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Compile geological data and develop methods to predict the distribution and properties of features hypothesized to be responsible for sonar geoclutter. Contribute to the reduction or mitigation of geologic clutter observed on fleet sonar systems.

Two issues define the problem.
Landscape forming issue: In area x, can the Navy expect geoclutter features and if so what are their sonar characteristics, i.e. channel orientation?
Landscape burial issue: If geoclutter features are expected in area x, will the features be exposed

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Predicting the Distribution and Properties
of Buried Submarine Topography On Continental Shelves

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LONG-TERM GOALS

Compile geological data and develop methods to predict the distribution and properties of features hypothesized to be responsible for sonar geoclutter. Contribute to the reduction or mitigation of geologic clutter observed on fleet sonar systems.

Two issues define the problem.
- Landscape forming issue: In area 'x', can the Navy expect geoclutter features and if so what are their sonar characteristics, i.e. channel orientation?
- Landscape burial issue: If geoclutter features are expected in area 'x', will the features be exposed or buried? Areas of low interest to the Navy include locations where Holocene deposits are thick. Areas of high interest to the Navy include locations where Holocene deposits are thin thereby allowing for the shallow burial of Pleistocene topography.

JUSTIFICATION

A major goal of the U.S. Office of Naval Research is to reduce or mitigate geologic clutter observed on fleet sonar systems. Geological structures just beneath the seafloor, with high-angle reflecting surfaces, can return false sonar alarms. Examples include steep-walled channels from buried paleo-river valleys, faults or iceberg furrows.

OBJECTIVES

- Define the character of different kinds of buried channels (size, shape, properties).
- Define the spatial distribution of these buried channels (river, tidal, hyperpycnal).
- Develop a global atlas of candidate geoclutter features and their characteristics.
- Develop and merge global databases of pertinent geological and oceanographic data.
- Develop predictive models and apply to margins of interest. Test predictive models in a known geoclutter rich area.
- Share and merge these databases, models and results with those in the Geoclutter Research Group working on tracking algorithms.

APPROACH

1) Compile a global database of pertinent geological and oceanographic data, for use as initial inputs and constraints for sediment flux models (*HydroTrend* and *SedFlux*).

2) Measure and analyze terrain attributes. Perform a comprehensive analysis of real and

simulated elevation grids using RiverTools® and other GIS software. Calculate the geometric and statistical characteristics of landforms and how these characteristics vary from one geologic setting to another.

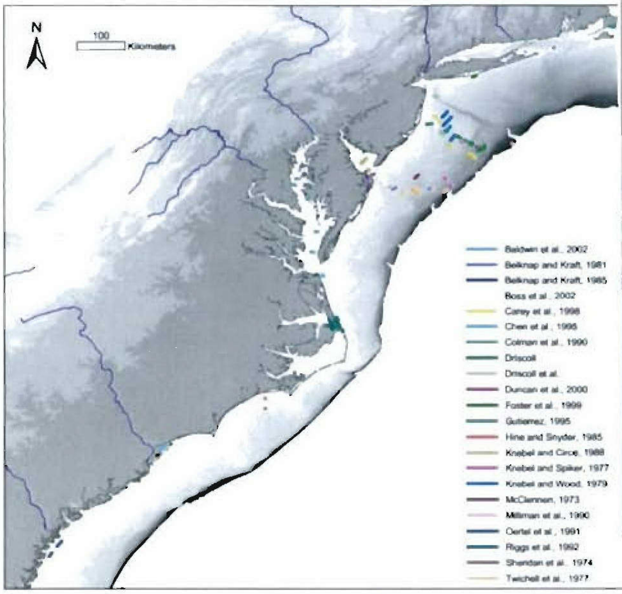
3) Classify terrain from geologic information. Classify "terrain types" in terms of the initial and boundary conditions (e.g. geology, erosion rates, excess rain rates) that produced the terrain types, using physics-based landform models.

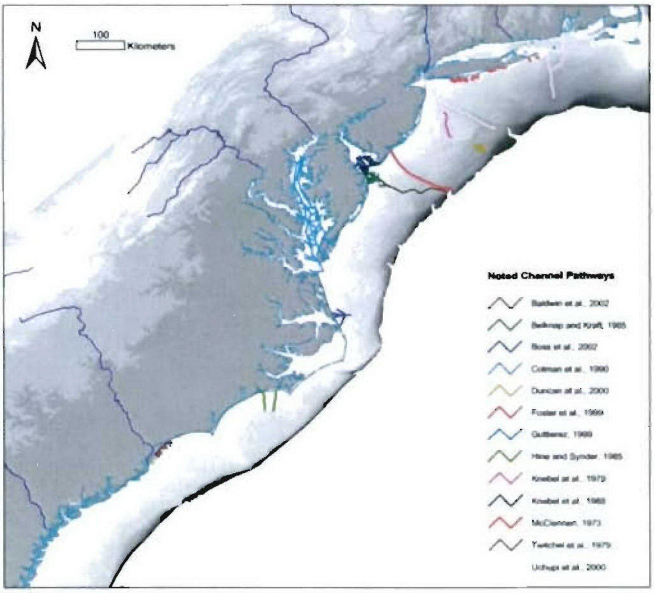
4) Determine the burial depth potential of low-sea level produced topography. Develop simple scaling relationships for deposition rate as a function of sediment input rates from rivers, wave and current conditions, and shelf geometry. Refine these bulk estimates with more detailed consideration of the nature of sediment delivery to the shelf (e.g., episodic storm-driven flooding vs. seasonal snowmelt flooding; the role of estuaries) and sediment redistribution, bypassing and deposition on the shelf (e.g., the long-term manifestation of short-term, episodic, storm-driven transport on the shelf).

5) Model the flux of sediment to and across continental shelves. Use process-based models (*HydroTrend*) to obtain a detailed consideration of the nature of sediment delivery to the shelf and sediment redistribution, bypassing and deposition on the shelf.

WORK COMPLETED

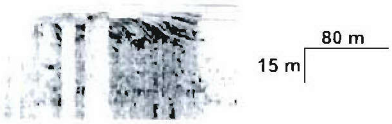
1) From the U.S. East Coast shelf (NY to Georgia), pathways and attributes of paleochannels (e.g., width, depth, sidewall slopes) have been compiled in a database using available field data (i.e., chirp sonar) and data from extensive literature searches. Surficial sediment samples and core locations from a variety of sources are also contained in the database.

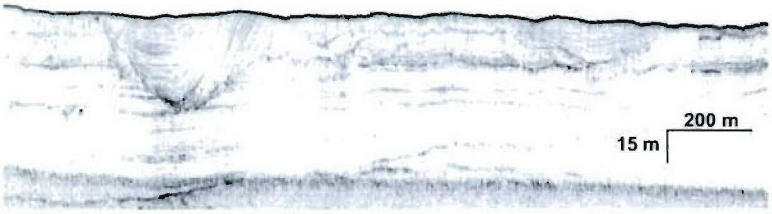




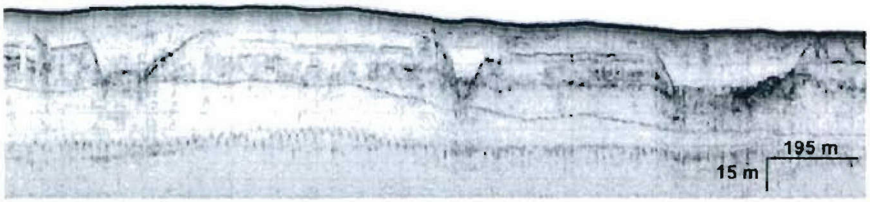
Great diversity is evident in the shape, size and fill of channels on the U.S. East Coast continental shelf (below). The Albemarle Sound channel has pronounced laterally filled beds with areas of high reflectivity with acoustic blanking below, which is interpreted to be the result of trapped gas. It is believed to represent a former tidal inlet.

