinations carried on pulmonate gastropods point out three phases of dune belt formation occurred about 6.000, 2.500 and 700 years B.P.

The oldest aeolian unit is composed by grey bioclastic sands, partly cemented and showing well-developed cross-stratification. Along the Adriatic coast, at T.Canne locality this unit rests on red soil retaining Neolithic pottery and fireplace remains; these last ones yielded a radiometric age of 6900±90 years B.P. (Coppola & Costantini, 1987). At Rosa Marina locality dune deposits have been dated about 5290±120 by means of an AMS radiocarbon determination. The contact with the related beach deposits is placed at about 1 meter above m.s.l.. Other two radiocarbon age determinations carried out on pulmunate gastropods yielded ages of 6084±52 and 5290±120 years B.P. (**Table 1**).

Dunes belonging to this first unit are widespread also along the Ionian coast of southern Apulia. Numerous age determinations have been performed by means of radiocarbon and isoleucine racemization methods (Cotecchia et al., 1969; Dai Pra & Hearty, 1989; Hearty & Dai Pra, 1992) (**Table 2**).

The whole of stratigraphical, morphological and chronological data points out that this first Holocene aeolian unit formed without breaks in a short span of time from about 6500 to about 5000 years B.P..

The second unit is made by brownish, loose sands marked by thin, discontinuous layers of soil and retaining archaeological remains of Greek and Roman age. It is recognisable along long stretches of southern Apulia coast. Samples of *Helix* sp. collected along the Adriatic coast at Torre Canne and at Fosso Pantore localities yielded a radiometric age of 2110±90 years B.P. (Magri & Zezza, 1970) and 2910±80 years B.P., respectively. Along the Ionian coast, *Helix* sp. specimens coming from this unit show ages from 3360±95 and 1995±95 B.P. (Cotecchia et al., 1969).

Finally, in some localities (Torre Santa Sabina, Laghi Alimini, Torre Castiglione) thin deposits of grey aeolian sands marked by soil levels, *Pomatia* sp. and medieval remains have been recognised. Radiometric age determination yielded an age of 565±80 years B.P. along the Adriatic coast and of 865±90 B.P. along the Ionian one.

The presence of relict Holocene dune belts in southern Apulia allow the reconstruction of coastal changes during the last millennia.

The first aeolian unit formed along numerous coastal tracts during the Holocene Climatic Optimum when wide beaches nourished a dune belt without breaks as the lack of soil level testifies. Dunes mark the maximum position reached by the Holocene transgression at about 1-2 m present sea-level.

The regressive phase which followed the mid-Holocene high stand occurred about 2500 years B.P. and was characterised by sea-level about 3-4 m below its present position as numerous archaeological evidences occurring along southern Apulia coast suggest (Vlora, 1975; Di Ceglie, 1981; Coppola, 1977; Mastronuzzi et al.1994) It was responsible for the partial cementation and preservation of mid-Holocene dune belt and for the development of the second aeolian unit which was characterised by numerous breaks of deposition as the presence of numerous soil layers suggests.

The last phase of dune belt formation occurred in medieval times when beaches shown active progradation probably because human activity. At present, the last sea-level rise is accompanied by a strong erosion of beaches with development of cliffs cut in the Holocene aeolian deposits.

References

Coppola, D. & Costantini, L., 1987. Le néolitique ancien littoral et la diffusion des céréales dans le Poulles durant le VI millénaire: les sites de Fontanelle, Torre Canne ed de Le Macchie. Premiéres Communantés Paysannes en Méditerraneé Occidentale. Colloque du CNRS, Montpellier 1983, 249-253

Coppola, D., 1977. Civiltà antiche nel territorio di T.Santa Sabina (Carovigno, Brindisi).Ricostruzione topografica ed avvicendamenti culturali. Ricerche e Studi, 10, 47-110

Cotecchia, V., Dai Pra, G. & Magri, G., 1969. Oscillazioni tirreniane e oloceniche del livello del mare nel Golfo di Taranto, corredate da datazioni con il metodo del radiocarbonio. Geol.Appl. e Idrogeol., 4, 93-148

Dai Pra, G. & Hearty, P .J., 1989. Variazioni del livello del mare sulla costa ionica salentina durante l'Olocene. Epimerizzazione dell'isoleucina in *Helix* sp.. Mem.Soc.Geol.It, 42, 311-322

Dini, M., Mastronuzzi, G. & Sansò, P. 1999. Relative Holocene sea-level changes in southern Apulia, Italy, *in* Slaymaker O. (ed): Geomorphology and Human Activity: Their Role in Global Environmental Change. John Wiley & Sons, Ltd.

Di Ceglie, S., 1981. Gnathia.Forma della città delineata mediante la prospezione archeologica. Lab.Centro Aereofot., Facoltà di Lettere, Università di Bari

Hearty, P. J. & Dai Pra, G., 1992.The age and stratigraphy of Middle Pleistocene and younger deposits along the Gulf of Taranto. Journ.Coastal research, 8 (4), 882-905

Magri, G. & Zezza, F., 1970. I depositi dunari della costa adriatica tra Monopoli (Bari) e Torre Santa Sabina (Brindisi) in rapporto alle oscillazioni del livello marino. Geol.Appl.Idrogeol., 5, 49-54

Mastronuzzi, G., Palmentola, G. & Sansò, P., 1994. Le tracce di alcune variazioni del livello del mare olocenico tra Torre dell'Orso e Otranto (Lecce). Geogr. Fis. Din. Quat., 17, 55-60

Vlora, N. R., 1975. Considerazioni sulle variazioni della linea di costa tra Monopoli (Bari) ed Egnazia (Brindisi). Ist.Geogr.Univ.Studi di Bari, 2, 1-62

Table 1

Locality	Description	^{14}C age (yrs B.P.)
Torre Canne (a)	*Helix* sp.	2110±90
Torre Canne (b)	Fireplace remains	6900±90
Torre S. Leonardo - TSL6	*Helix* sp.	6185±90
Rosa Marina - RMD	*Helix* sp.	6084±52
Fosso Pantore - P17	*Helix* sp.	2910±50
Torre Santa Sabina - SSB3	*Helix* sp.	565±80
Torre Santa Sabina - SSB2	*Helix* sp.	5290±120

Table 2

Locality	Description	^{14}C age (yrs B.P.)	Alle/Ille Ratio	Inferred age	Aminozone
Torre Marinella	*Helix* sp.	3360±95			
Torre San Vito - LB1	*Helix* sp.	6386±70			
Torre Zozzoli	Coal	3910±110			
"	*Helix* sp.	5360±115			
"	*Helix* sp.		0.12±0.02	~4000	A
"	*Helix* sp.		0.10±0.01	~3900	A
"	*Helix* sp.		0.14±0.01	~5000	A
"	*Helix* sp.		0.14±0.01	~5000	A
"	*Helix* sp.		0.17	~6000	A?
Torre Ovo	*Helix* sp.		0.07±0.03	~2500	A
Torre Borraco	*Helix* sp.		0.025±0.006	~2000	A
"	*Helix* sp.		0.026±0.001	~2100	A
"	*Helix* sp.		0.15±0.01	~5300	A
Torre Castiglione	*Helix* sp.	1995±95			
"	*Helix* sp.	865±90			
Punta Prosciutto	*Helix* sp.	2160±100			
Torre Sabea	*Helix* sp.		0.15±0.03	~5300	A
Posto Li Sorci	*Helix* sp.	6780±125			
"	*Helix* sp.		0.15±0.03	~5300	A
Torre SanGiovanni	*Helix* sp.		0.18±0.01	~6700	A
"	*Helix* sp.		0.17±0.01	~6000	A

Eustatic sea-level and climate changes over the last 600 ka as derived from mollusc-based ESR-chronostratigraphy and pollen evidence in the Eurasian North

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It is generally agreed that the oxygen isotope record is associated with both global ice volume and sea-level. In the first approximation it may be used as a tool for global correlation (Shackleton, 1967). Up to now pollen analytical investigations have dominated in the studies of Upper Cenozoic terrestrial sections in Northern Eurasia, including the most complete sedimentary deposits - loess-palaeosoil sequences, which provide a detailed record of climate changes on land (Bolikhovskaya, 1995). Mollusc faunas are also widespread in various genetical types of the Upper Cenozoic deposits but have been largely ignored during the course of many years in Quaternary stratigraphy because insufficient evolutionary changes of malacofauna hampered its use for fractional stratigraphical subdivision. Introduction of the mollusc-based ESR-chronostratigraphy in the late-80s (Molodkov, 1989) allowed along with the solving the stratigraphy/age problems to retrieve a missing link between deep-sea and terrestrial records. The present work is the first attempt to integrate data of pollen and mollusc-based ESR-chronostratigraphical investigations to provide valuable information about climatic changes and associated sea-level highstands during Middle and Late Pleistocene climatic ameliorations and to link marine and terrestrial palaeoclimate records.

The primary objective of this paper is to report the temporal distribution and preliminary correlation on the basis of two pollen profiles (Arapovichi and Likhvin type sections) from loess-palaeosoil formation (LPF) in the centre of the East-European Plain, and ESR-chronostratigraphic evidence derived from warm-climate-related marine, lacustrine and terrestrial Acheulian-bearing cave-site deposits (**Fig.1**). The data presented are also correlated with the warm phases of the oxygen isotope records, periods of interglacial sea-level highstands and times of deposition of sapropel beds in the eastern Mediterranean sediments during Brunhes chrone. As the juxtaposition of the results usually becomes more disputable towards the older formation we shall begin to consider our data down from the relatively well studied last interglacial (s.lato) episode.

About a hundred datings on marine and freshwater mollusc shells obtained within the time interval from 142 to 70 ka B.P. and palaeoclimatic reconstructions on LPF suggest that the first Late Pleistocene marine transgression in Eurasia can be correlated with some substages or the whole marine isotope stage (MIS) 5 (**Fig. 2**).

The palynostratigraphical record from Arapovichi suggests the existence of climatic oscillation between stadial and interstadial conditions just below the MIS 6/5e boundary: climatic amelioration was interrupted by a return to cold climate. It would be the reason, as indicated by ESR for some raised marine deposits, that the sea-level rise started prior the MIS 5.

Climatic signal on LPF (Likhvin) and three datings from the Arctic islands indicate ameliorated conditions and some sea-level rise ca. 170 ka BP within the Dnieper/Warthe glacial (MIS 6).

Apparent interglacial conditions derived from pollen profiles on LPF (pollen zones Chr1-Chr5) and ESR-datings obtained from the Arctic region imply high sea-level stand about 220 ka BP (MIS 7).

A suite of ESR datings (283-336 ka BP) obtained on marine (Northern Eurasia) and lacustrine (South Baltic) sediments can firmly be correlated with the third (from the top) Chekalin (=Dömnitz ?) Interglacial and high sea-level stand during MIS 9. In the LPF (Likhvin) this event (pollen zones Ch1-Ch3) is represented by a strongly developed palaeosoil complex. The next high sea-level event is dated in the time interval of 455 to 365 ka BP (MIS 11). Judging from the pollen evidence from the Likhvinian section (pollen zones L1-L8), it was the warmest epoch during the past 500,000 years, known as Likhvinian (=Holsteinian (ss)). The interglacial resulted in the largest sea-level rise during this period (up to 20 m according to Hovard, 1997). The correlation of this interglacial on the East-European Plain with marine isotope stages 13 to 11 or 11 only is a matter of discussion.

ESR-datings between 555 and 535 ka BP were obtained on raised marine levels in the Arctic, and 545 to 610 ka - on terrestrial shells from Acheulian-bearing deposits (of normal polarity) of the cave-site in the Northern Caucasus situated in the zone of periodical development of mountain glaciation at an elevation of 1510 m above sea-level. Finds of subfossils from the first (upwards) culture-bearing layer suggest forestation in the vicinity of the cave-site and warm climate. It may be indicative of global climate amelioration (and consentaneous sea-level raise) during "warm" oxygen isotope stage 15, subsequent decay of the mountain ice domes in the Caucasus and elevation of the snowline above the cave shelter that allowed the ancient man to occupy the cave. The sharp shange of vegetation and climate in Arapovichi section (**Fig. 2**) also marks the onset of the very warm Belovezhje (=Voigstedt?) interglacial.

The age of the next culture-bearing layer is about 400,000 years that can firmly be correlated with stage 11. According to the palaeontological data and pollen evidence, the layer could have accumulated during the warm interglacial optimum. The archaeologically sterile layer sandwiched between the two dated cultural layers may be indicative of the time interval from about 540 to 420 ka (stage 14 to 12) when ancient man was forced to left the cave shelter because of a remarkable cooling of the climate during which the mountain glaciation developed and the altitude of the snow line fell well below the cave bottom.

Thus, in accordance with the direct data on warm-climate-related deposits not less than six sea-level highstands (full interglacial periods) are distinguished within the past 600,000 years, including the Holocene. The results obtained exemplifies the potential of integrated palyno-chronostratigraphic sequence in linking marine and terrestrial palaeoclimate records extending back at least over the whole Brunhes time.

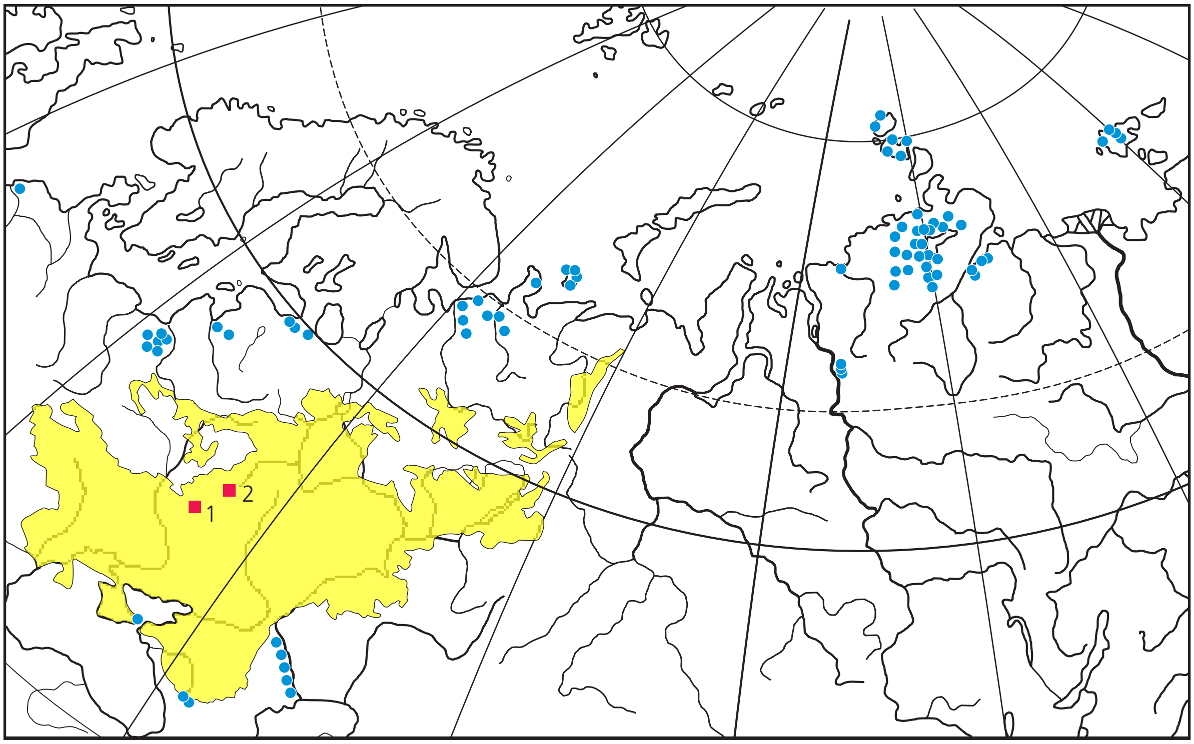

Fig. 1 Map showing the localities of collected shell samples (circles), studied loess-palaeosoil sections (squares: 1-Arapovichi, 2 - Likhvin) and distribution of loesses on East-European Plain (yellow area).

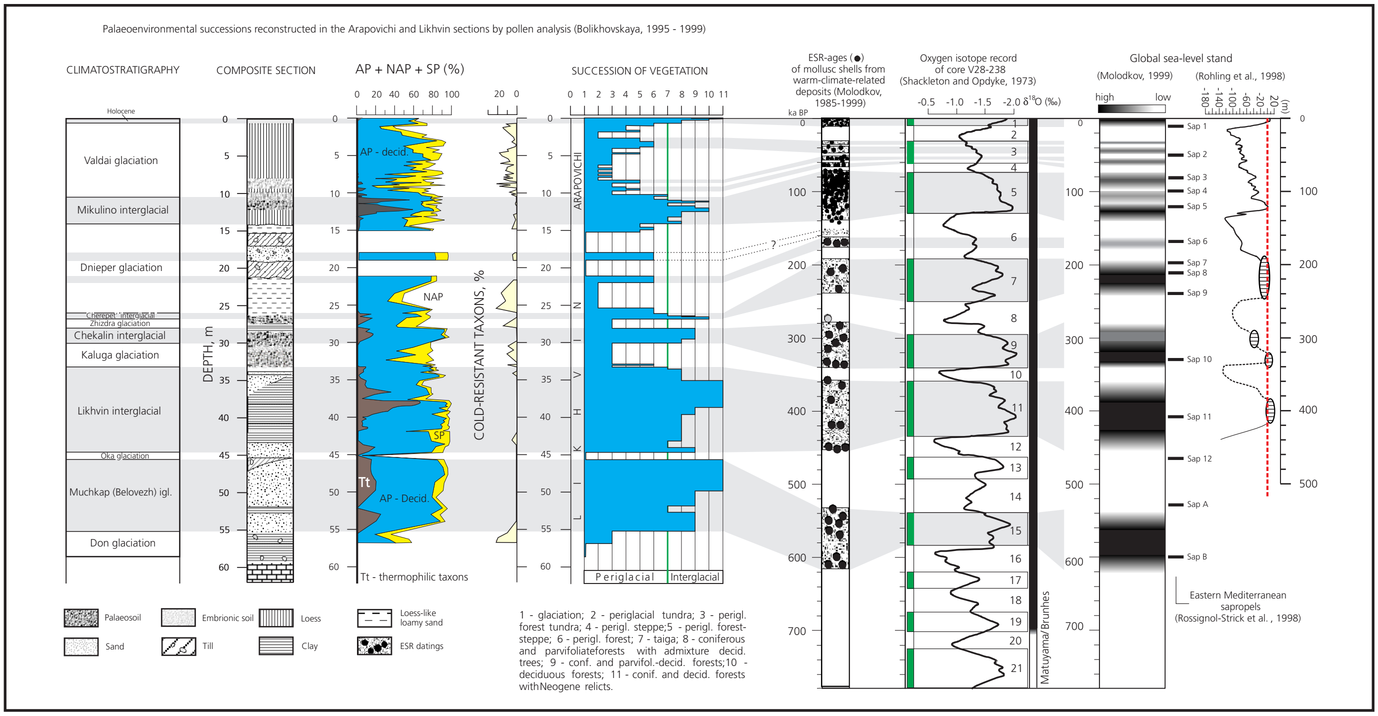

Fig. 2 Chronology and correlation of main palaeoenvironmental events of the last 600,000 years

From the past via the present to the future: Facts and fiction in sea-level estimates

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Change of sea-level is a multi-faceted problem which requires understanding of various subjects and interacting processes. Sea level can only change within limits determined by its physical causes. It thus reflects various geodynamic processes. On the million-year time scale, sea-level is mainly determined by ocean basin volume, mass distribution, and rotationrate. On the thousand-year time scale, sea-level varies mainly due to glacial eustasy and related glacio-isostasy, earth rotation and geoid shape, itself determined by lithospheric mass change. Sea-level changes on the hundred-year time scale seem, during the Late Holocene, primarily to reflect changes in water-mass distribution related to changes in the oceanic circulation in a feed-back coupling with the Earth's rate of rotation. On a yearly scale, sea-level varies locally because of dynamic factors and ENSO effects. For various reasons, both geophysicists and geologists tend to oversimplify the picture, especially concerning changes during the last centuries and the predicted future changes. Glacial eustatic change was virtually completed by mid-Holocene time. Significantly, Antarctic glaciers increased (not decreased) during northern hemisphere warm periods in mid-Holocene and Medieval times. The steric expansion of the water column is limited to individual oceanic layers with quite different recycling times. Hence it is only the surface layer that can experience rapid changes which accordingly are less than 10 cm in a century. The shape of the geoid, the gravity potential surface to which sea-level closely approximates, is constantly changing, and has evidently changed its height locally by several metres since the last interglaciation. The main process which causes rapid regional sea-level change is the variability in the main oceanic circulation system as a function of interchange of angular momentum between the solid Earth and the hydrosphere. If global sea-level has risen in the last 150 years, its average rate cannot have exceeded than 1.1 mm/yr. On the basis of this rate, about 10 cm per 100 years, a good approximation of the maximum expected rate of sea-level rise in the near future must be about 10 cm per century (20 cm at the most). The expected global warming will not greatly modify this rate, but a collapse of the West Antarctic Ice Sheet (for dynamical, rather than climatic reasons) would change it significantly.

References

Mörner, N.-A., 1999. Sea level and climate . Rapid regressions at local warm phase. Quaternary International, in press.

Mörner, N.-A., 1999. Sweden Excursion. Sea level changes, uplift, paleoseismicity, climate, coastal dynamics. Excursion guide, P&G. Stockholm Univ., 81 pp.

Mörner, N.-A., 1999. Paleo-tsunamis in Sweden. Phys. Chemistry Earth (B), 24, 443-448.

Mörner, N.-A., 1998. New trends in global tectonics. Phys. Chem. Earth, 23, 825-830.

Mörner, N.-A., 1996. Global change and interaction of the Earth rotation, ocean circulation and plaeoclimate. An. Acad. bras. Ci., 68 (supl. 1), 77-94.

Mörner, N.-A., 1996. Sea level variability. Z. Geomorph. N.F., Suppl-Bd 102, 223-232.

Mörner, N.-A., 1995. Earth rotation, ocean circulation and pleoclimate. GeoJournal, 27, 419-430.

Mörner, N.-A., 1995. Sea level and climate – the decade-to-century signals. J. Coastal Res., Sp.I. 17, 261-268.

Mörner, N.-A., 1995. Recorded sea-level variability in the Holocene and expected Future changes. In: D. Eisma (ed.) Climate Change. Impact on Coastal Habitation, p. 17-28. Lewis Publ.

Mörner, N.-A., 1994. Intarnal responce to orbital forcing and external cyclic sedimentary sequences. Spec. Publ. Int. Ass. Sediment., 19, 25-33.

INQUA's contribution to sea-level Research: The new commission and its new program

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At the INQUA XV conference in Durban, the old Shoreline Commission was reorganized and re-named to "the INQUA Commission on Sea Level Changes and Coastal Evolution", by that emphazising that that our research is by no means limited to shorelines but the entire coastal zone, its evolution and dynamics.

Changes in sea-level are one of the most characteristic phenomenon of the Quateranry Period. The problems related to the recording and understanding of sea-level changes are far from simple: on the contrary, they need our constant examination and attention. Today we are not only asked to reconstruct the Past but also to predict the Future; the near future on a decadal to centennial basis as well as the distant future of major glacial-eustatic cycles. Our commission has always been the leading forum for the understanding of sea-level changes within the Holocene and the Pleistocene. We hope to re-establish this position (1) establishing an effective global network on sea-level research, (2) defining the processes and factors driving sea-level changes and coastal evolution, (3) reconstructing the spacial and temporal differentiation of these factors, and (4) estimating coastal vulnarability and future prospects.

Besides local, regional and global studies of sea-level changes and coastal evolution by Sub-Commissions, research groups and individual members, our commissione will devote special attention to a number of research topics (agreed upon in Durban), out of which we will select a few research projects. Our program also includs two training program.

Very much of the commissional work will be performed via networking, and we, therefore, invite all sea-level investigation to visit our homepage (in prep).

Sea-level changes in NE Brazil, regional eustasy and local tectonics

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Holocene sea-level data from the Belém-San Luis area in NE Brazil indicate that sea-level never exceeded the present one, that sea-level was at or very close to the present at 5100-4400 BP and that it was at around -4.0 m at 6200 BP. If this, as is proposed, represents regional Brazilian eustatic changes, the famous Salvador-Rio de Janeiro curves must be affected by a significal local uplift factor.

In the Marnhaño coast of north-northeastern Brazil, the last interglacial sea-level can now be determined at +0.5 m. We propose that this represents some sort of regional eustatic level. This implies that the +5-10 m levels found in the Salvador and Rio de Janeiro regions are affected by local tectonic uplift, a conclusion supported by the Holocene records, too.

An exploration model for sand resources, Kailua Bay

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We used geostatistical methods to analyze the spatial distribution of the thickness of sand deposits in the reef-front area of Kailua Bay, Oahu, and provide probabilistic maps that can be used as the basis for an exploration model for sand resources in the study area. The data used in the study, which were collected by the U.S. Geological Survey, consist of seismic reflection measurements of the thickness of carbonate sand draped over a Pleistocene lowstand terrace.

After transformation of the data to a coordinate space that is elongate parallel to the Kailua Bay reef front, we used variogram analysis to determine that the sand thickness in the Kailua Bay area has well-developed spatial continuity. Variogram models fit to the data indicate that the spatial continuity of the sand thickness has a range of 750 m in the direction parallel to the reef front, and 270 m perpendicular to the reef front, yielding an anisotropy ratio of about 3:1. We used the variogram model as input to a stochastic simulation program and generated 100 equiprobable maps of the sand thickness, each of which honors the seismic data and the spatial continuity model. The 100 maps provide an estimate of the conditional distribution of the sand thickness at each point of the map area. Those conditional distributions were summarized by several statistics useful for an exploration model, including the expected value of the sand thickness, as well as measures of uncertainty, percentiles, and the probability of exceeding an economic limit. This allowed us to create maps that show the level of uncertainty associated with the sand thickness maps. We also created maps that show the probability that the sand thickness exceeds several given values. The maps could be used to target portions of the study area to develop the sand as a resource.

Whole-rock Aminostratigraphy of the Coorong Coastal Plain, South Australia: a one million year record of sea-level highstands

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The Coorong Coastal Plain in southeastern South Australia preserves a long Quaternary record of temperate carbonate sedimentation in the form of high wave energy, barrier shoreline deposits and associated back-barrier lagoon facies. The barriers occur sub-parallel to the modern coastline, and to each other, and increase in age landwards. The calcareous to siliceous barriers formed during successive Quaternary interglacials and interstadials. The relict coastal barriers are typically up to 30 m above the general level of the coastal plain, up to 10 km apart, and may be traced laterally for up to 300 km.

The coastal plain succession has been the subject of numerous geochronological investigations (summarized in Murray-Wallace et al. 1998). The now well-established chronostratigraphic framework based on radiocarbon, luminescence, and uranium-series disequilibrium dating and magnetostratigraphy, has provided a unique opportunity to assess critically the utility of applying the whole-rock method of amino acid racemisation dating to this spectacular Quaternary coastal succession.

In this investigation the succession younger than the Brunhes-Matuyama geomagnetic polarity reversal at 780 ka was examined, as well as the barrier immediately inland of this magnetic reversal (i.e. East Naracoorte Range). Whole-rock samples of bioclastic skeletal carbonate sand with subordinate quartz (63 to 500 mm), from aeolian facies of interglacial barriers younger than 780 ka were analysed for the extent of leucine racemisation (total acid hydrolysate and free amino acids). With the exception of the modern beach shoreface sand, samples were obtained from deeply buried contexts ranging from 1.2 to 25 m below the ground surface. This was to minimize the effects of diurnal temperature changes, such that temperatures associated with longer-term climate change represent the dominant influence on diagenetic racemisation.

The residence time (i.e. time lag between skeletal carbonate production and final incorporation within a geological deposit) of the carbonate sediments from the Coorong Coastal Plain was determined partly through a comparison of the amino acid racemisation results with the luminescence ages reported by Huntley et al. (1993, 1994). A direct comparison of the extent of leucine racemisation in the whole-rock samples with the luminescence ages reported by Huntley et al. was possible as the amino acid racemisation samples were collected from the same auger holes as those reported by Huntley et al., or from the same allostratigraphic units. Amino acid racemisation results for entire fossil molluscs of Holocene, Late- and Middle-Pleistocene age were also compared with the extent of racemisation evident in their host sediments. Modern beach sand from 2 cm below the foreshore surface at Long Beach, Guichen Bay near Robe was also analysed to determine the extent of leucine racemisation in 'modern' skeletal carbonate sediment.

The extent of leucine racemisation (total acid hydrolysate) for the whole-rock samples generally increases steadily with age. The extent of leucine racemisation in the whole-rock samples is consistently higher than evident for the entire fossil molluscs from the same allostratigraphic units. The offset in these data reflects the lengthy residence time for bioclastic sediments in this high wave energy coastal environment subject to reworking events. The extent of racemisation in the whole-rock samples when plotted against the luminescence ages reported by Huntley et al. (1993, 1994) reveals that the data are consistent with a model of apparent parabolic racemisation kinetics (Mitterer & Kriausakul, 1989). The amino acid racemisation data, when plotted against the square root of the luminescence ages reported Huntley et al. reveals a highly concordant relationship with a correlation coefficient of $r=0.9922$ and a coefficient of determination of $r^2=0.9845$. The apparent parabolic kinetic model ages are generally in accord with the luminescence ages reported by Huntley et al. Particularly close agreement in the numeric ages derived by these two methods is evident for Robe III, Woakwine II, Reedy Creek, West Avenue and Baker Ranges. The numeric age for the whole-rock sample from Guichen Bay, when evaluated in the context of its associated uncertainty term, is in general accord with the early Holocene radiocarbon ages reported by Thom et al. (1981) when the radiocarbon ages are calibrated to sidereal years.

The whole-rock derived numeric ages for the East and West Naracoorte Ranges differ significantly to the ages reported by Huntley et al. (1993, 1994: **Table 1**). A noteworthy point in the interpretation of these data is that the Brunhes-Matuyama geomagnetic polarity reversal occurs between these two barriers, and that the West Naracoorte Range is the younger structure (i.e. <780 ka). The whole-rock age of 543±103 ka for the West Naracoorte Range and its uplift corrected palaeosea-level of 17 m above present sea-level may be consistent with the 20 m high stand reported by Hearty et al. (1999) for Oxygen Isotope Stage 11. Apart from this possible reinterpretation of the significance of the West Naracoorte Range, the coastal plain succession indicates that interglacial sea-levels did not deviate by more than 6 m of present sea-level for the Middle- and Late Pleistocene.

References

Hearty, P. J., Kindler, P., Cheng, H. and Edwards, R. L., 1999. A +20 m middle Pleistocene sea-level highstand (Bermuda and the Bahamas) due to partial collapse of Antarctic ice. Geology, 27, 375-378.

Mitterer, , R.M. and Kriausakul, N., 1989. Calculation of amino acid racemization ages based on apparent parabolic kinetics. Quaternary Science Reviews, 8, 353-357.

Huntley, D. J., Hutton, J. T. and Prescott, J. R., 1993. The stranded beach-dune sequence of south-east South Australia: a test of thermoluminescence dating, 0-800 ka. Quaternary Science Reviews, 12, 1-20.

Huntley, D. J., Hutton, J. T. and Prescott, J. R., 1994. Further thermoluminescence dates from the dune sequence in the southeast of South Australia. Quaternary Science Reviews, 13, 201-207.

Murray-Wallace, C. V., Belperio, A. P. and Cann, J. H., 1998. Quaternary neotectonism and intra-plate volcanism: the Coorong to Mount Gambier Coastal Plain, Southeastern Australia: a review. In, Stewart, I.S. & Vita-Finzi, C. (eds). Coastal Tectonics, Geological Society, London, Special Publications, 146, 255-267.

Thom, B. G., Bowman, G. M., Gillespie, R., Temple, R. and Barbetti, M., 1981. Radiocarbon dating of Holocene beach-ridge sequences in southeast Australia. University of New South Wales. Department of Geography Monograph. 11.

Table 1

Comparison of leucine racemisation whole-rock numeric ages with the luminescence ages reported by Huntley et al. (1993, 1994).

Dune Range	TL age (ka)	AAR-age (ka)
Robe I (modern beach)	0	0
Guichen Bay (Holocene)	-	9.4±1.8
Robe III	116±6	127±24
Woakwine I	132±9	[125*]
Woakwine II	230±11	214±41
Reedy Creek	258±25	251±48
West Avenue	342±32	382±73
East Avenue	414±29	-
Baker	456±37	438±83
Harper	585±44	693±132
West Naracoorte	800±100	543±103
East Naracoorte	720±70	935±178

*calibration sample: age independently derived by uranium-series disequilibrium dating

Megaclasts on a shoreline reef terrace near Sharks Cove, Oahu's North Shore, Hawaii: Preliminary results

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Megaclasts on a shoreline reef terrace have been studied with the aims of clarifying their sources of origin and possible mechanisms of transport. An adjacent subaerial terrace, as well as the underwater area around it were also investigated.

On the shore terrace 6 areas of various surface morphology were distinguished based on visual observations and aerial photographs (**Fig.1**). Most megaclasts cluster in the northern part of the terrace. They occur singly as well as in groups. The megaclasts vary in shape from irregular to tabular. The great majority of them are tabular, however. Tabular megaclasts are often piled against each other forming an imbricate pattern. Some clasts within groups were nearly vertical position. Most of tabular megaclasts dip toward 270 to 300 at angles from 18 to nearly 80 . Dimensions of the megaclasts vary from 2-8.7 m (long axes) and thickness from 0.3-2.9 m (short axes). The degree of fit of the megaclasts with each other and with the subjacent terrace is highly variable. Smaller megaclasts tend to have a somewhat better fit than the largest megaclasts. Traces left by wave action and rock-boring organisms (sea urchins) facilitated the tracking of megaclasts back into their original position.

Underwater observations revealed a 8-10 m high submarine cliff adjoining the SW part of the reef terrace. The cliff was locally severely undercut. Toward the head of the terrace which is pointed NW, a second step gradually develops at ca. 7 m water depth. An underwater reef plateau above the second step is 150-200 m wide at the NW tip of the terrace and it narrows gradually to 10-15 m at the NE end where it is covered by the sand from the adjacent beach. Topography of the underwater reef plateau is smooth and locally covered by a thin layer of sand (similar to the low smooth topography on the shore terrace). On the sand bottom in front of the second step, which is very lobate and ca. 0.5-3 m in height, numerous loose clasts were observed. The clasts vary from ca. 0.5 to 20+ m across. Larger clasts of over 7-8 m across were usually tabular with one (usually upper) surface distinctly planate (eroded). The planate surface is probably the former surface of the plateau from which these clasts have been broken off.

Data collected on the shore terrace and in the underwater area around it suggest:

1. The shore terrace is subject to erosion by the sea waves that wash continuously its edge and by the extensive backwash on its surface during storms.
2. Those processes result in formation of crevasses and channels in the rock. Reef rock prepared in that way easily yields the megaclasts that were observed on the shore terrace as well as at the base of the submarine cliff.
3. Consistent orientation of the megaclasts on the shore terrace, imbricate structure of megaclasts in groups and the good fit between megaclasts and subjacent terrace suggest that high-energy storm waves are responsible for the transport and emplacement of the megaclasts. An alternative mechanism would include a catastrophic event such as a tsunami.
4. Direction of storm waves is most likely from W to NW, as recorded in the orientation of the tabular megaclasts. Flat surfaces dipping NW exhibit least resistance to waves approaching from that direction.
5. Later storms of lesser magnitude than those that emplaced the megaclasts on terrace are responsible for the slight movements of megaclasts needed in order to develop good fit between each other and with the subjacent terrace. Variable degree of fit shows that this process is going on continuously.
5. Rock samples were taken in order to estimate density of the rocks for future calculations of the mass of the megaclasts and required minimum wave force for their transport. At this time we are not able to determine whether a major storm(s) would be sufficient to emplace the megaclasts to their present location or a catastrophic event (tsunami) is required.

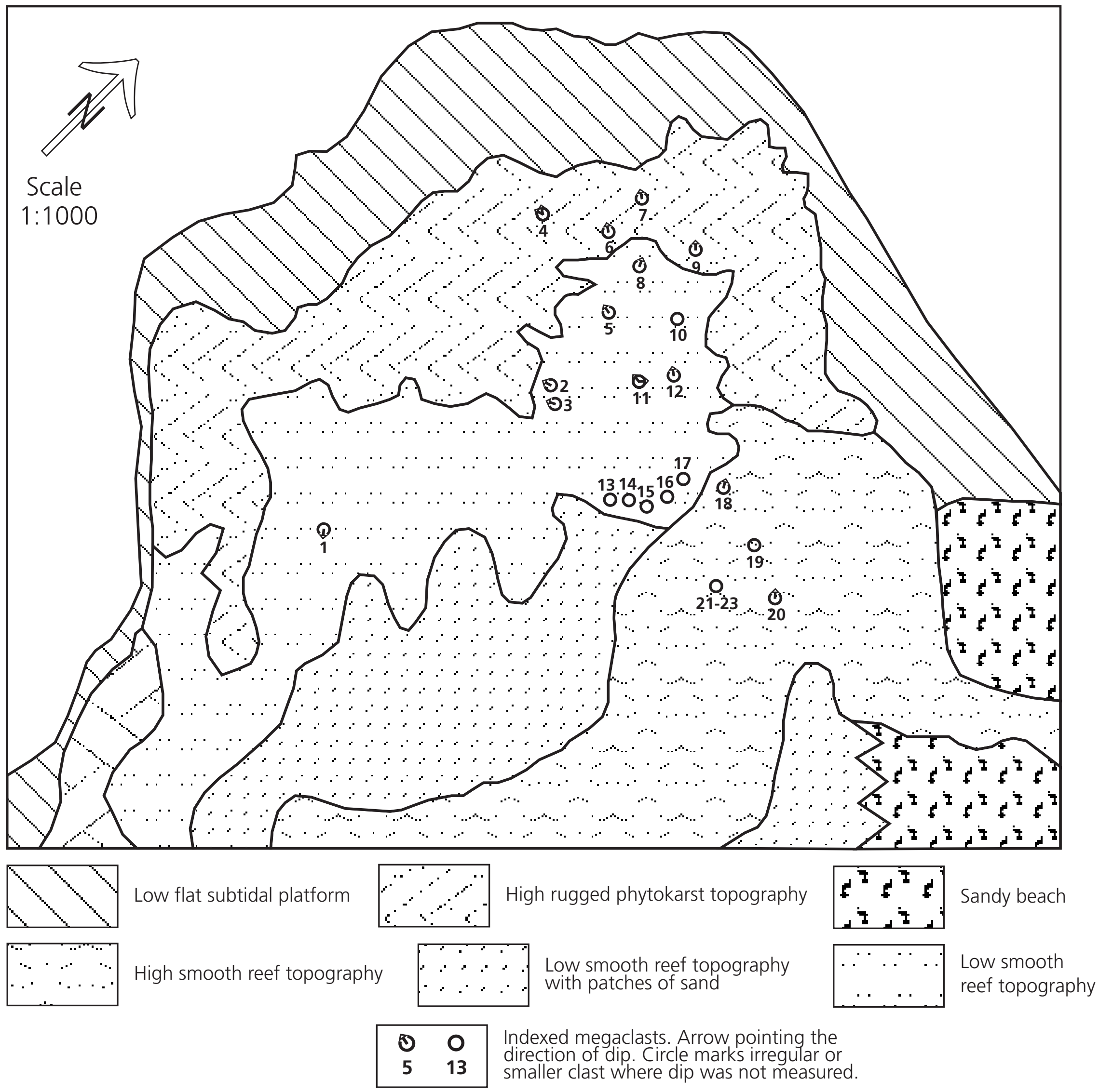

Fig 1 Shore platform north of Sharks Cove, Oahu's North Shore. Locations and orientations of megaclasts are shown with arrowed circles.

Illuminating sea-level fall around AD 1220-1510 (730-440 cal yr BP) in the Pacific Islands: implications for environmental change and cultural transformation

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This paper focuses on the climatic transition between the Little Climatic Optimum (approximately 1200-650 cal yr BP or AD 750-1300) and the Little Ice Age (approximately 650-150 cal yr BP or AD 1300-1800) in the Pacific Islands. This transition was marked by rapid temperature and sea-level fall, and perhaps by sharply-increased precipitation associated with an increase in El Niño frequency.

Combining the best available dates for palaeosea-level position with New Zealand palaeotemperatures allows the precise nature of two sea-level falls to be identified within the transition period. The first involved a fall of 75 cm 680-625 cal yr BP (AD 1270-1325), the second a fall of 40 cm 495-475 cal yr BP (AD 1455-1475): rates of 14 mm/yr and 20 mm/yr respectively.

Examples from throughout the Pacific Islands demonstrate the possible and/or likely effects of sea-level fall at this time on inland horticulture through water-table fall; on coral reefs and lagoons through the emergence of reef surfaces and the consequent reduction of nearshore water circulation; on the emergence of reef islets and the conversion of tidal inlets to brackish lakes. The effects of such changes on human lifestyles are explored.

Temporal hiatuses in Holocene sea-level records from the Southwest Pacific

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Reconstruction of changes in sea-level during the past 6000 years for various island groups in the low-latitude Pacific using largely radiocarbon ages of *Porites microatolls* reveal significant hiatuses, many of which have persisted even as more data have been collected. The timing of these hiatuses varies considerably, as does their duration from 600-1000 years. These hiatuses are considered statistically significant.

Explaining these hiatuses by rapid sea-level change would involve shifts of improbably great magnitude and rapidity to explain particular hiatuses. Added to this is the fact that they occur at different times in adjacent island groups. Rapid tectonic change is also considered improbable for these locations.

