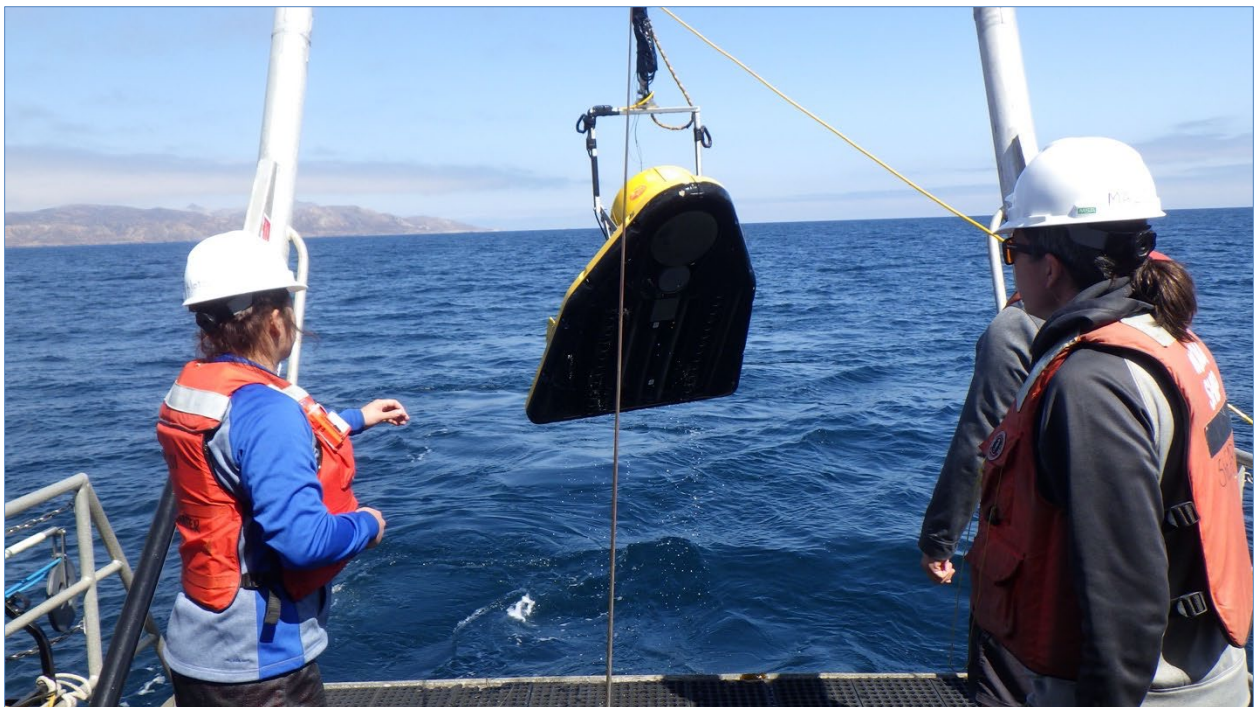


Archaeological and Biological Assessment of Submerged Landforms off the Pacific Coast of California and Oregon, USA



US Department of the Interior
Bureau of Ocean Energy Management
Pacific OCS Region



Archaeological and Biological Assessment of Submerged Landforms off the Pacific Coast of California and Oregon, USA

June 2025

Authors:

Todd J. Braje, Jillian Maloney, Loren Davis, Neal Driscoll, Jenifer Dugan, Jon M. Erlandson, Amy Gusick, Shannon Klotsko, Alexander Laws, Robert Miller, Alexander Nyers, Henry Page, and Leslie Reeder-Myers

Prepared under Cooperative Agreement M15AC00012

By

San Diego State University Foundation
5250 Campanile Drive
San Diego, CA 92182-1913

DISCLAIMER

Study collaboration and funding were provided by the U.S. Department of the Interior, Bureau of Ocean Energy Management (BOEM), Environmental Studies Program, Washington, DC, under Agreement Number M15AC00012. This report has been technically reviewed by BOEM, and it has been approved for publication. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the opinions or policies of the U.S. Government, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

REPORT AVAILABILITY

Download a PDF file of this report at https://espis.boem.gov/Final%20Reports/BOEM_2025-032.pdf.

Visit BOEM's website to [search other studies](#) completed by BOEM's Environmental Studies Program.

CITATION

Braje TJ, Maloney J, Davis L, Driscoll N, Dugan J, Erlandson JM, Gusick A, Klotsko S, Laws A, Miller R, Nyers A, Page H, and Reeder-Myers L. 2021. Archaeological and biological assessment of submerged landforms off the Pacific Coast of California and Oregon, USA. Camarillo (CA). U.S. Department of the Interior, Bureau of Ocean Energy Management, Pacific OCS Region. 181 p. Report No.: OCS Study BOEM 2025-032. Contract No.: M15AC00012.

ABOUT THE COVER

Co-Principal Investigator, Jillian Maloney, and graduate student Shannon Klotsko launching the chirp system offshore California's Northern Channel Islands for geophysical surveys.

ACKNOWLEDGMENTS

This study is the result of work by numerous individuals including faculty, students, and staff at San Diego State University (SDSU), the University of Oregon Museum of Natural and Cultural History (UO MNCH), Oregon State University (OSU), University of California Santa Barbara (UCSB), The Natural History Museum of Los Angeles County, University of North Carolina Wilmington (UNCW), and Scripps Institution of Oceanography, as well as outside contributors who provided valuable expertise. This study was made possible by the important consultation and collaborative efforts of the Santa Ynez Band of Chumash Indians (SYBCI), the Chumash Tribal community, the Confederated Tribes of Grand Ronde, the Coquille Indian Tribe, the Confederated Tribes of Siletz Indians, and the Confederated Tribes of Coos, Lower Umpqua, and Siuslaw (CTCLUSI). Special thanks go to Brian Holguin (SYBCI) and Brendan Chase Scott (Coquille Indian Tribe), who participated in fieldwork. Thanks to David Harrelson and Briece Edwards (Grand Ronde), Robert Kennta, and Peter Hatch (Siletz), Kassie Rippee and the late Chief Don Ivy (Coquille), Stacy Scott (formerly CTCLUSI), Courtney Krossman (CTCLUSI), and Brian Holguin for reviewing an earlier draft of this report. Generous logistical support, including transportation, island housing, and staff time, was provided by Channel Islands National Park, the National Park Service (NPS), the University of California Natural Reserve System, Santa Cruz Island Reserve, The Nature Conservancy (TNC), Channel Islands National Marine Sanctuary, California State University Channel Island Santa Rosa Island Research Station, The Catalina Conservancy, and the University of Southern

California's Wrigley Marine Science Center. Thanks go to everyone listed below for their valuable contributions and assistance:

David Ball, BOEM
Shannon Klotzko, UNCW
Loren Davis, OSU
Jillian Maloney, SDSU
Neal Driscoll, Scripps
Robert Miller, UCSB
Jenny Dugan, UCSB
Alex Nyers, OSU
Jon Erlandson, UO MNCH
Mark Page, UCSB
Amy Gusick, NHMLA
Leslie Reeder-Myers, Temple U.
Bert Ho, NPS
Donna Schroeder, BOEM
Kristin Hoppa, NPS
Amira Aini, UO MNCH
Kristina Gill, UO MNCH
Greg Retallack, UO MNCH
Alan Salazar, Chumash Consultant
Jessica Madden, UCSB
Steve Whitaker, NPS
Laura Beresford, UCSB
Juliann Schamel, NPS
Linnea Palmstrom, UCSB
Lyndal Laughrin, UCSB
Michael Cornish, UCSB
Brandon Doheny, UCSB
Kyle Emery, UCSB
Brian Guerrero, UCSB

David Hubbard, UCSB
Valerie Kramer, UCSB
Christopher Chan, UCSB
Anthony Huang, UCSB
Kristin Michaud, UCSB
Brian Holguin, SYBCI
Elders Council, SYBCI
David Harrelson, Grand Ronde
Briece Edwards, Grand Ronde
Robert Kennta, Siletz
Peter Hatch, Siletz
Kassie Rippee, Coquille
Chief Don Ivy, Coquille
Stacy Scott, CTCLUSI
Courtney Krossman, CTCLUSI
Francesca Puerzer, UCSB
Nicholas Schooler, UCSB
Steve Schroeter, UCSB
David Vanderzee, UCSB
Paul Barber, UCLA
McKenzie Koch, UCLA
Zachery Gold, UCLA
Seth Newsome, UNM
Robyn Shea, CSCI
Terence Shin, CINMS
John Knapp, TNC
Jennifer Baker, TNC
Torben Rick, SI
Laura Kim, NPS

Contents

List of Figures	iii
List of Tables	vii
List of Abbreviations and Acronyms.....	viii
1 Project overview	1
1.1 Background and significance	1
1.2 Geologic setting and background	5
1.2.1 Study Area #1: the Northern Channel Islands	5
1.2.2 Study Area #2: the central Oregon Coast	8
2 Model building and field methods: Tasks 1 and 2	11
2.1 Task 1: Model building	12
2.2 Task 2: Target Identification	17
3 Tasks 3 and 4: Field investigations for the Northern Channel Islands	17
3.1 Archaeological surveys	17
3.2 Coastal biological surveys	21
3.3 Offshore geophysical surveys	51
3.4 Seafloor coring	52
3.4.1 Core descriptions with optical and CT images	55
3.4.2 Multi-sensor core logs	55
3.4.3 Itrax analysis	55
3.4.4 Grain size analysis	56
3.4.5 Radiocarbon dating	56
3.5 Results from NCI field work	56
3.5.1 Observed regional surfaces and acoustic units in sub-bottom data	57
3.5.2 Box 2: Western Santa Cruz Passage	60
3.5.3 Box 4: Verde Canyon paleodrainage, north of Santa Rosa Island	64
3.5.4 Box 5: Central Santa Cruz Passage	74
3.5.5 Box 6: Christy and Sauces canyons paleodrainage, eastern Santa Cruz Passage	86
3.5.6 Submerged Terraces and Shoreline Angles in Regional NCI data	104
3.5.7 Paleoshoreline mapping around the NCI platform	105
3.5.8 NCI summary and recommendations	109
4 Task 5: Field investigations and model validation for the central Oregon coast	110
4.1 Offshore geophysical surveys	110
4.2 Seafloor coring	112
4.2.1 Core descriptions with optical and CT images	113
4.2.2 Multi-sensor core logs	113
4.2.3 Itrax analysis	113

4.2.4	Grain size analysis	113
4.2.5	Radiocarbon dating	113
4.3	Results from Oregon field work	114
4.3.1	Structure (reprinted from Klotsko et al., 2021)	114
4.3.2	Siuslaw and Umpqua drainages (reprinted from Klotsko et al., 2021)	117
4.3.1	Box 1: Siuslaw erosion surface	122
4.3.2	Box 2: Siuslaw erosion surface and channel	123
4.3.3	Box 3: Umpqua incision	125
4.3.4	Box 4: Umpqua large paleovalley	127
4.3.5	Oregon summary and recommendations	130
5	Task 6: Model revision and final analysis.....	131
5.1	Revised GIS predictive model for Pacific Coast submerged cultural resources (Davis et al., 2020) 131	
5.2	Recommendations for offshore survey and testing parameters methodology	136
5.2.1	HRG survey guidelines	137
5.2.2	Geotechnical investigation guidelines.....	142
5.2.3	Paleolandscape reconstruction	144
5.2.4	Future research	145
6	References.....	146
	Appendix A: Radiocarbon Dates	161

List of Figures

Figure 1.2.1 Map of Southern California, the Santa Barbara Channel region, and the offshore Channel Islands	6
Figure 1.2.2 Sea level curves from 140 ka to present.....	7
Figure 1.2.3 Physiographic map of Southern California showing the location of the Northern Channel Islands and the reconstructed shorelines of Santarosae Island ~20,000 and 10,000 cal BP	8
Figure 1.2.4 Overview map of the tectonic regime of the Oregon Coast study area (shown as small black box labeled B).....	9
Figure 1.2.5 Map of Oregon study area showing major stream systems and offshore geomorphic features ...	10
Figure 2.1.1 GIS predictive model results from the Northern Channel Islands	16
Figure 3.2.1 The Santa Barbara Channel region with locations of biological surveys identified in yellow	22
Figure 3.2.2 Mean values for overall beach widths of Channel Islands beaches coastal surveys in 2016 to 201825	
Figure 3.2.3 Mean values (+ std error) of abundance (as cover) of all marine macrophytes or wrack (top), and of all drift kelps, kelp wrack (bottom), on island beaches for 2016-2018 coastal surveys	26
Figure 3.2.4 Total species richness of intertidal invertebrates recorded in 2016 to 2018 coastal surveys of sandy beaches on the Channel Islands	27
Figure 3.2.5 Mean values of abundance (+ std. error) (top) and biomass (+ std. error) (bottom) for talitrid amphipods recorded in coastal surveys of island beaches from 2016 to 2018.....	28
Figure 3.2.6 Relationship between the species richness of wrack-associated invertebrates and the abundance of marine macrophyte wrack as cover ($r^2 = 0.48$, $p < 0.001$).....	29
Figure 3.2.7 Mean values of abundance (+ std. error) for sand crabs recorded in coastal surveys of island beaches from 2016 to 2018.....	30
Figure 3.2.8 Estimated values of mean (+ std error) abundance of purple olive snails from coastal surveys in 201731	
Figure 3.2.11 Relationship between the combined species richness of fish observed in seines and BRUVs and that from eDNA analyses of surf zone water for surveys (2018).....	34
Figure 3.2.12 Mean values of abundance (+ std error) of barred surfperch reported in beach seines in the 2018 surveys of Channel Island surf zones.....	36
Figure 3.2.13 Relative abundance of barred surfperch recorded in surveys with beach seines and BRUVs in 201836	
Figure 3.2.14 Distribution of total lengths for <i>A. argenteus</i> used for regression analyses on bones in Table 3.2.3 (n=32)	38
Figure 3.2.15 Example of the bone measurement approach using the inferior pharyngeal bone and associated measurements.....	39
Figure 3.2.16 Comparison of size frequency distributions for barred surfperch calculated from midden remains plotted with data from modern surveys.....	40
Figure 3.2.17 The relationship between the species richness of wrack-associated invertebrates and mean CO ₂ flux ($r^2 = 0.32$, $p < 0.001$)	41
Figure 3.2.18 Mean ($\pm$ SE) A) abundance (count) and B) biomass of sand crabs (<i>Emerita analoga</i>) sampled from Santa Rosa and Santa Cruz Islands in 2018 and the relative contribution (as percent) in terms of C) abundance (count) and D) biomass to juvenile and adult surfperch stomach contents	44

Figure 3.2.19 Mean (+SE) A) abundance (count) and B) biomass of upper beach wrack-associated invertebrates sampled from Santa Rosa and Santa Cruz Islands in 2018 and the relative contribution (as percent) in terms of C) abundance (count) and D) biomass to juvenile and adult surfperch stomach contents	45
Figure 3.2.20 Mean ($\pm$ SE) A) abundance (count) and B) biomass of other invertebrate prey in the stomach contents of surfperch sampled from Santa Rosa and Santa Cruz Islands in 2018	46
Figure 3.2.21 Mean (+SE) $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values for A) juvenile barred surfperch and B) adult barred surfperch together with isotope values for <i>Emerita analoga</i> and <i>Megalorchestia</i> spp. (<i>M. californiana</i> , <i>M. corniculata</i> , or <i>M. minor</i>). Trophic fractionation factors of 0.5‰ for $\delta^{13}\text{C}$ and 3.4‰ for $\delta^{15}\text{N}$ have been added to the prey species (Post 2002)	47
Figure 3.2.22 Relationships between beach material in scats and endemic beach invertebrate abundance and biomass (from Page et al. 2021)	49
Figure 3.2.23 $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of island fox whisker segments (From Page et al 2021)	50
Figure 3.3.1 Map of NCI survey area showing where geophysical data were acquired	51
Figure 3.4.1 Map of NCI survey area showing core locations	53
Figure 3.5.1 Generalized stratigraphic columns for chirp data around the NCI platform	57
Figure 3.5.2 Chirp Line ShearW_D02L05 showing regional stratigraphy in Santa Cruz Passage	58
Figure 3.5.3 Interpolated surface of the regional unconformity interpreted to be the transgressive surface (Laws et al. 2019:12)	58
Figure 3.5.4 Isopach maps of sedimentary units (Laws et al. 2019:13)	60
Figure 3.5.5 Fence diagram of Chirp profiles offshore eastern Santa Rosa Island	61
Figure 3.5.6 Location of cores within Box 2	62
Figure 3.5.7 Summary figure of Box 2 core data	63
Figure 3.5.8 Map of survey area north of Santa Rosa Island	64
Figure 3.5.9 Chirp Line ShearW_D05L09	65
Figure 3.5.10 Location of cores within Box 4	66
Figure 3.5.11 Chirp profile showing location of collected cores and core logs	68
Figure 3.5.12 Optical image, CT scan, Core Log, and Magnetic Susceptibility results for Core 4F	69
Figure 3.5.13 Core 4F selected XRF Data	70
Figure 3.5.14 Optical image, CT scan, Core Log, and Magnetic Susceptibility results for Core 4E	71
Figure 3.5.15 Core 4E selected XRF data	72
Figure 3.5.16 Age model for radiocarbon dates from Core 4E	73
Figure 3.5.17 Chirp profile in center of Santa Cruz Passage showing v-shaped channels and wavy, discontinuous reflectors	74
Figure 3.5.18 Location of Cores 5a and 5c (approximate core depth marked as pink rectangle)	75
Figure 3.5.19 Location of Cores 5b and 5d (approximate core depth marked as pink rectangle)	76
Figure 3.5.20 Core logs (left) and CT scans (right) for Box 5 cores	77
Figure 3.5.21 Optical image, CT scan, Core Log, and Magnetic Susceptibility results for Core 5A	78
Figure 3.5.22 Selected XRF data for Core 5A with reference core log illustrated at top	79
Figure 3.5.23 Optical image, CT scan, Core Log, and Magnetic Susceptibility results for Core 5B	81
Figure 3.5.24 Selected XRF data for Core 5B with reference core log illustrated at top	82

Figure 3.5.25 Optical image, CT scan, Core Log, and Magnetic Susceptibility results for Core 5C.....	83
Figure 3.5.26 Selected XRF data for Core 5C with reference core log illustrated at top	84
Figure 3.5.27 Optical image, CT scan, Core Log, and Magnetic Susceptibility results for Core 5D.....	85
Figure 3.5.28 Chirp fence diagram offshore western Santa Cruz Island	87
Figure 3.5.29 Chirp profile ShearW_D01L07	89
Figure 3.5.30 Mapped thickness of terrestrial and marine units offshore Santa Cruz Island	90
Figure 3.5.31 Location of cores within Box 6	91
Figure 3.5.32 Optical image, CT scan, Core Log and Magnetic Susceptibility results for Core 6A.....	93
Figure 3.5.33 Optical image, CT scan, Core Log, and Magnetic Susceptibility results for Core 6B.....	94
Figure 3.5.34 Optical image, CT scan, Core Log, and Magnetic Susceptibility results for Core 6C.....	95
Figure 3.5.35 Optical image, CT scan, Core Log, and Magnetic Susceptibility results for Core 6D.....	96
Figure 3.5.36 Stratigraphic descriptions of cores CI-VC-6A, CI-VC-6B, and CI-VC-6D by Retallack	97
Figure 3.5.37 Age-depth model for radiocarbon dates in eastern SCP	98
Figure 3.5.38 Dates closest to the base of the upper marine unit for each core plotted on a sea level curve showing Age (ka) vs. Sea Level (m)	99
Figure 3.5.39 Core 6A selected XRF data	100
Figure 3.5.40 Core 6B selected XRF data	101
Figure 3.5.41 Core 6C selected XRF data	102
Figure 3.5.42 Core 6D selected XRF data	103
Figure 3.5.43 Morphology of onshore marine terraces and submerged abrasion platforms (Laws et al. 2019:2) 104	
Figure 3.5.44 Northeastern segment of chirp profile D02L04b between SRI and SCI (Laws et al. 2019:8)....	106
Figure 3.5.45 Map of the NCI, showing interpreted paleoshoreline angle locations on chirp survey lines, with various other relevant geomorphic and geologic features (Laws et al. 2019:14)	107
Figure 3.5.46 Uplift rate models for the NCI used to reconcile the rate of late Quaternary uplift (Laws et al. 2019:16).....	108
Figure 4.1.1 Map of Oregon Survey area geophysical surveys	111
Figure 4.2.1 Map of Oregon survey area showing core locations	113
Figure 4.3.1 Maps of regional structure (Klotsko et al. 2021:4)	115
Figure 4.3.2 Chirp Line 54 with more vertically exaggerated section of outer shelf Umpqua valley on bottom (Klotsko et al. 2021:6)	116
Figure 4.3.3 Sections of chirp profiles highlighting incision of the inner shelf portion of the Paleo-Umpqua drainage valley (Klotsko et al. 2021:7).....	117
Figure 4.3.4 Chirp Line 42 with uninterpreted (top) and interpreted (bottom) versions (Klotsko et al. 2021:9)	118
Figure 4.3.5 Chirp Line 48 with uninterpreted (top) and interpreted (bottom) versions (Klotsko et al. 2021:10) 118	
Figure 4.3.6 Chirp Line 44 with uninterpreted (top) and interpreted (bottom) versions (Klotsko et al. 2021:5) 119	
Figure 4.3.7 Chirp Line 13 with uninterpreted (top) and interpreted (bottom) versions (Klotsko et al. 2021:8) 119	

Figure 4.3.8 Knudsen Line 251_0205 with uninterpreted (top) and interpreted (bottom) versions (Klotsko et al. 2021:11).....	120
Figure 4.3.9 Knudsen Line 251_1345 highlighting the absence of stratigraphy on the outer shelf (Klotsko et al. 2021:12).....	121
Figure 4.3.10 Fence diagram of the paleodrainage system offshore from the modern Umpqua River (Klotsko et al. 2021:13).....	121
Figure 4.3.11 Chirp Line PS1705_L32	122
Figure 4.3.12 Box 1 cores (Davis et al., 2020:41)	123
Figure 4.3.13 Chirp Line PS1705_L22	124
Figure 4.3.14 Box 2 cores (Davis et al., 2020:43)	125
Figure 4.3.15 Chirp Line PS1705_L11	126
Figure 4.3.16 Box 3 cores (Davis et al., 2020:47)	127
Figure 4.3.17 Chirp Line PS1705_L17	128
Figure 4.3.18 Box 4 cores (Davis et al., 2020:49)	129
Figure 5.1.1 Generated LGM stream network for the Northern Channel Islands	132
Figure 5.1.2 Digital elevation model with estimated kelp bed extent at 20 ka shoreline (salmon color polygons) 133	
Figure 5.1.3 Mean zonal aspect.....	133
Figure 5.1.4 GIS predictive model of archaeological site potential offshore San Miguel Island.....	134
Figure 5.1.5 GIS predictive model of archaeological site potential offshore Santa Rosa Island.....	135
Figure 5.1.6 GIS predictive model of archaeological site potential offshore Santa Cruz Island.....	136
Figure 5.2.1 Regional vs. 1 km line in the NCI.....	138
Figure 5.2.2 Regional vs. 1 km line in Oregon.....	138
Figure 5.2.3 Oregon Box 2 detailed mapping	141
Figure 5.2.4 Oregon Box 2 rough surface mapping at different grid spacing.....	142
Figure 5.2.5 Plot of grain size statistics mean (in microns) vs. standard deviation (sorting) for NCI cores.....	144
Figure 5.2.6 Map showing rocky continental shelf offshore southern Oregon	146

List of Tables

Table 3.1.1 102 Known Paleocoastal sites from the Northern Channel Islands (adapted and updated from Gusick and Erlandson 2019).....	18
Table 3.2.1 Sandy beach sites where coastal biological surveys were conducted on the Channel Islands and Santa Barbara County mainland (2016 to 2018)	23
Table 3.2.2 Fish and elasmobranch species recorded in surf zone surveys using beach seines and surf BRUVs on the Channel Islands	32
Table 3.2.3 Comparisons of the three survey methods used for surf zone fish.	35
Table 3.2.4 Linear regressions for bone measurements and standard length in <i>A. argenteus</i> (n=30 to 32)....	38
Table 3.2.5 List of prey items in barred surfperch stomachs grouped by prey categories used in analysis.	43
Table 3.4.1 NCI Coring Locations.	54
Table 3.5.1 Mapped paleoshoreline depths and corresponding age estimates.....	109
Table A-2 Oregon Coring Locations.	163
Table A-3 Oregon Radiocarbon Dates.	165

List of Abbreviations and Acronyms

$\delta^{13}\text{C}$	delta 13 carbon
$\delta^{15}\text{N}$	delta 15 nitrogen
μm	Micrometer
BOEM	Bureau of Ocean Energy Management
BRUV	Baited remote underwater video
BP	Before present
cal BP	Calibrated years before present
chirp	Compressed high-intensity radiated pulse
CIA	Channel Island Amol
CIB	Channel Island Barbed
CINMS	Channel Islands National Marine Sanctuary
CINP	Channel Islands National Park
CO_2	Carbon dioxide
CSCI	California State University Channel Islands
CT	Computerized tomography
CTCLUSI	Confederated Tribes of Coos, Lower Umpqua, and Siuslaw
DEM	Digital elevation model
DistLM	Distance-based linear modeling
DOI	U.S. Department of the Interior
eDNA	Environmental DNA
ES	Erosional surface
ESPIS	Environmental Studies Program Information System
GIA	Glacial isostatic adjustment
GIS	Geographic Information System
HRG	High-resolution geophysical
IACUC	Institutional Animal Care and Use Committee
IFC	Ice-free corridor
ind m^{-1}	Individuals per meter
LGM	Last glacial maximum
$\text{mg CO}_2 \text{ hour}^{-1} \text{ m}^{-1}$	Milligrams carbon dioxide per hour per minute
mbsl	Meters below sea level
m/ka	Meters per thousand years
MIS	Marine isotope stage
MMS	Minerals Management Service
MS	Magnetic susceptibility
MST	Multi-sensor track
NCI	Northern Channel Islands
NHMLA	Natural History Museum of Los Angeles County
NOAA	National Oceanic and Atmospheric Association
NPS	National Park Service
OCS	Outer Continental Shelf

OSU	Oregon State University
OSUMGR	Oregon State University Marine and Geology Repository
PCR	Pacific Coast route
PNW	Pacific Northwest
PNWHF	Pacific Northwest hydrography framework
PI	Principle investigator
POCS	Pacific Outer Continental Shelf
ROV	remotely operated vehicle
SCal	Santa Catalina Island
SCIF	Santa Cruz Island Fault
SCP	Santa Cruz Passage
SCRI	Santa Cruz Island
SDSU	San Diego State University
SI	Smithsonian Institution
SMI	San Miguel Island
SRC	National Park Service Submerged Resources Center
SRI	Santa Rosa Island
SRIF	Santa Rosa Island Fault
STD	Standard deviation
SYBCI	Santa Ynez Band of Chumash Indians
Temple U	Temple University
THPO	Tribal Historic Preservation Officers
TNC	The Nature Conservancy
TWTT	Two-way time travel
UCLA	University of California Los Angeles
UCSB	University of California Santa Barbara
UNCW	University of North Carolina Wilmington
UNM	University of New Mexico
UO	University of Oregon
UO MNCH	University of Oregon Museum of Natural and Cultural History
XRF	X-ray fluorescence

1 Project overview

Off the Pacific Coast of North America, rising post-glacial sea levels have submerged a vast paleolandscape that likely contains submerged terrestrial archaeological resources. In a cooperative agreement between San Diego State University (SDSU) and the Bureau of Ocean Energy Management (BOEM), and in collaboration with a variety of academic institutions and governmental agencies, the scientific team undertook a project to explore submerged geological landforms using terrestrial analogs, paleoshoreline mapping, sediment coring, ground-truthing techniques, and biological assessments. This project was conducted along California's Northern Channel Islands (NCI) and off the central Oregon coast and targeted submerged landforms that could contain cultural resources. These data have been used to build a predictive model identifying the most likely locations where pre-contact submerged geological landforms, archaeological sites, and traditional cultural properties might be found and preserved along the Pacific outer continental shelf (POCS). This report is the latest in a series of similar baseline reports that evaluate the archaeological potential of the POCS and other regions managed by BOEM. For this study, the scientific team focused on nearshore environments off California and Oregon and identified the most likely locations where submerged pre-contact archaeological sites and traditional cultural properties might be subject to direct or indirect impacts resulting from offshore development.

The results of this study will be used in the evaluation of future exploration, development, and transportation plans for offshore energy projects. The identification of significant archaeological sites, traditional cultural properties, and culturally sensitive submerged landforms will assist BOEM in determining specific resources or areas of sensitivity that offshore development could directly or indirectly impact.

As a critical part of this project and within the appropriate study areas, the scientific team regularly consulted, both formally and informally, with Chumash Tribal members, the Elders Council for the Santa Ynez Band of Chumash Indians (SYBCI), the Confederated Tribes of Siletz Indians, and the Tribal Historic Preservation Offices and cultural staff from the Confederated Tribes of Grand Ronde, the Coquille Indian Tribe, and the Confederated Tribes of Coos, Lower Umpqua, and Siuslaw Indians (CTCLUSI). Prior to any fieldwork or model building, the scientific team also conducted information sharing and collaboration meetings with the Channel Islands National Marine Sanctuary (CINMS), Channel Islands National Park (CINP), the National Park Service Submerged Resources Center (SRC), the Oregon State Historic Preservation Office, and the National Oceanic and Atmospheric Administration's Office of Exploration and Research. These consultation and collaboration meetings were critical to integrate local and regional knowledge, build partnerships with agency scientists and local stakeholders, and develop avenues for collaboration.

The project produced a large dataset of high-resolution Compressed High-Intensity Radiated Pulse (chirp) and side-scan sonar imagery, sediment cores, and a geographic information system (GIS) model to predict and test where submerged landform features and critical modern biological resources might be located and preserved in offshore environments along the POCS. Ultimately, the project refines best practices to identify and avoid potential impacts on biological resources, intact paleolandforms, and paleontological resources from offshore energy development on the outer continental shelf (OCS).

1.1 Background and significance

Less than three decades ago, most archaeologists believed the first humans to enter the Americas were Ice Age hunters who walked across the Bering Land Bridge, passed through an Ice-Free Corridor (IFC), and spread rapidly across the New World beginning ~13,500 years ago, hunting mammoths, mastodons, and other Pleistocene megafauna with fluted and fishtail points (e.g., Holliday 2000; Meltzer 1995, 2009; Waters and Stafford 2007). This Clovis-first model of New World colonization became dogma, and,

despite some opposition (e.g., Erlandson 1994, 2002; Fladmark 1979), was supported by most of the available archaeological, genetic, and paleoecological data. Under the Clovis-first model, coastlines were largely overlooked, and most archaeologists believed that New World hunter-gatherers only began to focus on aquatic and maritime resources after the extinction of Pleistocene megafauna, when the disappearance of these high-ranked food sources forced them to adapt. This model viewed human use of Pacific Coast land and seascapes as a relatively late phenomenon in the history of the Americas. Rising post-glacial seas, under this model of the peopling of the New World, would have had little to no impact on coastal archaeological sites and coastal traditional cultural properties in the Americas. By contrast, the Pacific Coast Route (PCR) suggests that early humans migrated from northeast Asia to the Americas by traveling along the Pacific coastline, with migration occurring by boat or along the shorelines, exploiting marine and littoral (shoreline) resources.

By the late 1990s, the discovery and widespread acceptance of the ~14,500 to 14,000-year-old occupation of the Monte Verde site in southern Chile (Dillehay et al. 2008) caused archaeologists to reconsider long-held paradigms about when and how the first Americans arrived. Some turned their attention to long-marginalized Pleistocene coastlines as a potential dispersal corridor into the Americas (e.g., Erlandson 2002), which was open and viable millennia prior to the IFC (Darvill et al. 2018; Lesnek et al. 2018). In recent decades, evidence for the deep antiquity of coastal adaptations, seafaring, and island colonization has been discovered and maritime resources are no longer considered marginal or less productive than their terrestrial counterparts (e.g., Cortés-Sánchez et al. 2011; Erlandson 2001, 2010; Mearns et al. 2007; Steele and Álvarez-Fernández 2011).

The antiquity of seafaring stretches back at least 800,000 to 1,000,000 years ago, with short marine crossings by archaic members of our genus, including the colonization of Flores and other Southeast Asian islands (Brown et al. 2004; Ingicco et al. 2018; Morwood et al. 2014) and the discovery of greater Australia (Sahul) by Anatomically Modern Humans as much as 55,000 to 60,000 years ago (Clarkson et al. 2017). After 50,000 years ago, there is evidence for a dramatic increase in seafaring, island colonization, and the exploitation of maritime resources in Island Southeast Asia, Australia, and New Guinea (O'Connell and Allen 2012; O'Connor et al. 2011), New Ireland and the Solomon Islands (Allen et al. 1989; Wickler and Spriggs 1988), Okinawa (Fujita et al. 2016) and the other Ryukyu Islands (Matsu'ura 1996), and Honshu in Japan (Ikeya 2015).

The Pleistocene archaeological record along Pacific New World coastlines remains exceptionally thin, which is, perhaps, the primary reason that debates continue about the relative likelihood of the IFC versus the PCR as the earliest dispersal corridor for the first Americans (see Braje et al. 2017, 2018; Potter et al. 2018a, b). Currently, the earliest widely accepted evidence of Pleistocene-aged archaeological sites along the New World Pacific Coast comes from the Monte Verde II (~14,600 to 14,000 calibrated years before present [cal BP]) and Huaca Prieta (~15,000 to 13,500 cal BP) sites in Chile and Peru, respectively (Dillehay et al. 2008, 2012). In North America, the earliest evidence of coastal occupations comes from British Columbia, where deeply buried chipped stone artifacts and a hearth feature date to ~13,800 cal BP on Triquet Island, and stone tools and human footprints in Pruth Bay on Calvert Island date to ~13,000 cal BP (McLaren et al. 2018). Human remains discovered on Santa Rosa Island in Southern California also date to around 13,000 cal BP (Johnson et al. 2002).

Despite the continuing debate over the timing and route or routes of the first Americans, archaeologists now agree that some of the first peoples in the Americas traveled along and exploited Pacific Coast land and seascapes since at least the terminal Pleistocene. Now that it is widely accepted that the vast submerged intact paleolandscapes of the Pacific Coast could contain evidence of pre-contact cultural resources, BOEM has begun work to better identify and consider potential impacts on these, along with natural resources, by energy development projects. This has become especially important in recent years since the passage of the 2005 Energy Policy Act that led to increased interest in renewable energy development on the POCS. For the past decade, BOEM received applications for both offshore wind and

wave projects along the central Oregon coast, and interest has been expressed in renewable energy development off California. BOEM and other federal agencies need science-based tools to help evaluate the potential impacts on cultural and natural resources along the POCS.

Research on potential submerged intact landform features and critical natural resources on the POCS, however, has been slow to develop, especially when compared to long-term sustained research on submerged landscapes in other regions of North America (*inter alia* Dunbar et al. 1988; Evans et al. 2012; Faught 1988, 2004; Faught and Donahue 1997; Gagliano et al. 1982; Lowery and Martin 2009; Ruppe 1980). This could be partly due to the limited amount of offshore energy development and marine minerals extraction off the West Coast. In stark contrast, extensive oil and gas exploration along the Gulf Coast, which began in the 1940s, and interest in offshore wind energy along the Atlantic Coast for the past 15 years, has provided relatively abundant geophysical survey data from these regions compared to the POCS. Scientific analysis of these data has identified several potential submerged paleolandforms and resulted, in some cases, in follow-up research funded by federal agencies such as BOEM and its predecessor, the Minerals Management Service (MMS). In addition, investigations of submerged paleolandscapes of the POCS have been hindered by the assumption that the high wave energy along the Pacific Coast and offshore tectonic activity in the Pacific Northwest (PNW) would have destroyed any submerged pre-contact archaeological resources, making research efforts more practical and successful along the Gulf and Atlantic coasts.

The POCS remains a challenging environment to conduct research on submerged resources and paleolandscapes, but this should not and has not stopped researchers from developing projects intended to better understand the dynamics of the continental shelf (e.g., Carabis et al. 2014; Dixon and Montelone 2014; Faught and Gusick 2011; Fedje and Josenhans 2000; Fedje and Christensen 1999; Gusick and Faught 2011; Gusick and Davis 2010; Mackie et al. 2013, 2017; Masters and Flemming 1983; Watts et al. 2011). The systematic search for submerged late Pleistocene archaeological sites along the Pacific Coast of North America has been limited in scope and intensity, and scientists are grappling with how to effectively and efficiently search the ocean floor for archaeological resources (Gusick and Faught 2011).

The scale of this challenge is immense. If it is assumed, for example, that the PCR opened ~17,000 years ago (see Darvill et al. 2018; Lesnek et al. 2018) and modern sea levels stabilized around 7,000 years ago, the intervening 10,000 years of eustatic sea level rise resulted in the inundation of ~10 million square kilometers (km²) of New World Pacific coastal plains, with as little as 5 to 10 kilometers (km) of shoreline transgression in areas with steep offshore bathymetry, and up to ~500 km in areas, such as Beringia, with shallow offshore bathymetry. The Pacific Coast is also characterized by relatively high wave energy, with few protected shorelines south of the convoluted coastlines of Alaska and British Columbia. Identifying the best places among the vast submerged landscapes off the Pacific Coast to look for intact submerged landform features (and the cultural materials they might contain) remains a formidable challenge.

Especially critical is developing a regional methodology for POCS research efforts. The absence of a scientifically proven, standardized, “best practices” methodology to identify submerged relict landscapes on the conterminous U.S. POCS, and the ancient Tribal archaeological resources these landscapes could contain, has long been a concern among federal and state agencies and Tribal Historic Preservation Officers (THPO) and has made environmental decision-making challenging for BOEM.

Beyond assisting BOEM to evaluate the potential for encountering cultural resources on the POCS during future energy development, this study contributes to Pacific marine spatial planning efforts and a better understanding of the submerged landscape. Ultimately, the study was designed to accomplish six tasks: 1) to synthesize existing geological and geophysical datasets from offshore the NCI in Southern California and central Oregon; 2) to develop and field-test a new geospatial model to aid in identifying and classifying potential cultural landforms from existing remote sensing data, seafloor maps, and the

distribution of known and newly discovered paleocoastal sites above current sea level; 3) to conduct field investigations of areas identified as having high potential to be associated with submerged cultural landforms; 4) to improve models of submerged archaeological resources by incorporating archaeological and biological sampling data, and where possible, mapping submerged terraces and shoreline angles representing sea level stillstands and mapping paleochannels and possible submerged springs, toolstone outcrops, caves, and rockshelters; 5) to collect and analyze relevant biological data on the distribution of natural resources that would have facilitated human settlement along the Northern Channels to help refine the GIS predictive model; and 6) to compile a final report of all findings and interpretations.

Task 1 consists of synthesizing all available geophysical datasets and summarizing the geological setting along the California Bight, near the NCI, and offshore central Oregon (U.S. Geological Survey, NOAA, BOEM, MBARI); synthesizing current theories of human migration in North America and site formation processes; and synthesizing information (e.g., archaeological site reports, sites listed on the National Register of Historic Places) on terrestrial analogs.

Task 2 involves target identification and model building, and includes performing a new GIS analysis of the 2013 BOEM POCS model to aggregate the potential site distribution scores into one-hectare grid squares between and adjacent to the shorelines of interest to narrow the search for intact submerged landform features around the NCI and along Oregon's central coast; creating new high-resolution (10 meter [m] grid square) GIS models of potential site distribution in the hectares with the highest aggregate scores at millennial scales to predict key changes in local hydrology corresponding with marine transgression; identifying geomorphic features based on digital elevation model (DEM) projections on the POCS GIS model between the targeted shoreline zone within the GIS modeled areas of highest probability; and identifying high-probability areas for pre-contact archaeological site occurrence and habitat areas on potential relict geomorphic features within highest probability portions of the POCS study areas.

Task 3 includes conducting broad geophysical surveys and tight-grid (maximum 25 m lane spacing on an at least 1,000-m-long grid) geophysical surveys of at least four GIS-predicted high-probability areas in the Southern California Bight. This was designed to resolve archaeological targets and features, especially acoustic profiling to identify sub-seafloor horizons and geologic events. Processing and analyzing newly acquired geophysical data were designed to identify intact submerged landform feature signatures and potential biological features. Task 3 also includes conducting limited terrestrial surveys along the NCI to provide wider coverage of the distribution of terminal Pleistocene and Early Holocene sites.

Task 4 includes collecting physical specimens (e.g., vibracores) on identified potential submerged pre-contact site signatures in the Southern California Bight for analysis (e.g., core logger including p-wave, bulk density, and magnetic susceptibility; X-radiograph; elemental geochemistry; optical imaging; radiocarbon dating) and processing and analyzing physical specimens and site characterization survey data.

Task 5 includes conducting broad and tight-grid (maximum 25 m lane spacing on an at least 1,000-m-long grid) geophysical surveys of at least four GIS-predicted high-probability areas off the central Oregon coast to resolve archaeological targets and features, especially acoustic profiling to identify sub-seafloor horizons and geologic events; processing and analyze newly acquired geophysical data for intact submerged landform features signatures; collecting physical specimens (e.g., vibracores) on identified potential intact submerged landform features signatures off the central Oregon coast for analysis (e.g., core logger including p-wave, bulk density, and magnetic susceptibility, X-radiograph, elemental geochemistry, optical imaging, radiocarbon dating, etc.); and processing and analyzing physical specimens and site characterization survey data.

Task 6 includes processing and analyzing all datasets, reviewing results against the developed predictive model, making appropriate revisions, and compiling all the information into a final report of findings.

The following sections provide discussions on each Task, details on how each was accomplished, and the resulting data and interpretations. First, the report begins with the geological setting and background for the two study areas: the California NCI and the central Oregon coast.

1.2 Geologic setting and background

This project involves studies in two study areas along the POCS: California's NCI and the central Oregon coast. These areas were selected based on the availability of existing datasets and the stark differences in local geologic histories. The NCI, due to the high density of terrestrial paleocoastal archaeological sites and available offshore geophysical data, acted as the pilot study area where the scientific team developed the GIS predictive model. The central Oregon coast acted as the baseline for model testing and refinement.

1.2.1 Study Area #1: the Northern Channel Islands

The NCI are offshore of Southern California and consist of San Miguel Island (Chumash name: *Tuqan*; SMI), Santa Rosa Island (*Wima*; SRI), Santa Cruz Island (*Limuw*; SCI), and Anacapa Island (*'Anyapax*) (Figure 1.2.1). The NCI compose the southwestern region of the western Transverse Range physiographic province, which formed during the Southern California margin's transition from a subduction to transform boundary beginning in the early Miocene epoch (Atwater 1989; Nicholson et al. 1994). During the transition, the western Transverse Range province, including the NCI, rotated clockwise over 90° to the current position (Kamerling and Luyendyk 1979; Nicholson et al. 1994). Along the modern transform boundary, the San Andreas fault makes a westerly restraining bend (the Big Bend) through the onshore Transverse Ranges, resulting in transgression and associated faulting and folding within the province that is oriented more east/west than the typical northwest/southeast structural trend of the Pacific-North American plate boundary (Atwater 1989).

The geology of the NCI is characterized by marine terrace features formed when periods of relative stability in sea level provided the necessary time for wave energy to carve out abrasion platforms (terraces) and produce remnants of paleoshorelines in the landscape (Emery 1958; Reeder-Myers et al. 2015). Terrace morphology consists of a low-gradient, seaward-dipping abrasion platform formed by wave-base erosion during slow sea level change or still-stand. The landward edge of the abrasion platform is characterized by an increase in slope, representing a paleoshoreline. The base of the high-gradient slope is known as the shoreline angle, representing the location of an ancient shoreline. While this can occur during both sea level highstands and lowstands, submerged wave-abrasion platforms in the NCI are associated with periods of low sea level (Chaytor et al. 2008). Last-interglacial, highstand paleoshorelines and associated marine terraces are preserved onshore the NCI and provide a long-term record of tectonic vertical motion (e.g., Dickinson 2001; Muhs et al. 2014; Pinter et al. 2003; Sorlien 1994). Sorlien (1994) proposed uplift rates of 0.5 to 1.0 meters per thousand years (m/ka) based on estimated marine terrace ages from SRI. On SCRI, the 120 thousand years (ka) sea level highstand (Marine Isotope Stage [MIS] 5e; Figure 1.2.2) gives a maximum uplift rate of ~0.1 m/ka (Pinter et al. 2003). Recent work by Muhs et al. (2014) dated the MIS 5a and MIS 5c/5e terraces using uranium-series dating and amino acid geochronology on SRI and determined an uplift rate of 0.12 to 0.20 m/ka.



Figure 1.2.1 Map of Southern California, the Santa Barbara Channel region, and the offshore Channel Islands

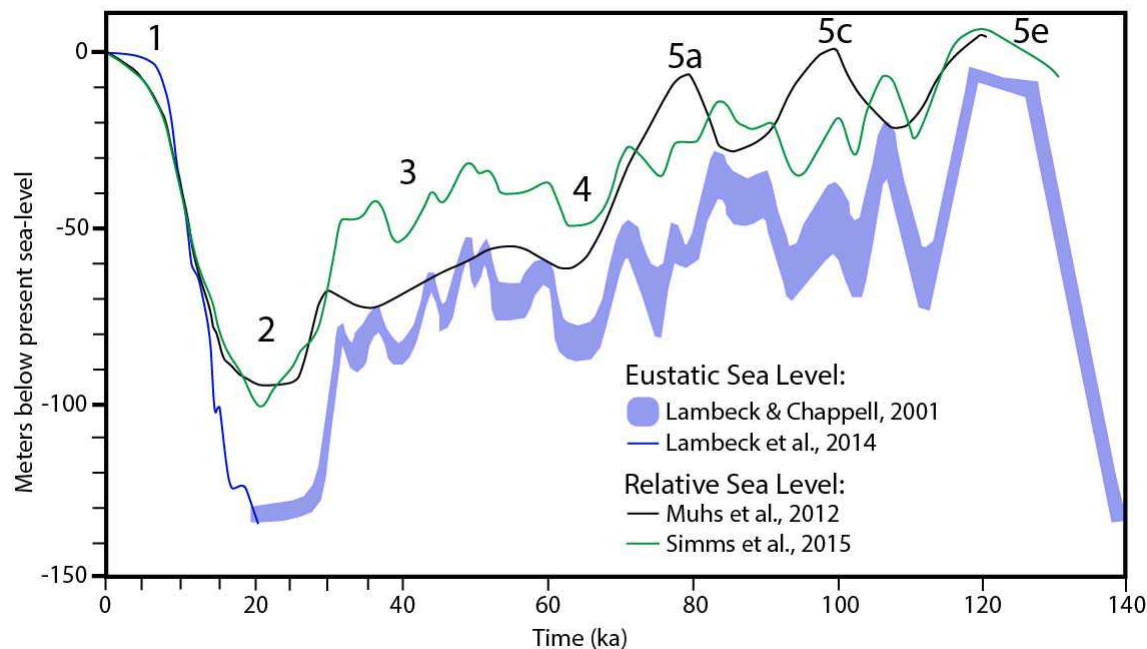


Figure 1.2.2 Sea level curves from 140 ka to present

The numbers at the top of the figure show the marine isotope stages (MIS). Muhs et al. (2012) sea level is relative for San Nicolas Island. Simms et al. (2015) sea level is relative to Southern California.

Submerged terraces around the NCI were first described by Emery (1958) based on single-beam bathymetric profiles. Five marine terraces between ~15 to 130 m below sea level (mbsl) offshore the NCI were identified by Emery (1958). Chaytor et al. (2008) later mapped submerged marine terraces around the NCI using high-resolution multibeam bathymetry and identified five marine terraces of the eastern NCI platform offshore SCI, with paleoshoreline depths ranging from ~22 to 90 mbsl. Chaytor et al. (2008) interpreted a Last Glacial Maximum (LGM) shoreline at ~90 mbsl and used the terrace age, elevation, and sea level curve of Lambeck et al. (2002) to generate an uplift rate of ~1.5 m/ka for the past ~23 ka. The Lambeck et al. (2002) sea level curve, however, did not account for local glacial isostatic adjustment (GIA) and the uplift rate may be overestimated because eustatic sea level at the LGM was 14 m lower than local sea level at the NCI (Clark et al. 2014; Muhs et al. 2014). The lower uplift rate estimates for the islands are more consistent with regional uplift rates from Southern California of 0.13 to 0.27 m/ka (e.g., Grant et al. 1999; Ku and Kern 1974; Mueller et al. 2009) than with uplift rates within the onshore Transverse Range province (e.g., Muhs et al. 2014; Rockwell et al. 2016). Recent measurements of vertical motion on SCI and SRI using GPS stations north of the Santa Cruz Island Fault (SCIF) and Santa Rosa Island Fault (SRIF) show a slight (< 0.5 mm/yr) subsidence.

During the LGM, with local sea level ~106 m lower than present (Clark et al. 2014), the NCI were connected by a series of land bridges into a single island known as *Santarosae* (see Figure 1.2.3), exposing wide tracts of the now-submerged shelf (Orr 1968; Reeder-Myers et al. 2015). Shoreline reconstructions using modern seafloor bathymetry indicate that *Santarosae* reached its greatest extent at ~20 ka with about 8 km separating the mainland from *Santarosae*, then rapidly shrank until the islands began to be separated by watergaps just after 11 ka (Reeder-Myers et al. 2015). Accurate reconstructions of paleoshorelines allow archaeologists to better understand the ancient environments available to people and target areas where onshore and offshore archaeological sites could be preserved (Gusick and Faught 2011, McLaren et al. 2014).

The earliest evidence for human occupation on the NCI comes from human remains dated to ~13 ka on northwestern SRI (Johnson et al. 2002). This site, as well as numerous other archaeological sites dating between ~12.5 to 11 ka and found on uplifted marine terraces on SRI and SMI, suggests early island inhabitants maintained a protein diet focused on marine resources (Braje et al. 2013; Erlandson et al. 2011). These findings demonstrate that *Santarosae*'s ancient shorelines provided important resources for early inhabitants, who occupied the island during lower sea level, before rising seas separated *Santarosae* into the four modern islands. A better understating of the submerged paleoshorelines of *Santarosae* could help archaeologists identify additional, and possibly earlier, evidence of human occupation in this region of the New World.

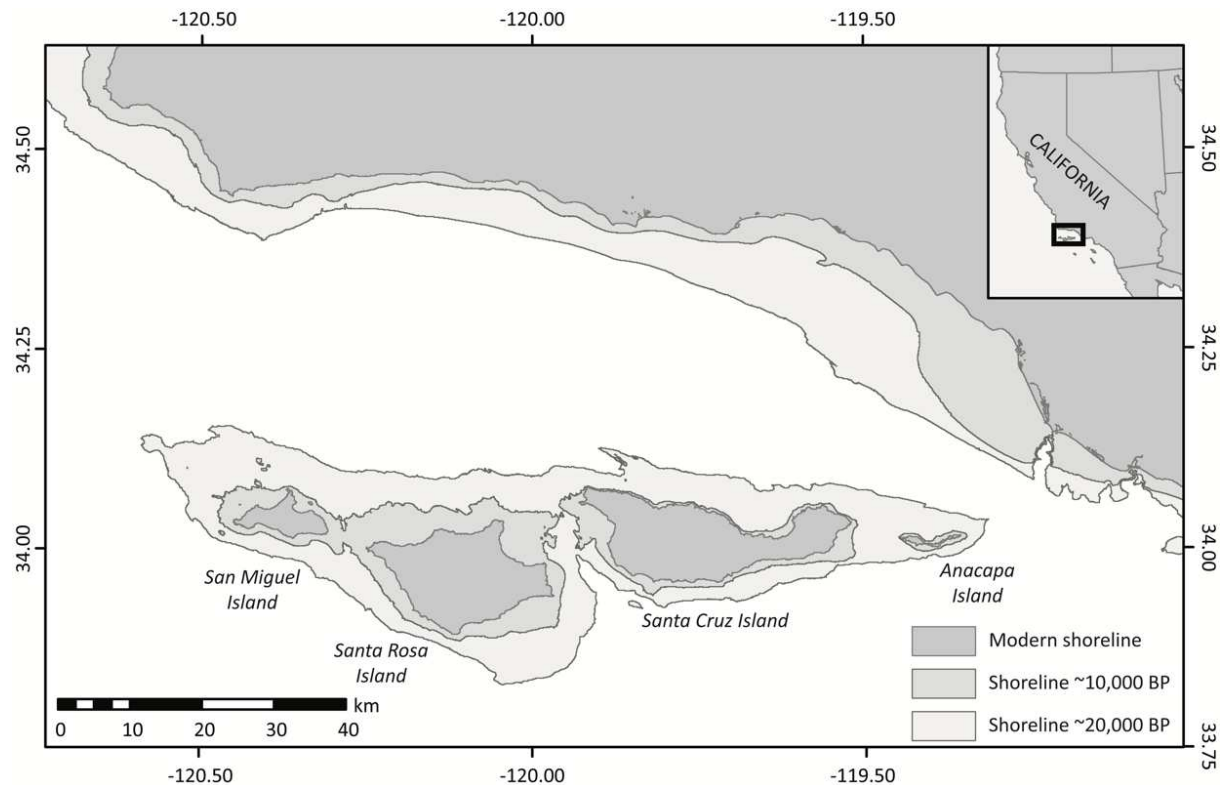


Figure 1.2.3 Physiographic map of Southern California showing the location of the Northern Channel Islands and the reconstructed shorelines of Santarosae Island ~20,000 and 10,000 cal BP

1.2.2 Study Area #2: the central Oregon Coast

The central Oregon coast lies within the seismically active Cascadia subduction zone margin (Figure 1.2.4). As such, the physiography of the central Oregon continental shelf is an effect of tectonic deformation, as well as sea level cycles. In this region, the shelf structure is dominated by folds and faults formed by Miocene-aged and younger compression adjacent to the plate boundary (Goldfinger et al. 2014). The shelf is also characterized by a low-relief wave-abrasion platform formed via sea level transgression-regression driven by glacial cycles in the late Quaternary. Currently, the shelf represents a submerged landscape of the most recent lowstand, the LGM, ~20 ka, when sea level was 147 mbsl in this region, based on a GIA sea level curve at 44.5° N latitude (Clark et al. 2014). Previous studies demonstrated that paleodrainages are preserved on the shelf stemming from a rapid rise in sea level between 14.5 and 8 ka (Yeats et al. 1998). These features are evident in some bathymetric surveys and high-resolution seismic data (Goldfinger et al. 2014).

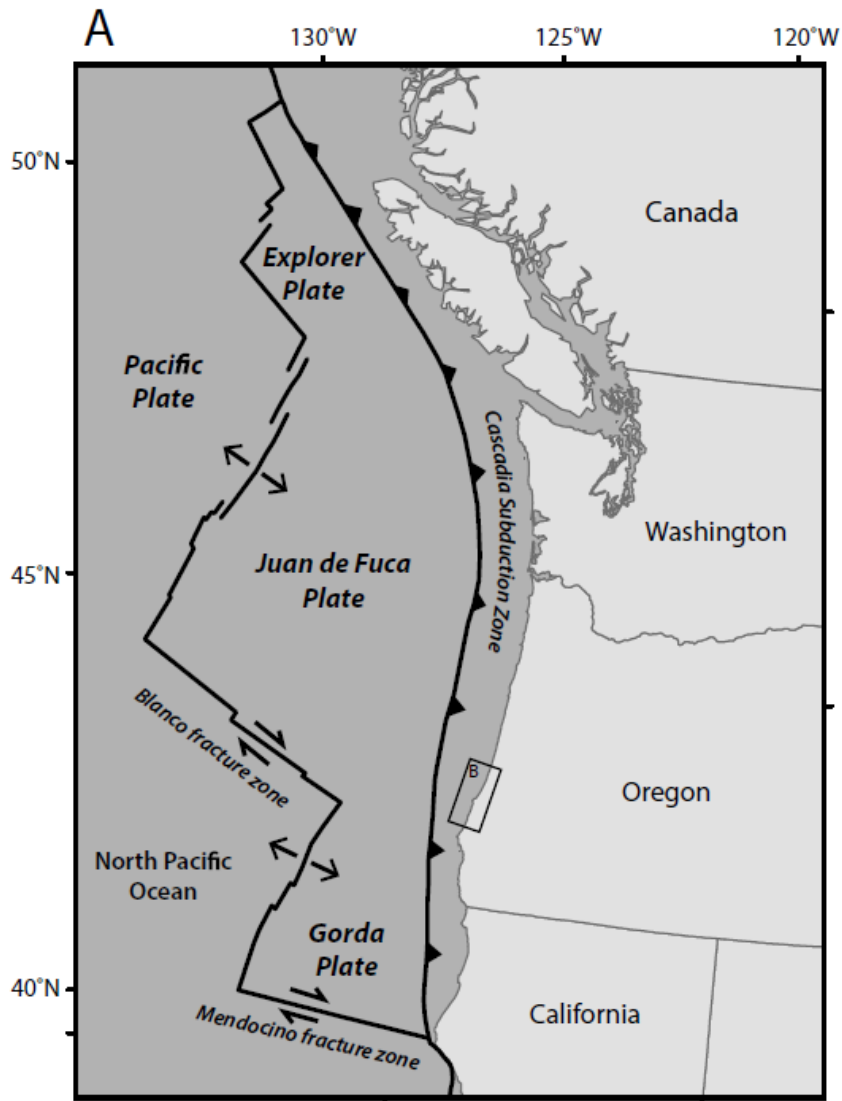


Figure 1.2.4 Overview map of the tectonic regime of the Oregon Coast study area (shown as small black box labeled B)

The modern onshore geology is dominated by Eocene sandstones and siltstones of the Tyee Formation (Santra et al. 2013; Walker and MacLeod 1991). The modern coastal ranges in this region contain a sequence of marine terraces that formed during the Quaternary, providing evidence of long-term uplift. Simms et al. (2016) calculated GIA marine terrace uplift rates along the Pacific Coast of North America using MIS 5a, 5c, and 5e terraces. The Simms et al. (2016) study included two sites within the study area, at Newport, Oregon, and Cape Arago, Oregon. The average of the MIS 5a, 5c, and 5e (Figure 1.2.2) GIA-corrected uplift rates are 0.84 mm/yr at Newport and 0.69 mm/yr at Cape Arago.

Although the regional tectonic and sea level forces acting on the shelf are similar, localized deformation resulted in variability of shelf morphology. Contractional-related faulting and folding during the middle-to late-Miocene created several bathymetric highs and lows (Clarke et al. 1985) and caused the shelf to vary in width from 18 to 65 km. The widest part of the shelf is just north of the Siuslaw River mouth, where Heceta Bank comprises the outer shelf (Figure 1.2.5). During the LGM, Heceta Bank would have formed a significant headland; this contrasts with the relatively straight modern shoreline of the study

area. Two other, smaller bathymetric highs are on the mid-shelf. Siltcoos Bank is to the south of Heceta Bank, between the Siuslaw and Umpqua rivers, and Stonewall Bank is to the north of Heceta Bank near the Yaquina River.

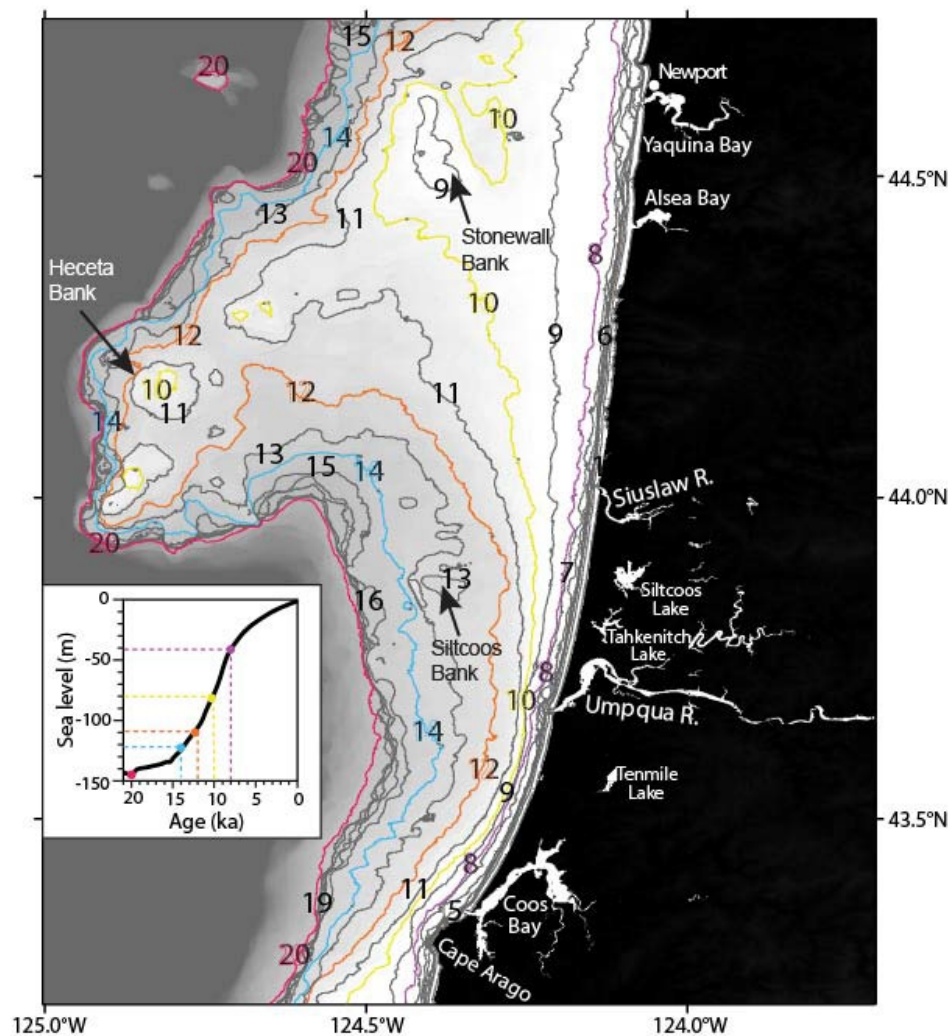


Figure 1.2.5 Map of Oregon study area showing major stream systems and offshore geomorphic features

Bathymetric contours are shown with colored and labeled contours representing different paleoshoreline ages based on the inset sea level curve.

Stonewall Bank, offshore of Newport, Oregon, was highlighted by Yeats et al. (1998) for its preservation of a paleochannel from the Yaquina River. Based on side-scan sonar data, the paleochannel cuts through the bank with a channel width ranging from 275 to 550 m. The preservation of this feature is attributed to a rapid rise in sea level at 14.5 ka. Yeats et al. (1998) proposed that the paleochannel was later uplifted ~15 m in the past 11 to 12 ka, due to a localized blind-thrust fault directly beneath Stonewall Bank. This section of the Yaquina paleodrainage is now at a depth of 60 to 70 mbsl along the crest of the anticlinal structure. The two other major modern drainage systems extending across the study area are the Siuslaw and Umpqua rivers, but prior to this project, no evidence of their extension across the continental shelf had been identified.

The modern regional climate of central Oregon is temperate (-3°C to 18°C). Precipitation rates, which impact discharge and vegetation, as well as influence sediment erosion and transport, only vary slightly across the study area. The average annual precipitation is 1.65 m at 43.5°N and 1.70 m at 44.5°N , based on data collected from 1981 to 2010 by the NOAA National Climatic Data Center. The central coast of Oregon is the southern extent of the Western Hemlock zone, a densely vegetated, coniferous forest starting in coastal British Columbia (Pojar et al. 1991). Because the modern climate, precipitation, and vegetation are so similar across the study area (covering ~ 1 degree of latitude), it is expected that any climatic changes during glacial-interglacial cycles also would have been similar. Further, as climate zones likely shifted southward during full glacial conditions, and as conifer vegetation extends well to the north in British Columbia, any changes are expected to have been small in terms of forest cover and type.

Although precipitation and vegetation patterns are consistent across the study area, the three major drainage basins encompassed by the study area are different in terms of basin size, water discharge, and sediment yield. The Umpqua and Yaquina rivers are the largest and smallest, respectively, in terms of drainage basin size, discharge, and sediment yield, with annual average discharge of 8.38 cubic kilometers per year (km^3/yr) and $1.72\text{ km}^3/\text{yr}$, respectively. For comparison, two other major North American rivers that drain into the Pacific Ocean are the Columbia River, with a discharge rate of $251\text{ km}^3/\text{yr}$ (Milliman and Meade 1983) and the Eel River with a discharge rate of $6.5\text{ km}^3/\text{yr}$ (USGS Station #11477000, 2017).

The late Pleistocene and Early Holocene archaeological record of the southern PNW Coast is exceptionally sparse. There are no well-documented sites from this time along the Washington Coast, only one from the Oregon coast, and none from the northern California coast (Erlandson et al. 2008). This has led some archaeologists to propose that humans developed coastal or maritime lifeways relatively late in this region, perhaps from a dearth of high-quality intertidal shellfish resources or sophisticated maritime technologies (Lightfoot 1993; Lyman 1991). Other scientists suggest that this pattern is related to the archaeological visibility of the region, connected to either a less intensive history of research in the area or to the taphonomic effects of the Cascadia subduction zone (Moss and Erlandson 1995, 1998). The Cascadia subduction zone was once thought to be aseismic, but scientists now know that every few centuries, very large earthquakes strike this area, leading to a combination of subsidence and tsunamis for large portions of the coast (see Atwater 1987; Darienzo and Peterson 1990). In addition, the Cascadia subduction zone corresponds to the region where early archaeological sites along the Pacific Northwest Coast are rare or absent. It is possible that the combination of earthquakes, tsunamis, landslides, and coastal erosion has negatively impacted the terminal Pleistocene and Early Holocene archaeological records along the southern PNW Coast (Erlandson et al. 1998; Punke and Davis 2006). Work by Davis (2006) at the Indian Sands site suggests that humans occupied terminal Pleistocene and Early Holocene localities along the Oregon coast and might be effectively located and studied along paleodrainages. Geophysical survey and sampling along submerged drainages, in fact, could help identify early archaeological sites that are better preserved compared to their terrestrial counterparts.

2 Model building and field methods: Tasks 1 and 2

The first consideration of model building was predicting not just where submerged archaeological sites might be located, but also where paleolandforms might be preserved and testable offshore the NCI. This requires detailed understanding of modern seafloor characteristics and the compilation of previous offshore research. Previous geophysical mapping in the area is critical to help identify offshore areas with high research potential. Taken together, this information could help identify preserved and intact paleosols and sediments offshore the NCI.

In addition, the approach in this project to predict the location of submerged pre-contact sites on the POCS rests heavily on assumptions about human behavior within coastal paleolandscapes and what is known of terminal Pleistocene and Early Holocene archaeological sites in subaerial localities within the two study areas. Pre-contact maritime foragers along the North Pacific Coast relied on a variety of easy-to-capture intertidal and nearshore shellfish species, estuarine hunting, fishing, and foraging, and some bird and sea mammal hunting and nearshore fishing. These resources acted as magnets for early coastal foragers, and archaeological evidence of their activities might be found in close proximity to the location of these natural resources. The scientific team also assumed that terminal Pleistocene and Early Holocene foragers located their campsites on appropriate terrain (e.g., well-drained, relatively flat, in sheltered localities) near important freshwater, toolstone, and other such resources. Accepting these assumptions, the team used information about the distribution of different resource patches (biological, geological, paleoecological) projected to have once existed on the POCS as a proxy of potential site locations.

To predict and locate the distribution of submerged pre-contact archaeological sites on the POCS, the scientific team built models that considered the spatial distribution of ancient resource productivity on paleolandscapes that once existed on the POCS. To accomplish this, the team combined data on the archaeology, geology, and biology of paleolandscapes along the NCI and the central Oregon coast. These interdisciplinary datasets, first collected for the NCI, then refined and tested along the central Oregon coast, allowed the team to build a GIS predictive model of where submerged pre-contact archaeological sites and traditional cultural properties might be found and preserved along the entirety of the POCS.

2.1 Task 1: Model building

To identify potential high-probability areas for submerged paleocoastal sites around the NCI, the scientific team designed a GIS predictive model using, as the critical guiding component, what is known about the distribution, geographic setting, and archaeology of the nearly 100 documented subaerial paleocoastal sites. Archaeologists know that terminal Pleistocene and Early Holocene sites on the NCI occur near freshwater and toolstone sources, caves and rockshelters, productive kelp forest, estuarine and wetland habitats, and on elevated landforms with strategic viewsheds. In all likelihood, early coastal mariners along the Pacific Coast occupied similar areas of the then-subaerially exposed continental shelf.

A thorough literature review and search for available data from the California Bight, near the NCI, and central Oregon coast was conducted. All available data from previous geophysical surveys were collected and reviewed. In addition, all recorded terminal Pleistocene and Early Holocene archaeological sites from the NCI were combined with geological and geomorphic seabed data to provide a robust ecological dataset. These data were reviewed by project team members with the ultimate goal of collecting samples of the submerged landscape. For instance, an area that is known to have a hard substrate with no sediment cover would not be conducive to the sediment sampling regime needed to identify landscape evolution and paleoenvironmental conditions.

One dataset that was especially important for helping narrow initial search parameters was the predictive model developed for BOEM by ICF International, Davis Geoarchaeological Research Group, and Southeastern Archaeological Research (2013). Their study modeled coastal and submerged site potential in and adjacent to the POCS off Washington, Oregon, and California. Modern bathymetry, crustal deformations, ancient stream systems, and eustatic and relative sea level histories were used to construct a GIS-based model of areas with potential to have preserved archaeological sites (ICF International, Davis Geoarchaeological Research Group, and Southeastern Archaeological Research 2013:1). The model did not predict site locations, only the landscapes on which more data should be collected to consider their feasibility for additional research.

Collection of relevant datasets for this BOEM project focused on publicly available federal data, as well as data collected through research by the project collaborators and their colleagues. There were numerous federal datasets available for the project region that focused on a variety of information including habitat zones, seafloor character, seabed geology, faults, surficial sediment, nautical charts, fishing maps, terrestrial environmental data, geomorphology, and others. The team also collected terrestrial hydrography data specific to the Channel Islands region that was not included in the 2013 BOEM project to enable better paleolandscape reconstructions and predictive modeling in GIS. Newly published data on radiocarbon dated POCS cores from the Oregon and California study areas were also included. These data provide chronometric evaluations of shoreline positions and allowed the scientific team to integrate the most accurate information about local relative sea level into new paleoshoreline projections. Biological surveys of beaches on the NCI were conducted by the UCSB team to produce datasets on patterns of biological productivity associated with different landforms across the archipelago. Finally, all archaeological sites from the NCI that date older than 8,500 cal BP (radiocarbon dates or temporally diagnostic technology) were compiled into ArcGIS. In total, more than 150 datasets were gathered and analyzed.

Detailed mapping of offshore landforms can provide high-resolution reconstructions of landforms, rock outcrops, and other features to help identify areas of high archaeological potential. As described in the 2013 POCS submerged site predictive model report (ICF International et al. 2013) for BOEM, the potential for site preservation on the submerged continental shelf is based on several factors: rate of sea level rise, tectonics, sedimentation rate and patterns, wave energy, seafloor geology, and the distribution of natural resources targeted by foragers. Pre-contact sites may be found offshore only when mechanisms are in place to preserve a locale from the taphonomic effects of transgressive shorelines. Because the 2013 model specifically excludes the 0- to 3-mile state waters area, the team developed a revised GIS model that incorporates these areas adjacent to the chosen POCS study areas of the NCI (a process the team refined and repeated for the central Oregon coast, described in detail below). Using this expanded model, a new GIS analysis of the 2013 GIS model was conducted to determine where the highest probability grid cells are clustered along nearshore paleoshorelines adjacent target areas along the NCI. Finally, these GIS layers were further modified with a GIS layer to highlight terrestrial landform analogs that are commonly associated with early archaeological sites and exist within the POCS study area.

This method of relying on the archaeological record to guide where to focus research efforts was based on regionally specific archaeological, geologic, paleoenvironmental research. The use of terrestrial analogs to guide underwater research is one that should always be explored, but not without applicability considerations. Currently, subaerial sites could lie in different landscape and environmental contexts than during the time period of habitation. This could be particularly true for deeply submerged landscapes (Ford and Halligan 2010: 278). Sites near modern shorelines may have been far removed from the coast during time of habitation and characterized as inland sites prior to marine transgression, which can present different patterns of settlement and resource use. Also, as sea levels rose, massive changes in landscapes and habitats occurred and could have influenced behavioral patterns that differ from those recognized during times of more stable sea level changes. These factors were considered but based on current knowledge of the Pleistocene archaeological record as well as knowledge of the continental shelf from previous studies, the scientific team was confident that using land-based analogs as one of numerous guiding factors was appropriate.

For that reason, the team also used existing knowledge of the terminal Pleistocene paleogeography of the NCI to identify potential locations where preservation of submerged sites was most likely to occur. The strong and predominantly northwesterly wind and wave patterns today and in the late Pleistocene, for instance, suggest that marine erosion along *Santarosae*'s unprotected northern shore would have hindered site preservation. The relatively protected southern shore of *Santarosae*, in contrast, would have seen less erosion and potentially higher rates of site survival. This was especially likely within the boundaries of a

large south-facing paleo-embayment known as Crescent Bay (Erlandson 2016), a geographic feature submerged beneath the modern Santa Cruz Channel between Santa Rosa and Santa Cruz Islands, where protected marsh and estuarine habitats are thought to have attracted paleocoastal peoples. For more information on Crescent Bay, see Section 3.1.

Post-glacial marine transgression forced coastal foragers to relocate their nearshore settlements across the POCS through time. To account for this, research emphasis was placed on ground-truthing high-probability areas that coincide with slower periods of sea level rise, which are expected to have enabled longer periods of repeated occupation at coastal sites, potentially leading to the formation of larger and more discoverable archaeological targets on the POCS. However, periods of slowly rising sea levels might offer poor preservation contexts as they are exposed to wave action for longer periods, encouraging the formation of sea cliffs and destructive sea cliff retreat. Targeting areas near paleocoastlines with substantial archaeological deposits that were inundated quickly could mitigate this challenge. Periods of slower eustatic sea level rise occurred during the Younger Dryas (circa 12,900–11,700 cal BP) and after the 8,200 cal BP meltwater pulse. By conducting a series of high-resolution remote sensing surveys at different depths that correspond to these shoreline positions, within well-developed ancient drainage networks or on other key landform features, the chance of locating submerged sites of different ages that reflect inland displacement of coastal foragers during post-glacial marine transgression is increased.

Building an effective GIS model to predict the locations of preserved archaeological sites offshore involved several critical steps. The team's approach to modeling potential pre-contact period site locations on the POCS is based on methods reported by ICF International et al. (2013) and is a two-part process wherein coastal paleolandscape reconstructions are first created and then associated pre-contact period site location predictions are made.

After all datasets were gathered and analyzed, data were synthesized in various software applications. Data were organized into geodatabases for visualization and analysis. Georeferenced datasets were compiled into an ESRI ArcGIS database and mapped (<http://www.arcgis.com/features/>). Where possible, the gathered geophysical datasets were also visualized and interpreted using IVS Fledermaus software (<http://www.qps.nl/display/fledermaus/main>), providing three-dimension (3D) visualization capability not available through ESRI ArcGIS. Sub-bottom datasets also were compiled into a Kingdom Suite project (<http://ihs.com>) when they were available in the proper data format. This program provided a platform for tracing acoustic horizons, mapping and measuring sediment units, generating isopach maps, mapping faults and paleochannels, and comparing sub-bottom data with sediment core data.

The team began by creating a GIS-based paleolandscape model that showed the extent of emergent lands on the POCS at 19,000 cal BP. The team then projected the positions of relative shorelines at each millennium since 19,000 cal BP onto this maximum paleolandscape extent model using GIA calculations provided by Clark et al. (2014). To generate the potential site preservation models, the scientific team assigned heuristic numerical values to 10-meter DEM grid squares imposed on the POCS, which allowed establishment of a semi-quantitative basis to make predictions about where past coastal sites were probably distributed on now-submerged coastal landscapes. These numerical values are arbitrary but relate to different environmental aspects of the paleolandscape that Snethkamp et al. (1990: Table III-1) correlate with different frequencies of pre-contact period coastal settlement patterns along the Washington, Oregon, and California coastlines. In their study, the greatest number of pre-contact period terrestrial coastal sites were found along the outer coast, followed by aquatic environments (bays, estuaries, rivers, lakes), and finally by sites located on islands and coastal bluffs. Ethnographically and historically, the largest archaeological sites are known to occur adjacent to estuaries and within bays.

For the biological assessment in California, datasets based on the results of the 2016 to 2018 biological surveys of 20 sandy beach sites on the Channel Islands and mainland were assembled by the UCSB team for use in the spatial analyses and model refinement. These data offer insights into important subsistence

(e.g., kelp, shellfish communities, nearshore fish) and other biological resources (e.g., shells for bead construction) that would have been important for early hunter-gatherers on the islands. Understanding concentrations in these resources can help predict where Pleistocene island visitors could have located their campsites and deposited shell midden features.

