# The Geoarchaeology of Beach Ridges and Cheniers: Studies of Coastal Evolution Using Archaeological Data

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## ABSTRACT ■

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Nineteenth century naturalists discovered that Roman ports and Eskimo villages were often stranded inland, a discovery that led to the independent development of "beach ridge archaeology" in the United Kingdom and Alaska. The first principle of beach ridge archaeology requires that human subsistence favored the open ocean and that occupation sites parallel changes in the shoreline. Thus, the use of archaeological data to infer coastal evolution requires consideration of the taphonomic processes that create accumulations of cultural debris. Otherwise, geologists run the risk of misinterpreting radiocarbon dates from archaeological sites that do not mirror the prograding shoreface, as along the Gulf and Atlantic coasts of the U.S.A. If properly applied the beach ridge method has applications world-wide, as discussed for Southeast Asia, Australia, the Netherlands, both coasts of the U.S.A., Canada, Norway, México, and Peru.

**ADDITIONAL INDEX WORDS:** *Storm history, paleoclimatology, isostatic uplift, sea level, Holocene.*

## INTRODUCTION

The scientific discovery of coastal evolution during the late nineteenth century paralleled Darwinian evolution, yet occurred in an undramatic, largely parochial manner. Possessing accurate maps, observers such as engineers, naturalists and historians compared sequential map sets along the coast, finding significant changes in the last several hundred years. During the last 50 years, the dynamism of shoreline changes has claimed wide scholarly attention, especially in light of the catastrophic effects of hurricanes on now well-populated resorts on formerly remote barrier islands of the eastern United States. Doomsday predictions of massive coastal erosion due to the greenhouse effect fuels modern coastal research (GIBBS, 1984; TITUS, 1987).

For a century or more, geomorphologists have grappled with the problem of how to obtain a better chronology in documenting coastal evolution. Nineteenth century investigators in widely separated environments from the Arctic to the English Channel observed abandoned settlements along the coast and inferred relative changes in shoreline position. From such embryonic ob-

servations, in the 1950's J. Louis Giddings defined the method of "beach ridge archaeology" in northwest Alaska.

For archaeologists, multifaceted interpretations have been based on prehistoric shifts in the relative position of the coast, and ranging from the effects on the origin of domestication (BINFORD, 1968) to the problems of intercontinental migration (MASTERS and FLEMING, 1983). Archaeologists widely acknowledge the probability that eustatic sea level changes have rendered a significant part of the prehistoric record invisible (YESNER, 1980). In a sense, coastal archaeology requires a synthesis of geological and archaeological techniques (KRAFT et al., 1985).

## BEACH RIDGES AND THEIR SIGNIFICANCE TO COASTAL EVOLUTION

A beach ridge is any coast-parallel deposit of sands, gravels and (shell or other) debris, that is emplaced, most often, during the waning phases of storms (REINECK and SINGH, 1980, pp. 352–359; CARTER, 1988, p. 121). Successions of beach ridges are linked to micro- or mesotidal conditions, the availability of abundant sediment in the near-shore zone, regressive or near constant sea levels and alternations in the periodicity of high magnitude storms and wave systems (CURRAY,

1964; HAYES, 1979; KRAFT and CHRZASTOWSKI, 1985).

Seventy years ago, D.W. JOHNSON (1919) reviewed nineteenth century beach-ridge studies and provided a treatise on "shore ridges and their significance," which formulated a set of principles for their study. Several of Johnson's axioms remain relevant today:

(a) a single ridge is constructed by many storm events and should be regarded as a composite of events rather than as a reflection of a particular shoreline;
(b) the height of ridges cannot be assumed to provide sea level records if tectonic uplift or subsidence has occurred;
(c) the rate of beach ridge formation is variable and requires repeated observations or fixed chronological markers;
(d) erosion in one part of a beach ridge complex may be coupled with deposition in another part of a complex.

In the past thirty years, chronometric records from beach ridges have led researchers to postulate shifts in the prevailing wind regime (MOORE and GIDDINGS 1961; CURRAY et al., 1969), infer the initiation of El Niño (ROLLINS et al., 1983; SANDWEISS, 1986), to determine sea level history (MOORE, 1960; SEARLE and WOODS, 1986; FAIRBRIDGE, 1986), the rate of isostatic rebound (ANDREWS et al., 1971) and the solar cycle periodicity of storms in the Arctic (FAIRBRIDGE and HILLIARE-MARCEL, 1977). TANNER (1988) discusses the wide range of applicability of beach ridge studies, especially in examining storm recurrence interval by using ridge/swale relationships. The coupling of archaeological data with its geological context provides a wide canvas for scientific inquiry. In this paper, I explore the history of beach ridge studies, describe a geoarchaeological approach to their study and apply this method to beach ridge complexes worldwide.

## THE BIRTH OF BEACH RIDGE STUDIES

### British Precursors

Some of the first efforts to use cultural evidence to infer changes in coastal position date from the 1850's. Much of this work resulted from improved mapping and geodetic leveling. With detailed maps, British researchers soon became absorbed with the history of the Dungeness foreland (Figure 1), a gravel beach ridge plain on the English

Channel coast, 100 km southeast of London. Using the map sheets of the Geological Survey of Great Britain, J.B. REDMAN (1854 in JOHNSON, 1919) documented 1.6 km of progradation since the time of Queen Elizabeth (1600 AD). REDMAN also undertook field observations to calculate an average annual rate of progradation, "5 to 6 yds" (4.5 to 4.8 m). Other researchers counted the number of ridges, with variable results, up to a total of 135.

Historical records provided further chronometric resolution on the geomorphic evolution at Dungeness and Appach believed that the foreland did not exist at the time of Caesar's invasion of Britain, 55–54 BC. JOHNSON (1919, p. 426) rejected this hypothesis because Roman artifacts and farms were found on Romney Marsh, the innermost portion of the foreland. Medieval records indicate that a section of the foreland had been dyked at 774 AD and that only 23 ridges added from ca. 774 to 1900 AD.

In the twentieth century, Dungeness continued to interest British geomorphologists and historians, who used archaeological remains to date its geomorphic evolution, before the advent of radiocarbon dates. Saxon land surveys aided in reconstructing the extent of Romney Marsh, landward of the foreland (STEERS, 1964). LEWIS (1932) offered the first reconstruction of its successive positions. Subsequently, LEWIS and BALCHIN (1940) used precise leveling data to infer sea level history at Dungeness:

(1) 2–3 m below modern at 1 AD (i.e., Roman times);
(2) 0.3 m lower than modern at 800 AD;
(3) same level as today in 1300 AD, followed by a fall;
(4) increase of about 0.3 m since 1500 AD.

The Dungeness chronology was addressed further as the 1950's soil surveys produced detailed maps (GREEN, 1968) and a radiocarbon date list (SMART, 1964). CUNLIFFE (1980) synthesized these data with Lewis' reconstructed shorelines to produce a depositional history. Initially, a longshore spit formed before 2,000 BP (uncalibrated age), but sea level remained about 2 m below modern levels during Roman times, based on Cunliffe's excavations at a Roman fort. Re-adjustments in shore orientation occurred 300–600 AD, accompanied by silting-in of the Romney estuary and the port of Hythe, northeast of Dungeness, had to be moved several times during early medieval
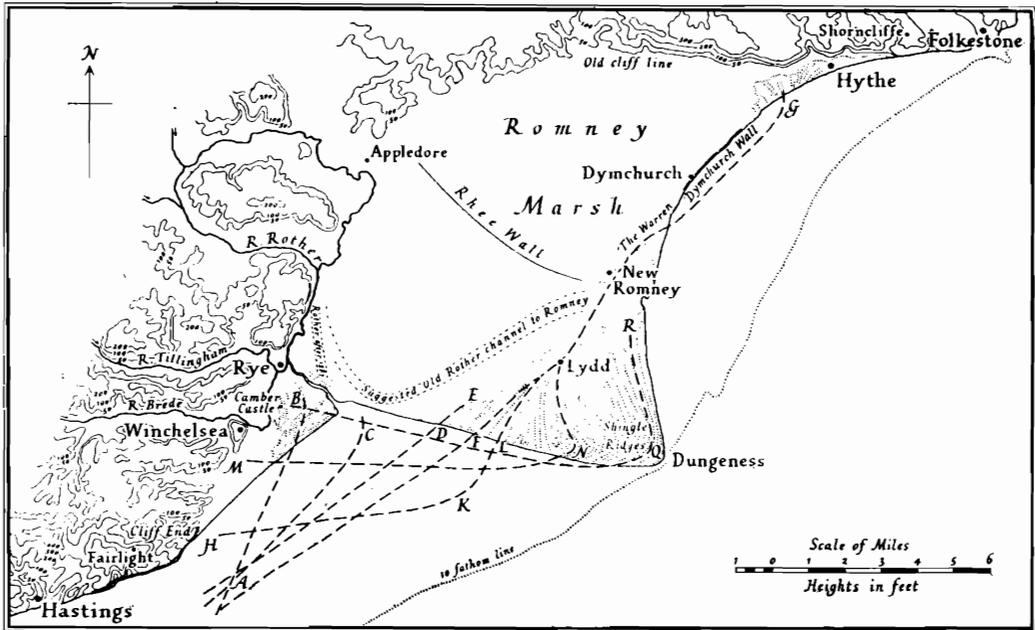
Figure 1. Map of the evolution of the shoreline at Dungeness foreland, southern coast of Britain, SE of London, as reconstructed by LEWIS (1932). Archaeological sites were used by nineteenth and twentieth century researchers to provide ages for shoreline position.

times. The foreland underwent major transformations during severe storm tides in 1250 and 1287 AD; the headland advanced, several through-flowing channels were re-oriented and high beach ridges were constructed (6.0 m above mean sea level, the highest on the foreland). After the 13th Century storms, Romney Marsh silted in and aided in land reclamation. Variability in shingle supply led to the opening and maintenance of an estuary at the updrift western end of the foreland in the 13th and 14th centuries. This inlet filled gradually in the last 250 yr (EDDISON et al., 1983, p. 48).

The classification of Dungeness as an "endangered" coastline has led to renewed interest in its geomorphic history (EDDISON et al., 1983; MC-GREGOR and GREEN, 1989). In proposing a conservation strategy for Dungeness, MCGREGOR and GREEN (1989, p. 123) argue that "the main interest of the buried shingle areas lies in the stratigraphic relationship between the shingle and the associated alluvial deposits." Since 1934 the Dungeness coast has received imported shingle to compensate for the sea walls which flank the beach ridges updrift to the west. Comprised of 99% flint from

the Upper Chalk, the Dungeness shingle is late Pleistocene cryogenic shatter soliflucted down hillsides and transported by rivers into the littoral zone (EDDISON et al., 1983, p. 41). Following sea level rise in the early Holocene, Dungeness began to build, around 5,300 BP, based on $^{14}$C dates from topmost peat layers (EDDISON et al., 1983, p. 44). Sedimentological studies indicate that a 4 to 6 m thickness of gravel lies on sand of undetermined thickness, with five or six up to 15 cm thick beds of gravel deposited during storms (HEY, 1967).

