ANTECEDENT GEOLOGIC CONTROLS ON THE DISTRIBUTION OF OYSTER REEFS IN COPANO BAY, TEXAS

A Thesis

by

ERIN ALYNN PIPER

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2010

Major Subject: Oceanography

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Approved by:

Chair of Committee,	Timothy Dellapenna
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ABSTRACT

Antecedent Geologic Controls on the Distribution of Oyster Reefs in
Copano Bay, Texas. (May 2010)
Erin Alynn Piper, B.S., Texas A&M University at Galveston
Chair of Advisory Committee: Dr. Timothy Dellapenna

Copano Bay is a shallow (< 2-3 m), microtidal estuary in south central Texas. In an effort to both determine the distribution as well as investigate the controls on the distribution of oyster reefs, a geophysical survey of Copano Bay was conducted in June and July 2007. Surficial sediment analysis confirms that the recent sedimentation in Copano Bay is comprised of mostly estuarine mud with little sand or shell, large extents of oyster reefs and smaller areas of sand. Seismic stratigraphy analyses verify that the first oyster reefs in Copano Bay formed atop topographic highs in the Pleistocene surface. About 6 ka, sea level rise slowed to near its present rate and sediment supply decreased tremendously to Copano Bay decreasing the amount of suspended sediment. The first oyster reefs began forming around this time using these fluvial terraces as suitable substrate. Once the initial reefs were established, additional reefs began forming atop these initial reefs, or on the eroded shell hash material from the initial reefs. During this time of slow sea level rise and low sediment input to the bay, oyster reefs thrived and reef and shell hash material covered a majority of the bay surface. Once climate change increased sediment input to the bay, the reefs began to decrease in size due to siltation. The reefs have continued to decrease in size causing a 64 percent reduction in oyster reef and shell hash area from approximately 4.8 ka to today.

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1. INTRODUCTION

Oysters play an important role in maintaining water quality and providing habitat for juvenile fish, such as black drum, toadfish and sheepshead, and other organisms including crabs, shrimp, mud worms and mussells in estuaries (Kilgen and Dugas, 1989). It is important to understand what factors control oyster distribution to effectively maintain and manage the present oyster reefs and associated habitats. Understanding controls on distribution can also aid in oyster reef protection and restoration projects.

The American or Eastern Oyster (*Crassostrea virginica*) is the prevalent oyster species along the northern Gulf of Mexico coast, including Copano Bay, Texas. *C. virginica* has a free-swimming larval stage, lasting 14 to 30 days, after which the larva goes through a settling, or spatting process in which it must permanently attach itself to the bottom (Kennedy, 1996). During the larval stage, the oyster is susceptible to the multitude of estuarine hydrodynamic processes that distribute the larva throughout the estuary. *C. virginica* is a filter feeder, so it needs to settle and attach to a site which will permanently keep it out of the fine bay bottom mud to avoid suffocation by fine-grained sediment. It also needs to settle within the intertidal to subtidal portion of the bay, to allow it access to tidal flow and nutrients (Kennedy, 1996). Over the course of history in Texas bay systems, the oysters have been able to accumulate and form reefs in areas that are favorable to their success. Copano Bay is an “upper bay” system within the Mission-Aransas-Copano Bay system (Fig. 1). Copano Bay has undergone very little modification, it has no dredged navigational channels and in general lacks significant infrastructural modifications found in other bays, such as Galveston, Corpus Christi or Lavaca Bays. As a result, it is an ideal setting to investigate the natural controls on oyster reef distribution. The oyster reefs in Copano Bay appear to consist of transverse reefs attached to the shoreline extending perpendicularly into the bay, longitudinal reefs in the middle of the bay oriented parallel to shoreline and patch reefs that are randomly

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This thesis follows the style of Estuarine, Coastal and Shelf Science.

oriented throughout the bay. Surficial sediments contained within Copano Bay consist primarily of unconsolidated muds, sands and shell gravel. With the lack of obvious controls on the distribution of oyster reefs, such as rock outcrops, the big question is, what does control their distribution? It is our contention that the natural distribution of oyster reefs in Copano Bay are controlled mainly by the antecedent geology found beneath the bay sediment. Oysters will form in areas where there exists shallow, hard substrate ideal for oyster attachment.

Studying the underlying geology of oyster reefs could have major implications on understanding their distribution. This study could have very important implications in future research and resource management in Copano Bay, such as oyster reef protection and restoration. Restored reefs can be placed in areas where known stable underlying geology is present to ensure the reef is successful and the oysters not subside into the soft bay mud and become suffocated by fined grained sediment particles. If large extents of buried oyster reefs are found, this could indicate an enormous decline in oyster reef population over time and actions could be taken to prevent any further decline from happening.

For the purpose of this study, the substrate type will be considered the most important influence for the initial distribution of oyster reefs. Regardless of other environmental conditions, the substrate must be suitable for initial oyster colonization or the oyster will not survive. Where there are oyster reefs present in the geologic past, there was adequate substrate for initial settlement. Adequate substrate includes any hard, smooth surface such as compacted mud, sand or shell shoals, loose shell or sunken logs. Loose sand or mud can shift and break the oyster free of its anchor, or bury and suffocate it (Kennedy, 1996). The ideal substrate for larval oysters has been found to be existing reef or oyster shells (Kilgen and Dugas 1989; Stanley and Sellers 1986; Michener and Kenny 1991; Kennedy, 1996). Some current oyster reefs are most likely built on top of reefs that initially grew thousands of years ago when the incised paleo-river valleys began to fill with sediment (Bouma, 1976). The oyster reefs build up vertically and out horizontally with new oysters growing atop older ones. Ideally, without significant outside physical influences to move them, the present day oyster reefs would exist in the same general locations as where they were initially colonized, only to a larger extent. However, oyster reefs do not only build atop other reefs. If suitable substrate is formed or becomes available elsewhere, larvae will also settle atop it, forming a new reef. Therefore each reef in the current oyster reef distribution may have different geologic controls.

2. BACKGROUND

2.1 Local Setting

Copano Bay is a shallow (< 2-3 m), microtidal estuary in south central Texas (Figs. 1 and 2). It has an area of ~110 km^2. The maximum depth of the bay is approximately 3 m near the Aransas Bay inlet, yet its average depth throughout is about 2 m (Calnan, 1980). Three rivers drain fresh water into the bay including Aransas River, Mission River and Copano Creek. Copano Bay's only indirect connection to the Gulf of Mexico is a 3.2 km wide inlet to Aransas Bay. There are two sub-bays within the Copano Bay system including Mission Bay and Port Bay. These bays were not included in the survey due to their extremely shallow depths, generally less than 1 m. Sediment transport throughout the bay is mostly wave dominated. Although the estuarine classification system created by Dalrymple et al. (1992) does not consider subestuaries in their classification, Copano Bay would generally fall into the classification of a wave-dominated estuary. Copano Bay is microtidal and can experience high wave energy at the tidal inlet to Aransas Bay. Live Oak peninsula exists on the southern end of Copano Bay and extends across a portion of its mouth (Fig. 2). Additionally, Copano Bay generally receives very little energy from the fluvial components of the system. Because of the small inlet size to the bay, most of the waves present in the Copano Bay proper are generated internally (Dalrymple et al., 1992). Sediment transport throughout the bay entrance, under fair weather conditions, is primarily due to tidal advection of suspended sediment. In a shallow wave dominated estuary such as Copano Bay, the central portion is generally dominated by mud, and the margins by sand. Waves erode the shoreline along the margins of Copano Bay, depositing sandy Pleistocene sediments along marginal shoals (Morton and McGowen, 1980). Episodically, during large tropical storms and hurricanes, large storm surges may move large volumes of sediment into the bay. Conversely, during the retreat of the surge, large volumes of sediment may be flushed out of the bay. Only small margins of Copano Bay are urbanized and/or bulkheaded, limiting anthropogenic influence on natural sediment transport throughout the bay.

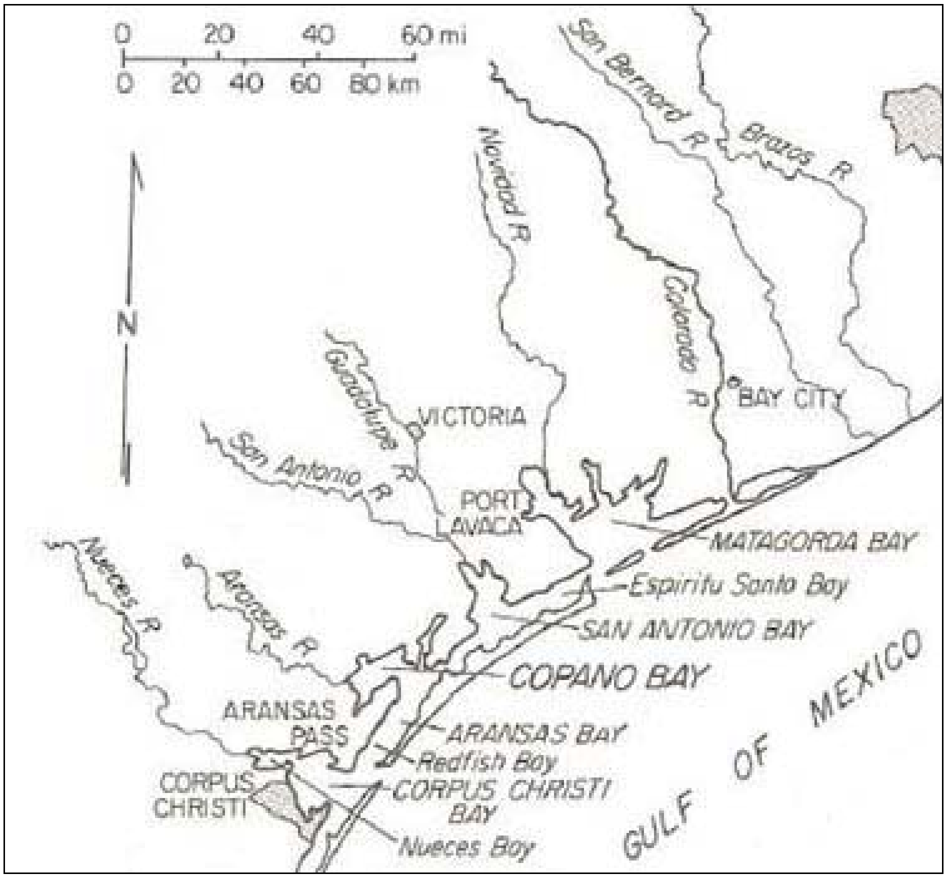

Fig. 1. Map of the Central Texas Coast showing the location of Copano Bay, Texas (Calnan, 1980).

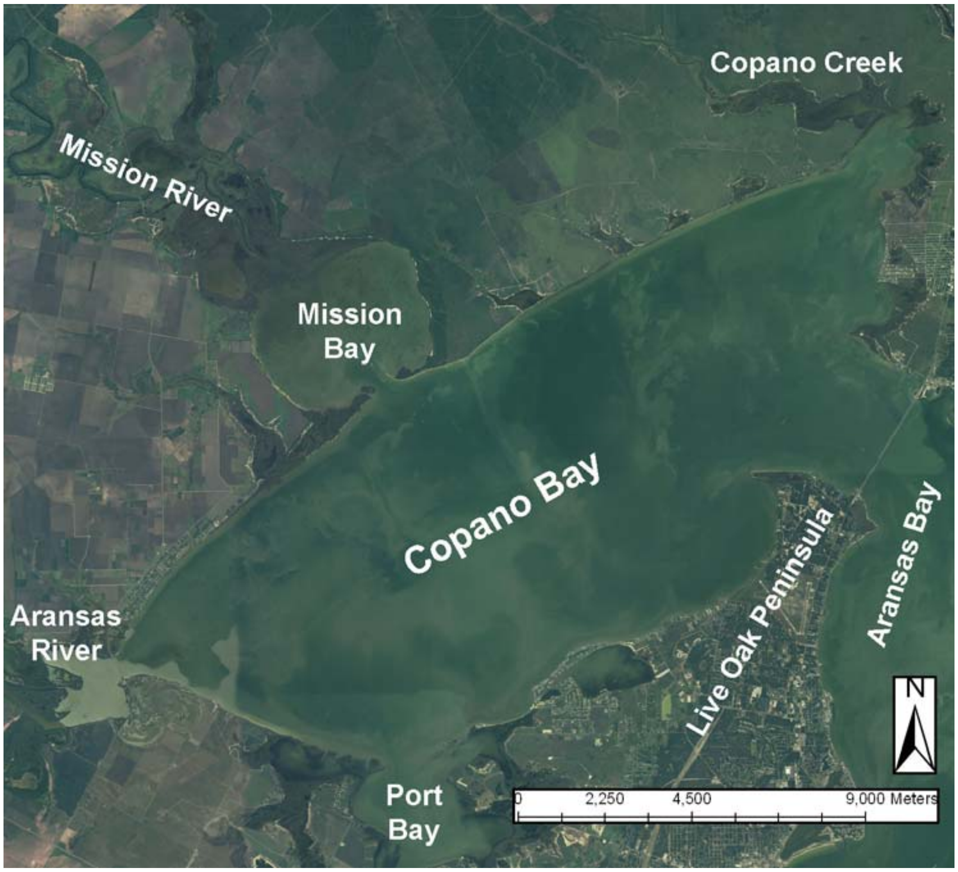

Fig. 2. Aerial photograph of Copano Bay, Texas from the Texas Natural Resources Information System (TNRIS) showing locations of surrounding features.

2.2. Geologic Setting

Copano Bay is a coastal plain estuary made up of the drowned river mouths of the Aransas and Mission Rivers (Morton and McGowen, 1980). Due to their location within incised paleo-river valleys, coastal plain estuaries are effective sediment sinks that have high preservation efficiency (Dalrymple et al. 1992). During the last glacial maximum low stand in sea level, river valleys were cut deep (~20m) into Pleistocene sediments. This created a Pleistocene unconformity which now underlies the more recent Holocene sediment. When sea level rose again, those Pleistocene valleys began to fill with alluvium sediment. Copano Bay began infilling about 7,000 years ago when sea level reached ~20 m below present sea level (Morton and McGowen, 1980). The bay was filled with sediment at an average rate of about 2.65 mm per year (Shepard, 1953). Due to their location at the interface of land and water, estuaries have several sediment sources. These include marine sediment, terrestrial sediment input by rivers, resuspension of deposited sediment and shoreline erosion and the grain-size of Holocene sediment fill in estuaries exhibits a general fining upward trend (Nichols, 1989). The sequence of infill began with fluvial sand and gravel from river bed load, deposited at the base of the Pleistocene-Holocene unconformity. Estuarine muds then began to accumulate when the recent sea level rise reached a "stand still" ~3,000 years ago and have been filling the bay ever since (Wright, 1980). These changes in facies record a shift from a fluvial to an estuarine environment (Nichols, 1989). Since the stand still, sea level has risen at an average rate of 3mm/year (Wright, 1980). This is fairly consistent with the 2.65 mm/year sediment accumulation in Copano Bay, indicating that the bay has been mostly filled throughout its history.

2.3 Oysters, Reefs and Settlement

Crassostrea is a reef-building oyster. Oysters can exist individually, or in small groups, but tend to build extensive reefs onto which new oyster spat settles and grows (Kennedy et al., 1996). There are two types of oyster reefs: intertidal and subtidal. Intertidal oyster reefs are located in shallow areas and are exposed at low tide. Subtidal oyster reefs are located deeper in the water and are not exposed by lunar tides (Nestlerode et al., 2007). Both types exist in Copano Bay.

C. virginica is an estuarine species that can withstand a very wide range of temperatures and salinities. Adult oysters can tolerate salinities between 0-42‰; however the ideal is 14-28‰. A salinity of 10‰ is needed for sustained growth. Oysters do not do well in high temperatures (>25°C) combined with other stresses such as low salinities (<5‰) therefore may die in the summers because of combined high heat and rainfall (Heilmayer et al. 2008). Several factors can cause burial of oyster reefs. If oysters are exposed to too much freshwater or too high levels of salinity for prolonged periods of time, they will die. Once the community dies, it will ultimately be buried by sediment because the sediments are no longer being filtered out of the water by the oysters. Burial by sediment from large storm events such as hurricanes also can decimate oyster populations (Norris, 1953).

Based on their physical shapes and morphology, there are three major classifications of reefs that form on the Texas Coast and in Copano Bay: longitudinal reefs, transverse reefs and patch reefs. Longitudinal reefs form with their axes parallel to prevailing water currents. Transverse reefs, also called string reefs, form perpendicular to prevailing currents. The generalized circulation patterns and current directions in Copano Bay are displayed in Figure 3. Areas where oysters create thin reefs on ideal substrates are called patch or pancake reefs, and can occur in any shape or location where ideal sediment is deposited (Scott, 1968).

The eastern oyster is a commercial species on the Atlantic and Gulf of Mexico coasts of the United States. While oyster harvesting has occurred in Copano Bay, it was to a much less extent than many of the other bays in Texas, including Galveston, Corpus Christi and Aransas Bays (Wilson, 1950). From a logistical standpoint, this makes Copano Bay an ideal location for this study. The distribution of oysters are largely natural and not be influenced either by the "seeding" of oyster beds or the redistribution of discarded shell during the culling of the catch during harvest or by extensive shell mining. Nor are there significant anthropogenic features for which oysters to settle on, such as pipelines, production platforms, dredge spoil piles, or sunken construction debris.

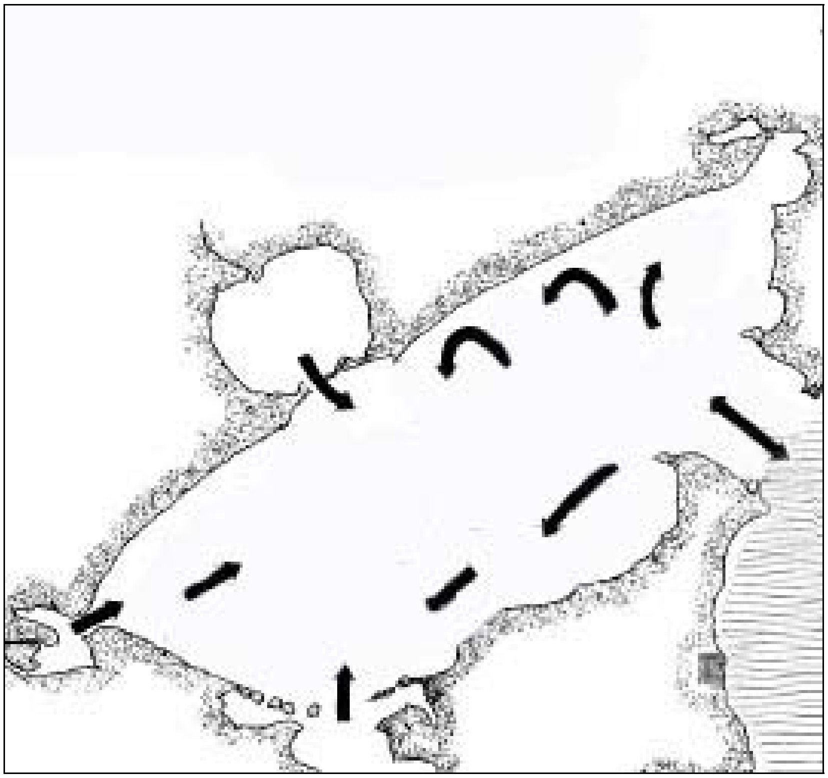

Fig. 3. Generalized water circulation of Copano Bay, Texas. Modified from Scott (1968).

2.4 Previous Work

Many studies have been conducted to determine the controls on oyster reef distribution. (eg., Anderson and Underwood 1994; Bartol and Mann 1997; Michener and Kenny 1991; O'Biern et al. 1995). Studies are widely variable and the conclusions vary case by case, therefore no one definitive control is evident (Kennedy, 1996). Substrate type, temperature, salinity, tidal currents, nutrient and food availability and turbidity have all been shown by these studies to influence oyster distribution (Kilgen and Dugas, 1989).

Many studies along the Atlantic and Gulf of Mexico coasts of the United States have shown that larval oysters prefer to spat atop existing reef or oyster shells (Kilgen and Dugas 1989; Stanley and Sellers 1986; Michener and Kenny 1991). Sediment type can have an effect after initial colonization if there is significant turbidity in the reef environment. Turbidity is important because oysters are filter feeders and cannot survive when there are very high concentrations of suspended sediment in the water column. They will suffocate and die if too much sediment is filtered into their gills. Geological controls are most likely more important for initial oyster reef colonization. Once an oyster reef is established in an area where the environment is favorable for oyster development, new larvae settle atop existing oyster shells. However, without a stable subsurface geologic feature to support the weight of additional shells, the reef could subside into the soft bay mud (Scott, 1968). Reefs built on stable geologic features continue to build atop themselves overtime, compacting the underlying shells. The underlying shells compacted to the stable geologic feature, become stable features themselves and are at little risk for subsidence. The bay has been filling with soft, unconsolidated fine grained sediments for the last ~3000 years. Consolidation of this sediment is very unlikely; therefore any oyster reef formed on a thin deposit of adequate substrate atop the mud is at risk of subsiding into the unconsolidated sediment. Even if adequate substrate and support is available, other factors must be present to allow for oyster reef growth.

Subtidal, or low intertidal areas are more favored by oysters because of the lower wave action and sunlight levels (Bartol and Mann 1997; Michener and Kenny 1991; O'Biern et al. 1995). Oysters have a weak swimming larval stage; therefore, their initial dispersion is very dependent upon water currents. Salinity is the physical factor that has the most effect on larvae because it has the ability to change the density of the water and increase/decrease larval sinking rates (Dekshenieks et al. 1996). Ebb and flood tides can also affect the distribution of larvae by moving them into and out of the estuary. It is very hard for the larva to settle in high energy environments, which is another reason they tend to settle more in subtidal, lower energy environments. While the factors listed above affect the distribution and settlement of larvae throughout the estuary, ideal temperature, salinity and adequate current velocities must be present in the areas of settlement for the reef to flourish.

Geophysical mapping projects very similar to the Copano Bay mapping project have been conducted within estuaries along the northern coast of the Gulf of Mexico (Bronikowski 2004; Patch 2005; Twitchell at al. 2007; Bouma, 1976; Wright, 1980). In Lavaca Bay, Texas, oyster reef distribution was linked to the bay's geomorphology and the presence of submerged reefs and other hard substrate as well as recent anthropogenic features (Bronikowski, 2004). Similarly, Bouma (1976) found reef distribution to be related to the ancient channel locations in San Antonio Bay, Texas. Buried reefs were found proximal to current reefs throughout the bay and were thought to be connected. Twitchell et al. (2007) found that the present oyster reefs in Apalachicola Bay, Florida were formed atop sandy late Holocene delta deposits. Wright (1980) confirms the presence of sand and gravel overlying the Pleistocene/Holocene unconformity up to 6 m thick in Copano Bay, Texas. Wright (1980) also delineated the Pleistocene surface under Copano Bay using roughly ten seismic profile lines. He mapped a dendritic pattern of river valleys originating from the Aransas River, Mission Bay, Copano Creek and Salt Lake converging at the tidal inlet.

In nearby Corpus Christi Bay, oyster reefs formed first near the tidal inlet when salinity conditions became ideal for oyster growth. As sea level reached ~25 meters below the present sea level, the bay's salinity was too low to support oyster growth due to the significant freshwater inflow. As sea level rose and saltwater began to mix with fresh water, oysters began to grow. Oyster growth then migrated up bay at later dates when sea level rose enough to create ideal conditions in those areas (Wright, 1980).

Longitudinal reefs found occurring in pairs may have developed in areas where the Pleistocene river valley levees existed, providing ideal substrate for settlement. Transverse reefs initially form in areas of suitable substrate close to the shoreline, and then extend seaward growing out into the bay mud (Scott, 1968). The extent of buried oyster reefs found by Norris (1953) indicated that oyster reefs have been a major feature in Copano Bay for about three thousand years, yet their distribution has changed over time.

Troiani (2010) conducted an analysis of the stratigraphic succession and seismic facies of the Holocene bay-fill deposits to determine the sedimentary history of Copano Bay. Five environmental events were contained within the Copano Bay strata and seismic facies and were defined by specific flooding surfaces or other types of gradual environmental change (Troiani, 2010). Figure 4 shows the location of the various events and facies in a seismic line as interpreted by Troiani (2010). An event is composed of layers of sediment deposited above a facies or reflector which represents a flooding surface or environmental change within a seismic profile. Each facies marks a reflector which correlates to the beginning of each event. These flooding surfaces or environmental changes are seen in the seismic lines as reflectors or facies.

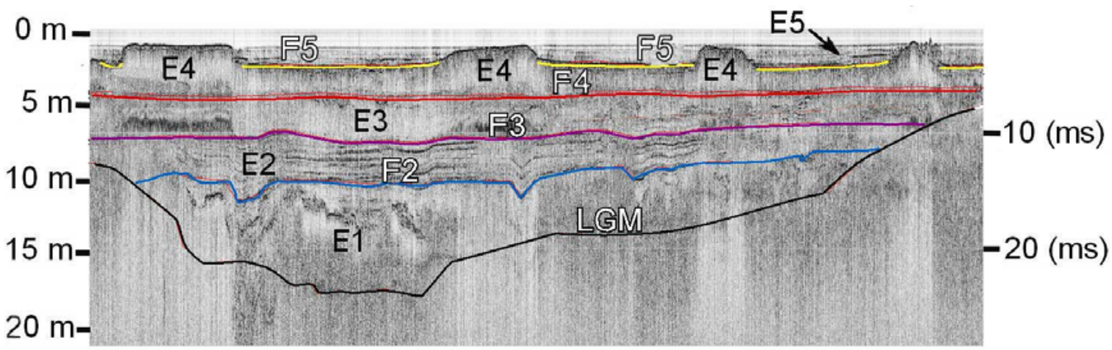

Fig. 4. Location of Events (E1-E5) and Facies (F1-F5) within a seismic profile from Troiani (2010).

Copano Bay is an incised Pleistocene valley filled with Holocene sediments. The base of the Holocene succession is marked by the unconformity surface that was carved out by rivers during the Last Glacial Maximum (LGM). The first event in the Holocene valley fill succession is (E1), which was formed during the initial flooding of the Pleistocene valleys within Copano Bay about 9.6 ka. Reflector LGM marks the base of Event 1 (Troiani, 2010). The second event (E2) was formed during a flooding event caused by increased meltwater flow from the breakup of the Laurentide ice sheet approximately 8.2 ka. Facies 2 (F2) marks the base of E2 (Troiani, 2010). Event 3 (E3) was formed during a flooding event where the last deep, narrow Pleistocene valleys were inundated. Facies 3 (F3) marks the base of E3 (Troiani, 2010). Event 4 (E4) was formed during a flooding event during which the fluvial terraces, or shallow areas of the Pleistocene, mentioned above were flooded. Facies 4 (F4) marks the base of E4. E4 took place around 7 ka and lead to a significant increase in the surface area of the bay (Troiani, 2010). E4 also occurred during the time that sea level rise slowed to a rate of 4.2 mm/yr (Troiani, 2010). Around 6 ka, sea level rise had slowed to 1.3 mm/yr, and the rate has been relatively stable since. A dry climate persisted during this time and reduced sediment input into the bay (Troiani, 2010). Event 5 (E5) was formed during an environmental change from a dry climate, to a more humid one. Reflector F5 or Facies 5 marks the base of E5. Due to this climate change, sediment input drastically increased to the bay starting between 2.5 and 1.9 ka (Troiani, 2010).

