

CONTROLS ON SUBMARINE CHANNEL ARCHITECTURE, UPPER MIOCENE –
LOWER PLIOCENE CAPISTRANO FORMATION,
SAN CLEMENTE STATE BEACH,
CALIFORNIA

by

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A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Earth Sciences

MONTANA STATE UNIVERSITY
Bozeman, Montana

May, 2013

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ACKNOWLEDGEMENTS

I would like to thank Dr. Michael H. Gardner for sharing his passion and knowledge, and for providing guidance and direction during my time at Montana State University. I would like to thank my committee members Dr. James G. Schmitt and Dr. David W. Bowen for their input and assistance in my research. This project would not have been possible without financial support in the form of a scholarship and internship from Marathon Oil Company, as well as support from the Slope and Basin Consortium - GAIA project sponsors including BHP-Billiton, Marathon Oil Company, Petrobras, and Statoil.

I love you Megan; you are my number one fan. I hope that one day I can repay you for all you have given me. Thank you to my family for your never-ending support while I traveled down this long road. Jesse, Jonathan, Kim and the Girls; I consider you part of my family. I love you all.

Jeannette Wolak and John Porter, you are the very definition of friendship. I couldn't imagine doing this without you guys. Thanks to The Guys, without whom life would have been far too serious. Finally, thanks to other graduate students within the department and those that are too numerous to name on a single page.

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ABSTRACT

Outcrops of the upper Miocene – Pliocene Capistrano Formation in San Clemente State Beach provide near continuous exposures of nested sandstone channel bodies. Numerous outcrop studies have reached varying conclusions on fundamental characteristics of the outcrop. Varying interpretations of channel stacking, confinement, hierarchy, and gradient profile position reflect the uncertainty associated with three-dimensional interpretation of a two-dimensional outcrop.

The northwest – southeast oriented cliffs range from 3 to 15 m in height and 2.3 km in length. The study focuses on three outcrop segments oriented sub-parallel to northwest (341°) paleoflow. The southernmost segment has been the subject of the most intense study while the two northern outcrops have only recently been incorporated. Eleven sedimentological sections totaling 124 meters, and two kilometers of outcrop photo panel were integrated and interpreted within a hierarchy of sedimentary attributes.

A new channel hierarchy for Capistrano Formation is proposed where the outcrop belt at San Clemente State Beach is interpreted to represent a single upper-slope channel fairway. Three sedimentation regions are defined by sedimentary facies, sedimentation units, and sedimentary bodies and surfaces, which record varying degrees of confinement on the upper-slope profile position. Four channel complexes represent allogenic phases of sedimentation recording the initiation, growth, and retreat of the channel fairway. Each channel complex is composed of multiple composite channels that represent repeated cutting and filling episodes of autogenic sedimentation. Within the composite channel, elementary channels represent channel thalweg migration within an open channel course.

INTRODUCTION

The plan-form morphology of submarine channels has not been directly observed in outcrop. Sedimentary attributes at multiple scales must be used to predict map-view patterns from one- and two-dimensional data. Facies, sedimentation units, and sedimentary bodies represent attributes that form a sedimentary architecture. As sedimentary responses, they correlate to increasing magnitude and time-averaged sedimentation processes. Correlation of this hierarchy of sedimentary attributes to the correct scale process-response relationship is critical to prediction. Changes in the facies, event beds, and bodies framing the architecture of a two-dimensional outcrop can then be used to evaluate the four-dimensional evolution of the channel system.

Outcrops of the late Miocene to Pliocene aged Capistrano Formation in San Clemente, California are used to investigate the sedimentology and architecture of a “nested” submarine channel complex interpreted to represent the evolution of a sinuous slope channel system. Twenty sedimentary facies describe the variation in grain size and sedimentary structures representing hydrodynamic energy at deposition. Six sedimentary body types describe the sedimentary architecture at multiple scales.

Deep-water hydrocarbon exploration has made outcrop analog models of submarine channel reservoirs of increased importance. Acquisition of large-scale, three-dimensional, seismic datasets provides a regional context, but is limited in internal resolution. This study utilizes direct measurements of bed thickness, bed length, grain-size trends, and architectural elements that cannot be directly obtained from remotely-sensed datasets. A rigorous characterization of the Capistrano Formation provides

submarine channel analog data, classified in a scalar hierarchy of features, which help manage uncertainty associated with four orders of magnitude of heterogeneity.

Statement of Problem

All channel systems, whether terrestrial or submarine, display similar morphologic patterns and dimensional characteristics. This similarity reflects similar process-response relationships that exist independent of environment. Plan-view attributes such as meander wavelength, channel width, and radius of curvature, are independent of geomorphological setting (Leopold and Wolman, 1957, 1960; Jackson, 1976; Flood and Damuth, 1987; Bridge, 1993, 2003; Pirmez and Imran, 2003; Kolla et al., 2007). Similarly, channel-related features such as scroll bars, cut-offs, and splays are present in both settings (Flood and Damuth, 1987; Abreu et al., 2003; Kolla et al., 2007).

Common processes operate in all sinuous channels. Channel barforms migrate downstream (sweep) and laterally (swing) leading to lateral migration of the channel and the formation of point bars (Brice, 1974). Abreu and others (2003) described shingled seismic reflectors along channel margins and concluded they represented continuous lateral migration of the channel system. These lateral accretion packages, or LAPs (Abreu et al., 2003), were also called lateral accretion deposits, or LADs, in outcrop by Arnott (2007).

Sinuous submarine channels resemble meandering fluvial channels in map view, yet fundamentally different sediment transport process are responsible for their formation. Clark and Pickering (1996a) document an increase in sinuosity with gradient,

opposite of what is observed in fluvial environments (Schumm, 1972, 1985). Kolla and others (2001) document upstream bar accretion in sinuous channels from West Africa, rather than downstream bar accretion observed meandering rivers (Schumm, 1972, 1985). Mayall and Stewart (2000) and Mayall et al. (2006) observed extreme variability in deposit type along subsequent bends of the same sinuous submarine channel. Additionally, Dykstra and Kneller (2009) observed inclined accretion surfaces within a gravel channel fill that was interpreted to be a product of a meandering submarine channel. These are counter to terrestrial rivers where grain-size distributions can be predictably related to radius of curvature around a sinuous channel bend (Jackson, 1976). These differences in sinuous submarine channel behavior emphasize that while sinuous channels occur across the Earth, disparate processes produce these similar patterns.

Channel Systems

Studies of modern channel systems have a direct relationship to process but only reveal a snapshot of geologic time. Ancient channel deposits record the response of the process system, but the record of the long-term behavior also results in a preservation bias. Attempts at modeling fluvial processes have been successful in predicting grain size, sedimentary structures, and bed thickness around fluvial channel bends (Jackson, 1976; Bridge, 1976, 1977, 1982, 1992; Bridge and Jarvis, 1982). Willis (1989, 1993) modeled sedimentary response and behavior of a sinuous fluvial system and showed that the interaction of point-bar geometry, outcrop orientation, and channel migration style combine to create unique relationships that are reflective of plan-form morphology. Results of flume simulations by Peakall et al. (2007) supported the conclusions of Willis

(1989, 1993) and added that bank cohesion is a key parameter in the modeling of channel systems.

Sinuuous Channel Systems

Lateral migration requires translation of the channel bend. Flow around the bend results in erosion of the cut bank and deposition on the point bar, which maintains the cross sectional area of the channel (Bridge, 1993; Abreu et al., 2003). This minimizes momentum loss and is thought to record quasi-equilibrium of a graded channel (Mackin, 1947). The rates of erosion and deposition correlate to the rates of lateral migration of the channel. Three processes are fundamental to the lateral migration of the channel and operate in both terrestrial and submarine channels: bank cohesiveness, sediment load, and secondary flow (Schumm, 1985; Thorne et al., 1985; Smith, 1998; Peakall et al., 2000).

Bank Cohesiveness: Bank cohesiveness affects the rate of erosion at the channel bend, thus affecting lateral migration (Smith, 1998). As the radius of curvature of the channel bend increases, velocity and shear stress along the outside of the bend decreases. If velocity and shear stress decrease to the point where the cut bank can no longer be eroded, the bend ceases to migrate and deposition of the point bar reduces the cross-sectional area of the channel (Peakall et al., 2000). The channel, unable to maintain its cross-sectional area is considered out of grade, and may either fill, avulse, or straighten its course.

Sediment Load: Flow size (discharge) and the composition of transported sediment are directly recorded by grain size, sedimentary structures, and bed thickness. The amount of suspended load and bed load in terrestrial channels has been linked to changes in sinuosity and width-depth ratio (Schumm, 1985). Rivers dominated by suspended and mixed sediment loads have lower width-depth ratios and higher sinuosity values than rivers dominated by bed-load transport (Schumm, 1985). Terrestrial flood events carry both suspended load and bed load similar to multipartite submarine flows, which consist of granular and suspended sediment loads (Fisher, 1983; Allen, 1991; Gardner et al., 2003; 2008).

Secondary Flow: Secondary flow (cross-stream, spiral, or helical flow) considers the transverse component of flow. Flow directed at the outside channel bend increases the water surface elevation, producing a boundary layer that slopes toward the inside channel bend (Thorne et al., 1985). The resulting centrifugal and pressure-gradient forces around the channel bend generate secondary helical flow (Thomson, 1876). Secondary flow transfers the momentum around the channel bend and also is responsible for the movement of sediment along the depositional surface of the point bar. Every increment of cut-bank erosion is balanced by an increment of lateral bar growth recorded as a scroll bar (Leopold and Wolman, 1957, 1960). Without secondary flow, point-bar sedimentation ceases and the channel cannot maintain its cross-sectional area. This results in a change in velocity, bed shear, and sedimentation pattern.

Hypotheses

The hypotheses this study seeks to address are the following:

1. The Capistrano lithosome in the study represents an upper-slope channel fairway containing compensationally stacked channel complexes.
2. Composite channels are multilateral and multistory bodies recording migration of a sinuous submarine channel.
3. Sedimentary bodies reflect the state of flow confinement.
4. A hierarchy of sedimentary attributes can be used to reconstruct ancient channel architecture. These attributes include: (1) sedimentary facies, (2) sedimentation units, (3) sedimentary bodies, (4) and sedimentation regions.
5. Lateral channel complex stacking pattern can be used to infer the stratigraphic evolution of channel fairways.

Study Area

Outcrops of the upper Miocene-lower Pliocene Capistrano Formation at San Clemente State Beach in the south, to San Clemente City Pier in the north (2.3 km transect), provide excellent exposures of nested submarine channel architecture (Figs. 1 & 2) (Weser, 1971; Walker, 1975; Hess, 1979; Clark and Pickering, 1996a, 1996b; Busby et al., 1998; Campion et al., 2000, 2005; Camacho et al., 2002; Bouroullec et al., 2007a, 2007b; Jennette, unpublished, 2005). The Capistrano Formation is composed of coarse- to fine-grained, biotite-rich, arkosic sandstone (75%), siltstone and mudstone (20%), and minor intraformational- and extraformational-clast conglomerates (5%) (Fig. 3) (Ehlig,

1979). The north-northwest to south-southeast trending cliff-face is 3 to 15 m in height, and is dissected by paths and gullies that reveal limited three-dimensional exposures.

This outcrop is divided into three segments (Figs. 1 & 2). The southernmost segment A is dominantly sandstone and increases in sand proportion northward. Sediment transport shifted from the north-northwest, to west across the 850 m exposure. Segment B is dominantly mudrock with minor sandstone beds that dip to the north and away from sandstones in segment A. Segment C repeats the trend seen in segment A, but sandstones increase in proportion to the south, where thick, amalgamated sandstones change to thinly bedded sandstones northward.

Segment A is the most studied part of the outcrop (Weser, 1971; Walker, 1975; Hess, 1979; Clark and Pickering, 1996a, b; Busby et al., 1998; Campion et al., 2000, 2005; Camacho et al., 2002; Bouroullec et al., 2007a, b; Jennette, unpublished, 2005). A series of nested channels stack laterally in the south, and vertically in the north, but there is little consensus in the hierarchy and number of channel bodies (Weser, 1971; Walker, 1975; Hess, 1979; Clark and Pickering, 1996 a,b; Busby et al., 1998; Campion et al., 2000, 2005; Camacho et al., 2002; Bouroullec et al., 2007a,b; Jennette, unpublished, 2005).

Data and Methods

Fieldwork in San Clemente, California was conducted in two field sessions in February and April, 2010. Eleven sedimentological sections (124 meters) were measured in accessible gulleys and along trails to define sedimentary facies and the event beds they compose (Fig. 2). Section thickness data were measured with a Jacob's staff and grain

size was collected every 10 cm and/or at the base and top of every bed. Sedimentological sections capture the following attributes used to interpret hydrodynamic conditions at deposition: facies and event bed thickness; texture; matrix composition; clast composition, shape, and roundness; sorting; grading; bed contacts; primary and secondary sedimentary structures; paleoflow indicators; and sedimentary bodies. Field measurements were transferred to standardized 1:20 scale data sheets and scanned and drafted into digital format.

Attributes captured in sedimentological sections were grouped into sedimentary facies that record the complete spectrum of grain size and sedimentary structures that can be deposited by a single multipartite sediment gravity flow. A passing sediment gravity flow deposits a succession of facies that are recorded by a sedimentation unit, also called an event bed. Multiple sedimentation units, bound by common surfaces mapped in photo panel, were grouped into sedimentary bodies.

Sedimentological section data were synthesized into a table with individual event beds in rows and sedimentary facies in columns. Each of the 239 event beds were classified by the flow acceleration matrix of Kneller (1995), and by occurrence within a sedimentary body, channel hierarchy, sedimentation region, and stratigraphy. This table was used to create facies proportion pie charts and grain-size distributions in the study.

Photo-panel data was acquired from two sources: 1072 meters of high-resolution photo panels collected in this study, and approximately 1900 meters of continuous regional photo panels used with permission from the California Coastal Records Project.

Photo-panel and map data were integrated to link lateral and vertical changes in sedimentary attributes between sedimentological sections and across the outcrop.

GPS data were collected to geo-reference section and photo-panel data in a geospatial framework. GPS waypoints were taken to tie section and photo-panel data to geo-referenced aerial photography and topographic maps. GPS data were collected using a consumer grade Garmin Oregon 550t. Waypoints were collected at the base and top of every section. Photo panels were recorded by marking waypoints at margins of the image. Additional surfaces and landmarks were captured in a similar manner. GPS data were collected in the World Geodetic Coordinate System of 1984 (WGS84) datum and was projected using Teale Albers Equal Area Projection into the North American Datum of 1983 (NAD83) Zone 6.

Results

Lateral submarine channel migration is determined by the following: (1) flow composition; (2) bank cohesiveness; (3) the development of secondary flow; and (4) depositional topography. Changes in these conditions are recorded in the style of channel filling and bar migration. Multilateral channel architecture is documented in outcrops of the Capistrano Formation at San Clemente State Beach at multiple sedimentary scales.

Six scales of sedimentary architecture record the long-term evolution of the channel system. The outcrops from San Clemente State beach to San Clemente Pier represent a single channel fairway containing four channel complexes, and 15 composite bodies. Twenty sedimentary facies are interpreted to represent a range of subaqueous flow density, viscosity, and behavior within sedimentation units recording the temporal

and spatial evolution of a subaqueous flow event. Changes in these sedimentary attributes record changes in channel, and channel-related sedimentation. Six sedimentary bodies record varying degrees of flow confinement and sedimentation energy and are arranged in a hierarchy of composite bodies, channel complexes, and channel fairway features that reflect the long-term evolution of this upper-slope channel system. Differences in facies, sedimentary units, and body attributes are used to define channel axis, channel margin, and channel flank sedimentation regions and to construct a stratigraphic framework where the relative age of the four channel complexes can be determined.

Paleogeography

The Capistrano Formation represents a sandstone lithosome deposited in the Capistrano Embayment, a reentrant of the Los Angeles Basin (Fig. 4) (Ingle, 1962,1971; Ehlig, 1979; Campion, 2005). Early Miocene formation of the Los Angeles Basin records the transition from a forearc to a transtensional basin associated with extension and clockwise rotation of the Western Transverse Range (Hornafius et al., 1986; Luyendyk, 1991; Crouch and Suppe, 1993; Nicholson et al., 1994). The onset of coarse clastic sedimentation of the San Onofre Breccia was followed by a period of relative quiescence and sediment starvation recorded by siliceous chert and petroliferous mudrocks in the Monterey Formation (Fig. 3) (Ehlig, 1979; Stewart, 1979). The Capistrano Formation records late Miocene to early Pliocene rejuvenation of clastic sedimentation in the Los Angeles Basin and associated Capistrano Embayment (Campion, 2005). The nested channels were formed in a high-gradient setting (Campion et al., 2000, 2005; Bouroullec

et al., 2007a, b). The coeval shoreline was located 5.5 km to the east of the outcrop (Fig. 4) (Corey, 1954; Ingle, 1971; Crowell, 1972; Schwartz and Colburn, 1987). Foraminiferal assemblages from coeval strata at Dana Point, 9 km to the northwest indicate midbathyal paleowater depths of approximately 2000 to 3000 m (Ingle, 1971, 1979).

Previous Work

The upper Miocene to lower Pliocene deposits of the Capistrano Formation were first interpreted by Weser (1971) as the fill of a submarine channel in the proximal part of a deep-water submarine fan. Walker (1975) recognized eight, laterally migrating channels forming a larger braided suprafan (distal mid fan) channel on a submarine fan. Hess (1979) confirmed Walker's interpretation of nested channels but, based on studies of the modern Navy Submarine Fan by Normark et al. (1979), suggested the channels formed in an inner suprafan (proximal mid fan) setting. Clark and Pickering (1996a, b) emphasized lateral migration of mid-fan channels in a lower gradient, sinuous channel. More recent work on San Clemente (Busby et al., 1998; Campion et al., 2000, 2005; Camacho et al., 2002; Jeanette, Unpublished, 2005; Bouroullec et al., 2007a, b) center on various interpretations of the planform channel morphology and hierarchy.

Large Single Channel Model

Busby et al. (1998) and Camacho et al. (2002) group the San Clemente outcrop into three sedimentation regions: (1) low-gradient slope, (2) channel margin, and (3) channel axis within a single channel filled by vertical aggradation (Fig. 5). This interpretation emphasizes application of process-based model which relates the smaller

elementary channel cuts to scours, with the scours recording lateral migration of the channel thalweg. They report paleoflow in contrast to the consistent westward sediment transport reported by many other authors. They also interpret the drapes at the base of elementary channels to record deposition of the upper, low-density fraction of a turbidity current moving through basal region of the channel.

Slope Valley Model

Architectural models proposed by a number of ExxonMobil geoscientists have evolved from two confined channel complexes (Campion et al., 2000), to three channel complexes within a slope valley (Fig. 5) (Campion et al., 2005). Channel complexes are defined changes in lithology, grain size and paleoflow direction. These interpretations focus on the four-fold hierarchy of bodies, but do not consider morphology (sinuosity) may relate to channel stacking. Finally mudrock-draped erosional surfaces are related to sediment bypass along the margin of a submarine channel (Campion, 2005)

Laterally Offset Channel Complex Model

A study by the LASR consortium at the Bureau of Economic Geology at the University of Texas at Austin, (Jennette, unpublished, 2005; Bouroullec et al, 2007a, b) includes data from outcrop segments B and C, and uses LIDAR data to correlate across the parking lot in outcrop segment A to generate a paleohorizontal datum. Jeannette (unpublished, 2005) recognized two channel complexes defined by changes in channel trajectory (Fig. 5). Trajectory is defined by degradational, downward-stepping or aggradational, upward-stepping arrangement of successive channel bodies. Downward-

stepping channels are associated with the fine-grained drapes that record bypass of the coarse sediment fraction, and deposition of the low-density cloud on channel margins. Channels stacking upward lack shale drapes and are much more amalgamated, which is related to channel aggradation.

Highly Sinuous Composite Channel Complex Model

As part of the LASR consortium study, Bouroullec et al. (2007a, b) propose a meandering channel morphology for the three outcrop segments (Fig. 5). Ten northward-stepping, laterally-accreting channel fills form a point bar in segment A, which are correlated to ten southward-stepping, lateral-accretion packages forming a separate point bar in outcrop segments B and C. Paleoflow measurements in outcrop segments A, B, and C are used to support a sinuous interpretation. These observations are used to conclude that the outcrop represents a single, meandering channel course with side-attached point bars.

Summary

Interpretations of the Capistrano Formation in the San Clemente State Beach area have evolved from various positions on a submarine fan (Weser, 1971; Walker, 1975; Hess, 1979; Clark and Pickering, 1996a, b) to lower slope (Busby et al., 1998; Camacho et al., 2002) to a mid-slope position (Fig. 6 & 7) (Campion et al., 2000, 2005; Jeanette, Unpublished 2005; Bouroullec et al., 2007a, b). Grain size, paleoflow direction, cross-cutting relationships, channel trajectory, and plan form morphology were all investigated, but at a varying scale of processes. Dimensional measurements associated with previous

interpretations are inconsistent in both scale of feature and channel form hierarchy, which is illustrated in Figure 8.

Recognition criteria synthesized from these studies and applied in this study include: (1) changes in grain size, (2) changes in paleoflow direction, (3) cross-cutting relationships, (4) channel hierarchy, and (5) correlation to planform morphology. This study seeks to integrate sedimentary attributes that are common to all previous work, but grouped within a consistent hierarchy of increasing scales processes including: (1) sedimentary facies; (2) sedimentation units and event beds; (3) hierarchy of channel bodies; and (4) sedimentation regions.

Table 1. List of measured sedimentological section and uninterpreted photo panel data and lengths.

Section Name	Length (m)	Panel Name	Length (m)
Camacho Section 1	11.3 m	North Gulley - North Wall	55 m
Lifeguard Overlook	7.2 m	North Gulley - South Wall	42 m
South Path Section	16.6 m	Channel 4.1 Complex Drape	47 m
Lunch Break	13.15 m	Channel 3.4 Bank Collapse	39 m
C-12	11.9 m	North Path to Outhouse	56 m
North Gulley	7.75 m	Outhouse to South Path	40 m
Parking Lot	8.5 m	Channel Complex 3 Margin	73 m
Volleyball	13.4 m		
Guardhouse	14.95 m		
Outhouse	10.55 m		

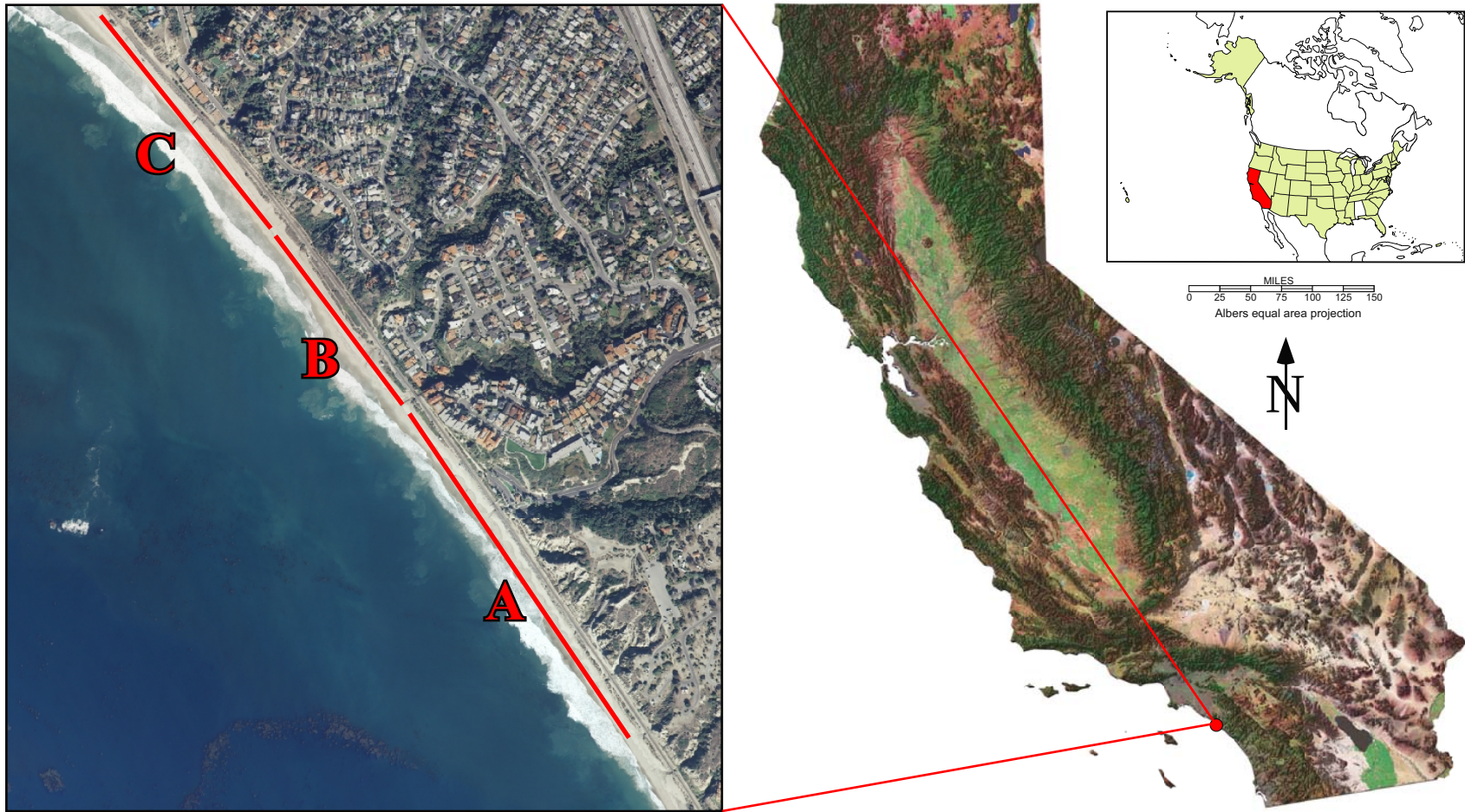


Figure 1. Location map showing San Clemente State Beach and surrounding area. Labels A, B, and C denote outcrop segments that are referred to throughout the text and figures of the study. The aerial photography, California Landsat imagery, and United States location map are used courtesy of the USGS.

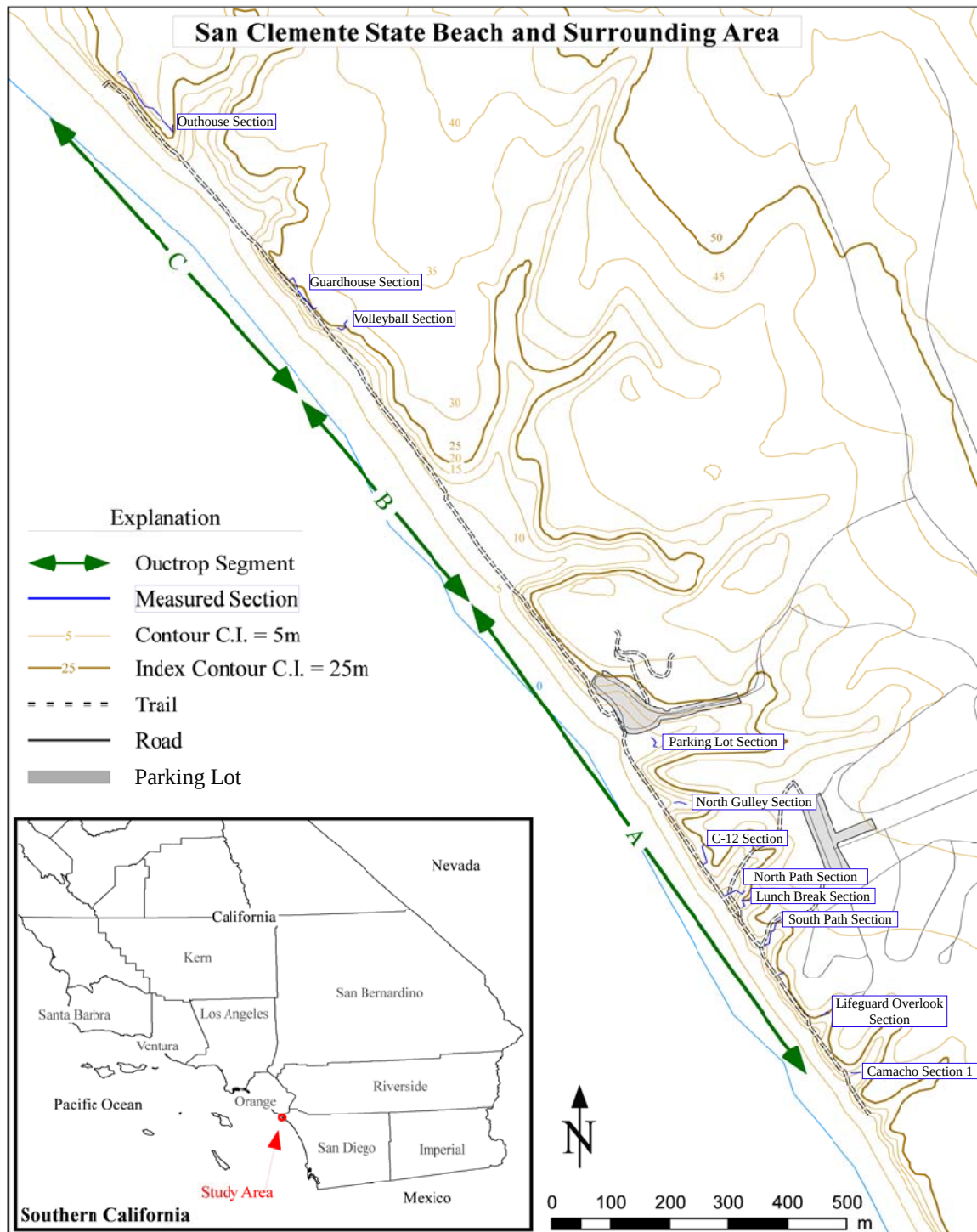


Figure 2. Topographic map of San Clemente State Beach and surrounding area. Green lines mark outcrop segments described in the text. Blue lines denote the location of sections measured in this study.

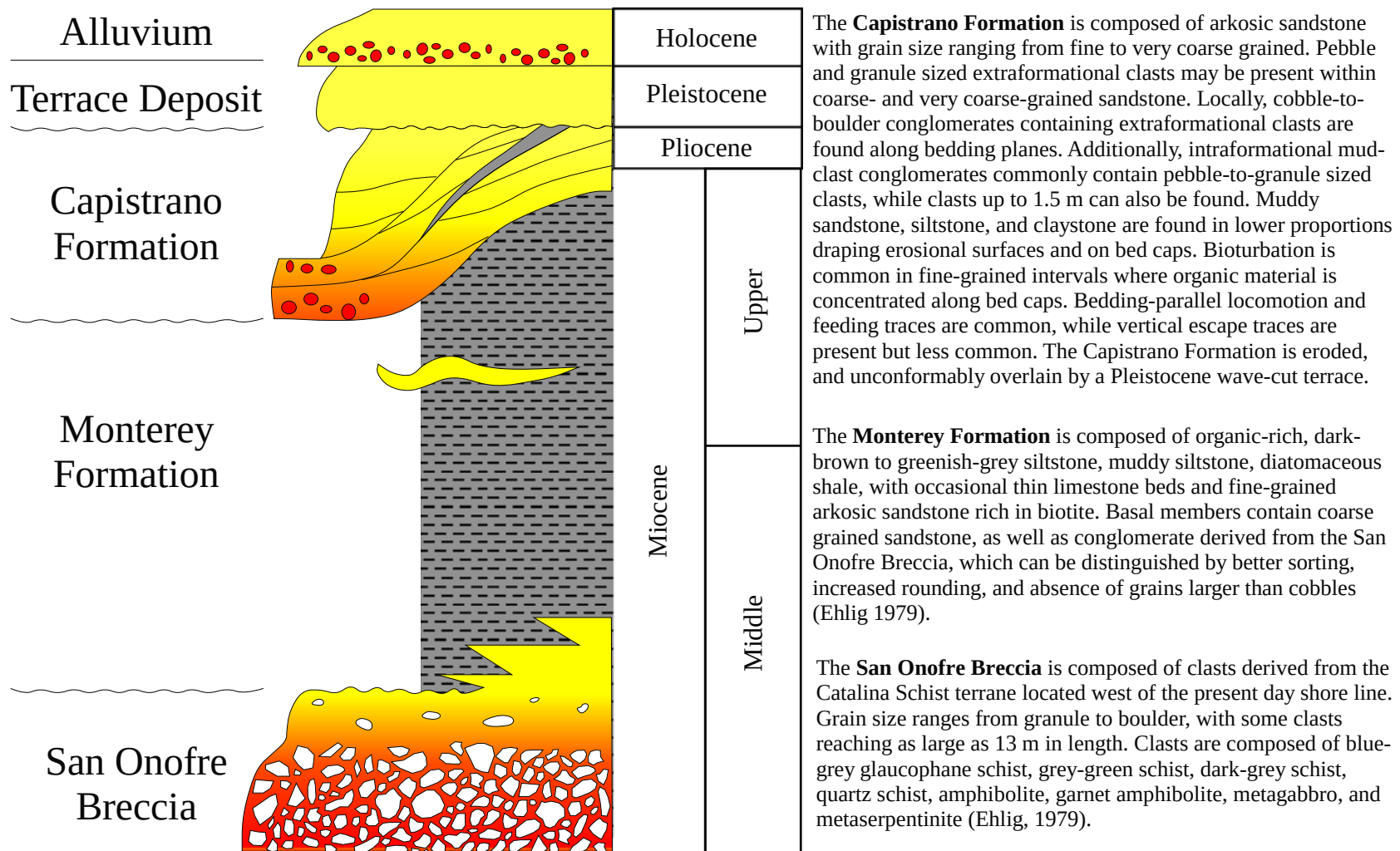


Figure 3. Generalized stratigraphic section for the area north and south of San Clemente State Beach. The San Onofre Breccia is not exposed in the beach cliffs at this locale, but may be observed east of the Christianitos fault. The upper Miocene to Pliocene aged Capistrano Formation formed in water depths of 1500 - 1900 m (Ingle, 1971).