Though not explicitly termed a methodological approach, the sustained British research at Dungeness uses the principal postulates of "beach ridge geoarchaeology":

(a) Coastal settlements were situated in reference to protected maritime access, a most important condition for interpretation;
(b) Sites are younger toward more recent geomorphic features;
(c) Dates of cultural occupation provide minimum age estimates on depositional history;
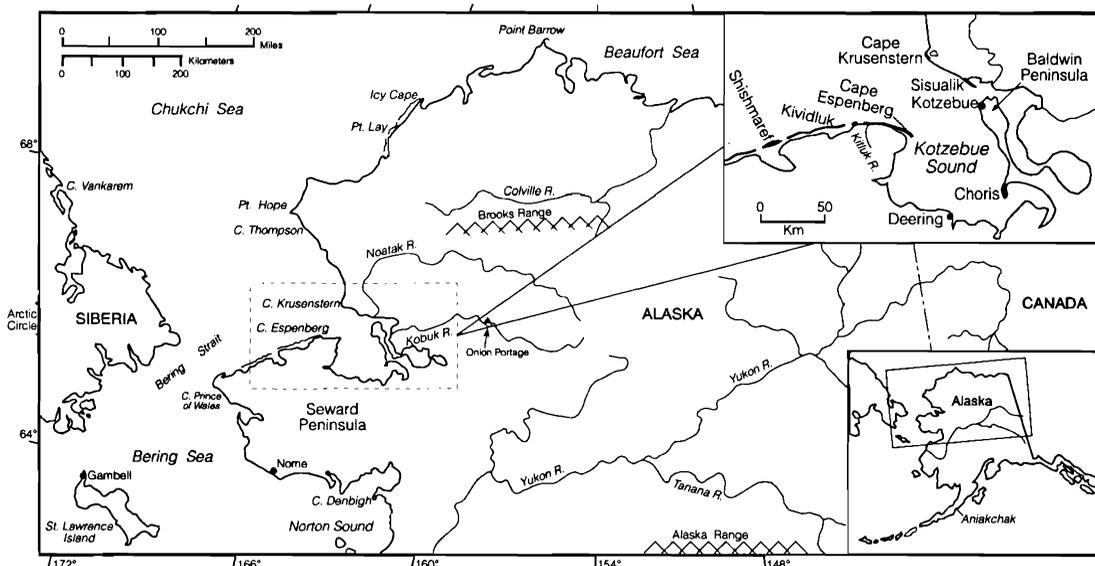(d) Shifts in ridge alignment provide clues about wind direction;

Figure 2. Beach ridge plains surrounding Kotzebue Sound, northwest Alaska. In the 1950's James L. Giddings conducted extensive archaeological surveys and excavations at nearly all of the major complexes. A total of more than 100 archaeological and geological radiocarbon ages allow cross-correlations between beach ridges at Safety Sound, Wales, Shishmaref, Cape Espenberg, Choris Peninsula, Sisualik and Cape Krusenstern.

(e) Heights of ridges allow inferences about relative sea level changes.

## Alaskan Precursors: Edward W. Nelson and Henry B. Collins

The American frontier provided a scientific *tabla rasa* for several generations of observers backed by the Smithsonian Institution's Bureau of Ethnology. In the 1870's, Edward W. Nelson, an ornithologist, accepted a post at St. Michael, Alaska, on the Bering Sea. NELSON (1899) visited numerous Eskimo settlements along the shores of both western Alaska and eastern Siberia. Near Cape Vankarem, on the northern Chukotsk Peninsula (Figure 2), Nelson observed a series of abandoned settlements, unrelated to the contemporary Chukchi Sea coast. Using his observations on the orientation of houses, "well-marked ancient high waterline" indicators and stranded beach gravels, he proposed a chronological relationship between the four villages, assuming "gradual uplifting" of the land since occupation. He observed that "the western Eskimo have an almost invariable custom of building their villages facing the water and parallel with the shore line." NELSON's (1899, pp. 265–266) observations were

buried within his voluminous ethnological treatise, and as he lamented:

> The severity of the Arctic climate on this bleak coast renders it very difficult, if not impossible to make an estimate ... as to the length of time that has elapsed since an ancient site was occupied. If data were at hand to estimate the rate of the rise of the land on the northwestern Alaska and Siberian coasts, we would have a key to the approximate age of the villages ... at Cape Wankarem [sic] and probably to the age of numerous other settlements along the same shore.

[We may comment that Soviet investigations (DIKOV, 1977, pp. 198–199) from the late 1950's confirm some of Nelson's interpretations at Cape Vankarem, yielding radiocarbon dates of about 870 ± 50 BP (MAG-201) for one of the sites landward of the present shore, indicating that massive erosion and re-deposition after occupation by Birnirk and Punuk cultures. A similar depositional history is known from other Chukchi Sea locations.]

Nelson's observations went unnoticed by Arctic archaeologists. Finally, sixty years later, in 1930 Henry COLLINS (1937, pp. 33–34), also backed by

the Smithsonian, observed Eskimo site prefer-
ences and reinvented the beach ridge method dur-
ing the course of his own research on St. Lawrence
Island (Figure 2). Collins used the position of
abandoned villages on the Gambell beach ridges
to estimate relative age, described variations in
ridge direction and noted an erosional discon-
formity. However, Collins did not use these de-
scriptions to relate topographic changes to changes
in depositional regime or climatic parameters. Site
position presented only a survey strategem.

Working at the gravel ridge spit at Point Hope
(Figure 2) in 1939–1941, Helge Larsen and Froe-
lich Rainey observed geomorphic processes but
did not integrate geology into the archaeological
goals of their excavations. LARSEN and RAINEY
(1948, p. 19) postulated (mistakenly) that winter
ice push was responsible for adding ridges to the
spit on its south margin while wave-induced ero-
sion during open water periods was eroding its
northwest aspect. As at Gambell, the oldest ar-
chaeological remains at Point Hope are farthest
from the actively building portion of the spit on
south. Although "many parallel old beaches form
the peninsula . . . a uniform succession of house
pits and villages" could not be recognized by Lar-
sen and his co-workers (GIDDINGS, 1967, p. 18).
Because the incident angle of longshore transport
has not shifted significantly to create prominent
disconformities, only the variable widths of inter-
ridge swales are useful in defining depositional
history at Point Hope (MASON, 1990). The sub-
tlety of the Point Hope system could not be rec-
ognized until the 1967 mapping project (HOSLEY,
1972) undertaken because of the planned relo-
cation of Point Hope village, which also led to
SHARMA's (1972) first purely geological excavation
of beach ridges in Kotzebue Sound.

## THE DEVELOPMENT OF THE
## BEACH RIDGE DATING METHOD

In the 1950's James Louis Giddings, Jr. realized
the potential of beach ridges as an archaeological
research tool. Giddings had accompanied Larsen
and Rainey to Point Hope while he was a graduate
student at the University of Arizona. In 1956 he
returned to Kotzebue Sound, examining a series
of nine beach ridges within a sheltered cove on
Choris Peninsula. Here, GIDDINGS (1967, p. 18)
"first acquired faith in beach ridges as time mark-
ers, observing the regularity of cultural succession
. . . envision[ing] in them a kind of horizontal stra-
tigraphy that might carry with it a built in cal-

endar." The idea of a beach ridge plain as an
immense stratigraphic section on a region wide
scale is one first explicitly stated by him.

Giddings' 1958 season in Kotzebue Sound was
monumental in scope; including a circumnavi-
gation of the entire southeast shore of the Chuk-
chi Sea from Deering to Cape Espenberg, then to
Shishmaref, up to Sisualik spit and finally to Cape
Krusenstern (Figure 2). At Cape Espenberg, a low,
sandy spit, previously disregarded by archaeolo-
gists, GIDDINGS (1967, p. 25) found the confir-
mation of the beach ridge method that he sought—
a succession of old to young sites matching the
ridge succession, although without direct chrono-
metric control at that time. Further, he observed
that the earlier dunes at Espenberg had been
"covered over by later beach ridges [dunes], pro-
truding at an angle at a lower elevation farther
toward the eastern tip of the peninsula."

Giddings turned to the gravel ridge foreland at
Cape Krusenstern to conduct an extensive survey
and excavation program because of its easily de-
fined house pits and the absence of re-deposition
associated with dunes. In the course of this re-
search from 1958 to 1962, Giddings encountered
George W. Moore, a geologist engaged by the
Atomic Energy Commission to study the geo-
morphic effects of a proposed atomic blast to cre-
ate a deep water port ("Project Chariot") near
Ogortoruk Creek, on the north shore of Kotzebue
Sound. In examining potential impacts, MOORE
(1966) examined the longshore transport system
of the entire coast from Sisualik to Point Hope
and outlined the depositional units at Krusen-
stern. Jointly, MOORE and GIDDINGS (1961) sub-
mitted an abstract postulating that beach ridges
at Krusenstern and Sisualik respond to the shifts
in the position of the Polar Front, an important
concept developed in MOORE (1968).

Giddings' research at Cape Krusenstern in-
volved excavations of hundreds of archaeological
features but produced radiocarbon dates (n = 33)
on only seven of the 114 ridges. Neither Giddings
or Moore formalized stratigraphic nomenclature
and only the barest outlines of their system are
published (MASON and LUDWIG, 1990). Unfortu-
nately, Moore and Giddings did not have the op-
portunity to write up a detailed geological inter-
pretation of the Krusenstern succession (MOORE,
1989, *written communication*).

After 1962 Giddings turned inland and exca-
vated Onion Portage, a well-stratified alluvial site
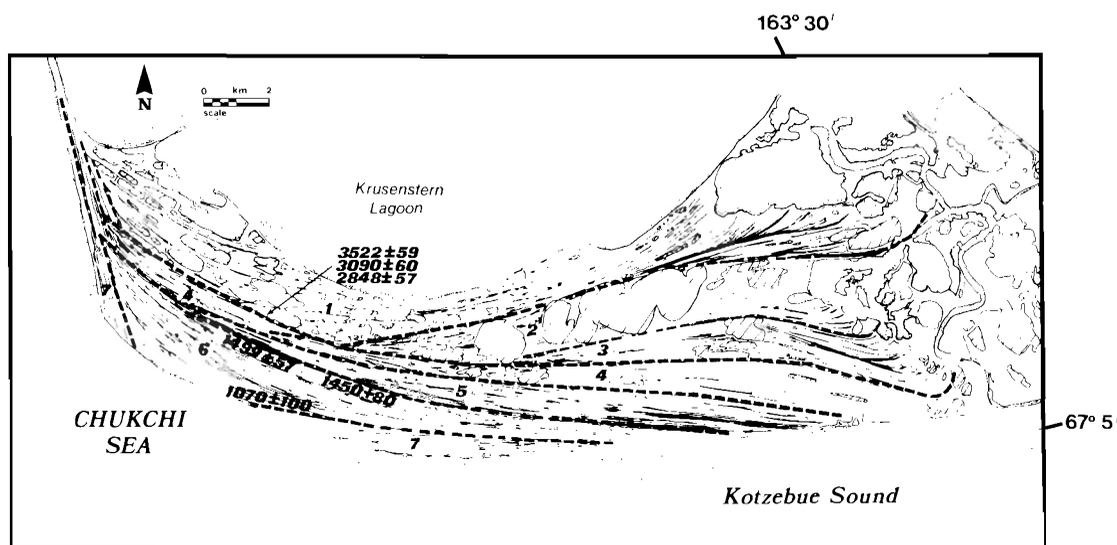on the Kobuk River paralleling the cultural chro-

Figure 3. Cape Krusenstern beach ridge complex, depositional units as defined by MASON and LUDWIG (1990). A total of 33 radiocarbon ages from seven ridges are available to define chronostratigraphic units.

nology at Krusenstern. After Giddings' death in 1964, the pursuit of beach ridge archaeology in Kotzebue Sound lapsed. Giddings' successor, his graduate assistant, Douglas D. Anderson, also at Brown University, continued to work at Onion Portage and provided a synthesis of both inland and coastal regions, linking the undated portions of the beach ridge sequence (GIDDINGS and ANDERSON, 1986) to the cultural chronology of the Kobuk River (ANDERSON, 1988).

## THE GEOARCHAEOLOGICAL METHOD

The geoarchaeological methodology developed in Kotzebue Sound involves correlating surficial deposits from regionally distributed beach ridge complexes, using the principle of horizontal stratigraphy, defined by GIDDINGS (1966). Critical disconformities are easily observed on aerial photos and assigned minimum ages based on overlying archaeological or geological $^{14}$C assays (MASON, 1992). Relative age correlations between complexes lacking radiometric ages can be postulated by establishing temporal sequences of landform evolution for features such as deflation hollows (blowouts), frost cracks and thermokarst lakes. Differences in vegetation succession, soil pH and paleosol development in coastal dunes provide accessory methods of relative age estimation. The distance between beach ridges can provide an ap-

proximation of the recurrence interval between storms, although it can be obscured if dunes cover the beach facies. Sedimentary structures are essential in identifying marine from eolian facies (ROEP, 1986), although granulometric statistics are often useful. Most of the Kotzebue Sound beach ridge chronologies use archaeological radiocarbon dates on driftwood charcoal or clinker enriched with old carbon ingested by sea mammals. A major problem in using driftwood for age estimates involves the uncertain residence time of wood in the oceanic current system. Residence times may be relatively short, 10–100 yr, if the wood is susceptible to waterlogging (GIDDINGS, 1952; ANDREWS, 1986). However, sea mammal contamination may be a more considerable bias in arctic radiocarbon ages, averaging 300–400 yr, based on the interpretations of McGHEE and TUCK (1976) and ARUNDALE (1981) in the eastern Arctic and MASON and LUDWIG (1990) in the western Arctic.