3. METHODS

3.1 Geophysical Methods

Geophysical data were collected aboard the R/V *Sammy Ray* over an eight week period in June and July 2007. The research vessel was a 7.6 m long trawler with a 0.5 m draft, powered by twin outboard engines. Over 200 survey lines, each with a spacing interval of 150 m, provided nearly complete coverage of the bay bottom. Survey cover was limited to areas with a minimum of 1.2 m water depth to protect the equipment from damage. A NOAA nautical chart was used to outline safe survey areas (Fig. 5). Copano Bay was surveyed using CHIRP subbottom profiler, sidescan sonar and single beam bathymetry. 2-3 meter long vibracores were collected and used for correlation and interpretation of shallow stratigraphy from the seismic data. 77 grab samples were taken throughout the bay to ground truth bottom and sediment type interpretations from the sidescan sonar data and to help delineate where the present day oyster reefs exist.

The CHIRP survey was conducted using an Edgetech® 216S Full Spectrum Subbottom CHIRP seismic sonar towfish and the Triton Elics Delph Seismic® software package. The seismic sonar operates over a range of 2 – 16 kHz to profile sedimentary strata. The CHIRP fish was suspended just below the water's surface from a davit on the port side of the of the research vessel's stern. The CHIRP data were used to both delineate where current oyster reefs exist in the bay as well as identify any underlying geological features. Subsurface sedimentary layers that are seen consistently throughout the bay are picked out and labeled in the Delph Seismic software for each seismic line. Text files were then exported from each line containing x,y,z information to display where the reflectors are in relation to the bay as well as how deep they are under the sediment-water interface. This was done by importing the x,y data for each line into ArcGIS. Isopach maps were created using the inverse distance weighted function. Areas in the CHIRP data that contained a very strong surface multiple (indicating very hard substrate) were delineated as oyster reef.

The side scan sonar survey was conducted using an Edgetech® 272TD sidescan sonar towfish operating at 100 kHz. Due to the shallow water depths of the bay the towfish was attached on a PVC catamaran on the starboard side of the research vessel. Data were acquired digitally using CodaOctopus® Geosurvey software that combines sonar images with navigation data supplied by a Trimble®DGPS receiver. The data were then mosaicked and exported as a georeferenced image. Light colored, high backscatter areas were delineated as potential oyster reef because of the indication of hard substrate. CHIRP data and ground truthing aided in accurately delineating oyster reefs.

Single-beam bathymetry was collected using an Odom Hydrotrac echosounder operating at a 200kHz frequency and Hypack® software. Tide corrections were made to the data in Hypack® using the Texas Coastal Ocean Observation Network (TCOON) tidal station (ID #8774513) located at the main opening of Copano Bay near the Highway 35 Bridge. All navigation and corrected depth data were imported into ArcMap as xyz data to be displayed using the inverse distance weighted function.

Areas in the seismic profiles where there exists a strong surface multiple and areas of high backscatter in the sidescan record were delineated as potential reef areas due to the presence of hard substrate. As described below, surface sediment samples were taken to aid in creating a bottom type map as well as groundtruth for significant shell content in reef areas. Oyster reefs were delineated in areas where CHIRP, sidescan sonar and sediment data all indicated reef structure.

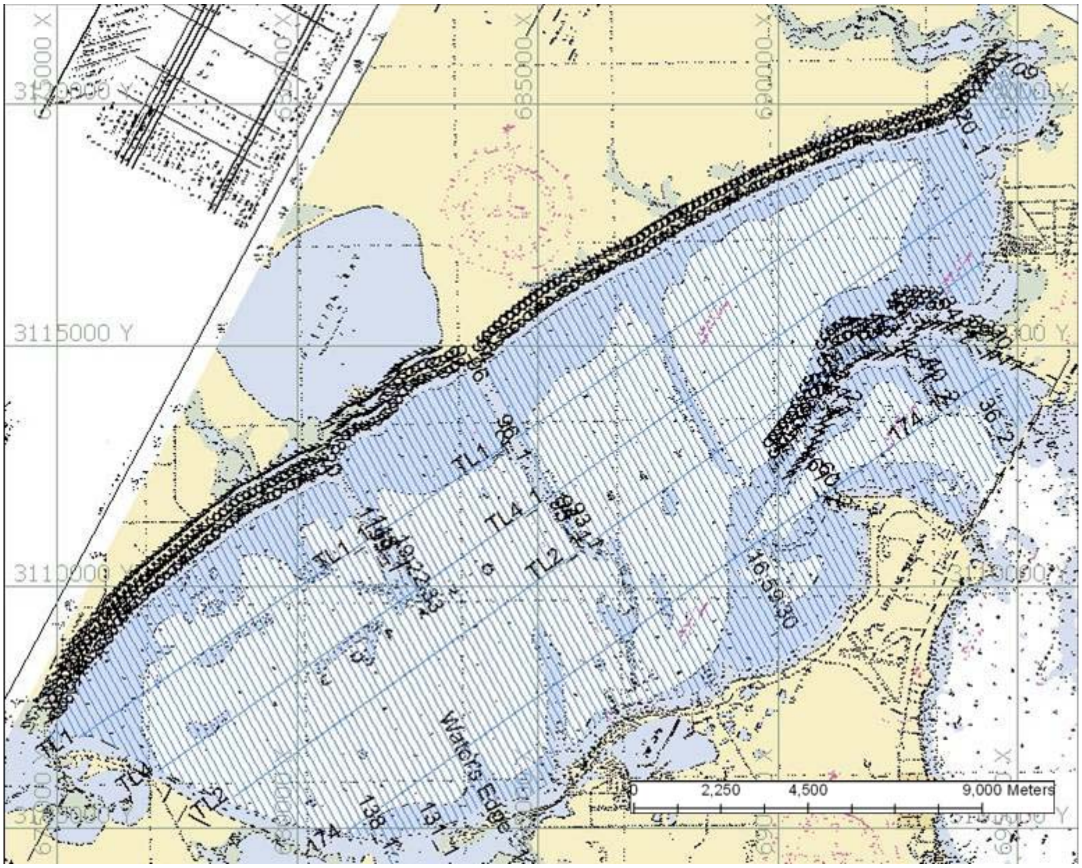

Fig. 5. NOAA nautical chart with actual survey lines.

3.2 Core Collection and Sediment Analysis Methods

A total of 22 vibracores were taken throughout the bay using 7.5 cm diameter aluminum core barrels. Vibracores were taken back to the lab, split in half lengthwise and visually described and photographed. They were then divided into vertical sections based on lithology and placed into whirlpak bags. The vibracore sections and grab samples were then analyzed using a Malvern Mastersizer 2000, which uses laser diffraction to produce a grain-size distribution ranging from .02 µm to 200µm. Samples with significant shell content were analyzed using the Rotap method which mechanically sorts the shell through a series of sieves to determine shell size distribution.

In addition to the vibracore and sediment grab samples, Texas Parks and Wildlife Department (TPWD) collected sediment samples from 30 second long dredge pulls. To choose TPWD sample locations, a geo-referenced grid was placed over the mapped area in GIS with a grid area of 4 kilometers squared, or a grid length/width of 2,000 meters. Then points were randomly selected in each grid using GIS for each mapped category, for a total of 155 survey sites. At each station physico-chemical data (depth, water temperature, dissolved oxygen, percent saturation, pH, salinity), secchi depth, wind speed and direction, and sea state data were collected. For the oyster dredge collections, the data collection procedures employed by the TPWD Coastal Fisheries Division for their oyster population surveys were used. This includes, in addition to counts of live oysters and dead shell, a count of live spat on five live oysters and five dead shells, plus the lengths of up to 19 live oysters are measured. This oyster data were used to verify the "oyster reef" bottom type. The details of the TPWD data can be found in the CMP Cycle 11 Oyster reef and bottom mapping of Copano Bay Final Report (Dellapenna et al, 2010).

4. RESULTS

4.1. Bathymetry

The bathymetry (Fig. 6) shows the average bay depth to be approximately 2 meters. The shallower areas are found near oyster reefs and at the margins of the bay, with the deepest areas near the tidal inlet, where the depth reaches 3.2 meters. There were small gaps in the bathymetry data where the NOAA nautical chart, used as a base map to construct the survey, showed areas too shallow to survey safely. The bathymetry over these areas, which included portions of Lap, Copano and Shellbank reefs, was interpolated from surrounding data by the inverse distance weighted function in ArcGIS.

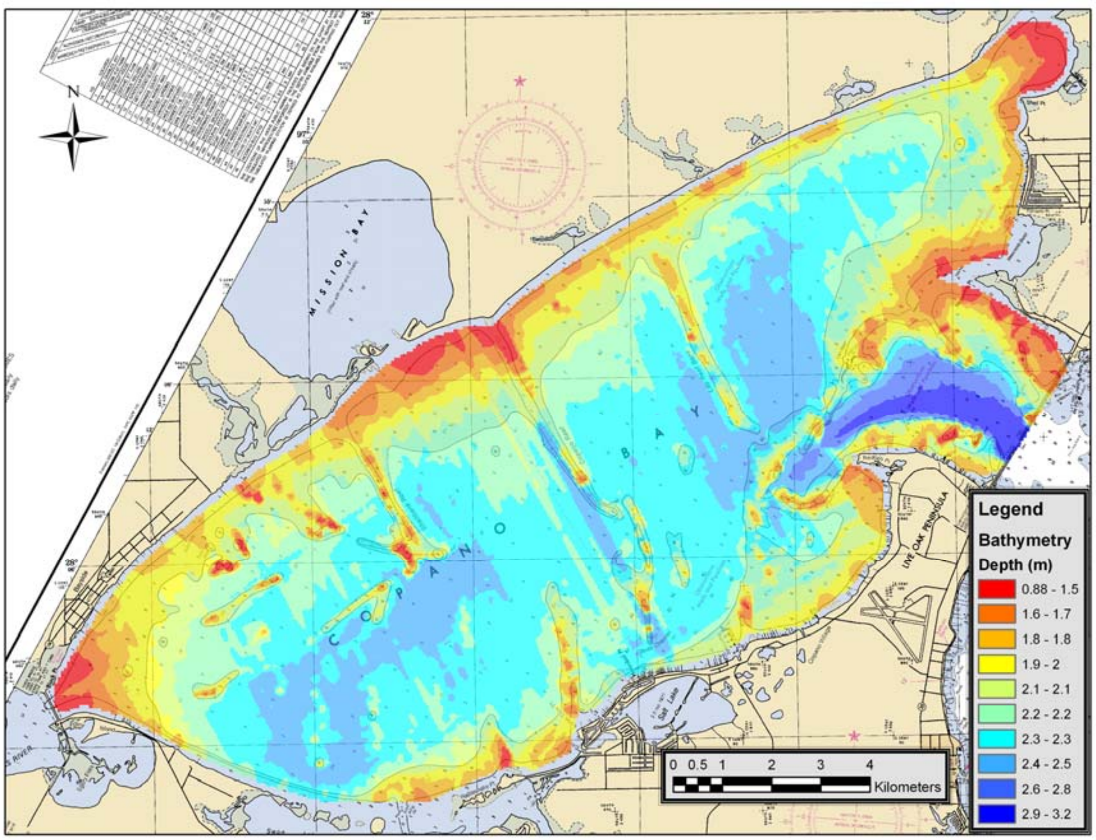

Fig. 6. 2007 Copano Bay bathymetry data atop a 2000 NOAA nautical chart #11314.

4.2. Surficial Sediment Data

The sidescan sonar mosaic (Fig. 7) shows areas of high and low backscatter on the bay bottom. Areas of high backscatter, displayed in lighter tones, correlate to hard substrate such as oyster reef or sand. Low backscatter areas, displayed in darker tones, correspond to soft muddy substrate. Gaps in the sidescan sonar mosaic exist in areas too shallow to safely survey. These are the same areas that were not surveyed for bathymetry and subbottom data. Oyster reef data for these non-mapped sections were provided by aerial photography to map oyster reefs in these shallow areas (Finkbeiner et al., 2009).

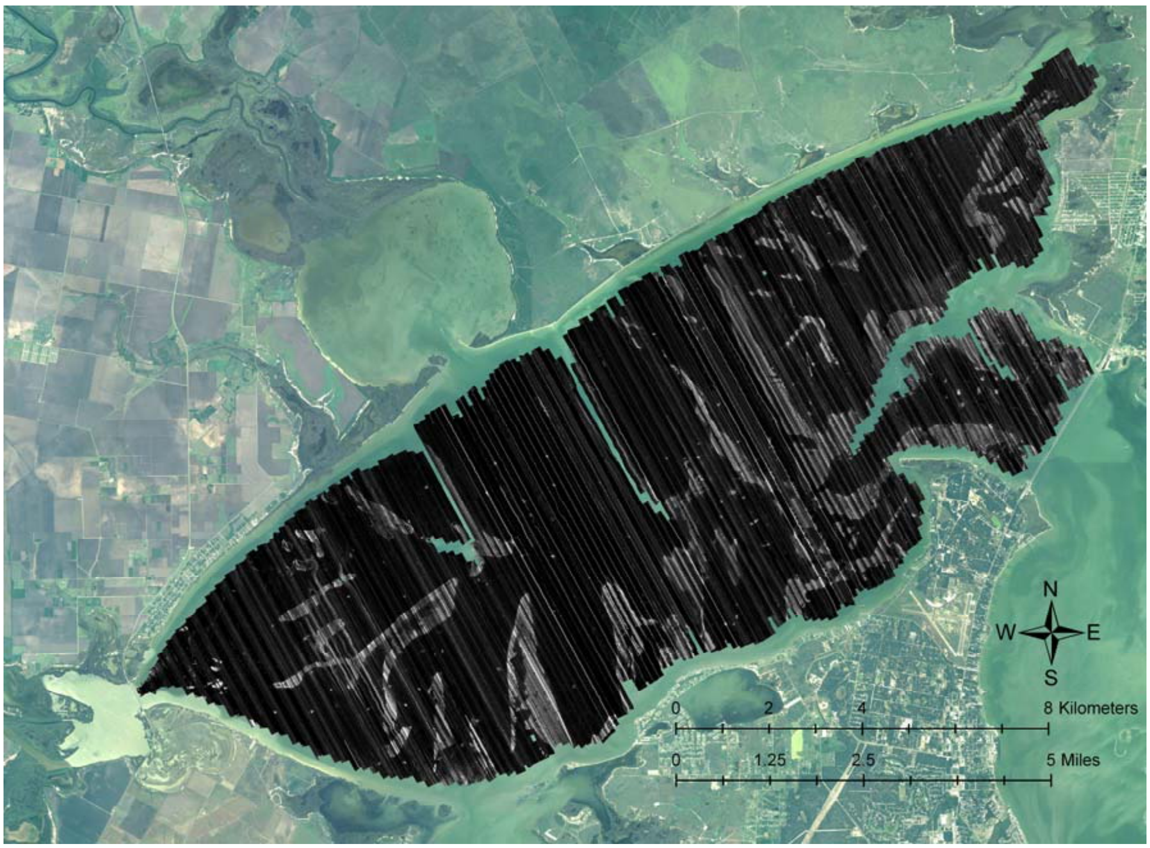

Fig. 7. Sidescan mosaic atop Texas Natural Resources Information System (TNRIS) aerial photograph. Light areas indicate presence of hard substrate while darker areas indicate presence of mud.

CHIRP seismic subbottom data were used along with the sidescan sonar mosaic and grain-size data from various locations across the bay to delineate bottom types. Bottom types mapped are: Oyster Reef, Patch Reef, Sand and Mud. Oyster and Patch reefs are dominated by densely packed oyster shells, live or dead. Analyses of sediment cores, grab samples and oyster dredges reveal that the strong surface reflectors with a strong multiple located in the subsurface are Oyster Reef or Patch Reef based on the abundance of shell (Fig. 8). Medium surface reflectors with the sediment/water interface displayed by a distinct line with semi-transparent layers below were found to be estuarine mud (Mud bottom type) with little or no sand or shell, based on sediment analysis from grab samples (Fig. 8). Oyster and Patch reef were delineated as areas where both the sidescan and CHIRP data show evidence of hard substrate and the grain-size data indicate an abundance of shell gravel. Intermediate surface reflectors with a weak multiple in the subsurface were found to be sandy mud with fine shell hash (labeled as “sand”) from grain-size and oyster dredge data. Shell gravel (>2mm diameter) analyzed by mean grain-size analysis was found to consist primarily of oyster shells and shell hash. The Sandy Mud with Fine Shell Hash (sand) bottom type includes any area where the dominant grain-size diameter was less than 2 mm and greater than .06 mm. No distinction was made between siliciclastic and carbonate sand; however, most of the sand analyzed in the oyster dredges was carbonate sand (fine shell hash). Mud bottom type was classified where the dominant grain-size was less than .06mm (i.e., in the silt or clay range). The Sandy Mud with Fine Shell Hash (sand) layer had several signatures in the acoustic data and also revealed wide ranges of oyster dredge and grain-size data (Fig. 9). The location and composition of surface sediment samples that were analyzed by the Malvern Mastersizer are displayed in Figure 10. The location of verification points analyzed by Texas Parks and Wildlife are displayed in Figure 11. Live and dead oyster counts, per each 30 second dredge, were displayed atop the bottom type map (Figs. 12 and 13). Figure 14 shows the distribution of surface sediment facies in Copano Bay, Texas, based on the distribution of these bottom types.

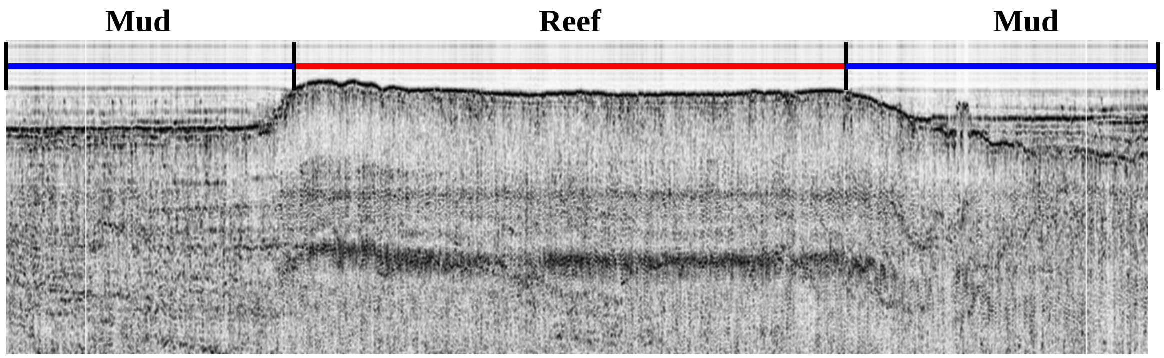

Fig. 8. Example of oyster reef and mud signatures in a seismic profile.

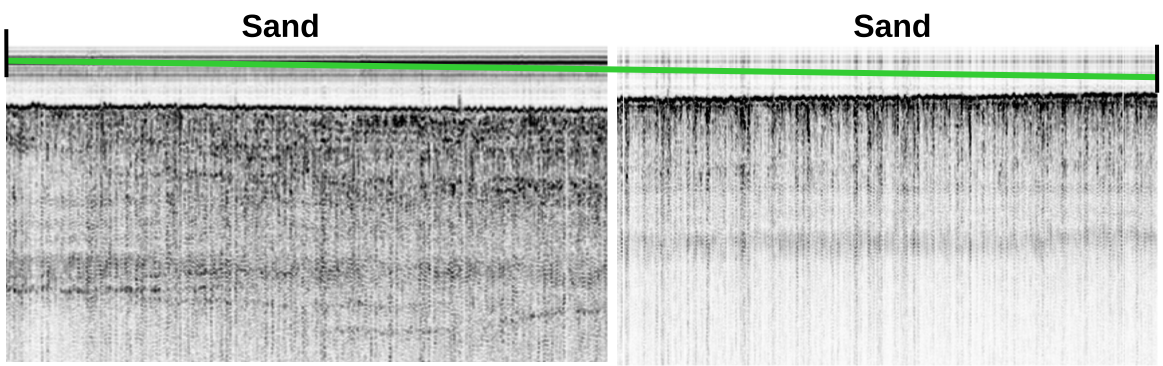

Fig. 9. Example of sand signature in the seismic lines.

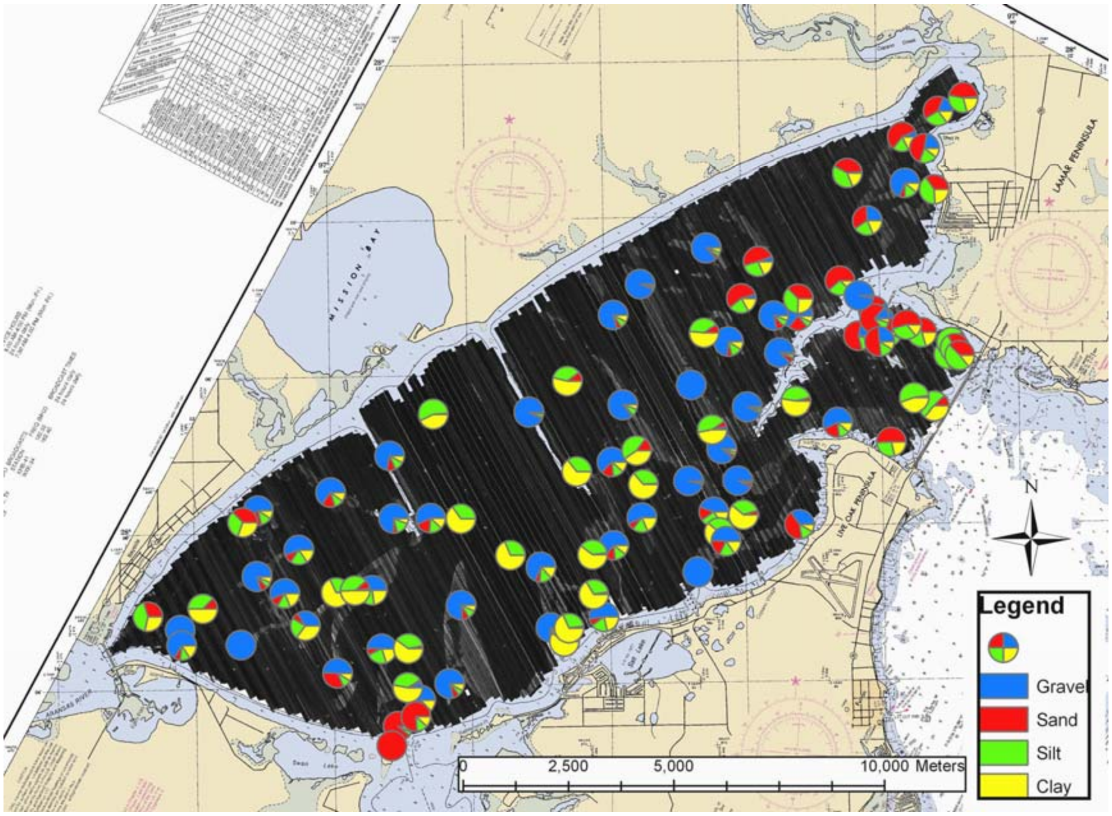

Fig. 10. Texas A&M surface sediment sample location and composition plotted over the sidescan mosaic.

Fig. 11. Location and labels of 30 second dredge sample points used for bottom type map verification by Texas Parks and Wildlife Department.

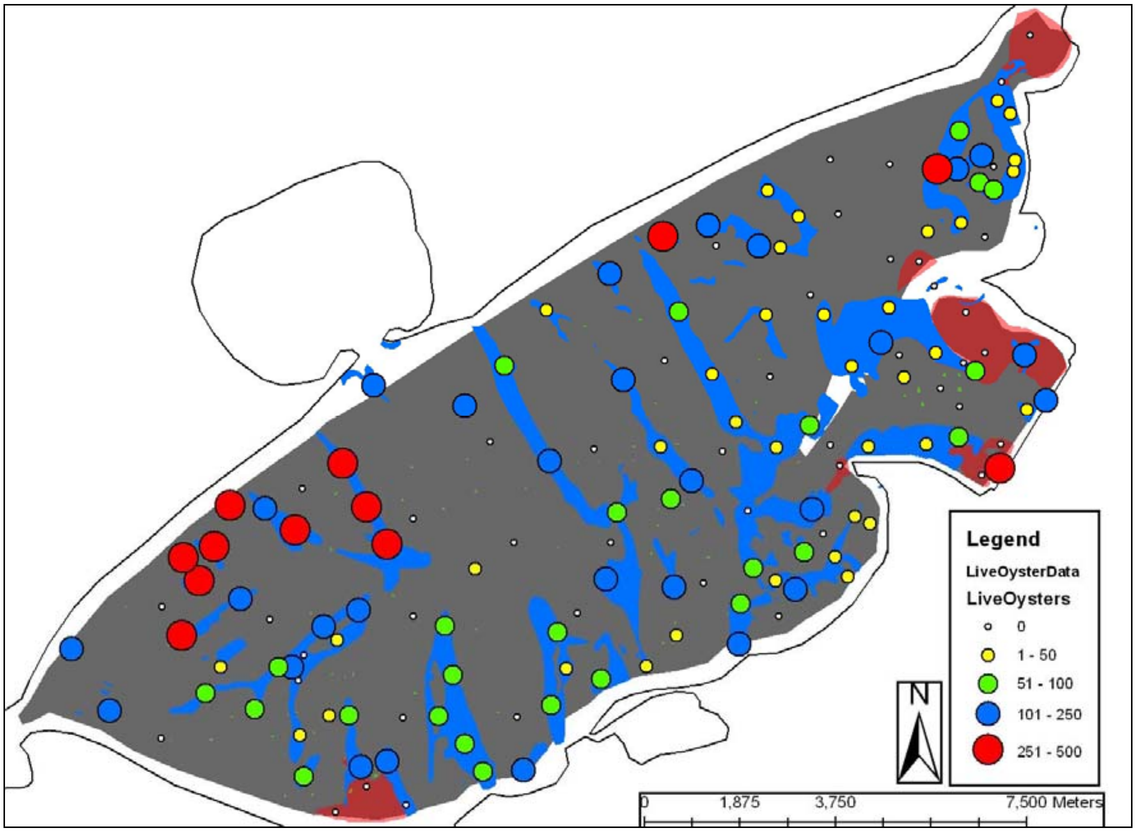

Fig. 12. Number of live oysters per 30 second dredge plotted atop bottom type map.