Several possible explanations for the hiatuses are considered. Among these are the possibilities that reef flats were destroyed locally by tsunami or storm surges, and that such events triggered invasions by predators such as *Acanthaster*. The best possible explanation involves the arrival of humans on fringing reefs hitherto untouched by people.

Dates of earliest-known human arrivals in particular island groups coincide with the temporal hiatuses in their sea-level records; others are less compelling.

Holocene sea-level and tectonic history at Kikai Island, the northern Ryukyu Islands, as deduced from drilling survey through coral reef terraces

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Kikai Iskand in the northern Ryukyu chains, 80 km from the Ryukyu Trench, has the highest uplift rate in Japan, 1.8 m/ka since isotope stage 5e. Subdivided four Holocene terraces, from the highest I to the lowest IV, fringe this island and record the Holocene uplift. We discuss Holocene tectonic and sea leval history of Kikai Island, using subsurface data, in addition to surface data.

We have drilled cores at five sites at Shidooke coast, with maximum thickness of 28m. Holocene sediments are classified into five lithologies from A to E. Fourty in situ corals are dated by the alpha-spectrometric ^{230}Th/^{234}U method. Isochrons for Holocene sediments indicate the upward coral growrth from ca. 10 ka to ca. 6.5 ka, followed by seaward growth since that time.

The highest, Terrace I, is mostly underlain by non-coral sediments of Facies C. In contrast, Terrace II, the widest and with moat and crest system, is underlain by Facies A, typical coral limestone. Thus, Terrace II is a constructional terrace of coral limestone and emerged at 5.3 ka. Narrow terraces III and IV are essentially cut surface into steeep fore reef slope of major Holocene cora tract, characterised by Facies A, but with some younger corals at their outer margin. Timing of their emergence is not determined at moment, but estimated to be 3.1 ka and younger than 2.5 ka, respectively.

Holocene coral terraces at Kikai are compared with those at Huon Peninsula, Papua New Guinea, which is located in the core region of coral growrh in contrast to Kikai at the marginal region. One of the significant difference is that the highest Holocene terrace at Huon is a transgressive constructional one, underlain by thick coral limestone, while that of Kikai is represented by constructional terrace of non-coralline deposits, reflecting slower coral growth at marginal area. Coseismic uplifts are more clearly recorded at Huon with higher uplift rate than Kikai.

Oxygen level control on foraminiferal distribution in Effingham Inlet, Vancouver Island, British Columbia: Implications for assessing long-term variability in pelagic fish abundance and paleoceanographic conditions

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Sediment/water interface samples were analyzed from Effingham Inlet (**Fig. 1**), southwestern Vancouver Island, British Columbia, to assess the oceanographic controls on foraminiferal distribution. In conjunction with sedimentary, geochemical and data from other fossil groups (e.g. dinoflagellates, foraminifera, diatoms) the resultant proxy data is being used to interpret cores collected throughout the basin, and assess the causes of periodic variation in fish populations over time. Restricted conditions in Effingham Inlet create ideal conditions for this research as the noise of open-ocean background productivity is filtered out permitting easier recognition of actual events. **Figure 2** shows oxygen and salinity profiles for selected stations at the head of Effingham inlet, the inner basin, the outer basin, and outside the outer sill.

Information on the natural variability of marine fish abundance and its relationship to fish production and oceanographic and climatic conditions is urgently needed. The highly publicized recent Pacific salmon crisis off British Columbia and Washington State, and particularly the economically disastrous collapse of the Atlantic cod fishery were at least partially the result of ocean/atmospheric impacts, and clearly illustrate why an understanding of these processes is strategically important. Effingham Inlet has a well-preserved sedimentary record of fish scale deposition that will help us to develop a long-term history of economically important pelagic fish populations (Pacific anchovy, Pacific herring, Pacific hake, Pacific sardine, and Pacific mackerel). We are developing an integrated history of the space-time variability of these fish populations in the North American Upwelling Zone over the past 2000 years. We are documenting large-scale climate and oceanographic changes embedded in the same sedimentary matrix as the fish scales. This will enable us to relate the fish population histories to climate-scale oceanographic changes. The results of our research will thus define the dominant forcing functions and scales of temporal variability in the coastal ocean and help the fishing industry to best utilize their resources to respond to natural variations in fish stocks that are not solely the result of fishing pressures.

To accurately interpret the fossil record it is critical to develop an accurate assessment of current oceanographic conditions in the area. Foraminifera are amongst the best tools available to document benthic environments and forms the basis for a significant portion of this presentation.

Five foraminiferal assemblage zones were recognized based primarily on cluster analysis results (**Fig. 3**). The controlling factors are oxygen content and level of organic matter. The *Buliminella elegantissima* Assemblage (includes Cluster A) characterizes well-oxygenated environments with high levels of terrestrial vegetative matter. This assemblage disappears when oxygen levels fall beneath 40µM/kg. The *Buccella* Assemblage (includes Cluster B), dominated in part by attached forms and islandiellids, is typical of well-oxygenated bank environments in the region. The *Stainforthia-Nonionella* Assemblage (only sample 41 from Cluster C) characterizes well-oxygenated environment outside the inlet. The *Stainforthia-Bolivinellina* Assemblage (includes Cluster D, Cluster E and samples 24 and 29 from Cluster C), typical of dysoxic conditions (>10µM/kg) in the outer basin, is characterized by increasing proportions of *S. feylingi* as oxygen levels decline with depth. The similar *Stainforthia* Assemblage (includes samples 13 and 14 from cluster C), identified from anoxic environments of the inner basin, provides evidence that even the most isolated portions of the Effingham Inlet are periodically oxygenated. A gradation between the *Stainforthia-Bolivinellina* Assemblage and *Stainforthia* Assemblage is significant as a whole range of dysoxic/anoxic conditions are detectable, potentially permitting recognition of subtle variations in paleoceanographic/ atmospheric circulation.

Preliminary sedimentary, geochemical and paleontological analysis of the cores collected in the inner and outer Basins of Effingham Inlet indicate that they contain one of the highest quality proxy data sets ever collected on the west coast of North America.

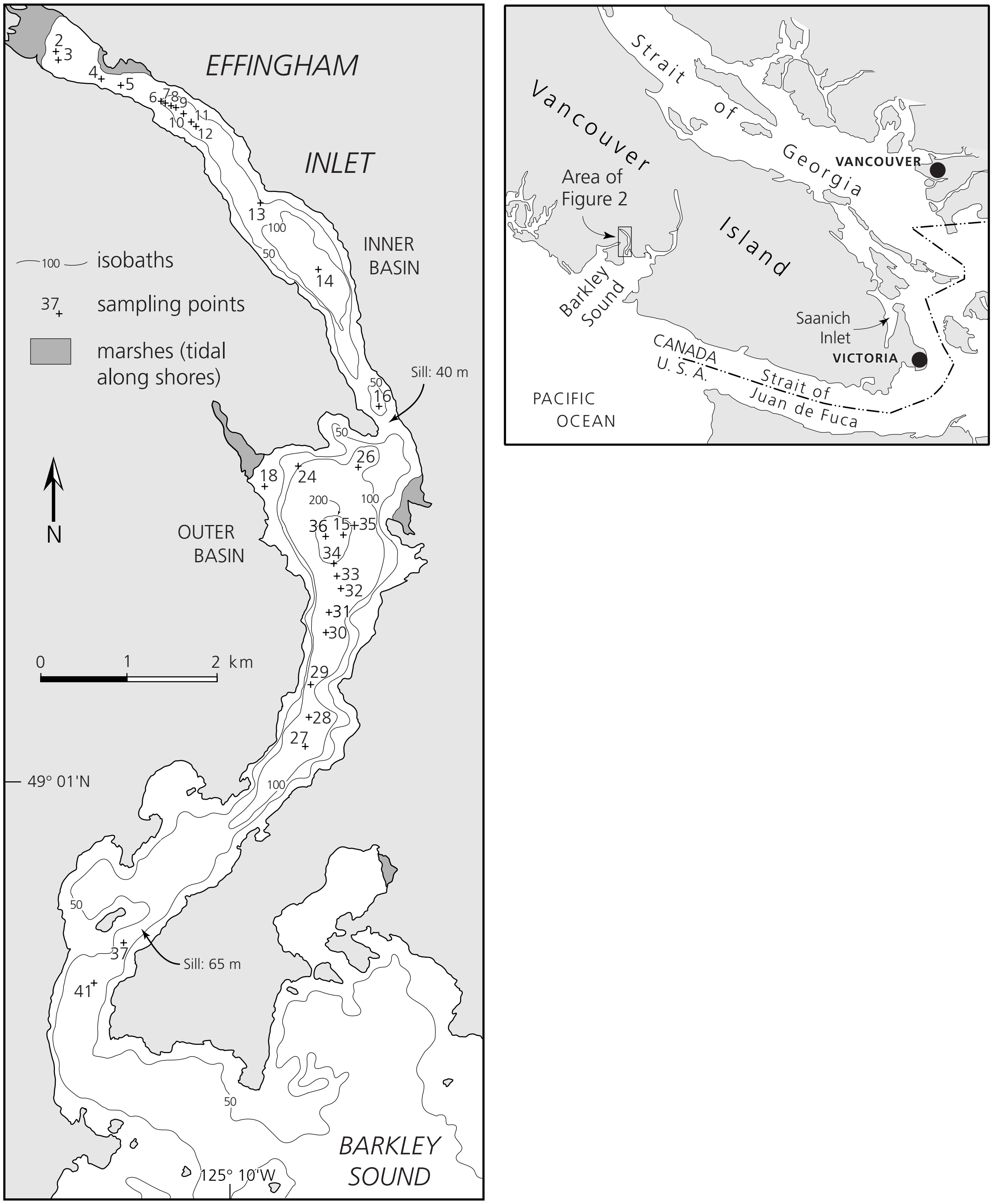

Fig. 1 Location map of Effingham Inlet showing position of inlet, sample locations and depth contours

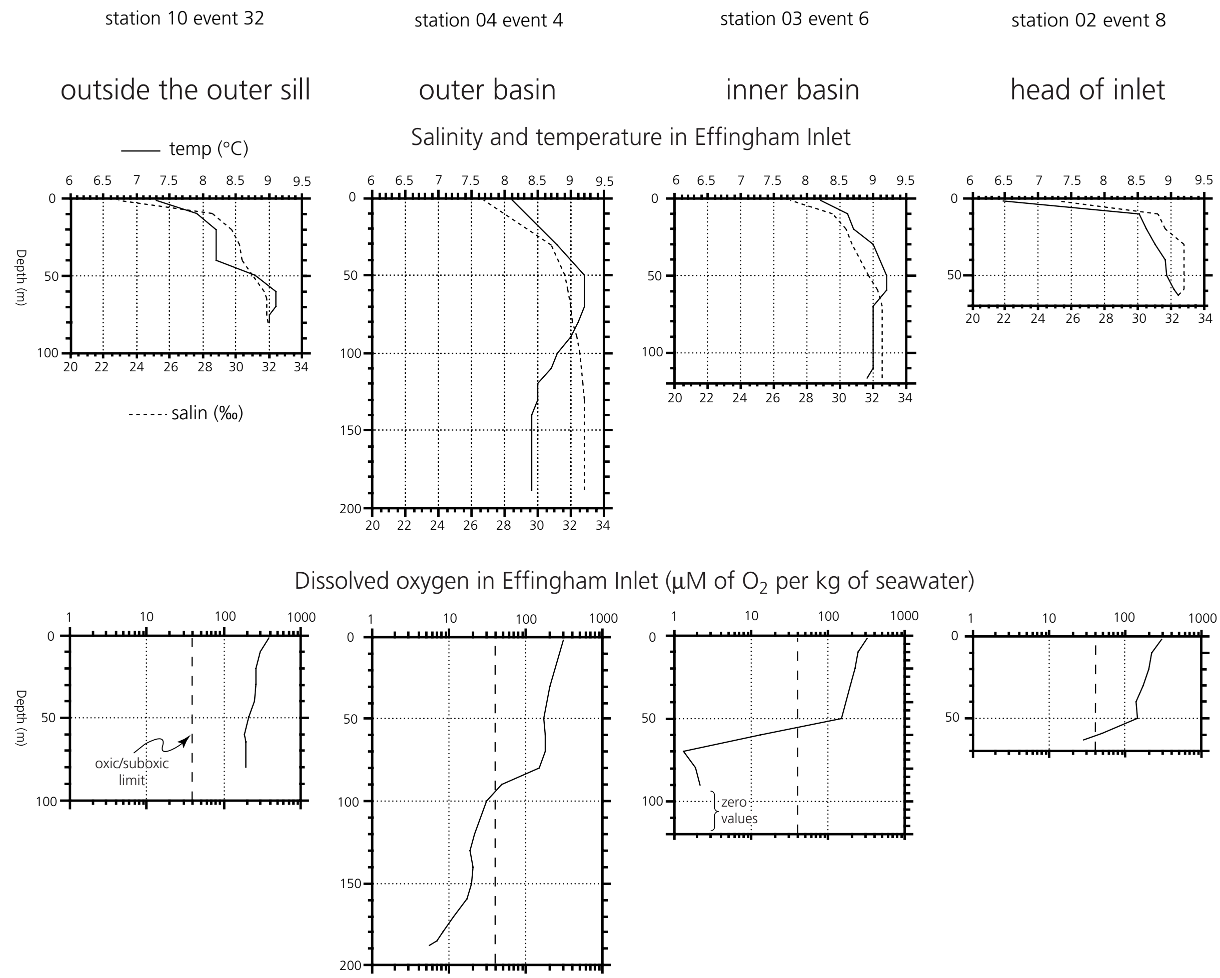

Fig. 2 Oxygen and salinity profiles for selected stations at the head of Effingham Inlet, the inner basin, the outer basin and outside the outer sill.

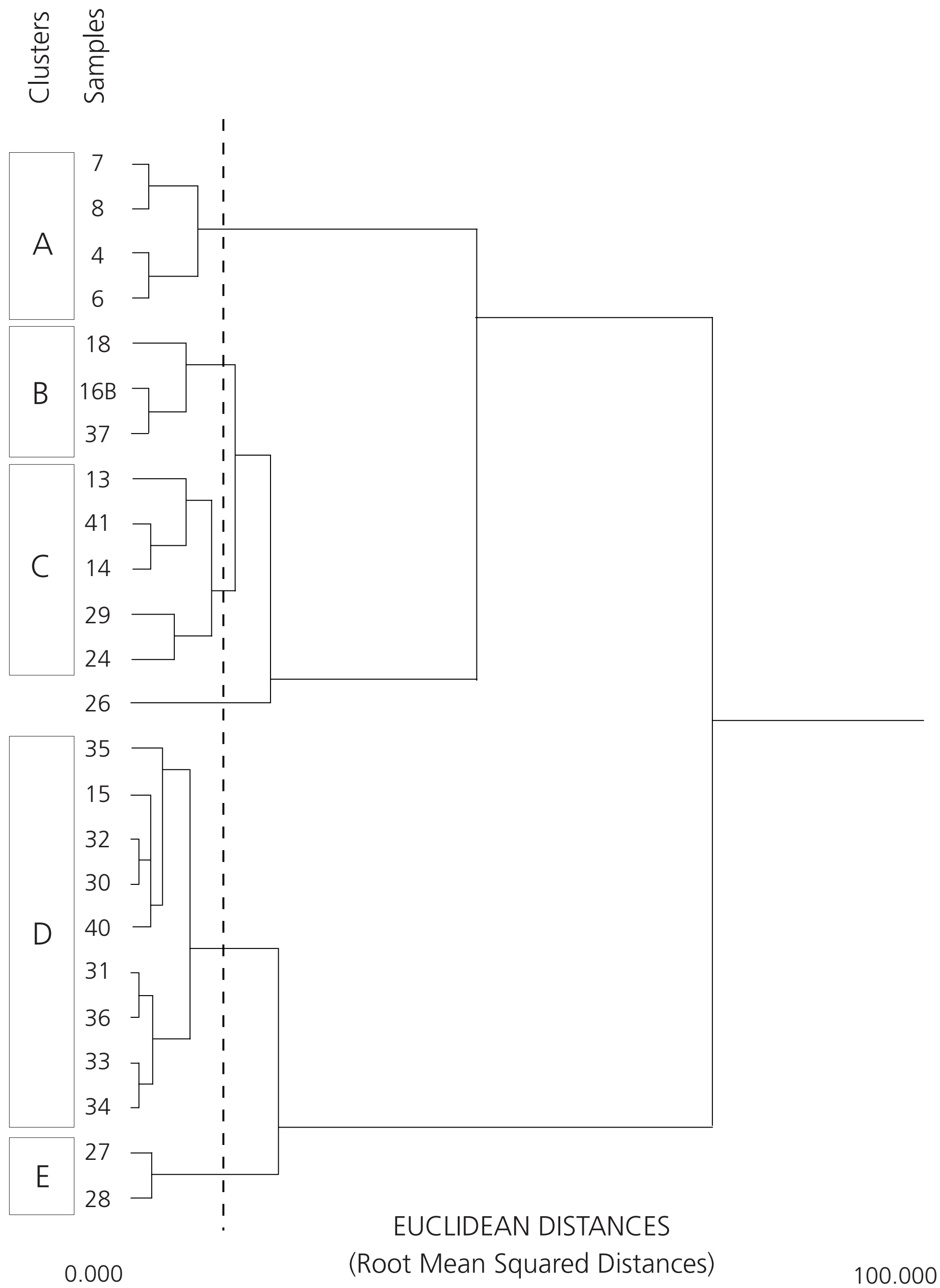

Fig. 3 Q-Mode cluster dendrogram showing the 31 samples with statistically significant number of specimens from Effingham Inlet. Clusters of samples with correlation coefficients greater than a selected level (dashed vertical line) are considered to be assemblage zones.

Global glacial isostasy and coastal evolution

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The global process of glacial isostatic adjustment that continues to occur in response to the most recent deglaciation event of the late Pleistocene ice age has left an indelible mark on shorelines everywhere. This is true not only of regions that were once ice covered and which continue to emerge as a consequence of the postglacial "rebound" phenomenon but also at exterior locations. At sites immediately peripheral to previously ice-loaded areas, where Holocene relative sea-level history is dominated by the phenomenon of forebulge collapse, sea-levels at present may be observed to be rising at rates as high as 2 mm per yr due to this cause alone. The east coast of the continental US is the region on Earth's surface in which this effect is most prominent. Even at sites that are furthest afield of the previously glaciated polar regions, such as island locations in the central equatorial Pacific, sea-level is currently falling due to the GIA process at rates as high as 0.4 mm per yr. The global impact of the phenomenon is therefor of great importance to the presently occuring global rise of sea-level that may be significantly influenced by the enhanced greenhouse effect. There currently exists a highly refined theory of the GIA process that is being employed in a variety of different applications, including mantl viscosity inference, ice age paleotopography inference, theoretical models of the ice age cycle, filtering of tide gauge estimates of secular sea-level trends to more clearly reveal the modern climate change related effect and , finally, low frequency analyses to more clearly reveal the influence of coastal tectonics. In this paper I will review the basic structure of this global theory and then focus primarily on the discussion of recent examples of the latter application.

Relative sea-level change influence in a mangrove of Sepetiba Bay–RJ (Brasil), in the last 6000 years

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Introduction

The studied area is an integrant part of the Guaratiba/Sepetiba Coastal Complex, situated in the southwestern area of Rio de Janeiro State. It is limited at north, by the parallel 23º 00’ S; at south, by the parallel 23º 23’ S; at west, by the meridian 43º 37’ W; and, at east, by the meridian 43º 32’ W (**Fig. 1**).

Nearby area has developed a flood plain due to the low energy and the tidal oscillations, forming a great intertidal area dominated by mangroves. The mangroves are estuarine ecosystems of sub-tropical and tropical regions developed on intertidal zones in regions with low energy of the coast. They are transition ecosystems between the marine and earthy environment.

Sea-level changes promote a migration of the mangroves zones and a succession of another vegetation species due to the variations: in the pattern and quantity of the fresh water influx; in the tax of sedimentary; and in the water salinity. In order to identify and, when possible, to date that migration, seven cores were collected, in a profile (SW-NE) almost perpendicular to the shoreline, in the Guaratiba mangrove, for a sedimentological, biological and geochemical characterization of the sedimentary column.

Material and Methods

The field works were made between march/1995 and june/1996, when 7 cores were collected, in a perpendicular profile to the shoreline in the tidal plain of the Guaratiba mangrove - Sepetiba Bay. The core were collected by the vibracore system with a aluminum tube, 6 meters long, 3 inches of internal diameter, and wall thickness of 3 millimeters. The engine included also a 6 hp motor, a vibration cable and a tripod for the core sustentation and recuperation (Pereira, 1998).

The core was processed according to the procedures establish by Figueiredo Jr. (1990) and sub-samples were taken for the following analyses: grain size; Palynology; radiocarbon dating; Malacology; and carbon stable isotopes in organic matter. The grain size analyses were based on Krumbein & Pettijohn (1938), Loring and Rantala (1992) and Ponzi (1995). The palynological and $\delta^{13}C$ studies were restricted to the core D, because its recuperation, localization and lithological variation. Specific to this research, two age determinations were accomplished (in the core D) by the radiocarbon method, in Woods Hole Oceanographic Institute.

Results

Sediments in cores taken at the Guaratiba mangrove are mainly constituted by silt and, in a few levels, with predominance of fine sand. The greatest concentration of clay (between 30% and 60%) was found in the most superficial level of the cores, situated in the Superior Tidal Plain.

Pollen types from sand bank vegetation and ombrofilous dense forest are predominant through out the core. However, the mangrove pollen types show a percent increasing between 3,30 and 2,70 m and from 0,80 to 0,10 m depth. The occurrence of *Felaniella vilardeboana* (Orbigny, 1846) in the cores B (1,80 and 2,00 meters) and C (1,50 and 2,10 meters), indicate a sandy bed deposited in a water depth between 25 and 77 meters. The occurrence of *Corbula* sp in the cores B (2,05 meters) and D (4,62; 5,03; 5,20 and 5,25 meters), suggest a water depth about 15 until 125 meters. The *Corbula cubaniana* Orbigny, 1853 present in the cores C (1,10 and 1,73 meters); D (4,28 and 4,43 meters); E (4,62 and 4,73 meters) and G (2,00 meters), indicate sandy and clayish floors in the range from 10 to 40 meters of water depth. The occurrence of *Chione* in the core D (2,25 meters), suggest a depth between 1 and 100 meters at the deposition time.

The isotopic analyses of the core D (**Fig. 2**), show four well defined clusters (A,B,C,D). It can represent four distinct environment types, with the organic matter percent going in the inverse way of the $\delta^{13}C$. The values of the isotopic data found in the B cluster are characteristic of prograding systems. This results agree with the environments interpretation for the core D, based in the grains size distribution, with values going from those characteristic of marine environment (in the base of the core) to values of earthy environments (top of the core) (**Fig. 3**).

Conclusions

This research in the intertidal area of Mangaratiba mangrove showed initially the development of a deep bay sedimentation (basal bed) corresponding to a transgressive event. These sediments are characterized by medium to fine silt with clay; $\delta^{13}C$ values between -23 and -22 ‰, suggesting an environment more marine; the presence of *Corbula* sp. species (sand-clay and carbonate beds - 15 to 25 meters in deep), *Corbula cubaniana* Orbigny, 1853 (sand and clay beds - 10 to 40 meters in deep), characteristic of deep water depth of this environment in the back bay area, and Veneroida; and, age of 6130 years B.P. to 5.20 meters in deep. In bibliographic references, that event rise its maximum at 5100 years B.P., with the sea-level arriving to 4.8 meters above the actual.

The zone corresponding to the regressive event is composed, mainly, by fine sand and medium to fine silt sediment, with the percent of sand growing up until the formation of a sandy bed; the $\delta^{13}C$ values stay more negatives to the top, where can arrive to values of -24.5 ‰, indicating a gradual increase in the proportion of earthy plants in the organic matter composition, normal in prograding systems; and, the shells identified in that deep are *Anomalocardia brasiliana* (Gmelin, 1791), characteristics of clay-sandy beds in shallow waters, *Bulla striata* Bruguière, 1792 who is common buried in sand-clay bed in intertidal zone, indicating an environment of shallow deposition; and, Tellinidae. Bibliographic references indicate that gradual lowering of sea-level beginning at 4900 years B.P.

With the beginning of a new transgression, we have a clay sediment deposition (predominantly medium to fine silt); the $\delta^{13}C$ values increase to -22 ‰ suggesting, again, an environment with more marine influence; and, the shells are represented by *Bulla striata* (Bruguière, 1792) that occurs buried in a sand-clay bed in an intertidal zone; *Corbula cubaniana* (Orbigny, 1853) (sand and clay beds - 10 to 40 meters in water deep); and, *Felaniella vilardeboana* (Orbigny, 1846), characteristic of sandy beds occurring at 25 to 77 meters deep, indicating deposition in an environment deeper than the anterior.

Finally, with the beginning of a regressive event, occurs a sedimentation characteristic of a lagunar and mangrove area (fine to very fine silt); $\delta^{13}C$ values diminishing to the top of the interval, where can obtain values of -26 ‰, that are typical of actual mangrove vegetation; and, with the few present shells represented by the *Anomalocardia brasiliana* (Gmelin, 1791), characteristic of clay-sandy beds in shallow waters, indicating deposition in a more shallow environment. Bibliographic references indicate that this last event should be occurred at 2400 years B.P.

References

Coelho, L. G., 1999. Seis mil anos de variações climáticas e do nível do mar na região da Baía de Sepetiba, RJ - Um registro palinológico. Curso de pós-graduação em Análise de Bacias, Universidade do Estado do Rio de Janeiro. Dissertação de Mestrado. 84 p.

Figueiredo Jr, A. G., 1990. Norma de controle de qualidade para o processamento de testemunhos inconsolidados. Projeto Sedimentos de Talude. Contrato PETROBRÁS/UFF N0 3-570-794-0-90. 37 p.

Krumbein, W. C. and Pettijohn, F. J., 1938. Manual of sedimentary petrography. Appleton Century Crofts Inc., 594 pp.

Loring, D. H. and Rantala, R. T. T., 1992. Manual for the geochemical analyses of marine sediments and suspended particulate matter. Earth-Science Reviews, 32: 235-283.

Pereira, S. D., 1998. Influência da variação relativa do nível do mar no manguezal de Guaratiba - Baía de Sepetiba - RJ. Curso de pós-graduação em Geociências, Universidade Federal do Rio Grande do Sul. Tese de Doutorado. 120 pp. (inédito).

Ponzi, V. R. A., 1995. Método de análises sedimentológicas de amostras marinhas. Representação de resultados através de gráficos e mapas. Curso de Especialização em Geologia e Geofísica Marinha. LAGEMAR/UFF. 51 pp.

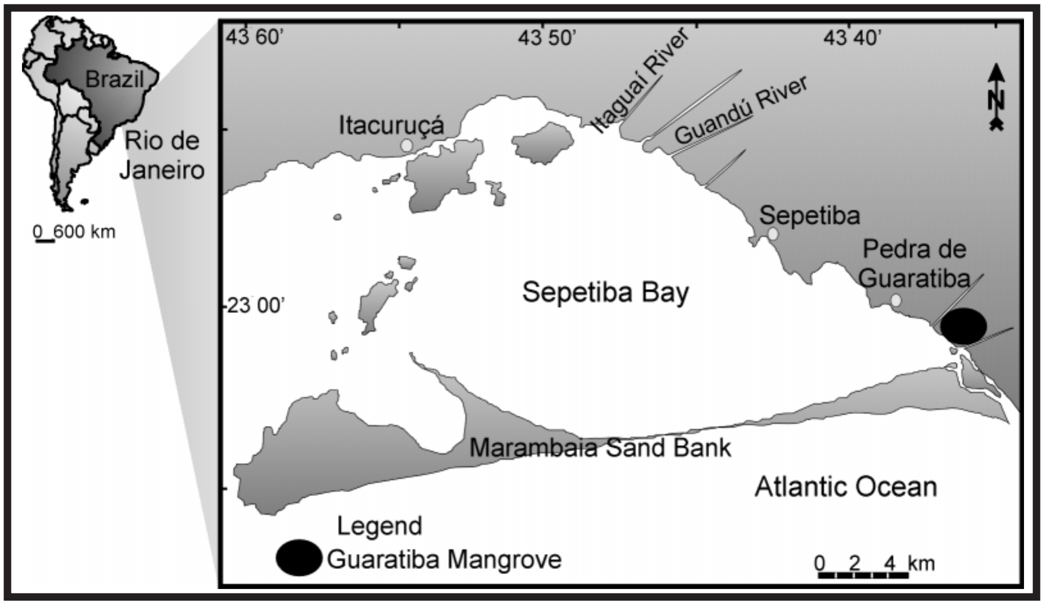

Fig. 1 Localization map of the studied area (modified from COELHO, 1999)

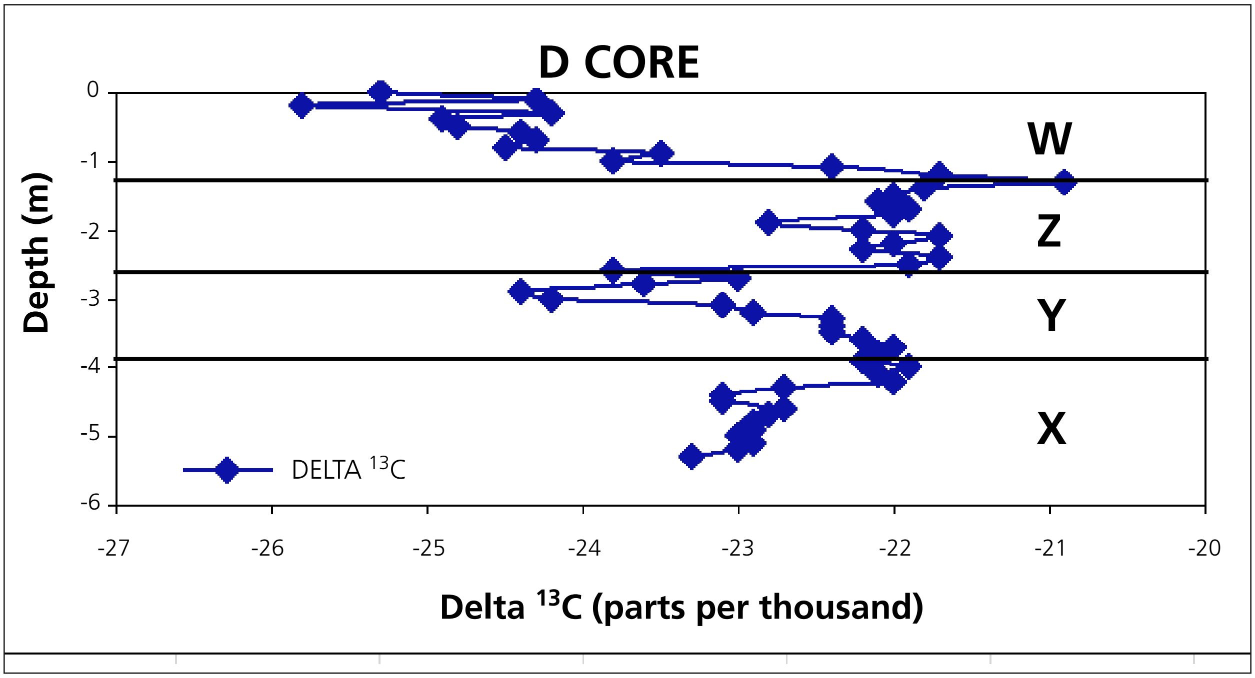

Fig. 2 Isotopic ratios of C to core D

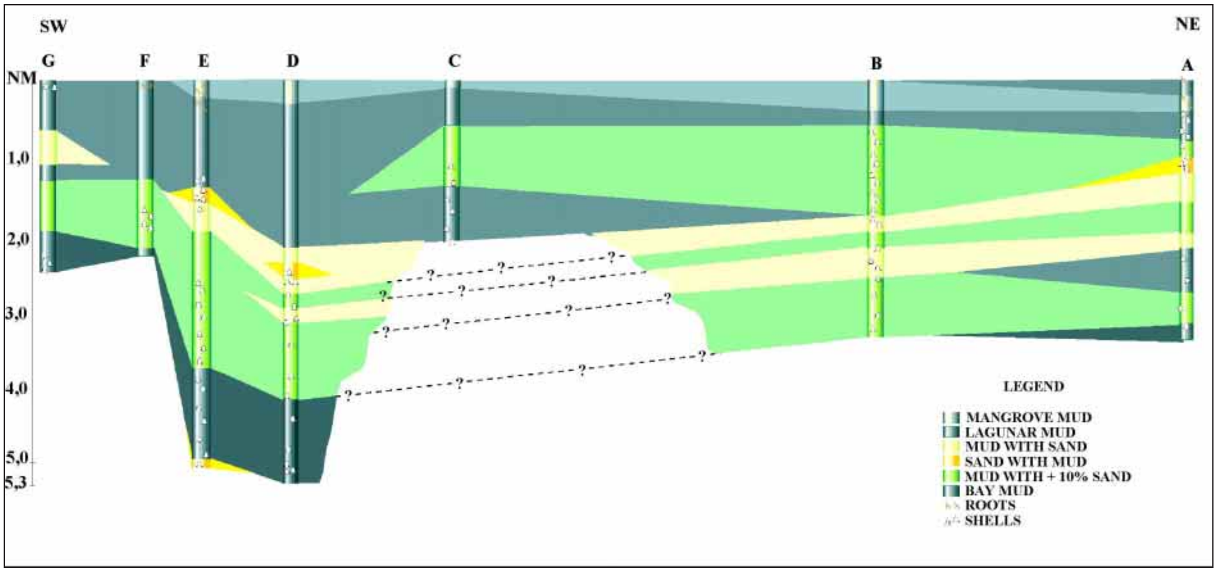

Fig. 3 Stratigraphic section of the studied area

Variability of beach profiles and meso-scale evolution of dune morphology: a linked approach (Brittany, France)

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The northern coast of Brittany (English Channel) is a macro tidal environment (up to 13m of tidal range) with short period waves. The southern coast (Atlantic Ocean) has a meso tidal environment (5to 8 m) and is exposed to oceanic swell. On both coasts, some beaches and associated dune systems have been monitored for several years (1992-1999). A set of 65 beach profiles and 50 cores has been analysed. Micro scale evolution (day to weeks) of beach profiles is higly variable. Statistical analysis doesn't show any good corelations between profile evolution and wave climate, neither with tidal cycles nor with wind speed/direction. Very different is the behaviour of the dune system which accumulates sand and retreats landward at the same time. Most of the retreat is linked to storms by over topping. Many cores were done through the storm deposits. The material of the dunes and of the storm deposits comes from the shore face. This means that beach profile changes should present some sort of corelation with dune evolution.

Modelling of beach profile evolution was tried : we have searched for functions which would describe the mouvement of the beach between two (or three, or n) successive profiles. We found some functions which relate each point of the profile at time T with the same point at time T+1, (T+2, T+n). For the upper part of the beach and for the lowest part of it, the evolution through time is described, quite simply' by regression lines. The (positive) slope of the upper beach evolution is 3 times lower than that of the lower beach, suggesting that some of the sand which accumulates at the lower level doesn't reach the upper beach.

The central part of the profiles (around mid tide level) is very variable and cannot be described by regression lines, neither by sinusoidal functions (damped or not). The best approach is a regression with artefacts, which are described as wavelets.

This description of beach profile evolution and dune retreat suggest a qualitative model for the entire beach/dune system evolution at meso scale (month to years). Sand accumulates at the low tide level during long period of fair weather (mostly Summer). If two conditions are met, the sand is moved to the upper beach : 1) accumulation at the lower level was important, 2) bad weather occurs during a spring tide , with waves lasting from the low tide to the high tide, and fading out when the tide goes out. This is, typically, an event which takes place during the end of September or the beginning of October. If fair weather succeeds to this event and if the first big storm occurs during next spring tides (November), then a lot of sand is availiable on the upper beach for over topping, and associated dune retreat. Any storm occuring after this one will strike a sediment starved beach and will have little or no effect. These observations imply that dune retreat (which is lasting for the last 3600 years on these sites) is not simply linked to sea-level rise, but also to the type of weather and to the distribution of storms during the year. It seems that sea-level rise has to be linked with a very definite pattern of storminess to result in the landward migration of these dunes systems.

Pacific Island beach systems: Examples from Hawaii and Micronesia

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The islands of the Pacific are natural laboratories for the study of coastal evolution at a variety of spatial and temporal scales. Variation in geologic, biologic, and climatic controls on coastal environments may vary dramatically over relatively short distances. In this study we examine beach systems from selected islands in Hawaii and Micronesia to determine controls on beach evolution. Where a beach is an area of sediment accumulation, usually sand or gravel, along a shoreline between low tide and the upper limit of wave action, the beach system includes the movement of the beach through time and interactions with adjacent environments such as aeolian dunes and the nearshore zone including adjacent reefs. Here, we describe beach systems in Pacific Islands and develop a provisional classification scheme, and, report on selected monitoring efforts to gain insights into process response mechanisms. These results are used to gain a better understanding of beach formation and stability for improved predictive capabilities and input towards management decisions.

Classification of Beach Systems in Pacific Islands

There are a number of distinct physiograhic settings where beaches occur in Pacific Islands. These include (with Hawaiian Island examples): drowned river valley with bayhead beach (Kahala, Oahu; Hanalei, Kauai); structural embayment with beach (Kailua Bay, Oahu; Ma'alaea Bay, Maui); pocket beach (Poipu, Kauai; Napili, Maui); coastal plain/cuspate foreland beach (Nohili - Barking Sands, Kauai); delta beach (Olowalu, Maui); fringing beach (Punalu'u – Hau'ula, Oahu); and, perched storm-beach (Kawaihae Bay, Hawaii). In addition to these beach systems of high islands there are atolls which are almost entirely encompassed by beaches along their shorelines. Atoll islet beaches can be further subdivided based on islet type and exposure.

Beach Morphodynamics

Beach morphology responds rapidly to changes in the incident wave and current field. The present morphology of a beach is some combination of rapid response to current conditions and the cumulative effect of antecedant conditions. Beaches monitored in Hawaii and Micronesia exhibit variations in beach profile shape based on annual changes in wave climate and in response to individual extreme events. Individual beach systems tend to display a characteristic change in profile shape and volume on an annual and/or event basis.

Measurements of local waves and currents are typically non-existent, however, beach profile characteristics and variations can be used as a proxy for the physical activity of a system. Annual changes in beach width and volume give some indication of "beach activity" which, in turn, is indicative of wave energy levels and sediment exchange rates between the beach and adjacent environments. The upper limit of beach profile change is directly related to the maximum height of wave run-up which varies according to wave characteristics and slope of the beach/nearshore system. Identification of the maximum elevation and inland excursion of wave run-up, either by direct observation, profile change measurements, or shoreline geologic mapping, is extremely important for defining hazard limits on beaches.

Coupled inner shelf-shoreline sediment responses to small-scale Holocene sea-level fluctuations: North Carolina coastal zone

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Albemarle-Pamlico Embayment System (APES)

The Albemarle-Pamlico Embayment is one of the larger Quaternary basins on the U.S. Atlantic continental margin with an extensive Holocene record. APES is situated in northeastern NC, extends from the NC-VA line southward to Cape Lookout, and includes the Roanoke, Tar, and Neuse Rivers; Albemarle, Pamlico, Croatan, and Roanoke Sounds and associated tributaries and drowned-river estuaries; the barrier islands of the Outer Banks; and the adjacent inner-continental shelf. Today, the riverine-estuarine component of the modern coastal system is tightly coupled with the Atlantic Ocean by four inlets through an almost continuous barrier island chain. The oceanic portions of the coast are microtidal (0.5 to 1 m), wave-dominated systems and the estuaries are shallow (0 to 6 m), flat-floored, nannotidal(1 to 10 cm) systems dominated by irregular wind tides.

APES contains an enigmatic stratigraphic record displaying a large-scale embayment history dominated by multiple episodes of riverine incisement during glacial events followed by depositional sequences of riverine-estuarine-barrier island-shelf sediment infilling the incised valleys during subsequent interglacials. The multiple Pleistocene glacial-interglacial episodes have resulted in exceedingly complex sequences of erosional-depositional geometries of similar lithofacies that only recently have become resolvable (York, 1990; Riggs et al., 1992). Within each glacial-interglacial cycle there is a more detailed stratigraphic record of multiple smaller-scale erosional and depositional events suggesting relative instabilities, changes, or fluctuations within the continental margin system (Riggs et al., 1992).

Fairbridge (1987) outlined numerous processes that result in relative sea-level changes. Some processes are based upon glacial eustatic variations in water volume and include changes in glacial ice masses, variations in the hydrologic cycle, and the molecular volume and density of water. Other processes are related to short-term changes associated with dynamic oceanic processes including degree of storminess, velocity of boundary currents, and amplitude of astronomical tides. In addition, there are numerous sources of local changes in basin shape that can also effect relative sea-level such as hydro-isostatic loading, sedimentary loading and compaction, glacial ice loading and unloading, and nonglacial-related structural movements. All of these processes will effect relative sea-level and the associated patterns of sedimentation in a coastal system. Sea-level fluctuations in response to complex coastal system dynamics is virtually guaranteed. Our challenge is to resolve these sediment responses within coastal systems to better understand the detailed history of coastal response to changing conditions. The post-glacial Holocene sediments of APES contain such a detailed record.