### Alaskan Beach Ridge Chronologies

The largest of the Chukchi Sea beach ridge plains, the Cape Krusenstern foreland (Figure 3), prograded in two alternate systems, directed to the south or southeast, within six depositional units, across 114 ridges, and is subdivided by three disconformities (MOORE, 1966, 1968; GIDDINGS,

1966). Distinctive regional archaeological assemblages of "cultures" provide a relative ordering of ridge ages, together with ¹⁴C dates for seven ridges, supplemented by radiometric dates (n = 46) from the inland site of Onion Portage, 170 km east, which help to flesh out the depositional history. Southward progradation at Krusenstern started ca. 4,000 BP, based on finds of the microlithic artifacts of the Denbigh Flint culture on ridges 102–104, dated at Onion Portage. The first major erosional event occurred after 2,900–2,800 BP, based on 18 dates from Old Whaling houses on the 53rd ridge (MASON and LUDWIG, 1990). Progradation shifted southeastward following an erosional interval, with a disconformable set of ridges added 2,900 to 2,000 BP, which are dated by the linear and check-stamp ceramics of the Choris and Norton cultures and by Onion Portage radiocarbon ages. Progradation to the southwest resumed after ca. 2,000 BP, based on a series of ¹⁴C dates on the Ipiutak culture ridges 35–29, and continued until about 1,200 BP. The third disconformity is marked by settlements of western Thule people and a series of erosional events that began 1,200 to 1,000 BP and again resulted in the re-distribution of gravels southeastward; this process continues intermittently until the present.

The earliest ridges before 4,000 BP may represent lower sea levels and date from the initial stabilization of sea levels, following HOPKINS (1967, p. 86) who used Krusenstern as a type section for the Holocene establishment of near modern sea levels in Alaska. MOORE (1960) argued that higher eustatic sea levels produced high ridges at 950–850 BP and 150–100 BP at Cape Krusenstern and Point Hope. HUME (1965) also thought that elevated ridges dated at 1,000 BP at Point Barrow were evidence of higher eustatic sea levels. However, high gravel ridges may just as likely form during transient water level increases associated with low pressure during storms, as in the 1963 surge at Barrow which carried gravel 1 m atop the Barrow spit (HUME and SCHALK, 1967, p. 98).

MOORE and GIDDINGS (1961) implicitly proposed that climatic conditions acting through variable wind direction controlled deposition at the various complexes. Due to Giddings' death in 1964, the project remained unfinished. To continue their study, I worked at Cape Espenberg and Choris Peninsula and cross-correlated depositional units from six other Chukchi and Bering Sea complexes to reveal a common Holocene history

(MASON, 1990; MASON, 1992; MASON and JORDAN, 1991; MASON and LUDWIG, 1990). Disconformable, higher gravel storm ridges on Choris Peninsula, Point Hope, Point Barrow and Cape Krusenstern are correlative with disconformable dune ridges atop elevated beach facies at Cape Espenberg and the Shishmaref barrier islands that date to 3,000–2,000 BP and after 1,200 BP (Figure 2). The beach ridge chronology of Kotzebue Sound is contemporaneous with the record of Neoglaciation in northern Alaska (MASON and JORDAN, 1991). It remains to integrate coastal storm history with the alluvial flood, colluvial and eolian sequence at the interior site of Onion Portage.

Beach ridges have also been employed as a guide to archaeological survey in arctic Canada, with little extension of the method to climatic history.

## DISTINGUISHING RAISED BEACHES FROM BEACH RIDGES

### Canada

Successions of raised beaches are also common along the shores of the Queen Elizabeth archipelago (TAYLOR and McCANN, 1983) and Hudson Bay (FAIRBRIDGE and HILLAIRE-MARCEL, 1977; MARTINI, 1986) in northern Canada. The geomorphic significance of elevated shore-parallel ridges was appreciated by Therkel MATHIASSEN (1927, p. 8) during his excavations at Naujan on the Melville Peninsula during the Fifth Thule expedition of 1921–1924. Ascribing present ridge position to uplift, he set the stage for successive generations of Arctic archaeologists. The difficulty of using archaeological data in shoreline reconstructions is addressed by COLLINS (1962, p. 128–129) who observes that logistical or winter travel needs may eclipse the maritime functions of low beach ridge sites and favor high ridges with multiple occupations. However, frequently the isostatic nature of high Arctic ridges is emphasized and the long-term, storm-dependent depositional nature of beach ridge sequences is ignored.

In most cases, the raised beaches of Canada are isostatic in origin, rising above sea level as the lithosphere rebounds, relaxing in the absence of the load associated with continental glaciation of the late Pleistocene (ANDREWS, 1986). Thus, beach ridges are deposited in the littoral zone during storm cycles and uplifted gradually. The occurrence of archaeological sites on the ridges allows

geologists to estimate the changing rate of iso-static uplift (ANDREWS et al., 1971).

The postulated constancy of isostatic uplift, has led Canadian archaeologists to use beach ridges as a survey strategem and/or chronological ref-erent. For example, at Port Refuge on Devon Is-land, McGHEE (1979) used the extrapolated uplift rate of ANDREWS et al. (1971) to estimate 5,000–4,000 BP as the age of a Paleo-Eskimo occupation, located on a 22–25 m high ridge now 600 m inland. The beach ridge plain at Igloolik, North West Territories, has 60 to 130 gravel ridges over a grad-ual slope, allowing MELGAARD (1962) to delineate a chronology based on the relative position of pre-Dorset and Dorset culture sites. MAXWELL (1976) also used the differential occurrence of cultures by ridge elevation as a purely classificatory device. Even the recent work of BIELAWSKI (1988) uses ridge position merely to help distinguish archae-ological cultures. Similarly, CLARK and FITZHUGH (1992) establish relative sea-level changes in Lab-rador in order to evaluate the preservation of ar-chaeological sites.

Though the survey-oriented methodological approach of many Canadians is effective, a con-siderable amount of local climatic information re-mains untapped. At Port Refuge (McGHEE, 1981, Figure 4), the variations in ridge and swale width may be related to meteorological controls over ridge formation. The work of STEWART and ENGLAND (1983) illustrates a purely geological ap-proach based on the collection of a series of drift-wood samples from beach ridges for radiocarbon assay from the now ice-bound northwest shore of Ellesmere Island. Assuming that driftwood age is nearly (± 100 yr) contemporaneous with beach ridge deposition, STEWART and ENGLAND (1983) infer times of open water from 8,000 to 4,200 BP and link this with climatic change. For the suc-cession of beach ridges at Richmond Gulf, Hudson Bay, FAIRBRIDGE (1983, Figure 1) briefly discussed and illustrated the potential for using variable beach ridge heights as climatic indicators; unfor-tunately, few radiocarbon ages are available to support claims of solar-cycle periodicities, and ar-chaeological data could help.

In Labrador, FITZHUGH (1972) combined the accepted isostatic rebound model with an ecolog-ical perspective to infer the consequences of vari-able coastal positions. Using dated sites (n = 15) from raised beaches and limited geological data (n = 5), FITZHUGH (1972, p. 27) constructed an uplift curve for Labrador that is useful in pre-dicting the age of undated sites by elevation. He extended his analysis to use reconstructed sea-level position to infer changes in the availability of marine mammals.

Researchers on the British Columbia coast (CLAGUE et al., 1982) use a combination of ar-chaeological and geological data interchangeably to document the interplay of eustatic sea level changes, tectonism and isostatic compensation. Most coastal terraces in British Columbia may not fit the definition of beach ridges, in that most terraces consist of scoured platforms with accu-mulations of shell or wood stranded in a region of high uplift rates. Although archaeological sites in British Columbia are routinely used as eleva-tional or chronological datum levels, little cli-matological use of beach ridges is attempted, due to the rare development of prograding deposits; a notable exception is the Graham Island spit unstudied as yet. In Southeast Alaska, MOBLEY (1988) has delineated sea level changes using a small sample of dated archaeological sites on el-evated terraces. All in all, little or no paleoclimatic information is yet available from the uplifted coasts of British Columbia and Southeast Alaska.

### Scandinavia

Finnish researchers use the occurrence of ar-chaeological sites atop uplifted shorelines in dat-ing the early Holocene transgressions of Baltic Sea (ERONEN, 1983). The Finnish shorelines may not always be beach ridges sensu stricto, in that some are minimally reworked by waves from esker sediments and form "shore niches" as water levels receded (ERONEN, 1983, p. 203). Similar use of archaeological ^{14}C dates in Norway (MØLLER, 1987) noted altitudinal ranges of between 1.9 and 9.5 m above MSL for non-agricultural prehistoric sites as evidence of site seasonality and employed mi-crostratigraphy for evidence of marine transgres-sion.

However, the use of archaeological data solely as a chronological referent severely limits the po-tential of the beach ridge geoarchaeological meth-od. Human settlement pattern is an intimate data source and should be scrutinized for relevant re-gionally specific details related to paleoclimate. In order to assess the validity of using archaeo-logical sites and shell to establish elevation or timing of deposition, one must address the site

formation processes involved. The following dis-
cussion is synthesized from MEEHAN (1982).

## SHELL MIDDENS FROM THE SHELL
## COLLECTOR'S PERSPECTIVE

(1) The location of *in situ* shell beds is deter-
mined by tidal fluctuations and interface of mud
and sand. This is likely to be a considerable dis-
tance, up to several hundred meters, from the
beach ridge setting on a low-relief shoreface.

(2) Several different types of camps are found:
short-term "dinner camps" and long-term sea-
sonal settlements. Short-term camps may be lo-
cated on the active beach, subject to storm water
reworking. Long-term camps are probably beyond
the reach of storm waves and often on places pre-
viously used over decades or centuries. Old mid-
dens, possibly topographic high points, may be
preferentially used.

(3) The possibility of older shells introduced
into younger sites is high: either by the household
modifications of the inhabitants or if the storm
waves exhume and deposit shell on modern beach-
es. Storm accumulations of shell may superficially
resemble midden accumulations.

(4) Shell can accumulate comparatively rap-
idly within middens; MEEHAN (1982, pp. 165–166)
records the annual disposal of 7,300 kg of shellfish
(nearly 250,000 shells) producing a volume of 8
m³ by a northern Australia community of 100 peo-
ple who depended significantly on shellfish (20 to
48% gross weight of diet, seasonally, *ibid.*, p. 152*ff*).
Thus, population density is a prime consideration
in gauging the likelihood of rapid accumulations
of shell.

The greatest problems in accepting a single shell
date from a midden involve the possibility that a
lengthy human occupation may result in the mix-
ing of discrete occupations or the possibility of
accepting biased, non-representative samples of
a long occupation. Geologists should be asking
what is important: the earliest date of occupation?
the time span of occupation? the time of aban-
donment? which date is critical to answer the
question being asked?

The use of shell middens as sea level indicators
can be ill-advised if researchers use midden ele-
vation without considering the peculiarities of hu-
man discard behavior (MEEHAN, 1982) or do not
consider the rapidity of accumulation rates or dif-
ferential compaction (as in South Carolina, see
below). An important consideration is what
ROLLINS *et al.* (1990) term the "stratigraphic fi-

delity" of shell midden material: does the midden
represent the season of use or are several seasons
mixed? As SHACKLETON and VAN ANDEL (1986,
p. 142) found, cultural selection and taste may be
the more likely cause of shell accumulations than
geomorphic processes. More precise paleogeo-
graphic reconstructions may be possible if re-
searchers determine the seasonality of mollusk
use, rates of accumulation and temperature pref-
erences (ROLLINS *et al.*, 1990; DEVRIES and WELLS,
1990). Further, as BEATON (1985) showed in Aus-
tralia, it is important to secure multiple, strati-
graphically related dates from shell middens in
order to gauge the amount of time in producing
the midden.

In the following sections, geoarchaeological
principles will be used to assess both explicit and
implicit studies of beach ridges from around the
world. Although studies of beach ridges are wide-
spread, the use of archaeological data is not.

## THE NEED FOR GEOARCHAEOLOGICAL
## STUDY OF BEACH RIDGES:
## THE INCIDENTAL USE OF
## ARCHAEOLOGICAL DATA
## BY GEOLOGISTS

Frequently, geologists have seized upon the
possibility of using archaeological sites as a chro-
nological referent. However, this usage is typically
anecdotal and often uncritical. It is worth review-
ing several cases of such usage and assessing them
in light of beach ridge geoarchaeology.