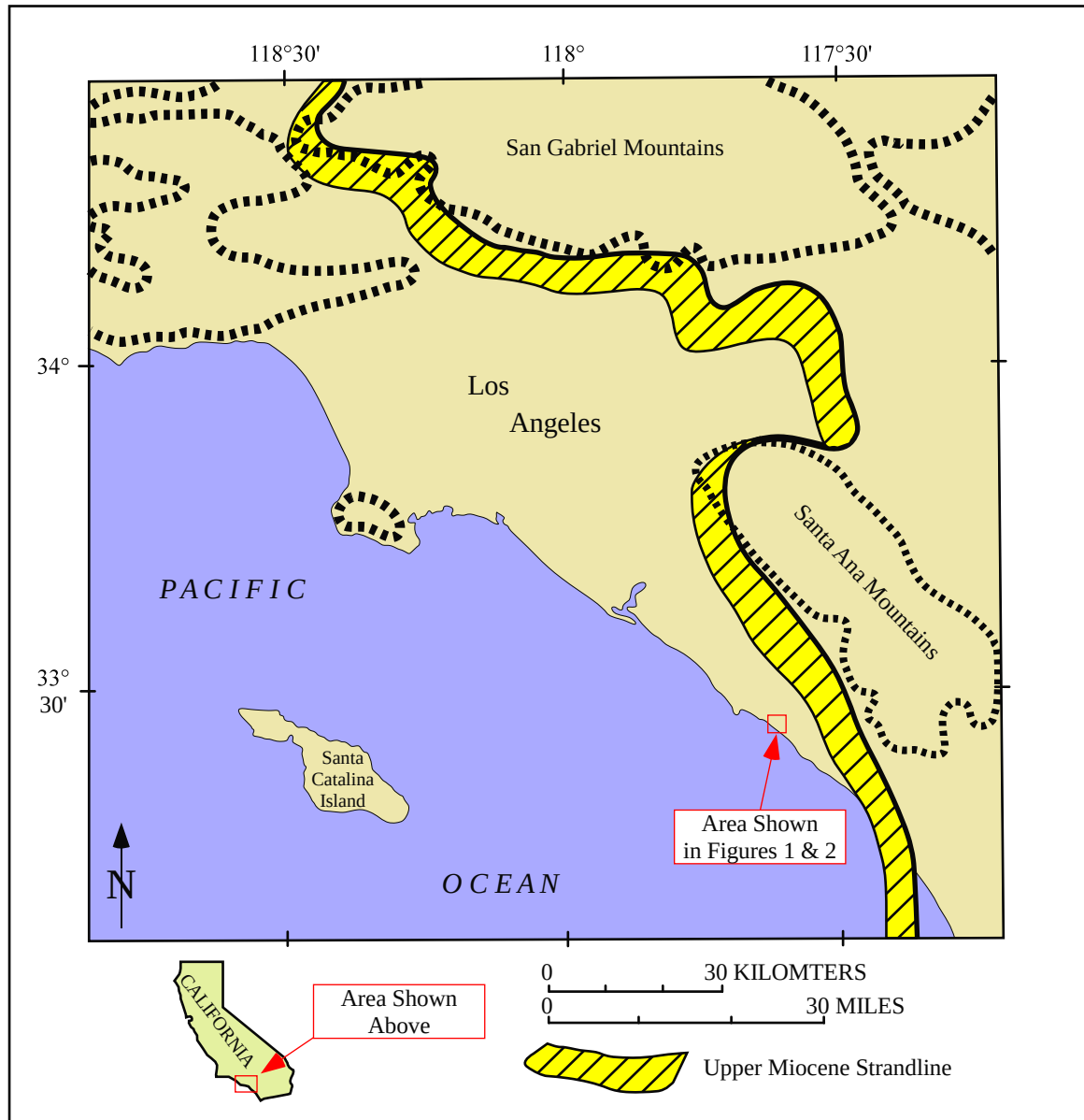
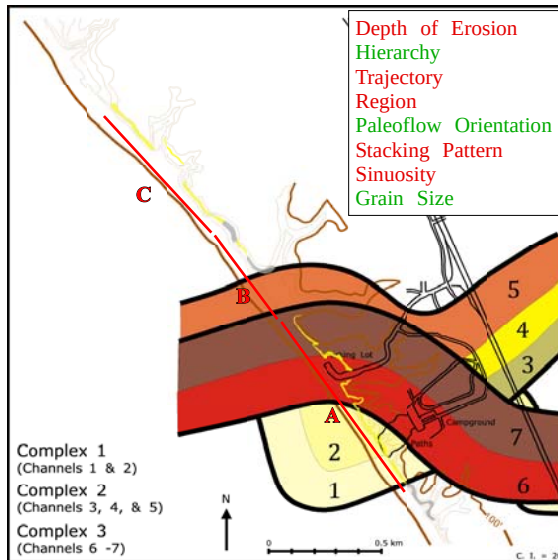
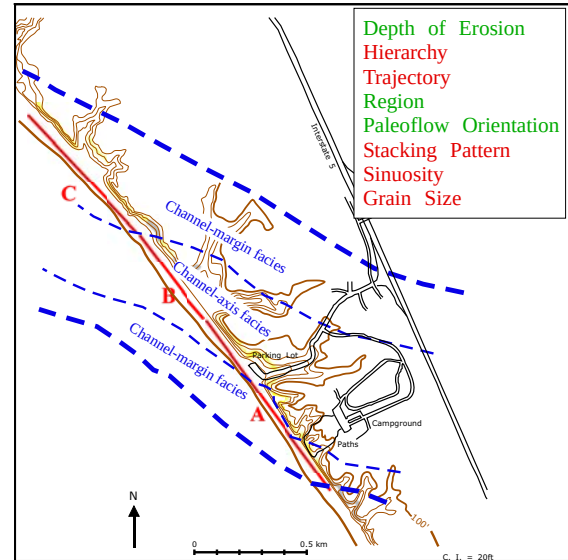


Figure 4. Paleogeographic map of the Los Angeles Basin during late Miocene time. The Upper Miocene strandline is denoted in a yellow hatcher fill. The geographic limits of strandline sediments are constrained by subsurface mapping and subaerial occurrences of Upper Miocene marine sediments (Corey, 1954; Ingle, 1971).

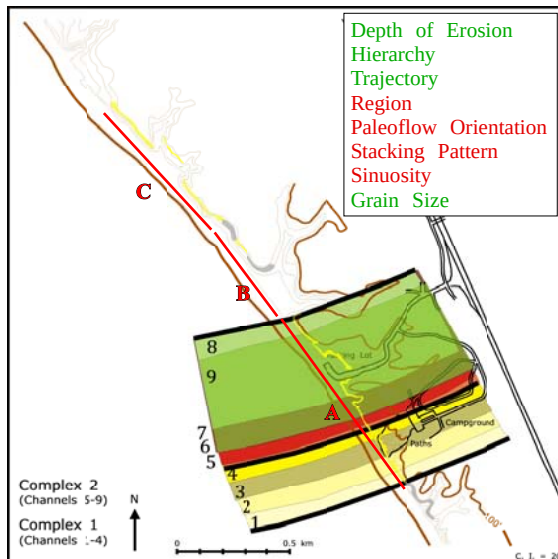
A) Confined Valley



B) Large Single Channel



C) Laterally Stacking Channel Complexes



D) Highly Sinuous Composite Channel

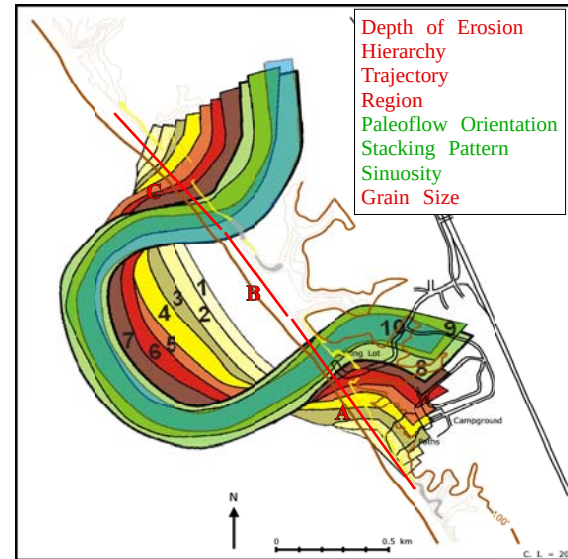


Figure 5. Location maps showing the San Clemente, California area with four interpretations of the beach outcrop. A) Three channel complex interpretation (Campion et al., 2005). B) Single channel interpretation (Camacho et al., 2002). C) Two channel complex interpretation (Jennette, Unpublished). D) Single channel with 10 lateral accretion packages (Bouroullec et al., (2007b). The confined valley (A) and laterally stacking channel complex (C) models only consider outcrop segment A and B, while the large single channel (B) and highly sinuous composite channel (D) models consider outcrop segments A, B, and C. Inset box lists attributes in green that were highlighted in the interpretation, while red attributes were either not considered or not used in the interpretation.

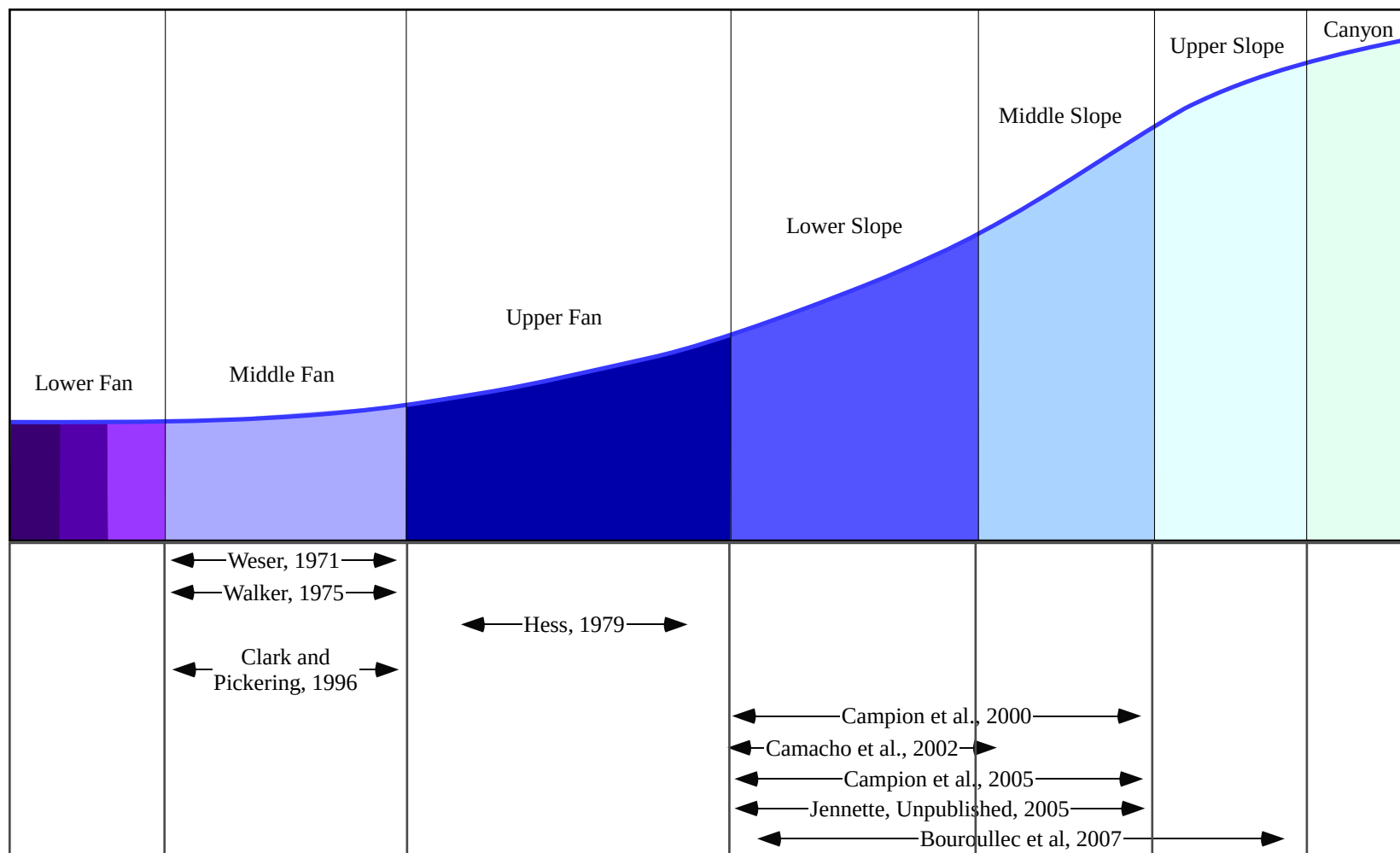


Figure 6. Previous work at San Clemente State Beach have not generated consensus on the depositional environment for deposits of the Capistrano Formation. Position on the slope profile is directly correlated to gradient. Early work focused on the deep-water fan models of Normark (1970), Normark et al. (1979) and Mutti and Normark (1987), while later work placed additional emphasis on the slope as a site of deposition.

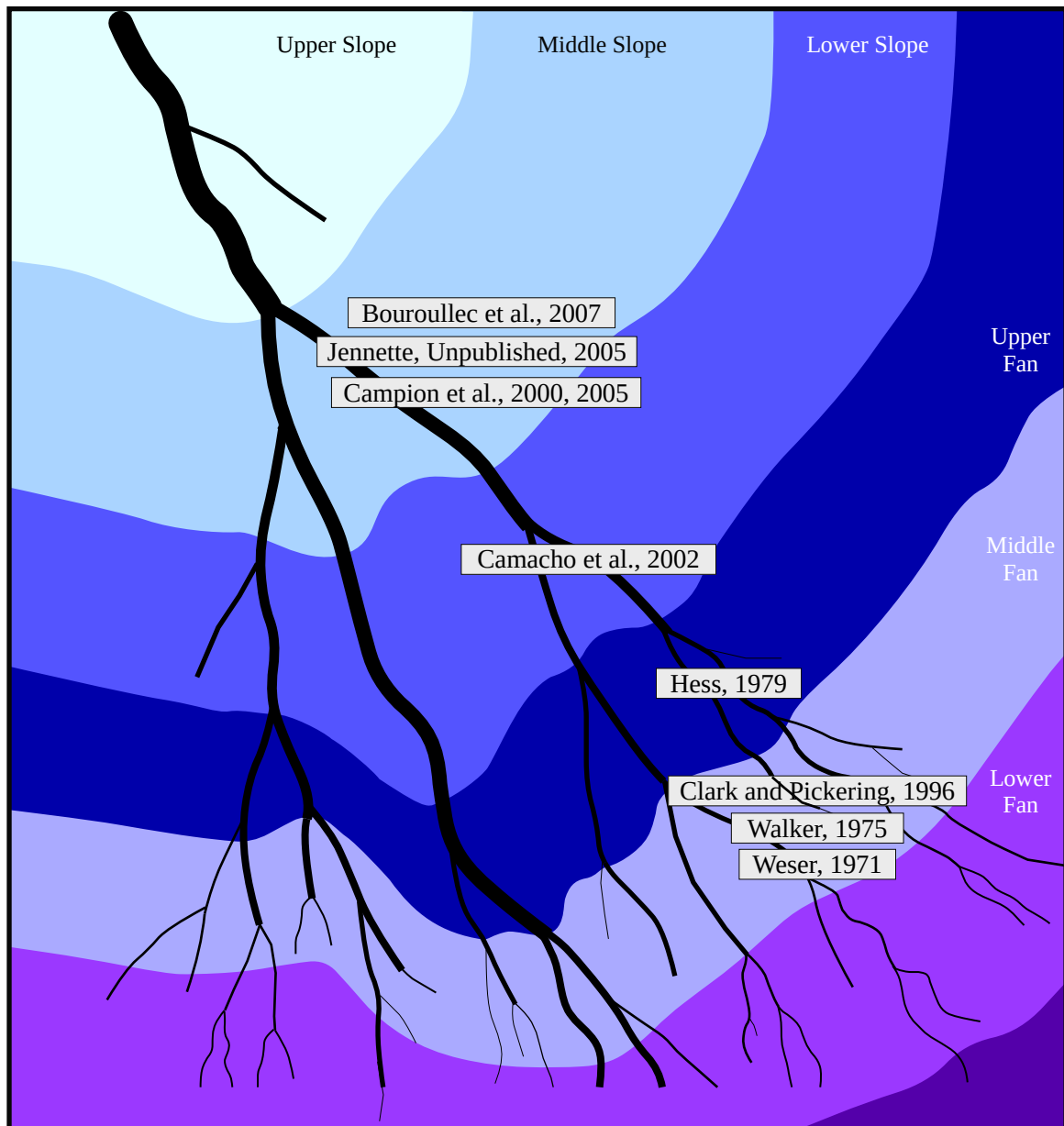


Figure 7. Previous work at San Clemente State Beach have not generated consensus on the depositional environment for deposits of the Capistrano Formation. Position on the slope profile is directly related to gradient, which can be correlated to confinement. Higher profile positions have increased confinement causing decreased channel branching, and increased channel size. Channels lower on the slope profile have decreased confinement, causing increased channel avulsion and decreased channel size.

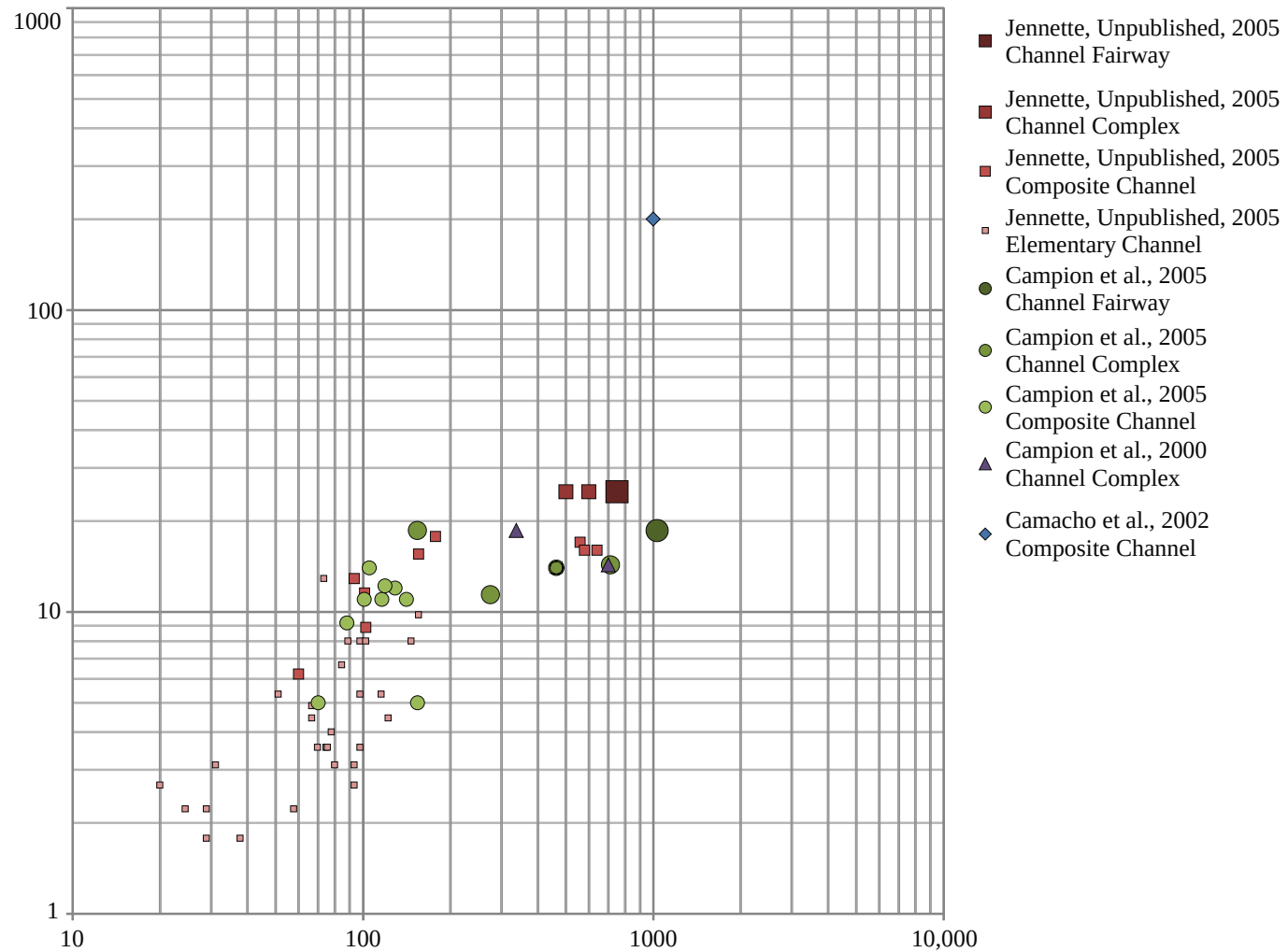


Figure 8. Dimensional measurements of hierarchical channel elements from Jennette (unpublished BEG report, 2005), Campion et al. (2000, 2005) and Camacho et al. (2002). Hierarchical channel elements are classified by the channel hierarchy of Gardner and Borer (2000) and Gardner et al. (2008). This plot underscores the problems with inconsistent hierarchical classification where the same features have been classified at varying hierarchical levels by multiple authors.

SEDIMENTOLOGY

Sediment gravity flows are the primary sedimentation agent in deep-water environments. Sediment gravity flows are multipartite, in that they exhibit multiple flow behaviors (e.g. turbulent and laminar) and sediment support mechanisms within a single flow event (Mutti and Ricci Lucchi, 1972; Fisher, 1983; Allen, 1991; Gardner et al., 2003, 2008; Haughton et al., 2009). Grain size and primary sedimentary structures are used to infer density, viscosity, and sediment support mechanisms recorded at the time of deposition. The twenty sedimentary facies record the complete spectrum of grain size and sedimentary structures deposited by a multipartite sediment gravity flow (Fig. 8).

One or more sedimentary facies stack to form a sedimentation unit or event bed recording the longitudinal and temporal evolution of the flow. Sediment gravity flows are often unsteady and non-uniform, owing to variable acceleration generating differences in sediment-support mechanisms (Kneller and Buckee, 2000). The vertical succession of facies comprising a sedimentation unit records both temporal changes in flow velocity (unsteadiness), and the longitudinal structure of flow velocity passing a depositional site (non-uniformity), within a single event (Kneller, 1995; Kneller and Branney, 1995). One or more sedimentation units stack to form a sedimentary body, which records time-averaged state of flow confinement within a suite of flow events.

Sedimentary Facies

Sixteen primary sedimentary facies and four secondary facies are defined based on grain size and sedimentary structures (Fig. 10a-d). Pebble-to-granule, clast-rich

sandstone and muddy sandstone facies were further divided to capture variability in those facies present within the outcrop. Sedimentary facies are related to flow density, viscosity, and sediment support mechanisms. Figure 11 shows the part of the flow from which sediment is derived at the time of deposition. Flow density is related to grain size and sediment concentration. Viscosity is inferred from the amount of matrix (mud and fine sand) in the deposit. Finally, the support mechanism is inferred from the primary sedimentary structures, sorting and grading.

The sedimentary facies data is summarized in Figure 12. Five sedimentary facies were found to be the most significant in proportion and occurrence across the outcrop. In order of increasing sedimentary energy they are: (1) bioturbated sandstone, (2) muddy sandstone, (3) scour-and-fill cross-stratified sandstone, (4) pebble-to-granule sandstone, and (5) mudstone intraclast breccia (Fig. 13). These are described in detail in the following section.

Bioturbated Sandstone

Description: Bioturbated sandstone contains very fine-grained sandstone to muddy sandstone with horizontal and vertical burrows. Carbonaceous debris concentrated at sandstone bed tops forms thick, rusty-to-black colored laminae. This facies is dominantly found in sedimentation units with ripple-laminated sandstone, but also occurs associated with structureless and plane-parallel laminated sandstone (Fig. 11). Bioturbated sandstone is low in proportion (4% of measured section thickness) but is an important indicator facies in the outcrop (Fig. 13).

Interpretation: Burrowing organisms preferentially consume carbonaceous material concentrated at bed caps of infrequent, low-density, low-viscosity turbulent flows. Bioturbation of the organic matter may also represent a significant interval of time. Preservation of bioturbated sandstone bed tops also indicate that subsequent flows were not erosive, creating sequences of event beds multiple meters in thickness.

Muddy Sandstone

Description: Muddy sandstone facies is very fine- to fine-grained, poorly- to moderately-sorted sandstone containing mud- and silt-sized particles. Primary structures include wavy-lenticular, plane-parallel-laminated, or structureless sandstone that weathers dark brown to orange depending on organic content. The friable and slope-forming nature of this facies commonly obscures bedding and sedimentary structures. Muddy sandstone has been subdivided into (12a) wavy-laminated sandstone, and (12b) structureless muddy sandstone based on different occurrences in the Capistrano Formation. Wavy-laminated sandstone forms thick successions (up to 50cm) at bed tops of thicker sedimentation units, and is associated with asymmetric ripple-cross-laminated, plane-parallel-laminated and structureless sandstone (Fig. 12). Structureless muddy sandstone forms thin, isolated beds (up to 20 cm) but bed thickness may be overestimated due to poor exposure quality.

Interpretation: Structureless muddy sandstone is interpreted to represent the transformation of a low-density, low-viscosity flow, to a low-density, high-viscosity flow along the margin of a submarine channel (Fig. 11). Sand and silt suspended in the

turbulent cloud locally incorporates mud on the seabed, resulting in a change to cohesive and laminar flow conditions. Structureless muddy sandstone facies are found in varying proportions along the margin of channels and reflects the nature and complexity of the channel drape.

Wavy-laminated sandstone is interpreted to represent deposition from low-concentration, turbulent part of the flow containing only very fine sand and silt. Thick intervals of wavy-laminated sandstone are interpreted to represent uniform to depletive flow developed along the margins and tail of the flow.

Scour-and-Fill Cross-Stratified Sandstone

Description: Scour-and-fill cross stratification occurs in medium- to very coarse-grained, moderately sorted sandstone. It consists of low-angle stratification (below angle of repose) and resembles the “S1” division characteristics of Lowe (1982). It is characterized by scoop-shaped scours up to 0.3 m deep and draped by coarse laminae that fine upward, and show an upward decrease in foreset angle (Gardner et al., 2003). Scour-and-fill cross-stratified sandstone commonly occurs in thick sedimentation units overlying pebble-to-granule sandstone and is often overlain by plane-parallel laminations (Fig. 13).

Interpretation: Scour-and-fill cross-stratified sandstone is the most abundant facies documented and accounts for 22% of the total facies (Fig. 12). It records deposition from combined flow and from tractive deposition in the high-density body of a

sediment gravity flow (Fig. 11). This facies forms the thickest successions of sandstone and the dominant style of channel filling in the outcrop.

Pebble-to-Granule Sandstone

Description: Clast-rich, pebble-to-granule sandstone contains gravel-sized extraformational clasts less than 2 cm in diameter and in concentrations less than 20%. The sand-sized fraction is coarse to very coarse, moderately sorted, and may contain floating, angular, mudstone intraformational clasts up to 3 cm in diameter, with sparse outsized clasts up to 60 cm in diameter. This facies was subdivided into scour-and-fill cross-stratified, plane-parallel stratified, and graded pebble-to-granule sandstones (Fig. 10a). Coarser sediment occurs at the base of irregular and/or planar erosional contacts up to 1.0 m in depth. Pebble-to-granule sandstone commonly occurs in thick event beds and is often overlain by cross-stratified, plane-parallel-stratified, or structureless sandstones (Fig. 13).

Interpretation: Pebble-to-granule sandstone is the second most abundant facies documented and accounts for 15% of the total facies measured (Fig. 12). It represents tractive deposition from the high-density, low-viscosity, turbulent to non-turbulent part of the flow (Fig. 11). Further division of pebble-to-granule sandstone facies captures traction-dominated bedload transport (facies 5a), to sedimentation recording alternations between bed shear and cohesion generated by dispersion and hindered settling (facies 5b and 5c).

Mudstone Intraclast Breccia

Description: Mudstone intraclast breccia is composed of locally-derived and angular intraformational-mudstone clasts up to 1.0 m in diameter. Clasts are supported by a matrix of very fine- to coarse-grained, very poorly-sorted sandstone. Sedimentation units up to 3 m in thickness are commonly overlain by clast-rich and scour-and-fill sandstones (Figs. 12).

Interpretation: Mudstone intraclast breccia is an important indicator of erosion and bank collapse of the channel margin. Thick sequences of mudstone intraclast breccia indicate failure of a channel margin into an active channel site and record expansion of the channel width often in association with channel migration. Thin packages of mudstone intraclast breccia at the base of thick sand successions suggest erosion and incorporation of channel drape at the base of a depositing flow. Incorporation of mud increases cohesion and promotes frictional freezing of the base of the flow, which may not propagate upward into the main body of a bypassing flow.

Sedimentation Units

Sedimentation units are genetically related groups of facies are primarily defined by bounding surfaces and changes in grain size, but also incorporate primary and secondary sedimentary structures, grading, and stratification. Sedimentation units, or event beds, are the vertical record of the lateral and longitudinal evolution of a sediment

gravity flow. Ten types of sedimentation units are recognized in this study recording variations in flow velocity steadiness and uniformity as described by Kneller (1995).

Waning Uniform Sedimentation Units

Thick-bedded sedimentation units that fine upward and contain abundant traction structures with dispersed mudstone intraclasts and macerated carbonaceous debris increasing upward record waning uniform flow velocity (Fig. 14) (*sensu* Kneller, 1995). These units lack structureless or graded sandstone and are interpreted to represent gradual accumulation of bed load during bypass of the main body of the flow. Dispersed mudstone intraclasts suggest continual erosion and incorporation of the channel drape sediment into the flow and may account for limited drape preservation in sedimentary bodies containing these sedimentation units.

Thin-bedded sedimentation units containing plane-parallel laminations and capped by muddy sandstone also record waning uniform flow velocity (Fig. 14) (*sensu* Kneller, 1995). In this case, the plane-parallel laminations record the gradual accumulation of the granular layer during bypass of the main body of the flow, while the muddy-sandstone cap is interpreted as cohesive freezing at the margin of the flow because of erosion and local addition of mud rather than from turbulent flow collapse.

Waning Depletive Sedimentation Units

Thick-bedded sedimentation units that contain abundant structureless or graded sandstone, and capped by plane-parallel-laminated and/or asymmetric ripple-cross-laminated sandstone record waning depletive flow velocity (Fig. 14) (*sensu* Kneller,

1995). These units lack thick successions of traction stratification and are interpreted to represent complete flow collapse and deposition from increasingly finer grained and lower velocity regions of a flow. Other than debris flows, these event beds contain the most complete record of original flow thickness and composition.

Thin-bedded sedimentation units contain structureless, to plane-parallel-laminated, to asymmetric ripple-cross-laminated sandstone also record waning depletive flow velocity (Fig. 14) (*sensu* Kneller, 1995). Similar to their thick-bedded counterpart, these event beds lack thick intervals with traction structures and are interpreted to record complete turbulent flow collapse and deposition of fine sediment in the lower velocity regions of a sediment gravity flow. They may also contain carbonaceous rich, very fine-grained bed caps that are disrupted by a high density of horizontal and vertical burrows suggesting a pause between sediment gravity flow events.

Steady Depletive Sedimentation Units

Thick-bedded sedimentation units that record steady depletive flow velocity are present in low proportions. They contain stratified sandstone that fine upward and commonly contain floating mudstone intraclasts near the top of the bed (Fig. 14) (*sensu* Kneller, 1995). The decreased facies variability reflects steady flow velocity, in that the event records a single, continuous process.

Thin-bedded, steady depletive flow change upward from structureless to wavy-lenticular sandstone, and are capped muddy sandstone (Fig. 14) (*sensu* Kneller, 1995). Alternation between plane-parallel and wavy-laminated interlaminations in thin

sandstone beds records quasi-steady surge-like behavior in the tail region or margins of the sediment gravity flow.

Waxing Depletive Sedimentation Units

Thick-bedded sedimentation units that record waxing depletive flow velocity are present in low proportions. They are composed of coarsening-upward stratified sandstone, and may also contain floating mudstone intraclasts throughout the event bed (Fig. 14) (*sensu* Kneller, 1995). The decreased facies variability reflects increasing flow velocity, in that the event records a single, continuous process.

Thin bedded sedimentation units that coarsen upward transition from wavy-lenticular muddy sandstone to asymmetric ripple-cross-laminated, to plane-parallel-laminated sandstone record waxing depletive flow velocity (Fig. 14) (*sensu* Kneller, 1995). These event beds have sharp to irregular upper surfaces suggesting increased basal shear and sediment bypass.

Waning Accumulative Sedimentation Units

Finally, thick-bedded sedimentation units containing fining-upward successions with gaps in grain size and facies transitions record waning accumulative flow velocities (Fig. 14) (*sensu* Kneller, 1995). These gaps are interpreted to represent lateral and longitudinal changes in velocity creating sediment bypass surfaces within individual sedimentation units. The missing grain-size fraction is inferred to be present in a deposit lateral to, or down profile from, the observed sedimentation unit.

Thin bedded sedimentation units containing structureless or plane-parallel-laminated sandstone overlain by a sharp to erosional surface, separating the bed cap consisting of very fine sandstone or mudstone also record waning accumulative flow velocity (Fig. 14) (*sensu* Kneller, 1995). The sharp to erosional upper bounding surface is interpreted to record the bypass of sediment as the longitudinal flow velocity accelerates down profile.

Conglomerate		Sandstone	
1	 Clast-supported, cobble-to-boulder conglomerate (Extraformational)	5a	 Inclined-stratified, pebble-to-granule sandstone
2	 Clast-supported, pebble-to-cobble conglomerate (Extraformational)	5b	 Plane-parallel stratified, pebble-to-granule sandstone
3	 Clast-supported, granule-to-pebble conglomerate (Extraformational)	5c	 Graded, granule-to-pebble sandstone
4	 Matrix-supported conglomerate (Mudstone/Intraformational)	6	 Plane-parallel stratified sandstone (spaced stratification) (bed base)
Mudrocks		7	 Cross-stratified sandstone (Angle of repose)
13	 Siltstone	8	 Cross-stratified sandstone (Scour and fill)
14	 Muddy Siltstone	9	 Structureless sandstone
15	 Mudstone	10	 Plane-parallel laminated sandstone (LSPB) (contains organics and mica, bed top)
16	 Claystone	11	 Asymmetric ripple cross-laminated sandstone (silty)
Post Depositional		12a	 Wavy-lenticular muddy sandstone
17	 Soft-sediment deformed sandstone	12b	 Muddy sandstone
18	 Burrowed sandstone		
19	 Burrowed mudstone		
20	 Soft-sediment deformed mudstone		

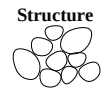
Figure 9. Sedimentary facies scheme characterizing lithology, grain size, and sedimentary structures, and post-depositional modification. Colored boxes correspond to sedimentological profile colors. Facies are numbered by relative sedimentation energy interpreted from grain size and sedimentary structures, with one being the highest depositional energy, and 16 being the lowest. Facies 17 through 20 are post depositional secondary features, and often do not represent primary sedimentary conditions.

2: Clast-supported, pebble-cobble conglomerate (extraformational)



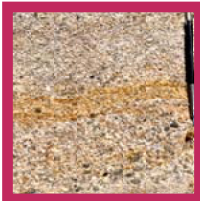
Description: Clast supported beds with contacts ranging from irregular to gradational. Poorly sorted, rounded to subrounded pebble-cobble framework with upper fine to lower medium, very poorly- to poorly-sorted sandstone matrix. Commonly contains angular mudstone intraclasts.

Interpretation: Deposition from a high density, high viscosity, turbulent to non-turbulent flow where the flow is supported by dispersive pressure, hindered settling, pore fluid pressure, and matrix shear strength. Normally graded beds are indicative of differential grain settling within a turbulent flow (Middleton and Hampton, 1976). Inversely graded beds indicate non-turbulent flow where grain interaction limits particle freedom (Lowe, 1982). Ungraded beds suggest deposition *en masse* due to matrix shear strength and frictional freezing.



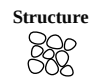
Correlation
R1-R3

3: Clast-supported, granule-pebble conglomerate (extraformational)



Description: Clast supported beds with contacts ranging from irregular to gradational. Poorly sorted, rounded to subrounded pebble-cobble framework with upper fine to lower medium, very poorly- to poorly-sorted sandstone matrix. Commonly contains angular mudstone intraclasts.

Interpretation: Deposition from a high density, high viscosity, turbulent to non-turbulent flow where the flow is supported by dispersive pressure, hindered settling, pore fluid pressure, and matrix shear strength. Normally graded beds are indicative of differential grain settling within a turbulent flow (Middleton and Hampton, 1976). Inversely graded beds indicate non-turbulent flow where grain interaction limits particle freedom (Lowe, 1982). Ungraded beds suggest deposition *en masse* due to matrix shear strength and frictional freezing.



Correlation
R1-R3

4: Mudstone intraclast breccia



Description: Composed of locally derived and angular mudstone clasts supported by a matrix of very poorly-sorted, very fine- to coarse-grained sandstone. Pebble-to-granule sandstone and scour-and-fill sandstone commonly overlie mudstone breccia forming beds are up to three meters thick.