Results

Since 1968, a data base has been developed that includes >2,500 km network of high-resolution seismic, side-scan sonar, and ground-penetrating radar profiles; 120 15-40 m deep drill-core holes, 487 2-10 m deep vibracores, 117 6-18 m deep wash bores, and 634 0.5-1 m deep hand cores; and 499 radiocarbon age dates (SRR = 313; literature = 186). Integration of these data have enabled deciphering the complex sedimentological history preserved within the Holocene sediment infill record. Erosional incisement and riverine deposition were dominant within the present area of APES during the last glacial maximum and early portion of the post-glacial transgression. The general Holocene infill record represents a fining upward sequence of thin basal riverine sediments that grade upsection into thick finely interlaminated estuarine organic-rich mud and very fine sand, and culminate in organic-rich mud with periodic incursions of marginal marine sand. The estuarine sediments contain fauna that range from fresh to low brackish during initial flooding and following development of the bay-mouth barrier island system in their present location. The fauna shifted to high brackish and marine when the flooded embayment was open to the ocean either prior to formation of the barrier islands, in response to development of numerous inlets through the barriers, or subsequent elimination of major portions of the barriers.

However, this apparent simple Holocene flooding sequence was occasionally truncated by extensive erosional surfaces and incised by extensive sets of deep channels. Subsequent depositional features buried the erosional surfaces and backfilled the channels with similar lithologies as the underlying host sediments. Radiocarbon data suggest that different channel systems and erosional truncation surfaces are characterized by distinct ages within the Holocene. If these relationships are correct, the general post-glacial, sea-level transgression has been modified by smaller-scale fluctuations causing channel incisement and subsequent infilling of riverine-estuarine sediments, as well as wave-base erosional truncation of previous depositional sequences. Coring and dating specific incised channel sequences and erosional unconformities has led to development of a record of Holocene coastal erosional and depositional events that reflect climatic and sea-level fluctuations within the North Carolina region.

To date, two erosional incisement events, two erosional truncation events, and four flooding cycles have been recognized and defined that characterize the Holocene sediment record of APES. The first and most extensive erosional and incisement event was the fresh water riverine system that preceded coastal drowning, which began shortly after 8000 BP (radiocarbon years). The second erosional incisement event occurred within the Holocene climatic maximum (sometime between 5800-5000 BP radiocarbon years) with a relative sea-level fall up to 6 m below present MSL. The two subsequent erosional truncation events occurred in response to relative sea-level falls of about one to two m below present MSL. These sea-level drops lowered wave base within the embayed estuaries resulting in broad-scale truncation of pre-existing estuarine sediments. The two truncation events occurred sometime between 3300-2500 BP and 700-200 BP (radiocarbon years). These events are synchronous with the climatic deterioration that followed the Holocene climatic maximum and 'little ice age' climatic event, respectively. The latter truncation event resulted in 1000 to 2500 BP (radiocarbon years) estuarine sediments being exposed below the thin layer (ave. = 0.5 m) of modern estuarine sediment deposited since ~1800 AD.

Following each erosional event was a flooding cycle that brought relative sea-level to the vicinity of present MSL and possibly up to 1 m above. Each flooding event raised wave base providing accommodation space within the estuaries for accumulation of a lithologically similar suite of estuarine sediments. A new barrier island sequence was formed on top of the shoreface ravinement surface; location and character of the barriers were dictated by the paleotopography of the former drainage system cut into the underlying geologic framework sediments (Riggs et al., 1995). Multiple flooding events, in areas with adequate sand supplies on the inner continental shelf (i.e., deltaic sediments at the mouths of the Roanoke, Neuse, and Tar Rivers, and Diamond Shoals off Cape Hatteras), developed wide and complex barriers consisting of stacked sequences of two or more island components. Within sediment-starved coastal segments, the paleo-interfluvs, the barriers associated with each flooding event were dominantly erosional, reworking the pre-existing barrier sands into single, narrow barrier islands characterized by overwash processes.

The first two flooding events followed sea-level drops with significant amplitudes that led to activation of inner-shelf sand bodies and local production of wide barriers dominated by beach ridge structures with vast back-barrier sand dune complexes. However, inner shelf sand supplies were not available for reactivation by the flooding events following the two smaller-amplitude fluctuations of the erosional truncation events. Consequently, these latter flooding events were only able to develop narrow and simple overwash dominated barrier beach ridges that either totally reworked or were systematically stacked on front of pre-existing barrier segments.

Discussion

Fairbridge (1961, 1992) generated a conceptual global model of post-glacial eustatic sea-level rise based upon climatic, geomorphic, and stratigraphic criteria. He documented a series of major cooling and warming events that were superimposed upon the general Holocene transgression and should be reflected in fluctuations in sea-level. Howard and DePratter (1977), DePratter and Howard (1981), and Colquhoun and Brooks (1986) recognized several 2 to 3 m amplitude fluctuations in sea-level during the late Holocene coastal record by combining archeological studies with coring data in Georgia and South Carolina, respectively. Similar late Holocene patterns of sea-level fluctuation have been recognized in coastal sediments in other areas including Connecticut (Varekamp et al., 1992), Delaware (Fletcher et al., 1992, 1993), and western Europe (Mörner, 1976, 1980; Ters, 1987) to name a few.

Changes within the sedimentologic record reflect the history of change through time. Thus, if climate and/or sea-level fluctuate, so will the processes of sediment production, transportation, and deposition which should be recorded in the coastal sediment record. The detailed coastal zone record of the Holocene has been difficult to resolve partly because of the short duration of many of these regional responses. Standard time vs depth plots of radiocarbon age dates do not demonstrate these events for the following reasons. The times involved in lowstand conditions may actually be quite short (years to decades and possibly centuries) and error bars on most radiocarbon dates fall within this same time scale. Also, small amplitude sea-level events (< 2 to 3 m) will not be uniformly characterized by either erosion or deposition throughout the coastal system. Thus, restricted portions of the coastal system may actually be dominated by the opposite sediment process as environments are laterally displaced and sediments reworked.

Conclusions

Sedimentologic, seismic, and chronostratigraphic data suggest that the shallow, micro- to nannotidal Albemarle-Pamlico Embayment contains a record of non-steady state conditions through the Holocene. The general post-glacial, sea-level transgression was frequently and extensively modified by small-scale sea-level fluctuations driven by some combination of changes in climate and oceanographic conditions and processes. These sea-level fluctuations resulted in multiple erosional and depositional events that impacted the coupled inner shelf—shoreline environments. Episodes of lowered sea-level caused channel incisement and erosional truncation within the estuarine system and erosion of the barrier island system. Subsequent coastal flooding led to deposition within the new accommodation space by estuarine sediments and redevelopment of the barrier islands. Whether a wide, complex barrier system or a narrow, simple overwash barrier formed in any location was dependent upon the underlying geologic framework and availability of sand on the inner shelf.

Small-scale oscillations (years to possibly centuries) in Holocene climatic and oceanographic conditions cause fluctuations in sea-level that produce recognizable interactions between the riverine, estuarine, barrier island, and inner shelf components. Due to the low slope and micro- to nanno- tidal character of APES, these large, shallow depositional systems are intimately coupled resulting in significant impacts to the sediment record in response to small-scale changes in conditions. However, the coastal stratigraphic record is complex with subtle sediment patterns that require detailed, multidisciplinary field surveys integrating the old field approach with multiple modern technologies and detailed chronostratigraphy. Many researchers and considerable coastal evidence now suggest that small-scale, sea-level fluctuations exist regionally and are recognizable within the sediment record of the Holocene transgression. Are these coastal fluctuations shotgun through the Holocene and totally the response to regional influences or is there some synchronism that represents a record of global sea-level processes within these data?

References

Colquhoun, D. J., and Brooks, M. J., 1986, New evidence from the southeastern U.S. for eustatic components in the late Holocene sea-levels: Geoarchaeology, v. 1, no. 3, p. 275-291

DePratter, C. B., and Howard, J. D., 1981, Evidence for a sea-level lowstand between 4500 and 2400 years B.P. on the southeast coasts of the United States: Jour. Sedimentary Petrology, v. 51, p. 1287-1295

Fairbridge, R. W., 1961, Eustatic changes in sea-level, in L.H. Ahrens, et al., eds., Physics and Chemistry of the Earth: London, Pergamon Press, v. 4, p. 99-185

Fairbridge, R. W., 1987, Climatic variation, historical record, in Oliver, J.E., and Fairbridge, R.W., eds., The Encyclopedia of Climatology: New York, Van Nostrand Reinhold, p. 305-323

Fairbridge, R. W., 1992, Holocene, marine coastal evolution of the Unite States, in C.H. Fletcher and J.F. Wehmiller, eds., Quaternary Coasts of the United States: Marine and Lacustrine Systems: SEPM (Society of Sedimentary Geology), Special Publication No. 48, p. 9-22

Fletcher, C. H., Knebel, H. J., and Kraft, J. C., 1992, Holocene depocenter migration and sediment accumulation in Delaware Bay: a submerging marginal marine sedimentary basin: Marine Geology, v. 103, p. 165-183

Fletcher, C. H., Van Pelt, J. E., Brush, G. S., and Sherman, J., 1993, tidal wetland record of Holocene sea-level movements and climate history: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 102, p. 177-213

Howard, J. D., and DePratter, C. B., 1977, History of shoreline changes determined by archaeological dating: Georgia coast: Transactions, Gulf Coast Association of Geological Societies, v. 27, p. 251-258

Mörner, N. A., 1976, Eustatic changes during the last 8000 years in view of radiocarbon calibration and new information from the Kattegatt region and other northwestern European coastal areas: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 19, p. 63-85

Mörner, N. A., 1980, The northwest European “sea-level laboratory” and regional Holocene eustasy: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 29, p. 281-300

Riggs, S. R., Cleary, W. J., and Snyder, S. W., 1995, Influence of inherited geologic framework on barrier shoreface morphology and dynamics: Marine Geology, v. 126, no. 1/4, p. 213-234

Riggs, S. R., York, L. L., Wehmiller, J. F., and Snyder, S. W., 1992, Depositional patterns resulting from high-frequency Quaternary sea-level fluctuations in northeastern North Carolina, in C.H. Fletcher and J.F. Wehmiller, eds., Quaternary Coasts of the United States: Marine and Lacustrine Systems: SEPM Special Pub. No. 48, p. 141-153

Ters, M., 1987, Variations in Holocene sea-level on the French Atlantic coast and their climatic significance, in M.R. Rampino, et al., eds., Climate: History, Periodicity, and Predictability: New York, Van Nostrand Reinhold, p. 204-237

Varekamp, J. C., Thomas, E., and Van de Plassche, O., 1992, Relative sea-level rise and climate change over the last 1500 years: Terra Nova, v. 4, p. 293-304

York, L. L., 1990, Aminostratigraphy of U.S. Atlantic coast Pleistocene deposits: Maryland continental shelf and North and South Carolina coastal plain: PhD Dissertation, University of Delaware, Newark, 580 pp.

Response of Gulf of Mexico coastal systems to Holocene sea-level rise and implications for the future of our coasts

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An increased rate of sea-level rise will have a number of adverse impacts on world coasts, such as wetlands loss and accelerated coastal erosion; however, the magnitude of these changes remains unpredictable. The predicted rates of sea-level rise from global warming by the year 2,100 range from 20-23 cm/century to 86-96 cm/century (Warrick et al., 1996), with the main uncertainty in this prediction being the stability of polar ice sheets, particularly the West Antarctic Ice Sheet. A more conservative forecast of 49-55 cm/century (Warrick et al., 1996) is close to the average rate of sea-level rise during the Holocene (10,000 BP to Present). This being the case, we should be able to better predict coastal response to accelerated sea-level rise by examining the geological record of coastal change during the Holocene.

During the last lowstand in sea-level, most rivers eroded deep valleys on the continental shelves in response to falling base level. As sea-level rose, these incised fluvial valleys were flooded to create bays, and these bays should contain one of the best records of coastal response to rising sea-level (Belknap and Kraft, 1981). The record of sea-level rise is recorded as a stratigraphic succession of fluvial and estuarine sediments. Sedimentological and seismic data from Gulf of Mexico bays (Mobile Bay, Lake Calcasieu, Sabine Lake, Galveston Bay, and Corpus Christi Bay) and the east Texas continental shelf show the superposition of more open marine (distal) deposits over coastal, estuarine, and fluvial deposits. The contacts between these deposits are typically quite abrupt, suggesting that landward shifts in coastal environments and their associated ecosystems occurred rapidly.

The results of a study of the ancestral Trinity River Valley, now occupied by Galveston Bay (**Fig. 1**), indicate that two episodes of rapid shoreline retreat occurred during the Holocene in response to sea-level rise. As sea-level rose during the last deglaciation, the Trinity/Sabine incised valley backfilled with continuous fluvial and bay-head delta sediments and discontinuous middle bay, and coastal (tidal delta complex facies) deposits (Thomas and Anderson, 1994). The elevation of the top of the bay-head delta surface is a sea-level marker representing ± one to two meters. This surface has been mapped regionally and is characterized by a series of flat steps and inclined risers (**Fig. 2**). Stratigraphically above the bay-head delta, middle bay and ebb/flood tidal delta facies are discontinuous; these facies alternate up the axis of the incised valley. In places on the inner shelf, banks (Sabine, Heald, and Shepard banks) lie adjacent to and over the incised valley (**Fig. 1**). Detailed work by Rodriguez et al. (1999) indicate that these banks represent submerged paleoshorelines composed of three facies (from bottom to top): (1) a back barrier estuarine facies (2) a fore-barrier, lower shoreface/ebb-tidal delta facies and (3) a storm reworked facies (**Fig. 3**). The observed risers and landward shifts in the bayline flooding surface and the discontinuous distribution of middle bay, tidal delta complexes, and shoreline deposits within the incised valley indicate episodes of dramatic environmental change. The landward shifts in the bayline flooding surface represent periods of landward translation of coastal environments. The risers represent periods of aggradation and therefore, adjustment of the fluvial and bay-head delta environments to a higher sea-level position.

Two prominent flooding surfaces exist within Galveston Bay, at around -10 m and -14 m (**Fig. 2**). Sabine and Heald banks currently exist at water depths of -12 m and -15 m respectively (Figs. **1**, **3**). The depths of the ravinement surfaces that separates shoreface/ebb-tidal delta facies from the storm influenced facies are ~-10 m for Sabine Bank and ~-14 m for Heald Bank (**Fig. 3**) matching the depths of the two flooding surfaces within Galveston Bay (**Fig. 2**). Radiometric and AMS age dates from the shoreface/ebb-tidal delta deposits (below the ravinement surface) of Sabine and Heald banks were measured to be 4655±107 cal. BP and 8325 ±38 cal. BP respectively. These ages closely resemble radiometric ages from upper bay deposits of 4555±122 cal. BP and bay-head delta deposits of 8371±315 cal. BP (Rehkemper, 1969) sampled above the ~-10 m and below the ~-14 m flooding surfaces within the bay. Thus, the linkage between the offshore and onshore flooding events is reasonably well constrained. Age dates below the ~-14 m flooding surface within the bay and Heald Bank are similar, indicating that both the shoreline and the bay-head delta stepped landward simultaneously. During the later (~-10 m) flooding event, the barrier shoreline and bay-head delta did not step landward simultaneously. Because the age date above the ~-10 m flooding surface within the bay is similar to the age date below the ~-10 m flooding surface within Sabine Bank, the landward shift in the bay-head delta must have occurred prior to barrier shoreline submergence. Hence, Sabine Bank remained as a barrier island, similar to modern Galveston Island, separated from the new paleoshoreline by a distance of over 30 km. The bay-head delta shifted landward a similar distance. This landward shift in coastal environments would have transformed the low-salinity upper bay ecosystem into a higher-salinity middle bay, and the lower-bay ecosystem would have been inundated with marine waters and transformed into an open marine environment. The question of how rapid did these environmental changes take place still remains, and the answer is important for determining how ecologically destructive this event was.

The most likely forcing mechanism for shifting the bay and shoreline landward such great distances is sea-level rise. These landward shifts were followed by intervals of aggradation, upward steps in the bayline, and associated increase in sediment accommodation space. This increase in accommodation space is not likely to have been created by a sudden increase in coastal subsidence because the subsidence rate for this area is too low (0.1 mm year^{-1}; Paine, 1993). Furthermore, a decrease in the rivers sediment supply could not have caused submergence of the ancestral Heald and Sabine coastal barriers because river discharge occurred 30 km landward of these barriers. The barriers were predominately nourished by sands derived from offshore and along-shore, similar to Galveston Island whose fate by "drowning" seems inevitable.

The modern Galveston Bay system formed around 3,300 yr. BP (Siringan and Anderson, 1993) and at this time sea-level was rising slower than at any other time during the Holocene (1-2 mm/year). If the rate of sea-level rise does revert back to more typical Holocene rates (4-5 mm/yr), Gulf of Mexico coastal environments and ecosystems may again experience a rapid landward shift. Ongoing research is aimed at trying to constrain the timing and magnitude of flooding events of the past 10,000 years and at better documenting the environmental and ecological impacts of these events.

References

Belknap, D. F., and Kraft, J. C., 1981, Preservation potential of transgressive coastal lithosomes on the U.S. Atlantic shelf, in Nittrouer, C. A., ed., Sedimentary dynamics of continental shelves, developments in sedimentology: New York, Elsevier, v. 32, P. 429-442.

Paine, J. G., 1993, Subsidence of the Texas coast: Inferences from historical and late Pleistocene sea-levels: Tectonophysics, v. 222, p. 445-458.

Rehkemper, J. L., 1969, Sedimentology of Holocene estuarine deposits, Galveston Bay, in Lankford, R. R., and Rogers, J. J. W., eds., Holocene Geology of the Galveston Bay area: Houston, Houston Geological Society, p. 12-52.

Rodriguez, A. B., Anderson, J. B., Siringan, F. P., and Taviani, M., 1999, Sedimentary facies and genesis of Holocene sand banks on the East Texas inner continental shelf, in Bergman, K.M., and Snedden, J.W., eds: Isolated Shallow Marine Sand bodies: Sequence Stratigraphic Analysis and Sedimentologic Interpretation, SEPM Special Publication 64, p. 165-178.

Siringan, F. P., and Anderson, J. B., 1993, Seismic facies, architecture, and evolution of the Bolivar Roads tidal inlet/delta complex, east Texas Gulf Coast: Journal of Sedimentary Petrology, v. 63, p. 794-808.

Thomas, M. A. and Anderson, J. B., 1994, Sea-level controls on the facies architecture of the Trinity/Sabine incised-valley system, Texas continental shelf, in Boyd, R., Zaitlin, B. A., and Dalrymple, R., eds., Incised-valley systems: Origin and sedimentary sequences: Tulsa, Society of Economic Paleontologists and Mineralogists Special Publication 51, p. 63-82.

Warrick, R. A., LeProvost, C., Meier, M. F., Oerlemans, J., and Woodworth, P. L., 1996, Changes in sea-level, *in* Houghton, J. T., Meira Filho, L. G., Callander, B. A., Harris, N., Kattenberg, A., and Maskell, K., (eds.) Climate change 1995, the science of climate change: Cambridge, Cambridge University Press, p. 361-405.

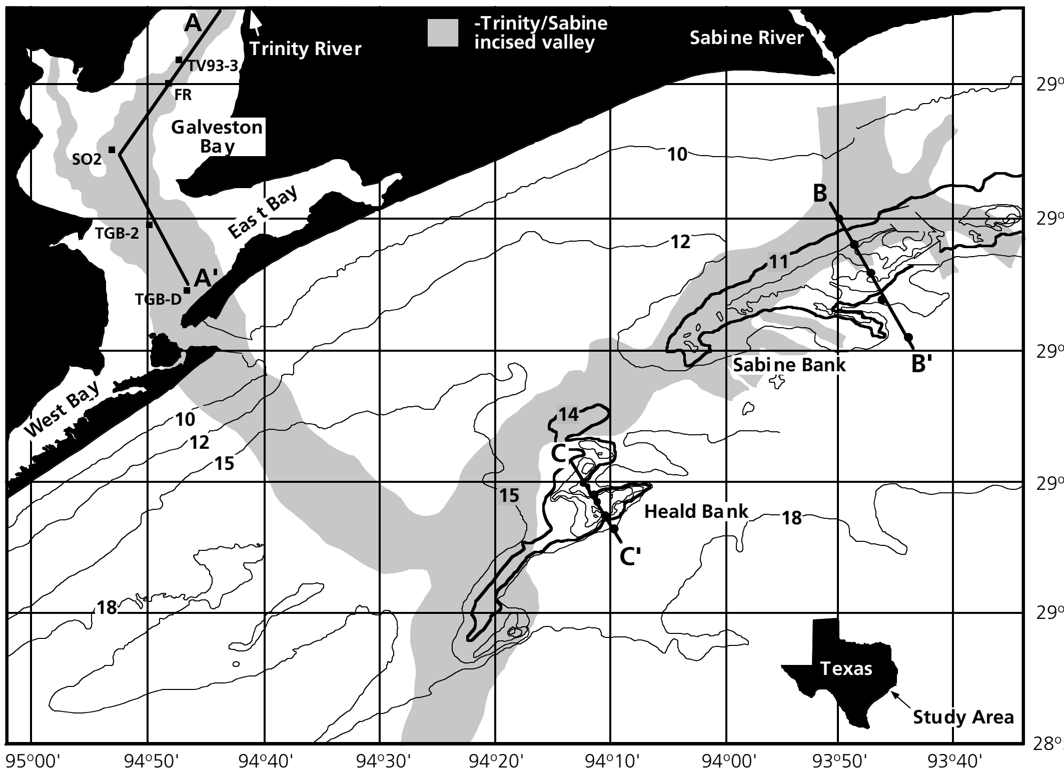

Fig. 1 Bathymetric map (bathymetry in meters) of the east Texas shelf and Galveston Bay showing the locations of cross-sections. The Trinity/Sabine incised river valley is shown in gray.

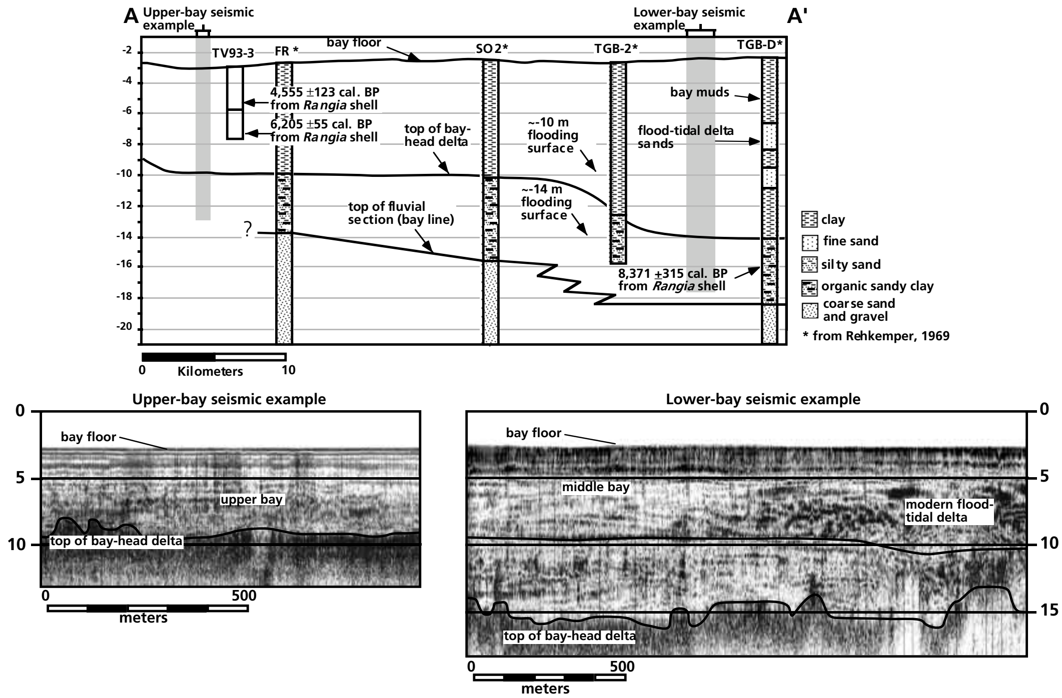

Fig. 2 Cross-section A-A' through Galveston bay based on seismic and lithologic data. Locations of two seismic examples are indicated in gray on the cross-section. Flooding surfaces are outlined on the representative seismic examples.

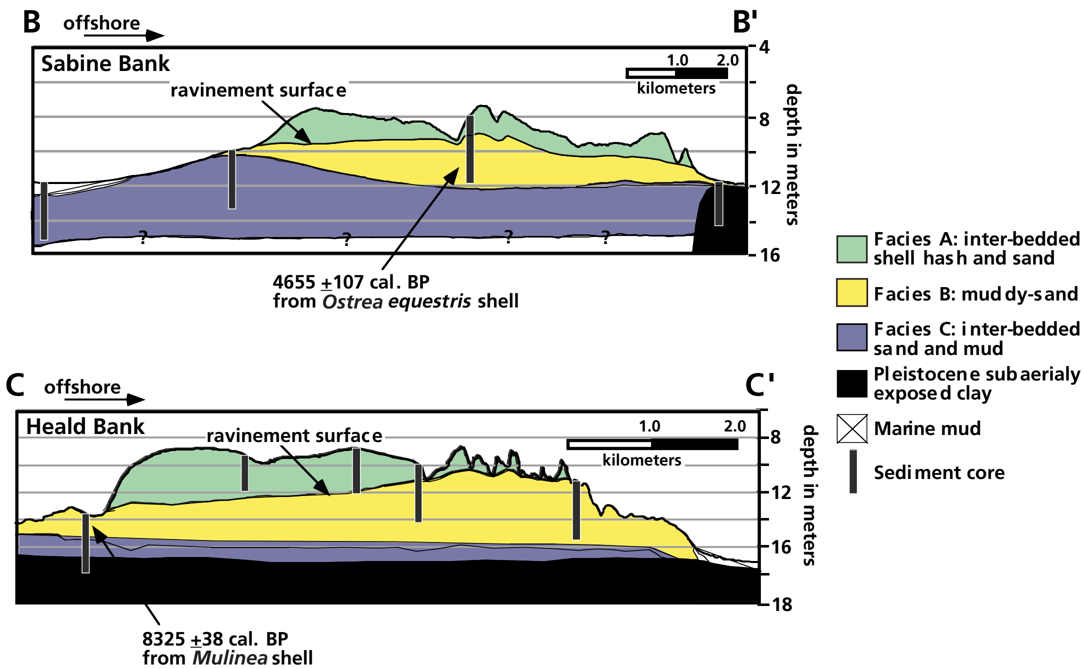

Fig. 3 Cross sections B-B' through Sabine Bank and C-C' through Heald Bank. The ~-10 m (Sabine Bank) and ~-14 m (Heald Bank) flooding surfaces are indicated by dashed lines.

Position of the Middle Wisconsin shoreline on the Texas inner continental shelf

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High-resolution seismic, lithologic, paleontologic, and radiocarbon data from the east Texas continental shelf were used to map the position of a middle Wisconsin (oxygen isotope stage 3) shoreline. The shoreline was placed in regional context with a study of the Texas shelf, based on seismic profiles, core, and platform boring descriptions that identifies the stage 3 maximum flooding surface and the stage 2 sequence boundary. These surfaces were then traced up-dip on the east Texas shelf where a shore parallel escarpment was recognized. Landward of the escarpment the stage 3 maximum flooding surface is amalgamated with the stage 2 sequence boundary. Therefore, the location of the escarpment marks the up-dip limit of stage 3 deposits and the stage 3 shoreline. Lagoonal sediments with in-situ brackish water fossils onlap the escarpment. Seaward of the escarpment, remnants of barrier island facies have been preserved as a bank, Freeport Rocks Bathymetric High, located in -18 m of water. The shoreline (adjusted for subsidence) is located at -15 m ± 2 m, which is shallower than what oxygen isotope and coral records indicate.

Decadal to century scale movement of a Hawaiian Coastline

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Sand beaches are a very dynamic part of the Hawaiian coastal environment. Over the latter half of the 20th century human development in the coastal zone has dramatically increased to the point where natural fluctuations of sandy shorelines frequently impact developed property. This has often led to degradation of both the beach environment and coastal structures and landscaping. We are studying a littoral cell on the west coast of the island of Maui in an effort to quantify, better understand, and adapt to decadal to century scale coastal sediment dynamics.

Sediment flux was quantified by delineating the historic position of the shoreline (crest of the beach step) and landward boundary of the beach (vegetation line). These lines were digitized on rectified images of aerial photographs from seven different years between 1949 and 1997, and topographic survey charts from 1900 (covering the northern part of the study site) and 1912 (covering the southern part). Four years of seasonal beach profile data were used to develop an equation relating the change in volume under the profile to changes in shoreline and vegetation line position. This equation was applied to the historical shoreline movement data to estimate changes in sediment volume. The change in sediment volume at any point along the coast is the net result of all the processes that move the sediment, or net sediment transport.

Our data show that there was severe erosion at the southern end of the littoral cell between 1912 and 1949. By 1949 the shoreline at the southern subcell had stabilized and the focus of erosion had shifted several hundred meters to the north. This "erosion hotspot" gradually moved north and by 1997 was almost 2 km up the coast from its original location. Altogether about 1.5×10^5 m^3 of sediment was transported out of the cell. In the northern part of the littoral cell we found net accretion of 4.4×10^5 m^3 of sediment between 1900 and 1997, or roughly three times more accretion than erosion. We hypothesize that much of the sediment that was eroded from the southern part of the littoral cell was subsequently deposited in the northern portion. Production and delivery of sand to the beach from the fringing reef that fronts the littoral cell is estimated to be 1.8×10^4 m^3 over the 97 year period between 1900-1997, or about 6% of the net gain. This site is apparently receiving and storing a significant volume of sediment from outside the cell.

The shoreline changes discussed above began prior to 1912 and a major portion of the total change had occurred by 1949, prior to significant human perturbation of the coastline. This suggests that natural rather than anthropogenic forcing is primarily responsible. By 1975 however, armoring of the coastline with seawalls and revetments was impacting coastal sediment dynamics and causing significant beach narrowing and loss. Both the northern and southern areas have experienced erosion since 1975. We are currently investigating the hypothesis that some combination of changes in storm and tradewind characteristics and relative sea-level rise have caused the observed readjustment of the shoreline.

El Niño induced coastal change: implications for the decadal scale evolution of coastal morphology

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On the northern and central California coast, the long-term (hundreds of years) development of coastal morphology has been controlled by waves from the northwest inducing a net longshore transport to the south. The classic log-spiral shaped bays that occur along this coast (e.g. at Drakes and Half Moon Bays) are a direct result of this long-term coastal evolution. In contrast, during El Niño, the North Pacific storm tracks are farther south inducing an anomalous southwest swell during the winter and northerly sand transport along the coast. This net northerly transport was documented during the 1997-98 event using airborne scanning laser altimetry. In October 1997, prior to the onset of the El Niño winter, USGS, NASA and NOAA collaborated to survey topography of 1200 km of the west coast using NASA's Airborne Topographic Mapper (ATM). In April 1998, after the storms subsided, the same areas were resurveyed to detect changes.

Consistently along the coast, beach sand preferentially accumulated against headlands at the north ends of pocket beaches and along the south sides of natural and man-made structures that extended into the ocean. Beaches were wider and higher at these accumulations and protected adjacent sea cliffs from the attack of waves. To the south of these accumulations beaches were narrower and lower and adjacent cliffs were, in places, eroded by wave action. In contrast, during non-El Niño winters, net sand transport is reversed and, hence, different parts of the coast are preferentially exposed to cliff erosion by wave attack.

Severe El Niño's occur every few decades. For example, prior to the 1997-98 event, the last severe El Niño causing major coastal impacts was in 1982-83. As a consequence, on decadal scales, the coast is subjected to patterns of erosion that tend to be in dis-equilibrium with long-term (hundreds of years) trends.

El Niño, storm surges and sea-level change in the development of the Rio de La Plata coastal plain, Argentina

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Introduction

The Rio de la Plata (**Fig. 1**) receives the discharge of two river basins: Parana-Paraguay and Uruguay. The former provides the major contribution. The relationship between El Niño events and extreme flooding in the Parana and Uruguay rivers has been established (Andersen et al., 1993; Depetris et al., 1996). Several extreme events occurred during this century, but also some have been recorded in the 1800´s. The 1982/1983 flood was the maximum ever recorded because of its duration and impacts, with a 60,000 m3/s discharge at Corrientes, on the Paraná river (July 1983). Other extreme situations occurred in 1992 and 1998, following strong ENSO events (**Table 1**).

Due to the basin geometry, extreme discharges on the Rio de la Plata do not cause significant changes in water levels. Storm surges ("southeasterlies"), originating in the Southwest Atlantic by meteorological processes, are a common feature and constitute the main morphogenetic factor in coastal plain development, causing periodic flooding (D´Onofrio et al., in press). The maximum level ever recorded was + 4.44 m (the reference datum is the Riachuelo zero, 0.80 m below mean sea-level, near Buenos Aires City) and entered the coastal plain for up to 10 km, reaching the former high Holocene shoreline. Extreme values analysis indicates a return period of 2.5 years for surges reaching 3.00 m O.D., while a return period of 366 years was calculated for a 5.00 m rise in water level, slightly above the 1940 flood (D´Onofrio et al., in press).

Postglacial sea-level rose into the Rio de la Plata to a maximum of 3.00-3.5 m around 6,000 years BP. Reference is given to the curve of northern Argentina shown in Angulo et al. (this volume) because it is based upon stormless deposits. During the regressive phase with a lowering to the present situation, fresh-water conditions were established around 2,000 years BP.

The Subtropical Ecosystems

Subtropical forest develops along very restricted patches on the levée of the Rio de la Plata. Nowadays this ecosystem is under stress and only a 500 ha reserve at Punta Lara (Latitude ca. 35º S), hosting the subtropical ecotone, is under protection. The marginal forest is the southernmost subtropical forest in the world. It also develops at a small island coast (Martin Garcia), close to the Parana delta front (**Fig. 2**). Botanists have stated that the composition of this forest derives from both the Uruguay and Parana rivers, and attributed its development to fluvial transportation of seeds and other constituents (Cabrera and Dawson, 1944). In addition, aquatic insects of subtropical origin have been found in artificial wetlands (abandoned quarries) near this area (Schnack et al., 1981). When extreme discharges occur, aquatic floating vegetation (*Eicchornia crassipes*= water hyacinth) massively arrives to the Rio de la Plata shore. This plants host several types of biological components, including vertebrates. In addition, organic matter in suspension arrives during these situations. Formerly the subtropical ecotone may have developed extensively on the fringe of the estuarine coastal plain (Cabrera and Dawson, 1944), provided fresh-water conditions were available. However, nowadays it is becoming progressively restricted due to human development.

It is herein sustained that the subtropical forest is the result of El Niño-induced floods from the Parana and Uruguay river basins, contributing the biological constituents and nutrients into the Rio de la Plata system. Storm surges ("southeasterlies") are a common feature, and they build up the levée on which the marginal forest develops. The hydroperiod is provided by small tides (amplitude < 1 m) entering the little creeks. Since El Niño seems to have occurred for at least the last 6,000 years, as suggested for the Pacific Ocean (Guzmán et al., 1998), it can be assumed that, once a freshwater environment was established around 2,000 years BP, conditions for the colonization of subtropical species on the Rio de la Plata shore were established.

Preliminary Conclusions

A combination of both El Niño-induce floods from the Parana Basin and storm surges ("southeasterlies") is primarily responsible for coastal plain development on the Argentine margin of the Rio de la Plata.

Sea-level changes have also contributed environmental conditions. During maximum SL stand (ca. 6,000 years BP), salty to brackish water prevailed up to the present upper delta location.

During the regressive phase, fresh-water conditions were established around 2,000 years BP, and conditions for the colonization of subtropical ecosystems (marginal forest) were available.

The colonization of the subtropical forest is attributed to massive transportation of seeds, organic matter and nutrients from the upper basin during extreme discharges associated to El Niño. Storm surges are thought to be the deposition agent (sediments and organic components) on the levée at the fringe of the coastal plain.

In the light of the preliminary ideas exposed, the Parana-Rio de la Plata system offers a unique target for paleoenvironmental reconstruction in the last 10,000 years, with focus on pulsatile conditions associated with global, regional and local processes.

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References

Andersen, R. J., Santos, N. and Díaz, H. F., 1993. An analysis of flooding in the Paraná/Paraguay river basin. LATEN Dissemination, Note No. 5, The World Bank, Latin American Technical Dep. Environ. Div. September 1993, 19 pp.

Angulo, R., Isla, F., Schnack, E.. and de Souza, M., 1999. A review of Holocene sea-level curves from the Southwest Atlantic. Extended Abstract, *Int. Symp. on "Coastal Change on the Decadal to Millennial Scale"*, Honolulu, Hawaii, Nov. 1999.

Cabrera, A. L. and Dawson, G., 1944. La Selva Marginal de Punta Lara en la ribera argentina del Río de la Plata. Rev. Mus. La Plata (n.s.), 5 (22): 18-382.

Depetris, P. J., Kempe, S., Latif, M. and Mook, W. G., 1996. ENSO-controlled flooding in the Paraná River (1904-1991). *Naturwissenschaften* 83, 127-129.

D´Onofrio, E., Fiore, M. and Romero, S., in press. Return periods of extreme water levels estimated for some vulnerable areas of Buenos Aires. *Cont. Shelf Research*.

Guzmán, N., Díaz, A., Ortlieb, L. and Clarke, M.,1998. "TAMAS" Ocurrencia episódica de moluscos tropicales en el norte de Chile y su relación con el fenómeno El Niño. Resúmenes, *Seminario-Taller:"El Niño"en América Latina, sus Impactos Biológicos y Sociales*. Lima, Perú, 9-13 de noviembre de 1998, p. 31.

Schnack, J. A., Domizzi, E., Spinelli, G. R. and Estévez, A. L., 1981. Influencia de la densidad sobre la fecundidad y competencia interespecífica con referencia espacial a una población de Belostomatidae (Insecta Hemiptera). *Limnobios*, 2:230-246.

Table 1

El Niño events and extreme flooding in the Parana-Paraguay Basin (After Andersen et al., 1993)

ENSO events	Extreme flooding in the basin
1877	1878
1904	1905
1911	1912
1913	1913
1918	1919
1923	1923
1925	1926
1930	1931
1932	1932
1939	1939
1951	1951
1953	1954
1957	1957
1963	1963
1965	1965/66
1972	1974
1976	1977
1982	1982/83
1986	1987
1991	1992
1997	1998*

* added

Fig. 1 General location of the Paraná and Uruguay Rivers

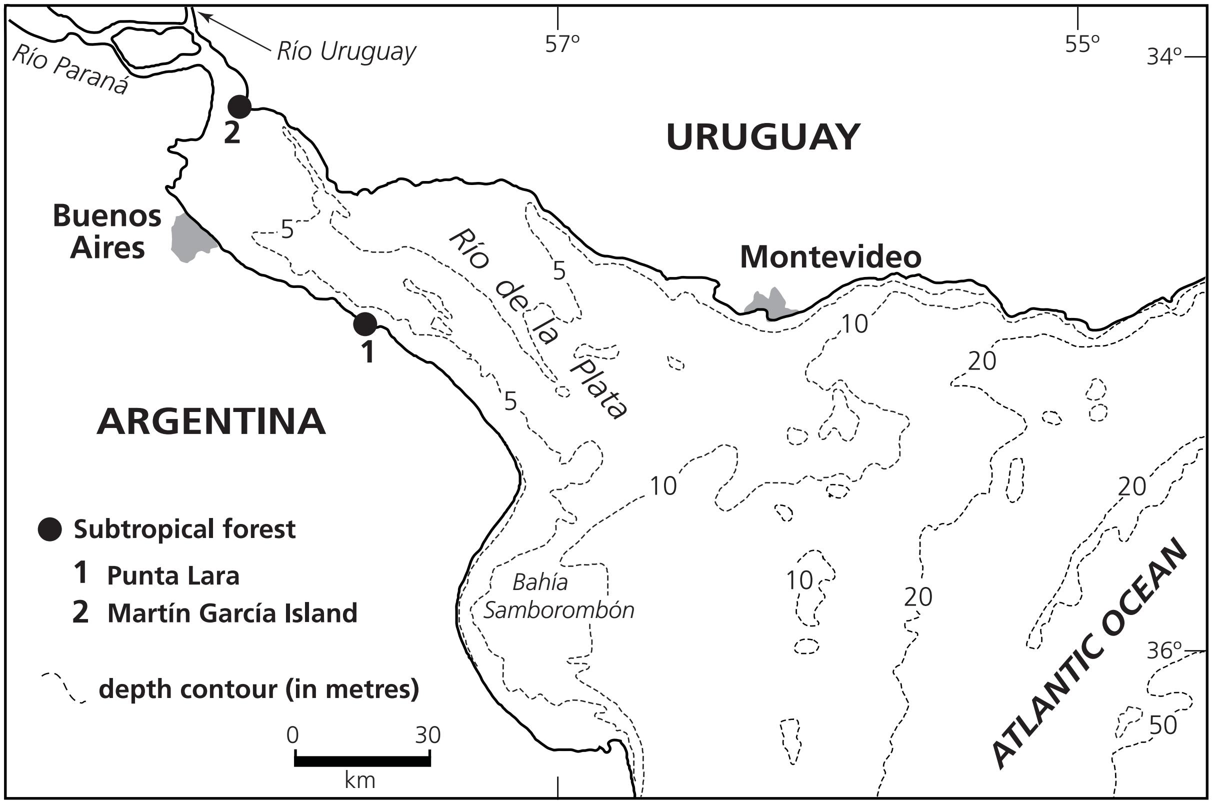

Fig. 2 The Rio de la Plata and location of main protected areas

Shoreline displacement along the Southern Baltic Sea coastline due to sea-level changes and human impact

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Introduction

Coastlines are focal points in many national economies. Due to their high socio-economic value, a large number of social and economic activities and their impacts are concentrated in these zones (human impact by fishing, aquaculture, industry, recreation facilities, discharge of nutrients and toxic substances, nature preservation, shore protection etc.). They are to be regarded as a multi resource- and at the same time as a multi user system. While, on the one hand, these areas around the Baltic Sea are a key factor for the role of sediment flux, they are, on the other hand, the most vulnerable areas with regard to physical (anthropogenic and natural) disturbances.