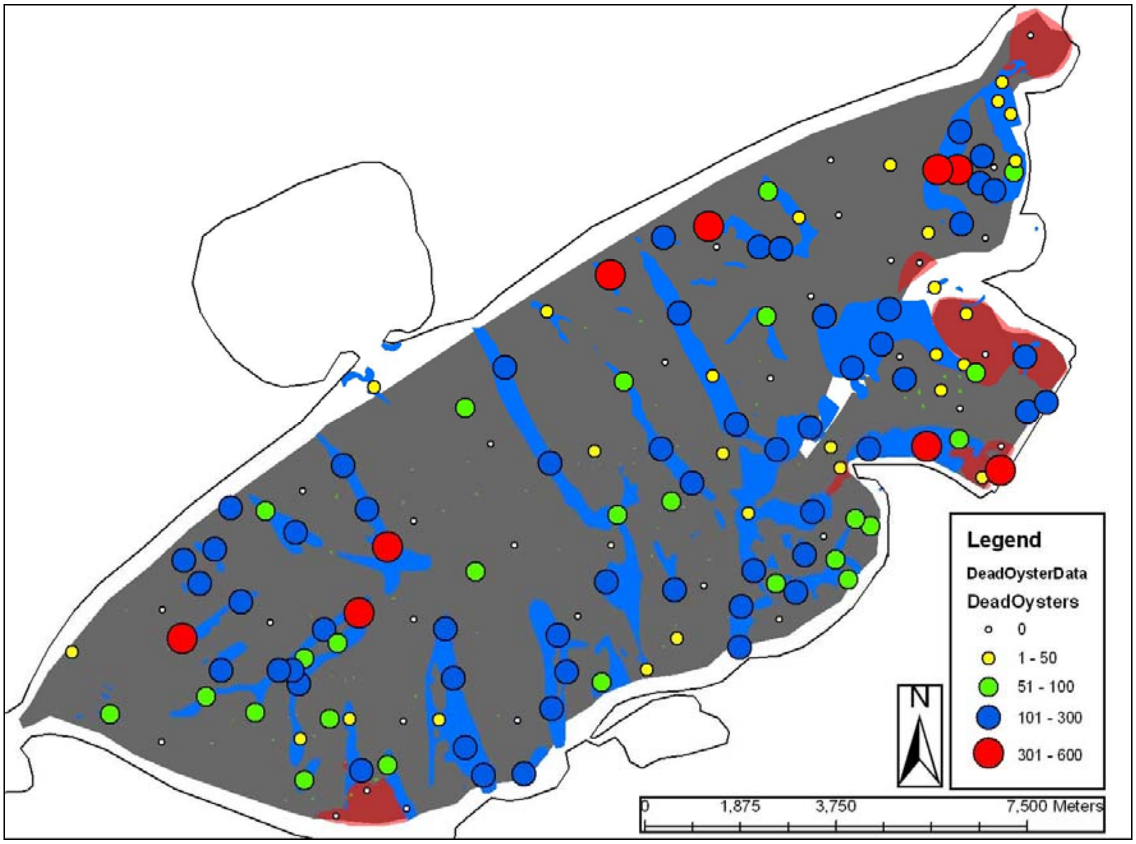

Fig. 13. Number of dead oysters per 30 second dredge plotted atop bottom type map.

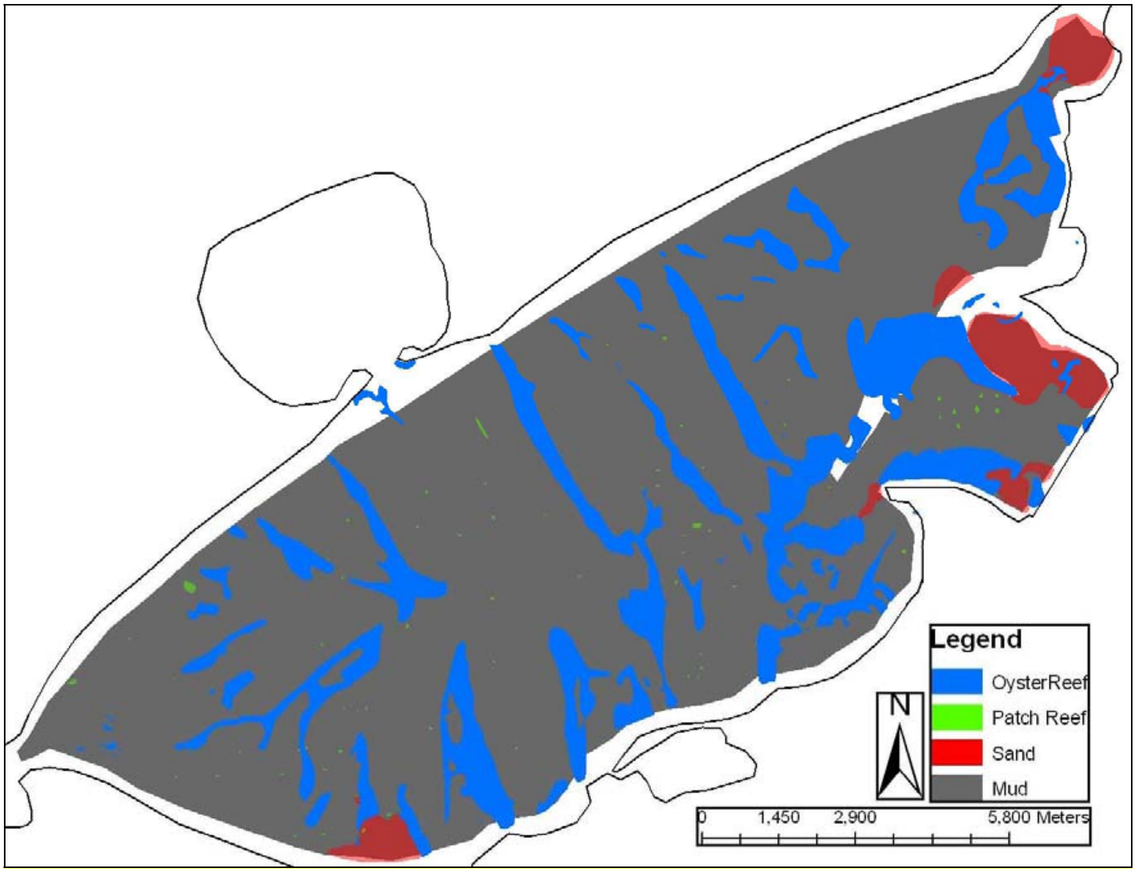

Fig. 14. Distribution of bottom types in Copano Bay, Texas.

For the sake of description, the bay was divided into three sections shown in Figure 15: Southwest Copano Bay (SWC), Central Copano Bay (CCB) and Northeast Copano Bay (NEC). The large reefs that had not been previously named were assigned names for reference (Fig. 16).

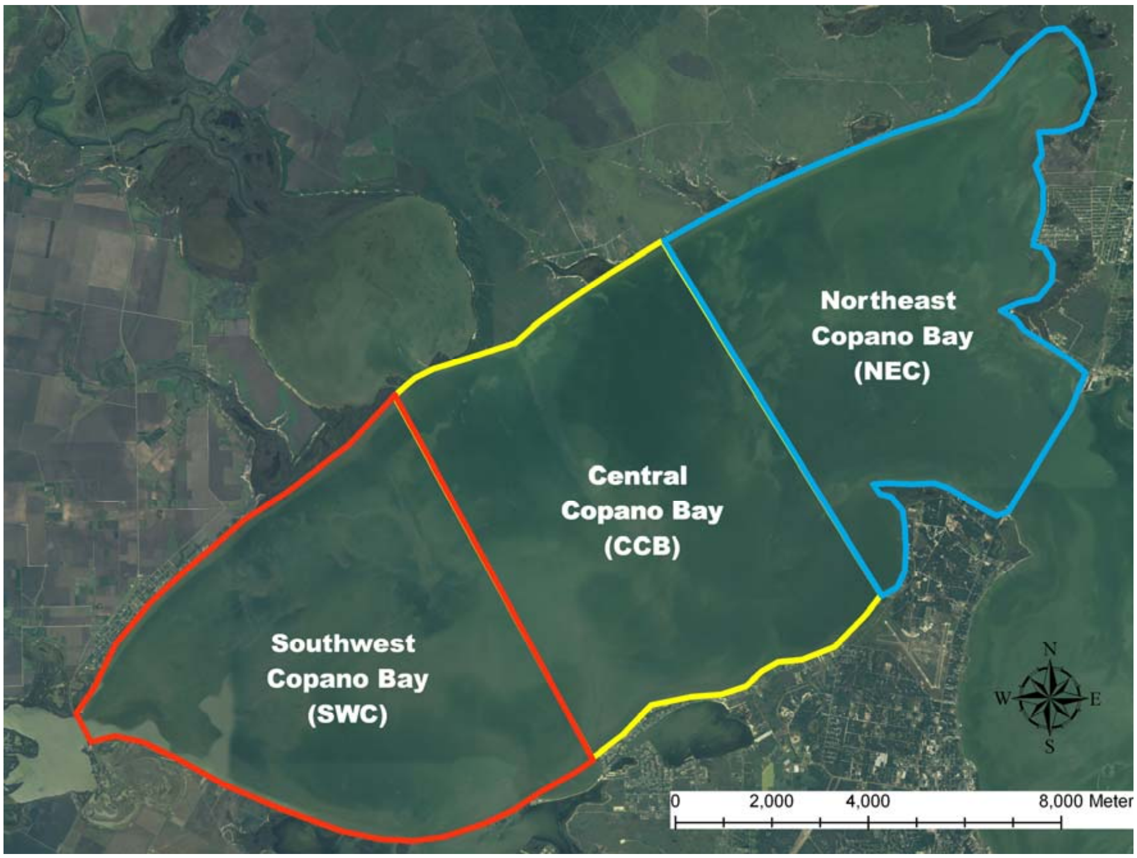

Fig. 15. Sections of Copano Bay.

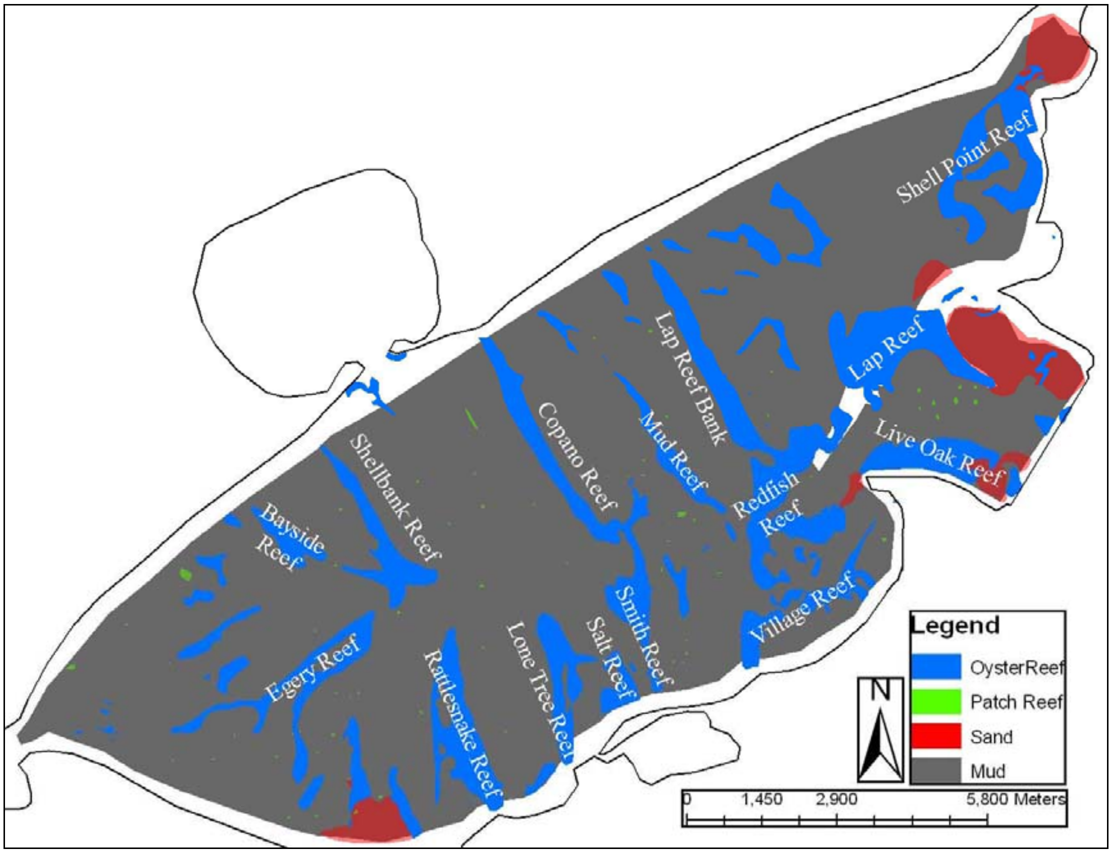

Fig. 16. Copano Bay oyster reef names.

4.2.1. Southwest Copano Bay (SWC)

The bottom type map of SWC (Fig. 17) shows that the majority of the seafloor is mud. Mud in the low backscatter areas is comprised of silty clay. Most reefs connected to land are oriented perpendicular to the shoreline while the oyster reefs located in the middle of the bay, including Egery reef are oriented parallel to the northern shoreline. These are indicative of transverse and longitudinal reefs. There are many small (~50 m diameter) patch reefs located throughout SWC. Little Sand is found along the margins of SWC except for a small area near Port Bay. The sand concentration in this area near Port Bay is much higher than any other area in SWC, with over 75% sand-sized shell hash in each grab sample. The sand-sized shell hash concentration of the samples in the rest of SWC is less than 33%. Two samples along the northern shore contain equal amounts of sand, silt and clay.

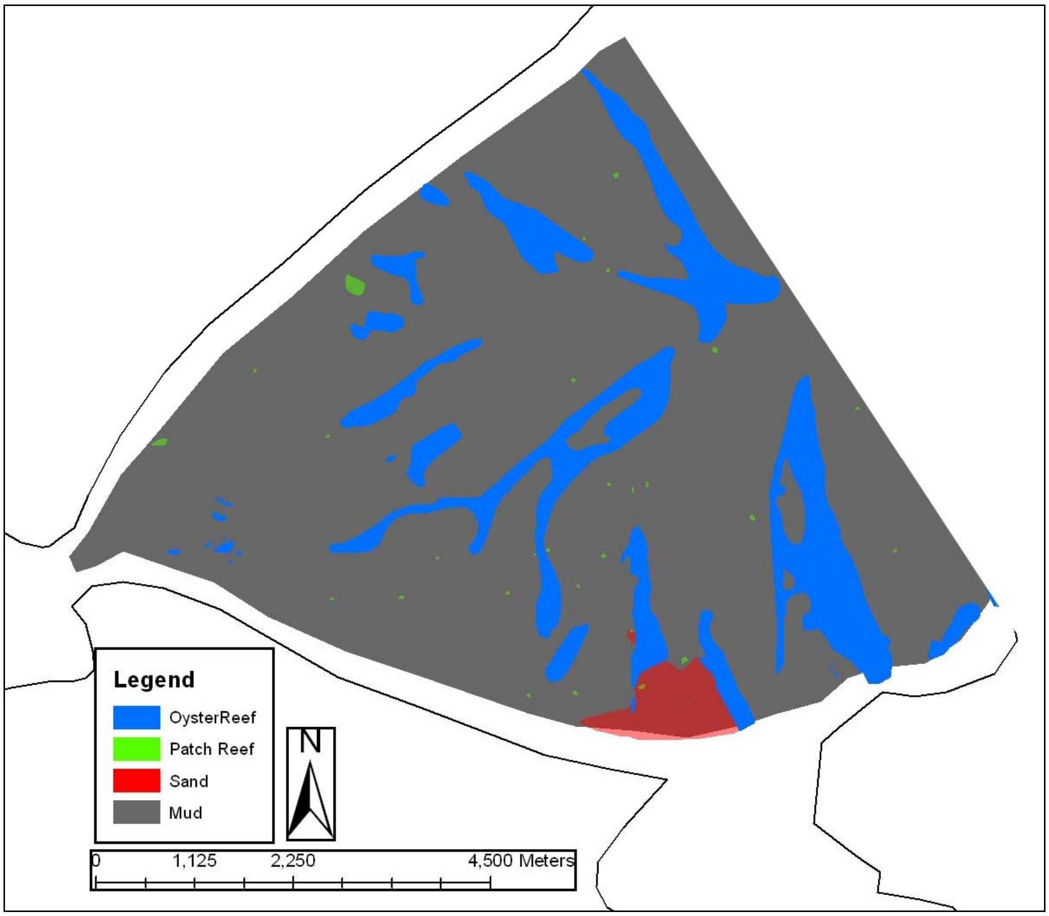

Fig. 17. Distribution of bottom types in Southwest Copano Bay, Texas (SWC).

4.2.2. Central Copano Bay (CCB)

The bottom type map of CCB (Fig. 18) shows that mud dominates the bottom in this region. The mud is composed of silty clay. Most of the oyster reefs are long, linear and oriented perpendicular to the northern or southern shoreline. These reefs all indicate transverse reefs formed perpendicular to the shoreline and prevailing water currents. Two of the oyster reefs span the entire width of Copano Bay from north to south. Small patch reefs are found in this portion of the bay as well. The majority of CCB is composed of mud or oyster reef.

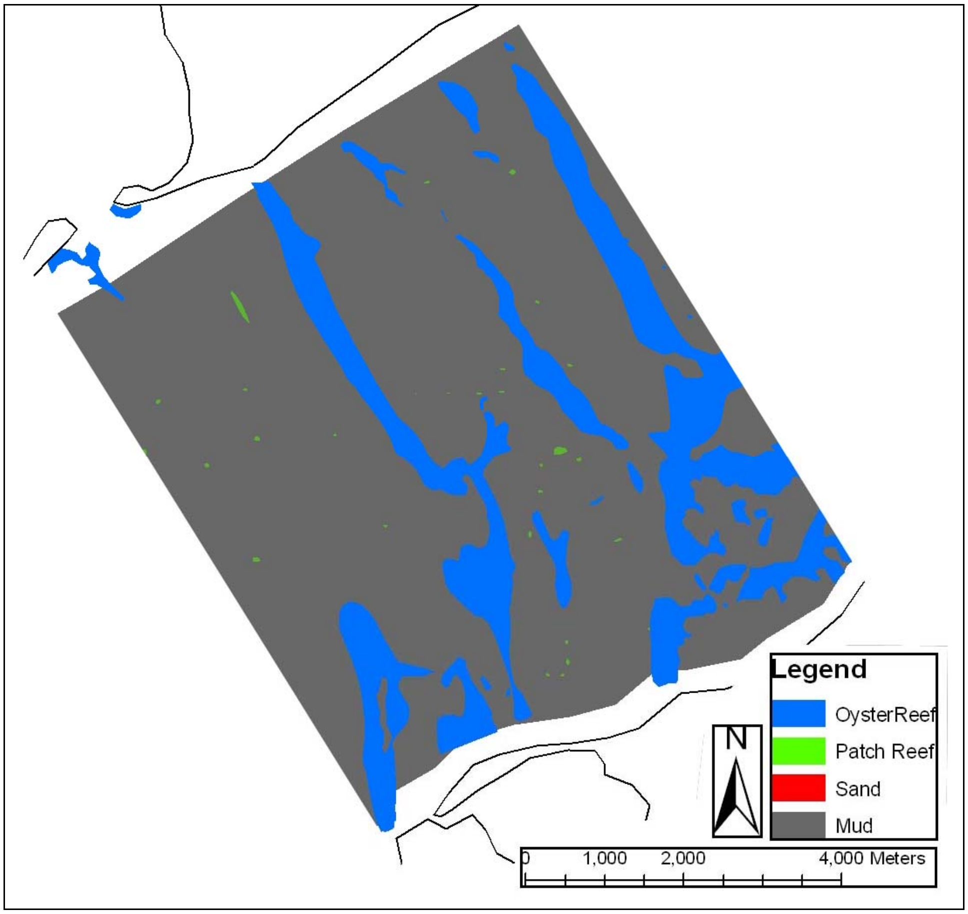

Fig. 18. Distribution of bottom types in Central Copano Bay, Texas (CCB).

4.2.3. Northeast Copano Bay (NEC)

The bottom type map of NEC (Fig. 19) shows that mud also covers the larges area of the bottom in this portion of the bay as well. There is a much greater area of sand in NEC, compared to other portions of the bay. The same patch reefs are found in NEC. The largest reef in this area is Lap Reef. Reefs in south NEC are oriented along the edges of the tidal inlet and those in northern NEC are randomly oriented, indicative of patch reefs.

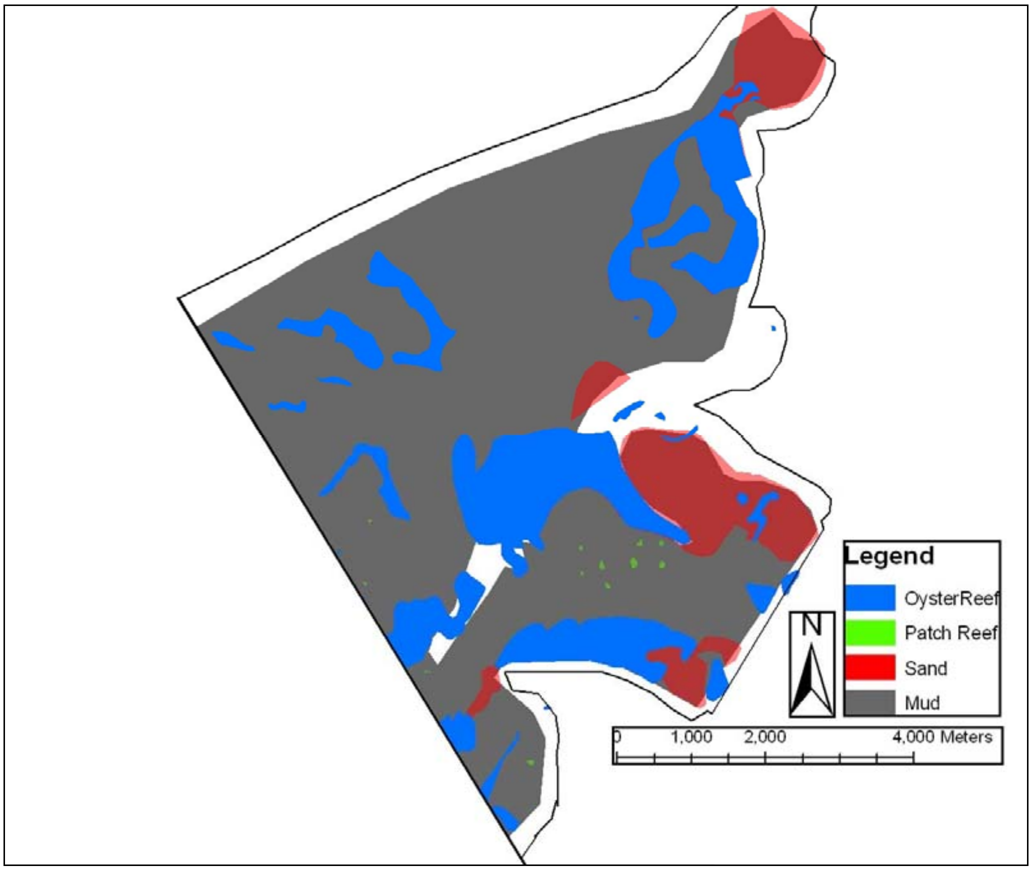

Fig. 19. Distribution of bottom types in Northeast Copano Bay, Texas (NEC).

4.3. Seismic Stratigraphic Analyses

4.3.1. Interpreted Seismic Reflector Data

All 197 seismic lines were used to map out surface sediments to create the bottom type map. When mapping Reflector LGM, many areas were unable to be accurately imaged due to deep acoustic wipeout from strong surface or shallow subsurface reflectors. This occurred in NEC and is why Reflector LGM is not delineated in this portion of the study area. The far west portion of the bay has relatively short seismic lines which decrease in length westward. Distinct seismic horizons are very difficult to delineate in the shorter seismic lines, as a result, no subsurface reflectors were documented in this portion of SWC. While the extent of Reflector LGM could be accurately identified in most lines, the exact depth of Reflector LGM could not be determined in several seismic lines. The presented data displays the shape and extent of the valley accurately; however the exact depth is an interpretation in some areas. To avoid large interpretation errors, over 140 consecutive seismic lines where the reflectors were able to be identified were used to map Reflectors F5 and LGM.

4.3.2. Subsurface Seismic Reflector F5

Reflector F5 is a strong, buried seismic reflector that appears to underly most of the present day oyster reefs (Fig. 20) and marks the surface of Event 5, which coorelates to an environmental change to dry climate as described on page 12 (Troiani, 2010). In most of the bay, Reflector F5 reaches a depth of ~3.5 meters below mean sea level (MSL). The distribution and depth of Reflector F5 below MSL is displayed in Figure 21. Reflector F5 was found to mark the surface of a muddy sediment layer containing sand and/or shell. The layer and seismic reflector is most prominent near present oyster reefs. The seismic reflector associated with the layer (Refector F5) is most prominent near present oyster reefs and diminishes in strength away from present oyster reefs. Sediment layers of estuarine mud with little or no sand or shell are present above and below Reflector F5.

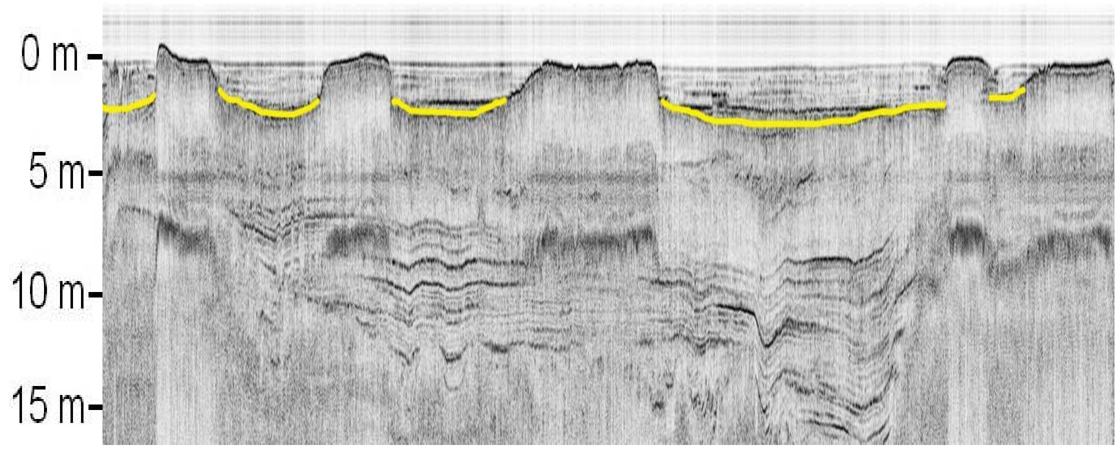

Fig. 20. Example of Reflector F5 signature in the seismic lines.

