A Quaternary Stratigraphic Framework for the Santee Delta Region of the Atlantic Coastal Plain and Inner Continental Shelf of South Carolina

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Abstract

Modern fluvial valleys, paleovalleys and paleochannels, regional stratigraphic bounding surfaces, as well as aggradational and progradational lithosomes are key components of an integrated stratigraphic framework for the coastal plain and inner shelf of the Santee Delta region along the SE Atlantic margin of the United States. The Piedmont-draining Santee River of South Carolina forms the only river-fed delta along the US east coast, and as such, has been a major sediment source for the region throughout recent geologic history. In addition to the modern river valley, offshore and onshore mapping incorporating various geophysical and geological datasets confirm the location of a separate precursor Santee paleovalley. Both valleys incise into pre-Quaternary siliciclastic and carbonate rocks. On the basis of previous age assignments of mapped onshore stratigraphy and geometric relationships with onshore geomorphic features, the more southerly paleo-Santee valley was active as recently as the mid-Pleistocene. The avulsion from this older valley may be attributable to the creation of fault-related accommodation. Offshore, a complex network of paleochannels can be projected onshore where they align with these ancient river valleys.

In addition to the readily identifiable fluvial paleoincisions, the pre-Quaternary sedimentary units of the inner continental shelf are covered by a patchwork of Pleistocene and Holocene marine and paralic deposits. Many of these units appear massive, lacking internal stratal geometries that would yield clues as to their origin. However, evidence of several regression phases are evidenced by distinct stratigraphic units containing internal geometries that indicate significant progradation. The oldest of these progradational units are of Pleistocene age, extend from the nearshore to the outer shelf, and exhibit internal geometries and stacking patterns consistent with deposition within a deltaic shoreface. The younger progradational units are of Holocene age, coincident with the seafloor, and have internal and external geometries similar to sand ridges documented elsewhere on the US Atlantic inner shelf.

Seismic Facies and Surfaces

Seismo-stratigraphic Facies: Primary	Seismo-stratigraphic Facies: Modifier	Extrenal Bounding Surfaces Order	Facies Codes and Colors	Cross-sectional Geometry: Internal	Cross-sectional Geometry: External	Interpretation
Progradational Facies (PG)	s	6	PGs	High to moderate amplitude, tangential to parallel oblique, seaward dipping reflectors	Wedge	Holocene shoreface.
	r		PGr	High to moderate amplitude, steeply dipping, parallel oblique, uniform, seaward dipping reflectors	Lenticular to mounded. Up to 5 m thick	Transgressed shoreface deposits or Holocene sand ridges.
	p		PGp	High to moderate amplitude, oblique to sigmoidal, non-uniform seaward dipping reflectors. Common reactivation surfaces and bottomset development	Tabular to irregular with erosional and/or channelized upper surface. Up to ~9 m thick	Pleistocene regressive shoreface, delta front, or beach ridges. Complex internal and external geometries have been observed.
Channel Facies (CH) – Basal Bounding Surface	4	4	CH4	Variable	Broadly Lenticular	Secondary channel-fill
	5	5	CH5	Variable		Channel fill contained within a single stratigraphic unit
	6	6	CH6	Variable		Channel fill incised entirely into underlying unit and related to base level fall
Channel Facies (CH) – Fill Type	Concentric (c)	4, 5, 6	CH4c	High to moderate amplitude, aggradational, concentric reflectors		Mud-rich, aggradational fill. Suspension domianted.
	Horizontal (h)		CH4h	High to moderate amplitude, horizontal to sub-horizontal reflectors		Passively filled, likley fine-grained channel fill.
	Asymmetric (a)		CH4a	High to moderate amplitude, uniformally-dipping reflectors		Point bar deposits of meandering fluvial or estuarine channels.
	Chaotic (k)		CH4k	Apparently disorganized, moderate amplitude, discontinous reflectors		High energy channel deposits
	Transparent (t)		CH4t	Low amplitude homogeneous fill		Homogeneous channel fill
Horizontally Stratified Facies (HS)		6	HS	High to moderate amplitude, horizontal to sub-horizontal reflectors	Highly irregular with erosional upper surface	Bottomsets of shoreface deposits, mud-rich shelfal or backbarrier deposits, sand sheet
Indistinct Facies (ID)		5 or 6	ID	transparent to chaotic	any	Holocene transgressive sand sheets or indeterminate
Pre-Quaternary Basement (PQ)		6	PQ	Variable. Transparent to high amplitude horizontal to gently dipping reflectors	Highly irregular, erosional upper surface.	Cretaceous through Pliocene consolidated to lithified sediments of variable lithology.