General Conditions of the Baltic Sea

The current situation of the nearshore Baltic Sea rim, with its big differences in the topographical, geological and hydrodynamical character along the different coastal regions, results of the last glacial and postglacial period. Generally the Baltic Sea coastline development is stongly influenced by the relative glacioisostatic crustal rebound, causing uplift rates up to 9 mm/year in its northern part and subsidence up to 2 mm/year in its southern part (Voipio, 1981). The coastal city Stockholm, for example, is raised 46 cm/century relative to the sea-level. Whereas archipelagos, consisting of solid rocks, dominate the Swedish and Finnish coastline, klint coasts are found in Esthonia. Along the southern coastline, from Lithuania via Poland and Germany to Denmark, the coast is mainly build up of soft glacial and postglacial deposits, boulder clay, melt water deposits (sands and gravel), kames and sediments of limnic origin.

This varying lithological composition combined with the exposure of the coast to the main wind direction, which determines the hydrodynamic forces (short term water level fluctuations, wave attack and resulting currents), are the controlling factors for the different anthropogenic use and physical functioning of these coastal areas. Where in front of lowlands sandy coasts are appearent, dune formation develops, increasing from West (Denmark, Germany) to East (Poland, Lithuania). Examples are the migrating dune fields of Leba (Poland), covering an area of 80,4 km^2 or the ca. 100 km long Curonian spit, extending from the Kaliningrad region (Russia) to Lithuania. Dunes up to 40 m in height developed on this spit. On the opposite dune height in the southwestern part of the Baltic Sea do not exceed 3 - 4 m and the dune covered areas are smaller than 1 km^2.

Shoreline development

Due to the postglacial development (uplift in the North, subsidence in the South) which is superimposed by the worldwide sea-level rise, the Southern Baltic coastline is generally under erosion.The retreat of the shoreline varies between 20-30 cm/year for the German and Polish coastline in general, whereas along some stretches the coastal displacement exceeds 1 m/year (Sterr et al. 1998). To slow down or to stop these erosion processes and to protect the populated areas against flooding is one of the most important tasks in all bordering countries. These efforts play a major role in the national coastal zone management strategies (Zeidler, 1992).

In areas under long term erosion the whole coastal profile including the nearshore slope, the bar and trough-system, the beach, the dune or cliff section and lagoonal areas behind dunes or beach ridges retreat due to the hydrodynamic impact. Substantial changes in the succession of geomorphological features will not appear. For active cliff sections this is expressed by the so called "constancy of the retreating profile" (**Fig.1**, Gurwell, 1989). This constancy of retreat above and below the waterlevel was prooved for several sites along the Southern Baltic coastline.

In an ongoing research-program[1], carried out in the Southern Baltic Sea, seafloor abrasion in front of active cliffs is measured by scuba divers in water depths ranging from -2 m to -6 m. Due to first results it became obvious that the lowering of the seafloor is a slightly discontinous process primarily controlled by storm events.

Effects of human impact

Attempts of coastline stabilisation are carried out either above the water line or/and in the very shallow water but mainly not in the deeper parts (below -10m). Shoreline stabilizations by coastal structures as well as the stabilization of dunes by planting forests or dune grass intervene in the dynamic process of shifting the system as a whole. Whereas for a certain period the retreat of dunes, beaches and the very shallow areas can be slowed down or stopped, erosion in the deeper parts of nearshore areas continues. Additionally, due to relative sea-level rise and the lack of sediment input , some erosion is observed in the inner parts of lagoons of the Southern Baltic Sea like for example in the Curonian Lagoon (Povilanksas1998). Resulting problems of the stability of the Southern Baltic Sea coastline will be discussed.

References

Gurwell, B., 1989. Grundsätzliche Anmerkungen zur langfristigen Abrasionswirkung und ihrer Quantifizierung. - Mitt. Forschungsanstalt f. Schiffahrt, Wasser- und Grundbau 54: 22-39; Berlin.

Povilanksas, R., 1998. Morphodynamics of the Lagoon Shore-Zone of the Curonian Barrier Spit, South-East Baltic. - Thesis of the Doctor´s Dissertation: 34 p; Kleipeda.

Sterr, H., Schwarzer, K. and Kliewe, H., 1998. Holocene evolution and mor-phodynamics of the German Baltic Sea coast –recent research advances. In: Kelle-Tat, D.H.: German geographical coastal research, the last decade: 107 - 135; Tübingen.

Voipio, A., 1981. The Baltic Sea: 418 p.; Amsterdam, Oxford, New York (Elsevier).

Zeidler, R., 1992. Assessment of the vulnerability of Poland´s coastal areas to sea-level rise. - Case study report, Institute of Hydroengineering IBW PAN:165 p.; Gdansk.

[1]The program was funded by the German Ministery of Education and Science, grant-number KIS307-1A.

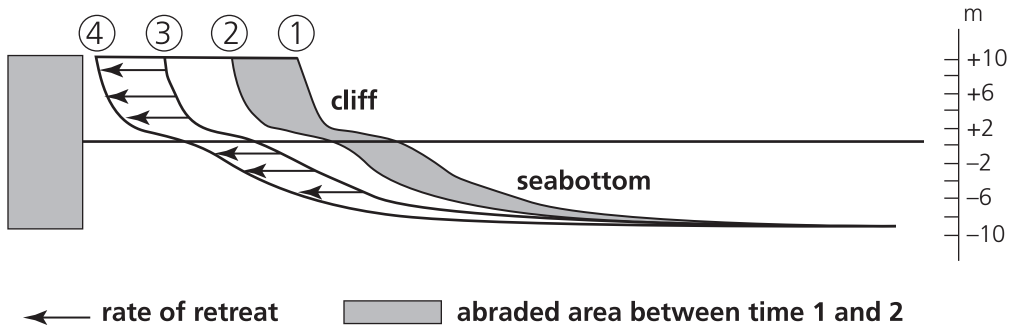

Fig. 1 Principle of the constancy of cliff retreat and seabottom abrasion (Gurwell, 1989, modified)

Late Quaternary relative sea-level variations in the North Atlantic: Comparison of mid-Holocene highstands to the last interglacial (isotope stage 5e) highstands

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We have sea-level curves covering the last 16,000 years from several locations in Maritime Canada but the most interesting part of the record is the last 8000 years when there is a combination of water level and land level changes that interact to produce some complex sea-level records. From Texas to Nova Scotia we have accelerated sea-level rise between about 6000 to 4000 yr BP and in South Carolina we are able to see a drop after 4200 yr BP. In most places in the N. Atlantic there are no higher than present Holocene sea-levels except perhaps Texas. However we do see, especially in Nova Scotia, what have been called "stage 5e" shorelines which predate the last glacial and are 5-10m above present sea-level. These have been discussed in the past as correlative with the worldwide stage 5e highstands of sea-level, but are they really time correlative? Sea-level is presently rising all along the Atlantic coast of North America and nowhere is it rising faster than in Nova Scotia. This rise has been going on for at least the last 7000 years at a rate of 20-30cm/century with an acceleration between 5000 and 4000 yr BP where rates of rise were up to a meter/century. With the exception of the rapid acceleration, we believe this rise is a result of crustal adjustment following deglaciation and if the present is the key to the past this would have happened in the last interglacial also. Most of the mid-Holocene highstands that are above present sea-level are in South America or Africa where there was no glacial-isostatic adjustment-these levels are comparable to the stage 5e shorelines in the same areas. However in the N. Atlantic we have not attained the highstand yet and hence probably the "stage 5e" shorelines in Nova Scotia are not really time correlative with other stage 5e shorelines. They also do not represent the climatic optimum but some time after related to when either another glacial (stage 4) commenced or the earth finally adjusted isostatically. Judging by the Holocene experience that would be at least 4000 to 5000 years AFTER the climatic optimum of stage 5e. This same relationship must also be true for many other N. Atlantic shorelines, especially in the UK where the sea-level history is similar to Nova Scotia.

Patterns of changes in sea-level and coastal responses of the North Black Sea and the Sea of Azov during the last millennia: From the past to the future

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The North Black Sea and the Sea of Azov represent the broad variety of the Middle and Late Holocene sea-level histories and coastal responses to them. A series of submerged and emerged Holocene coastal terraces, mainly of erosional character, on the Caucasian coast of the sea was tentatively correlated to the traditional stratigraphic scheme of Nevesskaya and Fedorov (Ostrovskii et al., 1977; Balabanov and Izmailov, 1988 etc.). The Bugazian, Vityazevian, and Kalamitian terraces, which were correlated with the Drevnechernomorian (Ancient Black Sea) layers, were found at the depths of 16, 10, and 3-4 m below sea-level and dated from 9.5-7.9; 7.9-7; and 7-5.9 ka BP respectively. Ancient estuaries formed 8-7 ka BP. in limans of the north-western Black Sea coast at the altitudes of up to minus 8 m. In the Kerch Strait area, submerged ancient coastal barriers at minus 30 m are dated from 7 ka BP. and at minus 17 m from 6.5 ka BP (Shcherbakov, 1983). However, all these areas were obviously subjected to neotectonic deformation and can hardly serve as references.

There is an opinion that at the end of this period, 6.5-5.8 ka BP, the sea-level fell to minus 25-27 m and incised valleys formed on the Caucasian shelf (Ostrovskii et al., 1977). However, these valleys are not dated and their age can not be determined.

Depositional coastal features of the Novochernomorian (New Black Sea) stage are of greatest extent in the Black Sea basin. They are represented by gravel and sand terraces and associated barriers that separate limans and lagoons in the north-western corner of the sea and in Bulgaria, as well by spits in West Crimea and the Kuban River delta in the Sea of Azov. They usually elevate up to 4-5 m above sea-level both in tectonically stable and unstable coastal areas. Considering wave run-up, the highest sea-level during the Novochernomorian stage was most likely to be 2-3 m above the present one.

It is only in Kolchis Lowland in Georgia and in the Karkinit Bay in the north-west of the Black Sea that the Novochernomorian coastal sediments are covered by the younger Nymphean sediments and no signs of sea-level indicators higher than the present one are known. Both these regions are well known for tectonic subsidence.

The Novochernomorian transgression on the coast of Bulgaria is dated from 5.5-4.5 ka BP. (Svitoch et al., 1998), in the north-western corner of the sea 4.5 ka BP (Molodykh et al., 1984), on the north coast 5.5-4 ka BP (Fedorov, 1985), and in the Kerch region and on the Caucasian coast 4.2-3.8 ka BP or nearly 3 ka BP. From drilling cores, the transgression was possibly of two-peaked character. This may be proved both by several coastal morphological indicators (Fedorov, 1985) and by the existence of two transgressive-regressive series in the Novochernomorian sediments in Kolchis Lowland. In the last area, transgressive phases are dated from 5.7-5.2 and 4.2-3.9 ka BP respectively.

It is evident that sea-level curves for the different coastal stretches of the Black Sea vary much from each other. Possible reasons for these differences are briefly discussed below. Valuable additional information on sea-level changes may be obtained from coastal areas of steady deposition. The Kuban River delta is one of the most representative areas of this type (**Fig. 1**). The Kuban River deltaic plain is an extremely gently sloping surface up to 150 km in width. Elevations do not surpass 3-5 m above MSL. Extensive areas are covered by swamps, limans, active and inactive deltaic channels etc. Holocene depositional complex overlies Late Pleistocene loess sediments and are 11-14, at places up to 20 m, in thickness. Holocene sedimenrs were studied by an extensive series of driling cores supported by the analysis of mollusc fauna, lithological studies and radiocarbon dating. Holocene sediments are represented by the intricate intercalation of alluvial, deltaic, liman and coastal sediments (**Fig. 2**). They form several coastal complexes, both submerged and emerged. The most indicative features of these complexes are coastal depositional barriers composed primarily of shells and detritus (up to 70-80%) with fine quartz sand. Radiocarbon dating was carried out on inner layers of thick *Cerastoderma glaucum (Cardium edule)* shells from these barriers (Izmailov et al., 1989).

Our studies distinguish five primary coastal complexes:

(1) A submerged coastal complex at minus 8.6-9.9 m dated from 7380 a BP (Vityazevian stage)

(2) A submerged coastal complex at minus 3-5 m. It is preliminarily correlated with the Kalamitian stage of the Black Sea (approx. 6-7 ka BP). However, direct radiocarbon datings have not been obtained yet. The maximum inundation of the coastal area, up to 43 km in width, occurred during this period

(3) An emerged coastal complex at plus 0.5-2.5 m with ages from 5.7 to 4.5 ka BP (Dzhemetian stage). The mollusc fauna of this period indicates the highest salinity during the Holocene. This fact confirms the most intensive water exchange with the Black Sea possibly resulting from the highest sea-level during the Holocene

(4) An emerged coastal complex at 0-plus 1.5 m aged from 2.2-1.7 ka BP (Nymphean stage). This complex is similar in morphology and altitudes to the previous one but is clearly differentiated from it by its position nearly 8-10 km to the west

(5) The present coastal barriers with elevations of up to 1.5 m above MSL.

In general, landward migration of the shoreline occurred until the Middle Atlantic period (Kalamitian stage) and changed to its seaward migration since that time. This phenomenon is typical for many coasts of the world and is possibly conditioned by decceleration of sea-level rise during that period (Selivanov, 1996). Bearing data on these complexes in mind, relative sea-level position in the area during the Holocene transgressive stages can be estimated. It should be noted that complexes (4) and, possibly, (3) may have been partially modified in recent time by storm surges exceeding 3 m according to direct observations. It is reasonable also to allow for tectonic subsidence of the deltaic area. According to direct observations, rates of subsidence in the 20th century in the central part of the Kuban delta is nearly 4.5 mm/a and 3 mm/a in peripheral parts (Selivanov, 1995). A correction of 4.5 mm/a to the altitudinal position of respective sea-level indicators is made. However, such a correction should be regarded as an extreme one because mean rates of tectonic movements usually decrease drastically with the increasing time interval from decades to millennia (Selivanov, 1996). Additionally, changes in the sedimentary budget of particular deltaic areas due to migration of channels or position of barrier forms can not be excluded. In any case, correlation of transgressive phases with the Early Atlantic, Late Atlantic and Middle Subatlantic is obvious.

No direct indicators of low sea-levels during the Holocene regressive stages are available. However, beds of lagoonal silts and gyttja are situated not lower than minus 2 m. This level can be possibly regarded as the "base" for minimum sea-level position during the Middle and Late Holocene regressive stages.

The Late Holocene history of sea-level in the Black Sea is most reliably known owing to the abundance of archaeological sites of the Greek and Roman civilizations in the north-west of the sea, in Crimea, and in the Kerch Strait. Coastal depositional features and, rarely, erosional surfaces of the Novochernomorian transgression in the middle 1st millennium BC were occupied by ancient towns of Tira, Olbia, Khersones, Panticapaeum, Phanagoria, Dioskuria, etc. The lowermost built-up level of the 5th-3th centuries BC lies at 3-4 m below sea-level and in Dioskuria (near the present Sukhumi) even at minus 10 m (Agbunov, 1992). The ancient Istria in the Danube River delta was also inundated (Stefan, 1987).

Therefore, the sea-level during that time, known as Phanagorian regression, possibly fell by several meters. However, estimates of its lowermost position vary from minus 5-7 (Fedorov, 1985) to minus 8-10 (Ostrovskii et al., 1977), minus 10 (Shilik, 1997) or even to minus 13 m. Meanwhile, the most part of archaeological sites of that time are naturally situated in river mouths widely known as areas of recent submergence. The more reliable estimate of minus 3 m may be deduced from the studies of ancient Khersones, near the present Sevastopol in Crimea. On the Bulgarian coast, the terrace surface of supposedly Phanagorian age lies at minus 4-5 m.

The most recent coastal features in the Black Sea were first distinguished by Pavel Fedorov near the ancient town of Nymphei at the east coast of the Kerch Strait. Correlative, Nymphean, coastal depositional features (terraces, barriers, rarely spits) elevated up to plus 2.5-3 m are known from the north-west corner of the sea and from the coast of Bulgaria. In some places transgressive series overlay Greek (not Roman) cultural remnants and, therefore, may be dated from the 1st millennium AD. Meanwhile, Roman archaeological sites are always situated above the present sea-level. It may be deduced that the rise of sea-level after the Phanagorian regression began from the first centuries A.D. The few radiocarbon dates range from 1.5 to 1 ka BP. (Fedorov, 1985). The highest level of the transgression was possibly in the range of plus 1.5-2 m and, most probably, plus 1 m.

Later, the Black Sea water level gradually decreased until the middle of the 19th century. A number of researchers believes in its fall in Medieval times, namely 1.4-1.5 ka BP (Korsunian regression), to minus 2-3 (Shilik, 1997) or to minus 3-5 m (Ostrovskii et al., 1977). However, reliable geological and archaeological data on this regression are few in number as yet.

References

Agbunov, M. V., 1992. The antique geography of the North Black Sea Coast. Nauka, Moscow, 240 p. (in Russian).

Balabanov, I. P. and Izmailov, Ya. A., 1988. Changes in level and hydrochemical regime of the Black Sea and the Sea of Azov during the last 20 ka. Water Resour. 15, 539-546.

Fedorov, P. V., 1985. On water-level fluctuations in the Black Sea during the Holocene. In: Alexeev, M.N. (ed.): Geology and geomorphology of shelves and continental slopes. Nauka, Moscow, 131-136 (in Russian).

Izmailov, Ya. A., Arslanov, Kh. A., Tertychnaya, T. V. and Chernov, S. B., 1989. Reconstruction and dating of the Holocene shorelines in the Kuban River delta. Herald Leningrad St. Univ., ser. 7, 3, 61-69 (in Russian).

Kaplin, P. A. and Selivanov, A. O., 1999. Holocene sea-level data from the European coast and shelf of the Black Sea. Palaeoclimate Res., 21, spec. vol. 14, 168-179 (in press).

Molodykh, I. I., Usenko, V. P., and Palatnaya N. N., 1984. Limany: Geology of the Ukrainian SSR shelf. Naukova Dumka, Kiev, 176 p. (in Russian).

Ostrovskii, A. B., Izmailov, Ya. A., Shcheglov, A. P., and Arslanov, Kh. A., 1977. New data on Pleistocene stratigraphy and geochronology from marine terraces of the Caucasian Black Sea coast and Kerch-Taman region. In: Alexeev, M.N. (Ed.), Pleistocene palaeogeography and sediments of the southern USSR seas. Nauka, Moscow, 61-68 (in Russian).

Selivanov, A. O., 1995. Possible future coastal evolution of the North Black Sea and the Sea of Azov under greenhouse-induced sea-level rise. Proc. Int. Conf. Coastal Change'95. Bordomer-IOC, Bordeaux, 44-59.

Selivanov, A. O., 1996. Morphological changes on Russian coasts under the rapid sea-level changes: Examples from the Holocene history and implications for the future. J. Coast. Res., 12 (4), 823-830.

Shcherbakov, F. A., 1983. Continental margins in the Late Pleistocene and Holocene. Nauka, Moscow, 214 p. (in Russian).
Shilik, K.K., 1997. Oscillations of the Black Sea and ancient landscapes. Colloquia Pontica, 3, 115-130.

Stefan, A.-S., 1987. Evolution de la cote dans la zone des bouches du Danube durant l'antiquite. In: Kraft J. (ed.) Deplacements lignes rivage Mediterr: D'apres donnees l'archeol. CNRS, Paris, 191-209.

Svitoch, A. A., Selivanov, A. O., Yanina, T. A., 1998. Pleistocene Palaeogeographic Events in the Ponto-Caspian and Mediterranean Basins: Data on Reconstruction and Correlation/ Moscow State University, Moscow, 292 p (in Russian).

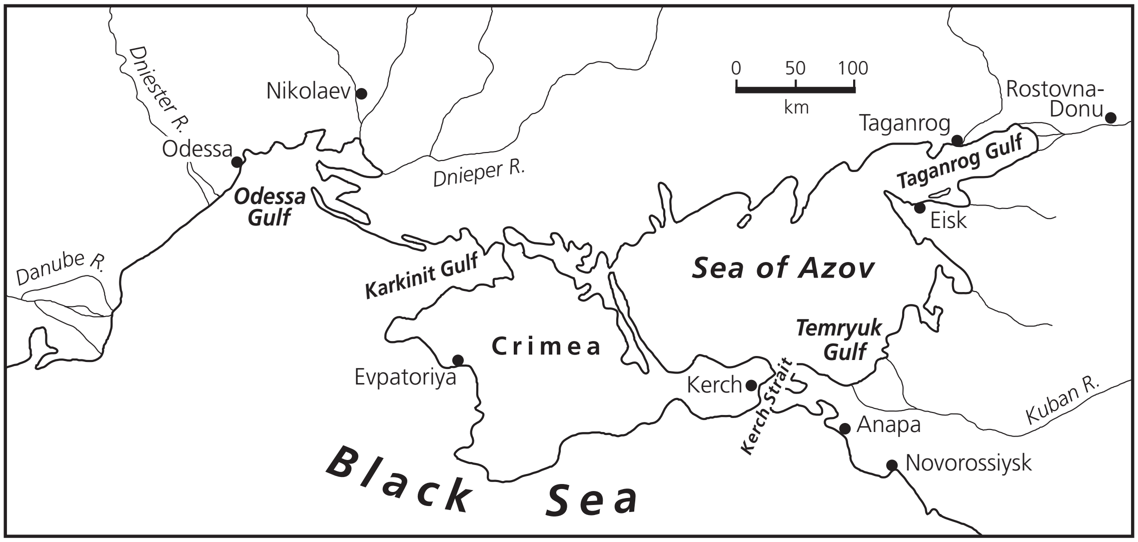

Fig. 1. General scheme of the North Black Sea and the Sea of Azov

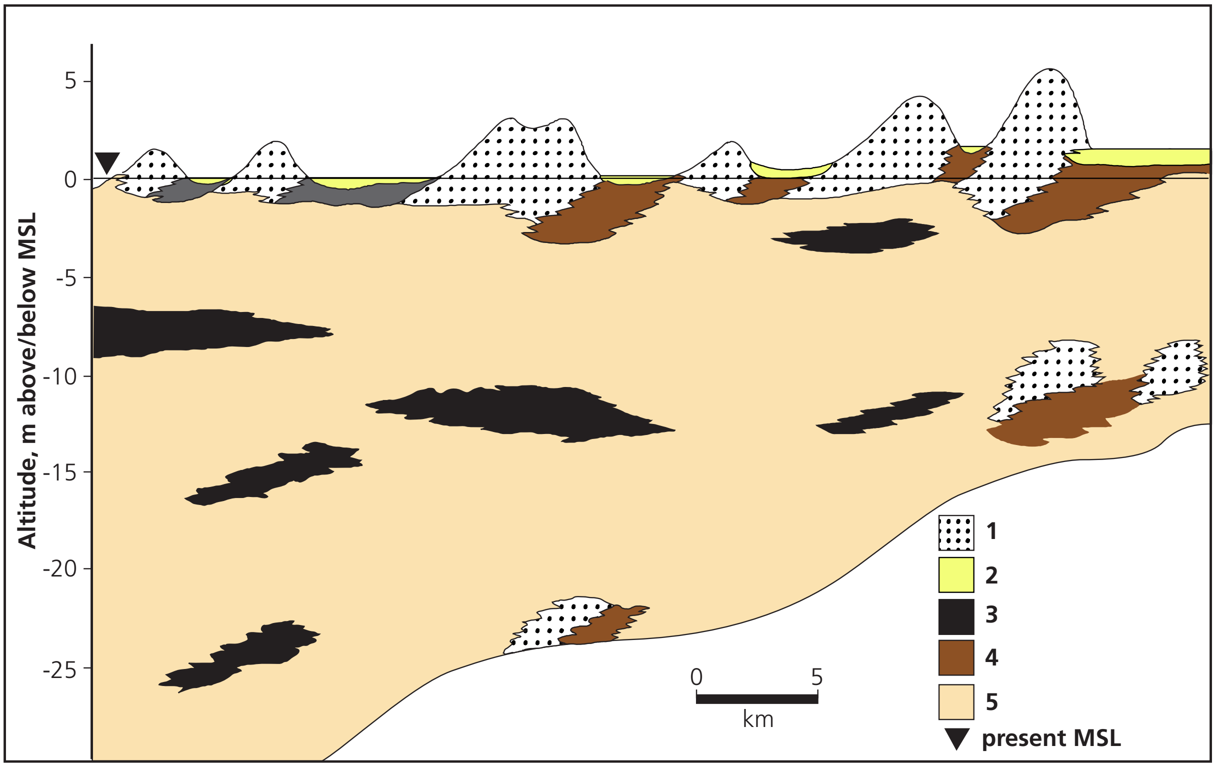

Fig. 2 Schematic geological profile of the Holocene sediments in the Kuban River delta: (1) sandy shells of coastal barriers; (2) lagoon silts and gyttia; (3) lagoon peats; (4) deltaic silts and sandy silts with peat layers; (5) deltaic shell sands and loams; (6) present mean sea-level.

Global meltwater discharge and the deglacial sea-level record from Scotland

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Quantitative models of earth-ice sheet-ocean interactions predict that periods of rapid eustatic sea-level rise, indicating enhanced meltwater discharge to the oceans, should be manifest in the relative sea-level histories from sites within the limits of Late Devensian ice sheets. Areas once under thickest ice record exponentially falling relative sea-levels since deglaciation. The rate of uplift is so great in such areas that any meltwater pulses are predicted only as temporary changes in the rate of sea-level fall. Resolution of the age and altitude of sea-level index points make it difficult to quantify variations in the rate of sea-level fall with the precision necessary to identify the meltwater pulses. In contrast, the same models predict that sites in Scotland, where the ice sheet was much smaller, will have a highly non-monotonic pattern of sea-level-change and also predict that at least one meltwater peak, ~14,000 yr BP, should be recorded as a temporary change from sea-level fall to sea-level rise of ~5m in 1,000 years.

Analysis of a record of relative sea-level change for the last 16,000 years from Scotland constrains the magnitude and timing of two major pulses of meltwater, ~14,000 and ~11,300 calendar years BP, inferred from coral records. The lithologies and microfossils from isolation basins 15m – 20m above present sea-level in the Arisaig area of NW Scotland constrain the magnitude of the meltwater pulse ~14,000 yr BP to an equivalent sea-level rise about 22mm/yr (~8,000 km^3/yr meltwater discharge). The second meltwater pulse ~11,300 yr BP is not evident from either the lithology or biostratigraphy of the isolation basin sediments. These results indicate little change from a eustatic rise ~10mm/yr (3,600 km^3/yr). If meltwater pulses are trigger mechanisms for major climate changes then we need to understand better and quantify the mechanisms by which meltwater discharges much smaller than previously envisaged can lead to non-linear changes to global systems.

Accretion and diagenesis of Pleistocene reefal carbonates from a nearshore submarine terrace, Oahu, Hawaii

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Results of sedimentologic and geochronologic investigations of a nearshore terrace begin to fill important gaps in the Pleistocene carbonate record of Oahu and provide information on reef accretion and paleo-sea-level during periods when sea-level was below present within marine oxygen isotope stage 7 and the latter part of isotope stage 5. The shallow submerged slope of Oahu consists of a shallow-dipping shelf extending from the shoreline out to the ~-20 m contour where there is a sharp break (wall) down to ~-30 m forming the start of a deeper terrace. The composition as well as shoreward zonation of facies suggests that the nearshore terrace consists of *in situ* fossil reef tracts. Th-U ages of in situ corals indicate that the terrace complex is entirely Pleistocene in age and suggest that the bulk of the feature is composed of a fossil reef complex formed during marine oxygen isotope stage 7. Later accretion along the seaward front of the terrace occurred during the latter part of stage 5 (post-5e). Reefal units from these periods are not documented in the emerged carbonate record of Oahu.

Although the diagenetic record is incomplete, three periods of diagenesis are identified: early shallow marine, meteoric, and post-meteoric shallow marine. The present seafloor is undergoing extensive biological and physical erosion. No Holocene limestones were recovered. Petrographic and geochemical signatures of subaerial exposure and meteoric diagenesis are recognized in the upper several centimeters of all cores. Thus, the present seafloor in the study areas is a flooded Pleistocene subaerial exposure surface.

A record of coastal change preserved in high-stand littoral lakes from a stable passive margin (central eastern coast of Australia)

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Introduction

The Myall Lakes system of the central NSW coast of Australia (latitude 32°30' S) contains a continuous epiclastic and bioclastic sequence that is at least 42,000 years old (oxygen isotope stage 3). The lake system lies within the Great Lakes Shire, about 150 km north of Sydney (**Fig. 1**). Previous studies of Quaternary sedimentation along this part of the coast, notably Melville (1984), Thom *et al.* (1992) and Roy & Boyd (1996), have dealt mainly with the age, structure and distribution of highstand beach ridge systems. A preliminary study of sediments within Myall and Smiths Lakes, two of the lakes within the coastal system, is presented here.

The southeastern Australian coast is a wave-dominated sediment-deficient stable passive margin (Roy & Boyd, 1996) that formed during opening of the Tasman Sea 80-55 million years ago (Weissel & Hayes, 1977). Both lakes in the study area overlie irregular Carboniferous (~320Ma) basement comprising rhyodacitic-to-basaltic forearc basin volcanics and metasediments of the New England Fold Belt (Skilbeck & Cawood, 1994) and most of the small islands within the lakes are basement outcrops. Myall Lake lies within 2.5 km of the Tasman Sea from which it is separated by sandy Late Pleistocene and Holocene dune systems (Roy & Boyd, 1996, **Fig. 1**). To the north and west, basement rocks outcrop around the lake shores. An indirect connection with the sea is located approximately 30 km to the southwest of the study area at Port Stephens. Despite this connection, and its proximity to the sea, Myall Lake contains virtually fresh water (2-3 ppt) and has no existing tidal or external wave current influences. The maximum water depth approaches 5m. This situation is unique along the NSW coast where all other lakes, including the adjacent Smiths Lake, are either directly or periodically open to the sea and contain widespread reworked sand deposits.

Data Base

We have recovered 32 cores from Myall Lake and 8 from Smiths Lake (**Fig. 1**). Sediment recovery is restricted by the vibrocoring method employed but ranges from 0.45m (ML29) to 6.95m (ML11). From these cores we have defined many of the physical parameters that are important in interpreting the evolution of the lakes including stratigraphy, depositional environment, and sediment composition and spatial distribution.

We have so far attempted a single-channel seismic survey within Myall Lake but an abundant aquatic flora dominated by *Najas marina* (prickly waternymph) has resulted in a noisy signal with poor subbottom definition.

Stratigraphy and Composition

Seven main and five subordinate facies have been identified from the unconsolidated sediment of the lakes. In the central part of both, three organic facies are present; an uppermost gyttja (facies 1) comprising olive-yellow/green amorphous organic matter (AOM) (**Fig. 2A**), sapropel (facies 3) mainly dark brown to black silty clay, AOM and disseminated plant material (**Fig. 2C**), and peat (facies 4) which is brown to dark brown friable plant debris. Silty clay with disseminated sand (facies 2) (Figure 2A,B), and a palaeosol unit comprising brown silty clay with rootlets (facies 5, **Fig. 2E**), are interbedded with the organic-rich facies. Around the northern and western shores of the lakes irregularly distributed lithic sand (facies 6), clearly derived from the Carboniferous basement, predominates. Along the southern and eastern shores, quartz-rich sand representing the distal edges of the marine dune system, dominates (facies 7). Thin disseminated quartz sand layers and shells (**Fig. 2B**) are present within the finer-grained facies, particularly facies 2. The sands are not sufficiently widespread to permit correlation within the lithostratigraphic units, but two prominent shell layers near the base of the younger facies 2 layer across most of Myall Lake may represent time-lines. These are currently being ^{14}C dated.

Minor facies include clay-rich sapropel, various mottled sandy-muds (mostly restricted to the lake margins) and humate-impregnated sandy podsol. In the northern part of Myall Lake and in Smiths Lake, silty-clay (facies 2) units are commonly mottled with irregular orange stains (Figure 2D) which are interpreted to result from periodic subaerial exposure of material that was originally deposited subaqueously. The facies form well-defined stratigraphic units which can be correlated across the lakes (**Figure 3**).

Twenty-two carbon analyses have been carried out at a down-hole spacing of 10 cm on Core ML19. Total carbon ranges between 1.16 and 36.45% and variation corresponds well with the visible lithostratigraphy (**Fig. 4**). One disappointing aspect is the virtual absence of inorganic carbon in the sediments (Figure 4). The two shell bands mentioned above, and rare isolated macroshells elsewhere, are the only skeletal carbonate present. Carbonate microfossils are absent, but we are hopeful that stable oxygen isotope analyses can be carried out on siliceous microfossils (Figure 5). Other selected elemental analyses shown on **Fig. 5** were determined by x-ray fluorescence and confirm the chemical variability of the lithofacies.

Age and Rate of Sedimentation

The sediments have been placed into a broad temporal framework based on 8 AMS ^{14}C dates (**Fig. 6**) of bulk sediment sample from core ML19. The age data indicate that the sequence: 1. extends back at least 42,000 years (^{14}C detection limit) and 2. is not grossly affected by bioturbation, so is in chronological order. Combined with the recognised facies, these data demonstrate that the lake has undergone at least two major environmental changes, one at ~38,000 yr BP and the other at around 8,900 yr BP.

If we assume that the layers are isochronous, sedimentation rates can be calculated for the main facies. The oldest dated unit is the peat (facies 4) which accumulated from 42,300-37,600 yr BP at a rate of 11cm/ka. This was followed by the sapropel layer which was deposited at an average rate of 5 cm/ka in the southern and eastern parts of Myall Lake, until rising sea-level in the Holocene reached the lake about 8,900 yr BP. Since then silty clay has been the sediment accumulating over much of the lake area. It has been deposited at a relatively slow average rate of 27cm/ka which is not unexpected given the small catchment area. Gyttja has been accumulating over the last 1200 years at an average rate of 45cm/ka, however, as this layer is uncompacted, the rate should not be considered indicative.

Because of the detection limits on ^{14}C dating (~45-50,000 yr BP) we have yet to determine an age for the brown silty palaeosol (facies 5) and underlying sediments. Technical limitations of the vibrocoring method employed for this study mean that we are yet to reach the base of the Quaternary sequence. There is no reason, however, why the sediments could not date back to the last interglacial.

High Resolution Records

Within the broad stratigraphic framework provided by the radiogenic dates and the distribution of seven major lithofacies, we have established *prima facie* evidence for high-resolution correlation within each facies, using down-hole variation in magnetic susceptibility (**Fig. 7**). The data were collected at a 1cm spacing on split cores removed from the Al casing, using a Bartington MS2E/1 high resolution sensor, and the profiles are presented herein as 3-point moving averages. We are currently dating the more prominent peaks to test isochroneity.

The sediments also contain a continuous palynological record. Identification and interpretation of this is being conducted by Professor Eric Colhoun and co-workers at the University of Newcastle, and should be complete by the end of 1999. We have demonstrated viability of the technique for high-resolution correlation both within Myall Lake and between Myall and Smiths lakes (**Fig. 8**). We believe there is also good first order evidence that downhole variation in susceptibility correlates with the SPECMAP oxygen isotope curve (**Fig. 6**) to mid oxygen isotope stage 3. Beneath this, the curve has been matched on shape alone and would require an improbable sedimentation rate of ~2cm/ka to achieve the match. As there is a broad correlation between susceptibility and both bulk sediment grainsize and carbon content (Figure 4), we now need to demonstrate the downhole variation has not been produced by local depositional mechanisms or subsurface alteration before it can be employed as an oxygen isotope proxy in the absence of carbonate microfossils.

Environmental Interpretation

Our interpretation of the data currently available is that the lake level was approximately 5.8m lower during the period between ~37,000 and 8,900 yr BP than it is at present. During this period, silty-clay sediments deposited either during the previous sealevel highstand, or during intermittent flooding events, were exposed to subaerial processes, including oxidation and erosion. Prominent orange mottling in facies 5 sediment and strong positive magnetic susceptibilities in cores from above –5.8m below current lake water levels (**Fig. 8**) support this scenario. Cores recovered from deeper parts of both lakes do not show evidence of subaerial exposure suggesting that swamp or wetland environments were maintained in restricted areas, even though sea-level may have been between 70 and 120m lower than it is today. Peat and sapropel development was restricted to the southern and eastern parts of Myall Lake only – in the northwestern part of Myall Lake Holocene lake fill unconformably overlies the palaeosol facies. Climate conditions during the period(s) of flooding, and the extent of removal of exposed sediment have yet to be established. By 8,800 yr BP sea-level had risen to flood the former swamp and continued across the present geographic extent of the lake.

Acknowledgements

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References

Melville, G., 1984. Headlands and Offshore Islands as dominant controlling factors during Late Quaternary Barrier Formation in the Foster-Tuncurry Area, New South Wales, Australia. *Sedimentary Geology* 39, 243-271

Roy, P. S. and Boyd, R., 1996: Quaternary geology of a tectonically stable, wave-dominated, sediment-deficient margin, southeat Australia. IGCP Project #367, Field Guide to the central NSW coast. November 1996, NSW Geological Survey. 174p.

Skilbeck, C. G. and Cawood, P. A., 1994: Provenance history of a Carboniferous Gondwana margin forearc basin, New England Fold Belt, Eastern Australia: Modal and geochemical constraints. *Sedimentary Geology* 93, 107-133.

Thom, B. G., Shepherd, M. J., Ly, C. K., Roy, P. S., Bowman, G. M. and Hesp, P. A., 1992: Geomorphology and Quaternary geology of the Port Stephens-Myall Lakes area. Department of Biogeography and Geomorphology, Australian National University. Monograph 6, 407p.

Weissel, J.K. and Hayes, D. E., 1977: Evolution of the Tasman Sea re-appraised. *Earth and Planetary Science Letters* 36, 77-84.