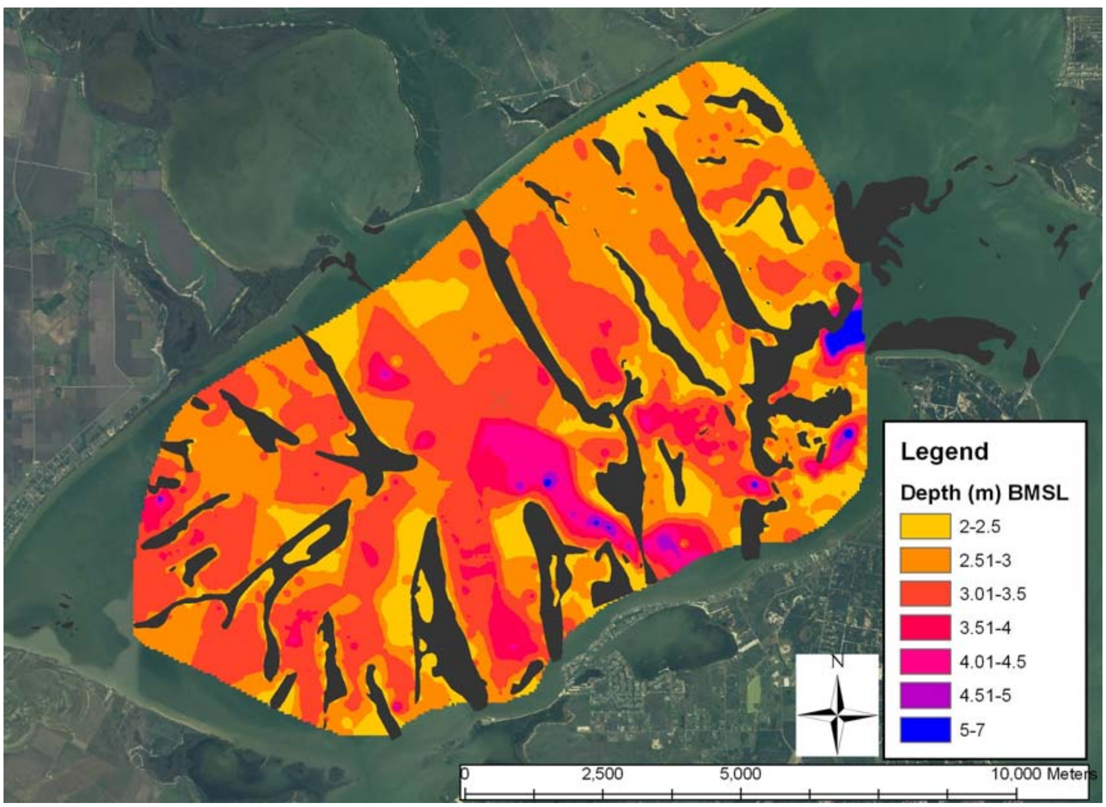

Fig. 21. Depth of Reflector F5 below mean sea level.

4.3.3. Subsurface Seismic Reflector LGM

Reflector LGM was the deepest consistent seismic reflector observed in the seismic lines (Fig. 22). Reflector LGM was difficult to identify in some areas due to acoustic wipeout from strong surface or shallow subsurface reflectors such as Reflector F5. The high acoustic impedence of these layers precluded most of the acoustic signal from penetrating below, resulting in a general lack of deeper seismic imaging. The distribution and depth of Reflector LGM below mean sea level, as well as the valley border, are displayed in Figure 23. The buried, incised valley found throughout the bay exhibits a dendritic drainage pattern with valley axes originating in Port Bay, Aransas River, Mission River, and possibly Copano Creek.

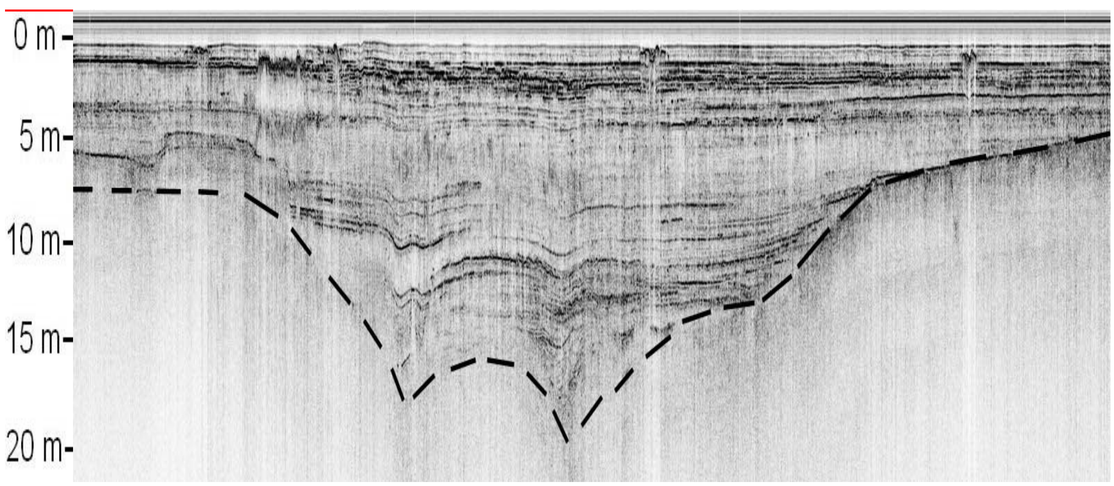

Fig. 22. Example of Reflector LGM signature in the seismic lines.

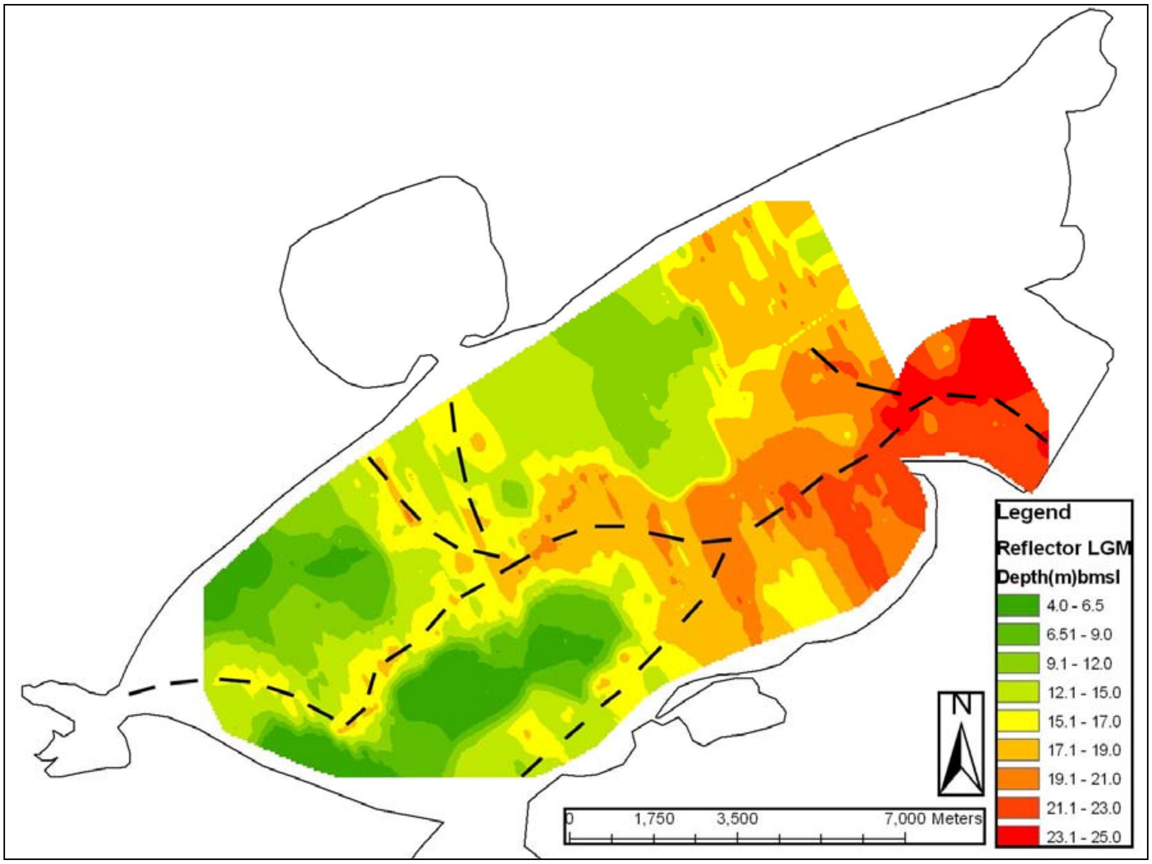

Fig. 23. Map showing depth of Reflector LGM below mean sea level. Dashed line is the interpreted Pleistocene valley axis.

4.4. Subsurface Sedimentary Facies Analyses

4.4.1. Estuarine Mud Facies (MF)

The estuarine mud facies consists primarily of silt and clay with little or no sand, oyster shell or shell fragments (<25% combined). This facies correlates to Mud Facies 1 (MF1) as defined by Troiani (2010). The color of this sediment ranges from dark to light gray. The deeper estuarine mud facies, below Reflector F5, consists primarily of silt with <40% clay while the shallow, more recent facies, above Reflector F5, consist mostly of clay with <30% silt (Fig. 24). The acoustic signature of this facies consists of semi-transparent closely stacked horizontal reflectors which lie both above and below Reflector F5 (Fig. 25).

4.4.2. Estuarine Shell Hash Facies (ShF)

The estuarine shell hash facies consists of sand, oyster shell and shell fragments (>50% combined) among a muddy matrix (Fig. 24). The mud within this layer has the same characteristics as the estuarine mud facies, only with higher concentrations of sand, oyster shell and shell fragments interpreted to be oyster-reef debris. This sediment facies underlies Reflector F5 and exists in thickness of up to 1 meter. Reflector F5 marks the surface of this estuarine shell hash facies (Fig. 25).

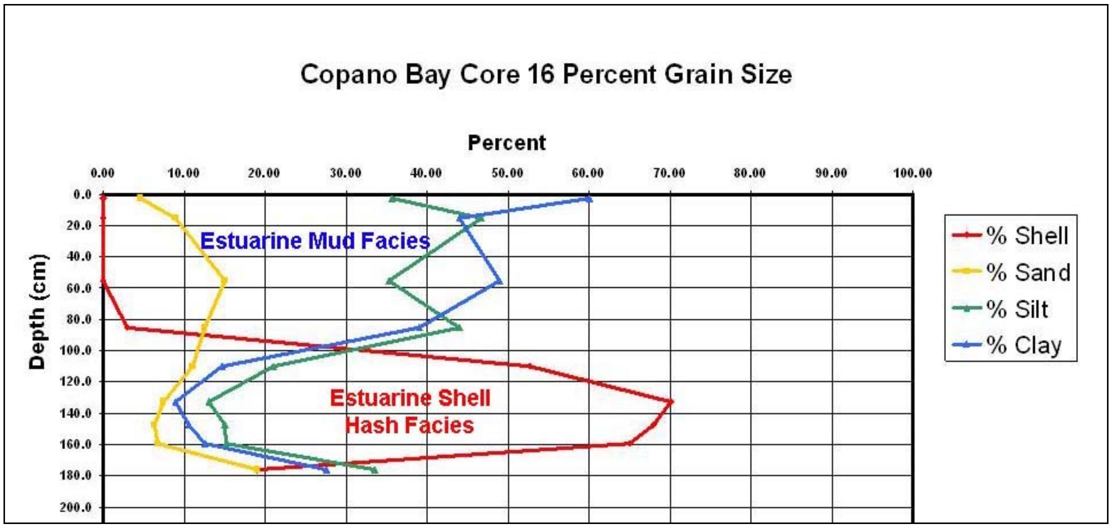

Fig. 24. Grain-size distribution chart from Copano Bay Core 16 showing the grain-size characteristics of the Estuarine Mud Facies and Estuarine Shell Hash Facies.

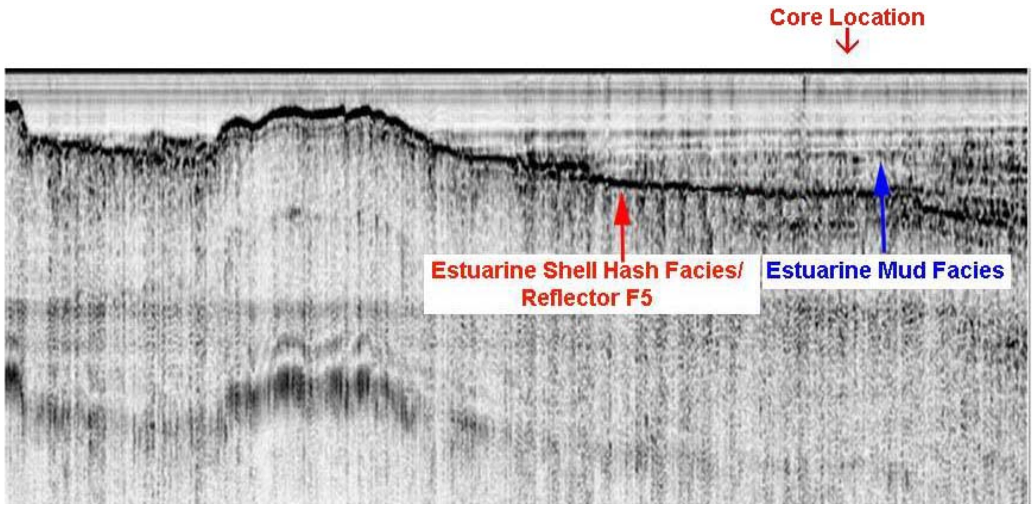

Fig. 25. Seismic line cross section showing location of Copano Bay Core 16 and seismic characteristics of Reflector F5 which marks the surface of the Estuarine Shell Hash Facies and Event 5 which represents the Estuarine Mud Facies.

4.4.3. Oyster Reef and Patch Reef Facies (OF)

Oyster reef facies consists primarily of gravel (shell) >80% with smaller amounts of silt and clay among the shells. Although the Patch Reef facies has the same grain-size and acoustic characteristics as the Oyster Reef facies, the Patch Reefs can exist in any shape, are isolated and much smaller than regular oyster reefs, usually ~50 m diameter. Oyster Reef facies are linear, usually attached to the shoreline and are much larger, can be up to 4.5 km long in Copano Bay. No distinction was made between live and dead oyster reef due to the variation between environmental factors in the bay from year to year changing live and dead oyster ratios. The surface seismic characteristics of the oyster reef facies is a very strong surface reflector with a strong subsurface multiple as described above.

4.4.4. Shallow Sediment Stratigraphy

The location of vibracores taken in Copano Bay is displayed in Figure 26. Only the upper two to three meters of the bay sediment is contained within these cores. Grain-size distribution and seismic line cross section for each core are located in APPENDIX

A. The majority of the cores taken throughout Copano Bay confirm a general fining upward trend (COP-1, COP-2, COP-4, COP-5, COP-17). This trend starts at depths varying between 1-2m below the current bay bottom (Appendix A). The cores taken in the northeast portion of the bay (COP-8, COP-9, COP-10) actually exhibit a coarsening upward trend. The cores near the tidal inlet (COP-11, COP-12) show a dominance of silt and clay (>80%) throughout the length of the cores. Several cores confirm existence of buried oyster reef underneath current bay bottom (COP-5, COP-7, COP-16, COP-19, COP-21, COP-22). Several other cores also show buried layers of sand (COP-1, COP-3, COP-6, COP-7, COP-8, COP-15, COP-20, COP-21). These layers of buried oyster reef and sand correlate to Reflector F5 in the seismic lines. COP-13, COP-14, and COP-15 were taken through shallow, intertidal oyster reefs and in turn have no seismic data for grain-size comparison. COP-15 penetrated through a reef and showed the presence of sand just beneath the reef. COP-18 exhibits varying ~10 cm thick layers alternating between clayey silt and sand throughout, indicating transitional depositional environments in that area from low to high energy throughout the recent Holocene.

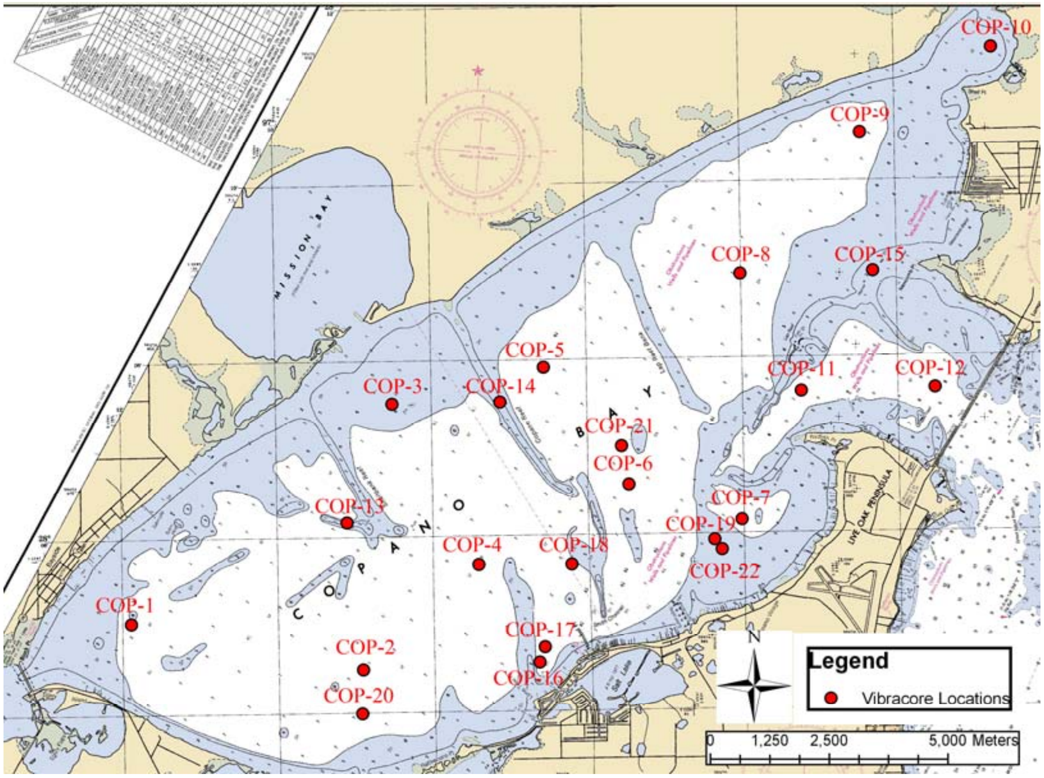

Fig. 26. Map showing location of vibracores taken in Copano Bay, Texas.

5. DISCUSSION

5.1. Overview

Copano Bay is characteristic of most coastal plain estuaries along the Texas Coast in that the sequence of Holocene sediments and seismic facies within the bay illustrate a classic transgression (Troiani, 2010). Oyster reefs do not appear in the seismic and sedimentary record of Copano Bay until approximately 6 - 4.8 ka when sediment input into the bay decreased. The current bay bottom is dominated by estuarine mud with about 16.3% of the current bay bottom covered by oyster reef. The LGM reflector was delineated to compare to past and present oyster reef location as a potential geologic control on the distribution of oyster reefs.

5.2 Recent Sedimentary History of Copano Bay

The bottom type map along with the upper ~50 cm of the vibracore grain-size data were analyzed to investigate the upper Holocene strata in Copano Bay. The upper Holocene strata includes estuarine mud, large extents of oyster reef and small areas of sand. Most of the vibracores in the bay contain a general fining upward trend, characteristic of wave-dominated estuaries (Dalrymple et al., 1992). The rise of relative sea level transitioned Copano Bay from a high energy fluvial environment to a bayhead delta, which transitioned to a deeper, lower energy estuarine basin, resulting in the deposition of estuarine muds. The transition of facies upward throughout the estuary, mirrors the transition of grain-sizes from coarse to fine grained throughout the recent Holocene. The low energy, estuarine environment allowed for the formation of large oyster reefs. Because the sand fraction was not differentiated between silica-clastic or carbonate in composition, either erosion of the siliciclastic Pleistocene shoreline or existing oyster reefs allowed for the accumulation of sand in higher energy portions of the bay. Cores in northern NEC show a coarsening upward trend. This could reflect a higher energy environment which increasingly eroded the sandy shoreline or existing oyster reefs over time. Sandier substrates may exist closer to shore and simply were not encompassed in the survey tract.

5.3. Seismic Stratigraphy

The seismic stratigraphy was analyzed to determine which reflector and correlating facies most likely controls the distribution of oyster reefs in Copano Bay. Wright's (1980) delineation of the Pleistocene surface, or the LGM, was overlain onto the structural isopac map of Reflector LGM (Fig. 27). Although the general dendritic and meander patterns are very similar, as are the depths, variations between these interpretations of the Pleistocene or LGM surface exist. North of Port Bay, the 2007 data set reveals a shallow area of the Pleistocene about 1500 meters north of the shore, while in the 1980 map, it was interpreted that a valley extended throughout this area. Wright (1980) also interpreted a valley originating in Salt Lake in south-central Copano Bay, while the 2007 data revealed this are to be a topographic high. North of Lap Reef, at the northeastern corner of the extent of the 2007 interpretation, Wright (1980) interpreted a valley originating at Copano Creek and extending through an area where the 2007 dataset was interpreted to be another topographic high. The Valley axis originating from Aransas River, Mission River and just west of Mission River were interpreted between the two maps to be nearly identical. The discrepancies between the two maps primarily result from the limited data set used to generate the 1980 map in comparison to the more comprehensive data set used to generate the 2007 map.

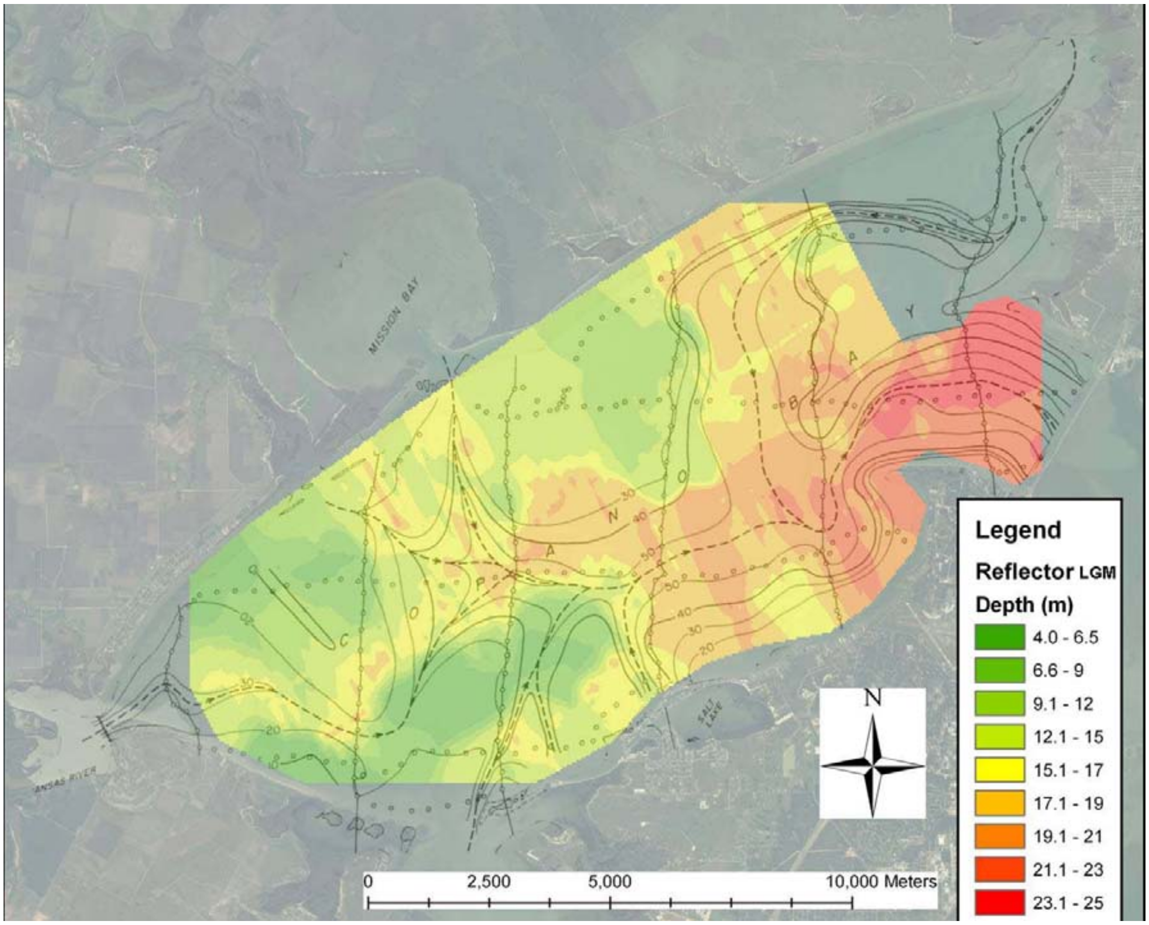

Fig. 27. Comparison between LGM surface maps of Wright (1980) (contours) and this study (colors). Labels on Wright's contours are feet below mean sea level.

5.4. Subsurface Geologic Controls on Initial Oyster Reef Growth

Figure 28 shows the distribution of the oyster reefs in Copano Bay plotted on top of the LGM isopach map. Unfortunately, the chirp record under most reefs is obscured by the hard reflection of the reef and shell hash layers and little detail can be found directly under the reefs, so their origins are largely inferred from circumstantial evidence such as seismic reflectors attached to present day reefs (Fig. 29). These reflectors can indicate how deep in the seismic record the reef began forming. In comparing these reflectors from different reefs, the reefs with the deepest connecting reflectors can be interpreted to have formed prior to those reefs with shallow connecting reflectors in the seismic lines.

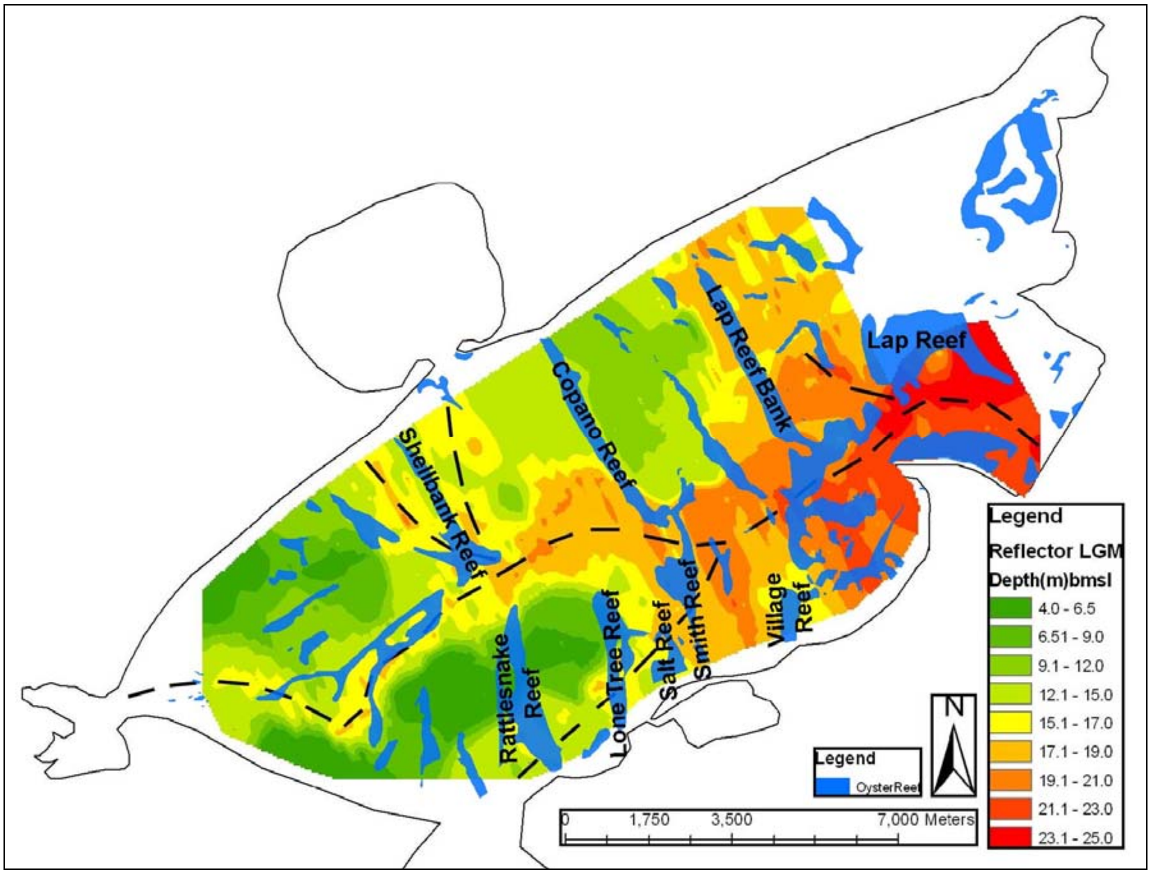

Fig. 28. Structural Isopach map of the Last Glacial Maxima (LGM Reflector) and positions of modern oyster reefs plotted on top. Note that each labeled reef sits on or proximal to structural highs of the LGM near the shoreline.