### The Mississippi Delta: Archaeology in the Service
### of Geology

Beach ridges are also common on river deltas
thus often bordered by marshes and then are
termed chenier (from the French, *chêne*, "oak")
ridges (REINECK and SINGH, 1980). Although the
application of the word chenier remains imprecise
(OTVOS and PRICE, 1979), the history of the study
of cheniers parallels that of beach ridges and shows
the seemingly necessary cross-fertilization be-
tween Quaternary geology and archaeology, HOWE
*et al.* (1935, pp. 30–31) recognized the utility of
paleosol formation and shell weathering as rela-
tive age indicators and inferred erosional events
from truncated ridge trends, as well as postulating
that cheniers built in relation to decreased sedi-
ment input from active delta tributaries.

During the 1930's Louisiana geologists studying
modern deltaic environments of the Mississippi
River struggled with the perennial problem of es-

timating rates of deposition (reviewed by GAG-LIANO, 1984). In surveying the delta's numerous shell "kitchen" middens were encountered and geologists used them as indicators of subsidence (HOWE *et al.*, 1935). F.B. KNIFFEN (1936, p. 417) recognized the potential of archaeological sites in geomorphic research, for "along the natural levees of the main stream or on the major distributaries were the sites favorable to human settlement. As the flow of fresh water was diverted to new channels, the older ones lost their habitable qualities." McINTIRE (1958) produced a voluminous body of site-specific data bearing on the abandonment of various sub-deltas, using diagnostic artifacts to estimate the age of depositional units. Unfortunately, not all use of chenier high ground is related to shellfish collection, prehistoric people also hunted muskrat, racoons, and deer (BROWN, 1984). Re-use of older, inland cheniers continued as the shoreline prograded; a 550 BP occupation is described for the Little Chenier ridge (BROWN, 1984, p. 106) although it is at least 2,250 BP on geological grounds.

The advent of radiocarbon dating in the 1950's meant that geological and archaeological data could be integrated. GOULD and McFARLAN (1959) postulated that the four principal cheniers, building up during discrete periods of low sediment influx, dated at 2,800, 2,100, 1,200 and 650 BP, with three other minor cheniers dated at 2,400, 1,600 and 1,300 BP. Although the age of Louisiana cheniers appears to be tightly constrained by GOULD and McFARLAN's (1959) 127 radiocarbon dates; only 53 were judged "significant." Further examination reveals that the dates are reported without standard deviations as absolute years BP, an imprecise use of $^{14}C$ assays that distorts their nature as probability estimates. The $^{14}C$ assays run in the 1950's may be additionally imprecise if the solid carbon method of radiocarbon counting was used. Hence, the age assignment and correlation of ridge sets may differ significantly from that presented by GOULD and McFARLAN (1959). A review of the dates published independently (BRANNON *et al.*, 1957; McFARLAN, 1961) shows that some of the Louisiana chenier dates overlap at two sigma (95% confidence interval). On Pecan Island, part of the F shoreline, that GOULD and McFARLAN (1959, plate 3) place at 1,250 to 1,100 BP, five $^{14}C$ age estimates (McFARLAN, 1961, p. 152) overlap in the range 1,040 to 1,820 BP. The 780 yr error bar means that the F shoreline may overlap in time with the older D and E shorelines.

Archaeological materials spanning the entire range 2,000–1,000 BP imply that the Pecan ridge was indeed near the active coast for a long period (BROWN, 1984, p. 100).

Although GOULD and McFARLAN (1959, p. 264) wisely argue that shell provides only a minimum age in view of the possibility of re-deposition, there is no mention of the origin of shell as archaeological or any comparison of the few peat and wood dates with the shell dates. Because many archaeological sites contain brackish water clams (BROWN, 1984, p. 100), a further difficulty is added to interpretation. Further, the enigmatic date of "modern" shell as 520 ± 100 BP (O–9) suggests that reworking of older deposits is a serious problem in the Louisiana chenier system.

Despite all these problems, the dates from GOULD and McFARLAN (1959) continue to be used in recent interpretations. PENLAND and SUTER (1989) reinterpret the Louisiana chenier sequence as evidence of periodic still stands of sea level after a high stand at 3000–2500 BP. However, the chronology used by those authors remains that of Gould and McFarlan, although several new subsurface dates are provided. Penland and Suter's prime contribution is to offer different correlations between deltaic lobes and cheniers. PENLAND and SUTER (1989, pp. 244, 246) describe the oldest chenier, the Junus/Little Pecan ridge, as the "most continuous regional erosional shoreline" and the younger, 1,250 BP, Grand Chenier ridge as a transgressive, regional shoreline that truncates older deposits. Transgressive shorelines, although conceptualized as 100–200 yr eustatic elevations of sea level, may actually result from heightened storm frequencies during climatic anomalies such as the Neoglaciations or the Little Ice Age.

A complement to the chenier record may be derived from studies of alluvial history in the Upper Mississippi valley. KNOX (1988, pp. 294–295) reports a sharp rise in flood magnitude about 3,000 BP, a brief period of small floods after 2,000 BP and larger floods after 1,000 BP. By comparing chenier/beach ridge records with alluvial chronologies and pollen evidence, we can integrate several proxy climatic records and obtain a clearer paleoclimatic signature.

The cross-fertilization between Louisiana geology and archaeology continues to the present time. The Louisiana geological literature routinely uses archaeological cultures to distinguish paleo-shorelines, as in the "Teche" shoreline (PENLAND and SUTER, 1989) or to provide chro-
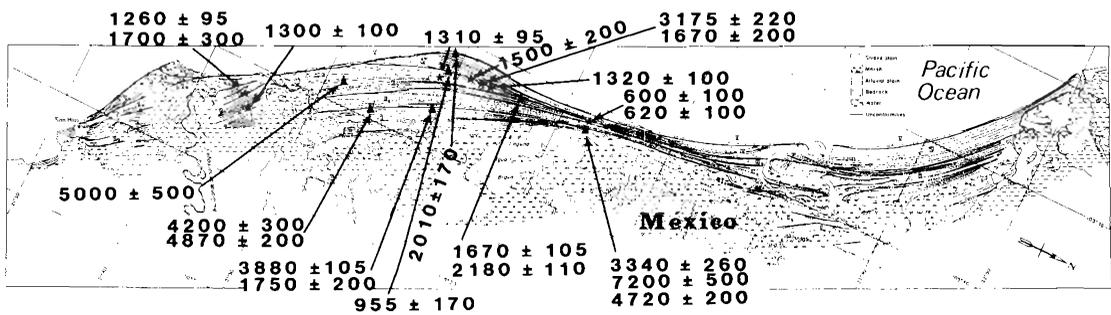
Figure 4.  Beach ridge plain along the western coast of Mexico, modifying CURRAY et al. (1969). Archaeological radiocarbon ages are placed on the upper portion of the map, geological, core-derived radiocarbon ages on the lower portion. Multiple samples are listed in vertical relationship. Archaeological samples are concentrated from one depositional unit of the complex and provide evidence of a major disconformity after 1,300 BP, but before 600 BP. The core samples are from intertidal shell and loosely constrain the evolution of the complex. In both sets of samples, older, apparently anomalous ages indicate reworking of older deposits.

nological limiting dates, as GERDES (1985, p. 124) does in referring to the age of the Caminada-Moreau beach ridge plain as less than 1,000 yr, due to a lack of archaeological remains earlier than 1200 A.D.

GAGLIANO (1984) uses an explicitly geoarchaeological approach to deltaic and coastal environments. Employing a systems approach, Gagliano summarizes data on the depositional environments for the entire Gulf of Mexico coast and then considers the influence of eustatic sea level changes, concentrating on the problem of midden subsidence, and eroded and re-deposited sites. Still, Gagliano's aims are descriptive and site-contextual and Quaternary scientists could reveal a paleoclimatic, time-parallel stratigraphic perspective.

### The Nayarit Beach Ridge Plain of México

One of the landmark studies of beach ridge evolution was conducted on the west coast of Mexico by CURRAY et al. (1969). The west Mexican ¹⁴C chronology is based equally on shell samples from drill cores (n = 12) and from archaeological middens (n = 12), but with only a few peat (n = 3) samples. The indiscriminate mixture of surface and subsurface dates is not convincing for several reasons. First, the middens are restricted to very few of the 280 ridges. In addition, the midden data provide only minimum age estimates on beach ridge formation while the shell in core samples are intertidal or lagoonal facies of uncertain, possibly redeposited, provenance. Nearly all the dated core or surface midden sequences contain dating reversals and large counting errors. CURRAY et al. (1969, pp. 91–92) do acknowledge that archaeo-

logical data are "risky" basis for dating the age of the ridges because of the possibility that the inhabitants transported shells inland. However, two other lessons were not apparent to Curray and his co-workers. Single dates from surface accumulations were used in some cases and the importance of older, "anomalous" dates was not addressed. The apparently older shell incorporated into middens indicates that non-cultural shell was being exhumed and re-transported. This process is apparently operative in the subsurface shell data and highlights the need for well-defined growth position shell or peat beads in interpretation. In sum, CURRAY et al. (1969) have no definitive dates for beach ridge formation at Nayarit or on its four depositional units.

### Gulf Coast of Florida

Geological researchers along the northwest coast of Florida have used shell dates from middens in a largely uncritical manner. The beach ridge plain of St. Vincent Island contains over 200 ridges divided into twelve distinct depositional units but is dated by only five radiocarbon dates from shell middens (DEMIRPOLAT and TANNER, 1987). Most of the archaeological sites on St. Vincent island lie on the lagoon side of the island and do not adequately provide a measure of the horizontal progradation (STAPOR, 1975, Figure 5). As if to compensate, the comprehensive (310 radiocarbon dates) beach ridge correlation study of STAPOR et al. (1991, pp. 834–835) in southwest Florida uses archaeological data sparingly as an "independent confirmation . . . of a sea level rise" about 1,600 BP. Still, a few dates are used without establishing their relationship to the prograding shoreline.
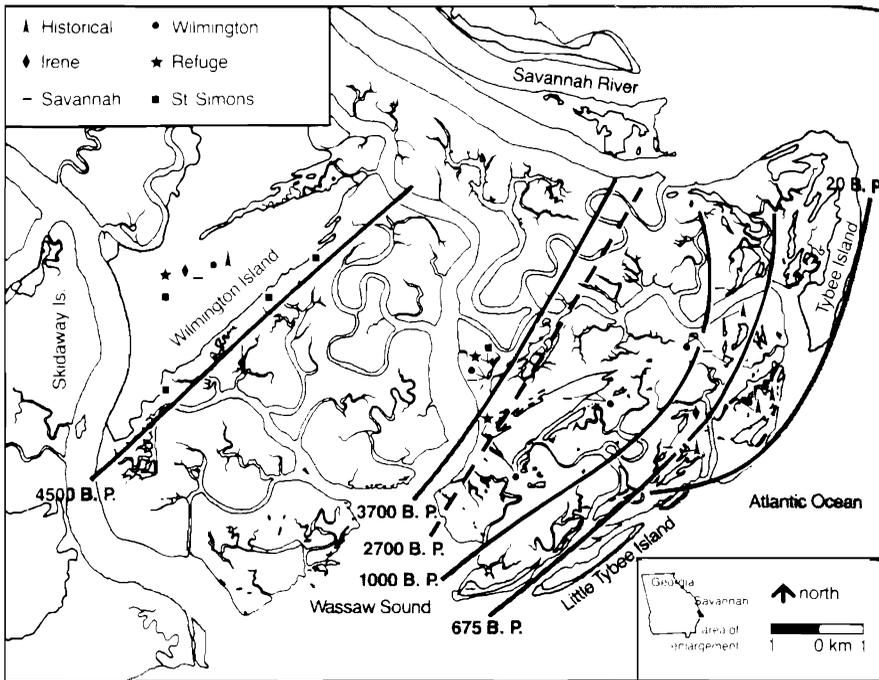
Figure 5. Map of Savannah River chenier/beach ridges dated in reference to archaeological remains. The symbols refer to temporally diagnostic types of ceramics and the distributions show decrease in sherd diversity younger or seaward. (from De PRATTER and HOWARD 1977).