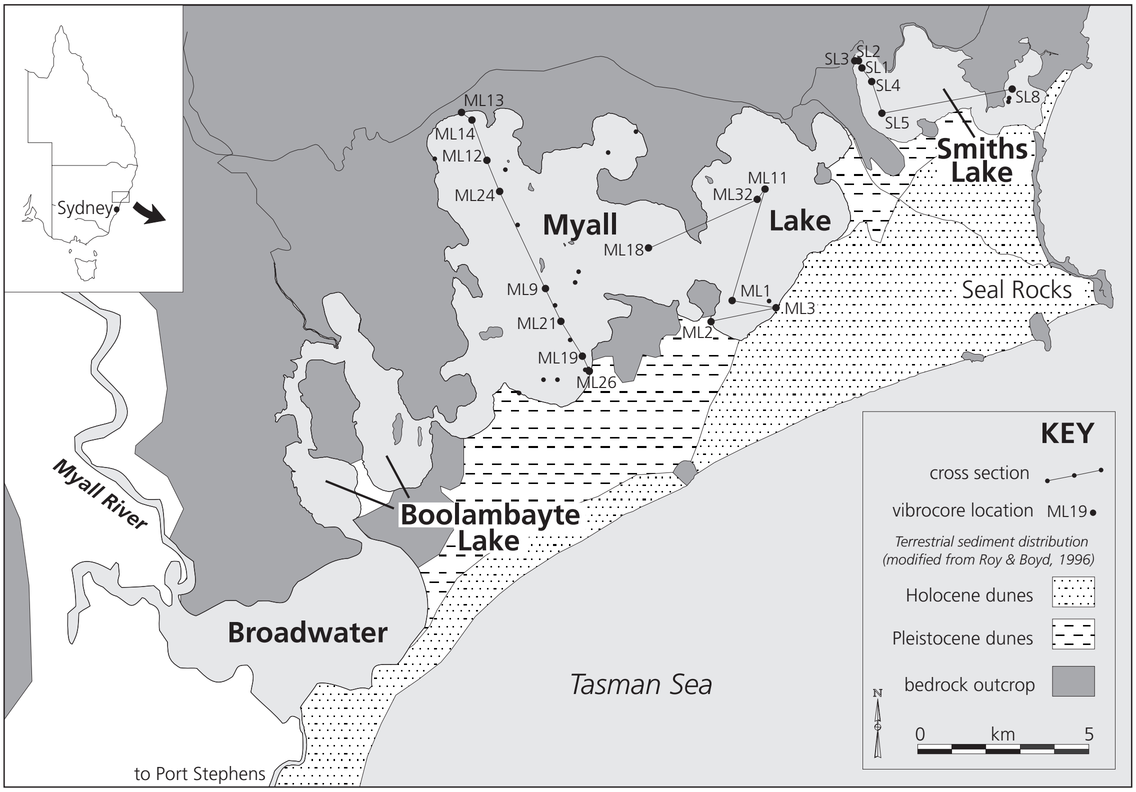

Fig.1 Myall Lakes system showing location of cores and cross sections

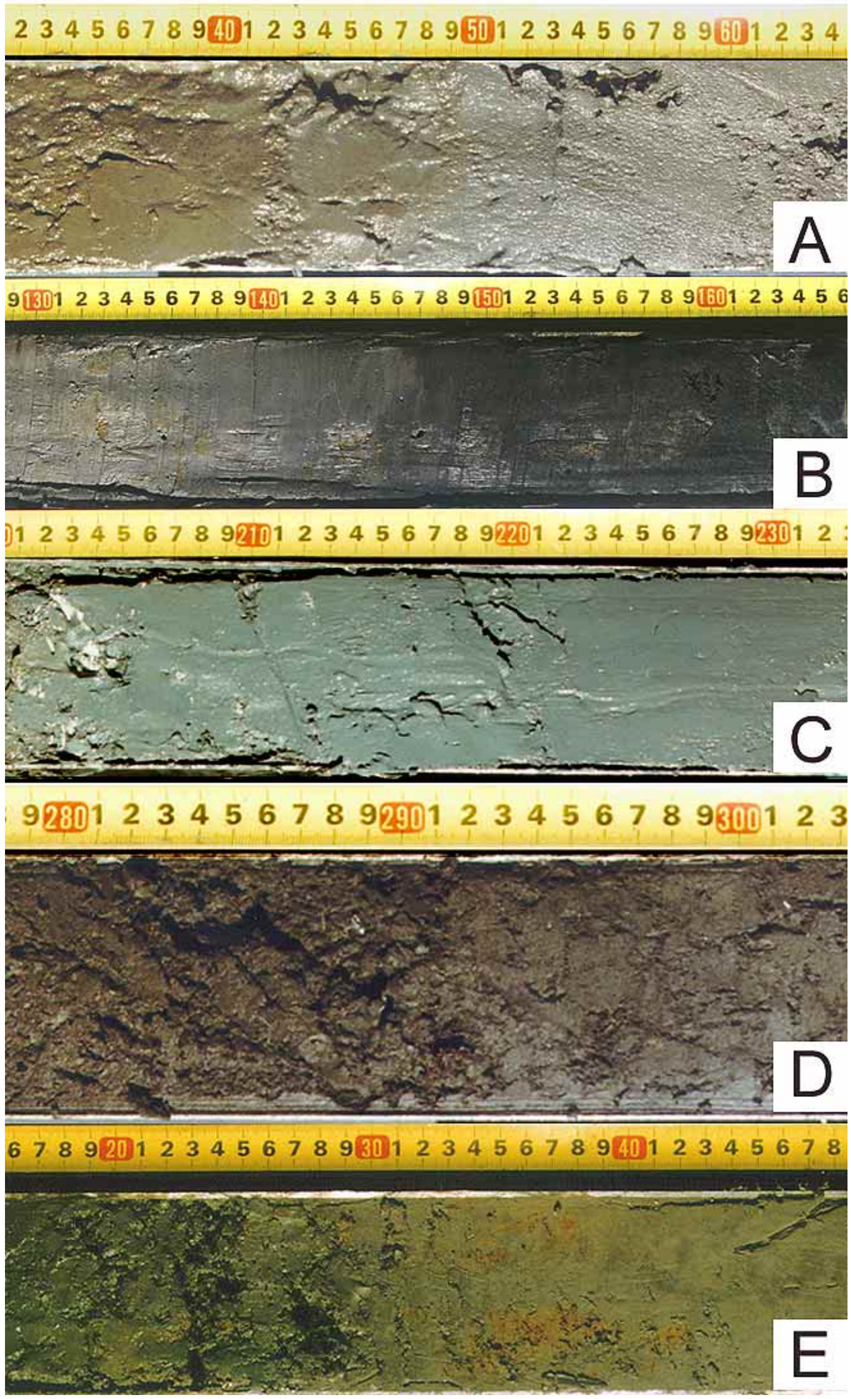

Fig 2 Representative core photographs (see text for description). (A-ML9, B,D:ML19, C:ML11, E:SL4)

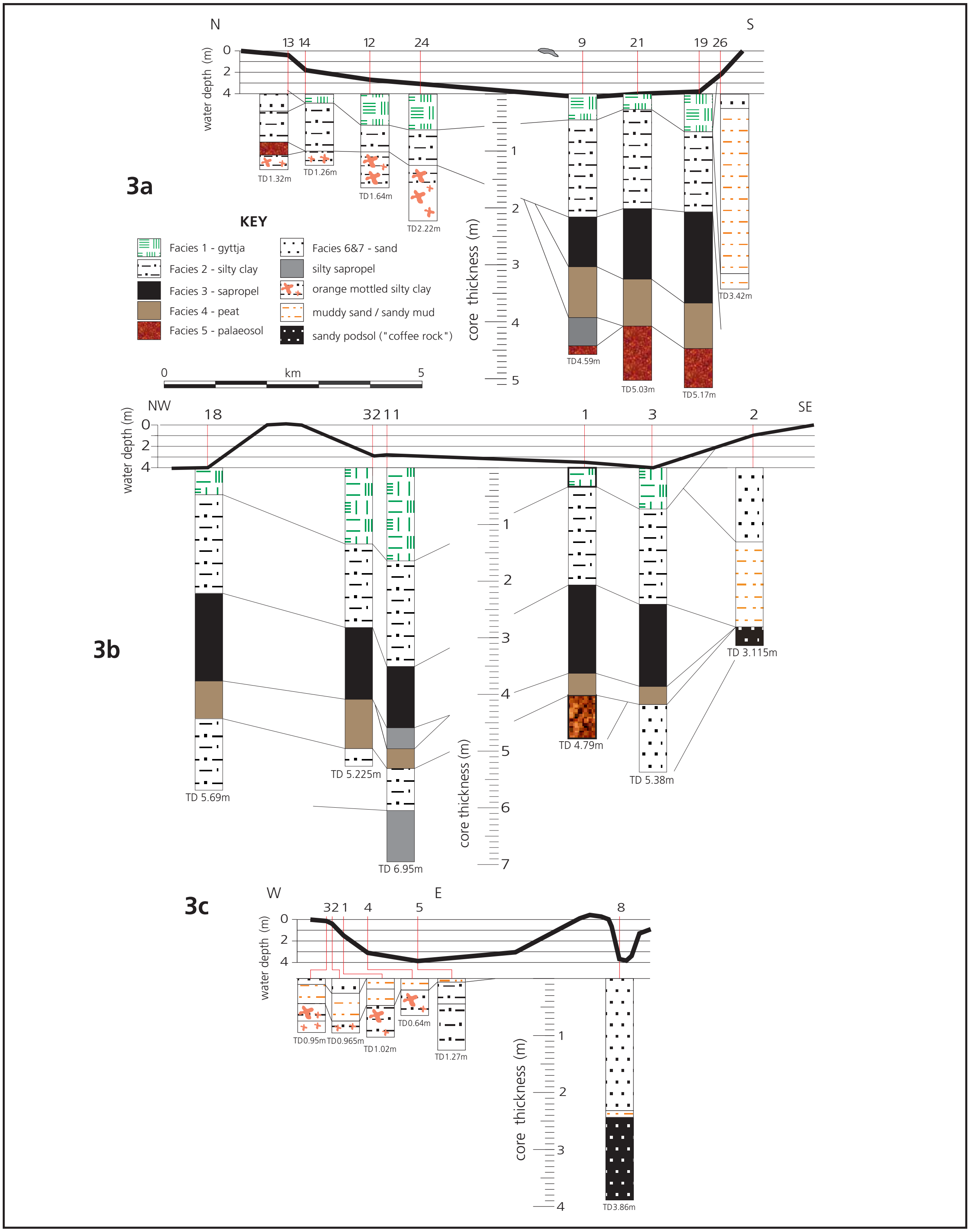

Fig. 3 Cross sections showing correlation of Quaternary facies in Myall (a,b) and Smiths (c) lakes.

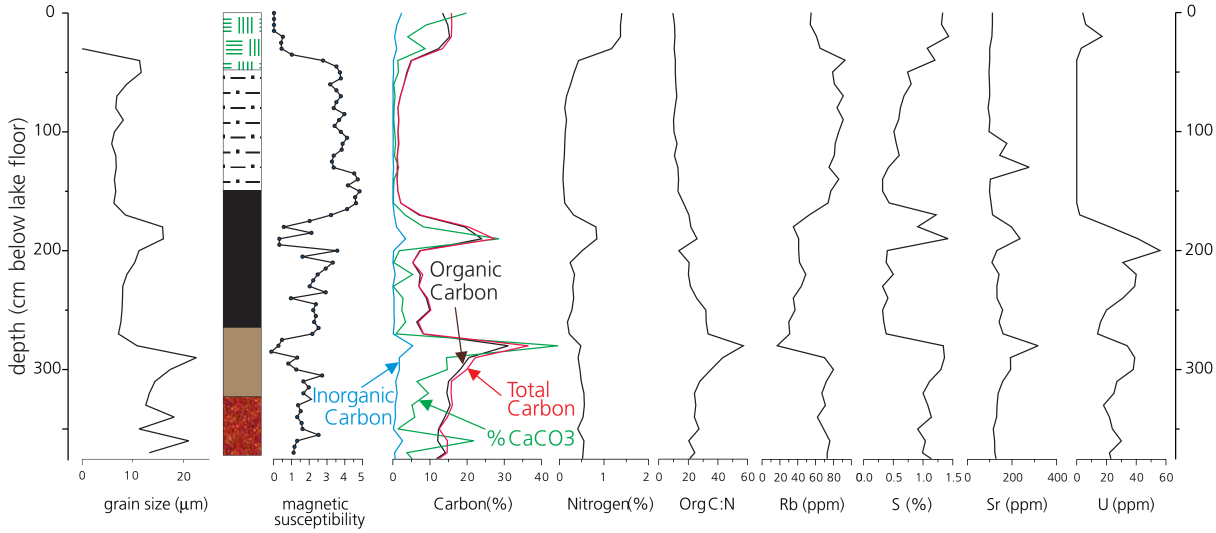

Fig. 4 Downhole variation in selected physical and chemical parameters in ML19. See Fig. 3 or Fig. 8 for lithology legend.

Fig. 5 Siliceous spicules from 240cm (core depth) in ML19.

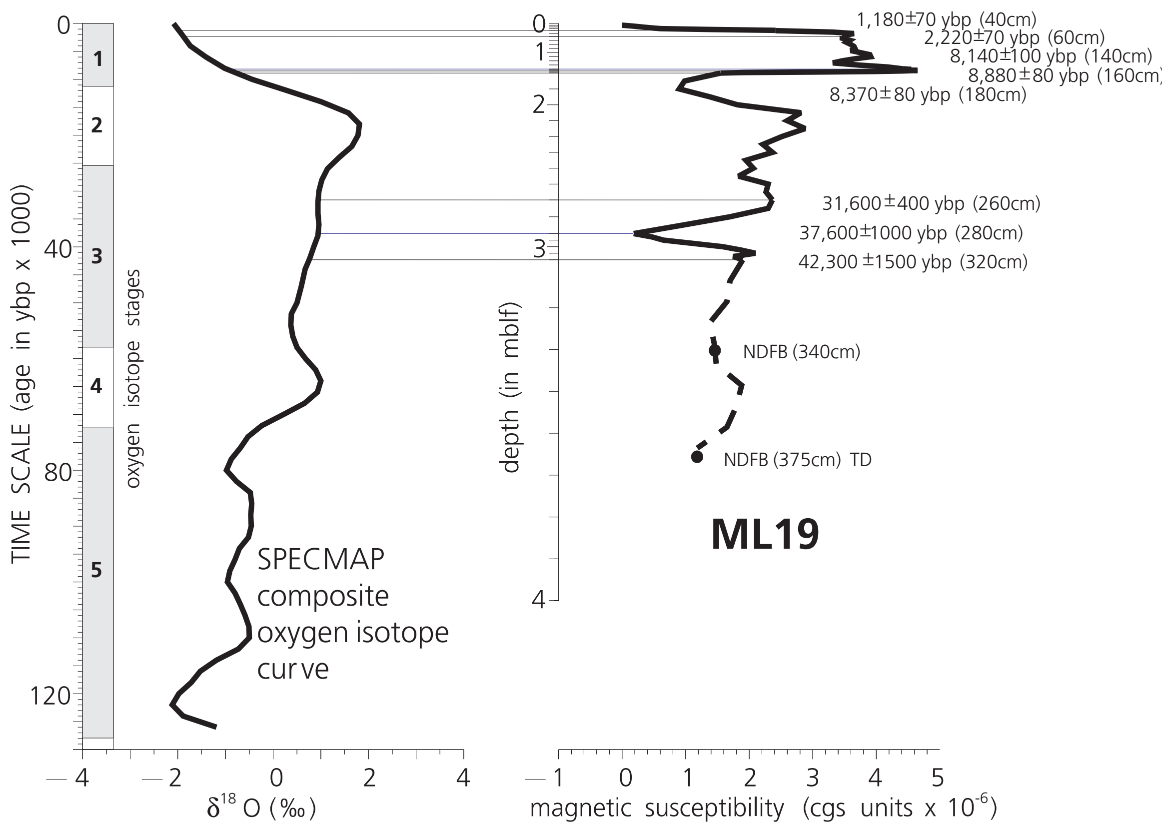

Fig. 6 Correlation between magnetic susceptibility in ML19

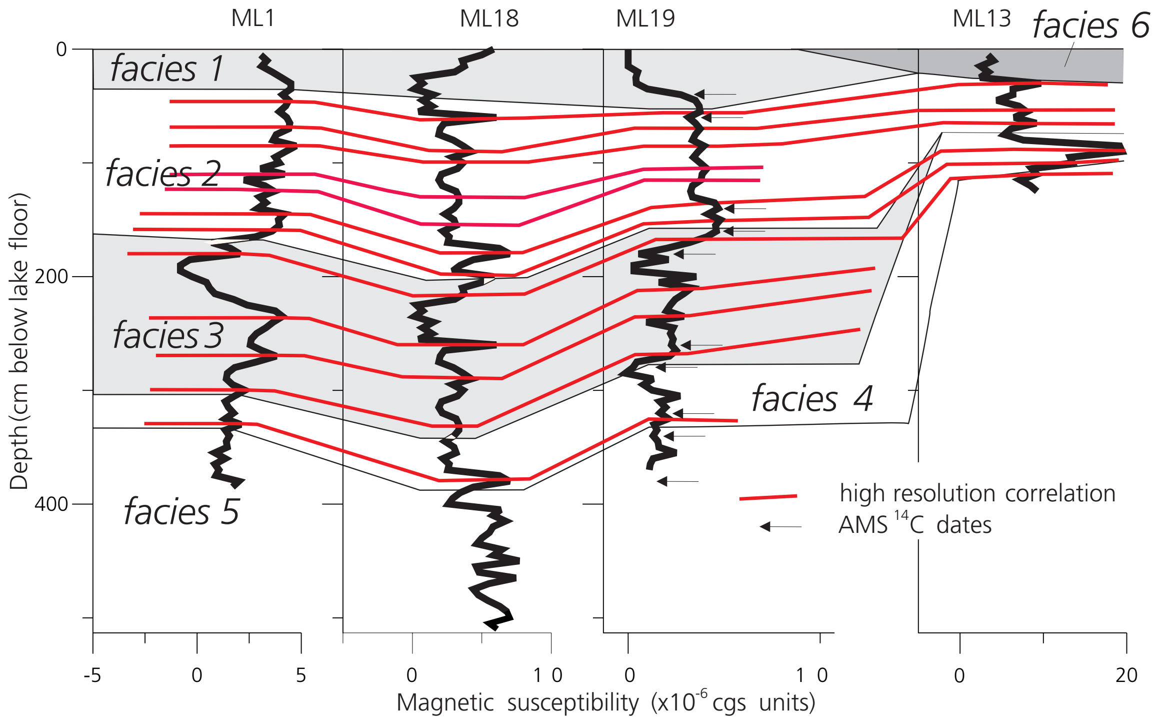

Fig. 7 Correlation of magnetic susceptibility profiles for Myall Lakes cores.

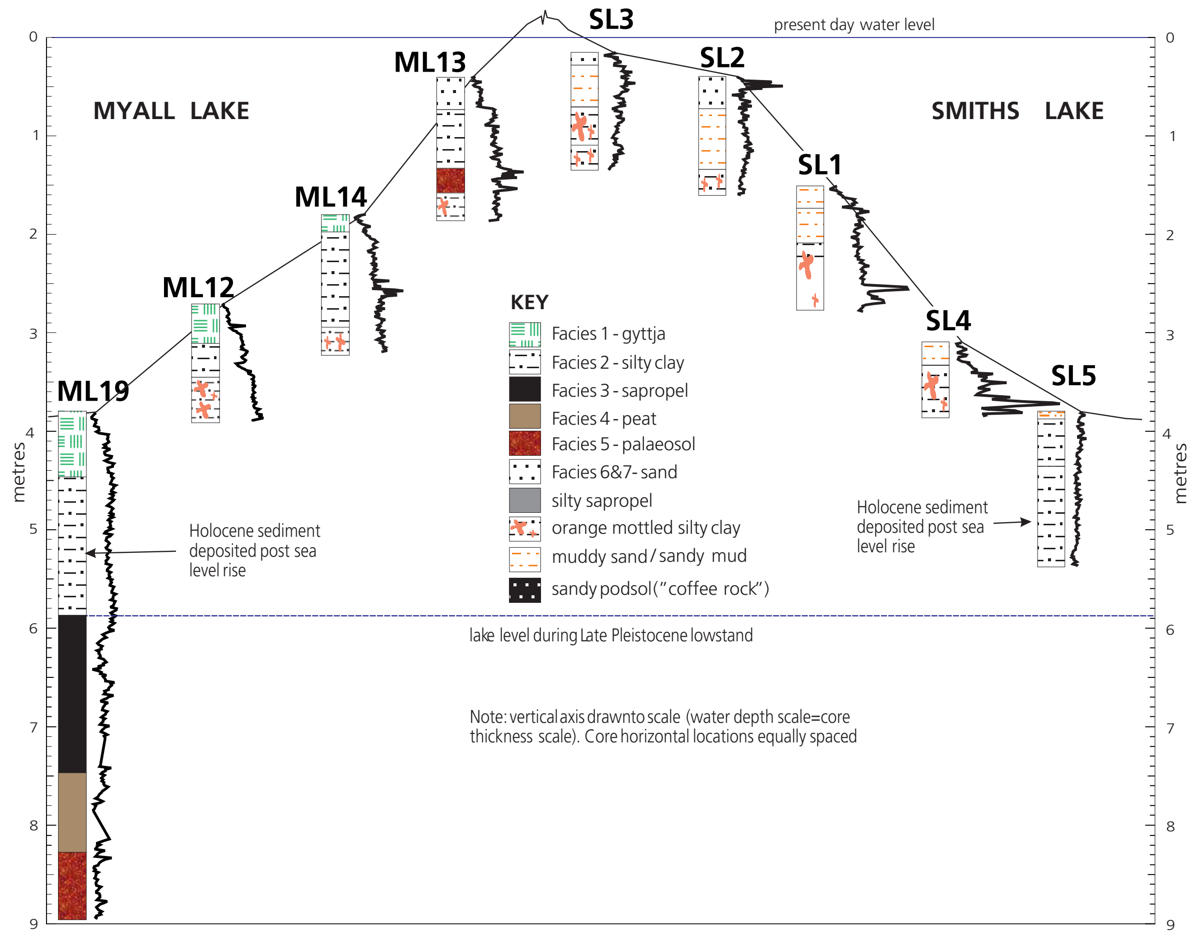

Fig. 8 Correlation of magnetic susceptibility profiles between Myall and Smiths Lake showing peaks associated with weathered units.

The Mid-Holocene rise in sea-levels off Northwest Europe

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A prominent feature of the sea-level record during the Holocene is the rapid rise which took place in North West Europe between circa 8500 and 6000 radiocarbon years BP. This is well documented in many sea-level curves, summarised in Pirazzoli (1991).

During this event, sea-levels may have risen by at least 25m, possibly continuously. Coastal areas were progressively inundated, particularly away from those areas experiencing glacio-isostatic uplift, where the rise was less marked.

Determination of the rate of sea-level rise is difficult yet it is essential to understanding the response of coastlines to the changing water level. Most graphs of sea-level change only record the rise between index points at the beginning of the rise and those at the culmination, so that no information is presently available for the detail of the rise or if any variation in the rate occurred during this period. However, recent work in Scotland is beginning to disclose the detail of the rise and identify its commencement more precisely than has hitherto been possible. In addition, a marker horizon towards the end of the rise has been identified, in the sand layer deposited during a major tsunami, the Storegga Tsunami. These developments make assessment of the detail and rate of the rise possible for the Scottish coastline.

In the light of these developments, this paper examines the timing, detail and rate of the mid-Holocene rise around the northern and eastern Scottish coastlines. The sites examined show that the overall rate of rise increases away from the glacio-isostatic uplift centre, and that within the rise there is a progressive increase in the rate towards the end of the event, presumably reflecting the decline in glacio-isostatic uplift.

The evidence from across the Scottish glacio-isostatic uplift centre permits an assessment of the rise in areas beyond the area affected by glacio-isostasy, by comparison with available published information from the adjacent coasts of England and the European mainland. Estimates are provided of the rate of sea surface rise during this event and comparisons are made with the sea-level graphs for this period of Fairbanks (1989), Blanchon and Shaw (1995) and others.

References

Blanchon, P. and Shaw, J., 1995. Reef drowning during the last deglaciation: evidence for catastrophic sea-level rise and ice-sheet collapse. Geology, 23, 4-8.

Fairbanks, R. G., 1989. A 17,000-year glacio-eustatic sea-level record: influence of glcial melting rates on the Younger Dryas event and deep-ocean circulation. Nature, 342, 637-642.

Pirazzoli, P. A., 1991. World atlas of Holocene sea-level changes. Elsevier, Amsterdam.

The influence of tectonics and sea-level fluctuations on sediment distribution and modes of littoral transport along the rocky inner shelf of central California

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Introduction

The shoreface and innermost shelf of northern and central California are sparsely covered with sediment and have bedrock exposed in many nearshore areas. Bathymetric variations along this area commonly mirror the onshore topography, with headlands typically extending offshore as rocky bathymetric highs and pocket beaches or coastal stream valleys fronted by more gently sloping bathymetric depressions. This type of coast, common to areas of tectonic uplift and glacio-static rebound, pose significant problems to modeling nearshore hydrodynamics and littoral transport. Although rocky, cliffed coasts characterize many shorelines worldwide, there is seemingly little information documenting shoreface morphology and its control on local sediment processes. Our goal here is to summarize recent studies with emphasis on the linkages between shoreface morphology and modes of littoral sediment transport along rocky coastlines.

Methods and Results

Remote sensing and geophysical surveys were used to image much of the shoreface along the Monterey Bay National Marine Sanctuary, California. High-resolution seismic reflection data and side-scan sonar images provided information on the inner shelf at depths greater than 10 m while aerial imagery was used to image the surfzone and the upper shoreface to depths of approximately 15 m. Three dominant modes appear to characterize the distribution of littoral sediments along the study area:

1) Shore-parallel patches of sediment at depths greater than 15 m as shown schematically in **Fig. 1a**.
2) Shore-parallel ribbons of sediment in shallow (2 m to 6 m) depths connecting shore-normal sediment-filled depressions that merge at depths greater than 15m (**Fig. 1b**).
3) Shore-normal sediment-filled depressions between barren rocky bathymetric highs that coalesce at depths greater than 15m (**Fig. 1c**).

All of this littoral sediment is situated within the depth zone for dynamic suspension and transport by wave orbital motions (Hunter et al., 1988) and above the ‘closure depth’ determined for locations in the study area (Hallermeier, 1981; Seelbach, 1993; Tait, 1995). These sediments are typically found in areas of negative relief or on more gently sloping areas that characterize the nearshore and inner shelf off most beaches along the study area. Most of the shore-normal patches of sediment are found in depressions offshore present or paleo-stream channels that we interpret to be the result of fluvial incision during periods of lower sea-level. Shore-parallel ribbons of sediment are generally observed along sections of shoreline oriented approximately normal to the dominant wave and wind direction either (a) at depths greater than 15m (**Fig. 1a**), or (b) in a narrow zone between a depth of 2 m and 6 m that is typically bounded to the offshore by more steeply sloping outcropping bedrock (**Fig. 1b**). This shallow zone of alongshore sediment transport lies within the depth range for active bi-directional transport for pocket beaches in northern Monterey Bay (Hallermeier, 1981; Seelbach, 1993). The morphology and distribution of these shore-normal sediment-filled channels appears to be a function of the size and location of onshore drainage basins; a high correlation between drainage basin area and the mean width of these shore-normal features is observed.

Discussion

The drainage patterns along the central coast of California are largely dictated by the northwesterly-trending local fault patterns and tectonics associated with the Pacific-North American plate boundary. These drainages developed along structural weaknesses and their courses were determined by the local topography. During periods of lower sea-level, these streams flowed across the continental shelf and discharged at or near the shelf edge. At this time, these streams incised the bedrock along the present nearshore and inner shelf with a drainage pattern similar to that observed onshore today. As sea-level rose, these channels were inundated and filled, probably initially with stream sands and gravels, followed by nearshore beach sands. Many of the channels are still serving as catchment basins for sediment transported alongshore, while others are filled completely; they both, however, undergo substantial seasonal fluctuations. The combined effect is a general framework that was shaped by local geologic structure and further modified by fluvial incision during sea-level oscillations.

The dominant oceanographic regime provides a key secondary influence on sediment distribution. Wave and wind approaches determine the primary direction of sediment transport over intermediate time-scales and the bathymetry and shoreline orientation dictate wave refraction patterns, the resulting wave energy gradients, and wave-driven currents. These gradients and currents then define the finer-scale modes and directions of sediment transport as reflected in the beaches' mineralogic and textural properties.

The shore-normal bathymetric depressions that we interpret to be paleo-stream channels have maximum relief on the order of 10 m (Tait, 1995). This relief creates barriers to alongshore transport and precludes significant alongshore transport by conventional littoral currents that are common to sandy shorelines. While littoral sediments have been shown to move downcoast along the rocky shoreline of central California, headland bypassing and/or transport outside of the surf zone substantially reduces the efficiency and complicates the pathways of transport. This inefficiency and the non-continuous nature of alongshore littoral transport is reflected in the wide variation in morphologic, mineralogic, and textural properties observed between pocket beaches. Alongshore transport in our study area is therefore dependent on high orbital wave velocities and bed shear stresses to resuspend sediment to sufficient heights that will allow alongshore flow to transport the sediment over the intervening bedrock highs and into the paleostream channels downcoast. This is in contrast to much of the U.S. Atlantic and Gulf coasts where wind-driven and/or tidal currents are the primary forcing factor in the alongshore transport of suspended sediment on the inner shelf. Since these highly energetic conditions are often the result of local storm activity, it seems evident that the frequency and intensity of storms exerts significant control on the timing and magnitude of sediment transport along rocky coastlines.

Conclusions

First order controls on the distribution and transport of littoral sediments along the rocky, sediment-deficient nearshore and inner shelf off northern and central California are the historic tectonic regime intrinsic to the region and the oceanographic forcing that acts to modify the patterns imposed by the geologic structure. Much of the shoreline of the Monterey Bay National Marine Sanctuary is characterized by rocky headlands that extend offshore as barren, bathymetric highs adjacent to sediment-filled bathymetric depressions that tend to lie offshore of pocket beaches and coastal drainages. These headlands and bathymetric highs form barriers to the alongshore transport of littoral sediments. It appears that storm events are necessary to bypass headlands and transport sediment outside the surf zone, which is in sharp contrast to the mechanisms and timing of alongshore littoral transport observed along the nearly continuous sandy shoreface of coastal plain shelves. In situ observations of near-bed hydrodynamics, sediment fluxes, and bed responses appear necessary to further constrain the finer-scale mechanisms of both beach-shoreface cross-shore coupling and alongshore transport of littoral sediments in this type of environment.

References

Hallermeier, R. J., 1981. Seaward limit of significant sand transport by waves: an annual zonation for seasonal profiles. U.S. Army Corps of Engineers, Coastal Engineering Research Center, U.S. Coastal Engineering Technical Aid 81-2, 23 pp.

Hunter, R. E., Dingler, J. R., Anima, R.J., and Richmond, B.M., 1988. Coarse-sediment bands on the inner shelf of southern Monterey Bay, California. Marine Geology, v. 80, p. 81-98.

Seelbach, R. R., 1993. Shoreface sediments in northern Monterey Bay, California: Grain- size distributions and transport boundaries [M.Sc. dissert.]: Santa Cruz, California, University of California at Santa Cruz, 56 pp.

Tait, J. F., 1995. Rocky coasts and inverse methods: Sediment transport and sedimentation patterns of Monterey Bay National Marine Sanctuary [Ph.D. dissert.]: Santa Cruz, California, University of California at Santa Cruz, 138 p.

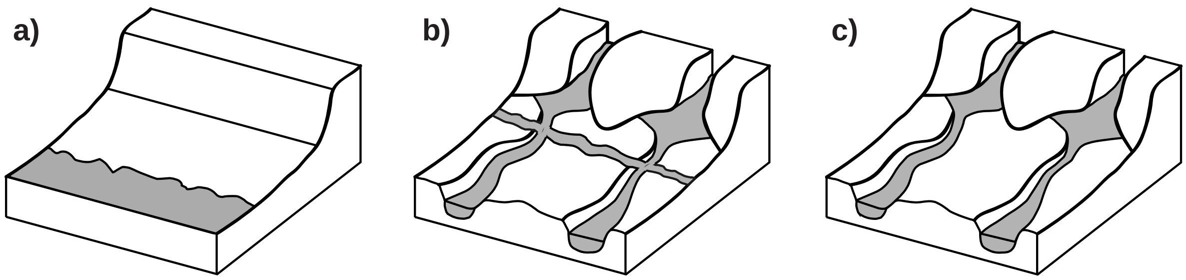

Fig 1 Schematic diagram showing general modes of sediment distribution observed in the study area. Gray areas designate unconsolidated sediment and white areas are bedrock. (a) Continuous rocky coastline where no streams have incised the topography and the dominant offshore wave direction is parallel to the coast. (b) Embayed coastline with pocket beaches and shore-normal, sediment-filled paleo-stream channels connected by shallow, shore-parallel ribbons of sediment in shallow water. The dominant offshore wave direction is shore-parallel. (c) Embayed coastline with pocket beaches and shore-normal, sediment-filled paleo-stream channels. The dominant offshore wave direction in this configuration is shore-normal.

Paleoshorelines on the U.S. Atlantic and Gulf Continental Shelf: Evidence for sea-level stillstands and rapid rises during deglaciation

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Systematic mapping projects by the USGS have furnished regional-scale, high-resolution information on the morphology and shallow stratigraphy of portions of the Atlantic and Gulf of Mexico continental shelves. Such surveys include complete sidescan-sonar coverage, bathymetry, and CHIRP and boomer subbottom data over areas ranging from 100 km^2 to 3800 km^2 with a trackline spacing of approximately 300 m. Supporting data include cores, sediment and rock samples, and ROV video observations. The data furnish a detailed geophysical and stratigraphic framework that is used as baseline information for environmental, resource, and sediment dynamics studies. However, these data also reveal a remarkably well-preserved suite of paleoshorelines that record at least three discrete stillstands or significant reductions in the rate of deglacial sea-level rise.

Paleoshoreline deposits described here include: 1) a mixed clastic/carbonate shoreline located at the shelfbreak in the northeastern Gulf of Mexico; 2) an estuarine complex in the upper Hudson Shelf Valley and southern Long Island, New York shelf; and 3) clastic barrier-spit complexes on the inner shelf off southeastern North Carolina and southern Long Island, New York. The style and extent of paleoshoreline preservation at each location is dependent primarily upon the regional paleo-sediment supply, and regional isostatic adjustment.

The oldest paleoshoreline we have mapped lies at the shelf break in the northeastern Gulf of Mexico, 140 km south of Panama City, FL. The shoreline consists of a 7 m high shoreface scarp, which is capped upward and landward by beachrock at a water depth of 70 m. Using sidescan-sonar, seismic-reflection and ROV data, we have traced this seafloor outcrop over a distance of at least 5 km and perhaps as much as 14 km. We have not yet directly dated this shoreline, but it appears to be correlative in water depth with a paleoshoreline to the southeast (the S3 shoreline of Locker et al. 1996, dated at 14,000 ^{14}C yr BP). If true, this finding suggests there may be a "bathtub ring" paleoshoreline along much of the west Florida shelf edge.

A large estuarine complex of Younger Dryas age exists in the upper Hudson Shelf Valley and on the southern Long Island, New York inner shelf at a present water depth of 31 m. The deposits include a brackish-water basal peat that crops out over 3 km^2 on the inner shelf, and regionally extensive estuarine deposits containing articulated, growth-position oysters (*Crassostrea virginica*). All of this material is ~11,300 cal. ^{14}C yr in age.

Preserved barrier island lithosomes on the inner continental shelf off the southeastern part of North Carolina at Wrightsville Beach (present water depth 13 m) and the off south shore of Long Island, New York (present water depth 18.5 m) permit a detailed paleogeographic reconstruction of the basal sections of discrete early Holocene (8-9 ka) barrier island and lagoon complexes. These nearshore complexes include tidal inlet and backbarrier lagoon, as well as tidal creek environments containing articulated oysters in growth position. In New York, the deposits are coeval with those found off North Carolina, and are much better preserved. Additional preserved lithosomes include a series of formerly shoreface-attached ridges, and an extensive (~2 km^2) charred basal salt marsh peat that records a large, lightning-strike (?) fire at 8500 cal. ^{14}C yr BP. Paleotopographic modeling with the ICE-4G (Peltier, 1996) isostasy model indicates these two age-equivalent sites were at the same elevation with respect to sea-level.

The distribution and stratigraphy of these paleoshorelines indicate pauses in transgression during periods of relative stillstand or slow sea-level rise that permitted shoreline development and maturation (e.g., barrier/beach formation and growth, vertical estuarine sedimentation, shoreface incision). The preservation of these shoreline deposits is best-explained by three rapid rises in sea-level – on the order of several meters in a few hundred years – that terminated each stillstand. Such rapid rise events renewed transgression and quickly raised the depth of shoreface ravinement. The first two rapid rise events are recorded in Barbados corals as mwp-Ia and mwp-Ib (Fairbanks 1989). The third event has been proposed for the Caribbean-Atlantic region by Blanchon and Shaw (1995) and correlates approximately with the termination of early Holocene cool interval identified in Greenland ice cores and other climate proxies (Alley et al. 1997; Barber et al. 1999).

Reconstruction of the timing and mechanism of barrier island and shoreface evolution on the Atlantic continental shelf from ~6 ka to present can be constrained by seismic and litho-stratigraphy, coupled with ^{14}C dating of in-place salt marsh peats and estuarine fauna. Additional radiometric dates on in-place shoreface fauna indicate that the North Carolina barrier islands were sited within 1.5 km of their present location by 6 ka, and <1 km by 4.5 ka. Similar geographic constraints can be placed on the New York barrier islands. The chronology of marine flooding and salt marsh formation in the modern backbarrier lagoons is consistent with this model. Thus, the rate of barrier island migration at both New York and North Carolina sites since about 6 ka has been relatively low, which is attributed to the low rate of eustatic sea-level rise characteristic of the late Holocene. This low rate of barrier island migration was coupled with the erosion and maturation of the coastal system by steepening of an initially broad, shallow shoreface. For the past 6 ky, shoreface sediment in these two regions, and on many barrier island coasts, has been redistributed by onshore transport (barrier regression), offshore transport (inner shelf sand sheet development), and shoreline straightening (spit growth). Since modern shorefaces are steep and thus contain minimal sediment volume, they should be extremely sensitive to future changes in sea-level.

References

Alley, R. B. et al., 1997. Holocene climatic instability: a prominent, widespread event 8200 yr ago. Geology, 25: 483-486.

Barber, D. C., et al., 1999. Forcing of the cold event of 8,200 years ago by catastrophic drainage of Laurentide lakes. Nature, in press.

Blanchon, P. and Shaw, J., 1995. Reef drowning during the last deglaciation: Evidence for catastrophic sea-level rise and ice-sheet collapse. Geology, 23: 4-8.

Fairbanks, R. G., 1989. A 17,000-year glacio-eustatic sea-level record: influence of glacial melting rates on the Younger Dryas event and deep-ocean circulation. Nature, 342: 637-642.

Locker, S. D., Hine, A.C., Tedesco, L.P. and Shinn, E.A., 1996. Magnitude and timing of episodic sea-level rise during the last deglaciation. Geology, 24: 827-830.

Peltier, W. R., 1996. Mantle viscosity and ice age ice sheet topography. Science, 273: 1359-1364.

Evolution of the Rhine-Meuse coastal plain (west-central Netherlands) during the last Quaternary glacio-eustatic cycles

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An almost 50-m-deep core from the Weichselian [oxygen-isotope stage (OIS) 2-4] Rhine-Meuse palaeovalley, near the present Dutch coast, reveals new insights into how this continental-scale fluvial system responded to relative sea-level fluctuations associated with the last Quaternary glaciations. Furthermore, it provides new evidence on coastal evolution during relative sea-level highstands. A multidisciplinary study of this core included sedimentological and stratigraphic analysis augmented with data on shell, diatom, and pollen content to infer depositional environments. Optically stimulated luminescence (OSL) dating provides a first numerical chronostratigraphy for these strata.

Deposition during sea-level highstands is represented in our core by estuarine deposits scoured into underlying fluvial strata. OSL ages and biostratigraphic evidence indicate that these sediments were formed during OIS 1 (Holocene) (**Fig. 1**) and 5 (Eemian/Early Weichselian). The older of these two estuarine units is dated to OIS 5a rather than 5e (Eemian), indicating that a significant transgression occurred in this area around 80 ka. We propose that coastal prism formation and destruction occurred repeatedly during alternating sea-level highstands and lowstands of OIS 5. However, these interglacial or interstadial transgressive and highstand systems tracts have a relatively low preservation potential due to subsequent fluvial erosion.

Net fluvial incision due to relative sea-level fall associated with the Weichselian glaciation (notably OIS 4) is estimated at >10 m, and we argue that this amount of incision decreases both updip and downdip, because our study area is located near the thickest part of the OIS 5 highstand coastal prisms that were particularly sensitive to erosion during ensuing sea-level fall. Coastal prism geometry, with a relatively steep upper shoreface, is extremely important in promoting erosion, as demonstrated by the Rhine-Meuse system that borders an exceptionally wide, low-gradient continental shelf. Our results show that fluvial deposits associated with sea-level fall (80-50 ka) constitute a considerable part of preserved strata ('falling-stage systems tract').

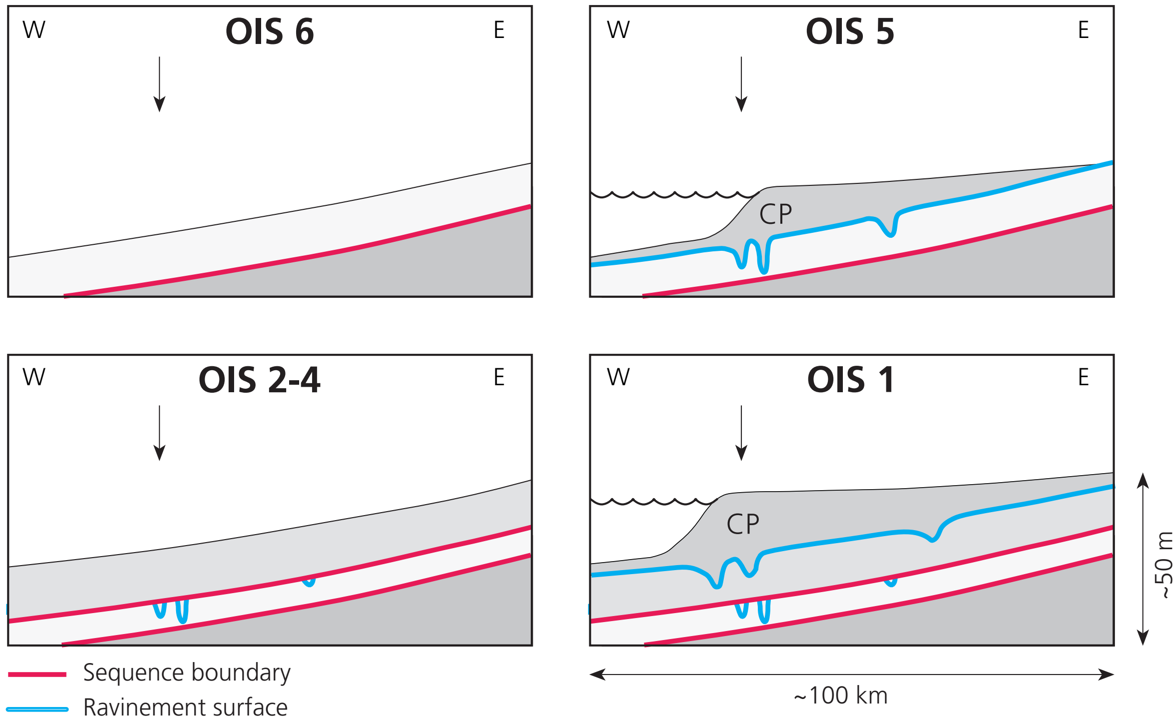

Fig. 1 Schematic dip-oriented section illustrating the evolution of the Rhine-Meuse system in the west-central Netherlands during the last glacio-eustatic cycles. Arrow indicates the position of the core. Sequence boundaries result from fluvial erosion due to sea-level fall; ravinement surfaces result from transgressive scour. Note the occurrence of both wave, tidal and fluvial ravinement surfaces. OIS = oxygen-isotope stage, CP = coastal prism.

Geophysical and geological monitoring of Hawaiian ocean disposal sites

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Continental shelves adjacent to metropolitan centers are a focus of public concern owing to contamination from runoff, pesticides, wastewater, and other forms of pollution. Many sites have environmental and management concerns that require geologic information and accurate base maps. A strong focus of the U. S. Geological Survey (USGS) Coastal and Marine Geology Program is the systematic acoustic mapping of the shallow Exclusive Economic Zone (EEZ) using the latest in acoustic technology. Data from sidescan sonar, multibeam sonar, subbottom profiling, bottom photography, and bottom sampling provide key information on the seafloor morphology, and the distribution, transport, and long–term fate of sediment and potential contaminants. The aim is to develop accurately georeferenced base maps and detailed regional syntheses of the seafloor geology that provide the information for a wide range of marine-environmental management decisions. The maps also form a basis for further process-oriented investigations and are prerequisite for long-term monitoring studies, the precise location of sampling sites or critical habitat, and change detection analyses between temporally separated surveys over the same sites.