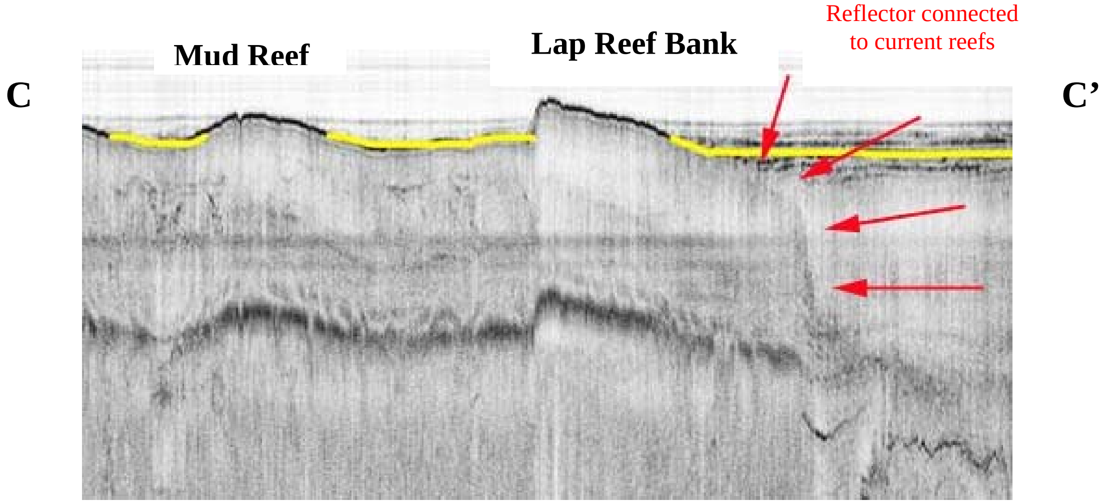

Fig. 29. Example of a seismic reflector attached to a present day oyster reef. Seismic line shown is a close up section of line C-C’ “(Figures 30 and 31C).

Analysis of the seismic data found that all the oyster reefs began to form on or above Reflector F4 (Figures 31A – 31G). Several reefs appear to form directly atop the Reflector F4, while most are formed higher in the stratgraphic section within Event 4 (Figures 31A-31E and 31G show both instances). This suggests that although the reefs in Copano Bay did not form at the exact same time, all of them formed during or after the E4 event. The reefs which formed directly atop Reflector F4 are the first reefs to have formed which still exist today. Evidence via seismic reflectors attached to these current reefs is shown in Figures 31A – 31 C, and 31F.

Figure 31A shows an example of three reefs that formed directly atop Reflector F4. Reefs which formed directly atop Reflector F4 include Shellbank, Bayside, Copano, Lap Reef Bank, Lap, Rattlesnake, Lone Tree, Salt, Smith and west Village Reef. According to Scott (1968), transverse reefs initially establish along the shoreline and grow out perpendicularly from the shoreline toward the middle of the bay overtime. These reefs that established atop Reflector F4 are all oriented either perpendicular to the north or south shore and are transverse reefs. Because they formed atop Reflector F4, they were the first oyster reefs to have formed in Copano Bay. Because these reefs established first, they most likely provided a base for other oyster reefs to grow upon.

Figure 28 shows that Shellbank Reef is situated on the river levee that exists between the interpreted Mission Bay valley and a valley which runs to the west of Mission River, indicating that this reef is sitting atop a subsurface levee of the incised Mission River channel and an ancient smaller tributary channel. Copano Reef and Lap Reef Bank also sit on a structural high on the LGM surface to the southeast of Mission Bay (Fig. 28).

Lap Reef, though not currently mapped to extend to the eastern shoreline, does extend to the shoreline according to the NOAA Nautical Chart #11314. The area where the NOAA chart places the reef was not encompassed in the survey due to the shallow depths in the area; therefore, the reef may exist and simply was not mapped during this study. The existing seismic data did not show any specific geologic control on Lap Reef; however, it is likely a transverse reef based on the direction of growth perpendicular to the shoreline and the major tidal currents. Inferring that Lap Reef is a transverse reef, then the northern Pleistocene river levee just northeast of the current reef is likely the control on the initial settlement of Lap Reef. It is likely that after initial settlement, the reef grew out westward, perpendicular to the direction of the major tidal current flow and over the river valley, to where the current Lap Reef exists today. Live Oak Reef, along the western shoreline of the tidal inlet, is a longitudinal reef that is situated over the incised subsurface channel and is most likely sitting on a tidal delta situated structurally above the LGM (Figs. 30 and 31D).

Village Reef, Smith Reef, Salt Reef and Lone Tree Reef are all transverse reefs that began forming along the southern river levee of the main Pleistocene river valley along southern shoreline of Copano Bay (Figs. 28, 31D and 31F). Rattlesnake Reef is also a transverse reef that formed atop the fluvial terrace that exists just north of Port Bay (Fig. 28). The 2007 interpretation of the Pleistocene surface places a valley on the southern shore near Port Bay and the topographic high more north toward the center of the bay (Fig. 28). This is different from all the other transverse reefs in Copano Bay that established on topographic highs along the shoreline and grew out toward the middle of the bay overtime. It is possible that there was ample area for Rattlesnake reef to establish in the middle of this fluvial terrace at the same time the other transverse reefs first established in the bay, and that Rattlesnake reef grew southward toward the shore overtime, still perpendicular to prevailing water currents.

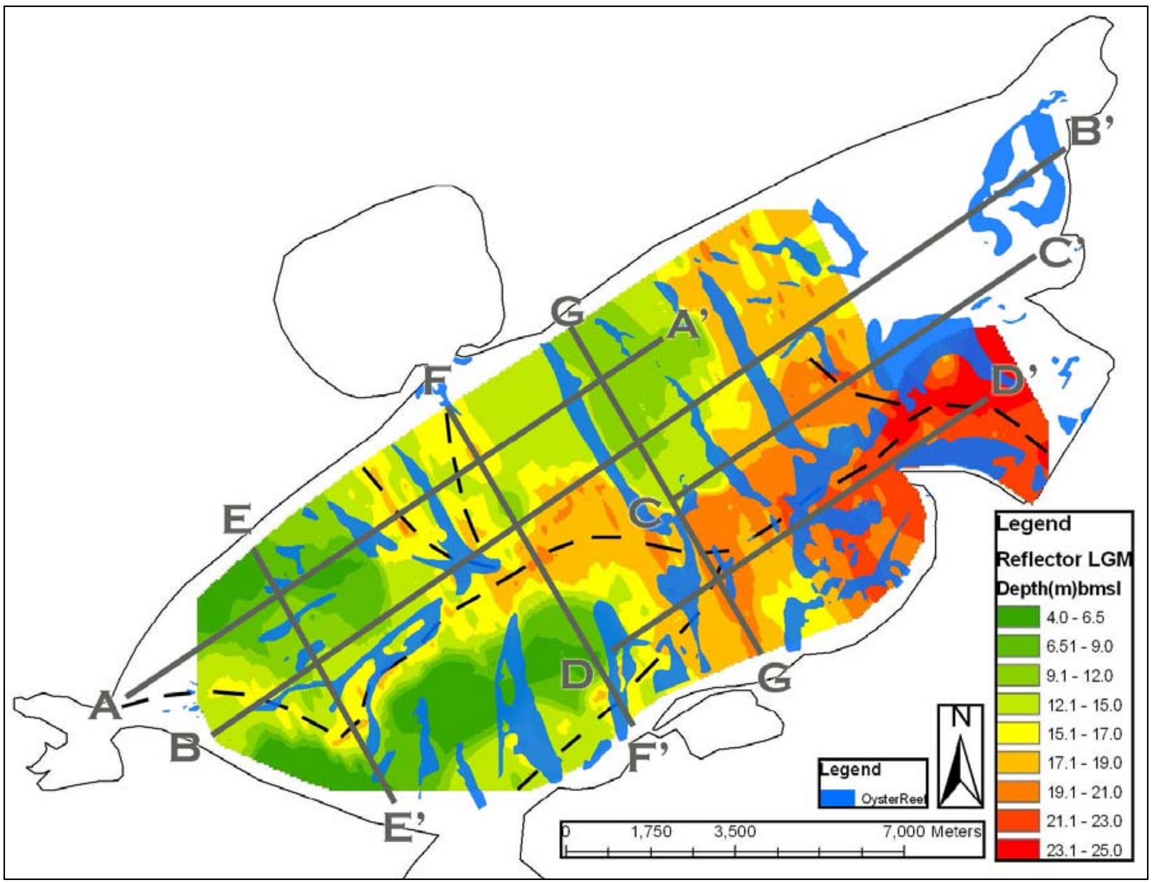

Fig. 30. Location of Seismic Lines A-A' through J-J' atop LGM isopac map and current reef locations.

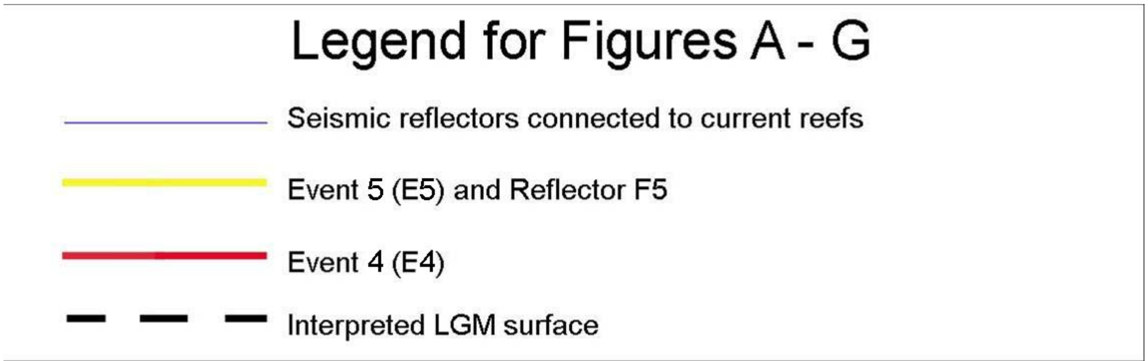

Fig. 31. Legend for Seismic reflectors interpreted in Figures 31A-31G.

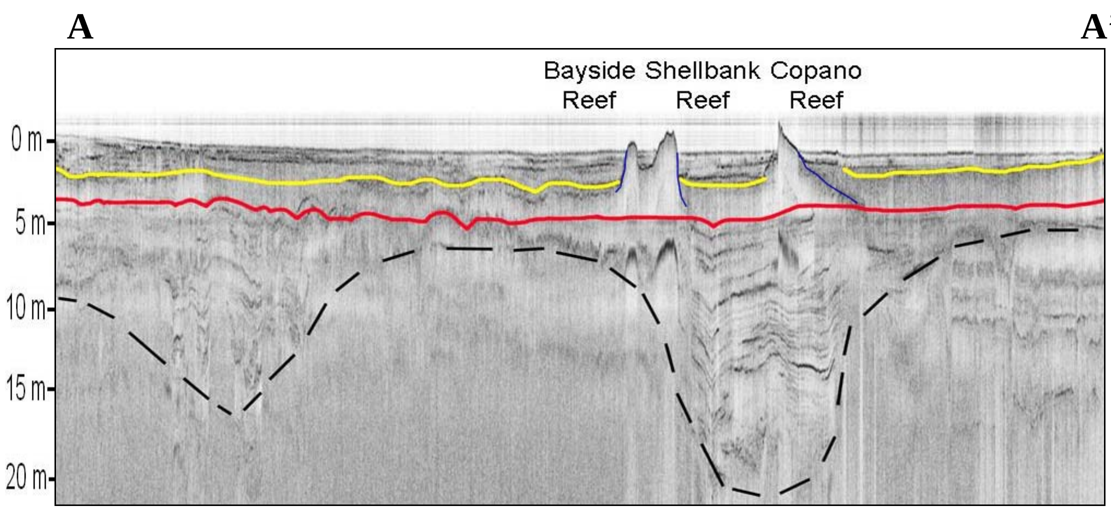

Fig. 31A. Seismic Line A-A'.

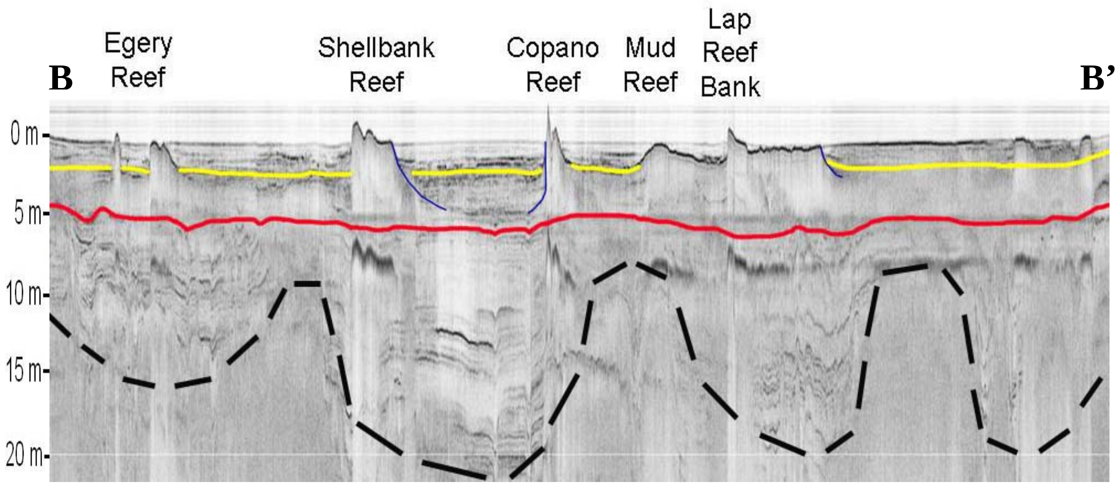

Fig. 31B. Seismic line B-B'.

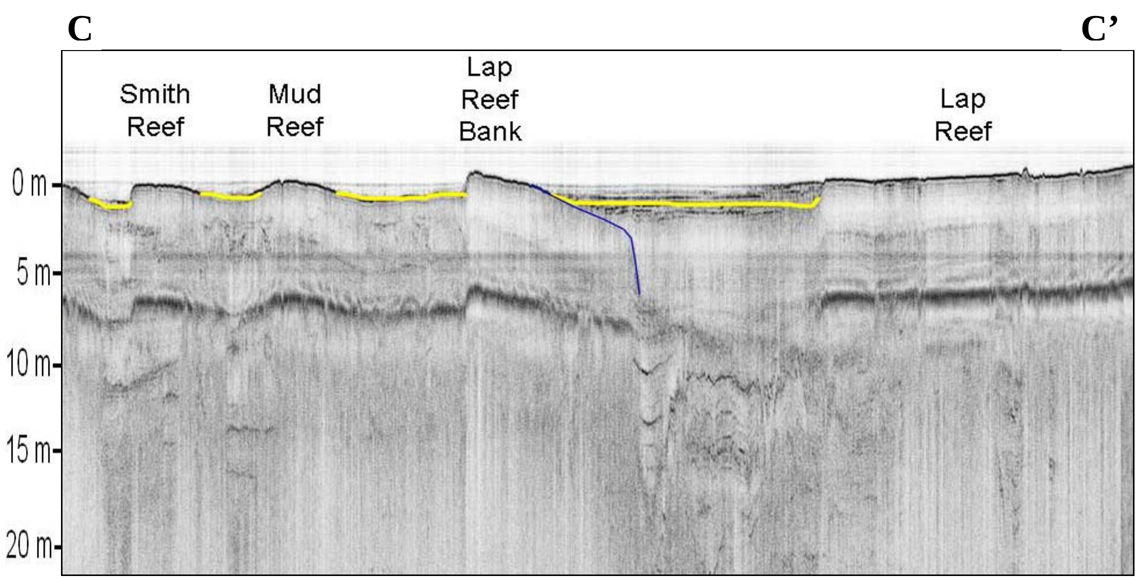

Fig. 31C. Seismic Line C-C' Note E5 cannot be delineated due to acoustic wipeout.

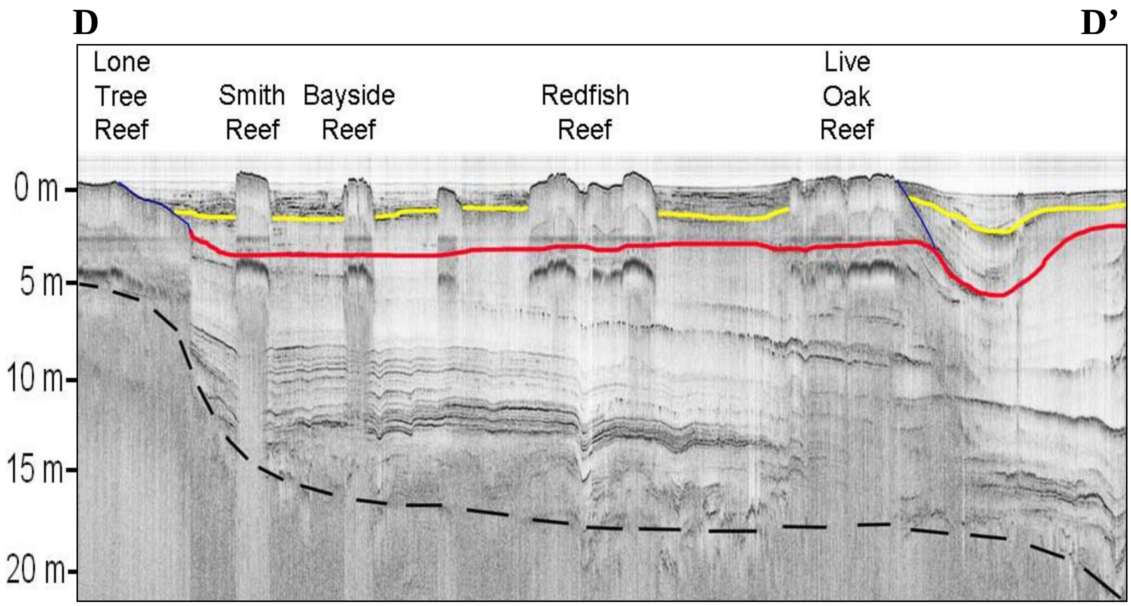

Fig 31D. Seismic Line D-D’.

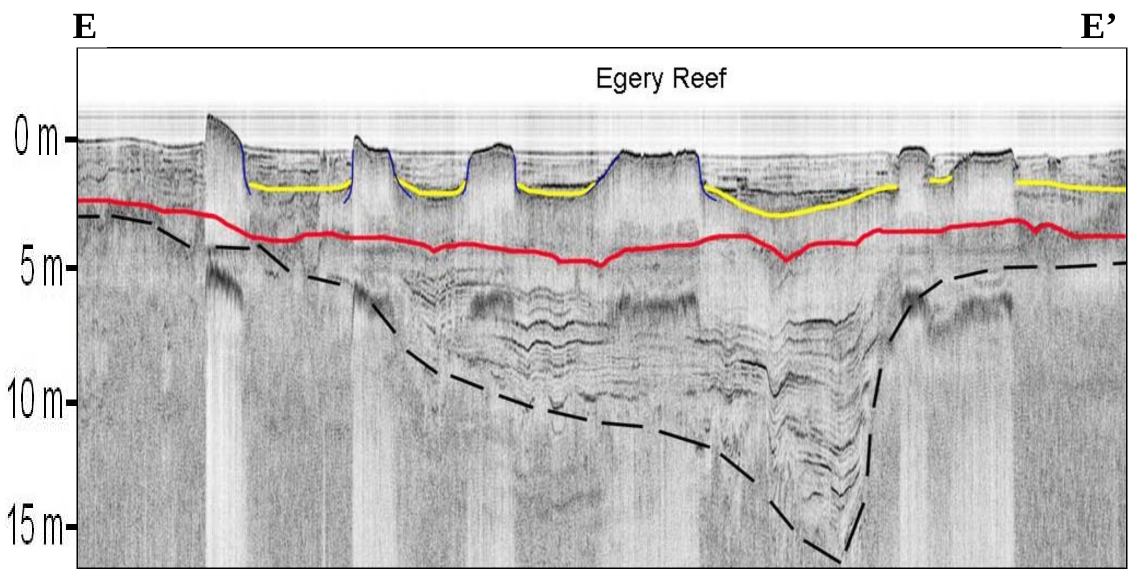

Fig. 31E. Seismic Line E-E’.

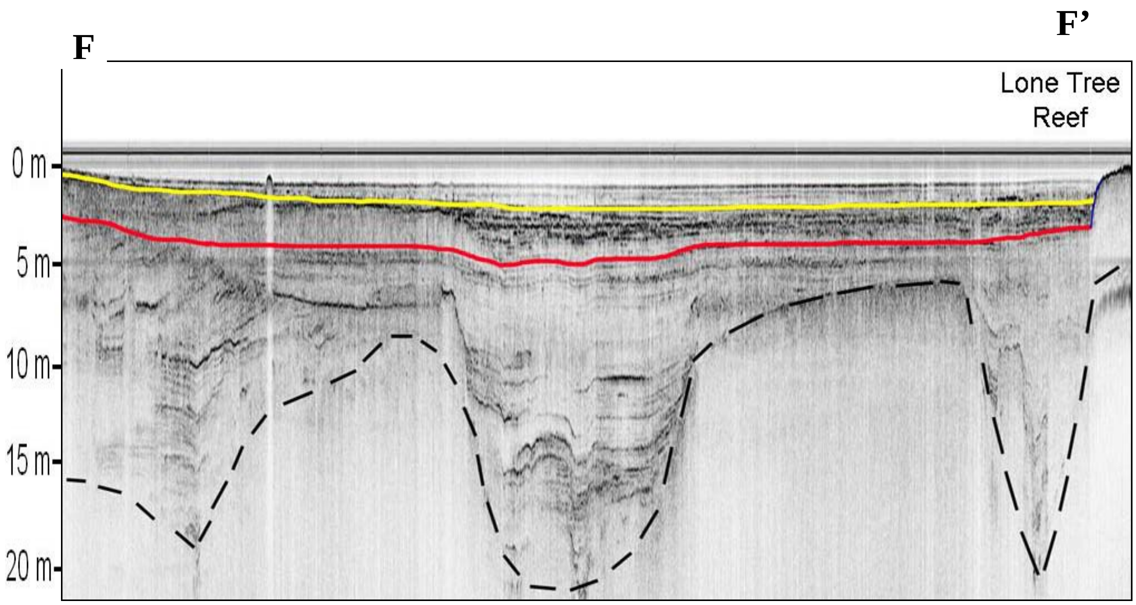

Fig. 31F. Seismic Line F-F'.

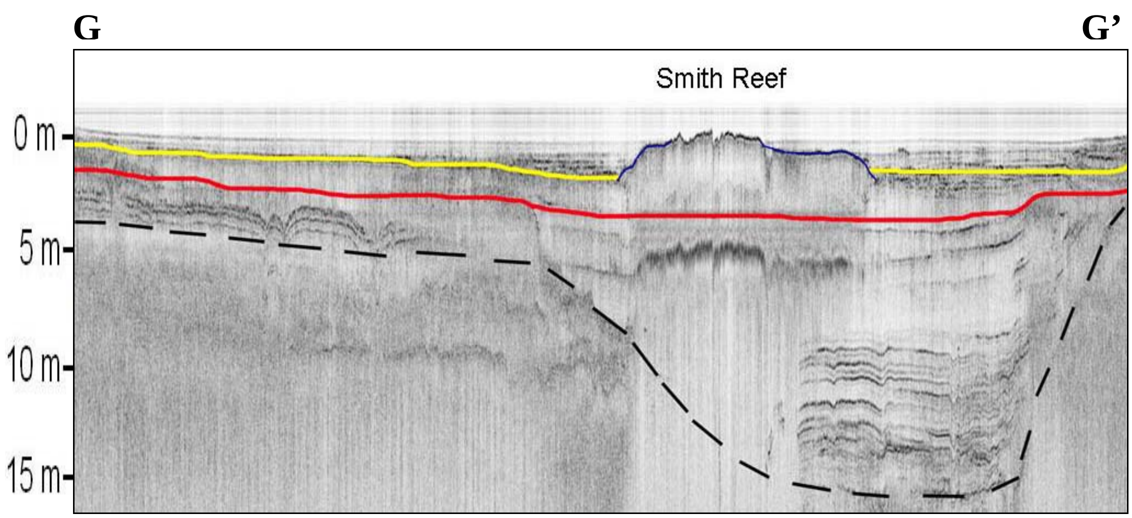

Fig. 31G. Seismic Line G-G'.

Based on the above seismic analysis of Reflector LGM and seismic layers attached to current reefs, it is evident that the first reefs to form in Copano Bay were formed near topographic highs in the Pleistocene surface, these highs primarily being river channel levees and fluvial terraces (Fig. 30). Only the large transverse reefs that currently stretch across most of the bay were first established on topographic highs in the Pleistocene surface (Fig. 30). After initial oyster reef development, the formation of the remaining reefs most likely occurred due to the expansion and erosion of the major transverse reefs. Figure 32 shows the distribution of oyster reef and shell hash deposit at the end of Event 4. Both reef and shell hash deposits would be capable of providing suitable substrate for oyster growth. These two substrates combined cover 75.864 km^2 or 53.8% of the entire bay bottom. The reefs shown in blue are in the same location as the present day reefs. The remaining reefs in Copano Bay are longitudinal reefs, patch reefs or sunken transverse reefs that all formed after the establishment of the major longitudinal reefs described above (Fig. 30). The current reefs not encompassed in the E5 surface area are most likely patch reefs that formed very recently either using eroded Pleistocene sands off the shoreline or erosion of present day reefs as suitable substrate.