For ease of modeling potential site locations in GIS, the team collapsed these sub-environmental types into four categories: outer coast, estuary (which includes embayments), streams (fluvial reaches of all sizes), and interfluvial areas (i.e., in the areas between all other environmental categories). The team modeled potential site locations across the POCS through a process by which numerical values associated with grid squares, or rasters, are summed; higher values are interpreted to reflect more favorable locations for pre-contact period site placement than grid squares with lower numerical values. Following ICF International (2013), coastline rasters were buffered to 200 m, extending landward, and were assigned a value of 75. Stream rasters were buffered to 100 m (50 m to each side of stream) and given a value of 75. A background value of 25 was given to the entire POCS to assign a fundamental numerical value to areas away from coastlines and streams. In this way, the team was able to model the locations of estuaries in places where stream rasters overlapped with coastline rasters, resulting in a base value of 150.

To further simulate the environmental variance of the POCS paleolandscape in greater detail, the scientific team applied slope and aspect/insolation raster modifiers following Jenevein's (2010: 56–57) method:

A slope raster in degrees was created from the DEM using the slope function of the Spatial Analyst extension in ArcGIS. The slope raster was reclassified to reflect desired slope values to equal $0-2^{\circ} = 50$, $2^{\circ}-5^{\circ} = 30$, and $>5^{\circ} = 5$. The solar radiation analysis tool within the Spatial Analyst extension of ArcGIS was then used to determine the amount of radiant energy that was received from the sun for each grid square included within the DEM. This function was used in place of the “aspect” function that calculates the downslope direction of grid squares where a value is assigned by the operator, which corresponds to the expected amount of radiant energy that particular aspect would receive. Before running the solar radiation analysis tool, the integrated DEM was resampled to a grid cell size of 100 m to reduce the file size and processing time. Solar insolation was calculated for the winter solstice and classified into seven standard deviation (STD) levels to include: STD 1 = 408–476, STD 2 = 476–481, STD 3 = 481–487, STD 4 = 487–492, STD 5 = 492–497, STD 6 = 497–503, STD 7 = 503–568 (values rounded to the nearest whole number). Winter solstice was used to represent the low end of values expected within an annual insolation pattern of each cell being sampled. The seven classes were then reclassified into grid values equaling STD 1 = 0, STD 2 = 5, STD 3 = 25, STD 4 = 40, STD 5 = 65, STD 6 = 80, STD 7 = 100. The 100 m grid was then resampled back to a 10 m cell size for analysis.

The team purposely removed the categories of bay/estuary, river/stream mouth, and coastal bluff from the calculation matrix because these areas would receive numerical modifiers simply on the account that they represented zones of overlap between buffered coastline and stream rasters. The team envisioned difficulty in correctly identifying headlands within modeled paleolandscapes on the POCS and simply increased the coastline buffer inland by 200 m to capture its heightened site location potential value. The summed values of POCS rasters produced quantitative variance across space that symbolize hypothetical patterns of coastal site location.

The POCS became inundated as sea level rose after 19,000 cal BP, steadily moving the coastline and its buffered raster values farther eastward through time, ultimately resulting in a distribution of coastline raster values across the entire POCS. This reflects an important post-glacial pattern of marine inundation—the Pacific shoreline and its associated settlement potential stood at thousands of different

positions during the past 19,000 years, moving the higher productivity shoreline and estuary zones inland through time. When viewed from a modern perspective, this complete distribution of raster values across the POCS provides a realistic model of potential site locations given that every grid square was either coastline or estuarine habitat at some point during the history of marine transgression. However, the team expects that sites are most likely to be concentrated or will have the greatest areal extents in those areas that experienced estuarine conditions at one point in time. Therefore, estuary locales consistently scored highest in the GIS model. These data were synthesized into the GIS analysis and aggregated potential site distribution scores into one-hectare grid squares between and adjacent to the shorelines of interest (Figure 2.1.1).

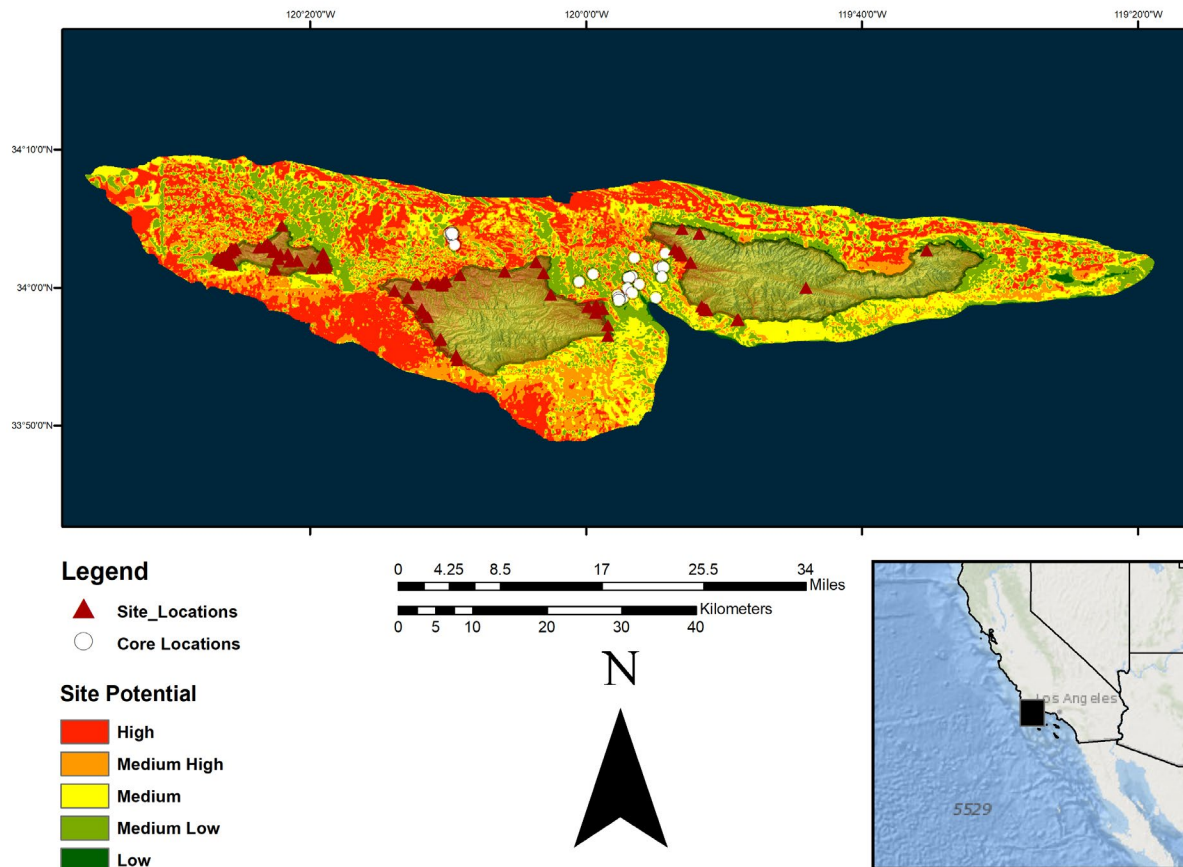


Figure 2.1.1 GIS predictive model results from the Northern Channel Islands

Shows a heat map of high-probability areas (the warmer the color, the higher probability) for submerged pre-contact archaeological sites. The approximate locations of subaerial terminal Pleistocene and Early Holocene sites also are included. Shoreline contour at ~18 ka derived from Clark et al. (2014), map by Nyers.

2.2 Task 2: Target Identification

Combining these spatial datasets into the software platforms listed above allowed the team to display and analyze them in 3D, which facilitated the team’s ability to identify potential submerged landforms and archaeological sites. The software also allowed the team to measure feature extent and sediment thickness, which was critical to identify target study areas. Based on observations from all the combined data, knowledge of Pacific Coast archaeological history, and GIS “heat maps” generated from compiled datasets, the team selected four areas from each region (the NCI and central Oregon) for targeted geophysical survey and ground-truthing.

For California, four primary areas were identified for landscape scale geophysical surveys based on geomorphic make-up, geological context, archaeological sensitivity, biological resource distribution, and ability to produce samples that could yield terrestrial sediment. The same criteria were followed to identify target locations for central Oregon, but these were deemed preliminary and subject to review based on the results of geophysical activities along the NCI.

3 Tasks 3 and 4: Field investigations for the Northern Channel Islands

As the center of model building, testing, and refinement, a variety of field investigations were conducted along the NCI. On land, these included archaeological reconnaissance and radiocarbon dating along high-probability shorelines on San Miguel, Santa Rosa, or Santa Cruz islands and biological assessments across a variety of Santa Barbara Channel ecozones. Offshore, geophysical surveys were conducted using side-scan sonar, multibeam bathymetry, backscatter, chirp sub-bottom profiles, and coring.

3.1 Archaeological surveys

The terrestrial archaeological survey portion of Task 2 was designed to support submerged research by filling in critical gaps in site identification on the NCI. Many of the paleocoastal site surveys on these islands have focused on San Miguel and Santa Rosa islands (e.g., Erlandson et al. 2011; Rick et al. 2013). As such, several paleocoastal site clusters have been identified on these islands. As part of the current project, additional terrestrial surveys were conducted on Santa Cruz, Santa Rosa, and San Miguel islands by Braje, Erlandson, and colleagues. Small survey grants obtained by Braje and Erlandson from the University of Oregon (UO), National Park Service (NPS), and The Nature Conservancy (TNC) were used to leverage BOEM-sponsored surveys, resulting in the identification and recording of more than a dozen new paleocoastal sites since 2015 (see Table 3.1.1). These include several sites on western San Miguel Island dating between 10,000 and 8,000 cal BP, a second cluster of sites on eastern Santa Rosa Island dated between ~11,500 and 8,000 cal BP (Erlandson et al. 2019a, b; Gill et al. 2021), and a third cluster of sites on western Santa Cruz Island (Erlandson et al. 2016) with several shell middens radiocarbon dated between ~11,400 and 8,000 cal BP, and several additional undated lithic scatters that produced diagnostic paleocoastal artifacts such as flaked stone crescents and Channel Island Barbed (CIB) points. Crescents, CIB, and Channel Island Amol (CIA) points are all reliable terminal Pleistocene and Early Holocene chronological markers for the Channel Islands and Santa Barbara Channel region (see Braje et al. 2013; Erlandson et al. 2011; Gusick and Erlandson 2019). When combined with other projects, significant clusters of paleocoastal sites have now been identified on eastern and western San Miguel; eastern, north-central, and southwestern Santa Rosa; and western Santa Cruz Island (Braje et al. 2013; Erlandson 2016). In a major literature review, Gusick and Erlandson (2019) summarized the nature and contents of 96 paleocoastal sites on the NCI—including one previously recognized site (CA-ANI-11) on Anacapa (see also Rick and Reeder-Myers 2018). Continuing field surveys have recorded six additional sites since that 2019 paper was published, bringing the total number of paleocoastal components on the NCI to 102.

Table 3.1.1 102 Known Paleocoastal sites from the Northern Channel Islands (adapted and updated from Gusick and Erlandson 2019).

Site No.	Date (cal BP)	Crescent	CIB Pt	CIA Pt	Location
Santa Cruz (<i>Limuw</i>; n=18)					
SCRI-857	11460-11135				West
SCRI-691	10090-9900				Northeast
SCRI-951	9890-9700				Northwest
SCRI-1034	9385-9240				Southwest
SCRI-1020	9310-9150				West
SCRI-931	9070-8960				Northwest
SCRI-118	9030-8895				Southcentral
SCRI-109	9025-8120		X		Southcentral
SCRI-792	8965-8785				West
SCRI-895	8790-8595				Southwest
SCRI-894	8785-8625				Southwest
SCRI-861	8725-8560	X			Northwest
SCRI-798	8660-8365				West
SCRI-896	8590-8450				Southwest
SCRI-549	8588-8390				West
SCRI-547	8570-8380				West
SCRI-920	?	X	X		Central Valley
SCRI-860	?	X			Northwest
San Miguel (<i>Tuqan</i>; n=47)					
SMI-678	12200-11190	X	X	X	East
SMI-679	12200-11500	X	X	X	East
SMI-261	11600-8500	X	X		East
SMI-701	11540-11410	X		X	East
SMI-274	10510-10250				East
SMI-522	10200-9800				West
SMI-595	10190-9970				West
SMI-604	10140-9130				North-central
SMI-548	9950-8960				Northwest
SMI-610	9750-9020				West
SMI-607	9750-8100				West
SMI-588	9600-8810				Northwest
SMI-507	9550-8890				West
SMI-608	10000-8300		X		Southcentral

Site No.	Date (cal BP)	Crescent	CIB Pt	CIA Pt	Location
SMI-606	9440-8410				West
SMI-447N	9210-9060				North-central
SMI-577	8980-8800	X			Southwest
SMI-575SE	8955-8425	X	X	X	West
SMI-693	8940-8230				West
SMI-578	8860-8660				Southwest
SMI-BuBa7	8785-8600				Northwest
SMI-438	8760-8510				North-central
SMI-623	8750-8580				Southcentral
SMI-526NE	8720-8560				Northwest
SMI-BrwnMnd2	8700-8530				North-central
SMI-442	8590-8375				North-central
SMI-427	8580-8760				Central
SMI-Brown Mnd1	8535-8430				North-central
SMI-575NE	8520-8350		X		West
SMI-684	8490-8380				Central
SMI-527N	8460-8290				Northwest
SMI-523	8415-8335				West
SMI-575C	8410-8300				West
SMI-603	8410-7480				Northeast
SMI-594	8400-8110				West
SMI-433	8380-8100				North-central
SMI-699	8370-8210				West
SMI-593	8290-7980				West
SMI-698	8270-7990				West
SMI-169	?			X	East
SMI-303	?	X	X		Central
SMI-454E	?	X	X		Central
SMI-528SE	?				West
SMI-583 (Knox)	?	X	X		Southeast
SMI-614	?	X	X		West
SMI-680	?	X			East
SMI-681	?	X	X		Central
Santa Rosa (Wima; n=36)					
SRI-173	~13,000				Northwest
SRI-723	12170-11930	X		X	Southwest

Site No.	Date (cal BP)	Crescent	CIB Pt	CIA Pt	Location
SRI-512	11700	X	X		Northwest
SRI-26-SW	11600-11200	X	X	X	Northwest
SRI-706	11560-11210	X		X	West
SRI-997B	11500-10600	X	X		East
SRI-725	11360-11220	X	X		Southcentral
SRI-708	11190-11120	X	X	X	Southeast
SRI-26-S	10400-10290				Northwest
SRI-116	10170-9500				North-central
SRI-6	9280-8930				Northwest
SRI-1	9260-8890				Northwest
SRI-568	8955-8575				North-central
SRI-780	8410-8285				Northwest
SRI-5	8370-7490				Northwest
SRI-3	8300-7160				Northwest
SRI-666	8400-7930				East
SRI-187	8120-7870				Southeast
SRI-84	8020-7930				East
SRI-1020	?			X	East
SRI-19	?	X			Northwest
SRI-207	?	X	X		East
SRI-684	?	X			East
SRI-707	?	X	X		West
SRI-711	?	X	X		West
SRI-717	?	X	X		West
SRI-724	?		X		Southwest
SRI-829	?	X			Southwest
SRI-846	?	X	X	X	Southwest
SRI-969	?	X			Southwest
SRI-984	?	X	?		West
SRI-985	?	X	X		East
SRI-986	?		X		East
SRI-997A	~8,000	X	X		East
SRI-995	?	X			Southeast
SRI-1005	?			X	West
Anacapa ('Anyapah; n=1)					
ANI-11	?	X			West

Study of the paleogeography of *Santarosae* Island, along with the growing number of paleocoastal sites identified around the margins of the Santa Cruz Channel, led Erlandson (2016) to identify a large south-facing, semi-protected paleo-embayment known as Crescent Bay. Several of the largest drainages on *Santarosae* flowed into this large (~8 km-wide) embayment and then into a large offshore submarine canyon (Santa Cruz Submarine Canyon), portions of which have been submerged by rising post-glacial seas. One or more estuaries existed around the margins of Crescent Bay—the only examples known from California’s Channel Islands—and two shell middens (CA-SCRI-857 and CA-SRI-708) located above current sea levels around the margins of the bay provide some of the earliest evidence for human harvesting of estuarine clams (*Chione* spp.) in North America, between ~11,400 and 11,200 cal BP (Erlandson et al. 2019b). This BOEM-sponsored research helped identify several additional paleocoastal sites in this area. These sites expanded the inventory of mapped paleocoastal site locations on land to date, providing important insights into the human settlement patterns and landscape use that can be applied to the submerged landscapes now surrounding the NCI. For instance, Braje and Erlandson mapped four large paleocoastal sites along the south bank of perennial Cherry/Windmill Creek at Bechers Bay on eastern Santa Rosa Island, sites that cover roughly half (350 m of a 700 m stretch of the creek) of the distance between the modern coast and the upland landforms of the second terrace. The density of sites here suggests that the submerged southern bank of Cherry Canyon has a high potential for producing submerged paleocoastal sites.

Importantly, the semi-protected nature of Crescent Bay, protected from the dominant winds and swells that battered the northern coast of *Santarosae*, provides a setting where submerged archaeological sites are most likely to have been protected from marine erosion as sea levels rose. As such, the Crescent Bay area and the floor of the current Santa Cruz Channel became the primary focus of submarine mapping and coring efforts.

3.2 Coastal biological surveys

The coastal biological field surveys of Task 2 conducted by UCSB were designed to provide new data and ecological context on the marine biological productivity associated with different coastal landforms and across regional gradients in exposure, sea surface temperature, and productivity in the NCI, suitable for use in the GIS model. Biological surveys focused on identifying productive maritime resources that would have been attractive to terminal Pleistocene and Early Holocene foragers on the NCI. While biological surveys can only test modern environments, these data can be applied to paleoenvironments by understanding how resources and environments shifted through time. Coupled with paleoenvironmental reconstructions of NCI land and seascapes, these data can help inform ancient settlement and land use patterns.

Coastal landforms, such as headlands, bays, estuaries, reefs, and beaches, also shape the delivery and fate of marine subsidies, including drift kelp, that support coastal ecosystems and food webs. These subsidies fuel marine productivity by providing food and habitat to a diverse community of animals, including surf zone fishes, an important economic and cultural resource. The bones of surfperch are an important component of faunal remains for many archaeological sites on the NCI. This research focused on implications of the marine subsidies supply to sandy beach ecosystems for the biodiversity and secondary productivity of intertidal and surf zone habitats in the Channel Islands. A primary goal was to assess the effects of coastal landforms on key members of biotic communities in sandy beach ecosystems, including intertidal suspension feeding and drift kelp feeding macroinvertebrates and the assemblages of juvenile and adult fishes that forage in the surf zone and potentially use drift algae as habitat and a source of prey.

To better understand the range of biological productivity across the coast today, which can be used as one component in the GIS predictive model, quantitative surveys of intertidal and surf zone biota were conducted along 15 beaches representing different exposures, oceanographic regimes, and landforms. Beaches were surveyed on San Miguel ($n = 1$ site), Santa Rosa ($n = 8$), Santa Cruz ($n = 3$) and Santa Catalina Island (SCaI, $n = 3$) (Figure 3.2.1, Table 3.2.1) in the late summers of 2016 to 2018. Biological surveys included beach sites in Crescent Bay on Santa Rosa (Abalone Rocks, Water Canyon, Bechers Bay, Southeast Anchorage) and Santa Cruz Islands (Christy Beach, Forney Cove). Selected beach sites ($n = 5$) were surveyed on the Santa Barbara mainland coast in early Fall 2017 and 2018 (Table 3.2.1) but analyses presented here focus on the results from the Channel Islands sites.



Figure 3.2.1 The Santa Barbara Channel region with locations of biological surveys identified in yellow

For intertidal sandy beach ecosystems, field data collection included surveys of marine wrack abundance and composition, the abundance of freshly stranded giant kelp plants, beach characteristics (slope, grain size, zone widths), intertidal macroinvertebrate abundance and richness, bird species richness and abundance, and intertidal carbon dioxide (CO_2) flux. Beach characteristics, wrack cover, and intertidal invertebrates were surveyed using methods similar to those in Dugan et al. (1990, 2003, 2015). Data on the abundance and size structure of purple olive shells (*Callianax biplicata*- formerly *Olivella*) and pismo clams (*Tivela stultorum*) were collected at selected sites using NPS monitoring methods as in Dugan et al. (1990).

Table 3.2.1 Sandy beach sites where coastal biological surveys were conducted on the Channel Islands and Santa Barbara County mainland (2016 to 2018)

Site Name	Location	2016	2017	2018
Cuyler Harbor	San Miguel Island		x	x
Sandy Point	Santa Rosa Island	x	x	x
Soledad	Santa Rosa Island	x	x	x
China Camp	Santa Rosa Island	x	x	x
Ford Point	Santa Rosa Island	x	x	x
Becher's Bay	Santa Rosa Island	x	x	x
Water Canyon	Santa Rosa Island	x	x	x
Southeast Anchorage	Santa Rosa Island	x	x	x
Abalone Rocks	Santa Rosa Island	x	x	
Forney Cove	Santa Cruz Island	x	x	x
Christy Beach	Santa Cruz Island	x	x	x
Coches Prietos	Santa Cruz Island	x	x	x
Little Harbor	Santa Catalina Island			x
Ben Weston	Santa Catalina Island			x
Emerald Bay	Santa Catalina Island			x
North Beach-Dangermond	SB County mainland			x
R Beach	SB County mainland		x	x
Sands Beach	SB County mainland		x	
Santa Claus Lane	SB County mainland		x	x
Carpinteria State Beach	SB County mainland		x	
Total sites		11	16	17

For surf zone biota, UCSB biologists collected data on surf zone fish composition (using beach seines, hook, and line in all years). In 2016, the biological team used a 10 m seine without a bag for surf zone surveys. In 2017 and 2018, the biological team used a 15.3 m x 1.8 m seine net (10 millimeter [mm] knotless nylon mesh, 2 m poles, 20 m leader ropes) with a bag, floats, and weighted lead line. At each site, the scientific team conducted four haphazardly spaced seine hauls in the shallow surf zone. Each seine haul consisted of two researchers opening the beach seine parallel to shore in approximately 1.5 m of water. Keeping the weighted line flush with the bottom, the seine was dragged perpendicular to the shoreline until reaching the beach. Fish were immediately removed from the seine, placed in aerated 1 m x 0.5 m x 0.5 m live wells, identified, enumerated, measured on glazed (smooth) fish boards, and released alive at the site of capture in accordance with Institutional Animal Care and Use Committee (IACUC) protocols.

In 2018, baited remote underwater video apparatus (BRUV) were used to collect data on species that could easily avoid beach seines. BRUV surveys followed Vargas-Fonseca et al. (2016) and Borland et al. (2017) guidelines, with modifications. Each BRUV consisted of a GoPro Hero2 camera mounted on a 5 kilograms (kg) weight with a line and float attached for easy retrieval. The weight was attached to a bait bag with ~152 grams (g) of frozen squid (*Loligo* sp.) held 1 m in front of the camera by a PVC pipe. Within two hours of low tide, snorkelers deployed three evenly spaced BRUVs along the outer edge of the surf zone at a depth of >2 m after seining was complete. Each BRUV was deployed for one hour, producing three hours of video per beach. The biological team reviewed videos to determine fish abundance, species richness, and community composition, using the MaxN statistic employed in BRUVs analyses, where MaxN is the maximum number of individuals of one species in one frame during the

hour-long footage (Ellis 1995). In 2018, triplicate samples of surf zone water collected at the sites were filtered and analyzed for environmental DNA (eDNA) in collaboration with UCLA scientists to explore the use of this emerging approach for surveying the diversity of fish in surf zones.

To explore the use of archaeological material containing barred surfperch (*Amphistius argenteus*) bones to estimate and interpret size structure for paleo-populations of this culturally important fish species and food resource, the biological team collected fresh samples of barred surfperch to develop new allometric relationships between bone size and body size for this species. The team collected samples of this widespread species from the study beaches, including tissue for stable isotope analyses and stomach contents for analyses. The team also evaluated the use of marine intertidal resources by endemic island foxes (*Urocyon littoralis*) across the productivity gradient of the Channel Islands. For this component, the scientific team collected samples of island fox scat from sandy beaches and adjacent terrestrial habitats for use in diet analysis and conducted stable isotope analyses of fox whiskers.

The 15 study beaches on the islands represented a range of orientations, lengths, and widths as well as a variety of landward boundaries (bluffs, dunes, mixed). Orientation of the beaches varied from east-facing Abalone Rocks, SRI, to west facing Soledad, SRI, and from north-facing Water Canyon, SRI, to south-facing Ford Point, SRI (Figure 3.2.1). Beach lengths ranged from pocket beaches of 0.25 km to 0.36 km with adjacent rocky reef and intertidal habitat (Ford Point, Bechers Bay, SRI; Coches Prietos, SCI; and Emerald Bay, Ben Weston and Little Harbor SCaI) to beaches ≥ 1 km in length (Cuyler Harbor SMI; Sandy Point, Soledad and Water Canyon, SRI; and Christy Beach, SCI). The overall widths of the study beaches varied nearly four-fold ranging from 24 m (Little Harbor, SCaI) to 95 m (Sandy Point, SRI) (Figure 3.2.2). Bluff-backed study beaches included Sandy Point, Ford Point, Becher's Bay and Water Canyon, SRI; Forney Cove, SCI; and Emerald Bay, SCaI. Dune-backed beaches included Cuyler Harbor, SMI; Soledad, China Camp, Abalone Rocks, SRI; Christy Beach, Coches Prietos SCI; and Little Harbor and Ben Weston, SCaI. Streams and wetlands were important features at several of the study beaches (Abalone Rocks, SRI; Coches Prietos, SCI; Little Harbor and Ben Weston, SCaI).

Results from the biological surveys of sandy beaches and surf zones revealed the existence of strong gradients and patterns in marine subsidies and ecological response variables across the Channel Islands study area. These strong gradients in coastal productivity and diversity have important implications for the availability of different types of marine resources to pre-contact human populations. Subsidies of drift macrophytes, or wrack, from kelp forests and reefs to sandy beaches varied strongly across the productivity gradient from the west to the east along the NCI and SCaI. The proximity to giant kelp forests, the presence of headlands, beach condition, and exposure to prevailing currents and wind all affect the abundance of kelp wrack subsidies delivered to sandy beaches. Mean values of total abundance (as cover) of macrophyte wrack varied by three orders of magnitude across sites (0.03 to $12 \text{ m}^2 \text{ m}^{-1}$) over the three years of surveys with peak values on the west facing beaches of SRI (Soledad and Sandy Point) (Figure 3.2.2). Kelps, including *Macrocystis*, *Egria* and *Cystocleira*, made up most of the wrack observed at most of the study sites. The abundance of kelp wrack varied over two orders of magnitude across sites with cover ranging from 0.01 to $6.73 \text{ m}^2 \text{ m}^{-1}$ over the three years of surveys (Figure 3.2.3). Surfgrass, *Phyllospadix*, was the second most important component of wrack at many sites with mean values of cover ranging from 0.00 to $5.26 \text{ m}^2 \text{ m}^{-1}$ over the three years of surveys. *Phyllospadix* was the most abundant component of macrophyte wrack at some sites including Becher's Bay and Abalone Rocks, SRI; and Emerald Bay and Little Harbor, SCaI.

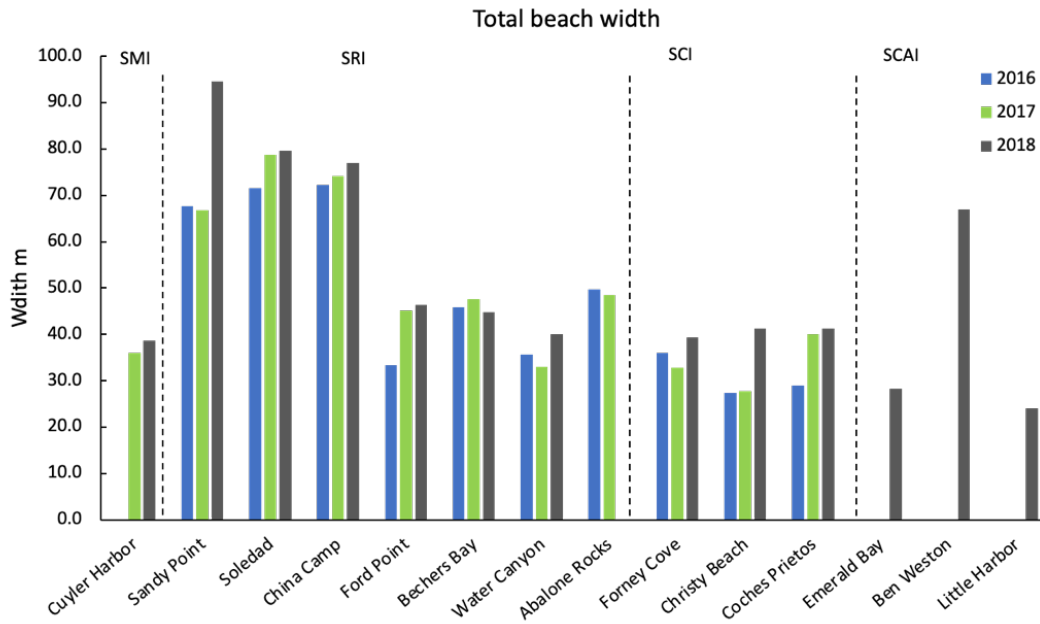


Figure 3.2.2 Mean values for overall beach widths of Channel Islands beaches coastal surveys in 2016 to 2018

Note number of surveys per site varied from 1 to 3.

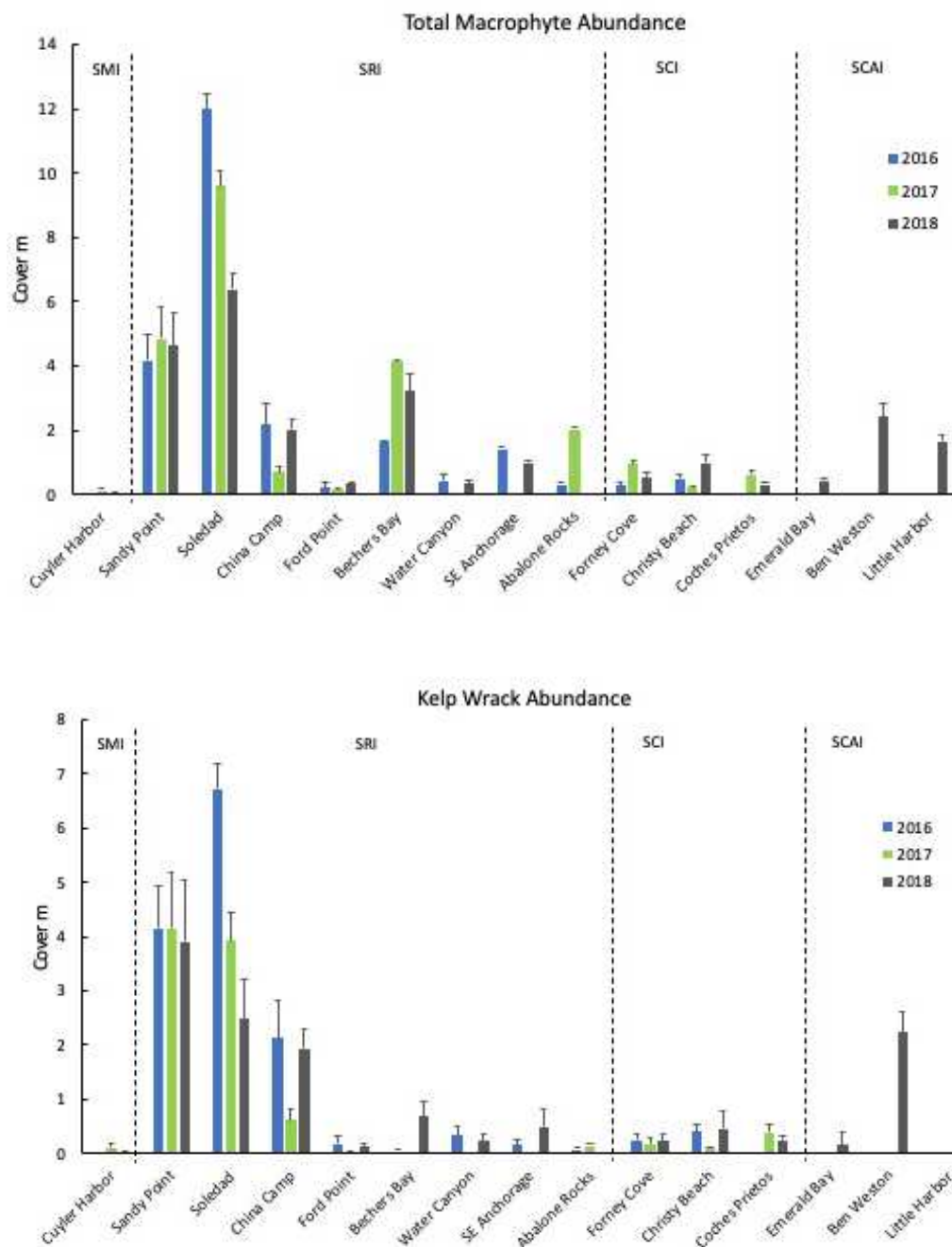


Figure 3.2.3 Mean values (+ std error) of abundance (as cover) of all marine macrophytes or wrack (top), and of all drift kelps, kelp wrack (bottom), on island beaches for 2016-2018 coastal surveys
Note the number of surveys per site varied from 1 to 3.

The total species richness of intertidal invertebrates observed in the three years of surveys varied more than 5-fold across the island study beaches ranging from a low value of nine species observed at Emerald Bay on SCAI to a peak value of 50 species observed at Sandy Point on SRI (Figure 3.2.4). Species associated with wrack subsidies were a very important component of the biodiversity of intertidal invertebrates at all sites with the species richness of these taxa ranging from 5 (Emerald Bay, SCAI) to

38 species (Soledad, SRI) (Figure 3.2.4). Wrack-associated invertebrates made up a major proportion of the total invertebrate species observed in our surveys, ranging from 52% (Christy Beach, SCI) to 81% (Soledad, SRI) and making up an average of 66% of the total intertidal species at the study sites. This finding for the pristine beaches of the Channel Islands underscores the significant contribution of these endemic and highly vulnerable wrack-associated invertebrates to coastal biodiversity and food webs.

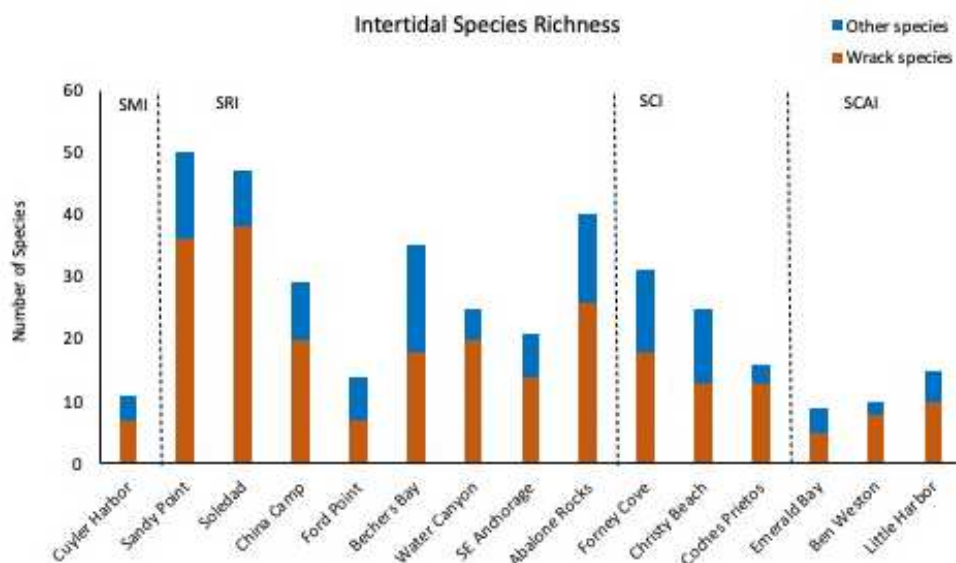


Figure 3.2.4 Total species richness of intertidal invertebrates recorded in 2016 to 2018 coastal surveys of sandy beaches on the Channel Islands

Note the number of surveys per site varied from 1 to 3.

These patterns also track the location of terminal Pleistocene and Early Holocene sites identified on the NCI. High densities of sites are in the Becher's Bay area, for example, but patterning does not always follow modern biological patterns. The high biological richness and sandy beaches of SMI and SRI could help partially explain the high density of very early archaeological sites on these islands.

The abundance of intertidal invertebrates also varied strongly across the productivity gradient and among sites. This was particularly evident for the wrack-associated intertidal invertebrate species. Four species of talitrid amphipods (*Megalorchestia* spp) were observed during surveys and at least one species occurred at every study site. For talitrid amphipods mean values of abundance varied over two orders of magnitude ranging from 174 individuals per meter (ind m⁻¹) (Ford Point, SRI) to 55,576 ind m⁻¹ (Sandy Point, SRI) (Figure 3.2.5). Observed mean values of abundance of talitrid amphipods were >10,000 ind m⁻¹ at three of the 15 study beaches during surveys. Variation in the biomass of talitrid amphipods across sites was greater than in abundance ranging from 0.61 grams per meter (g m⁻¹) (Ford Point, SRI) to 682 g m⁻¹ (Sandy Point, SRI). Two species of upper beach isopods, *Alloniscus perconvexus* and *Tylos punctata* were also important at some sites. These two wrack-associated species were more abundant than the talitrid amphipods at the sites on SCI (up to 35,442 ind m⁻¹ at Christy Beach, up to 13,798 ind m⁻¹ at Forney Cove and up to 12,333 ind m⁻¹ at Cochese Prietos) and reached an unprecedented peak abundance value of 107,338 ind m⁻¹, on SCAI at Ben Weston beach.

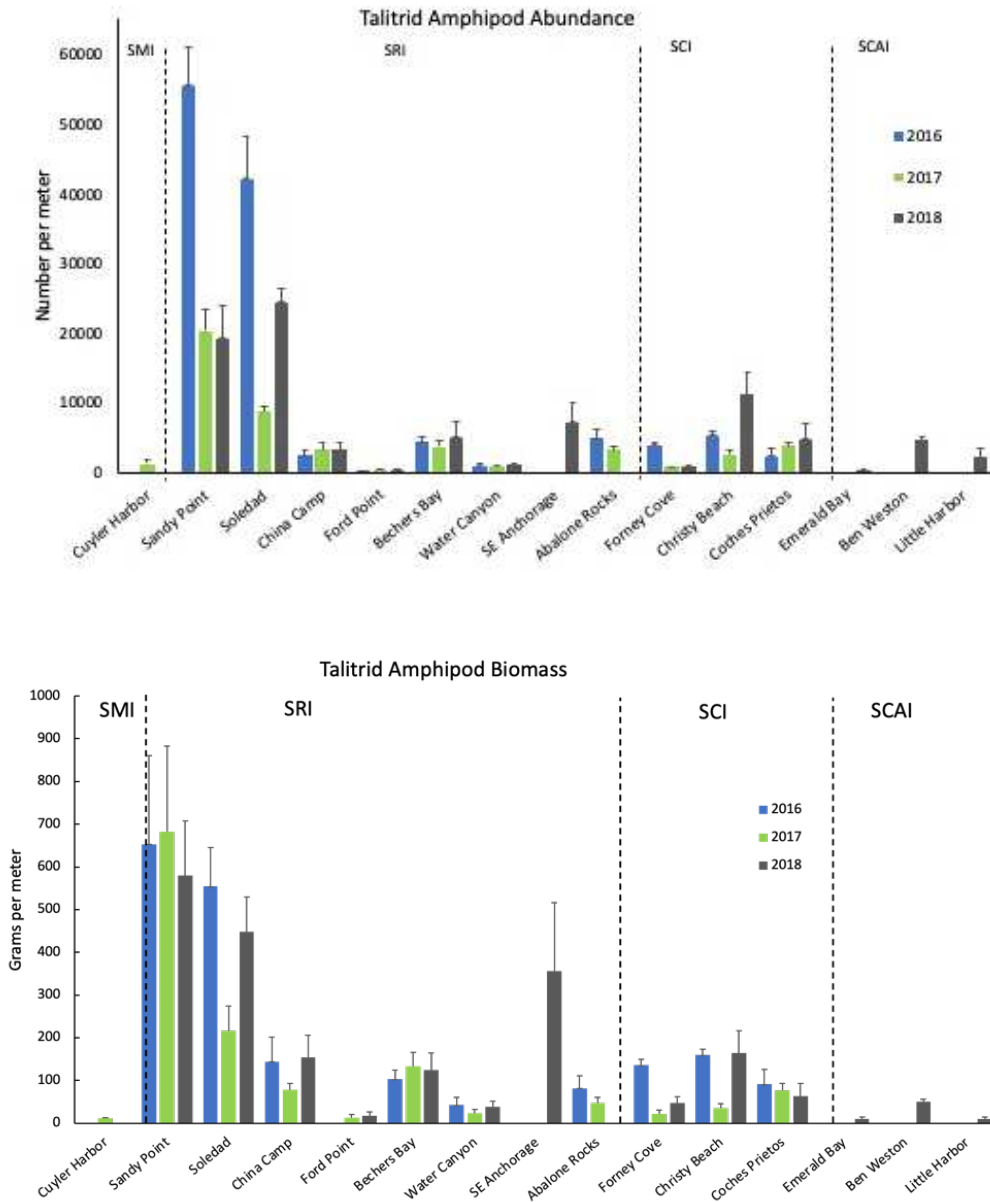


Figure 3.2.5 Mean values of abundance (+ std. error) (top) and biomass (+ std. error) (bottom) for talitrid amphipods recorded in coastal surveys of island beaches from 2016 to 2018
 Note the number of surveys per site varied from 1 to 3.

The species richness, biomass, and abundance of wrack-associated invertebrates were positively correlated with wrack abundance (Figure 3.2.6). This finding for the pristine beaches of the Channel Islands extends the strong relationships shown between wrack subsidies and beach biodiversity for mainland beaches in the region and state.

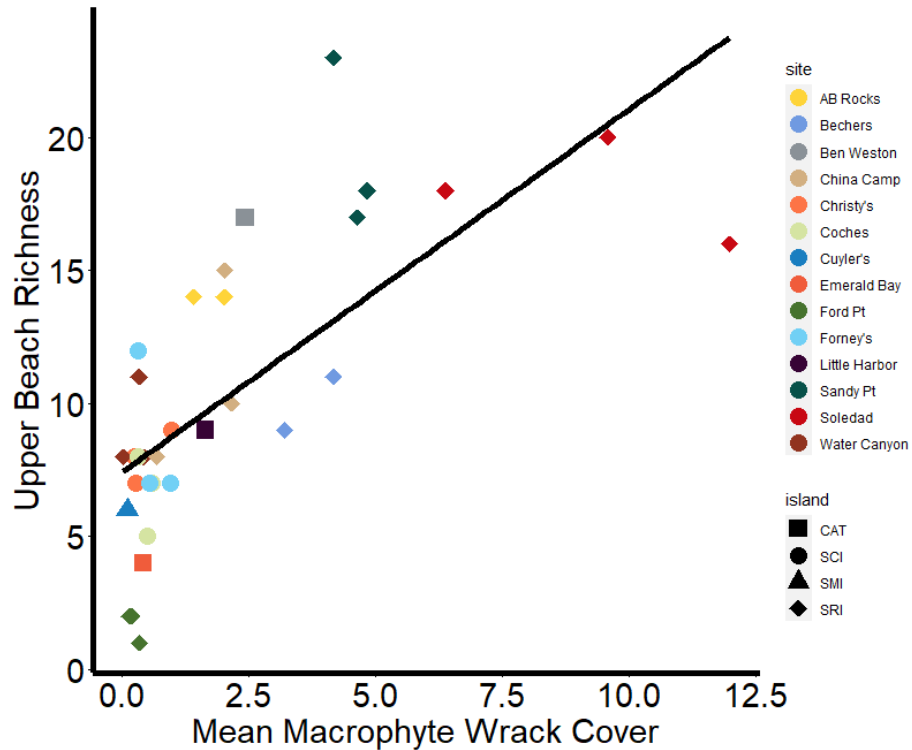


Figure 3.2.6 Relationship between the species richness of wrack-associated invertebrates and the abundance of marine macrophyte wrack as cover ($r^2 = 0.48$, $p < 0.001$)
 Data point shape reflects study island and data point color reflects study beach. Data points are mean values for all surveys ($n = 1$ to 3) from 2016 to 2018.

Lower on the intertidal beach face, the highly mobile sand crab (*Emerita analoga*) was found at all study sites. This crab is the most important suspension-feeding invertebrate found on California beaches in terms of biomass and is an important component of coastal food webs, serving as prey for birds, fish, and marine mammals. This intertidal crab has long-lived planktonic larvae that recruit in large numbers to almost any type or size of beach in the spring months. Abundance of sand crabs often reflects annual recruitment success while size structure represents growth and survival. Strong gradients in body size that matched gradients in water temperature (SST) were evident in sand crabs with body size increasing with declining SST from east to west along the islands. Mean values of abundance of *Emerita* varied three-fold among sites ranging from 212 ind m^{-1} at Emerald Bay (SCaI) to 18,768 ind m^{-1} at Christy Beach (SCI) (Figure 3.2.7). Observed mean values of abundance of this crab species were $>10,000$ ind m^{-1} at eight of the 15 study beaches during surveys.

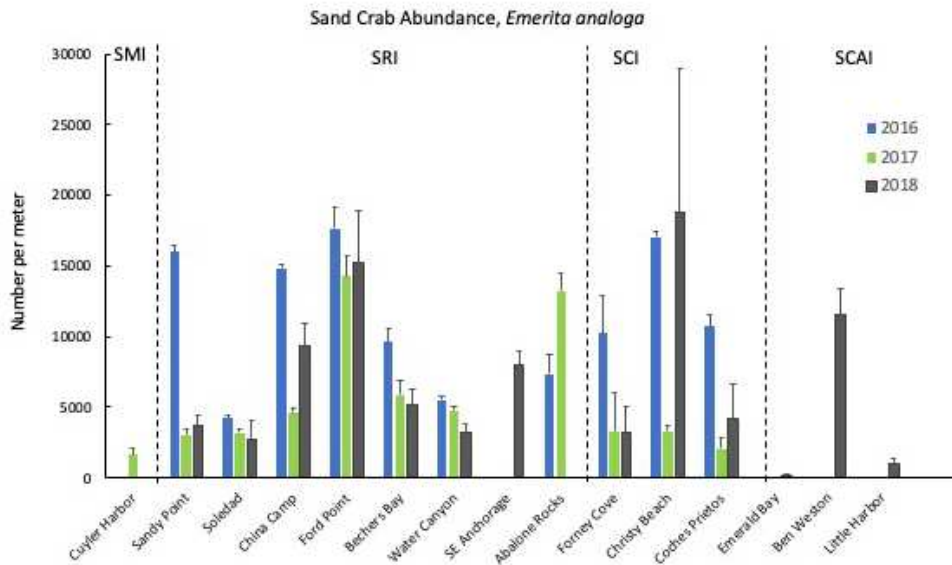


Figure 3.2.7 Mean values of abundance (+ std. error) for sand crabs recorded in coastal surveys of island beaches from 2016 to 2018

Note number of surveys per site varied from 1 to 3.

Populations of purple olive snails, *Olivella biplicata* (*Callianax*), are patchily distributed in intertidal and shallow subtidal zones of sandy beaches and surf zones of the region (Figure 3.2.8). These long-lived gastropods were highly valued and made into beads used as currency by pre-contact humans on the Channel Islands and mainland. Populations of this snail species were abundant in the low intertidal and subtidal zones of several sandy beaches on SRI (Figure 3.2.8) in 2017 surveys with peak abundance exceeding 25,000 ind m^{-1} at Southeast Anchorage, the site where it occurs most consistently. The wider distribution of this species in 2017 could reflect successful recruitment and good conditions for survival.

A total of 40 species of fish and elasmobranchs were recorded during surf zone surveys of island beaches (Table 3.2.2). In the beach seines, 25 different species of teleost fishes were recorded. In the surf BRUVs, the biological team identified 30 different species, including six species of elasmobranchs. The composition of surf zone fish communities based on beach seine and surf BRUV surveys were generally complementary. However, large elasmobranch species, particularly bat rays and leopard sharks, were observed only in the BRUV surveys. Together, these two methods provided a more complete picture of surf zone fish at the study sites with BRUVs providing new information on elasmobranch species using the surf zone (Figure 3.2.9).

For beach seines, the total species richness of fish recorded over the study ranged from one species at Soledad, SRI, to nine species at Forney Cove, SCI, across the sites (Figure 3.2.10). For the surf BRUVs, species richness was greater than observed in seines in 2018, ranging from 2 (China Camp, SRI) to 16 (Little Harbor, SCAI) total species with up to 12 teleost species and up to four elasmobranch species observed at that site. In general, higher species richness of surf zone fishes was observed on smaller pocket beaches, such as Little Harbor on SCAI, where rocky habitat is adjacent to the surf zone. Lower species richness of surf zone fishes was more often observed on the longer beaches, such as China Camp, Soledad, and Sandy Point on SRI.

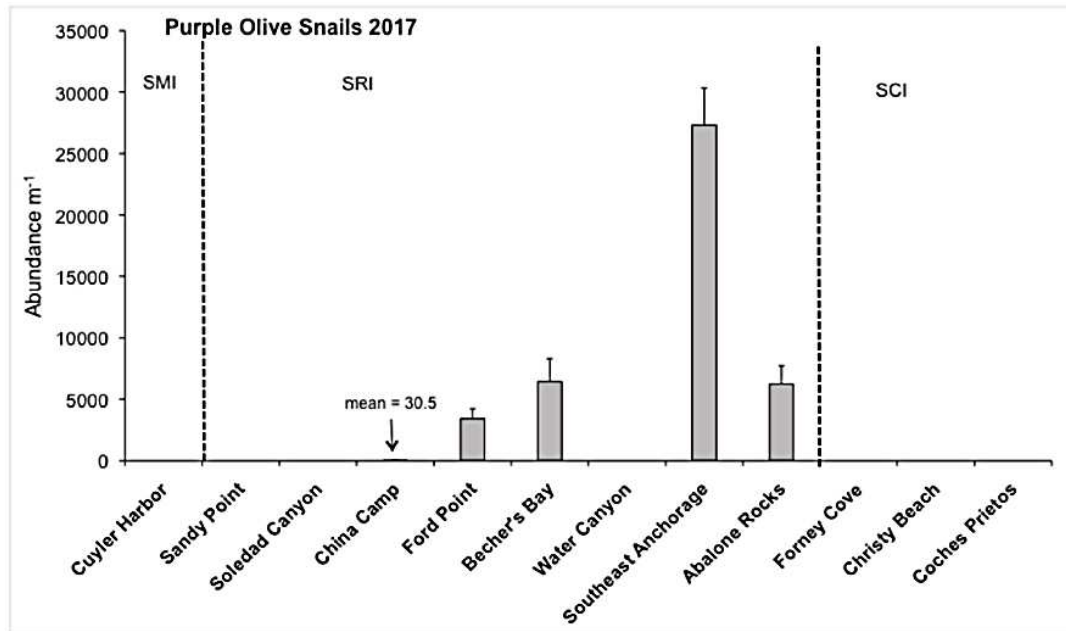


Figure 3.2.8 Estimated values of mean (+ std error) abundance of purple olive snails from coastal surveys in 2017

Table 3.2.2 Fish and elasmobranch species recorded in surf zone surveys using beach seines and surf BRUVs on the Channel Islands

Common name	Species	Seine	BRUV
Topsmelt	<i>Atherinops affinis</i>	X	X
California grunion	<i>Leuresthes tenuis</i>	X	
Pacific jack mackerel	<i>Trachurus symmetricus</i>		X
Giant kelpfish	<i>Heterostichus rostratus</i>	X	X
Sardine	<i>Sardinops sagax</i>	X	
Barred surfperch	<i>Amphistichus argenteus</i>	X	X
Kelp perch	<i>Brachyistius frenatus</i>	X	
Shiner perch	<i>Cymatogaster aggregata</i>	X	
Black perch	<i>Embiotoca jacksoni</i>	X	X
Walleye surfperch	<i>Hyperprosopon argenteum</i>	X	X
Silver surfperch	<i>Hyperprosopon ellipticum</i>	X	
Dwarf perch	<i>Micrometrus minimus</i>	X	X
Northern anchovy	<i>Engraulis mordax</i>	X	X
Sargo	<i>Anisotremus davidsonii</i>	X	X
California salema	<i>Haemulon californiensis</i>	X	X
Opaleye	<i>Girella nigricans</i>	X	X
Zebra surfperch	<i>Kyphosus azureus</i>	X	
Halfmoon	<i>Medialuna californiensis</i>		X
Rock wrasse	<i>Halichoeres semicinctus</i>	X	X
Señorita	<i>Oxyjulis californica</i>		X
California Sheephead	<i>Semicossyphus pulcher</i>		X
California moray	<i>Gymnothorax mordax</i>		X
Speckled sand dab	<i>Citharichthys stigmaeus</i>	X	X
California halibut	<i>Paralichthys californicus</i>	X	X
Kelp bass	<i>Paralabrax clathratus</i>		X
Barred sandbass	<i>Paralabrax nebulifer</i>		X
Hornyhead turbot	<i>Pleuronichthys verticalis</i>	X	
White seabass	<i>Atractoscion nobilis</i>	X	
California corbina	<i>Menticirrhus undulatus</i>	X	
Queenfish	<i>Seriphus politus</i>	X	
Yellowfin croaker	<i>Umbrina roncadore</i>	X	X
Pacific chub mackerel	<i>Scomber japonicus</i>		X
Pacific barracuda	<i>Sphryaena argentea</i>		X
Kelp pipefish	<i>Syngnathus californiensis</i>	X	X
Bat ray	<i>Myliobatis californica</i>		X
Thornback guitarfish	<i>Platyrrhinoidis triseriata</i>		X
Shovelnose guitarfish	<i>Rhinobatos productus</i>		X
Soupfin shark	<i>Galeorhinus galeus</i>		X
Leopard shark	<i>Triakis semifasciata</i>		X
Haller's round stingray	<i>Urolophus halleri</i>		X

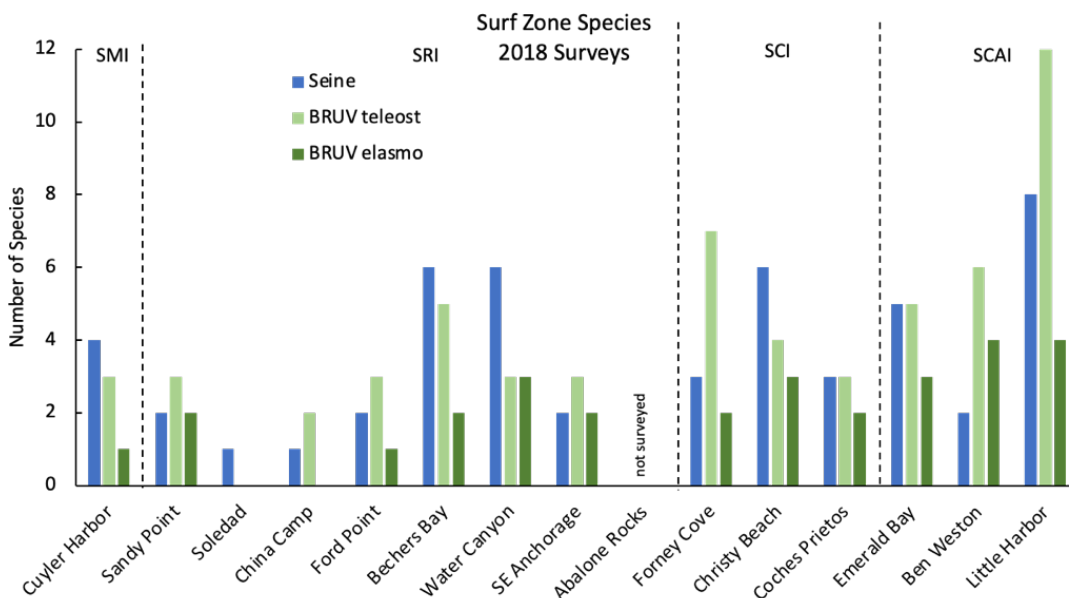


Figure 3.2.9 Species richness of fish and elasmobranchs observed in surveys using beach seines and BRUVs during 2018

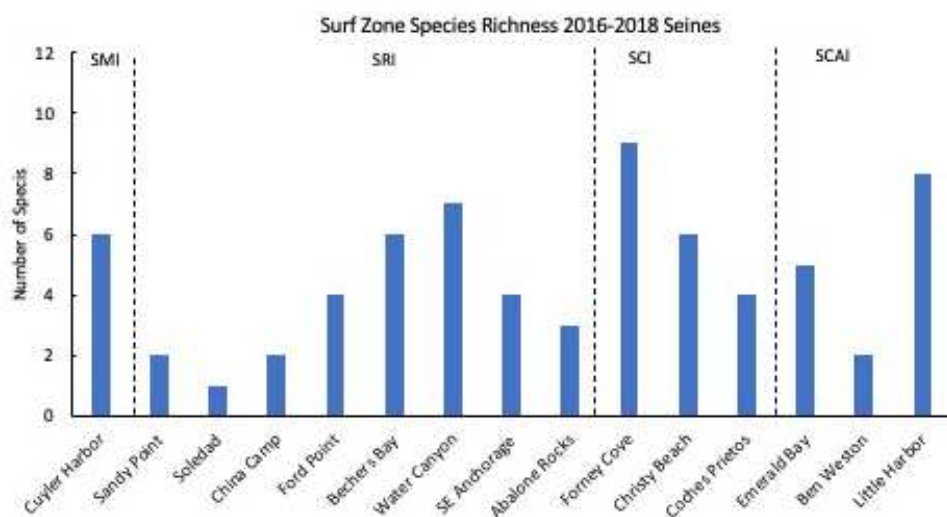


Figure 3.2.10 Total species richness for surf zones recorded in beach seines for coastal surveys from 2016 to 2018

Note the number of surveys per site varies from 1 to 3.

The composition of surf zone fish communities based on beach seine and surf BRUV surveys were complementary with elasmobranch species, particularly bat rays and leopard sharks, observed only in the BRUV surveys. Together, these two methods provided a more complete picture of surf zone fish at the study sites with BRUVs providing new information on elasmobranch species using the surf zone.

The biological team also explored the use of eDNA to evaluate the diversity of surf zone fish during surf zone surveys (Table 3.2.3). Triplicate filtered samples of surf zone water collected in 2018 at all the island beaches and analyzed for eDNA recorded consistently higher diversity in surf zone fish communities (14 to 43 species per site) than for the combined beach seine and BRUV survey results (1 to 19 species per site) (Figure 3.2.10). However, the time span of sampling represented by the surf zone water samples is unknown and is likely far longer than the time span for sampling represented by the beach seines or the BRUVs. Nonetheless, the team found significant correlations in species richness across the three methods (Figure 3.2.11).

Another caveat is the need to refine the eDNA analyses to better distinguish important surf zone fish taxa, particularly the surfperch family, Embiotocidae, a group where it was not possible to resolve the species in the current eDNA analyses. Surveys using emerging methods (BRUVs, eDNA) allowed detection of top predators (e.g., sharks, rays) with minimal impact. Overall, results suggest that island surf zones are productive enough to support high densities of fish and elasmobranchs. A summary of metrics for the three methods we used details their relative needs, effort, and strengths (Table 3.2.3). Results suggest that, with additional calibration and improved genetic libraries and resolution of key taxonomic groups, such as the surfperch, eDNA has the potential to become a useful tool for characterizing surf zone and other fish communities. Our findings also illustrate how combining traditional and emerging methods can greatly improve the characterization of surf zone fish biodiversity.

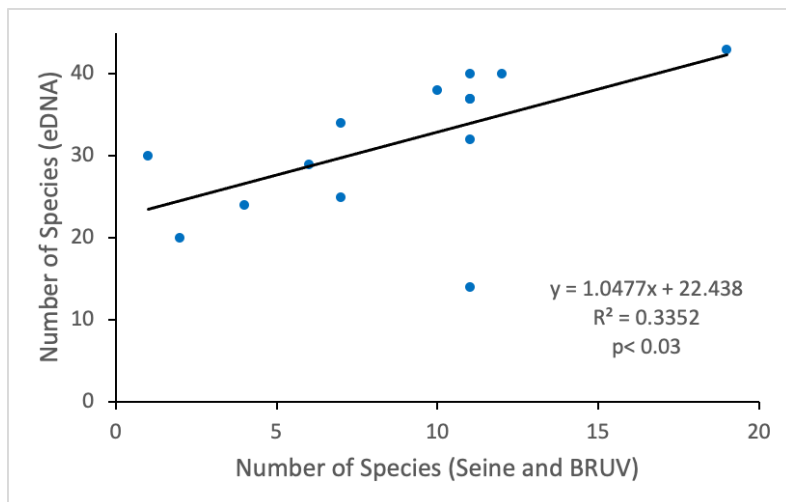


Figure 3.2.9 Relationship between the combined species richness of fish observed in seines and BRUVs and that from eDNA analyses of surf zone water for surveys (2018)

Table 3.2.3 Comparisons of the three survey methods used for surf zone fish.

Metric	Beach Seine	BRUV	eDNA
Team size needed	4-6	2	2
Set up and Field time	20 minutes per seine, 20-85 minutes to measure & release	1.5 to 2.0 hours	20 minutes
Field Gear required	Seine, poles, lines	Weighted video rigs, bait	Sampling bags, filters, ice chest
Field Sample processing	Minimal, gear clean up and repair	Minimal, gear clean up and repair	~1.5 hours for gravity filtering and preserving samples
Post-field sample processing	None	1.5-3.0 hours per video	12-24 hours per sample (DNA extraction, PCR, library preparation, sequencing), but can be automated and optimized for high throughput
Sample archiving	No – fish released	Yes – video record	Yes – DNA extractions archived & sequence record
Abundance	Relative	Relative	Relative (needs ground-truthing)
Size and age distribution	Yes	No	No
Injury/mortality of fish	A small percentage of catch	No	No
Effect of sea conditions	Significant: affects net behavior and safety	Significant: affects visibility	Wider tolerance but unknown effects on spatial and temporal variability

Barred surfperch were an important and widespread species in the surf zone fish communities of the NCI. Barred surfperch were the species of fish most consistently caught in beach seines, particularly at sites on the NCI. Mean values for abundance of barred surfperch in beach seines ranged from zero fish at sites on SCAI to 92 fish at Christy Beach SCI in 2018 (Figure 3.2.12). The size range and total length of barred surfperch observed in the beach seines ranged from 60 to 368 mm over the survey years. The surf zone fish assemblages of many of the island beaches (eight out of 14 sites) were dominated by barred surfperch (>50% of total fish caught). This surfperch species was caught in seines at all nine NCI sites surveyed in 2016, 10 of the 11 sites surveyed in 2017, and 12 of the 14 sites in 2018 surveys (the two sites with no barred surfperch were on SCAI). In 2018, this species made up 9% to 100% of the fish caught in seines at the sites where it occurred and more than 50% of the fish recorded in seines or BRUVs at eight of the 14 sites (Figure 3.2.13). Surf BRUVs were relatively less effective at observing barred surfperch than seines, detecting this important species at only six of the 13 sites where BRUVs were used in 2018.

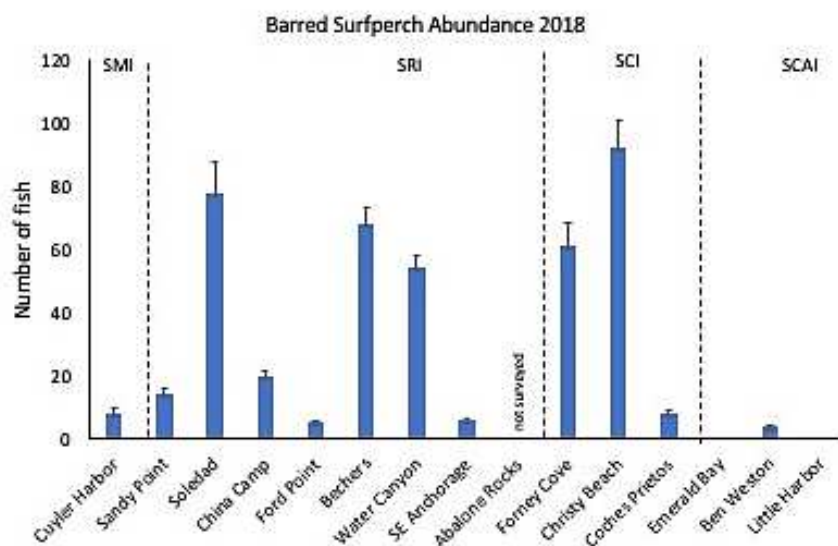


Figure 3.2.10 Mean values of abundance (+ std error) of barred surfperch reported in beach seines in the 2018 surveys of Channel Island surf zones

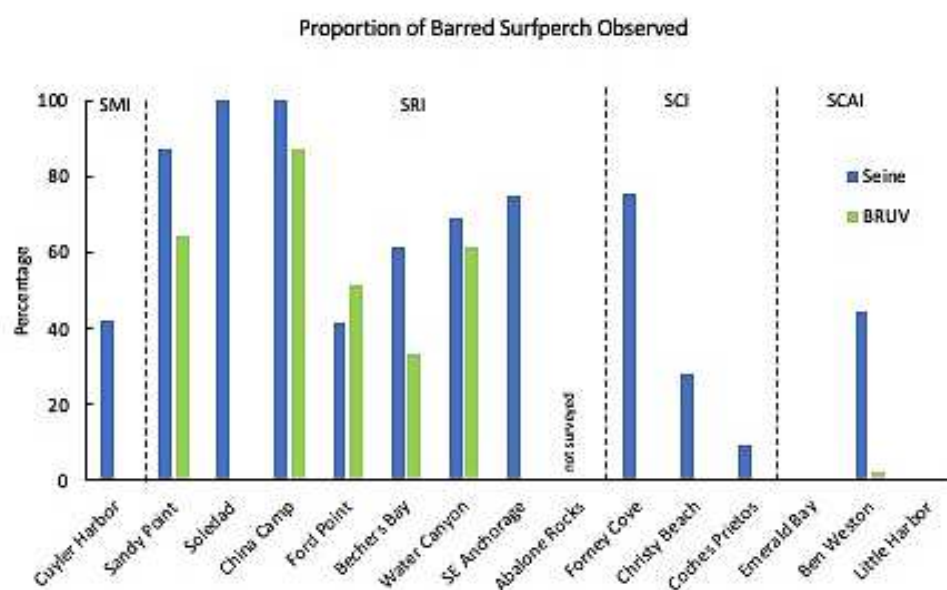


Figure 3.2.11 Relative abundance of barred surfperch recorded in surveys with beach seines and BRUVs in 2018

A diversity of the datasets resulting from the biological surveys of island beaches were provided for use in the GIS model. These Channel Island datasets included new information on kelp and macrophyte wrack, beach characteristics, intertidal invertebrate communities (sand crabs, Pismo clams, purple olive snails and wrack-associated fauna), surf zone fish communities, bird use of beaches, and CO₂ production.

To estimate the size distribution of populations of barred surf perch from pre-contact remains, the team used modern fish specimens to develop a set of allometric relationships between the dimensions of different bones and body lengths. The team collected *A. argenteus* from the surf zones of island and mainland sandy beaches in Southern California during Summer 2018. Total length was recorded for each fish at the time of capture (Figure 3.2.14). Fish were frozen prior to analysis. Each fish was thawed, baked for ease of dissection then candidate bones were removed and measured. A variety of candidate bones were selected for measurement with a focus on non-repeated cranial skeletal elements, and bone types that have yielded known relationships with body length in other species of fish. Bone characteristics were measured to the nearest 0.01 mm with digital calipers. The team developed linear regressions for different measurements of six candidate bones (Table 3.2.4). Based on regression results, as well as the structural integrity of the different bones, the inferior pharyngeal could be the best candidate for use in analysis of midden material (Figure 3.2.14).

Table 3.2.4 Linear regressions for bone measurements and standard length in *A. argenteus* (n=30 to 32)

Bone	Measurement	Intercept	Slope	R squared
Vomer	1	-0.827	0.0344	0.955
Vomer	2	-0.824	0.0251	0.797
Dentary	1	-2.0545	0.0754	0.979
Dentary	2	-0.9942	0.0321	0.666
Quadrate	3	-0.8814	0.0252	0.952
Quadrate	4	1.3503	0.0779	0.972
Premaxilla	1	-0.3979	0.0831	0.971
Premaxilla	2	-0.9656	0.0641	0.962
Premaxilla	3	0.61	0.0513	0.890
Pharyngobranchial 2	1	-2.0361	0.0502	0.917
Pharyngobranchial 2	2	-2.4811	0.0438	0.877
Inferior Pharyngeal	1	-2.6567	0.0732	0.957
Inferior Pharyngeal	2	-2.2305	0.0366	0.923
Inferior Pharyngeal	3	-3.876	0.1245	0.945

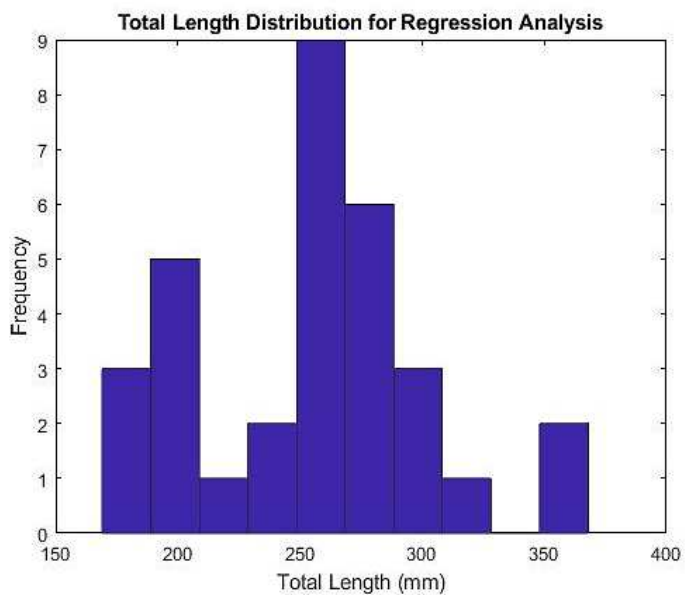


Figure 3.2.12 Distribution of total lengths for *A. argenteus* used for regression analyses on bones in Table 3.2.3 (n=32)

Samples of fish remains from archaeological pre-contact midden deposits were obtained from the Santa Barbara Museum of Natural History. These samples represent five different sites on two of the NCI (SMI and SRI). Samples that were already identified as “perch” or “surfperch” were examined and sorted for the presence of bones matching those used in the regressions. Measurements to the nearest 0.01 mm were made on each specimen in accordance with the dimensions consistent with the allometric relationships (Figure 3.2.15). There were 44 bones that matched requirements and were undamaged in at least one of the axes of measurement. These measurements were used to calculate total length of each individual using allometric relationships to build an “ancient” size frequency distribution for barred surfperch from archaeological remains. Data from 2017 to 2018 field surveys on the NCI were used to provide a “modern” comparison of size distribution of barred surfperch to the midden remains of this important species. Measurements of barred surfperch caught using beach seines on SMI, SRI, and SCI were aggregated into the “modern” size frequency distribution (N=525) (Figure 3.2.16). The size range of the ancient and modern samples of barred surfperch broadly overlapped at larger sizes (125 mm and up) but the lack of small fish in the archaeological materials suggests analyses of surfperch material from a broader range of archaeological sites are needed.

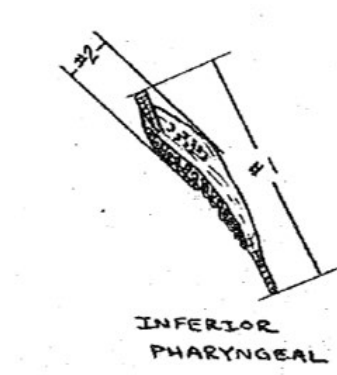


Figure 3.2.13 Example of the bone measurement approach using the inferior pharyngeal bone and associated measurements

Bone from sampled specimen of barred surfperch (left) and diagram from Orchard 2001 for Atka Mackerel (right).

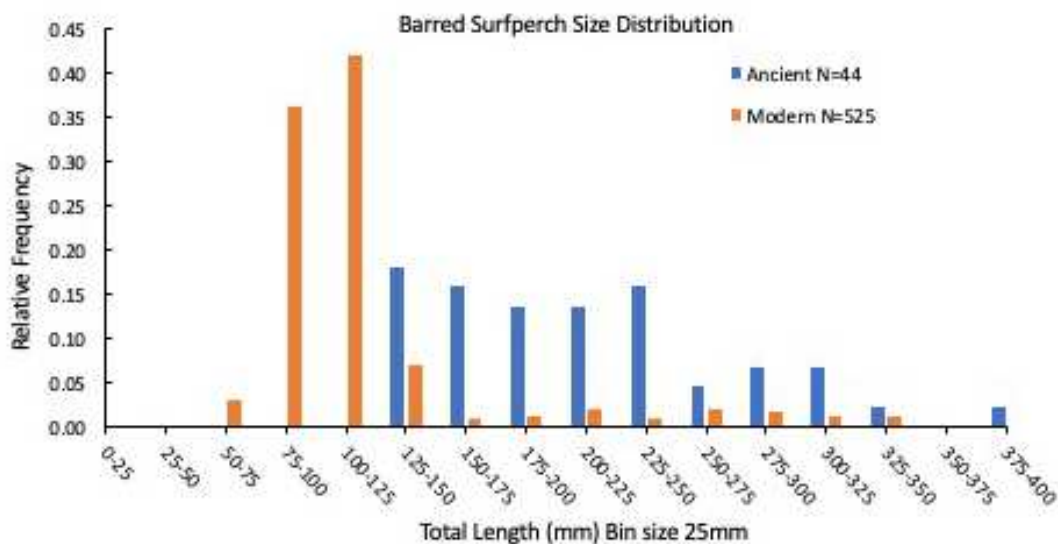


Figure 3.2.14 Comparison of size frequency distributions for barred surfperch calculated from midden remains plotted with data from modern surveys

Mean value of total length: ancient = 212.72 mm + 62.04 mm, modern = 120.79 mm + 54.26 mm

Another area of investigation was ecosystem functioning in terms of CO₂ production at the high tide strand line. Ecotones and sharp environmental gradients are often zones of high biodiversity and ecosystem functioning and are at risk for disproportionate impacts of climate change. With increasing pressures from land and sea, shorelines exemplify this issue. Sandy beaches are shoreline ecosystems, where cross-ecosystem subsidies of marine wrack support diverse, productive food webs. The biological team measured CO₂ flux, a proxy for a key ecosystem function (wrack decomposition) on 14 beaches of California's Channel Islands that varied in wrack abundance. At each site, the team surveyed wrack and associated macroinvertebrates and measured sediment CO₂ flux at the high tide line. The team took five sediment CO₂ flux measurements at each site on the 24-hour high tide line using an EGM-5 Portable CO₂ Gas Analyzer with an SRC-2 Soil Respiration Chamber and collars (PP Systems, Amesbury, Massachusetts, USA).

Measurements were taken at the high tide line because this zone of the beach is the most biologically active (fresh wrack deposition, highest invertebrate abundance) and the team found that the sand is dry and has little to no flux above this zone, as does the saturated sand below this zone. The biological team calculated the mean respiration rate for each site survey. These rates reflect net ecosystem metabolism measurements and in all cases were net fluxes out of the beach; there was no net uptake of CO₂. To evaluate the contribution of the most abundant wrack-associated invertebrates to CO₂ flux, the biological team collected adults of four talitrid amphipods (*Megalorchestia californiana*, *M. corniculata*, *M. benedicti*, and *M. minor*), two isopod species (*Alloniscus perconvexus* and *Tylos punctatus*), and a beetle (*Phaleria rotundata*) on beaches in Santa Barbara County, California, USA. Respiration rates of each species were estimated on these live animals using stop-flow respirometry within 24 hours of collection.

CO₂ flux of the study beaches was highly variable among island sites, ranging from 0.05 to 1.2 g CO₂ m⁻² hour⁻¹, and was strongly correlated with wrack abundance (Figure 3.2.17). Estimated rates of beach-scale respiration for wrack consumers, based on their field abundance and laboratory measured respiration rates, varied from 8 to 449 mg CO₂ hour⁻¹ m⁻¹ among sites. The estimated fraction of beach CO₂ flux contributed by wrack consumers ranged from 0.6% to 28%, averaging 10.5%. These results demonstrate

tight coupling of subsidies, intertidal consumers, and ecosystem function on sandy beaches—ecosystems that are critically imperiled by rising sea levels and coastal development.