Interpretation: Deposition from non-turbulent, laminar flows that incorporate channel drape material into the flow or from channel margin collapse into an active high-concentration, non-turbulent flow (Middleton and Hampton, 1973, 1976; Lowe, 1982).



5: Pebble-to-granule sandstone



Description: Contains pebble-to-granule sized sediment less than 2 cm in diameter and in concentrations less than 20%. The sand-sized fraction is coarse to very coarse, moderately sorted, and may contain floating mudstone intraclasts up to 3 cm in diameter with sparse out-sized clasts up to 60cm in diameter. Structures include scour-and-fill stratification, plane-parallel stratification, and normal to inverse grading.

Interpretation: Deposition from high density, low viscosity, turbulent and non-turbulent granular flows where hindered settling, dispersive pressure, and fluid turbulence are the main support mechanisms. Scour-and-fill stratification is produced by traction dominated flow over a non-migrating bedform (Gardner et al., 2003). Plane-parallel stratification is produced by a laminar sheared layer at the base of a high density flow, where inverse grading is due to kinetic sieving of small grains through larger grains. (Hiscott and Middleton, 1980; Hiscott, 1994; Sumner et al., 2008). Graded and ungraded bedding may be a product of rapid deposition, gradual flow collapse, or liquefaction (Walker, 1978; Lowe, 1982; Kneller and Branney, 1995; Nichols, 1995).



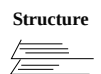
Correlation
S1-S3

7: Plane parallel-stratified sandstone



Description: Medium- to very coarse-grained, well to moderately sorted, inversely to ungraded sandstone with plane-parallel stratification. Exhibits sharp gradational contacts with underlying pebble-to-granule sandstone, scour-and-fill sandstone, or conglomerates and forms beds up to 1.2 meters thick.

Interpretation: Deposition at the base of a high density, low viscosity, turbulent flow where shear and dispersive pressure suppress turbulence and create a laminar layer (Hiscott, 1994; Sumner et al., 2008). A laminar shear layer at the base of a high-density flow creates centimeter spaced stratification where inverse grading is caused by kinetic sieving (Hiscott, 1994; Sumner et al., 2008). Continued sediment fallout increases grain concentration and causes the region to freeze and the development of a new overlying laminar shear layer to develop (Hiscott, 1994; Sumner et al., 2008).



Correlation
S2, Tb

Figure 10a. Summary diagram of sedimentary facies described in this study of the Capistrano Formation. Description and interpretation fields describe occurrence and process interpretation of the facies. The structure field shows a graphical representation of the facies. The correlation field ties facies to interpretations by other authors. Ta - Te facies are from Bouma (1962), S1 - S3 and R1 - R3 facies are from Lowe (1982).

8: Scour-and-fill stratified sandstone



Description: Medium- to very-coarse grained, moderately sorted scour-and-fill sandstone containing low-angle stratification, characterized by scoop shaped scours up to 0.3 meters in thickness that are draped by laminae that fine up and show an upward decrease in foreset angle (Gardner et al., 2003).

Interpretation: This facies represents a stationary bedform produced by velocity, density, and pressure differences within a non-uniform, unsteady flow. Turbulence and hindered settling are the main support mechanisms (Richardson and Zaki, 1954; Lowe, 1982; Kneller and Branney, 1995). Scour-and-fill stratification can be formed by two processes. Erosional scour-and-fill stratification is formed by shear from pressure and density differences (Rayleigh-Kelvin instability) in the flow forming a cleft and lobe topography on the underlying seafloor. Flow expansion over lows causes deposition by the trailing flow and filling of the topography. Flow contraction over highs erodes the substrate and bulks the flow (Gardner et al., 2000). Alternatively, aggradational scour-and-fill stratification is formed by shear from velocity differences (Kelvin-Helmholtz instability) within the body of the flow. Areas of high sediment concentration and stationary billows produced by Kelvin-Helmholtz waves produce non-migrating bedforms by suppressing flow reattachment (Gardner et al., 2003). High rates of suspension fallout are recorded by the upward decrease in dip angle of the laminae filling the scour and resemble swaley cross stratification formed by combined-flow process in shallow-marine environments (Gardner et al., 2003).

Structure



Correlation

Tt, S1

9: Structureless Sandstone



Description: Fine- to very coarse-grained, moderate- to well-sorted, graded and ungraded sandstone lacking internal structures. May contain sparse outsized extraformational clasts and mudstone intraclasts. Beds occur as gradational or sharp contacts up to one meter thick.

Interpretation: Represents deposition from a high-density, low-viscosity, turbulent to non-turbulent flow where hindered settling and fluid turbulence are the main support mechanisms. Internal stratification may be absent due to rapid deposition or gradual flow collapse, or destroyed by liquefaction (Walker, 1978; Lowe, 1982; Kneller and Branney, 1995; Nichols, 1995). Internal stratification may also be masked by grain size homogeneity within the deposit.

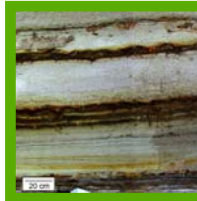
Structure



Correlation

Ta, S3

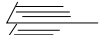
10: Plane-parallel laminated sandstone (bed top)



Description: Very-fine to medium-grained, well-sorted sandstone with ungraded- to normally-graded plane-parallel laminae. Beds are laterally continuous with a sharp or irregular basal contact, and up to 0.45 meters thick.

Interpretation: Represents upper-flow regime, traction deposition from a high- or low-density, low-viscosity, turbulent flow where turbulence is the main support mechanism. Two processes can be responsible for its formation: low-density, high-velocity flows with low aggradation rates; and high-density, decelerating flows with elevated aggradation rates (Leclair and Amott, 2005).

Structure



Correlation

Tb

11: Asymmetric ripple cross-laminated sandstone



Description: Medium- to very fine-grained, moderate- to well-sorted sandstone with asymmetric ripple cross lamination. This facies may be observed in two forms: isolated asymmetric ripple forms encased in mudstone and sets of climbing ripples. Climbing ripples are usually subcritical, with lee side preservation and very low angles of climb. Bed thickness ranges from 0.05m to 0.2m.

Interpretation: Represents lower flow regime traction deposition from a low-density, low-viscosity, turbulent flow where turbulence is suppressed at a hydraulically smooth boundary and a layer of laminar flow develops. Low angles of climb suggest low sediment supply (Walker, 1963; Allen, 1970). In subaqueous settings, ripple cross lamination is commonly associated with waning depletive flow although thick sequences of climbing ripple cross lamination may indicate depletive steady flow (Kneller, 1995).

Structure



Correlation

Tc

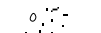
12: Muddy sandstone



Description: Silty to very fine-grained, poorly- to moderately-sorted, sandstone that may be structureless, wavy lenticular, or plane-parallel laminated. Weathers dark brown to orange depending on organic content. Wavy-laminated muddy sandstone forms thick successions (up to 0.5m) at bed tops. Silty sandstone is structureless and forms thin (up to 0.2m) isolated beds. Muddy sandstone bed thickness may be overestimated due to poorly defined bed contacts at the scale of observation.

Interpretation: Represents mixing of sand and silt on the walls of the submarine channel. Lamination indicates flow collapse and tractive deposition or frictional freezing from the tail or margin of the flow (Leeder, 1999; Gardner et al., 2003; Haughton et al., 2003, 2009).

Structure



Correlation

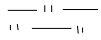
Slurry/Hybrid

Figure 10b. Summary diagram of sedimentary facies described in this study of the Capistrano Formation. Description and interpretation fields explain occurrence and process interpretation of the facies. The structure field shows a graphical representation of the facies. The correlation field ties facies to interpretations by other authors. Ta - Te facies are from Bouma (1962), S1 - S3 facies are from Lowe (1982).

13: Siltstone

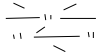
Description: Dark brown to grey in color, weathering orange with increased organic content. Occurs at the top of fining-upward successions.

Interpretation: Suspension fallout of the fine-grained fraction of super-elevated flow and/or flow stripping from the tail of a turbidity current (Gardner and Borer, 2000).

Structure**14: Muddy siltstone**

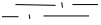
Description: Brown to grey in color with varying amounts of organic content. Occurs at the top of fining upward sequences and may be interbedded with isolated, very fine-grained, ripple-laminated sandstone stringers.

Interpretation: Suspension fallout of the fine-grained fraction of super-elevated flow and/or flow stripping from the tail of a turbidity current (Gardner and Borer, 2000). Incorporation of material derived locally from the seabed is responsible for transformation of a turbidity current to a debris flow.

Structure**Correlation**
Slurry/Hybrid**15: Mudstone**

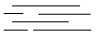
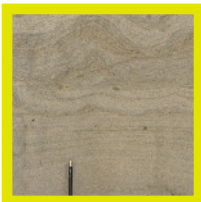
Description: Light grey, thinly laminated, and highly bioturbated with a fissile, knobby texture.

Interpretation: Overbank deposition from a low-density turbulent cloud of a sediment gravity flow.

Structure**16: Claystone**

Description: Dark grey, thinly-laminated, clay-dominated mudrock occurs at the base of a channel-drape complex.

Interpretation: Hemipelagic suspension-fallout sedimentation of clay-size material on the sea bed.

Structure**Correlation**
Graded
hemipelagic**17: Soft sediment deformed sandstone**

Description: Very fine- to very coarse-grained, poor- to moderately-sorted sandstone containing dishes, pipes, consolidation lamination, convolute stratification, or convolute lamination. This facies exhibits some "S3" division characteristics described by Lowe (1982) and "Ta" division characteristics described by Bouma (1962). Soft sediment deformed sandstones can have an irregular or loaded basal contact, or overlie pebble-to-granule sandstone, cross-stratified sandstone, or matrix-supported mud intraclast conglomerate. Bed thickness ranges from 0.1 m to 1.2 m and can pass into convolute-laminated mudstone, or be overlain by a loaded contact with soft-sediment deformed sandstone.

Interpretation: Internal stratification of unlithified sediment destroyed or altered by liquefaction, fluidization, and shear stress of the seabed (Walker, 1978; Lowe, 1982; Kneller and Branney, 1995; Nichols, 1995). Fluidization represents the upward exchange of pore fluids and a decrease in grain packing and is represented by dishes, pipes, and sand injections. Liquefaction represents the reorganization of grains within a bed and an increase in grain packing, destroying primary sedimentary structures and creating undulatory, loaded bedding contacts. Bed shear creates flames and convolute lamination (Lowe, 1976; Nichols, 1995; Lowe and Guy, 2000).

Structure**Correlation**
S3 Ta

Figure 10c. Summary diagram of sedimentary facies described in this study of the Capistrano Formation. Description and interpretation fields explain occurrence and process interpretation of the facies. The structure field shows a graphical representation of the facies. The correlation field ties facies to interpretations by other authors. Ta - Te facies are from Bouma (1962), S1 - S3 facies are from Lowe (1982).

18: Burrowed sandstone

Description: Very fine-grained to muddy sandstone with horizontal and vertical burrows. Carbonaceous debris is concentrated at sandstone bed tops suggesting most bioturbation records locomotion and feeding traces.

Interpretation: Burrows indicate low energy conditions between flow events where biological activity dominates and mines organic-rich bed caps (Ekdale et al., 1984; Frey et al., 1990; Pemberton et al., 1992).

Structure**19: Burrowed mudstone**

Description: Grey to light brown in color, orange weathering, siltstone to mudstone with horizontal and vertical burrows along organic-rich bed caps.

Interpretation: Burrows indicate pauses between flow events where biological activity dominates, and is most common along organic-rich bed caps (Ekdale et al., 1984; Frey et al., 1990; Pemberton et al., 1992).

Structure**20: Soft sediment deformed mudstone**

Description: Contorted, discontinuous, irregular and chaotic mudstone beds dipping at various angles. Bedding contacts are gradational with undeformed mudstone.

Interpretation: Resedimentation by mass transport or slump (Piper et al., 1997).

Structure

Figure 10d. Summary diagram of sedimentary facies described in this study of the Capistrano Formation. Description and interpretation fields explain occurrence and process interpretation of the facies. The structure field shows a graphical representation of the facies.

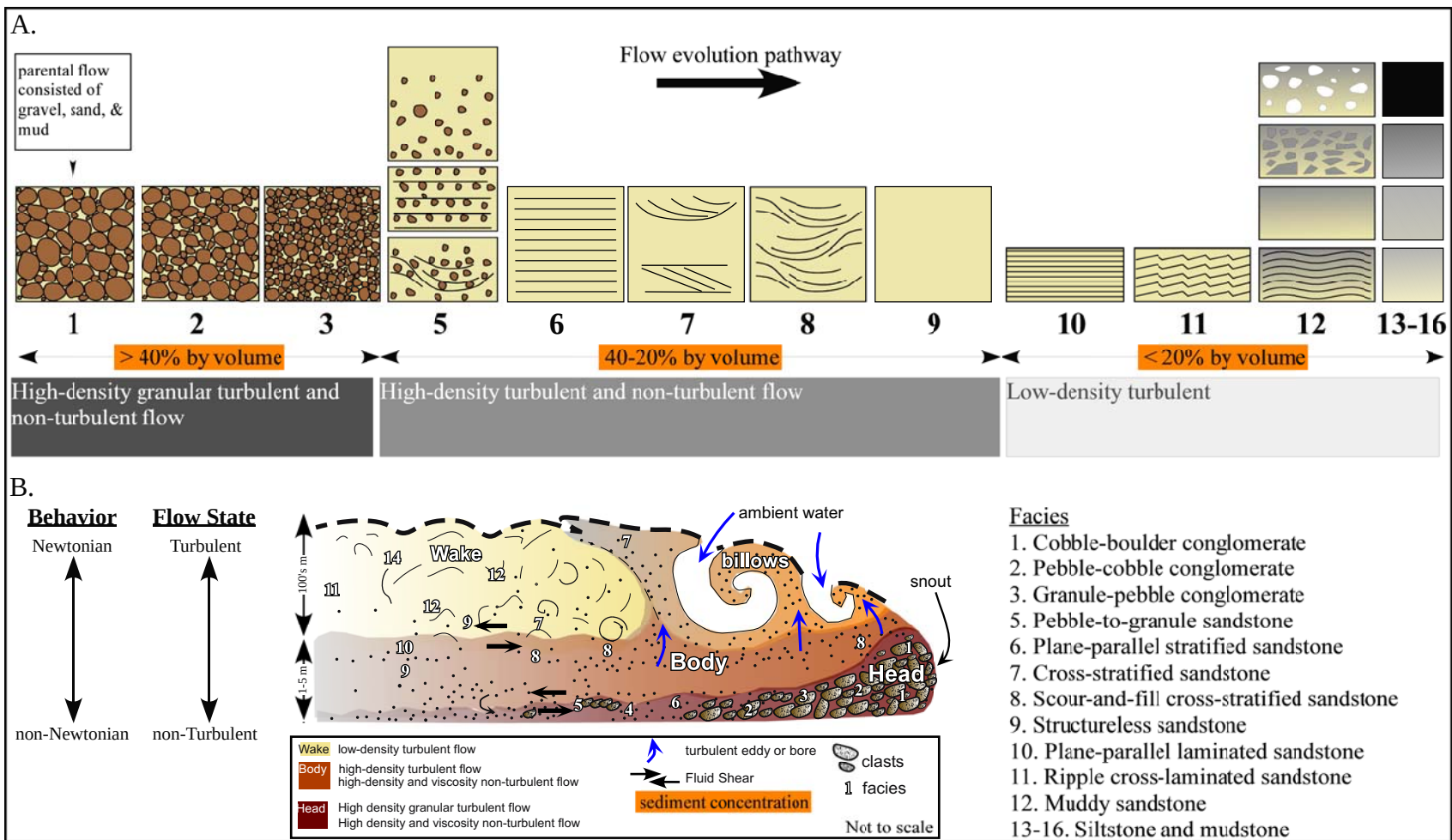


Figure 11. Facies tract produced by a gravel-rich multipartite subaqueous flow showing organization and transformations along the run-out length of a single sedimentation event. A) The succession of facies deposited by a single multipartite subaqueous flow. The initial flow is high density, containing gravel, sand and mud. Gravel, then sand is deposited as the flow evolves resulting in a decrease in flow density. Finally, fine-grained sediment held aloft in the turbulent cloud is deposited. B) Cross section through a multipartite subaqueous flow. Sedimentary facies are numbered and placed at their interpreted depositional position within the sedimentation event.

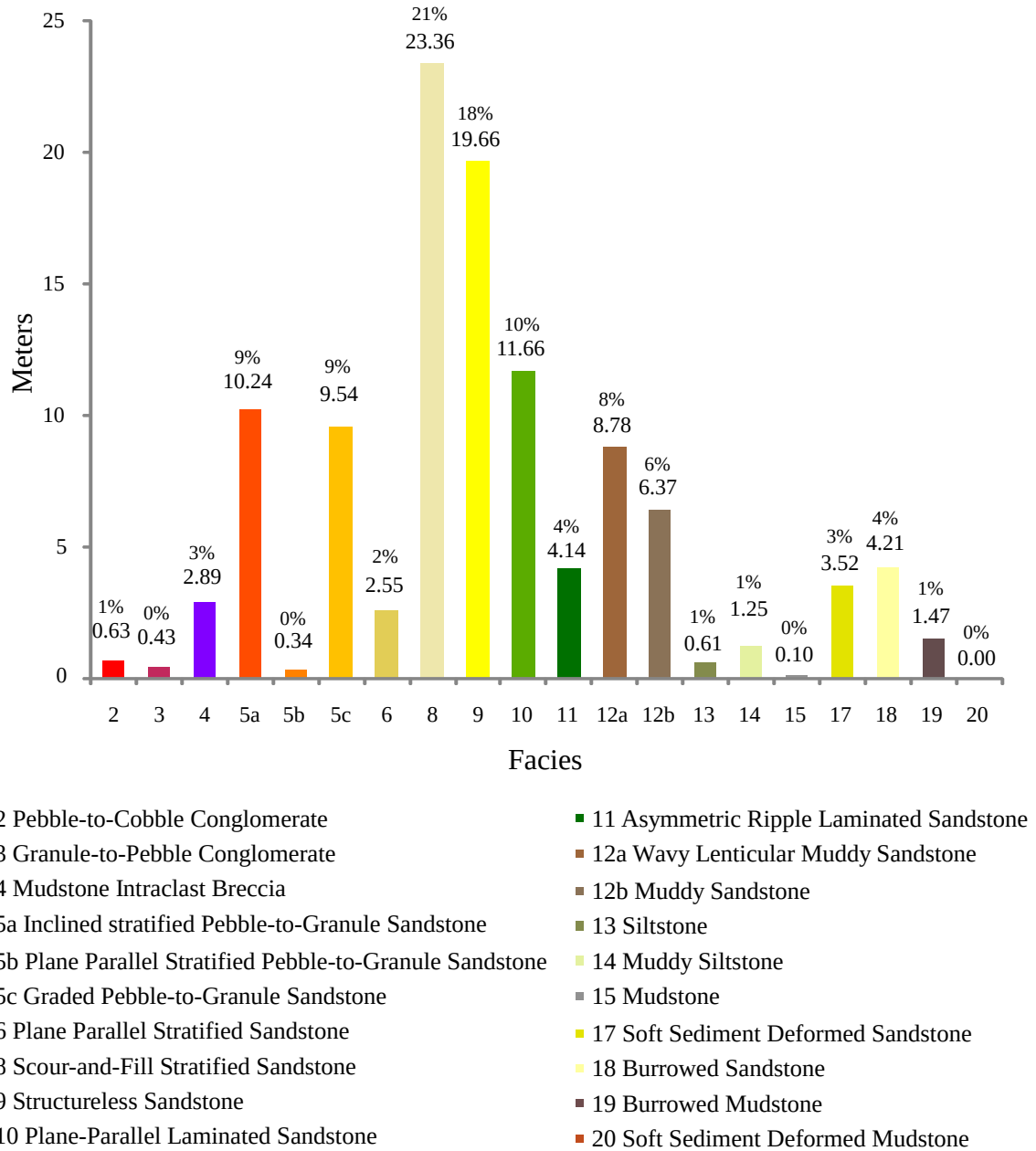
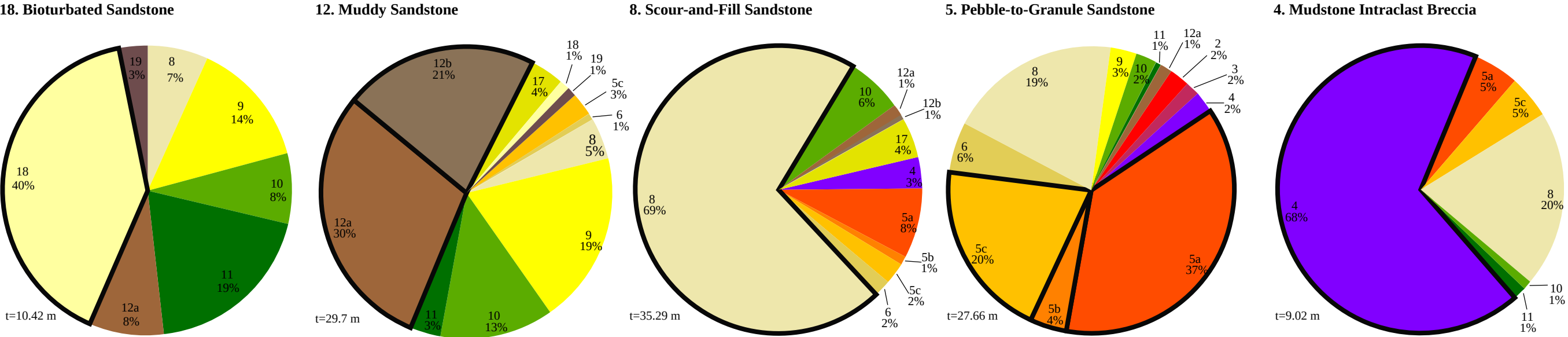


Figure 12. Bar graph showing total thickness in meters of each facies documented in this study. Percentage of facies occurrence vs. total thickness measured included above each bar. Overall, 124 meters of sedimentological section data was analyzed.

A. Percent thickness of facies contained in sedimentation units associated with five key facies.



B. Percent occurrence of facies contained in sedimentation units associated with five key facies.

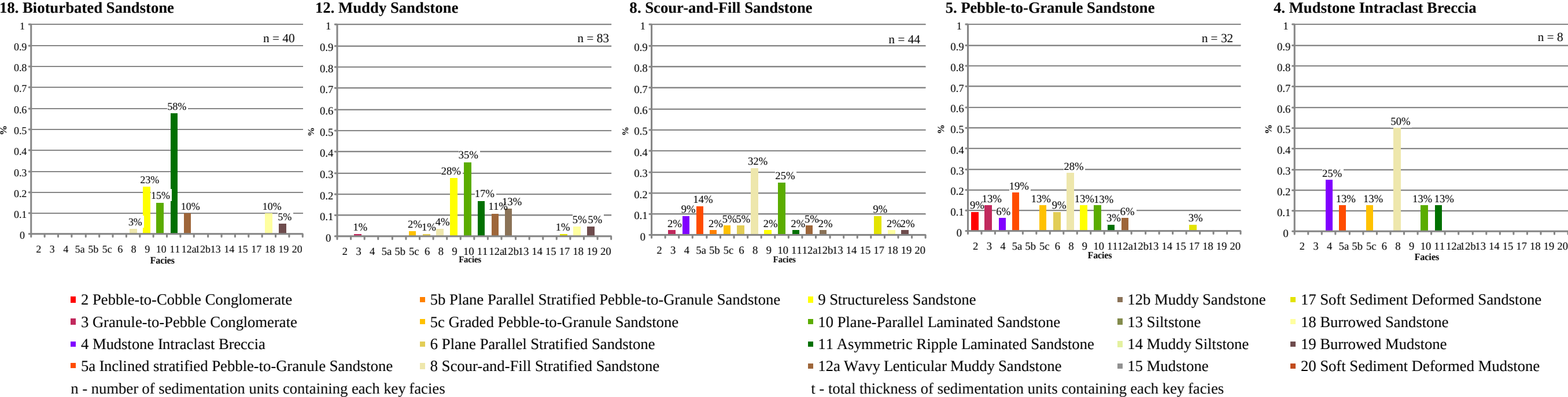


Figure 13. Pie charts and bar graphs showing the facies contained in sedimentation units with (18)bioturbated sandstone, (12)muddy sandstone, (8)scour-and-fill sandstone, (5)pebble-to-granule sandstone, and (4)mudstone intraclast breccia. A) Pie charts showing the percent thickness of all facies in sedimentation units containing the highlighted facies outlined in black. B) Bar graphs showing the percentage occurrence of all facies in sedimentation units containing each highlighted facies. The bar associated with the highlighted facies in each graph represents a sedimentation unit that only contains that facies.

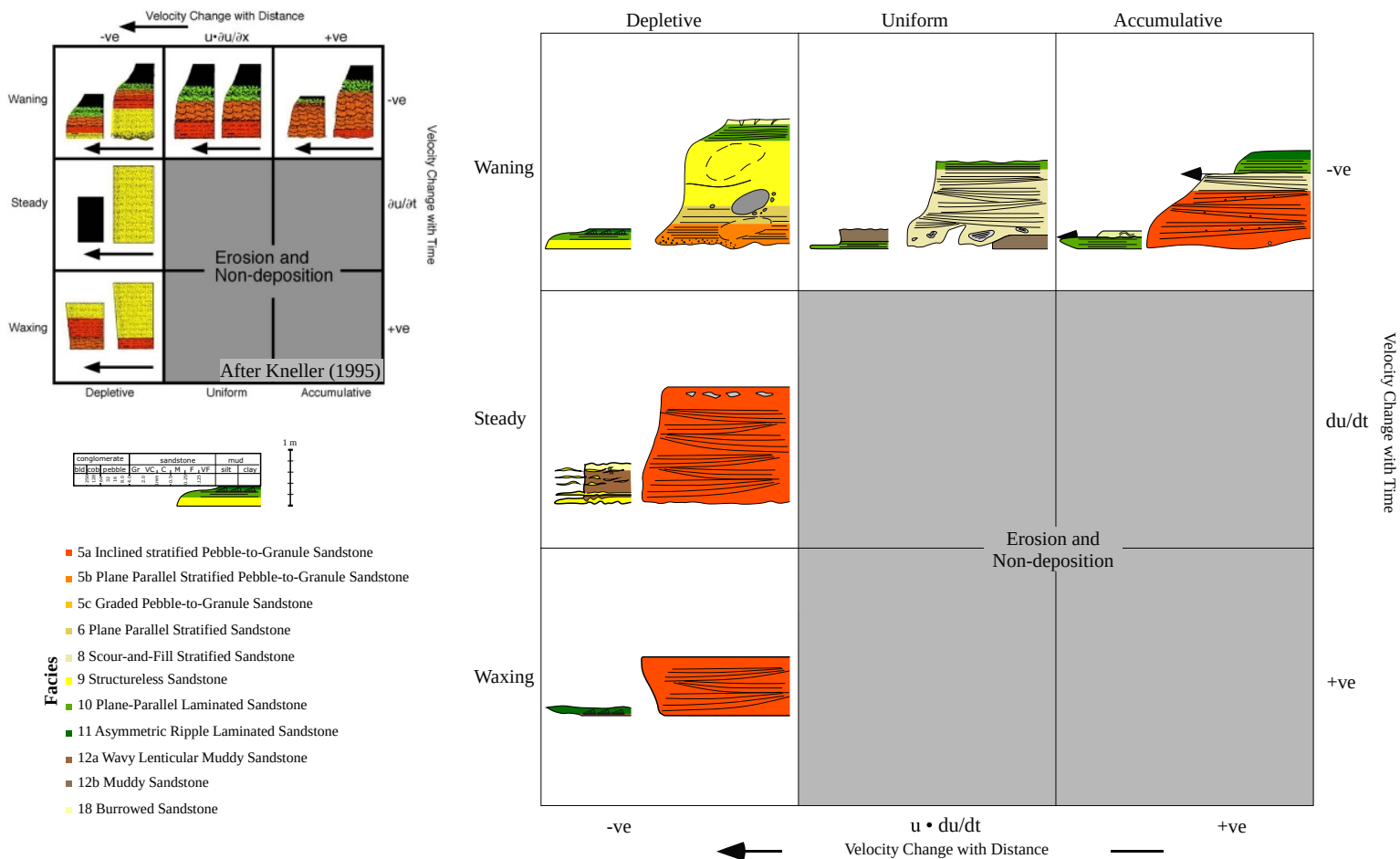


Figure 14. Sedimentation units of the Capistrano Formation superimposed on the acceleration matrix of Kneller (1995). Each box represents a unique velocity domain of time (waxing, steady, waning) and distance (accumulative, uniform, depletive) within a single sediment gravity flow. Sedimentation units within each box represent the spatial variation of a sedimentation unit from channel axis (right) to channel margin (left).

SEDIMENTARY BODIES

Introduction

Sedimentary bodies are lithosomes, characterized by upper and lower bounding surfaces, external geometry, internal composition, and scale; and can represent a single process or a suite of processes occurring within a depositional system (Miall, 1985). In vertical profile, sedimentary bodies are represented by one or more sedimentation units, which in turn are composed of one or more sedimentary facies. Sedimentary bodies, also called architectural elements (Allen, 1983; Miall, 1985, Clark and Pickering, 1996a, b), as one of the largest scale sedimentary attributes, is detectable and reveals change within and between stratigraphic deep-water cycles (Fig. 15) (Mutti and Normark, 1987; Pickering et al., 1995; Clark and Pickering, 1996a; Gardner et al., 2003).

Sedimentary bodies are composed of one or more sedimentation events that in deep-water systems, record the state of confinement and lateral and longitudinal gradient of the seabed (Fig. 16) (Gardner et al., 2003). Deep-water channelform, wedgeform, and lobeform sedimentary bodies record confined, partially confined, and unconfined flow conditions respectively. Drapes composed of non-turbidite events and resedimentation produce chaotic and irregular mass-transport deposits (Barnes and Normark, 1985; Pickering et al., 1995; Clark and Pickering, 1997; Gardner and Borer, 2000; Deptuk et al., 2003; Gardner et al., 2003; Hadler-Jacobsen et al., 2007). The suffix “-form” is used to describe a sedimentary body that exhibits a specific shape, but lacks a hierarchical context.

Further division of the five fundamental deep-water sedimentary body types reflects variation in preservation, position, and the size of the depositional system (described above) (Gardner et al., 2008). The composition of a sedimentary body changes laterally, while incomplete preservation in amalgamated sedimentary bodies contains a preservation bias. Therefore, sedimentary architecture reflects both deposition and preservation. The stacking of similar shaped sedimentary bodies at multiple scales generates a spatial hierarchy that must be accounted for prediction.

Jackson (1975) suggested that channel roughness elements scale to different flow boundary conditions. He called these three scalar features microforms, mesoforms, and macroforms, which correlate to ripples and plane-parallel lamination, dunes, and barforms, which are present in all open channels. These elements scale to flow boundary conditions that overlap in time in space, thus creating a hierarchy of smaller features that are similar in form to the larger-scale, longer-lived features they compose. To document sedimentary bodies, the following attributes were collected: (1) trajectory, (2) width, (3) thickness, (4) shape, and (5) composition (Fig. 15). Sedimentation units and component sedimentary facies are related to body type to generate a hierarchy of attributes for stratigraphic analysis.

This principle of process-based scaling of sedimentary attributes is used in the Capistrano Formation to analyze the hierarchy of sedimentary bodies. In this study channelforms, wedgeforms, lobeforms, and drapes are recognized. Body types are defined by their cross-sectional geometry, sedimentary facies distribution, and bedding architecture, and are recorded in photo panel interpretations and measured section

descriptions summarized in Figure 15. Channelforms were subdivided into active, inactive, and remnant channelform bodies. Drapeforms were subdivided into simple, composite, and complex drapeforms. . Variations of these basic body types reflect incomplete preservation of primary depositional geometry, and differences in composition, orientation, and trajectory.

Confinement and Gradient

Higher gradient longitudinal profiles exhibit more confinement than the lower gradient basin floor. Confinement is produced by more erosion, mass wasting, bypass, with depositional topography from flanking levee contributions. The product of the relationship between gradient and confinement is expressed in the sedimentary body types (Fig. 16). This correlation makes sedimentary body a proxy for gradient because of its relationship to confinement. Confined flow is represented by channelforms, which in this system often contain drapes at the channel base. Partially-confined flow, over spilling from the channel axis, forms wedgeforms, whereas unconfined flow forms lobeforms.

In deep-water settings, overbank sedimentation builds topography that contributes to channel confinement (Mutti and Normark, 1987; Gardner et al., 2003). Channelforms flanked by wedgeforms are referred to as depositionally confined, whereas channelforms bound by genetically unrelated strata are referred to as erosionally confined. Depositional confinement facilitates lateral channel migration because the bounding wedgeform often shifts laterally with migration of its genetically related channel (Gardner et al., 2008). Erosional confinement limits lateral migration and promotes multistory channel stacking.

Channelform Bodies

Active Channelform Bodies

Active channelform bodies are erosional to sharp-based, concave-up features containing predominantly thick-bedded sedimentation units composed up scour-and-fill, pebble-to-granule, and/or structureless sandstone facies (Fig. 15). Organic content is dispersed throughout the sandy channel fill with higher concentrations at bed tops and on accretion surfaces. Active channelform bodies in the Capistrano extend up to 384 m in length (Campion et al, 2005), up to 6.9 m in thickness, and contain surfaces with variable dip. Active channelforms laterally or vertically offset other active, inactive, or remnant channelforms, and can also be bound laterally by drapes, wedgeforms, or lobeforms (Fig. 15). Examples of active channelform bodies are shown in Figure 17b, bodies 3.3.2 to 3.3.6.

Active channelform bodies are elementary bodies interpreted as preserved channel thalweg deposits that record deposition in the lowest part of the channel (Mutti and Normark, 1987, 1991). Active channelform bodies filled by thick-bedded, steady depletive and steady uniform sedimentation units record gradual accumulation of the granular layer during bypass of sediment in the main body of the flow. Active channelform bodies may also be filled with thick-bedded, waning-depletive sedimentation units suggesting complete flow collapse and deposition from the increasingly finer-grained and lower-velocity regions of the flow. These two styles of filling vary in process but represent sedimentation in the axis of a high-magnitude flow.

Inactive Channelform Bodies

Inactive channelform bodies are erosional to sharp-based, concave-up features containing dominantly vertically stacked thin-bedded sedimentation units composed of structureless, plane-parallel-laminated, and asymmetric ripple-cross-laminated sandstone, and wavy-lenticular muddy sandstone (Fig. 15). Organic content is concentrated at bed caps, commonly bioturbated with horizontal and vertical burrows. Body dimensions range from up to 3.9 m in thickness thick and up to 90 m in width and contain planar bedding surfaces. Inactive channelforms commonly laterally or vertically replace active, or remnant channelforms, and can be laterally bound by drapes. Examples of inactive channelform bodies are shown in Figure 17b, bodies 3.2.4 to 3.2.4.

Inactive channelform bodies are interpreted as preserved channel thalwegs recording abandonment of the channel site. Thick successions of thinly bedded, waning depletive sedimentation units record deceleration of the low-density, low-viscosity tail and cloud regions of a sediment gravity flow. Significant accumulations of carbonaceous debris and a high degree of bioturbation along bed tops suggest infrequent sedimentation from weakly erosive flows during channel abandonment.