Bounding Surfaces

Increasing extent

- **6th Order:** Regional surfaces that separate primary depositional units. Likely combined subaerial exposure and transgressive erosional surfaces related to glacioeustatic sea level changes. 4th-5th order sequence boundary of Catuneanu (2006).
- **5th Order:** Bases of individual channels or significant internal unit boundaries.
- **4th Order:** Minor internal discontinuities such as reactivation surfaces or diastems.
- **3rd Order:** Concordant surfaces within genetically-related depositional units.

*Bounding surface heirarchy adapted from concepts by Miall (1985)

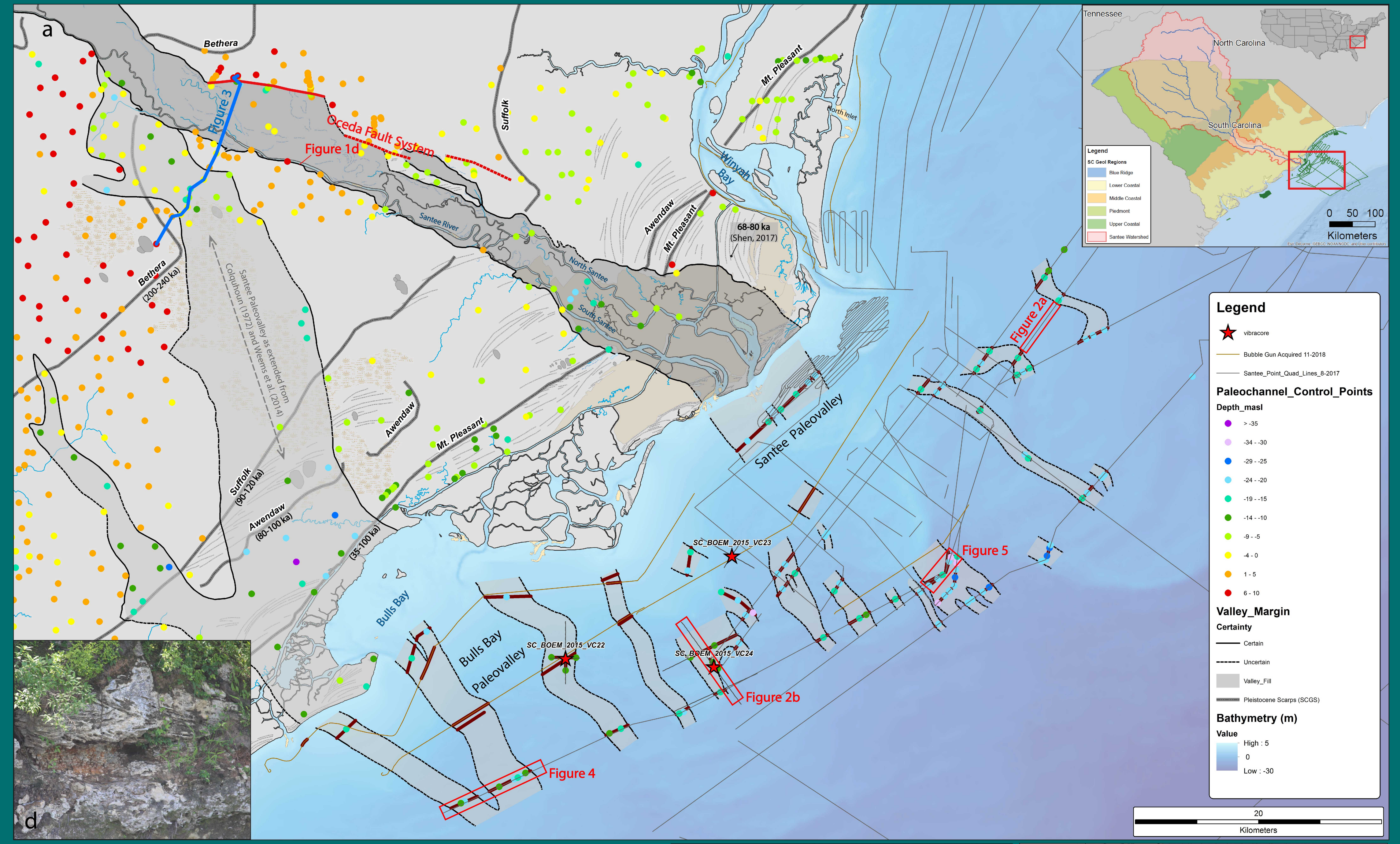
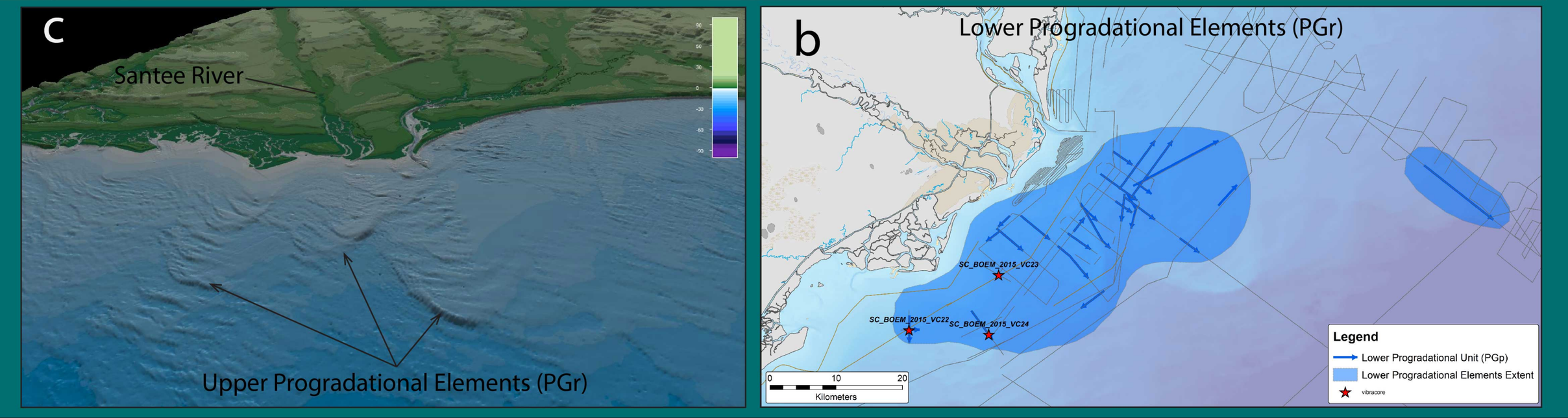