Food web and diet analyses of barred surfperch and the island fox were also an important area of coastal investigation. Surf zones are dynamic, turbulent areas at the interface between pelagic and intertidal ecosystems. On exposed sandy beaches, the shifting sands and lack of hard substrate within the surf zone preclude the attachment of kelp and other macroalgae that could support local secondary production. Consequently, secondary production in the surf zone is largely sustained through flows of organic material from neighboring pelagic and rocky reef ecosystems. These allochthonous subsidies include phytoplankton, drift macrophytes, and carrion. The pathways and relative importance of these subsidies to surf zone food webs are poorly understood.

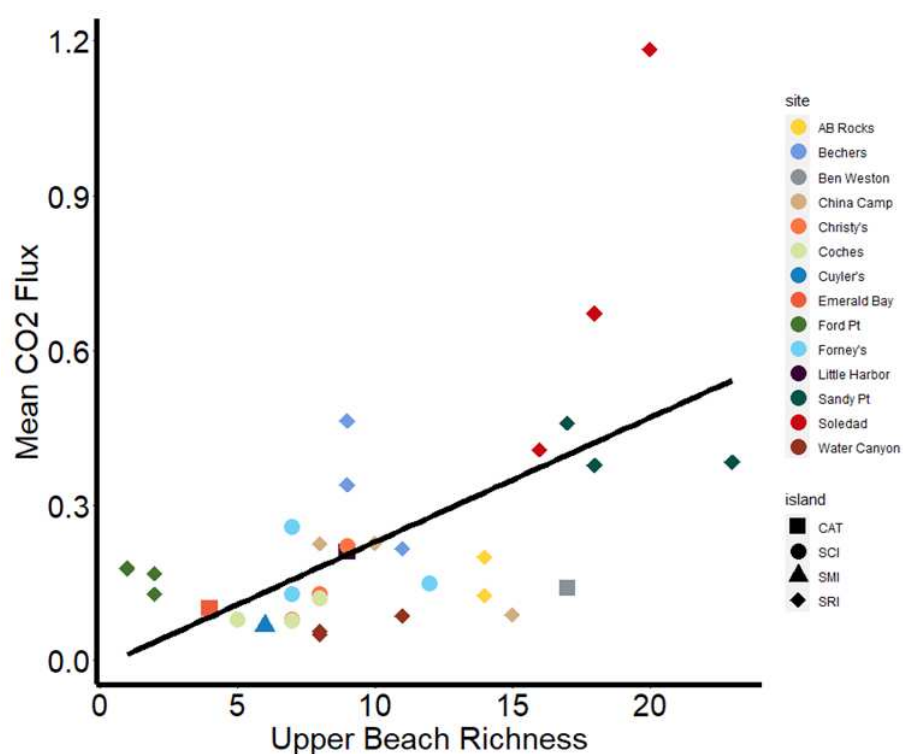


Figure 3.2.15 The relationship between the species richness of wrack-associated invertebrates and mean CO₂ flux ($r^2 = 0.32$, $p < 0.001$)

Data point shape reflects study island and data point color reflects study beach. Data points are mean values per site visit ($n = 1$ to 3) from 2016 to 2018

Phytoplankton advected into the surf zone of sandy beaches are exploited by populations of suspension-feeding invertebrates that include sand crabs (*Emerita analoga*), the most important macroinvertebrate species by biomass in this habitat in California, and a trophic-intermediate species supporting higher-level consumers, including surf zone fish (e.g., surfperch, croakers) and birds. Drift macrophytes, or wrack, originating from subtidal rocky reefs, support diversity, secondary production, and food webs of the upper intertidal beach ecosystem. The importance of these upper beach wrack-associated species in supporting surf zone fish has not been investigated and could vary among locations, depending on the abundance of wrack and accessibility of this resource to nearshore fishes.

Barred surfperch is one of only two species of fish specializing in the surf zones of sandy beaches in Southern California. These surfperch are widespread and abundant along the beaches of mainland and islands of southern and central California, and targeted by both recreational and commercial fisheries and known to have been exploited by Chumash people on the Channel Islands back to at least the Early Holocene. Barred surfperch (hereafter surfperch) are known to feed on several types of suspension-feeding invertebrates along the mainland coast, particularly sand crabs (Carlisle et al. 1960). However, variation in surfperch diet among beaches, and the potential importance of upper beach wrack-associated macroinvertebrates in the diet of these fish is unknown. In this study, the biological team assessed the diet of surfperch at beaches bordering Santa Rosa and Santa Cruz Islands, and relationships between diet and beach physical and biological characteristics, including the abundance of suspension feeding and grazing prey species.

This study of surfperch diet focused on seven beaches on SRI and two beaches on SCI (Figure 3.2.1). The beaches on SRI, which encircled the island, varied in size and morphology, and included relatively short, narrow, and bluff-backed beaches (i.e., Southeast Anchorage, Becher's Bay, Water Canyon, Ford Point), longer, wider beaches backed by dune fields, bluffs or both (i.e., Soledad, Sandy Point, China Camp). The sites on SCI included an expansive, exposed dune-backed beach at the western end of the island (Christy Beach) and a smaller, protected south-facing pocket beach at Coches Prietos.

The biological team measured several beach physical and biological variables that could influence surfperch foraging behavior, access to prey, and/or prey abundance. These included beach length and width; beach orientation with respect to currents; and swell, slope, and the abundance of macrophyte wrack, including giant kelp, *Macrocystis pyrifera*, on the beach. Biomass of giant kelp (*Macrocystis pyrifera*) in beds offshore that could provide wrack to the study beaches was also estimated using Landsat imagery and mapped using ArcGIS.

The team estimated the abundance and biomass of sandy beach invertebrates posited to be an important component of surfperch diet (Carlisle et al. 1960) at each site during daytime spring low tides in the late summer to fall (August to October) of 2018 following methods modified from Dugan et al. (2003). Coincident with the sampling of beach invertebrates, the team sampled surfperch for diet analysis using replicate hauls of a beach seine and hook and line from the shore. Stomachs of approximately 10 specimens were removed and preserved for analysis in the laboratory. In the laboratory, surfperch stomach contents were identified under a dissecting microscope to the lowest taxonomic level possible, counted, and weighed wet (blotted). The effect of beach site on food resource use was explored separately for juvenile and adult surfperch using non-parametric analysis of variance (PERMANOVA) and a multivariate regression model (DistLM).

Stomach contents are invaluable for identifying recently consumed food items. However, stable isotope analysis is a complementary approach that can provide information on diet integrated over a longer period. A piece of dorsal muscle tissue was removed from each fish following collection for stable carbon and nitrogen isotope analysis, which was conducted in the University of California, Santa Barbara Marine Science Institute Analytical Laboratory. The biological team also prepared samples of invertebrates that typically specialize on phytoplankton or kelp-suspension feeding sand crabs and talitrid amphipods (*Megalorchestia* spp.), respectively for isotope analysis. These data enable an evaluation of the relative importance of phytoplankton-based versus kelp-based resources to surfperch nutrition over time.

Thirty-eight taxa were identified in the stomachs of barred surfperch across all sites (Table 3.2.5). For analysis, the team assigned ingested prey to three categories: 1) sand crabs, which are widely distributed and used by surfperch; 2) 11 wrack-associated taxa that rely on beach-cast macrophyte wrack for food and shelter; and 3) all other prey that included five taxa found lower on sandy beaches and 21 other taxa that do not inhabit beaches, or were not identified to a low enough taxonomic level to determine their

habitat preference. This heterogeneous group contained subtidal rocky reef and pelagic taxa that are very patchily distributed and not easily sampled, and their abundance was not measured during this study.

The abundance of sand crabs varied significantly ($p < 0.001$) and nearly seven-fold across sites, from 2,773 crabs m^{-1} at Soledad to 18,768 crabs m^{-1} at Christy Beach, with a trend of highest abundance on the southeastern beaches of SRI (Figure 3.2.18A), and with higher abundance on Christy Beach than Coches Prietos Beach on SCI. Sand crab biomass also varied greatly across beaches ($p < 0.001$), ranging from 209 to 18,167 g m^{-1} with a trend of highest biomass on the two most southeastern beaches on SRI (Figure 3.2.18B) and higher on Christy Beach than Coches Prietos on SCI.

Table 3.2.5 List of prey items in barred surfperch stomachs grouped by prey categories used in analysis.

Beach Invertebrates	Other Taxa	Other Taxa
<u>Decapoda</u>	<u>Bivalvia - unknown</u>	<u>Cirripedia</u>
<i>Emerita analoga</i>	<u>Amphipoda</u>	<i>Pollicipes polymerus</i>
<u>Upper beach taxa</u>	<i>Atylus tridens</i>	<u>Miscellaneous</u>
<u>Amphipoda</u>	Gammaridae	Ostracoda
<i>Megalorchestia</i> spp.	<u>Isopoda</u>	Cumacea
<u>Isopoda</u>	<i>Excirolana</i> sp.	Mysida
<i>Alloniscus perconvexus</i>	<i>Gnoremospaeroma noblei</i>	Caprellidae
<u>Coleoptera</u>	<i>Ancinus granulatus</i>	<u>Cnidaria</u>
<i>Akephorus marinus</i>	<u>Decapoda</u>	Actinaria
<i>Thalasselephas testaceus</i>	<i>Cancer</i> sp.	<u>Mollusca</u>
<i>Cercyon fimbriatus</i>	<i>Pugettia producta</i>	Patellidae
<i>Phaleria rotundata</i>	<i>Pleuroncodes planipes</i>	<i>Mytilus</i> sp.
Staphylinidae	<i>Crangon nigricauda</i>	Other Bivalvia
Histeridae	Caridea	Gastropoda
<u>Diptera</u>	Other Decapoda	Teleost eggs
Anthomyiidae	<u>Isopoda</u>	Algae
Coelopidae	<i>Idotea</i> sp.	
Other Diptera	Other Isopoda	

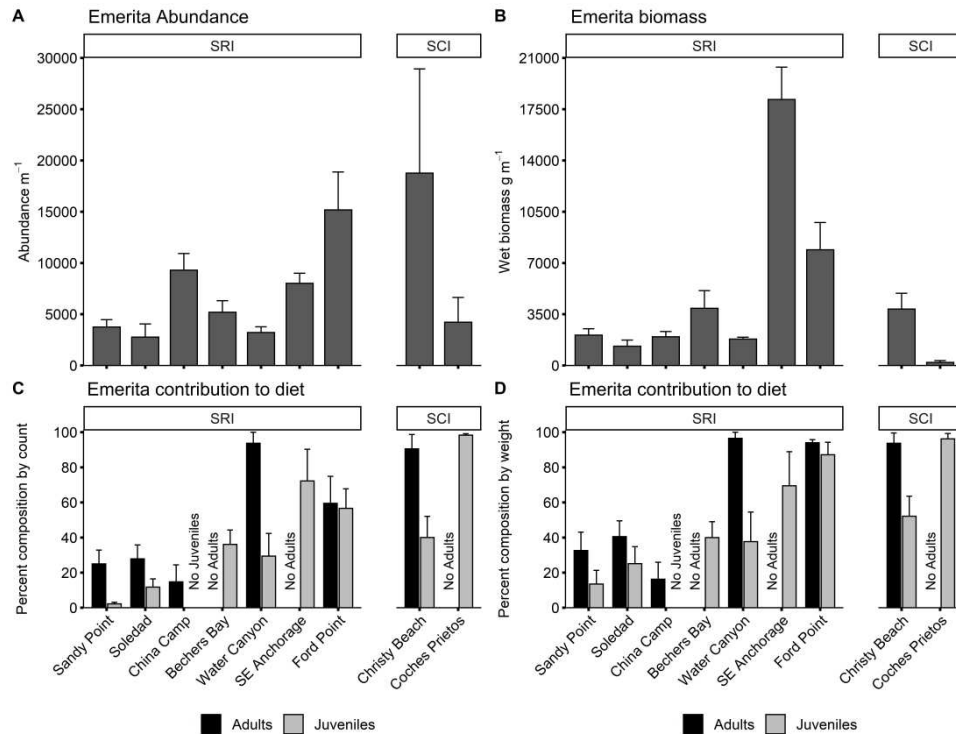


Figure 3.2.16 Mean ($\pm$ SE) A) abundance (count) and B) biomass of sand crabs (*Emerita analoga*) sampled from Santa Rosa and Santa Cruz Islands in 2018 and the relative contribution (as percent) in terms of C) abundance (count) and D) biomass to juvenile and adult surfperch stomach contents

Study beaches arrayed from northwest to southeast (left to right).

In contrast, the abundance and biomass of upper beach, wrack-associated invertebrates showed a trend of highest values ($p < 0.001$) on the northwestern beaches (Sandy Point, Soledad) and lowest values on the southeastern beaches (Southeast Anchorage, Ford Point) of SRI (Figure 3.2.19A, B). On SCI, these species were higher in biomass at Christy Beach than at Coches Prietos (Figure 3.2.19A, B).

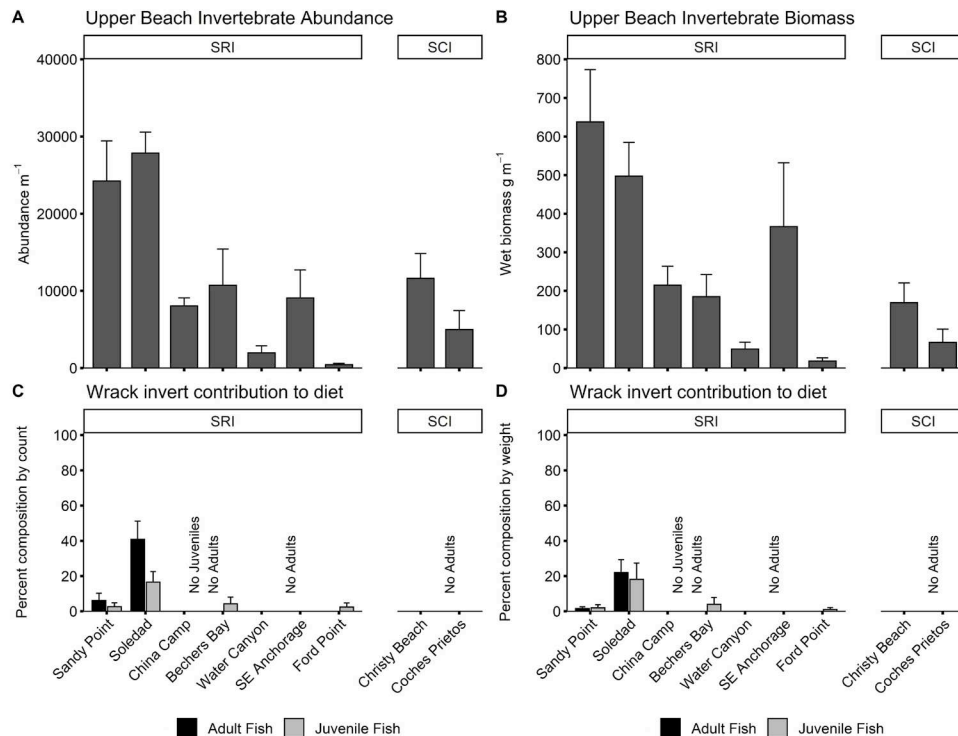


Figure 3.2.17 Mean (+SE) A) abundance (count) and B) biomass of upper beach wrack-associated invertebrates sampled from Santa Rosa and Santa Cruz Islands in 2018 and the relative contribution (as percent) in terms of C) abundance (count) and D) biomass to juvenile and adult surfperch stomach contents

Study beaches arrayed northwest to southeast (left to right).

Juvenile and adult surfperch exploited sand crabs at every beach with a general increase in the relative use of these crabs from beaches in the northwest (Sandy Point, Soledad) compared with those in the southeast of SRI (SE Anchorage, Ford Point) (Figure 3.2.18 C, D). Surfperch also exploited taxa from the upper beach at four study beaches; these taxa comprised up to 40% by count and 20% by weight of stomach contents of adults at one northwestern site, Soledad (Figure 3.2.19 C, D). Prey consisted largely of talitrid amphipods, but also included beetles, and kelp fly larvae that are found in close association with macrophyte wrack. The use of other prey, which included the pelagic red crab, *Pleuroncodes planipes*, the kelp grazing isopod, *Idotea* sp., suspension-feeding mysids, cumaceans, and polychaetes, as well as fish eggs, also varied among sites ($p < 0.001$, Figure 3.2.20), with a general trend of greater use of this diverse prey group at beaches in the northwest (Sandy Point, Soledad) and least use at the two most southeastern beaches, southeastern Anchorage and Ford Point (Figure 3.2.20).

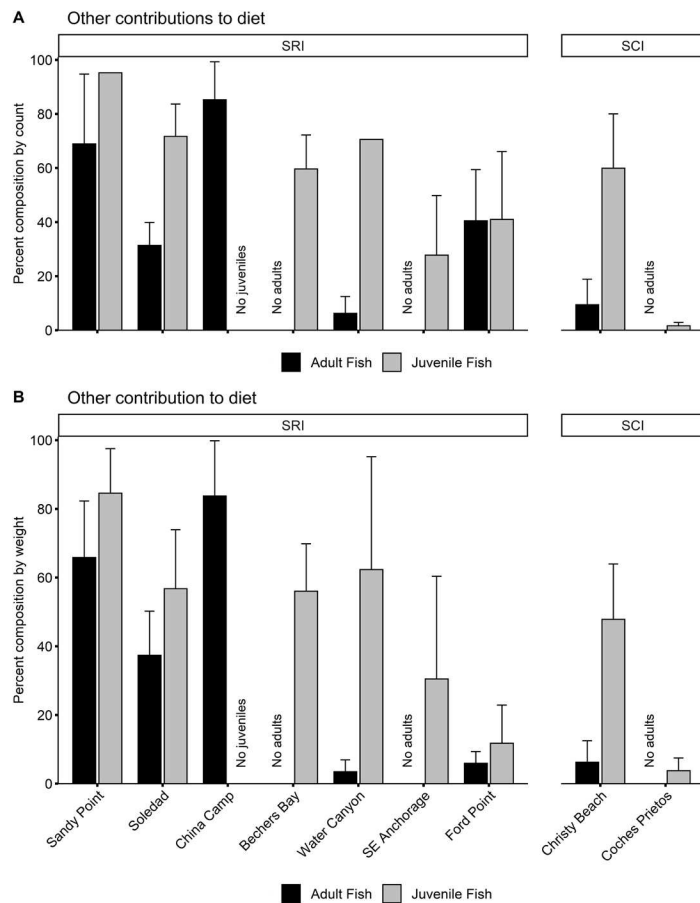


Figure 3.2.18 Mean ($\pm$ SE) A) abundance (count) and B) biomass of other invertebrate prey in the stomach contents of surfperch sampled from Santa Rosa and Santa Cruz Islands in 2018
Study beaches arrayed northwest to southeast (left to right).

Distance-based linear modeling (DistLM) analysis revealed that the abundance of macrophyte wrack accounted for a significant ($p = 0.008$) amount of variation (68.6%) in the use of wrack-associated invertebrates by juvenile surfperch, which were available from eight beaches. The abundance and biomass of wrack-associated talitrid amphipods was highly correlated ($p = 0.001$, $r^2 = 0.904$) with the abundance of total macrophyte wrack on the beach. However, none of the other physical or biological variables included in the models accounted for a significant amount of variation in the use of sand crabs or other prey.

Mean delta 13 carbon ($\delta^{13}\text{C}$) values of surfperch juveniles and adults across beaches were similar, ranging from -16.2‰ to -14.8‰ (Figure 3.2.19). Mean delta 15 nitrogen ($\delta^{15}\text{N}$) values of surfperch ranged from 14.5‰ to 16.2‰ for juveniles and 15.3‰ to 17.0‰ for adults. In general, the mean $\delta^{13}\text{C}$ values for juvenile and adult surfperch fell within the range of suspension feeding (sand crabs) and grazer (talitrid amphipod) prey species when adjusted for expected trophic enrichment between predator and prey ($\delta^{13}\text{C} = 0.5\text{‰}$, $\delta^{15}\text{N} = 3.4\text{‰}$) (Post 2002) (Figure 3.2.21). At a given beach, $\delta^{13}\text{C}$ values of surfperch were generally similar to values for sand crabs, and isotopically distinct from talitrid amphipods that rely on kelp wrack (Figure 3.2.21). Exceptions occurred for juvenile surfperch from the northwestern beaches of Sandy Point and Soledad, and adult surfperch from China Camp, where $\delta^{13}\text{C}$ values suggested some use of kelp grazers. However, $\delta^{15}\text{N}$ values of juvenile and adult surfperch were generally in alignment with

values for sand crabs, and isotopically distinct from talitrid amphipods (Figure 3.2.21), suggesting the general reliance on phytoplankton-based prey.

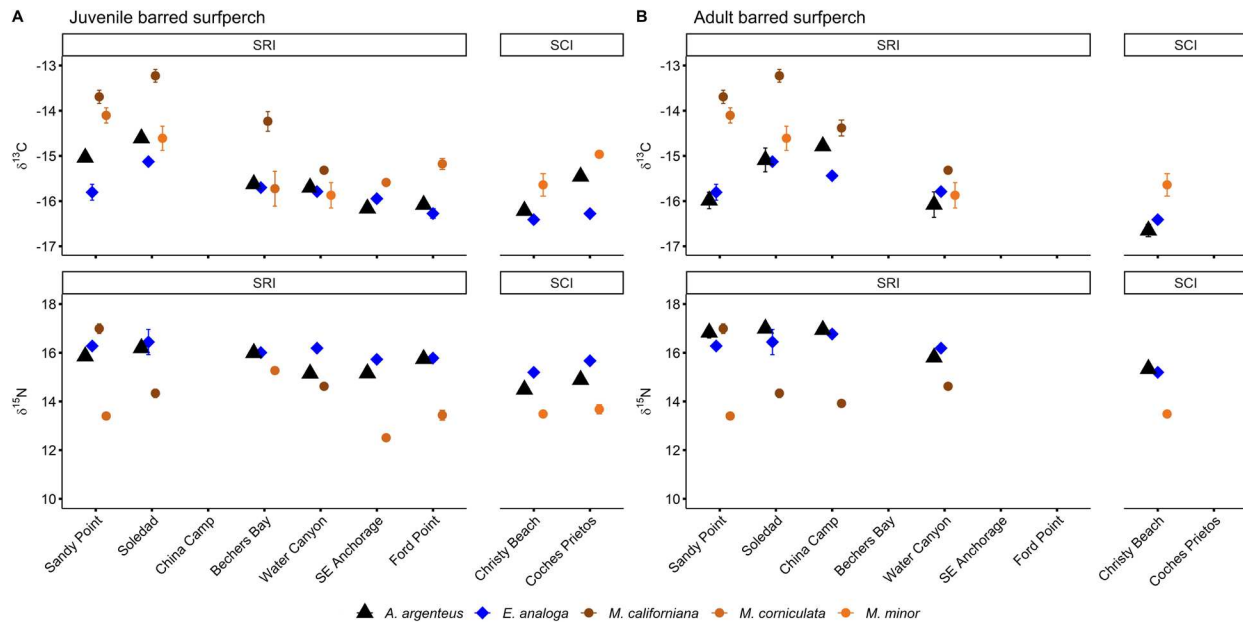


Figure 3.2.19 Mean (+SE) $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values for A) juvenile barred surfperch and B) adult barred surfperch together with isotope values for *Emerita analoga* and *Megalorchestia* spp. (*M. californiana*, *M. corniculata*, or *M. minor*). Trophic fractionation factors of 0.5‰ for $\delta^{13}\text{C}$ and 3.4‰ for $\delta^{15}\text{N}$ have been added to the prey species (Post 2002)
Study beaches arranged from northwest to southeast (left to right).

In conclusion, results show that barred surfperch eat a variety of prey at SRI and SCI, and that overall diet can vary substantially among sites. Surfperch exploited the widespread and abundant sand crab, *Emerita analoga* (Dugan et al. 2003), shown to be important to surfperch diet at mainland beaches (Carlisle et al. 1960). Sand crabs are trophic intermediates that enable the transfer of phytoplankton-based carbon to higher-level consumers that include surfperch, other surf zone fish, and shorebirds.

Although stomach content and stable isotope results suggest that surfperch are primarily sustained by phytoplankton-based food sources, biological team results identified the potentially important, but variable contribution of kelp-based carbon to surfperch nutrition through the consumption of kelp grazers. Juvenile and adult surfperch stomachs contained upper-beach, wrack-associated species at Soledad and Sandy Point beaches, at the northwestern end of SRI. Talitrid amphipods, *Megalorchestia* spp., the most numerically important of these taxa, rely on macroalgal wrack for food and habitat and reached highest abundance and biomass on the beaches of Sandy Point and Soledad. Other upper-beach, wrack-associated taxa (isopods, flies, and beetles) were also found in surfperch stomachs. Although wrack-associated macroinvertebrates can attain high abundances on upper beaches, as shown in this study and others (e.g., Dugan et al. 2000, 2003), this study is the first to report the use of this resource by surf zone fish. Results suggest that trophic connectivity between kelp forest and beach ecosystems extends to the fish and food webs of open coast surf zones.

Variability in surfperch diet across study beaches, and a strong gradient in wrack subsidies, illustrates the dietary plasticity of this fish, which could be advantageous with changing environmental conditions and resource availability. Changing environmental conditions, such as ocean warming, could introduce new resources to foraging surfperch. For example, surfperch exploited pelagic red crabs (*Pleuroncodes*

planipes) at Sandy Point. Once rarely found near shore in California, pelagic red crabs have been washing into nearshore habitats including beaches more frequently as global warming and marine heat waves increase (e.g., El Niño Southern Oscillation or marine heat waves) (Zuercher & Galloway 2019). Results suggest that surfperch diet could reflect broader changes in ocean climate over time and could be useful in monitoring these changes.

In terms of island fox diet, the coastal zone provides foraging opportunities for insular populations of terrestrial mammals, allowing for expanded habitat use, increased dietary breadth, and locally higher population densities. The biological team examined the use of marine resources of sandy beaches by the threatened island fox on the California Channel Islands using scat analysis, surveys of potential prey, beach habitat attributes, and stable isotope analysis.

Consumption of beach invertebrates, primarily intertidal talitrid amphipods (*Megalorchestia* spp.) by island fox varied with abundance of these prey across sites (Figure 3.2.22). DistLM revealed that abundance of giant kelp (*Macrocystis pyrifera*) wrack, rather than beach physical attributes, explained the largest amount of variation in talitrid amphipod abundance and biomass across beaches.

Values of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ for fox whisker (vibrissae) segments (Figure 3.2.23) suggested individualism in diet, with generally low $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of some foxes consistent with specializing on primarily terrestrial foods, contrasting with more enriched isotope values of other foxes that suggested a more sustained use of marine sandy beach resources, the importance of which varied over time. Abundant allochthonous marine resources on beaches, including inputs of giant kelp, could expand habitat use and diet breadth of the island fox, increasing population resilience during declines in terrestrial resources associated with climate variability and long-term climate change.

Results for diet of contemporary island foxes contribute to the discussion on the effects of human habitation on the foraging ecology of island fox. Hofman et al. (2016) explored the hypothesis that humans “provisioned” island foxes across 7,300 years of human occupation on seven California Channel Islands using a comprehensive dataset on the isotopic composition of ancient and modern island foxes, mainland foxes, and humans. Their isotope data confirmed that marine resources comprised a large proportion of the diet of ancient peoples on the islands. Provisioning of island fox could occur either through the intentional feeding of foxes by humans or through the scavenging of human refuse by these animals. Hofman et al. (2016) found limited evidence for considerable marine resource use by island fox across islands and 7,300 years, but questions remained regarding whether the analyzed samples fully represented variability in island fox diet across space and through time. Their finding of elevated $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of some foxes on San Nicolas and San Clemente islands suggested human provisioning, but the scavenging of marine mammal carrion or other marine resources also had to be considered.

Although there are differences in temporal scale across which bone collagen, analyzed in Hofman et al. (2016), and the keratin in island fox whiskers integrate diet (whiskers integrate diet over previous five to seven months, whereas bone collagen integrates diet over several years), results suggested that foxes could have elevated $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ isotope values in the absence of human provisioning, or the scavenging of carrion, through the exploitation of endemic beach invertebrate fauna.

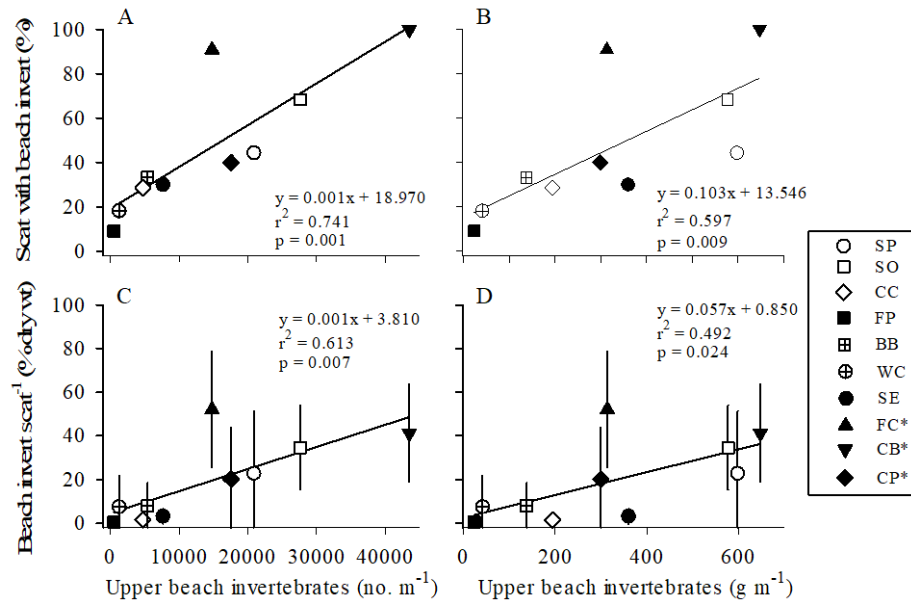


Figure 3.2.20 Relationships between beach material in scats and endemic beach invertebrate abundance and biomass (from Page et al. 2021)

Proportion (as percent) of scat with endemic beach invertebrates and (A) invertebrate abundance and (B) biomass, and mean percent of invertebrates per gram scat versus (C) invertebrate abundance and (D) biomass at Santa Rosa and Santa Cruz Island study sites. Mean values for (C) and (D) $\pm$ 95% confidence intervals. Regression fits and r^2 values weighed for differences in sample size among sites. Site abbreviations: SP - Sandy Point, SO - Soledad, AS - Arlington Springs, BB - Bechers Bay, WC - Water Canyon, SE - Southeast Anchorage, FP - Ford Point, CC - China Camp, FC - Forney's Cove, CB - Christy Beach, CP - Coches Prietos. *Santa Cruz Island.

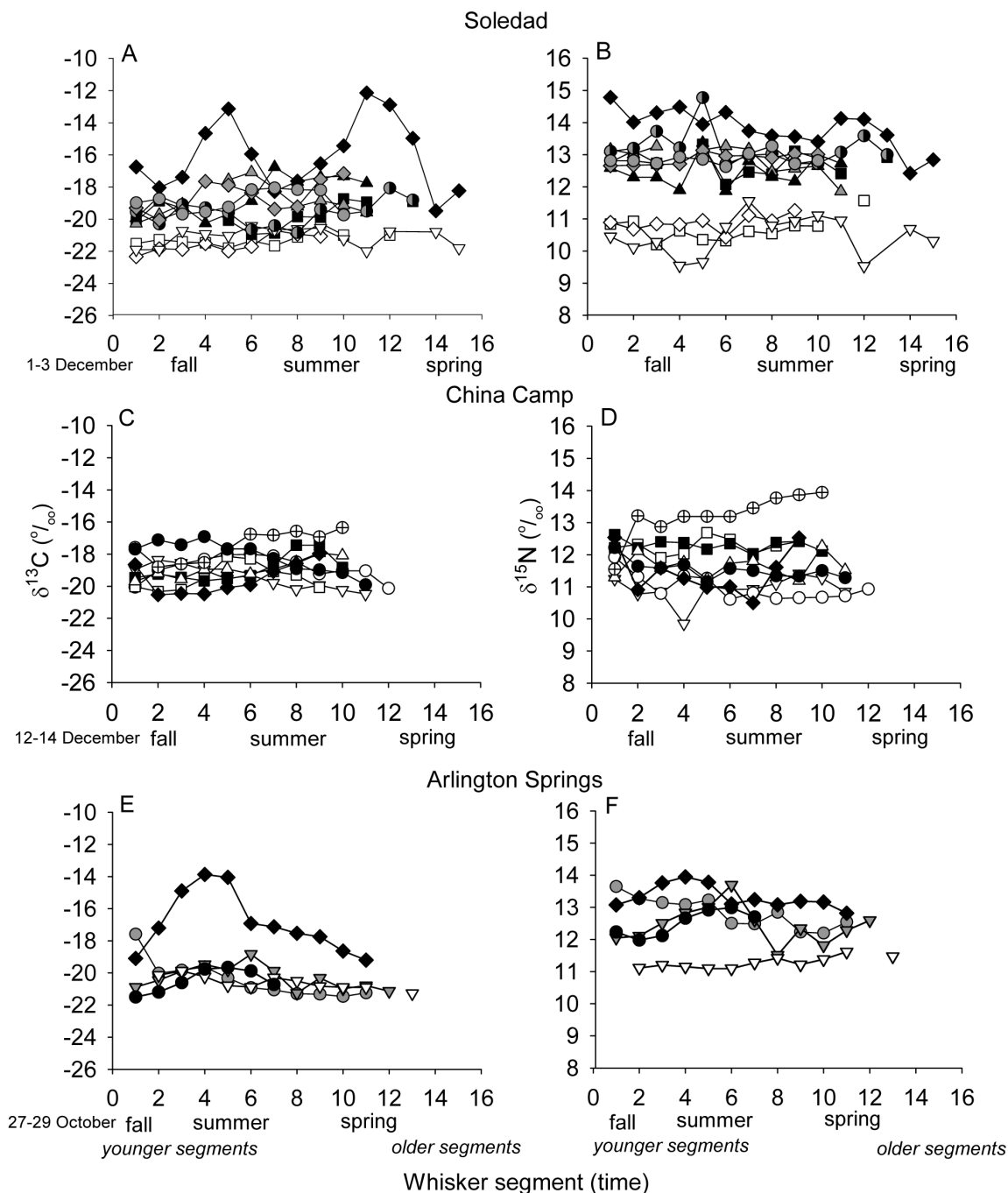


Figure 3.2.21 $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of island fox whisker segments (From Page et al 2021)
 Values from individual foxes trapped at A, B) Soledad ($n = 10$ foxes), C, D) China Camp ($n = 8$ foxes) and E, F) Arlington Springs sites during December 1 to 3 and December 12 to 14, 2018, respectively. Whiskers varied in length and therefore number of segments. Segment 1 is most proximal to the face. Each segment represents an approximate two week time period.

3.3 Offshore geophysical surveys

At the time of the NCI geophysical surveys, there were few existing datasets that mapped subsurface geology around the NCI platform. Legacy seismic data were collected in the 1970s (Junger, 1979), but these low-resolution reflection data were best suited to mapping of the deeper geology. There were no publicly available high-resolution subsurface data available from the NCI platform. Therefore, regional-scale chirp survey lines were needed to map and interpret near subsurface geologic units and surfaces and to explore for paleolandform features. These first, regional surveys focused on three areas (Figure 3.3.1): (1) north of Santa Rosa due to the presence of archaeological sites on that part of the island, and modeled drainages extending north across the platform (e.g., Arlington and Verde Canyons); (2) the area between Santa Rosa and Santa Cruz Island where protected marsh and estuarine habitats are thought to have attracted paleocoastal peoples (e.g., Crescent Bay); (3) the area between Santa Rosa and Anacapa Island due to the presence of a modeled drainage and its location protected from large, northwestern swell.

From June 6 to 10, 2016, ~190 km of high-resolution sub-bottom chirp survey lines were acquired offshore of the NCI from NOAA's R/V *Shearwater* using Scripps Institution of Oceanography's Edgetech 512i chirp system. A NPS Klein 3000H side-scan sonar was towed simultaneously. A total of 65 regional survey lines were run during this effort (Figure 3.3.1). Chirp data were processed using SIOSEIS (Henkart 2006) and Seismic Unix software (Cohen and Stockwell 1999) to remove heave artifacts and adjust gains. Side-scan sonar data were processed by Bert Ho at NPS and provided as mosaic seafloor images. Data were imported into IHS Kingdom Suite software package (www.kingdom.ihs.com) and ESRI ArcGIS v. 10.5 (www.esri.com) for interpretation. Kingdom Suite was used to calculate layer thicknesses and the depth to acoustic reflectors. A nominal sound velocity of 1,500 meters per second was used to convert time to depth. These initial geophysical surveys were designed to capture images of large swaths of the seafloor and sub-seafloor for broad-scale paleolandscape interpretations. Sonar image interpretation focused on identification of large-scale features including fault systems, major geomorphological features (i.e., paleochannels, canyons, dune fields, paleoshorelines and terraces), and geologic units and surfaces that were either buried (sub-bottom) or visible on the seafloor (side-scan). Survey line spacing and frequency of equipment was adjusted based on the landscape and to optimize image quality. Initial observations and potential targets were recorded live during surveys.

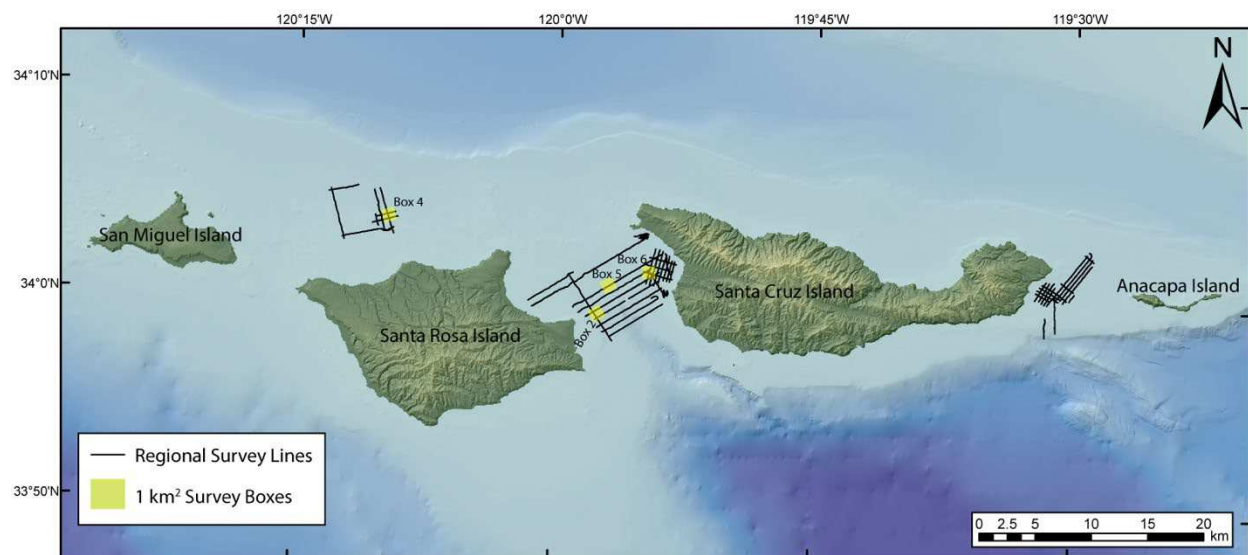


Figure 3.3.1 Map of NCI survey area showing where geophysical data were acquired

After completing the regional sonar survey, all data were compiled and reviewed in IHS Kingdom Suite and QPS Fledermaus software. The goal for the interpretation was to select four 1 km² areas for targeted, tight-grid spacing (25 m) geophysical surveys. This follow-up survey focused on small sections of the landscape deemed to have high potential to yield paleolandscape and paleoenvironmental data during the sampling phase of the project. Initially, six boxes were identified, but those were ultimately narrowed down to four based on priority. However, the initial numbering system was maintained, such that the four boxes surveyed are named Box 2, Box 4, Box 5, and Box 6 (Boxes 1 and 3 were not surveyed).

Each site was selected based on a unique acoustic signature interpreted to represent different types of paleoenvironments. The goal of the second sonar survey was to collect closely spaced sonar data to help identify specific targets for sediment core sampling. Three of the 1 km² survey areas fell between SRI and SCI, an area referred to as Crescent Bay, where an ancient estuary, marsh habitats, a submarine canyon, and abundant freshwater could have attracted early maritime peoples (Figure 3.3.1).

The four box locations were selected based on features observed in regional lines. For details on these features, refer to Section 3.5. Box 5, near the head of Santa Cruz Canyon, was selected across an interpreted paleovalley with potential for marsh deposits and high-amplitude features adjacent to mapped channels. Box 6, just west of SCI, was selected based on an interpreted paleovalley represented by laminated acoustic reflections below the seafloor. Box 2, east of SRI's Carrington Point, was selected based on interpreted dune deposits (transparent acoustic signature) and a well-defined transgressive surface (high-amplitude reflector). The fourth site, Box 4, was along northwestern SRI near Arlington Canyon, where a paleovalley feature was interpreted during the regional survey. This paleovalley appeared to preserve fluvial terraces, which could be important for locating archaeological resources.

The second geophysical cruise effort was aboard R/V *Point Loma*, beginning on July 31, and ending on August 4, 2016. The surveys were completed using a Reson 7125 multibeam sonar operated at 400 kHz and an Edgetech 512 profiler at 1 to 15 kHz. A total of 112 survey lines, covering ~112 km, were run during this effort. To fill in gaps in this survey, a second set of tight-grid spacing lines were collected aboard R/V *Sally Ride* from February 2 to 8, 2018, using a Kongsberg EM712 multibeam and Knudsen 3.5 kHz sub-bottom profiler.

3.4 Seafloor coring

Based on features identified during geophysical surveys, a vibracoring cruise on R/V *Sally Ride* was conducted from February 2 to 8, 2018. Selection of targets for the coring regime focused on four core locations within each of the 1 km² survey boxes (Figure 3.4.1). Core names within the boxes are identified by the box number and then a letter (i.e., 2A, 2B, 2C, and 2D). Due to the wide variety of acoustic signals observed outside of the four boxes, additional “bonus” targets were selected along some of the regional profiles. These are identified with the naming convention “B” followed by a number (e.g., B4, B9), except for Core 4E, which is just outside of Box 4 and was selected on board the ship based on good recovery of previous cores in the area and available time. Table 3.4.1 indicates the reason each target was chosen. Some planned target locations could not be cored due to time constraints, and these numbers were skipped (e.g., B6). At some locations, cores were attempted but came up without any sediment. Those cores are indicated with 0 cm length in Table 3.4.1. Water depths at coring locations varied from 30 to 75 mbsl. In the areas surrounding the NCI, the landscape between these depths would have been inundated 13,000 to 7,000 years ago (Reeder-Meyers et al. 2015), providing an opportunity to understand how marine transgression impacted local habitat and landscape development. Targets for coring were selected based on a variety of factors, including thickness of marine sediment, presence of a shallow buried transgressive surface, presence of acoustic signatures suggestive of estuary environments, presence of interpreted paleochannels, possible freshwater seeps, and presence of buried anomalies near fresh water sources.

The scientific team deployed core tubes 4.5 m-long and 38 cm in diameter using a Rossfelder P-5 vibracore system and recovered a total of 26 cores, with a minimum of four from each target location. This surpassed the goal of 16 cores by 61.5%. Table 3.4.1 includes details of core location, total recovered length, and the intended targets for each core location. See Section 3.5 for chirp profiles with core locations for the four 1 km² boxes. All cores were transported to Oregon State University's core facility for processing and analysis.

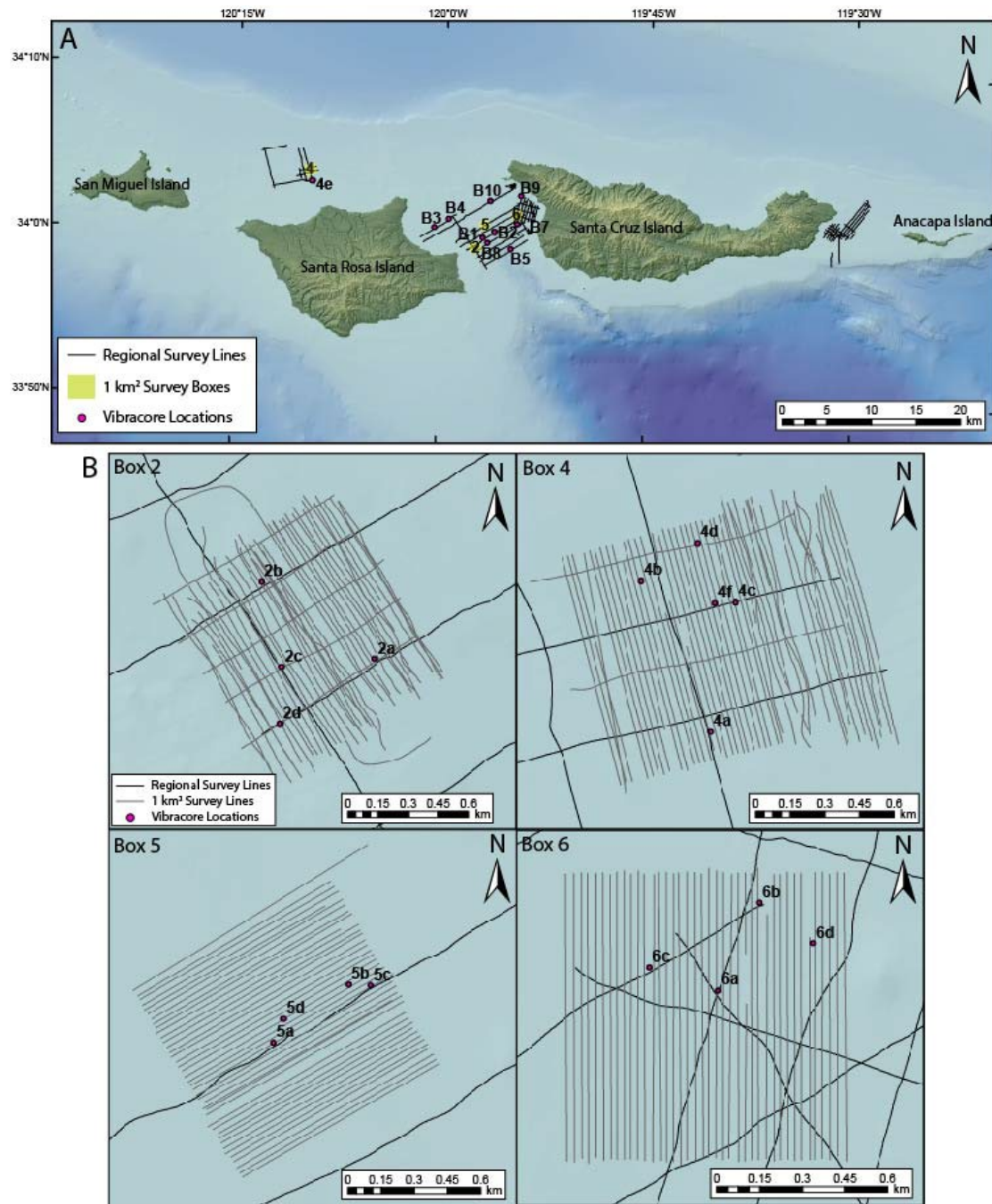


Figure 3.4.1 Map of NCI survey area showing core locations

A. Overall locations including “bonus cores” (B# labels) located outside survey boxes, and location of each box (numbered). B. Zoomed in to show core locations collected within each box.

Table 3.4.1 NCI Coring Locations.

Core_ID		Latitude (DD)	Longitude (DD)	Total Length (cm)	Target
CI-VC-	2A	33.987407	-119.955397	58	Sand mound
CI-VC-	2B	33.990718	-119.961586	46	Thin Holocene, possible channel/deformation below transgressive surface
CI-VC-	2C	33.986929	-119.960379	0	Fault below transgressive surface, thin Holocene unit
CI-VC-	2D	33.984385	-119.960382	46	Large sand dune offshore SRI dunes
CI-VC-	4A	34.059621	-120.161570	183	Laminated channel-type feature below transgressive surface
CI-VC-	4B	34.065389	-120.165036	158	High-amplitude feature, associated with offset transgressive surface (possible channel edge or cliff face?)
CI-VC-	4C	34.064677	-120.160593	80	Chaotic sediment, possibly gas over estuarine deposits
CI-VC-	4D	34.066919	-120.162458	36	Chaotic sediment, possibly gas, over mounded feature - cliff/fault offset of transgressive surface
CI-VC-	4E	34.051427	-120.158398	213	Channel below transgressive surface
CI-VC-	4F	34.064631	-120.161550	196	Stratigraphy above transgressive surface
CI-VC-	5A	34.011067	-119.948725	42	High-amplitude anomaly at channel bank
CI-VC-	5B	34.013540	-119.945167	219	Mound feature adjacent to channels
CI-VC-	5C	34.013520	-119.944066	213	Middle of channel feature - depth to channel ~3 m
CI-VC-	5D	34.012067	-119.948283	189	Middle of channel feature - depth to channel ~2.7 m
CI-VC-	6A	34.022960	-119.909564	95	Transition from layered to chaotic reflectors, edge of channel/shoreline, high-amplitude anomaly
CI-VC-	6B	34.025780	-119.908103	148	Laminations
CI-VC-	6C	34.023634	-119.912200	165	High-amplitude chaotic anomaly, adjacent to paleochannel, thin to no Holocene sediment
CI-VC-	6D	34.024538	-119.906014	153	Faulted, horizons near surface (no Holocene unit), laminated package folded up
CI-VC-	B1	33.998914	-119.949830	186	Head of canyon
CI-VC-	B2	34.004197	-119.935481	141	Dipping beds, head of canyon
CI-VC-	B3	34.007316	-120.008305	0	Transgressive lag, Bechers Bay
CI-VC-	B4	34.016279	-119.991349	136	Mound near Bechers Bay
CI-VC-	B5	33.987494	-119.915477	194	High-amplitude feature anomaly, edge of canyon
CI-VC-	B7	34.012462	-119.908106	70	Chaotic unit near Box 6
CI-VC-	B8	33.993384	-119.943915	0	Dune with internal stratigraphy
CI-VC-	B9	34.041253	-119.904115	148	Laminated unit
CI-VC-	B10	34.035793	-119.941693	107	High-amplitude anomaly

3.4.1 Core descriptions with optical and CT images

The first data collected from the NCI cores were whole core computerized tomography (CT) scans using the OSU College of Veterinary Medicine's Toshiba Aquilion 64 Slice medical CT scanner. The CT scans were viewed in 3D using OsriX Lite software and images from the center of each core were captured and saved as .png files. Scale bars were fit to the CT scan images using Adobe Illustrator and the recorded total length of the cores. If cores were cut into sections (any core longer than 1.5 m had to be sectioned due to instrument constraints), core section images were stitched together using scaling, image overlay, and color corrections in Adobe Illustrator to create whole core images (see BOEM Coring Data Repository).

The cores were stored whole at the Oregon State University Marine and Geology Repository (OSUMGR) until ready to split and analyze. The cores were split by Alex Nyers and Jennifer Thatcher using the core splitter facility at OSUMGR. Overall, the core surface condition was good, but some cores had rough faces, often due to shell material or coarser rock fragments. When possible, these rough surfaces were smoothed by removing material. After splitting, cores were wrapped in plastic, placed into D-tubes, and one-half was labeled as "Archive" and the other as "Working." The Archive core halves will be kept for reference purposes as per OSUMGR guidelines while sampling and any analyses will be performed on working halves.

In November 2019, co-principle investigator (PI) Maloney and her graduate student, Luke Johnson, completed a geological description of each core, including sediment character, shell content, color, and stratigraphic features (see BOEM Coring Data Repository). These logs were converted to digital graphical representations using Adobe Illustrator for use in interpretation and publication (see BOEM Coring Data Repository). At the time of description, samples were also collected for grain-size analysis where there were notable changes in sediment character. Cores with stratigraphy that suggested a change in depositional environment (e.g., changes in sediment characteristics down the length of the core) were also identified for radiocarbon dating, and Jon Erlandson collected shell material for radiocarbon at this time.

Optical core imaging was performed using the OSUMGR GeoTEK Geoscan III Linescan Imager. Line scan imaging is considered superior to other methods for core imaging as it does not suffer from spherical aberration or photo stitching issues. Imager was configured for 100 pixels per cm and data were stored in TIF format with associated xml metadata on OSU's "Box" cloud storage application.

3.4.2 Multi-sensor core logs

Prior to splitting, whole cores were also scanned using the OSUMGR's GEOTEK MSCL-S multi-sensor track (MST) that provides gamma ray attenuation bulk density, loop magnetic susceptibility (MS), P-wave velocity (PWA) and electrical resistivity. These data were imported to Microsoft Excel and values for each characteristic were plotted versus depth in the core (see BOEM Coring Data Repository). One notable observation was that very high MS peaks in the cores appeared to correspond with horizons where a steel core catcher finger had broken off and been captured in the core sediment. These steel pieces could be observed on CT scan images in cores B5, 4B, 4C, and 4F.

3.4.3 Itrax analysis

Elemental and radiograph data were collected using an Itrax X-Ray Fluorescence (XRF) core scanner. The scanner was configured using 600ms exposures at 60kV and 50mA. Additional per-segment configuration details were retained in metadata files along with analysis results for each core segment. Data acquisition protocols were provided by OSUMGR ("Itrax Core Scanner Data Processing for OSUMGR, Version 3.0" by Val Stanley, see <https://osu-mgr.org/policies>). Radiographic image processing (rotation, brightness, and contrast adjustments) was performed in batches using the

ImageMagick 7.1 application. Raw, processed, and all metadata were archived on OSU's "Box" cloud storage application (see BOEM Coring Data Repository).

3.4.4 Grain size analysis

Grain size samples were analyzed at SDSU using a Beckman Coulter LS13320 laser particle size analyzer. The size range for this instrument is <1 to 2000 micrometer (μm) and anything larger than 2000 μm was noted and removed prior to analysis. The shell fragment percentage of some samples was too high for meaningful grain size results, so these samples were instead viewed under a microscope and described in detail. Grain size data were exported from the Beckman Coulter LS13320 software as Excel files that include size fractions as percent volume and statistical data (e.g., mean, median, skewness) (see BOEM Coring Data Repository).

3.4.5 Radiocarbon dating

Cores were sampled for radiocarbon dating to constrain ages of sediment layers and interpretations. All sampled material consisted of calcium carbonate shells. For shell samples, intact shells were sampled preferentially, but most were at least partially fragmented. Shells were identified to the genus level and pre-treated for dating by UO MNCH. Pre-treatment included etching in a 10% HCl solution and rinsing with deionized water. Some samples were powdered with a drill, but smaller samples were kept whole. All samples were sent to DirectAMS Radiocarbon Dating Services in Bothell, Washington, for analysis (www.DirectAMS.com). Samples were prepared and analyzed by DirectAMS using their National Electrostatics Corporation 1.5 SDH Compact Pelletron Accelerator Mass Spectrometer. Results were reported by DirectAMS as uncalibrated radiocarbon ages, corrected for isotopic fractionation with an unreported $\delta^{13}\text{C}$ value measured on the prepared carbon by the accelerator. The provided radiocarbon ages were calibrated using OxCal version 4.3 and the Marine13 calibration curve. All samples were also adjusted using a reservoir age of 261 ± 21 years (Ingram and Southon 1996). See Appendix A, Table A-1, for all sample and radiocarbon information.

3.5 Results from NCI field work

The high-resolution, sub-bottom data revealed variable geologic units and geometries across the NCI platform. First, the more regional-scale surfaces and units are discussed, followed by a description of areas with local variability. Generalized stratigraphic columns for these sequences are illustrated in Figure 3.5.1. See Appendix A, Table A-2 for the key to core log illustrations used throughout this section.

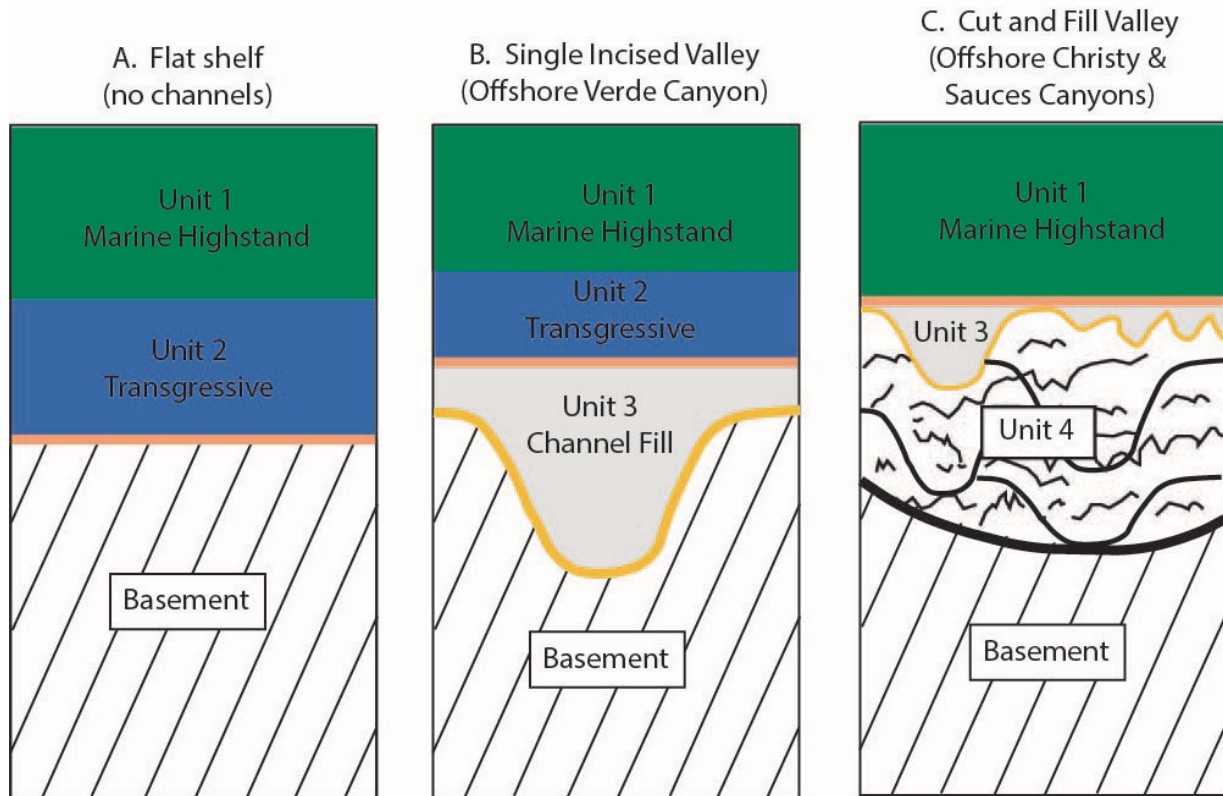


Figure 3.5.1 Generalized stratigraphic columns for chirp data around the NCI platform

Left: Typical profile on much of the shelf where deeper incision into the basement is not observed. Units 1 and 2 vary in thickness and are not always present (Section 3.5.1). Middle: Typical profile for single incised channels, including that observed north of Santa Rosa Island offshore from Verde Canyon (Section 3.5.3). Right: Profile for stratigraphy in eastern Santa Cruz Passage where deeper cut and fill structures are observed (Section 3.5.4 and Section 3.5.5).

3.5.1 Observed regional surfaces and acoustic units in sub-bottom data

A regional unconformity was identified in chirp profiles and mapped throughout the NCI study area. The unconformity surface is characterized by a high-amplitude reflector that commonly separates deformed, faulted, and truncated strata below from onlapping, semi-transparent units above (e.g., Figure 3.5.2). The unconformity is commonly the highest amplitude reflector beneath the seafloor and has a seaward-dipping topography that is relatively smooth with few changes in dip. In some areas north of SRI and east of SCI, the regional unconformity merges with the seafloor where the upper semi-transparent layers are absent. In other areas, the surface is overlain by semi-transparent units with variable geometries including downlapping reflectors. The regional unconformity surface was mapped to identify topographic features and changes in slope (Figure 3.5.3). This regional unconformity is interpreted as the transgressive surface of erosion formed by wave-base erosion during sea level rise following the LGM. However, this part of the shelf has been subaerially exposed during many sea level lowstands in the Pleistocene and the current morphology probably reflects multiple sea level cycles, as opposed to strictly the most recent sea level rise.

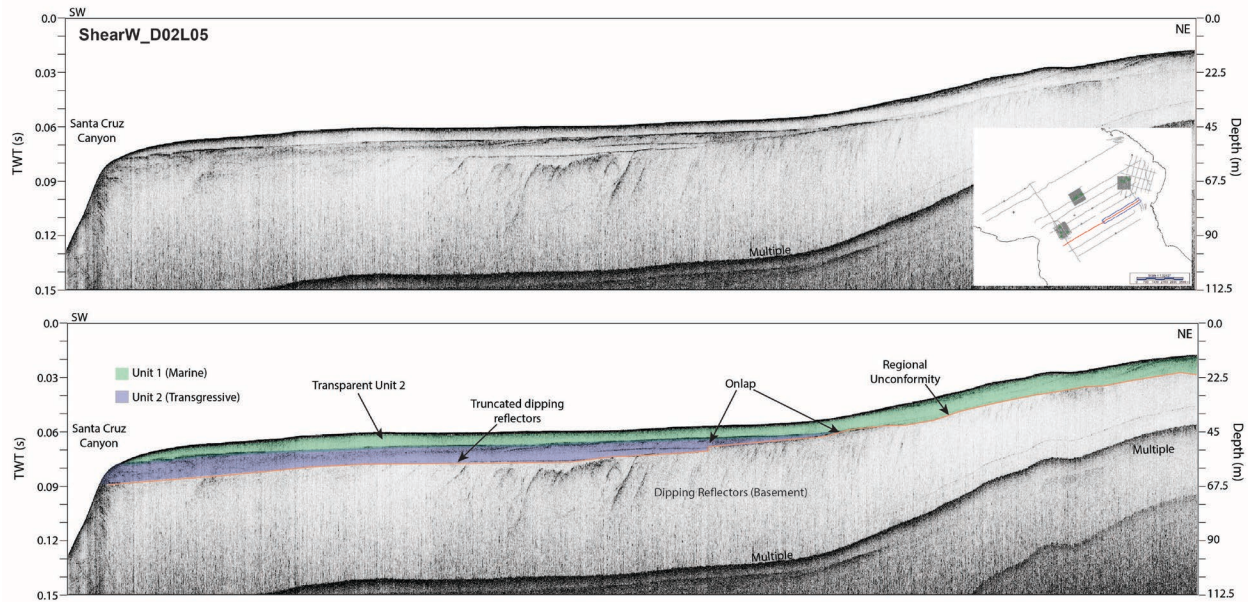


Figure 3.5.2 Chirp Line ShearW_D02L05 showing regional stratigraphy in Santa Cruz Passage Pink line tracks the regional unconformity interpreted as the transgressive surface of erosion. See map inset for location where red line is entire Chirp profile and blue indicates the section displayed in this figure.

Across much of the survey area, folded and dipping reflectors are imaged below the unconformity and are the deepest unit resolved by the chirp data (e.g., Figure 3.5.2). This unit was not penetrated with any vibracores and in many locations was the termination depth for the core, indicating it was hard. Due to the deformed geometry and inferred compact nature, this unit is interpreted as bedrock. The bedrock units mapped in the area include Miocene Monterey Shale, Miocene Volcanics, and Miocene Blanca Formation (Junger, 1979).

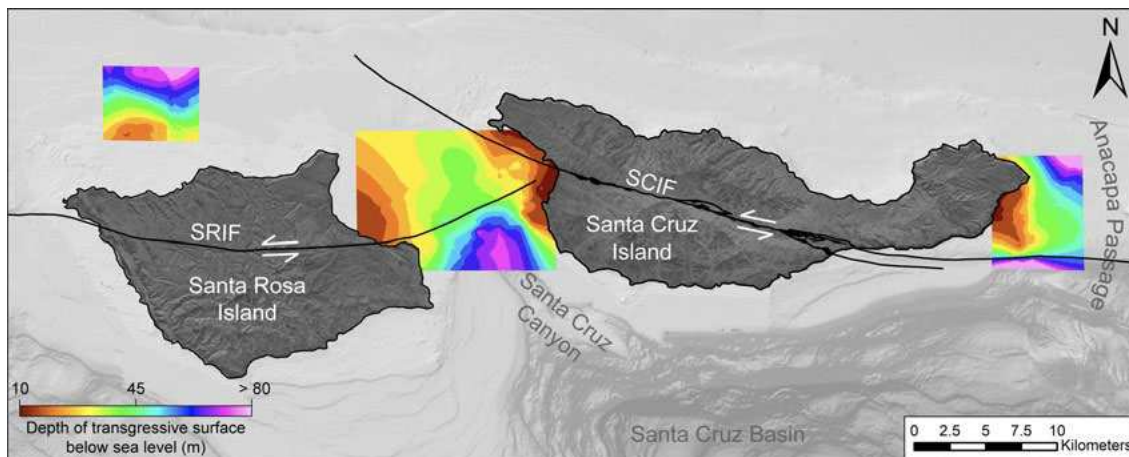


Figure 3.5.3 Interpolated surface of the regional unconformity interpreted to be the transgressive surface (Laws et al. 2019:12)

The surface ranges ~10 to 100 m below sea level and shallows as it approaches the coastlines of Santa Rosa Island and Santa Cruz Island. SRIF – Santa Rosa Island Fault; SCIF – Santa Cruz Island Fault.

Stratigraphy overlying the regional unconformity was interpreted as two separate acoustic units: Unit 1 and Unit 2 (e.g., Figure 3.5.2). The contact between Unit 1 and Unit 2 is characterized by moderate- to high-amplitude, continuous reflectors. The units vary in thickness and extent across the study area (Figure 3.5.4). Unit 2 is bounded at the bottom by the high-amplitude reflector identified as the regional unconformity and at the top by a reflector of moderate amplitude that diminishes intermittently throughout the study area. Unit 2 is primarily observed between SRI and SCI, is mapped ~20 to 75 mbsl, and is not present in all portions of the study area. Where present, Unit 2 contains discontinuous, low-amplitude internal reflectors. Unit 2 is interpreted to be transgressive deposits, which form during periods of rising relative sea level when accommodation outpaces sediment supply (Klotsko et al. 2015; Posamentier 2001). The location of this unit, which is often observed at, and overlapping onto, paleoshoreline angles, along with the presence of internal, low-amplitude reflectors, is consistent with transgressive deposits described elsewhere on the Southern California continental shelf (Klotsko et al. 2015). Additionally, transgressive deposits are relatively thin due to the rapid landward migration that transgressive shorelines make in areas of low elevation (e.g., Cattaneo and Steel 2003), which is consistent with the thickness of Unit 2 (Figure 3.5.4).

Unit 1 overlies Unit 2, or, in areas where Unit 2 is not present, the regional unconformity. Unit 1 thins landward and is not present where the regional unconformity is exposed at the seafloor north of SRI and east of SCI (Figure 3.5.4). Where Unit 2 is present, Unit 1 is bounded at the bottom by a reflector of moderate amplitude associated with the top of Unit 2 and at the top by the seafloor. Where Unit 2 is not present, Unit 1 is bounded at the bottom by the regional unconformity and at the top by the seafloor. Unit 1 is acoustically transparent and displays thickness variability both parallel and perpendicular to the inner shelf (Figure 3.5.2; Figure 3.5.4). It is observed ~20 to 60 mbsl. Although mostly transparent, Unit 1 contains some high- and low-amplitude internal reflectors that are discontinuous. Unit 1 is interpreted to be marine Holocene sediment deposited during sea level highstand. Marine highstand sediments deposit over transgressive deposits, or the transgressive surface, once the shoreline has transgressed landward (Posamentier and Allen 1993). During the most recent sea level transgression, the rate of sea level rise decreased when the shoreline was ~10 m below present at ~7 ka (Clark et al. 2014). Therefore, deposition of Unit 1 likely began around this time. The average thickness of this unit is within the range of other mapped Holocene marine sediment units on the Southern California continental shelf (Klotsko et al. 2015). This unit was captured in sediment cores that are discussed in the subsequent sections focused on the detailed survey boxes.

The next sections discuss detailed geophysical and coring results from the four tightly gridded boxes around the NCI.

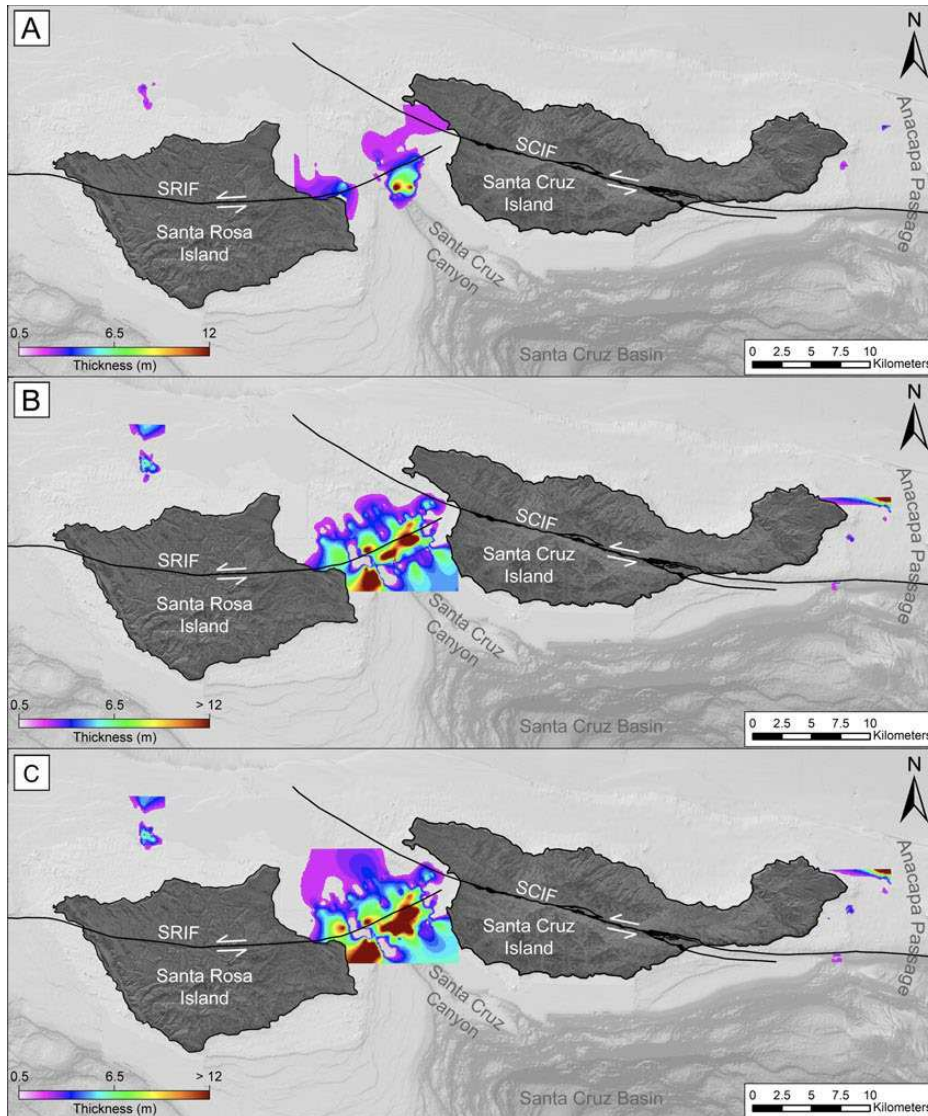


Figure 3.5.4 Isopach maps of sedimentary units (Laws et al. 2019:13)

(A) Unit 2 isopach of transgressive deposits. Unit 2 thickness is greatest where there is an increase in slope in the underlying regional unconformity. (B) Unit 1 isopach of marine Holocene deposits. Unit 1 thins landward and exhibits thickness variability both parallel and perpendicular to modern shorelines. (C) Isopach between the seafloor and transgressive surface/regional unconformity. Zero thickness is displayed in areas where the transgressive surface becomes the seafloor. Variable thickness illustrates a difference in topography between the seafloor and sub-bottom surfaces.

3.5.2 Box 2: Western Santa Cruz Passage

Box 2 was selected based on regional sub-bottom lines that showed potential dune features (Figure 3.5.5). The dune-like features were observed offshore from the point on the southern end of Becher's Bay on SRI. The dune-like features are characterized by mounds of sediment above the Surface 1 regional unconformity that truncates dipping and folded reflectors below. The unit is thickest closest to SRI where the character is mostly transparent. Moving west, the unit thins to almost nothing before thickening toward Santa Cruz Canyon as a series of mounded features with chaotic to dipping internal reflectors. The location of these features just offshore from a large dune field at the far southeastern point on SRI,

supported their interpretation as potential relict Pleistocene dunes. Archaeological and paleontological sites have been discovered within dune fields on the NCI, so this was considered a landform with potential to contain archaeological resources offshore. The detailed 1 km² survey box was in an area where multiple mounded features could be sampled, as well as where the deepest seismic facies of faulted and folded dipping reflectors was exposed at the seafloor and so would be reachable by sediment cores for ground-truthing.

Within the 1 km² survey box, four core locations were selected (Figure 3.5.6). Core 2A was atop a smaller mound feature observed in geophysical data. Core 2B was where recent sediment was thin and a small channel-like feature was imaged below the transgressive surface. Core 2C was where recent sediment was thin over deformed reflectors in the basal unit. Core 2D was on a large dune feature that appears to extend offshore from the onshore dunes.

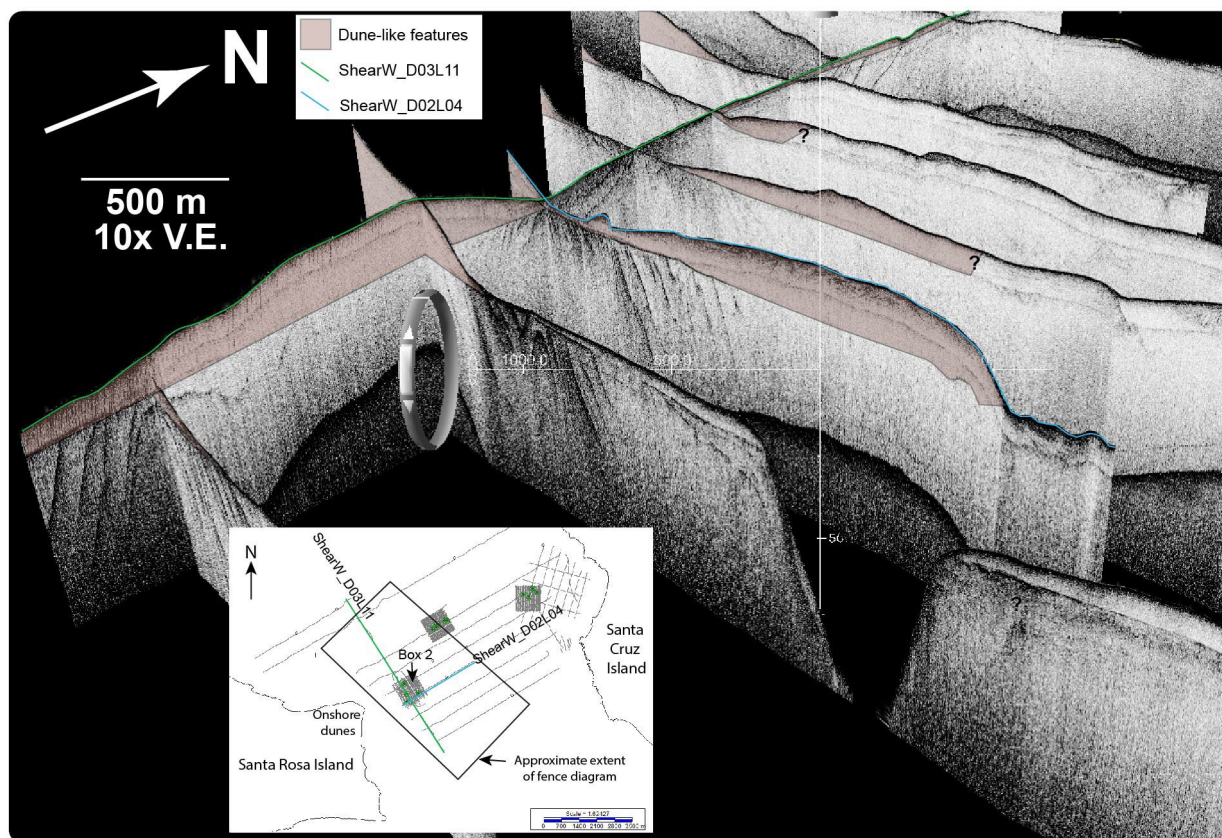


Figure 3.5.5 Fence diagram of Chirp profiles offshore eastern Santa Rosa Island

Inset map shows approximate extent. Green and blue lines trace individual chirp profiles for orientation. The location of Box 2 is indicated in the inset map, but these profiles are not shown in the fence diagram.