Geological and archaeological reasoning is not precisely defined: ". . . in the Everglades . . . an oyster reef, at an unknown but low elevation (less than 50 cm) above present-day sea level, is embedded in a shell midden." STAPOR et al. (1991) continue the unfortunate practice of reporting $^{14}$C dates without standard deviations.

### Brazil

On the prograding southern coast of Brazil, FAIRBRIDGE (1976) and his Brazilian colleagues use the paleoecology of mollusks and the archaeological record to establish five principal types of shell middens. Finding that middens occur relatively close to mollusk-favorable substrates, Fairbridge establishes relative sea level position and salinity using molluskan ecology together with topographic relationships such as estuarine, mangrove, lagoon spit or platform (Pleistocene or rock). To establish sea level, FAIRBRIDGE (1976, p. 356) argues that "if the Brazilian data are to be helpful in indicating a true relation to past sea levels, it is desirable that the key midden sites be tied closely to the crystalline basement." The hard rock nature of such surfaces minimizes bias due to com-

paction and such elevations above sea level theoretically provide a reliable paleo-sea level estimate. A similar method is used by SUGUIO et al. (1992) on shell mounds on coastal dunes to establish sea level fluctuations during the Holocene.

Fairbridge's approach is similar to beach ridge archaeology, as is the approach of SUGUIO et al. (1992), but the prograding spits and beach ridge plains of southern Brazil could yet be scrutinized for cross-correlations and paleoclimatic data, extending the geological approach of DOMINGUEZ et al. (1987).

## PALEOCLIMATOLOGY AND BEACH RIDGES

### Australia

In Australia, a variety of research allows a geoarchaeological synthesis on a beach ridge/chenier plain at Princess Charlotte Bay, Queensland (CHAPPELL and GRINDROD, 1984; BEATON, 1985). A major factor in the depositional processes at Princess Charlotte Bay involves the interplay between high magnitude storm events and the variations in the production of shell material and

the clay content within the nearshore belt. Clay concentration is related to wet season rainfall and drainage basin fire history. All these factors enter into the availability of shell at the shoreface, in that when clay deposition is low, high storm waves are able to winnow mud from shellbeds, leading to an increase in biological productivity of mollusks and crustaceans, and increase the number of shells, as well as exposing more shell for remobilization on land. Consequently, chenier ridges are built when shell material is plentiful. By contrast, beach ridges prograde only during the absence or inaccessibility of shell. The record may be read as a proxy for Holocene climatic change in that conditions of heightened regional aridity result in less clay input, while more sediment is available during more stable, mesic intervals. The coarser, sandy cheniers are the result of "a series of closely spaced storms during periods of reduced fluvial input" (LEES and CLEMENTS, 1987, p. 312).

Human occupation of the Princess Charlotte cheniers is also episodic, but very distinctive stratigraphically. In a particularly well-dated section, with over 20 radiocarbon dates, BEATON (1985, p. 8) documents a shell midden, the South Mound, constructed nearly 2 meters high from 1715 ± 55 (Beta-1754) to 660 ± 10 BP (ANU-3383). The mound is composed of only eight discrete, probably rapid, depositional events, separated by "sediment-rich" phases of abandonment. Several prominent date reversals in the South Mound show the probability of redistribution of midden material by later use and the continued use of ridges distant from the actively aggrading shoreline. The researchers (CHAPPELL and GRINDROD, 1984, p. 222) assert that human predation is not a factor in limiting the availability of shell for constructing chenier ridges.

## Peru

In Peru, archaeological limiting dates from gravel ridges near the Santa River allow SANDWEISS (1986) to estimate the increase in sediment supply at the shore as torrential rainfall connected with El Niño. Stratigraphic observations within archaeological sites (ROLLINS et al., 1986) confirm Sandweiss' interpretation. The Peruvian beach ridges consist of only eight discrete shore-parallel ridges deriving sediment from the nearby Santa River. However, the dating of the storm-induced deposition is imprecise because only a few superimposed radiocarbon samples constrain the chronology (SANDWEISS et al., 1983). Differences in

ridge height of about 1.0 m are interpreted as tectonic uplift and not storm intensity, a finding apparently corroborated by a stranded marine scarp over 1 km inland that dates to 5,000 BP (ROLLINS et al., 1986). At the Chira beach ridges in northern Peru, RICHARDSON (1983) describes an uplifted and stranded beach ridge complex 2.7 km wide in which only nine ridges formed at irregular intervals between 4,500 BP and the present. Though uplift is also the rationale offered by Richardson for differences in elevation, the actual range of ridge elevation may contradict this since both the youngest and oldest ridges are about 5 m in elevation with intervening ridges varying from 1 to 2.5 m above MSL (RICHARDSON, 1983, Figure 4). Because swale widths provide an approximation of storm recurrence intervals, the Chira ridge elevations may result from differences in storm intensity. Correlations of Peruvian beach ridge chronology should be re-evaluated with respect to the increasingly detailed alluvial and archaeological stratigraphy reviewed by WELLS (1987) and DEVRIES (1987) recording increased upvalley flooding associated with El Niño events 600, 1100 and 1300–1400 and 1720 AD.

## The Netherlands

The western shore of the Netherlands, north of the Rhine River, reveals a series of transgressive coastal dunes over barrier facies, similar in some respects to beach ridge settings (VAN STRAATEN, 1965). Dutch researchers (JELGERSMA et al., 1970; BERENDSEN and ZAGWIJN, 1984) use a variety of techniques and interdisciplinary approaches, which range from pollen and pedological analyses to sedimentary facies analyses of geologic cores, archaeological excavations and historical researches. Working with evolving agricultural economies, Dutch workers carefully attempt to distinguish between cultural impacts such as land clearance and climatic influences. Shell midden archaeological sites generally predate the late Holocene and have not been reported from subsurface barrier deposits.

The Holocene history of the Dutch coast reveals an alternation between progradation 5,000–2,900 BP, followed by erosional episodes that formed transgressive dunes, the Older and Younger Dunes. Minor dune activity is recorded as early as 3,000 BP and continued intermittently until the culmination of dune-building during the Little Ice Age. ROEP (1984) attributed decreases in sediment supply from the Rhine 2,300 BP to 2,000

BP, coupled with climatic or sea level fluctuations, to explain Dutch coastal erosion and dune formation.

## EXTENDING THE BEACH RIDGE METHODOLOGY WORLDWIDE

The possibilities for using the beach ridge approach are widespread. Beach ridge plains occur on all the continents, including Antarctica. In an encyclopedic treatment of the world's coastlines, BIRD and SCHWARTZ (1985) report beach and/or chenier ridges on diverse shorelines: in Europe, from the Baltic Sea to France and even Albania; in Africa from Sierra Leone and Nigeria to Mozambique; in Asia from the Caspian shores of Iran, to Thailand and Russia; and in Mexico, Guyana and Australia. A similar variety of locales may be found in the photographic atlas of U.S. coasts by SHEPARD and WANLESS (1971).

### Atlantic and Gulf Coasts

One of the basic postulates of the beach ridge method involves the preference of maritime populations in Alaska for the resources of the open shoreface. It is this preference which led Giddings and other Arctic researchers to successfully use the beach ridge method. However, resources and preferences may differ and the situation on other coastlines may not be similar. In fact, such differences hinder the progress and potential for beach ridge archaeology on the East coast and perhaps other places as well.

Along coastlines such as northwest Florida, the Carolinas, or Brazil, the resource base on the sheltered lagoons is greater than on the exposed beach side. Aboriginal groups preferred the lagoons to gather the plentiful shellfish and shrimp (FAIRBRIDGE, 1976; LARSON, 1980, p. 6). The lagoonal shoreline remains comparatively static as the beach ridge plain builds seaward. Consequently, human populations could remain focused on the (more or less) static portion of the inner beach ridge plain instead of following the prograding strand.

### Cape Hatteras and Other Atlantic Barrier Island Settings

The Atlantic coast undergoes a radical shift in orientation at Cape Hatteras, which records at least seven depositional cycles resulting in the progradation of over 100 ridges (FISHER, 1967). Despite Fisher's detailed geological mapping of the numerous beach ridges from the Outer Banks of North Carolina and the early archaeological surveys of HAAG (1958) no integration of geological and archaeological data has yet been attempted. FISHER (1967, p. 26) did not encounter any "carbonaceous material" or datable shell and did not date grass beds. Instead, Fisher relied on pedogenic weathering horizons for tentative relative age estimates and correlations. HAAG (1958) describes nine sites oriented primarily toward the lagoon dated to early late Woodland period times (1,000 BP). A major problem in using beach ridge methods here seems to be the continued use of the lagoon side of the island by all subsequent inhabitants (LOFTFIELD, 1988).

Several other possible sites for beach ridge studies exist on the Eastern seaboard: Cape Cod, surveyed archaeologically by the National Park Service in the late 1970's (McMANAMON, 1984), Cape Canaveral, Florida, the severely controlled Sandy Hook spit at the entrance to New York bay, and Cape Henry near Norfolk, Virginia (FISHER, 1967).

### The Georgia and South Carolina Coast

DE PRATTER and HOWARD (1977) used prograding shore-parallel deposits at the mouth of the Savannah River to document alluvial history (Figure 5). Their work has much in common with beach ridge archaeology, but the Savannah River deposits closely resemble a chenier system. Four principal sedimentary facies and depositional regimes are evident along the Georgia coast: (1) in areas adjacent to outlets of rivers and abundant sediment supply, coastal progradation was rapid, consisting of hammocks ("marsh islands") which are taken to be eroded remnants of older beach ridges [though OERTEL (1979, p. 279), interprets hammocks as related to overwash processes]; (2) accretional recurved spits, (3) alternating phases of erosional episodes and depositional beach ridge "bundles" and (4) straight beach ridges. DE PRATTER and HOWARD (1977, pp. 255–256) use the occurrence of temporally distinct pottery types to date the progradational sequence. Since "the sites are nearly always associated with the shells of estuarine fauna [one may] assume that the Indians chose their dwelling sites on or behind the barrier ridge . . ." the actual shoreline would be to the east and cannot be precisely delineated due to subsequent erosion. Since younger sites occur considerably inland, the oldest site on a surface provides a minimum age. A further peculiarity of the Georgia barrier coast involves the inlet margin which is the most active location for beach ridge

development, as evident from OERTEL's (1975) delineation of eighteen discrete and truncated depositional (undated) sets of ridges at the mouth of St. Catherine's Sound. Using archaeological data, OERTEL (1977, 1979) sketches a chronology for the inlet ridges.

Much of the research along the Georgia and Carolina coasts has been conducted by archaeologists for the specifically archaeological purpose of building cultural chronologies. Meanwhile, geologists have used cutbank exposures or the deep coring methodology, e.g., MOSLOW (1980) at Kiawah Island, South Carolina. The two groups have frequently joined forces to assess sea level changes (BROOKS et al., 1986; COLQUHOUN and BROOKS, 1986). DE PRATTER and HOWARD (1981, 1983) postulated a sea level fall of about 4 m about 3,100–2,400 BP, based on the heights of middens adjacent to beach ridge complexes or by reference to dated submerged tree stumps (with elevations imprecisely known ±0.5 m MSL, but also attested by reputable nineteenth century observers). As BELKNAP and HINE (1983, p. 681) note, such enterprises must consider whether middens were constructed close to the shore, the effects of sediment compaction (up to 2 m), spring tidal ranges of up to 3 m, and other problems with cultural practices as mentioned above.

As of yet, no one has connected the various Atlantic coastal changes with other proxy climatic records or correlated the various localities into a unified sequence. Climatic controls may be responsible for the common histories of the cheniers of the Mississippi and the Savannah Rivers, as evidenced by rapid progradation 3,000–2,000 BP, the relative stasis 2,000–1,000 BP and progradation from 1,100 to 650 yr ago.

## Beach Ridges on Pacific Coasts

### Oregon and Washington

While East Coast researchers appreciate the possibility of combining geological with archaeological data, to date, few West Coast archaeologists seem to have integrated the two bodies of data. As an example of the unrealized possibilities, I will examine the situation on the Oregon and Washington coast. As of yet, no one has attempted to integrate the archaeological with geological data.

Sand dunes and spits are very extensive along the Pacific coast of Oregon and Washington with extensive beach ridge plains forming at the mouths of these estuaries. COOPER (1958) reported on sev-

eral prograding sequences located at the mouths of rivers and bays from north of the Columbia River at Grays Harbor and Willapa Bay, Washington to south of the Columbia at Coos Bay, Oregon. A series of nine prominent beach ridges on the Clatsop prairie south of the mouth of the Columbia River. The Clatsop ridges built from north to south, away from the Columbia River, its sediment source, and are grouped into three depositional units by COOPER (1958, p. 122).