Remnant Channelform Bodies

Remnant channelform bodies are erosional to sharp-based features of variable shape containing predominantly thick-bedded sedimentation units with clast-rich, pebble-to-granule, structureless, and plane-parallel-laminated facies (Fig. 15). Organic content is dispersed throughout the channel fill with higher concentrations on accretion surfaces. Body dimensions range from 0.9 to 4.1 m in thickness, and 7 to 16 m in width. Top or

side truncation is common with the erosive basal contact typically overlain by a drape. Remnant channelform bodies have short correlation lengths reflecting lateral truncation by overlying channel bodies. An example of a remnant channelform body is shown in Figure 17b, body 3.3.1.

Remnant channelform bodies are interpreted to be the erosional remnant of active or inactive channel bodies. Remnant channelform bodies leave little record for interpretation. Short correlation lengths and small aspect ratios of remnant channelform bodies are controlled by truncation and erosion by subsequent channel incision. Remnant channelform bodies indicate a high degree of confinement, where lateral offset is limited and younger channels cannibalize older channel fills.

Drape Bodies

Drape sedimentary bodies are laterally continuous, fine-grained deposits that drape erosional and depositional topography, and in this study, line erosional surfaces and the base of channelforms at multiple scales. Sedimentation units up to 10 cm in thickness drape erosional surfaces. Drapes contain muddy to fine-grained sandstone, siltstone, and claystone with organic material concentrated as discrete layers at bed tops. Drapes bodies occur at three scales based on sedimentation units, degree of bioturbation, and correlation to the channelform hierarchy (Figs. 18 and 19).

Simple Drapes

Simple drapes consist of thin sedimentation units with the lowest facies diversity. They are muddy sandstone with isolated fine-grained sandstone stringers and organic-rich

bed caps. Simple drapes overlie erosional surfaces with convolution at the base and top, with minor to no bioturbation. Correlation lengths are short due to erosional truncation or lateral pinch-out (Figs. 18 and 19).

Muddy sandstone, the principal component of simple drapes, is interpreted to record the frictional freezing of fine-grained material deposited from the turbulent tail and wake of bypassing sediment gravity flows. Sediment in the flow mixes with mud eroded from the seabed to form a cohesive debris flow, which freezes due to increased viscosity and cohesion (Haughton et al., 2003). Simple drapes have low preservation potential in the channel axis with preservation increasing toward the margin. Sandy deposits of active channel bodies will often contain suspended mud intraclasts interpreted to be drape deposits eroded from simple drapes. Simple channel drapes are most common in the channel margin region (Fig. 16).

Composite Drapes

Composite drapes have moderate facies diversity and contain muddy sandstone, very fine-grained sandstone and siltstone, and asymmetric ripple-cross-laminated sandstone. Composite drapes overlie erosional surfaces and have sharp tops with concentrations of carbonaceous material. Bioturbation can be present along the bed tops where organic content is concentrated. Composite drapes are longer than simple drapes, but dimensions are complicated by the amalgamation of multiple drape surfaces (Figs. 18 and 19).

Composite drapes record a combination of suspension fallout and bed shear sedimentation generated from multiple sediment gravity flows depositing sediment along

the margin of a submarine channel. Like simple drapes, muddy sandstone records frictional freezing of fine-grained sediment from the tail and wake of a passing sediment gravity flow. Wavy-laminated muddy sandstone and asymmetric ripple-cross-laminated sandstone facies are interpreted to record decreased velocity from bedload transport of sediment derived from the cloud and tail regions of a sediment gravity flow expanding along the margin of the channel. Preservation of composite drapes reflects widening and deepening of an outsized depression enabling expansion of the site of active sedimentation, where the margin records sedimentation from the edge of the turbulent cloud. The presence of concentrated organic and bioturbated bedding surfaces also suggest decreased event frequency and magnitude, with the axes of flows focused in the deepest part of the channel and distant from the elevated channel margin.

Complex Drapes

Complex drapes are the most diverse drapeform body (Fig. 18). Facies include asymmetric ripple-cross-laminated sandstone, muddy sandstone, siltstone, muddy siltstone and claystone. Additionally there is increased organic debris concentrated on drape surfaces and associated with bioturbation. Bed contacts are gradational to irregular at the base while sharp at the top. Component simple and composite drape surfaces are hard to distinguish. They have the longest correlation lengths in beds up to 25 cm in thickness.

Complex drapes are interpreted to suspension fallout and bedload transport in the deepest and widest channels. The higher proportion of mud suggests that sediment is derived from the edges of the turbulent cloud. The implications of this are that the

channel is large enough to record sedimentation from the margins of the completely confined to the outsized depression. They represent the record of sediment bypass from multiple composite channels.

Lobeform Bodies

Lobeform bodies are convex-up to sheet-like sedimentary bodies found laterally adjacent to, and often cut by channelform bodies (Fig. 15). Individual event beds thin away from the body axis. They have a sharp, planar lower contact and a convex-up, gradational, or sharp upper contact. Sedimentation units include thick-bedded, waning depletive successions of graded, pebble-to-granule sandstone, changing upward to structureless sandstone and thin-bedded successions of ripple-cross-laminated sandstone, changing upward to muddy sandstone and bioturbated sandstone. Body dimensions of the single lobe recorded are 68 m wide and 4.5 m in height. This lobeform body is truncated laterally by an adjacent channelform body.

Lobeform bodies record sedimentation from unconfined flow beyond the channel mouth. Flow expansion and divergent streamlines record deposition of a radial, fan-shaped sediment thick with a convex-up upper, and a planar lower bounding surface. Waning depletive sedimentation units record the loss of competence and deposition of coarse-grained sediment. Unconfined flow occurs at the channel mouth, or by overspilling or breaching of the channel as a splay.

Wedgeform Bodies

Wedgeform sedimentary bodies flank channelform bodies and thin laterally away from the channel margin (Fig. 15). Beds taper and thin from the channels they flank with beds inclined at high angles (up to 60°) away from adjacent channel axes (Fig. 20). Typical sandstone bed thickness is up to 10 cm in thickness with correlation lengths and body dimensions limited by the outcrop exposure. Muddy sandstone is the most common facies and encases isolated, very fine-grained sandstone-filled scours, which shingle away from the channel margin (Fig. 21). Deformation increases toward channel margin.

Wedgeform bodies are interpreted to record overbank sedimentation from multiple, partially-confined sediment gravity flows, with flow streamlines oriented down and along the axis of the adjacent channel (Fig. 16) (Clark and Pickering, 1996a; Gardner et al., 2003). Wedgeform deposits record traction and suspension fallout sedimentation from parts of the super-elevated turbulent cloud. Super elevation of the turbulent cloud is governed by the densimetric Froude number which describes the relationship between gradient and flow height. The flow height increases with gradient (Middleton, 1993). The increased flow height of the turbulent cloud must displace more ambient fluid, which acts to reduce the flows momentum. Fine-grained sedimentation from the turbulent cloud mixes with the muddy substrate from the levee surface to promote cohesive freezing of a fine-grained debris flow.

The presence of sandstone scours in the wedgeform body suggest overspilling of coarse sediment in flows large enough to escape the confinement. Multiple shingling of

very-fine sand-filled scours record deposition from turbulent eddies within larger flows expanding away from the confinement.

Flow stripping is an additional sedimentation process operating in the formation of wedgeform sedimentary bodies. Flow stripping and detachment of the turbulent cloud from the main body of the flow occurs when a subaqueous flow undergoes a momentum transfer around the channel bend, and the upper fine-grained portion of the flow detaches from the main body of the flow (Piper and Normark, 1983; Normark and Piper, 1984). The resulting detached sediment can accelerate down the levee slope to form scour fields and sediment waves with paleoflow at a high angle to that of the channel (Normark et al., 1980).

Channel Hierarchy

A fourfold channel hierarchy scheme describes the stacking of smaller channel bodies to form larger composite features. From smallest to largest they include elementary, composite, channel complex, and channel fairway. Figure 22 illustrates the scalar hierarchy, which follows the scheme of Gardner et al. (2003). Significant overlap in channel dimensions can occur at each level within the hierarchy. This process-based classification links sedimentary processes to each level in the hierarchy. Elementary channels correlate to the migration of the channel thalweg within an open channel course. They are equivalent to channel stories of Campion et al. (2000, 2005). One or more sedimentation units fill an elementary channel. Lateral and vertical offset of the channel thalweg produces a composite channel, which in turn stacks to form a channel complex.

Sandstone-rich regions with a high channel density are referred to as channel fairways (Gardner et al., 2003).

Plate 1 shows outcrop segments A, B, and C classified within the channel hierarchy. The channel bodies are labeled with a number then a decimal for each level represented in the channel hierarchy. For example, 1.2.3 represents the third elementary channel, in the second composite channel, occupying the second channel complex in the channel fairway.

Elementary Channels

Elementary channels (n = 62) are the smallest scale architectural element and represent episodic deposition of the channel thalweg. They range from 2 to 7 m in thickness, and 12 to 384 m in width, with aspect ratios (width:thickness) of 1.5 to 130. The smaller aspect ratios are remnant channel fills controlled by preservation.

Elementary channel connectivity varies with body type. Active and remnant channel bases are scoop shaped and erosional and may include a partially preserved simple drape at the base. These channels show the greatest lateral and vertical connectivity. Inactive channels are scoop shaped with erosional bases and often have a fully preserved channel drape at their base. Inactive channels have limited lateral connectivity but may connect vertically by a subsequent active channel.

Composite Channels

Composite channels (n = 16) record the episodic migration of the channel thalweg and are composed of one or more elementary channels and drapes. They range in size

from 4 to 14 m in thickness and 40 to 600 m in width, with aspect ratios ranging from 1 to 153. Like elementary channels, the range of aspect ratios of composite channels is affected by preservation. Composite channels bases are scoop-shaped and erosional surfaces fully-to-partially lined by composite drapes. Composite channels are equivalent to channels of Walker (1975) and Campion et al. (2000, 2005).

Channel Complex

Channel Complexes ($n = 4$) are correlative to a geomorphic channel belt and record longer duration channel behavior (Gardner et al., 2003). They are composed of two or more composite channels and often contain a complex drape along the margin of the complex. Outcrop height and preservation limit composite channel and channel complex measurements. Channel complex measurements range from 15 to 22 m in thickness and 150 to 890 m in width. The thickness measurement is a minimum value that reflects the outcrop height.

Channel Fairway

The channel fairway ($n=1$) is the largest scalar feature in the hierarchy. Channel fairways are defined by a high density of channels and a large ratio of channel-to-interchannel related facies and sedimentary bodies (Gardner et al., 2003). The Capistrano lithosome represents a single channel fairway more than 22 m in height and 1980 m in length. Outcrop segments A and C are dominated by channel axis and channel margin deposits. Outcrop segment B is partially covered, but contains a channel-flank wedgeform body flanking channel complex 4 in the middle of outcrop segment B.

Channel Stacking Patterns

Stacking of more than one elementary channel creates a composite channel. Multilateral and multistory stacking refers to channels stacking in a horizontal or vertical sense, whereas channel trajectory describes a component of aggradation or degradation (Fig. 23). Aggradational and degradational channel stacking are described by the stratigraphic rise or fall of successive channel bases, respectively. Aggradational stacking suggests higher sediment accumulation rates. Aggradational channel fill decreases confinement and promotes lateral offset determined by its depositional topography. Conversely, degradational stacking results when sedimentation is less than erosion, with little or no preserved deposit. Channel degradational increases channel confinement and limits lateral channel offset because of its increased size and relief.

The aspect ratio of channel complexes at San Clemente is controlled by stacking pattern and trajectory of the component elementary and composite channel bodies (Table 1). Composite channel dimensions overlap with measurements from the mud-poor Brushy Canyon Formation up to the outcrop height limit of the Capistrano formation (Fig 24). This and comparison with other outcrops that span the entire range of grain sizes suggest that grain size is not a control on composite channel aspect ratio. Rather, the arrangement and preservation of elementary bodies controls the aspect ratio of the composite feature.

Channel Complex 1

Channel complex 1, located at the northern margin of outcrop segment C, is poorly exposed with limited access to the exposures. The smallest complex measures 150 m wide and 20 m thick, and contains four composite channels composed of seven elementary channels. Composite channels 1.1 through 1.4 stack laterally, with the increased dip of the channel margins suggesting a degradation of successive composite channel fills (Plate 1, Fig. 26). Composite channel 1.1 contains two multistory channel remnants containing beds that dip to the north. This contrasts with the southward dip of the other channel fills in this complex. Composite channel 1.2 also contains two multistory elementary channel remnants containing beds that dip to the south. The channel fills contain thick bedded sedimentation units but direct measurement of the outcrop was not possible. Composite channel 1.3 is offset laterally to the south by composite channel 1.2, but the nature of the contact between the two channels is covered. Composite channel 1.3 contains three inactive channel bodies filled with thin-bedded, waning depletive sedimentation units. Channel 1.3 appears to be cut by an erosional surface that steps to the south, but the channel fill is poorly exposed.

The 23 sedimentation units present in channel complex 1 show an average thickness of 0.38 m. Waning depletive sedimentation units are the dominant type (61%), followed by waning uniform (22%), and finally steady depletive (8.5 %) and waxing depletive (8.5%) sedimentation units. The high proportion of waning depletive sedimentation units record lower energy conditions. Structureless, plane-parallel-laminated, asymmetric ripple-cross-laminated, and wavy-laminated sandstone facies

comprise 84% of the event beds documented in the channel complex. Finally, channel complex 1 contains the most restricted grain-size population containing dominantly medium to very-fine grained sandstone and siltstone.

Channel Complex 2

Channel complex 2 is present in the southern end of outcrop segment C. This complex measures 398 m wide and 15 m thick, and contains four composite channels composed of 18 elementary channels. Composite channels 2.1 through 2.4 initially stack vertically, and then offset laterally to the south where they again stack vertically (Plate 1). Composite channel 2.1 is composed of two multistory inactive channel bodies. Composite channel 2.2 is composed of two multilateral active channel bodies eroded by later channelization. Composite channel 2.3 contains six multilateral active channel bodies with prominent lateral accretion surfaces inclined to the south. Finally, composite channel 2.4 contains three multistory, and two multilateral active channel fills.

The 62 sedimentation units in channel complex 2 show an average thickness of 0.46 m. Sedimentation units are almost evenly split between waning uniform (42%) and waning depletive (58%). The higher proportion of waning uniform sedimentation units record higher energy conditions than the dominantly waning depletive sedimentation units of channel complex 1. Additionally, this channel complex records the first occurrence of mudstone breccia and a high percentage of muddy sandstone (18%) compared to wavy-laminated sandstone (2%). Additionally, when compared to channel complex 1, channel complex 2 has a higher maximum grain size reaching pebble-to-granule sandstone.

Channel Complex 3

The most studied interval is represented by the multilateral- to multistory-stacked composite channels of channels 3.1 through 3.6 (Fig. 25, Plate 1). This complex measures 330 m wide and 22 m thick, and contains six composite channels composed of 18 elementary bodies. The low aspect ratios (0.7 – 13.1) of composite channels are related to the limited lateral offset and erosion by subsequent channels. Though the bases are not exposed, the increase in dip of successive composite channel margins indicates a degradational channel trajectory with increased preservation of successively younger composite channel margins. Additionally, the presence of channel remnant, simple drape, and composite drape bodies composed of mudstone intraclast conglomerate is evidence of erosion, bank collapse, and reworking of older channel deposits. Composite channels 3.1 through 3.5 stack laterally. Composite channel 3.6 stacks vertically on composite channel 3.5, which in turn is eroded by the laterally offset and draped surface of composite channel 4.1.

Composite channel 3.1 is incised into the slope mudstone of the Monterey formation and represents the southernmost extent of channelized sedimentation (Fig. 26). This composite channel is composed of four elementary channels: three channel remnants and one inactive channel stack vertically before being eroded by the northward stepping channel 3.2. This composite channel is dominated by thin-bedded sedimentation units that contain waning and steady depletive flow as well as bioturbated sandstone and muddy-sandstone caps.

Composite channel 3.2 steps northward and contains the oldest channel base drape observed in complex 3 (Figs. 25 and 26). This composite channel contains five elementary channels: four inactive and one remnant channel fill. The oldest channel remnant suggests initial lateral offset followed by vertical stacking of four successive inactive channel fills. In addition, elementary drapes of the four inactive channel bodies merge laterally into composite drapes that amalgamate southward into a complex drape. The inactive channel fills contain waning depletive and waning uniform sedimentation units, consisting of structureless and wavy lenticular laminated muddy sandstone facies.

Composite channel 3.3 contains three dimensions exposures along the north and south footpaths as well as in an erosional gully behind the beach restrooms (Plate 1). It contains one remnant, one inactive, and five active elementary channel bodies (Fig. 17). Active channel fills contain thick bedded, waning uniform sedimentation units. Additionally, mudstone intraclasts up to 0.5 m in width are present throughout the fill of active channel fills. Elementary bodies within composite channel 3.3 initially stack laterally, but the final four bodies stack vertically filling the composite channel (Plate 1). The coarsest and highest energy facies tends to occur in event beds composing the vertically stacked channel bodies.

Composite channel 3.4 steps northward from 3.3 and contains four elementary channel bodies and one composite drape. The channel drape is unique and contains mudstone intraclasts up to 1.0 m in width, encased in a very-coarse muddy sandstone matrix. Active channel bodies are multistory above this channel drape and contain thick-bedded, waning uniform sedimentation units. The oldest active-channel-body fill

contains inclined lateral accretion surfaces that dip northward and contain pebble-to-cobble conglomerates at the base of each sedimentation unit. This suggests the thalweg of composite channel 3.4 offset laterally prior to aggradation of the multistory fills (Plate 1).

Composite channel 3.5 again steps northward and contains a composite drape with one remnant, and one active elementary channel body. Elementary bodies within composite channel 3.5 are laterally offset before being eroded at their tops by the base of the overlying composite channel. The fill of composite channel 3.5 is composed of thick-bedded, waning depletive sedimentation units.

Composite channel 3.6, which stacks vertically on composite channel 3.5, is composed of two composite drapes and three inactive elementary channel bodies. The inactive channel fills contain thin-bedded waning depletive sedimentation units. Composite channel 3.6 is the final composite channel of channel complex 3 and is offset northward by channel complex 4.

The 124 sedimentation units present in channel complex 3 have an average thickness of 0.46 m. Waning depletive sedimentation units are the dominant type (52%), followed by waning uniform (29%), steady depletive (7%), waning accumulative (6%), and waxing depletive (6%) sedimentation units. The high proportion of waning depletive sedimentation units represents lower energy conditions recorded along the margins of the channel complex. Channel complex 3 has the highest facies diversity of the four cycles and contains 16 of the 20 sedimentary facies. Additionally, channel complex 3 contains the largest proportion of inclined-stratified, pebble-to-granule sandstone, scour-and-fill sandstone, and mudstone intraclast conglomerate. Average grain size increases northward

from the southern margin of channel complex 3 reaching a maximum in the mudstone intraclast breccia and clast-supported pebble-granule conglomerate of composite channel 3.4, then decreasing to the top of composite channel 3.6.

Channel Complex 4

Composite channels 4.1 through 4.3 represent multistory bodies (Plate 1). This complex measures 890 m wide and 20 m thick, and contains three composite channels composed of 22 elementary bodies. Aspect ratios of elementary bodies range from 32 to 153. Vertical stacking of successive channel bases can be observed in outcrop south of the state beach parking lot. North of the parking lot, successive elementary and composite channels are amalgamated active channel bodies that stack vertically before being laterally offset to the south. The final fill of channel 4.3 migrates south with lateral accretion surfaces inclined away from the complex axis.

Composite channel 4.1 incises channel complex 3 and contains 7 elementary bodies: one complex drape, two composite drapes, and 4 active channel fills. They initially are multilateral and degradational. A complex drape lines the erosional surface at the base of channel complex 4. The two successive elementary channels are multilateral and extend to the north across the state beach parking lot. The final two elementary active channel bodies are multistory and pinch out onto the complex drape to the south (Plate 1). The active channel fills in 4.1 are dominated by thick-bedded, waning uniform sedimentation units.

Composite channel 4.2 contains ten elementary bodies: three composite drapes, one channel remnant, one inactive and five active channel fills. The composite drape is

overlain by a channel remnant, which in turn is overlain by active channel fills. The active channel fills are dominated by thick-bedded successions of waning depletive sedimentation units, whereas the composite drape consists of thin-bedded waning accelerative sedimentation units. The multistory to multilateral stacking pattern steps to the south toward the margin of channel 4.1. The final active and inactive channel fills pinch out southward onto the channel complex boundary, with composite drapes at the channel bases merging with the complex 4 drape (Plate 1).

Composite channel 4.3 contains five active channels arranged in a multistory to multilateral stacking pattern offset southward toward the complex margin. The final active channel of 4.3 contains lateral accretions surfaces inclined to the south.

The 29 sedimentation units recognized in channel complex 4 have an average thickness of 0.56 m. Waning depletive flow is the dominant sedimentation unit type (45%) followed by waning uniform flow (24%). Channel complex 4 strata have moderate facies diversity represented by 12 of the 20 process facies. Finally, channel complex 4 contains the lowest proportion of fine-grained facies, which also reflects the dominance of thick-bedded sedimentation units in the axis of the channel complex (Fig. 27).

Table 2. Elementary and composite channel dimensions, with channel width corrected for outcrop orientation and paleoflow direction when available.

Hierarchy	Channel Hierarchy	Body Type	Width (m)	Thickness (m)	Aspect	Outcrop Orientation	Paleoflow
1	Channel Complex		150.0	20.0	7.5		
1.1	Composite Channel		32.2	8.8	3.7	340	n/m
1.1.1	Elementary Channel	Active Channel	20.0	3.9	5.1		
1.1.2	Elementary Channel	Active Channel	13.4	5.9	2.3		
1.2	Composite Channel		32.4	12.7	2.6	340	n/m
1.2.1	Elementary Channel	Active Channel	23.0	2.4	9.6		
1.2.2	Elementary Channel	Active Channel	28.8	11.2	2.6		
1.3	Composite Channel		95.1	12.5	7.6	315	n/m
1.3.1	Elementary Channel	Inactive Channel	84.3	2.5	33.7		
1.3.2	Elementary Channel	Inactive Channel	93.8	6.5	14.4		
1.3.3	Elementary Channel	Inactive Channel	69.3	4.7	14.7		
1.3.4	Elementary Channel	Inactive Channel	20.8	3.5	5.9		
1.4	Composite Channel		16.4	6.9	2.4	315	n/m
1.4.1	Elementary Channel	Inactive Channel	16.4	6.9	2.4		
2	Channel Complex		398.0	15.0	26.5		
2.1	Composite Channel		128.3	11.5	11.2	320	n/m
2.1.1	Elementary Channel	Inactive Channel	125.9	4.6	27.4		
2.1.2	Elementary Channel	Inactive Channel	127.7	3.9	32.7		
2.2	Composite Channel		344.1	11.2	30.7	320	n/m
2.2.1	Elementary Channel	Active Channel	97.2	3.9	24.9		
2.2.2	Elementary Channel	Inactive Channel	45.1	8.9	5.1		
2.2.3	Elementary Channel	Active Channel	33.9	3.8	8.9		
2.3	Composite Channel		332.4	9.9	33.6	325	n/m
2.3.1	Elementary Channel	Active Channel	14.1	3.2	4.4		
2.3.2	Elementary Channel	Active Channel	41.6	4.5	9.2		
2.3.3	Elementary Channel	Active Channel	210.2	5.9	35.6		
2.3.4	Elementary Channel	Active Channel	131.6	4.2	31.3		
2.3.5	Elementary Channel	Active Channel	134.3	3.8	35.3		
2.3.6	Elementary Channel	Active Channel	137.3	3.1	44.3		
2.4	Composite Channel		183.5	11.2	16.4	325	n/m
2.4.1	Elementary Channel	Active Channel	45.4	4.9	9.3		
2.4.2	Elementary Channel	Active Channel	32.6	3.5	9.3		
2.4.3	Elementary Channel	Active Channel	41.0	4.2	9.8		
2.4.4	Elementary Channel	Active Channel	165.5	5.4	30.6		
2.4.5	Elementary Channel	Active Channel	42.9	2.1	20.4		
3	Channel Complex		330.0	22.0	15.0		
3.1	Composite Channel		22.5	8.6	2.6	310	300
3.1.1	Elementary Channel	Channel Remnant	16.3	4.1	4.0		n=5
3.1.2	Elementary Channel	Inactive Channel	18.1	2.6	7.0		
3.1.3	Elementary Channel	Channel Remnant	12.8	2.6	4.9		
3.1.4	Elementary Channel	Channel Remnant	8.9	1.8	4.9		
3.2	Composite Channel		42.4	16.0	2.7	310	294
3.2.1	Elementary Channel	Channel Drape	34.2	1.5	22.8		n=12
3.2.2	Elementary Channel	Inactive Channel	7.7	1.3	5.9		
3.2.3	Elementary Channel	Channel Drape	7.2	0.8	9.0		
3.2.4	Elementary Channel	Channel Remnant	7.1	1.1	6.5		
3.2.5	Elementary Channel	Channel Drape	8.0	0.7	11.5		
3.2.6	Elementary Channel	Inactive Channel	21.1	3.4	6.2		
3.2.7	Elementary Channel	Channel Drape	17.6	1.3	13.5		
3.2.8	Elementary Channel	Inactive Channel	17.3	3.4	5.1		
3.2.9	Elementary Channel	Channel Drape	12.6	1.4	9.0		
3.2.10	Elementary Channel	Inactive Channel	17.2	3.9	4.4		
3.2.11	Elementary Channel	Channel Drape	5.8	0.7	8.3		
3.3	Composite Channel		41.7	12.4	3.4	320	294
3.3.1	Elementary Channel	Channel Remnant	10.7	1.7	6.3		n=6
3.3.2	Elementary Channel	Channel Drape	11.4	0.6	19.0		
3.3.3	Elementary Channel	Active Channel	12.8	2.6	4.9		
3.3.4	Elementary Channel	Active Channel	22.9	3.0	7.6		
3.3.5	Elementary Channel	Active Channel	35.1	3.9	9.0		
3.3.6	Elementary Channel	Active Channel	35.3	3.5	10.1		
3.3.7	Elementary Channel	Active Channel	33.7	4.5	7.5		
3.4	Composite Channel		9.6	13.4	0.7	300	294
3.4.1	Elementary Channel	Channel Drape	7.7	2.4	3.2		n=4
3.4.2	Elementary Channel	Active Channel	9.2	5.6	1.6		
3.4.3	Elementary Channel	Active Channel	3.6	2.4	1.5		
3.4.4	Elementary Channel	Active Channel	3.8	2.3	1.6		
3.4.5	Elementary Channel	Active Channel	3.7	2.7	1.4		
3.5	Composite Channel		35.3	3.9	9.1	300	240
3.5.1	Elementary Channel	Channel Drape	24.2	1.3	18.6		n=2
3.5.2	Elementary Channel	Channel Remnant	16.5	0.9	18.3		
3.5.3	Elementary Channel	Active Channel	29.5	3.9	7.6		

Table 2 cont. Elementary and composite channel dimensions, with channel width corrected for outcrop orientation and paleoflow direction where available.

Hierarchy	Channel Hierarchy	Body Type	Width (m)	Thickness (m)	Aspect	Outcrop Orientation	Paleoflow
3.6		Composite Channel	92.7	7.1	13.1	340	252
3.6.1	Elementary Channel	Channel Drape	68.9	1.5	45.9		n=4
3.6.2	Elementary Channel	Inactive Channel	43.4	1.1	39.4		
3.6.3	Elementary Channel	Channel Drape	75.5	0.9	83.8		
3.6.4	Elementary Channel	Inactive Channel	89.8	2.2	40.8		
3.6.5	Elementary Channel	Inactive Channel	80.6	2.7	29.8		
4		Channel Complex	890.0	20.0	44.5		
4.1		Composite Channel	597.7	3.9	153.3	340	253
4.1.1	Elementary Channel	Channel Drape	64.8	2.8	23.1		n=5
4.1.2	Elementary Channel	Active Channel	73.5	5.2	14.1		
4.1.3	Elementary Channel	Active Channel	83.0	4.7	17.7		
4.1.4	Elementary Channel	Active Channel	116.0	3.8	30.5		
4.1.5	Elementary Channel	Channel Drape	13.8	2.0	6.9		
4.1.6	Elementary Channel	Active Channel	116.3	2.7	43.1		
4.1.7	Elementary Channel	Channel Drape	8.2	0.5	16.4		
4.2		Composite Channel	481.0	14.9	32.3	330	269
4.2.1	Elementary Channel	Channel Drape	298.8	1.8	166.0		n=16
4.2.2	Elementary Channel	Channel Remnant	10.1	1.2	8.5		
4.2.3	Elementary Channel	Active Channel	87.1	4.0	21.8		
4.2.4	Elementary Channel	Active Channel	15.0	5.6	2.7		
4.2.5	Elementary Channel	Active Channel	40.0	2.4	16.7		
4.2.6	Elementary Channel	Active Channel	75.5	6.9	10.9		
4.2.7	Elementary Channel	Active Channel	315.8	5.2	60.7		
4.2.8	Elementary Channel	Channel Drape	18.6	0.5	37.3		
4.2.9	Elementary Channel	Inactive Channel	235.2	1.8	130.6		
4.2.10	Elementary Channel	Channel Drape	14.4	0.9	16.0		
4.3		Composite Channel	451.8	14.0	32.3	340	271
4.3.1	Elementary Channel	Active Channel	93.8	5.0	18.8		n=2
4.3.2	Elementary Channel	Active Channel	81.6	3.0	27.2		
4.3.3	Elementary Channel	Active Channel	101.3	4.0	25.3		
4.3.4	Elementary Channel	Active Channel	30.0	2.9	10.3		
4.3.5	Elementary Channel	Active Channel	383.9	3.5	109.7		

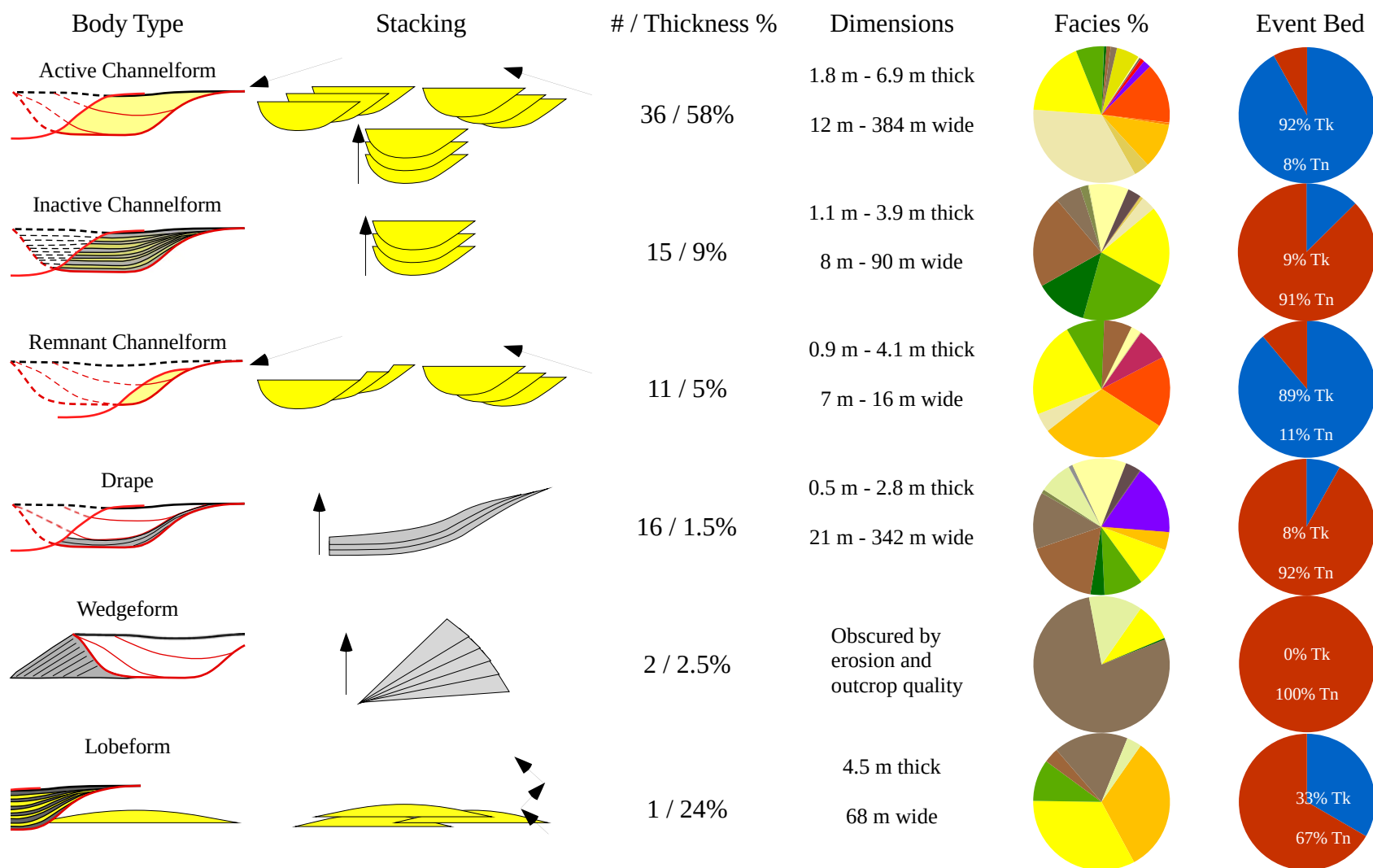


Figure 15. Sedimentary bodies classified in the Capistrano Formation. Stacking patterns, dimensional data, and count are captured in photo panel data. Facies attributes are recorded from measured section data. Event bed data are interpreted from sedimentation unit thickness where thick beds are greater than 40 cm. Thick beds are interpreted to represent an axial sedimentation region within channel and channel related deposits. Facies colors correlate to colors used in Figure 9.

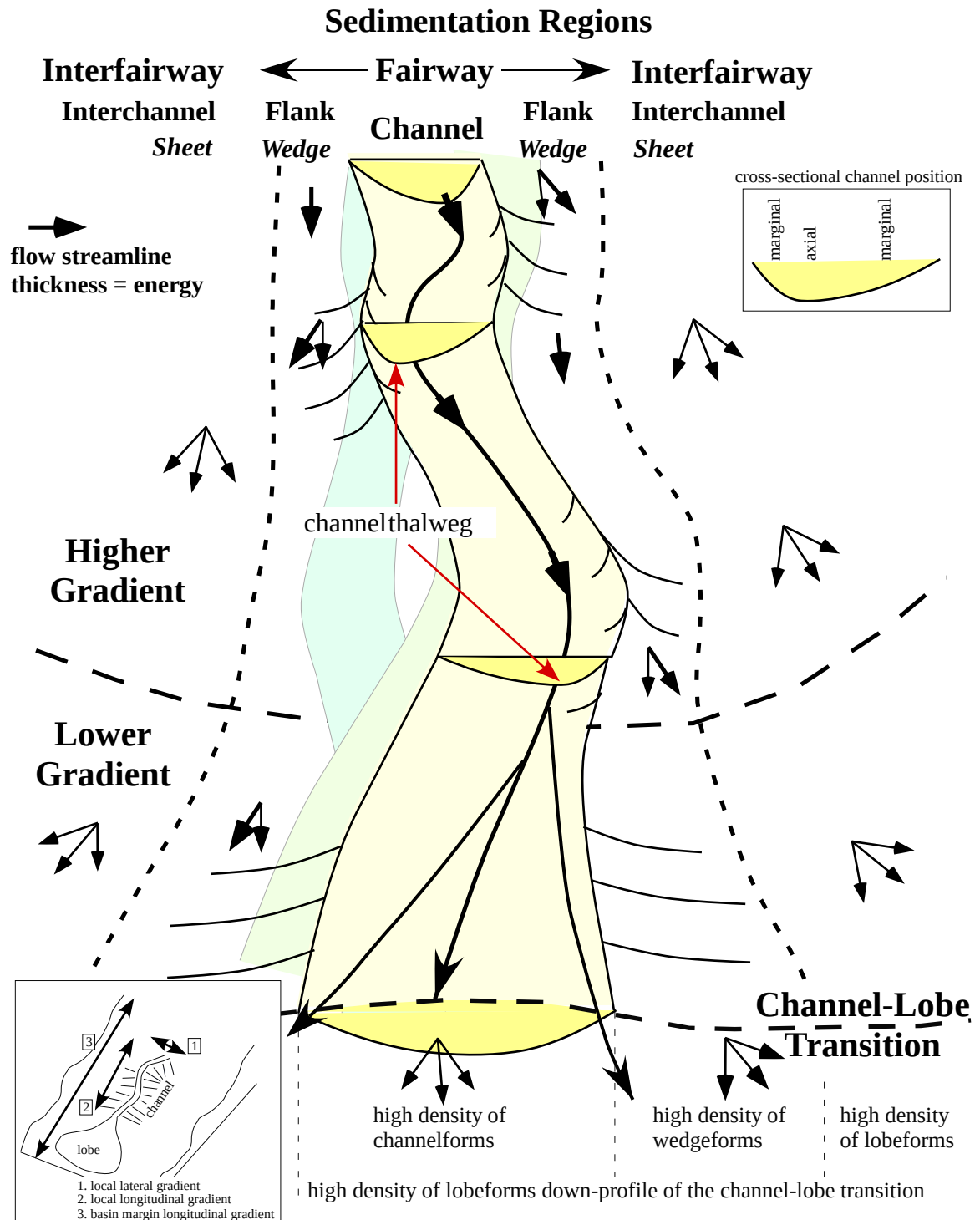


Figure 16. Diagram showing sedimentation regions recording lateral and longitudinal variations in the degree of confinement and the longitudinal gradient (after Gardner et al. 2008). Arrows represent flow streamlines related to confined, partially-confined, and unconfined flow, which generates channelform, wedgeform, and lobeform sedimentary bodies.