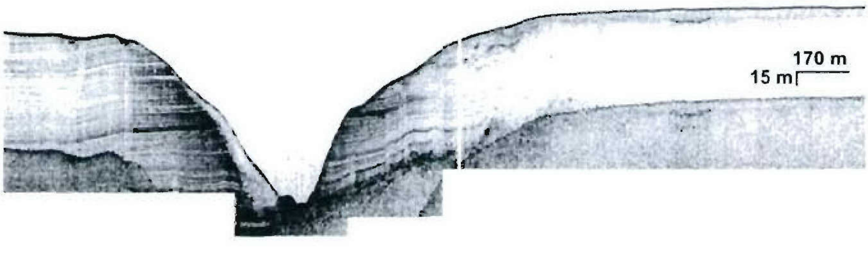
Two moderately large channels (B) are filled by upbuilding beds. These are probably associated with waning river or estuarine flow. A broad channel with a relatively flat but rough bottom is shown in C. These characteristics combined with mostly transparent fill suggest formation during a large and episodic discharge event at lowered sea level. Several V-shaped channels with transparent fill are located on the outer shelf. Data from the Geoclutter Field Group indicate they form a dendritic drainage pattern. Massive channels found in Block Island Sound (E) were likely carved during catastrophic drainage of glacial lakes and maintained by tidal currents.


A) Albemarle Sound Channel

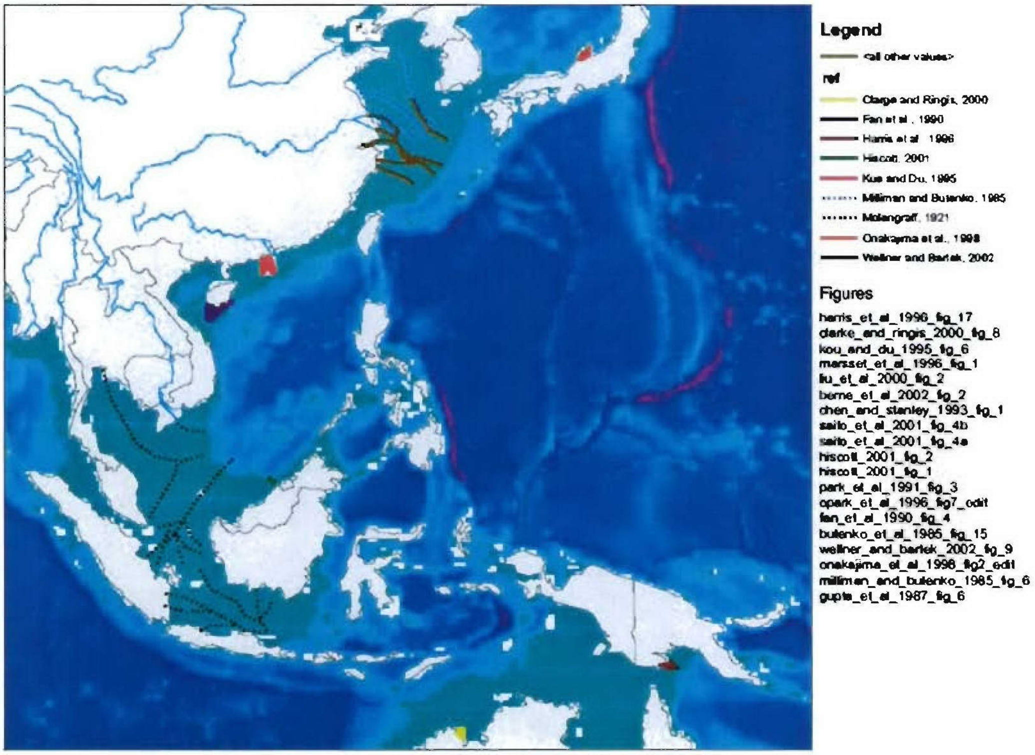

B) New Jersey Mid-shelf Channels


C) New Jersey Mid-shelf Channel

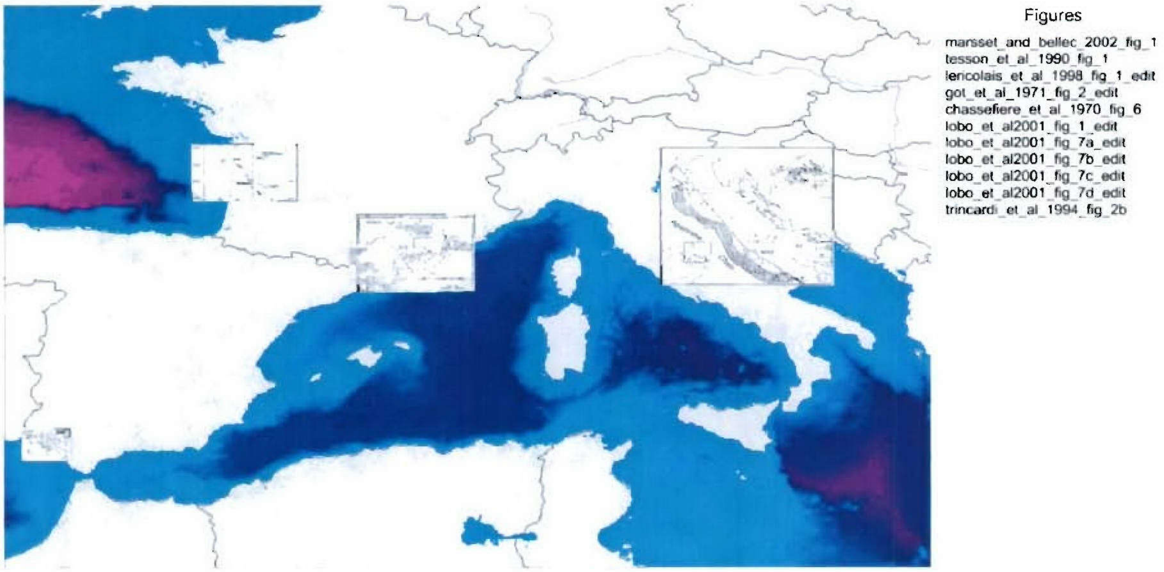

D) New Jersey Outer-shelf Channels


E) Block Island Sound Channel

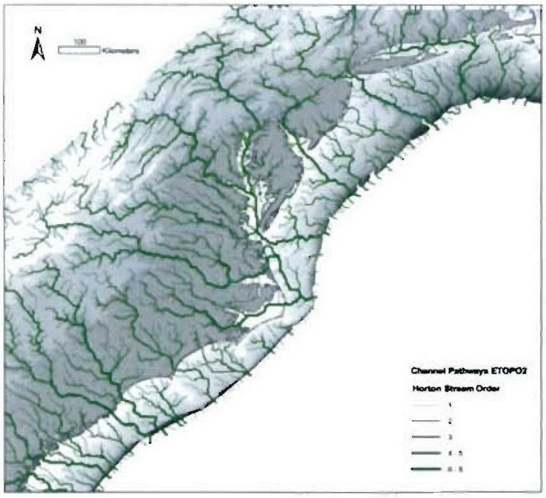
2) Southeast Asia is potentially an important area for buried paleochannels due to its wet, tropical nature and extensive continental shelf area. As a result, a similar channel database is in production for this region. An extensive literature search has been conducted.