River channel levees, or fluvial terraces, are generally composed of coarser sediment than the areas landward of the levees because as the flooding river water rises to the point where they overbank the levees. The water exits onto the flood plain where the flow of the current dramatically diminishes and the competence of the flow is dramatically reduced. As a result, the coarsest of the suspended load is deposited closest to the river channel causing the levee to build up and also to contain the coarsest sediment of the flooded terrace. As the bay fills with sediment and transitions to an open bay environment, the Holocene sediment filling the bay is both fine-grained and very soft. These channel levees also formed bathymetric highs and from a geotechnical standpoint, the channel levees have a higher compressional strength than the open bay deposits not underlain by levees. As a result, as the bays fill, oysters settling on the levee shoals not only would initially be slightly higher in the water column, as reefs formed on the levee deposits, the levees would be better suited to bear the load of the developing reefs.

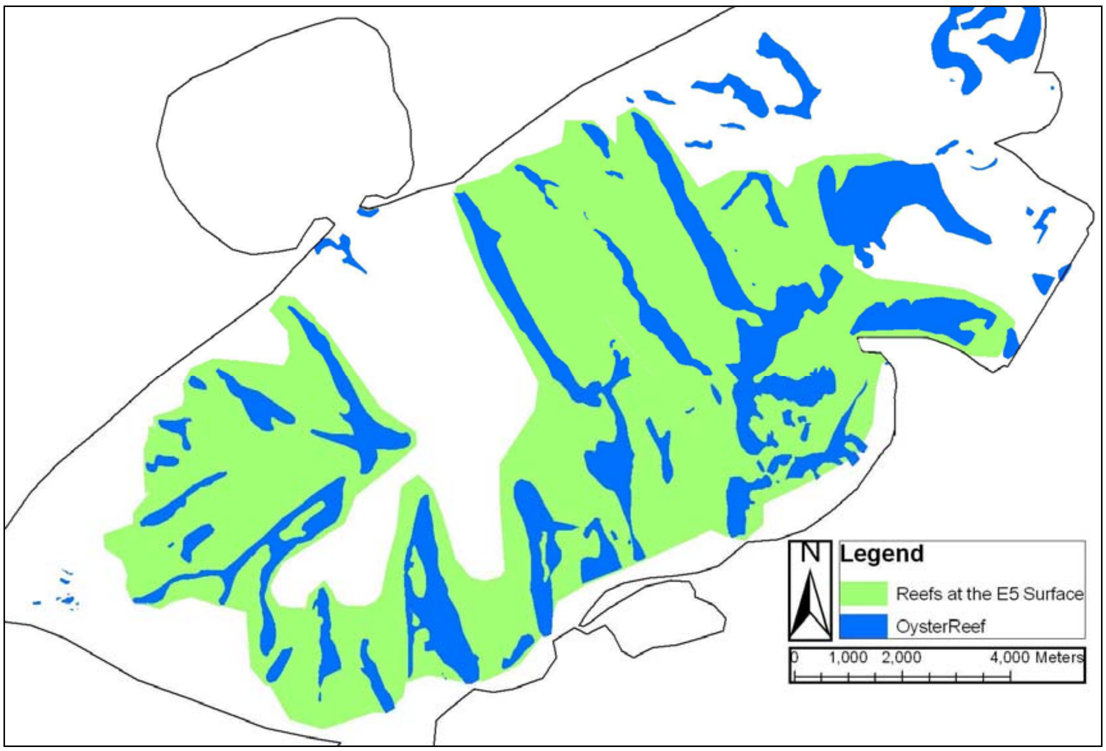

Fig. 32. Map showing location of past oyster reefs and shell hash or oyster reef debris atop Reflector F5 and current reefs.

5.5. Environmental Changes That Led to Oyster Reef Establishment

E5 represents a time when sea-level rise rates had stabilized to those closer to recent times. During the period of time represented by E5, the climate was much drier and there was less river input, as a result, sedimentation rates were presumably lower and we find that there was 2.8 times as much bay bottom capable of supporting oysters. The decrease in sediment supply and therefore freshwater input and suspended sediment, along with the slowing in sea level rise created ideal conditions for oyster reef growth. Turbidity, salinity and water depth conditions were ideal throughout the entire bay at this time; however, the oysters could only settle on areas where there was adequate substrate for attachment. These areas were the Pleistocene river levees as described above. Once those initial reefs were established, they provided adequate substrate, either by providing existing reef upon which to build or creating layers of eroded shell hash surrounding the reefs, upon which the rest of the reefs could become established. Because adequate substrate was the limiting factor at that time, once substrate was established, the oyster reefs likely expanded across the bay very rapidly. This created the E5 layer in the seismic and sediment profile (Fig. 32). E6 is interpreted as a period of environmental change, with the sequence of sediment above E6 dominated by middle bay mud deposits and oyster reef, with much of the mud deposited on the shell hash deposits mapped in E5. As sediment input to the bay increased, the bay filled with fine mud and the lower lying shell bearing areas likely subsided into the bay sediment. This occurred because shell growth could not keep pace with both the rapid fill of bay sediment and also because of the enhanced sinking of these habitats into the bay bottom in those area not supported by the subsurface channel levees or other foundation material. The distribution of oyster reefs continually decreased until we have the present day reef distribution.

5.6. Trends of Oyster Reef Growth in Copano Bay

GIS analysis of Reflector F5 at 1.5 m below the present sediment surface of the bay indicates that the majority of individual oyster reefs in Copano Bay formed with broad bases, on Reflector F5, and with the subsequent increase in sedimentation and sea-level rise, the reefs grew upward and dramatically narrowed in width causing a 64% reduction in reef distribution from 2.5 ka to today. It should also be noted that nearly all of the reefs found within Copano Bay appear to have started forming during the E5 period, suggesting that the reefs are as old as 4.8 ka. There are older reefs found within the subsurface, but they do not extend to the surface. The cause of the decreasing area of oyster reefs is most likely due to increases in fine sediment input to the bay, which has suffocated the oysters on the fringes of the reef, causing the reef to become narrow. Also, high salinity levels and temperatures found recently in Copano Bay can decrease oyster growth rate and even cause mortality (Heilmayer et al. 2008). With increasing sea level rise and in turn increasing sedimentation rates, and decreasing water quality for oyster growth, the ongoing trend of decreasing natural oyster reef area over the past 4.5 ka is likely to continue, for the present day reefs in Copano Bay proper. Mission Bay was not mapped in this study because the water depths are generally 1 m or less and too shallow for surveying with the techniques used in this study. The present day bayhead delta for the Mission River resides primarily in Mission Bay and with increased sea level, it would be expected that these reefs would increase in distribution and expand up the Mission River valley, expanding further across the submerged bayhead delta.

5.7. Future Restoration, Research and Regulation Implications

These observations and associated dataset will provide a vital tool for choosing future oyster reef restoration sites in Copano Bay. Restoration sites can be chosen in areas where known underlying coarse strata suggest a geotechnically competent subsurface layer for the support of shell and reef as opposed to those areas which are underlain by thicker sequences of Holocene mud with no foundation layers of coarser sediment available. This study also uncovered many previously unknown oyster reefs in Copano Bay. Little is known about the biological health and function of these flat, subtidal reefs. This dataset will provide biologists with the opportunity to study these reefs in more detail. Copano Bay has historically seen a great deal of oil and gas exploration and is seeing a resurgence of this activity. Barge traffic and exploration projects must avoid impact to delicate oyster reefs and this data set will provide resource agencies the needed information to ensure the oyster reefs are protected from such activity. Also, the Texas Department of Transportation is planning on widening the existing Highway 35 Bridge across Copano Bay. This dataset will allow them to avoid impacts to existing oyster reefs as much as possible.

6. CONCLUSIONS

Most of the oyster reefs found today in Copano Bay likely formed on top of the E5 surface, during the period of time when sea level rise had stabilized and there was a depressed amount of suspended sediment entering the bay. The first oyster reefs in Copano Bay were transverse reefs that formed atop shallow areas of the Pleistocene surface, using these fluvial terraces as suitable substrate upon which to settle. Transverse reefs, after initial formation, grow out perpendicularly to prevailing water currents which is perpendicular to the shoreline in Copano Bay. Other longitudinal and patch reefs were then able to establish after these initial transverse reefs were formed by using them as a base to expand upon or by using the eroded shell material as suitable substrate. Longitudinal reefs, after initial formation, grow parallel to prevailing water currents and in turn the shoreline in Copano Bay. Patch reefs can form atop any suitable substrate and exist in any shape but are usually much smaller than transverse or longitudinal reefs. The oyster reefs in Copano Bay thrived in the low suspended sediment conditions and established over a large area (53.8%) of the bay. Then the climate then shifted to a much wetter environment (E6) which significantly increased the suspended sediment in the bay. The oysters on the fringes of the reefs were suffocated by the large amounts of suspended sediment in the water. The general trend of Reflector F5 indicates that the majority of oyster reefs in Copano Bay formed over a very large area which covered 53.8% of the bay, then grew upward and narrowed to a smaller extent where they currently are today, covering 16.3% of the bay surface. This confirms that this trend of fringe reef dying and becoming silted in by estuarine mud, allowing the inner portions of the reef to survive has been going on for the past approximately 4.8 ka.

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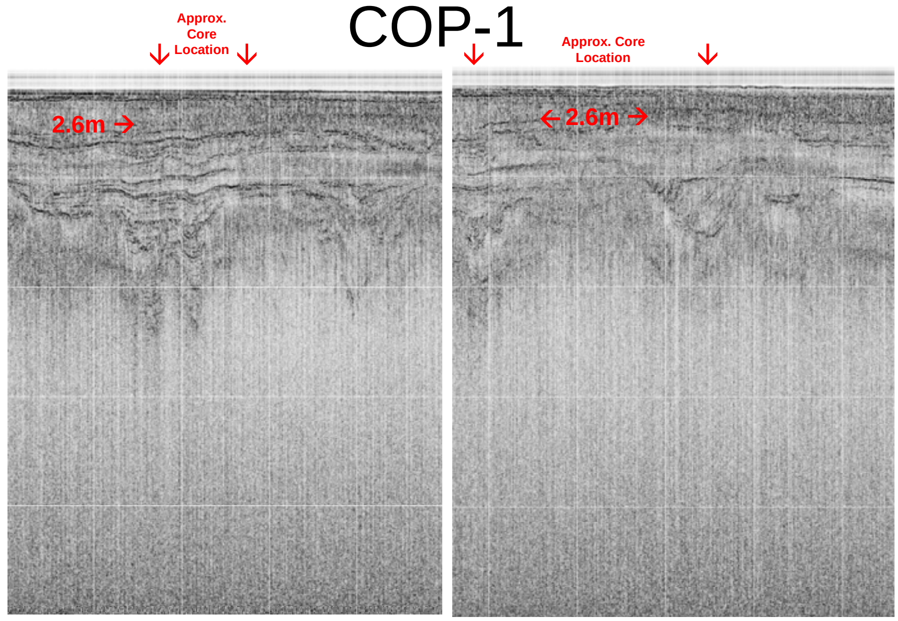
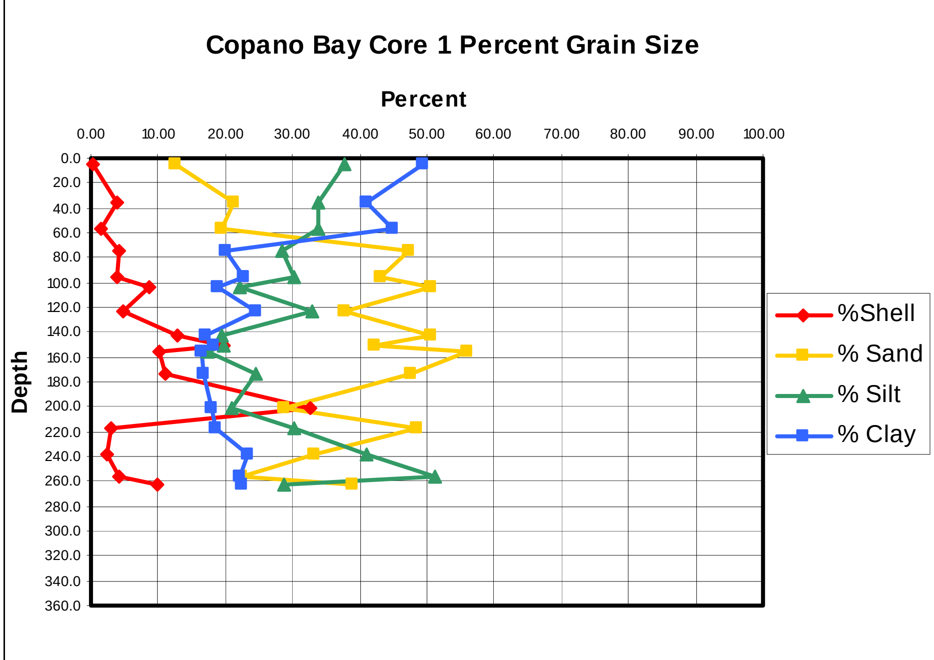
APPENDIX A

- 0677041 m N, 3107840 m E, Zone 14N
- Between Chirp Lines 156 and 157





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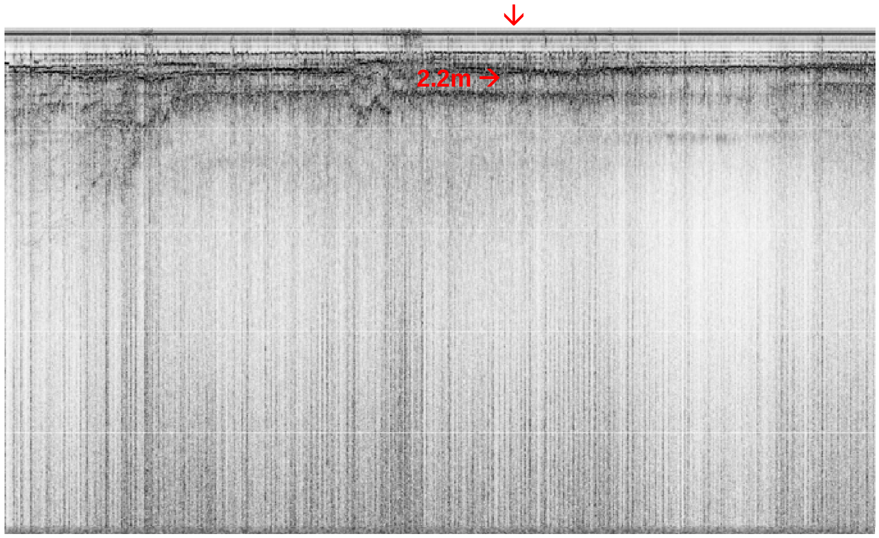
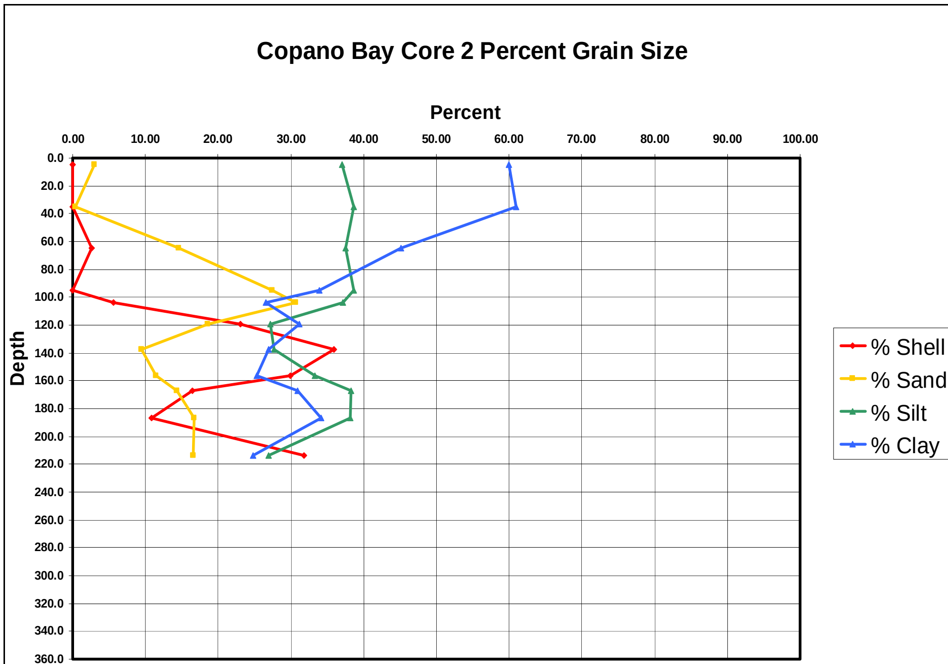
- Line 130

COP-2





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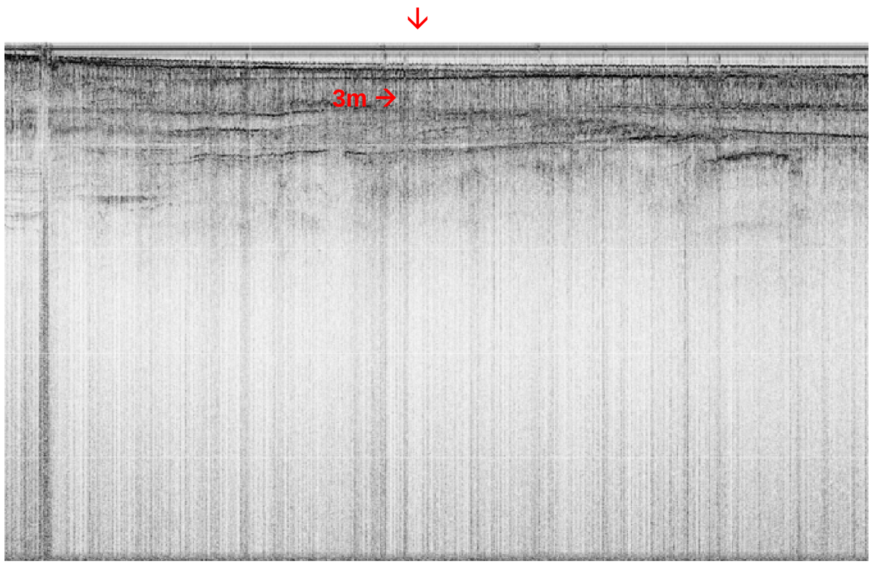
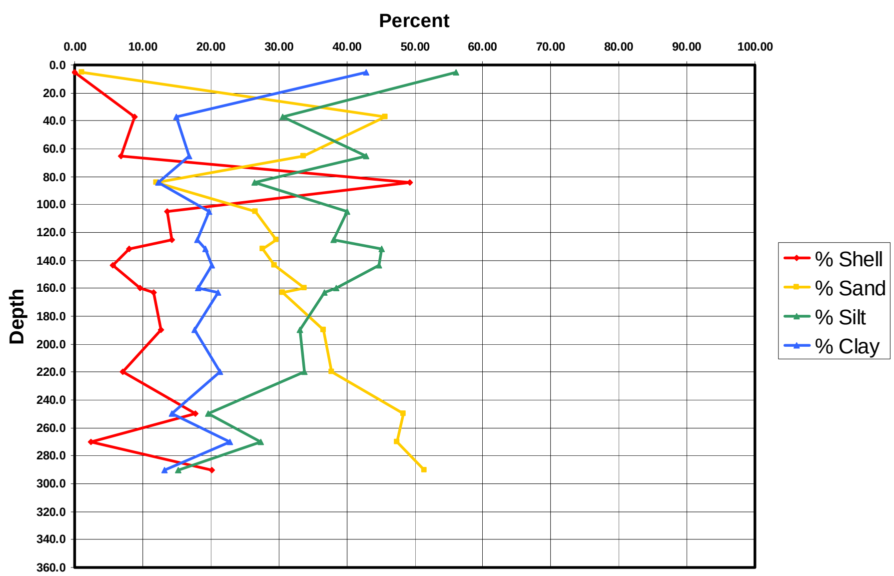
- Line 109

COP-3



Copano Bay Core 3 Percent Grain Size



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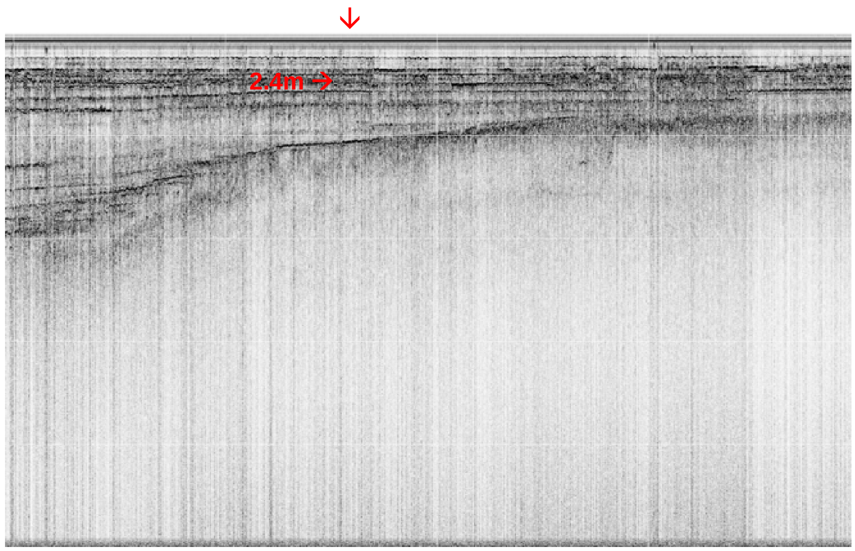
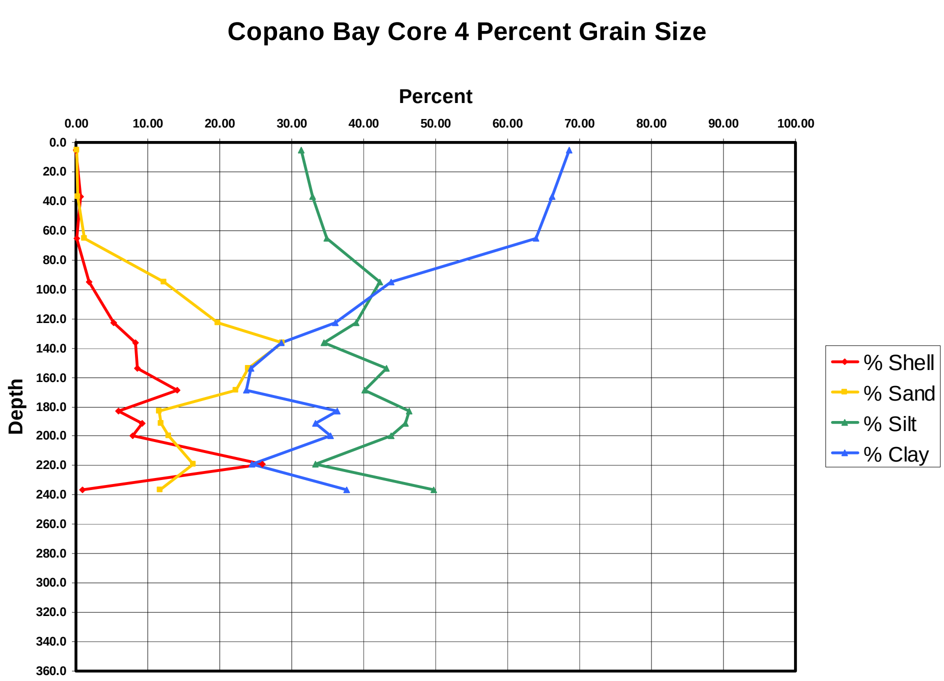
- Line 109

COP-4





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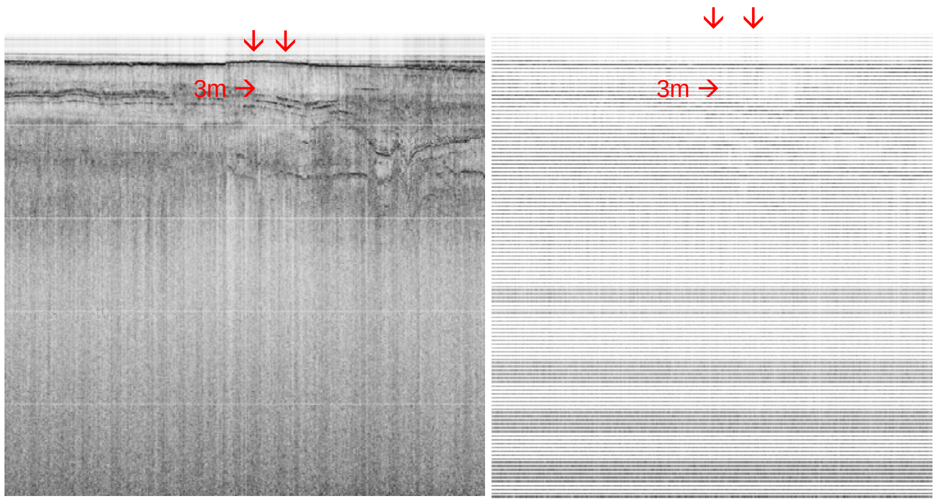
- Line 87-88

COP-5



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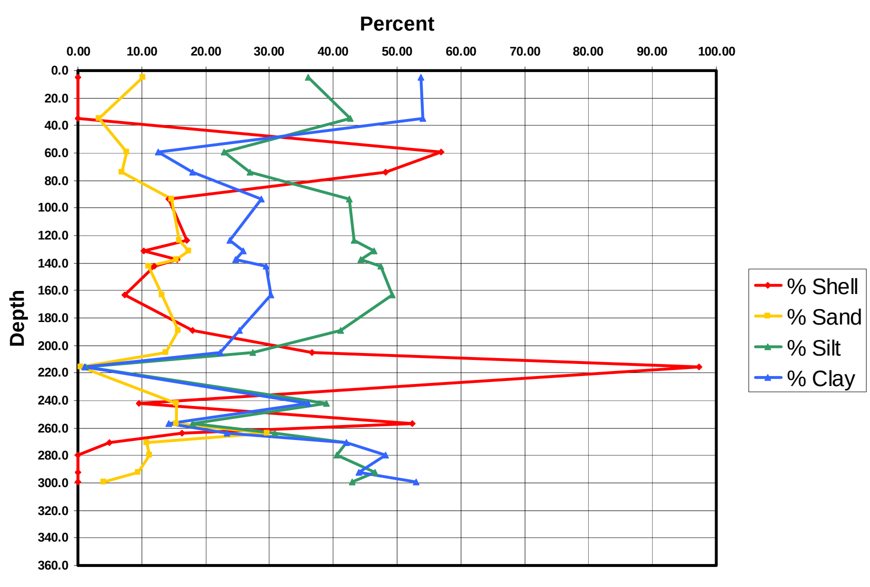