Figure 1. (a) Location map showing the distribution of key data and stratigraphic elements. Onshore base Quaternary control points based on borehole data from the South Carolina Geological Survey (SCGS), South Carolina Department of Health and Environmental Control and Weems et al. (1985); interpretations from Weems et al. (2014), Eckard (1986); and seismic mapping. Offshore base Quaternary control points and distribution of paleovalleys/paleochannels from seismic mapping. Fault locations from SCGS borehole descriptions and cross-section by W. Clendenin (in prep, SCGS). Distribution of highstand scarps from SCGS. Age of scarps from Doar (2014). (b) Distribution and depositional dip direction of the lower progradational elements (PGp) off the coast of the Santee River delta. (c) Seafloor bathymetry showing the surficial relief of the upper progrational elements (PGr). (d) Outcrop of a cross bedded, coarse-grained, fossiferous grainstone unit of the Eocene Santee Limestone along the margin of the active Santee river valley downstream from Jamestown, SC.

Progradational Elements

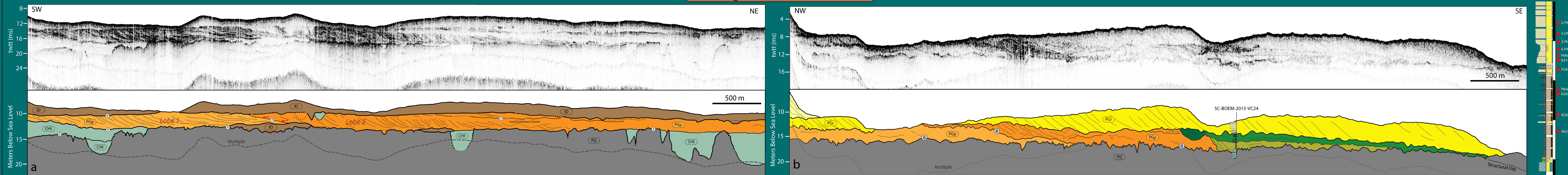

Figure 2. a) Internal architecture and external geometry of lower progradational element (PGp) and small basement paleochannels (CH) offshore of the North Santee River. The internal surfaces of the PGp unit exhibit a non-uniform seaward-dipping orientation, reflecting distinct phases of deposition. The uppermost unit (ID) has a morphology similar to PGr facies but, at this location, lacks the internal surfaces required to identify it as such. ID facies above the erosional basement (PQ) surface is identical to similar facies seen above paleovalley successions in figures 4 and 5. b) Chirp data and corresponding geoseismic interpretation off of Cape Romain. Preserved lower progradational elements (PGp) exhibiting several reactivation surfaces (4th order surfaces) and is incised by a broad channel. PGr units contain uniformally-dipping progradational surfaces and lack the reactivation surfaces that are common in the underlying PGp facies. The PGr units were interpreted by Swift (1975) and Sexton et al. (1996) as transgressed shoreline features, however, these features do share similar internal and external geometries to inner shelf sand ridge systems documented along the east coast of the US (Pendleton et al., 2017; Snedden et al., 1999; and Snedden et al., 2011) (b) Vibracore log (Long, 2018) showing lithology and composition for the various units. PGr units are primarily coarse-grained shelly sand, channelfill units (CHa and CHh) are mud-rich estuarine deposits. PQ at this location is an indurated, fine-grained, calcareous sand and likely (Eocene ?). Basal unit has a structural dip to the SSE which is common in this area.

Paleovalleys and Paleochannels

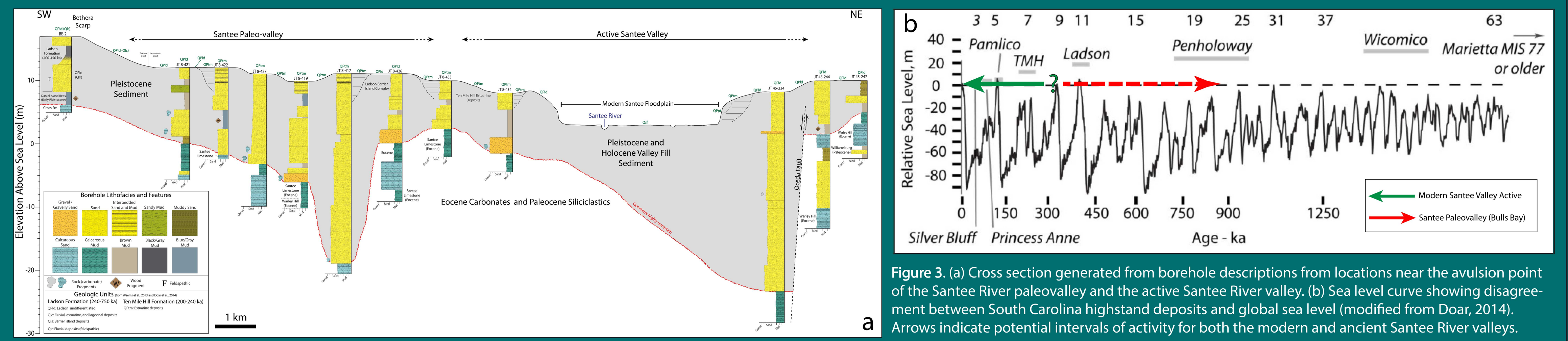

Figure 3. (a) Cross section generated from borehole descriptions from locations near the avulsion point of the Santee River paleovalley and the active Santee River valley. (b) Sea level curve showing disagreement between South Carolina highstand deposits and global sea level (modified from Doar, 2014). Arrows indicate potential intervals of activity for both the modern and ancient Santee River valleys.