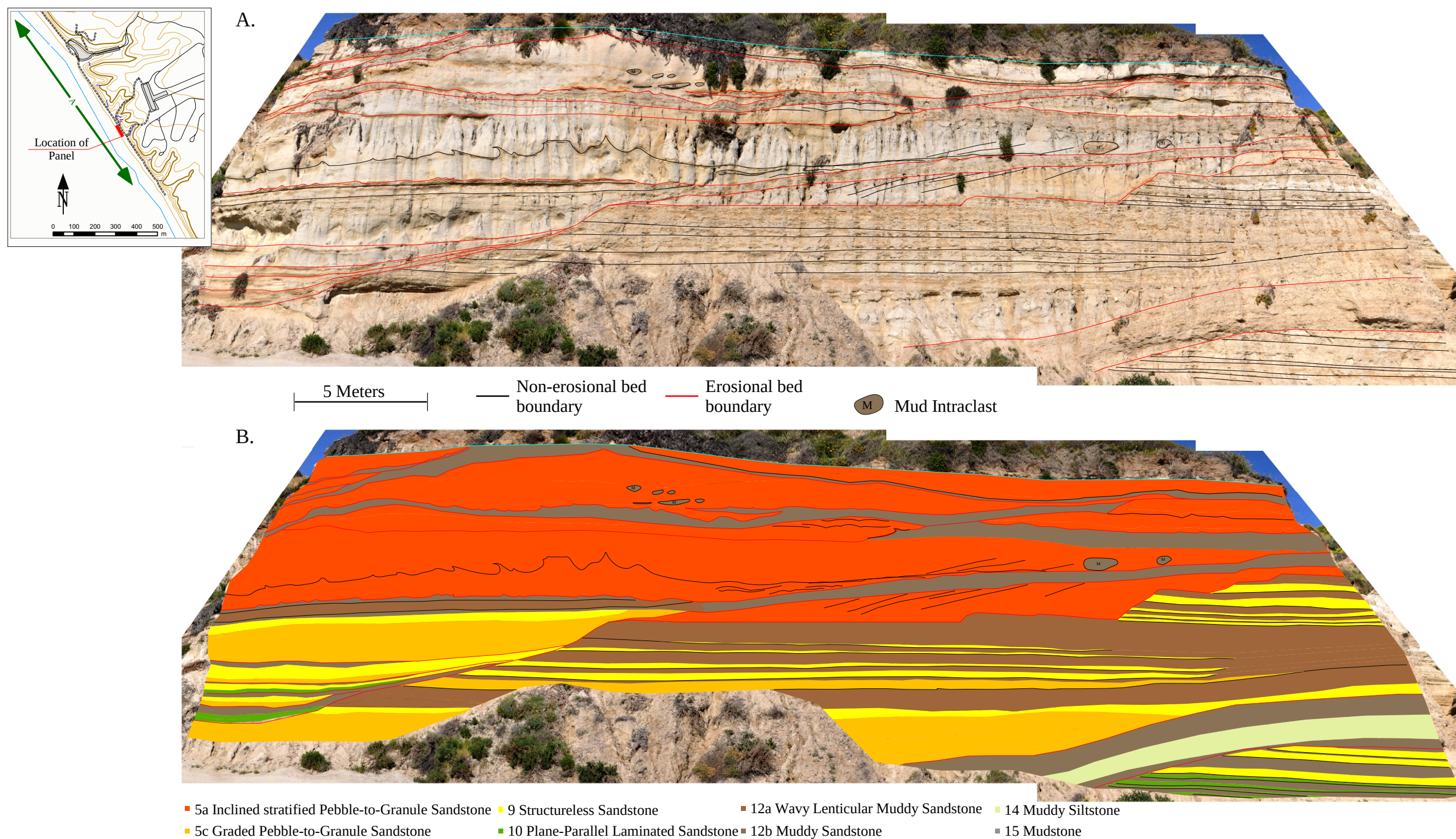


Figure 17a. Bed boundary (A) and facies diagram (B) for outcrop segment A between the southernmost state park trail and the park outhouse (shown on map). A) Bedding diagram shows erosive contacts in red and non-erosive contacts in black. Bed boundaries record surfaces that bound event beds, and contain multiple facies. B) Bedding diagram with interpreted sedimentary facies overlain over the outcrop. Multiple facies within a sedimentation unit record the evolution of a single flow as it passes over the site of deposition.

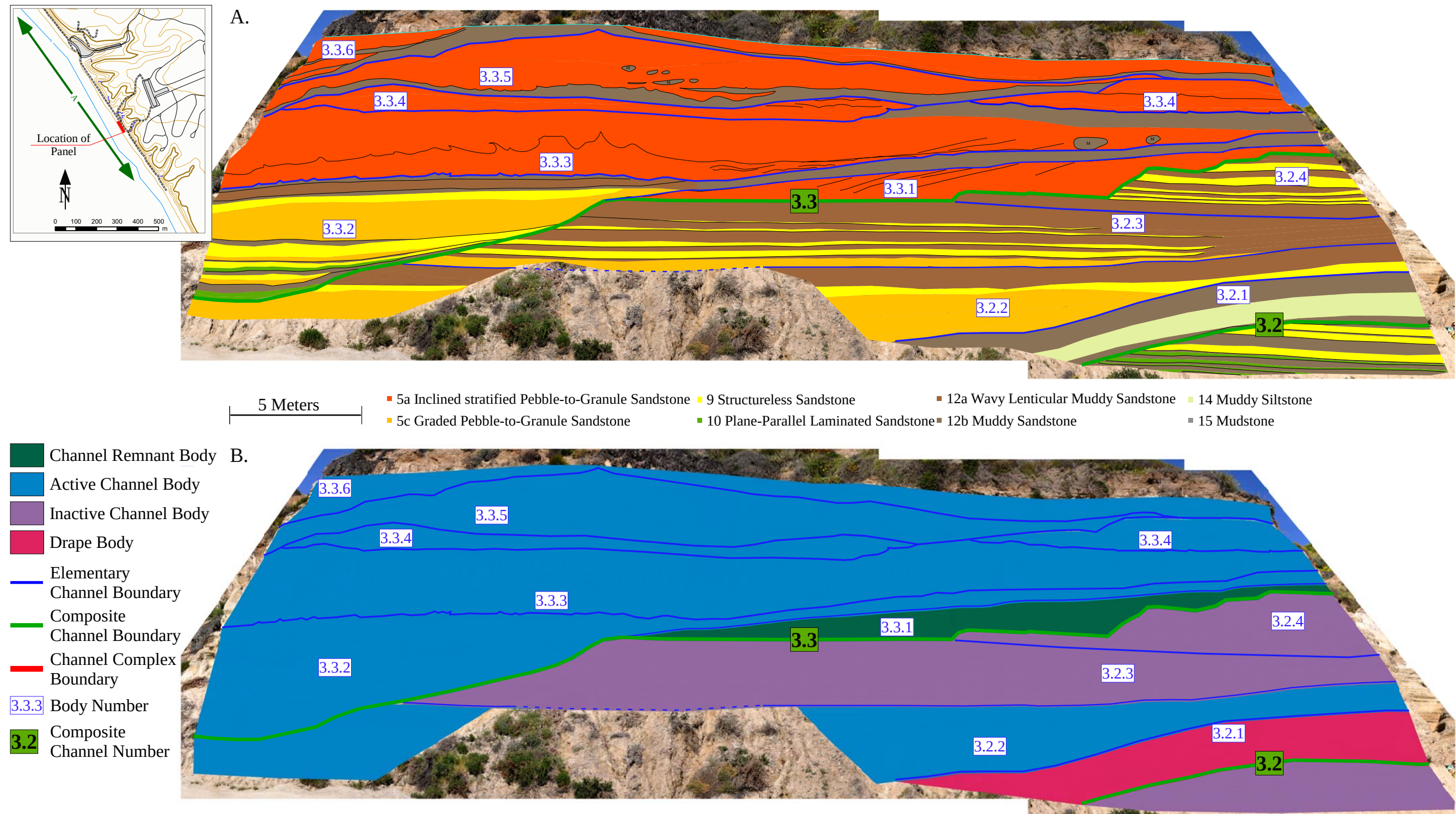
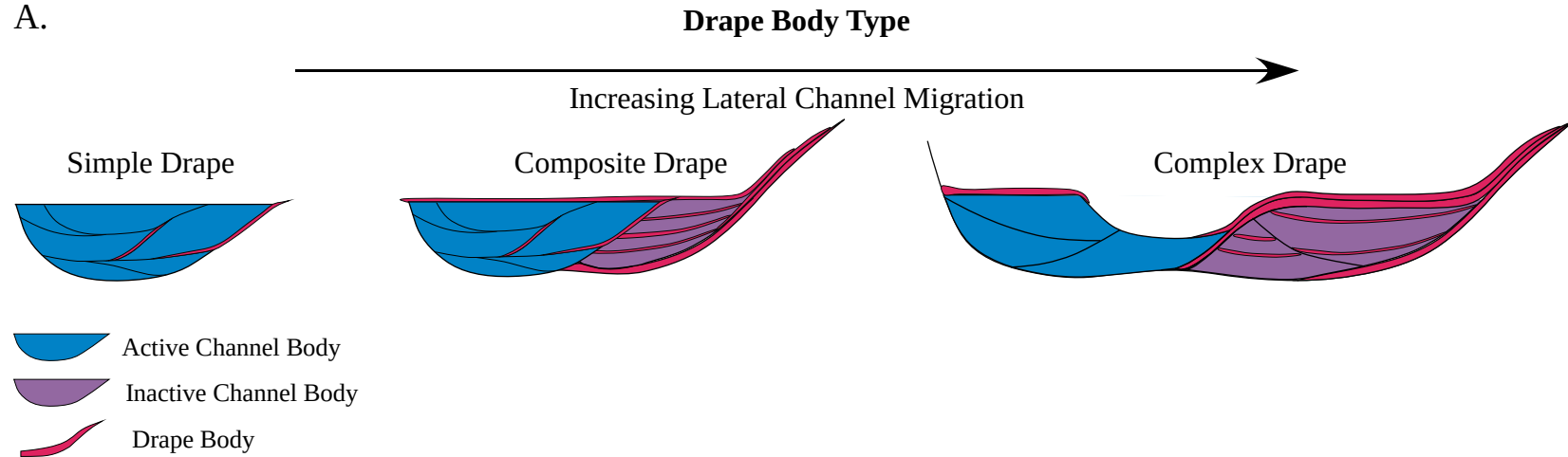
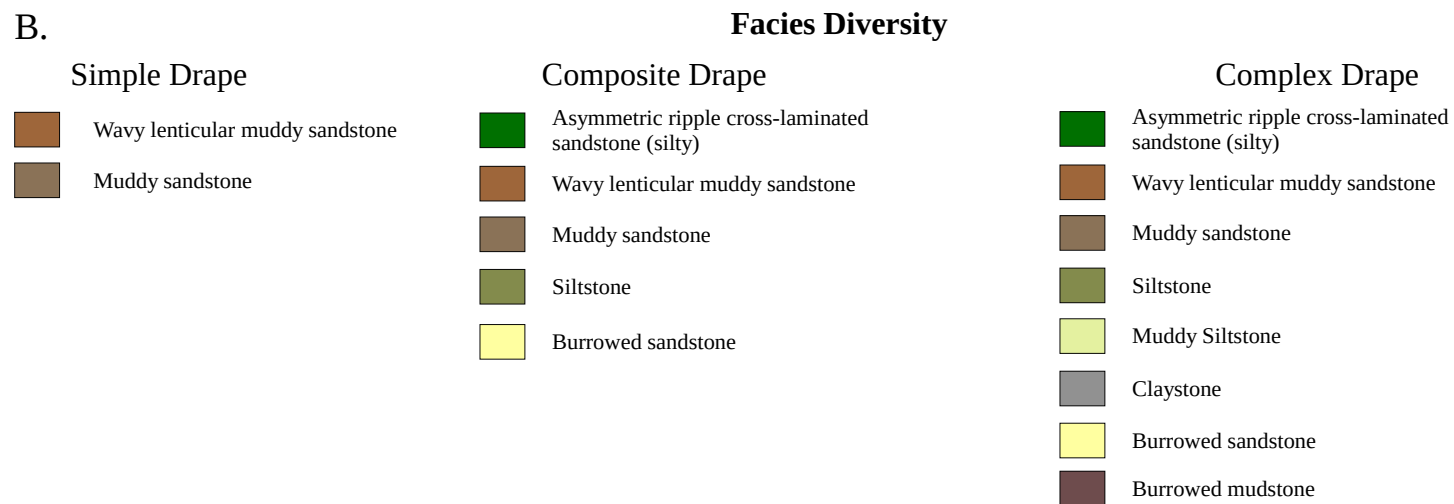


Figure 17b. Facies diagram (A) and body diagram (B) for the outcrop segment A between the southernmost state park trail and the park outhouse (shown on map). A) Interpreted sedimentary facies are overlain on the outcrop along with interpreted channel hierarchy. This outcrop segment represents composite channel 3.2 and 3.3, each composed of multiple elementary channels. B) Sedimentary body diagram overlain with channel hierarchy. Colors represent different sedimentary body types.

A.



B.



70

Figure 18. A) Diagram showing drapeform sedimentary body classification. Drapeform complexity increases with increasing channel growth permitting more sediment to be preserved on higher reaches of the channel margin. B) Facies found in sedimentation units composing simple, composite, and complex drapes. More sedimentary facies in a sedimentary body record a higher facies diversity.

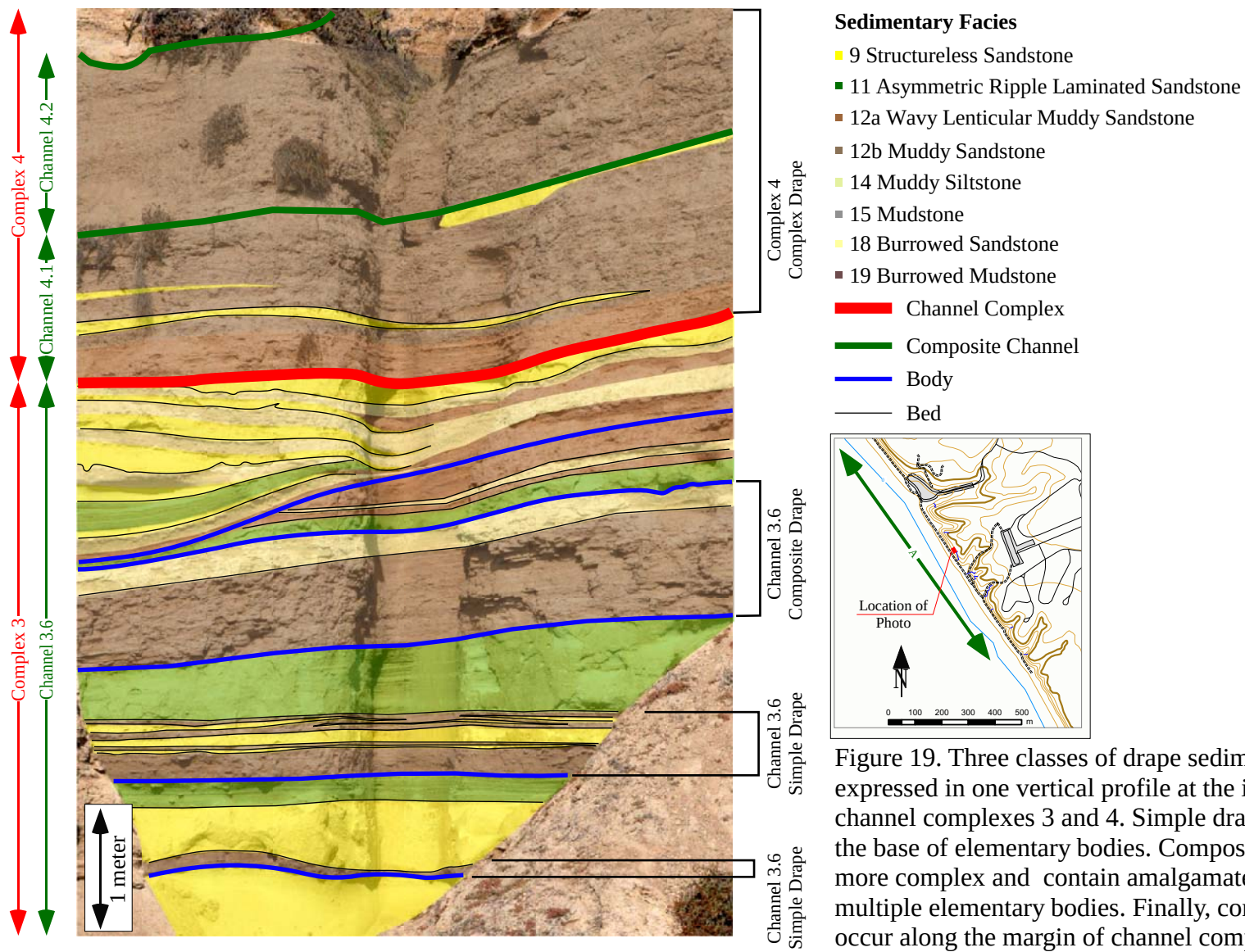


Figure 19. Three classes of drape sedimentary bodies expressed in one vertical profile at the intersection of channel complexes 3 and 4. Simple drapes occur along the base of elementary bodies. Composite drapes are more complex and contain amalgamated drapes from multiple elementary bodies. Finally, complex drapes occur along the margin of channel complexes.



Figure 20. Wedgeform body showing bedding dipping at a high angle normal to the dominant channel trend. Beds taper and thin from the channels they flank with beds inclined at high angles (up to 60?) away from adjacent channel axes. Deformation of sandy mudstone at the crest of the body decreases with distance away from the channel margin. Isolated, very fine-grained sandstone beds also shingle away from the channel.

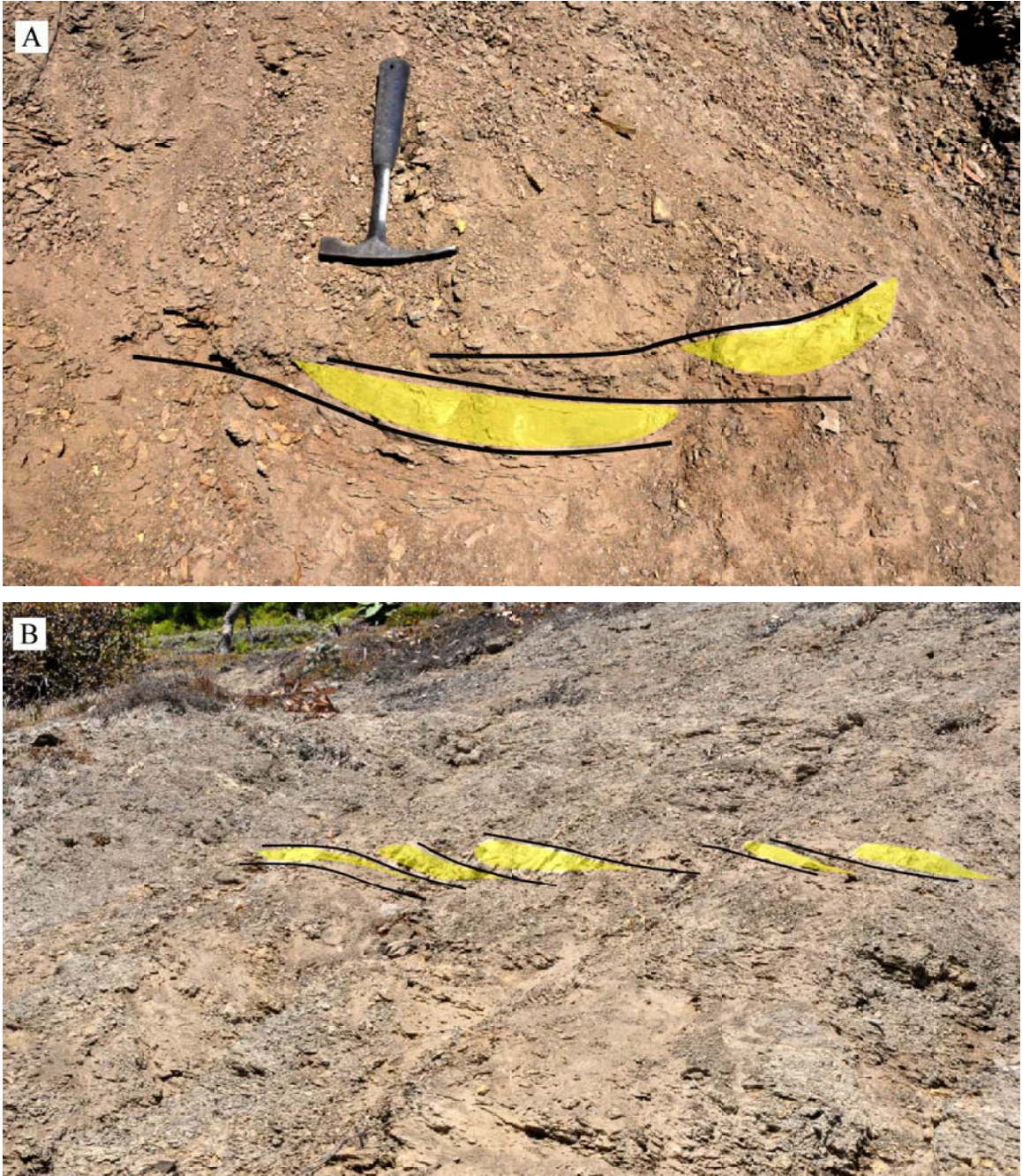
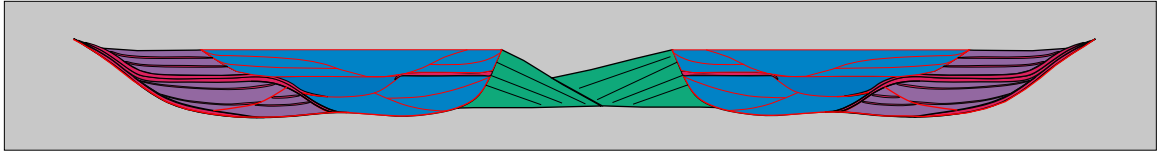


Figure 21. Offlapping sand shingles in the levee deposits of outcrop segment B. A) Beds taper and thin from the channels they flank with beds inclined at high angles (up to 60 degrees) away from adjacent channel axes. B) Sandstone beds shingle to the northeast and record the overbanking of very fine-grained sand along the outside bend of the channel complex 4.

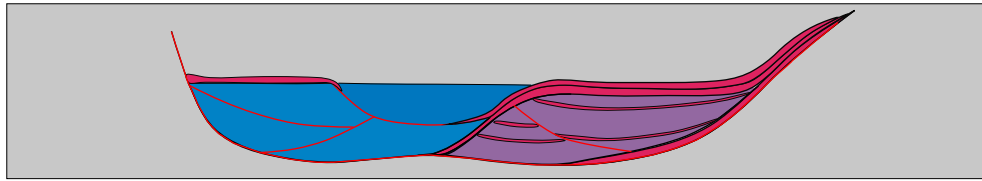
4. Channel Fairway (4th-order scale shown)

>1.9 km wide



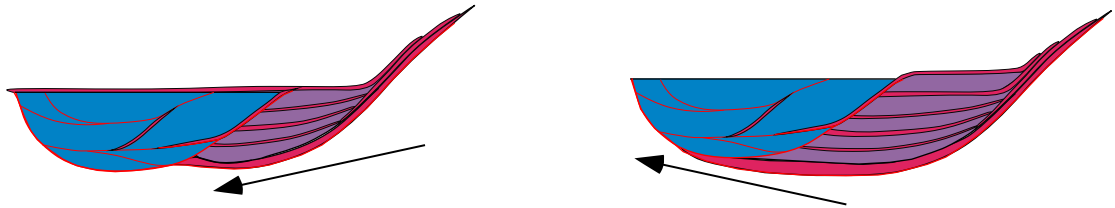
3. Channel Complex

150 - 900 m wide



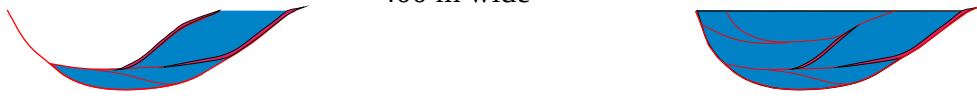
2. Composite Channel

10 - 600 m wide



1. Elementary Channel Fill

<400 m wide



Scroll bar representing remnant channel thalweg

Preserved channel thalweg

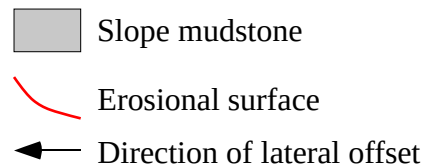
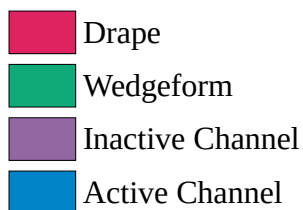


Figure 22. Channel hierarchy used in the classification of the Capistrano Formation (after Gardner and Borer, 2000). Channel widths and stacking patterns reflect those observed in this outcrop. Elementary channels are the record of a preserved channel thalweg. Two or more elementary channels stack to form a composite channel. Two or more composite channels stack to form a channel complex. A channel fairway is a sandstone-rich area of the sea floor with a high density of channels.

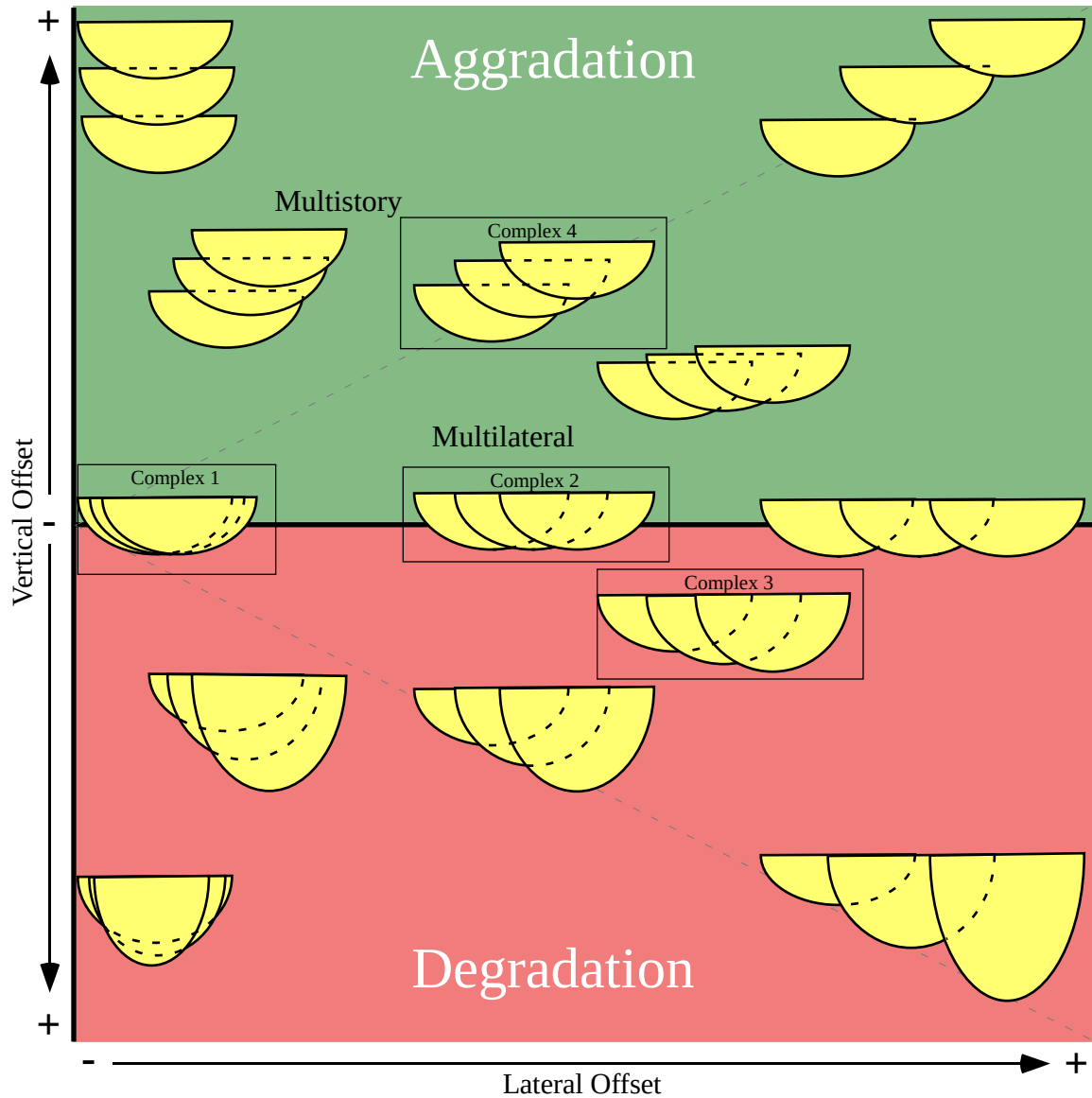


Figure 23. Illustration showing composite channel stacking as a function of vertical and lateral offset of component elementary bodies. Channels located in the green region are aggradational, where successive channel bases overlie the underlying composite channel. Composite channels appearing in the red region are degradational, where successive channel bases erode and lie below the previous channel base. The dominant stacking arrangement of composite channels recorded by each channel complex is labeled on the diagram.

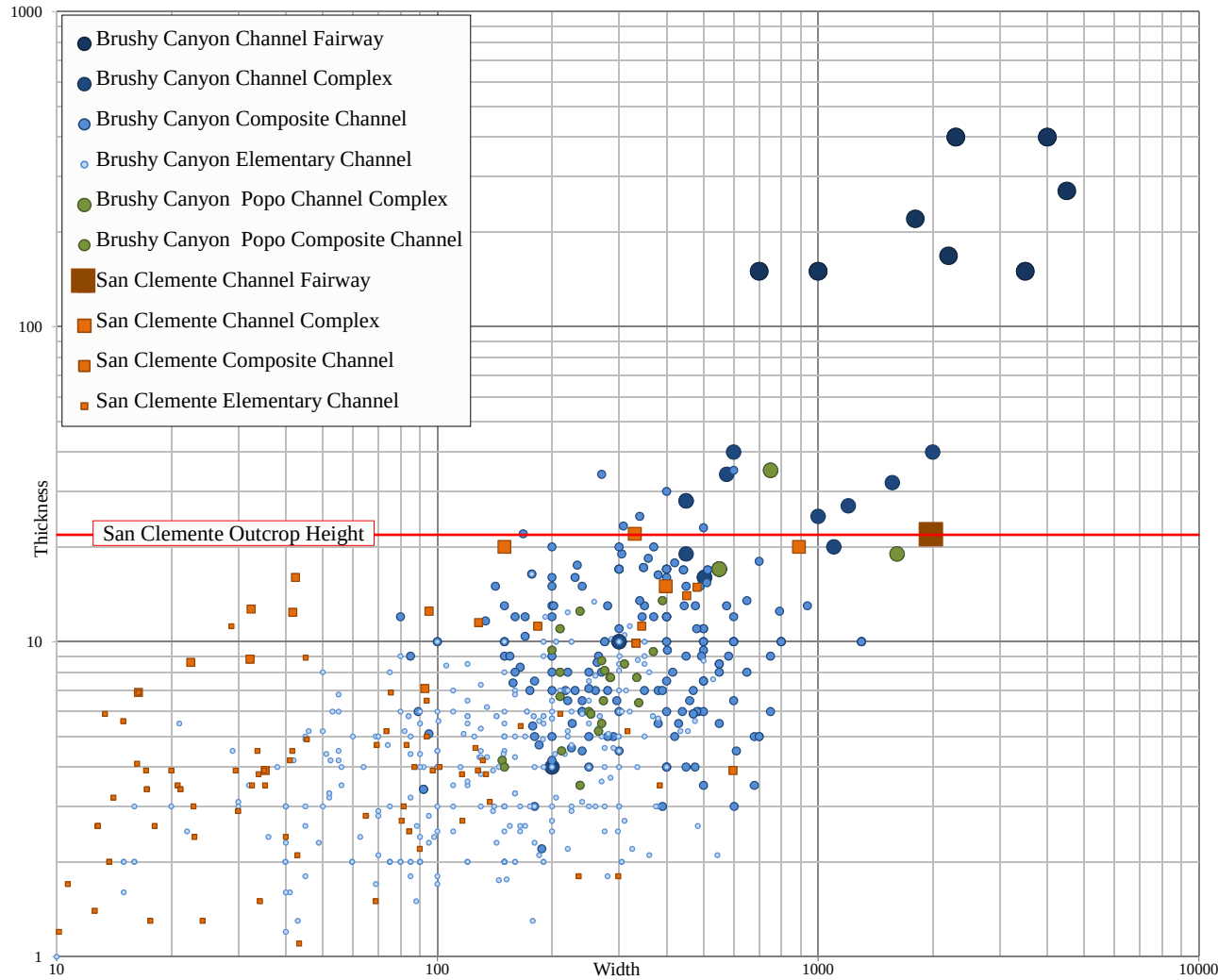


Figure 24. Comparison of outcrop measurements of channelform bodies at San Clemente with measurements from the Brushy Canyon formation, West Texas. No matter the grain size, composite features across multiple outcrops show that the composite feature scales longer term evolution of the channel pathway.