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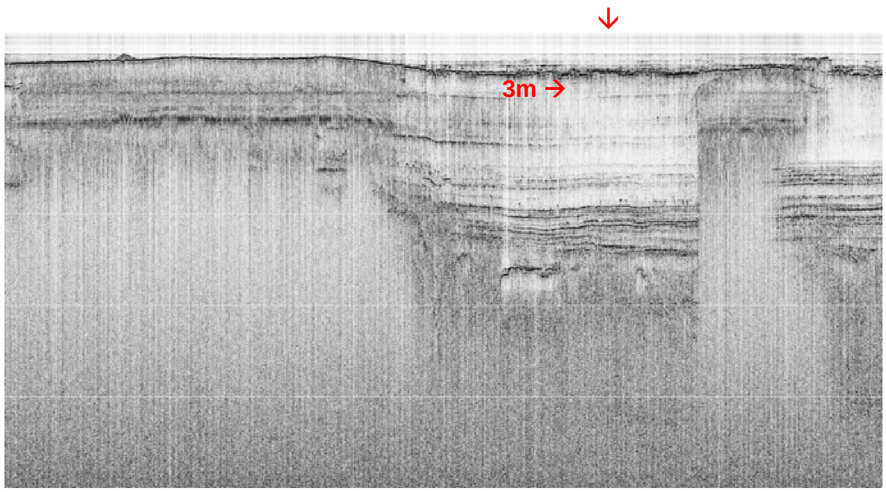
- Line 85

COP-6



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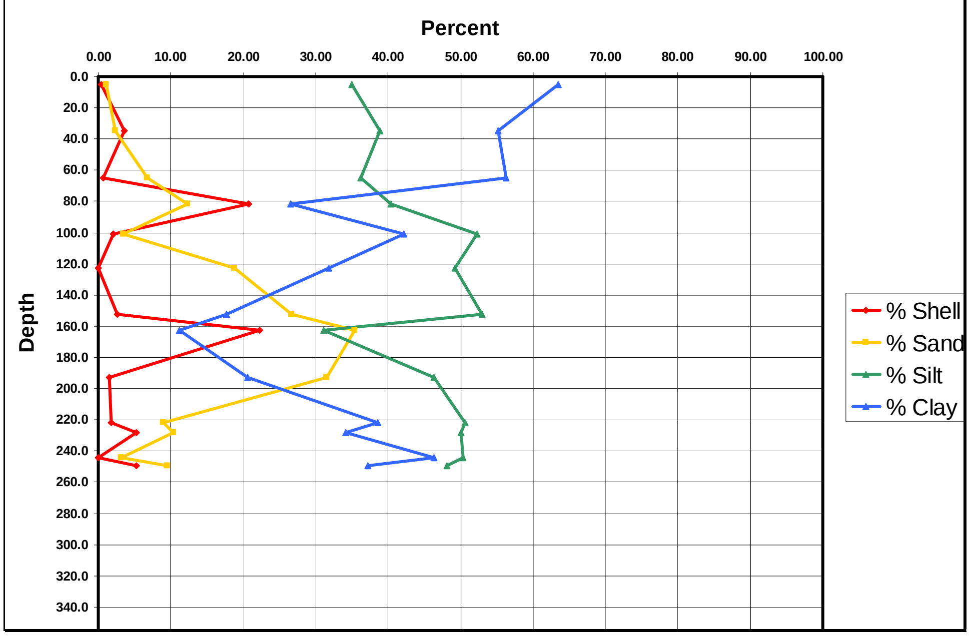

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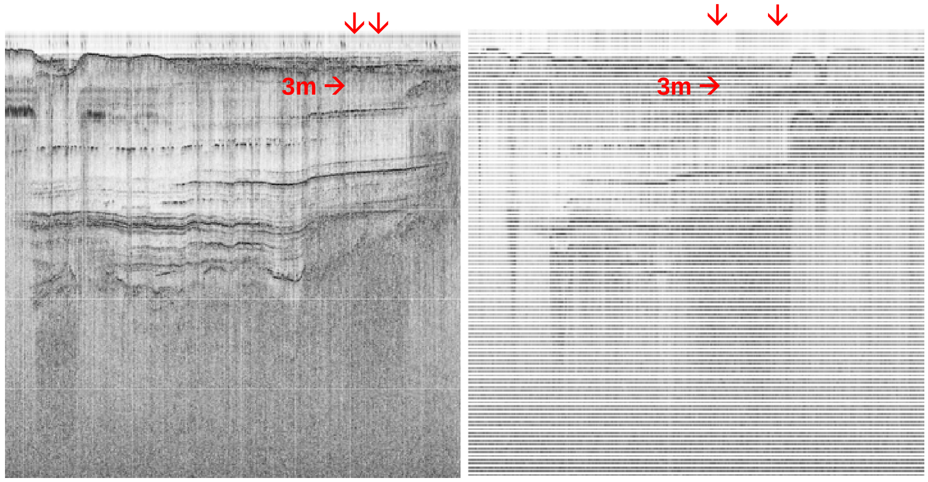
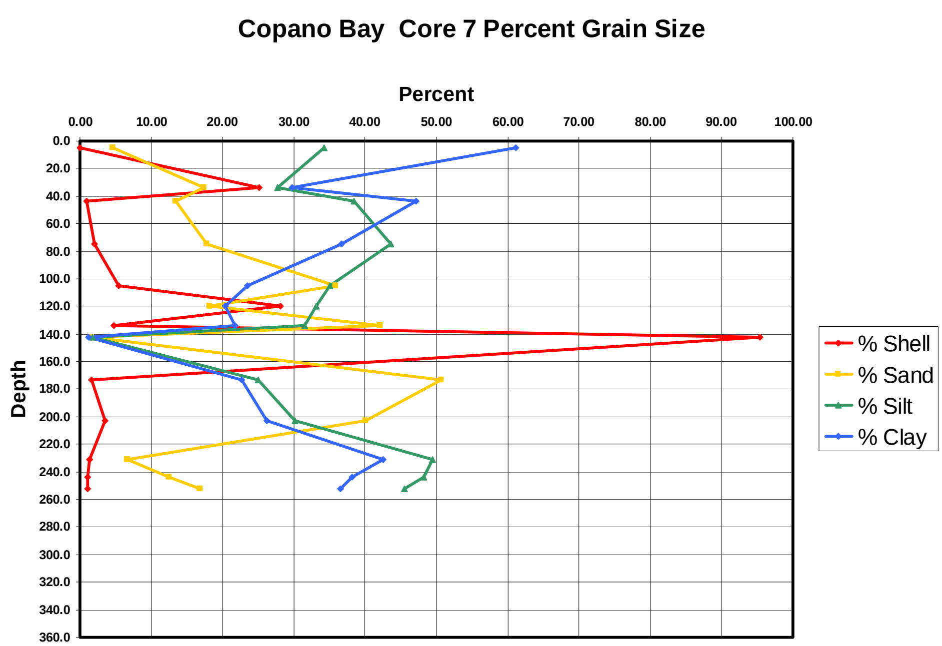
- Line 73-74

COP-7





COP-8

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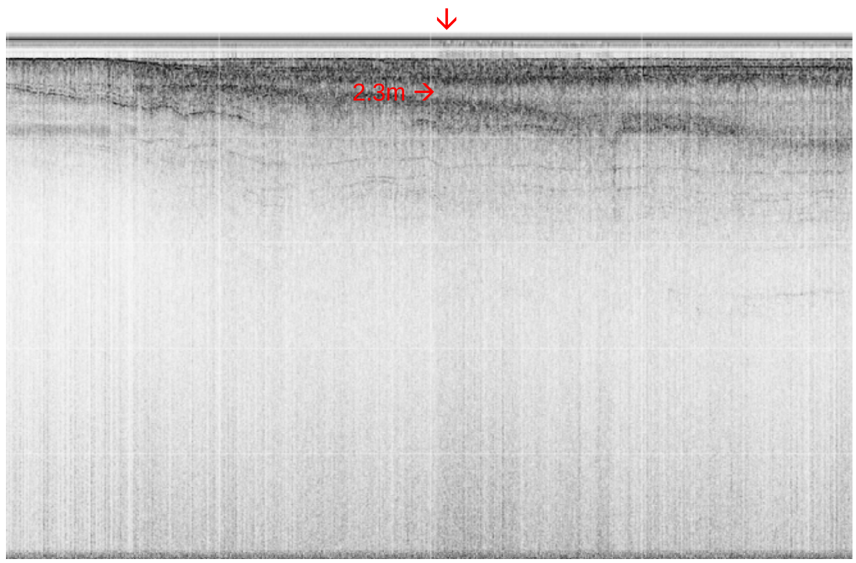

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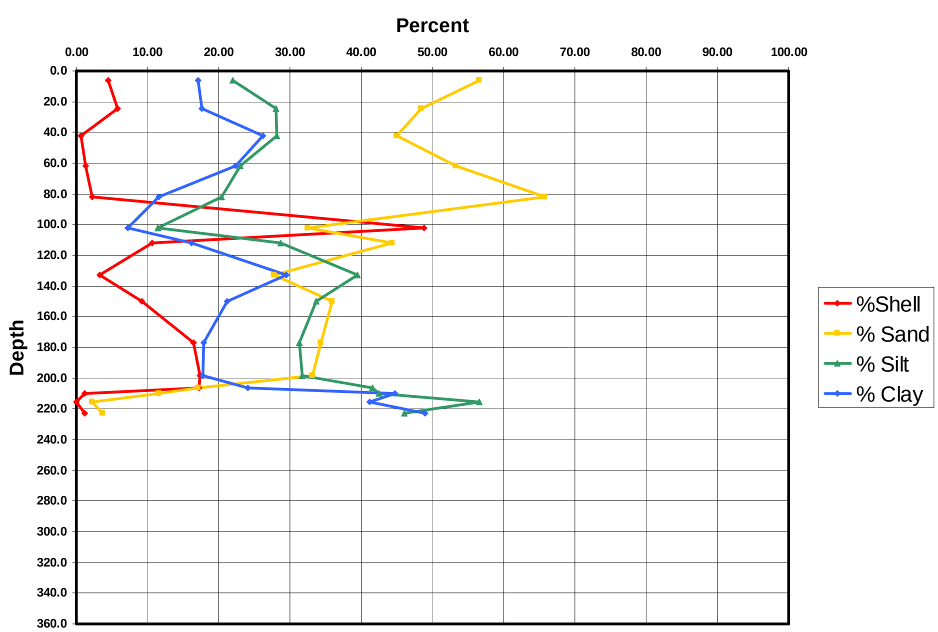

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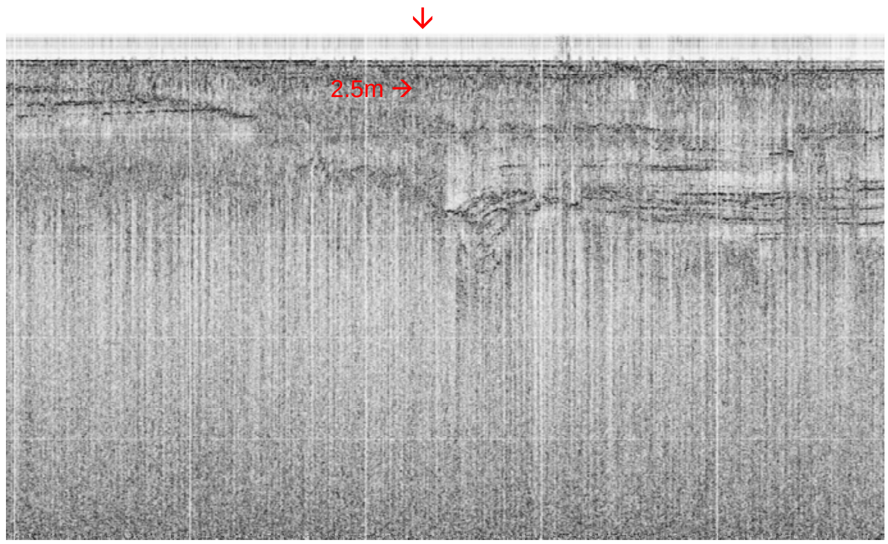
COP-9



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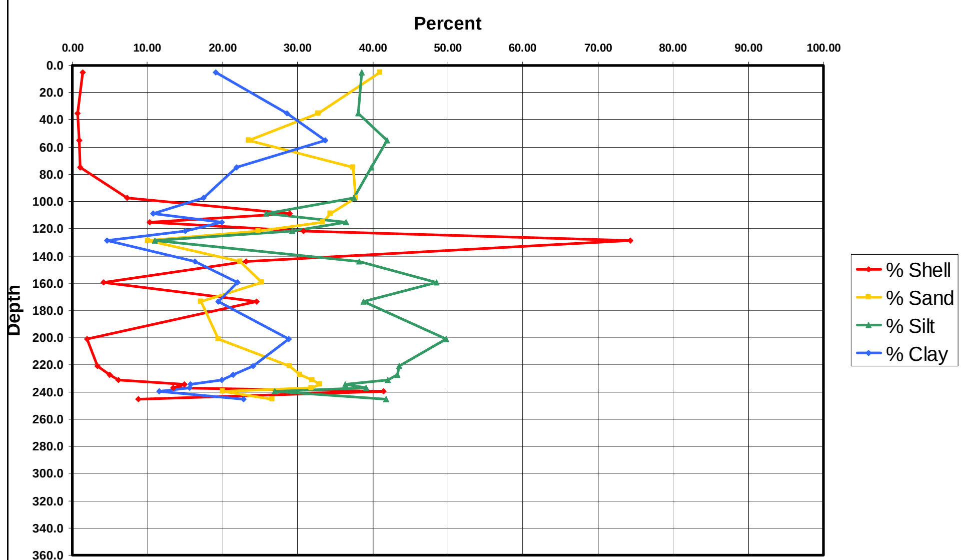

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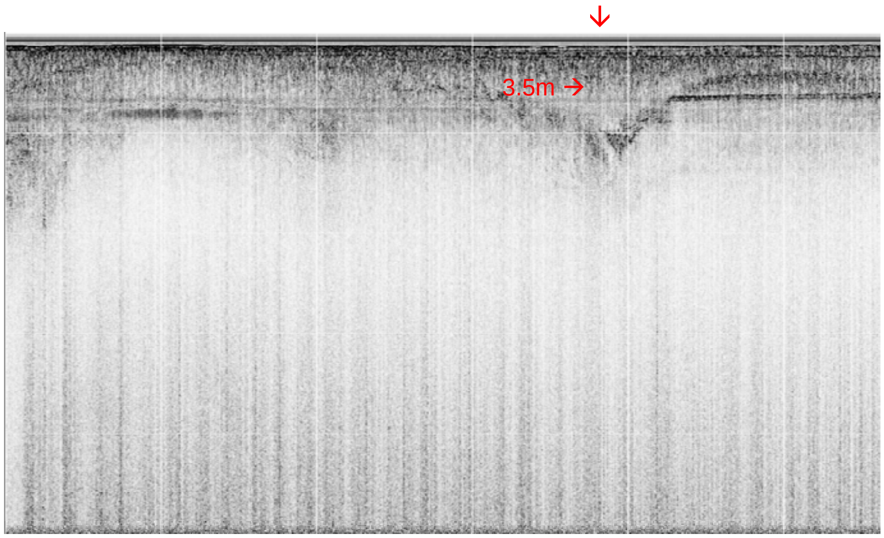
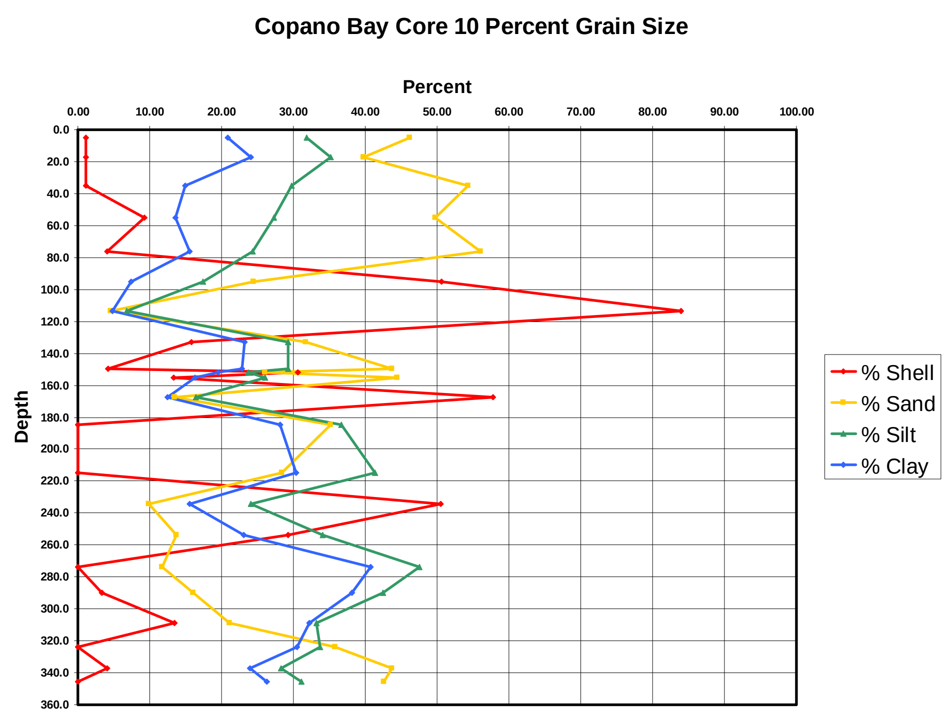
COP-10





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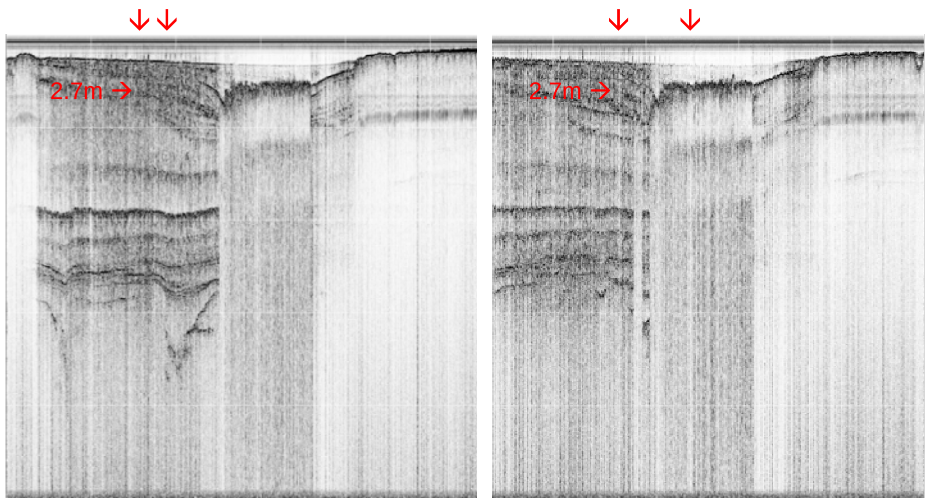
COP-11



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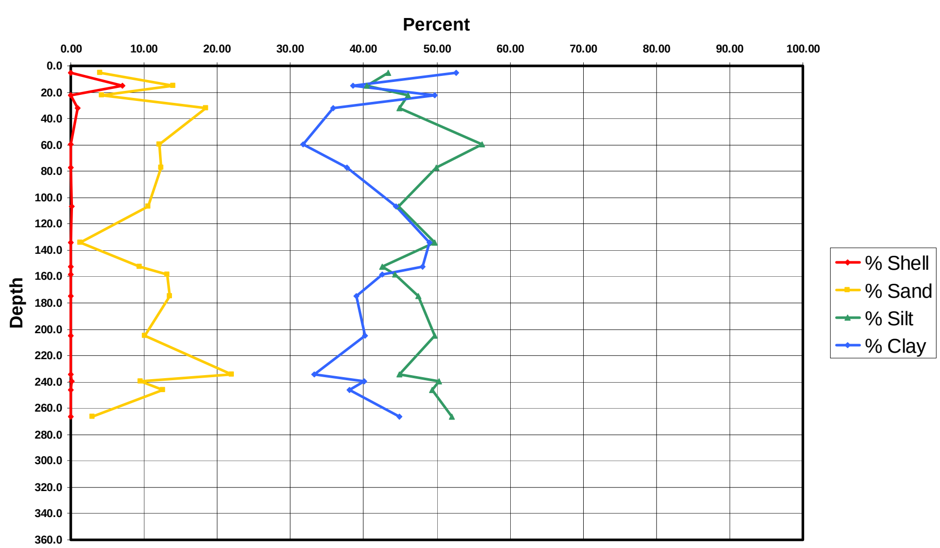

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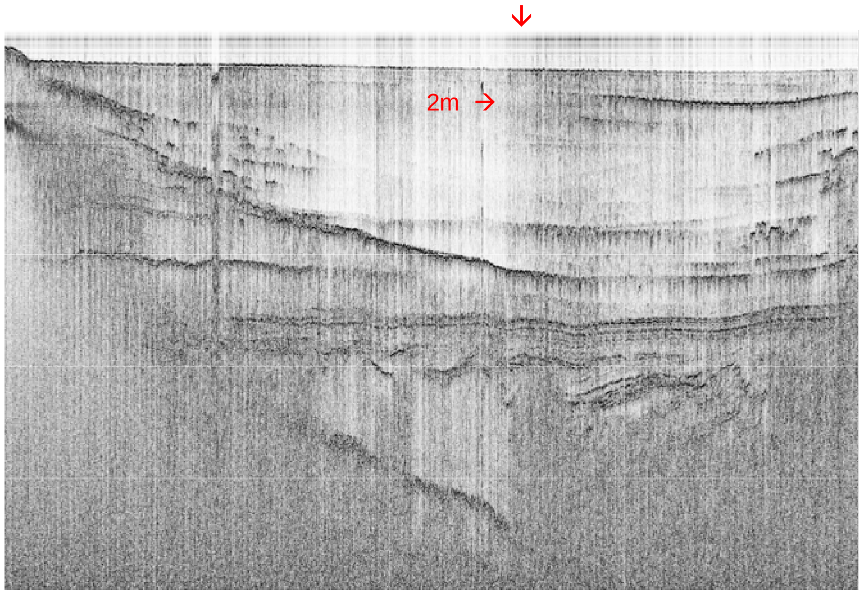
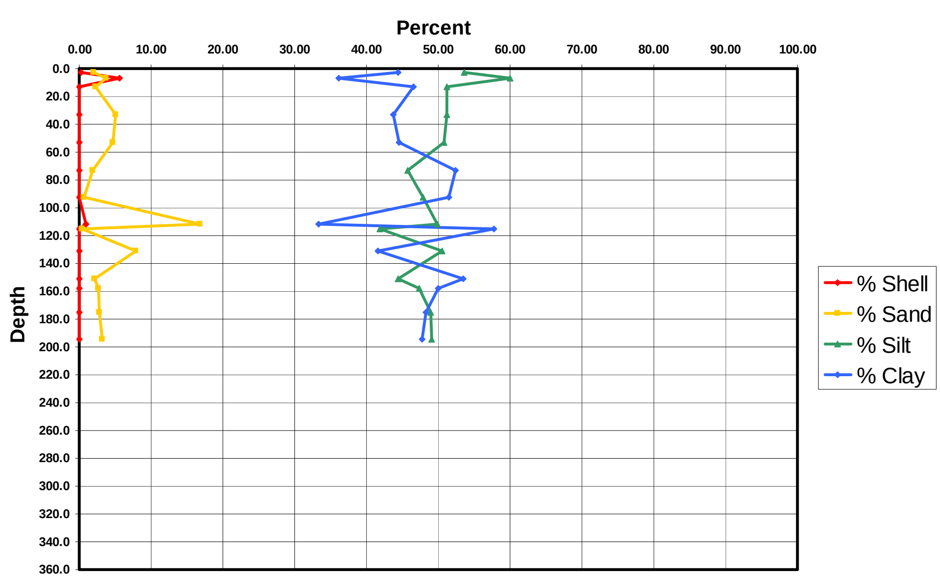
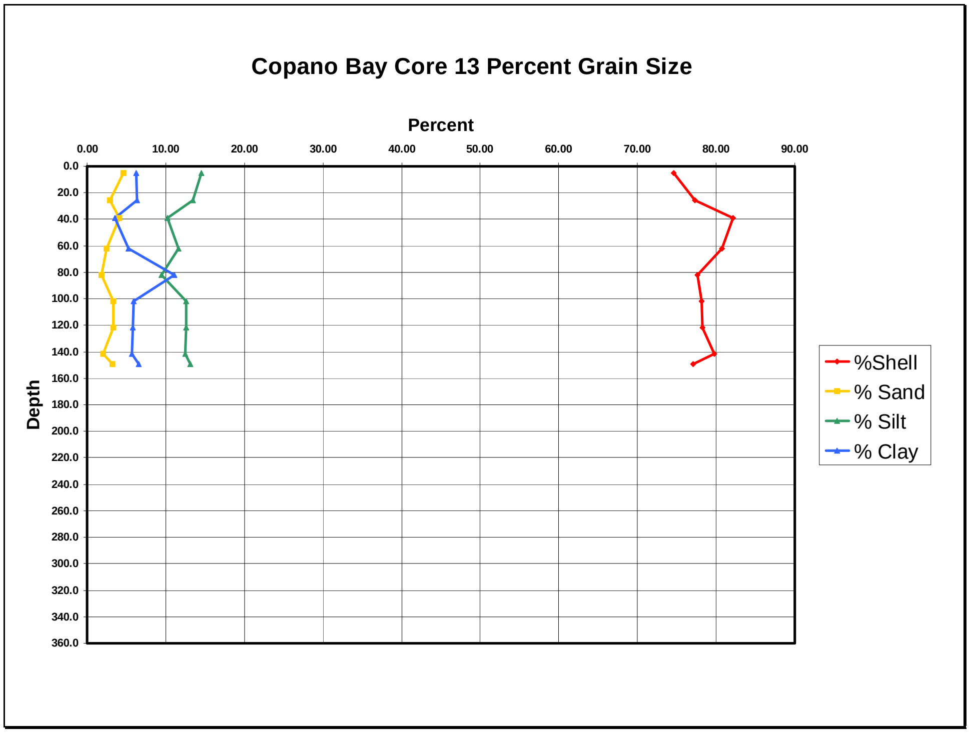
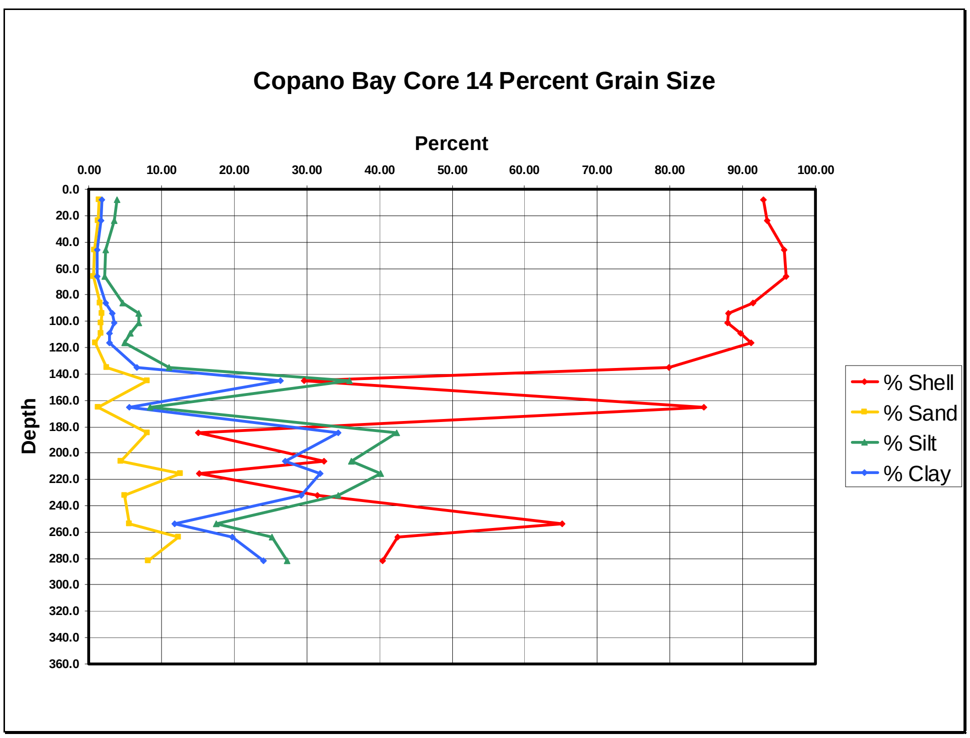
COP-12