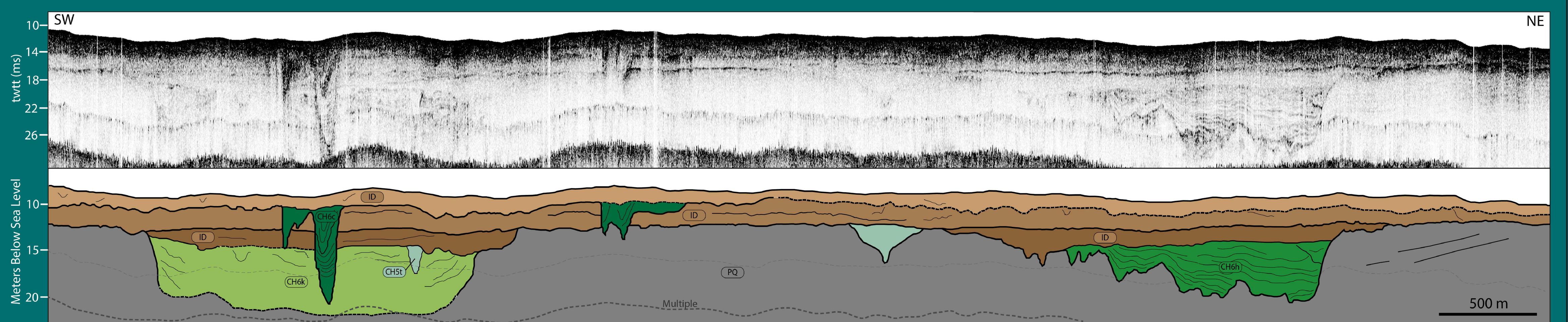

Figure 4. Shore parallel chirp data and interpretetive geoseismic line off of Bulls Bay. Southwestern paleovalley exhibits evidence of multiple incisions with each paleochannel containing different fill types. Northeastern paleochannel is strongly asymmetrical and is characterized by aggradational, horizontal fill. Stratigraphic units (ID) that overlie the lower most channels are internally massive.

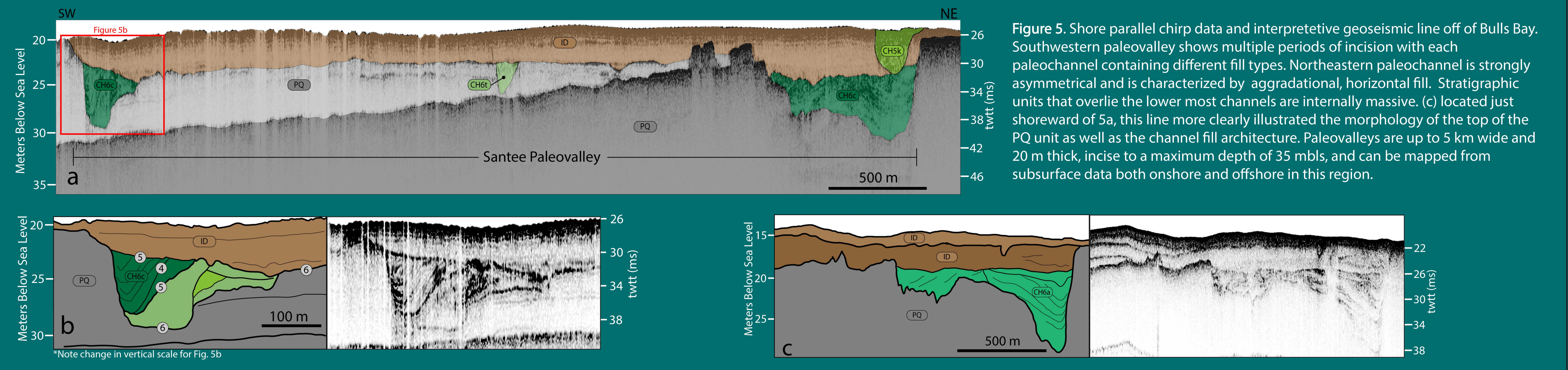

Figure 5. Shore parallel chirp data and interpretetive geoseismic line off of Bulls Bay. Southwestern paleovalley shows multiple periods of incision with each paleochannel containing different fill types. Northeastern paleochannel is strongly asymmetrical and is characterized by aggradational, horizontal fill. Stratigraphic units that overlie the lower most channels are internally massive. (c) located just shoreward of 5a, this line more clearly illustrated the morphology of the top of the PQ unit as well as the channel fill architecture. Paleovalleys are up to 5 km wide and 20 m thick, incise to a maximum depth of 35 mbls, and can be mapped from subsurface data both onshore and offshore in this region.