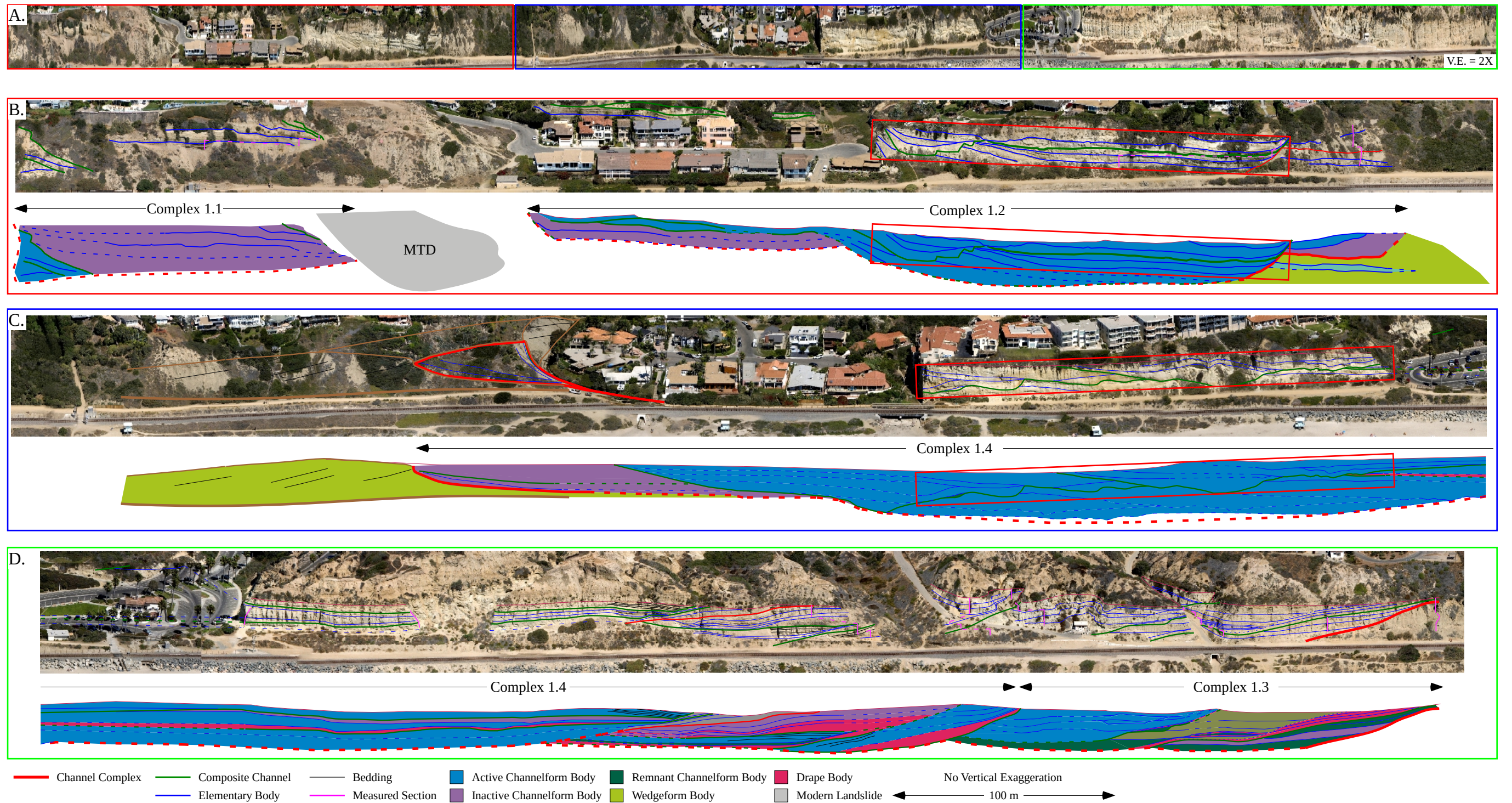
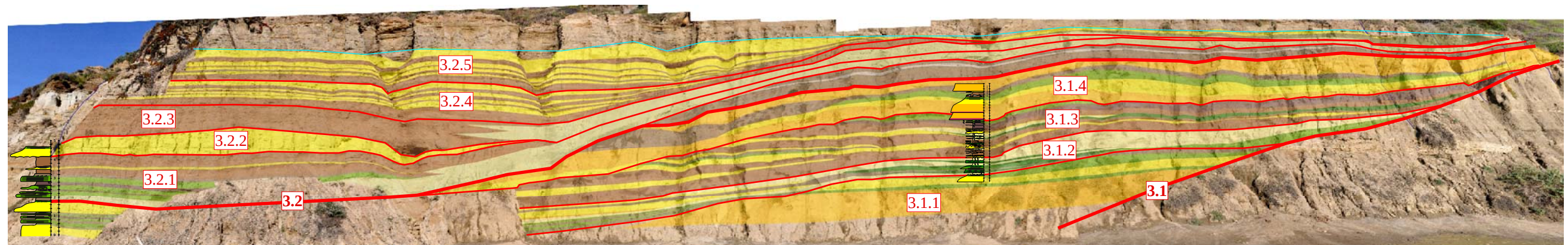
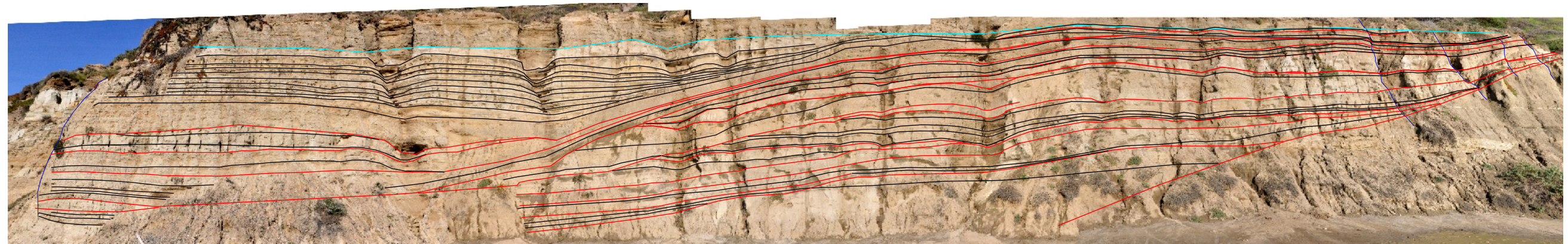


Figure 25. Full outcrop interpretation panel. A) Entire outcrop from north to south. Red, blue, and green boxes correspond to panel B, C, and D respectively. B) The north end of the outcrop contains complex 1 and 2 separated by a modern landslide. C) The middle section of outcrop contains the north end of complex 4. D) The south section of outcrop contains complex 3 and the south end of complex 4.



- | | | | | |
|------------------------|---------------------|---------------------------------|-----------------------------------|---------------------------------|
| — Depositional Surface | — Erosional Surface | — Pleistocene Erosional Surface | — 3.1 — Composite Channel Surface | [3.1.1] Elementary Channel Body |
|------------------------|---------------------|---------------------------------|-----------------------------------|---------------------------------|
-
- | | | | | |
|--|--|--|-----------------------|---------------------------------------|
| ■ 2 Pebble-to-Cobble Conglomerate | ■ 5b Plane Parallel Stratified Pebble-to-Granule Sandstone | ■ 9 Structureless Sandstone | ■ 12b Muddy Sandstone | ■ 17 Soft Sediment Deformed Sandstone |
| ■ 3 Granule-to-Pebble Conglomerate | ■ 5c Graded Pebble-to-Granule Sandstone | ■ 10 Plane-Parallel Laminated Sandstone | ■ 13 Siltstone | ■ 18 Burrowed Sandstone |
| ■ 4 Mud Intraclast Conglomerate | ■ 6 Plane Parallel Stratified Sandstone | ■ 11 Asymmetric Ripple Laminated Sandstone | ■ 14 Muddy Siltstone | ■ 19 Burrowed Mudstone |
| ■ 5a Inclined stratified Pebble-to-Granule Sandstone | ■ 8 Scour-and-Fill Stratified Sandstone | ■ 12a Wavy Lenticular Muddy Sandstone | ■ 15 Mudstone | ■ 20 Soft Sediment Deformed Mudstone |

Figure 26. Outcrop panel showing the interpretation of two composite channels in outcrop segment A. Composite channel 3.1 represents the southernmost cut of the Capistrano Formation into the slope mudstone of the Monterey Formation. Composite channel 3.2 steps northward and cuts the fill of composite channel 3.1. The fill of channel 3.2 onlaps the erosional surface and complex drape.

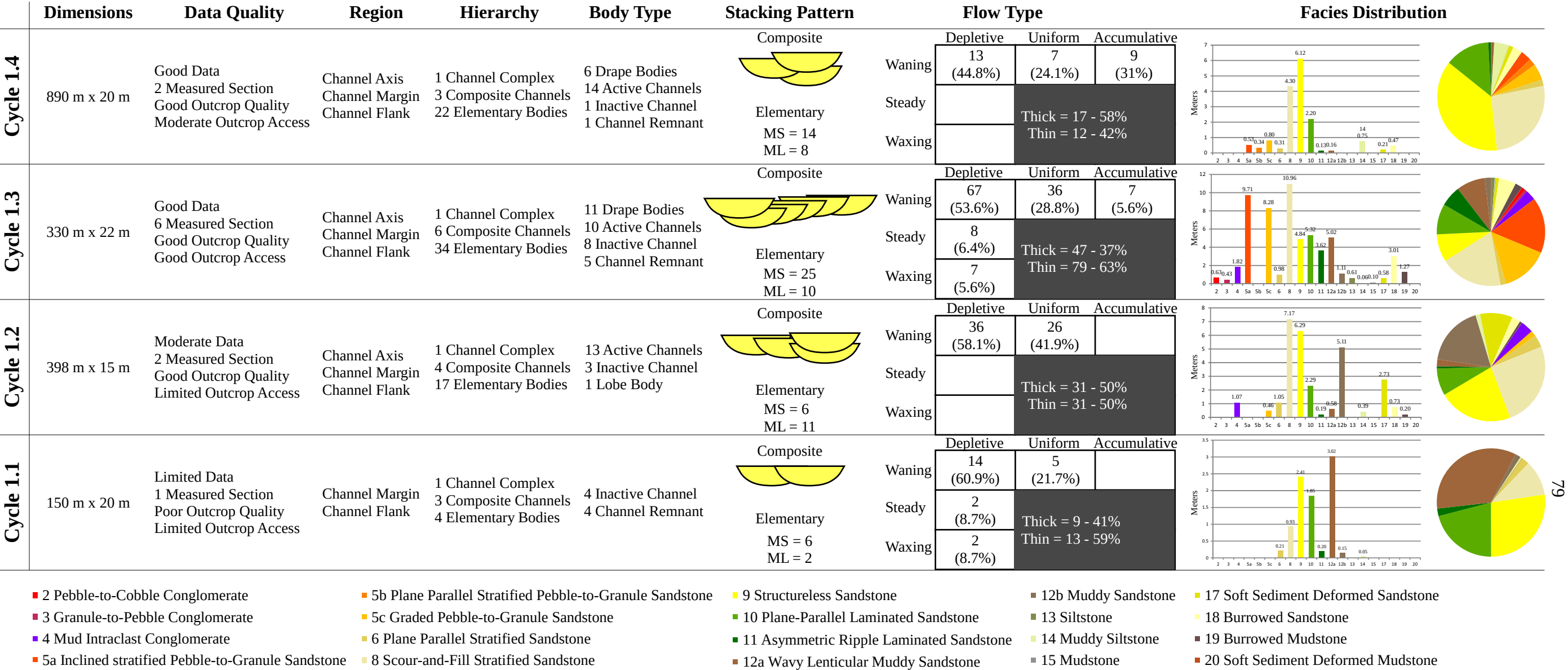


Figure 27. Attributes of the four cycles described in the Capistrano Formation. Each cycle of sedimentation is recorded by a single channel complex with the dimensions recorded in column one. Column two describes the data quality and limitations encountered for each cycle. Column three describes the sedimentation regions observed within each cycle. Column four describes the number of channel elements recorded at each level in the channel hierarchy. Column five describes the sedimentary body types found in each cycle. Column six describes the stacking pattern of composite channels as well as the number of multistory (MS) and multilateral (ML) elementary channels. Column seven describes the number, acceleration type, and percentage of sedimentation units recorded in each cycle, as well as the number of thick- and thin-bedded sedimentation units. Finally, column eight describes the facies distribution recorded in each cycle.

STRATIGRAPHY

Introduction

The stratigraphic framework for the Capistrano Formation at San Clemente State Beach is based on a threefold hierarchy of stratigraphic cycles that document the evolution of an upper-slope channel fairway encased in slope mudstones. The limited outcrop height results in a stratigraphic interpretation that emphasizes lateral rather than vertical changes, and divides the Capistrano lithosome into 4 discrete episodes of channel complex development.

A hierarchy of sedimentary attributes, listed in increasing scale, includes facies, sedimentation unit, sedimentary body type and stacking pattern. These attributes are used to correlate trends in depositional system energy to sedimentary architecture. Stratigraphic changes in sedimentary architecture are used to define channel axis, margin, and intrachannel sedimentation regions that aid in paleogeographic reconstruction, and in turn constrain the spatial and temporal evolution of this submarine channel system.

Sedimentation Regions

Sedimentation regions correspond to preserved environments of deposition describing lateral and longitudinal variations in sedimentary architecture. Regions are defined by sedimentation units, surface type, sedimentary body type, process facies, grain size, and lithology (Fig. 28). Three channel-related sedimentation regions define the channel fairway at San Clemente State Beach; channel axis, channel margin, and channel

flank regions. The channel axis region is laterally replaced by channel margin regions, whereas the channel margin region is laterally replaced by the channel flank region (Fig. 16).

Two general patterns of sedimentation events are recognized at San Clemente State Beach: thinly-interbedded sandstone and mudstone, and thickly-bedded sandstone with thin mudstone caps (Fig. 29). It has been suggested that thick- and thin-bedded event beds record different flow processes related to variations in sediment concentration and particle settling (Talling, 2001). Observations in this study, however, show that similar facies are present in thick- and thin-bedded sedimentation units. In this case, the distribution of these processes records the spatial and temporal evolution of a single event, as well as variation in the magnitude of events (Fig 30).

Thick-Bedded Channel Axial Sedimentation Region

The channel axis region records deposition from the axis of subaqueous flow pathways. The degree of confinement is reflected by the dominance of channelform and drape bodies (Fig. 28). Among channelform sedimentary bodies, active bodies are the most abundant. The channel axis region has the highest proportion of thick-bedded sedimentation units, the highest proportion of traction-dominated sedimentary facies, the only mudstone intraclast conglomerate, and the lowest proportion of mudstone (Fig. 28).

Thick-bedded sandstones of the channel axis region form multi-meter packages of amalgamated and non-amalgamated sandstone beds with abundant mudstone intraclasts and dispersed carbonaceous material. Of the multiple styles of thick-bedded sedimentation units observed, those containing scour-and-fill stratified and structureless

sandstone are dominant across the outcrop and represent 80% of the facies recorded in thick-bedded successions (Fig. 29).

Thin-Bedded Channel Margin Sedimentation Region

The channel margin region records deposition from the edge of the flow along the margin of a channel. Like the channel axis region, the degree of confinement is reflected by the dominance of channelform and drape bodies (Fig. 28). Unlike the channel axis region, inactive and remnant channelforms dominate. The channel margin region has a high proportion thin-bedded sedimentation units and a uniform distribution of sandstone and mudstone (Fig. 28).

Thin-bedded sedimentation units in the channel margin region form multi-meter successions of non-amalgamated sandstone and mudstone, commonly with carbonaceous rich muddy sandstone bed tops. Structureless, plane-parallel laminations, ripple-cross laminations, and muddy sandstone, represent 80% of the facies in this region (Fig. 29).

Channel Flank Sedimentation Region

The channel flank region records deposition from partially confined and unconfined subaqueous flows. This region is poorly constrained but wedgeform and lobeform sedimentary bodies dominate. These bodies reflect sedimentation outside the channel confinement. The channel flank region has the highest proportion of thin-bedded sedimentation units containing over 50% unstructured muddy-sandstone (facies 12b) and mudstone (Fig. 28).

Lateral Variability

Thick- and thin- bedded sedimentation units record lateral variations within a single sediment gravity flow event from the axis to the margin of the channel (Fig. 30). In waning depletive flow events, thick beds of stratified, structureless, laminated, to bioturbated sandstone in the axis of the channel correlate to thin beds of structureless, plane-parallel laminated, to asymmetric ripple-cross-laminated sandstone along the margin of the channel. Absence of the basal stratified sandstone in the margin region suggests more basal shear in the axis of the channel. The overall upward decrease in grain size suggests waning flow velocity over time.

Sedimentation units recording steady depletive flow change laterally from scour-and-fill stratification in the axis of the channel to successions of structureless sandstone alternating with wavy-lenticular sandstone along the margin of the channel. This suggests lateral flow deceleration from flows smaller than the open channel course. Flow expansion and divergent streamlines promote sedimentation from sustained and steady flow.

Sedimentation units recording waxing depletive flow exhibit decreased velocity in both channel axis and margin regions. However, the grain size and sediment concentration is higher in the axis than along the margin, which is reflected in the increased proportion of structureless sandstone in the axis region. The upward increase in grain size in the sedimentation unit indicates the velocity increased over time.

Stratigraphy of the Capistrano Formation

Early Miocene formation of the Los Angeles Basin records the transition from a forearc to a transtensional basin associated with extension and clockwise rotation of the Western Transverse Range (Hornafius et al., 1986; Luyendyk, 1991; Crouch and Suppe, 1993; Nicholson et al., 1994). The San Onofre Breccia was shed from uplifts of the Catalina Schist metamorphic terrane formed by transpressional tectonics resulting from the right-lateral, strike-slip faulting along the California Borderland (Ehlig, 1979; Stewart, 1979). Coarse clastic sedimentation was followed by a period of relative quiescence and sediment starvation recorded by siliceous chert and petroliferous mudrocks in the Monterey Formation (Fig. 3) (Ehlig, 1979; Stewart, 1979). The Capistrano Formation records late Miocene to early Pliocene rejuvenation of clastic sedimentation into the Capistrano Embayment of the Los Angeles Basin (Campion, 2005). The coeval shoreline was located 5.5 km to the east of the outcrop (Fig. 4) (Corey, 1954; Ingle, 1971; Crowell, 1972; Schwartz and Colburn, 1987).

The upper Miocene to Pliocene Capistrano Formation is a 725 m thick sandstone lithosome encased in the upper part of the Monterey Formation (Campion et al., 2005). While the Capistrano Formation at San Clemente exposes far less of this 725 m thick interval, the contact between the Monterey Formation and Capistrano Formation is visible on both the north and south extents of the San Clemente outcrop belt.

Paleoecologic and paleobathymetric investigation by Ingle (1971) uses benthonic and planktonic foraminiferal assemblages to assign the base of the Capistrano Formation to the California Mohenian Stage, and the top to the California Repettian Stage. The

entire Capistrano interval thus represents approximately five million years from 7.5 Ma to 2.2 Ma (Ingle, 1971). While the base is not exposed in outcrop, the Capistrano Formation is unconformably overlain by Pleistocene marine terrace deposits.

The 1980 m wide, 22 m tall outcrop belt represents a discrete sandstone lithosome. The Capistrano lithosome correlates to a single slope channel fairway composed of four channel complexes each recording an autogenic cycle of deposition. Cycles are defined by channel trajectory, changes in paleoflow direction, grain size, hierarchy of sedimentary attributes, stacking pattern, and cross cutting relationships. The northernmost complex in outcrop segment C contains the oldest strata (cycle 1) followed by the southernmost in outcrop segment C (cycle 2), then the southernmost in outcrop segment A (cycle 3), and finally the northernmost in outcrop segment A (cycle 4), which erosionally truncates channel complex 3.

Stratigraphic Cycle Definition

Definition of cycles is based on correlation of changes in deep-water system energy as reflected by a hierarchy of sedimentary attributes. Changes in system energy are related to either flow frequency and/or magnitude. Spatial variations in a hierarchy of sedimentary attributes record modulation of the evolving geomorphic expression of a depositional site over time (Gardner et al., 2008). Phases of sedimentation recording an increase in frequency and/or magnitude (waxing energy) often record erosion and degradation of the seabed. These erosional surfaces record maximum energy and are often associated with thinly-bedded, fine-grained deposits recording bypass on high-gradient positions, and as thickly-bedded, coarse-grained deposits at lower gradient

positions. Phases of sedimentation recording decreased frequency and/or magnitude of subaqueous flow events (waning energy) transfer less sediment along the profile and occur when sediment is preserved at high-gradient positions.

The modulation of changes in system energy is estimated by stratigraphic surfaces, grain size, lithology, process facies, sedimentary body type, and surfaces recording deposition and erosion. Surfaces and facies recording maximum erosion and bypass of sediment record the turnaround from waxing to waning system energy. This maximum energy condition is used to subdivide the Capistrano formation into four cycles that correspond to channel complexes within the lithosome. Surfaces and facies recording the minimum system energy conditions, and the turnaround from waning to waxing system energy, occur at the tops of the channel complexes.

Cycle 1

The northernmost channel complex is interpreted to record the initiation of the channel fairway on the slope. This complex has the least data with only one measured section due to limited access and poor outcrop exposure. This complex has the smallest width (150 m), the lowest aspect ratio (7.5), contains the fewest bodies (9) and shows the lowest body diversity (2) (Fig. 27). The lack of channel-base drapes suggests less time as an open channel course available for sediment bypass.

The 23 sedimentation units present in cycle 1 show an average thickness of 0.38 m. Waning depletive sedimentation units are the dominant type (61%), followed by waning uniform (22%), and finally steady depletive and waxing depletive sedimentation units (8.5%). The high proportion of waning depletive sedimentation units record lower

energy conditions of the channel margin sedimentation region. Structureless, plane-parallel laminated, asymmetric ripple-cross-laminated, and wavy-laminated sandstone facies comprise 84% of the thinly-bedded event beds documented in complex 1. Complex 1 contains the most restricted grain-size population containing dominantly medium to very-fine grained sandstone and siltstone. It should also be noted that channel remnant bodies, while present in outcrop, were not recorded in measured section data and thus sedimentation unit and facies data are highly biased toward inactive channel bodies in this complex.

Cycle 2

Channel complex 2 is offset 143 m to the south and records more active sedimentation. This cycle has moderate data quality with two measured sections and good outcrop exposure. This complex is intermediate in width (398 m) and aspect ratio (26.5), contains the second fewest bodies (18) with four different body types (Fig. 27). This complex contains the only lobeform body present in the study area representing the channel flank sedimentation region.

The 62 sedimentation units composing cycle 2 have an average thickness of 0.46 m. Sedimentation units are almost evenly split between waning uniform (42%) and waning depletive (58%). When compared to the channel margin region of channel complex 1, the high proportions of waning uniform sedimentation units record the higher energy conditions of a channel axis sedimentation region. Additionally, this channel complex records the first occurrence of mudstone breccia and a high percentage of

muddy sandstone (18%) compared to wavy-laminated sandstone (2%) recording an increase in energy relative to cycle 1 strata.

Cycle 3

Channel complex 3 is the southernmost complex of the channel fairway system. Complex 3 is offset 1409 m from complex 2 and represents the most active channel system in the fairway. Continuous and easily accessible outcrop provide good data quality recorded by six measured sections. Complex 3 is intermediate in width (330 m) and aspect ratio (15), contains the most elementary bodies (34), as well as the highest number of channel-base drapes (11) and channel remnants (5). Multiple channel-base drapes combine to form a complex drape on the southern margin of the channel complex. The complex drape, as well as numerous channel remnant bodies, provides evidence for bypass of sediment during the creation of an outsized erosional depression.

The 124 sedimentation units present in cycle 3 have an average thickness of 0.46 m. Waning depletive sedimentation units are the dominant type (52%), followed by waning uniform (29%), and minor steady depletive (7%), waning accumulative (6%), and waxing depletive (6%) sedimentation units. The high proportion of waning depletive sedimentation units document low-energy conditions recorded in the channel margin region of the channel complex. Cycle 3 strata have the highest facies diversity with 16 of the 20 sedimentary facies recognized. Additionally, cycle 3 strata contain the largest proportion of thick-bedded sedimentation units containing inclined-stratified pebble-to-granule sandstone, scour-and-fill sandstone, and mudstone intraclast conglomerate. These sedimentation units record event beds in the channel axis sedimentation region. Average

grain size increases northward from the southern margin of channel complex 3 reaching a maximum in the mudstone breccia and clast-supported pebble-granule conglomerate of composite channel 3.4, which decreases to the top of composite channel 3.6.

Cycle 4

Cycle 4 is represented by channel complex 4 and is the youngest channel complex in channel fairway. This complex records change from bypass to deposition resulting in aggradation and filling of the channel axis. Continuous outcrop exposure is limited by near vertical cliff faces that make detailed study difficult. Two sections were measured in cycle 4 strata.

Cycle 4 strata form the largest channel complex with a width of 890 m and an aspect ratio of 44.5. Unlike the older channel complexes, the composite channel stacking is dominantly multistory. This complex contains the second highest number of elementary bodies, the majority of which are active channel bodies (14) with only one inactive channel body recognized. The channel flank sedimentation region is represented by the northern margin of the channel complex. The region contains a composite wedgeform body interpreted as a channel levee complex. The channel margin region is recorded by multiple drape bodies that combine to form a complex drape body on the southern margin of the channel complex. The complex drape is evidence for the creation of an outsized depression, but unlike complex 3, the dominant mode of channel filling is thick-bedded stratified and unstratified sedimentation units (Fig. 27).

The 29 sedimentation units recognized in cycle 4 strata have an average thickness of 0.56 m. Waning depletive flow is the dominant sedimentation unit type (45%) followed

by waning uniform flow (24%). Cycle 4 strata have moderate facies diversity represented by 12 of the 20 process facies. Cycle 4 contains the lowest proportion of fine-grained facies, which also reflects the dominance of thick-bedded sedimentation units in the axis of the channel complex (Fig. 27).

Deep-water Stratigraphic Models

Stratigraphic models are used to predict sedimentary architecture. Application of a stratigraphic model requires understanding the process-response relationships that define change within the system. Important attributes include thickness, lithology, and sedimentary body type, which define energy phases in system evolution. Energy changes within the sedimentary system are driven by internal, or autogenic, and external, or allogenic, controls (Gardner et al., 2008).

Sedimentation generates topography, which causes deposition to compensate and spatially shift sedimentation to a new site. This transforms active sites of sedimentation to inactive ones, creating a repetitive pattern of sedimentation internal to regions and forming autogenic cycles. In deep-water systems, autogenic cycles can be generated by the retrogressive failure of slumps, the lateral offset and compensational stacking of lobes, channel switching, migration, and avulsion, and longitudinal translation of the channel-lobe transition zone (Gardner et al., 2008).

Allogenic cycles are generated in response to modulation of external controls, namely eustasy, climate, and tectonic movements. While the discrete contribution from any one

of these controls is difficult to establish, the overall response of the system energy is also characterized by the hierarchy of sedimentary attributes (Gardner et al. 2008).

Two stratigraphic models, derived from outcrop studies of the Brushy Canyon Formation in west Texas, describe allogenic and autogenic controls on deep-water sedimentation. The architecture of channel and channel-related bodies reflects diachronous episodes of autogenic sedimentation described by the Build-Cut-Fill-Spill stratigraphic model (Fig. 31) (Gardner and Borer, 2000; Gardner et al., 2003). These sedimentation phases generate a lobe-channel-lobe architecture that vary in proportion and arrangement along the longitudinal profile.

The Build-Cut-Fill-Spill model explicitly incorporates sedimentation patterns associated with longitudinal migration of the channel-lobe transition zone. Channel migration, switching and avulsion describe lateral shifts in channel sites in response to depositional topography produced by longitudinal shifts in sedimentation. Sediment gravity flows are focused down a high profile gradient, with cut and fill phases dominant. Reoccupation or limited lateral offset of the channel reflect continued deepening and enlargement of the depression (Gardner and Borer, 2000; Gardner et al., 2003).

The Build-Cut-Fill-Spill model is embedded within the Adjustment-Initiation-Growth-Retreat (AIGR) model that describes large-scale allogenic controls on sedimentation, emphasizing the correlation of temporal phases in sedimentary system energy across a sedimentary basin (Gardner et al., 2008). For complete reviews on the Build-Cut-Fill-Spill and the Adjustment-Initiation-Growth-Retreat model, the reader is referred to Gardner and Borer (2000) and Gardner et al. (2003, 2008).

Application to the Capistrano Formation

Cycle 1 through 4 channel complexes are interpreted to represent a complete allogenic energy cycle. Cycle 1 and 2 represent the initiation phase reflecting the establishment of a channel fairway (cycle 1) and the creation of increasingly effective bypass (cycle 2). The cycle 3 channel complex represents the growth phase where the slope becomes a site of active bypass, when channels extend their reach into the basin (Gardner et al, 2008). This phase also contains the most composite channels and presumably, before erosion by cycle 4, would have formed the largest confined channel complex in the fairway. Finally, cycle 4 represents the retreat phase, when the upper slope becomes the depositional site on a high-gradient position in the system (Gardner et al., 2008). This is represented in cycle 4 by the dominance of thick-bedded structureless sandstone and the multistory stacking of elementary and composite channels.

Composite channels represent autogenic cycles of the Build-Cut-Fill-Spill model. Each channel is the record of a cut and fill phase of sedimentation. Lack of build phase reflects a high-gradient position dominated by sediment bypass. Lack of a spill phase reflects continued focus of sedimentation down a high gradient channel course. Cut and fill phases represent continued focus of sedimentation with limited lateral offset, which requires a high degree of confinement. Cut phases generate outsized erosional depressions promoting channel reoccupation of the same site. This leads to complex channel margins composed of remnant channel bodies and composite siltstone drapes. Fill phases generate more fully preserved sand-rich channel elements with fewer channel remnants, basal lags and fine-grained drapes (Gardner et al., 2008).

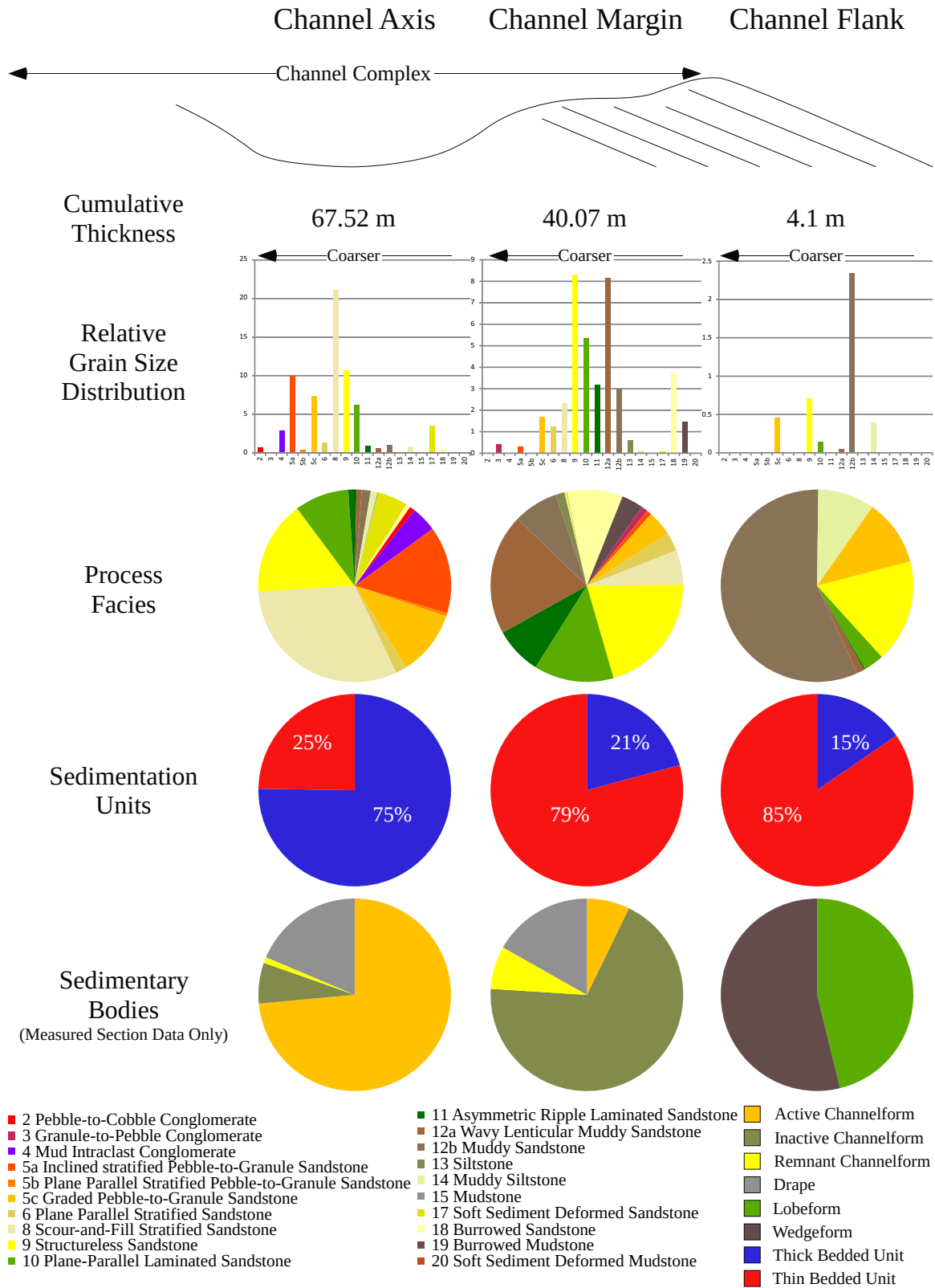
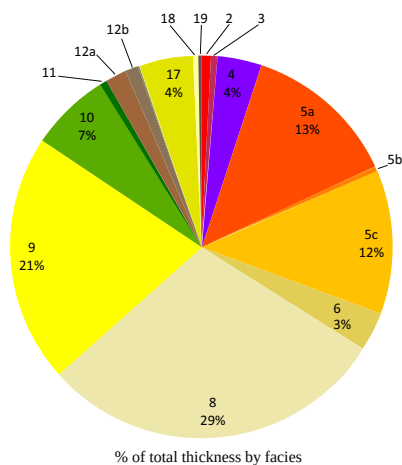


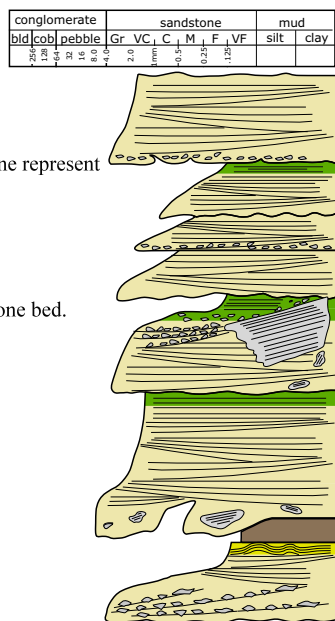
Figure 28. Plots of relative grain size, process facies, and sedimentary body proportions classified by sedimentation region within the channel fairway.

Channel Axis Region

- Thick bedded sandstone.
- Mudstone intraclasts at various positions in a bed.
- Thin, laterally discontinuous packages of muddy sandstone represent simple channel drapes.
- Amalgamated and erosive contacts are common.
- Carbonaceous material distributed throughout the sandstone bed.



- 2 Pebble-to-Cobble Conglomerate
- 3 Granule-to-Pebble Conglomerate
- 4 Mud Intraclast Conglomerate
- 5a Inclined stratified Pebble-to-Granule Sandstone
- 5b Plane Parallel Stratified Pebble-to-Granule Sandstone
- 6 Plane Parallel Stratified Sandstone
- 8 Scour-and-Fill Stratified Sandstone
- 9 Structureless Sandstone
- 10 Plane-Parallel Laminated Sandstone
- 11 Asymmetric Ripple Laminated Sandstone
- 12a Wavy Lenticular Muddy Sandstone
- 12b Muddy Sandstone
- 13 Siltstone
- 14 Muddy Siltstone
- 15 Mudstone
- 17 Soft Sediment Deformed Sandstone
- 18 Burrowed Sandstone
- 19 Burrowed Mudstone
- 20 Soft Sediment Deformed Mudstone



Channel Margin Region

- Thin bedded sandstone and muddy sandstone.
- Mudstone intraclasts at the bed base when present.
- Thick, continuous packages of muddy sandstone representing complex channel drapes.
- Sharp and gradational contacts are common.
- Carbonaceous material concentrated at bed caps.