Since 1993 the USGS, the US Environmental Protection Agency, and the US Army Corps of Engineers have conducted cooperative studies to assess the effects of ocean dumping in the Hawaiian Islands. Through 1997 the studies focussed on Mamala Bay, an embayment adjacent to Honolulu and located on the south shore of Oahu (**Fig. 1**). Mamala Bay has been a repository for dredged material disposal for over a century. Initially, the purpose of the program was to map and sample the Mamala Bay seafloor, delimiting the extent of dredged material deposits and determining the physical and chemical character of the surficial and near–surface materials in and around the disposal sites. The studies included seafloor mapping with sidescan sonar, high-resolution subbottom profiling, bottom photography, seafloor sampling, and sedimentological, chemical, and biological analyses of bottom sediment and dredged material for EPA-defined contaminants of concern.

In 1998 the USGS expanded the mapping efforts to include all Hawaiian disposal sites (**Fig. 1**) by conducting multibeam surveys off of Oahu (Mamala Bay), Kauai (Port Allen and Nawiliwili), Maui (Kahului), and Hawaii (Hilo). The sites are all located within 5 nautical miles of shore on insular shelves or slopes. The purpose of the 1998 surveys was to map the geographic extent of dredged material deposits, and to derive detailed bathymetric and backscatter maps of the seafloor having a ± 1 m spatial accuracy and <1% depth error (Torresan and Gardner, 1999).

The acoustic and visual data reveal spectacular details of the seafloor in and around the Hawaiian disposal sites (**Fig. 2**). Shaded-relief, backscatter, and perspective-view images clearly show deposits created by disposal activities, drowned reef complexes, volcanic features, and a wide array of bedform types. In Mamala Bay for example, there is abundant evidence of sediment reworking in and around the disposal sites: symmetrical and asymmetrical ripples on bottom photos, sand waves in the multibeam, sidescan, and 3.5-kHz data, and moats around the reefs in 3.5-kHz profiles and multibeam images (Hampton et al., 1997; Torresan et al 1995, Torresan and Gardner, 1999). The bedforms document the occurrence of active sediment transport within the disposal sites and have important implications for the transport and fate of potential contaminants associated with the dredged material. Most current-indicators imply a westerly to northwesterly transport direction, along contours or upslope. The transport mechanism is shown by current-meter data that document near-bottom flows of 50 cm/s.

The multibeam imagery depicts three principal types of seafloor material in and around the disposal sites: low-backscatter natural sediment and high-backscatter drowned carbonate reefs and dredged-material deposits. Where dredged-material deposits are visible, the sites are characterized by isolated, circular to subcircular high-backscatter overprints formed by individual disposal events. In Mamala Bay, which historically has received about 90% of all Hawaiian dredged material, the overprints coalesce to form a nearly continuous high-backscatter blanket over the sites. Based on bottom sampling, the high-backscatter dredged material in Mamala Bay is a heterogeneous mixture of cohesive gray mud that is mixed with particles ranging in size from sand to cobble-sized clasts of reef material. In contrast, low-backscatter natural sediment is beige-colored, muddy carbonate sand. Surface samples of dredged material and natural sediment were analyzed for EPA-defined contaminants of concern. Contaminant concentrations are low to non-detectable and yield no trends in either natural sediment or dredged material. Relatively higher concentrations of some contaminants exist (i.e., lead, zinc, chromium), but these are not clearly associated with either dredged material or natural sediment.

The Port Allen and Nawiliwili disposal sites off southern Kauai do not exhibit the effects of dredged material disposal when compared to Mamala Bay. Multibeam images in these areas lack the profound high-backscatter overprints of the dredged material deposits. Both sites are located in areas of intermediate backscatter, and the designated disposal sites appear identical to the surrounding natural seafloor. Unfortunately, core samples have not been collected from the Kauai sites. The lack of an apparent dredged material deposit can be explained in a three ways. Both Port Allen and Nawiliwili receive less than 1% of the volume of material disposed of in Mamala Bay and both sites are located in water depths greater than 1000 m, over twice the depth of the Mamala Bay sites. Thus, the Kauai dredged material deposits may be so small and so deep that they are below the resolution of the multibeam system. Also, the dredged material may disperse during and after disposal, migrating away from the sites leaving behind no resolvable deposit. Alternatively the dredged material may be so similar in composition and in particle size distribution to the natural seafloor material that it has similar backscatter values and a similar appearance to natural seafloor sediment that mantles the flanks of southern Kauai.

The multibeam data from the region surrounding the Kahului, Maui and the Hilo, Hawaii disposal sites show that the Kahului and Hilo site deposits are extremely small and quite sparse when compared to the Mamala Bay sites. Nonetheless, the Kahului and Hilo sites display the characteristic high-backscatter acoustic overprints associated with dredged materials off Honolulu. Backscatter imagery shows that both Kahului and Hilo disposal sites affect a cumulative area of less than 10 km^2 as compared to over 100 km^2 in Mamala Bay. This distribution is probably a function of the lower volumes of dredged material disposed of at these sites. Kahului and Hilo account for only about 1% and 2% respectively of the total material dredged from all Hawaiian harbors.

References

Hampton, M. A., Torresan, M. E., and Barber, J.H. Jr., 1997, Sea-Floor Geology of a part of Mamala Bay, Hawaii: Pacific Science, v. 51, no. 1, p. 54-75.

Torresan, M. E., Hampton, M. A., Gowen, M.H., Barber, J.H., Jr., Zink, L.L., Chase, T.E., Wong, F.L., Gann, J.T., and Dartnell, P., 1995, Final Report: Acoustic mapping of dredged material disposal sites and deposits in Mamala Bay, Honolulu, Hawaii: U.S. Geological Survey Open-File Report 95-17, 53 p., 1 Plate.

Torresan, M. E., and Gardner, J. V., 1999, Multibeam acoustic mapping of Hawaiian ocean dredged material disposal sites: U.S. Geological Survey Open-File Report.

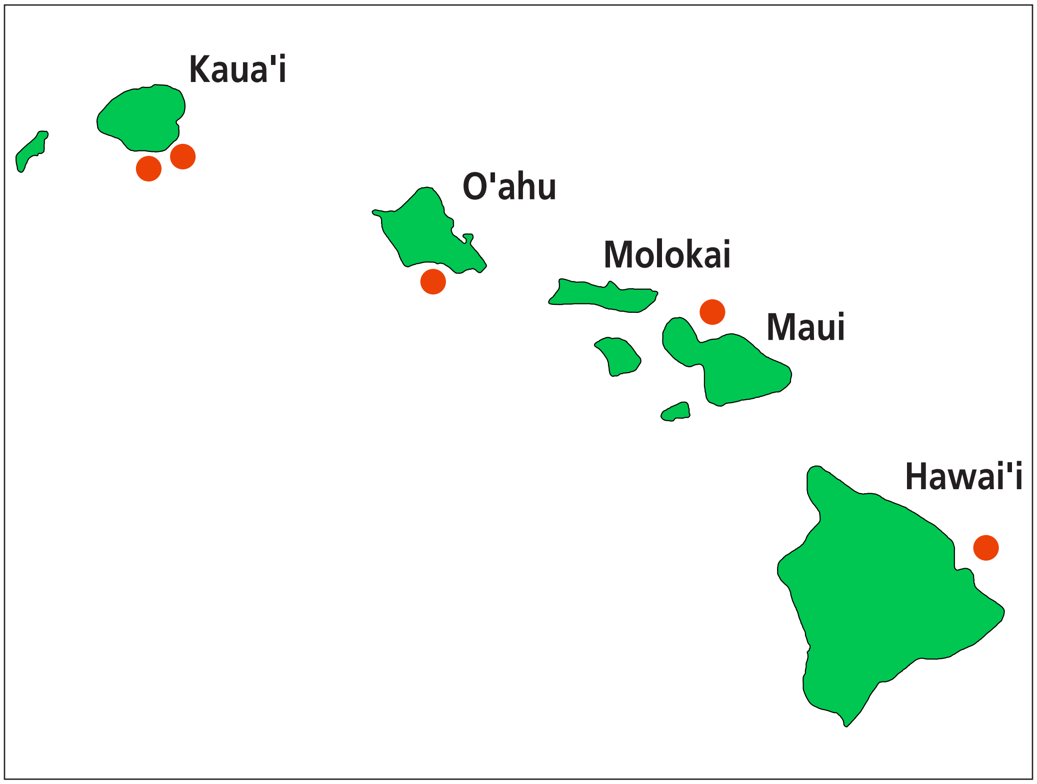

Fig. 1 Location of Hawai'ian ocean disposal sites

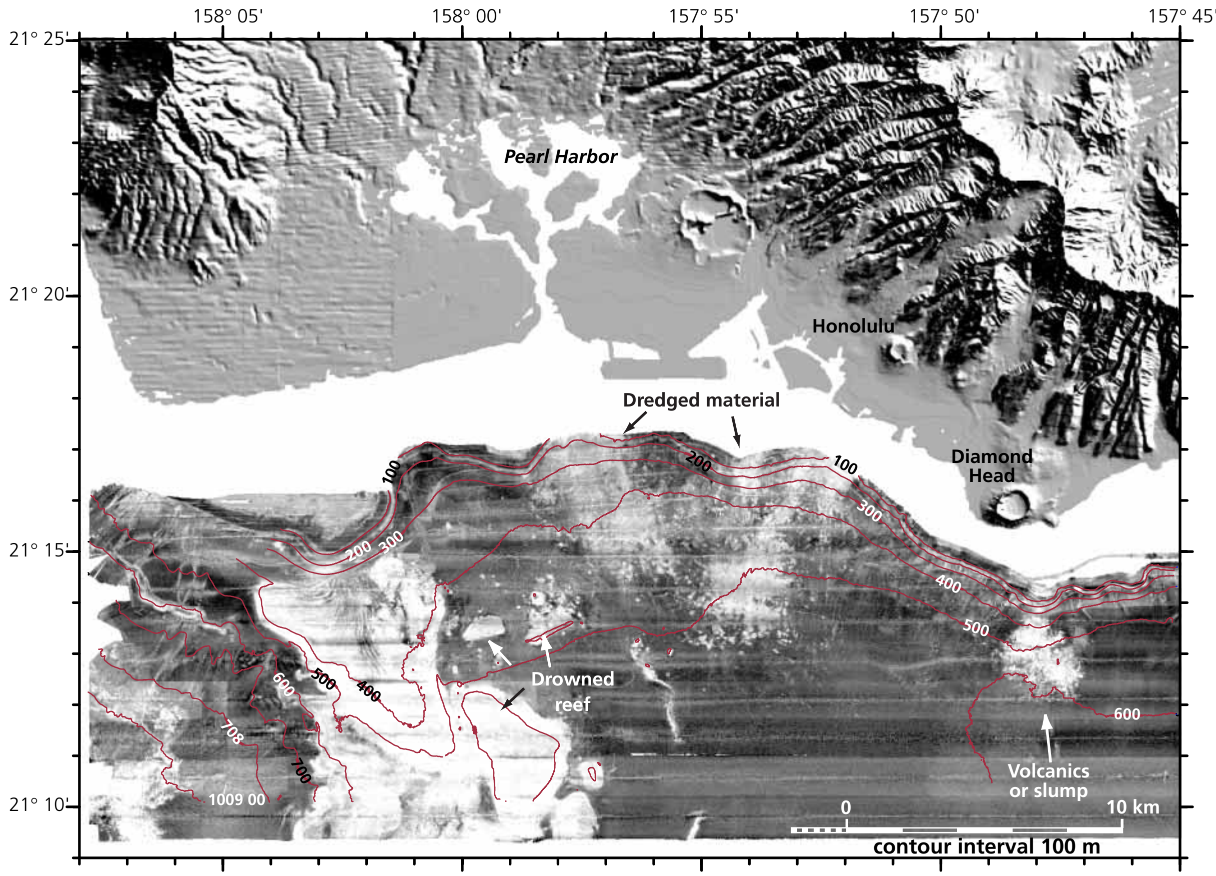

Fig. 2 Multibeam backscatter image from Mamala Bay. Note the high backscatter (bright tones) dredged-material deposits and drowned reef platforms. In contrast, natural sediment is characterized by low backscatter (dark tones).

Evidence for Early-Mid Holocene sea-level on O'ahu, Hawai'i from coastal pond sediments

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Introduction

Models of late Pleistocene-Holocene sea-level on O'ahu indicate that in the late Pleistocene, sea-level was many meters below the current level. Rapid rise during the early-mid-Holocene led to a proposed mid-Holocene highstand of 1-2 m about 3500 yr BP. Sea level then gradually declined to roughly its current level. Sources of data for the proposed sea-level curve for the northern main Hawaiian Islands include Hanauma Bay, O'ahu coral reef cores (Easton and Olson, 1976), windward O'ahu shoreline deposits (Fletcher and Jones, 1996), coastal stratigraphy of Hanalei, Kauai (Calhoun and Fletcher, 1996), and the emerged bench and fossil beach of Kapapa Island, O'ahu (Grossman and Fletcher, 1998).

The sediments of Ordy Pond on the 'Ewa Plain of O'ahu date from roughly 26,000 yr BP and appear to contain a continuous record of sedimentation from about 10,000 yr BP. These sediments provide additional data for tracking the changes in sea-level on O'ahu during the early-mid Holocene.

Physical Setting

Ordy Pond occupies a sinkhole in the Pleistocene limestone caprock in the 'Ewa district of O'ahu, Hawai'i. The pond is located 750 m from the coast at 1.5 m above sea-level, and contains 5 m of brackish water. The 'Ewa Plain is an arid region of grasslands, shrubs, and kiawe forest. Ordy Pond represents the only permanent surface water feature in the vicinity.

Annual rainfall on the 'Ewa Plain averages 20 inches (508 mm) and is highly seasonal. There is also wide interannual variability in 'Ewa Plain rainfall. One factor influencing interannual variability of rainfall in Hawai'i is the occurrence of El Niño-Southern Oscillation (ENSO) events. During ENSO events, the North Pacific atmospheric high shifts closer to the islands leading to abnormally dry weather in Hawai'i. Dry periods associated with ENSO events typically are of 1-2 year duration, and recur roughly once every 3-5 years.

Coring Operations

The sediments of Ordy Pond have been sampled during three separate coring programs. The study of Athens et al. (1997) was based on piston cores taken in Ordy Pond and a nearby evaporite pan in 1994 and 1995. Coring in the pond during that study terminated at a sub-bottom depth of 8.7 m in sediments dated from 1500 yr BP. At the evaporite pan, the entire sediment column overlying Pleistocene limestone bedrock was sampled in cores up to 2 m in length. The oldest sediments were dated at 7200 yr BP. During July, 1997, the upper 7.7 m of the Ordy Pond sediment column were cored in triplicate using a portable vibracorer and 9 m sections of 3" diameter aluminum irrigation pipe. Although the vibracoring was considered very successful, especially in terms of core quality, it was decided in August 1997 to attempt deeper coring using a portable piston-coring rig. The upper ~4 m of sediment were cased and washed. Beyond a sediment depth of ~4 m, the sediment column was sampled in duplicate using 1 m sections of 1" diameter pipe. Total penetration in the pond was 17.5 m sub-bottom.

Ordy Pond Stratigraphy

The cores contain a relatively complete record of sedimentation in the pond from the time of its initial formation in a sinkhole in the Pleistocene limestone caprock (**Fig. 1**). The bottom-most sediment is gray shell hash in a fine-grained carbonate matrix, with pebbles of reef rock. The shells are terrigenous snails; no aquatic forms are present, indicating the sinkhole was dry at the time of deposition. The shell hash grades up into a thin, black, peat-like interval, marking the terrestrial-aquatic transition. The sediment section from the terrestrial-aquatic transition up to a sub-bottom depth of ~5 m is composed of finely laminated to thinly bedded carbonate and organic matter-rich sediment, with occasional diatom-rich interbeds (**Fig. 2**). The linear nature of the age-depth plot for this section (Athens et al., 1997) suggests the lack of significant hiatuses in the section.

The upper ~5 m of core are dominated by organic-rich, gelatinous to spongy, sediment. Color banding (incipient lamination?) is present throughout, but is much less distinct than that in the lower section. A sharp boundary separates the dark, organic-rich sediment from underlying lighter sediment that grades into the banded and laminated section. The pollen record of the core indicates that this sharp boundary corresponds to the beginning of the historic period on O'ahu (~150 yr BP).

Sediment Composition

Compositional analysis by XRD and microscopic examination shows that the sediments are made up of four major components: calcite, aragonite, amorphous silica, and organic matter. The visually striking layering and laminations in the cores (**Fig. 2**) are generally the result of variations in the relative concentrations of organic matter and carbonate. Organic carbon concentrations vary from less than 0% up to 23%; carbonate concentrations vary from 5 to 99%. Faunal components include, in order of decreasing abundance, diatoms, ostracods, and minor foraminifera. Although ostracods and foraminifera contribute carbonate to the sediment, the bulk of the carbonate in all samples is very fine grained, apparently authigenic, calcite and/or aragonite.

Aragonite is the main carbonate mineral in the shallowest sediments, and in several intervals at depth in the sediment column. The carbonate in the remaining intervals is dominated by calcite.

Sediment Dates

One pollen date and three AMS ^{14}C dates from Athens et al. (1999) have been supplemented by five radiocarbon dates from carbonate shells in the terrigenous shell hash. The sediment just below the boundary with the laminated interval was dated at 9780 yr BP. Dates from deeper sediments range up to 25,750 yr BP.

Environmental Interpretations

The Ordy Pond sinkhole formed in the limestone caprock during the Pleistocene lowstand, sometime before about 26,000 yr BP. Sediment consisting of eroded caprock and terrigenous snails accumulated in the sinkhole until roughly 10,000 yr BP at which time deposition of organic-rich, peat-like sediments marked the initial inundation of the sinkhole with ground water. Assuming a slope of the water table similar to that of Barber's Point today (0.1m/km) and negligible compaction of the underlying shell hash, sea-level at the beginning of the Holocene would have been approximately 17 meters below that of today.

Frequent shifts of faunal content, organic vs inorganic carbon content, and mineralogy in the overlying laminated aquatic sediments probably reflect temporal variations in pond conditions, particularly in nutrient concentrations and/or salinity. These factors may be related to fluctuations in rainfall and possibly temperature. Frequencies of sediment variations range from the sub-millimeter-scale up to several meters and may correspond to seasonal, multi-year (ENSO-related), or millennial changes in pond conditions.

The distribution of aragonite versus age shows that the pond has been dominated by calcite, rather than aragonite, precipitation throughout much of its history (**Fig. 3**). The laminated sediment of the early and mid-Holocene is exclusively calcitic, with the exception of one interval roughly 3000 years old that contains some aragonite. This aragonite-bearing interval may coincide with the proposed mid-Holocene sea-level highstand (e.g. Calhoun and Fletcher, 1996). Although there is no direct evidence for inundation of the pond with seawater, either increased temperatures, or increased salinity of pond waters due to incursion of saline ground water, are possible explanations for the presence of aragonite in this interval. Interestingly, the Medieval Warm Phase (750-1200 yr BP) also corresponds to a period of aragonite-dominated sedimentation in the pond. The Warm Phase was followed by the Little Ice Age (150-600 yr BP) during which calcite was the dominant inorganic precipitate. Finally, the climatic warming following the Little Ice Age was accompanied by a return to aragonite-dominated sediments in Ordy Pond.

The correlations of Ordy Pond sediment mineralogy with shifts of global climate are intriguing. It must be emphasized, however, that they are based on a preliminary chronology. Thorough and detailed investigation of the mineralogy, isotopic composition, faunal content, and age of the sequence is necessary before definitive correlations can be drawn.

References

Athens, J. S., Ward, J. V., Tuggle, H. D., Welch, D. J., Blinn, D. W., Cowie, R., Murakami, G. M., and Sherman, C., 1997. Environment, vegetation change, and early human settlement on the ‘Ewa Plain: A Cultural resource inventory of Naval Air Station, Barbers Point, O’ahu, Hawai’i, Part III: Paleoenvironmental investigations. International Archeological Research Institute, Inc., Honolulu, HI, 312 pp.

Calhoun, R. S. and Fletcher, C. H., III, 1996. Late Holocene coastal plain stratigraphy and sea-level history at Hanalei, Kauai, Hawaiian Islands. Quaternary Res., 45: 47-58.

Easton, W. H. and Olson, E. A., 1976. Radiocarbon profile of Hanauma Reef, O’ahu, Hawaii. Geol. Soc. Amer. Bull., 87: 711-719.

Fletcher, C. H. and Jones, A. T., 1996. Sea-level highstand recorded in Holocene shoreline deposits on O’ahu, Hawaii. Journal of Sedimentary Research, 66: 632-641.

Grossman, E. E., and Fletcher, C. H., III, 1998. Sea level higher than present 3500 years ago on the northern main Hawaiian Islands. Geology, 26: 363-366.

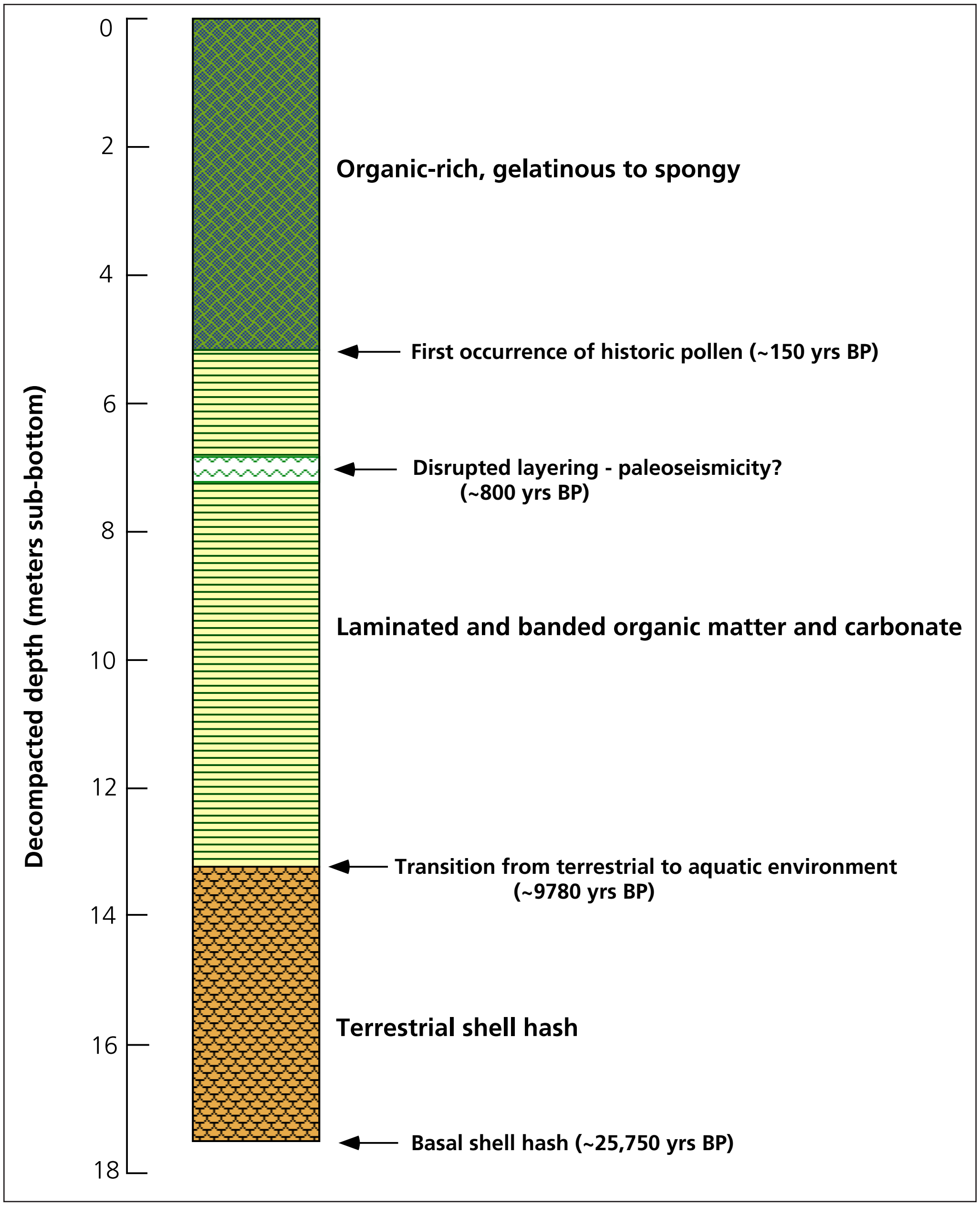

Fig. 1 Ordy Pond Stratigraphic Column

Fig. 2 Representative section of laminated sediment from Ordy Pond. Light intervals are enriched in carbonate relative to green and brown, organic-rich layers.

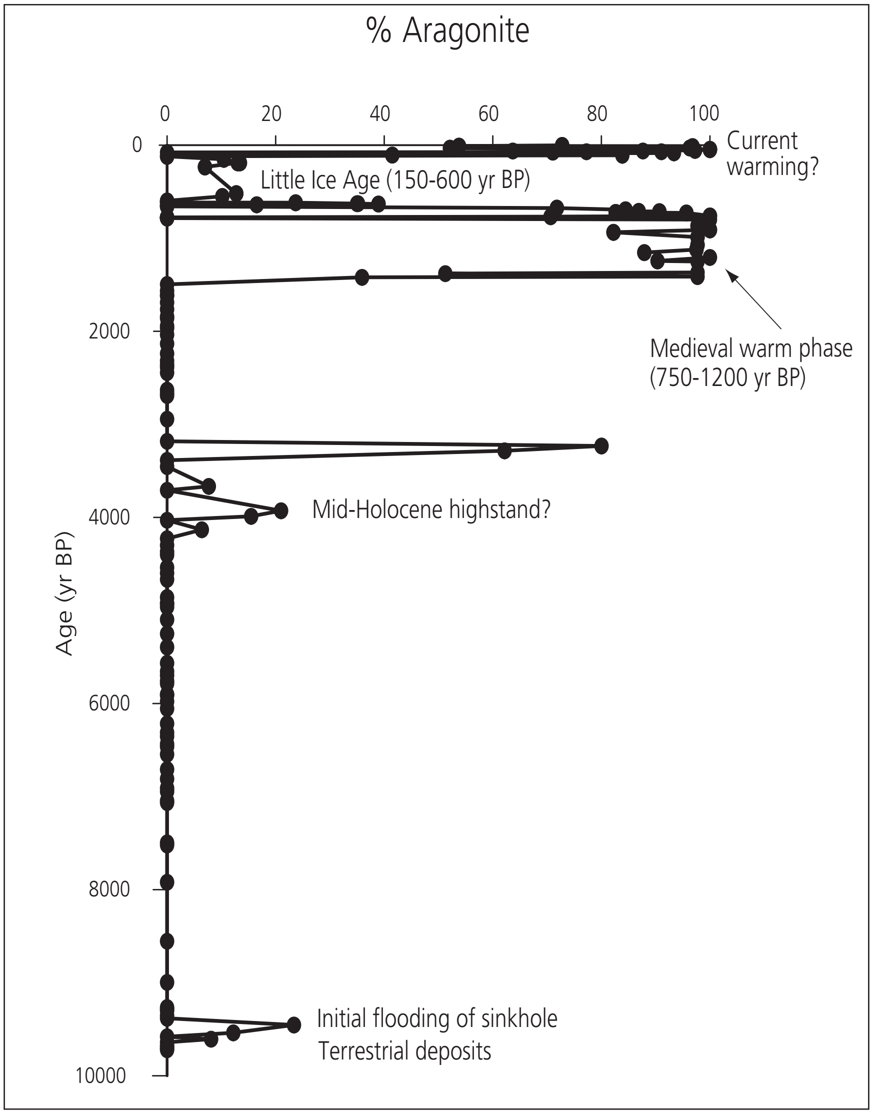

Fig. 3 Percentage of total carbonate present as aragonite versus sediment age.

The evolution of beachrock morphology and its influence on beach morphodynamics

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Coastal erosion of low latitude beaches frequently results in exposure of beachrock, layers of beach sand cemented in the subsurface by the intergranular precipitation of calcium carbonate. Exposed beachrock can have a profound impact on the event, seasonal, and long-term morphodynamics of a beach. The influence of beachrock on beach processes will largely depend on the extent and morphology of the exposure, both of which evolve over time.

Five distinct stages in the life cycle and morphological evolution of beachrock are identified in a conceptual model based on research conducted on the coast of Puerto Rico (**Fig. 1**). Stage I is the pre-exposure cementation phase (**Fig. 2**), which primarily takes place in the foreshore subsurface between the high tide and low tide water table excursion. The duration of beach stability necessary for formation of erosion-resistant beachrock ranges from a few months to decades and is negatively correlated to seawater temperature. Upon initial exposure (**Fig. 3**), the more weakly cemented landward portion of the beachrock is preferentially eroded and the landward edge of a beachrock unit is defined (Stage II). After several weeks of exposure, the outer surface of the beachrock is case hardened and colonized by epilithic biota (Stage III). Cumulative exposure and erosion of a beachrock platform over a period of months to decades (**Fig. 4**) fosters a gradual increase in the landward and seaward relief of the beachrock units and the development of shore-parallel channels and shore-perpendicular breaches in the beachrock (Stage IV). Exposure over several decades without significant new cementation results in the disintegration of the beachrock units into blocks and slabs that become displaced and buried in unconsolidated sediment (Stage V).

As a beachrock platform evolves from Stage I to Stage IV in its erosional development, its influence on beach processes increases. The characteristically high seaward relief of a Stage IV beachrock unit reflects the most wave energy and effectively retards onshore sediment transport. The high landward relief of a Stage IV beachrock unit acts as the seaward wall of a channel that blocks offshore return of backwash and forces impounded seawater and entrained sand to flow laterally on the foreshore to low spots and shore-normal breaches in the beachrock formation (**Fig. 5**). Beachrock breaches and channels are erosionally enlarged over time, locally increasing onshore inputs of wave energy and longshore sediment transport rates.

Currents in the shore-parallel beachrock channels on the west coast of Puerto Rico are strongly unidirectional, can flow in the direction opposite incident wave approach, and exhibit a pulsing behavior associated with low frequency fluctuations of the sea surface at discharge points. Longshore current power and frequency composition are better correlated to tide height than to wave height, despite the microtidal range. Median current velocities exceed 30 cm/sec even when wave heights are less than 0.5 m.

Enhanced reduction of incident wave energy by Stage II, III, and IV beachrock exposures provides protection for the backshore and results in unusually narrow, sediment deficient beaches. Morphodynamic variability of the study beach with beachrock is more a function of proximity to breaches in the seaward beachrock unit and degree of shore-parallel beachrock channel development than of alongshore variation in incident wave energy. Sections of beach with Stage IV beachrock exhibit the highest frequencies and durations of beachrock exposure, the lowest volumes of subaerial sand storage, and the slowest beach erosion recovery rates.

The Life Cycle and Morphological Evolution of a Beachrock

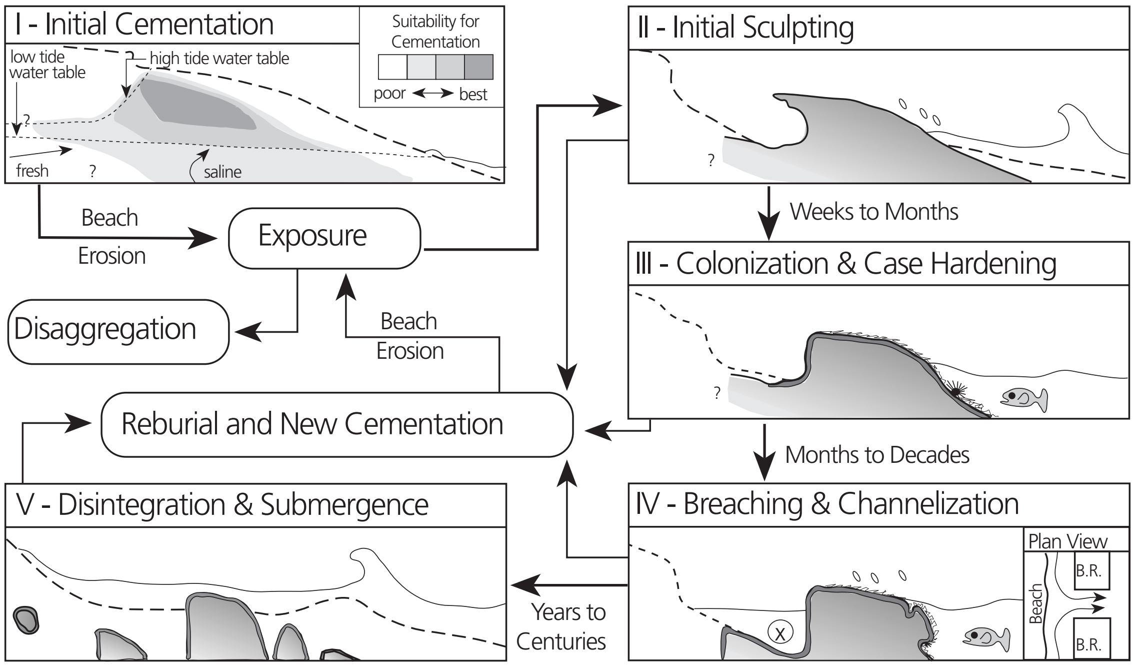

Fig. 1 Conceptual model of the stages of beachrock development. Although this model only illustrates the evolution of a single beachrock unit, it does allow for multiple episodes of beachrock formation.

Fig. 2 Weakly cemented sand layers at the water table at Barrio Rio Grande de Aguada, Puerto Rico. This incipient beachrock was exposed by an erosion event and was subsequently reburied.

Fig. 3 Beachrock in Stage II of its development. This beachrock is weakly cemented and the outer surface has the same color as the unconsolidated sand. Longshore flow of seawater impounded on the foreshore during high tide is eroding the landward margin of the unit, increasing its relief and fostering the development of an overhang. This overhang subsequently failed, resulting in a nearly vertical landward edge. Barrio Rio Grande de Aquada, Puerto Rico.

Fig. 4 This photograph displays multiple stages of beachrock development. The beachrock platform as a whole is in Stage IV of its development, as indicated by the shore-parallel channel and the breach in the seaward beachrock unit in the background. The beachrock under the notebook is Stage IV as well. Extended exposure is indicated by the dark staining of the outer surface by cyanobacteria, the colonization of the outer surface by algae, the sculpted morphology, the vertical landward edge, and the shore-perpendicular fracture. Following the formation of the shore-perpendicular fracture and displacement of the block in the foreground, this unit was buried for an extended period of time and another cementation episode occurred. The light colored beachrock in the foreground and landward of the sculpted beachrock is a Stage II eroded remnant of that more recent cementation. Barrio Rio Grande de Aguada, Puerto Rico.

Fig. 5 Multiple unit beachrock exposure at Barrio Rio Grande de Aguada, Puerto Rico. Seawater impounded by the beachrock flows from right to left and discharges to the sea in a rip current where there is an eroded gap in the seaward beachrock unit. Maximum variability of beach volume and width occurs opposite this gap.

Late Holocene evolution of the Central Plain, Thailand

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The Central Plain, one of the largest deltaic and tidal plains in Southeastern Asia, is located in the lower reaches of the Chaophraya River in the central Thailand. There are several studies on the landforms and sediments of the plain, but detail characteristics of the late Holocene sediments and sea-level change in the plain is not clarified yet. This paper aims to clarify the characteristics of the sediments of the plain and the evolution of its landforms in the late Holocene.

Stratigraphy and Lithology

The Holocene sediments in the central plain consist mainly of silt and clay with occasional organic matter. They are classified into four units; basal peat, marine, tidal and fluvial units from the bottom to the top.

The basal peat develops over the Pleistocene sediments in places and is covered with marine units. It develops at the depths of about –5 to –10 m in the southwestern part of the plain, and of about –5 to 0 m in the eastern and northern parts of the plain. The marine unit, so called Bangkok clay, consists of very soft greenish gray silty clay with more than 10 m thickness in the central and southern parts of the plain, and the thickness decreases towards the marginal part of the plain. The marine unit overlays the basal peat or Pleistocene sediments.

The tidal unit consists of grey silt or silty clay with very thin organic rich sandy layers. The thickness of it is 2-3 m in the central part of the plain, and decreases in the southern end of the plain. In the marginal part of the plain, the thickness of the unit is 3-5 m in some places. The top of the unit is almost flat or has a very low gradient, and it is covered with fluvial units. The top horizon of the unit is usually characterized by yellow gray colored silty clay with jarosite. The fluvial unit consists of brownish grey or reddish mottled grey silty clay with occasional plant fragments. The thickness of the unit is 1-2 m in the central part of the plain, 0-1 m in the southern part of the plain. In the alluvial fan region in the western part of the plain, it is more than 2 meters. The contact between fluvial unit and tidal unit lies in 0-2 m a.s.l.

Radiocarbon Ages

Some radiocarbon ages of the Holocene sediments have been obtained from the sediments of the central plain. Radiocarbon ages of fossil woods obtained from the basal peat are in the period from 6500 to 8500 yrs BP, and indicate the age of mangrove forest in the early to middle Holocene. Radiocarbon ages were also obtained from the tidal unit. They are in the period between 4000 to 7000 yrs BP. These ages also indicate approximate former relative sea-level.

Geomorphic Evolution and sea-level change

Depths of the basal peat layers distribute from –10 m to +2 m, and the ages of the peat layers indicate the Holocene transgression. The embayment of the Holocene transgression extended towards the region around Ayutthaya, 100 km from the present coast. Around there, the Holocene sediments develop over the Pleistocene sediments with 1-2 m thickness. The Holocene sediments consist of relatively thin fluvial sediments, tidal sediments and basal peat. In the southwestern part of the plain, two rows of former beach ridges which consist of shell fragments can be seen, and their height is 3-5 m a.s.l.

After the expansion of the embayment, the expanded inner bay changed into the tidal flat or tidal plain from the north to south. Since the tidal sediment can be seen in the central and southern parts of the central plain from Ayuthaya and there are no distinct deltaic sediments in the same horizon, it is considered that there has been no distinct deltaic condition in the central plain. Detailed fluctuation of the Holocene sea-level change is not clarified yet, but the maximum height of the sea-level in the mid-Holocene was higher than 2 meters.

Century-scale sea-level changes in Long Island Sound since AD 500: Correlation with North Atlantic climate-ocean changes

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Introduction

Stratigraphic, foraminiferal and radiocarbon analyses of peaty salt-marsh deposits in Connecticut, USA have demonstrated the feasibility of detecting century- and decimeter-scale sea-level variability during the past 2000 yr (van de Plassche, 1991; Thomas and Varekamp, 1991; Varekamp et al., 1992; Nydick et al. 1995). Recently, van de Plassche et al. (1998) found that mean high water (MHW) fluctuations since 850 cal yr AD, recorded in Hammock River marsh, correlate positively with summer-temperature anomalies in the Northern Hemisphere and northern Fennoscandia, and for the past 1000 yr, with changes in sea-surface temperature (SST) in the Sargasso Sea. Further progress awaits (a) more and longer high-quality records of (sub-)century-scale sea-level variations from Connecticut, the North Atlantic seaboards and other coastal areas of the world, (b)longer (annually-resolved) proxy-records of regional, hemispheric, and global changes in the atmosphere-ocean-ice system, and (c) better quantitative understanding of how this system operates and affects coastal sea-level.

In the poster, the record of MHW fluctuations from Hammock River marsh is extended back in time to ca. 500 cal yr AD and compared with temperature time series from northern Fennoscandia, northern Eurasia, Greenland, and the Sargasso Sea, and with a recent record of deep-ocean flow in the Iceland Basin. The main goal is to determine if this longer record and broader database confirms or challenges the positive sea-level-climate correlation reported by van de Plassche et al. (1998).

Results

For the period since AD 850 , the curve of detrended MHW fluctuations reflects, with time lags of 0-100 yr, the main pattern of surface-air temperature (SAT) variations noted for northern Fennoscandia/Eurasia and central Greenland, suggesting that SAT is a dominant variable in influencing sea-level in the northwestern North Atlantic. It is noted in support that, first, the two most pronounced temperature increases, between AD 800/850-1000 and since AD 1850/1900, correspond with the two largest increases in MHW, and second, the temperature minima around AD 825, AD 1300, and AD 1600 reach comparable values as do the associated MHW lows of, respectively, ca. 875 cal yr AD, ca. 1400 cal yr AD, and ca. 1650 cal yr AD. It is also noted, however, that the small MHW rise from ca. 1400 to ca. 1525 cal yr AD stands in better proportion to the modest 'temperature' increase in the GISP2 d18O record of ca. AD 1350-1450 than to the prominent SAT increase over northern Fennoscandia/Eurasia of ca. AD 1300-1450.

Of the two possible MHW curves for the period AD 500-850, that with the tentative rapid negative oscillation is consistent in time with the SAT and GISP2 $\delta^{18}O$ records. If the, partly inferred, MHW reconstruction is correct, this result suggests a strong SAT-sea-level link. But even if a rapid negative oscillation centered on ca. 700 cal yr AD did occur, the limited resolution of the MHW record implies the possibility that this positive SAT-MHW correlation is apparent.

Finally, MHW levels between ca. 550 and ca. 700 cal yr AD equal the MHW maxima of the warmer 11th and 20th centuries. The SAT data from northern Fennoscandia/Eurasia do not explain these high levels, but they are consistent with the high GISP2 'temperature' values between AD 300 and AD 600. For the past millennium, the Sargasso Sea SST curve and the MHW reconstruction correlate closely, confirming the expectation that changes in SAT affect the ocean level through changes in, among other variables, SST. For the period ca. 500-950 cal yr AD, the MHW and SST records show a positive correlation between ca. 500 and 700 cal yr AD, but a close negative correlation between ca. 700 and 950 cal yr AD.