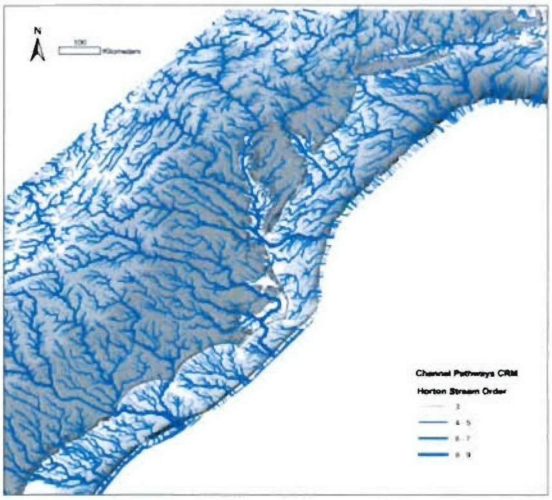


3) Similar to the U.S. East Coast, extensive geologic and oceanographic studies have been conducted along the European margins. A database for paleochannels in this region is near completion. Data are compiled in a consistent fashion with the existing data base.

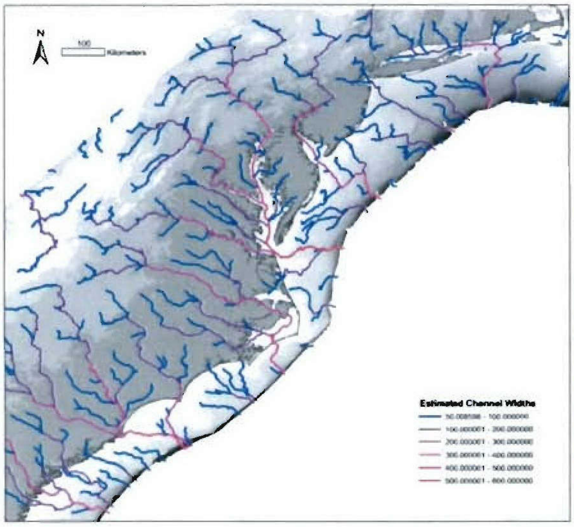


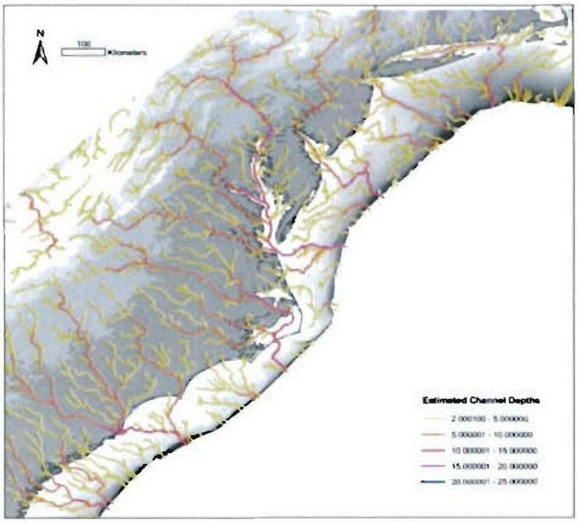
4) Topographic data from ETOPO2 and the Coastal Relief Model (CRM) were used as inputs to RiverTools (software developed by Scott Peckham, INSTAAR) to evaluate the pathway of paleo-rivers across the continental shelf. Results from these analyses indicate that the relatively low-resolution data of ETOPO2 (2 minute pixel size) produce drainage pathways comparable to the CRM (pixel resolution initially at 3 seconds but averaged to 12 seconds). Interestingly, the observed paleo-Delaware River appears to flow more northerly on the outer shelf (see above; Twichell et al., 1977). This is hypothesized to result from glacial loading during the LGM.





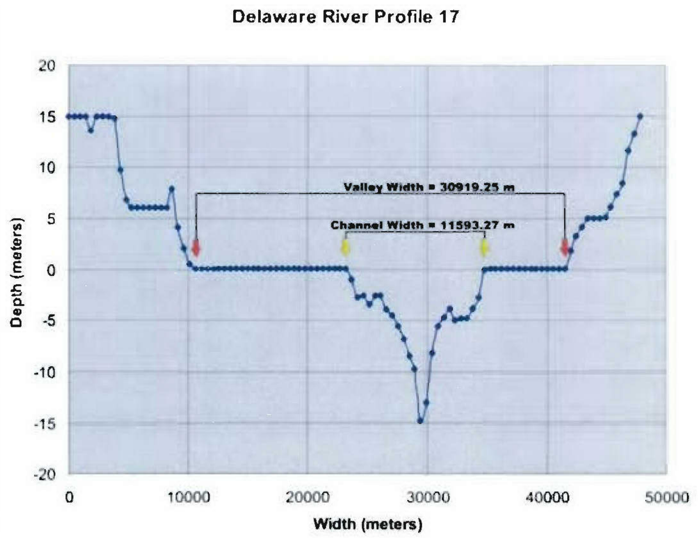
5) To compare the geometry of observed channels with that predicted by fluvial drainage, we used modern hydraulic geometry relationships to predict the width and depth of paleo-river channels on the continental shelf. Based on these relationships, channel widths on the continental shelf are predicted to be <500m. Many observed channels are considerably greater in size than predicted, supporting the idea that these features are "incised valleys". However, several potential "valleys" have characteristics of channels (i.e., shape, fill, geometry), possibly reflecting large discharge events.

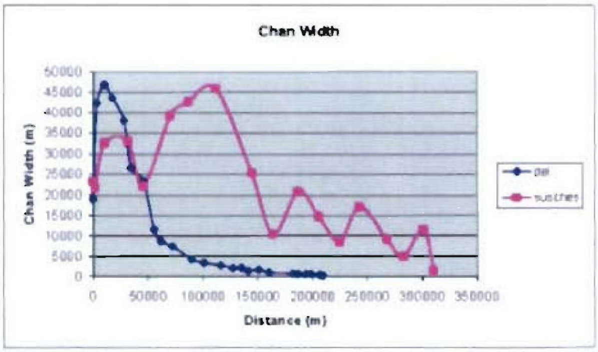


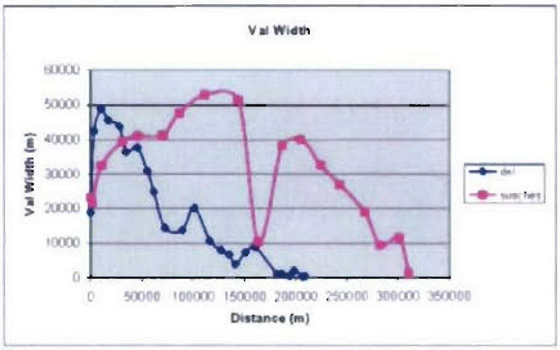


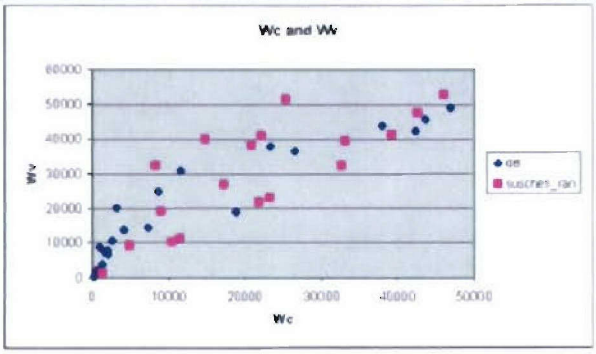
Also, to better understand areas of likely fluvial incision and deposition during periods of lowered sea level, stream elevation profiles of the estimated channel pathways were determined. These data highlight the potential for fluvial deposition on the New York Bight shelf during lowered sea level. Furthermore, coastal and outer-shelf areas are highlighted as possible locations for enhanced fluvial incision.