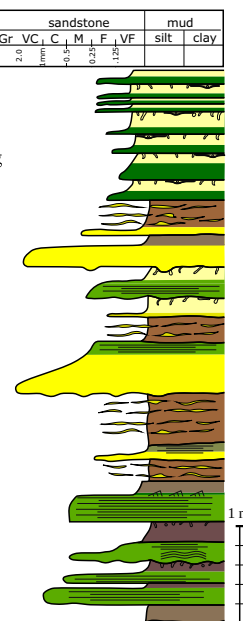
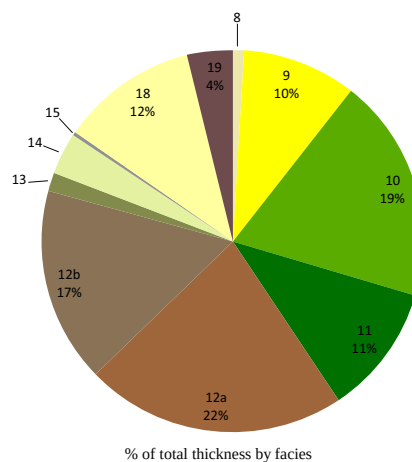


Figure 29. Channel axis and channel margins are recorded by thick- and thin-bedded facies successions respectively. A representative sedimentological section is presented for each region. Pie charts show relative percentage of component facies

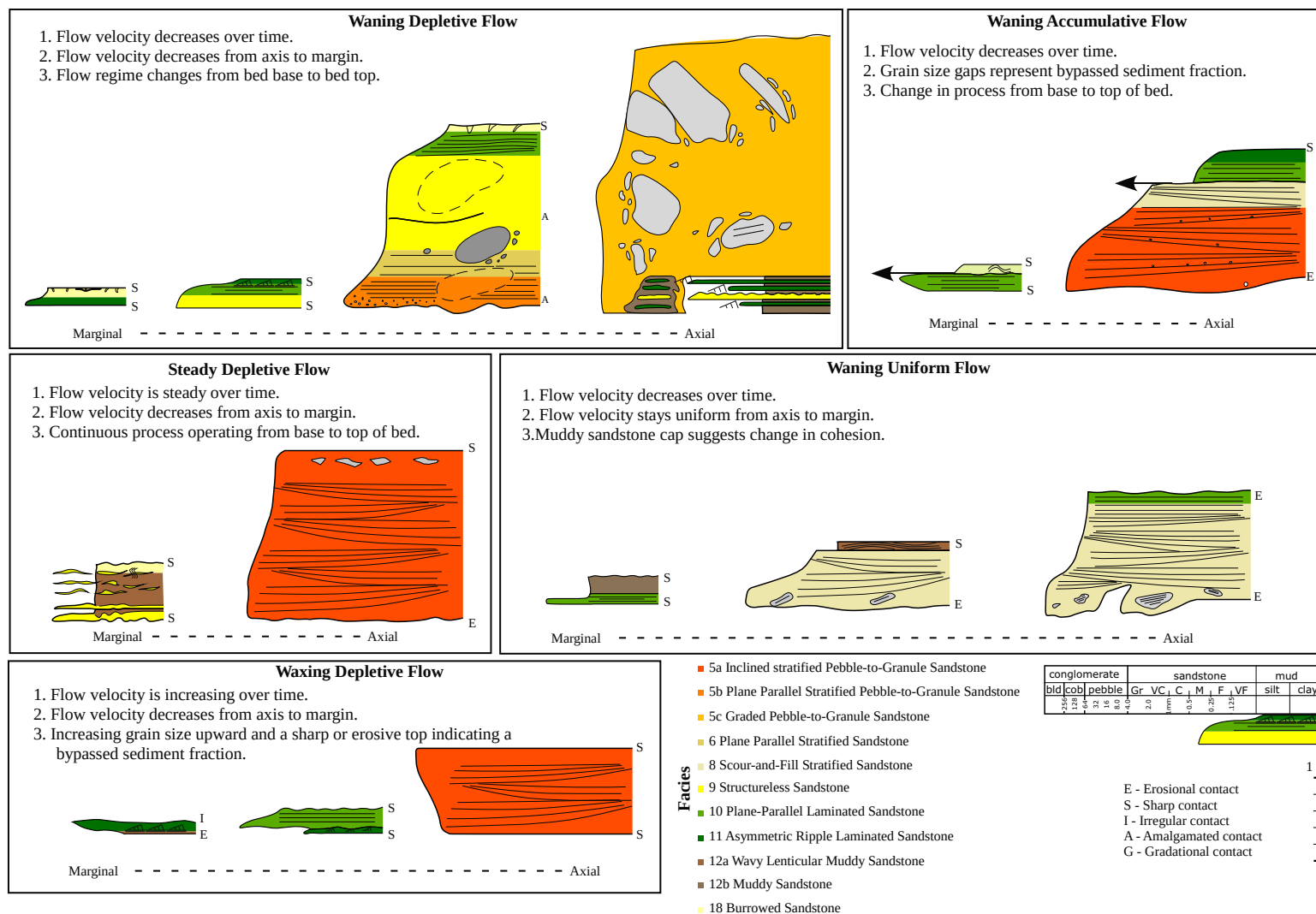


Figure 30. Spectrum of facies comprising sedimentation units deposited by various flow types in the Capistrano Formation from the channel axis to channel margin region of an open channel.

Cross Sectional View and Description

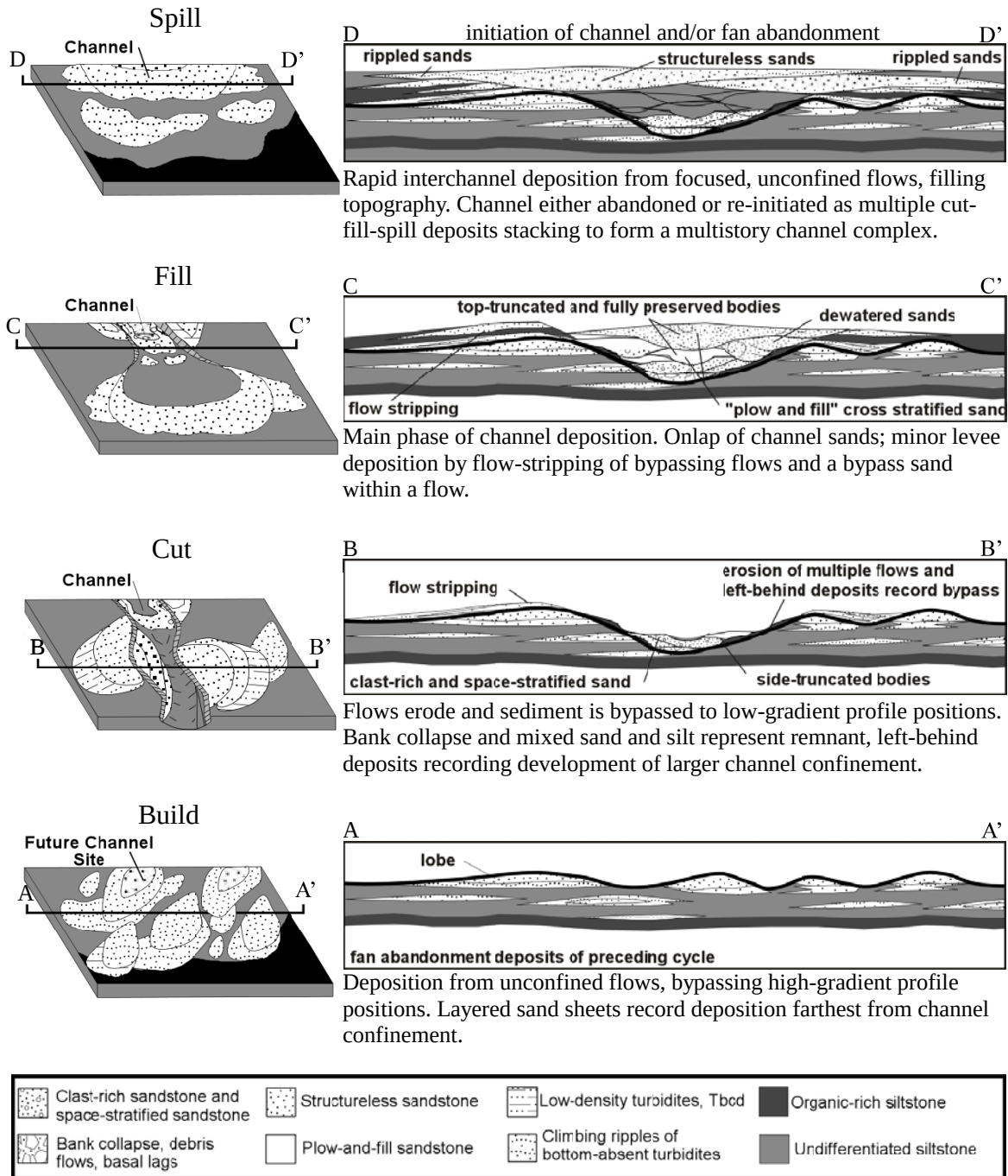


Figure 31. This diagram shows the Build, Cut, Fill, Spill (BCFS) phases through the evolution of a single-story channel. These domains relate variable confinement to the probable facies recording depositions from a region within a series of related flows and their contribution to channel, wedge and lobe sedimentary bodies. Repetition of these phases as multiple single-story channel fills stack to form composite channels and channel complexes. Modified after Gardner and Borer (2000).

CONCLUSIONS

Sedimentology

Eleven sedimentological sections, totaling 126 m, were measured and correlated to continuous photo panels of the ~2 km long coastal sea cliff of the Capistrano Formation. Sixteen primary sedimentary facies record the spectrum of primary depositional processes at deposition of a multipartite sediment gravity flow. Five sedimentary facies were found to be the most significant in proportion and occurrence across the outcrop. In order of increasing energy they include: (1) bioturbated sandstone, (2) muddy sandstone, (3) scour-and-fill cross-stratified sandstone, (4) pebble-to-granule sandstone, and (5) mudstone intraclast breccia. These facies reflect the variation in flow concentration, viscosity, and turbulence recorded in sedimentation units of the Capistrano Formation. The 239 sedimentation units represent turbidite event beds, which average 0.46 m in thickness. The complete spectrum of the flow acceleration matrix defines sedimentation units suggesting the control on event bed thickness is a function of lateral variability from the axis to the margin of sediment gravity flows with flow pathways parallel to the channel axis.

Sedimentary Bodies

Four basic sedimentary body types are recognized and represent varying degrees of flow confinement. Channelform bodies and drapes record confined flow, wedgeform bodies record partially confined flow, and lobeform bodies record unconfined flow.

Channelforms and drapes were subdivided to capture the key elements describing the channel architecture.

Channelforms are divided into active, inactive, and remnant channel types. Active channelform bodies contain dominantly thick-bedded sedimentation units representing the preserved remnants of the channel thalweg deposits. Inactive channelform bodies contain dominantly thin-bedded sedimentation units representing decreased flow activity and/or lateral movement of the depositional site. Remnant channelform bodies are the erosional remnants of active or inactive channelform bodies and record reincision of channel sites.

Drape bodies are laterally continuous fine-grained drapes that line erosional surfaces at the base of channel fills at multiple scales. Drape bodies are divided into three classes based on their relationship to the channel hierarchy, degree of bioturbation, and facies. Simple drapes represent frictional freezing of fine-grained material from the turbulent tail and wake of bypassing sediment gravity flow onto the channel margin. Composite drapes consist of a mixture of hemipelagic and tractive deposits resulting from the interaction of multiple sediment gravity flows with the channel margin. Complex drapes also contain both hemipelagic and tractive deposits recording multiple episodes of channelization.

Stratigraphy

The Capistrano Formation lithosome represents a single upper-slope channel fairway containing four offset stacked channel complexes. Each channel complex

contains up to six composite channels and drapes, typically with a complex drape bounding the channel complex. Composite channels initially stack multilateral during expansion of the channel width, and then they stack vertically as the channel site fills and plugs. This represents the evolution of an open, sinuous channel system to one that is backfilling and plugging.

Three sedimentation regions are defined by a hierarchy of sedimentary attributes that includes sedimentary facies, sedimentation units, and sedimentary bodies and their bounding surfaces. The channel axis region is characterized by thick-bedded sedimentation units of low diversity filling multilateral and multistory active channel bodies. The channel margin region is characterized by thin-bedded sedimentation units of higher diversity filling multilateral inactive and remnant channelform and drape bodies. The channel flank region is characterized by thin-bedded sedimentation units of low diversity filling multistory wedgeform bodies, as well as thin- and thick-bedded sedimentation units of high diversity filling lobeform bodies.

The evolution of the channel fairway records a combination of internal (autogenic) and external (allogenic) controls that explain lateral changes in channel complex architecture. The Adjustment-Initiation-Growth-Retreat (AIGR) and Build-Cut-Fill-Spill (BCFS) models of Gardner and Borer (2000) and Gardner et al. (2003, 2008) describe stratigraphic modulation of patterns at the basin and channel scales, respectively. The four channel complexes are correlated to a complete allogenic cycle of sedimentation with the initiation phase represented by channel complexes 1 and 2, the growth phase represented by channel complex 3, and the retreat phase represented by channel complex

4. Composite channels represent autogenic cycles of sedimentation where each composite channel records a cut and fill phase of sedimentation. The cut phase is recorded by complex channel margins composed of remnant channel bodies and siltstone drapes. The fill phase is recorded by more fully preserved sand-rich channel elements with fewer channel remnants, basal lags, and fine-grained drapes. Lack of build and spill phases reflect continued focus of sedimentation down the high-gradient channel course.

Future Work

The results of this study have identified five key areas for future work. These include:

- 1) Collection of additional measured section data from outcrop segment C to add more sedimentological control on the early phases of sedimentation.
- 2) Dimensional comparison of the Capistrano Formation architecture with systems of varying lithology and size to better understand the dimensional data documented in this study.
- 3) Detailed SEM and XRD analysis of slope and channel drape mudstones to better constrain composition and depositional fabric and possible their links to primary sedimentary processes;
- 4) Behind-outcrop coring or collection of ground penetrating radar data to add more three-dimensional control to the outcrop surfaces.
- 5) Additional investigation of how outcrops segments A, B, and C relate to the entire 725 m thickness of the Capistrano Formation.

This study analyzed LIDAR data collected by previous work and found that it didn't significantly improve description of the exposed sedimentary architecture. The addition of outcrop segments B and C does better constrain correlations and age relationships of the four complexes comprising this sandstone lithosome.

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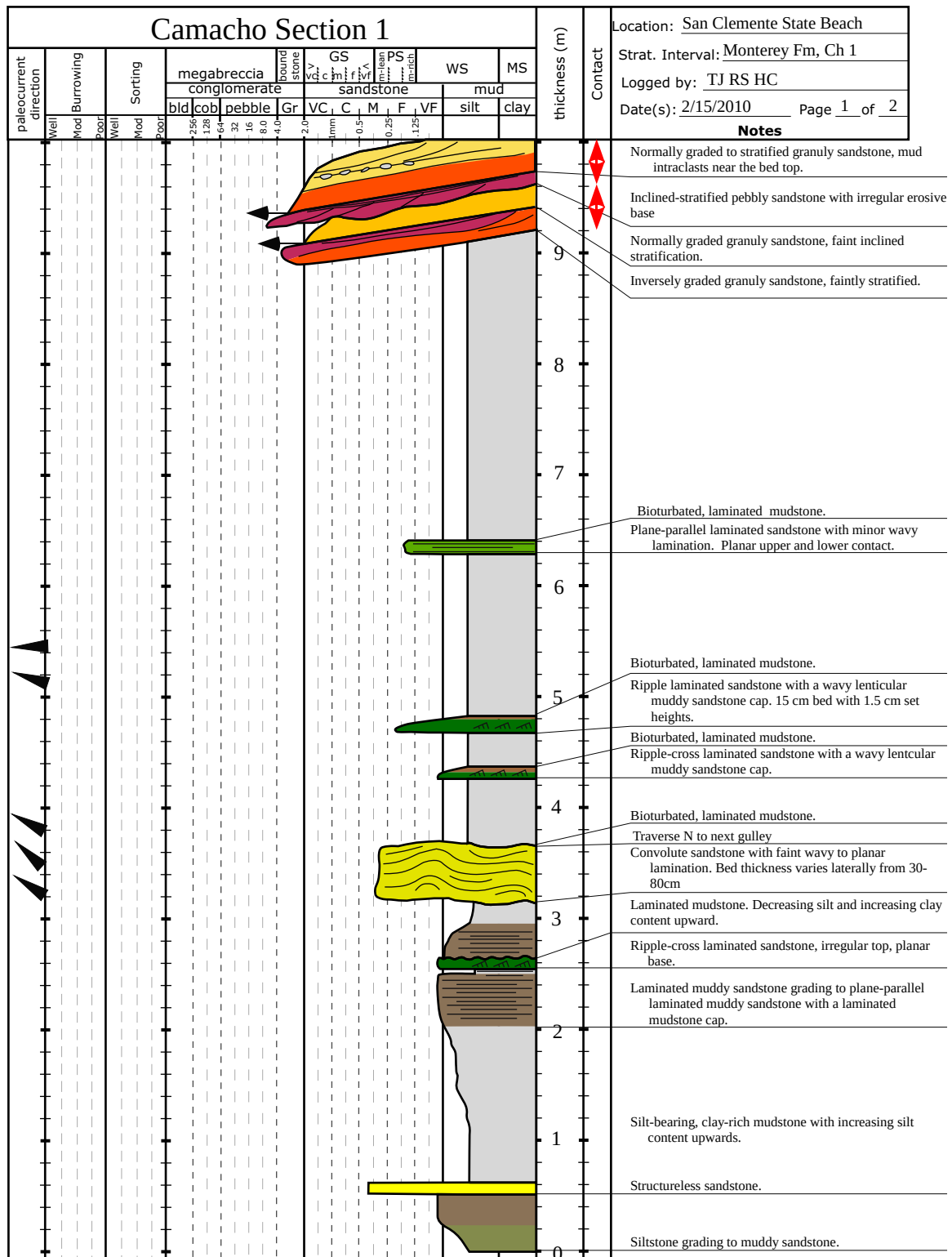
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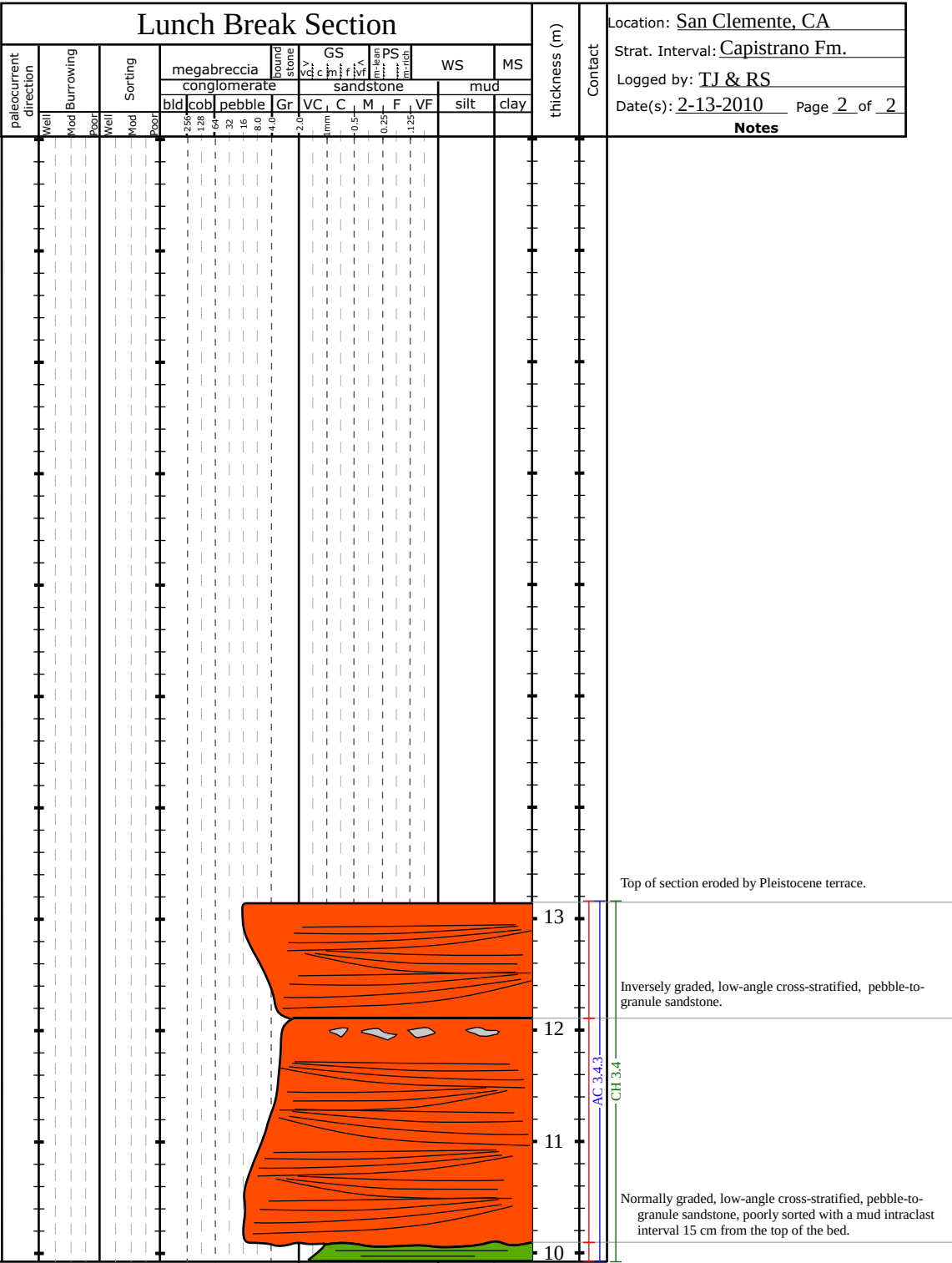
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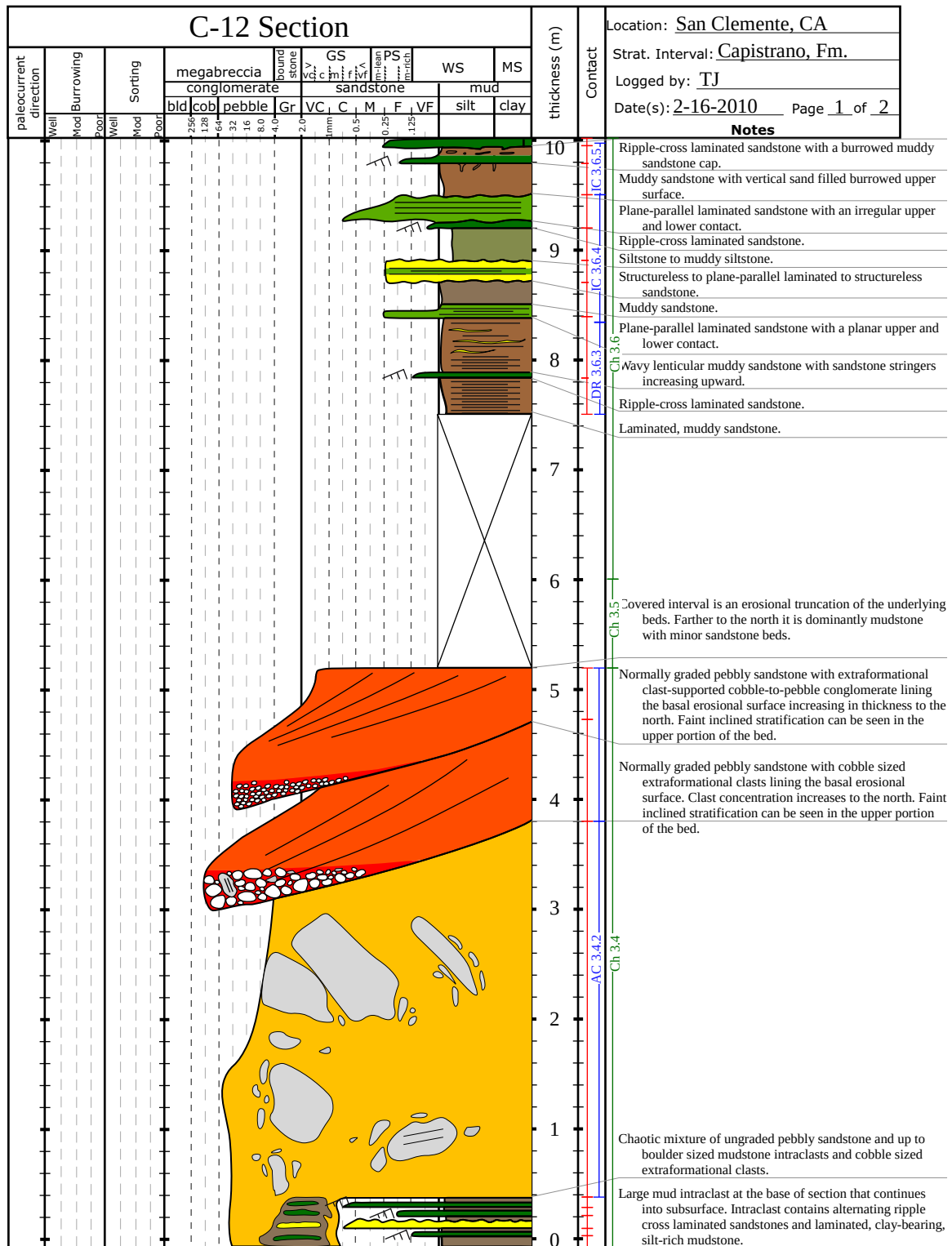
APPENDICES

APPENDIX A

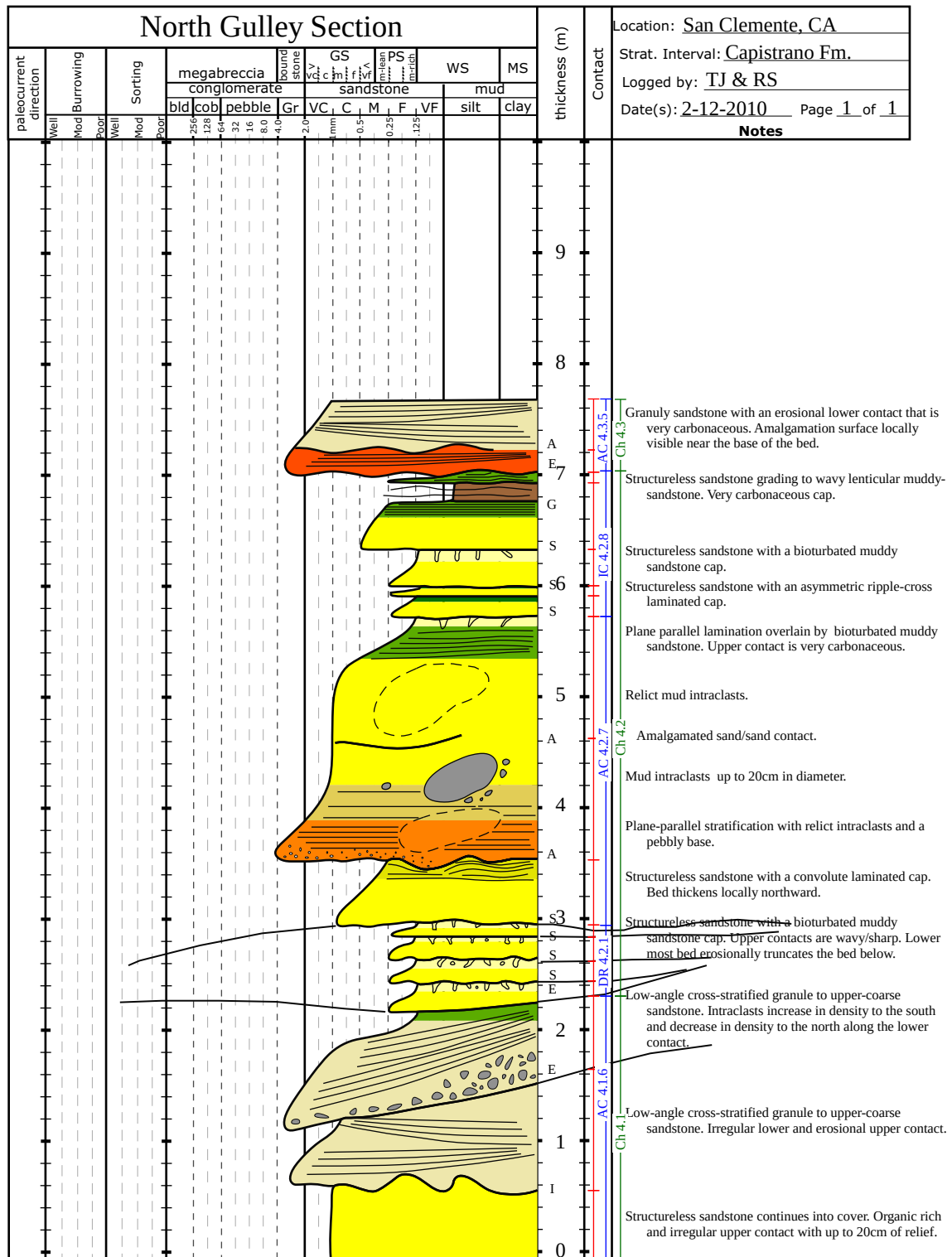
MEASURED SEDIMENTOLOGICAL SECTIONS

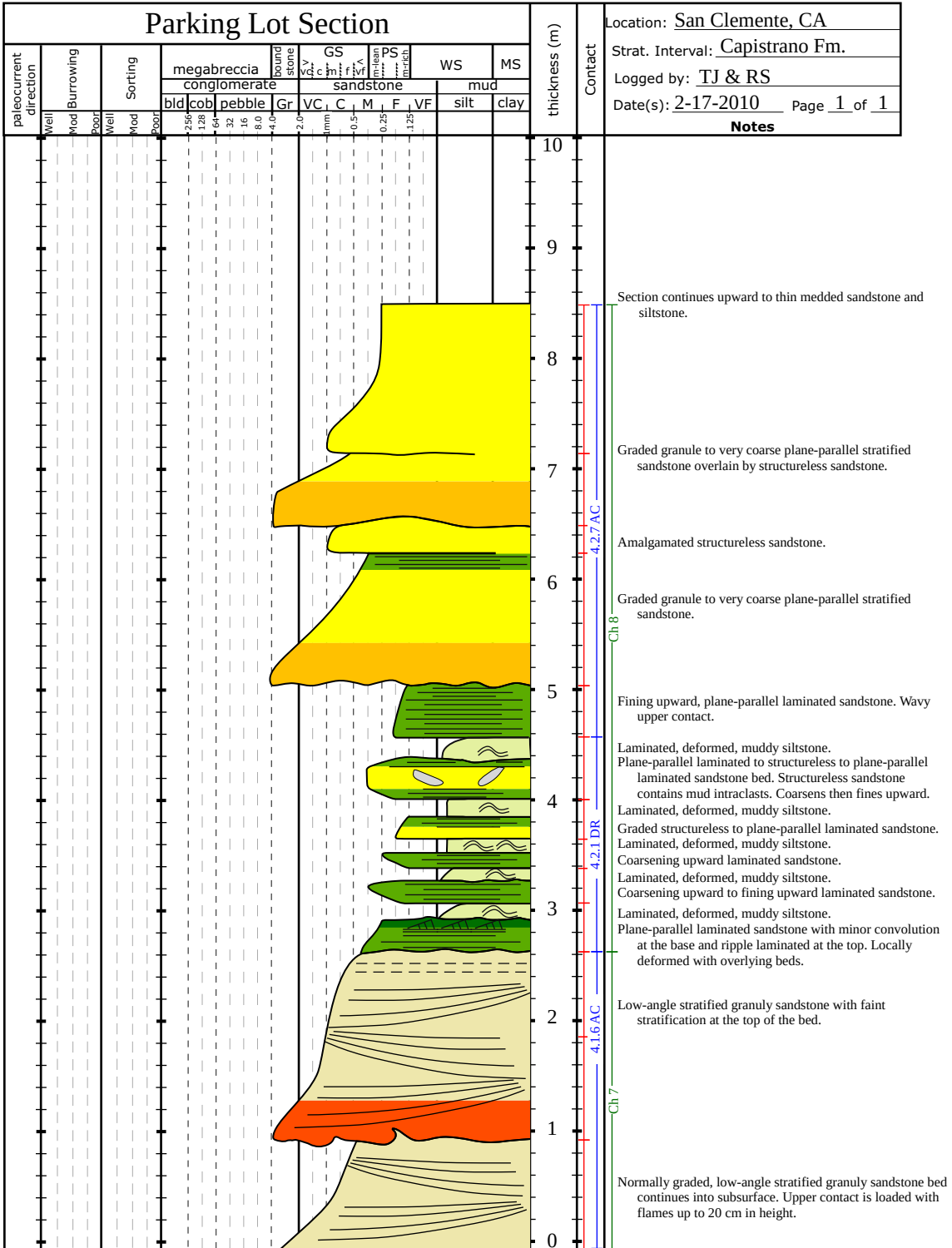


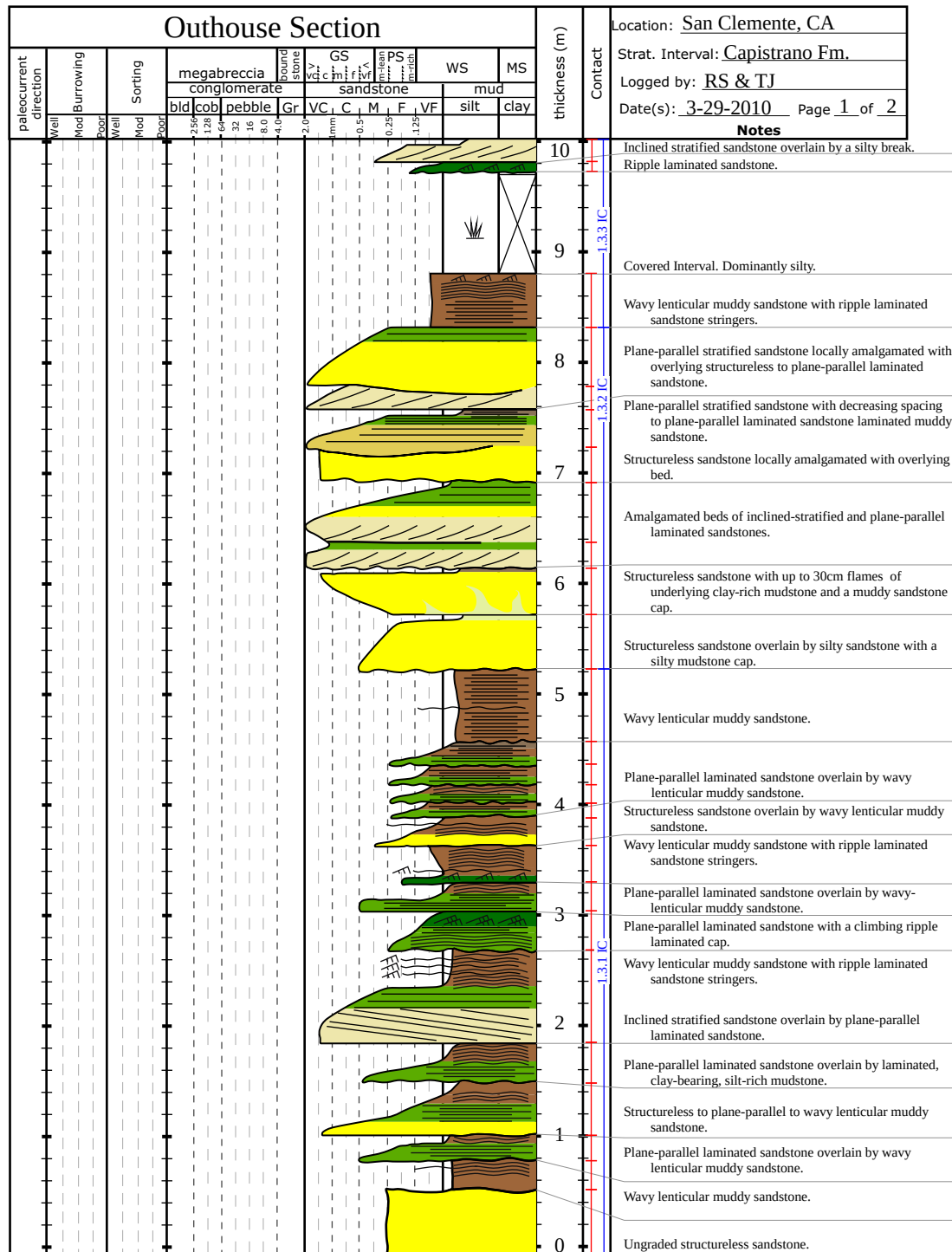




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APPENDIX B

SEDIMENTATION UNIT DATA

Appendix B. Part one of the table of sedimentation units recorded in measured sedimentological sections of the Capistrano lithosome.