Discussion and Conclusions

The positive correlation between the extended MHW record from Hammock River marsh and the broader temperature database from northern Eurasia and central Greenland confirms, be it more firmly for the past 1100 yr than for the period AD 500-850, the link between changes in SAT and sea-level as reported by van de Plassche et al. (1998). The fact that MHW levels at ca. 650 cal yr AD and at 1500 cal yr AD are in better quantitative agreement with the GISP2 $\delta^{18}O$ record than with the SAT record from northern Fennoscandia/Eurasia may suggest that the former record represents an ocean-mass effect too.

I consider these results as preliminary or partial until: (a) it is shown that no significant MHW oscillations occurred during the ca. 1000-1400 cal yr AD hiatus in the MHW record from Hammock River marsh, (b) it is resolved why, for the period since ca. 900 cal yr AD, the MHW records from three other Connecticut marshes differ considerably from the Hammock River marsh MHW record, and among themselves, (c) the course of regional (sub-century-scale?) MHW variations during ca. 500-850 cal yr AD has been documented with greater accuracy, (d) it is explained why the good correlation between SAT, SST (Sargasso Sea) and MHW over the past 1000 yr breaks down in the centuries prior to 950 cal yr AD, (e) the significance of the GISP2 $\delta^{18}O$ record is better understood and changes in the global hydrological budget during the past 1500 yr can be taken into account, and (f) the influence of ocean-current strength on SST and ocean-surface topography is better known and understood.

References

Nydick, K. R., Bidwell, A. B., Thomas, E. and Varekamp, J. C., 1995. A sea-level rise curve from Guilford, Connecticut, USA. Marine Geology 124, 137-159.

Van de Plassche, O., 1991. Late Holocene sea-level fluctuations on the shore of Connecticut inferred from transgressive and regressive overlap boundaries in salt-marsh deposits. Journal of Coastal Research, 11, 159-180.

Van de Plassche, O., van der Borg, K. and de Jong, A. F. M., 1998. Sea level-climate correlation during the past 1400 yr. Geology 26, 319-322.

Varekamp, J. C., Thomas, E. and van de Plassche, O., 1992. Relative sea-level rise and climate change over the last 1500 years. Terra Nova 4, 293-304.

Holocene tidal and wave-driven sand transport in the southern North Sea and the evolution of the Dutch coast

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During the Holocene the Dutch and Belgian coasts evolved, influenced by post-glacial eustatic sea-level rise, spatially varying vertical subsurface motions (glacio-hydro-isostatic crustal rebound, compaction, tectonics) and spatially varying sediment supply (mainly marine sand). The large-scale marine sand supply to the coast changed as the tidal dynamics and the wave climate were modified due to the changing geometry of the North Sea during the Holocene transgression. Also, there were differences in sand supply to various sectors of the coast due to differences in location, orientation, crustal rebound and consequent differences in hydro-dynamical forcing. This study presents numerical model calculations of the Holocene large-scale tidally and wave-induced sand transport in the southern North Sea and compares the results with new and existing geological data of the Dutch and Belgian coastal area, showing a generally good correlation.

The Holocene sea-level rise in the North Sea was a function of place, depending on the distance to the main Weichselian land-ice masses and the corresponding glacio-hydro-isostatic rebound (Lambeck et al., 1998). Near the Dutch and Belgian coasts, sea-level rose quickly (8 mm/yr) until approximately 6 ky BP, and slowly after that (1.5 mm/yr). The sea-level rose about 10 m more along the Dutch coast than along the Belgian coast, however. Throughout the North Sea, the differences were even larger. Taking this rebound into account and neglecting the contribution of sedimentation and erosion to the basin change, the southern North Sea evolved from dry land around 10 ky BP into two separate basins (the Southern Bight and the German Bight, respectively) (**Fig. 1**). The basins were separated by a land bridge between Britain and the north of Holland. Around 8 ky BP, the land bridge was flooded and the basins merged. The flooding of the southern North Sea continued until the coastlines were close to their present location around 7 ky BP.

Until 5.6 ky BP, the south-eastern coasts of the North Sea retreated (e.g., Beets et al., 1992). Depending on the local pre-existing Pleistocene topography, tidal basins of various sizes were present, presumably protected by open coastal barriers. Between 5.6 ky BP and 2 ky BP, the tidal basins in the western shores filled up and the barriers closed. The timing of the closures varied along the coast. Some parts of the coast expanded seaward, while other parts remained stationary. The tidal basins in the northern shore remained open. Around 2 ky BP, the progradation stopped and the coast started to retreat once more. New tidal basins were formed, most of which still exist today. The filling up of the tidal basins and closure of the coast after 5.6 ky BP are attributed to the reduction in the rate of sea-level rise around that time with simultaneous large sediment supply. Evidently, the sediment sources were depleted in the course of time, enabling the coast to resume its retreat.

The patterns of sand transport by tides and waves were investigated separately with model simulations. This approach enables a maximum of understanding to be gained, but may yield transports that are smaller than would be obtained with the combined processes. Simulation of tides, waves and wind together is the subject of future research. The numerical hydro-dynamical model shows that the tidal conditions in the southern North Sea changed from micro-tidal around 8 ky BP to meso- and macro-tidal around 6 ky BP (Van der Molen, in prep.1). The micro-tidal conditions were caused by the constricted access of the ocean tides into the Southern Bight through the Strait of Dover and into the German Bight through a strait between the exposed Dogger Bank and the land bridge. When the basins deepened and first the land bridge and subsequently the Dogger Bank were flooded, the tidal conditions evolved to close to the present conditions around 6 ky BP. The tidally induced net sand transport in the Southern Bight increased between 8 ky BP and 6 ky BP. Initially, it was directed towards the Dutch and Belgian coasts, but as the tidal conditions changed the direction of the sand transport changed to along-shore. Thus, the tidal sand supply for the combined Dutch and Belgian coasts peaked around 7 ky BP and decreased ever since. There was substantial variation along the coast, however.

A simple wave model shows that the average wave height in the southern North Sea increased until 6 ky BP (Van der Molen, in prep.2). The increase was due to the enlargement of the basins and the increase in depth. Initially, the waves were sufficiently large compared to the small depth to stir sand into suspension in large areas during a substantial part of the time. As the sea deepened, stirring into suspension of sand by waves became less frequent. Around 6 ky BP, sand suspension by waves only happened locally under extreme conditions. Between 6 ky BP and today, sand was transported by waves as bed-load. The average direction of the transport was to the east, with transports increasing towards the east up to the coast. Thus, a thin layer of sand was eroded from the entire sea floor and deposited in a narrow zone along the coast. With the deepening sea, the bed-load transports decreased in time. The amounts deposited in the coastal zone were smaller than those for tides. Thus, the bed-load transport by waves may be neglected in first approximation. The stirring of sand into suspension by waves before 6 ky BP must have increased the coastward tidal transports substantially.

Comparison of the model data with the geologically derived coastal evolution generally shows a good fit (Van der Molen & Van Dijck, in prep.). There was a maximum in the sand supply which, combined with the decreasing sea-level rise, allows for a period of sediment excess and consequent coastal progradation. The decrease of tidal sediment supply to the present low values corresponds with the resumption of coastal retreat. On the smaller scale of coastal sectors, the model results also correspond well with the observed differences in coastal evolution. These details are not elaborated here, but will be presented at the conference.

References

Beets, D. J., Van der Valk, L., Stive, M., 1992. Holocene evolution of the coast of Holland. *Marine Geology* 103, 423-443

Jelgersma, S., 1979. Sea-level changes in the North Sea basin. In: Oele, E., Schüttenhelm, R.T.E., Wiggers, A.J., editors, The quaternary history of the North Sea. Acta Universitatis Upsaliensis, Uppsala, Sweden, ISBN 91-554-0495-2, p. 233-248.

Lambeck, K., 1995. Late Devensian and Holocene shorelines of the British Isles and North Sea from models of glacio-hydro-isostatic rebound. *Journal of the Geological Society, London*, 152, 437-448.

Lambeck, K., Smither, C., Johnston, P., 1998. Sea-level change, glacial rebound and mantle viscosity for northern Europe. *Geophysical Journal International* 134, 102-144.

Van der Molen, J. in prep.1. Holocene tidal conditions and tide-induced sand transport in the southern North Sea. submitted to: *Continental Shelf Research*.

Van der Molen, J. in prep.2. Holocene wave conditions and wave-induced sand transport in the southern North Sea. To be submitted to: *Continental Shelf Research*

Van der Molen, J., Van Dijck, B. in prep. The evolution of the Dutch and Belgian coasts and the role of sand supply from the North Sea. Submitted to: *Global and Planetary Change*

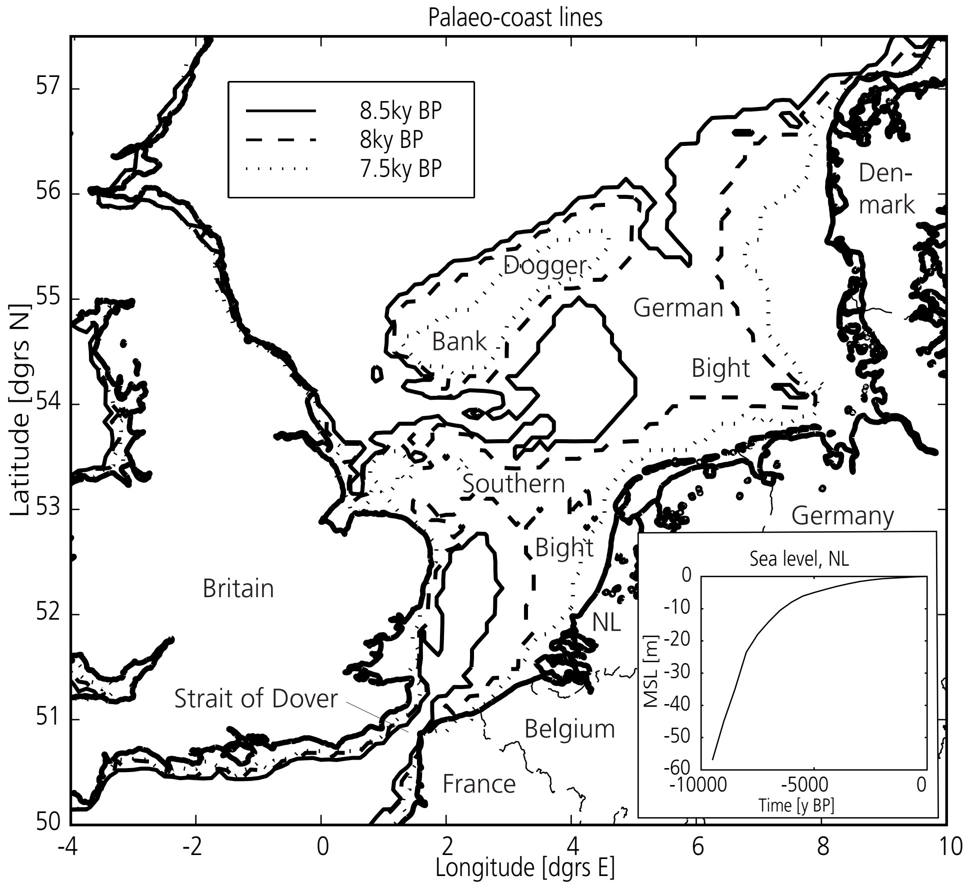

Fig. 1 Estimated palaeo-coastlines in the southern North Sea, calculated using the present bathymetry and model results of hydro-glacio-isostatic rebound (Lambeck, 1995). Inset: relative Holocene sea-level rise in the western Netherlands (Jelgersma, 1979).

Characteristics in formation and diagensis of Cenozoic reefs in South China Sea

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Fomational characteristics and distribution of reefs

Cenozoic reefs in China are developed only in late Tertiary and Quaternary carbonate rocks m South China Sea, if which late Tertiary Miocene reefs are unique, being one of the three major reef-forming periods in the geohistory. These reefs are mainly distributed on Xisha Island and in the central uplift area of the Zhujiang Basin and the intrabasin platform of Yinge Sea on the northern continental shelf

Tertiary Miocene reefs mainly consist of coralline bioherms and coralline- hexacoral reefs (mound), distributed in patches, while Quaternary reefs mainly consist of hexacoral reefs.

During late Oligocene, transgression began in the South China Sea region and in early Miocene, massive transgression entered from south to north, causing wide-spread regional marine Miocene sedimentation in the northern region of South China Sea On the uplifted basement controlled by regional block-fault tectonics, abundant reef- forming organisms like coralline and hexacorals appeared due to favorable environment, forming coralline mounds mainly composed of corallines and coral reefs mainly composed of hexacorals. Because the sea-level rise and and growth of the reef-forming organisms were coordinated well for a long time period, causing the sustained growths of the reefs which reached more than 500 m thick. As the sea transgressed northward, numerous bioherms were developed on the intrabasin platforms of the Yinge Sea located on the continental shelf of South China Sea. These bioherms were formed later than those on Xisha Island. The reef-forming periods are progressively later m the north.

Seismic profiles of the-Miocene reefs m northern South China Sea show mound- like uplifts (Hu Zhongping, 1985). These reefs lack fore-reef and back-reef facies with only 0.6% non-acid-solubles in the reef core. Based on observation of the thin- sections and other data analysis, it is shown that these reefs belong to coralline- hexacoral bioherms, with the primary reef-building organisms being encrusting coralline red algae, hexacorals and bryozoans. The primary reef-dwellers were foraminifers. Also common are corallines, gastropods and echinoderms, forming the clastics of the reefs. The primary reef rock types are coralline-hexacoral binding framestone and coralline- hexacoral binding coverstone. Filling material is limemud, indicating low energy environment.

Reef-forming model

When the growth rate of reef-forming organisms exceeds the rate of sea-level rise, the reef penetrates the weave-base and the environment becomes infavorable to the growth of the reef organisms. The corallines would be broken by the waves and spread into the limemud, forming bioclastic bank. The bioclasts include algae, corals and small gastropods and encrusting foraminifers, with very fine limemud matrices. This will end the growth of the reef. When sea water again trangresses and sea-level rises, the previous reef would be covered by deep-water containing lime mudstone

Based on the above model of reef development, it is apparent that the coralline-hexacoral reef (bioherm) was developed during transgression and finally terminated when the transgression widened and water depth increased. Therefore, the reef-building model of transgression growth and transgression end may be applied.

Quaternary, especially Holocene, marine carbonate rocks are widely developed in the South China Sea region, when the area was under subtropical, warm climate conditions with relatively large water depth, suitable for the flourishing of hexacorals, forming various types of reefs with hexacorals dominating the reef-building organisms. Reef-cores reach a thickness of above 150 m. These reefs grow, die and grow again, in accordance with the cycles of transgressions and regressions on the islands of South China Sea and on the northern continental shelves, which continues up to the present time.

The diagenesis

The diagenesis of Cenozoic reef limestone is characterized by the leading organic activities. The primary diageneses include the early stage of organic binding and encrusting and the early influence of freshwater filtration and dissolution.

The Cenozoic is the major period of development of various coralline algae. In the reef- building process, the binding and encrustation by algae are important to the formation and strengthening of the reef body. Besides the encrusting corallines, there are also encrusting foraminifers. Dolomitization is also common among Cenozoic reefs; sometimes, there occurs a dolomitized layer in the top part of a reef, serving the best storage of oil and gas.

References

Hu Zhong-ping, 1985. Introduction of the first oil-preserving reef in the Zhujiang Basin. (unpublished documents)

Zeng Lin, 1992. The Tertiary of the Zhujiang Basin. Shiyou Xuebao, 13(2): 178-183.

Yang Wan-rong, in press. Reef carbonate rocks m China.

Timescales for evolution of emergent and inner shelf Quaternary units, U. S. Atlantic Coastal Plain: Insights and enigmas from radiocarbon, U-series, paleomagnetic and aminostratigraphic results

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Understanding the evolution of Quaternary coastal sequences requires reliable geochronologic control. The record on the US Atlantic coastal plain (ACP) has been difficult to interpret because of the lack of suitable carbonate fossil material for U-series geochronology, the generally preferred isotopic dating method. This lack of suitable material is common outside tropical regions and has spurred interest in other dating methods, particularly amino acid racemization (AAR). This presentation will review critical examples of the evaluation and application of AAR to ACP Quaternary stratigraphic problems. New AAR data and recently-obtained U-series TIMS dates (Wehmiller et al., 1997; Simmons et al., 1997) provide additional calibrations for regional aminostratigraphic correlations. **Figure 1** shows seven different regions of the ACP where AAR data have been obtained – these regions are proposed as units within which AAR and other stratigraphic data probably represent common processes; similarities in AAR data between these regions can be used for intra-regional chronostratigraphic correlation, provided that suitable tests of these correlation models can be made.

For AAR to be successful as a dating method, it must meet at least three fundamental criteria: a) good analytical precision must be observed for multiple samples from a single outcrop or unit; b) D/L values must be consistent with known age (relative or calibrated) relationships for samples from local stratigraphic sequences (units with "similar or identical" temperature histories); c) D/L values must increase with temperature for samples of known equal age. Known taxonomic differences in racemization rates must be factored into the evaluation of AAR data against these standards.

In the US ACP, numerous local stratigraphic tests have provided the opportunity to evaluate the utility of AAR methods. Particularly clear examples of the ability of AAR to conform to local stratigraphic control include results from superposed sequences in southeastern Virginia (Gomez and Yadkin Pits – Wehmiller et al., 1988; Mirecki et al., 1995) and northeastern North Carolina (multiple units seaward of the Suffolk Scarp, including those at Stetson Pit, Dare Co., NC) (York et al., 1989; Riggs et al. 1992). Similar relationships can be documented with a bit more complexity in the Intracoastal Waterway of South Carolina (McCartan et al., 1982; Hollin and Hearty, 1990), in the region around Charleston SC (McCartan et al., 1982; Corrado et al., 1986; Harris et al., 1996; 1997; York, Harris, and Wehmller, unpublished). Sites in Florida also have been used for such evaluation (Mitterer, 1975; Wehmiller et al., 1999).

One of the more challenging aspects of the ACP Quaternary chronostratigraphy has been the preponderance of U-series coral dates in the late Stage 5 age range. These dates were first obtained in the late 1960's on samples from southeastern Virginia (Coch, Oaks, Goddard, and Broecker, unpublished). Additional studies in Virginia and South Carolina yielded more dates in this range, along with a few early stage 5 and stage 7 dates (Szabo, 1985). Recent TIMS analyses on carefully-cleaned corals from VA and SC yielded comparable results (Wehmiller et al., 1997; Simmons et al. , 1997). The existence of late stage 5 dates on samples that are today emergent has prompted ongoing debates regarding "passive" margin eustatic sea-level records (Ludwig et al., 1996; Toscano and Lundberg, 1999). The very limited number of reliable ACP early stage 5 dates (substage 5e) currently available imply that both early and late stage 5 units are at roughly the same present elevations (within ca. 4 meters) (McCartan et al., 1982; Szabo, 1985). These U-series data, combined with other approaches to calibration (paleomagnetics, Sr-isotopes, biostratigraphy), require that the ACP regional aminostratigraphy be interpreted in terms of either a "short chronology" or a "long chronology" (see, for example, York et al., 1989). The short chronology implies that the vast majority of the ACP emergent Quaternary coastal record is generally limited to deposits no older than stage 7 or 9, overlying a "basement" of earliest Pleistocene or late Tertiary strata. The long chronology implies that deposits of numerous isotopic stages throughout the Pleistocene are preserved in the ACP, not simply those of the last two or three interglacials. There are significant geochemical and geochronological implications associated with these conflicting chronologies, and it is important to evaluate these optional chronologies objectively using the actual geologic record as a test of their reliability. A particularly good example of this type of evaluation is the chronologic analysis by Colman and Mixon (1988) of the evolution of the southern Delmarva Penisula and the Susquehanna River paleochannel system: the two chronologic options described above propose that this system developed over roughly three sea-level cycles (stages 8 through 1) or over roughly 7 such cycles (stages 15 through 1).

This presentation will include new aminostratigraphic data from sites in New Jersey, Delaware, Virginia, North and South Carolina, and Florida, relating these data to local biostratigraphic, GPR, or geomorphic data. Calibrations based on either ^{14}C or TIMS U-Th data are available for several of the recognized aminozones. New Jersey results are from the northeast margin of Delaware Bay; in combination with GPR data, these results imply that deposition during stages 9 and/or 11 forms the majority of the preserved Quaternary record in the region (O'Neal et al, in press). Stage 5 deposits are relatively thin and restricted. Delaware data are from inner shelf cores that can be related to seismic stratigraphic and ^{14}C data, identifying at least one Pleistocene shelf unit and documenting the distribution of active Holocene sand resources. New data from the long-studied Gomez Pit section (Virginia Beach, VA) demonstrate the potential effects of diagenetic alteration on mollusk AAR data, including intrashell variations in D/L values much larger than normally expected (Wehmiller et al., 1998). Data from the NC shelf (including transported Pleistocene shells on beaches) can be related to the onshore aminostratigraphy, demonstrating the linkage between the emergent and submergent environments (Wehmiller et al., 1995; unpublished; Riggs et al., 1995). Data from excavated exposures and vibracores in central South Carolina can be related to GPR profiles, identifying aminozones that are represent either early and late stage 5 or stage 5 and stages 7/9 (short or long chronology, respectively) (Harris et al, 1996; 1997). The South Carolina studies are demonstrating important concepts regarding the ages of surficial units and those immediately (<3m) beneath, as well as the correlation between onshore and offshore units. AAR data from the Leisey Pit section in Florida (Jones et al., 1995; Wehmiller et al, 1999) can be compared with Sr-isotope, limited paleomagnetic, and biostratigraphic control. Although aminostratigraphic data at each of these sites conform to the local age control, correlation of D/L values between regions (**Fig. 1**) continues to be difficult (e.g., Wehmiller et al., 1988; 1992). These conflicts require the rejection of the theorem that plots of D/L vs. latitude would show gradually rising trends reflecting higher ambient or effective temperatures. Some conflicts between ACP AAR correlation models and available local chronostratigraphic control can be explained by diagenetic alteration or by revaluation of assumptions about the original calibration data of Mitterer (1975), but some results remain enigmatic and controversial. Experimental modeling of racemization using elevated temperature laboratory experimentation is proving some insight into the potential consequences of ambient temperature diagenetic alteration, and enigmatic data from selected sites will be discussed in this context.

References

Colman, S. M. and Mixon, R. B., 1988. The record of major Quaternary sea-level changes in a large coastal plain estuary, Chesapeake Bay, eastern United States. Paleogeography, Paleoclimatology, Palaeoecology 68, 99-116.

Corrado, J. C., Weems, R. E., Hare, P. E. and Bambach, R. K., 1986. Capabilities and limitations of applied aminostratigraphy as illustrated by analyses of Mulinia lateralis from the late Cenozoic marine beds near Charleston, South Carolina. South Carolina Geology, v. 30, no. 1, p. 19-46.

Groot, J. J., Ramsey, K. W. and Wehmiller, J. F., 1990. Ages of the Bethany, Beverdam, and Omar Formations of southern Delaware. Delaware Geological Survey Report of Investigations No. 47, pp. 1-19.

Harris, M. S., Krantz, D. E., Wehmiller, J. F., Gayes, P. T., Kindinger, J. I., and Flocks, J., 1996. High resolution stratigraphy and paleogeography of the upper Cenozoic system beneath the coastal plain and continental shelf, Charleston, SC. Geological Society of America Abstracts with Programs, National Meeting, Denver, Oct. 1996. Vol 28(7), p. A118.

Harris, M. S., Gayes, P. T., Kindinger, J. I., Flocks, J. G., Katuna, M. P., Wehmiller, J. F. and Krantz, D. K., 1997. Short- and Long-term geomorphic evolution of the central South Carolina coastal zone: coastal responses to a complex geologic framework. EOS 78(46) F334.

Hollin, J. T. and Hearty, P. J., 1990. South Carolina interglacial sites and Stage 5 sea-levels. Quaternary Research, 33: 1-17.

Jones, D. S., Mueller, P. A., Acosta, T., and Shuster, R. D., 1995. Strontium isotope stratigraphy and age estimates for the Leisey Shell Pit faunas, Hillsborough Co., Florida. Bull. Florida Mus. Nat. Hist. 37 Pt I(2)93-105.

Karrow, P. F., Morgan, G. S., Portell, R. W., Simons, E. and Auffenberg, K., 1996. Middle Pleistocene (early Rancholabrean) vertebrates and associated marine and non-marine invertebrates from Oldsmar, Pinellas County, Florida. *in* Stewart, K.M. and Seymour, K. L. (eds)., Paleoecology and paleoenvironments of late Cenozoic mammals: Tributes to the career of C. S. (Rufus) Churcher. Univ. of Toronto Press, Toronto. pp 97-133.

Ludwig, K. R., Muhs, D. R., Simmons, K. R., Halley, R. B. and Shinn, E. A., 1996. Sea-level records at ~80 ka from tectonically stable platforms: Florida and Bermuda. Geology 24, 211-214.

McCartan, L., Owens, J. P., Blackwelder, B. W., Szabo, B. J., Belknap, D. F., Kriausakul, N., Mitterer, R. M. and Wehmiller, J. F., 1982. Comparison of amino acid racemization geochronometry with lithostratigraphy, biostratigraphy, uranium-series coral dating, and magnetostratigraphy in the Atlantic coastal plain of the southeastern United States. Quaternary Research, v. 18, p. 337-359.

Muhs, D. R., Szabo, B. J., McCartan, L., Maat, P. B., Bush, C. A., and Halley, R. B., 1992. Uranium-series age estimates from Quaternary marine sediments of southern Florida, *in* Scott, T. M. and Allmon, W. D., (eds.), Plio-Pleistocene stratigraphy and paleontology of southern Florida. Florida Geological Survey Sp. Publ. #36, p41-50.

Mirecki, J. E., Wehmiller, J. F., and Skinner, A., 1995. Geochronology of Quaternary Coastal Plain deposits, southeastern Virgina, USA. Jour. Coastal Research, v. 11(4), 1135-1144.

Mitterer, R. M., 1975. Ages and diagenetic temperatures of Pleistocene deposits of Florida based upon isoleucine epimerization in *Mercenaria*: Earth and Planetery Science Letters, v. 28, p. 275-282.

O'Neal, M. L., Wehmiller, J. F. and Newell, W. L. (in press). Amino acid geochronology of Quaternary coastal terraces on the northern margin of Delaware Bay, southern New Jersey, USA. Perspectives on Amino Acid and Protetin Geochemistry, Oxford. Goodfriend et al., eds.

Riggs, S. R., L. L. York, J. F. Wehmiller, and S. W. Snyder 1992. Depositional patterns resulting from high frequency Quaternary sea-level fluctuations in northeastern North Carolina. *in* C. H. Fletcher III and J. F. Wehmiller (eds.), Quaternary Coasts of the United States: Marine and Lacustrine Systems. Society of Economic Paleontologists and Mineralogists Special Publication No. 48, pp. 141-153.

Riggs, S. R., Cleary, W. J. and Snyder, S. W., 1995. Influence of inherited geologic framework on barrier shoreface morphology and dynamics. Marine Geology 126, 213-234.

Simmons, K. R., Wehmiller, J. F., Krantz, D. E., Ludwig, K., Markewich, H. W., Rich, F. and Hulbert, R. C., Jr., 1997. TIMS U-series Ages for Atlantic coastal plain corals suggest 80 ka sea-level similar to the present. EOS, Transactions American Geophysical Union 78(46), p. F788.

Szabo, B. J. 1985. Uranium-series dating of fossil corals from marine sediments of the United States Atlantic coastal plain: Geological Society of America Bulletin, v. 96, p. 398-406.

Toscano, M. A. and Lundberg, J., 1999. Submerged late Pleistocene reefs on the tectonically stable S. E. Florida margin: high precision geochronology, stratigraphy, resolution of substage 5a sea-level elevation, and orbital forcing. Quaternary Science Reviews 18, 753-767.

Wehmiller, J. F., Belknap,D. F., Boutin, B. S., Mirecki, J. E., Rahaim, S. D. and York, L. L., 1988. A Review of the Aminostratigraphy of Quaternary Mollusks from United States Atlantic Coastal Plain Sites. Geol. Soc. Amer. Special Paper 227, Dating Quaternary Sediments, D. L. Easterbrook, ed. , pp. 69-110.

Wehmiller, J. F., York, L. L., Belknap, D. F. and Snyder, S. W., 1992. Theoretical correlations and lateral discontinuities in the Quaternary Amino-Stratigraphic Record of the U. S. Atlantic Coastal Plain. Quaternary Research, v. 38, 275-291

Wehmiller, J. F., York, L. L., and Bart, M. L., 1995. Amino acid racemization geochronology of reworked Quaternary mollusks on US Atlantic coast beaches: implications for chronostratigraphy, taphonomy, and coastal sediment transport. Marine Geology, v. 124, 303-337.

Wehmiller, J. F., Krantz, D. E., Simmons, K., Ludwig, K. R., Markewich, H. W., Rich, F. and Hulbert, R. C., Jr., 1997. US Atlantic coastal plain late Quaternary geochronology: TIMS U-series dates continue to indicate 80 kyr sea-level at or above present. Geological Society of America Abstracts with Programs, vol 29(6), p A-346.

Wehmiller, J. F. Lamothe, M., and Noller, J. S., 1998. Comparison of approaches to dating Atlantic Coastal Plain sediments, Virginia Beach, VA., *in* Sowers, J. M., Noller, J. S. and Lettis, W. R. (eds.), Dating and Earthquakes: Review of Quaternary geochronology and its applications to paleoseismology. U. S. Nuclear Regulatory Commission, NUREG/CR 5562, pp. 4-3 to 4-31.

Wehmiller, J. F. , York, L. L., Jones, D. S. and Portell, R. W., 1999. Racemization isochrons for the U. S. Atlantic coastal plain Quaternary: independent calibration and geochemical implications of results from marginal marine units, central Florida. Abstracts, 9th Annual Goldschmidt Geochemistry Conference, Harvard Univ.

York, L. L., Wehmiller, J. F., Cronin, T. M. and Ager, T. A., 1989. Stetson Pit, Dare County, North Carolina: an integrated chronologic, faunal, and floral record of subsurface coastal Quaternary sediments. Palaeogeography, Palaeoclimatology, Palaeoecology. v. 72, 115-132.

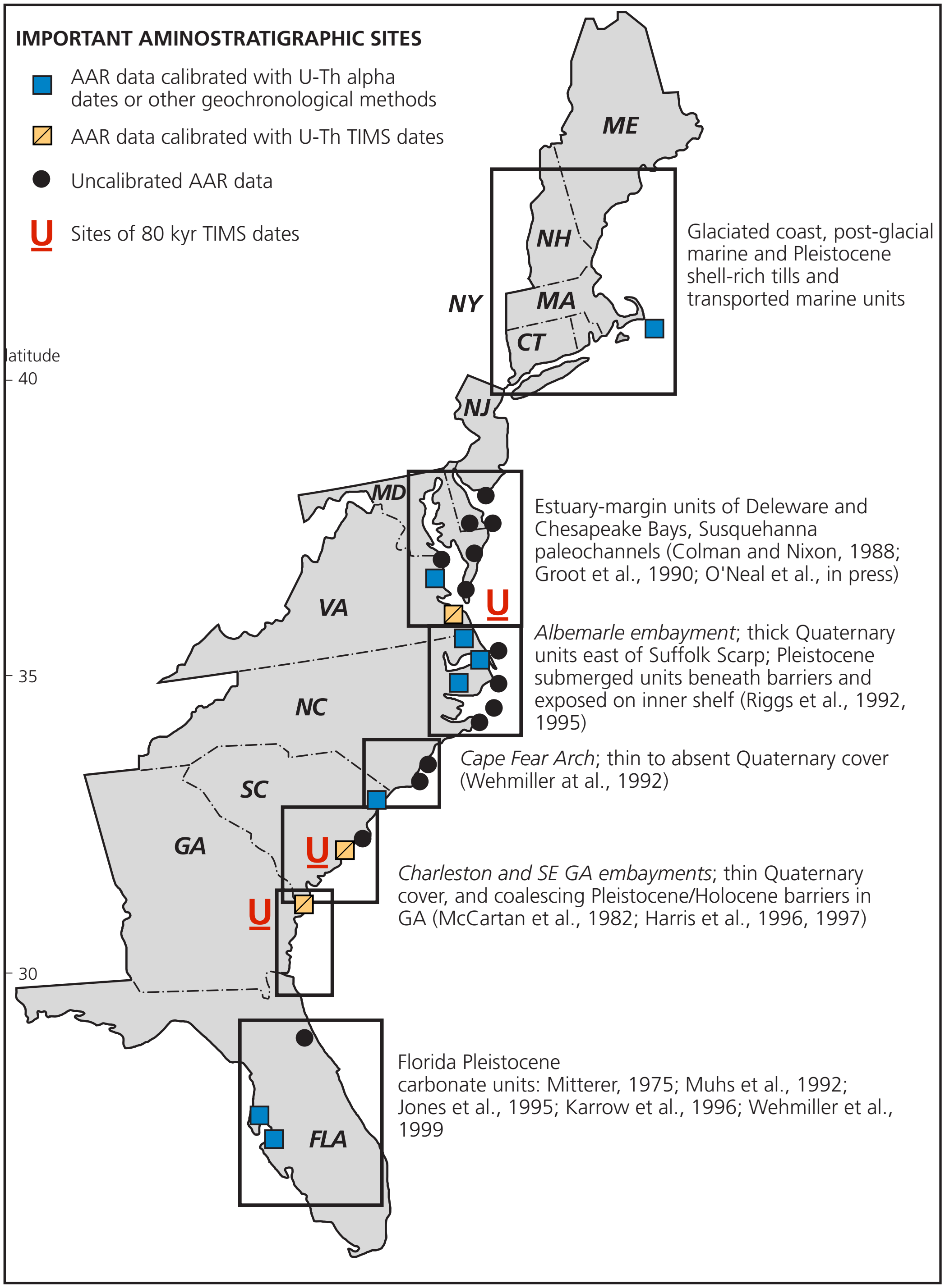

Fig. 1 Map of the US Atlantic coast, Maine to Florida, showing regions from which aminostratigraphic data have been obtained (see Wehmiller et al., 1988 for details regarding these regions). Areas south of the glacial limit (New Jersey to Florida) are the focus of this presentation. Delineated areas identify regions within which similar geomorphic processes appear to have functioned during the Quaternary. Selected references to aminostratigraphic data from each region are shown.

Morphodynamic response of shorelines to interglacials

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Understanding the response of highstand coastlines to sea-level change is a major focus of IGCP 437. This has a particular significance in view of anticipated global environmental change, and the recognition of changes in sea-level at a range of scales (such as ENSO, anthropogenically-modified greenhouse effect, and glacial to interglacial). Morphodynamics, the study of the co-adjustment of form and process, should be, but often is not, a central component of modelling shoreline response in the face of anticipated sea-level rise. There is also a need for incorporation of field-based and conceptual modelling into interpretation of highstand systems in the seismic stratigraphy approach to coastal and shelf sequences. Studies within IGCP 437 can build upon precursor IGCP projects, to further our understanding of shoreline morphodynamics. In addition to the intercomparison of examples across a broad geographic range, there will be an increasing role for comparison and contrast across a broader temporal range, as the greater resolution of dating techniques allows increasing definition of the last interglacial, and differentiation of previous interglacials. In contrast to much of the Quaternary where the pattern of sea-level change is dominated by glacio-eustasy, the Holocene is particularly anomalous, with highly geographically-variable patterns of sea-level change and shoreline response. The past 6000 years reflects relative stability of ocean volume, and the coincidence of sea-level with low gradient shoreline, often with a legacy from previous interglacials. This has resulted in a great diversification in the form of major coastal types, and re-establishment of deltas, estuaries, and reefs as we know them. During this period it has not been sea-level alone that has exerted overriding influence on the way in which coastlines evolve. This paper examines the range of other factors that will need to be incorporated into models of shoreline evolution if these are to have predictive value in terms of response to sea-level change, concentrating on deltaic-estuarine and reefal systems. In the case of deltas and estuaries, complex sediment movement patterns and availability of accommodation space mean that there is not a uniform response to sea-level boundary conditions. In the case of coral reefs, still more complex feedback mechanisms, influencing the production of sediment and its fate, compound a simple modelling of reef response to sea-level as a forcing factor. If morphodynamic modelling of coastal behaviour is to have predictive capability it will be important to incorporate spatial and temporal perspectives into the development of conceptual and simulation models.

Division of Late Quaternary marine beds in the Bohai Gulf

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According to some analytical data of microfossils, granularity, sporopollen, clay mineral and content of calcium carbonate and dating data such as paleomagnetism,^{14}C and ESR for a hole laid at the northeastern margin of the modern Yellow River Delta ,seven marine beds have been identified. They are marine bed H_7 with buried depth of 154-158m, 417.0-460.0 ka BP) and H_6 (with buried depth of 107.4-131.0m,157.5-231.0 ka BP) which were formed in middle and late Middle Pleisrocene, H_5 (with buried depth of 86-95.85m,100.6-124.3 ka BP) and H_4 (with buried depth of 73-79m, 76.5-87.6 ka BP) which were formed in the last interglacial period, H_3 (with buried depth of 64-69m, 58.2-67.4 ka BP) and H_2 (with buried depth of 43-52m, 28-36 ka BP) which formed in two interstades of the last glacial period and H_1 (with buried depth of 0-23m, 8.5 ka BP to now) which was formed in postglacial period. Of all of these beds,H_7 is identified recently as the oldest one in the Bohai Sea bottom. Based on the contrasting with the BC-1 hole which lies in the middle of the Bohai Gulf and Xinji hole which lies in the west of the Bohai Gulf, the evolutionary history of the transgression-regressional environment in Late Quaternary period of Bohai Gilf has been illuminated. Finally,the history of the sea-level in middle and late Quaternary in Bohai Gulf has been shown based on these data.

Internal structure and late Holocene evolution of Kabira Reef, Ishigaki Island, Southwest Japan

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Drilling cores from the reef flat of Kabira Reef, Ishigaki Island, Southwest Japan, have revealed the internal structure and sedimentary process of a modern coral reef flat. Kabira Reef is a well-developed fringing reef with a distinct topographical and ecological zonation (**Fig. 1**, Yamano et al. 1999a). Sea level around Kabira Reef is considered to have reached its present level at about 6000 yBP (Nakada 1986), and sea-level fall around 2000 yBP due to tectonic movement is suggested by Kawana (1986, 1989).

Reef flat can be divided into two structures: the reef framework (reef crest) constructed mainly by autochthonous hermatypic corals and the backreef structure (moat) constructed by allochthonous bioclasts. The evolution of Kabira Reef in late Holocene is divided into three stages: (a) 6000 - 4000 yr BP, (b) 4000 - 2000 yBP and (c) 2000 yr BP - The Present. The age and depth diagram of cores in Kabira Reef indicate that the reef crest of Kabira Reef caught up with the sea-level at 4000 yr BP. After 4000 yr BP, the sea-level stabilized and the reef crest could not grow upwards. Thus, the reef crest expanded oceanward, and the reef pavement has grown landward. The backreef structure is composed of bioclasts derived from the reef framework. Of all the bioclasts, corals and coral fragments were constantly abundant (**Fig. 2**). Benthic foraminifera such as *Calcarina gaudichaudii* which now live on the reef crest have occurred in the backreef cores since 4000 yr BP. After 2000 yr BP, the ratio of foraminifera significantly increased and *Baculogypsina sphaerulata* occur in addition to *C. gaudichaudii* (**Fig. 2**).

We consider typhoons cause the fragmentation of corals not only at a decadal time scale (Yamano et al., 1999a) but also at a millennium time scale, resulting in the existence of abundant coral fragments in the backreef facies. In Kabira Reef, the amount of shallow species of foraminifera (*B. sphaerulata*) in the backreef facies significantly increased after 2000 yBP, which date is coincident with the timing of sea-level fall due to tectonic movement. We argue that sea-level fall in the late Holocene caused the aerial exposure of the reef crest and killed corals there, causing the occurrence of foraminifera, which are suggested to play an important role for the formation of coral sand cays (Yamano et al., 1999b). Foraminifera were transported and accumulated in the moat, resulting in the change of constituents of the backreef facies. The backreef facies records the effect of both storm and sea-level fall in late Holocene (**Fig. 3**), and we conclude that the internal structure of coral reefs can be used as an indicator of paleoenvironment.

References

Kawana, T., 1986. Holocene crustal movement in and around the Sekisei Lagoon in Okinawa Prefecture, Japan. Earth Monthly, 9: 129-134. (in Japanese)

Kawana, T., 1989. Quaternary crustal movement in the Ryukyu Islands. Earth Monthly, 11: 618-630. (in Japanese)

Nakada, M., 1986. Holocene sea-levels in oceanic islands: implications for the rheological structure of the earth's mantle. Tectonophysics, 121: 263-276.

Yamano, H., Kayanne, H., Yonekura, N., and Kudo, K., 1999a. 21-year changes of backreef coral distribution: causes and significance. J Coast Res, in press.

Yamano, H., Miyajima, T., and Koike, I., 1999b. Importance of foraminifera for the formation and maintenance of a coral sand cay: Green Island, the Great Barrier Reef, Australia. Coral Reefs, in press.

Yamano, H., Kayanne, H., Yonekura, N. (submitted). Anatomy of a modern coral reef flat: a recorder of storms and sea-level fall in the late Holocene.