All the cores from Box 2 were less than 1 m in length, with Core 2C only recovering pebbles in the core catcher after two attempts (Figure 3.5.7). The other three cores were dominated by sand and shell fragments of varying percentages (Figure 3.5.7). Grain size samples were collected, but were not analyzed because of the dominance of shell material in the samples. Core 2B was located where the upper acoustic unit is very thin above the dipping and folded reflectors interpreted as bedrock. This core differs from 2A and 2D in the size of shell and gravel. It contains broken and intact shells up to 5 cm and gravel with few larger rock fragments, up to 5 cm. Cores 2A and 2D contain mostly sand and broken shell fragments of mm to 1 cm scale. Core 2D contained identifiable urchin spines and barnacle fragments. MS for Cores 2A

and 2D is low and not variable. Core 2D has a spike in MS at ~15 cm, coincident with the location of large rock fragments. All cores have similar iron (Fe) and calcium (Ca) signatures, with little variability down core. The drop in Fe and Ca at ~15 cm in Core 2B is due to the foam inserts that prevented XRF measurements at that depth.

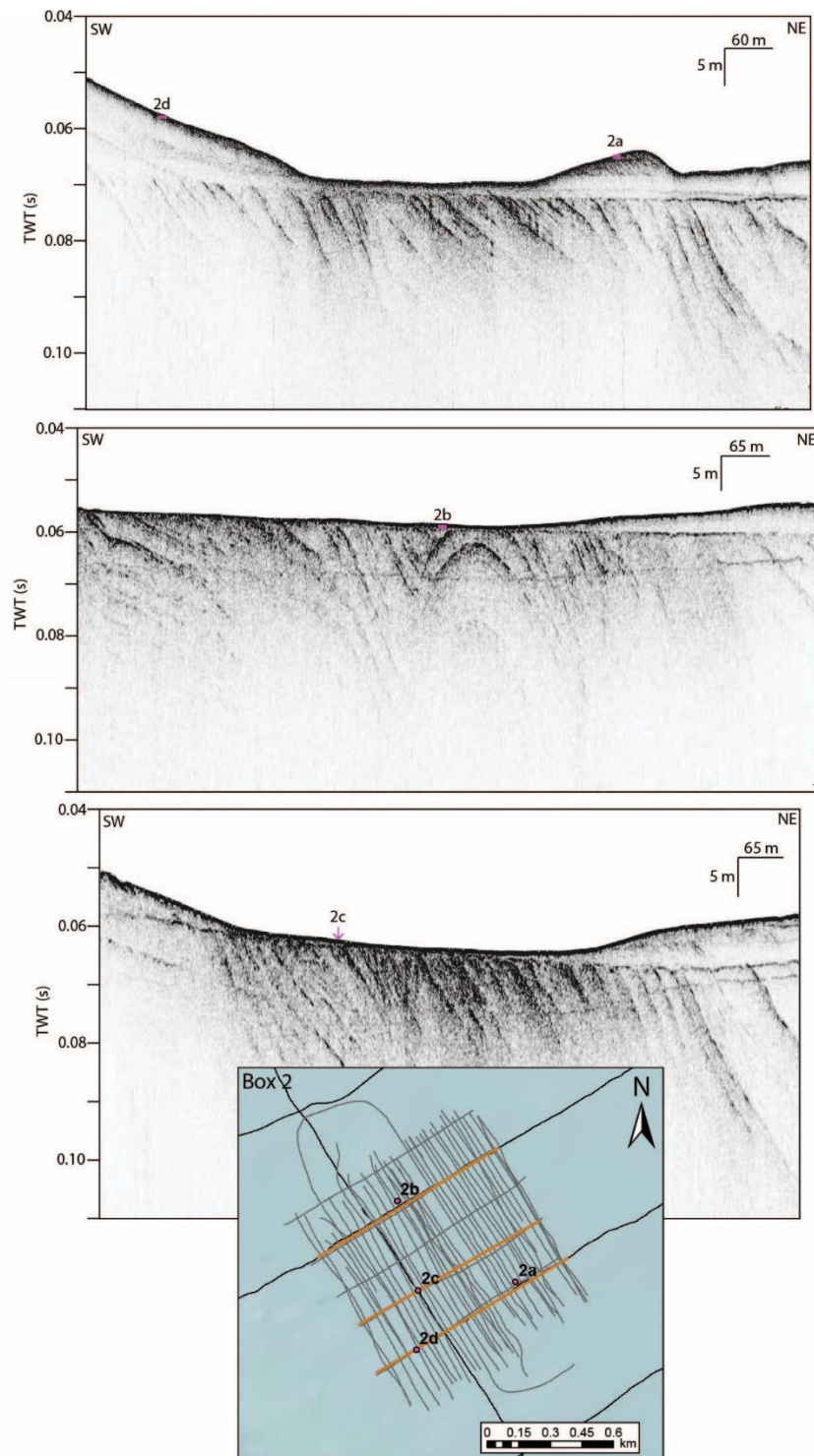


Figure 3.5.6 Location of cores within Box 2

Map shows regional survey lines in black, Box 2 survey lines in gray, and profiles shown in the figure in orange. Cores are shown on the map as labeled pink dots. Cores 2a, 2b, and 2d show pink rectangles indicating approximate depth of penetration. Pink arrow for 2c shows location of coring attempts that did not recover sediment.

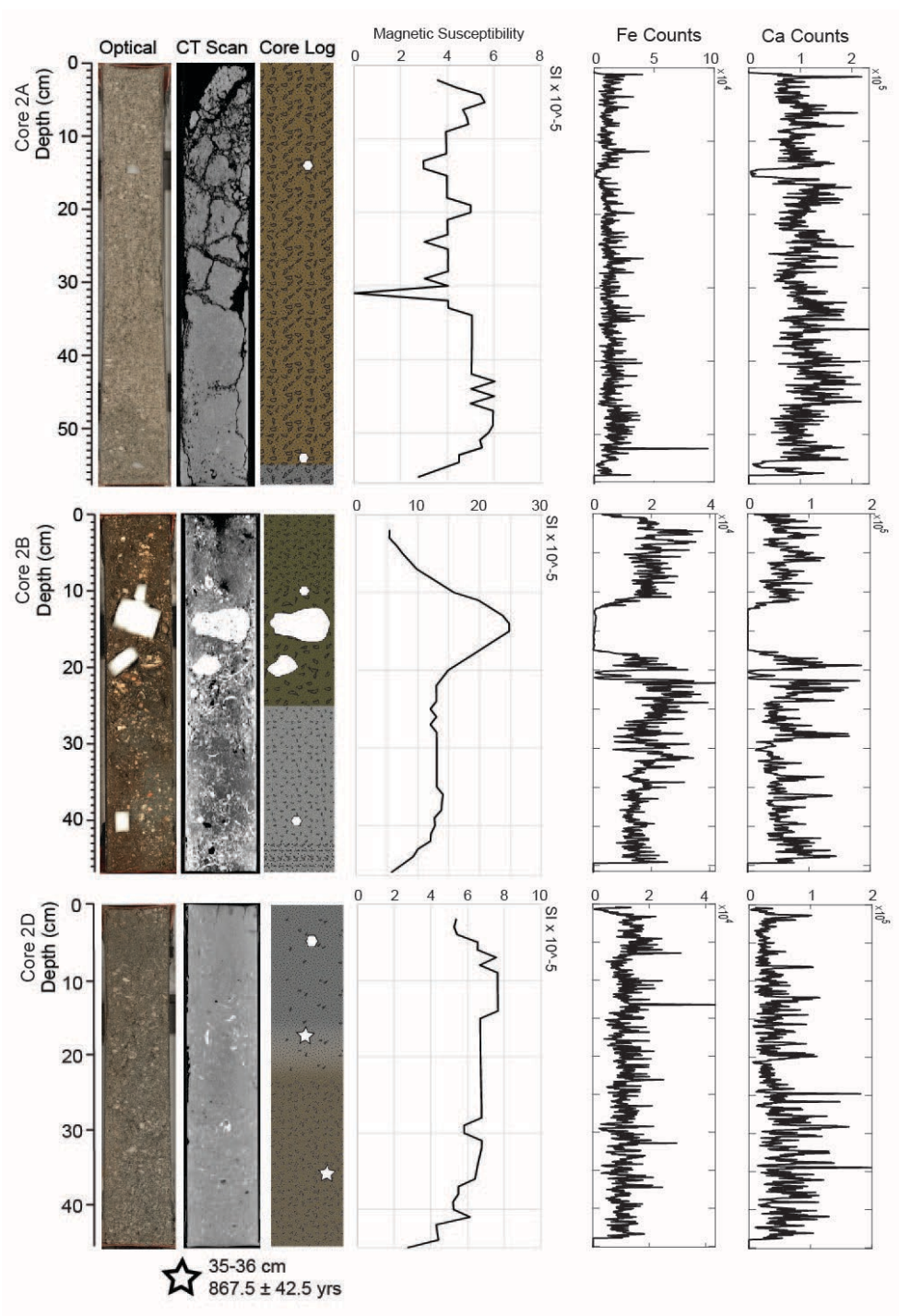


Figure 3.5.7 Summary figure of Box 2 core data

Top row is Core 2A, middle row is 2B, and bottom row is 2D. Note white squares in Core 2B optical image are foam pieces that were inserted after removal of rocks. The spike in MS at ~15 cm is coincident with

observed coarse material. The drop in Fe and Ca at the same depth is due to the foam that prevented XRF measurements at that depth. See Appendix A, Table A-2 for core log legend.

One radiocarbon date was collected from Box 2, taken at 35 cm in Core 2D. The calibrated age of this sample was 867.5 ± 42.5 years before present (BP) (Figure 3.5.7). This young age could indicate that the dune features are not relict Pleistocene dunes, but rather thick marine deposits, potentially focused into the area by modern oceanographic currents through the Santa Cruz Passage (SCP). However, the single date and short core length cannot rule out older deposits below the surface of the dunes. The fact that penetration was low at all locations suggests a relatively hard layer or very coarse layer was encountered that could not be sampled, possibly representing more cemented and older sediments below.

3.5.3 Box 4: Verde Canyon paleodrainage, north of Santa Rosa Island

Box 4 was selected based on a regional sub-bottom line that showed a wide paleovalley with potential incised channels (Figure 3.5.8; Figure 3.5.9). In bathymetric data, Box 4 is in a bathymetric low extending north from Verde Canyon that appears to represent a paleovalley (Figure 3.5.8). A second paleovalley is observed to the east, but the seafloor to the west, north of Arlington Canyon, appears rocky. This was confirmed with regional chirp profiles that show bedrock exposed at the surface, except within the valley. The predictive model indicated this was an area with high potential for containing archaeological resources.

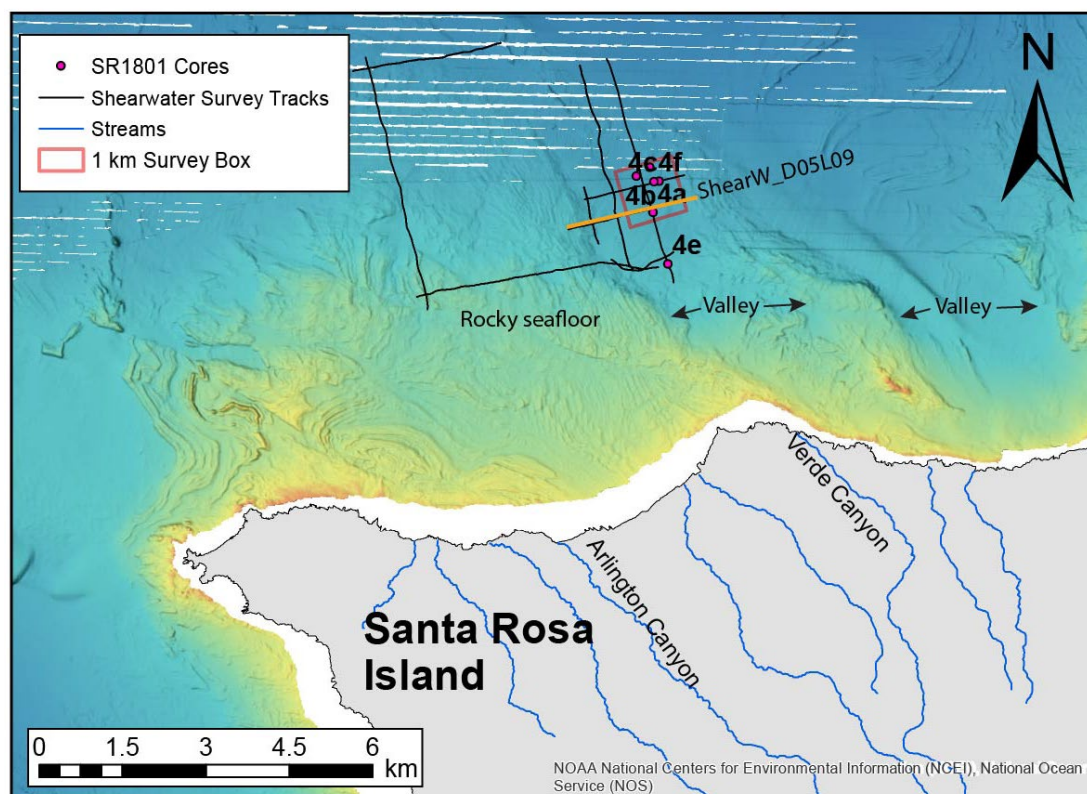


Figure 3.5.8 Map of survey area north of Santa Rosa Island

Orange line shows location of chirp profile shown in Figure 3.5.9. Seafloor bathymetry from NOAA (<https://www.ncei.noaa.gov/maps/bathymetry/>).

The interpreted paleovalley is ~1.5-2 km-wide and is observed as a low in the regional unconformity with step-like features at the edges that are interpreted as fluvial strath terraces (Figure 3.5.9). These are interpreted as strath terraces because dipping and folded beds are observed below the terrace surface indicating erosion into bedrock. Below the valley floor, two small erosional features are interpreted as paleochannels. Below the shallow channel features, the dipping beds are not observed, and the acoustic character is more chaotic to wavy. This could be a result of bedrock erosion and channel infill, but a reflector representing the channel bottom is not clearly observed. Alternatively, the observed dipping reflectors that are interpreted as channels could be related to folding of the older sedimentary units. The regional unconformity across this profile is topped by the transparent Unit 1, which is ~10 m thick and thins to the southwest and northeast away from the paleovalley (Figure 3.5.9).

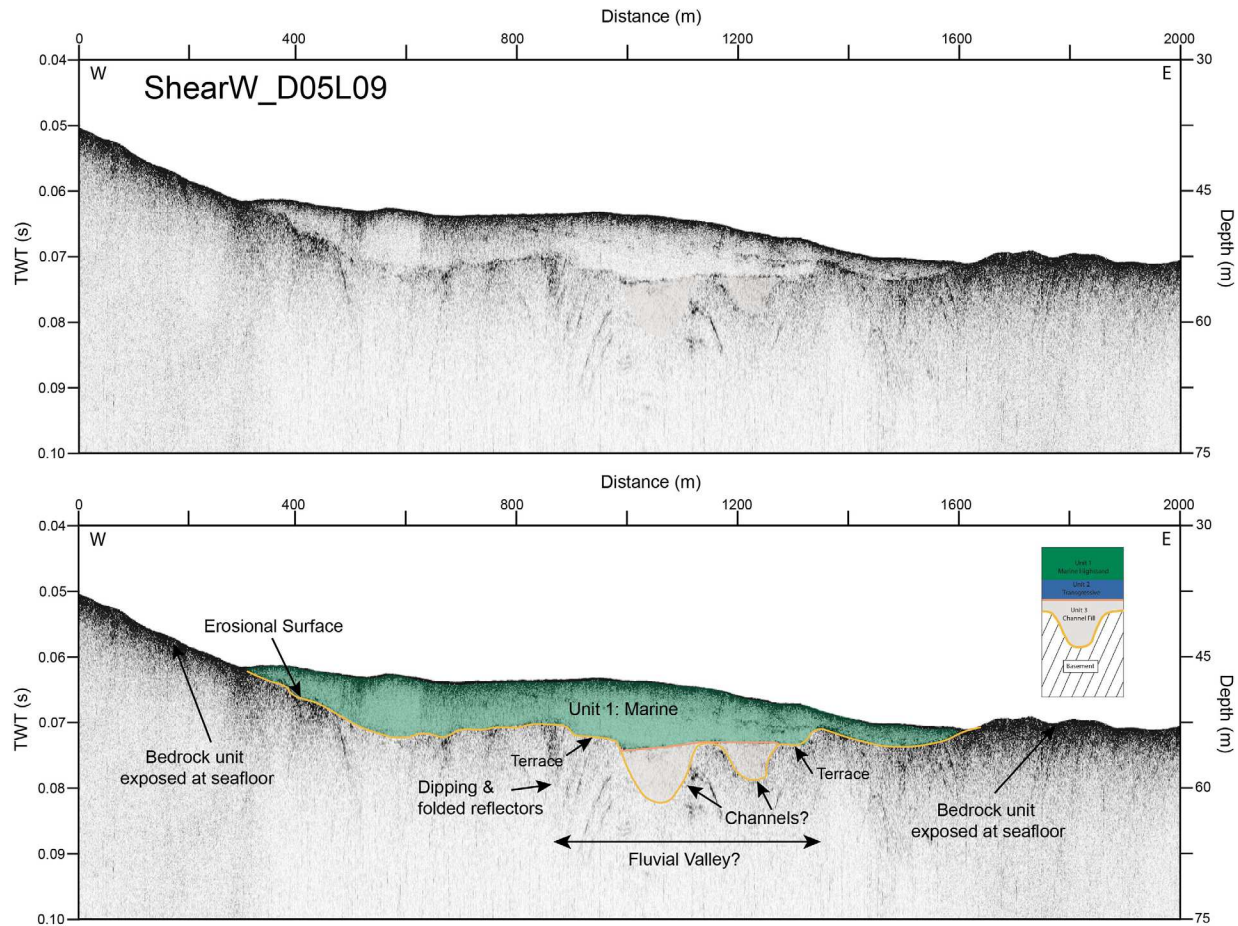


Figure 3.5.9 Chirp Line ShearW_D05L09

See Figure 3.5.8 for location. Inset stratigraphic column is middle column from Figure 3.5.1.

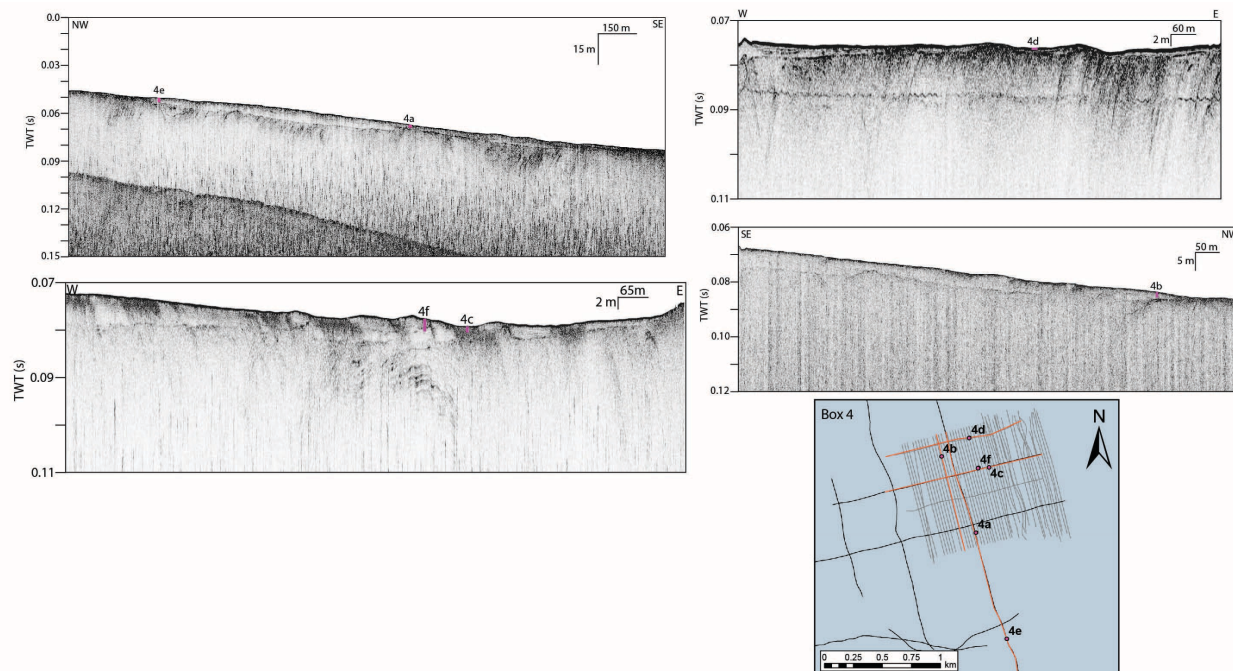


Figure 3.5.10 Location of cores within Box 4

Map shows regional survey lines in black, Box 4 survey lines in gray, and profiles shown in the figure in orange. Cores are shown on the map as labeled pink dots. In chirp profiles, cores show pink rectangles indicating approximate depth of penetration.

Within the 1 km² survey box, five core locations were selected, and one was selected nearby just landward of the box (Core 4E) (Figure 3.5.10). Core 4A targeted a laminated, channel-type feature below the transgressive surface. Core 4B targeted a high-amplitude feature associated with offset of the transgressive surface, possibly representing a channel edge or cliff face. Core 4C targeted a chaotic acoustic signature interpreted to potentially represent gas from estuarine sediment below. Core 4D targeted another chaotic unit that was also above an offset of the transgressive surface. Core 4E targeted a channel-like feature below the transgressive surface. Core 4F targeted a high-amplitude reflector within the upper transparent unit.

All cores contained sand, silt, and shell fragments of variable abundance (Figure 3.5.11). Core 4F is shown as an example of the sedimentology, MS, and XRF data from all the cores, except 4E, which is described below. Core 4F, similar to the other cores, included olive sand and shells with variable shell abundance and size (Figure 3.5.12). MS was low, except in this core, two metal core catcher fingers were pulled up into the core tube, resulting in a spike in MS at their location. Although grain size samples were collected, they were ultimately not analyzed due to the prevalence of shell material. Visual observation indicated mostly fine to medium sand with shell fragments of sand size to several cm scale. XRF appears to track mostly with shell abundance (Figure 3.5.13). Higher shell abundance tracks with higher Ca and strontium (Sr), and lower Fe, titanium (Ti), and rubidium (Rb). The characteristics of this unit are consistent with highstand marine sediments. All of the cores appear to have only penetrated the upper, mostly transparent Unit 1, confirming this is a marine unit in the chirp data.

Core 4E was the only one that contained a distinct change in sedimentology near the base of the core (Figure 3.5.14). It penetrated right to the base of the transparent unit in chirp data. The upper unit is olive gray (5Y 3/2), fine-medium sand with shell fragments of variable abundance ranging from 10–50% and generally increasing from 0–160 cm. A larger increase to 80% is observed in the deepest 10 cm from 160–170 cm. The shell fragments range in size from sand sized to 2–3 cm. There is a sharp contact with

the lower unit at 170 cm, but at 180 cm there appears to be a lens of the upper unit within the lower unit, suggesting intercalated contact of alternating deposition. The lower unit is gray (5Y 5/1) with more well-sorted sand and more intact and identifiable shell fragments. Shells include sand dollar fragments, echinoderm fragments, mostly articulated barnacle, moon snail fragment (*Naticidae*), *Olivella baetica*, *Olivella biplicata* and *Donax*. MS increases slightly moving down the upper unit but drops near the contact with the lower unit. XRF data show Ca, Fe, and Ti increase and become more variable moving down the upper unit (Figure 3.5.15). The lower unit is lower in Ca, Fe, and Ti counts and is less variable in those elements.

Seven radiocarbon samples were collected from Core 4E (Appendix A, Table A-1; Figure 3.5.16). The depths and dates of these samples suggest that the bottom unit was deposited between ~6000 and 10,000 cal years BP, while the upper unit was deposited in the last ~200 years. The lowest unit contains well-sorted sand and estuary and shallow-water fossils (e.g., *Naticidae*, *Tagelus*, *Olivella*, *Donax*). Local sea level around SRI during 10 to 6 ka rose from ~45 to 9 mbsl (Clark et al. 2014). The water depth at the base of Core 4E is ~45 mbsl, which matches with a time of sea level inundation around 10 ka. Therefore, the team interprets the lower unit of Core 4E to represent coastal to shallow marine sediment deposited during sea level transgression across this region. It is plausible that the core stopped penetrating when it reached a more resistant layer representing terrestrial deposits of the subaerial exposure surface (alluvial-fluvial deposits) or when it encountered indurated Miocene sedimentary rocks.

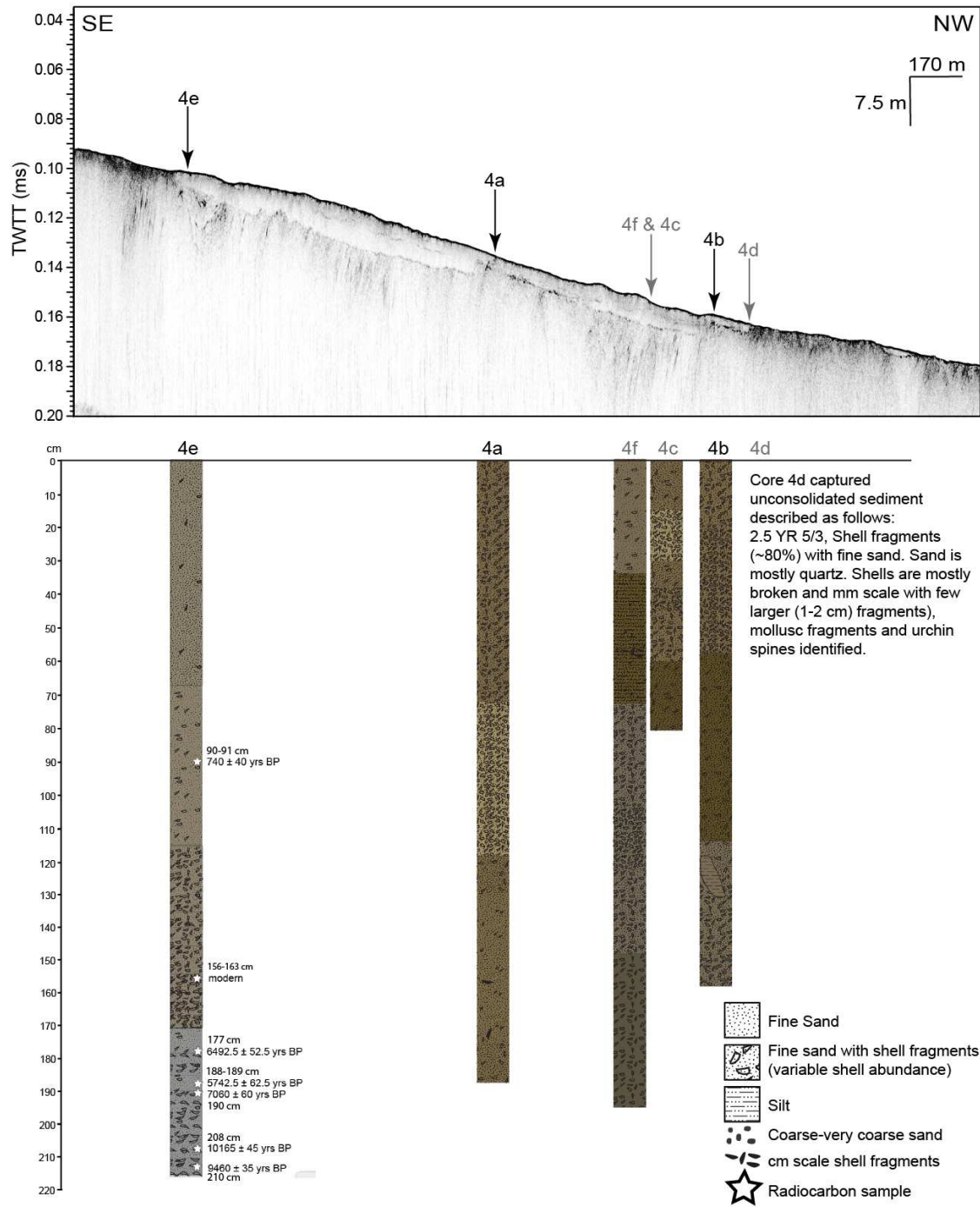


Figure 3.5.11 Chirp profile showing location of collected cores and core logs

Cores labeled in gray were not directly along the chirp profile but were projected from ~200 m away. See Appendix A, Table A-2 for full core log legend. Figure modified from Master's Thesis by Luke Johnson (Johnson, 2020).

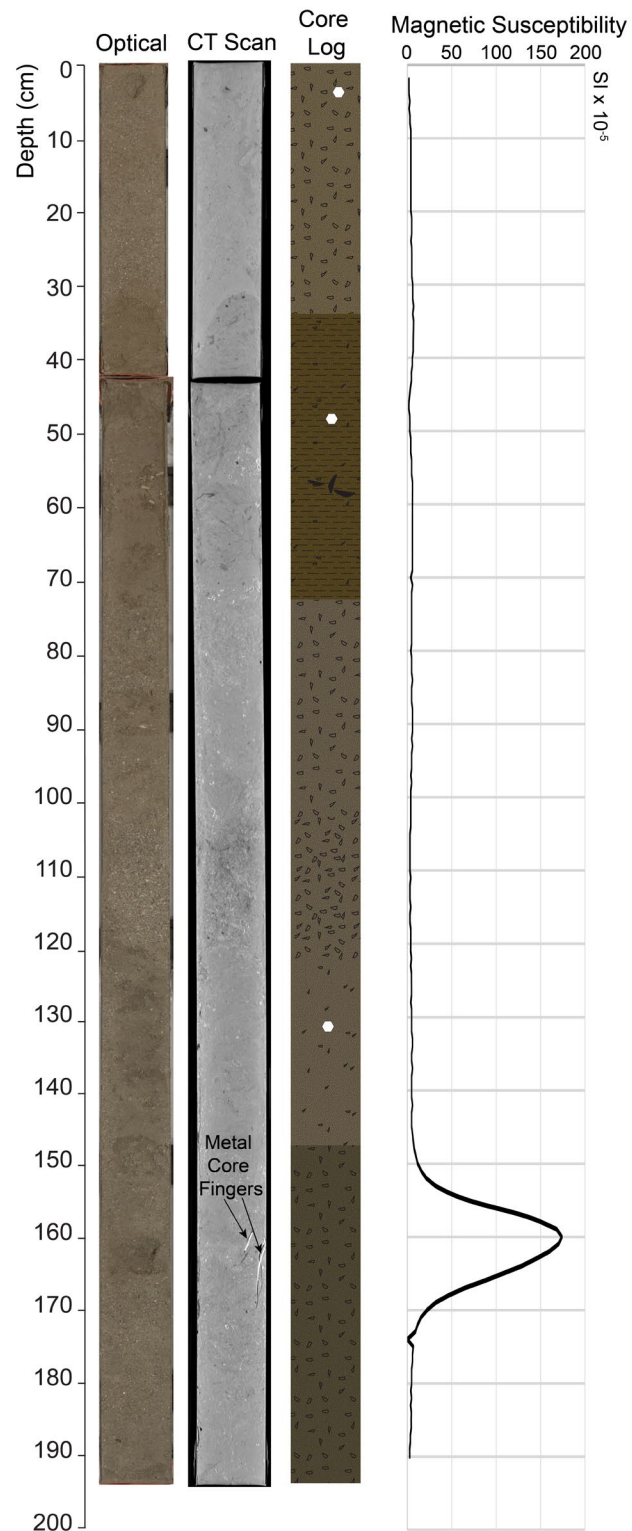


Figure 3.5.12 Optical image, CT scan, Core Log, and Magnetic Susceptibility results for Core 4F
 Note spike in MS associated with metal core fingers trapped in core liner. See Appendix A, Table A-2 for core log legend.

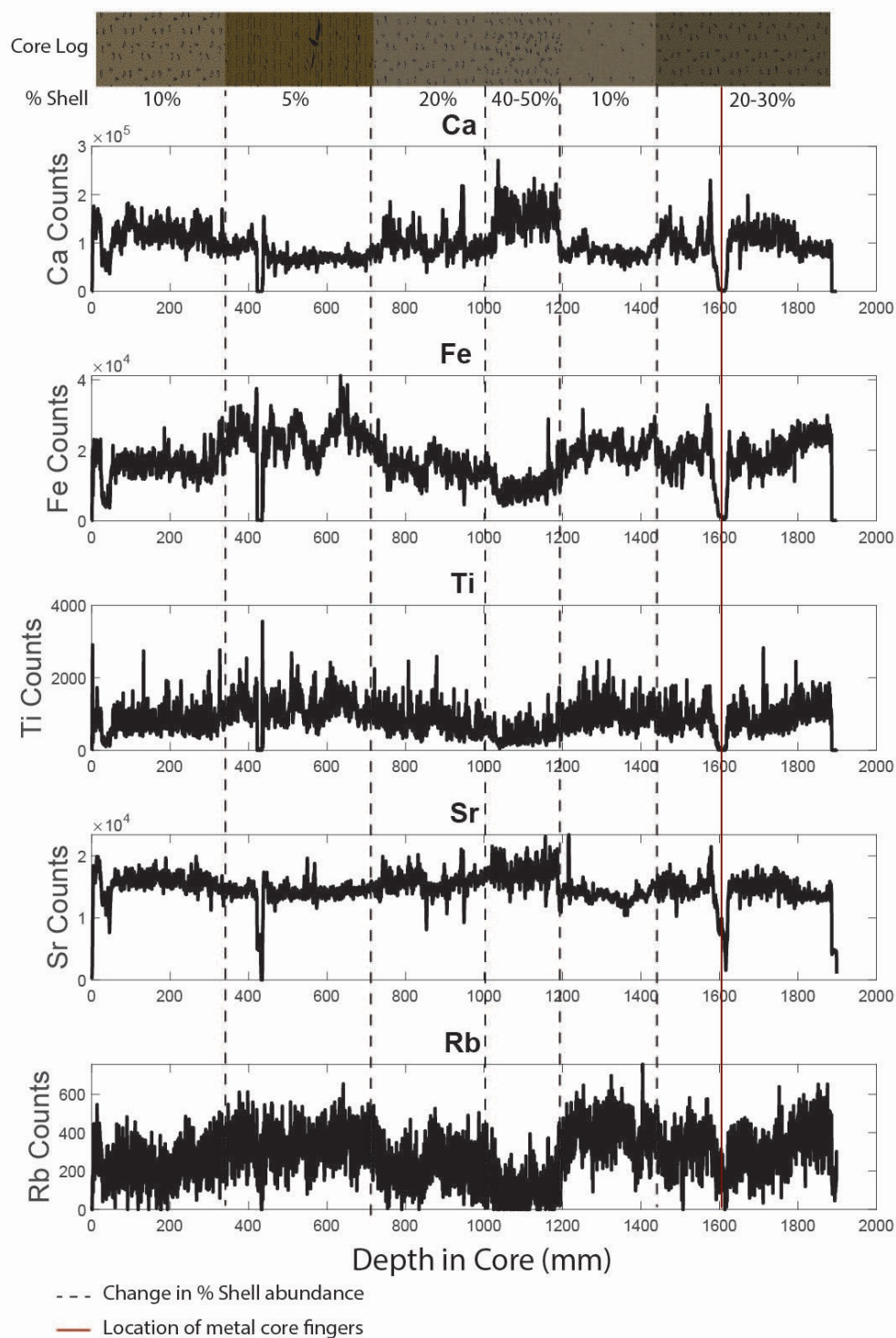


Figure 3.5.13 Core 4F selected XRF Data

Dashed lines show changes in shell abundance in the core. Red line shows depth of metal core catcher fingers.

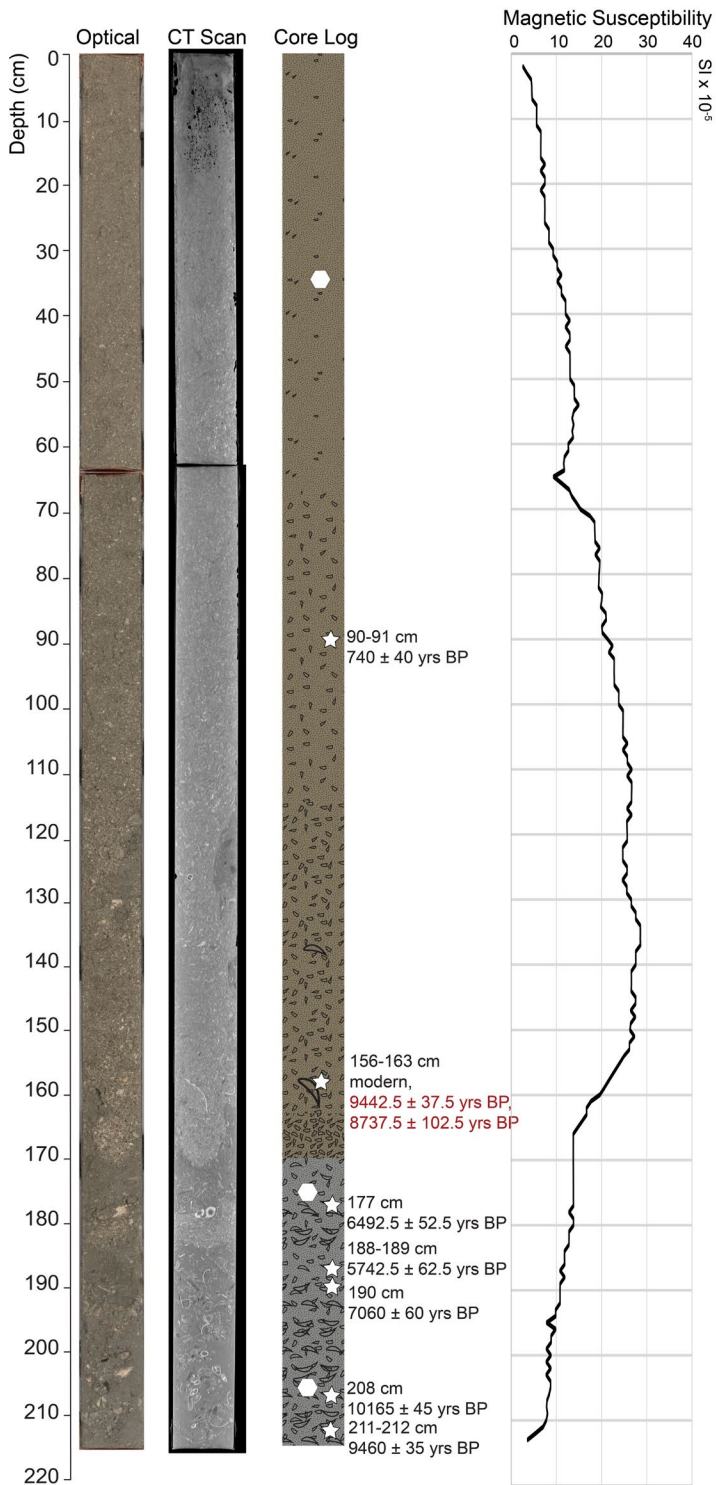


Figure 3.5.14 Optical image, CT scan, Core Log, and Magnetic Susceptibility results for Core 4E
 Red text for radiocarbon dates indicate reversal from younger to older dates. See Appendix A, Table A-2 for core log legend.

Core Log

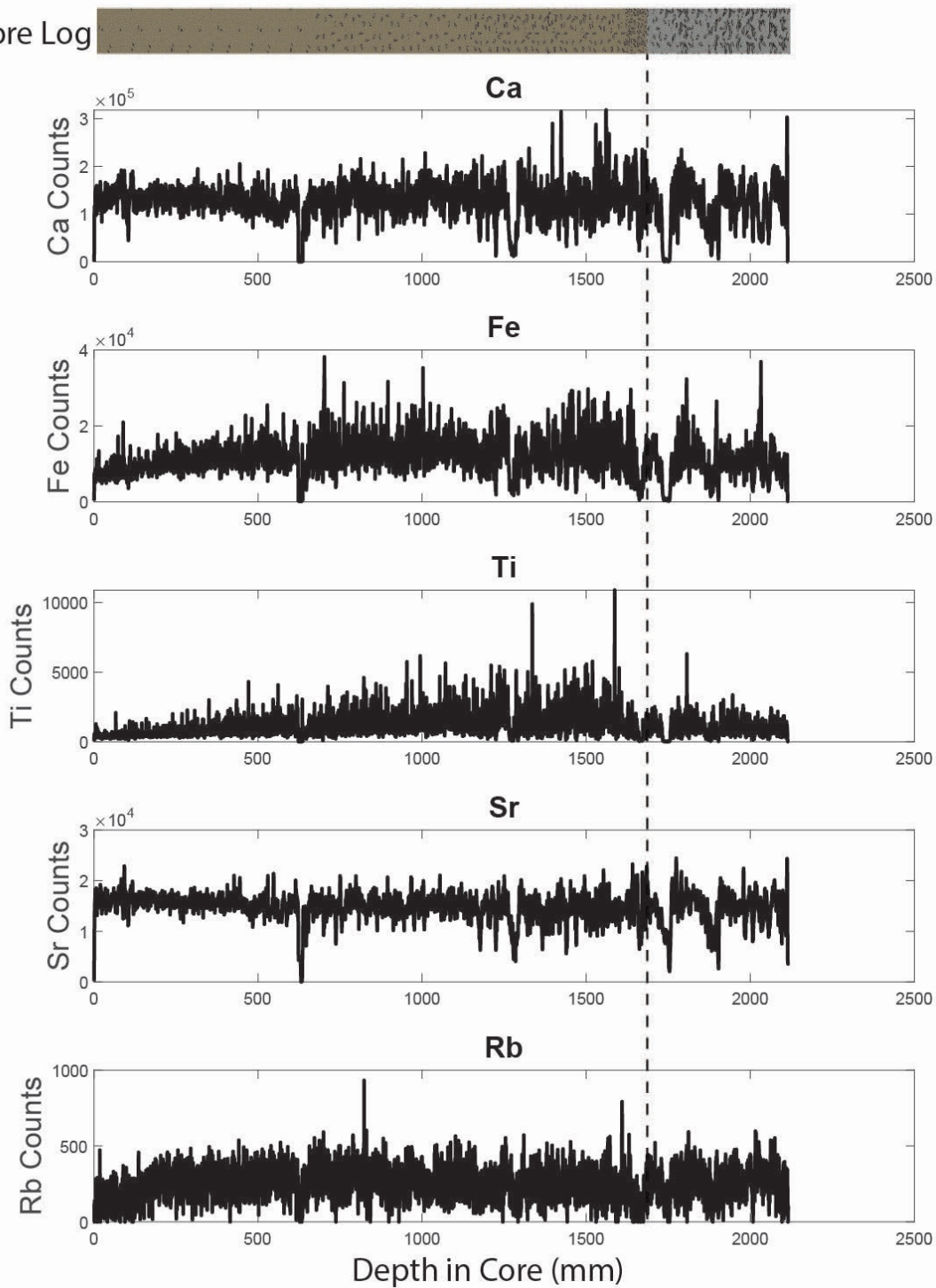


Figure 3.5.15 Core 4E selected XRF data
Dashed line shows change in sedimentology.

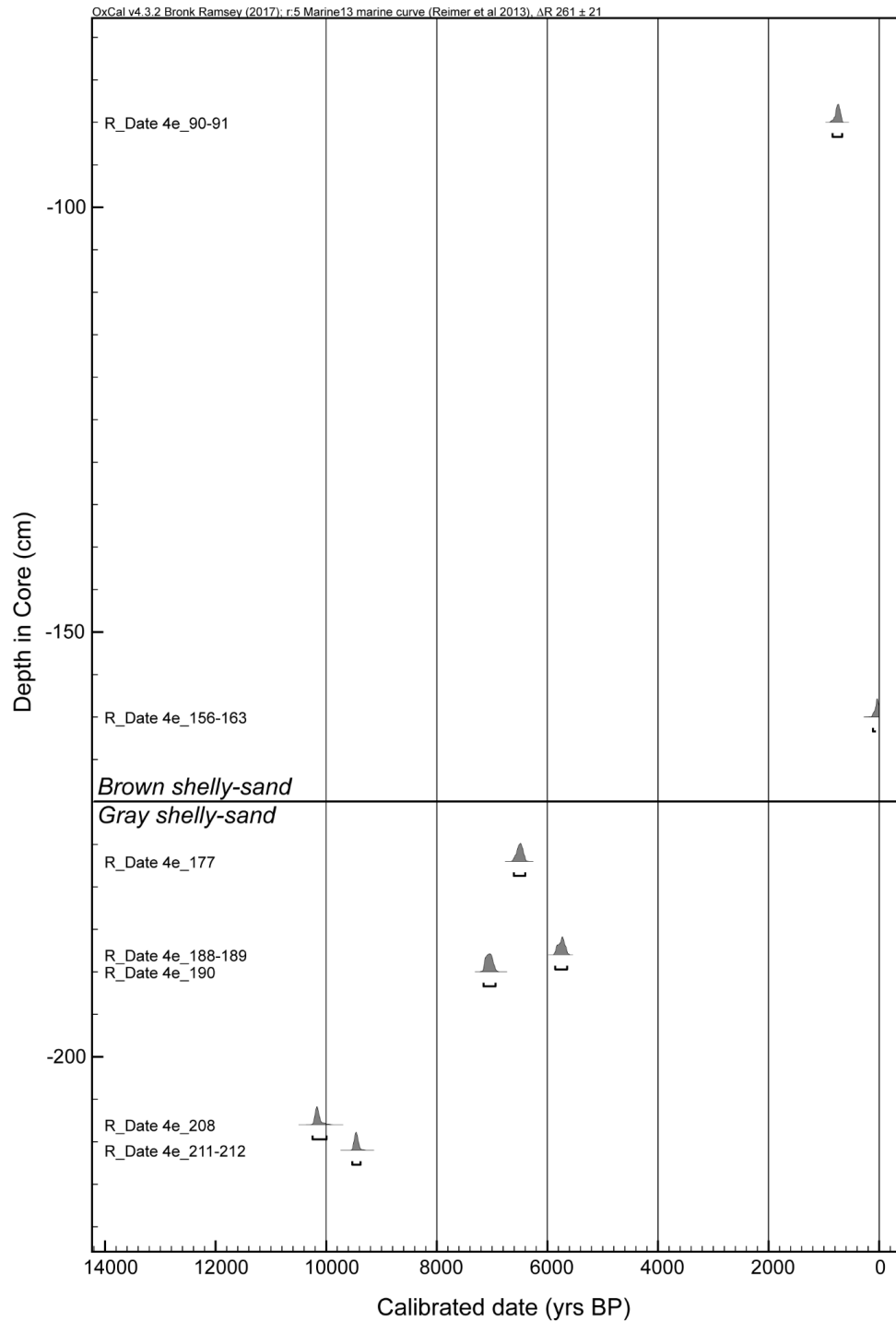


Figure 3.5.16 Age model for radiocarbon dates from Core 4E

The contact between sediment units is shown as a labeled horizontal line. Sample names shown at left with numbers after “4e” indicate depth in cm. Gray humps are probability distribution functions showing the range in calibrated ages for each sample. Figure modified from Master’s Thesis by Luke Johnson (Johnson, 2020).

3.5.4 Box 5: Central Santa Cruz Passage

Box 5 was selected based on a regional sub-bottom line that showed a series of v-shaped paleochannels, possibly within a wider paleovalley, near the head of Santa Cruz Canyon (Figure 3.5.17). These channels were connected to the wavy-hummocky unit (Unit 4, interpreted as terrestrial valley fill; Figure 3.5.1) observed offshore Christy and Saucos canyons by the high-amplitude, high-relief reflector interpreted as a subaerial erosion surface. The paleochannel bottoms are characterized by a medium-high-amplitude reflector with blotchy character. Channel fill is transparent to chaotic, with some sub-horizontal medium amplitude reflectors that onlap channel edges. The v-shaped paleochannels are topped by a discontinuous, wavy, high-amplitude reflector. These channels have widths of 150, 200, 150, and 200 m, and maximum depths below seafloor of 10, 11, 12, and 10 m, from west to east, respectively. Santa Cruz Canyon would have formed a bay at times of lower sea level, and it is hypothesized that the area around the head of the canyon could have contained large estuarine environments. The sub-bottom units that filled some of the v-shaped channels were also characterized by faint, closely spaced reflectors that could indicate estuarine-type fill deposited during sea level rise. Based on the evidence above, a 1 km² survey box with 25 m line spacing was collected across the v-shaped channel features and subsequently a series of cores were planned to ground-truth this environment, hypothesized to represent fluvial to estuarine conditions.

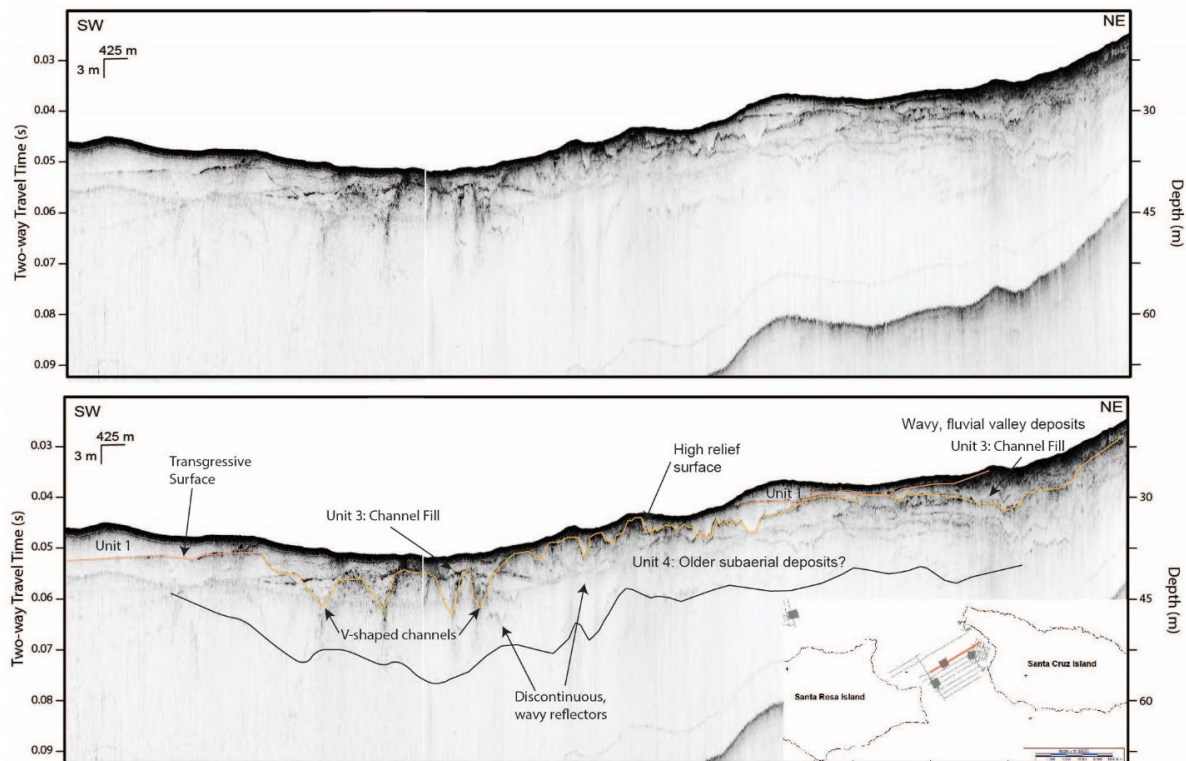


Figure 3.5.17 Chirp profile in center of Santa Cruz Passage showing v-shaped channels and wavy, discontinuous reflectors

Surfaces and Units 1, 3, and 4 as illustrated on Figure 3.5.1 left column. Inset map for location showing profile in red.

Within the 1 km² survey box, there was variability observed in the reflectors. The v-shaped channels are most pronounced near the center of the box, but they are difficult to trace north and south. As such, the four coring locations were selected near the box center. Core 5a was at an interpreted channel bank where

a high-amplitude anomaly was observed (Figure 3.5.18). Core 5b was at a mounded feature adjacent to the interpreted channels (Figure 3.5.19). Cores 5c and 5d were in the middle of channel features where it was possible for a core to reach the channel feature (~3 m below seafloor) (Figure 3.5.18; Figure 3.5.19). The core sedimentology and CT scans for all Box 5 cores are illustrated in Figure 3.5.20.

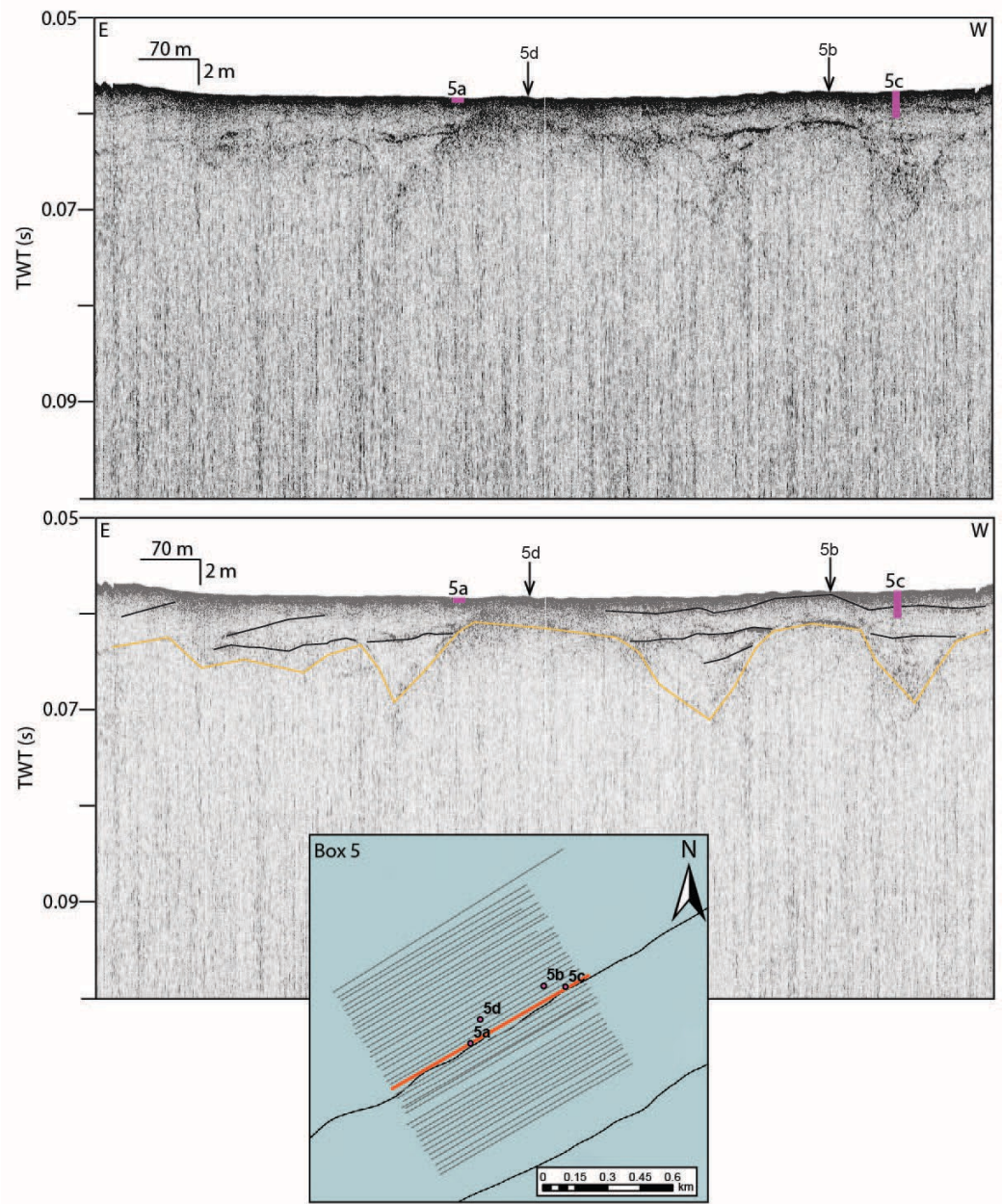


Figure 3.5.18 Location of Cores 5a and 5c (approximate core depth marked as pink rectangle)
 Projected location of Cores 5D and 5B shown as black arrows. Top - Uninterpreted chirp profile;
 Bottom – interpreted chirp profile. Yellow line is interpreted Surface 2. Black lines trace acoustic reflectors within Unit 3. Lower inset box shows regional survey lines in black, 1 km² box survey lines in gray, profile shown in this figure in orange, and core locations as labeled pink dots.

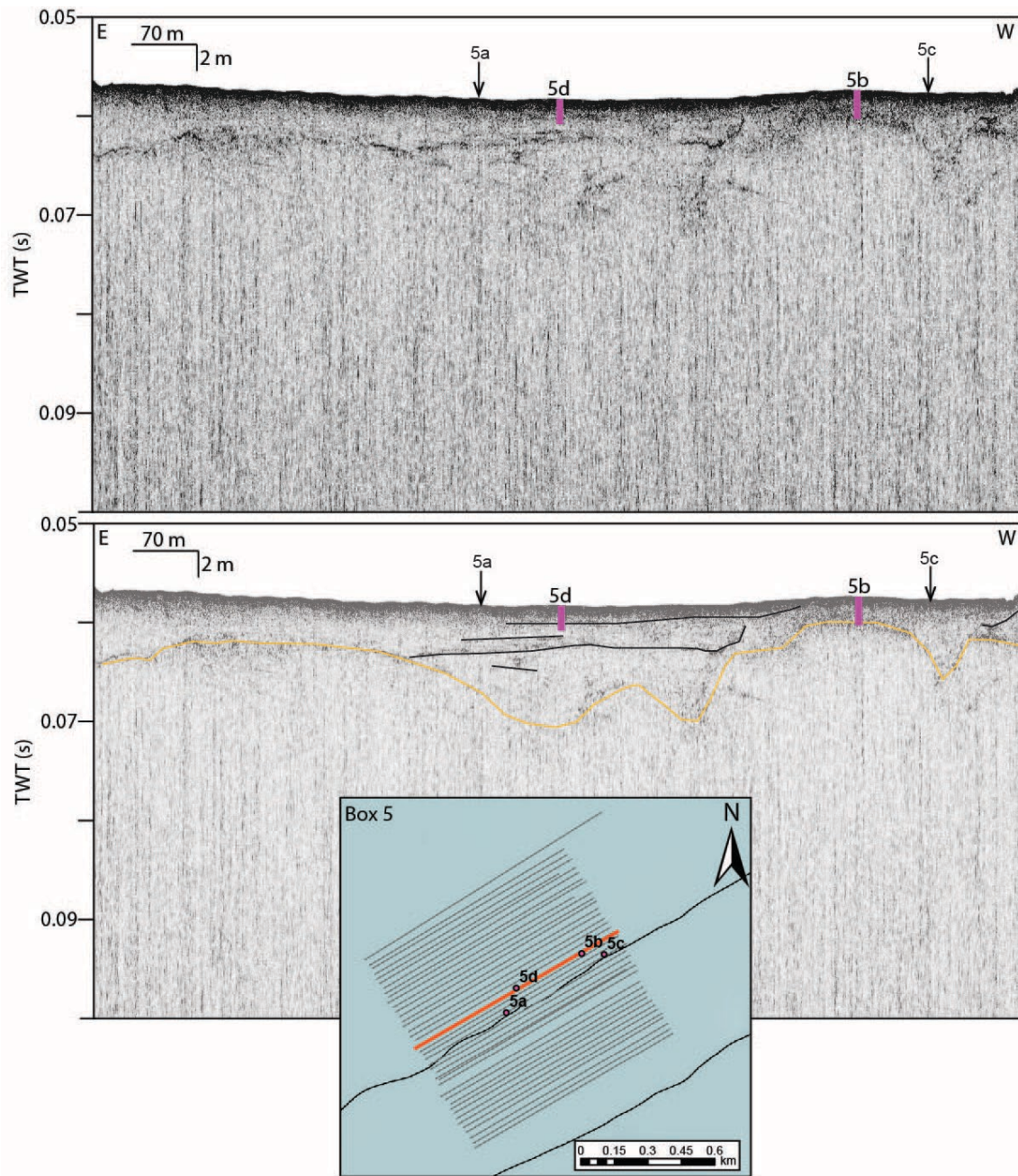


Figure 3.5.19 Location of Cores 5b and 5d (approximate core depth marked as pink rectangle)
 Projected location of Cores 5A and 5C shown as black arrows. Top - Uninterpreted chirp profile;
 Bottom – interpreted chirp profile. Yellow line is interpreted Surface 2. Black lines trace acoustic reflectors within Unit 3. Lower inset box shows regional survey lines in black, 1 km² box survey lines in gray, profile shown in this figure in orange, and core locations as labeled pink dots.

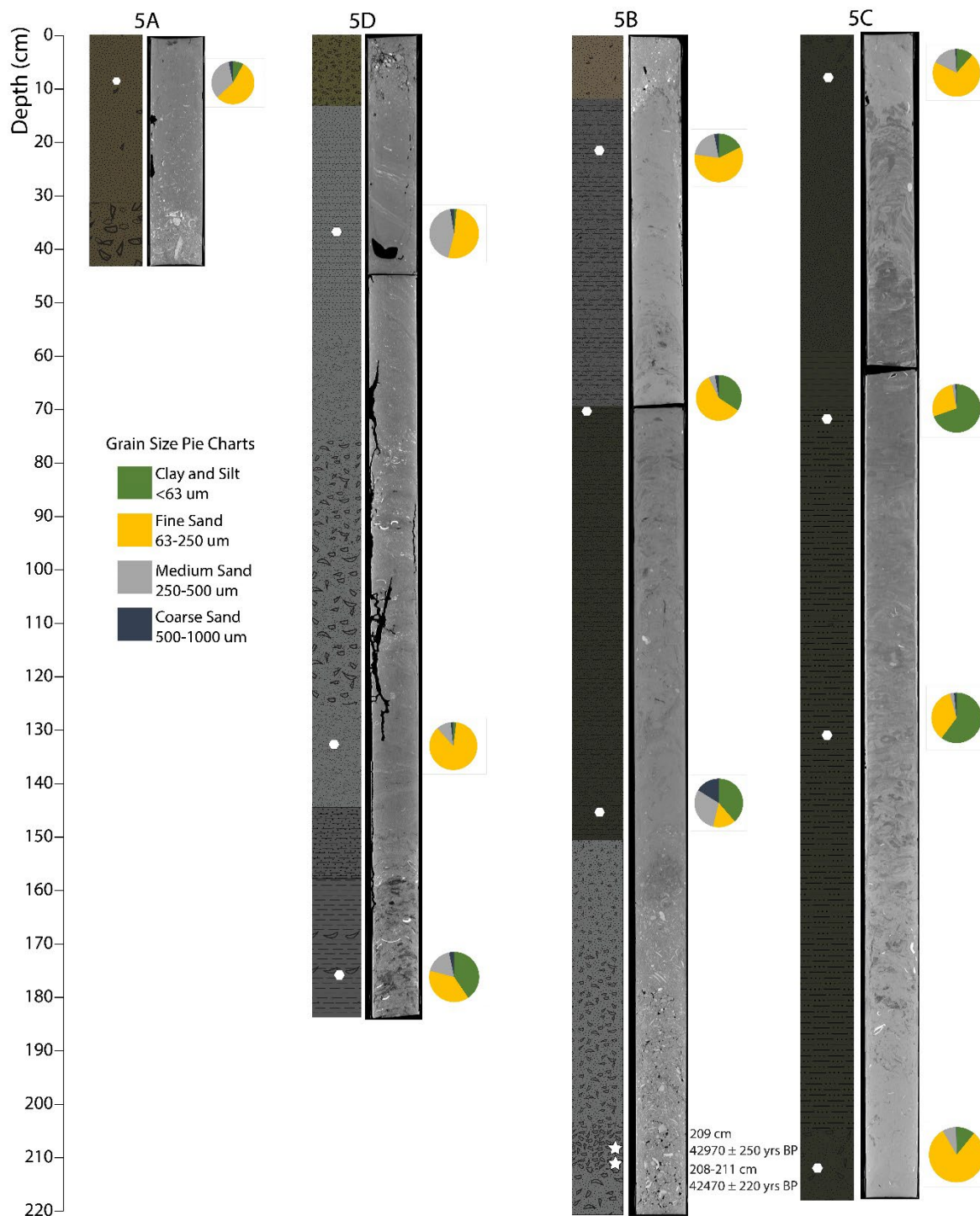


Figure 3.5.20 Core logs (left) and CT scans (right) for Box 5 cores

Grain size results are illustrated as pie charts. Radiocarbon ages are noted. See Appendix A, Table A-2 for core log legend.

Core 5A only penetrated 41 cm below the seafloor (Figure 3.5.21). It contains dark olive gray (5y 3/2) shelly sand. The bottom 10 cm includes more abundant shells, larger shells, and larger angular pebbles compared to the upper 30 cm. A grain size sample at 10 cm contained 92% sand and 8% mud (Figure 3.5.20). Only very slight variability in MS is observed throughout the core (Figure 3.5.21). XRF data show an increase in Ca, decrease in Rb, and increase in Sr coincident with the observed increase in shell toward the base of the core (Figure 3.5.22). No radiocarbon samples were collected from this core.

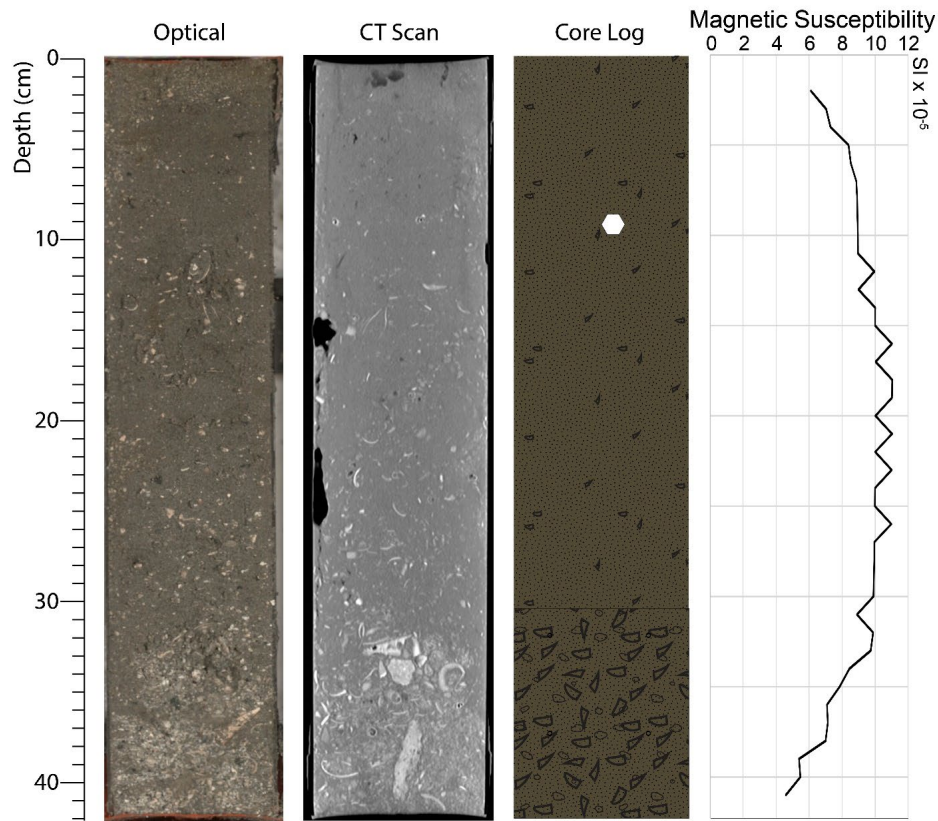


Figure 3.5.21 Optical image, CT scan, Core Log, and Magnetic Susceptibility results for Core 5A
See Appendix A, Table A-2 for core log legend.

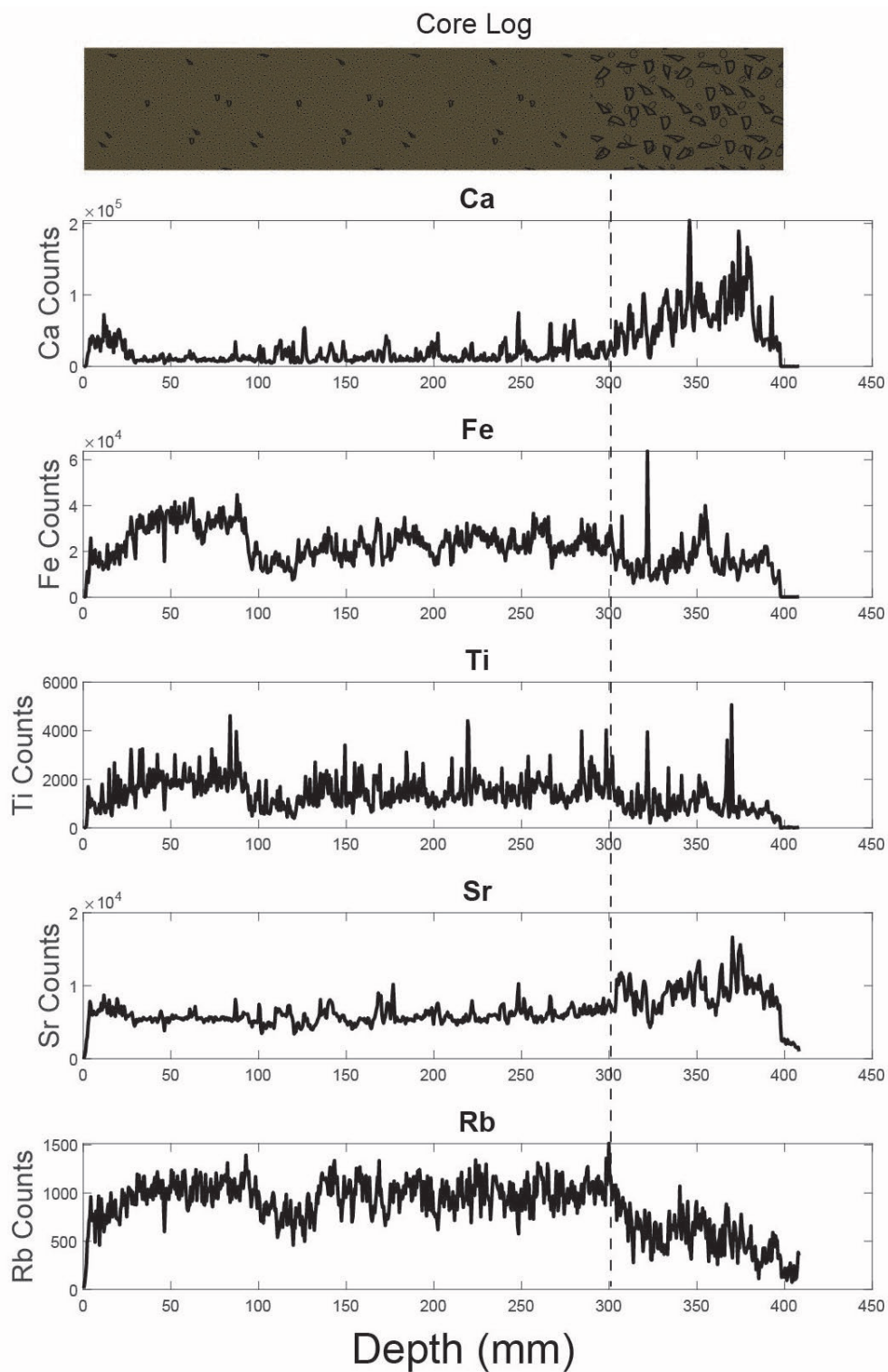


Figure 3.5.22 Selected XRF data for Core 5A with reference core log illustrated at top
Dashed line indicates change in XRF data discussed in text.

Core 5B can be described as three units (Figure 3.5.23). The upper unit consists of olive gray, shelly sand (5Y 4/2) with XRF results indicating relatively high Ca, low Rb, and high Sr (Figure 3.5.24). The middle unit is in sharp contact with the upper unit and is described as a dark gray to black (5Y 4/1 and 5Y 2.5/1) silty sand with few shells and faint laminations near the top. The unit becomes more mottled and coarser grained moving down the core. At the base of the layer, a grain size sample contained 39% mud, 45% fine-medium grained sand, and 16% coarse sand (Figure 3.5.20). The middle unit is lower in Ca, and higher in Fe and Ti (both increasing with depth as grain size increases) compared to the upper unit. There is a slight increase in MS toward the base of the unit. The lower unit is in sharp contact with the middle unit above and is described as shelly, gravely sand and silt. It contains angular gravel and fragmented shells, with an observed increase in coarseness and shell abundance with depth. The XRF data for this unit are high in Ca, moderate in Fe and Ti, low in Rb, and high in Sr. MS is relatively low. Two radiocarbon dates were collected from the base of Core 5B. Both were dated older than 42,000 cal yrs BP.

Core 5C includes an upper, thin (0-8 cm) shelly sand layer (Figure 3.5.25). Below the upper layer, the sediment is mottled, black (5Y 2.5/1) sandy mud (>60% mud) with sparse shell fragments. Toward the base of the core (~200 cm) there is a gradual contact into a sandier basal unit (silty sand, 80% fine sand). There is very little variability in MS down the core. Overall, the XRF shows the upper thin layer is higher in Ca, high in Sr, and low in Rb compared to the rest of the core (Figure 3.5.26). Few other patterns are observed in the XRF data. No radiocarbon samples were collected from this core.

Core 5D includes an olive (5Y 4/3) upper shelly sand layer (~12 cm thick) that grades into a dark gray (2.5Y 4/1), well-sorted sand unit (>95% fine-medium sand) (Figure 3.5.27). The sand unit is faintly laminated (more apparent in the CT scan), and the sand is mostly quartz (>90%) that is subrounded to subangular with 1-2% shell fragments. The middle of the sand unit contains an increase in shell fragments (size 1 – 50 mm). At 150 cm depth in the core, the middle, well-sorted sand is in sharp contact with the lower, very dark gray, muddy sand (41% mud) (Figure 3.5.20; Figure 3.5.27). The lower unit includes fragmented shells with a pink/yellow hue. Some shell fragments are large (several cm). There is a spike in MS within the middle sand unit from ~25-30 cm depth. A core catcher finger is not apparent in the CT scan, but this section of the core was underconsolidated and there could have been some mixing and accumulation of coarse material at this depth. XRF data are not available for this core and radiocarbon dates were not collected.

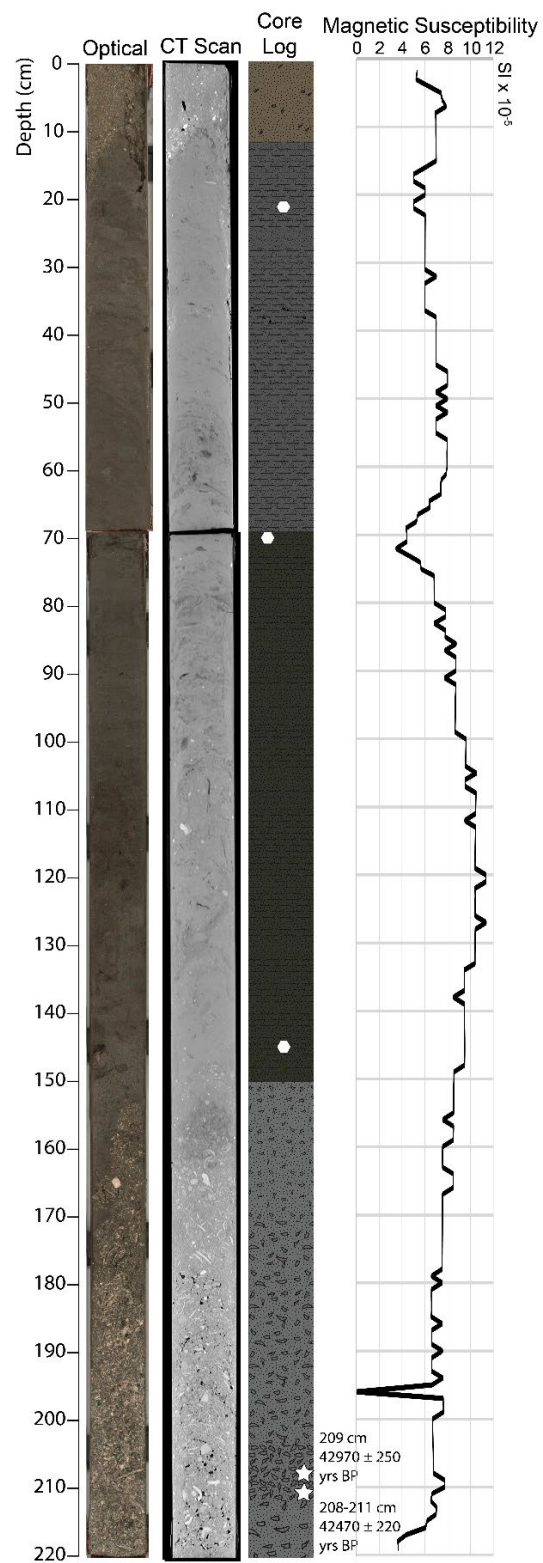


Figure 3.5.23 Optical image, CT scan, Core Log, and Magnetic Susceptibility results for Core 5B
See Appendix A, Table A-2 for core log legend.