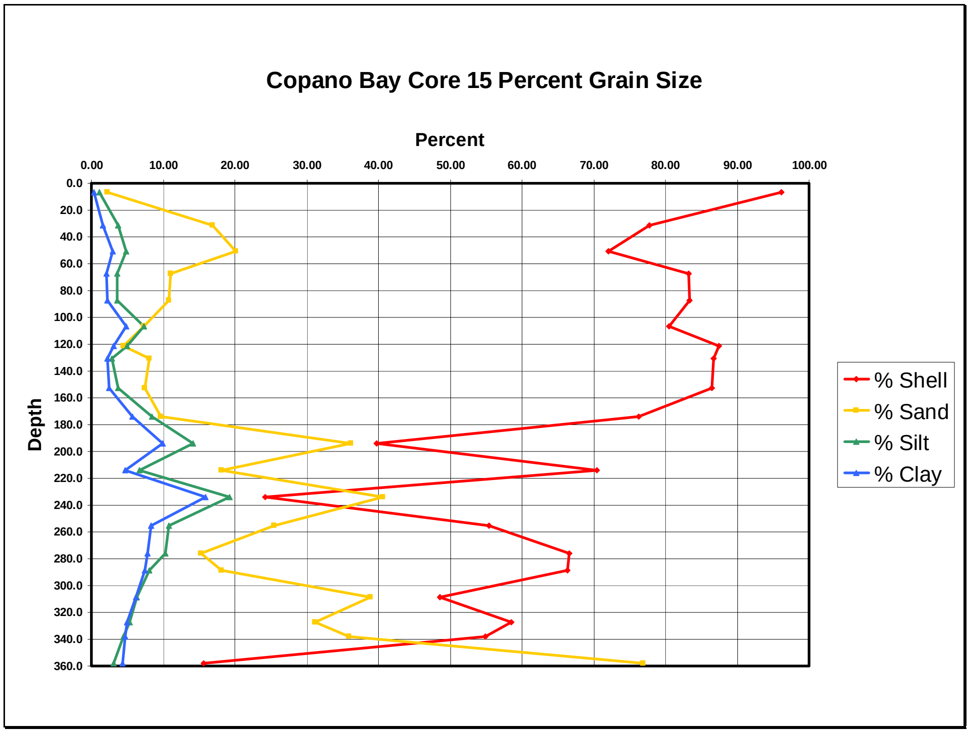


Copano Bay Core 12 Percent Grain Size




Copano Bay Core 13 Percent Grain Size
Percent
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
Depth
0.0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
160.0
180.0
200.0
220.0
240.0
260.0
280.0
300.0
320.0
340.0
360.0
%Shell
% Sand
% Silt
% Clay

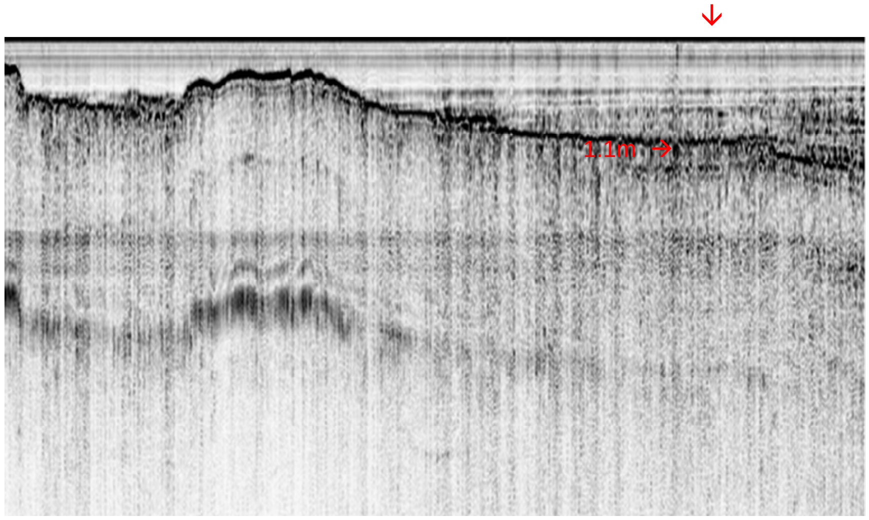

Copano Bay Core 14 Percent Grain Size
Percent
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
Depth
0.0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
160.0
180.0
200.0
220.0
240.0
260.0
280.0
300.0
320.0
340.0
360.0
% Shell
% Sand
% Silt
% Clay



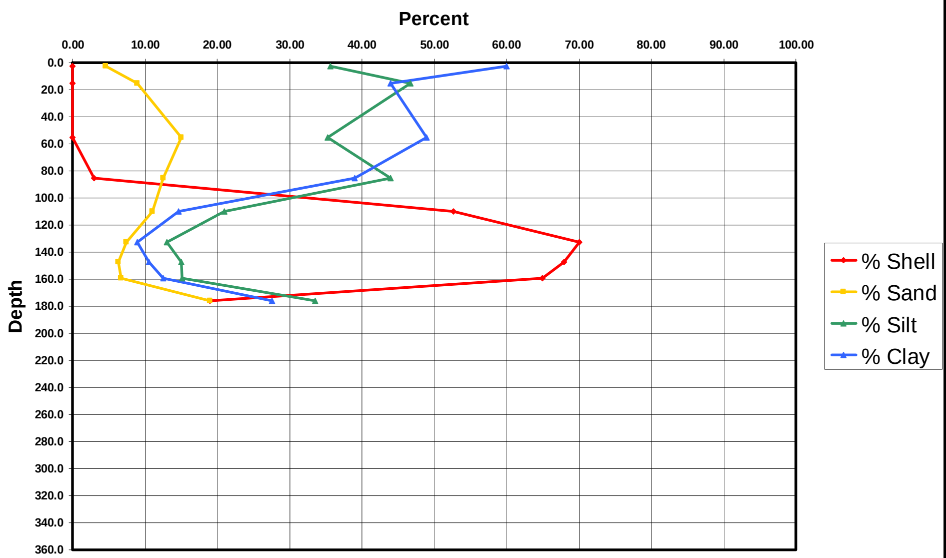
Copano Bay Core 15 Percent Grain Size
Percent
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
Depth
0.0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
160.0
180.0
200.0
220.0
240.0
260.0
280.0
300.0
320.0
340.0
360.0
% Shell
% Sand
% Silt
% Clay

- 0685632 m E, 3107054 m N
- Line 108

COP-16



Copano Bay Core 16 Percent Grain Size



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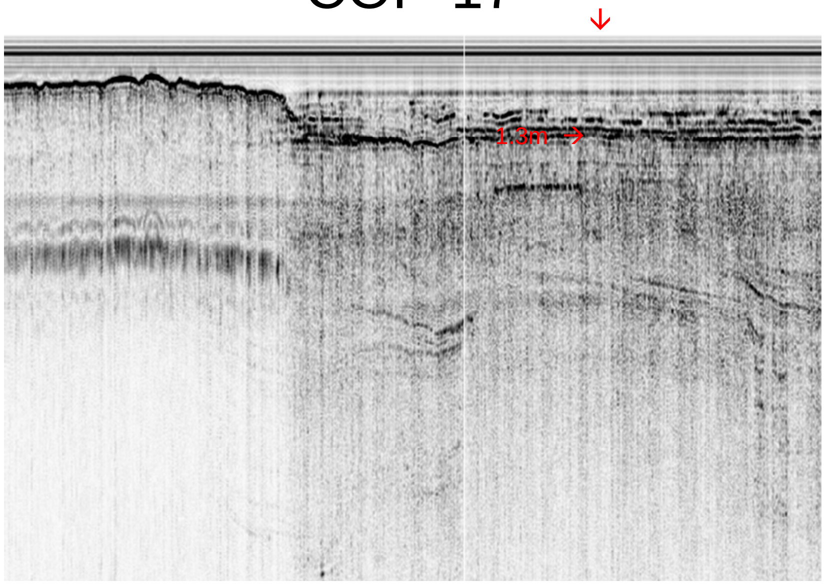
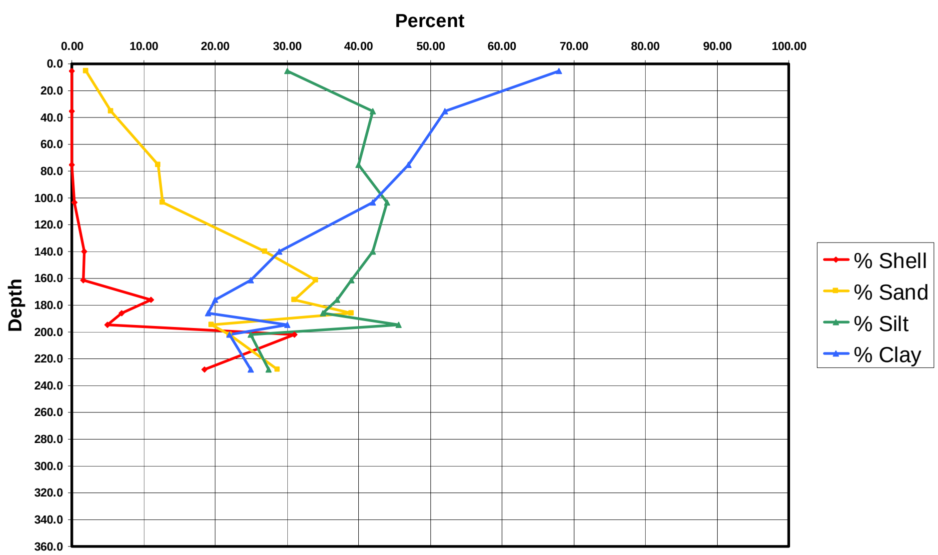
- Line 106

COP-17

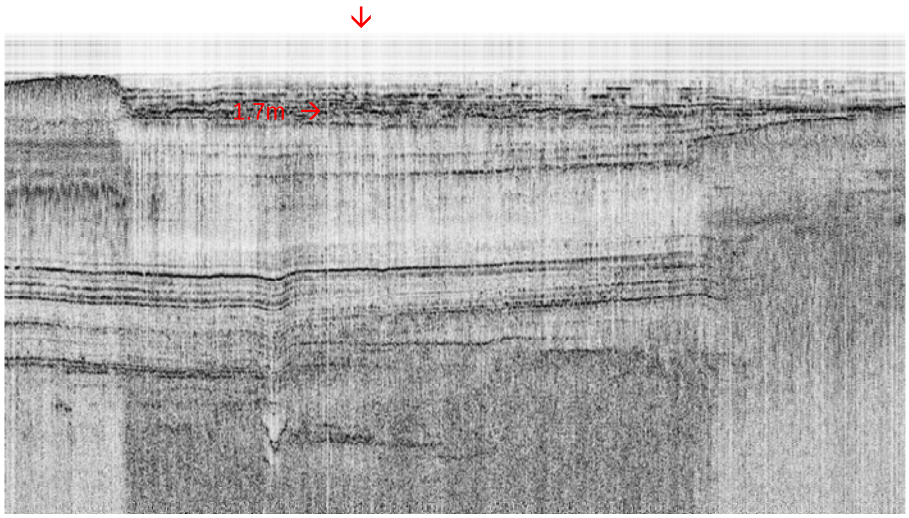


Copano Bay Core 17 Percent Grain Size

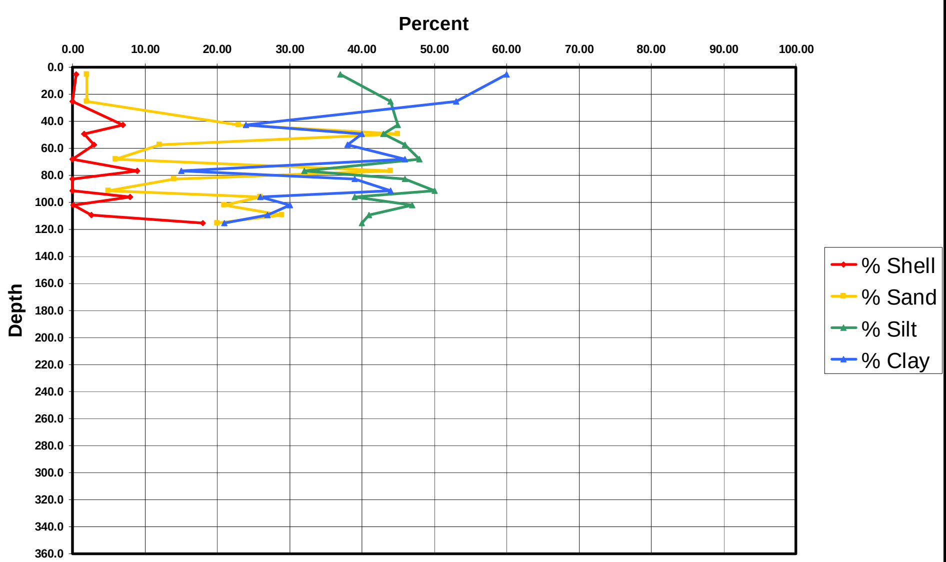


- 0686301 m E, 3109119 m N
- Line 97

COP-18

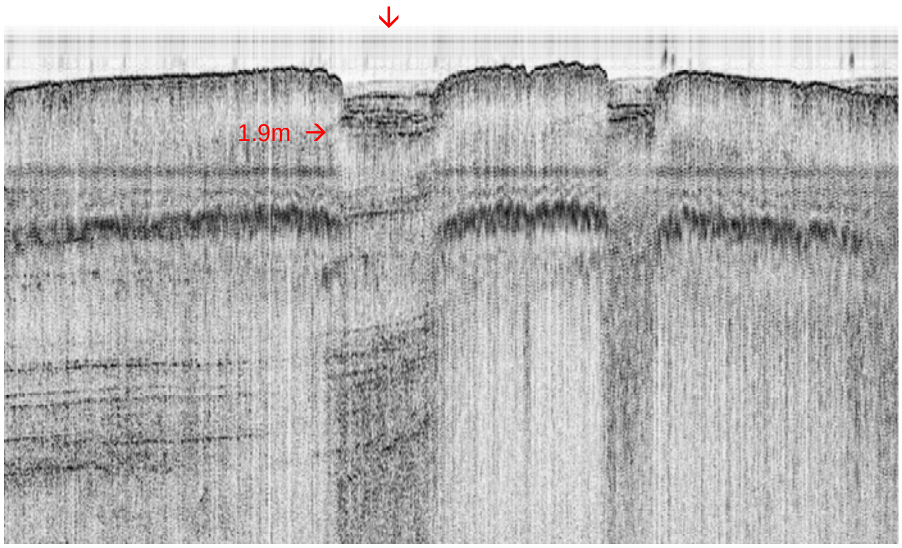


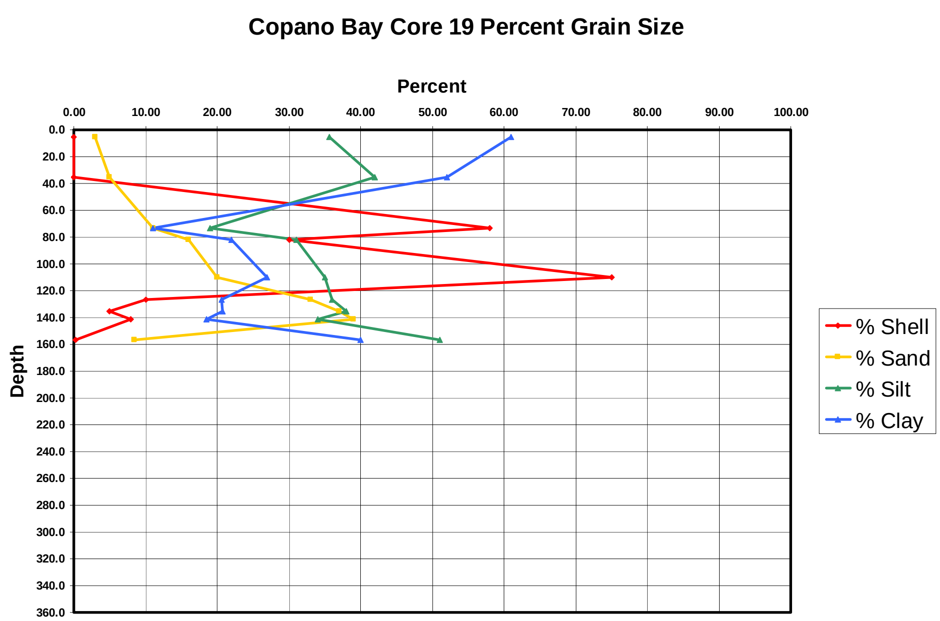
Copano Bay Core 18 Percent Grain Size



- 0689309 m E, 3109649 m N
- Line 78

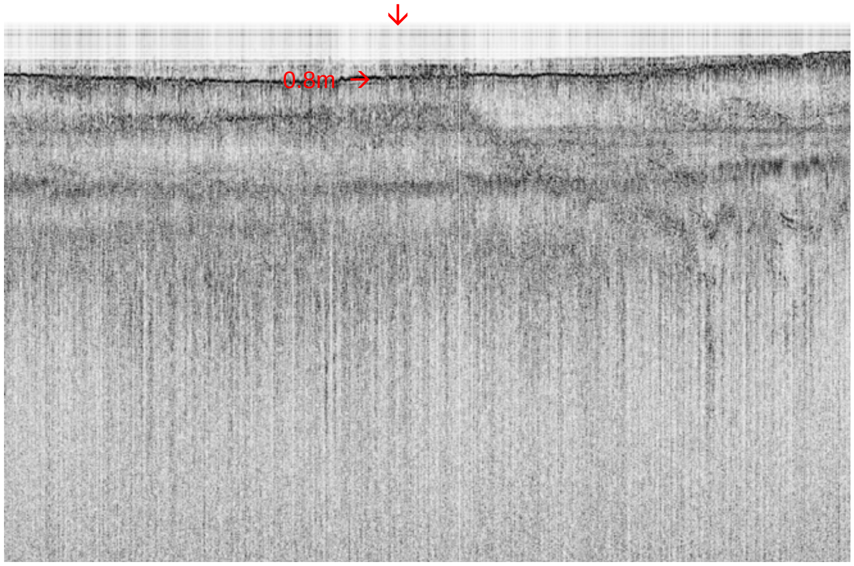
COP-19

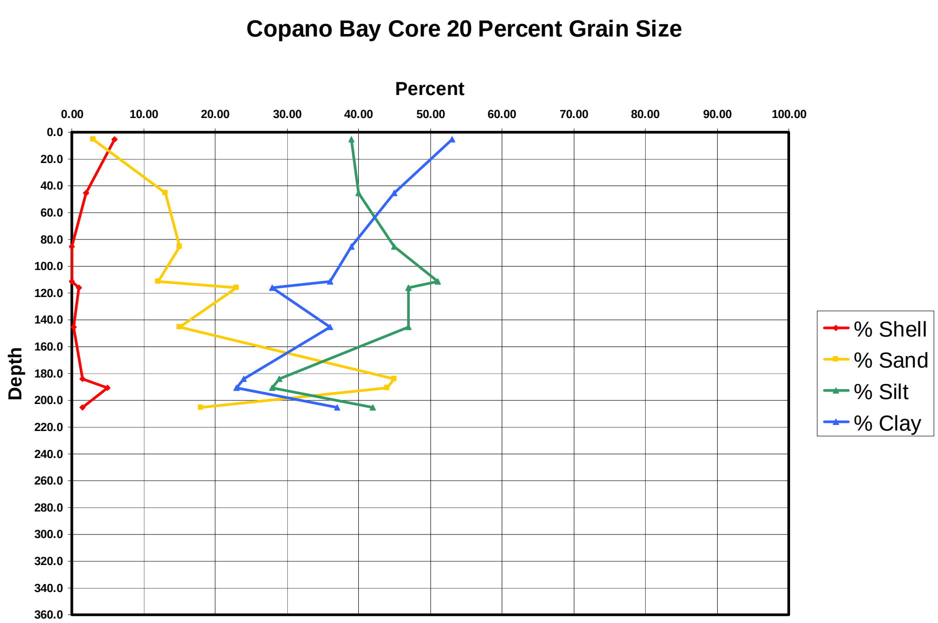




- 0681906 m E, 3105963 m N
- Line 134

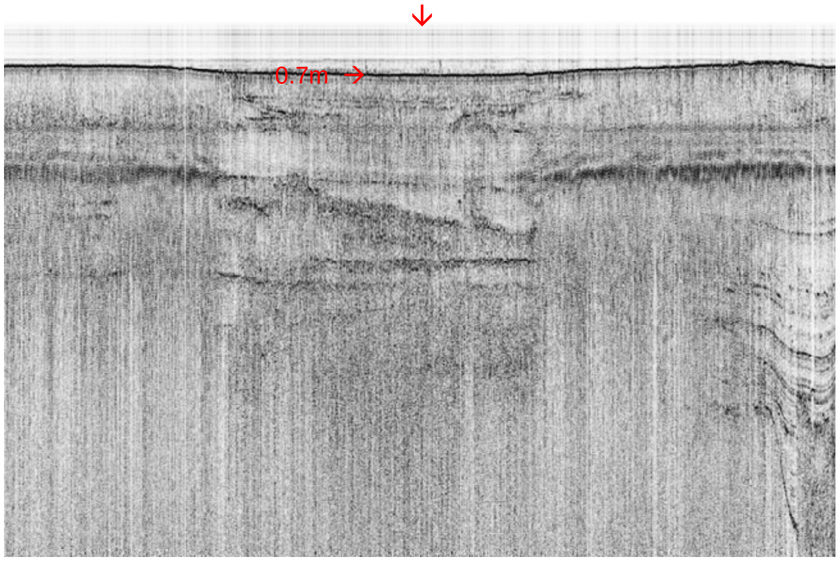
COP-20



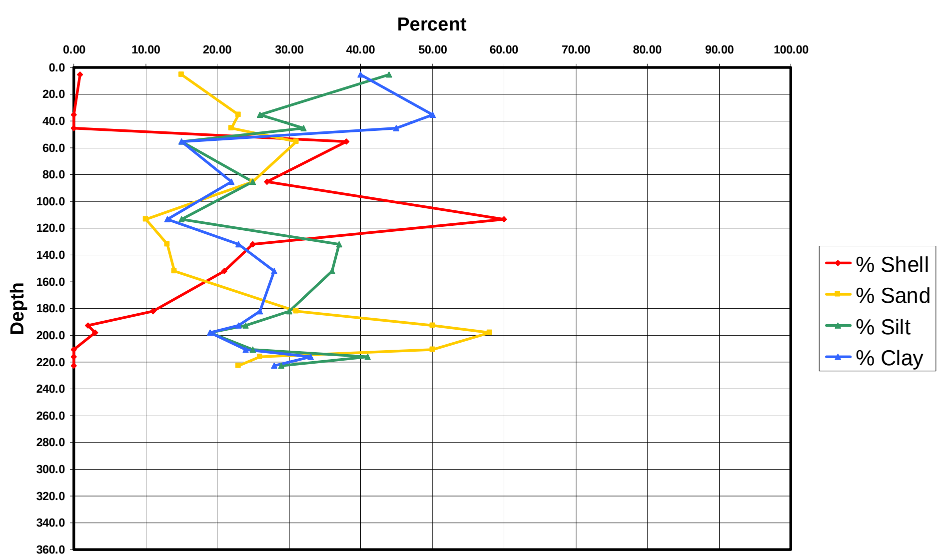


- 0687343 m E, 3111608 m N
- Line 83

COP-21

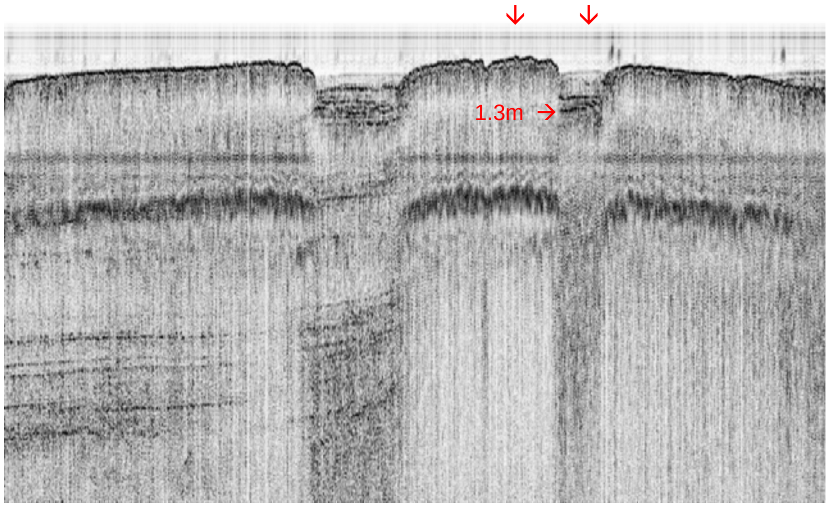


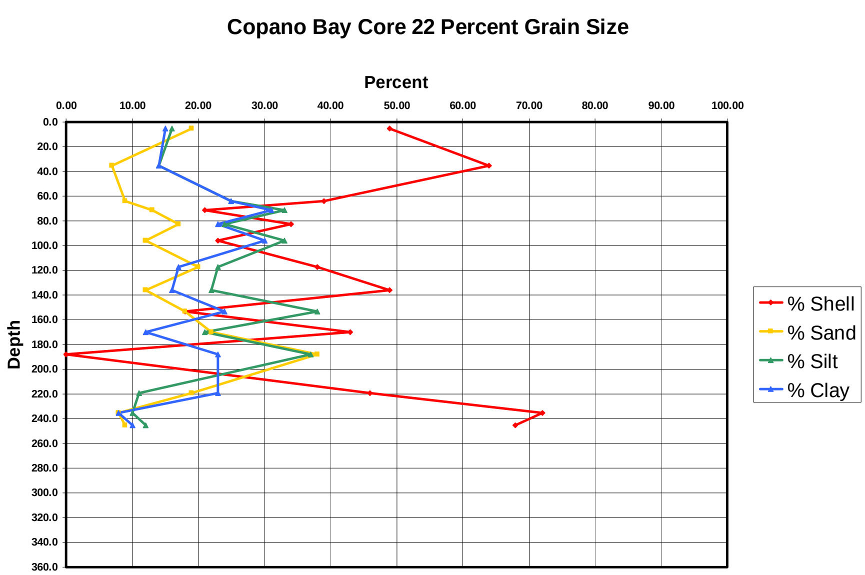
Copano Bay Core 21 Percent Grain Size



- **0689467 m E, 3109441 m N**
- **Line 78**

COP-22





VITA

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