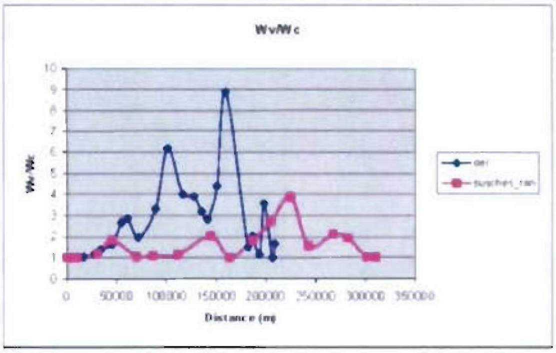
6) It is evident from this and other research that many "channels" on the U.S. East Coast are "incised valleys". To better understand relationships between valleys and their associated river channels, measurements were made on valley/channel characteristics of major East Coast coastal-plain systems. This research gives insight into how estuarine processes can impact the evolution of a river channel (Walsh et al., 2002).



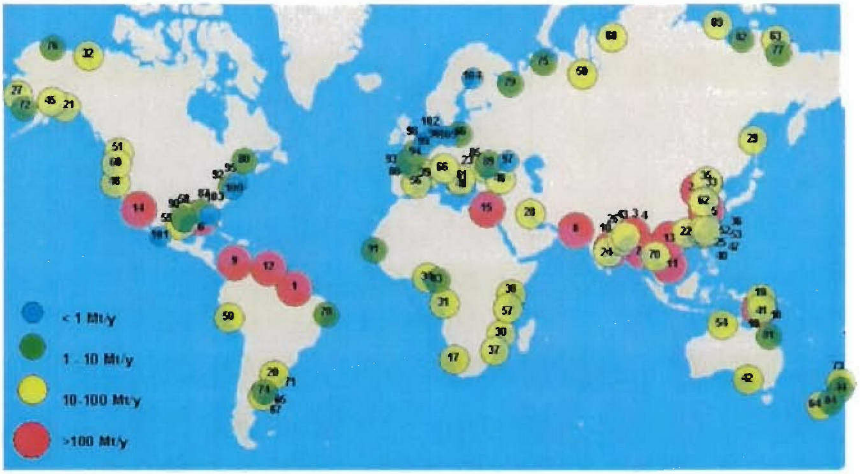


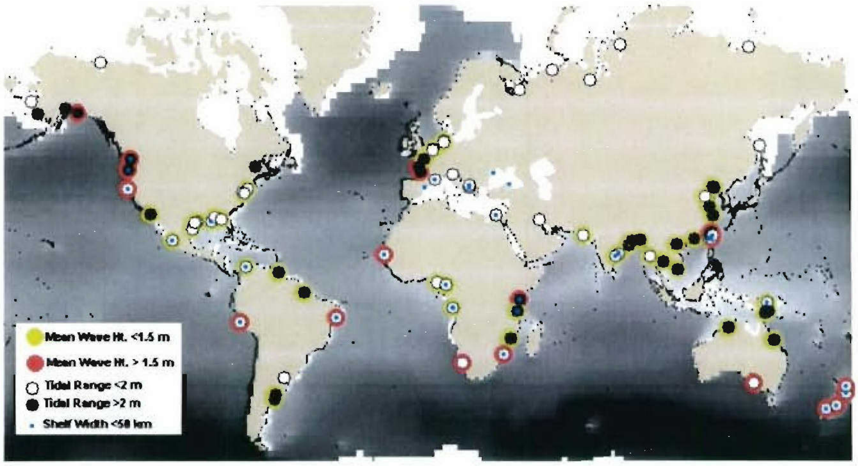


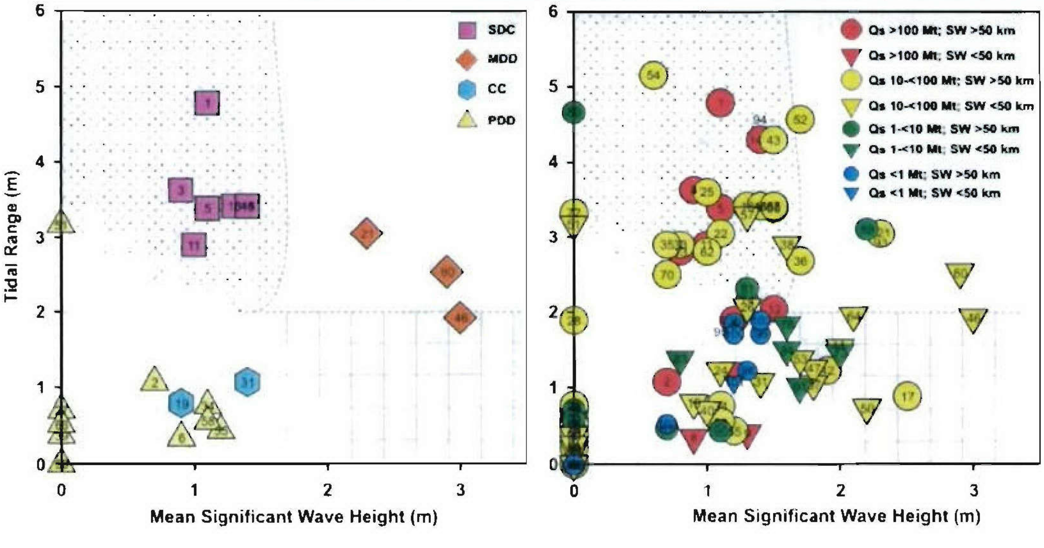




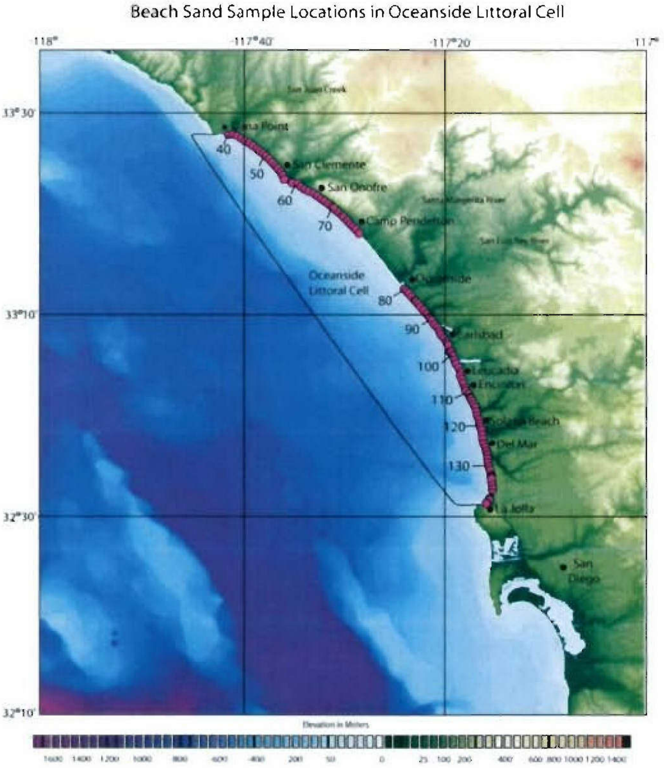
7) The burial of sediment by river systems is also a major concern of the Geoclutter Program. Several studies have examined sedimentation seaward of individual river systems in detail, but little attempt has been made to integrate observations. To evaluate river-sediment accumulation on continental shelves around the world, a database of river sediment discharge, mean significant wave height, tidal range and continental shelf width was created for >100 major rivers. These data reveal that 4 basic types of river sediment dispersal exist and these are predictably related to hydrological and oceanographic factors.