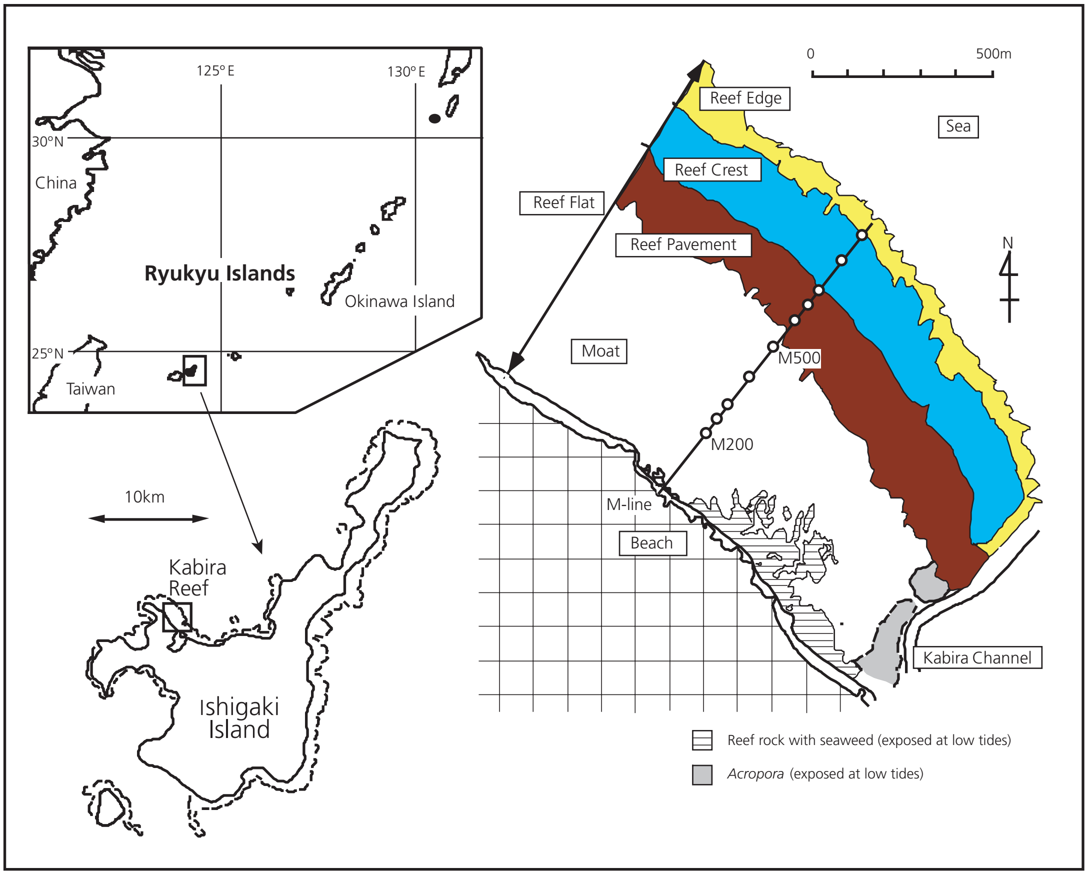

Fig. 1 Kabira Reef located at the northwestern coast of Ishigaki Island, the Ryukyu Islands, Southwest Japan (left). Geomorphological map of Kabira Reef and a transect (M-line) set perpendicular to the shoreline (right). Open circles show the drilling points.

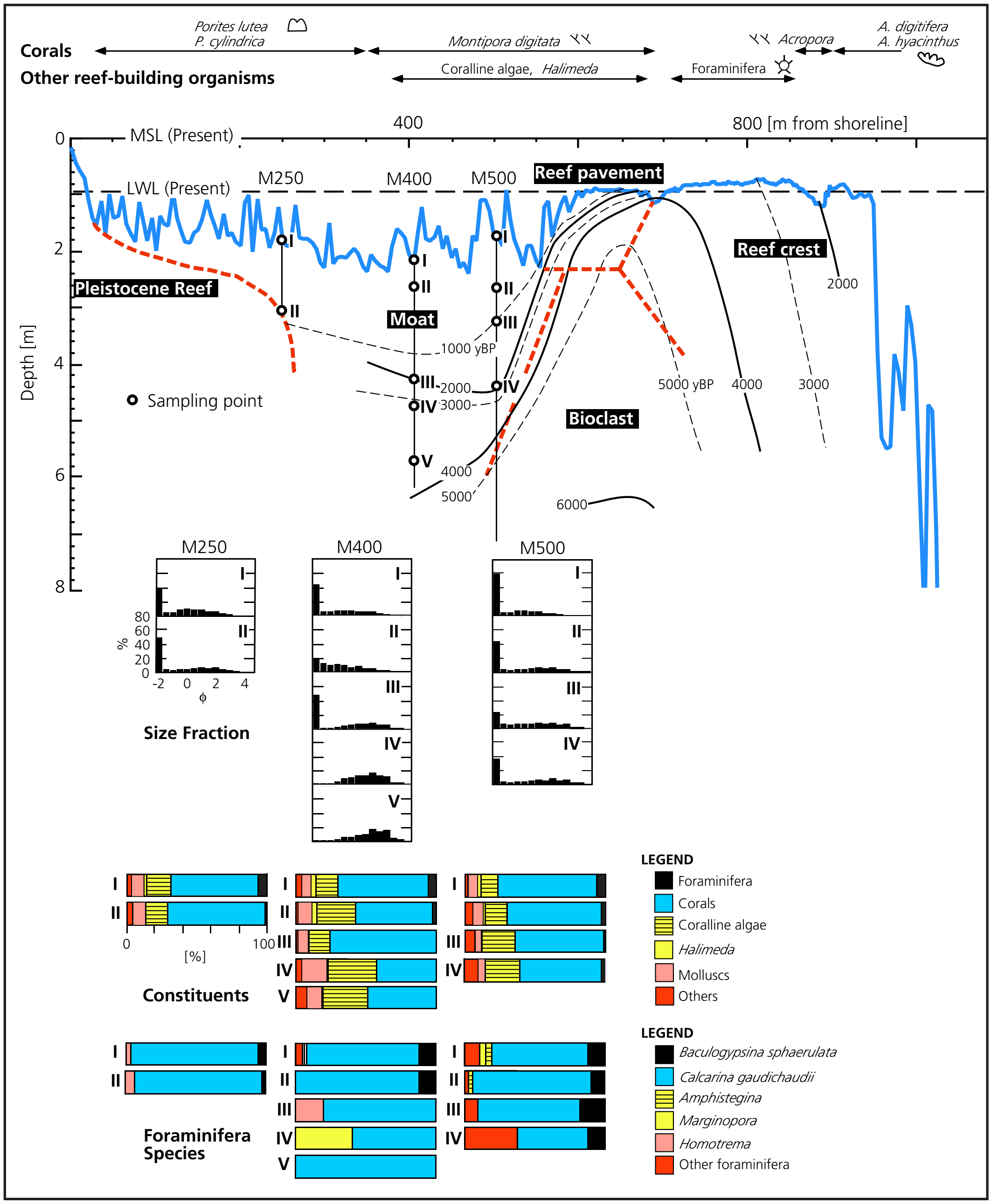

Fig. 2 The present distribution of reef-building organisms, the topographic profile, and internal facies of Kabira Reef flat. Isochronal lines based on the radiocarbon ages of coral and foraminifera specimens. Vertical lines show drill holes. The distribution of corals and the topographic profile are from Yamano et al. (1999a). Size fraction and constituents of the sediments, ratio of each foraminifera tests obtained from the moat cores (M250, M400 and M500). Adapted from Yamano et al. (submitted). The backreef structure (moat) was infilled after the establishment of the reef framework (reef crest). Corals and coral fragments coarser than 2.0 Ø is the major constituents of the backreef structure. Significant amount of shallow species of benthic foraminifera occurred after 2000 yr BP. *Calcarina gaudichaudii* occurred after 3500 yr BP, and *Baculogypsina sphaerulata* occurred after 2000 yr BP.

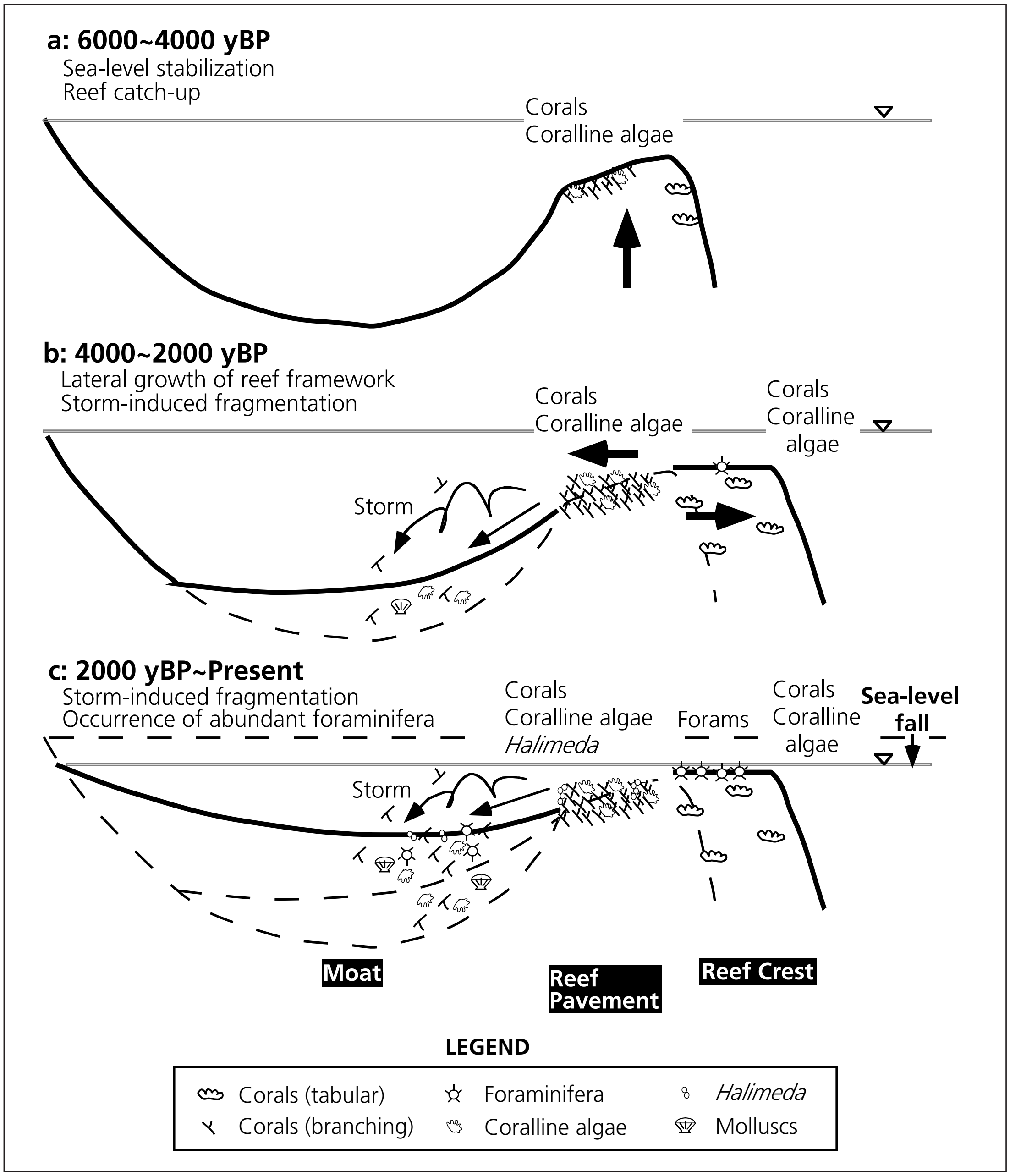

Fig. 3 The stage of sedimentation of Kabira Reef flat from 6000 yr BP to the present. The reef crest caught up with the sea-level at about 4000 yBP. Then, the reef framework expanded both oceanward and landward. The moat was infilled by coral fragments and coralline algae supplied by fragmentation due to typhoon events. Sea-level fall at about 2000 yr BP (Kawana 1989) caused the aerial exposure of the reef crest and caused the occurrence of shallow species of benthic foraminifera, thus resulting in the modification of the constituents of backreef facies (from Yamano et al. submitted).

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WELCOME TO IGCP PROJECT 437

Welcome to IGCP *Project 437* Coastal Environmental Change During Sea-Level Highstands: A Global Synthesis With Implications For Management Of Future Coastal Change. Project 437 was officially ratified by the IGCP Scientific Board in February of this year with a duration of five years. I would like to take this opportunity to welcome you all to the project and look forward to your continued enthusiastic and energetic contributions, as has characterized all previous coastal IGCP projects. Indeed, Project 437 has a healthy lineage and seeks to build upon the important contributions made in all of the previous projects over the past 25 years. For the record, these projects include *Project 61* Sea-level change during the last deglacial hemicycle directed by Arthur L. Bloom (1974-1982), *Project 200* Sea-level correlation and applications directed by Paolo A. Pirazzoli (1983-1987), *Project 274* Coastal evolution in the Quaternary directed by Orson van de Plassche (1988-1993) and *Project 367* Late Quaternary coastal records of rapid change - application to present and future conditions directed by David B. Scott (1994-1998).

Aims and objectives

Project 437 seeks to examine the nature and processes responsible for coastal changes during sea-level highstands, with the ultimate view of applying the results in the management of present and future coastal change. The history of coastal environmental changes during the last few thousand years up to the present day will be compared and contrasted with similar intervals of sea level highstands in the earlier geological record (e.g. comparison of the Last Interglacial Maximum or interstadials with the present Holocene Interglacial). During these episodes, sea level was at its highest or near highest points in the Milankovitch cycle of glacio-eustatic sea-level change. Thus, the changes which have occurred during similar sea-level highstands during the last few hundred thousand years will also be examined as a framework to model possible future change in the environmentally sensitive and extremely dynamic setting of the coastal zone.

As stated in the project proposal the objectives include:

To compare and contrast the evolution of coasts during the present, Holocene sea-level highstand with earlier highstands (e.g. particularly the last interglacial maximum; oxygen isotope substage 5e) and explain the geological and geophysical basis for any morphostratigraphic similarities or differences in these records. The results derived from these studies will provide the necessary data and scientific interpretations permitting the subsequent management of present and future coastal change;

To document through geological mapping and detailed stratigraphic analysis, the global distribution of highstand shoreline successions for the Holocene and last interglacial, and where possible, earlier highstands with the aim of elucidating the geological and geophysical basis for similarities and differences;

To quantify the magnitude of sea-level variation evident during highstands and document their basis (e.g. the contributions of glacio-hydro-isostatic processes, as well as relative sea-level changes associated with neotectonism);

To develop new, and refine existing technologies for the assessment of age of coastal sedimentary successions through the critical application of a range of Quaternary dating methods;

To evaluate the impact of human-induced environmental changes in coastal environments in the context of natural environmental changes; and

To synthesize the results of these global studies through publications in books and international journals and circulate information as widely as possible including the use of the World Wide Web.

Further Information about IGCP Project 437 may be obtained from me at the address below:

A/Prof Colin V. Murray-Wallace, Project Leader IGCP 437; School of Geosciences, University of Wollongong; New South Wales, 2522, Australia; Tel: 61 2 4221 4419; Fax: 61 2 4221 4250; email: colin_murray-wallace@uow.edu.au

In addition, regular updates will be placed on the IUGS Web Page; www.iugs.org

By all means write to me outlining any activities you propose to undertake (e.g. conferences of related interest, national meetings and workshops, new publications, so that we can publicize the information through the Web).

And don't forget to encourage your friends and colleagues to participate in the project.

With best wishes to you all!

Colin V. Murray-Wallace

Project Leader

Aloha and Welcome to Participants of the Late Quaternary Coastal and Inner Shelf Change Conference

The USGS is pleased to be a co-sponsor and participate in this important science conference. As the Nation's primary natural science research and information agency, the U.S. Geological Survey maintains a 120 yr. tradition of providing "Earth Science in the Public Service" not only to this Nation but to the world. Information on the many research activities underway at the USGS is available at: http://www.usgs.gov. The Survey's Coastal and Marine Geology Program addresses important national issues on regional and systems-scales in environmental quality/human health, geologic hazards (coastal/shelf erosion, storm effects, earthquakes, tsunamis, landslides, sea-level rise), and natural resources (energy, minerals, gas hydrates).

The goals of the program are to develop predictive capabilities from enhanced scientific understanding; to provide baseline data for long term planning and management in the coastal ocean; to provide a comprehensive source of scientific information that can be easily accessed for use by government, academia, and the public; and to facilitate marine geologic research across the community. Information on the Coastal and Marine Program and results from this research are available through publications and maps, as well as the WWW at: **http://marine.usgs.gov.**

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COASTAL CHANGE

National Science Foundation

Geology and Paleontology Program

Research in the Sedimentary Geology of the Coastal Zone and Inner Shelf

A Pre-Conference Report from the University of Hawaii
"The Non-Steady State of the Inner Shelf and Shoreline: Coastal change on the time scale of decades to millennia"
November 9-12, 1999
http://imina.soest.hawaii.edu/Coastal_Conf/PDF/NSF.PDF

A Critical Boundary

Today the coastal zones of the world support expanding human populations that depend on critical natural resources to sustain commerce, cultures and community development. Ironically, human use is a major cause of decline in the very coastal environments on which we depend. Many of these resources are naturally renewed over centuries to millennia, yet are drawn down by human use in mere decades. Coastal ecosystems are fragile and dependent upon sedimentary substrates and sedimentary transport processes for critical nutrient flux and trophic energy. The sedimentary processes are typically non-linear and highly complex, hence our understanding of the structure and function of sediment-dependent environments, although improving, remains at a moderate level.

It is through observation and modeling of sedimentary processes, morphodynamical substrate evolution and stratigraphic records that we are best able to understand the specific interrelationships of processes and responses within coastal environments as well as the interdependence of coasts with other global systems. Observation and modeling improves knowledge of the critical pathways, inputs and stress thresholds that govern the behavior and evolution of coastal sedimentary environments. Both applied and curiosity-driven investigations of coastal sedimentary processes and records work as equal partners in improving our state of knowledge. As the scientific state of knowledge grows, so too does our ability to assist in the development of future sustainable resource management programs. Without scientifically-framed conservation efforts that stem from improved knowledge of coastal sedimentary morphodynamics and stratigraphic histories, the future preservation and utilization of coastal environments will too frequently need to rely upon reactive and crisis-management decision criteria. This is a situation that does not promote sustainability, especially in a world with an unsure future climate and an expanding human population.

Common among the problems along our shores are the following:

1) High density development of urban and suburban coastal zones (e.g., high hazard vulnerability, growing financial loss from storms, increased polluted runoff and decreased upland permeability);

2) Disruption and degradation of environmental pathways from watersheds to the sea (e.g., coastal dune and wetland filling, stream channelization, estuarine pollution, disrupted sediment flux);

3) Weakened environmental carrying capacity (e.g., inadequate sewage disposal, shoreface ecosystem degradation, armored beaches and wetland boundaries);

4) Exhausted natural resources (e.g., over-pumping of coastal aquifers, over-fishing, shoreface mining, depleted sediment budgets).

Accentuating the anthropogenic impacts to coastal systems are changing patterns of global climate and meteorology that drive local shifts in humidity, storminess, sea surface temperature, coastal circulation, as well as a worldwide rise of sea level. These trends sharpen the severity of the specific human influence and, commonly, drive the level of environmental deterioration past the point of natural recovery and into the need for remediation and artificial restoration. With the advantage of hindsight, it is clear that many of these problems are related to poor coastal zone management stemming from a lack of scientifically-framed policies.

Recommendation

The scientific community can correct this deficiency with improved coastal sedimentary research in a framework that emphasizes multidisciplinary integration of the geophysical and geochemical sciences. This pre-conference report recommends to the National Science Foundation, Geology and Paleontology Program (NSF–EAR), to initiate a development process leading to a focused program of coastal sedimentary investigation based upon a nested hierarchy of interdisciplinary inquiry. The principal components of this integrative effort must, at a minimum, include:

1) **Mapping** the substrate and stratigraphic framework of the shoreline, inner shelf and related upland environments within a framework of inquiry based upon hypothesis-testing;
2) **Synoptic Observation**, sampling, and analysis of coastal oceanographic sedimentary processes and materials (including geochemical components and flux), again within a framework of critical inquiry designed to test hypotheses;
3) development of **Predictive Modeling** tools to integrate components 1 and 2 above, and for the purpose of extending knowledge and inference to coastal systems needing improved management but lacking an observational database.

The goal of this recommendation is to create a new investigative framework at the NSF Geology and Paleontology Program that will shift the investigative style of coastal sedimentology from its traditional profile of single-investigator driven inquiry to a new mode characterized by multidisciplinary/multi-investigator inquiry emphasizing the integrative application of tools and concepts to resolve long-standing coastal science problems. The idea is to conduct research on basic and fundamental coastal sedimentology problems with teams of investigators bringing to bear a spectrum of skills and experiences. Typically, such a team investigation would focus on a single, representative littoral cell and over a period of several years (say 5):

1) Quantify the sedimentary budget of production, flux and storage within a true mass balance framework;
2) Map the 2-D and 3-D architecture of the littoral cell, and relevant adjacent environments, using shallow-water deep coring, remote sub-bottom imaging, as well as towed and airborne imaging tools to determine substrate variability and change detection at spatial and temporal scales of high resolution;
3) Ascertain through deep coastal coring, dating and other historical tools, the detailed and high resolution history of sediment deposition and flux, and the history of forcing parameters and boundary conditions controlling coastal evolution and geologic framework such as tectonics, sea-level movements, storm and other high-energy events and changes in sediment source and paleogeography;
4) Observe (with *in-situ* sensors) coastal circulation, wave shoaling and sediment transport patterns for the purpose of improving understanding and developing improved predictability of sediment flux and hydrodynamic forcing to the substrate;
5) Model morphodynamic, and hydrodynamic observational data and in turn use models to guide the development of more complex and specific observational field programs;
6) Quantify geochemical flux parameters through the water column and coastal substrates to delineate uptake, sequestration, and remobilization states and thresholds;
7) Assess and integrate the morphodynamic history of the coastal zone on a range of time scales to improve understanding of its present condition and potential future state.

In the space of a decade, application of this structure of investigation at key representative coastal sites will greatly improve understanding of the coastal zone and its many complexities to the benefit of coastal societies worldwide.

Improved Understanding

Increasingly, curiosity-driven scientific inquiry along the world's shorelines and inner shelves provides data that are relevant to supporting informed and wise use of coastal resources. It is now well established among the coastal research community that applied, societally-relevant improvements in understanding arise from investigations of fundamental and basic natural processes, patterns, and histories. Among these improvements are knowledge of how the coastal zone plays an irreplaceable role in the vitality of neighboring environments, and in turn is heavily dependent upon its bordering neighbors for materials and energy.

For instance, the flux of nutrients, sediments, and geochemical constitutents that descend from the watersheds into the estuaries and embayments of the coastline, provide a ceaseless tide of mineral and organic ingredients that support the substrate morphodynamics and trophic activities of the oceans and their vast communities. Sustained disruptions to this system create a ripple effect of ever-expanding impacts along the abutting shoreline and across the adjoining shelf and shallow sea. Cases exist where upland water diversion has led to decreased estuarine diversity. This, in turn, impacted the dispersal of nutrients and degraded the juvenile nursery stocks in adjoining brackish environments. On adjacent coral reefs, ecologic imbalances were observed in the form of decreased herbivore stocks and increases in the ratio of fleshy & filamentous algae to calcareous algae and coral substrates. A decline in carbonate sediment production eventually results, along with both reef and beach degradation. Ultimately this problem would have been predicted if analyzed from a sedimentary processes point of view with an understanding of material fluxes and budgets, and substrate geochemical processes.

Recognizing the attributes of improving our knowledge of coastal system processes and patterns, for all the reasons mentioned above, the 1996 National Science Foundation – Ocean Sciences workshop on the Future of Marine Geology and Geophysics ("FUMAGES" [1]) identified to the research community:

> *…a need to investigate the basic dynamical and historical components of the shelf and shoreface such that the processes governing system behavior, and the role of antecedent controls, are better understood. There are fundamental scientific questions nested in the societally-relevant issues.*

Also, the Coastal and Marine Geology Program of the U.S. Geological Survey [2] stated in its plan for 1999:

> *The management challenge faced by all coastal communities is to balance the competing needs of citizens, government, industry, and the environment. Sound marine science is critical for making such management decisions.*

Recent National Science Foundation workshops on Sedimentary Geology [3, 4, 5] and Geomorphology [6] identify the need to change the culture of research from its current status as an individualistic field to one that has a community basis emphasizing common database development, overlapping observational sharing and community modeling tools.

> *…feel strongly that we would like to encourage a change in the culture of sedimentary geology away from individualistic to community-based, from individually acquired data to the sharing of larger community, industrial, and governmental data bases. The rapid advances in numerical modeling and the success with which these have been applied in the atmospheric and oceanographic sciences tell us that dramatic advances can also be expected in sedimentary geology by choosing similar approaches.*

These workshop reports also emphasize that interdisciplinary and basin-scale analyses [3, 6] need to be conducted in an integrated fashion such that a maximum of understanding can emerge from the study of characteristic field sites [7].

> *…..a commitment to measuring critical mass fluxes throughout a small set of carefully chosen transport systems over time spans long enough to include numerous transport events.*
>
> *…..a focus on an analytical, quantitative approach to measuring and understanding transport processes…..a commitment to an integrated view of the geomorphic system that would include key biological, chemical and physical processes*
>
> *…..a focus on integrating direct flux measurements with time-averaged measures of erosion and deposition in the system, which calls for a cooperative effort.*
>
> *…..a commitment to the use of field and experimental data as a springboard to begin work on community landscape evolution models, analogous to GCM's that could be used as general predictive tools to answer questions of both scientific and social interest.*
>
> *Understanding the linkages within entire sediment dispersal systems requires coordinated interdisciplinary investigations. Capturing this synergy will be important, and has the potential to foster much innovative research.*

As evidenced by these national themes, the research community of sedimentologists is increasingly asking to focus their inquiry onto the world of physical and chemical processes integrated across sedimentary systems that are basin-scale, using interdisciplinary tools for developing community research resources. The results of this approach promise high application in the coastal zone which is naturally divisible into littoral cells that are part of a larger hierarchy of uniform coastal segments and adjoining watersheds representing basin-scale systems.

A Non-Steady State

Coastal variability, that is, the tendency for all coastal and shoreface marine environments to perpetually undergo change [8], occurs in response to natural processes across a range of spatial, temporal and dynamical scales. The shoreline and inner shelf exist in a non-steady state of dynamic equilibrium with incident energies that are, today, largely unpredictable. The principal agents of coastal change are:

1) **Sediment Budget Processes** – sedimentary particle production, movement, and storage across a diversity of spatial and temporal scales within defined sedimentary systems and substrates such that a budget of production, flux and storage can be defined and measured;

2) **Tectonic Processes** – coastal zone emergence, submergence, flexure and coseismic movements, and associated geophysical processes (e.g., tsunami generation [9]) all of which constitute 3-dimensional shifts in natural sedimentary systems;

3) **Marine Energy Processes** - waves, currents, storms and other individual events [10, 11], seasonal energy patterns, recognized and unrecognized long-term cycles in incident energy all of which can be observed and measured with the aid of *in situ* and remote sensors;

4) **Relative Sea-Level Movements** – eustatic trends, geoidal patterns, ice volume controls and local tectonic processes can govern the position of sea level [12, 13] and therefore the spatial distribution of geochemical and geophysical processes governing coastal sedimentology;

5) **Interannual Processes** – including oceanographic and meteorologic processes such as ENSO, interdecadal sea-level episodes and cycles, interannual seasonal extremes to sea surface temperatures and meteorological patterns;

6) **Human Impacts** – sediment impoundment, source and production decreases, volume depletion, mineralogic flux restrictions, natural energy modifications, carbonate production changes due to reef degradation can all lead to fundamental shifts in natural sedimentary systems;

7) **Climate Change** – long-term shifts in sea surface temperature [14], upland humidity changes governing sediment source and flux, steric sea-level rise, catastrophic SL rise, carbonate production changes due to seawater acidity and coral bleaching are all related to climate change and need additional detailed analysis of past histories [15] before future trends can be fully understood through modeling [16].

Unfortunately, fundamental knowledge of many of these characteristics is limited to sparse observations of modern variability (often lacking the critically important extreme end members), and limited exploration of records of historical trends (little deep drilling has been achieved in the coastal sedimentary archive). These gaps greatly limit our ability to develop predictive models of morphodynamic variability through time.

The Fundamentals

Many aspects of coastal change are poorly understood. For instance, scientists have only a rudimentary understanding of how interannual processes (e.g., seasonal wave regimes related to ENSO, interdecadal sea-level oscillations, major river floods at the coast, post-storm downwelling processes) govern sediment sharing across the littoral energy fence. Nor do we possess a comprehensive understanding of the repeatability (or variability) of states of coastal stability or change on the interdecadal scale. What are the temporal and spatial characteristics of physical processes that link the shoreline to the inner shelf on the century to millennial scale? Which of these nested time scales is responsible for the greatest amount of work in determining the fate of coastal sediments, and the character of the shoreline system at any moment in time? What are the sensitivity thresholds of sedimentological records to any of the variability mentioned above?

The coastal zone, and its myriad processes and historical patterns, has resisted comprehensive modeling. For instance it is still not possible to predict coastal change (in more than vague and general terms) if there is a sediment deficiency, or if sea level were to rise at twice it's present rate (e.g., under present sea-level rise [2 mm/yr] many shorelines are still accreting, at what rate of rise does the ratio of accreting to eroding shoreline fundamentally change?). Any present attempt at this would find itself without knowledge of the contribution of sedimentary materials from adjoining environments, and so could not quantitatively address the response rate of, say beaches, or wetlands.

Despite the scientific and societal relevance of research into the nature of decadal to millennial-scale processes and antecedent patterns, there remains a low-level of understanding with regard to several underlying and basic characteristics of the inner shelf and shoreline.

1) Are there overarching geophysical/biochemical processes governing natural variability in the spectrum of decades to centuries? Can this knowledge be used to change environmental management policies to improve sustainability?

2) How do the inner shelf and shoreline respond to melt-water pulses and changes in the rate of sea-level movement resulting from periods of global change? How will modern coastal systems respond to future accelerations in sea-level rise resulting from steric heating and meltwater flux?

3) Can higher resolution studies of coastal morphodynamics during previous interglacial, or interstadial states improve our understanding of the modern shoreline and inner shelf?

4) What role do morphodynamic beach states play in governing sediment flux across the littoral energy fence? Do decadal-scale processes govern large-scale coastal change? When does most of the work determining the fate of sediment occur?

5) What is the repeatability of states of stability? Are coastal zone dynamics and behavior predictable on any temporal or spatial scale? Do random interannual high-energy events govern shoreline variability?

Additionally, the geologic record of global change events and patterns is particularly well-preserved in coastal archives and their study is a necessary component for testing global circulation models and separating natural change from anthropogenic influences. Despite this value, nearly all NSF marine sedimentary research resources are funneled into deep-sea drilling efforts that answer few questions pertaining to the temporal span covering the rise of human civilizations, and the resultant environmental stresses on the favored ecological niche of human settlements, the coastlines.

Nested Investigations

Answering these questions is possible, though difficult. The nature of coastal morphodynamical change is best understood to the fullest extent through the innovative and interdisciplinary application of multiple investigative tools from allied fields of chemical and physical science. True advances in coastal understanding will emerge from nested investigations involving teams of interdisciplinary researchers and their tools.

These include:

1) Sensors to collect physical oceanographic observations of waves and currents,

2) The ability to collect deep cores in shallow environments,

3) Samplers to determine the physical and chemical character of coastal deposits and sediments in flux,

4) Imagers to map the structure and change of coastal sedimentary environments,

5) Laboratories to quantify geochemical and geophysical parameters of sediments and fluids,

6) Numerical models with the ability to unify and integrate observational databases as well as improve prediction of unobserved phenomena and future patterns.

There is no unique disciplinary domain for this work. Sedimentologists, geochemists, physical oceanographers, and marine biologists are all needed to weave the cloth of understanding coastal change. No single phenomenon in the coastal zone exists in isolation. All physical and chemical processes there are part of a temporally and spatially complex network that will not be fully understood until investigated in a research framework that is comprehensive and interdisciplinary.

The underlying structure behind nested investigations should follow variations across a three-tiered integrated hierarchy consisting of the following themes: environmental mapping, observations of morphodynamic processes, and quantitative modeling to expand and integrate observations across the mapped framework. Each of these is considered below.

1) **Environmental Mapping** Perhaps the most fundamental role of the geologist is to map Earth's surface. Mapping within the coastal zone [17] takes on the character of a 3-dimensional investigation of the distribution of energy and materials across a particular environmental setting [8]. Mapping is a critical first step to understanding the structure and function of present and past sedimentary systems. Mapping should also include subsurface investigations. To understand the history of sedimentary processes it is necessary to obtain core samples representing antecedent environments, or to otherwise image the subsurface structure of coastal deposits. This will provide for quantitative definition to be assigned to the rate of former environmental changes and sedimentary processes, and the production and storage mass of mineralogic as well as biolithologic materials. Mapping can include remote sensing from ship, satellite or aircraft as well as ground- or benthic-based measurements of materials and their geologic framework. Mapping includes sub-bottom imaging as well as surface characterization. It is from mapping, and the detailed ground-truthing investigations that must accompany the classification of substrate variability, that hypotheses can emerge regarding the role of past events that force changes in coastal sedimentary environments [7], as well as the relative capacity of modern processes to influence the character of the sedimentary system. Mapping provides definition to the significant components of sediment budgets, which, if rigorously quantified through synoptic observations of dynamic processes, can provide important and far-reaching improvements in understanding the coastal environment. Indeed, nearly all significant agents of coastal change will first be recognized and incorporated into hypothesis building through detailed and comprehensive mapping.

2) **Synoptic Observations of Dynamic Processes and Sedimentary Materials** Without quantitative information on the incident climate of waves, winds, and currents that are responsible for sediment motion on the shallow shoreface and shoreline, it will never be possible to understand the processes responsible for coastal change or their history. Knowledge of dynamic processes is one very critical component to improving our ability to model environmental patterns and trends. It is impossible to divorce the role of the sedimentologist from that of the coastal physical oceanographer. Without an understanding of the dynamic processes driving sediment budgets, and the distribution of energy across all coastal environments, maps will just be clues to coastal diversity rather than keys to unlocking true

understanding. For this reason, it is of critical importance that synoptic observations of the wave field and nearshore currents and circulation patterns become a standard part of the menu of interdisciplinary sedimentological research along the coastal zone and inner shelf. Included with the building of a dynamic processes database should be the performance of field experiments using *in situ* sensors designed to understand 3-dimensional circulation patterns responsible for particle flux and accumulation. High resolution stratigraphic and bathymetric change-detection experiments, small instrument platforms able to resist high wave forces, real-time data delivery to onshore recording stations, rapid response teams able to capture before and after datasets of episodic events such as storms, collaborative studies of 4-dimensional (x, y, z, t) particle production/flux/and storage/fate, and model development and testing with observational data sets of morphodynamical processes - these are approaches that must be implemented with greater frequency and geographic diversity.

Let us not forget that geochemical processes (e.g., gross carbonate precipitation, methane escape from organic-rich substrates, air-water mixing phenomena, and other gas and dissolved component flux) are critical aspects of substrate evolution. The biological imprinting that is so important on coastal substrates, and that determines substrate role in both the modern environmental system and the stratigraphic record, is often in equal parts controlled by geochemical and geophysical processes. Synoptic observations of dynamic processes must include geochemical processes in the work. Lastly, part of the design in this section of effort is meant to incorporate laboratory analysis of sedimentological materials including samples of substrate, stratigraphic samples, fluid and dissolved components and other materials whose analysis will result in improved understanding of dynamic processes.

3) **Predictive Modeling** All of the white papers and reports referenced earlier point to the need to develop improved predictive modeling as a crucial direction for the future of sedimentological and geomorphic research. To accomplish integration across scales and environments, we must forge strong partnerships between modeling and observations. While this coupling is not new, it must set the course for future study. Commonly, sediment transport models exceed our ability to verify them [1], however, they have, and must continue to guide the observations before true progress is achieved in understanding the agents governing dynamic change in the coastal zone. Models are also a critical link to improving our interpretation of the stratigraphic record of past environmental shifts in response to fluctuations in sedimentological conditions and atmospheric/oceanographic change.

Modeling has developed into an important tool for improving our understanding of the processes that build stratal architecture [18]. Morphometric models begin with the geometry of measured strata and, running backwards through time, successively strip off sedimentary layers to duplicate past sea floor morphologies and substrate conditions. Numerical deposition models attempt to mimic sediment transport into and through a basin by assigning values to the major components of sediment budgets, then, with time running forward from some past starting point, strive to duplicate stratal geometry observed through sub-bottom imaging techniques (acoustic profilers). A third form of modeling stratigraphic architecture relies upon scaled flume experiments to provide empirical relationships designed to represent field-scale conditions [18]. One weakness of stratal modeling has been the limited sample archive of shallow-water sections, a result of poor funding for deep-drilling in nearshore regions, thus limiting our ability to anchor models to verifiable aspects of the rock record.

Modeling is also a significant aspect of developing improved ability to understand and predict dynamic processes. Fundamentally, three types of dynamic models are commonly employed by those studying dynamics: conceptual, empirical, and numerical. Conceptual models serve the important role of enlarging ones thinking regarding a particular problem and also strengthening communication with an audience of peers from whom critical input can improve understanding. Empirical models have the advantage of evolving through the use of scaled coefficients into better predictors of specific conditions, but they tend to be based upon probabalistic arguments rather than true understanding. Numerical models, if theoretical in approach, are presently still simplistic in the face of nonlinear, stochastic conditions with multiple physical agents, but they typically lead to true predictive ability when accounting for the major agents of dynamical change across the shoreface and shoreline. The importance of all models, both conceptual and numerical, is that they serve to unify the endeavors of various investigators who otherwise focus on different process time scales and spatial scales. For example, cross-shore transport models rely on sediment-transport equations that are based on small-scale considerations, together with observations of the overall response of the beach morphology to changing wave conditions. While unifying what is known, the level of disagreement between the numerical model and observations serves to illustrate what remains poorly understood and what should be the focus of future research, and can even serve to devise measurement schemes [1]. It is apparent that the development of improved models provides linkages between investigators who are otherwise focusing on a limited area within specific time/space ranges. At present, linkages still remain limited, but one can envision an entire range of time scales involved in process models and a full range of sediment features and morphologies covered by series of linked 3-dimensional models into a unified whole, into a general theory of ocean margin sedimentation [1].

A Research Conference

On November 9-12, 1999 a research conference attended by international scientists active in the broad field of coastal sedimentology/tectonics/and eustatic change, will convene at the University of Hawaii, Manoa Campus in Honolulu. The conference, The Non-Steady State of the Inner Shelf and Shoreline: Coastal Change on the Time Scale of Decades to Millennia in the Late Quaternary, is sponsored by the National Science Foundation Geology and Paleontology Program in partnership with the International Geological Correlation Program Project #437 "Coastal Environmental Change During Sea Level Highstands." Other key sponsors include the U.S. Geological Survey Coastal and Marine Geology Program and the Hawaii Sea Grant College. This is a pre-conference report. Conference sponsors will take advantage of the presence of a cross-section of over 100 national and international coastal scientists to assess critical future directions in coastal change research.

To provide comments, or with questions, please contact:

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References

[1] FUMAGES Chapter 4. Dynamics on the shelf and shoreface and its imprint on the seafloor and sediment column – Particle transport to melt-water pulses, 12 authors, available at . http://www.joi-odp.org/FUMAGES/FUMAGES.html

[2] US Geological Survey, Coastal and Marine Geology Program, Web Home Page, http://marine.usgs.gov/

[3] NSF Community Paper, 1999. Sedimentary Systems in Space and Time: High Priority NSF Research Initiatives in Sedimentary Geology. Workshop White Paper, 7pp.

[4] Casey, W. H. and Sposito, G., 1999. Directions and Priorities in Low Temperature Geochemistry for the Year 2000 and the Decade Beyond. Workshop White Paper, 8pp.

[5] Flessa, K. W., 1999. Dynamic History of the Earth-Life System. Workshop Paper, 3pp.

[6] NSF-EAR Community Paper, 1999. Vision for Geomorphology and Quaternary Science Beyond 2000, 15p.

[7] Nittrouer, C. and Driscoll, N., 1999. Source to Sink. MARGINS Newsletter No. 3, p. 2-3.

[8] Sallenger, A., Schwab, B., and Richmond, B., 1999. Report on the USGS Coastal & Marine Geology Program: Coastal Erosion Workshop, March 9-11, 1999, Herndon, VA. 8pp.

[9] Dillon, W. and Brink, U., 1999. Seismic and Tsunami Hazards in Northeast Caribbean Addressed at Meeting. AGU EOS, 309-310.

[10] Showstack, R. Report Warns of More Natural Disasters. AGU EOS, 317-318.

[11] Stone, G. W., Wang. P., Pepper, D. A., Grymes, J. M., Roberts, H. H., Zhang, X., Hsu, S. A., and Huh, O. K., 1999. The Importance of Hurricanes to the Northern Gulf of Mexico Coast. AGU EOS, p. 301-305

[12] Goodwin, I., Berkman P., and Hirakawa, K., 1999. Holocene Antarctic's Coastal Environment, Ice Sheet, and Sea Levels Explored. AGU EOS, 103, 107.

[13] Rahmstorf, S., 1999. Shifting seas in the greenhouse? Nature. 523-524.

[14] Kerr, R. A., 1999. The Little Ice Age – Only the Latest Big Chill. Science. 2069.

[15] Droxler, A. W., R. Poor, and Burckle, L., Data on Past Climate Warmth May Lead to Better Model of Warm Future. AGU EOS, 289-290.

[16] Weber, S. L. and von Storch, H., 1999. Cimate Workshop Urges Interdisciplinary Paleo Simulations, Analyses. AGU EOS, 380.

[17] Pratson, L., Divins, D., Butler, T., Metzger, D., Sharman, G., Steele, M., Berggren, T., Holcombe, T., and Ramos, R., 1999. Exposing the U.S. Coastal Zone. AGU EOS, 37-42.

[18] Fairbanks, R. Dynamics of the Land-Sea Interface. White paper presented to the Ocean Drilling Project Workshop, 1999.

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