Stratigraphic Framework

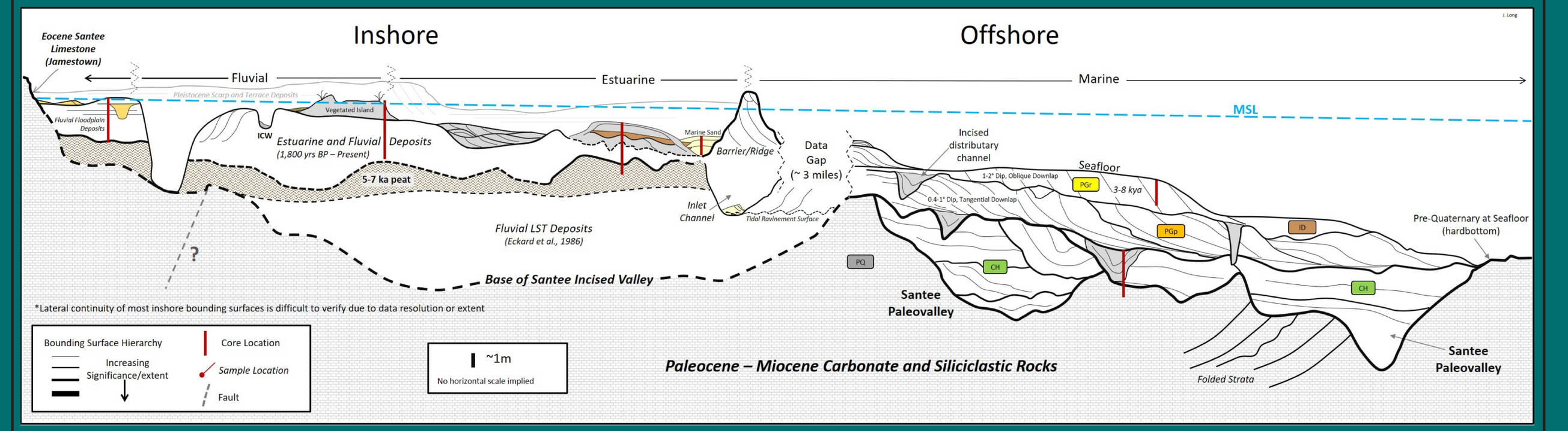

Figure 6. Conceptual depiction of the regional stratigraphic framework summarizing observations and interpretations from inshore, onshore, and offshore data sets.

Conclusions

Coastal plain and offshore stratigraphy is dominated by four prominant features: 1) progradational bodies (PG), 2) structureless tabular to undulatory sand bodies (ID), paleoincisions (CH), and regionally extensive erosional surfaces (6th order bounding surfaces).

1. Two distinct types of progradational bodies have been defined here.
   a) PGr units
      - Form extensive, cuspate shoal complexes with a pronounced ridge and swale morphology along the inner shelf offshore the Santee River and Cape Romain.
      - ^{14}C dates from several cores indicate that these units are of late Holocene age.
      - These have previously been interpreted as shoreline retreat features, but share certain morphological and architectural similarities to shelf sand ridges documented at numerous locals along the inner to middle continental shelf.
   b) PGp units
      - These units are largely limited to the subsurface and are distributed across the continental shelf.
      - The high degree of variability in foreset geometry suggests spatial or temporal variability in sediment supply, while associated small paleochannels are the products of abandonded distributary networks.
      - These units preserve evidence of a regressive phase of the Santee Delta likely associated with the onset of a glacioeustatic fall during the late Pleistocene.
2. Structureless sand bodies occur in various stratigraphic positions (ID units).
   a) Where they are coincident with the seafloor, they exhibit a highly variable morphology and may represent shoreface sands reworked during the Holocene transgression.
   b) In the deeper subsurface, the orgin of these features is ambiguous, occuring as the upper-most units of paleochannel fill successions as well as extensive sheets.
3. Paleoincisions occur as both large paleovalleys and smaller, isolated paleochannels (CH units). Both features commonly incise into pre-Quaternary rocks.
   a) There are two distinct paleovalleys that were incised during Pleistocene and Holocene sea level lowstands.
      - The Pleistocene-Holocene Santee River paleovalley can be projected up to 30 km's offshore along a trend roughly parallel to the active Santee River valley.
      - The Bulls Bay paleovalley crosses beneath the coastal plain onto the inner shelf around Bulls Bay and can be projected offshore up to 25 km's.
      - These two valleys diverge near Jamestown, SC. The avulsion phase associated with this reconfiguration likely occurred between 240-120 ka and may have been related to the development of structural accommodation created by movement along the Oceda Fault system.
   b) Numerous, smaller paleochannels displaying a variety of fill architectures exist along the inner shelf from North Inlet south to Bulls Bay.
4. Regionally extensive, 6th order, erosional bounding surfaces are likely the combined result of transgressive and subaerial erosion related to glacioeustactic fluctuations reflecting overall low accommodation across a stable, low gradient shelf.

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