Sporadic archaeological surveys in the Clatsop area, conducted from the 1950's to the 1970's, record fourteen shell middens interspersed between beach ridges (MINOR, 1983, Figure 13.2). One site (35-CLT-27) lies about 1.2 km from the ocean within Cooper's Stage II and dates 860 ± 100 (WSU-1454) to 730 ± 110 BP (WSU-1455) (SHEPPARD and CHATTERS, 1976, p. 145). Depositional Stage II is characterized by decreased progradation near the river mouth but increased progradation in the south. Perhaps with further research, Quaternary scientists will be able to establish the "obscure, perhaps undiscoverable causes" underlying the facts that COOPER (1958, p. 125) observed. Coastal progradation may be linked with the increased flooding upstream on the Columbia River described by CHATTERS and HOOVER (1986) 1200–700 BP, who attribute it to climatic warming.

### Gulf of California

An interesting possibility of relating beach ridge with inland geomorphic changes is available from the Colorado River delta. Within a tidal mud flat depositional regime, occasionally coarser grained beach ridges form due to wave processes and longshore currents. Beach ridges formed 3,000–2,000 BP and from 1,200–700 BP (THOMPSON, 1968, p. 112) and are related to the diversion of the Colorado River into Salton basin which created Lake Cahuilla, starving the nearshore system of finer sediments. Though no archaeological remains are reported from the Gulf of California ridges, the shores of Lake Cahuilla are rich in archaeological sites (WATERS, 1983). Four lacustrine intervals are noted at Lake Cahuila in the last 2,000 yr, with high stands during 1,200–400 BP. The lake did not exist from 2,000–1,300 BP, during the time of mudflat progradation on the Colorado.

### South-East Asia and China

Evidence for a middle Holocene marine transgression is reported in both Vietnam and Thai-

land using a geoarchaeological approach similar to that of the beach ridge method. At the Khok Phanom Di site, Thailand, now 22 km inland from the Gulf of Thailand, marine clays and brackish water plant pollen indicate that the site was probably on a coastal barrier island at 6,700–6,000 BP (HIGHAM, 1989, p. 66). Excavating on "raised beaches" Vietnamese researchers in the Red River valley region near Hanoi observe shellfish middens of middle and late Neolithic age, 4,000 BP (reviewed in JAMIESON, 1981). Once again, eustatic sea levels are thought to have been 3 m higher at this time of occupation. An explicitly geoarchaeological approach would help to clarify the interwoven effects of deltaic processes, eustatic changes and storm effects.

Research in north China indicates that the sea transgressed up to 100 km inland 6,000–5,000 BP and rose over 2–4 m above modern levels (OTA, 1987). A series of chenier ridges record the subsequent decline in sea level. Using $^{14}$C and historic documents, LIU and WALKER (1989) describe a series of four chenier ridges on the north China plain near the mouth of the Huang Ho. Archaeological radiocarbon ages and historic records indicate two principal cheniers formed after 2,000 BP but before 1,000 BP and at 600–300 BP (WANG and KE, 1989). The Chinese data must be weighed carefully to separate factors of climatic or alluvial change from shifts in dynastic and political stability that fostered the maintenance or disrepair of irrigation systems.

## CORE-DERIVED COASTAL RECONSTRUCTIONS VS BEACH RIDGE ARCHAEOLOGY

The beach ridge method is not the most common methodology employed to reconstruct the outlines of paleoshorelines. For many pre-Holocene landscapes, the beach ridge method is unsuitable. On transgressive, drowned shorelines, seismic reflection, side-scanning sonar or offshore boreholes are necessary to reconstruct Pleistocene-early Holocene paleoshores (STRIGHT, 1990; VAN ANDEL et al., 1980; VAN ANDEL and LIANOS, 1984). The geological practice of extracting cores is extensively employed in the field. A comparison of the beach ridge method with that of deep or auger coring reveals that while less equivocal, stratigraphic data may be obtained with cores, the beach ridge method may be more expeditious and provide more contextual evidence for human occupation or microscale climatic reconstruction.

Perhaps, the ideal approach would combine the two methods.

Along the exposed Delaware coast erosion predominates and the excess of eroded sediment is transported north and results in progradation at the entrance to Delaware Bay, at the Cape Henlopen spit (KRAFT, 1971). KRAFT et al. (1979) reconstruct generalized paleoshorelines for the Holocene at 2,000 yr increments, but irrespective of variations in climate. These reconstructions are based on interpretations of sedimentary facies within cores and provide a general picture of coastal evolution rather than a specific topographic setting (KRAFT, 1971; KRAFT et al., 1985). Working in conjunction with archaeologists KRAFT and JOHN (1976) integrate several Woodland period sites, ca. 2,000 BP, within the paleo-spit at Cape Henlopen; but over all, by necessity, specific context is subsumed within the schematic core-based reconstructions of coastal evolution.

## CONCLUSIONS

The history of science often records the parallel efforts of widely separated, often isolated researchers who independently discover a new technique or observe the same phenomena. The quantification of coastal evolution using archaeological sites is an example of such independent invention. Though Louis Giddings believed his "beach ridge archaeology" offered a radically new method, the method had already been invented—twice, first in England and then in Louisiana. In the nineteenth century, British historians used stranded villages to reconstruct the course of coastal evolution at Dungeness Foreland. Similarly, geologists working in the Mississippi delta inferred delta lobe abandonment based on archaeological sites.

One of the earliest recognized uses of prograding coastal sedimentary facies involved the construction of cultural chronologies. Investigators in Alaska, as well as on the Mississippi and in Vietnam, use the horizontal placement of sites to establish cultural continuity. The survey methodology of "beach ridge dating" requires an adequate ethnographic basis and can yet ultimately suffer from the circular reasoning implicit in ethnographic analogy. As may be seen along the Gulf Coast, the facile use of horizontal location must be tempered with cultural ecological factors such as resource use and discard behavior. Though the usage of relative beach ridge position provides a survey methodology, this usage does not exhaust

the potential implications of the beach ridge method.

In studies of shoreline evolution, archaeological sites are routinely used like any other chronological reference point, as a source of radiocarbon datable material. Geologists and archaeologists must consider the idiosyncratic factors associated with human settlements before using midden or settlement elevations as sea level indicators. In this regard, human settlements can provide a microfaunal, site specific description of coastal depositional environments. Reconstructions of paleoshoreline and sea levels are common research goals of beach ridge studies and the more commonly used deep coring methodology. Considering that shell middens are rapidly disappearing in much of the world due to their use as agricultural lime and in road construction, there is indeed an urgency in collecting and using middens as geological data sets.

Once again, geologists must expand their vision beyond facies relationships to include the climatic implications of regional records of progradation or erosion. There is a serious need for wide scale correlation studies of barrier island/beach ridge complexes along the Atlantic seaboard and in the Pacific Northwest. Such extended records could provide a proxy record of late Holocene paleoclimate. Studies of shoreline evolution can also focus on the interrelations between depositional environment and regional climatic parameters. A fertile area for study involves the relationship between upriver regions of sediment supply and coastal environments of storage and deposition — as in the cases of Peru, Australia, and the Mississippi, Columbia and Colorado Rivers cited above. Observations about the orientation of discrete ridge units or truncations in ridge deposition have led to reconstructions of regional climate in Mexico and Alaska.

A new approach among researchers involves the wider scope of problems including $CO_2$ induced warming and El Niño phenomena, as in Peru. The trend of seeking supra-regional linkages to explain beach ridge patterns offers the greatest potential but requires a comprehensive interdisciplinary approach, as a cross check. While a single technique provides one type of evidence, the results from two diverse fields may yield more ambiguous results. Consideration must be given to the range of variation in phenomena, as in Peru, for example, where the temperature tolerance of intertidal species must be established *before* cor-

relations of sea surface temperature with archaeological faunas can be made. As evident by the interdisciplinary review of DE VRIES (1987), the principal hurdles in interpretation are the simplistic uses of modern analogy, imprecise dating of deposits and the facile inferences based on paleontological samples.

## LITERATURE CITED

ANDERSON, D.D., 1988. Onion Portage: The archaeology of a stratified site from the Kobuk River, Northwest Alaska. *Anthropological Papers, University of Alaska,* 22, 1–163.

ANDREWS, J.T., 1986. Elevation and age relationships: Raised marine deposits and landforms in glaciated areas: Examples based on Canadian Arctic data. *In:* VAN DE PLASSCHE, O. (ed.), *Sea Level Research: A Manual for the Collection and Evaluation of Data.* Norwich: Geo Books, pp. 67–96.

ANDREWS, J.T.; MCGHEE, R., and MCKENZIE-POLLOCK, L., 1971. Comparison of elevations of archaeological sites and calculated sea levels in arctic Canada. *Arctic,* 24, 210–228.

ARUNDALE, W., 1981. Radiocarbon dating in eastern Arctic archaeology: A flexible approach. *American Antiquity,* 46, 244–271.

BEATON, J.M., 1985. Evidence for a coastal occupation time-lag at Princess Charlotte Bay (North Queensland) and implications for coastal colonization and population growth theories for aboriginal Australia. *Archaeology in Oceania,* 20, 1–20.

BELKNAP, D.F. and HINE, A.C., 1983. Evidence for a sea level lowstand between 4,500 and 2,400 years B.P. on the southeast coast of the United States—Discussion. *Journal of Sedimentary Petrology,* 53, 679–682.

BERENDSEN, H.J.A. and ZAGWIJN, W.H. (eds.), 1984. Geological Changes in the western Netherlands during the period 1000–1300 A.D. *Geologie en Mijnbouw,* 63.

BIELAWSKI, E., 1988. Paleoeskimo variability: The early Arctic Small-Tool tradition in the central Canadian Arctic. *American Antiquity,* 53, 52–74.

BINFORD, L.R., 1968. Post-Pleistocene Adaptations. *In:* BINFORD, S.R. and BINFORD, L.R. (eds.), *New Perspectives in Archaeology.* Chicago: Aldine Press, pp. 313–341.

BIRD, E.C.F. and SCHWARTZ, M.L., 1985. *The World's Coastline*. New York: Van Nostrand Reinhold.

BRANNON, H.R., JR.; SIMONS, L.H.; PERRY, D.; DAUGHTRY, A.C., and E. MCFARLAN, JR., 1957. Humble Oil Company radiocarbon dates II. *Science*, 125, 919–923.

BROOKS, M.J.; STONE, P.A.; COLQUHOUN, D.J.; BROWN, J.G., and STEELE, K.B., 1986. Geoarchaeological research in the Coastal Plain portion of the Savannah River valley. *Geoarchaeology*, 1, 293–308.

BROWN, I.W., 1984. Late prehistory in coastal Louisiana. *In:* DAVIS, D.D. (ed.), *Perspectives on Gulf Coast Prehistory*. Gainesville: University Presses of Florida, pp. 94–124.

CARTER, R.W.G., 1988. *Coastal Environments: An Introduction to the Physical, Ecological and Cultural Systems of Coastlines*. London: Academic Press.

CHAPPELL, J. and GRINDROD, J., 1984. Chenier plain formation in northern Australia. *In:* THOM, B.G. (ed.), *Coastal Geomorphology in Australia*. New York: Academic Press, pp. 197–232.

CHATTERS, J.C. and HOOVER, K.A., 1986. Changing late Holocene flooding frequencies on the Columbia River, Washington. *Quaternary Research*, 26, 309–320.

CLAGUE, J.; HARPER, J.R.; HEBDA, R.J., and HOWES, D.E., 1982. Late Quaternary sea levels and crustal movements, coastal British Columbia. *Canadian Journal of Earth Science*, 19, 597–618.

CLARK, P.U. and FITZHUGH, W.W., 1992. Postglacial relative sea level history of the Labrador coast and interpretation of the archaeological record. *In:* JOHNSON, L.L. and STRIGHT, M. (eds.), *Paleoshorelines and Prehistory: An Exploration of Method*. Boca Raton: CRC Press, pp. 189–213.

COLLINS, H.B., 1937. Archaeology of St. Lawrence Island, Alaska. *Smithsonian Institution Miscellaneous Collections*, 96(1). Washington, D.C.: Smithsonian Institution.