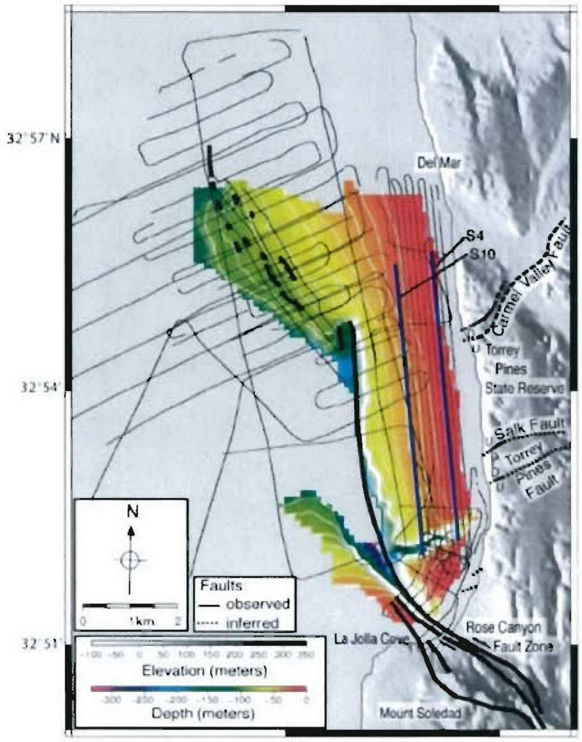


8) The source of nearshore and beach sediment for a given region is also important to understand in order to determine how rapid geologic features will be buried. In addition, sediment type will also impact seismic penetration and reflector character. Sediment characteristics in the Oceanside littoral cell were studied in order to define the sediment provenance of beach sands.


Beach Sand Sample Locations in Oceanside Littoral Cell

Recent studies have suggested the rivers may become hyperpycnal during storm and therefore may not contribute sand to local beaches. This greatly differs form the previous work that attributed 80-90% of the sand to river input (e.g., Inman, 1999). We employed grain size and mineralogical characteristics to define sediment source regions. This study looked at three possible sources for beach sand; rivers, sea cliffs and anthropogenic inputs such as the San Diego Regional Beach Sand Project. All three sources provided distinct mineralogical signals that could be found in beach sand. While river input is not ruled out as a sediment source, our work reveals that sea cliffs are an important source of sediment to the Oceanside littoral cell (Haas, 2005; Haas and Driscoll, submitted).

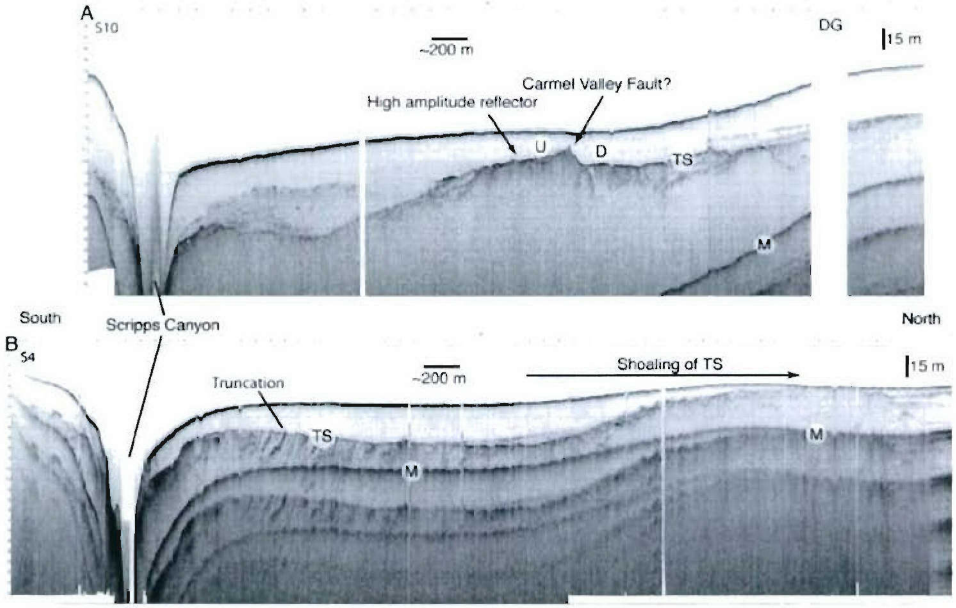
9) We have also examined the tectonic control on long-term sediment preservation, which may modify Geoclutter in a region by burying hardgrounds in one region while exposing them in another. A dense survey of high-resolution CHIRP seismic data reveals a marked shore-parallel variation in the Holocene sediment thickness offshore La Jolla. Sediment thicknesses decrease from greater than 20 m in the south near Scripps Canyon to zero in the north approaching Torrey Pines. In addition to the south to north variation in sediment thickness, the transgressive surface observed in seismic lines shoals from Scripps Canyon to the north. Despite these dramatic shore-parallel subsurface changes, the nearshore bathymetry



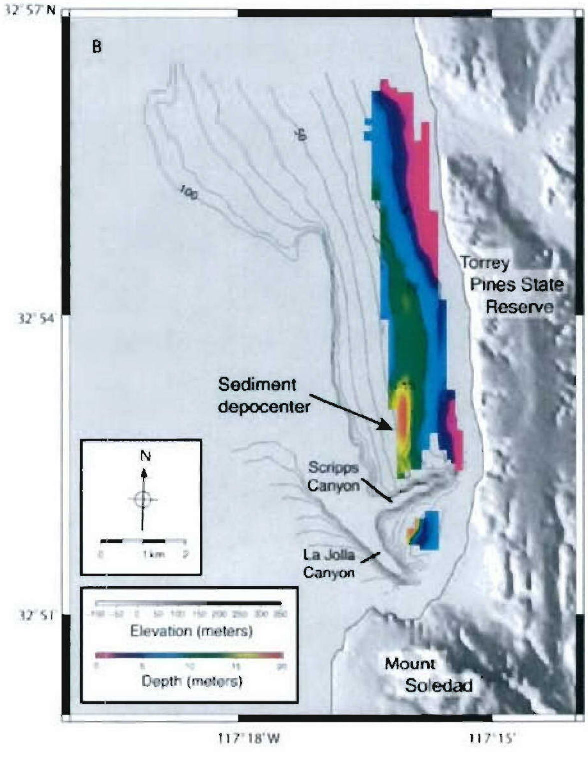
Survey ship track (black lines) superimposed on 2 m gridded bathymetry (color). White lines on bathymetry represents depth contours up to 100 m. Faults are shown in bold black: dashed for inferred location, D and U for downthrown and upthrown side, and the right-lateral sense of strike-slip shown with arrows. The left-lateral bend in the Rose Canyon Fault zone creates the active uplift of Mount Soledad. Normal faults in Torrey Pines State Reserve are inactive. S4 and

S10 (bold blue lines) indicate locations of strike lines shown.