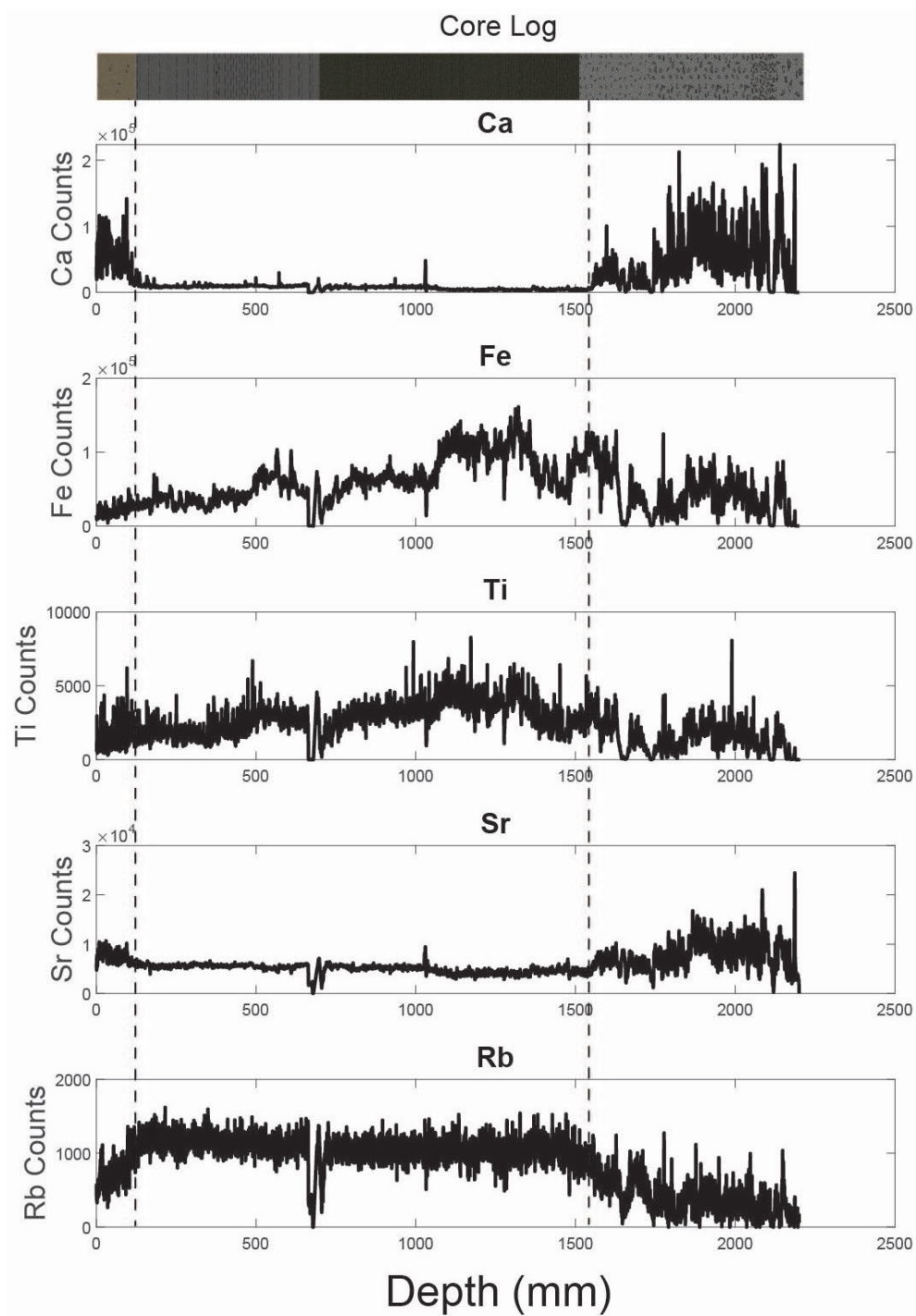


Figure 3.5.24 Selected XRF data for Core 5B with reference core log illustrated at top
Dashed line indicates change in XRF data discussed in text.

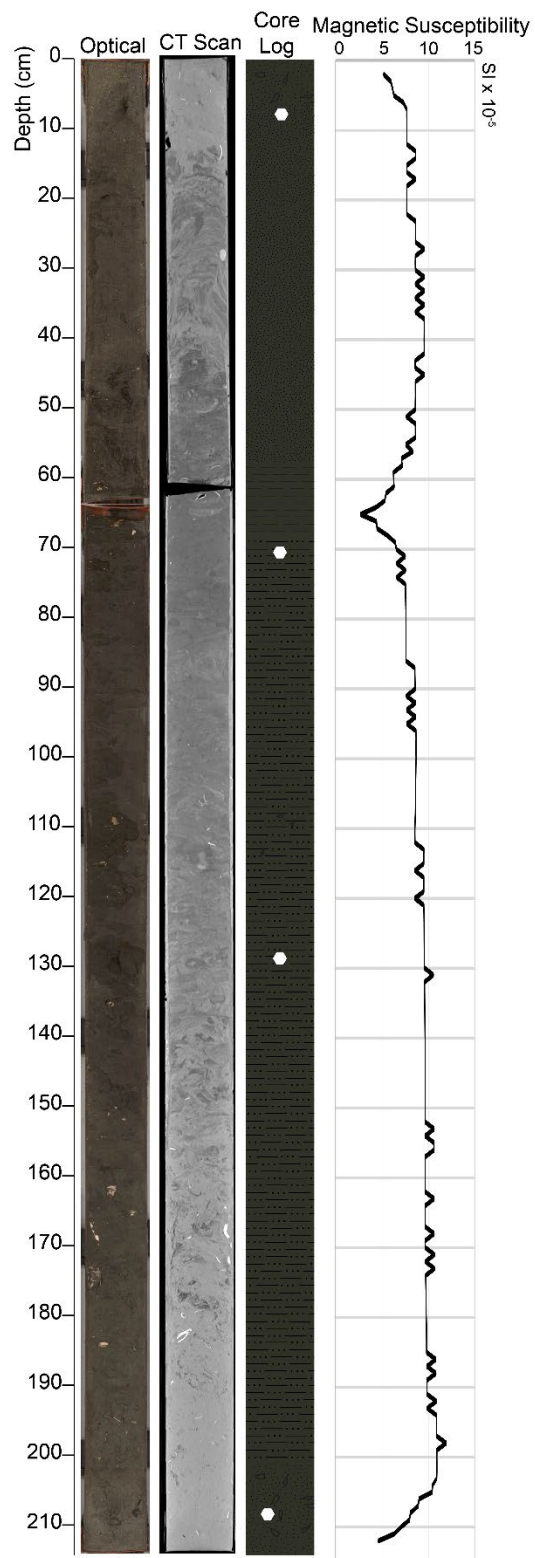


Figure 3.5.25 Optical image, CT scan, Core Log, and Magnetic Susceptibility results for Core 5C
 See Appendix A, Table A-2 for core log legend.

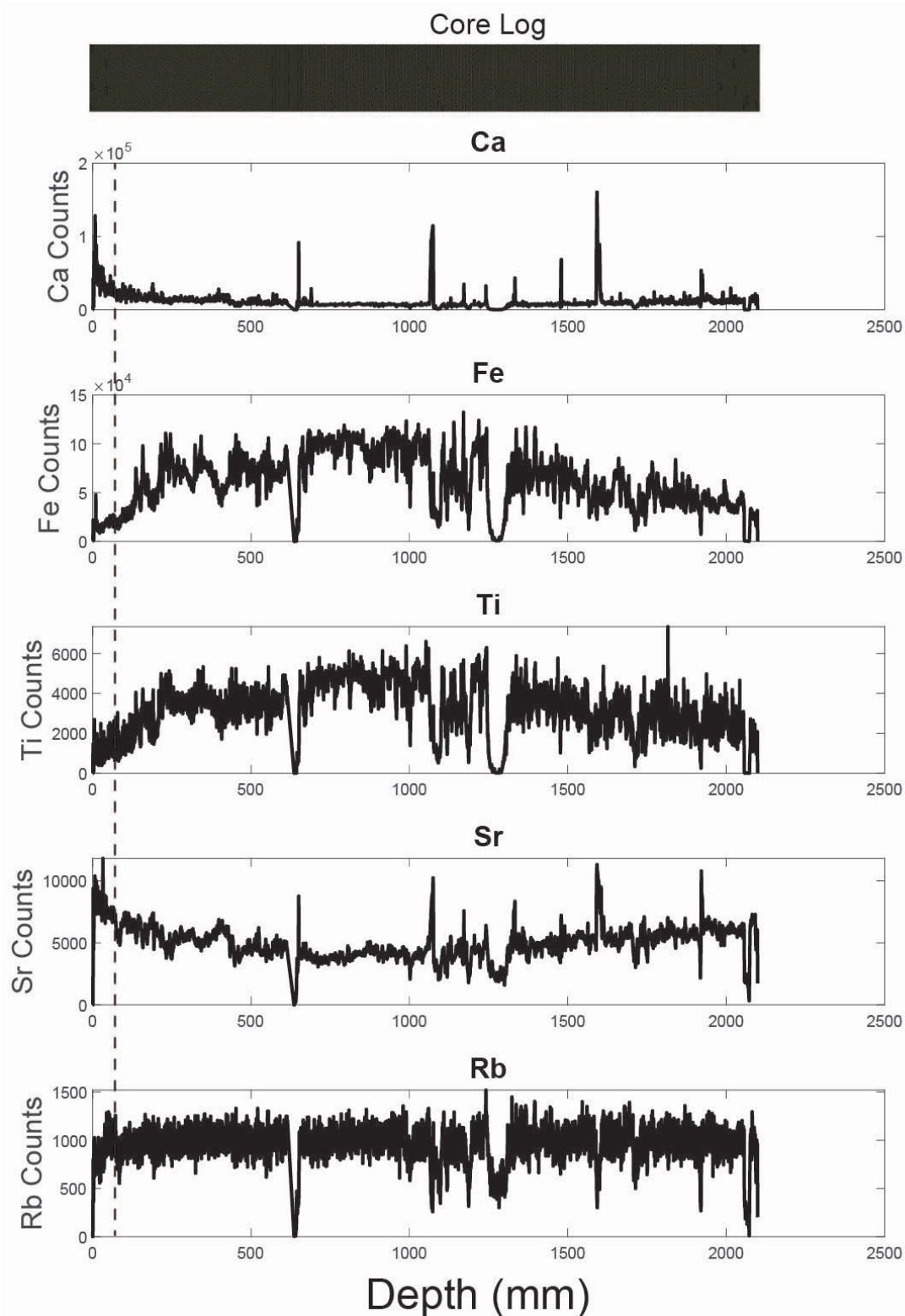


Figure 3.5.26 Selected XRF data for Core 5C with reference core log illustrated at top. Dashed line indicates change in XRF data discussed in text.

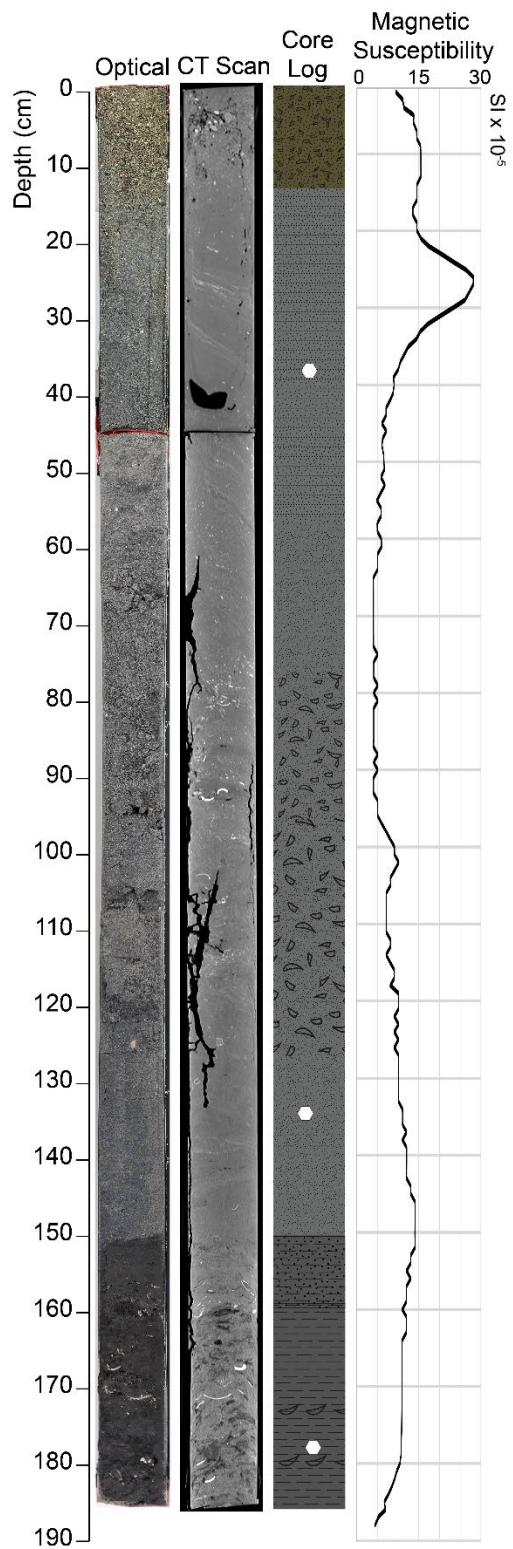


Figure 3.5.27 Optical image, CT scan, Core Log, and Magnetic Susceptibility results for Core 5D
See Appendix A, Table A-2 for core log legend.

The sub-bottom and sedimentological data from Box 5 indicate the preservation of estuarine and coastal environments in the area. The upper 10-30 cm of all cores is characterized by olive colored shelly sand with fragmented shells, low MS, and relatively high Ca and low Fe. This unit is consistent with Holocene highstand marine deposits (Unit 1). The muddier units with shell and mottled character could be indicative of calmer, bay-lagoon environments (Figure 3.5.20). The well-sorted, shelly sand unit of Core 5d is consistent with slightly higher energy, possibly a beach, sand bar, or tidal channel based on the sorting, subrounded grains, high quartz content, laminations, and shell content (Figure 3.5.20). In chirp data (Figure 3.5.17; Figure 3.5.18; Figure 3.5.19), it appears the upper marine unit was mostly not resolved because it was too thin and the strong seafloor reflector may overstep the signal. The shallowest resolved acoustic unit is transparent to chaotic with some internal, wavy, and discontinuous reflectors, above the high relief Surface 2, interpreted as an erosional surface. The cores that sampled this unit include both the shelly muddy deposits and the well-sorted sand, suggesting a laterally heterogeneous unit. Coastal and nearshore environments are laterally heterogeneous, with several sub-environments defined by different characteristics (e.g., tidal channels, tidal flats, beach, lagoon).

The only radiocarbon dates from Box 5 are from the gravelly, shelly unit at the base of Core 5B and these were dated at ~42,000 yrs BP. The dated unit is distinct from the other Box 5 cores, and based on the chirp data, it could have sampled a rough, high-amplitude reflector between two v-shaped channels (Figure 3.5.19). The timing of the shell ages corresponds to the sea level fall of MIS 3 when sea level around the Channel Islands was ~55 m below present levels (Muhs et al. 2012, 2014). At that time, the area around the submarine canyon would have been a large bay and it is plausible that shallow-water environments like estuaries existed near the location of Core 5B (Clark et al. 2014; Reeder-Meyers et al. 2015). If so, Surface 2 could record multiple periods of erosion and reworking from MIS 4 through MIS 1. The deepest, v-shaped channel features were likely eroded during maximum lowstand at MIS 2. These then could have filled with fluvial deposits at the base, followed by estuarine and marine sediments (Unit 3) (Posamentier and Vail 1988; Schumm 1993). The silty-sand laminated units and bioturbation in the upper parts of the cores could represent these estuarine to marine sediments deposited during post-LGM sea level rise. Additional radiocarbon dates from this unit are needed to confirm the timing of deposition.

3.5.5 Box 6: Christy and Saucers canyons paleodrainage, eastern Santa Cruz Passage

Box 6 was selected based on regional sub-bottom lines that showed a large paleovalley complex with possible repeated channel incision offshore from the Saucers and Christy Canyon valley onshore Santa Cruz Island (Figure 3.5.28).

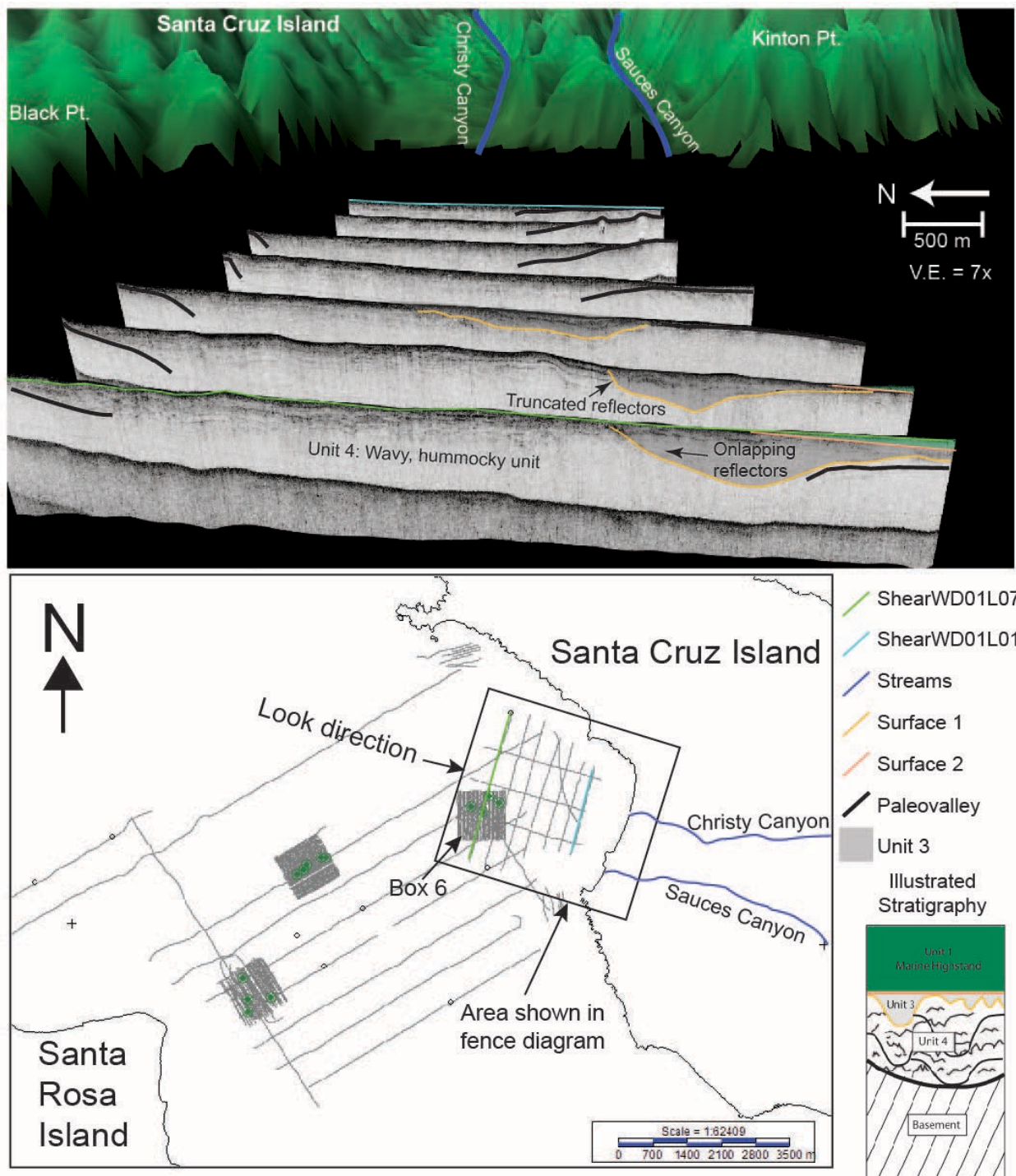


Figure 3.5.28 Chirp fence diagram offshore western Santa Cruz Island

Map shows location with gray lines mapping survey lines. Illustrated stratigraphic column from Figure 3.5.1.

The chirp data show a large, complex paleovalley, beneath the small, open bay between Black Point and Kinton Point (Figure 3.5.28). Much of the stratigraphy beneath the small bay is characterized by a unit with unique acoustic signature (Unit 4, Figure 3.5.1). The unit consists of high-amplitude, wavy, sub-parallel, discontinuous reflectors with transparent to chaotic signature between reflectors; herein referred to as the wavy-hummocky facies (Figure 3.5.29). This unit is observed mostly in the more offshore chirp profiles, while closer to shore the acoustic signature is more chaotic and stratigraphy is difficult to observe (Figure 3.5.28). This wavy-hummocky facies is imaged only within SCP, with most of its distribution in the eastern section of the survey area, directly offshore from SCI. The wavy-hummocky facies was mapped in seismic data and the base of the unit appears to form a trough-like feature, corresponding to where the unit is thickest (Figure 3.5.30). In the southwestern region of the bay, the wavy-hummocky facies is interrupted by a smaller channel shaped feature (Figure 3.5.28). The paleochannel is ~1,100 m wide and shows complex internal fill that could represent multiple stages of incision and aggradation. In some profiles, the reflectors of the complex unit appear truncated by the channel and reflectors within the channel feature onlap the more steeply dipping channel edge (Figure 3.5.28, Figure 3.5.29). The deepest incision observable on the chirp profiles reaches depths of ~20 m below the seafloor. On the northern and southern edges of the bay, a strong reflector dips into the bay, in some cases, truncating reflectors below (Figure 3.5.28). This appears to define the offshore extension of the basement-bounded valley onshore that contains Sauces and Christy canyons (Schumann and Pigati, 2018). The channel feature could represent the offshore extension of either Christy Canyon, Sauces Canyon, or a merged channel of the two.

The high-resolution 1 km² box was in a region within the larger paleovalley that appeared to contain shallow channel-like features and relatively thin marine sedimentation that could be penetrated by coring (Figure 3.5.28). This region was also identified in predictive models to have a high likelihood to contain archaeological sites. Within the 1 km² box, four locations were selected for coring targets (Figure 3.5.31). Core 6A was at what was interpreted as the edge of a channel feature. The acoustic facies transitioned from layered to chaotic reflectors and a high-amplitude anomaly was visible. Core 6B was chosen to reach the acoustic unit with wavy, laminated reflectors. Core 6C was also adjacent to a channel-like feature where a high-amplitude anomaly was present. The marine sediment was also thin at this location. Core 6D was located where the wavy, laminated unit appeared uplifted toward the seafloor by faulting and folding. This allowed for sampling of deeper units that were unreachable in other locations.

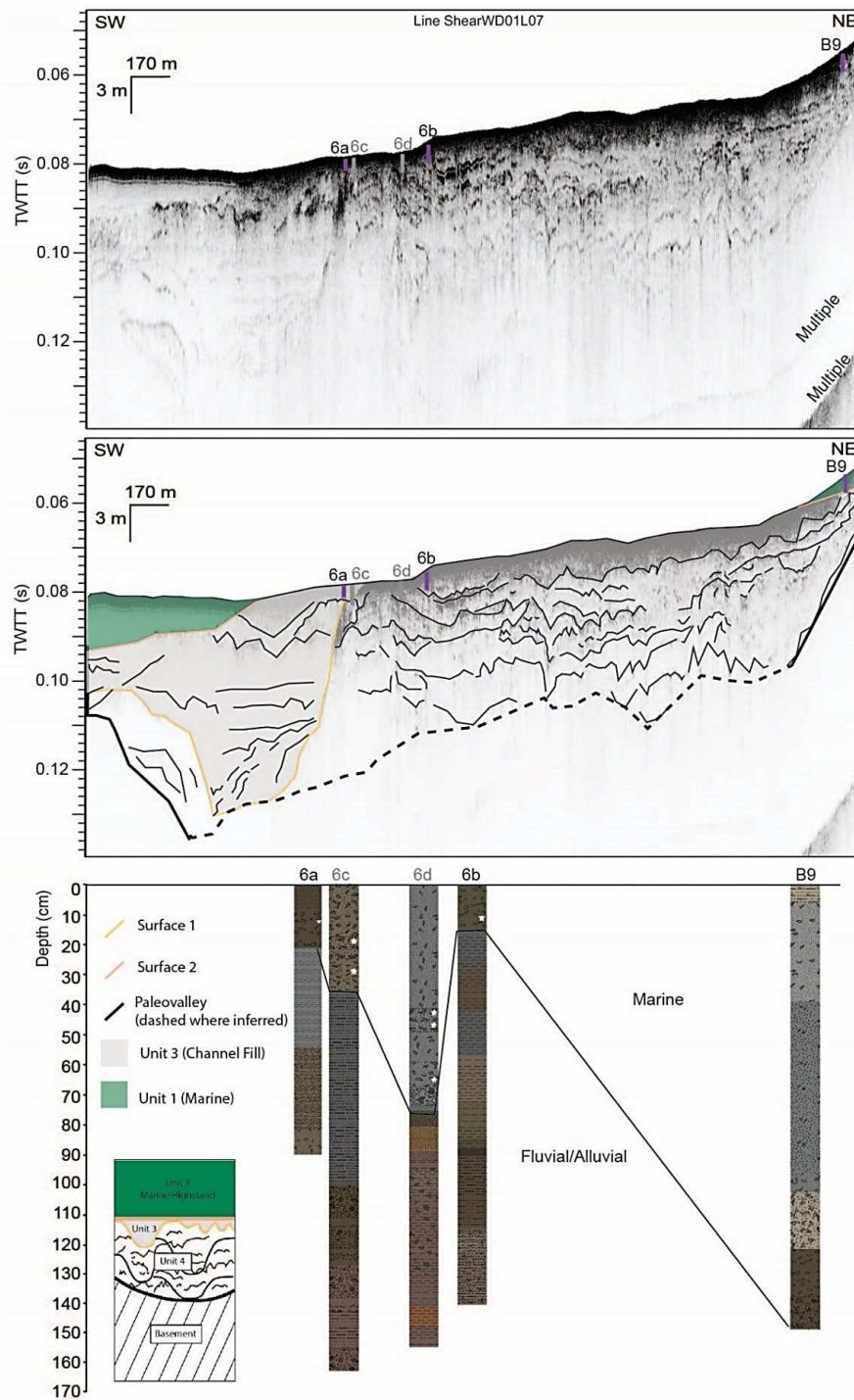


Figure 3.5.29 Chirp profile ShearW_D01L07

Top: Uninterpreted profile; Middle – interpreted profile; Bottom – transect of core logs with interpreted boundary between marine and fluvial/alluvial deposits shown as black line. On CHIRP profiles, core locations are shown as purple for cores lying directly on the line and gray for core locations projected onto the line. Bottom of rectangle shows approximate depth of penetration. See Figure 3.5.28 for location. Inset stratigraphic column from Figure 3.5.1. See Appendix A, Table A-2 for core log legend. Figure modified from Master's Thesis by Luke Johnson (Johnson, 2020).

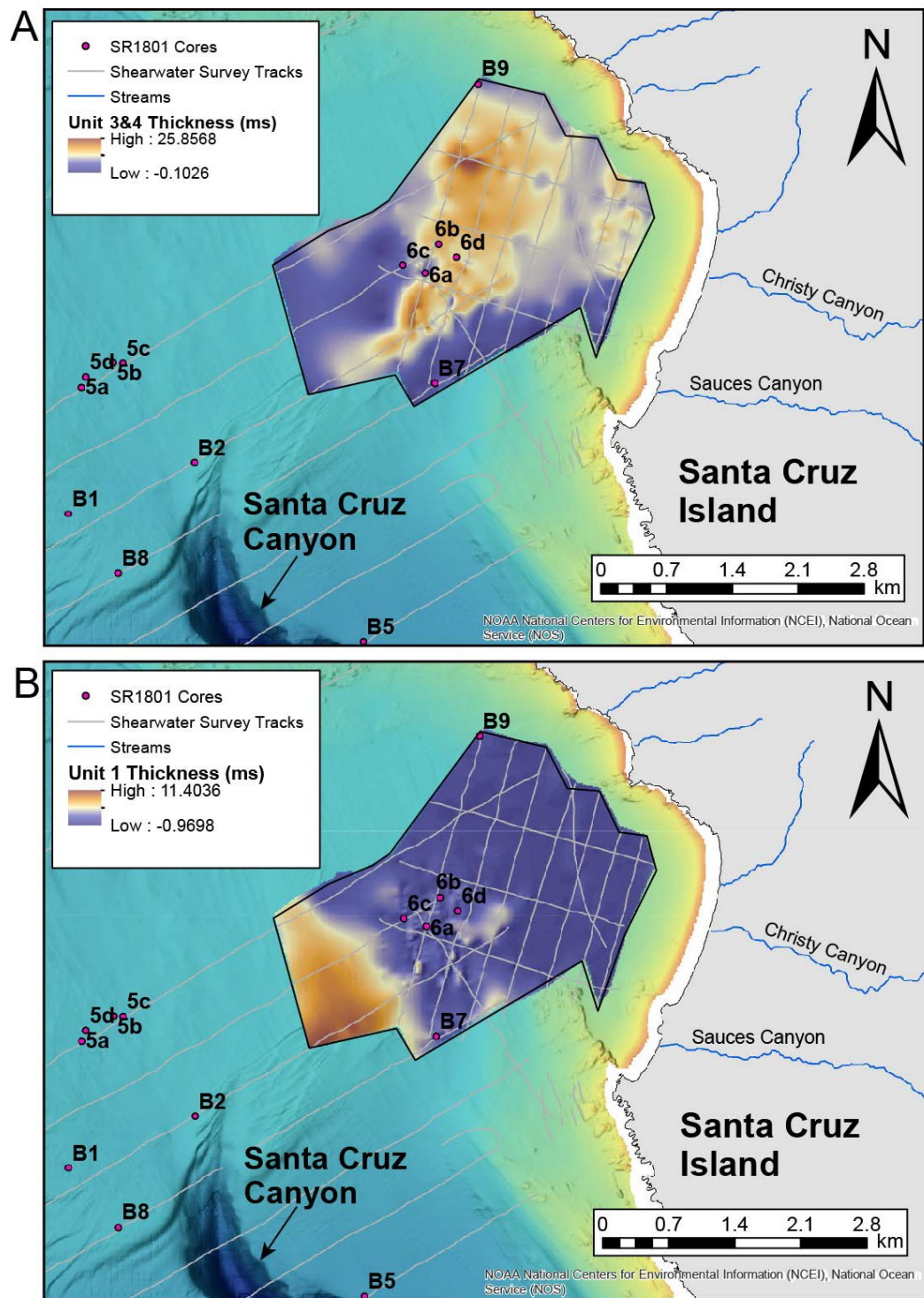


Figure 3.5.30 Mapped thickness of terrestrial and marine units offshore Santa Cruz Island
A. Terrestrial Unit thickness. B. Marine Unit thickness. Bathymetry data from NOAA
(<https://www.ncei.noaa.gov/maps/bathymetry/>)

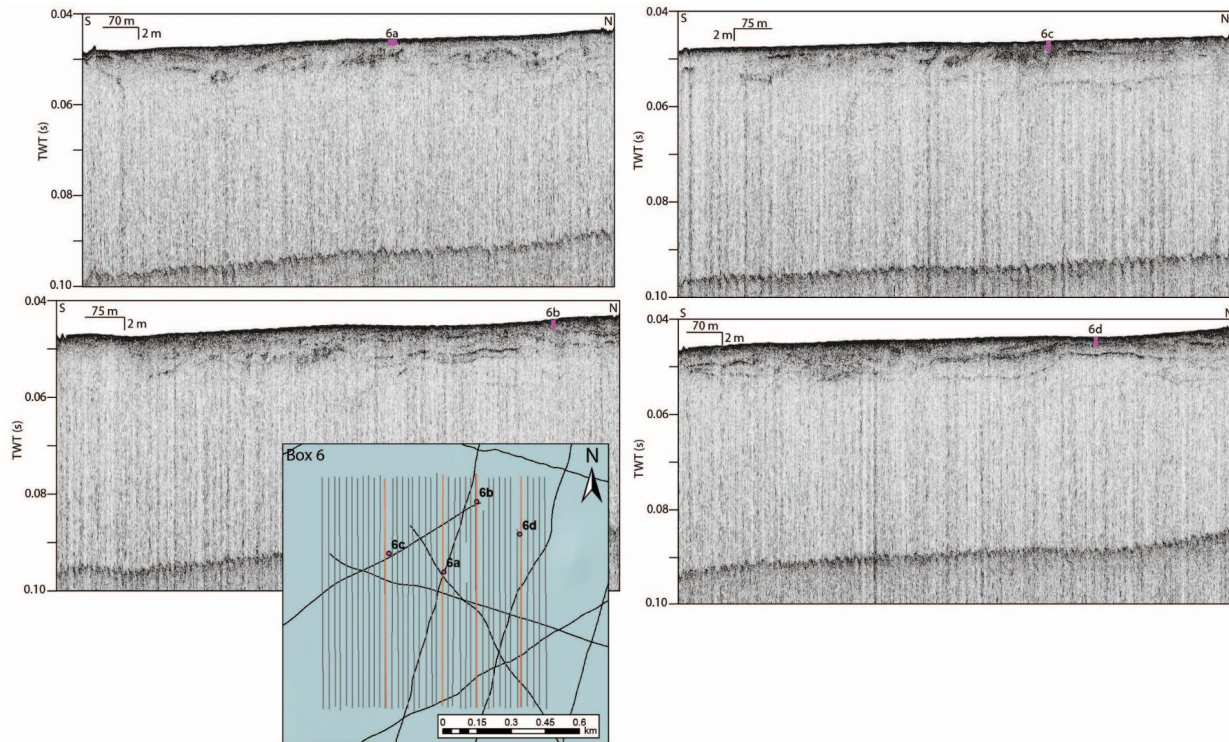


Figure 3.5.31 Location of cores within Box 6

Lower inset map shows regional survey lines in black, 1 km² box survey lines in gray, profiles shown in this figure in orange, and core locations as labeled pink dots. On CHIRP figures, depth of pink rectangle indicates approximate core depth.

All cores in Box 6 penetrated past the transparent upper unit into the wavy-hummocky facies, at which point a stark change in sediment composition is observed from overlying gray sands with shells to distinct reddish, oxidized, angular sand, rocks, and mud that lack marine shells (Figure 3.5.32, Figure 3.5.33, Figure 3.5.34, and Figure 3.5.35). In all four of these cores, just above the contact, the upper unit includes a high density of large shells, and subrounded-subangular pebbles. A similar change in sediment character from homogenous gray sand and fragmented marine shells at the top to large marine shell fragments with poorly sorted angular rocks and sand at the bottom is observable in Core B9, which penetrated the transparent unit to a depth directly above the wavy-hummocky unit (Figure 3.5.29).

Core 6C, from 100 cm to the base of the core, contains deposits of interbedded angular clasts and fine angular grains of sand and mud, all of which are distinctly oxidized (Figure 3.5.34). These sediments closely resemble those described directly onshore interpreted as alluvial/fluvial deposits in Christy and Saucos canyons (Schumann and Pigati 2018). The core location in the seismic data further shows that it is directly on the edge of a channel, and that it penetrates the wavy-hummocky facies at the depth in which the core changes to oxidized terrestrial material (Figure 3.5.31). The variable colors and dominant muddy grain size observed across all the cores' lower unit were interpreted to represent possible deposition within a floodplain, as the sinuosity of the area's rivers changed with changing base levels. The lower half of Core 6D includes oxidized red mud with large dark splotches that are suggestive of paleosol development (Figure 3.5.35). These observations led to more detailed analysis of these lower units.

Jon Erlandson contacted his UO MNCH colleague, Gregory Retallack, an expert in paleosols and paleontology, to ask for his assistance in confirming and describing the paleosols. Retallack confirmed that three cores (CI-VC-6A, CI-VC-6B, and CI-VC-6D) from the Santa Cruz Channel seafloor contained

intact paleosols, including a sequence of three discrete paleosols with intact A-horizons and plant root traces present in CI-VC-6B. Dr. Retallack examined and described the paleosols in these cores, including stratigraphic descriptions for each (Figure 3.5.36). Shortly thereafter, the COVID-19 epidemic hit the USA and further access and analysis of the paleosols was not possible.

The upper unit is interpreted as marine based on the shelly sand composition while the lower unit is interpreted as terrestrial deposits in an alluvial/fluvial valley. The sharp contact between the lower and upper units and the increase in shell and grain size at the base of the upper unit suggest the contact marks sea level inundation across this part of SCP. Eight radiocarbon samples were collected from the Box 6 cores, all from the upper marine unit (Appendix A, Table A-1). The dates range from ~5800 to 9900 cal yr BP (Figure 3.5.37). The ages from near the base of Cores 6A and 6C are consistent with a relative sea level model for the islands, but dates from the base of Cores 6B and 6D are younger than expected for their given depths (Figure 3.5.37; Figure 3.5.38). The younger dates could be related to reworking of marine sediments, or could indicate a period of slower sea level rise at these depths compared to the relative sea level curve model. The older dates associated with the shallow marine environment in this area are supported by models of the SCP being inundated around 9 to 10 ka (Clark et al. 2014; Reeder-Myers et al. 2015). These observations support the idea that the base of the upper unit represents the initial transgression and rise of sea level and that the underlying surface is the transgressive surface that was subaerially exposed prior to this flooding.

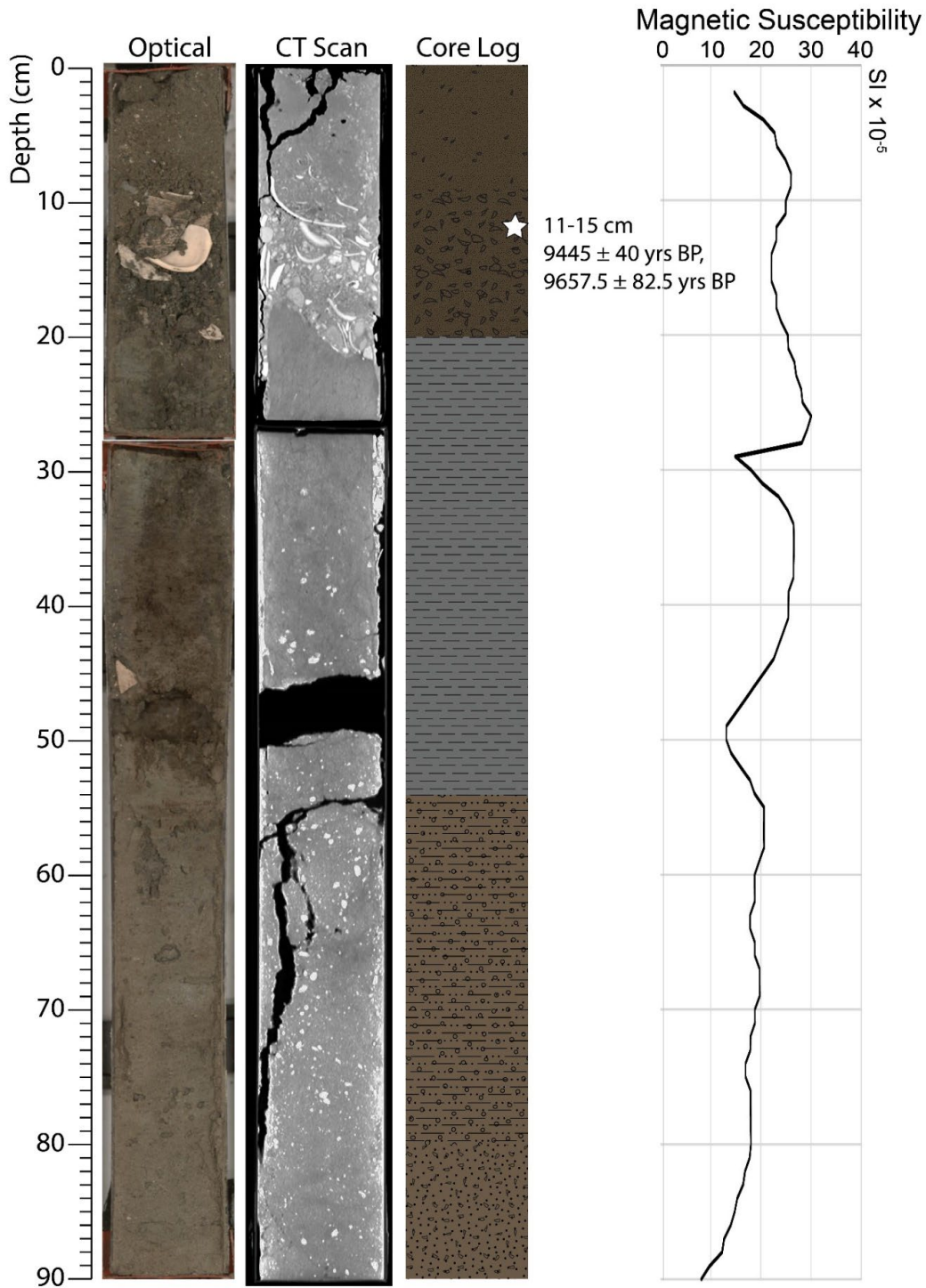


Figure 3.5.32 Optical image, CT scan, Core Log and Magnetic Susceptibility results for Core 6A
 See Appendix A, Table A-2 for core log legend.

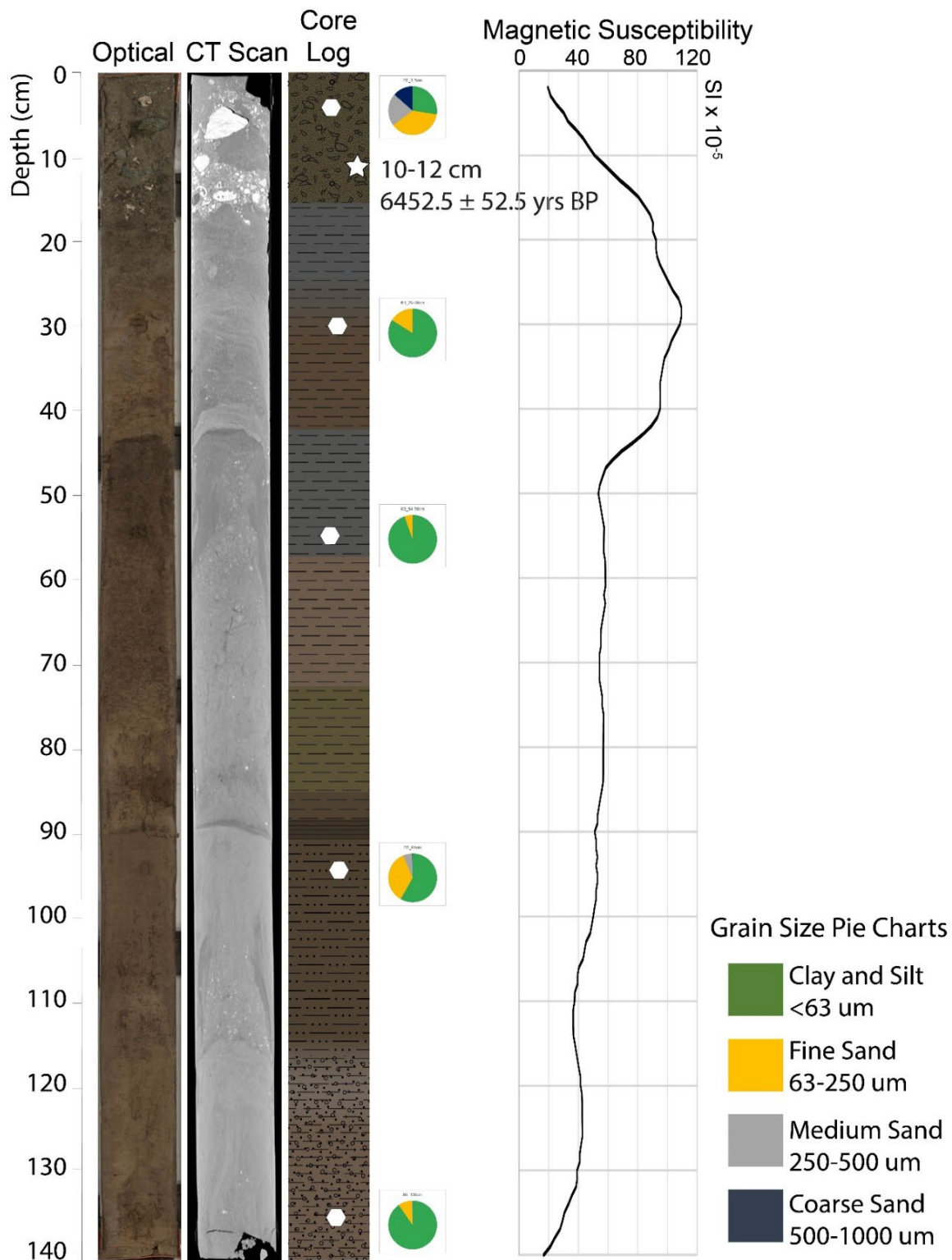


Figure 3.5.33 Optical image, CT scan, Core Log, and Magnetic Susceptibility results for Core 6B
See Appendix A, Table A-2 for core log legend.

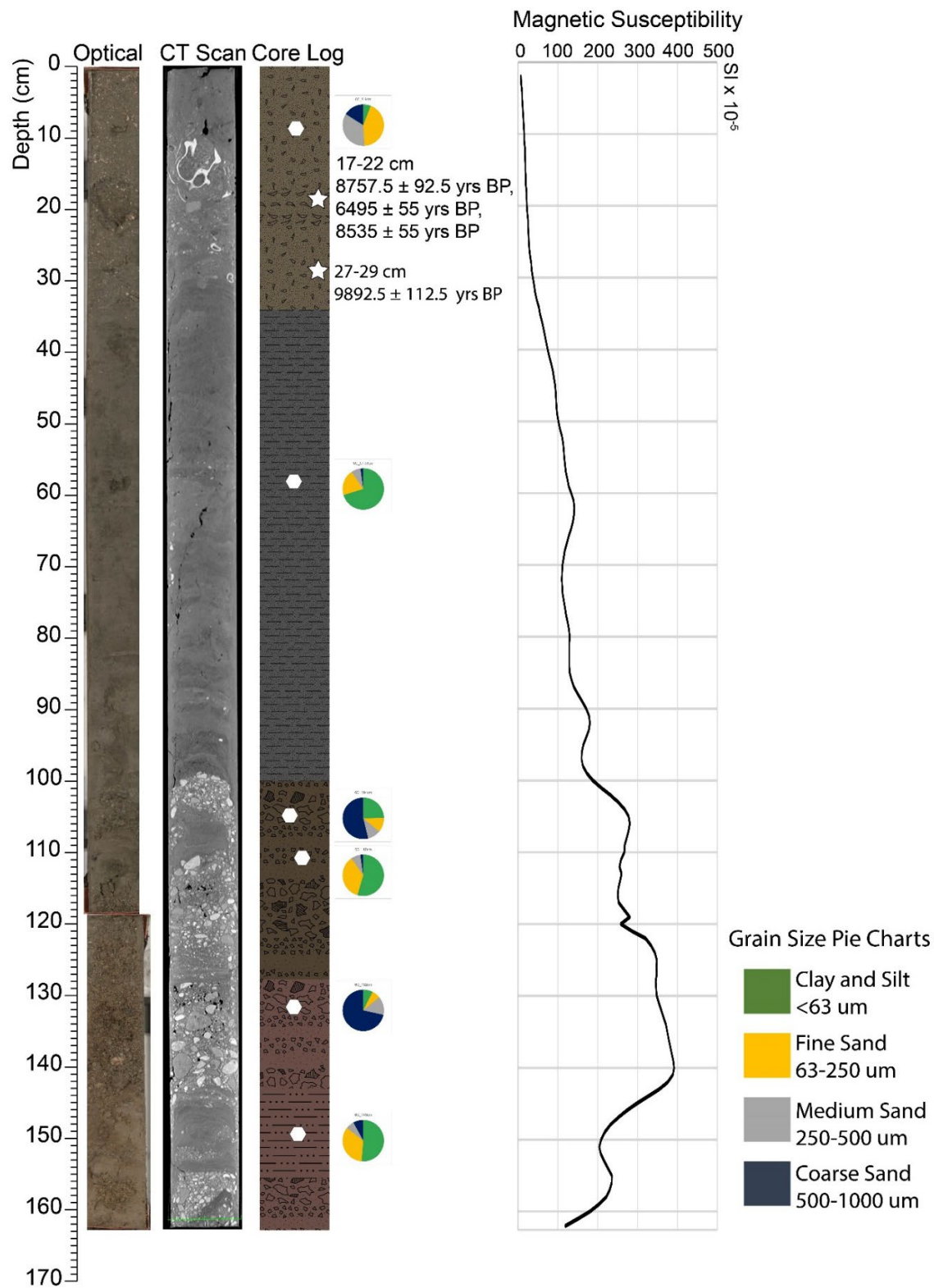


Figure 3.5.34 Optical image, CT scan, Core Log, and Magnetic Susceptibility results for Core 6C
See Appendix A, Table A-2 for core log legend.

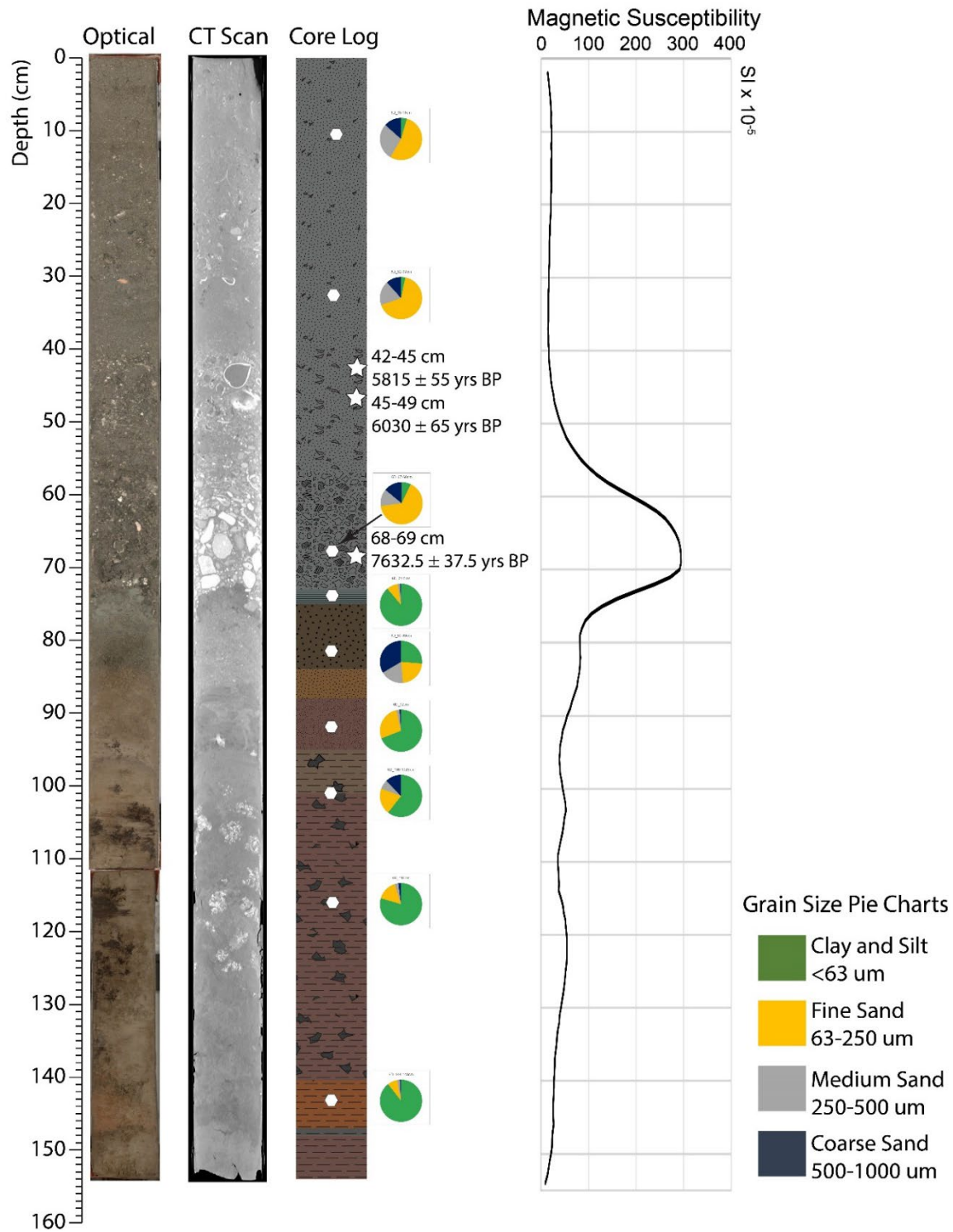


Figure 3.5.35 Optical image, CT scan, Core Log, and Magnetic Susceptibility results for Core 6D
See Appendix A, Table A-2 for core log legend.

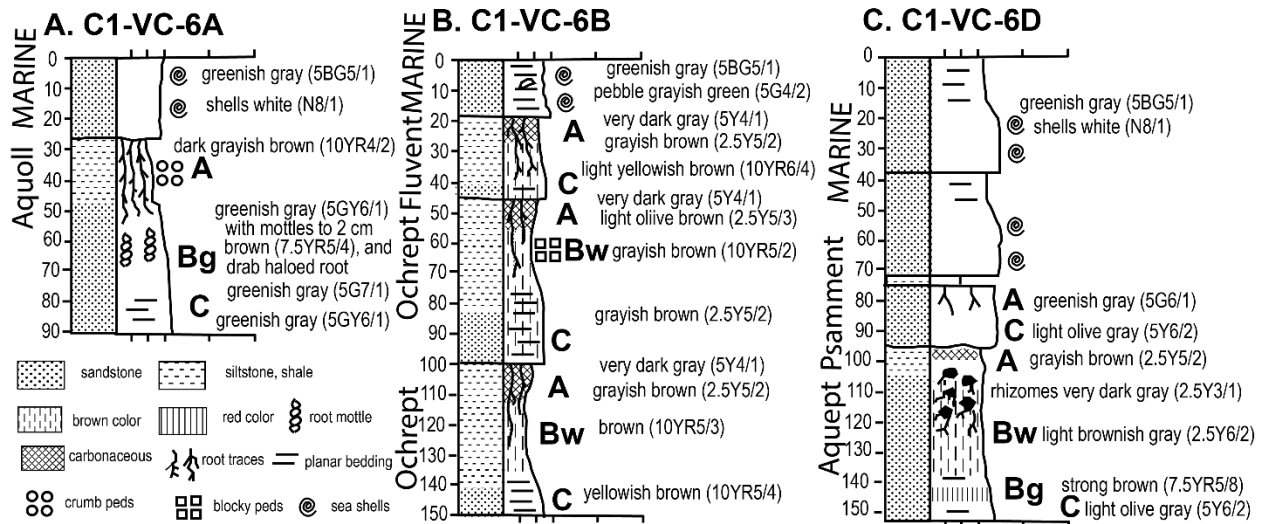


Figure 3.5.36 Stratigraphic descriptions of cores CI-VC-6A, CI-VC-6B, and CI-VC-6D by Retallack

Core CI-VC-6A, with just 27 to 28 cm of marine sediments capping an Aquoll soil, produced single fragments of two discrete butter clam (*Saxidomus* spp.) shells at -11 to -15 cm (that is, below core surface) that date to ~9,600 cal BP. These appear to have been articulated clam shells in a thin and discrete lens, suggesting no reworking and a likely age for the underlying soil of >9,600 cal BP. Retallack noted root traces in the A horizon of the Aquoll soil, a kind of mollisol found in areas with an aquic moisture regime. If these are preserved and can be recovered, they could potentially be dated via accelerator mass spectrometry carbon-14 to provide an age for the paleosol itself.

Core CI-VC-6B, with just 18 cm of marine sediments overlying three stacked Ochrept and Fluvent soils between -18 and -150 cm, produced a California cone (*Conus californianus*) shell fragment at 10 to 12 cm that was dated to ~6,450 cal BP. Fluvent soils are more or less freely drained Entisols that form in recent water-deposited sediments on floodplains, fans, and deltas along rivers and small streams. Most fluvents are frequently flooded and stratification of the materials is normal.

Core CI-VC-6D, with about 72 cm of marine sediments overlying two stacked Psamment and Aquept soils between -72 and -150 cm, produced three single fragments of *Trachycardium*, *Crepidula*, and *Modiolus* shell at -42 to -45 cm, that were AMS dated to ~5,800, 6,050, and 7,650 cal BP, respectively. This implies that the soils are older than 7,650 years. In the lower (Aquept) soil, Retallack observed several dark masses he believed to be plant rhizomes (perhaps cattail), which could potentially be dated. Psamment soils are defined as an Entisol, which consists basically of unconsolidated sand deposits, often found in shifting sand dunes. Aquepts are wet Inceptisols. Their natural drainage is poor or very poor, and, if the soils have not been artificially drained, ground water is at or near the soil surface at some time during normal years but typically not in all seasons. Many formed under forest vegetation, but they can have almost any kind of vegetation.

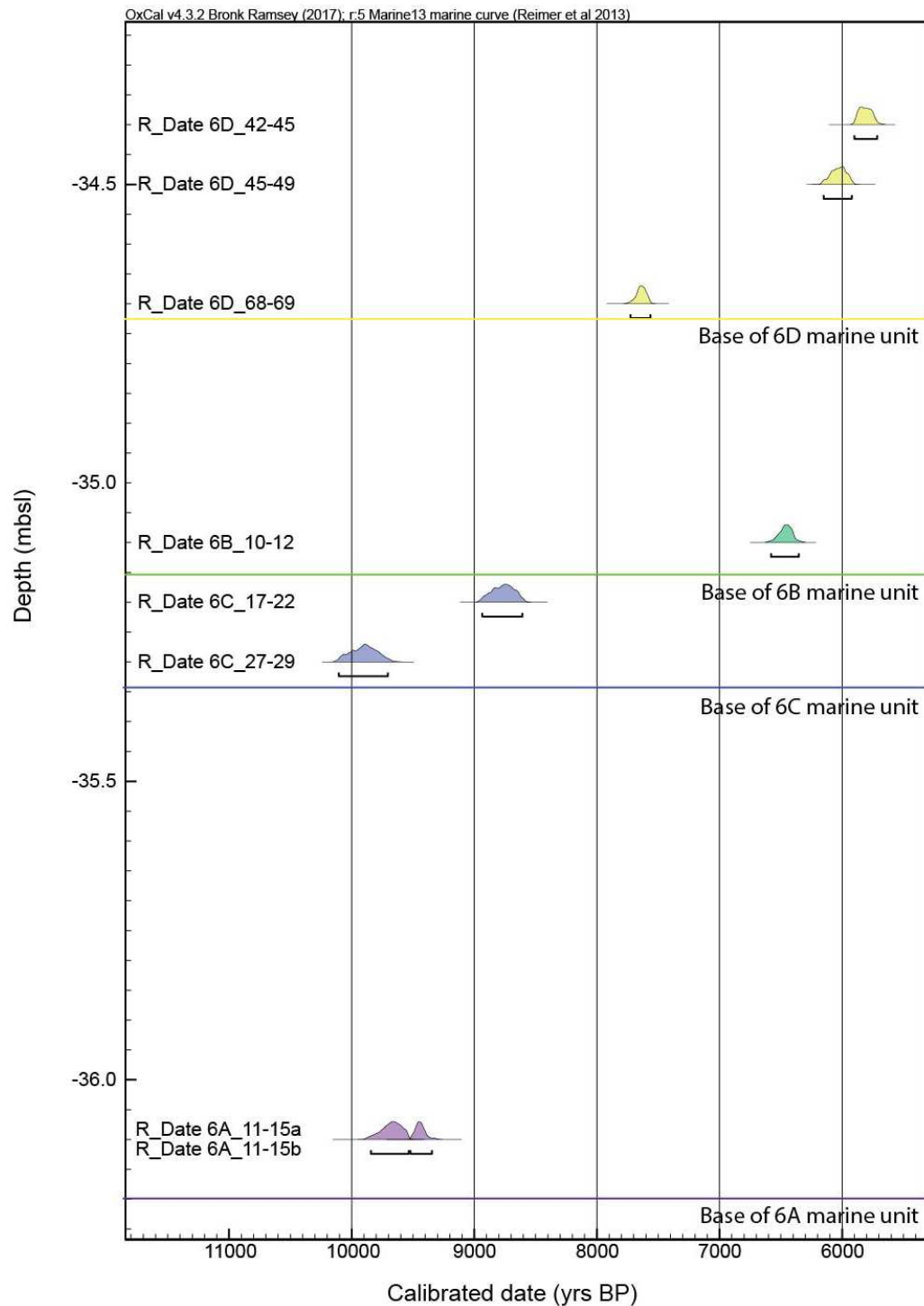


Figure 3.5.37 Age-depth model for radiocarbon dates in eastern SCP

Colors correspond to core (yellow – 6d; green – 6b; blue – 6c; purple 6a). Corresponding colored horizontal lines represent the base of the shallow marine facies in each core. Depth in core were converted to depth of samples below modern sea level (mbsl). Modified from Master's Thesis by Luke Johnson (Johnson, 2020).

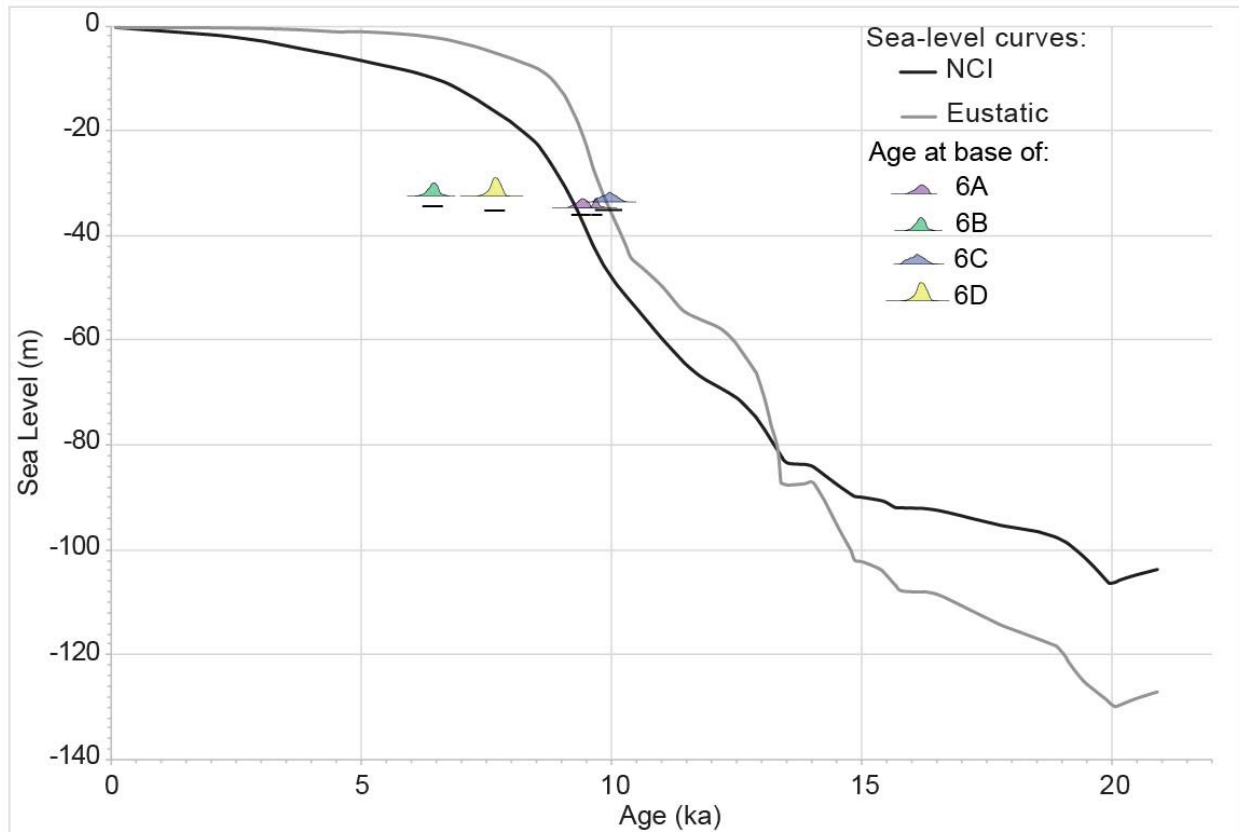


Figure 3.5.38 Dates closest to the base of the upper marine unit for each core plotted on a sea level curve showing Age (ka) vs. Sea Level (m)

The colored humps show date range placed in their corresponding age vs depth location. Sea level curves are a relative, GIA-corrected, NCI curve and a eustatic curve based on deglacial history, both from Clark et al., 2014.

The XRF data indicated variations of elemental abundance that reflect the change from marine to terrestrial deposits (Figure 3.5.39; Figure 3.5.40; Figure 3.5.41; Figure 3.5.42). Generally, the terrestrial unit shows higher amounts of Fe, Ti, barium (Ba), and zirconium (Zr) and lower amounts of Ca, Zr, and Sr, as well as more manganese (Mn) spikes and less variable potassium (K), sulfur (S), and Zr compared with the marine unit.

The discovery of intact terrestrial soils preserved beneath the transgressive marine sediments on the current floor of the Santa Cruz Channel provides a “proof of concept” that: (1) the south-facing Crescent Bay area, which was a focus of settlement by paleocoastal peoples, likely contains intact submerged terrestrial sites of Early Holocene and terminal Pleistocene age; and (2) terrestrial soils and sites survived the effects of rising seas and active transgression that included strong submarine currents and an often turbulent Northeast Pacific surf zone.

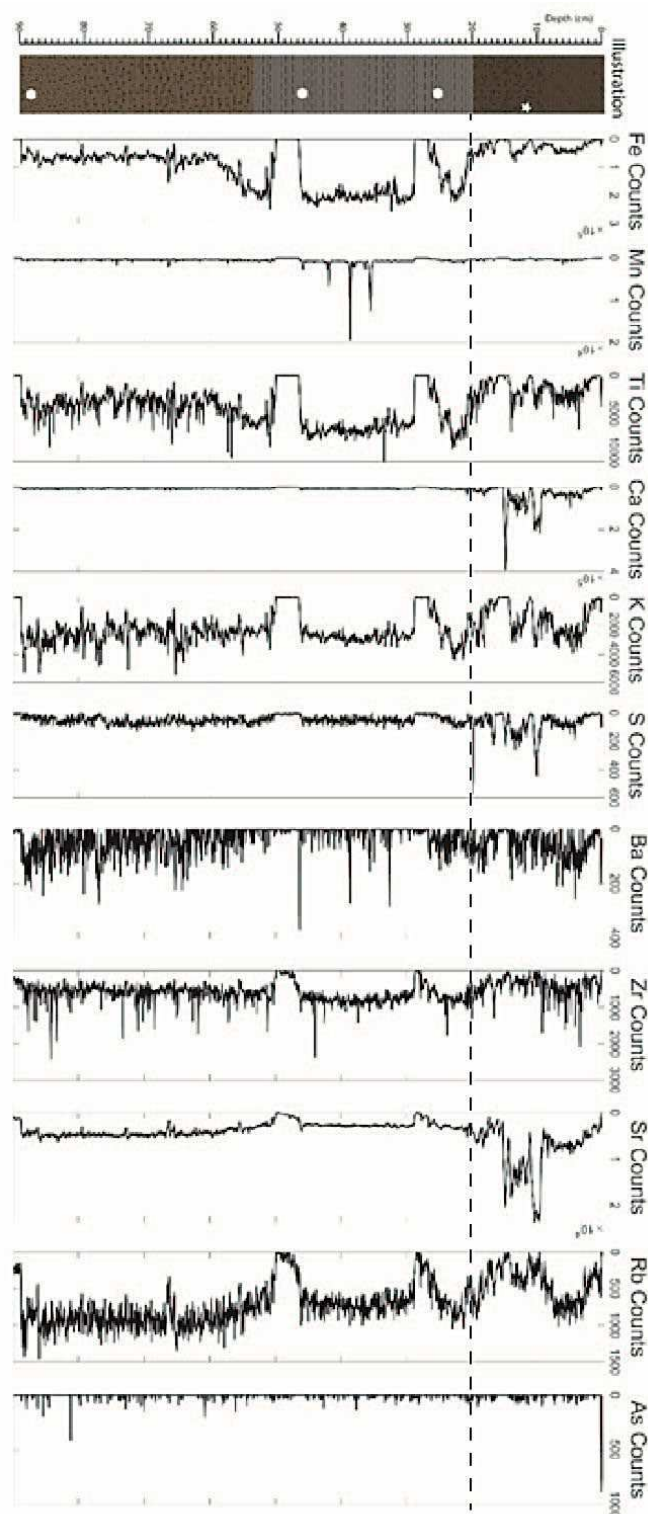


Figure 3.5.39 Core 6A selected XRF data

Dashed line shows boundary between upper marine unit and lower terrestrial unit.

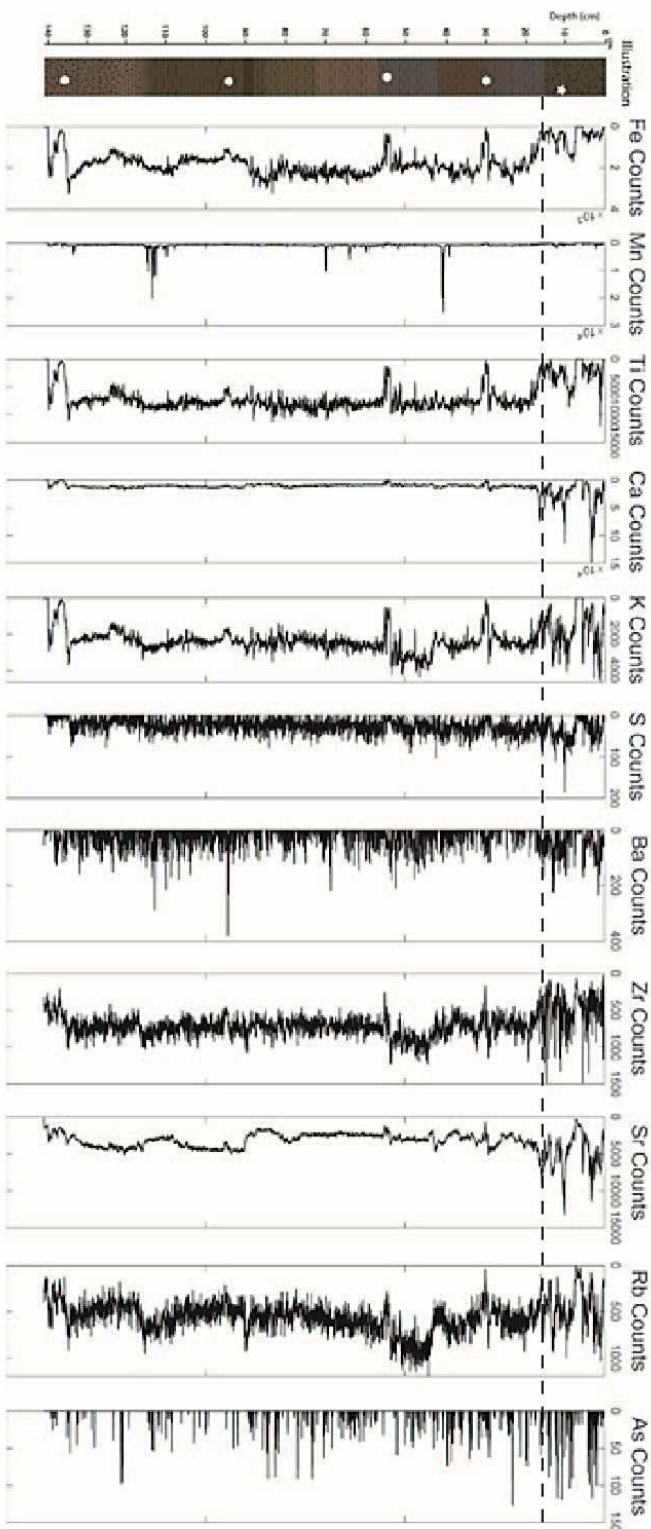


Figure 3.5.40 Core 6B selected XRF data

Dashed line shows boundary between upper marine unit and lower terrestrial unit.

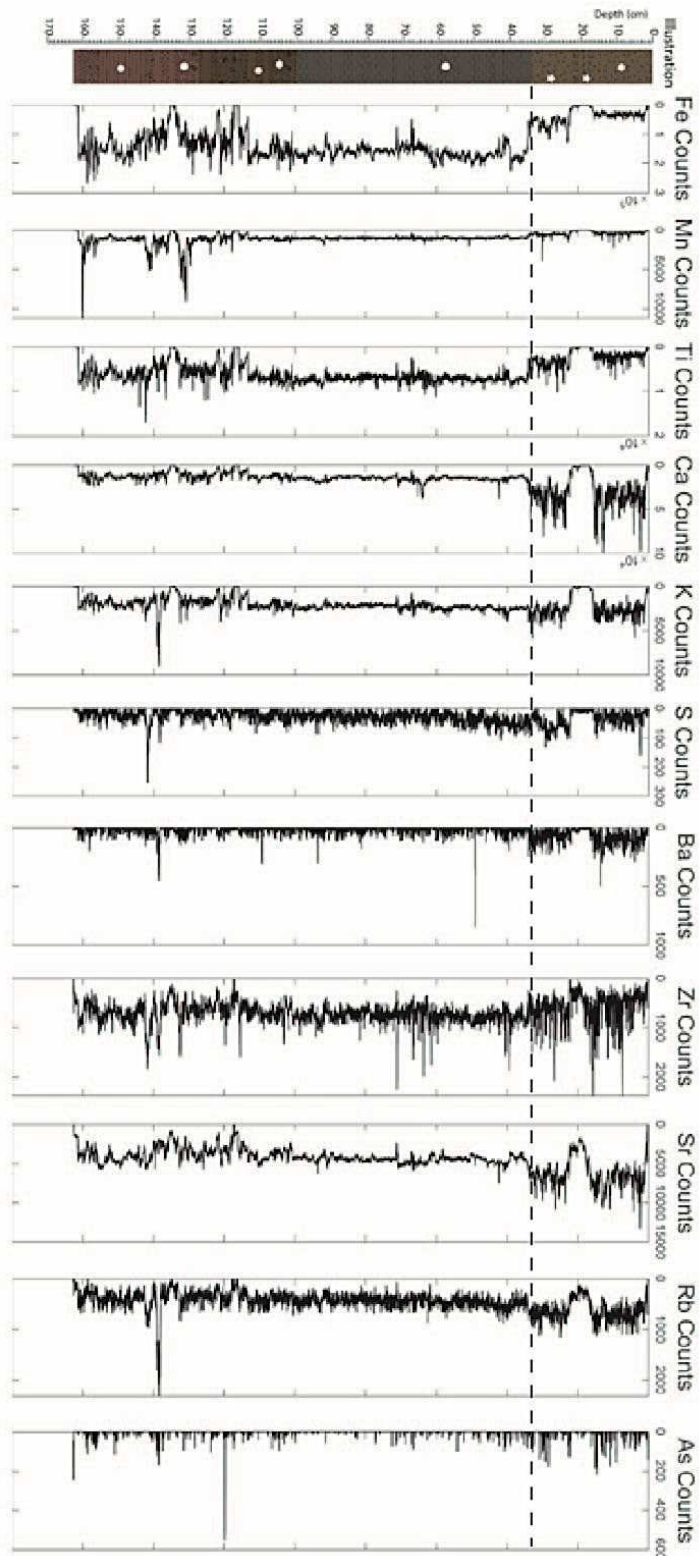


Figure 3.5.41 Core 6C selected XRF data

Dashed line shows boundary between upper marine unit and lower terrestrial unit.