COLLINS, H.B., 1962. Bering Strait to Greenland. *In:* Campbell, J.M. (ed.), *Prehistoric Cultural Relations between the Arctic and Temperate Zones of North America*. Arctic Institute Technical Paper 11. Calgary: Arctic Institute of North America, pp. 126–139.

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*, 1, 275–292.

COOPER, W.S., 1958. Coastal sand dunes of Oregon and Washington. *Geological Society of America Memoir*, 72.

CUNLIFFE, B.W., 1980. The evolution of Romney Marsh: A preliminary statement. *In:* THOMPSON, F.H. (ed.), *Archaeology and Coastal Change. Occasional Paper 1, Society of Antiquaries of London*. London: Burlington House, pp. 37–55.

CURRAY, J.R., 1964. Transgressions and regressions. *In:* MILLER, R.L. (ed.), *Papers in Marine Geology: Shepard Commemorative Volume*. New York: Macmillan, pp. 175–183.

CURRAY, J.R.; EMMEL, F.J., and CRAMPTON, P.J.S., 1969. Holocene history of a strand plain, lagoonal coast, Nayarit, Mexico. *In:* CASTANARES, A.A. (ed.), *Coastal Lagoons: A Symposium*. México City: Universidad Nacional Autonoma de México, pp. 63–100.

DE PRATTER, C.B. and HOWARD, J.D., 1977. History of shoreline changes determined by archaeological dating: Georgia coast, U.S.A. *Transactions, Gulf Coast Association of Geological Societies*, 27, 252–258.

DE PRATTER, C.B. and HOWARD, J.D., 1981. Evidence for a Sea Level Lowstand between 4,500 and 2,400 years B.P. on the southeast coast of the United States. *Journal of Sedimentary Petrology*, 51, 1287–1295.

DE PRATTER, C.B. and HOWARD, J.D., 1983. Evidence for a Sea Level Lowstand between 4,500 and 2,400 years B.P. on the southeast coast of the United States—Reply. *Journal of Sedimentary Petrology*, 53, 682–685.

DEMIRPOLAT, S. and TANNER, W.F., 1987. Advanced grain size analysis and late Holocene sea level history. *In:* KRAUS, E.C. (ed.), *Coastal Sediments '87*, volume 2. New York: American Society of Civil Engineers, pp. 1718–1731.

DEVRIES, T.J., 1987. A review of geological evidence for ancient El Niño activity in Peru. *Journal of Geophysical Research*, 92(C-13), 14,471–14,479.

DEVRIES, T.J. and WELLS, L.E., 1990. Thermally-anomalous Holocene Molluscan Assemblages from coastal Peru: Evidence for paleogeographic, not climatic change. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 81, 11–32.

DIKOV, N.N., 1977. *Arkheologicheskie Pamiatniki Kamchatki, Chukotki i Verkhnei Kolymy (Aziia na styke Amerikoi v drevnosti)*. Moscow: Izdatel'stevo, Nauka.

DOMINGUEZ, J.M.L.; MARTIN, L., and BITTENCOURT, A.C.S.P., 1987. Sea-level history and Quaternary evolution of river mouth-associated beach ridge plains along the east-southeast Brazilian coast. *In:* NUMMEDAL, D.; PILKEY, O., and HOWARD, J.D. (eds.), *Sea-Level Fluctuations and Coastal Evolution*. Society of Economic Paleontologists and Mineralogists Special Publication No. 41, pp. 115–128.

EDDISON, J.; CARR, A.P., and JOLLIFFE, I.P., 1983. Endangered coastlines of geomorphological importance. *Geographical Journal*, 149, 39–75.

ERONEN, M., 1983. Late Weichselian and Holocene shore displacement in Finland. *In:* SMITH, D.E. and DAWSON, A.G. (eds.), *Shorelines and Isostasy*. London: Academic Press, pp. 183–208.

FAIRBRIDGE, R.W., 1976. Shellfish-eating preceramic Indians in coastal Brazil. *Science*, 191, 353–359.

FAIRBRIDGE, R.W., 1983. Isostasy and eustasy. *In:* SMITH, D.E. and DAWSON, A.G. (eds.), *Shorelines and Isostasy*. London: Academic Press, pp. 3–25.

FAIRBRIDGE, R.W., 1986. The spectra of sea level in a Holocene time frame. *In:* RAMPINO, M.R.; SANDERS, J.E.; NEWMAN, W.S., and KÖNIGSSON, L.K. (eds.), *Climate: History, Periodicity and Predictability*. New York: Van Nostrand Reinhold, pp. 127–142.

FAIRBRIDGE, R.W., and HILLAIRE-MARCEL, C., 1977. An 8,000-yr paleoclimatic record of the 'Double Hale' 45-yr solar cycle. *Nature*, 268, 413–416.

FISHER, J.J., 1967. Development Pattern of Relict Beach Ridges of the Outer Banks, North Carolina. Ph.D. Thesis, University of North Carolina, Chapell Hill. 250 p.

FITZHUGH, W.W., 1972. Environmental archaeology and cultural systems in Hamilton Inlet, Labrador: A survey of the central Labrador coast from 3,000 B.C. to the present. *Smithsonian Contribution to Anthro-*

*pology*, 16. Washington, D.C.: Smithsonian Institution.

GAGLIANO, S.M., 1984. Geoarchaeology of the northern Gulf shore. *In:* DAVIS, D.D. (ed.), *Perspectives on Gulf Coast Prehistory.* Gainesville: University Presses of Florida, pp. 1–40.

GERDES, R.G., 1985. The Caminada-Moreau beach ridge plain. *In:* PENLAND, S. and BOYD, R. (eds.), *Transgressive Depositional Environments of the Mississippi River Delta Plain: A Guide to the Barrier Islands, Beaches and Shoals in Louisiana.* Guidebook Series No. 3. Baton Rouge: Louisiana Geological Survey, pp. 127–140.

GIBBS, M.J., 1984. Economic analysis of sea level rise: Methods and results. *In:* BARTH, M.C. and TITUS, J.G. (eds.), *Greenhouse Effect and Sea Level Rise: A Challenge for this Generation.* New York: Van Nostrand Reinhold, pp. 215–253.

GIDDINGS, J.L., 1952. Driftwood and problems of Arctic Sea currents. *Proceedings American Philosophical Society,* 96, 129–142.

GIDDINGS, J.L., 1966. Cross-dating the archeology of northwestern Alaska. *Science,* 153, 127–135.

GIDDINGS, J.L., 1967. *Ancient Men of the Arctic.* New York: A.A. Knopf.

GIDDINGS, J.L. and ANDERSON, D.D., 1986. Beach ridge archaeology of Cape Krusenstern: Eskimo and pre-Eskimo settlements around Kotzebue Sound. *Publications in Archaeology 20.* Washington DC: National Park Service.

GOULD, H.R. and MCFARLAN, E., 1959. Geological history of the chenier plain, southwestern Louisiana. *Transactions Gulf Coast Association of Geological Societies,* 9, 261–270.

GREEN, R.D., 1968. *The Soils of Romney Marsh.* London: Harpenden.

HAAG, W.G., 1958. *The Archeology of Coastal North Carolina.* Coastal Studies Series No. 2. Baton Rouge: Louisiana State University Studies.

HAYES, M.O., 1979. Barrier island morphology as a function of tidal and wave regime. *In:* LEATHERMAN, S.P. (ed.), *Barrier Islands from the Gulf of St. Lawrence to the Gulf of Mexico.* New York: Academic Press, pp. 1–28.

HEY, R.W., 1967. Sections in the beach-plain deposits of Dungeness, Kent. *Geological Magazine,* 104, 361–370.

HIGHAM, C., 1989. *The Archaeology of Mainland Southeast Asia from 10,000 B.C. to the Fall of Angkor.* Cambridge: Cambridge University Press.

HOPKINS, D.M., 1967. Quaternary marine transgressions in Alaska. *In:* HOPKINS, D.M. (ed.), *The Bering Land Bridge.* Stanford: Stanford University Press, pp. 47–90.

HOSLEY, E. 1972. Archaeological evaluation of ancient habitation site, Point Hope, Alaska. *In: Point Hope Beach Erosion, Point Hope, Alaska Appendix A.* Survey Report. Anchorage: United States Army Corps of Engineers, Alaska District.

HOWE, H.V.; RUSSELL, R.J., and MCGUIRT, J.H., 1935. Physiography of coastal southwest Louisiana. *In: Reports on the Geology of Cameron and Vermilion Parishes.* Geological Bulletin No. 6, Department of Conservation. New Orleans: Louisiana Geological Survey, 1–72.

HUME, J.D., 1965. Sea-level changes during the last 2,000 years at Pt. Barrow, Alaska. *Science,* 150, 1165–1166.

HUME, J.D. and SCHALK, M., 1967. Shoreline processes near Barrow, Alaska: A comparison of the normal and the catastrophic. *Arctic,* 20, 86–103.

JAMIESON, N., 1981. A perspective on Vietnamese prehistory based on the relationship between geological and archaeological data: Summary of an earlier article by Nguyen Duc Tam. *Asian Perspectives,* 24, 187–192.

JELGERSMA, S.; DE JONG, J.; ZAGWIJN, W.H., and VAN REGTEREN ALTENA, J.F., 1970. The coastal dunes of western Netherlands; geology, vegetational history and archeology. *Mededelingen Rijks Geologische Dienst. Nieuwe Ser.* 21, 93–167.

JOHNSON, D.W., 1919. *Shore Processes and Shoreline Development.* New York: Wiley.

KNIFFEN, F.B., 1936. A preliminary report on the Indian mounds and middens of Plaquemines and St. Bernard Parishes. *In: Lower Mississippi River Delta: Reports on the Geology of Plaquemines and St. Bernard Parishes.* Geological Bulletin No. 8, Department of Conservation. New Orleans: Louisiana Geological Survey, 407–422.

KNOX, J.C., 1988. Climatic Influence on Upper Mississippi Valley Floods. *In:* BAKER, V.R.; KOCHEL, R.C., and PATTON, P.C. (eds.), *Flood Geomorphology.* New York: Wiley, pp. 279–300.

KRAFT, J.C., 1971. Sedimentary facies patterns and geologic history of a Holocene marine transgression. *Bulletin Geological Society of America,* 82, 2131–2158.

KRAFT, J.C.; ALLEN, E.A.; BELKNAP, D.F.; JOHN, C.J., and MAURMEYER, E.M., 1979. Processes and morphologic evolution of an estuarine and coastal barrier system. *In:* LEATHERMAN, S. (ed.), *Barrier Islands from the Gulf of Lawrence to the Gulf of Mexico.* New York: Academic, pp. 149–184.

KRAFT, J.C. and CHRZASTOWSKI, M.J., 1985. Coastal stratigraphic sequences. *In:* DAVIS, R.A. (ed.), *Coastal Sedimentary Environments.* New York: Springer-Verlag, pp. 625–664.

KRAFT, J.C. and JOHN, C.J., 1976. Paleogeographic analysis of coastal archaeological settings in Delaware. *Archaeology of Eastern North America,* 6, 41–60.

KRAFT, J.C.; KAYAN, I., and ASCHENBRENNER, S.E., 1985. Geological studies of coastal change applied to archaeological settings. *In:* RAPP, G., JR., and GIFFORD, J.A. (eds.), *Archaeological Geology.* New Haven: Yale University Press, pp. 57–84.

LARSEN, H. and RAINEY, F., 1948. Ipiutak and the Arctic whale hunting culture. *Anthropological Papers American Museum of Natural History,* 42.

LARSON, L.H., 1980. *Aboriginal Subsistence Technology on the Southeastern Coastal Plain during the Late Prehistoric Period.* Gainesville: University Presses of Florida.

LEES, B.G. and CLEMENTS, A., 1987. Climatic implications of chenier dates in northern Australia. *Radiocarbon,* 29, 311–317.

LEWIS, W.V., 1932. The formation of Dungeness foreland. *Geographical Journal,* 80, 309–324.

LEWIS, W.V. and BALCHIN, W.G.V., 1940. Past sea-levels at Dungeness. *Geographical Journal,* 96, 258–285.

LIU, C. and WALKER, H.J., 1989.Sedimentary characteristics of cheniers and the formation of the chenier

plains of east China. *Journal of Coastal Research*, 5, 353–369.