exhibits little to no change along strike. Numerous observations indicate that longshore transport of sand is from north to south in the Oceanside Littoral Cell. Sediments then exit the nearshore through the Scripps and La Jolla Submarine Canyons. This simple explanation of longshore transport does not account for the unexpected distribution of sediments seen in the recent CHIRP data. A left-lateral constraining bend on the Rose Canyon Fault causes local uplift in the region and appears to explain the northward shoaling of the transgressive surface and the Holocene sediment thickness variation. The observed relationship between the shoaling transgressive surface, the bathymetric high



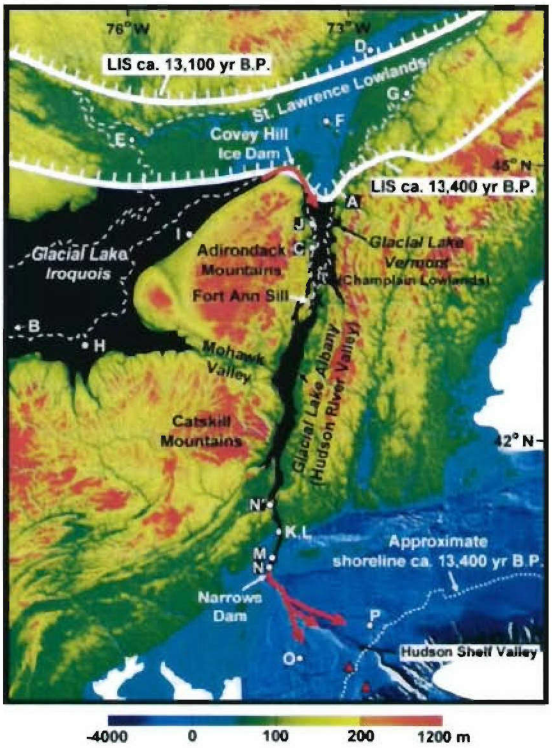
Chirp strike line profiles. A: Profile S10 from offshore shows the shoaling of the transgressive surface (TS) towards the seafloor to the north of Scripps Canyon. Sediments cover the entire extent of the transgressive surface at this depth. B: Nearshore profile S4 shows truncation of underlying layers at the transgressive surface and an abrupt shoaling of the transgressive surface. At the north end of the line we see evidence of the transgressive surface starting to dip to the north. See Figure 2 for locations. (M = multiple, DG = data gap)



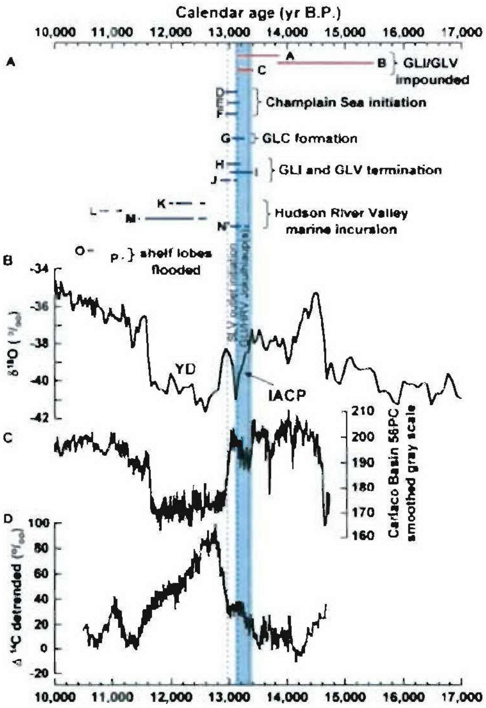
Holocene sediment thickness above the transgressive surface (contour interval = 3 m) superimposed on bathymetric contours (contour interval = 10 m). Isopachs show a depocenter of Holocene sediments directly north of Scripps Canyon (indicated by arrow) where sediments are nearly 20 m thick. Along strike to the north sediments thin to zero, *whereas the bathymetry does not change. Note the spatial correlation between the step offshore of the isobaths and that of the isopachs.*

offshore, and the sediment depocenters suggests that, while short-term processes such as wave climate control sediment transport, tectonics may control long-term sediment accumulation in the nearshore (Hogarth et al., submitted).

10) Catastrophic discharge during delglaction also may play an important role is shaping shelf morphology as well as impacting climate. Glacial freshwater discharge to the Atlantic Ocean during deglaciation may have inhibited oceanic thermohaline circulation, and is often postulated to have driven climatic fluctuations. Yet attributing meltwater-discharge events to particular climate oscillations is problematic, because the location, timing, and amount of meltwater discharge are often poorly constrained. Evidence from the Hudson Valley and the northeastern U.S. continental margin establishes the timing of the catastrophic draining of Glacial Lake Iroquois, which breached the moraine dam at the Narrows in New York City, eroded glacial lake sediments in the Hudson Valley, and deposited large sediment lobes on the New York and New Jersey continental shelf ca. 13,350 yr B.P (Donnelly et al., 2005).

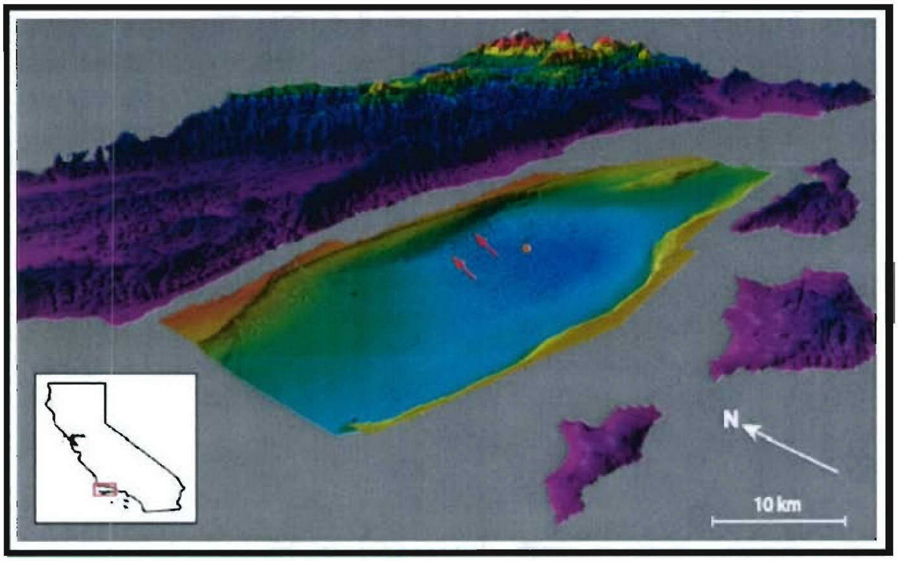


Relief map of northeast U.S. margin and southern Canada including bathymetric data from continental shelf and slope (data not plotted in white areas offshore). Locations A–P correspond to sites referred to in text, where 14C and stratigraphic ages provide constraints on timing of meltwater release from Glacial Lake Iroquois down Hudson Valley. Age range for each location is plotted in figure below. Black—approximate extent of glacial lakes ca. 13,400 yr B.P. Solid white lines—southern margin of Laurentide Ice Sheet (LIS) ca. 13,400 and 13,100 yr B.P. Red arrows—path of meltwater during Hudson Valley jokulhlaup. Sediment lobes deposited by jokulhlaup are evident on continental shelf (area around locations O and P). Red triangles - locations of glacial erratics inferred to have been transported to outer shelf during jokulhlaup (Uchupi et al., 2001). Dotted white line—location of shoreline ca. 13,400 yr ago. Hudson Shelf Valley is cut across shelf lobes and likely was cut during aqueous flow conditions following initial pulse of water and sediment to shelf. Dashed white line—approximate shoreline of Glacial Lake Candona just prior to opening of St. Lawrence Valley. Fort Ann sill controlled level of Glacial Lake Candona until St. Lawrence Valley was deglaciated and meltwater was routed to North Atlantic by that route (i.e., via Champlain Sea) ca. 13,000 yr B.P.