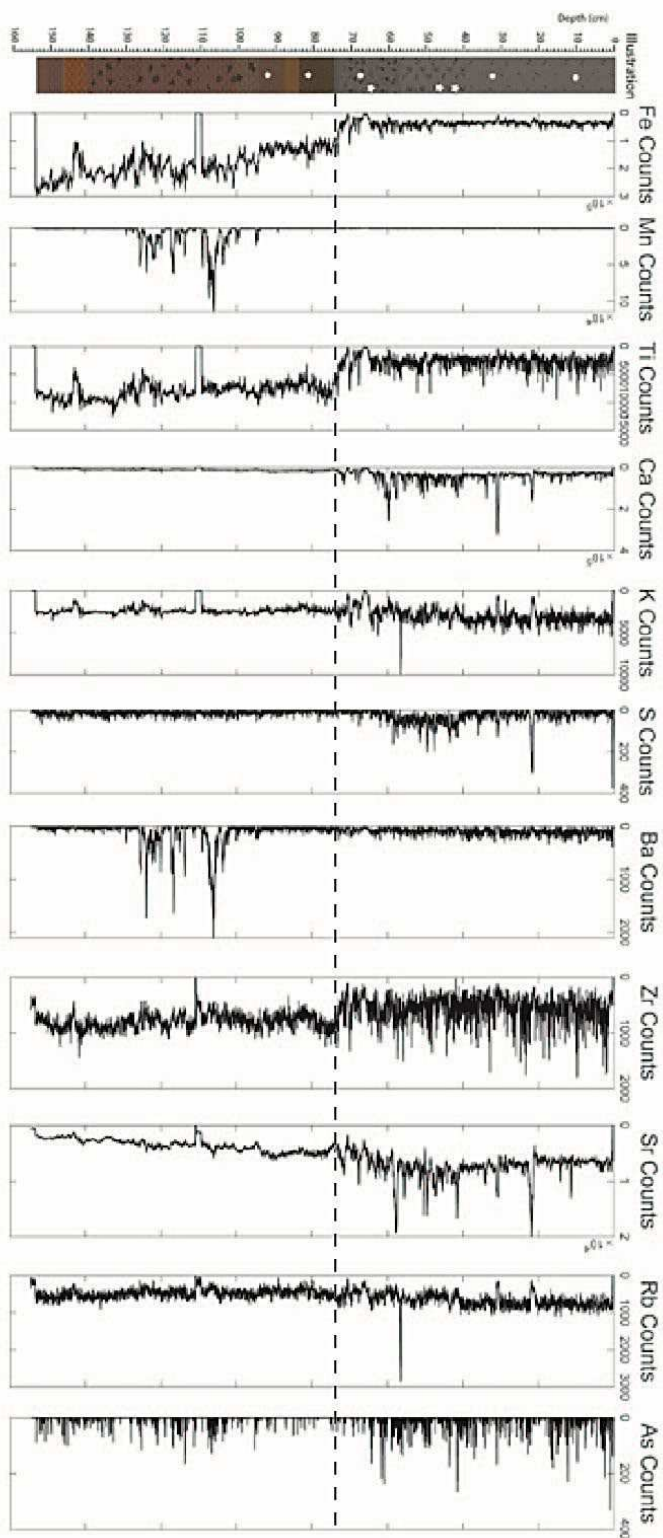


Figure 3.5.42 Core 6D selected XRF data

Dashed line shows boundary between upper marine unit and lower terrestrial unit.

3.5.6 Submerged Terraces and Shoreline Angles in Regional NCI data

Submerged terraces and shoreline angles were observed in sub-bottom data around the NCI platform but were not clearly identified in data from Oregon. In several locations on the NCI platform, the terraces and shoreline angles were observed buried beneath marine sediment. This suggests that using bathymetric data in paleoshoreline models would not identify locations where preserved paleoshoreline features are buried beneath modern sediment, even in relatively sediment-starved areas such as the Channel Islands. The following section summarizes the paleoshoreline mapping work conducted for this project around the NCI and is reprinted and adapted from Laws et al. (2019)..

3.5.6.1 Identification of Paleoshoreline morphology in sub-bottom data

Along tectonically active continental margins, coastlines are characterized by sea cliffs, coastal mountain ranges, elevated marine terraces, and narrow continental shelves. The modern shoreline morphology of these margins, including much of Southern California, is often represented by a gently seaward-dipping abrasion platform that terminates landward at steeper sea cliffs. The intersection of the abrasion platform and sea cliff marks the approximate location of the high tide shoreline, and this intersection is referred to as the shoreline angle (Figure 3.5.43) (e.g., Chaytor et al. 2008; Grant et al. 1999; Haaker et al. 2016; Kern and Rockwell 1992; Lajoie 1986; Muhs et al. 2012, 2014). These features are formed during times of slowly rising to stable sea level, when nearshore wave erosion flattens pre-existing landforms and causes sea cliffs to retreat landward to form the wave-cut abrasion platform (e.g., Lajoie 1986). Depending on local sediment supply, transport, and deposition patterns, the modern abrasion platform may be covered by coastal and marine deposits (Figure 3.5.43A).

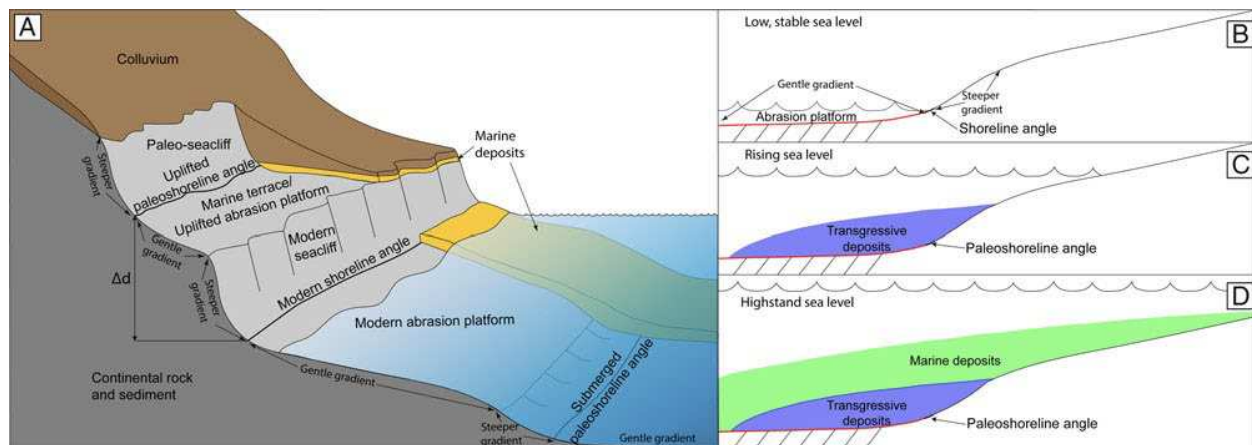


Figure 3.5.43 Morphology of onshore marine terraces and submerged abrasion platforms (Laws et al. 2019:2)

(A) Diagram depicting the relationship between the wave-cut abrasion platform, paleosea cliff, paleoshoreline angle, and modern shoreline features. The Δd marks the difference in elevation between the modern shoreline and an uplifted paleoshoreline. This elevation difference is due to uplift, combined with potentially higher sea level during formation of the paleoshoreline. (B) A schematic depicting an abrasion platform that formed during sea level low stands or slowdowns in the rate of sea level rise, which are now submerged. Red line highlights the abrasion platform. Changes in the slope of the transgressive surface indicate paleoshoreline angles. (C) As sea level rises, sediment gets reworked and is deposited above the shoreline angle. These sediments are interpreted as transgressive deposits. (D) A highstand in sea level is marked by the maximum flooding surface (dark blue line) and the deposition of marine sediments.

On uplifting coastlines, like that of Southern California, highstand abrasion platforms, seacliffs, shoreline angles, and related deposits become elevated above the modern shoreline and are known as marine terraces (Figure 3.5.43A). These terraces are subjected to subaerial erosion and depositional processes that can obscure their original morphology. The uplifted abrasion platforms could be covered by a thin layer of coastal and marine sediments that are overlain by colluvium. With constant uplift, a series of marine terraces creates a step-like morphology (e.g., Haaker et al. 2016; Kern and Rockwell 1992). The elevation and ages of preserved paleoshoreline angles on these marine terraces are commonly used to reconstruct sea level, uplift, and deformation histories for the region (e.g., Haaker et al. 2016; Kelsey and Bockheim 1994; Kern and Rockwell 1992; Muhs et al. 2012, 2014). Similar features can be formed during sea level lowstands and, on the same uplifting coastlines, could be preserved on the now-submerged continental shelf (Figure 3.5.43A-D) (e.g., Chaytor et al. 2008; Emery 1958; Klotsko et al. 2015; Lajoie 1986). After formation, lowstand paleoshoreline angles become submerged during subsequent sea level rise and could be buried by sediments deposited during sea level rise and sea level highstand. These deposits can conceal the paleoshoreline morphology at the seafloor (Figure 3.5.43B-D).

Highstand paleoshorelines and associated marine terraces are preserved onshore the NCI and provide a long-term record of tectonic vertical motion (e.g., Dickinson 2001; Muhs et al. 2014; Pinter et al. 2003; Sorlien 1994). Submerged abrasion platforms have also been recognized around the NCI, first described by Emery (1958). Five abrasion platforms between ~15 to 130 mbsl offshore the NCI were identified using single-beam bathymetric profiles. Submerged abrasion platforms and paleoshorelines around the NCI were later mapped by Chaytor et al. (2008) using high-resolution multibeam bathymetry, who also identified five paleoshorelines on the eastern NCI platform offshore SCI, with paleoshoreline depths ranging from ~22 to 90 mbsl. Both previous efforts to map submerged paleoshorelines around the NCI relied on modern seafloor data, but these data could conceal paleoshoreline morphology that has been buried by syn- and post- sea level rise sedimentation (Figure 3.5.43B-D).

3.5.7 Paleoshoreline mapping around the NCI platform

Paleoshoreline angles were mapped in regional chirp data by identifying the morphology illustrated in Figure 3.5.43 and calculating their depth (e.g. Figure 3.5.44). To account for uncertainty related to faulting and paleochannels, which can both create similar morphology to a shoreline angle, each paleoshoreline angle was assigned a confidence level based on morphology and location relative to potential channels and fault zones. Only those shoreline angles deemed of medium- to high-confidence were included in the final mapping and analysis.

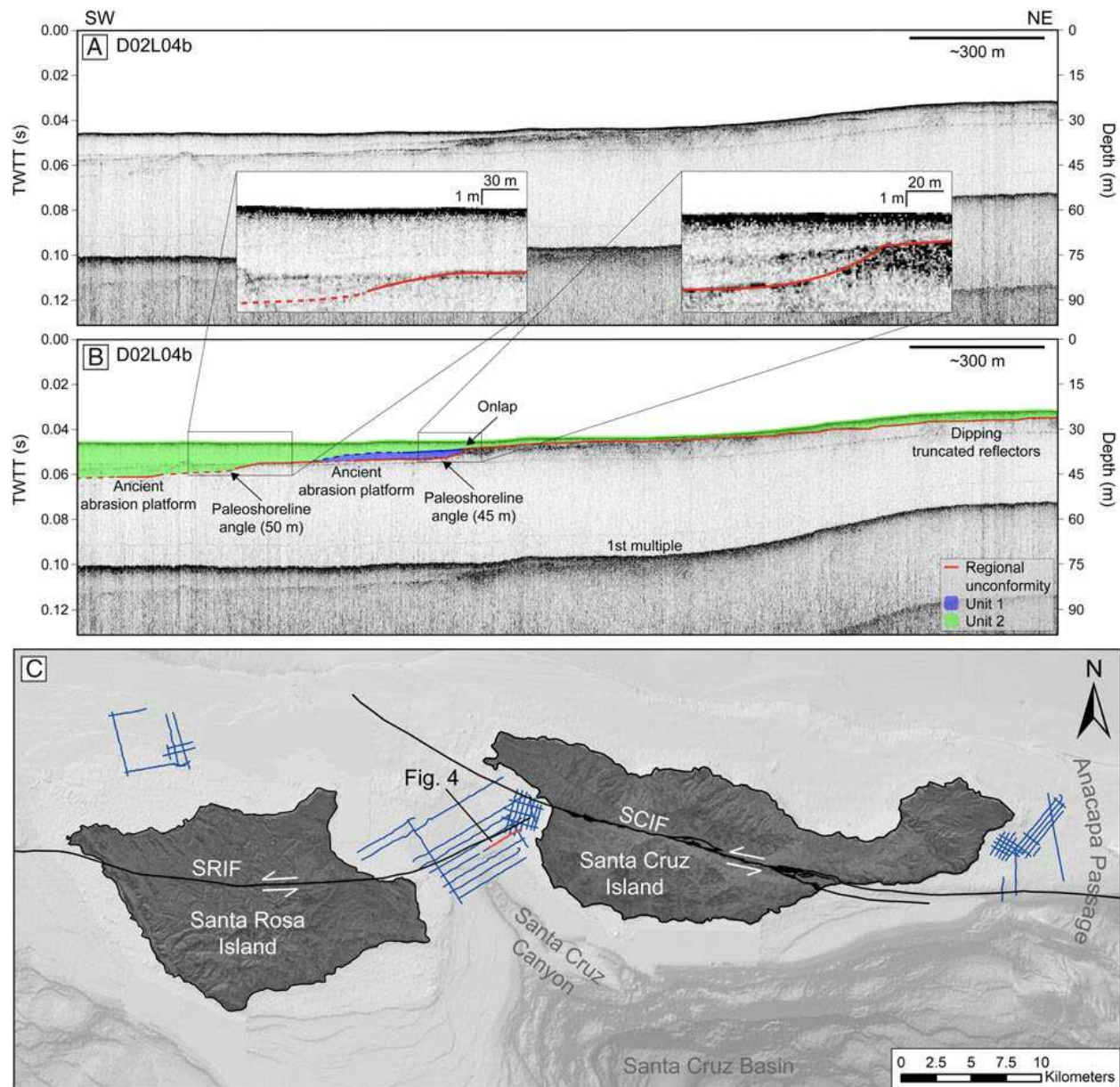


Figure 3.5.44 Northeastern segment of chirp profile D02L04b between SRI and SCI (Laws et al. 2019:8)

(A) uninterpreted and (B) interpreted versions. (C) shows the profile location. The regional unconformity and unit boundaries are dashed where uncertain. Moving toward the northeast along the ancient abrasion platforms, 45- and 50-m paleoshoreline angles are observed at the base of the change in slope in the regional unconformity. The top reflector of Unit 1 terminates by onlapping onto the regional unconformity. Unit 2 thins landward. The 50-m paleoshoreline angle is binned to the 57-m paleoshoreline and is infilled by Unit 2 (~11 m thick). The 45-m paleoshoreline angle is binned to the 44-m paleoshoreline and is infilled by Unit 1 (~3 m thick) and Unit 2 (~3 m thick).

Evidence of paleoshoreline angles was identified at 40 individual locations in chirp profiles, with 31 locations identified as medium- to high confidence (Figure 3.5.45A). The calculated depths of the mapped paleoshoreline angles ranged from 27.6 to 104.0 mbsl, which were binned into seven paleoshorelines. Paleoshoreline interpretations connect paleoshoreline angles in different chirp profiles

and then are inferred to extend roughly parallel to the modern shoreline and bathymetric contours (Figure 3.5.45).

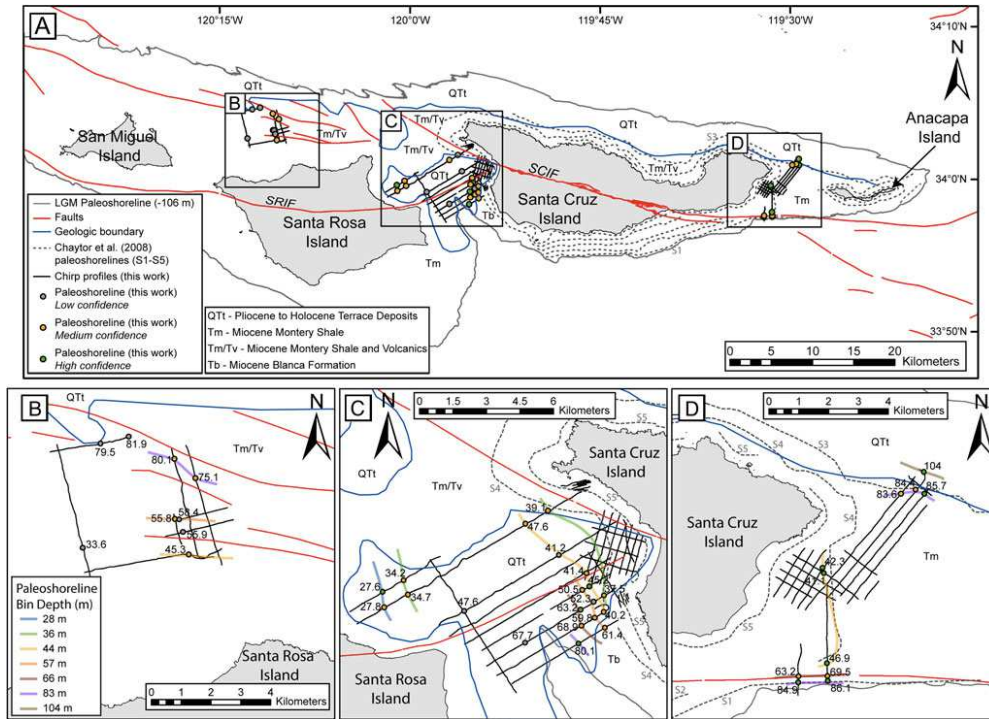


Figure 3.5.45 Map of the NCI, showing interpreted paleoshoreline angle locations on chirp survey lines, with various other relevant geomorphic and geologic features (Laws et al. 2019:14)

Features include: faults; the geologic boundary between Quaternary terrace deposits (QTt) and older formations (Tm, Tv, Tb); Chaytor et al. (2008) mapped paleoshorelines, labeled by name (S1–S5); the -106-m-depth contour, which reflects the LGM paleoshoreline based on the sea level curve of Clark et al. (2014) and modern bathymetric data. See legend for additional details. SRIF, Santa Rosa Island Fault; SCIF, Santa Cruz Island Fault. Black boxes mark locations of zoomed-in maps shown in (B) – (D). (B) – (D) includes the same content as (A), but with the addition of the mapped interpreted paleoshorelines, which are all colored by the legend shown in (B).

To estimate the age of the mapped paleoshorelines, the mean depth and range for each identified paleoshoreline was plotted at present time on a relative sea level curve (age versus depth) (Figure 3.5.46). A straight line was then drawn back in time, starting from the mean bin depth at present. The scientific team also accounted for an uplift rate of 0.16 m/ka, which is the most recent average rate calculated for the islands by Muhs et al. (2014). The slope of the plotted line is equal to the uplift rate. The effect of this is to plot the actual depth of the paleoshoreline if it had formed at various times in the past, essentially reversing the uplift. The relative sea level curves used were derived by Clark et al. (2014) for SRI (0 to 21 ka) and Muhs et al. (2012) for San Nicolas Island (21 to 120 ka). Any point where the uplift rate model crosses the sea level curve represents a possible time when that paleoshoreline formed (assuming constant uplift rates for the past ~120 ka). For each paleoshoreline, each point of intersection between the sea level curve and uplift rate line provides a y-value representing the depth of formation and an x-value representing the time of formation. Abrasion platforms and associated shorelines form during periods of relatively stable sea level in which there is enough time for sea level to erode continental sediment via wave-based erosion. Therefore, if the uplift rate model intersects the sea level curve during a period of slow change or stability in the independently derived sea level curves, the scientific team interpreted this

to be a likely candidate for formation of the paleoshoreline. Table 3.5.1 shows the best fit age for each of the identified paleoshorelines, based on this method.

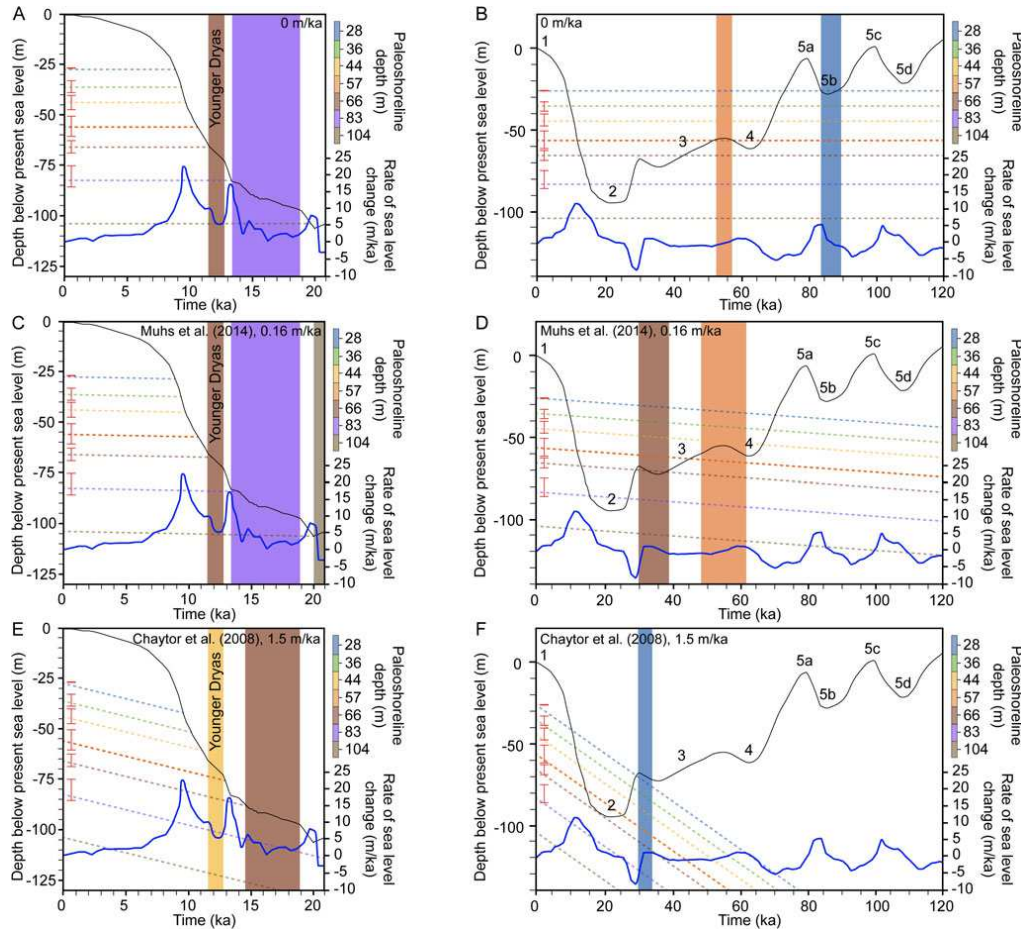


Figure 3.5.46 Uplift rate models for the NCI used to reconcile the rate of late Quaternary uplift (Laws et al. 2019:16)

The black curve represents the Clark et al. (2014) relative sea level curve from 0 to 21 ka (A, C, and E) and the Muhs et al. (2012) relative sea level curve from 21 to 120 ka (B, D, and F). Numbered labels represent marine isotope stages. The blue curve represents the rate of sea level change over time calculated from the respective sea level curves. At time zero, along the left-hand y-axis, red vertical bars represent the depth range corresponding to each paleoshoreline bin, with the mean for that bin projected back in time using a dashed line of the color indicated in the key. The dashed line, representing the mean paleoshoreline depth, is projected onto the relative sea level curves using various uplift rates that are reflected in the slope of the line. (A and B) A stable NCI platform (uplift rate 0 m/ka); (C and D) Muhs et al. (2014) average uplift rate (0.16 m/ka); (E and F) Chaytor et al. (2008) average uplift rate (1.5 m/ka).

Table 3.5.1 Mapped paleoshoreline depths and corresponding age estimates.

Mean Paleoshoreline Depth (m)	Interpreted Age
27.7	> 20 ka
36.4	>20 ka
43.7	>20 ka
56.8	MIS 3 (~55 ka)
66.2	Younger Dryas (11.5 ka)
82.5	13.5 ka
104	LGM (~21 ka)

3.5.8 NCI summary and recommendations

- Terrestrial and coastal paleoenvironments (pre-LGM sea level rise) were identified in chirp data and confirmed with sediment ground-truthing. These include estuary deposits in Box 5 and fluvial/alluvial deposits with paleosols in Box 6, both within the SCP.
- Some regional surfaces and geologic units could be mapped across the NCI platform, but several unique signatures were also observed locally around the islands (e.g., potential dunes in Box 2, wide paleovalley filled with marine sediment in Box 4, estuary in Box 5, and paleovalley with terrestrial deposits in Box 6.)
- Identification of paleolandscape features is complicated by the following active tectonic structures:
 - Folded stratigraphy can resemble channel morphology
 - Faults can influence paleochannel pathways
 - Faults can create similar morphology to paleoshoreline angles
 - Variable rates of uplift and subsidence can influence spatial patterns of paleolandforms and paleoshorelines.
- Marine sediment deposited after sea level inundation can obscure evidence of paleoshorelines and result in miscalculations of shoreline locations when relying only on modern bathymetry. Furthermore, the thickness of marine sediment was highly variable across the platform, making it difficult to predict how far off a modeled paleoshoreline could be in any given location.
- Regional sub-bottom survey lines were critical to identify paleolandscape features. The observed paleovalleys in Boxes 4 and 6 are several km wide and survey lines that did not cross their entire width would make their identification difficult. Additionally, as seen in Figure 3.5.17, for example, different landform features could be spatially connected, and understanding those relationships is critical for landscape interpretation.
- Sediment core data were critical for ground-truthing sub-bottom data and confirming paleolandscape signals. A general identification of recovered paleoenvironments was possible with just the geologic descriptions of core units, combined with CT scans that helped to visualize different core features. Additional analyses including quantitative grain size, MST, and XRF provided more detail on these environments, but patterns were not always clear. Expertise in terrestrial deposits and paleosols was critical for detailed interpretation of these environments.

- Based on the results from the NCI, the following guidelines are recommended:
 - High-resolution geophysical (HRG) surveys must include high-resolution sub-bottom data appropriate in penetration and resolution to the landforms anticipated. On the NCI, the Edgetech 512 chirp worked well.
 - Surveys should extend beyond just the area that could be impacted. If regional data exist, those should be reviewed and incorporated into the interpretation. If this is not possible, regional-scale data across and adjacent to the impacted area should be required.
 - Qualified marine geologists should be employed to interpret geophysical and geological data as these data are critical for identification of paleolandforms and paleoenvironments. These geologists should work jointly with qualified archaeologists. Where critical environments are encountered, experts should be brought in for further analysis.
- Future work that could advance understanding of the NCI shelf paleolandscape includes the following:
 - Additional radiocarbon dating to develop a more robust age model, especially across contacts interpreted to represent the transgressive surface
 - Pollen and environmental DNA analysis on identified sediment from coastal and terrestrial environments.

4 Task 5: Field investigations and model validation for the central Oregon coast

Using the refined model developed from the California work in Tasks 2 to 4, the scientific team selected four sites of high probability for preserved submerged paleolandscape features offshore central Oregon. The team followed methods outlined in Tasks 3 and 4 for geophysical surveys, sediment sampling, data processing, and data analysis, results of which served as a critical test of the predictive GIS model.

4.1 Offshore geophysical surveys

Similar to the NCI, there were no available high-resolution sub-bottom data on the central Oregon continental shelf. Based on experience in the NCI, the importance of regional survey data was recognized, and regional-scale surveys were conducted before paleolandscape targets were identified for more refined surveys and sampling. In May and September 2017, ~1,075 km of chirp sub-bottom and side-scan sonar data were collected on R/V *Pacific Storm* to characterize the paleolandscapes offshore the modern Siuslaw and Umpqua rivers in Central Oregon (Figure 4.1.1). Building on knowledge gained in the Channel Islands, the May 2017 cruise focused on collecting regional-scale data that could identify targets and provide context for more detailed surveys and sampling. These data were collected parallel, and at oblique angles, to the coast in an attempt to transect potential paleochannels that were modeled extending roughly east-west across the continental shelf. A rented Edgetech 512i chirp was used for sub-bottom data acquisition, operated with a 30-millisecond swept pulse of 0.5 to 7.2 kHz. These data have two types of data artifacts: (1) repeated diagonal lines, and (2) a wavy, undulating signal, and both interfere with real data at times. The crew attempted to reduce the artifacts during data collection but were unable to identify a solution. The team hypothesized one possible cause for the artifacts was interference between the instrument and the ship's electrical systems, but this is unconfirmed.

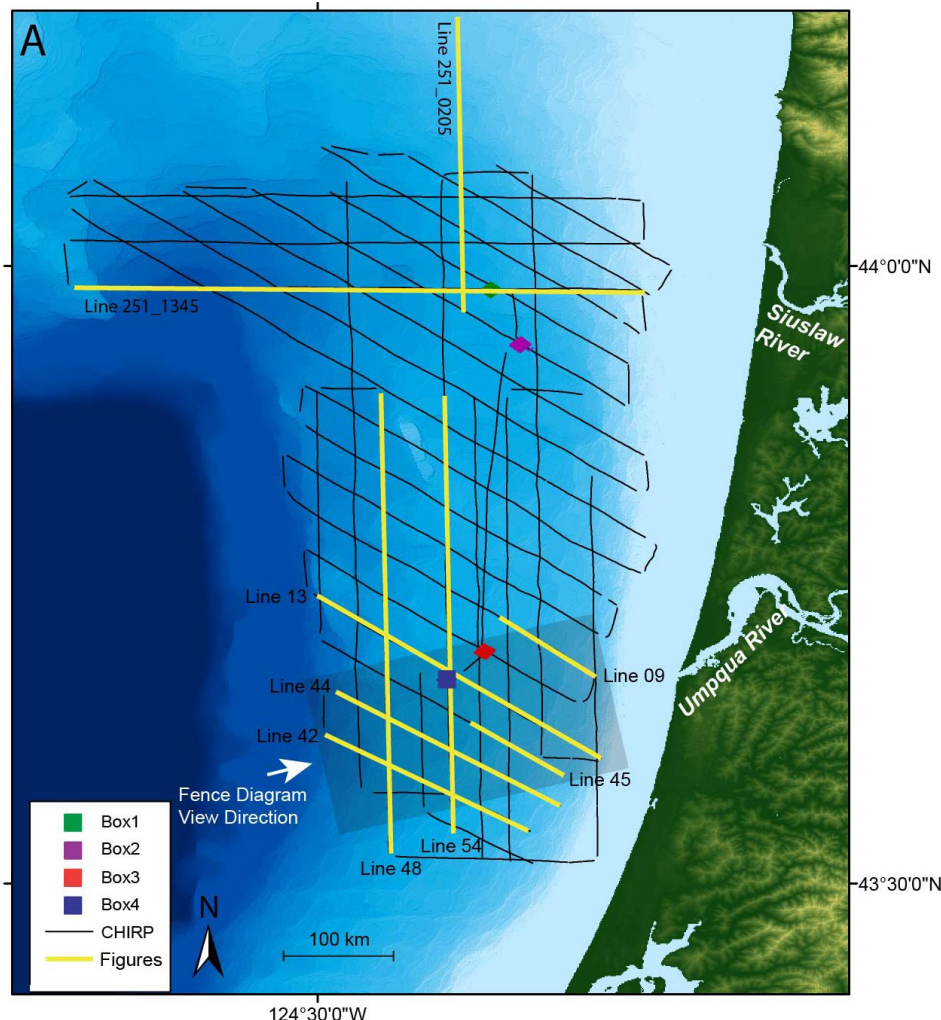


Figure 4.1.1 Map of Oregon Survey area geophysical surveys

Black lines show regional survey transects and colored boxes show locations of 1 km² detailed survey areas. Yellow lines indicate figures shown in Section 4.3 and are labeled with line names shown in those figures. Lightly shaded rectangle shows location of fence diagram from Section 4.3 and white arrow shows look direction.

The September 2017 cruise acquired additional regional survey data, and completed surveys across four 1 km² boxes with line spacing of 25 m. The box locations were selected based on the previously collected regional survey data (see Section 4.3 for details). Two boxes were offshore the Siuslaw River, where unique acoustic signatures were observed in the regional data (Boxes 1 and 2) and two were offshore the Umpqua River, where a large incised paleovalley was observed in the regional sub-bottom data (Boxes 3 & 4). The September 2017 cruise used Scripps Institution of Oceanography's chirp towfish, operated with a 30-millisecond swept pulse of 1 to 15 kHz.

Scripps Institution of Oceanography's Edgetech 4200 side-scan sonar was used for both the May and September cruises to record backscatter data from the seafloor; data were recorded in JSF format along with real-time GPS for position accuracy. The data were processed using Xsonar (Danforth 1997), which accounts for slant range beam angle distortion, merges navigation with the data, and generates a mosaiced image.

An additional 1,600 km of regional-scale 3.5 kHz Knudsen sub-bottom data were collected in September 2017 during cruise NA087 on E/V *Nautilus* to help constrain features north of the Siuslaw River (<http://www.nautiluslive.org/science/data-management>) (Davis et al., 2020). Multibeam and backscatter data were collected simultaneously with a hull-mounted Kongsberg EM302. The multibeam and backscatter data were processed by the E/V *Nautilus* crew using QPS Qimera software and were provided as floating point geotiff files of gridded depth (multibeam) and intensity (backscatter).

All sub-bottom data were recorded in SEG-Y format, along with real-time GPS data for position accuracy. These data were processed using SIOSEIS (Henkart, 2006), plotted using Seismic Unix (Cohen and Stockwell 1999), and then imported into the Kingdom Suite software package (<https://kingdom.ihs.com/>) for interpretation. A nominal velocity of 1,500 meters per second was applied to convert two-way travel time (TWTT) to depth.

4.2 Seafloor coring

Core locations were selected based on targets identified in geophysical data. Within the four boxes, a minimum of four locations were identified to sample different observed acoustic signatures. The scientific team collected 38 marine cores (containing 61.5 m of sediment) using a Rossfeller P-5 vibracore on a research cruise in June 2018 aboard SIO's R/V *Roger Revelle* (RR1807) (Figure 4.2.1; Appendix A, Table A-2). Core names within the boxes are identified by the box number and then a lower-case letter (i.e., 2a, 2b, 2c, and 2d). Due to the wide variety of acoustic signals observed outside of the four boxes, additional "bonus" targets were selected along some of the regional profiles. These are identified with the naming convention B followed by a number (e.g., B4, B9). Appendix A, Table A-2 indicates the reason each target was chosen. Some planned target locations could not be cored due to time constraints, and these numbers were skipped (e.g., B7). At some locations, cores were attempted but came up without any sediment. Those cores are indicated with 0 cm length in Appendix A, Table A-2. Cores were cut into maximum 150 cm sections on board and held in refrigerated storage on the vessel until the end of the cruise when they were transported directly from R/V *Roger Revelle* in Newport, Oregon, to their final storage location at the OSU Marine and Geology Repository. See BOEM Coring Data Repository for chirp profiles with core locations within the four 1 km² boxes. The following sections discuss core analysis procedures for the Oregon cores. Paleosol analysis was not conducted on these cores because after initial core imaging and description, clear evidence for terrestrial deposits was not identified.

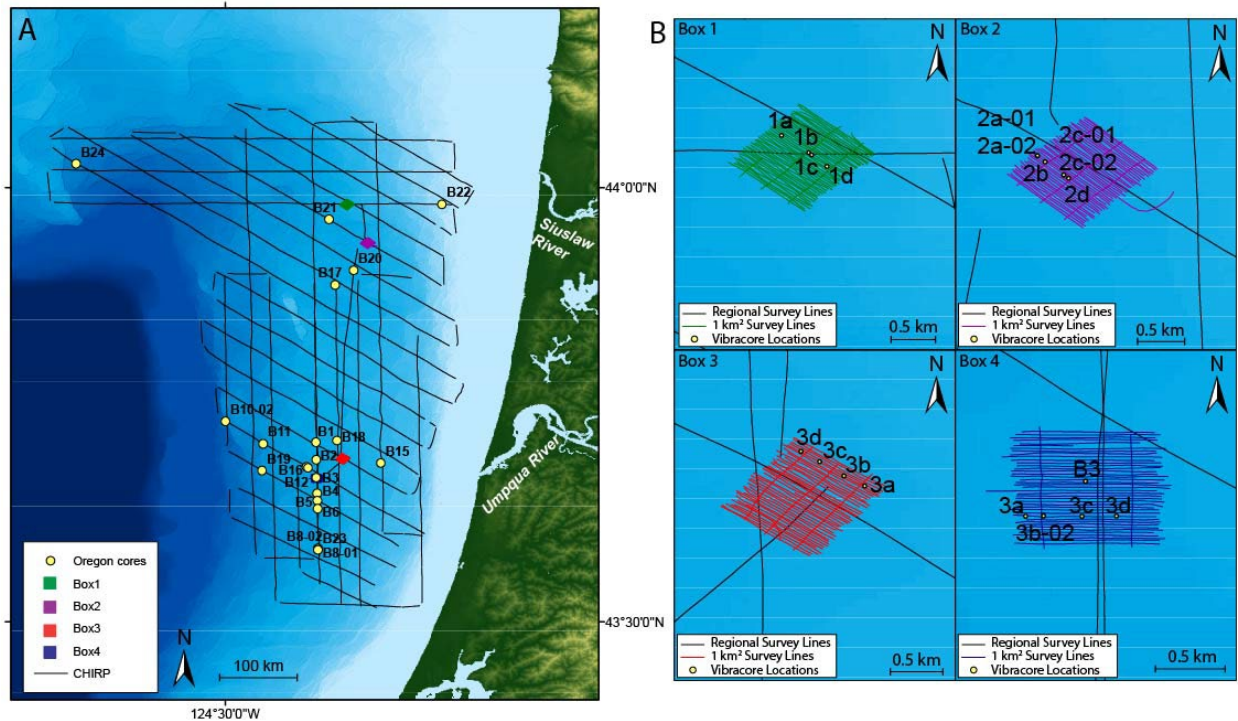


Figure 4.2.1 Map of Oregon survey area showing core locations

(A) Overall locations including “bonus cores” (B# labels) located outside survey boxes, and location of each box (numbered). (B) Zoomed in to show core locations collected within each box.

4.2.1 Core descriptions with optical and CT images

The core descriptions and images from Oregon were handled following the same methods as the NCI cores, outlined in Section 3.5. See BOEM Coring Data Repository for Oregon written core logs and for Oregon digital core figures.

4.2.2 Multi-sensor core logs

The Oregon cores were analyzed for physical properties using a whole core scanner following the same methods outlined in Section 3.5 for the NCI cores. See BOEM Coring Data Repository for Oregon MST data.

4.2.3 Itrax analysis

The Oregon cores were analyzed for elemental chemistry following the same methods described in Section 3.5 for the NCI cores. See BOEM Coring Data Repository.

4.2.4 Grain size analysis

Grain size samples were analyzed following the same methods described in Section 3.5 for the NCI cores. See BOEM Coring Data Repository.

4.2.5 Radiocarbon dating

Samples for radiocarbon dating were collected from select cores and depths based on initial core interpretations. All samples were sent to DirectAMS Radiocarbon Dating Services in Bothell,

Washington, for analysis (www.DirectAMS.com). Samples were prepared and analyzed by DirectAMS using their National Electrostatics Corporation 1.5 SDH Compact Pelletron Accelerator Mass Spectrometer. Results were reported by DirectAMS as uncalibrated radiocarbon ages, corrected for isotopic fractionation with an unreported $\delta^{13}\text{C}$ value measured on the prepared carbon by the accelerator. The provided radiocarbon ages were calibrated using Calib 8.20 (www.calib.org) and the Marine20 calibration curve (Khasanov et al. 2020). All radiocarbon ages produced from marine shell carbonate were adjusted using a marine reservoir age of 550 years. See Appendix A, Table A-3 for all sample and radiocarbon information.

4.3 Results from Oregon field work

The regional chirp data from Oregon is characterized by extensive bedrock deformation with variable thickness of sediment draped above. A key observation in the stratigraphy was the location of fluvial signatures offshore from the Siuslaw and Umpqua rivers. Klotsko et al. (2021) provides a detailed analysis of the two drainage systems and the likely controls on the different stratigraphic and morphologic patterns observed for each river, which include underlying structure and lithology, shelf gradient, and drainage basin characteristics. Excerpts from Klotsko et al. (2021) are presented below for an overview of the regional observations of tectonic structure and drainage characteristics. Subsequently, more detailed discussion of the 1 km² boxes are discussed; two from offshore the Siuslaw River and two from offshore the Umpqua River.

4.3.1 Structure (reprinted from Klotsko et al., 2021)

The continental shelf within the study area is characterized by complex tectonic structures (Figure 4.3.1). Folded and dipping strata of varying geometries are imaged in the regional chirp data, including syncline-anticline structures (Figure 4.3.2; Figure 4.3.3; Figure 4.3.4; Figure 4.3.5). Around Siltcoos Bank, the steepness of dipping beds increases, and strata are folded more tightly (Figure 4.3.2; Figure 4.3.5). Often, structures from the underlying strata protrude above the surrounding seafloor in the form of hardgrounds (Figure 4.3.1; Figure 4.3.3; Figure 4.3.4; Figure 4.3.5; Figure 4.3.6; Figure 4.3.7). These were mapped where they protrude, as well as where they extend upwards and come within 0.015 seconds of TWTT of the seafloor (Figure 4.3.1). Where imaged, these protruding hardgrounds have higher backscatter compared to the surrounding seafloor (Figure 4.3.1) and higher acoustic amplitude (Figure 4.3.5; Figure 4.3.6; Figure 4.3.7).

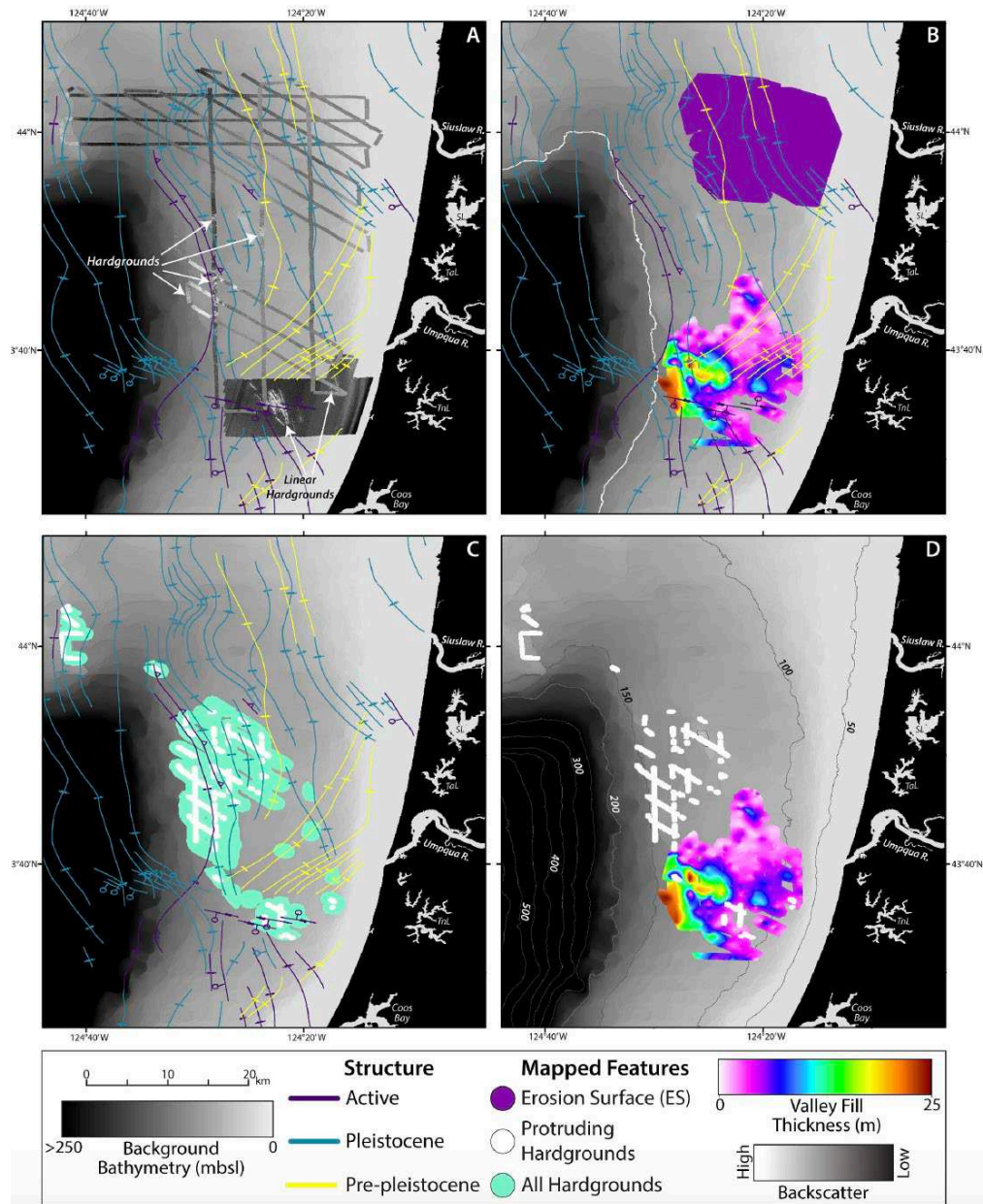


Figure 4.3.1 Maps of regional structure (Klotsko et al. 2021:4)

Source of structure data (http://activetectonics.coas.oregonstate.edu/casc_structure.htm) and features from geophysical data overlaying background bathymetry in grayscale. Structure reflects different controls on shelf morphology through time, mainly driven by compression along the Cascadia subduction zone. SL = Siltcoos Lake, TaL = Tahkenitch Lake, TnL = Tenmile Lake. (A) Regional structure and backscatter data (SDSU, BOEM, OSU). The backscatter highlights hardgrounds that have been uplifted due to tectonic motion in the region. Some of the hardgrounds are oriented in a linear fashion, creating a series of ridges, while others have a more modular coverage. (B) Map of Umpqua paleovalley fill thickness and location of the ES overlain by the regional structure. The white line is the 150 m contour, the approximate shelf edge. (C) Location of mapped hardground based on chirp data with regional structure. Protruding hardgrounds stick out above the surrounding seafloor where “all hardgrounds” includes those that came very close to the surface (within 0.015 seconds of TWTT). (D) Map comparing Umpqua paleovalley fill thickness and protruding hardground locations. Fill thickness thins towards protruding hardgrounds. Any overlap is a result of the gridding parameters.

In the chirp data, the exposed hardgrounds range from mound-like (Figure 4.3.6; Figure 4.3.7) to narrower and more pinnacled (Figure 4.3.2; Figure 4.3.4; Figure 4.3.5; Figure 4.3.6). When they protrude above the surrounding seafloor, the hardgrounds sometimes trend in a linear fashion (Figure 4.3.1), particularly in the southern region, but have either a modular or widespread coverage in other areas. Hardgrounds are most common in the middle and outer shelf (Figure 4.3.1), between the Siuslaw and Umpqua rivers. On the outer shelf, hardgrounds are mostly exposed, but some are covered by a thin veneer of sediment (Figure 4.3.1; Figure 4.3.4; Figure 4.3.5; Figure 4.3.7). Hardgrounds that do not extend above the surrounding seafloor also tend to have higher acoustic amplitude in chirp data (Figure 4.3.5; Figure 4.3.6; Figure 4.3.7). In general, hardgrounds occur at anticlinal axes (Figure 4.3.1; Goldfinger et al., 2014) or are associated with folded and faulted reflectors (Figure 4.3.2 and Figure 4.3.5).

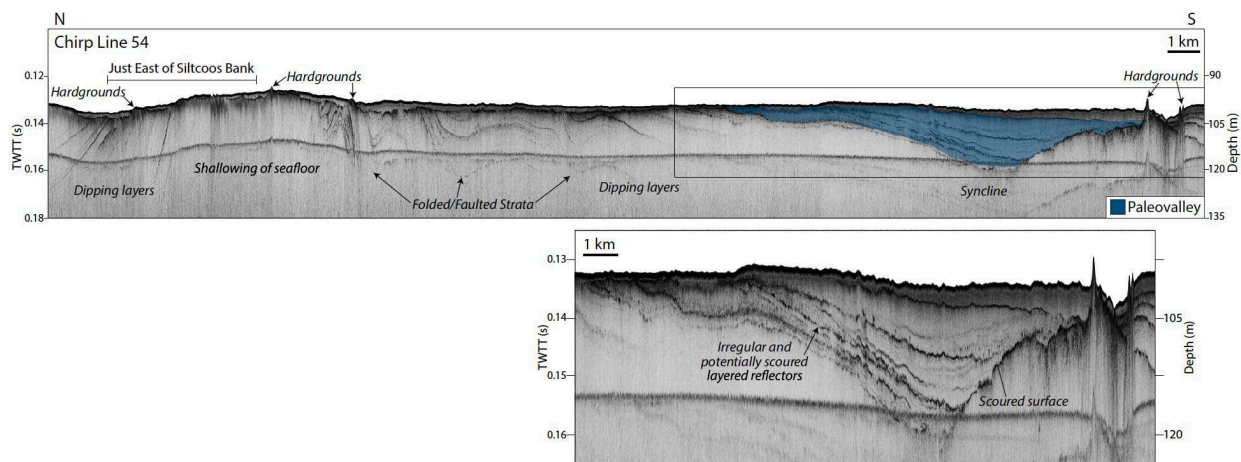


Figure 4.3.2 Chirp Line 54 with more vertically exaggerated section of outer shelf Umpqua valley on bottom (Klotsko et al. 2021:6)

This profile captures the most well-defined instance of the outer shelf valley, where it is located within a syncline. The paleovalley is bounded to the south by a set of uplifted linear hardgrounds. Folding and faulted strata are imaged on the northern extent of the profile. This is associated with a broad shallowing of the seafloor and hardgrounds that protrude above the surrounding seafloor. See Figure 4.1.1 for location.

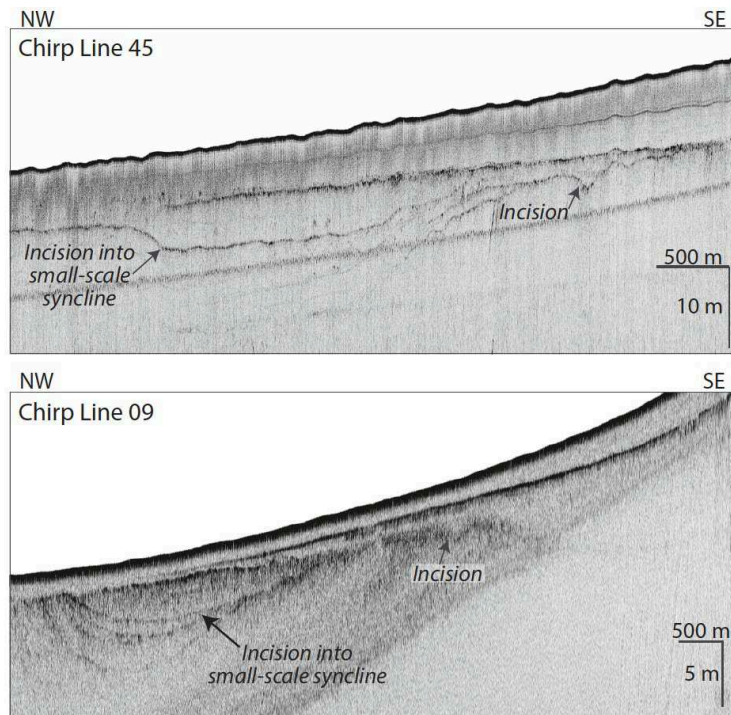


Figure 4.3.3 Sections of chirp profiles highlighting incision of the inner shelf portion of the Paleo-Umpqua drainage valley (Klotsko et al. 2021:7)
See Figure 4.1.1 for location.

4.3.2 Siuslaw and Umpqua drainages (reprinted from Klotsko et al., 2021)

There is a large, infilled valley system offshore from the modern Umpqua River. The valley is mapped in modern water depths of ~80 to 150 m (Figure 4.3.1). The acoustic character of the system (bottom reflector shape and acoustic character, fill thickness and character) varies throughout its extent (Figure 4.3.2; Figure 4.3.3; Figure 4.3.4; Figure 4.3.5; Figure 4.3.6; Figure 4.3.7). On the inner shelf, the valley bottom reflector ranges from nearly flat to undulating to sharply curved (Figure 4.3.4; Figure 4.3.6; Figure 4.3.7), reflecting clear incision into the underlying bedrock. In this area, the valley fill is thinnest (<10 m), but there could have been some truncation by wave action during sea level transgression (Figure 4.3.3; Figure 4.3.4; Figure 4.3.6; Figure 4.3.7). In this area, the fill is primarily acoustically transparent, but sometimes has internal reflectors indicative of progradation or migration of incision (Figure 4.3.3; Figure 4.3.4; Figure 4.3.6), typical of an incised valley. As the valley system extends to the outer shelf, it increases in depth, with fill up to ~25 m in thickness (Figure 4.3.1; Figure 4.3.2; Figure 4.3.4; Figure 4.3.5; Figure 4.3.6). The valley also widens here, covering at least 13 km in the north-south direction (Figure 4.3.1; Figure 4.3.2). The valley system bifurcates around structural highs that extend to the seafloor and protrude as hardground pinnacles (Figure 4.3.1; Figure 4.3.5). The valley bottom reflector ranges from low to high amplitude and has an irregular, uneven appearance (Figure 4.3.1; Figure 4.3.3; Figure 4.3.6).

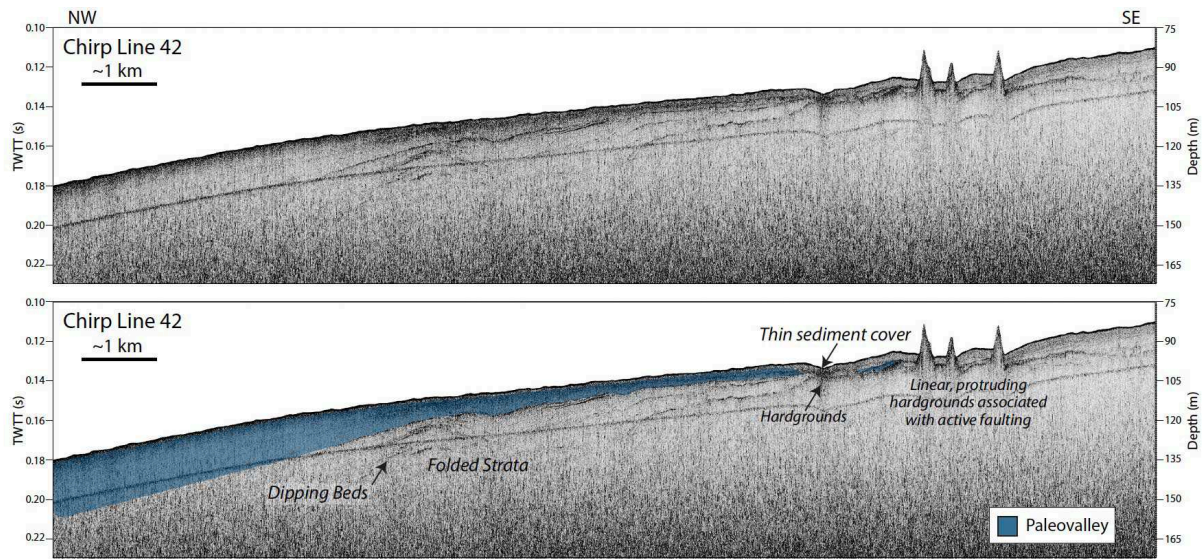


Figure 4.3.4 Chirp Line 42 with uninterpreted (top) and interpreted (bottom) versions (Klotsko et al. 2021:9)
See Figure 4.1.1 for location.

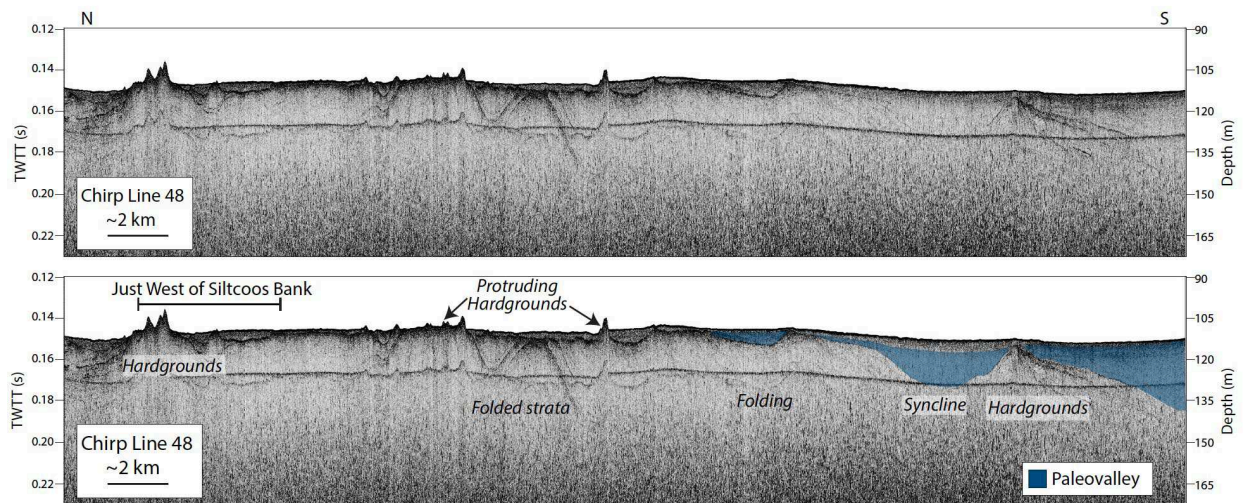


Figure 4.3.5 Chirp Line 48 with uninterpreted (top) and interpreted (bottom) versions (Klotsko et al. 2021:10)

Representative profile showing the extensive structure across the shelf. Anticlines and synclines underlie the seafloor in much of the area. Highs associated with this folding stick out above the surrounding seafloor as protruding hardgrounds. See Figure 4.1.1 for location.

The outer shelf valley fill is either acoustically transparent or has internal layered reflectors (Figure 4.3.1; Figure 4.3.2, Figure 4.3.4; Figure 4.3.6). These reflectors are typically medium- to high-amplitude and sometimes onlap the valley wall (Figure 4.3.2). The overall paleodrainage depth increases towards the southwestern portion of the study area (Figure 4.3.4; Figure 4.3.5), near the shelf break-slope transition, associated with greater valley fill thickness (Figure 4.3.1). A smaller channel with thinner fill extends from the outer shelf part of the valley to the northeast, offshore from Tahkenitch Lake (Figure 4.3.1).

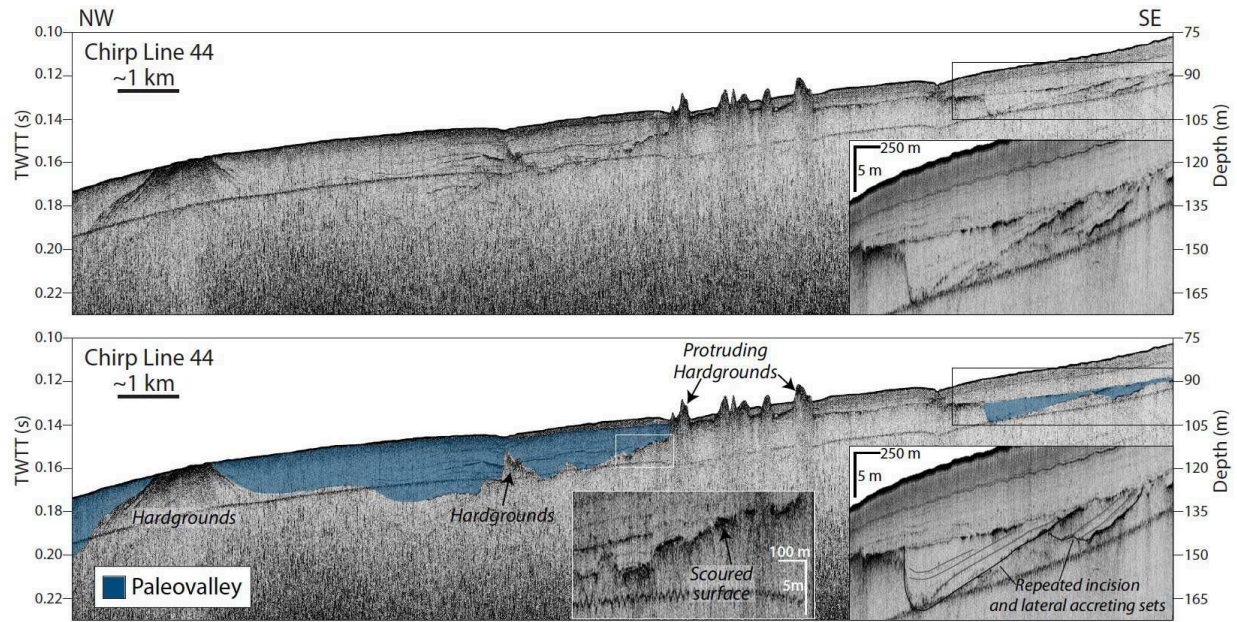


Figure 4.3.6 Chirp Line 44 with uninterpreted (top) and interpreted (bottom) versions (Klotsko et al. 2021:5)

Three different expressions of hardgrounds are imaged. Note the difference in paleodrainage valley character between inner shelf incision and outer shelf scour of pre-existing structural low. See Figure 4.1.1 for location.

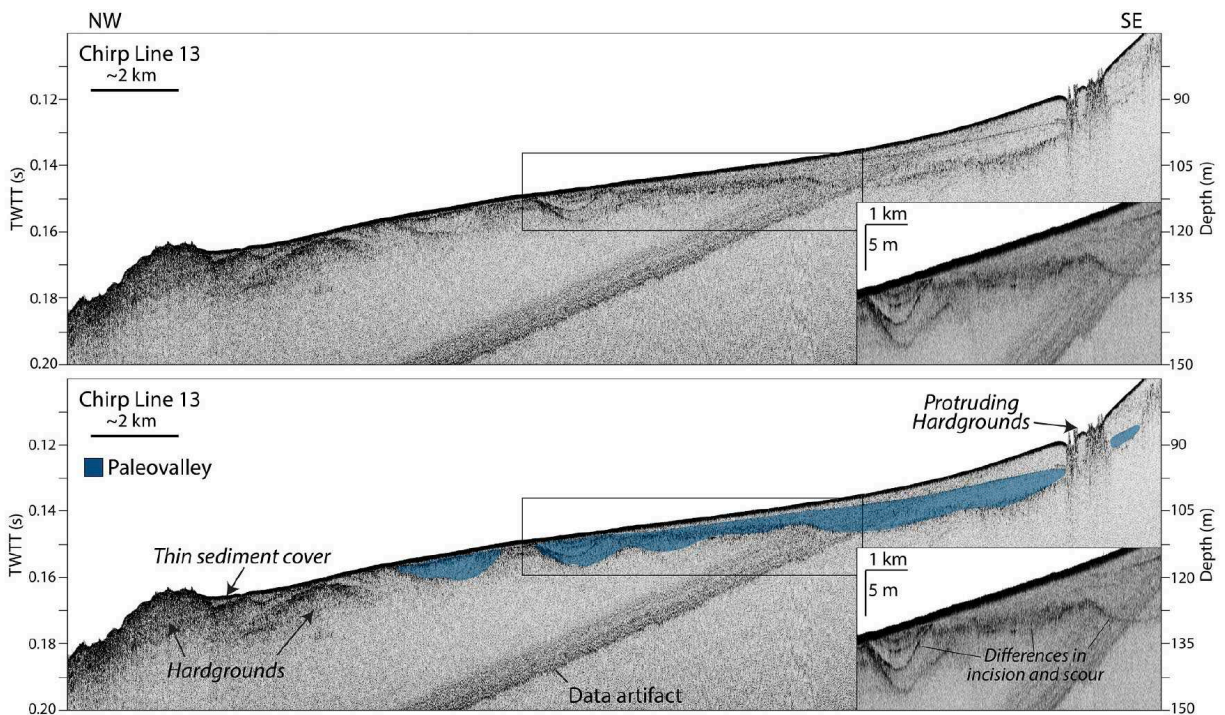


Figure 4.3.7 Chirp Line 13 with uninterpreted (top) and interpreted (bottom) versions (Klotsko et al. 2021:8)

This profile cuts across the northern extent of the paleo-Umpqua drainage system. See Figure 4.1.1 for location.

Offshore from the modern Siuslaw River, there is not a definable incised drainage channel or valley. There is, however, a distinctive medium to high amplitude reflector that has an almost blotchy acoustic character (Figure 4.3.8). The reflector truncates the small number of features that are imaged below it; in general, little stratigraphy is imaged in the northern portion of the study area. This reflector has an irregular, undulating appearance, both broadly shallowing and deepening, and is hummocky at a smaller scale (Figure 4.3.9; Figure 4.3.10). This is typical of an erosion surface (Lobo et al., 2018), and the reflector is denoted as such (Erosion Surface; ES). The ES ranges from ~6 m below the seafloor to occasionally merging with the seafloor, but it is primarily within 3 m of it (Figure 4.3.8; Figure 4.3.9). The ES is mapped throughout the northeastern portion of the study area (Figure 4.3.1), extending from ~125 mbsl offshore, to the eastern limit of the seismic data at ~55 mbsl. Beyond the shelf break offshore from the Siuslaw River is a sediment wedge more than 5 m thick (Figure 4.3.9).

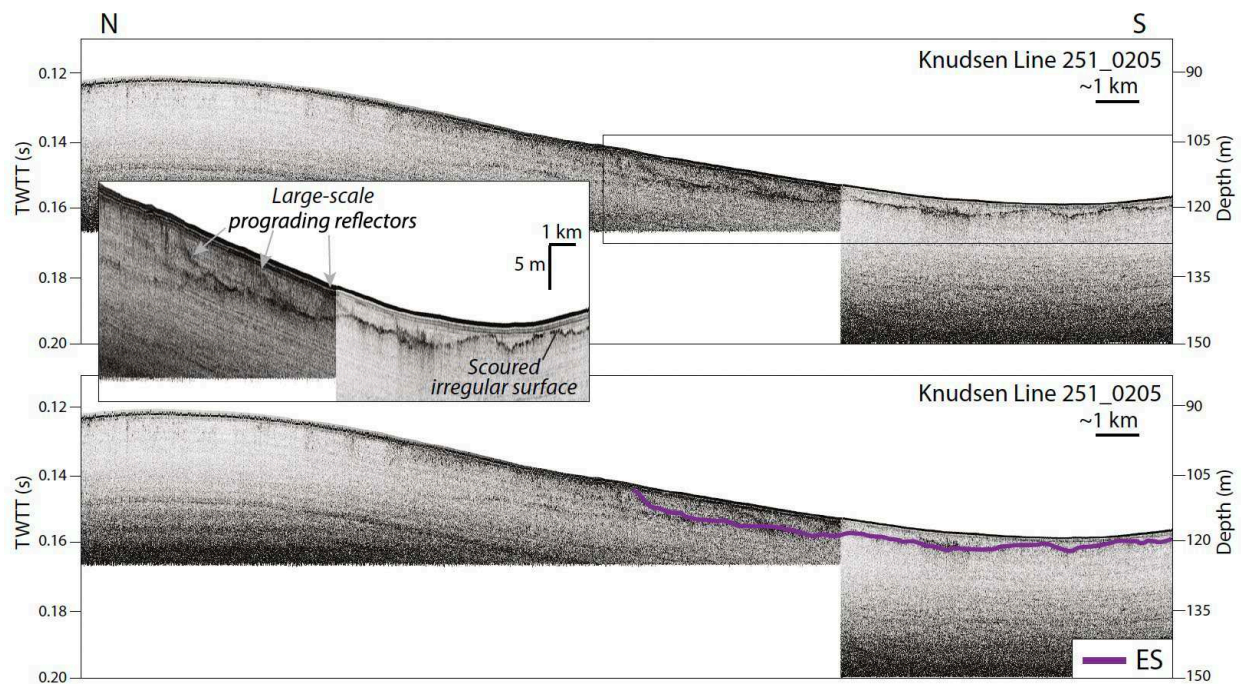


Figure 4.3.8 Knudsen Line 251_0205 with uninterpreted (top) and interpreted (bottom) versions (Klotsko et al. 2021:11)

There is no distinct channel feature offshore from the modern Siuslaw River. There is only a high-amplitude, hummocky reflector mapped in the region as the Erosion Surface (ES). Inset highlights the scoured surface of the ES and internal reflectors of the overlying sediments. See Figure 4.1.1 for location.

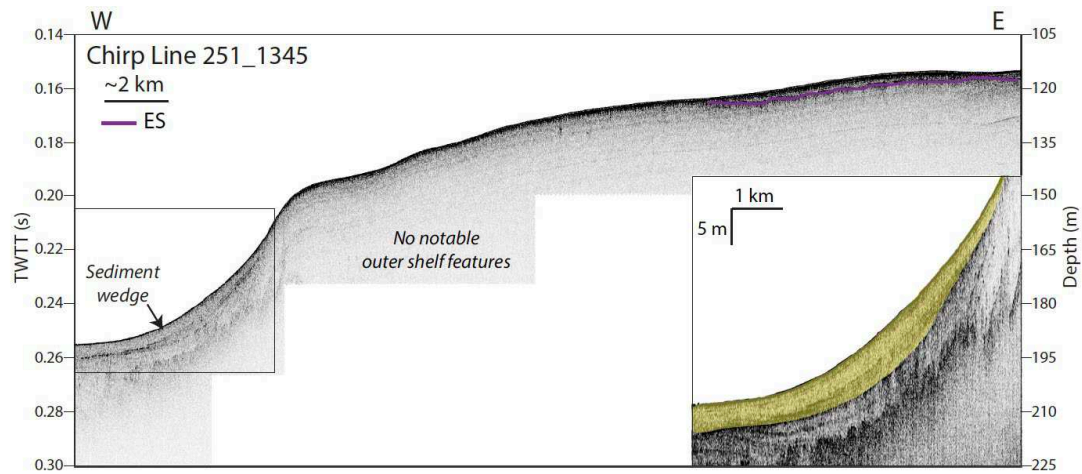


Figure 4.3.9 Knudsen Line 251_1345 highlighting the absence of stratigraphy on the outer shelf (Klotsko et al. 2021:12)

The shelf is sediment-starved in the vicinity of the Siuslaw River, but a wedge of sediment is imaged beyond the shelf break. See Figure 4.1.1 for location.

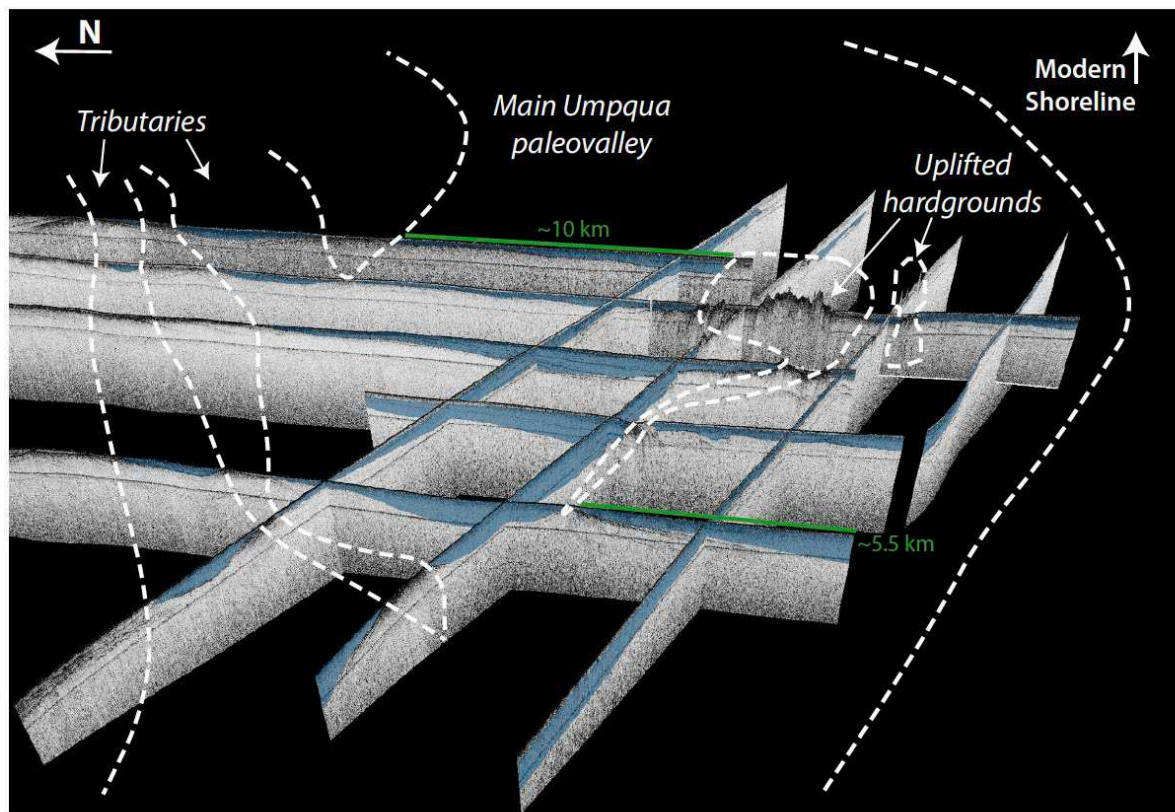


Figure 4.3.10 Fence diagram of the paleodrainage system offshore from the modern Umpqua River (Klotsko et al. 2021:13)

The drainage valleys are separated by uplifted hardgrounds, that are both exposed on the seafloor and buried. Blue interpretation colors fill within the Umpqua paleovalley. See Figure 4.1.1 for location.

4.3.1 Box 1: Siuslaw erosion surface

Box 1 was selected based on a regional line (PS1705_L32) that showed the ES (Figure 4.3.11). This reflector was interpreted as representing the paleo-Siuslaw cross-shelf extension. It is characterized by a hummocky, irregular surface with variable but generally high-amplitude character. Within the 1 km² box, four coring targets were selected (Figure 4.3.12). Cores 1A and 1D were selected because of thin sediments above the ES that had a defined reflector within the acoustic unit. This was interpreted to indicate a wetland/marine sediment unit boundary. Cores 1B and 1C were also from this area, but where there were additional mounded units above the ES that could represent shell middens, or deposits from some other paleolandform. The surficial unit for all of these cores contains mottled, homogenous mud with rare shell fragments (Lithofacies 1; Figure 4.3.12). Below is a muddy-sandy unit with some shell fragments. The bottom of Cores 1B, 1C, and 1D penetrated to just above the ES and the lowest unit contains fine laminated mud, fine sands, ichnofossil traces, and terrestrial organic fragments (Lithofacies 3). Radiocarbon samples from Box 1 included several dates within ~12 to 15 ka. Shell from the basal unit of Cores 1B, 1C, and 1D are ~17.9-21.2 ka.

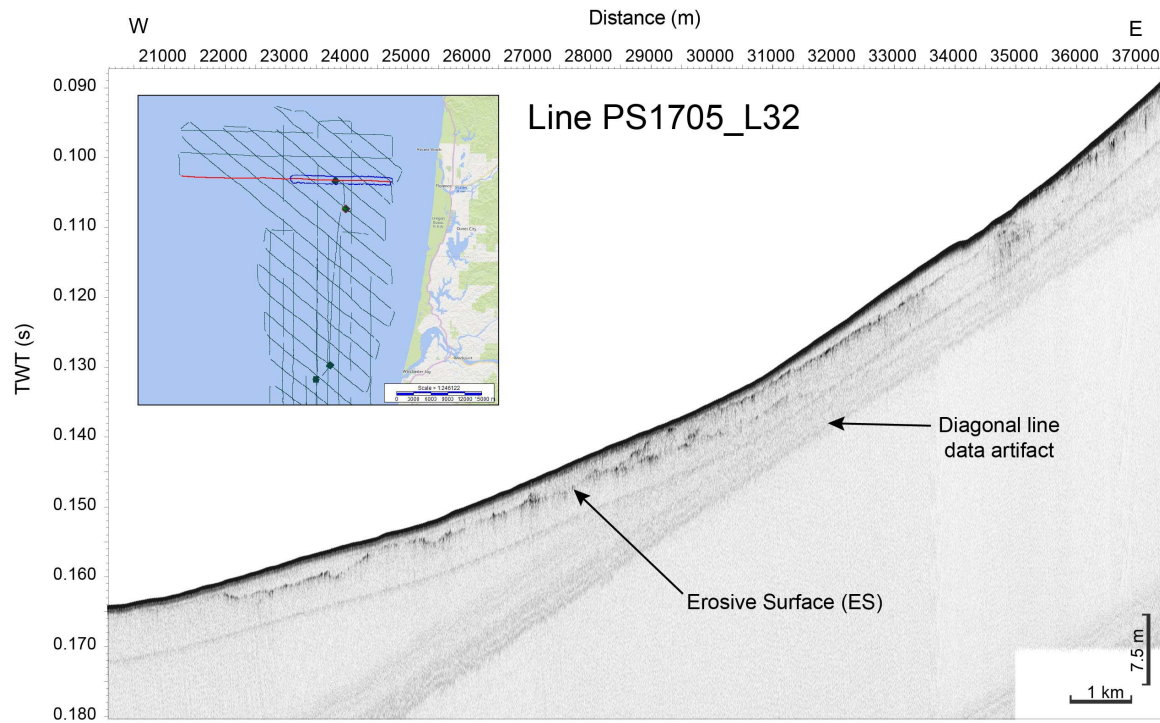


Figure 4.3.11 Chirp Line PS1705_L32

Shows erosive surface that was targeted for Box 1 survey and coring. Inset map shows location offshore Oregon. Red line is entire PS1705_L32 and blue is the portion shown in the figure. Black lines are other chirp lines and small squares are the four 1 km² boxes.