LOFTFIELD, T.C., 1988. Prehistoric oysterman of the central North Carolina coast. *In:* PEACOCK, J.L. and SABELLA, J.C. (eds.), *Sea and Land: Cultural and Biological Adaptations in the Southern Coastal Plain.* Athens: University of Georgia Press, pp. 106–121.

MARTINI, I.P., 1986. Coastal features of Canadian inland seas. *In:* MARTINI, I.P. (ed.), *Canadian Inland Seas.* Elsevier Oceanography Series, 44. Amsterdam: Elsevier, pp. 117–142.

MASON, O.K., 1990. Beach Ridge Geomorphology of Kotzebue Sound: Implications for Paleoclimatology and Archaeology. Ph.D. Thesis, Quaternary Science, University of Alaska, Fairbanks. 262 p.

MASON, O.K., 1992. A geoarchaeological methodology for studying prograding coastal sequences: Beach ridge geomorphology in Kotzebue Sound, Alaska. *In:* JOHNSON, L.L. and STRIGHT, M. (eds.), *Paleoshorelines and Prehistory: An Exploration of Method.* Boca Raton: CRC Press, pp. 55–91.

MASON, O.K. and JORDAN, J.W., 1991. A proxy Late Holocene climate record deduced from NW Alaska beach ridges. *In:* Gunter WELLER (ed.), *Proceedings, International Conference on the Role of the Polar Regions in Global Change.* Fairbanks: Geophysical Institute, pp. 649–657.

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.

MASTERS, P.M. and FLEMING, N.C., (eds.), 1983. *Quaternary Coastlines and Marine Archaeology: Towards a Prehistory of Landbridges and Continents.* New York: Academic Press, 641 p.

MATHIESSEN, T., 1927. *Archaeology of the Central Eskimo,* 2 vols. *Report of the Fifth Thule Expedition, 1921–1924,* vol. 4(1–2). Copenhagen: Gyldendalske Boghandel Nordisk Forlag.

MAXWELL, M., 1976. Pre-Dorset and Dorset artifacts: The view from Lake Harbour. *Society for American Archeology Memoir,* 31, 58–78.

McFARLAN, E., JR., 1961. Radiocarbon dating of late Quaternary deposits, south Louisiana. *Bulletin Geological Society of America,* 72, 129–158.

McGHEE, R., 1979. Paleo-Eskimo Occupation at Port Refuge. *Archaeology Survey of Canada Paper 92.* Ottawa: National Museum of Canada.

McGHEE, R., 1981. Dorset Occupation in the Vicinity of Port Refuge, High Arctic Canada. *Archaeological Survey Canada Paper 105.* Ottawa: National Museum of Canada.

McGHEE, R. and TUCK, J.A., 1976. Undating the Canadian Arctic. *Memoirs, Society for American Antiquity,* 31, 6–14.

McGREGOR, D.F.M. and GREEN, C.P., 1989. Geomorphology in conservation assessment—The Dungeness shingle system. *Ocean and Shoreline Management,* 12, 107–124.

McINTIRE, W.G., 1958. *Prehistoric Indian Settlements of the Changing Mississippi River Delta.* Baton Rouge: Louisiana State University Press.

McMANAMON, F.P. (ed.), 1984. *Chapters in the Archeology of Cape Cod: Results of the Cape Cod National Seashore Archaeological Survey, vol. 1. Cultural Research Management Study,* 8. Boston: National Park Service.

MEEHAN, B., 1982. *Shell Bed to Shell Midden.* Canberra: Australian Institute for Aboriginal Studies.

MELGAARD, J., 1962. On the formative period of the Dorset culture. *In:* CAMPBELL, J.M. (ed.), *Prehistoric Cultural Relations Between the Arctic and Temperate Zones of North America.* Arctic Institute Technical Paper No. 11. Calgary: Arctic Institute of North America, pp. 92–95.

MINOR, R., 1983. Settlement and subsistence at the mouth of the Columbia River. *In:* GREENGO, R.E. (ed.), *Prehistoric Places on the Southern Northwest Coast.* Seattle: Thomas Burke Memorial Washington State Museum, pp. 195–210.

MOBLEY, C.M., 1988. Holocene sea levels in Southeast Alaska: Preliminary results. *Arctic,* 41, 261–266.

MØLLER, J.J., 1987. Shoreline relation and prehistoric settlement in northern Norway. *Norsk geografisk Tiddsskrift,* 41, 45–60.

MOORE, G.W., 1960. Recent eustatic sea-level fluctuations recorded by Arctic beach ridges. *U.S. Geological Survey Professional Paper 400,* pp. B335-7.

MOORE, G.W., 1966. Arctic beach sedimentation, *In:* WILIMOVSKY, N.J. and WOLFE, J.N. (eds.), *Environment of the Cape Thompson Region, Alaska.* Oak Ridge: Atomic Energy Commission, pp. 587–608.

MOORE, G.W., 1968. Arctic Beaches, *In:* FAIRBRIDGE, R.W. (ed.), *Encyclopedia of Geomorphology.* New York: Van Nostrand Reinhold, pp. 210–220.

MOORE, G.W. and GIDDINGS, J.L., 1961. Record of 5,000 years of Arctic wind direction recorded by Alaskan beach ridges. *Abstract, Special Geological Society Papers,* 68.

MOSLOW, T.F., 1980. Stratigraphy of Mesotidal Barrier Islands. Ph.D. Thesis, Department of Geology, University of South Carolina, Columbia. 187 p.

NELSON, E.W., 1899. Eskimos about Bering Strait. *Bureau of American Ethnology Annual Report,* 18(1).

OERTAL, G.F., 1975. Post-Pleistocene island and inlet adjustments along the Georgia coast. *Journal of Sedimentary Petrology,* 45, 150–159.

OERTAL, G.F., 1977. Geomorphic cycles in ebb deltas and related patterns of shore erosion and accretion. *Journal of Sedimentary Petrology,* 47, 1121–1131.

OERTAL, G.F., 1979. Barrier island development during the Holocene recession, Southeastern U.S. *In:* LEATHERMAN, S.F. (ed.), *Barrier Islands from the Gulf of Lawrence to the Gulf of Mexico.* New York: Academic Press, pp. 273–290.

OTA, Y., 1987. Sea-level changes during the Holocene: The Northwest Pacific. *In:* DEVOY, R.V.N. (ed.), *Sea Surface Studies: A Global View.* New York: Croom Helm, pp. 348–374.

OTVOS, E.G. and PRICE, W.A., 1979. Problems of chenier genesis and terminology—An overview. *Marine Geology,* 31, 251–263.

PENLAND, S. and SUTER, J.R., 1989. The geomorphology of the Mississippi river chenier plain. *Marine Geology,* 90, 231–258.

REINECK, H.E. and SINGH, I.B., 1980. *Depositional Sedimentary Environments.* New York: Springer-Verlag.

RICHARDSON, J.B., 1983. The Chira Beach Ridges, sea level change and the origins of maritime economics

on the Peruvian coast. *Annals, Carnegie Museum*, 52, 265–276.

ROEP, T.B., 1984. Progradation, erosion and changing coastal gradient in the coastal barrier deposits of the western Netherlands. *Geologie en Mijnbouw*, 63, 249–258.

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.

ROLLINS, H.B.; RICHARDSON, J.B., and SANDWEISS, D.H., 1986. The birth of El Niño: Geoarchaeological evidence and implications. *Geoarchaeology*, 1, 3–16.

ROLLINS, H.B.; SANDWEISS, D.H., and ROLLINS, J.C., 1990. Mollusks and coastal archaeology: A review. *In:* LASCA, N.P. and DONAHUE, J. (eds.), *Archaeological Geology of North America.* Centennial Special Vol. 4. Boulder: Geological Society of America, pp. 467–478.

SANDWEISS, D.H., 1986. The beach ridges at Santa, Peru: El Niño, uplift and prehistory. *Geoarchaeology*, 1, 17–28.

SANDWEISS, D.H.; ROLLINS, H.B., and RICHARDSON, J.B., 1983. Landscape alteration and prehistoric human occupation on the north coast of Peru. *Annals, Carnegie Museum*, 52, 277–298.

SEARLE, D.J. and WOODS, P.J., 1986. Detailed documentation of a Holocene sea-level record in the Perth region, southwestern Australia. *Quaternary Research*, 26, 299–308.

SHACKLETON, N.J. and VAN ANDEL, T.J., 1986. Prehistoric shell environments, shellfish availability and shellfish gathering at Franchthi, Greece. *Geoarchaeology*, 1, 127–143.

SHARMA, G.D., 1972. Surface and submarine geology of Point Hope, Alaska. *In:* HOSELEY, E. (ed.), *Point Hope Beach Erosion Point Hope, Alaska.* Appendix A, Report to the Alaska district. Anchorage: Corps of Engineers.

SHEPARD, F.P. and WANLESS, P.J., 1971. *Our Changing Coastlines.* New York: McGraw-Hill.

SHEPPARD, J.C. and CHATTERS, J.M., 1976. Washington State University natural radiocarbon measurements II. *Radiocarbon*, 18, 140–149.

SMART, J.G.O., 1964. National Physical Laboratory radiocarbon measurements II. *Radiocarbon*, 6, 25–30.

STAPOR, F.W., 1975. Holocene beach ridge plain development, northwest Florida. *Zeitschrift für Geomorphologie*, N.F. 22, 116–144.

STAPOR, F.W.; MATHEWS, T.D., and LINDFORS-KEARNS, F.E., 1991. Barrier island progradation and Holocene sea level history in southwest Florida. *Journal of Coastal Research*, 7, 815–838.

STEERS, J.A., 1964. *The Coastline of England and Wales.* Cambridge: Cambridge University Press.

STEWART, T.G. and ENGLAND, J., 1983. Holocene sea-ice variations and paleoenvironmental change, northernmost Ellesmere Island, N.W.T., Canada. *Arctic and Alpine Research*, 15, 1–17.

STRIGHT, M.J., 1990. Archaeological Sites on the North American Continental Shelf. *In:* LASCA, N.P. and DONAHUE, J. (eds.), *Archaeological Geology of North America.* Centennial Special Vol. 4. Boulder: Geological Society of America, pp. 439–466.

SUGUIO, K.; MARTIN, L., and FLEXOR, J.M., 1992. Paleoshorelines and the sambaquis of Brazil. *In:* JOHNSON, L.L. and STRIGHT, M. (eds.), *Paleoshorelines and Prehistory: An Exploration of Method.* Boca Raton: CRC Press, pp. 83–100.

TANNER, W.F., 1988. Beach ridge data and sea level history from the Americas. *Journal of Coastal Research*, 4, 81–91.

TAYLOR, R.B. and McCANN, S.B., 1983. Coastal depositional landforms in northern Canada. *In:* SMITH, D.E. and DAWSON, A.G. (eds.), *Shorelines and Isostasy.* London: Academic Press, pp. 53–75.

THOMPSON, R.W., 1968. Tidal flat sedimentation in the Colorado River delta, Gulf of California. *Geological Society of America Memoir*, 107.

TITUS, J.G., 1987. The greenhouse effect, rising sea level and society's response. *In:* DEVOY, R.V.N. (ed.), *Sea Surface Studies: A Global View.* New York: Croom Helm, pp. 499–528.

VAN ANDEL, T.H.; JACOBSEN, T.W.; JOLLY, J.B., and LIANOS, N., 1980. Late Quaternary history of the coastal zone near Franchthi Cave, southern Argolid, Greece. *Journal of Field Archaeology*, 7, 389–402.

VAN ANDEL, T.H. and LIANOS, N., 1984. High resolution seismic reflection studies for the reconstruction of Post Glacial transgressive shorelines: An example from Greece. *Quaternary Research*, 22, 31–45.

VAN STRAATEN, L.M.J.U., 1965. Coastal barrier deposits in South and North Holland. *Mededelingen Geologische Stichting*, 17, 41–75.

WANG, Y. and KE, X., 1989. Cheniers on the east coastal plain of China. *Marine Geology*, 90, 321–335.

WATERS, M.R., 1983. Late Holocene lacustrine chronology and archaeology of ancient Lake Cahuilla, California. *Quaternary Research*, 19, 373–387.

WELLS, L.E., 1987. An alluvial record of El Niño events from northern coastal Peru. *Journal of Geophysical Research*, 92, 14463–14470.

YESNER, D.R., 1980. Maritime hunter-gatherers: Ecology and prehistory. *Current Anthropology*, 21, 727–750.