A: Calibrated 14C-based age constraints on Glacial Lake Iroquois (GLI)–Hudson Valley jo¨ kulhlaup (locations A–P; see location figure above). Red ranges provide age control for conditions prior to collapse of Covey Hill ice dam and jokulhlaup. Blue ranges provide age control for conditions after jo¨ kulhlaup. Data presented here constrain age of jo¨ kulhlaup to between 13,100 and 13,400 yr B.P. (light blue vertical shading); most likely age of event is ca. 13,350 yr B.P. (black dotted vertical line). GLC—Glacial Lake Candona; GLV—Glacial Lake Vermont. B: Greenland Ice Sheet Project (GISP) II oxygen isotopes (Stuiver et al., 1995); more positive values indicate warmer temperatures. Intra-Allerød cold period (IACP) and Younger Dryas (YD) climate oscillations are noted. C: Gray-scale record from Cariaco Basin (Hughen et al., 2000) shows many of same features as GISP II record, including Intra-Allerød cold period and Younger Dryas. Note that jokulhlaup most likely occurred immediately prior to or at beginning of Intra-Allerød cold period. Opening of St. Lawrence Valley and formation of Champlain Sea immediately predates Younger Dryas cooling (interval bracketed by blue dashed lines). D: Detrended D14C record from Cariaco Basin core PL07-58PC (Hughen et al., 2000). Excess atmospheric 14C likely indicates slowing of thermohaline circulation.

Excess 14C in Cariaco Basin sediments indicates a slowing in thermohaline circulation and heat transport to the North Atlantic at that time, and both marine and terrestrial paleoclimate proxy records around the North Atlantic show a short-lived (,400 yr) cold event (Intra- Allerød cold period) that began ca. 13,350 yr B.P.



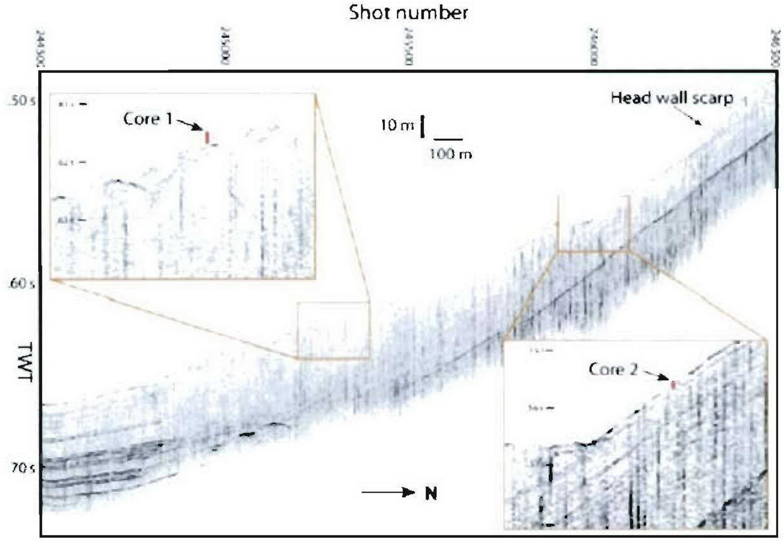
The Santa Barbara Basin (red box in the inset) is a part of the California Borderlands and is located south of the Transverse Ranges in California. The motion on the San Andreas Fault System has created a closed basin that is partially shielded from the flushing action of the

California Current. Rapid deposition on steep slopes combined with frequent large earthquakes have resulted in a number of slides in the recent Holocene sediments. The study areas are marked with red arrows: the Gaviota slide on the left, and the slope crack on the right. The bathymetry is from the MBARI EM300 multi-beam survey. Also shown is the location of ODP Site 893 (orange circle).

The meltwater discharge out the Hudson Valley may have played an important role in triggering the Intra-Allerød cold period by diminishing thermohaline circulation (Donnelly et al., 2005).

11) Understanding and predicting when and where submarine landslides will occur is a still a challenge to the marine science community. It is imperative to develop adequate techniques that allow insight into the pre- and post-failure stratigraphy. Slope failure and creep may sometimes be imaged with multibeam and chirp data, but these techniques do not provide the full spectrum of information required to completely interpret these features. Overpressured layers in sediment create zones of weakness in the strata that may localize failure or slide surfaces, whereas unconformities may lead to apparent overconsolidation that record the past history of failures and erosion. In clay-rich sediment, micro and macro structures influence how the sediments deform when under stress. When lithology is fairly constant, anisotropy of magnetic susceptibility (AMS) can be a simple technique for measuring the relative consolidation state of sediment, which reflects the sediment burial history Schwehr et al., submitted).

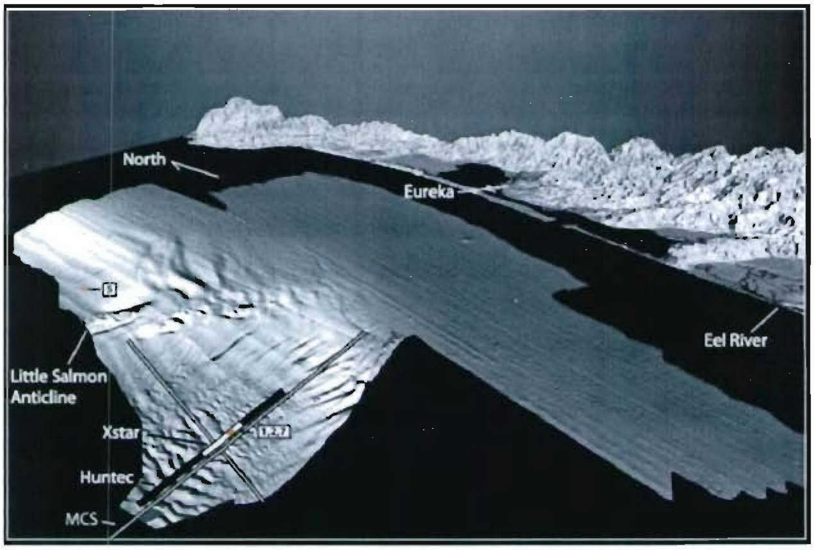
AMS can reveal areas of overpressure and apparent overconsolidation associated with unconformities where sediment overburden has been removed. Many other methods for testing consolidation and water content are destructive and invasive, whereas AMS provides a non-destructive means to focus on areas for additional geotechnical study. In zones where the magnetic minerals are undergoing diagenesis, AMS should not be used for detecting overpressure and compaction. By utilizing AMS in the Santa Barbara Basin, we were able to identify one clear unconformity, and eight overpressure zones in three cores.