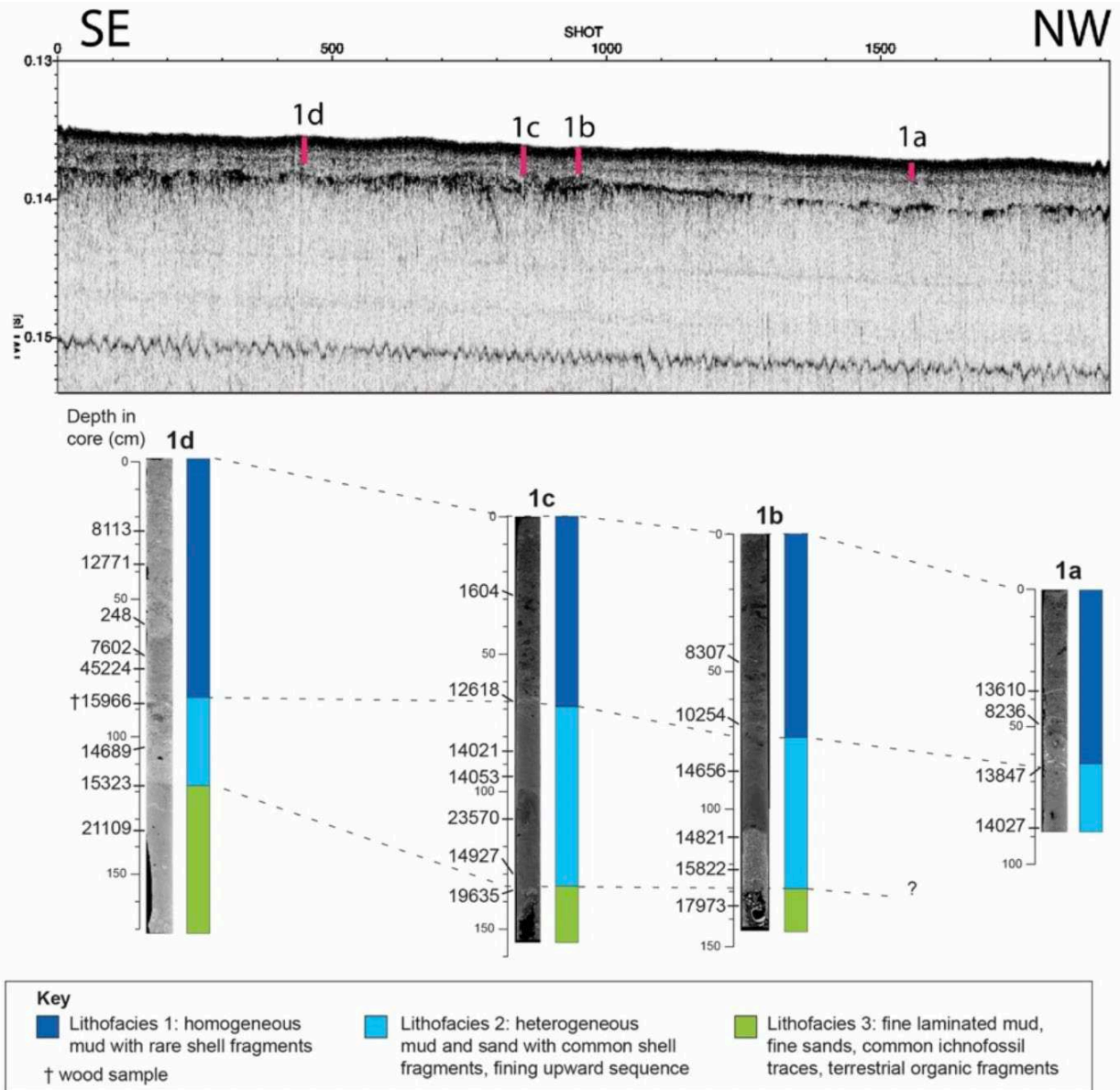


Figure 4.3.12 Box 1 cores (Davis et al., 2020:41)

Chirp Line that transects all four core locations. Pink rectangles indicate approximate depth of penetration for each core. Radiocarbon ages (at left of cores) shown in cal yr BP. See Figure 4.2.1 for location.

4.3.2 Box 2: Siuslaw erosion surface and channel

Box 2 was selected based on a regional line (PS1705_L22) that showed ES (paleo-Siuslaw) and evidence of small incision, potentially a small channel, with thin overlying sediments (Figure 4.3.13). The unit directly above the small incision has a different acoustic character than the overlying units. It is more high-amplitude and chaotic, whereas the uppermost is more acoustically transparent with a single, continuous internal reflector. Four coring targets were identified in a transect along the small, incised feature, with the goal of penetrating into the deepest sediment unit (Figure 4.3.14). The surficial unit for all Box 2 cores is homogenous mottled mud with radiocarbon dates less than ~8 ka (Lithofacies 1). Core 2A only penetrated the surficial unit. The other Box 2 cores penetrated into the deepest acoustic unit

above the ES. These are Cores 2B, 2D, 2C-01, and 2C-02; the location of 2C was cored twice because sediments acquired were of interest. The middle unit on all of these cores is mud and sand with shells, some whole and some fragments and radiocarbon dates range from ~8 to 13 ka (Lithofacies 2). The bottom unit is more variable, with sections of finer laminated muds and sections of sands and shells that could indicate an estuarine deposit (Lithofacies 3). The lower unit includes shells with radiocarbon dates 13 to 16 ka. A dense shell layer was encountered only at the base of Core 2B and is dated ~13.5 ka.

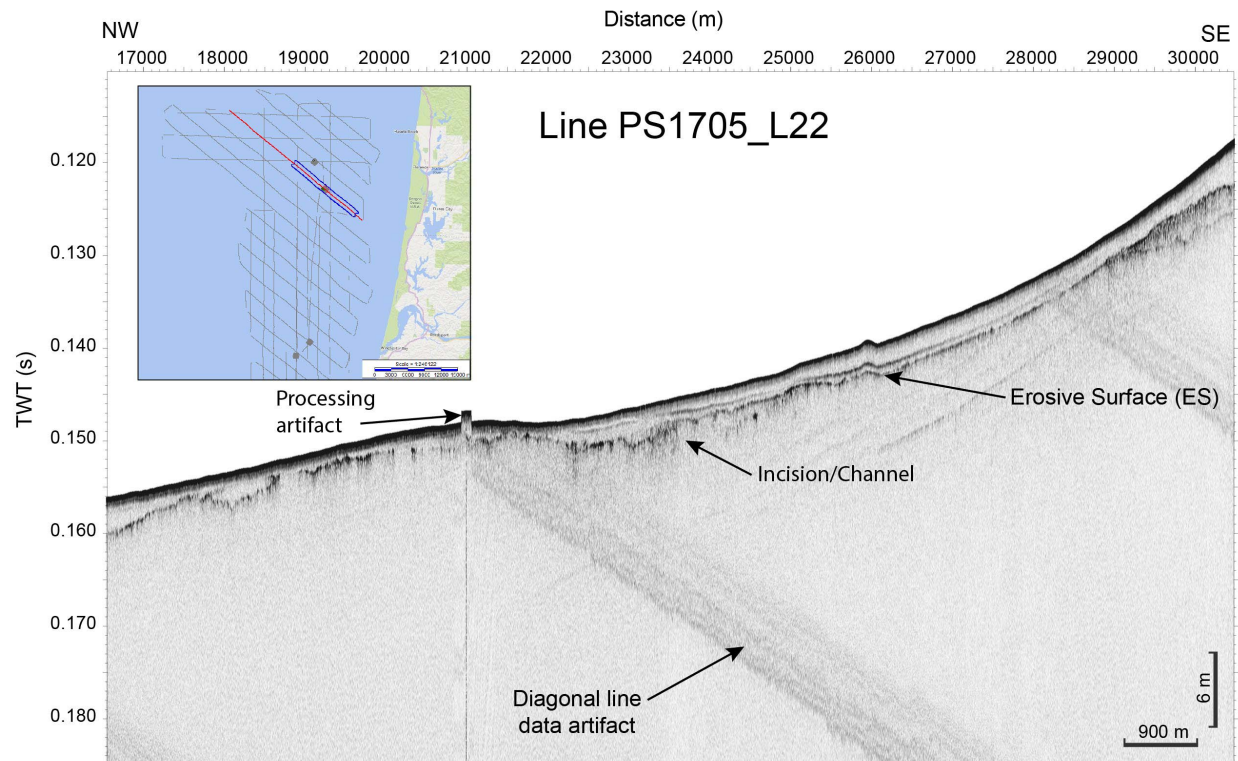


Figure 4.3.13 Chirp Line PS1705_L22

Shows erosive surface and small incision that were targeted for Box 2 survey and coring. Inset map shows location offshore Oregon. Red line is entire PS1705_L22 and blue is the portion shown in the figure. Black lines are other chirp lines and small squares are the four 1 km² boxes.

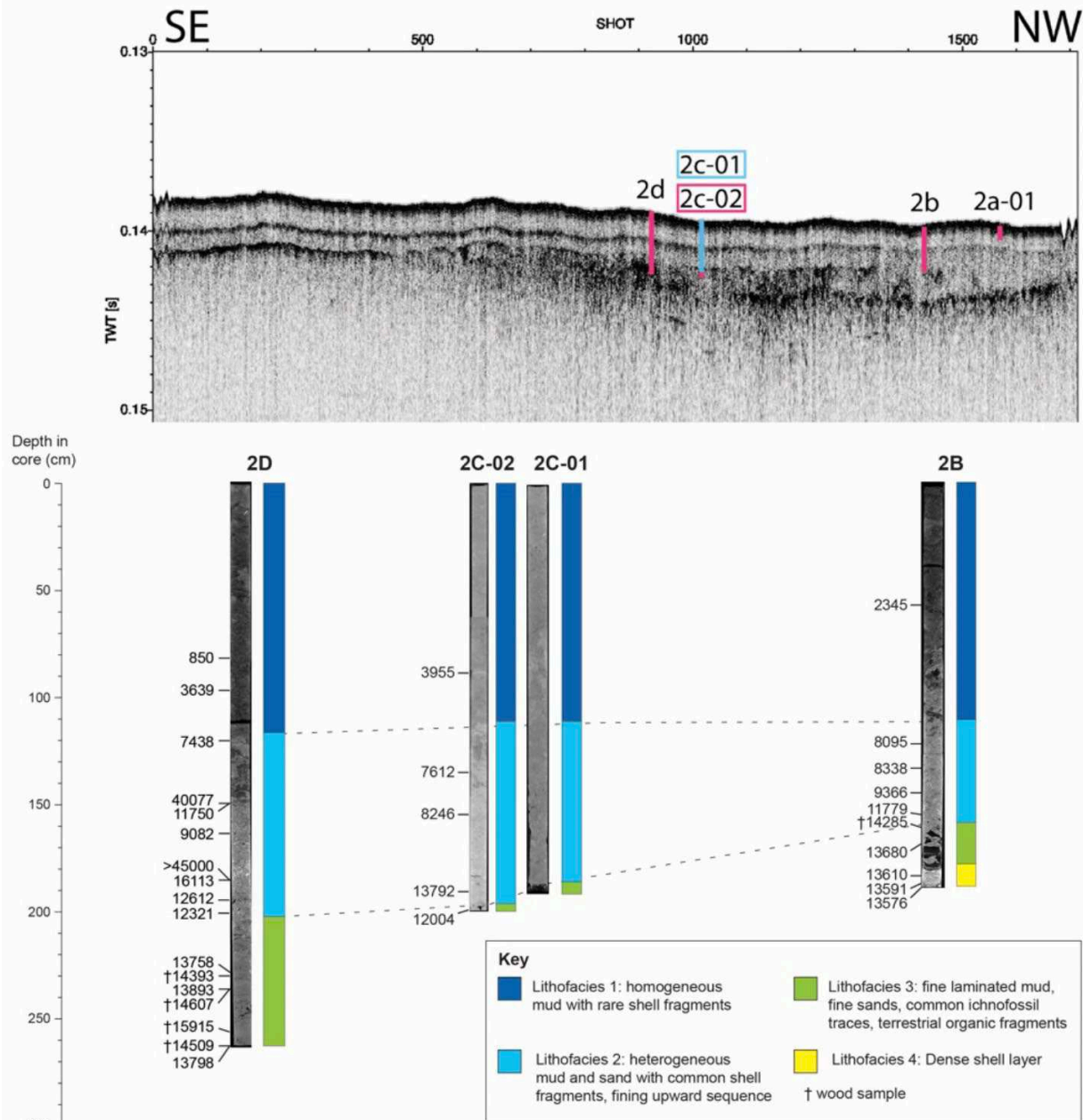


Figure 4.3.14 Box 2 cores (Davis et al., 2020:43)

Chirp line that transects all four core locations. Pink and blue rectangles indicate approximate depth of penetration for each core. Radiocarbon ages (at left of cores) shown in cal yr BP. See Figure 4.2.1 for location.

4.3.3 Box 3: Umpqua incision

Box 3 was selected based on a regional line (PS1705_L11) that showed repeated incision features, attributed to the paleo-Umpqua (Figure 4.3.15). There are also multiple reflectors and seismic units of varying acoustic character, indicating deposition from multiple paleoenvironments. Box 3 was picked where surficial, acoustically transparent sediments were thin to try and core into the layers below for environmental identification. Cores 3A, 3B, 3C, and 3D were collected along a transect in this region to

sample the varying acoustic signatures (Figure 4.3.16). The top unit in all of Box 3 cores consists of homogenous, mottled mud (Lithofacies 1). The bottom of 3B, 3C, and 3D are silty sand with shells, mostly fragments, but some large and intact (Lithofacies 2). Only Core 3B could have penetrated into a deeper unit, with fine laminated mud, sand, and ichnofossils (Lithofacies 3). Because the Box 3 cores did not penetrate into deeper sediment units, these cores were not sampled for radiocarbon dates.

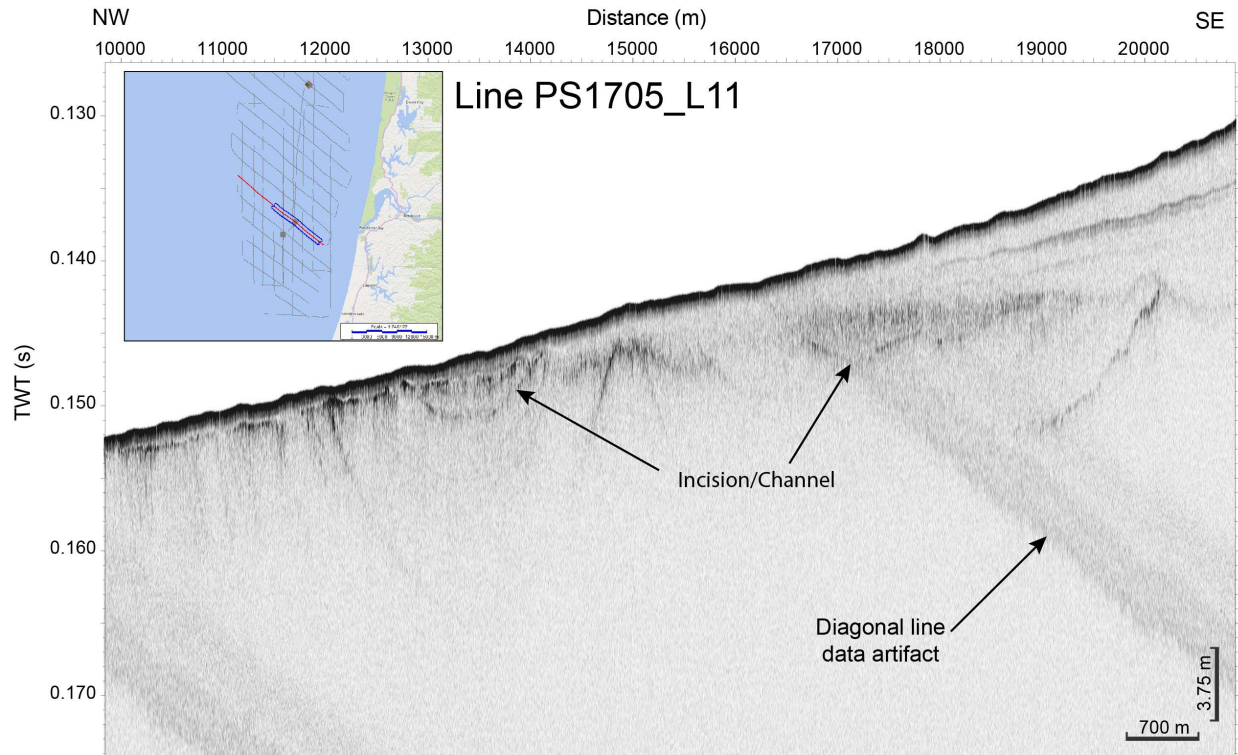


Figure 4.3.15 Chirp Line PS1705_L11

Shows small incisions that were targeted for Box 3 survey and coring. Inset map shows location offshore Oregon. Red line is entire PS1705_L11 and blue is the portion shown in the figure. Black lines are other chirp lines and small squares are the four 1 km² boxes.

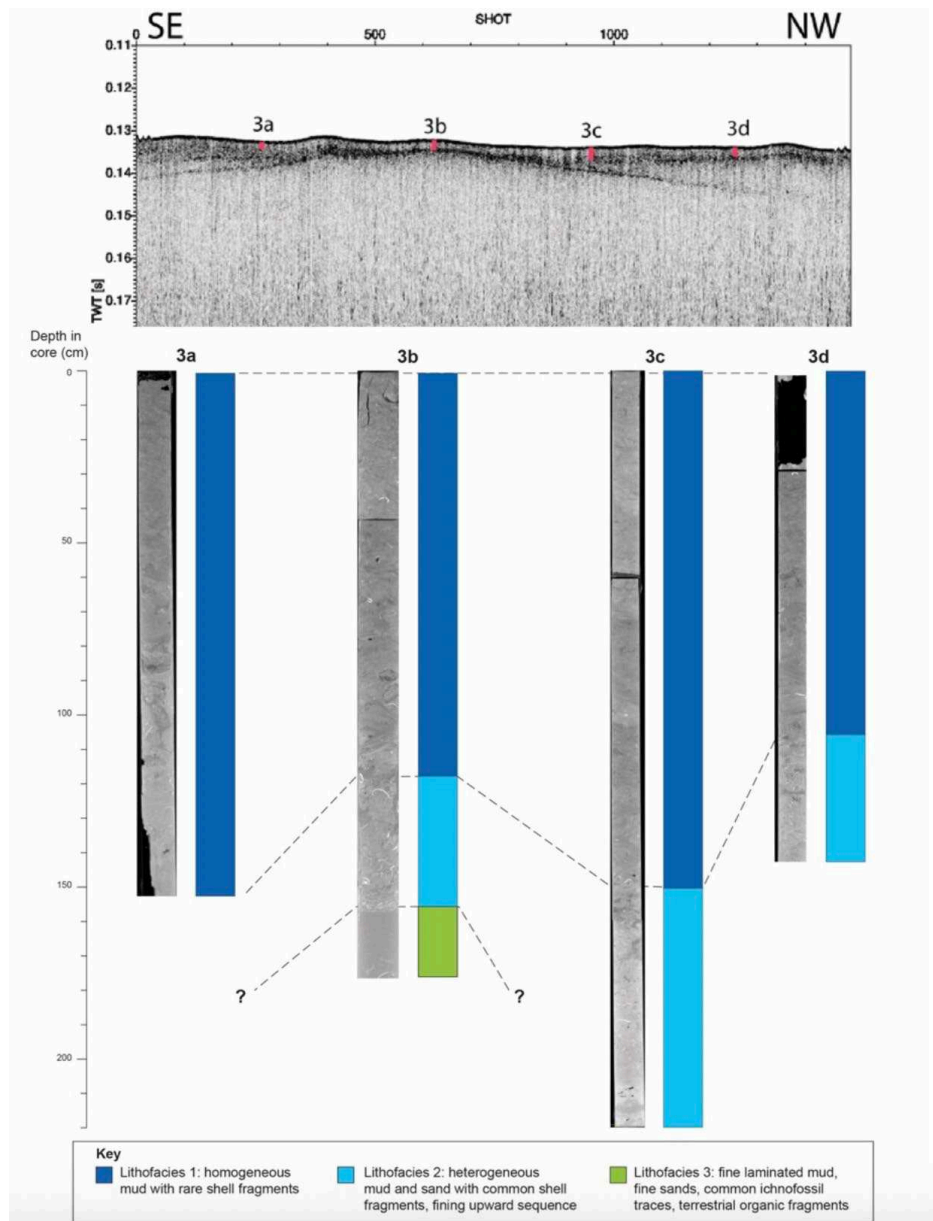


Figure 4.3.16 Box 3 cores (Davis et al., 2020:47)

Chirp line that transects all four core locations. Pink dots indicate approximate depth of penetration for each core. See Figure 4.2.1 for location.

4.3.4 Box 4: Umpqua large paleovalley

Box 4 was selected based on a regional line (PS1705_L17) that crossed the outer shelf portion of the Umpqua paleovalley (Figure 4.3.17). This valley is filled with layers of sediments that thin to the north. Box 4 was picked where these sediments thin to try and sample as many of the fill layers as possible (Figure 4.3.18). Core 4A has fine sand with some mud and sparse shell fragments at the top, then mud with sand and no shells, a sand layer with lots of shell fragments, then mottled muds, and fine sand with shells at the bottom. These oscillating sand-mud units are considered Lithofacies 1 based on an age of ~6.5 ka near the base of the core. Core 4B-01 was short, so Core 4B-02 was collected in the same location. Core 4B-01 is all mottled, homogenous mud (Lithofacies 1). Core 4B-02 has homogenous,

mottled mud at the top (Lithofacies 1) then laminated fine sand and shell fragments (Lithofacies 2), with mottled mud at the bottom (Lithofacies 3). Core 4C has some fine sand with mud at the top (Lithofacies 1), then is mostly mottled mud, with sand and shells at the bottom (Lithofacies 2). Core 4D has mottled mud at the top (Lithofacies 1) and fine sand with layers of shell fragments at the bottom (Lithofacies 2). Radiocarbon dates from Box 4 included several dates ~15 ka, as well as several dates older than 34 ka, which suggest reworking of these deposits.

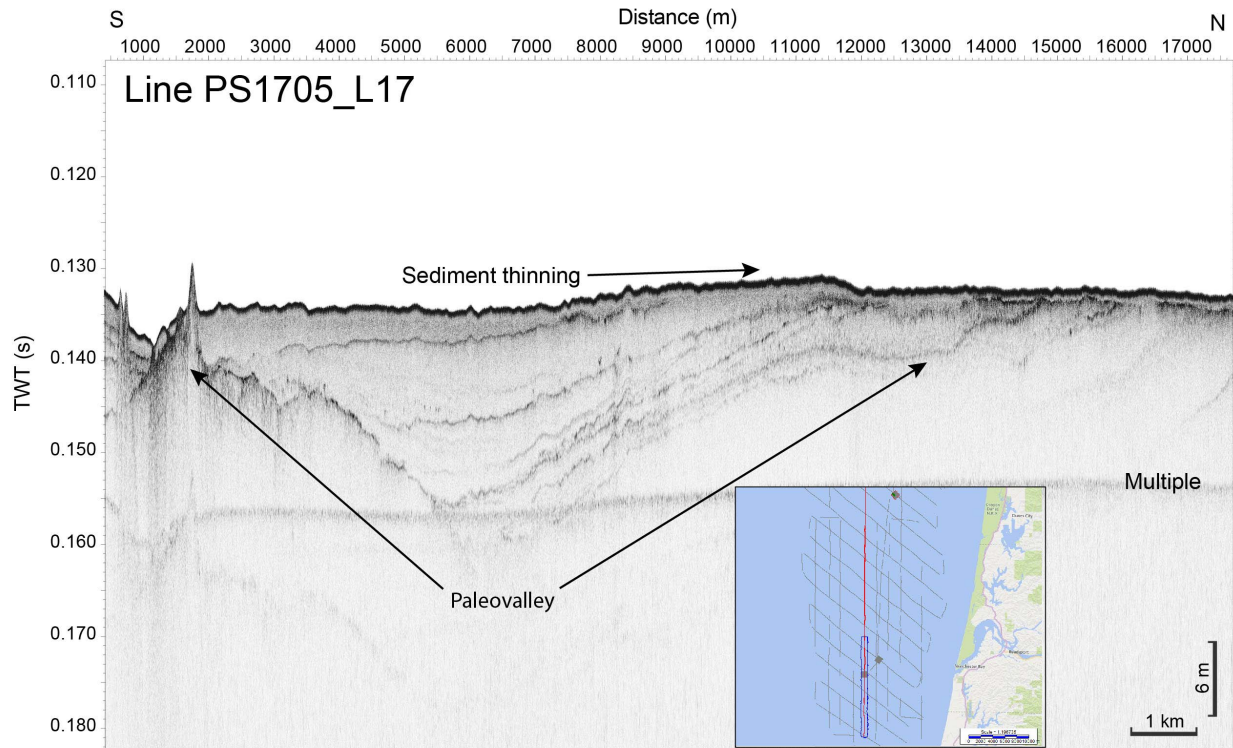


Figure 4.3.17 Chirp Line PS1705_L17

Shows small incisions that were targeted for Box 4 survey and coring. Inset map shows location offshore Oregon. Red line is entire PS1705_L17 and blue is the portion shown in the figure. Black lines are other chirp lines and small squares are the four 1 km² boxes.

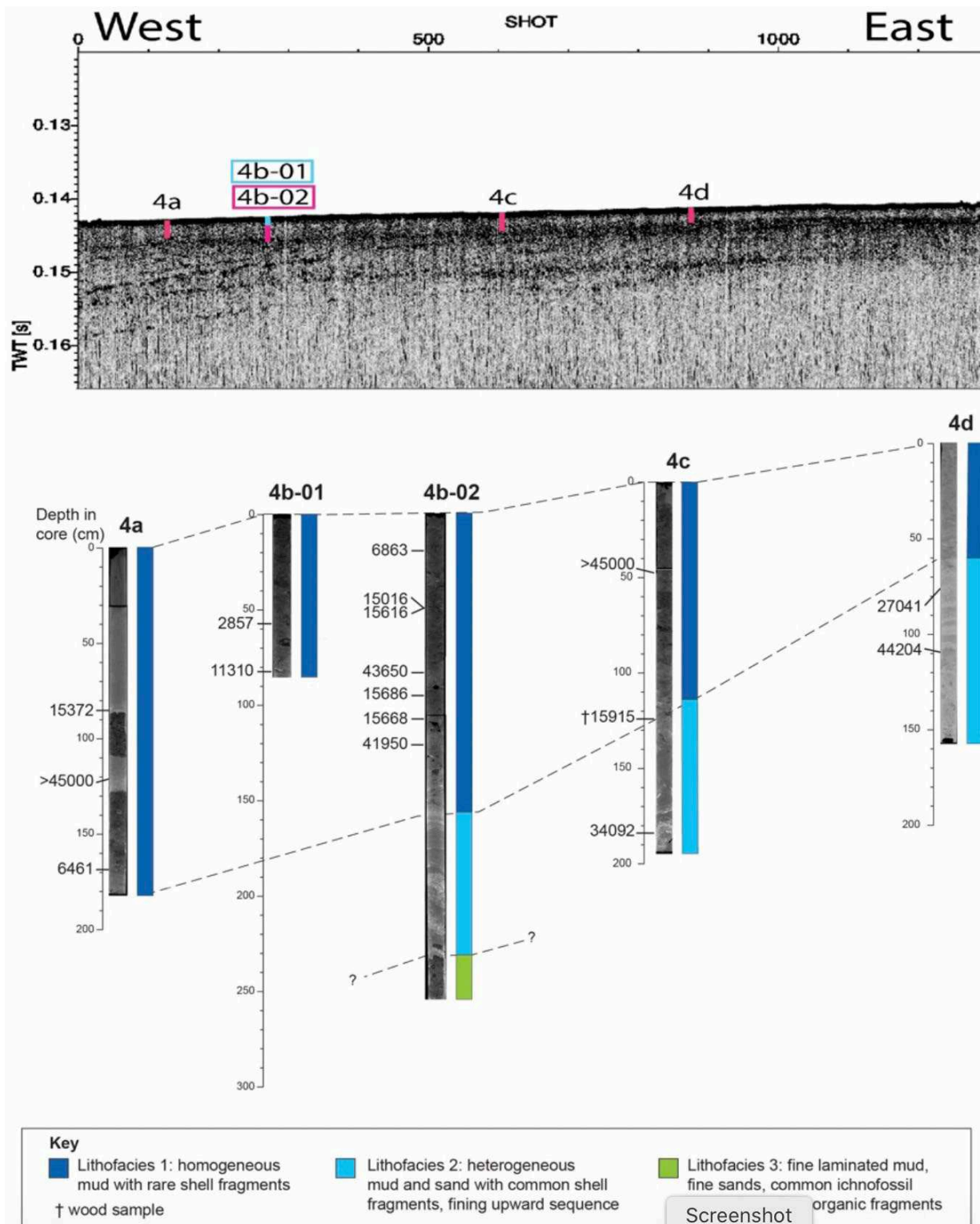


Figure 4.3.18 Box 4 cores (Davis et al., 2020:49)

Chirp line that transects all four core locations. Pink and blue rectangles indicate approximate depth of penetration for each core. Radiocarbon ages (at left of cores) shown in cal yr BP. See Figure 4.2.1 for location.

4.3.5 Oregon summary and recommendations

- Terrestrial and coastal paleoenvironments (pre-LGM sea level rise) were identified in chirp data and confirmed with sediment ground-truthing. These include Pleistocene-aged estuary, riverine, and adjacent floodplain environments (Lithofacies 3) that were submerged initially by higher energy tidal waters (Lithofacies 2) and ultimately beneath deeper water after sea level transgressed the shelf (Lithofacies 1).
- Adjacent river systems (Siuslaw and Umpqua) across the same margin can be expressed by very different morphology in their offshore, paleovalley extensions, as controlled by tectonic structures, shelf morphology, and drainage basin characteristics. As such, it is recognized that a single acoustic signature representing paleodrainages cannot be defined. Comparing the paleovalley signatures in Oregon to those in the NCI results in even more diverse acoustic signatures representing drainage systems.
- Identifying paleolandscape features is complicated by active tectonic structures, as described below:
 - Folded stratigraphy can resemble channel morphology
 - Faults and structures can influence paleochannel pathways
- Regional sub-bottom survey lines were critical for identification of paleolandscape features. The Umpqua paleovalley is up to 13 km-wide and the Siuslaw ES is mapped over an area larger than 10 x 10 km.
- Sediment core data were critical for ground-truthing sub-bottom data and confirming paleolandscape signals. A general identification of recovered paleoenvironments was possible with just the geologic descriptions of core units, combined with CT scans that helped to visualize different core features.
- Radiocarbon dates were helpful in interpreting depositional units, but several stratigraphic reversals indicate extensive reworking of sediment. More robust age models could be potentially resolved with microfossil radiocarbon dating.
- Based on the results from the Oregon, the following guidelines are recommended:
 - HRG surveys must include high-resolution sub-bottom data appropriate in penetration and resolution to the landforms anticipated. On the Oregon shelf, the Edgetech 512 chirp worked well.
 - Surveys should extend beyond just the area that could be impacted. If regional data exist, they should be reviewed and incorporated into the interpretation. If not available, regional-scale data across and adjacent to the potentially impacted area should be required. The observation of a 13 km-wide paleovalley indicates that regional survey lines of 20+ km parallel to the coast could be needed to fully interpret the landscape.
 - Qualified marine geologists should be employed to interpret geophysical and geological data as these data are critical for identification of paleolandforms and paleoenvironments. These geologists should work jointly with qualified archaeologists. Where critical environments are encountered, experts should be brought in for further analysis.
- Future work that could advance understanding of the Oregon shelf paleolandscape includes the following:
 - Microfossil radiocarbon dating to develop a more robust age model
 - Pollen and environmental DNA analysis on identified Pleistocene sediment from coastal and terrestrial environments
 - Incorporation of MST and XRF data into paleoenvironmental interpretations.

5 Task 6: Model revision and final analysis

Based on fieldwork and analysis, the final step in the project was to revise and update the GIS predicative model.

5.1 Revised GIS predictive model for Pacific Coast submerged cultural resources (Davis et al., 2020)

After the initial model creation, a subsequent GIS predictive model was developed with additional datasets gathered. While the original model considered data that archaeologists thought could be of interest based on previous research, the 2021 model took a different approach. A large number of different spatial datasets related to regional biology, geology, and hydrology were compared with known archaeological site locations to examine any spatial correlations. Spatial datasets where correlations were observed were then combined to make a predictive model of possible archaeological site locations.

1. One hundred and two known archaeological sites in the NCI were added as a series of points denoting site centroids and polygons representing site boundaries. Point data were buffered using a circular 50-m radius buffer to create one polygon per site. Centroids were calculated for sites with smaller extents than 7,500 square meters that were then buffered to 50-m circular radii.
2. Spatial datasets to be compared for correlations to archaeological site locations were added to the model. Datasets that were ubiquitous (such as animal habitat ranges) across the entire NCI were then removed as they would not have predictive power on the model.
3. Relative sea level rise (RSL) LGM stream network estimations were generated by merging a terrestrial DEM with high-resolution bathymetry. These data were smoothed using focal statistics as available bathymetry was plagued with data artifacts. Path distance rasters were then generated using this merged LGM dataset (Figure 5.1.1).
4. Using a DEM, a series of path distance rasters were created for each feature for the current NCI extent. Bathymetric data were combined with terrestrial data to calculate offshore resources such as kelp beds that would otherwise be disconnected from the terrestrial DEM (Figure 5.1.2).
5. Using the zonal statistics as table command, mean values were collected for each path distance raster where site polygons overlaid said raster.
6. Non-path distance data, such as aspect, were also calculated by recording mean values of each resource using the zonal statistics as table command. Mean aspect of sites was calculated using version 6 of Carl Beyerhelm's python script (see <https://community.esri.com/t5/arcgis-spatial-analyst-questions/calculate-mean-aspect-for-polygons/td-p/67951/>, accessed 2015) to calculate zonal mean aspect (Figure 5.1.3).
7. Statistical moments (mean, variance, skewness, and kurtosis) of the zonal statistics collected previously were then compared to overall raster path distance values for each resource. Datasets that diverged between zonal statistics moments and overall path distance moments were retained for further graphical examination.
8. Upon examination, if resources appeared to correlate with site locations, they were transformed via a log base-10 transformation. This transformation was applied to help alleviate any issues of scale between datasets. After transformation was applied, an additive raster calculation was performed summing all path distance rasters into a single raster. Non-path distance rasters (slope, aspect, and solar radiation) that appeared to have predictive power were reclassified to a 1 to 3 value with 1 being

the most predictive and 3 the least predictive based on observations. These rasters were then summed, forming a single predictive layer for potential site location of the current NCI.

Upon model completion, the same techniques and resources were leveraged for offshore locations that were projected to be terrestrial at the LGM (Figure 5.1.4; Figure 5.1.5; Figure 5.1.6).

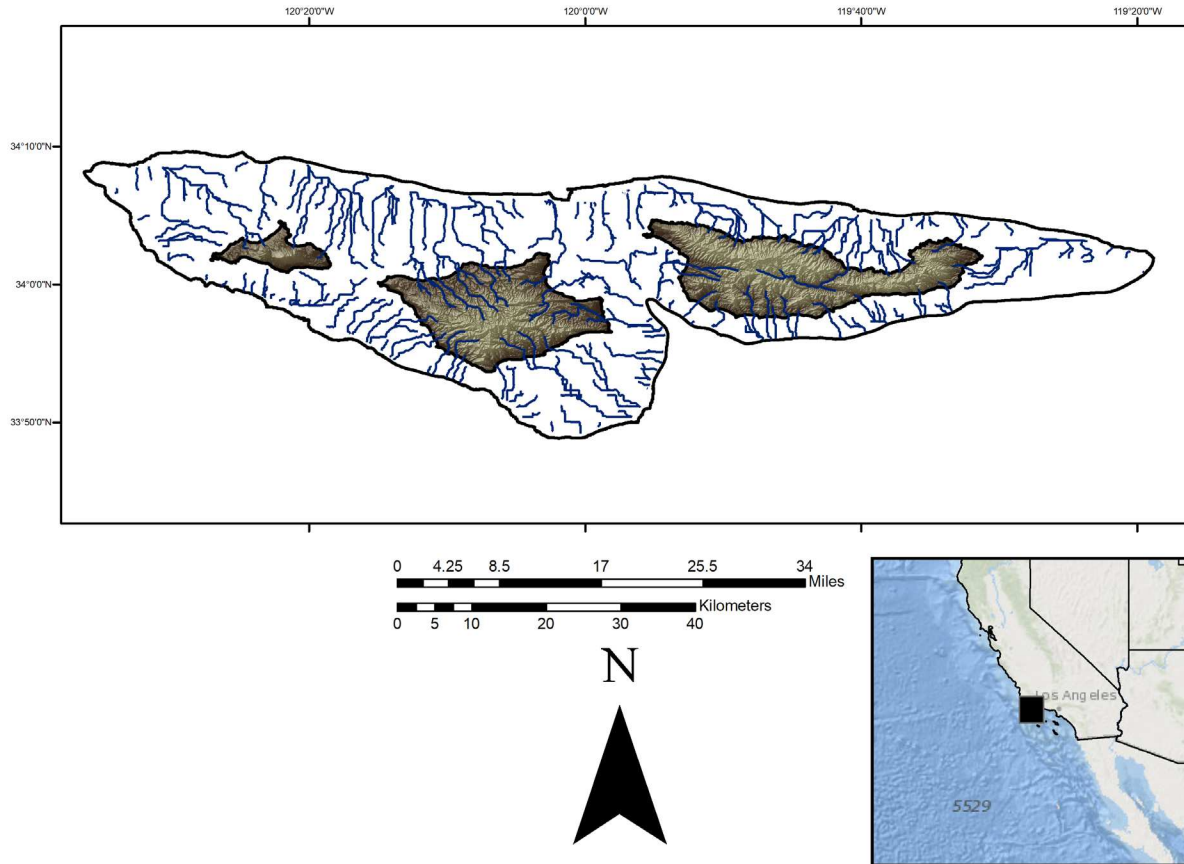


Figure 5.1.1 Generated LGM stream network for the Northern Channel Islands

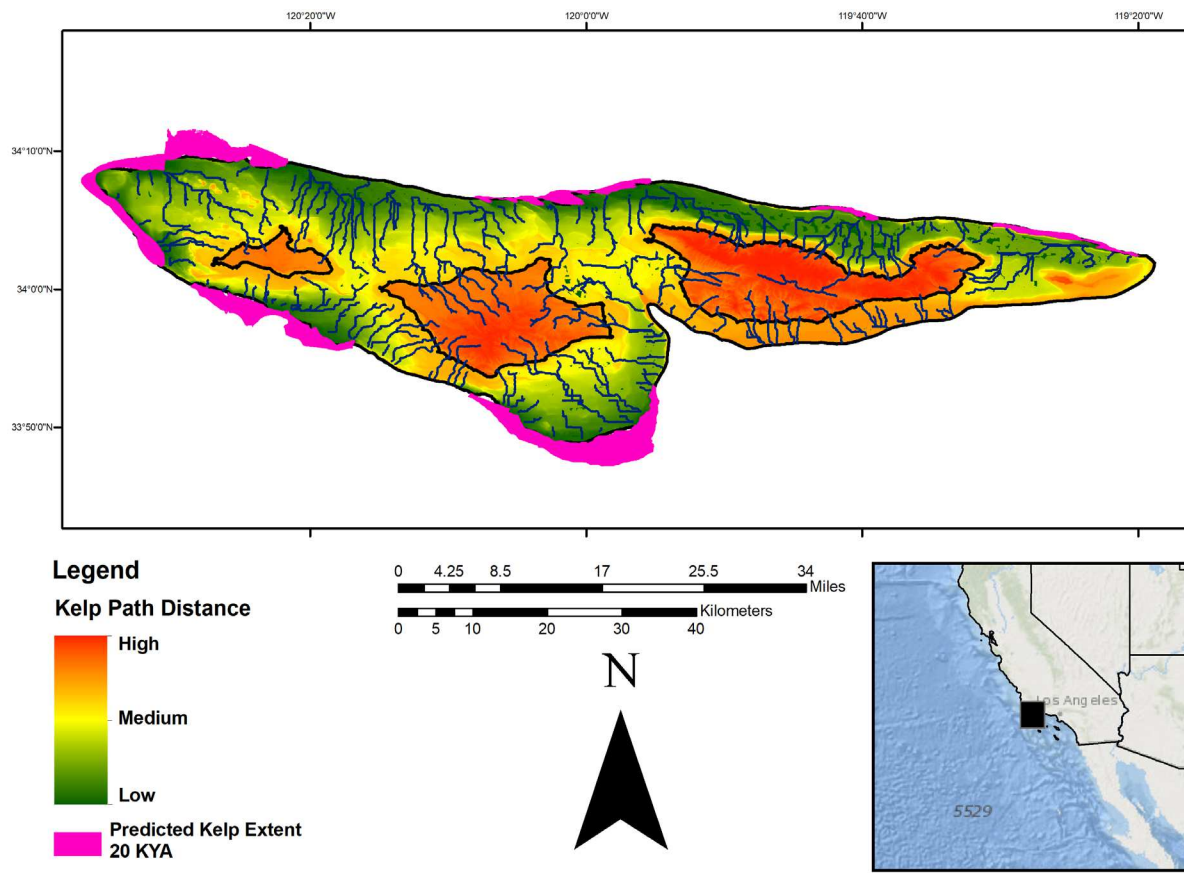


Figure 5.1.2 Digital elevation model with estimated kelp bed extent at 20 ka shoreline (salmon color polygons)

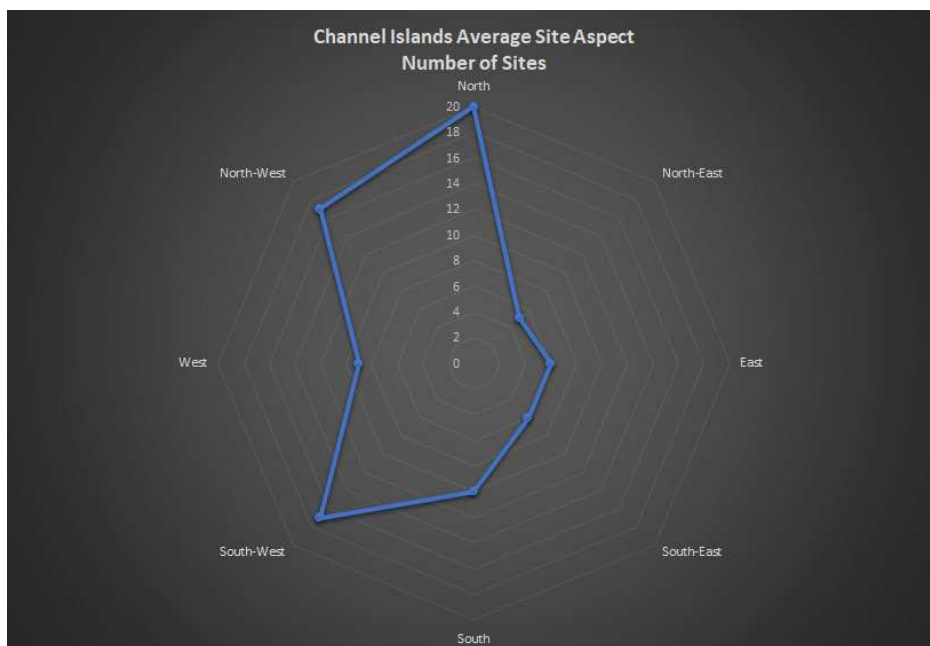


Figure 5.1.3 Mean zonal aspect

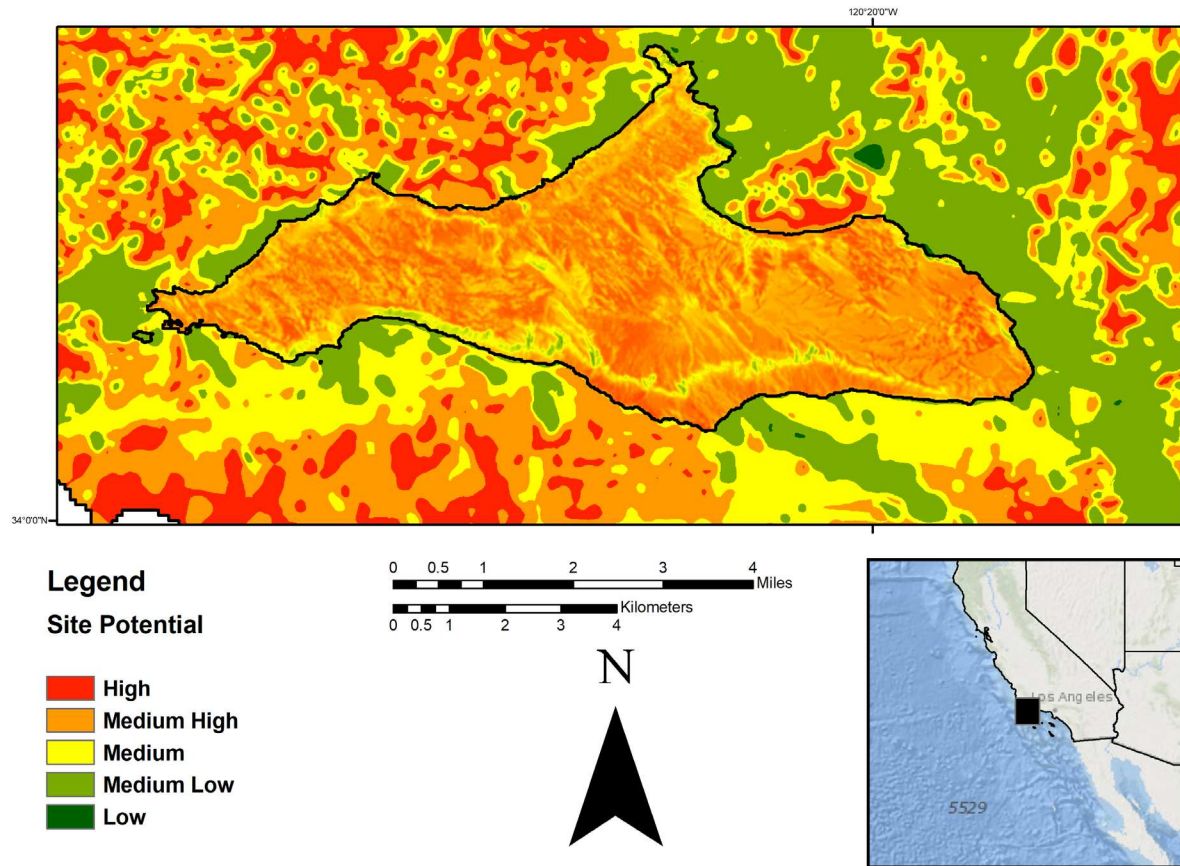


Figure 5.1.4 GIS predictive model of archaeological site potential offshore San Miguel Island

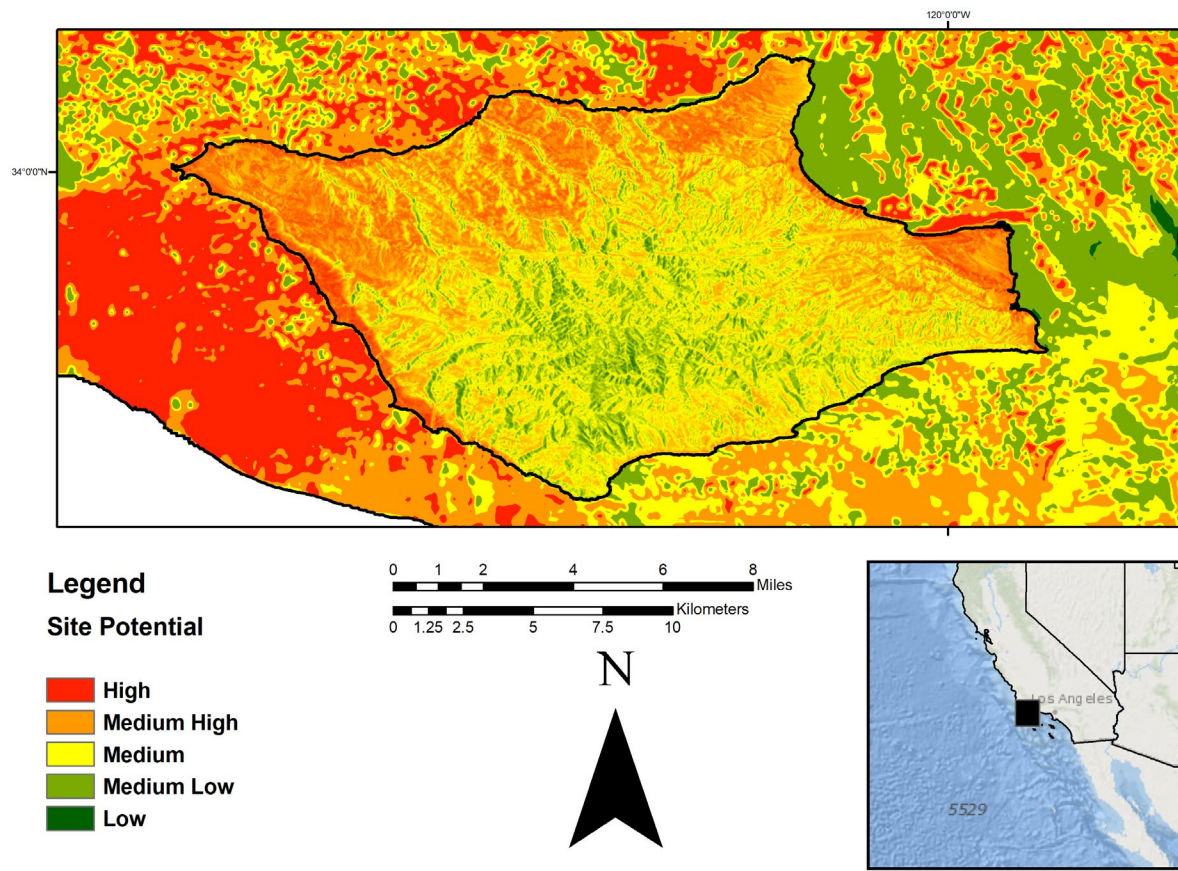


Figure 5.1.5 GIS predictive model of archaeological site potential offshore Santa Rosa Island

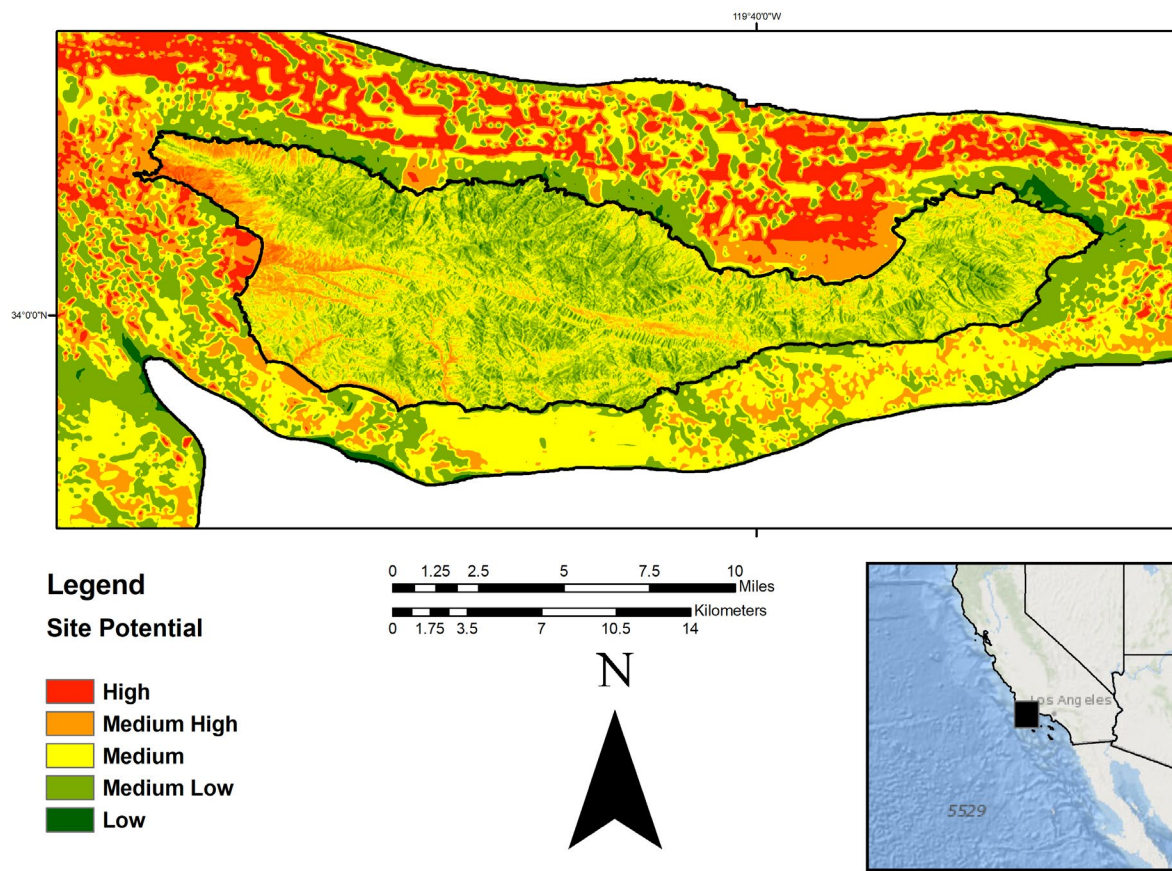


Figure 5.1.6 GIS predictive model of archaeological site potential offshore Santa Cruz Island

5.2 Recommendations for offshore survey and testing parameters methodology

The discovery of intact terrestrial and estuarine deposits preserved beneath the marine sediments on both the NCI platform and central Oregon continental shelf provides a “proof of concept” that: (1) these regions, and others along the U.S. Pacific Coast, likely contain intact submerged terrestrial archaeological sites of Early Holocene and terminal Pleistocene age; and (2) terrestrial sediment and archaeological sites survived the effects of rising seas and active transgression that included strong submarine currents and an often turbulent Northeast Pacific surf zone. This discovery indicates that any future development on the POCS that would disturb the seafloor and sub-seafloor should first require an investigation for preserved paleolandscape features and pre-contact archaeological sites. The following section outlines BOEM’s guidelines to identify archaeological sites on the OCS and recommendations for future guidelines based on lessons learned in this effort.

BOEM’s guidelines require an archaeological survey that employs both HRG survey techniques and geotechnical testing. The guidelines also require that a qualified marine archaeologist should be involved in survey design, data analysis, and interpretation. The primary objective of these surveys was to identify areas that have a high potential to contain intact archaeological features/resources and avoid impacts on those from offshore energy/mineral exploration/development. It is assumed that the areas with highest potential to contain intact pre-contact archaeological sites on the continental shelf are areas containing preserved landforms and sediment that formed prior to sea level inundation. Because these landforms are identified by their geomorphology and sedimentology using geophysical and geological techniques, **it is**

recommended that a qualified marine geologist be required to work with the qualified marine archaeologist for survey planning, data analysis, and interpretation.

The scientific team's work demonstrated the high likelihood of finding intact paleosols in submerged contexts. Since these paleosols could contain the preserved remnants of paleocoastal archaeological resources, **it is recommended that consultation and collaboration with appropriate Tribal authorities and stakeholders be an integral part of future research.**

Details of the HRG survey and geotechnical testing are further discussed below.

5.2.1 HRG survey guidelines

Current guidelines require that the area surveyed for archaeological identification purposes should be large enough to cover any portion of the project area that could be affected by the activities proposed. The HRG surveys conducted as part of this work indicate that **it could be necessary to survey an area larger than the impacted area to provide geological context for observations.**

In this study, the sub-bottom surveys successfully imaged several submerged landforms including paleochannels, paleoshorelines, and estuarine deposits. Because neither area had extensive existing sub-bottom data, the team first collected regional survey transects to identify target areas for more detailed mapping and sampling. These regional lines were critical for providing context for smaller-scale landform features. For example, in the NCI, a regional transect imaged a complex set of features within SCP (Figure 5.2.1). Near the center of the passage, a series of four small v-shaped channels were observed that appear linked with thick fluvial valley sediments offshore from Santa Cruz Island via a highly erosive, possibly subaerial or fluvial surface. The four v-shaped channels span the width of about 1 km. Due to their small extent, the likelihood of locating these features without regional survey lines is low. Additionally, the regional line provides context indicating a connection between the v-shaped channels and fluvial deposits to the east, allowing for better mapping of the larger-scale feature and identification of sub-environments. Another example from Oregon is shown in Figure 5.2.2. Here, the regional sub-bottom profile captured a ~13 km-wide valley offshore from the Umpqua River. However, the 1 km-long profiles from Box 4 do not offer evidence that they are within a large channel complex. If only the 1 km² box was surveyed it would be difficult to identify conclusive evidence of a fluvial environment. Without the regional line, these locations could easily be misinterpreted, and a fluvial environment would be missed.

It is difficult to recommend specific lengths and spacing for more regional lines as it could depend on the specific location and size of the proposed activities. However, in areas along the open continental margin, especially those with large modern river systems, regional lines up of 15-20 km could provide sufficient information. The spacing could be coarser than the survey within the proposed activity area, but again this would depend on the size and location of the activities. It would be helpful for the regional survey to cross the area of proposed activities with at least two lines each in orthogonal directions to tie the regional observations into the smaller survey area. It is recommended that a qualified marine geologist, particularly one with expertise in the survey area, be involved in the survey planning process to assess the length and spacing of these regional surveys. If existing high-resolution regional sub-bottom data are available, they would be adequate to use for the regional survey, assuming they are high enough quality for accurate interpretation as assessed by a qualified marine geologist.

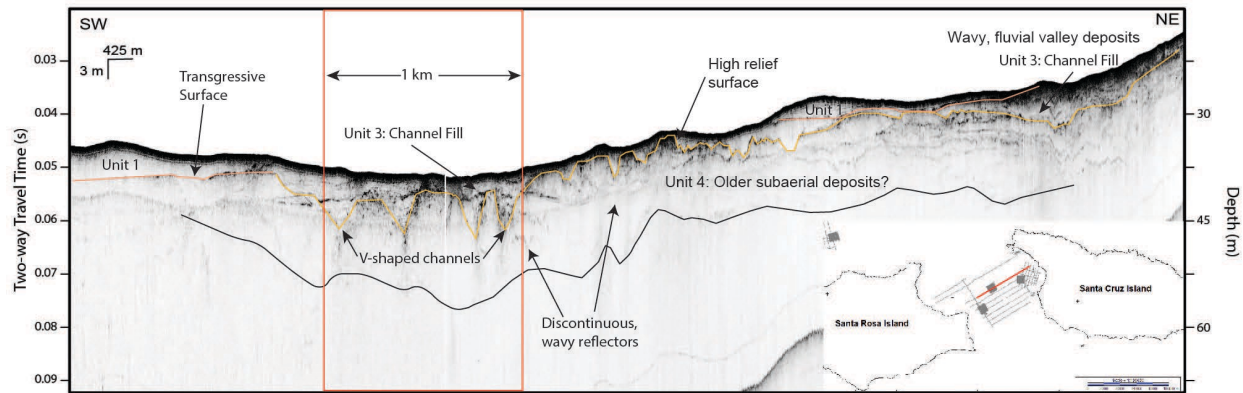


Figure 5.2.1 Regional vs. 1 km line in the NCI

The regional line shown here is ~5.5 km long. The red box shows the location of the 1 km line within Box 5. If only the 1 km line were available, the v-shaped valleys would likely be recognized, but the broader landscape interpretation of how these connect to other fluvial environments would be missed. Inset map shows regional line in red. Box 5 is the square box on top of the red line, showing where they overlap.

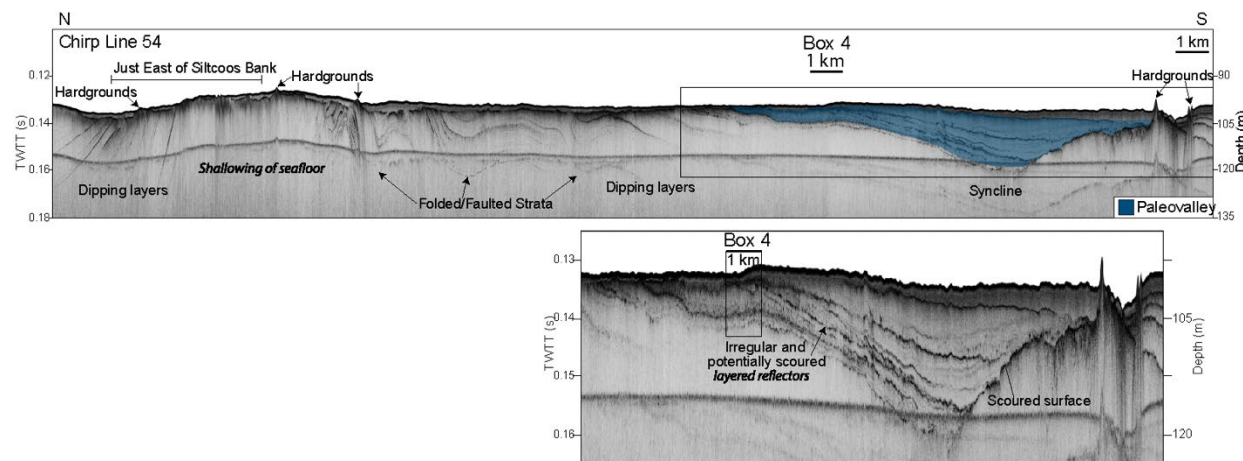


Figure 5.2.2 Regional vs. 1 km line in Oregon

Modified Figure 6 from Klotsko et al. 2021. See Figure 4.1.1 for location. Top shows regional chirp line 54 that is ~35 km long. The Box 4, 1 km bar shows the location of an overlapping 1 km-long survey line from Box four. The black box at right shows zoomed-in profile below. The blue fill shows the interpreted 13 km-wide paleovalley of the Umpqua River. Bottom shows zoomed-in profile from extents marked by black box in top figure. The Box 4, 1 km rectangle shows the location of an overlapping 1 km-long survey line from Box 4. If only the 1 km-long line were available, it would be difficult to interpret as fluvial in origin. The longer line provides context for the deposits being related to a channel feature.

Within the proposed activity site, current guidelines require 30 m line spacing with 500 m spaced orthogonal tie lines. In this work, the small-scale surveys used 25 m line spacing. This tight spacing means that small-scale anomalies are more likely to be imaged compared to a coarser spacing and that stratigraphy can be mapped in detail that approaches 3D coverage. These are valuable outcomes in areas that are thought to have a high likelihood of containing archaeological sites, or where there is a high amount of variability in stratigraphy (e.g., complex environments). For example, middens are expected to be anywhere from ~1 to 10 m or more in diameter and could be missed with coarse grid spacing.

However, as the goal is to identify broad-scale landform features that could have a high potential to contain archaeological sites, a coarser spacing could be sufficient. As an example, the team mapped the Oregon Box 2 stratigraphy across all 25 m spaced lines and were able to identify a topographic low in the “rough surface” that was interpreted as fluvial in origin based on the longer regional profiles across the area (Figure 5.2.3). The detailed mapping showed a northwest-trending topographic low in the western corner of the box (Figure 5.2.3C) that was filled with a chaotic unit (Figure 5.2.3D). The map also showed a small northwest-trending ridge within the low, and possibly two smaller channels bifurcating to the northeast (Figure 5.2.3C). Nevertheless, these same features were still captured in the grids that used 50 m and 100 m spacing (Figure 5.2.4). At 200 m and 500 m spacing, the topographic low and ridge are still visible, but the bifurcating channels are less clear. At all grid spacings shown, the broader interpretation would be the same: a topographic low filled with a unit that has a more chaotic acoustic character relative to transparent marine sediment above. Additionally, at all grid spacings, the short line length raises questions about this landform feature, such as: do the bifurcating channels pinch out to the north? How large and thick does the topographic low become to the south? Does the ridge separate two distinct topographic lows? Longer and more coarsely spaced lines could help to answer these questions.

As with the regional survey above, it is difficult to prescribe a universal set of spacing and length requirements, as site conditions can vary. Additional investigations could help develop more optimized spacing and length minimums. These investigations could involve focusing on a set of different landforms and conducting surveys that explore the extents of each given feature. Once the extents are known, a 30 m spaced survey across the feature could be conducted and a similar analysis of different spacings as above could be assessed. In any case, **it is recommended that time should be allowed for geophysical data to be processed and interpreted before any sampling is conducted. At this time, the qualified marine geologist and archaeologist should assess the need for and recommend additional surveying as needed.**

BOEM guidelines require a sub-bottom profiler, gradiometer, and side-scan sonar as part of the HRG surveys. This project included a sub-bottom profiler, side-scan sonar, and multibeam bathymetry system. Most useful for the interpretation of paleolandforms was the sub-bottom data, but the bathymetry and side-scan data aided in the interpretation. If multibeam data are available for the area, it is recommended that those data are reviewed and used during survey planning and assessment (<https://www.ncei.noaa.gov/maps/bathymetry/>). Some of these data became available around the NCI after HRG surveys were conducted, and they provide insight into many of the local features observed in the sub-bottom data (e.g., Figure 3.5.8; Figure 3.5.30). The guidelines recommend “state-of-the-art navigation systems with sub-meter accuracy and sub-bottom systems capable of achieving a depth of penetration and resolution of vertical bed separation that is sufficient to allow for the identification and cross-track mapping of features of archaeological potential,” and are supported by this work. The team also agrees that chirp is one of the best options for these surveys, but deeper penetrating systems could also be necessary in certain conditions.

There are several different options for chirp sonars that vary in size and frequency range. The team employed an Edgetech 512i sub-bottom profiler that generates different frequency pulses between 0.5 and 15 kHz. Edgetech also makes a 216 instrument with frequencies that vary between 2 and 16 kHz, and a 424 instrument with frequencies that vary between 4 and 24 kHz (<https://www.edgetech.com/>). The higher-frequency ranges generally offer higher resolution, but lower penetration depth. Parametric sub-bottom profilers are also available, which emit different frequency pulses simultaneously that interfere with each other in the water to create a new frequency pulse. These systems are available at a variety of depth and resolution ranges (e.g., <https://www.innomar.com/products.php>). Their main advantage is a narrower beam width compared to the chirp systems. For example, the Innomar “standard” parametric sub-bottom profiler has a 2 degree beamwidth compared to the Edgetech 512i which has a ~15 degree beamwidth. This results in less noise and better across track resolution. There are also more options for

high density and 3D high-resolution sub-bottom surveys including with chirp (<https://www.sandgeophysics.com/3d-chirp/>) and parametric sonars (<https://www.innomar.com/sbp-sixpack.php>). These 3D datasets could be useful for mapping the extent of anomalies, or for more detailed mapping of landforms and environments. For example, cores recovered fluvial sediment in the NCI and estuarine sediment in Oregon, but fluvial and estuarine environments are complex in space and time. Targeted 3D data across these features could map the complex sub-environments to further refine search areas.

In this study, while the sub-bottom data did capture numerous acoustic anomalies (e.g., small, highly reflective features that stand out from the overall acoustic units), the anomalies either could not be sampled due to depth, thickness of marine sediment, or poor recovery, or when sampled, they did not appear to represent anthropogenic signatures. Additionally, several anomalies were observed that could not be sampled due to time and budget constraints. The observed anomalies could represent various natural features including shell beds, pockets of gassy sediment, or rocky outcrops. To explore this issue of non-uniqueness, a larger suite of geophysical tools could be employed that would detect different characteristics of the anomalies. The sub-bottom systems use chirp sonar, which measures the acoustic impedance of material, but landforms and archaeological sites could also be identified by different magnetic and electromagnetic signals.

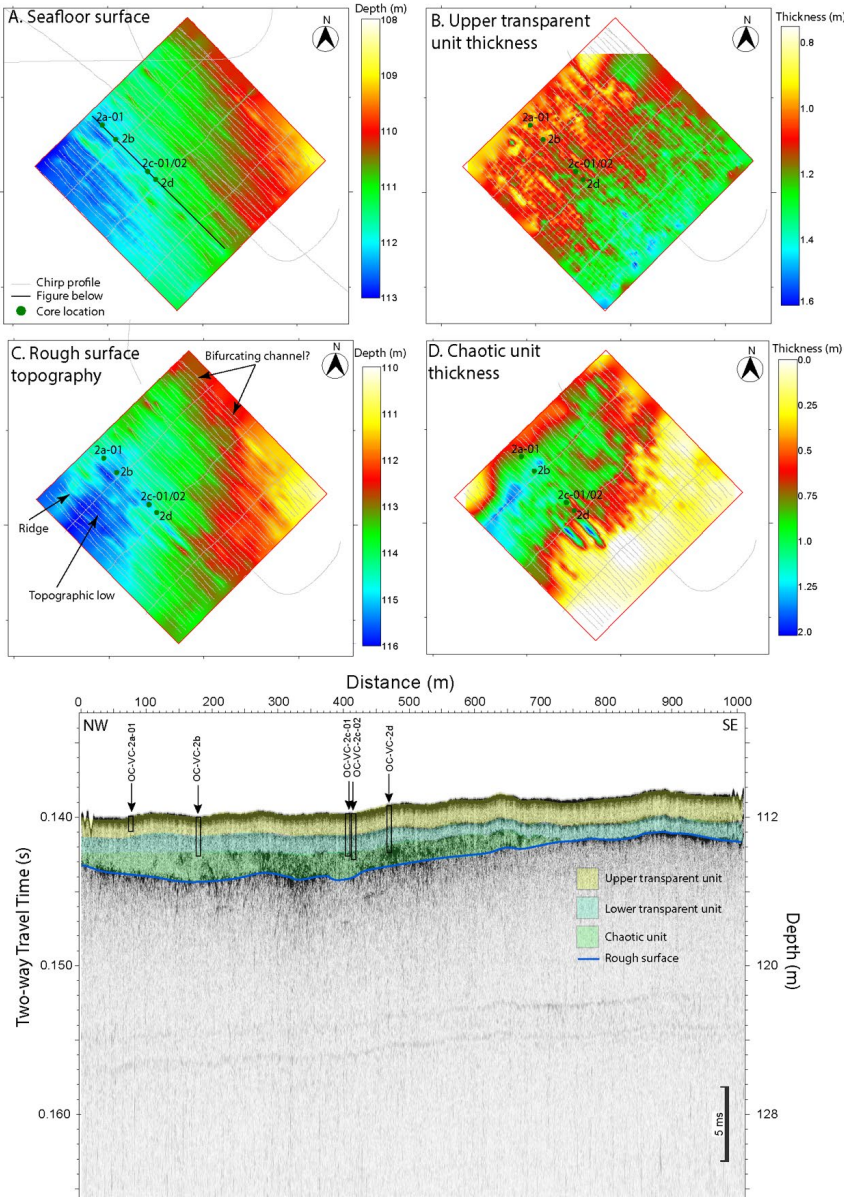


Figure 5.2.3 Oregon Box 2 detailed mapping

Grids of A – Seafloor depth; B – thickness of upper transparent unit; C – rough surface depth; Chaotic unit thickness. Lower chirp profile shows character of mapped surfaces and units. Profile trends SE-NW across all cores from Box 2. Cores are shown on chirp profile as black labeled rectangles. See Figure 4.2.1 for location.

As an extension of this project, the PIs have explored the use of controlled source electromagnetic systems (CSEM) in conjunction with sub-bottom profilers. CSEM systems can detect differences in resistivity of sub-seafloor sediment. Some common reasons for resistivity differences are presence of hydrocarbons, fresh or brackish pore water, or changes in porosity. Tar seeps and freshwater sources would have been important resources for people living on the exposed continental shelf and CSEM data are much better at detecting these compared with sub-bottom profilers. Additionally, very high-resolution CSEM could be used to detect porosity changes expected in midden deposits. The PIs have collaborated with Steven Constable at Scripps Institution of Oceanography to develop such a system, which is

currently in the field trial phase. An instrument such as this could be employed along with sub-bottom systems to better capture signals of hydrocarbons and freshwater, which indicate landscapes with high potential of containing archaeological sites. Furthermore, a very high-resolution CSEM system could help identify if acoustic anomalies captured in sub-bottom data could represent middens.

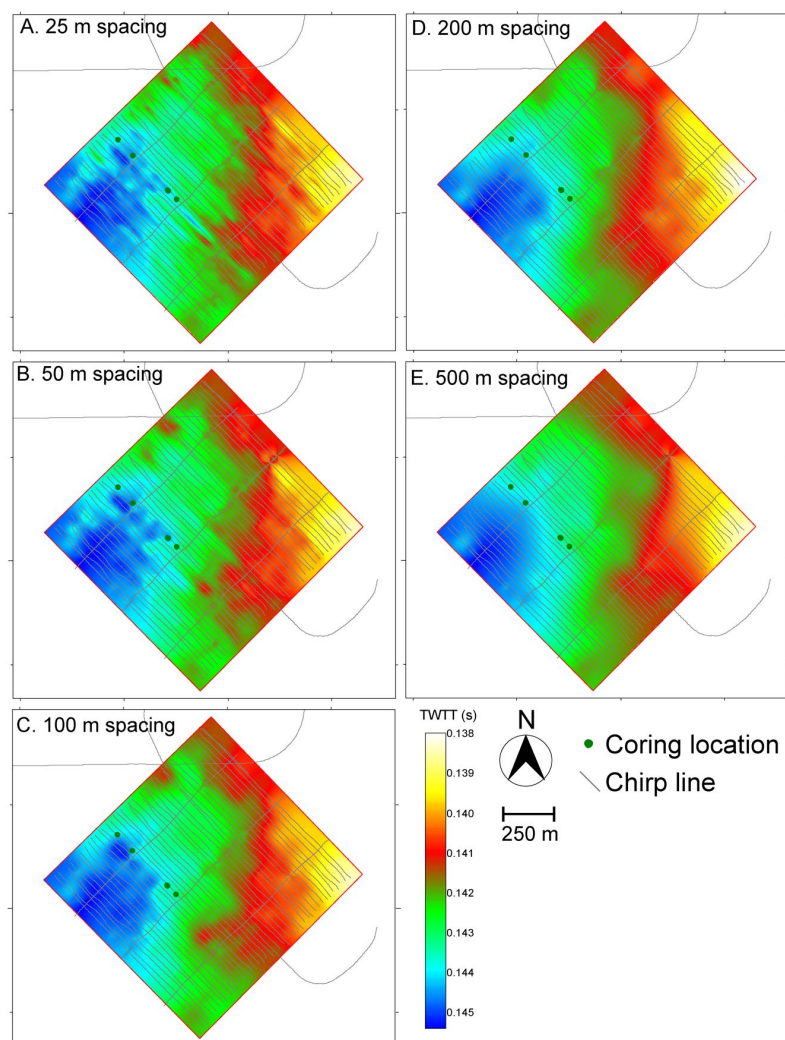


Figure 5.2.4 Oregon Box 2 rough surface mapping at different grid spacing
See Figure 4.2.1 for location.

5.2.2 Geotechnical investigation guidelines

The scientific team agrees with guidelines recommending HRG survey prior to geotechnical testing with the HRG survey data guiding the geotechnical testing. Geotechnical sampling should be conducted in consultation with a qualified marine archaeologist and marine geologist. The team also agrees that sampling method depends on site conditions.

In this work, due to the expected sandy sediment of the continental shelf, a Rossfelder P-5 vibracore was used for all coring. This vibracore uses electricity provided by the ship to operate two vibrating motors inside the vibracore head that vibrates a steel core tube, allowing it to sink into the sediment. Vibracores are best for sampling unconsolidated, water saturated, coarse sediment (sand size) compared to other

coring options like gravity, multicore, box core, and piston core. The P-5 vibracore uses a buoyant frame that does not require as much deck space as other options with rigid frames. In areas with strong currents, a ship that can maintain position over the vibracore while it is deployed is essential. On the first attempt to core with the P-5 aboard R/V *Sproul*, the ship drifted off station, which caused a weak link in the winch cable to break and the instrument was lost on the seafloor. Fortunately, it was recovered during a subsequent cruise aboard R/V *Sally Ride* and coring for the rest of the project was conducted from ships equipped with dynamic positioning to maintain position.

The core targets were selected based on numerous factors, including the thickness of marine sediment above the target. In the NCI study area, the longest core recovered measured 219 cm, and in the Oregon study area it measured 309 cm. However, most core lengths in both locations were less than 200 cm (~91% in NCI and 79% in Oregon) and some core locations did not recover any sediment (5 locations in NCI and two in Oregon). Vibrating time on the seafloor was extended to attempt deeper recovery, but beyond 60 seconds, little advances were made. Based on the core contents and sub-bottom data, core refusal seemed to occur at coarse layers, shelly layers, consolidated clay layers, or at the reflector interpreted to be the subaerial exposure surface which may represent harder material. The cores that did recover fluvial and estuarine sediments penetrated into targeted units with different acoustic signatures than the upper transparent marine unit. These acoustic units were not laterally extensive, suggesting terrestrial and coastal deposits may only be present on the shelf in isolated locations with higher preservation potential. There are alternative vibracore systems that could also be used to attempt deeper penetration, including those with hydraulic power systems and larger rigid frames (e.g., <https://oceaninstruments.com/product-category/purchase-equipment/vibracores/> and <http://www.alpineocean.com/services/vibracore-geotechnical-services/>). Alternative coring methods could also be attempted, but vibracoring is generally considered the best option for the types of sediment encountered. A number of gravity core attempts were made in the NCI from R/V *Sproul*, but no sediment was recovered.

For sample analysis, current guidelines require geologic logging of the cores with recommendation of other analysis to best inform archaeological interpretation. In this work, core analysis included CT scans, core imaging, visual core logging, multi-sensor core logging (MS, density, resistivity), XRF, radiocarbon dating, and grain size analysis. Ultimately, the identification of non-marine material was first made through visual core logging by team geologists. The 3D CT scans were helpful at imaging stratigraphy and sediment structures, large sediment (gravels and pebbles), and shells. Although the scientific team did not observe anthropogenic features in the cores, the CT scans would be a good method for detecting and imaging artifacts as they could be observed in 3D without disturbing the core material. The core images were useful for interpretation and core visualization. **The combination of visual core logging and CT scans were most useful for identifying non-marine material.** The most useful measurement from the multi-sensor core logger was the MS, although a characteristic MS signature for different environments was not identified and increases in MS appeared mostly related to increased grain size. Measurements of P-wave velocity are useful for converting TWTT to depth or thickness in sub-bottom data when accurate depth measurements are required. The XRF data did appear to show different elemental patterns between marine and non-marine deposits, which could be used to identify other non-marine deposits (Figure 3.5.42). However, elemental abundances can vary for many different reasons and identification of terrestrial deposits based solely on XRF data could be difficult, especially as there may be a variety of different terrestrial environments preserved, each with its own signature. Grain size analysis was useful for interpretations of depositional environment, but grain size varied across both marine and non-marine deposits, making identification of terrestrial deposits based solely on grain size difficult (Figure 5.2.5). This is due to the many variables that could affect grain size in both marine and non-marine environments. In marine environments, the sediment source, water depth, and oceanographic conditions all influence grain size distribution, while terrestrial environments can have highly variable sub-

environments (e.g., fluvial systems with sand-gravel grained channels, sandy levees, and muddy floodplains).

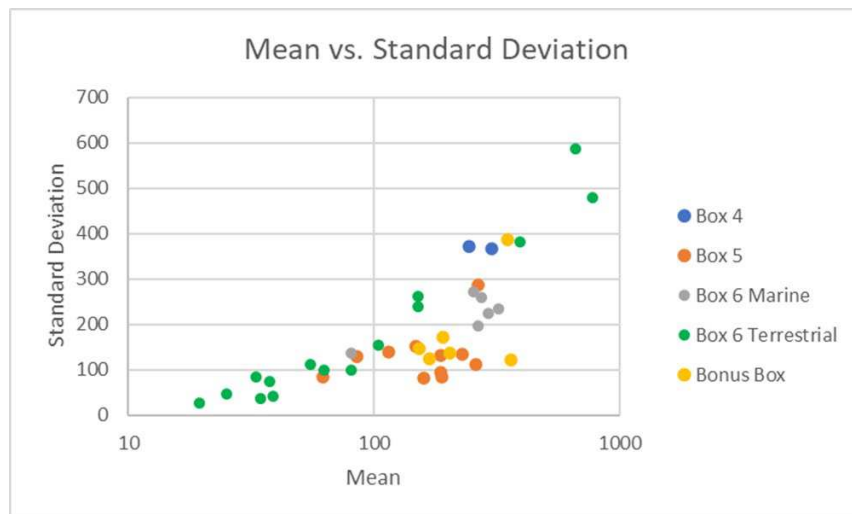


Figure 5.2.5 Plot of grain size statistics mean (in microns) vs. standard deviation (sorting) for NCI cores

There was high variability within sediment units and a distinct environmental signature could not be identified.

Radiocarbon dating of cores that contained shell and wood material was straightforward and provided reliable dates. Some reversals were observed where older material was located above younger material, likely due to reworking. The fluvial samples did not contain shell material, or any obvious pieces of organic matter or charcoal. Bulk sediment samples could be collected and sent for radiocarbon dating, or the sections of sediment could be investigated under a microscope and picked through for pieces of organic material. Bulk sediment radiocarbon dating can sometimes provide misleading dates because of mixed organic carbon sources (e.g., older carbon during deposition and younger carbon from plants later rooted in the same deposit). Optically stimulated luminescence dating is another option for dating material that does not contain enough organic material. The radiocarbon dates were useful in the interpretation of environments and for isolating the timing and depth of transgressive deposits even when deeper units were not reached with the core. **Radiocarbon dates could be included as a stronger recommendation in the guidelines**, ideally with dated material pulled from identified non-marine deposits, or at least regularly down the core to estimate sedimentation rates.

5.2.3 Paleolandscape reconstruction

BOEM currently requires a paleolandscape reconstruction for site surveys based on HRG and sampling data. These guidelines appear adequate for an understanding of archaeological potential within the impacted area. However, as recommended above, **more regional data may need to be incorporated into paleolandscape reconstructions for geographic context and understanding of how the site fits into the broader paleolandscape.**

While large-scale digital models of paleoshorelines and paleochannels generated from bathymetric data are useful tools because they can be generated with existing (and sometimes the only available) information that covers large areas, this work shows that these models should be considered first-approximation reconstructions as they may mis-represent shoreline and channel locations in areas with marine sediment cover. Additionally, because of the potential erosive actions of marine transgression, the

physical evidence of these geomorphic features is not always preserved on the continental shelf, although it may be present in the digital model. Where high-resolution sub-bottom data are available for use prior to embarking on geophysical data collection surveys, the thickness of marine sediment and/or the depth to the subaerial exposure surface can be mapped and incorporated into digital paleolandscape models to improve shoreline predictions. Information learned in this study about drainage patterns, geology, and shelf morphology could be included in future paleolandscape models to better predict the likely morphology of channels submerged on the shelf. Digital models are an important part of the process the team used to reconstruct coastal paleolandscapes and provided many testable hypotheses that were confirmed or rejected by subsequent geophysical cruises. These digital models of coastal paleolandscapes served as the first approximation of knowledge about where key environmental resources potentially useful to pre-contact peoples might have been found on an exposed continental shelf. Like all models, the digital paleolandscape reconstructions used in Oregon and California were both correct and incorrect in making these kinds of predictions in different ways; however, this should not be seen as a weakness of models, as they provided important insights that contributed to strategic decisions about where to perform the geophysical survey and sediment coring phases of this study. **When available, these types of large-scale models should be conducted prior to HRG and sampling surveys.**

5.2.4 Future research

The optimal geophysical survey methods could be explored in more depth. For example, the Oregon Box 2 location shown in Figure 5.2.3 could be expanded using longer lines at variable spacing to explore how much variability exists in the estuary feature that was sampled. A variety of geophysical methods (e.g., different chirp frequencies, parametric sub-bottom, magnetometer/gradiometer, CSEM) could also be tested over known archaeological sites (either existing or experimentally created) to characterize their signal in the different data types. Similar work has been conducted to identify lithic deposits using the Human-Altered Lithic Detection method for submerged pre-contact sites bearing stone tools and production debris (e.g., Grøn et al. 2021), but the method has not been fully explored for sites with different lithic and organic raw materials like those commonly found along the Pacific Coast (e.g., metamorphic or fine grained volcanic toolstones, shell middens, etc.).

Because of the sediment coring method chosen for sampling in this project, the landforms examined here focused on regions with sediment cover. However, much of the Pacific Coast is rocky, including different areas in the NCI and Oregon (Figure 3.2.7). These complex rocky areas may contain different landforms such as rocky cliffs/terraces or caves that were under-explored in this project. These environments would rely more heavily on multibeam and side-scan sonar data to map surficial morphology and would require different sampling methods, such as grab samples from a ship, or ideally, diver or remotely operated vehicle (ROV) operations for photo/video and grab/scoop sampling. This study also attempted to identify tar seeps, but the sub-bottom data were inconclusive. Tar seeps could be better mapped and investigated using CSEM technology and then ground-truthed and sampled using ROV methods.

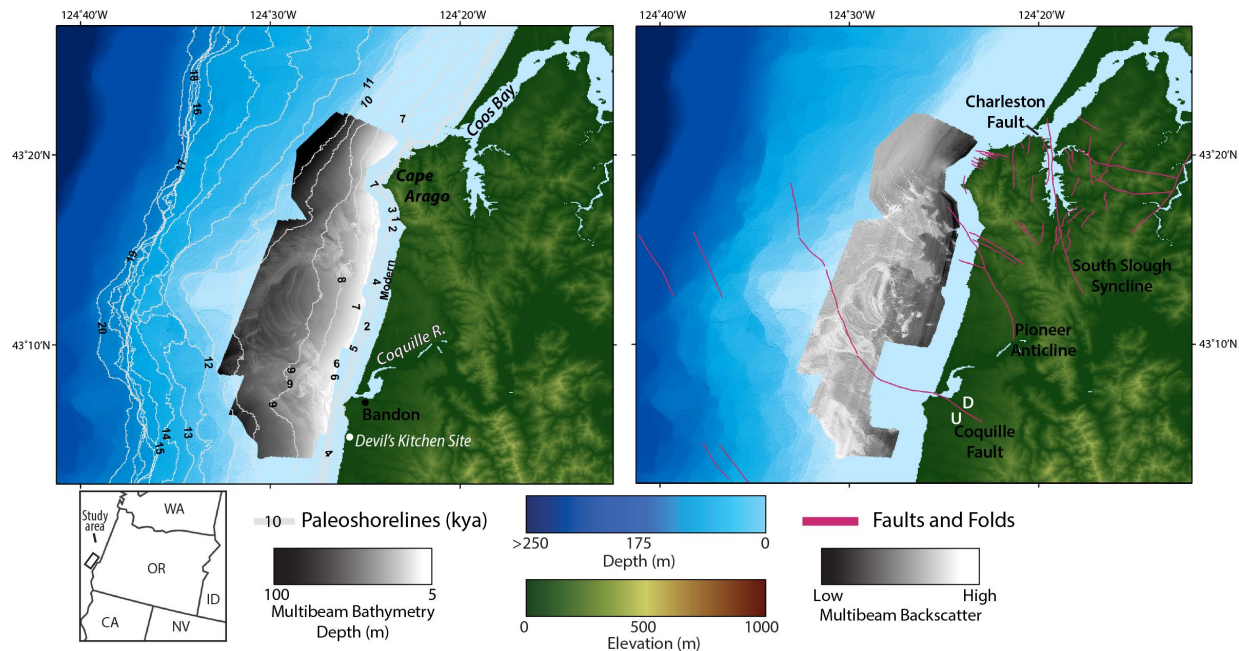


Figure 5.2.6 Map showing rocky continental shelf offshore southern Oregon
Areas with high backscatter (lighter color), indicate rocky seafloor.

Finally, there is more work that could be conducted on the sediment cores collected for this effort, and on collection of additional cores to target the identified fluvial and estuarine deposits. While the sediment analysis conducted here was useful for characterizing differences among sediment units, there are further analyses that could reveal even more about the paleoenvironment that existed when the sediments were deposited, especially for those cores that recovered fluvial and estuarine sediments. For example, environmental DNA (eDNA) and pollen could be analyzed to reconstruct biologic communities, climate, and even possibly identify the presence of humans.

6 References

- Abbott ST, Carter RM. 1994. The sequence architecture of mid-Pleistocene (c. 1.1–0.4 Ma) cyclothems from New Zealand: Facies development during a period of orbital control on sea level cyclicity, In: de Boer PL, Smith DG, editors. *Orbital forcing and cyclic sequences*: International Association of Sedimentologists Special Publication. p.367-394.
- Allen J, Gosden C, Jones R, White JP. 1989. Pleistocene dates for the human occupation of New Ireland, Northern Melanesia. *Nature*. 331:707-709.
- Atwater BF. 1987. Evidence for great Holocene earthquakes along the outer coast of Washington state. *Science*. 236:942-944.
- Atwater T. 1989. Plate tectonic history of the northeast Pacific and western North America. *The Eastern Pacific Ocean and Hawaii*. N:55–72.
- Bae SH, Kong GS, Lee GS, Yoo DG, Kim DC. 2018. Incised channel morphology and depositional fill of the paleo-Seomjin River in the continental shelf of the South Sea, Korea. *Quaternary International*. 468:49-61.

- Blum MD, Törnqvist TE. 2000. Fluvial responses to climate and sea level change: a review and look forward. *Sedimentology*. 47:2-48.
- Blum M, Martin J, Milliken K, Garvin M. 2013. Paleovalley systems: Insights from Quaternary analogs and experiments. *Earth-Science Reviews*. 116:128-169.
- Borland HP, Schlacher TA, Gilby BL, Connolly RM, Yabsley NA, Olds AD. 2017. Habitat type and beach exposure shape fish assemblages in the surf zones of ocean beaches. *Marine Ecology Progress Series*. 570:203–211.
- Braje TJ, Dillehay TD, Erlandson JM, Klein RG, Rick TC. 2017. Finding the first Americans. *Science*. 358:592-594.
- Braje TJ, Erlandson JM, Rick TC. 2013. Points in space and time: the distribution of paleocoastal points and crescents on California's Northern Channel Islands. In: Jazwa CS, Perry JE, editors. *California's Channel Islands: The archaeology of human-environmental interactions*. Salt Lake City (UT): University of Utah Press; p.72-106.
- Braje TJ, Rick TC, Dillehay TD, Erlandson JM, Klein RG. 2018. Arrival routes of first Americans uncertain – response. *Science*. 359:1225.
- Brown P, Sutikna T, Morwood MJ, Soejono RP, Jatmiko, Wayhu Saptomo E, Awe Due R. 2004. A new small-bodied Hominin from the Late Pleistocene of Flores, Indonesia. *Nature*. 431:1055-1061.
- Carabis D, Cartajena I, Simonetti R, López P, Morales C, Ortega C. 2014. Submerged paleolandscapes: site GNL Quintero 1 (GNLQ1) and the first evidences from the Pacific Coast of South America. In: Evans A, Flatman J, Flemming N, editors. *Pre-contact archaeology on the continental shelf*. New York (NY): Springer; p.131-149.
- Carlisle JD, Schott JW, Abramson NJ. 1960. The barred surfperch (*Amphistichus argenteus* Agassiz) in southern California. *Fish Bull*. 109.
- Cattaneo A, Steel RJ. 2003. Transgressive deposits: A review of their variability. *Earth-Science Reviews*. 62:187-228.
- Chaumillon E, Weber N. 2006. Spatial variability of modern incised valleys on the French Atlantic coast: comparison between the Charente (Pertuis d'Antioche) and the Lay-Sèvre (Pertuis Breton) incised-valleys. In: Dalrymple RW, Leckie DA, Tillman RW, editors. *Incised valleys in time and space*. SEPM Special Publication 85; p.57-85.
- Chaumillon E, Proust J-N, Menier D, Weber N. Incised-valley morphologies and sedimentary-fills within the inner shelf of the Bay of Biscay (France): A synthesis. *Journal of Marine Systems*. 2008;72:383-396.
- Chaytor JD, Goldfinger C, Meiner MA, Huftile GJ, Romos CG, Legg MR. 2008. Measuring vertical tectonic motion at the intersection of the Santa Cruz-Catalina Ridge and Northern Channel Islands Platform, California continental borderland, using submerged paleoshorelines. *Geological Society of America Bulletin*. 120:1053-1071.
- Clark J, Mitrovica JX, Alder J. 2014. Coastal paleogeography of the California–Oregon–Washington and Bering Sea continental shelves during the latest Pleistocene and Holocene: Implications for the archaeological record. *Journal of Archaeological Science*. 52:12-23.

- Clarke SH, Field ME, Hirozawa CA. 1985. Reconnaissance geology and geologic hazards of the offshore Coos Bay Basin, Oregon. U.S. Geological Survey Bulletin 1645. 1-41.
- Clarkson C, Jacobs Z, Marwick B, Fullagar R, Wallis L, Smith M, Roberts RG, Hayes E, Lowe K, Carah X, Florin SA, McNeil J, Cox D, Arnold LJ, Hua Q, Huntley J, Brand HEA, Manne T, Fairbairn A, Shulmeister J, Lyle L, Salinas M, Page M, Connell K, Park G, Norman K, Murphy T, Pardoe C. 2017. Human occupation of Northern Australia by 65,000 years ago. *Nature*. 547:306-310.
- Cohen JK, Stockwell Jr. JW. 1999. CWP/SU: Seismic Unix Release 33: A Free Package for Seismic Research and Processing. Center for Wave Phenomena, Colorado School of Mines.
- Cortés-Sánchez M, Morales Muñiz A, Simón-Vallejo MD, Lozano Francisco MC, Vera Peláez JL, Finlayson C, Rodriguez-Vidal J, Delgado-Huertas A, Jimenez-Espejo FJ, Martinez-Ruiz F, Martinez-Aguirre MA, Pascual-Granged AJ, Bergada-Zapata MM, Gibaja-Bao JF, Riquelme-Cantal JA, Lopez-Saez JA, Rodrigo-Gamiz M, Sakai S, Sugisaki S, Finlayson G, Fa DA, Bicho NF. 2011. Earliest known use of marine resources by Neanderthals. *PloS One*. 6: e24026.
- Danforth WW. 1997. Xsonar/ShowImage, a complete system for rapid sidescan sonar processing and display (No. 97-686). US Dept. of the Interior, US Geological Survey.
- Dalrymple RW. 2006. Incised valleys in time and space: introduction to the volume and an examination of the controls on valley formation and filling. In: Dalrymple RW, Leckie DA, Tillman R, editors. *Incised Valleys in Time and Space*. SEPM Special Publication 85; p.5-12.
- Darienzo ME, Peterson CD. 1990. Episodic tectonic subsidence of late Holocene salt marshes, northern Oregon central Cascadia margin. *Tectonics*. 9:1-22.
- Darvill CM, Menounos B, Goehring BM, Lian OB, Caffee MW. 2018. Retreat of the western Cordilleran ice sheet margin during the last deglaciation. *Geophysical Research Letters*. 45:9710-9720.
- Davis LG. 2006. Geoarchaeological insights from Indian Sands, a late Pleistocene site on the southern Northwest Coast, USA. *Geoarchaeology*. 21:351-361.
- Davis LG, Punke ML, Hall RL, Fillmore M, Willis SC. 2004. Evidence for Late Pleistocene Occupation on the Southern Northwest Coast. *Journal of Field Archaeology*. 29:7-16.
- Davis LG, Maloney J, Brennan M, Ball D, Gusick A, Klotsko S, Braje T, Nyers A, Driscoll N. 2020. *Discovering Oregon's Lost Coast: Finding and Studying Submerged Archaeological Sites and Landscapes on the Pacific Continental Shelf*. NOAA Office of Exploration and Research FY20 FFO Grantee Final Report. Grant No. NA16OAR0110197. p 135.
- Dickinson WR. 2001. Paleoshoreline record of relative Holocene sea levels on Pacific Islands. *Earth-Science Reviews*. 55:191-234.
- Dillehay TD, Bonavia D, Goodbred SL, Pino M, Vásquez V, Rosales Tham T. 2012. A Late Pleistocene human presence at Huaca Prieta, Peru, and early Pacific Coastal adaptations. *Quaternary Research*. 77:418-423.
- Dillehay TD, Ramírez C, Pino M, Collins MB, Rossen J, Pino-Navarro JD. 2008. Monte Verde: Seaweed, food, medicine, and the peopling of South America. *Science*. 320:784-786.
- Dixon JE, Monteleone K. 2014. Gateway to the Americas: Underwater archaeological survey in Beringia and the North Pacific. In: Evans A, Flatman J, Flemming N, editors. *Pre-contact archaeology on the continental shelf*. New York: Springer. p.95-114.

- Dugan JE, Hubbard DM, Davis GE. 1990. Sand beach and coastal lagoon monitoring handbook. Ventura, CA: Channel Islands National Park, National Park Service.
- Dugan JE, Hubbard DM, Engle JM, Martin DL, Richards DM, Davis GE, Lafferty KD, Ambrose RF. 2000. Macrofauna communities of exposed sandy beaches on the Southern California mainland and Channel Islands, In: Brown DR, Mitchell KL, Chang HW, editors. Proceedings of the Fifth California Islands Symposium, U.S Department of the Interior, Minerals Management Service, OCS Study MMS 99-0038. p.339-346.
- Dugan JE, Hubbard DM, McCrary M, Pierson M. 2003. The response of macrofauna communities and shorebirds to macrophyte wrack subsidies on exposed sandy beaches of southern California. *Estuarine, Coastal and Shelf Science*. 58S:133-148.
- Dugan JE, Hubbard DM, Nielsen KJ. 2015. Baseline Characterization of Sandy Beach Ecosystems in California's South Coast Region. Final Report to the Ocean Science Trust, California Ocean Protection Council and California Sea Grant https://caseagrant.ucsd.edu/sites/default/files/SCMPA-24-Final-Report_0.pdf.
- Dunbar JS, Webb DS, Faught MK. 1988. Page/Ladson (8Je591): An underwater paleo-Indian site in northwestern Florida. *Florida Anthropologist*. 41:442-452.
- Ellis DM. 1995. Evaluation of video camera technique for indexing abundances of juvenile pink snapper *Pristipomoides filamentosus*, and other Hawaiian insular shelf fishes. *Fish Bull*. 93:67-77.
- Emery KO. 1958. Shallow submerged marine terraces of southern California. *Bulletin of the Geological Society of America*. 69:39-60.
- Erlandson JM. 1994. Early hunter-gatherers of the California coast. New York (NY): Plenum Press.
- Erlandson JM. 2001. The archaeology of aquatic adaptations: Paradigms for a new millennium. *Journal of Archaeological Research*. 9:287-350.
- Erlandson JM. 2002. Anatomically modern humans, maritime voyaging, and the Pleistocene colonization of the Americas. In: Jablonski N, editor. *The first Americans: The Pleistocene colonization of the New World*. San Francisco (CA): California Academy of Sciences. p.59-92.
- Erlandson JM. 2010. Neptune's children: The origins and evolution of seafaring. In: Anderson A, Barrett JH, Boyle K, editors. *Global origins and development of seafaring*. Cambridge (England): Cambridge University Press. p.18-27.
- Erlandson JM. 2016. Seascapes of Santarosae: Paleocoastal seafaring on California's Channel Islands. In: Bjerck HB, Breivik HM, Fretheim SE, Piana EL, Skar B, Tivoli AM, Zangrando J, editors. *Marine ventures: Archaeological perspectives on human-sea relations*. Sheffield (England): Equinox Publishing. p.317-327.
- Erlandson JM, Braje TJ, Gil KM. 2019a. A Paleocoastal site complex from Santarosae Island, California. *PaleoAmerica*. 5:300-305.
- Erlandson JM, Gill KM, Glassow MA, Gusick AE. 2016. Three Paleocoastal lithic sites on Santa Cruz Island, California. *PaleoAmerica*. 2:52-55.
- Erlandson JM, Rick TC, Ainis AF, Braje TJ, Gill KM, Reeder-Myers L. 2019b. Late Pleistocene estuaries, paleoecology, and humans on North America's Pacific Coast. *Antiquity*. 93:e32.

- Erlandson JM, Moss ML, Des Lauriers M. 2008. Life on the edge: Early maritime cultures of the Pacific Coast of North America. *Quaternary Science Reviews*. 27:2232-2245.
- Erlandson JM, Rick TC, Braje TJ, Casperson M, Culleton B, Fulfroost B, Garcia T, Guthrie DA, Nicholas J, Kennett DJ, et al. 2011. Paleoindian seafaring, maritime technologies, and coastal foraging on California's Channel Islands. *Science*. 331:1181-1185.
- Erlandson JM, Tveskov MA, Byram S. 1998. The development of maritime adaptations on the southern Northwest Coast of North America. *Arctic Anthropology*. 356-22.
- Evans AM, Keith ME, Voisin EE, Hesp P, Cook G, Allison M, da Silva G, Swanson E. 2013. Archaeological analysis of submerged sites on the Gulf of Mexico outer continental shelf, U.S. U.S. Department of the Interior, Bureau of Ocean Energy Management, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study BOEM 2013-011110.
- Faught MK. 1988. Inundated sites in the Apalachee Bay area of the eastern Gulf of Mexico. *Florida Anthropologist*. 41:185-190.
- Faught MK. 2004. The underwater archaeology of paleolandscapes, Apalachee Bay, Florida. *American Antiquity*. 69:275-289.
- Faught MK, Donoghue JF. 1997. Marine inundated archaeological sites and paleofluvial systems: examples from a karst-controlled continental shelf setting in Apalachee Bay, northeastern Gulf of Mexico. *Geoarchaeology*. 12:417-458.
- Faught MK, Gusick AE. 2011. Submerged prehistory in the Americas. In: Benjamin J, Bonsall C, Pickard C, editors. *Submerged prehistory: The underwater archaeology of ancient sites and landscapes*. Oxford (UK): Oxford Books. p.145-157.
- Fedje DW, Christensen T. 1999. Modeling paleoshorelines and locating early Holocene coastal sites in Haida Gwaii. *American Antiquity*. 64:635-652.
- Fedje DW, Josenhans H. 2000. Drowned forests and archaeology on the continental shelf of British Columbia, Canada. *Geology*. 28:99-102.
- Fedje DW, Mackie AP, Wigen RJ, Mackie Q, Lake C. 2005. Kilgii Gwaay: An early maritime site in the south of Haida Gwaii. In: Fedje DW, Mathewes R. *Haida Gwaii, human history and environment from the time of loon to the time of the iron people*, Vancouver: UBC Press. p.187-203.
- Fladmark KR. 1979. Routes: Alternate migration corridors for early man in North America. *American Antiquity*. 44:55-69.
- Ford B, Halligan J. 2010. A North American perspective: Comment on Jonathan Benjamin's 'submerged pre-contact landscapes and underwater site discovery: reevaluating the 'Danish model' for international practice'. *Journal of Island and Coastal Archaeology*. 5:277-279.
- Fujita M, Yamasaki S, Katagiri C, Oshiro I, Sano K, Kurozumi T, Sugawara H, Kunikit D, Matsuzaki H, Kano A, Okumura T, Sone T, Fujita H, Kobayashi S, Naruse T, Kondo M, Matsu'ura S, Suwa G, Kaifu Y. 2016. Advanced maritime adaptation in the western Pacific coastal region extends back to 35,000-30,000 years before present. *Proceedings of the National Academy of Sciences of the United States of America*. 113:11184-11189.
- Gagliano SM, Pearson CE, Weinstein RA, Wiseman DE, McClendon CM. 1982. *Sedimentary Studies of Pre-contact Archaeological Sites: Criteria for the Identification of Submerged Archaeological Sites of*

- the Northern Gulf of Mexico Continental Shelf. Submitted to the National Park Service, Division of State Plans and Grants.
- Gill KM, Braje TJ, Smith K, Erlandson JM. 2021. Earliest evidence for geophyte use in North America: 11,500-year-old archaeobotanical remains from California's Santarosae Island. *American Antiquity*. 1-13.
- Gill KM, Fauvelle M, Erlandson JM. 2019. *An archaeology of abundance: Re-evaluating the marginality of California's Islands*. Gainesville: University Press of Florida.
- Goldfinger C, Henkel S, Romsos C, Havron A, Black B. 2014. Benthic Habitat Characterization of the Pacific Northwest, Volume 1: Evaluation of Continental Shelf Geology. U.S. Department of the Interior, Bureau of Ocean Energy Management, Pacific OCS Region, OCS Study BOEM 2014-662, 161 p. doi:10.13140/2.1.3345.0561
- Grant LB, Mueller KJ, Gath EM, Cheng H, Edwards LR, Munro R, Kennedy GL. 1999. Late Quaternary uplift and earthquake potential of the San Joaquin hills, southern Los Angeles Basin, California. *Geology* 27(11):1031-1034.
- Green AN, Dladla N, Garlick GL. 2013. Spatial and temporal variations in incised valley systems from the Durban continental shelf, KwaZulu-Natal, South Africa. *Marine Geology*. 335:148-161.
- Green AN, Cooper JAG, Salzmann L. 2018. The role of shelf morphology and antecedent setting in the preservation of palaeo-shoreline (beachrock and aeolianite) sequences: The SE African shelf. *Geo-Marine Letters*. 38:5-18.
- Grøn O, Boldreel LO, Smith MF, Joy S, Boumda RT, Mäder A, Bleicher N, Madsen B, Cvikel D, Nilsson B, et al. 2021. Acoustic Mapping of Submerged Stone Age Sites—A HALD Approach. *Remote Sens*. 13:445.
- Gusick AE, Braje TJ, Erlandson JM, Maloney J, Ball D. 2021. Above and below the waves: Advances in the search for a Late Pleistocene colonization of California's Islands. In: Napolitano M, Stone J, DiNapoli B., editors. *The archaeology of island colonization*. Gainesville: University Press of Florida. p.105-131.
- Gusick AE, Davis LG. 2010. Exploring Baja California's submerged landscapes. *Journal of California and Great Basin Anthropology*. 30:35-50.
- Gusick AE, Erlandson JM. 2019. Paleocoastal landscapes, marginality, and early human settlement of the California Islands. In: Gill KM, Fauvelle M, Erlandson JM, editors. *An archaeology of abundance: Reevaluating the marginality of California's Islands*. Gainesville: University Press of Florida. p.59-97.
- Gusick AE, Faught MK. 2011. Pre-contact underwater archaeology: A nascent subdiscipline critical to understanding early coastal occupations and migration routes. In: Bicho N, Haws J, Davis LG. *Trekking the shore: Changing coastlines and the antiquity of coastal settlement*. New York (NY): Springer. p.27-50.
- Haaker EC, Rockwell TK, Kennedy GL, Ludwig LG, Freeman ST, Zumbro JA, Mueller KJ, Edwards RL. 2016. Style and rate of long-term uplift of the southern California coast between San Diego and Newport Beach with potential implications for assessing blind thrust models. *Applied Geology of California*. 26:679-719.

- Henkart, P. 2006. SIOSEIS. <http://sioseis.ucsd.edu>; accessed 2015.
- Hill JC, Driscoll NW. 2008. Paleodrainage on the Chukchi shelf reveals sea level history and meltwater discharge. *Marine Geology*. 254:129-151.
- Hill JC, Driscoll NW, Brigham-Grette J, Donnelly JP, Gayes PT, Keigwin L. 2007. New evidence for high discharge to the Chukchi shelf since the Last Glacial Maximum. *Quaternary Research*. 68:271-279.
- Hofman CA, Rick TC, Maldonado JE, Collins PW, Erlandson JM, Fleisher RC, Smith C, Sillett TS, Ralls K, Teeter W, Vellanoweth RL, Newsome SD. 2016. Tracking the origins and diet of an endemic island canid (*Urocyon littoralis*) across 7,300 years of human cultural and environmental change. *Quaternary Science Reviews*. 146:147-160.
- Holbrook JM, Bhattacharya JP. 2012. Reappraisal of the sequence boundary in time and space: Case and considerations for an SU (subaerial unconformity) that is not a sediment bypass surface, a time barrier, or an unconformity. *Earth-Science Reviews*. 113:271-302.
- Holliday VT. 2000. The evolution of Paleoindian geochronology and typology on the Great Plains. *Geoarchaeology*. 15:227-290.
- ICF International, Davis Geoarchaeological Research, and Southeastern Archaeological Research. 2013. Inventory and analysis of coastal and submerged archaeological site occurrence on the Pacific outer continental shelf. U.S. Department of the Interior, Bureau of Ocean Energy Management, Pacific OCS Region, Camarillo, CA. OCS Study BOEM 2013-0115.
- Ikeya N. 2015. Maritime Transport of Obsidian in Japan during the Upper Paleolithic. In: Kaifu Y, Izuho M, Goebel T, Sato H, Ono A. Emergence and diversity of modern human behavior in Paleolithic Asia. College Station: Texas A&M University Press. p.362-375.
- Ingicco T, van den Bergh CD, Jago-on C, Bahain J-J, Chacón MG, Amano N, et al. 2018. Earliest known Hominin activity in the Philippines, ca. 709 thousand years ago. *Nature*. 557:233-237.
- Ingram BL, Southon JR. 1996. Reservoir ages in eastern Pacific coastal and estuarine waters. *Radiocarbon*. 38:573-582.
- Ishihara T, Sugai T, Hachinohe S. 2012. Fluvial response to sea level changes since the latest Pleistocene in the near-coastal lowland, central Kanto Plain, Japan. *Geomorphology*. 147-148;49-60.
- Ishihara T, Sugai T. 2017. Eustatic and regional tectonic controls on late Pleistocene paleovalley morphology in the central Kanto Plain, Japan. *Quatern. Int.* 456:69-84.
- Jenevein SA. 2010. Searching for early archaeological sites along the central Oregon coast: A case study from Neptune State Park (35LA3), Lane County, Oregon. Unpublished, Master's thesis, Department of Anthropology, Oregon State University.
- Johnson JR, Stafford Jr. TW, Ajie HO, Morris DP. 2002. Arlington Springs revisited. In: Brown D, Mitchell K, Chaney H., editors. Proceedings of the fifth California Islands symposium. Santa Barbara (CA): Santa Barbara Museum of Natural History. p.541-545.
- Johnson L. 2020. Paleolandform reconstruction offshore of the Channel Islands using sediment cores and high-resolution seismic data. MA Thesis, San Diego State University, Department of Geology.

- Junger A. 1979. Maps and seismic profiles showing geologic structure of the Northern Channel Islands platform. California Continental Borderland, Report MF-991. United States Geological Survey, Department of Interior.
- Kamerling MJ, Luyendyk BP. 1979. Tectonic rotations of the Santa Monica Mountains region, western Transverse Ranges, California, suggested by paleomagnetic vectors. *Geologic Society of America Bulletin*, Part 1. 90:331-337.
- Kelsey HM, Bockheim JG. 1994. Coastal landscape evolution as a function of eustasy and surface uplift rate, Cascadia margin, southern Oregon. *Geological Society of America Bulletin*. 106:840-854.
- Kelsey HM, Ticknor RL, Bockheim JG, Mitchell CE. 1996. Quaternary upper plate deformation in coastal Oregon. *Geological Society of America Bulletin*. 108:843-860.
- Kennett DJ, Kennett JP, West GJ, Erlandson JM, Johnson JR, Hendy IL, West A, Culleton BJ, Jones TL, Stafford Jr. TW. 2008. Wildfire and abrupt ecosystem disruption on California's Northern Channel Islands at the Ållerød-Younger Dryas boundary (13.0-12.9 ka). *Quaternary Science Reviews*. 27:2530-2545.
- Kern P, Rockwell TK. 1992. Chronology and deformation of Quaternary marine shorelines, San Diego County, California. *Quaternary Coasts of the United States: Marine and Lacustrine Systems*.
- Khasanov B, Fitzhugh B, Nakamura T, Okuno M, Hatfield V, Krylovich O, et al. 2020. New data and synthesis of ΔR estimates from the northern Pacific Ocean. *Quaternary Research*. 1-11.
- Klotsko S, Driscoll N. 2018. Geomorphological and stratigraphic evidence along the northeastern US margin for Laurentide glacial lake outburst floods during the MIS 2 deglaciation. *Quaternary Research*. 90:139-152.
- Klotsko S, Driscoll N, Kent G, Brothers D. 2015. Continental shelf morphology and stratigraphy offshore San Onofre, California: The interplay between rates of eustatic change and sediment supply. *Marine Geology*. 369:116-126.
- Klotsko S, Skakun M, Maloney J, Braje R, Gusick AE, Davis L, Nyers A, Ball D. 2021. Geologic controls on paleodrainage incision and morphology during sea level lowstands on the Cascadia shelf in Oregon, USA, *Marine Geology*, 434, 106444, <https://doi.org/10.1016/j.margeo.2021.106444>
- Ku T-L, Philip Kern J. 1974. Uranium-series age of the Upper Pleistocene Nestor Terrace, San Diego, California. *Geological Society of America Bulletin*. 85:1713-1716.
- Lague D. 2014. The stream power river incision model: Evidence, theory and beyond. *Earth Surface Processes and Landforms*. 39:38-61.
- Lajoie KR. 1986. Coastal tectonics. National Research Council Division on Engineering and Physical Sciences.
- Lamb MP, Finnegan NJ, Scheingross JS, Sklar LS. 2015. New insights into the mechanics of fluvial bedrock erosion through flume experiments and theory. *Geomorphology*. 244:33-55.
- Lambeck K, Yokoyama Y, Purcell T. 2002. Into and out of the Last Glacial Maximum: Sea level change during oxygen isotope stages 3 and 2. *Quaternary Science Review*. 21:343-360.

- Laws A, Maloney J, Klotsko S, Gusick A, Braje T, Ball D. 2019. Submerged paleoshoreline mapping using high-resolution chirp sub-bottom data, Northern Channel Islands platform, California, USA., *Quaternary Research*. 93(1): 1-22,
- Lesnek AJ, Briner JP, Lindqvist C, Baichtal JF, Heaton TH. 2018. Deglaciation of the Pacific Coast corridor directly preceded the human colonization of the Americas. *Science Advances*. 4(5):eaar5040.
- Lightfoot KG. 1993. Long-term developments in complex hunter-gatherer societies: Recent perspectives from the Pacific Coast of North America. *Journal of Archaeological Research*. 1:167-201.
- Liu JP, DeMaster DJ, Nguyen TT, Saito Y, Nguyen VL, Ta TKO, Li X. 2017. Stratigraphic formation of the Mekong River Delta and its recent shoreline changes. *Oceanography*. 30:72-83.
- Lowery D, Martin R. 2009. Archaeology of marine transgression: An inundated Middle Archaic burial in Chesapeake Bay, Maryland. *Archaeology of Eastern North America*. 37:159-173.
- Lyman RL. 1991. *Prehistory of the Oregon coast*. New York (NY): Academic Press.
- Mackie Q, Davis LG, Fedje DW, McLaren D, Gusick AE. 2013. Locating Pleistocene-age submerged archaeological sites on the Northwest Coast: current status of research and future directions. In: Waters M, Graff K, editors. *Paleoamerican odyssey conference companion*. College Station (TX): Center for the Study of the First Americans. p.133-147.
- Mackie Q, Vogelaar C, Fedje D, Lausanne A. 2017. New approaches to the underwater archaeology of Hecate Strait, British Columbia. Poster presented at the Society for American Archaeology Annual Meeting, Vancouver.
- Marean CW, Bar-Matthews M, Bernatchez J, Fisher E, Goldberg P, Herries AIR, et al. 2007. Early human use of marine resources and pigments in South Africa during the Middle Pleistocene. *Nature*. 449:905-908.
- Masters P, Flemming NC. 1983. *Quaternary coastlines and marine archaeology*. Orlando (FL): Academic Press.
- Matsu'ura S. 1996. A chronological review of Pleistocene human remains from the Japanese Archipelago. In: Omoto K, editor. *Interdisciplinary perspectives on the origins of the Japanese*. International Research Center for Japanese Studies, Kyoto. p.181-197.
- Mattheus CR, Rodriguez AB, Greene DL Jr., Simms AR, Anderson JB. 2007. Control of upstream variables on incised-valley dimension. *Journal of Sedimentary Research*. 77:213-224.
- Mattheus CR, Rodriguez AB. 2011. Controls on late Quaternary incised-valley dimension along passive margins evaluated using empirical data. *Sedimentology*. 58:1113-1137.
- McInelly GW, Kelsey HM. 1990. Late Quaternary deformation in the Cape Arago-Bandon region of coastal Oregon as deduced from wave-cut platforms. *Journal of Geophysical Research*. 95:669-6713.
- McLaren D, Fedje D, Dyck A, Mackie Q, Gauvreau A, Cohen J. 2018. Terminal Pleistocene Epoch human footprints from the Pacific Coast of Canada. *PLOS ONE*. 13:e0193522.
- McLaren D, Fedje D, Hay MB, Mackie Q, Walker IJ, Shugar DH, Eamer JBR, Lian OB, Neudorf C. 2014. A post-glacial sea level hinge on the central Pacific Coast of Canada. *Quaternary Science Review*. 97:148-169.

- McNeill LC, Goldfinger C, Kulm LD, Yeats RS. 2000. Tectonics of the Neogene Cascadia forearc basin: Investigations of a deformed late Miocene unconformity. *Geological Society of America Bulletin*. 112:1209-1224.
- Meltzer DJ. 1995. Clocking the first Americans. *Annual Review of Anthropology*. 24:21-45.
- Meltzer DJ. 2009. *First peoples in a New World*. Berkeley: University of California Press.
- Milliman JD, Meade RH. 1983. World-wide delivery of river sediment to the oceans. *Journal of Geology*. 91:1-21.
- Milliman JD, Syvitsky JPM. 1992. Geomorphic/tectonic control of sediment discharge to the ocean: The importance of small mountainous rivers. *Journal of Geology*. 100:525-544.
- Morwood MJ, Soejono RP, Roberts RG, Sutikna T, Turney CSM, Westaway KE, Rick WJ, Zhao J-x, van den Bergh GD, Rokus Awe Due, Hobbs DR, Moore MW, Bird MI, Fifield LK. 2004. Archaeology and age of a new Hominin from Flores in Eastern Indonesia. *Nature*. 431:1087-1091.
- Moss ML, Erlandson JM. 1995. Reflections on North American Pacific Coast prehistory. *Journal of World Prehistory*. 9:1-45.
- Moss ML, Erlandson JM. 1998. Early Holocene adaptations of the southern Northwest Coast. *Journal of California and Great Basin Anthropology*. 20:13-25.
- Mueller K, Kier G, Rockwell T, Jones CH. 2009. Quaternary rift flank uplift of the Peninsular Ranges in Baja and southern California by removal of mantle lithosphere. *Tectonics*. 28.
- Muhs DR, Rockwell TK, Kennedy GL. 1992. Late Quaternary uplift of marine terraces on the Pacific Coast of North America, southern Oregon to Baja California Sur. *Quaternary International*. 15/16:121-133.
- Muhs DR, Simmons KR, Schumann RR, Groves LT, DeVogel SB, Minor SA, Laurel D. 2014. Coastal tectonics on the eastern margin of the Pacific Rim: Late Quaternary sea level history and uplift rates, Channel Islands National Park, California, USA. 105:209-238.
- Muhs DR, Simmons KR, Schumann RR, Groves LT, Mitrovica JX, Laurel D. 2012. Sea level history during the last interglacial complex on San Nicolas Island, California: Implications for glacial isostatic adjustment processes, paleozoogeography and tectonics. *Quaternary Science Reviews*. 37:1-25.
- Naish TR, Kamp PJJ. 1997. Sequence stratigraphy of sixth order (41 ky) Pliocene-Pleistocene cyclothems, Wanganui basin, New Zealand: A case for the regressive systems tract. *Geological Society of America Bulletin*. 109:978-999.
- National Oceanic and Atmospheric Association (NOAA). 2018, Station 9411340, <https://tidesandcurrents.noaa.gov/>, accessed January 2018.
- Nicholson C, Sorlien CC, Atwater T, Crowell JC, Luyendyk BP. 1994. Microplate capture, rotation of the western Transverse Ranges, and initiation of the San Andreas transform as a low-angle fault system. *Geology*. 22:491-495.
- O'Connell JF, Allen J. 2012. The restaurant at the end of the universe: Modelling the colonization of Sahul. *Australian Archaeology*. 74:5-31.

- O'Connor JE, Mangano JF, Anderson SW, Wallick JR, Jones KL, Keith MK. 2014. Geologic and physiographic controls on bed-material yield, transport, and channel morphology for alluvial and bedrock rivers, western Oregon. *GSA Bulletin*. 126:377-397.
- O'Connor S, Ono R, Clarkson C. 2011. Pelagic fishing at 42,000 years before the present and the maritime skills of modern humans. *Science*. 334:1117-1121.
- Orr PC. 1968. Prehistory of Santa Rosa Island. Santa Barbara (CA): Santa Barbara Museum of Natural History.
- Pacific Northwest Hydrography Framework (PNWHF) and the US Geological Survey (USGS). Watershed Boundary Dataset layer for Oregon and Washington. <https://www.pnwhf.org/water-bound-dataset.aspx>. Accessed December 2020.
- Page HM, Schamel J, Emery KA, Schooler NK, Dugan JE, Guglielmino A, Schroeder DM, Palmstrom L, Hubbard DM, Miller RJ. 2021. Diet of a threatened endemic fox reveals variation in sandy beach resource use on California Channel Islands, *PLOS ONE*. 16(10): e0258919. <https://doi.org/10.1371/journal.pone.0258919>
- Paola C, Heller PL, Angevine CL. 1992. The large-scale dynamics of grain-size variation in alluvial basins, 1: Theory. *Basin Res*. 4:73-90.
- Peterson CP, Kuhn LD, Gray JJ. 1986. Geologic map of the ocean floor off Oregon and the adjacent continental margin. Oregon Department of Geology and Mineral Industries, Geologic Map Series. 42.
- Phillips JD. 2011. Drainage area and incised valley fills in Texas rivers: A potential explanation. *Sed. Geol*. 242:65-70.
- Pinter N, Johns B, Little B, Vestal WD. 2001. Fault-related folding in California's Northern Channel Islands documented by rapid-static GPS positioning. *GSA Today*. 11:4-9.
- Pinter N, Sorlien C. 1991. Evidence for latest Pleistocene to Holocene movement on the Santa Cruz Island fault, California. *Geology*. 19:909-912.
- Pinter N, Sorlien CC, Scott AT. 2003. Fault-related growth and isostatic subsidence, California Channel Islands. *American Journal of Science*. 303:300-318.
- Plink-Björklund P, Steel RJ. 2004. Initiation of turbidity currents: Outcrop evidence for Eocene hyperpycnal flow turbidites. *Sedimentary Geology*. 165:29-52.
- Pojar J, Klinda K, Demarchi DA. 1991. Coastal western hemlock zone. In: Meidinger D, Pojar J, editors. *Ecosystems of British Columbia*. Victoria, BC: Ministry of Forests. p.95-111.
- Posamentier HW. 2001. Lowstand alluvial bypass systems: Incised vs. unincised. *AAPG Bulletin* 85:1771-1793.
- Posamentier HW, Allen GP. 1993. Siliclastic sequence stratigraphic patterns in foreland ramp-type basins. *Journal of Geology*. 21:455-458.
- Posamentier HW, Allen GP, James DP, Tesson M. 1992. Forced regressions in a sequence stratigraphic framework: Concepts, examples and exploration significance. *AAPG Bulletin*. 76:1687-1709.
- Posamentier HW, Vail PR. 1988. Eustatic controls on clastic desposition II-sequence and systems tract. *Special Publications of SEPM*.

- Post DM. 2002. Using stable isotopes to estimate trophic position: models, methods and assumptions. *Ecology*. 83:703-718.
- Potter BA, Baichtal JF, Beaudoin AB, Fehren-Schmitz L, Haynes CV, Holliday VT, et al. 2018. Current evidence allows multiple models for the peopling of the Americas. *Science Advances*. 4:eaat5473.
- Potter BA, Beaudoin AB, Haynes CV, Holliday VT, Holmes CE, Ives JW, et al. 2018. Arrival routes of first Americans uncertain. *Science*. 359:1224-1225.
- Pretorius L, Green AN, Cooper JAG., Hahn A, Zabel M. 2019. Outer-to inner-shelf response to stepped sea level rise: Insights from incised valleys and submerged shorelines. *Marine Geology*. 416:105979.
- Punke ML, Davis LG. 2006. Problems and prospects in the preservation of late Pleistocene cultural sites in southern Oregon coastal river valleys: implications for evaluating coastal migration routes. *Geoarchaeology*. 21:333-350.
- Reeder-Myers L, Erlandson JM, Muhs DR, Rick TC. 2015. Sea level, paleogeography, and archaeology on California's Northern Channel Islands. *Quaternary Research*. 83:263-272.
- Rick TC, Erlandson JM, Jew NP, Reeder-Myers LA. 2013. Archaeological survey and the search for paleocoastal peoples of Santa Rosa Island, California, USA. *Journal of Field Archaeology*. 38:324-331.
- Rick TC, Erlandson JM, Vellenoweth R. 2001. Paleocoastal marine fishing on the Pacific Coast of the Americas: Perspectives from Daisy Cave, California. *American Antiquity*. 66:595-613.
- Rick TC, Reeder-Myers LA. 2018. Deception island: The archaeology of 'Anyapax, Anacapa Island, California. Washington DC: Smithsonian Institution Scholarly Press.
- Rockwell TK, Clark K, Gamble L, Oskin ME, Haaker EC, Kennedy GL. 2016. Large Transverse Range earthquakes cause coastal upheaval near Ventura, southern California. *Bulletin of the Seismological Society of America*. 106:2706-2720.
- Ruddiman WF. 2013. Tectonic uplift and climate change. Springer Science & Business Media.
- Ruppe RJ. 1980. The archaeology of drowned terrestrial sites: A preliminary report. In: Brose DS, editor. Coes Landing, Jackson County, Florida: A Fort Walton campsite on the Apalachicola River. Tallahassee (FL): Bureau of Historic Sites and Properties. p.35-45.
- Salzmann L, Green A, Cooper JA. 2013. Submerged barrier shoreline sequences on a high energy, steep and narrow shelf. *Marine Geology*. 346:366-374.
- Santra M, Steel RJ, Olariu C, Sweet ML. 2013. Stages of sedimentary prism development on a convergent margin – Eocene Tyee Forearc Basin, Coast Range, Oregon, USA. *Global and Planetary Change*. 103:207-231
- Scheingross JS, Brun F, Lo DY, Omerdin K, Lamb MP. 2014. Experimental evidence for fluvial bedrock incision by suspended and bedload sediment. *Geology*. 42:523-526.
- Schumm SA, Harvey MD, Watson CC. 1984. Incised Channels: Morphology, Dynamics and Control. Chelsea (MI): Water Resources Publication.
- Schumm SA. 1993. River response to baselevel change: Implications for sequence stratigraphy. *Journal of Geology*. 101:279-294.

- Schumann R, Pigati JS. 2018. Reply to the discussion of Pinter et al. on 'Fluvial system response to late Pleistocene-Holocene sea level change on Santa Rosa Island, Channel Islands National Park' by Schumann et al. (2016). *Geomorphology*. 301:144-146.
- Seeber L, Sorlien CC. 2000. Listric thrusts in the western Transverse Ranges, California. *Geological Society of America Bulletin*. 112:1067-1079.
- Shaw JH, Suppe J. 1994. Active faulting and folding in the eastern Santa Barbara Channel, California. *Geological Society of America Bulletin*. 106:607-626.
- Simms AR, Anderson JB, Taha ZP, Rodriguez AB. 2006. Over-filled versus under-filled incised valleys: lessons from the Quaternary Gulf of Mexico. In: Dalrymple R, Leckie D, Tillman R, editors. *Incised valleys through space and time*. SEPM Special Publication 85. p.117-139.
- Simms A, Rouby H, Lambeck K. 2016. Marine terraces and rates of vertical tectonic motion: The importance of glacio-isostatic adjustment along the Pacific coast of central North America. *Geological Society of America Bulletin*. 128:81-93.
- Siuslaw Basin Council and Ecotrust, January 2002. A watershed assessment for the Siuslaw Basin. Archived at <https://nrimp.dfw.state.or.us/DataClearinghouse/default.aspx?p=202&XMLname=73.xml> from <http://www.inforain.org/siuslaw/>, accessed March 15, 2020.
- Sklar LS, Dietrich WE. 2001. Sediment and rock strength controls on river incision into bedrock. *Geology*. 29:1087-1090.
- Snavely Jr. PD. 1987. Tertiary geologic framework, neotectonics, and petroleum potential of the Oregon-Washington continental margin. AAPG Datapages.
- Snethkamp P, Wessen G, York AL, Cleland JH, Hoyt SD, Gearhart II RL. 1990. California, Oregon, and Washington archaeological resource study. Volume III: Prehistory. Prepared under MMS Contract 14-35-0001-30439 by Espey, Huston and Associates, Inc., Austin, Texas.
- Sorlien CC. 1994. Faulting and uplift of the Northern Channel Islands, California. In: Halvorson WL, Maender GL, editors. *The fourth California Islands symposium: Update on the status of resources*. Santa Barbara (CA): Santa Barbara Museum of Natural History. p.281-296.
- Spratt RM, Lisiecki LE. 2016. A Late Pleistocene sea level stack. *Clim. Past*. 12:1079-1092.
- Steele TE, Álvarez-Fernández E. 2011. Initial investigations into the exploitation of coastal resources in North Africa during the Late Pleistocene at Grotte des Contrebandiers, Morocco. In: Bicho NF, Haws JA, Davis LG, editors. *Trekking the shore: Changing coastlines and the antiquity of coastal settlement*. Springer, New York. p.383-403
- Strong N, Paola C. 2008. Valleys that never were: Time surfaces versus stratigraphic surfaces. *J. Sed. Res.* 78:579-593.
- Summerfield MA. 1985. Plate tectonics and landscape development on the African continent. *Tectonic Geomorphology*. 27-51.
- Tahiry H. 2019. Characterization of paleochannels offshore from the Northern Channel Islands, California, USA. MA Thesis, San Diego State University, Department of Geology.

- Talling PJ. 1998. How and where do incised valleys form if sea level remains above the shelf edge? *Journal of Geology*. 26:87-90.
- Thieler ER, Butman B, Schwab WC, Allison MA, Driscoll NW, Donnelly JP, Uchupi E. 2007. A catastrophic meltwater flood event and the formation of the Hudson Shelf Valley. *Palaeogeography, Palaeoclimatology, Palaeoecology*. 246:120-136.
- Törnqvist TE, Wortman SR, Mateo ZRP, Milne GA, Swenson JB. 2006. Did the last sea level lowstand always lead to cross-shelf valley formation and source-to-sink sediment flux? *Journal of Geophysical Research: Earth Surface*. 111:1-13.
- U.S. Geological Survey. 2017. National Water Information System data available on the World Wide Web (USGS Water Data for the Nation). Accessed November 10, 2018, at https://waterdata.usgs.gov/nwis/annual?referred_module=sw&search_site_no=11477000&format=sites_selection_links
- Van Wagoner JC, Posamentier HW, Mitchum RM, Vail PR, Sarg JF, Loutit TS, Hardenbol J. 1988. An overview of sequence stratigraphy and key definitions. In: Wilgus CW, et al., editors. *Sea level changes: An integrated approach*. Society of Economic Paleontologists and Mineralogists Special Publication 42. p.39-45.
- Vargas-Fonseca E, Olds AD, Gilby BL, Connolly RM, Schoeman DS, Huijbers CM. 2016. Combined effects of urbanization and connectivity on iconic coastal fishes. *Divers Distrib*. 22:1328-1341.
- Vital H, Furtado SFL, Gomes MP. 2010. Response of the Apodi-Mossoró estuary-incised valley system (NE Brazil) to sea level fluctuations. *Brazilian Journal of Oceanography*. 58:13-24.
- Walker GW, McLeod SM. 1991. *Geologic map of Oregon*: Reston, U.S. Geological Survey, scale 1:500,000, 2 sheets.
- Wallick JR, O'Connor JE, Anderson S, Keith M, Cannon C, Risley JC. 2011. Channel change and bed-material transport in the Umpqua River basin, Oregon. U.S. Geological Survey Scientific Investigations Report 2011-5041.
- Wang R, Colombero L, Mountney NP, Veiga G. 2019. Geological controls on the geometry of incised-valley fills: Insights from a global dataset of late-Quaternary examples. *Sedimentology*. 66:2134-2168.
- Waters MR, Stafford TW. 2007. Redefining the age of Clovis: Implications for the peopling of the Americas. *Science*. 315:1122-1126.
- Watts J, Fulfrost B, Erlandson JE. 2011. Searching for Santarosae: surveying submerged landscapes for evidence of paleocoastal habitation off California's Northern Channel Islands. In Ford B., editors. *The archaeology of maritime landscapes: When the land meets the sea*. New York (NY): Springer. p.11-26.
- Wells RE, Jayko A, Niem AR, Black G, Wiley T, Baldwin E, Molenaar KM, Wheeler KL, Givler R, DuRoss C. 2001. *Geologic map and database of the Roseburg, Oregon 30' x 60' Quadrangle, Douglas and Coos Counties, Oregon*. U.S. Geological Survey Miscellaneous Investigations Map and Open-File Report OF00-376, 55 p., and 2 map sheets, scale 1:100,000.
- Wickler S, Spriggs M. 1988. Pleistocene human occupation of the Solomon Islands, Melanesia. *Antiquity*. 62:703-707.

- Woolfe KJ, Larcombe P, Naish T, Purdon RG. 1998. Lowstand rivers need not incise the shelf: An example from the Great Barrier Reef, Australia, with implications for sequence stratigraphic models. *Geology*. 26:75-78.
- Yeats RS, Kulm LD, Goldfinger C, McNeill LC. 1998. Stonewall anticline: An active fold on the Oregon continental shelf. *GSA Bulletin*. 110:572-587.
- Zuercher R, Galloway AWE. 2019. Coastal marine ecosystem connectivity: Pelagic ocean to kelp forest subsidies. *Ecosphere*. 10:e02602.

Appendix A: Radiocarbon Dates

Table A-1 NCI Radiocarbon Dates.

DirectAMS No.	Sample Name	Sample Description	Core	Depth (cm)	¹⁴ C Age (yrs BP)	Calibrated Age (yrs BP) (1 sigma)
D-AMS-37321	2D_35-36	Barnacle (<i>Balanus sp.</i>) shell	CI-VC-2d	35-36	1582 ± 23	867.5 ± 42.5
D-AMS-37322	B4_66-74	Horse (<i>Modiolus sp.</i>) mussel shell	CI-VC-B4	66-74	837 ± 25	207 ± 62
D-AMS-37323	B4_105-109	Purple (<i>Nuttallia sp.</i>) clam shell	CI-VC-B4	105-109	2490 ± 23	1834.5 ± 45.5
D-AMS-37324	B4_113-120	Gaper (<i>Tresus sp.</i>) clam shell	CI-VC-B4	113-120	6317 ± 30	6470.5 ± 54.5
D-AMS-37325	B4_113-120	Gaper (<i>Tresus sp.</i>) clam shell	CI-VC-B4	113-120	6334 ± 32	6492.5 ± 57.5
D-AMS-37326	B4_113-120	Horse (<i>Modiolus sp.</i>) mussel shell	CI-VC-B4	113-120	6278 ± 28	6432.5 ± 47.5
D-AMS-37327	4E_90-91	Tusk (<i>Dentalium sp.</i>) shell	CI-VC-4e	90-91	1471 ± 24	742 ± 42
D-AMS-37328	4E_156-163	Scallop (<i>Pecten sp.</i>) shell	CI-VC-4e	156-163	675 ± 21	33 ± 30
D-AMS-37331	4E_177	Moon (<i>Naticidae sp.</i>) snail shell	CI-VC-4e	177	6336 ± 28	6494 ± 54
D-AMS-37332	4E_188-189	Olive (<i>O. baetica sp.</i>) snail shell	CI-VC-4e	188-189	5636 ± 26	5745.5 ± 64.5
D-AMS-37333	4E_190	Jackknife (<i>Tagelus sp.</i>) clam shell	CI-VC-4e	190	6798 ± 30	7059.5 ± 60.5
D-AMS-37334	4E_208	Purple olive (<i>Olivella sp.</i>) snail shell	CI-VC-4e	208	9576 ± 40	10165.5 ± 44.5
D-AMS-37335	4E_211-212	Bean (<i>Donax sp.</i>) clam shell	CI-VC-4e	211-212	9048 ± 35	9458.5 ± 39.5
D-AMS-37336	5B_209	Purple olive (<i>Olivella sp.</i>) snail shell	CI-VC-5b	209	39859 ± 333	42975 ± 255
D-AMS-37337	5B_208-211	Gaper (<i>Tresus sp.</i>) clam shell	CI-VC-5b	208-211	39062 ± 312	42475 ± 220
D-AMS-37338	6A_11-15	CA butter (<i>Saxidomus sp.</i>) clam shell	CI-VC-6a	11-15	9031 ± 37	9445.5 ± 39.5

DirectAMS No.	Sample Name	Sample Description	Core	Depth (cm)	¹⁴ C Age (yrs BP)	Calibrated Age (yrs BP) (1 sigma)
D-AMS-37339	6A_11-15	WA butter (<i>Saxidomus sp.</i>) clam shell	CI-VC-6a	11-15	9267 ± 38	9658 ± 83
D-AMS-37340	6B_10-20	CA cone (<i>Conus sp.</i>) snail shell	CI-VC-6b	10-20	6303 ± 32	6453 ± 53
D-AMS-37341	6C_17-22	CA frog (<i>Crossata sp.</i>) shell	CI-VC-6c	17-22	8498 ± 35	8757 ± 95
D-AMS-37344	6C_27-29	Tusk (<i>Dentalium sp.</i>) shell	CI-VC-6c	27-29	9395 ± 41	9893.5 ± 112.5
D-AMS-37345	6D_42-45	Prickly cockle (<i>Trachycardium sp.</i>) shell	CI-VC-6d	42-45	5698 ± 29	5815 ± 55
D-AMS-37346	6D_45-49	Slipper (<i>Crepidula sp.</i>) shell	CI-VC-6d	45-49	5889 ± 30	6029.5 ± 64.5
D-AMS-37347	6D_68-69	Horse (<i>Modiolus sp.</i>) mussel shell	CI-VC-6d	68-69	7437 ± 32	7633 ± 40

Table A-1 Oregon Coring Locations.

Core_ID		Latitude (DD)	Longitude (DD)	Total Length (cm)	Target
OC-VC-	1a	43.983139	124.362281	89	Thick transparent unit
OC-VC-	1b	43.981086	124.359075	143	High-amplitude anomaly above transgressive surface
OC-VC-	1c	43.980820	124.358710	155	High-amplitude anomaly above transgressive surface
OC-VC-	1d	43.979445	124.356899	144	Thick transparent unit
OC-VC-	2a-01	43.937940	124.341029	59	Thick transparent unit with internal reflector
OC-VC-	2a-02	43.937964	124.340999	0	Thick transparent unit with internal reflector
OC-VC-	2b	43.937261	124.340148	188	Chaotic unit between transgressive surface and transparent unit
OC-VC-	2c-01	43.935750	124.337984	216	Chaotic unit between transgressive surface and transparent unit
OC-VC-	2c-02	43.935778	124.338007	238	Chaotic unit between transgressive surface and transparent unit
OC-VC-	2d	43.935387	124.337470	263	Chaotic unit between transgressive surface and transparent unit
OC-VC-	3a	43.688910	124.358371	133	Chaotic unit east of mound
OC-VC-	3b	43.689963	124.360539	180	Crest of mounded high-amplitude feature
OC-VC-	3c	43.691448	124.363062	220	Chaotic unit west of mound
OC-VC-	3d	43.692523	124.365009	166	Chaotic unit west of mound
OC-VC-	4a	43.662899	124.399955	180	Layered reflectors near interpreted channel bank
OC-VC-	4b-01	43.662929	124.398516	85	Layered reflectors near interpreted channel bank
OC-VC-	4b-02	43.662922	124.398494	257	Layered reflectors near interpreted channel bank
OC-VC-	4c	43.662892	124.395383	194	Layered reflectors near interpreted channel bank
OC-VC-	4d	43.662909	124.392583	157	Layered reflectors near interpreted channel bank
OC-VC-	B10-02	43.730673	124.499626	0	Mound feature
OC-VC-	B1	43.706776	124.395446	147	Channel transect
OC-VC-	B2	43.686453	124.395021	109	Channel transect
OC-VC-	B3	43.665731	124.395089	132	Channel transect
OC-VC-	B4	43.647880	124.394241	147	Channel transect
OC-VC-	B5	43.639370	124.393885	126	Channel transect
OC-VC-	B6	43.630186	124.393521	314	Channel transect
OC-VC-	B8-01	43.584173	124.393209	160	Possible seep
OC-VC-	B8-02	43.584132	124.393134	176	Possible seep

Core_ID		Latitude (DD)	Longitude (DD)	Total Length (cm)	Target
OC-VC-	B11	43.704973	124.456359	151	Syncline or channel feature
OC-VC-	B12	43.677065	124.404367	99	Small channel
OC-VC-	B15	43.682421	124.320724	240	Layered reflectors
OC-VC-	B16	43.678221	124.406403	113	Channel deposits
OC-VC-	B17	43.887820	124.373510	166	High-amplitude anomaly
OC-VC-	B18	43.708341	124.371189	185	Channel or fold
OC-VC-	B19	43.673927	124.457420	102	Fold crest
OC-VC-	B20	43.904587	124.352209	124	Rough transgressive surface
OC-VC-	B21	43.963431	124.380529	135	Rough transgressive surface
OC-VC-	B22	43.980425	124.250133	50	Rough transgressive surface
OC-VC-	B23	43.582686	124.393166	97	Mound feature
OC-VC-	B24	44.027291	124.671714	309	Channel edge

Table A-2 Oregon Radiocarbon Dates.

Direct AMS No.	Sample Name	Sample Type	¹⁴ C Age (yrs BP)	1 sigma	Calibrated Age (yrs BP) Median	1s range
D-AMS-40125	OCVC1D-Sec1-62cmbt	shell	1338	20	248	156-310
D-AMS-40074	OCVCB2-Sec1-78cmbt	shell	1856	22	696	639-752
D-AMS-39930	OCVC2D-Sec2-81cmbt	wood	939	21	850	794-834
D-AMS-39674	OCVC4D-Sec1-31cmbt	wood	1071	20	965	955-974
D-AMS-40131	OCVCB6-Sec3-77cmbt	shell	2250	22	1096	1026-1171
D-AMS-39684	OCVC1C-Sec1-30cmbt	shell	2737	24	1604	1538-1678
D-AMS-39915	OCVC2B-Sec1-16cmbt	shell	3338	26	2345	2276-2434
D-AMS-40087	OCVC4B-01-Sec1-57cmbt	shell	3769	24	2857	2777-2921
D-AMS-40080	OCVCB4-Sec1-110cmbt	shell	4221	27	3416	3344-3483
D-AMS-39928	OCVC2D-Sec2-96cmbt	shell	4405	25	3639	3553-3717
D-AMS-40106	OCVC2C-2-Sec1-29cmbt	shell	4645	24	3955	3874-4041
D-AMS-39687	OCVCB1-Sec1-28cmbt	shell	5287	26	4791	4703-4862
D-AMS-39670	OCVCB2-Sec1-79cmbt	shell	5474	30	5027	4915-5125
D-AMS-39922	OCVC2C-1-Sec2-59cmbt	shell	5549	27	5128	5039-5230
D-AMS-39665	OCVC4A-Sec1-137cmbt	shell	6776	28	6461	6382-6545
D-AMS-40079	OCVCB4-Sec1-96cmbt	shell	6898	30	6596	6506-6672
D-AMS-40089	OCVC4B-02-Sec1-20cmbt	shell	7131	29	6863	6777-6945
D-AMS-39925	OCVC2D-Sec1-11cmbt	shell	7684	29	7438	7367-7504
D-AMS-39660	OCVC2C-1-Sec1-139cmbt	shell	7743	29	7489	7428-7551
D-AMS-40126	OCVC1D-Sec1-75cmbt	shell	7870	32	7602	7538-7671
D-AMS-40107	OCVC2C-2-Sec1-75cmbt	shell	7881	30	7612	7550-7679
D-AMS-39916	OCVC2B-Sec1-81cmbt	shell	8365	32	8095	8021-8165
D-AMS-40123	OCVC1D-Sec1-28cmbt	shell	8383	30	8113	8030-8178
D-AMS-40099	OCVC1A-Sec1-49cmbt	shell	8491	30	8236	8172-8310
D-AMS-40108	OCVC2C-2-Sec1-105cmbt	shell	8502	32	8246	8179-8318
D-AMS-40094	OCVC1B-Sec1-49cmbt	shell	8565	58	8307	8215-8385
D-AMS-40102	OCVC2B-Sec1-95cmbt	shell	8593	35	8338	8268-8410
D-AMS-40112	OCVC2D-Sec1-55cmbt	shell	9173	35	9082	8989-9160
D-AMS-40103	OCVC2B-Sec1-105cmbt	shell	9408	31	9366	9299-9439
D-AMS-39682	OCVC1B-Sec1-69.5cmbt	shell	10103	37	10254	10172-10333
D-AMS-40086	OCVCB6-Sec2-50cmbt	shell	10521	42	10847	10733-10975
D-AMS-40085	OCVCB6-Sec2-28cmbt	shell	10861	37	11283	11191-11358
D-AMS-40088	OCVC4B-01-Sec1-87cmbt	shell	10880	44	11310	11205-11391
D-AMS-40111	OCVC2D-Sec1-40cmbt	shell	11165	35	11750	11639-11856
D-AMS-39917	OCVC2B-Sec1-115cmbt	shell	11184	39	11779	11673-11895

Direct AMS No.	Sample Name	Sample Type	¹⁴ C Age (yrs BP)	1 sigma	Calibrated Age (yrs BP) Median	1s range
D-AMS-40110	OCVC2C-2-Sec1-143.5cmbt	shell	11328	36	12004	11873-12118
D-AMS-39959	OCVC2D-Sec1-90cmbt	shell	11531	37	12321	12230-12447
D-AMS-40081	OCVCB4-Sec1-125cmbt	shell	11781	38	12601	12532-12678
D-AMS-39958	OCVC2D-Sec1-86cmbt	shell	11795	42	12612	12549-12693
D-AMS-39685	OCVC1C-Sec1-68.5cmbt	shell	11802	42	12618	12557-12698
D-AMS-40124	OCVC1D-Sec1-40cmbt	shell	11990	36	12771	12701-12833
D-AMS-40082	OCVCB4-Sec1-143cmbt	shell	12127	44	12899	12810-12988
D-AMS-40105	OCVC2B-Sec1-148cmbt	shell	12785	43	13576	13481-13661
D-AMS-39957	OCVC2B-Sec1-146.5cmbt	shell	12797	43	13591	13494-13676
D-AMS-40098	OCVC1A-Sec1-37cmbt	shell	12801	43	13595	13498-13682
D-AMS-40104	OCVC2B-Sec1-142cmbt	shell	12813	40	13610	13513-13694
D-AMS-39918	OCVC2B-Sec1-128cmbt	shell	12877	40	13680	13593-13764
D-AMS-39662	OCVC2D-Sec1-128cmbt	shell	12937	48	13758	13641-13856
D-AMS-40109	OCVC2C-2-Sec1-130cmbt	shell	12961	40	13792	13677-13889
D-AMS-39960	OCVC2D-Sec1-148.5cmbt	shell	12965	48	13798	13685-13909
D-AMS-39919	OCVC2B-Sec1-133cmbt	shell	12997	41	13842	13753-13950
D-AMS-40100	OCVC1A-Sec1-65cmbt	shell	13001	45	13847	13756-13957
D-AMS-40114	OCVC2D-Sec1-127cmbt	shell	13042	41	13893	13798-13984
D-AMS-40120	OCVC1C-Sec1-87cmbt	shell	13140	45	14021	13896-14118
D-AMS-40101	OCVC1A-Sec1-87cmbt	shell	13144	50	14027	13898-14132
D-AMS-40117	OCVC1C-Sec1-99cmbt	shell	13161	41	14053	13949-14166
D-AMS-39677	OCVC4C-Sec1-75cmbt	shell	13252	46	14193	14056-14299
D-AMS-39929	OCVC2B-Sec1-119cmbt	wood	12322	41	14285	14150-14339
D-AMS-39672	OCVCB4-Sec1-29cmbt	shell	13362	47	14392	14209-14537
D-AMS-39658	OCVC2D-Sec1-130cmbt	wood	12351	45	14393	14196-14449
D-AMS-40116	OCVC2D-Sec1-148cmbt	wood	12404	45	14509	14319-14561
D-AMS-39956	OCVC2D-Sec1-130.5cmbt	wood	12449	42	14607	14431-14722
D-AMS-40095	OCVC1B-Sec1-86cmbt	shell	13503	47	14656	14508-14820
D-AMS-40127	OCVC1D-Sec1-106cmbt	shell	13522	41	14689	14544-14843
D-AMS-39683	OCVC1B-Sec1-110cmbt	shell	13594	48	14821	14677-14969
D-AMS-40122	OCVC1C-Sec1-131cmbt	shell	13664	53	14927	14811-15055
D-AMS-40090	OCVC4B-02-Sec1-50cmbt	shell	13730	44	15016	14907-15126
D-AMS-40128	OCVC1D-Sec1-120cmbt	shell	13969	46	15323	15200-15442
D-AMS-39663	OCVC4A-Sec1-55cmbt	shell	14007	44	15372	15251-15490
D-AMS-39659	OCVC2B-Sec1-142cmbt	shell	14173	47	15590	15466-15715
D-AMS-39666	OCVC4B-02-Sec1-50cmbt	shell	14192	47	15616	15491-15740

Direct AMS No.	Sample Name	Sample Type	¹⁴ C Age (yrs BP)	1 sigma	Calibrated Age (yrs BP) Median	1s range
D-AMS-40092	OCVC4B-02-Sec1-109cmbt	shell	14231	45	15668	15545-15789
D-AMS-39667	OCVC4B-02-Sec1-95cmbt	shell	14244	47	15686	15560-15808
D-AMS-40096	OCVC1B-Sec1-122cmbt	shell	14348	48	15822	15697-15947
D-AMS-40115	OCVC2D-Sec1-146cmbt	wood	13252	59	15915	15811-16009
D-AMS-40119	OCVC1D-Sec1-90cmbt	wood	13286	71	15966	15836-16076
D-AMS-40113	OCVC2D-Sec1-74cmbt	shell	14572	54	16113	15988-16238
D-AMS-40097	OCVC1B-Sec1-135cmbt	shell	16060	50	17973	17860-18098
D-AMS-40084	OCVCB6-Sec2-12cmbt	shell	17149	59	19125	18983-19255
D-AMS-39686	OCVC1C-Sec1-138cmbt	shell	17562	68	19635	19497-19778
D-AMS-40129	OCVC1D-Sec1-137cmbt	shell	18788	62	21109	20952-21250
D-AMS-39669	OCVCB1-Sec1-95cmbt	shell	18815	59	21143	20988-21287
D-AMS-39675	OCVCB1-Sec1-139cmbt-2	wood	17616	60	21267	21152-21400
D-AMS-40121	OCVC1C-Sec1-112cmbt	shell	20939	66	23570	23445-23718
D-AMS-39679	OCVC4D-Sec1-81cmbt	shell	24173	106	27041	26924-27174
D-AMS-39688	OCVCB1-Sec1-79cmbt	shell	29566	143	32416	32127-32713
D-AMS-39678	OCVC4C-Sec1-134cmbt	shell	30953	151	34092	33937-34261
D-AMS-39678	OCVC4C-Sec1-134cmbt	shell	30953	151	34092	33937-34261
D-AMS-39671	OCVCB3-Sec1-93cmbt	shell	31314	143	34384	34238-34525
D-AMS-40075	OCVCB2-Sec1-85cmbt	shell	31716	162	34766	34549-34970
D-AMS-39661	OCVC2D-Sec1-40cmbt	shell	36518	212	40077	39839-40317
D-AMS-40093	OCVC4B-02-Sec1-122cmbt	shell	39156	263	41950	41812-42107
D-AMS-40077	OCVCB2-Sec1-107cmbt	shell	41509	310	43171	42842-43421
D-AMS-40091	OCVC4B-02-Sec1-86cmbt	shell	42093	409	43650	43268-44032
D-AMS-39680	OCVC4D-Sec1-112cmbt	shell	42740	345	44204	43956-44487
D-AMS-40130	OCVCB6-Sec3-69cmbt	shell	43867	359	45026	44697-45318
D-AMS-40118	OCVC1D-Sec1-77.5cmbt	wood	42724	344	45224	44879-45512
D-AMS-39926	OCVC2D-Sec1-75cmbt	shell				
D-AMS-39664	OCVC4A-Sec1-90cmbt	shell				
D-AMS-40076	OCVCB2-Sec1-94cmbt	shell				
D-AMS-39676	OCVC4C-Sec1-6cmbt	shell				
D-AMS-39689	OCVCB1-Sec1-139cmbt-1	shell				



U.S. Department of the Interior (DOI)

DOI protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors the Nation's trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.



Bureau of Ocean Energy Management (BOEM)

BOEM's mission is to manage development of U.S. Outer Continental Shelf energy and mineral resources in an environmentally and economically responsible way.

BOEM Environmental Studies Program

The mission of the Environmental Studies Program is to provide the information needed to predict, assess, and manage impacts from offshore energy and marine mineral exploration, development, and production activities on human, marine, and coastal environments. The proposal, selection, research, review, collaboration, production, and dissemination of each of BOEM's Environmental Studies follows the DOI Code of Scientific and Scholarly Conduct, in support of a culture of scientific and professional integrity, as set out in the DOI Departmental Manual (305 DM 3).