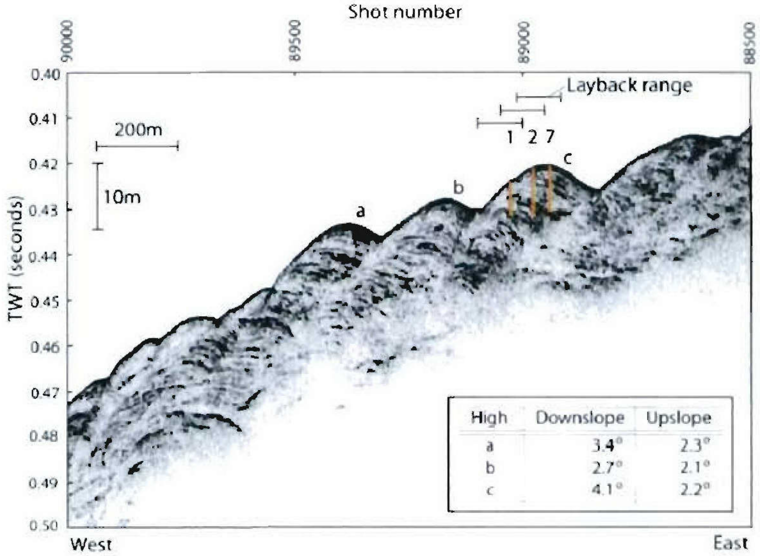
CHIRP seismic line imaging the western half of the Gaviota Slide. Cores 1 and 2 are marked in red on the figure insets with length scaled to a velocity of 1500 *m/s. The vertical axis is two way travel time (TWT) in seconds. The horizontal axis is in shot numbers and the scale bar is based on the average number of shots per 100 m. Note that the the CHIRP firing rate varies with water depth. Core 1 is located in the accumulation zone of the Gaviota Slide in an area of disrupted reflectors. Core 2 was collected in the evacuation zone of the slide and penetrates the overlying drape into the material below the slide surface.*

With the addition of χ, ARM, and IRM rock magnetic techniques, we excluded 3 out of 11 zones from being compaction disequilibrium. The AMS signal for these three zones are the result of diagenetic causes, coring deformation, and burrows. In addition, using AMS eigenvectors, we are able to accurately show the direction of maximum compression for the accumulation zone of the Gaviota Slide (Schwehr et al., submitted).
12) Landslides on continental margins can have a devastating effect on the coastal environment because of the possibility of tsunamis and the ensuing coastal erosion.

Accurate risk assessment demands that we know the probability of large landslides occurring. This in turn requires knowledge of the frequency of landslide events in the past. To assess frequency, it is necessary to identify, with some certainty, features that are products of slope failure. Given the controversy surrounding identification of features such as the Humboldt Slide, the development of criteria by which positive identification of post-depositional deformation gains urgency.



Location of XStar CHIRP, Huntec, and multi-channel seismic (MCS) lines on the Humboldt Slide amphitheater. The core locations are marked with orange dots. Cores 1, 2 and 7 are coincident with the Chirp, Huntec, and MCS E-W lines. Core 5, which was acquired outside of the Humboldt Slide, was used as a control core for the study. Image courtesy United States Geological Survey.



EdgeTech XStar CHIRP seismic line collected in 1999 (see above figure for location). This 1681 m long line trends NW-SE and images three prominent highs with internal reflectors (labeled a-c). Two way travel time is in seconds. Layback is calculated using wire angle and fish depth. The error bars are shown for wire angles ranging from 30-45 with the cores located at a wire angle of 35, which is why the error bars are not symmetric with respect to the cores. The inset table shows the downslope and upslope dip angles of the three prominent highs that are labeled a-c on the CHIRP seismic line.

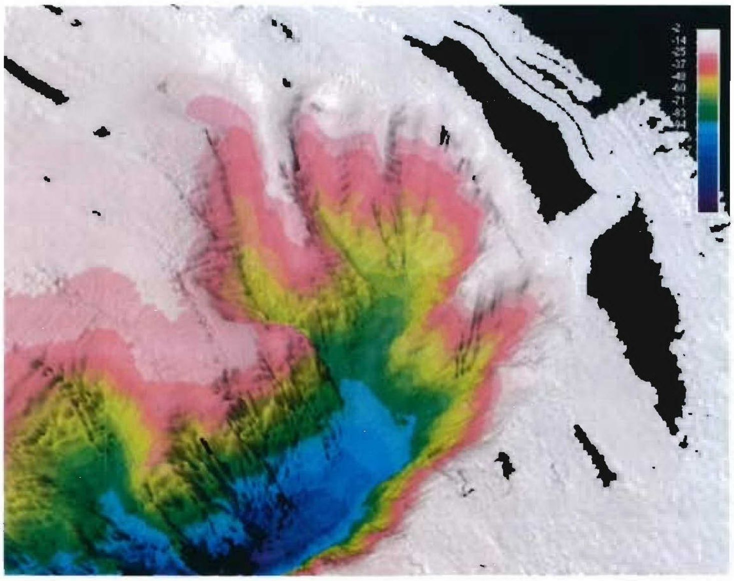
Morphological features observed in both multi-beam bathymetry and seismic reflection data are often ambiguous and can be interpreted as either failure deposits or sediment waves. The features observed in the Humboldt Slide have received a great deal of attention because controversy remains concerning the their origin. It is important to resolve this controversy because analogous

Structures are observed on many continental margins and the origin of these features needs to be understood. Anisotropy of magnetic susceptibility (AMS) measurements on sediment samples acquired from these features by piston coring reveal that the top 10 m of the Humboldt Slide have not experienced post-depositional deformation. Our results suggest that these features are formed by primary deposition associated with downslope currents. Subsurface morphology, observed in the multi-channel seismic data (MCS), also suggests that the majority of these features are current-controlled bedforms formed by downslope density flows. Using the same AMS technique on a core acquired north of the Humboldt Slide in a region with no geophysical evidence for post-depositional deformation, we were able to identify a 1 m thick slump deposit.

RESULTS AND INSIGHTS

A marked variety in channel architecture is observed along the U.S. East Coast, and this records the interplay of different processes operative during different times. Furthermore, the database highlights areas lacking data; more high-resolution geophysical data are required on the middle and outer continental shelf. Despite the plethora of research that has been conducted on the U.S. East Coast, paleo-river pathways across the continental shelf are aliased by the existing data.

Several studies have described "incised valleys" in estuaries and inner continental shelf areas. These features typically have width/depth ratios of >100 and can show complex cut-and-fill geometries related to channel migration. However, several large channels are evident in the NY Bight and Block Island Sound. These likely were carved during catastrophic lake drainage following the LGM. Tidal channels commonly are thought to be small features, but large river valleys are known to evolve into estuaries during the ensuing sea level rise. Several large channels exhibit sediment infill that subparallels the smooth rounded channel floor are interpreted as paleo-river channels enhanced by estuarine processes. A diversity of channels is also evident in SE Asia and European region. The compiled database will provide valuable inputs and constraints for the modeling efforts, which will help understand the distribution and architecture of channels in response to different forcing functions.



Prediction of paleo-channel pathways and architecture using modern bathymetric data is a useful exercise as it provides results that can be compared directly to observed data. These differences provide valuable constraints on modern and ancient conditions.

New submetrix bathymetry acquired in 2003 being processed by Nico LeDantec and merged with the Chirp subbottom data (Le Dantec et al., 2004) to understand sediment transport in the canyon systems.

For example, the observed paleo-drainage pathway for the Delaware River was farther north than predicted using Rivertools. This discrepancy may be explained in terms of glacio-isostatic loading. Differences between model predictions and observations will help focus further research.

Modern hydraulic geometry relationships indicate that most river channels that would have traversed the continental shelf would have been relatively narrow (50-100 m) with shallow relief (<5 m). If true, the majority of these channels would likely be cannibalized during sea level rise. Numerous large channels (or valleys) are found on the U.S. East Coast continental shelf in areas not predicted. Possible explanations must be further evaluated.

Understanding the burial of channels is a critical component to this project. Wave, tide, sediment discharge and shelf width data from >100 major river indicate that 4 basic types of sediment dispersal patterns exist. These findings have important implications for potential channel burial as well as the fate of carbon.

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Personnel

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