Complex #	Channel #	Sed Body Hierarchy	Sed Body Type	Thick Thin	Unit Type	Sed Region	Section Name	Sed Unit Height	Facies Thickness																			
									2	3	4	5a	5b	5c	6	8	9	10	11	12a	12b	13	14	15	17	18	19	20
1	3	1.3.1	IC	Tk	Wan Dep	Margin	Outhouse	0.58										0.58										
1	3	1.3.1	IC	Tn	Ste Dep	Margin	Outhouse	0.27												0.27								
1	3	1.3.1	IC	Tn	Wan Dep	Margin	Outhouse	0.22										0.14		0.08								
1	3	1.3.1	IC	Tn	Wan Dep	Margin	Outhouse	0.48										0.12	0.17		0.19							
1	3	1.3.1	IC	Tn	Wan Dep	Margin	Outhouse	0.35											0.18		0.17							
1	3	1.3.1	IC	Tn	Wan Uni	Margin	Outhouse	0.84								0.32		0.2		0.32								
1	3	1.3.1	IC	Tn	Wan Dep	Margin	Outhouse	0.34										0.2	0.14									
1	3	1.3.1	IC	Tn	Wan Dep	Margin	Outhouse	0.26											0.16		0.1							
1	3	1.3.1	IC	Tn	Wan Dep	Margin	Outhouse	0.33												0.06	0.27							
1	3	1.3.1	IC	Tn	Wan Dep	Margin	Outhouse	0.26										0.1			0.16							
1	3	1.3.1	IC	Tn	Wan Dep	Margin	Outhouse	0.14											0.07		0.07							
1	3	1.3.1	IC	Tn	Wan Dep	Margin	Outhouse	0.15											0.08		0.07							
1	3	1.3.1	IC	Tn	Wan Dep	Margin	Outhouse	0.17											0.07		0.1							
1	3	1.3.1	IC	Tn	Wan Dep	Margin	Outhouse	0.22											0.08		0.08	0.06						
1	3	1.3.1	IC	Tn	Ste Dep	Margin	Outhouse	0.65													0.65							
1	3	1.3.2	IC	Tk	Wan Dep	Margin	Outhouse	0.49										0.44						0.05				
1	3	1.3.2	IC	Tk	Wax Dep	Margin	Outhouse	0.42										0.38			0.04							
1	3	1.3.2	IC	Tk	Wan Uni	Margin	Outhouse	0.23									0.16		0.07									
1	3	1.3.2	IC	Tk	Wan Uni	Margin	Outhouse	0.54									0.23	0.1	0.21									
1	3	1.3.2	IC	Tk	Wax Dep	Margin	Outhouse	0.3										0.3										
1	3	1.3.2	IC	Tk	Wan Uni	Margin	Outhouse	0.35						0.21					0.09		0.05							
1	3	1.3.2	IC	Tk	Wan Uni	Margin	Outhouse	0.22								0.22												
1	3	1.3.2	IC	Tk	Wan Dep	Margin	Outhouse	1.01										0.39	0.13		0.49							
2	0	2.0.1	LV	Tn	Wan Dep	Flank	Volleyball	0.16													0.16							
2	0	2.0.1	LV	Tn	Wan Dep	Flank	Volleyball	0.09										0.07			0.02							
2	0	2.0.1	LV	Tn	Wan Dep	Flank	Volleyball	0.51													0.51							
2	0	2.0.1	LV	Tn	Wan Dep	Flank	Volleyball	0.2										0.17			0.03							
2	0	2.0.1	LV	Tn	Wan Dep	Flank	Volleyball	0.38													0.38							
2	0	2.0.2	LB	Tk	Wan Dep	Flank	Volleyball	0.27						0.27														
2	0	2.0.2	LB	Tk	Wan Dep	Flank	Volleyball	0.37						0.19				0.13		0.05								
2	0	2.0.2	LB	Tn	Wan Dep	Flank	Volleyball	0.24										0.09			0.15							
2	0	2.0.2	LB	Tn	Wan Dep	Flank	Volleyball	0.29										0.15	0.09				0.05					
2	0	2.0.2	LB	Tn	Wan Uni	Flank	Volleyball	0.15											0.05		0.1							
2	0	2.0.2	LB	Tn	Wan Dep	Flank	Volleyball	0.1										0.1										
2	0	2.0.3	LV	Tn	Wan Dep	Flank	Volleyball	0.99													0.99							
2	0	2.0.3	LV	Tn	Wan Dep	Margin	Volleyball	0.35												0.01			0.34					
2	2	2.2.2	IC	Tn	Wan Uni	Margin	Volleyball	0.14											0.05		0.09							
2	2	2.2.2	IC	Tn	Wan Dep	Margin	Volleyball	0.12											0.05		0.07							
2	2	2.2.2	IC	Tn	Wan Uni	Margin	Volleyball	0.18													0.18							
2	2	2.2.2	IC	Tn	Wan Dep	Margin	Volleyball	0.1												0.07	0.03							
2	2	2.2.2	IC	Tn	Wan Uni	Margin	Volleyball	0.19														0.19						
2	2	2.2.2	IC	Tn	Wan Uni	Margin	Volleyball	0.27											0.1		0.17							
2	2	2.2.2	IC	Tn	Wan Uni	Margin	Volleyball	0.14											0.12		0.02							
2	2	2.2.2	IC	Tn	Wan Uni	Margin	Volleyball	0.11											0.09		0.02							
2	2	2.2.2	IC	Tn	Wan Uni	Margin	Volleyball	0.18													0.18							
2	2	2.2.2	IC	Tn	Wan Dep	Margin	Volleyball	0.15										0.1		0.05								
2	2	2.2.2	IC	Tk	Wan Dep	Margin	Volleyball	0.74										0.61	0.04	0.04	0.05							
2	2	2.2.2	IC	Tn	Wan Uni	Margin	Volleyball	0.14											0.09		0.05							

Appendix B. Part two of the table of sedimentation units recorded in measured sedimentological sections of the Capistrano lithosome.

Complex #	Channel #	Sed Body Hierarchy	Sed Body Type	Thick Thin	Unit Type	Sed Region	Section Name	Sed Unit Height	Facies Thickness																			
									2	3	4	5a	5b	5c	6	8	9	10	11	12a	12b	13	14	15	17	18	19	20
2	2	2.2.2	IC	Tn	Wan Uni	Margin	Volleyball	0.18									0.07			0.11								
2	2	2.2.2	IC	Tn	Wan Uni	Margin	Volleyball	0.13									0.08			0.05								
2	3	2.2.3	AC	Tk	Wan Uni	Margin	Volleyball	0.36								0.36												
2	3	2.2.3	AC	Tk	Wan Uni	Margin	Volleyball	0.9								0.79										0.11		
2	3	2.2.3	AC	Tk	Wan Dep	Margin	Volleyball	0.38									0.21							0.08		0.09		
2	3	2.2.3	AC	Tk	Wan Uni	Margin	Volleyball	0.5						0.5														
2	3	2.2.3	AC	Tk	Wan Uni	Margin	Volleyball	0.55						0.55														
2	3	2.2.3	AC	Tk	Wan Dep	Margin	Volleyball	1.23									1.02			0.21								
2	3	2.2.3	AC	Tn	Wan Dep	Margin	Volleyball	0.13									0.08			0.05								
2	3	2.2.3	AC	Tn	Wan Dep	Margin	Volleyball	0.22									0.07			0.15								
2	3	2.2.3	AC	Tk	Wan Dep	Margin	Volleyball	0.75									0.54	0.1	0.07	0.04								
2	3	2.3.4	AC	Tk	Wan Uni	Axis	Guardhouse	0.55								0.55												
2	3	2.3.4	AC	Tk	Wan Uni	Axis	Guardhouse	0.79			0.29					0.5												
2	3	2.3.4	AC	Tk	Wan Dep	Axis	Guardhouse	0.56																0.56				
2	3	2.3.5	AC	Tk	Wan Uni	Axis	Guardhouse	0.78								0.78												
2	3	2.3.5	AC	Tk	Wan Dep	Axis	Guardhouse	0.97								0.42												
2	3	2.3.5	AC	Tk	Wan Dep	Axis	Guardhouse	1.73								0.43				0.19				1.11				
2	3	2.3.6	AC	Tk	Wan Uni	Axis	Guardhouse	0.47			0.23					0.24												
2	3	2.3.6	AC	Tk	Wan Uni	Axis	Guardhouse	0.42								0.42												
2	3	2.3.6	AC	Tk	Wan Uni	Axis	Guardhouse	0.65								0.65												
2	3	2.3.6	AC	Tk	Wan Uni	Axis	Guardhouse	0.91								0.62		0.15		0.13								
2	3	2.3.6	AC	Tk	Wan Uni	Axis	Guardhouse	0.6										0.33		0.27								
2	3	2.3.6	AC	Tk	Wan Uni	Axis	Guardhouse	0.44										0.28		0.16								
2	3	2.3.6	AC	Tk	Wan Dep	Axis	Guardhouse	0.46										0.37						0.09				
2	4	2.2.4	DR	Tn	Wan Dep	Margin	Volleyball	0.26																		0.26		
2	4	2.2.4	DR	Tn	Wan Dep	Margin	Volleyball	0.19																		0.19		
2	4	2.2.4	DR	Tn	Wan Dep	Margin	Volleyball	0.16																		0.16		
2	4	2.2.4	DR	Tn	Wan Dep	Margin	Volleyball	0.12																		0.12		
2	4	2.2.4	DR	Tn	Wan Dep	Axis	Volleyball	0.75												0.75								
2	5	2.4.3	AC	Tk	Wan Uni	Axis	Guardhouse	0.77								0.77												
2	5	2.4.3	AC	Tk	Wan Uni	Axis	Guardhouse	0.64								0.64												
2	5	2.4.3	AC	Tk	Wan Dep	Axis	Guardhouse	1.12									0.23							0.89				
2	5	2.4.3	AC	Tk	Wan Dep	Axis	Guardhouse	0.78									0.78											
2	5	2.4.4	AC	Tk	Wan Dep	Axis	Guardhouse	0.59									0.59											
2	5	2.4.4	AC	Tk	Wan Dep	Axis	Guardhouse	0.63									0.4	0.23										
2	5	2.4.4	AC	Tk	Wan Dep	Axis	Guardhouse	0.57									0.57											
2	5	2.4.4	AC	Tk	Wan Dep	Margin	Guardhouse	0.47									0.38			0.09								
3	1	3.1.1	CR	Tk	Wan Dep	Margin	Lifeguard Overlook	0.68									0.4	0.14								0.14		
3	1	3.1.1	CR	Tk	Wan Dep	Margin	South Path	0.7									0.6				0.1							
3	1	3.1.2	IC	Tn	Wan Dep	Margin	Lifeguard Overlook	0.29											0.21		0.08							
3	1	3.1.2	IC	Tn	Wan Dep	Margin	Lifeguard Overlook	0.43										0.1	0.17							0.16		
3	1	3.1.2	IC	Tn	Wan Dep	Margin	Lifeguard Overlook	0.39											0.2							0.19		
3	1	3.1.2	IC	Tn	Ste Dep	Margin	Lifeguard Overlook	0.69									0.18			0.42						0.09		
3	1	3.1.2	IC	Tn	Ste Dep	Margin	Lifeguard Overlook	0.33									0.15			0.11						0.07		
3	1	3.1.2	IC	Tn	Wan Dep	Margin	Lifeguard Overlook	0.4											0.11	0.2						0.09		
3	1	3.1.2	IC	Tn	Wan Dep	Margin	Lifeguard Overlook	0.2											0.08							0.12		
3	1	3.1.2	IC	Tn	Wan Dep	Margin	Lifeguard Overlook	0.22											0.04							0.18		
3	1	3.1.2	IC	Tn	Wan Dep	Margin	Lifeguard Overlook	0.26											0.12							0.14		

Appendix B. Part three of the table of sedimentation units recorded in measured sedimentological sections of the Capistrano lithosome.

Complex #	Channel #	Sed Body Hierarchy	Sed Body Type	Thick Thin	Unit Type	Sed Region	Section Name	Sed Unit Height	Facies Thickness																			
									2	3	4	5a	5b	5c	6	8	9	10	11	12a	12b	13	14	15	17	18	19	20
3	1	3.1.2	IC	Tn	Ste Dep	Margin	Lifeguard Overlook	0.49									0.03										0.46	
3	1	3.1.2	IC	Tn	Wan Dep	Margin	Lifeguard Overlook	0.11										0.05	0.02							0.04		
3	1	3.1.2	IC	Tn	Wan Dep	Margin	Lifeguard Overlook	0.1										0.05	0.02							0.03		
3	1	3.1.2	IC	Tn	Wan Uni	Margin	South Path	0.27										0.2			0.07							
3	1	3.1.2	IC	Tn	Wan Uni	Margin	South Path	0.19										0.12								0.07		
3	1	3.1.2	IC	Tn	Wan Uni	Margin	South Path	0.14										0.07			0.07							
3	1	3.1.2	IC	Tk	Wan Dep	Margin	South Path	0.59									0.52		0.07									
3	1	3.1.3	CR	Tk	Wan Acc	Margin	Camacho Section 1	0.4		0.08		0.14		0.18														
3	1	3.1.3	CR	Tk	Wan Dep	Margin	Lifeguard Overlook	0.54		0.14				0.4														
3	1	3.1.3	CR	Tk	Wan Dep	Margin	Lifeguard Overlook	1.5		0.08				0.57			0.34	0.18		0.33								
3	1	3.1.3	CR	Tn	Wan Dep	Margin	Lifeguard Overlook	0.09									0.05			0.04								
3	1	3.1.4	CR	Tk	Wan Acc	Margin	Camacho Section 1	0.57		0.13		0.19				0.25												
3	1	3.1.4	CR	Tk	Wan Dep	Margin	Lifeguard Overlook	0.55						0.55														
3	2	3.2.1	DR	Tn	Wan Dep	Margin	Camacho Section 1	0.24												0.21							0.03	
3	2	3.2.1	DR	Tn	Wan Acc	Margin	Camacho Section 1	0.16												0.15							0.01	
3	2	3.2.1	DR	Tn	Wan Dep	Margin	Camacho Section 1	0.06														0.06						
3	2	3.2.1	DR	Tn	Wan Dep	Margin	Camacho Section 1	0.12												0.1							0.02	
3	2	3.2.1	DR	Tn	Wan Dep	Margin	Camacho Section 1	0.1												0.1								
3	2	3.2.1	DR	Tn	Wan Dep	Margin	Camacho Section 1	0.16																	0.08	0.08		
3	2	3.2.1	DR	Tn	Wan Acc	Margin	Camacho Section 1	0.46												0.14					0.07	0.25		
3	2	3.2.1	DR	Tn	Wan Acc	Margin	South Path	0.16													0.16							
3	2	3.2.2	IC	Tn	Wan Uni	Margin	South Path	0.23										0.18									0.05	
3	2	3.2.2	IC	Tn	Wan Uni	Margin	South Path	0.23										0.13									0.1	
3	2	3.2.2	IC	Tn	Wan Uni	Margin	South Path	0.2										0.2										
3	2	3.2.2	IC	Tn	Wan Dep	Margin	South Path	0.2																			0.2	
3	2	3.2.2	IC	Tn	Wan Uni	Margin	South Path	0.41										0.3	0.02		0.09							
3	2	3.2.3	DR	Tn	Ste Dep	Margin	South Path	0.22												0.22								
3	2	3.2.3	DR	Tn	Wan Dep	Margin	South Path	0.18									0.09				0.09							
3	2	3.2.3	DR	Tn	Ste Dep	Margin	South Path	0.55												0.55								
3	2	3.2.4	CR	Tk	Wan Dep	Margin	South Path	0.52									0.4	0.12										
3	2	3.2.5	DR	Tn	Ste Dep	Margin	South Path	0.28												0.28								
3	2	3.2.5	DR	Tn	Wan Dep	Margin	South Path	0.21									0.04									0.17		
3	2	3.2.6	IC	Tn	Wan Uni	Margin	South Path	0.31										0.19								0.12		
3	2	3.2.6	IC	Tn	Wan Dep	Margin	South Path	0.32									0.22				0.1							
3	2	3.2.6	IC	Tn	Ste Dep	Margin	South Path	0.36									0.1			0.26								
3	2	3.2.8	IC	Tn	Wan Dep	Margin	South Path	0.21											0.1							0.11		
3	2	3.2.8	IC	Tn	Wan Dep	Margin	South Path	0.27											0.18							0.09		
3	2	3.2.8	IC	Tn	Wan Dep	Margin	South Path	0.19											0.09							0.1		
3	2	3.2.8	IC	Tn	Wan Dep	Margin	South Path	0.23											0.08							0.15		
3	2	3.2.8	IC	Tn	Wan Dep	Margin	South Path	0.08											0.04							0.04		
3	2	3.2.8	IC	Tn	Wan Dep	Margin	South Path	0.06											0.03							0.03		
3	2	3.2.8	IC	Tn	Wan Dep	Margin	South Path	0.14											0.05							0.09		
3	2	3.2.8	IC	Tn	Wan Dep	Margin	South Path	0.15											0.09							0.06		
3	2	3.2.8	IC	Tn	Wan Dep	Margin	South Path	0.1											0.08							0.02		
3	2	3.2.8	IC	Tn	Wan Dep	Margin	South Path	0.22											0.11							0.11		
3	2	3.2.8	IC	Tn	Wan Dep	Axis	South Path	0.15											0.15									
3	3	3.3.1	CR	Tk	Wan Uni	Axis	South Path	0.74				0.61					0.08	0.07										
3	3	3.3.3	AC	Tn	Wan Dep	Axis	Lunch Break	0.33									0.14	0.14	0.05									

Appendix B. Part four of the table of sedimentation units recorded in measured sedimentological sections of the Capistrano lithosome.

Complex #	Channel #	Sed Body Hierarchy	Sed Body Type	Thick Thin	Unit Type	Sed Region	Section Name	Sed Unit Height	Facies Thickness																			
									2	3	4	5a	5b	5c	6	8	9	10	11	12a	12b	13	14	15	17	18	19	20
3	3	3.3.3	AC	Tn	Wan Dep	Axis	Lunch Break	0.2										0.17	0.03									
3	3	3.3.3	AC	Tn	Wan Dep	Axis	Lunch Break	0.39										0.26	0.13									
3	3	3.3.3	AC	Tn	Wan Dep	Axis	Lunch Break	0.22										0.22										
3	3	3.3.3	AC	Tn	Wan Dep	Axis	Lunch Break	0.21										0.16	0.05									
3	3	3.3.3	AC	Tk	Wan Uni	Axis	North Path	0.74				0.74																
3	3	3.3.3	AC	Tk	Wan Uni	Axis	North Path	0.65						0.39		0.26												
3	3	3.3.3	AC	Tk	Wan Uni	Axis	North Path	0.16								0.16												
3	3	3.3.4	AC	Tk	Wan Uni	Axis	South Path	1.56									0.97											
3	3	3.3.4	AC	Tk	Wan Uni	Axis	South Path	0.78								0.66									0.12			
3	3	3.3.4	AC	Tk	Wan Uni	Axis	Lunch Break	0.54				0.54																
3	3	3.3.4	AC	Tk	Wan Uni	Axis	Lunch Break	0.66				0.32				0.34												
3	3	3.3.4	AC	Tn	Wan Uni	Axis	Lunch Break	0.11												0.11								
3	3	3.3.4	AC	Tk	Wan Uni	Axis	Lunch Break	0.47				0.47																
3	3	3.3.5	AC	Tk	Wan Uni	Flank	South Path	0.56				0.45													0.11			
3	3	3.3.5	DR	Tn	Wan Acc	Axis	South Path	0.23													0.23							
3	3	3.3.6	AC	Tk	Wan Uni	Axis	South Path	1.48								1.35		0.13										
3	3	3.3.6	AC	Tk	Wan Uni	Axis	South Path	1.01								0.75		0.26										
3	3	3.3.6	AC	Tk	Wan Uni	Axis	Lunch Break	1.23			0.13	0.46				0.64												
3	3	3.3.6	AC	Tk	Wan Uni	Axis	Lunch Break	0.79								0.79												
3	3	3.3.7	AC	Tk	Wan Uni	Axis	South Path	0.47								0.47												
3	3	3.3.7	AC	Tk	Wan Uni	Axis	South Path	0.37								0.37												
3	3	3.3.7	AC	Tk	Wan Uni	Axis	South Path	0.55								0.43		0.12										
3	3	3.3.7	AC	Tn	Wax Dep	Axis	Lunch Break	0.15											0.12	0.03								
3	3	3.3.7	AC	Tk	Wan Dep	Axis	Lunch Break	0.84									0.67	0.17										
3	3	3.3.7	AC	Tk	Wan Dep	Axis	Lunch Break	0.8									0.62	0.18										
3	3	3.3.7	AC	Tk	Wan Dep	Axis	Lunch Break	0.27						0.27														
3	3	3.3.8	AC	Tk	Wan Uni	Axis	South Path	0.9								0.9												
3	3	3.3.9	AC	Tk	Wan Dep	Axis	South Path	0.86	0.23					0.63														
3	4	3.4.1	DR	Tb	Wan Uni	Axis	Lunch Break	0.1																0.1				
3	4	3.4.1	DR	Tk	Wan Dep	Axis	Lunch Break	0.97				0.53		0.44														
3	4	3.4.1	DR	Tk	Wan Dep	Axis	Lunch Break	0.67				0.45						0.09	0.13									
3	4	3.4.1	DR	Tk	Wan Dep	Axis	North Path	0.71				0.71																
3	4	3.4.1	DR	Tn	Wan Dep	Axis	C-12	0.1															0.1					
3	4	3.4.1	DR	Tn	Wan Dep	Axis	C-12	0.07											0.04		0.03							
3	4	3.4.1	DR	Tn	Wan Dep	Axis	C-12	0.11									0.07				0.04							
3	4	3.4.1	DR	Tn	Wan Dep	Axis	C-12	0.08											0.05		0.03							
3	4	3.4.1	DR	Tn	Wan Dep	Axis	C-12	0.08											0.04		0.04							
3	4	3.4.2	AC	Tk	Wan Uni	Axis	Lunch Break	1.08								0.7		0.38										
3	4	3.4.2	AC	Tk	Wan Uni	Axis	North Path	0.4								0.2									0.2			
3	4	3.4.2	AC	Tk	Wan Dep	Axis	C-12	3.21						3.21														
3	4	3.4.2	AC	Tk	Wan Uni	Axis	C-12	0.89	0.25			0.64																
3	4	3.4.2	AC	Tk	Wan Uni	Axis	C-12	1.07	0.15			0.92																
3	4	3.4.3	AC	Tk	Ste Dep	Axis	Lunch Break	1.85																				
3	4	3.4.3	AC	Tk	Wax Dep	Axis	Lunch Break	0.95				0.95																
3	4	3.4.3	AC	Tk	Wan Dep	Axis	North Path	1.43						0.81	0.63													
3	4	3.4.3	AC	Tk	Wan Uni	Axis	North Path	0.52								0.37								0.15				
3	4	3.4.3	AC	Tk	Wan Uni	Axis	North Path	0.57							0.35	0.22												
3	4	3.4.4	AC	Tk	Wan Dep	Axis	North Path	0.38						0.38														

Appendix B. Part five of the table of sedimentation units recorded in measured sedimentological sections of the Capistrano lithosome.

Complex #	Channel #	Sed Body Hierarchy	Sed Body Type	Thick Thin	Unit Type	Sed Region	Section Name	Sed Unit Height	Facies Thickness																			
									2	3	4	5a	5b	5c	6	8	9	10	11	12a	12b	13	14	15	17	18	19	20
3	4	3.4.4	AC	Tk	Wan Uni	Axis	North Path	1.25						0.45		0.81												
3	4	3.4.5	AC	Tk	Wan Acc	Axis	North Path	1.56				0.84				0.32	0.24	0.16										
3	6	3.6.3	DR	Tn	Wax Dep	Margin	C-12	0.31											0.31									
3	6	3.6.3	DR	Tn	Ste Dep	Margin	C-12	0.55										0.06	0.49									
3	6	3.6.4	IC	Tn	Wan Uni	Margin	C-12	0.32									0.11			0.21								
3	6	3.6.4	IC	Tn	Wan Dep	Margin	C-12	0.2									0.14	0.06										
3	6	3.6.4	IC	Tn	Wan Dep	Margin	C-12	0.28													0.28							
3	6	3.6.4	IC	Tn	Wax Dep	Margin	C-12	0.31										0.24	0.07									
3	6	3.6.5	IC	Tn	Wax Dep	Margin	C-12	0.29												0.29								
3	6	3.6.5	IC	Tn	Wan Dep	Margin	C-12	0.14											0.07	0.07								
3	6	3.6.5	IC	Tn	Wan Dep	Margin	C-12	0.2											0.13							0.07		
3	6	3.6.5	IC	Tn	Wan Dep	Margin	C-12	0.2											0.08							0.12		
3	6	3.6.5	IC	Tn	Wan Dep	Margin	C-12	0.37											0.05	0.32								
3	6	3.6.5	IC	Tn	Wax Dep	Margin	C-12	0.32										0.29	0.03									
3	6	3.6.5	IC	Tn	Wan Dep	Margin	C-12	0.31											0.03							0.29		
3	6	3.6.5	IC	Tn	Wan Dep	Margin	C-12	0.09											0.07							0.02		
3	6	3.6.5	IC	Tn	Wan Dep	Margin	C-12	0.12											0.1							0.02		
3	6	3.6.5	IC	Tn	Wan Dep	Margin	C-12	0.07											0.07									
4	1	4.1.1	DR	Tn	Wax Dep	Margin	C-12	0.29												0.29								
4	1	4.1.6	AC	Tk	Wan Dep	Axis	North Gulley	0.64									0.64											
4	1	4.1.6	AC	Tk	Wan Uni	Axis	North Gulley	0.94									0.94											
4	1	4.1.6	AC	Tk	Wan Uni	Axis	North Gulley	0.72									0.57	0.15										
4	1	4.1.6	AC	Tk	Wan Uni	Axis	Parking Lot	0.99									0.99											
4	1	4.1.6	AC	Tk	Wan Uni	Axis	Parking Lot	1.69				0.34					1.35											
4	2	4.2.1	DR	Tn	Wan Acc	Axis	North Gulley	0.2									0.13									0.07		
4	2	4.2.1	DR	Tn	Wan Acc	Axis	North Gulley	0.2									0.1									0.1		
4	2	4.2.1	DR	Tn	Wan Acc	Axis	North Gulley	0.19									0.15									0.04		
4	2	4.2.1	DR	Tn	Wan Acc	Axis	North Gulley	0.14									0.09									0.05		
4	2	4.2.1	DR	Tn	Wan Acc	Axis	Parking Lot	0.45										0.22	0.08				0.15					
4	2	4.2.1	DR	Tn	Wan Acc	Axis	Parking Lot	0.32										0.21					0.11					
4	2	4.2.1	DR	Tn	Wan Acc	Axis	Parking Lot	0.26										0.14					0.14					
4	2	4.2.1	DR	Tn	Wan Acc	Axis	Parking Lot	0.37										0.12	0.08				0.17					
4	2	4.2.1	DR	Tn	Wan Acc	Axis	Parking Lot	0.55										0.17	0.2				0.18					
4	2	4.2.7	AC	Tk	Wan Dep	Axis	North Gulley	0.57									0.36							0.21				
4	2	4.2.7	AC	Tk	Wan Dep	Axis	North Gulley	1.07				0.34			0.31		0.42											
4	2	4.2.7	AC	Tk	Wan Dep	Axis	North Gulley	1.1									0.71	0.29							0.1			
4	2	4.2.7	AC	Tk	Wan Uni	Axis	Parking Lot	0.47									0.47											
4	2	4.2.7	AC	Tk	Wan Dep	Axis	Parking Lot	1.2						0.39			0.65	0.16										
4	2	4.2.7	AC	Tk	Wan Dep	Axis	Parking Lot	0.24									0.24											
4	2	4.2.7	AC	Tk	Wan Dep	Axis	Parking Lot	0.68						0.41			0.27											
4	2	4.2.7	AC	Tk	Wan Dep	Axis	Parking Lot	1.35									1.35											
4	2	4.2.9	IC	Tn	Wan Dep	Axis	North Gulley	0.17									0.12	0.05										
4	2	4.2.9	IC	Tn	Wan Dep	Axis	North Gulley	0.09									0.09											
4	2	4.2.9	IC	Tk	Wan Dep	Axis	North Gulley	0.34									0.23								0.11			
4	2	4.2.9	IC	Tk	Wan Dep	Axis	North Gulley	0.6									0.28	0.16		0.16								
4	2	4.2.9	IC	Tn	Wan Dep	Axis	North Gulley	0.12										0.12										
4	3	4.3.5	IC	Tk	Wan Uni	Axis	North Gulley	0.19				0.19																
4	3	4.3.5	IC	Tk	Wan Uni	Axis	North Gulley	0.45								0.45												

APPENDIX C

PHOTO PANELS

North Gulley - North Wall



North Gulley - South Wall



Channel 4.1 Complex Drape



Channel 3.4 Bank Collapse



North Path to Outhouse



Outhouse to South Path



Channel Complex 3 Margin Part 1

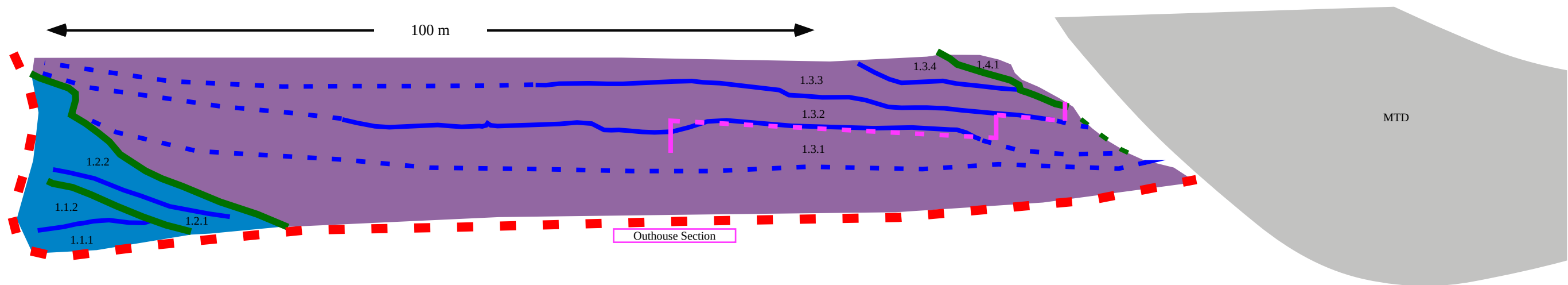


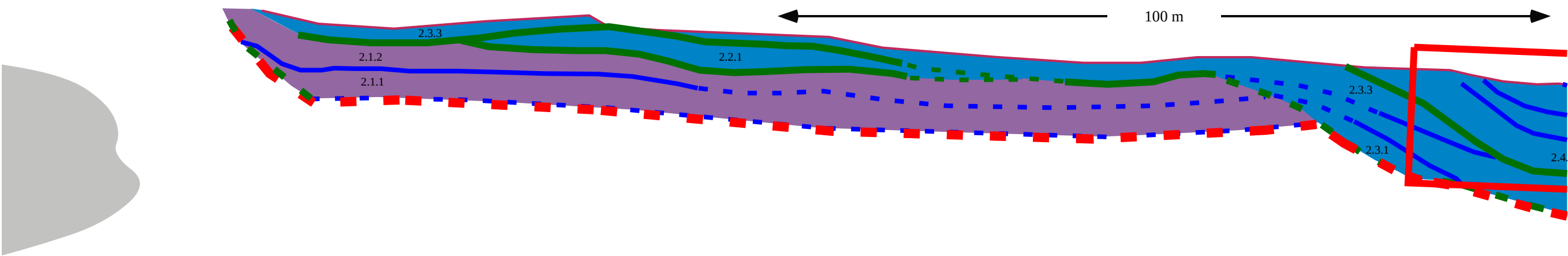
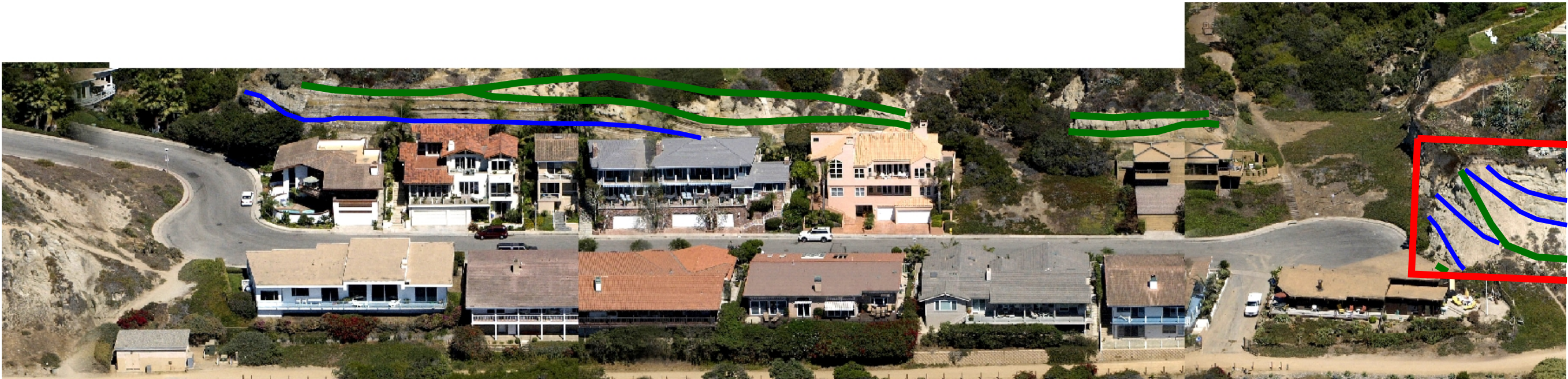
Channel Complex 3 Margin Part 2

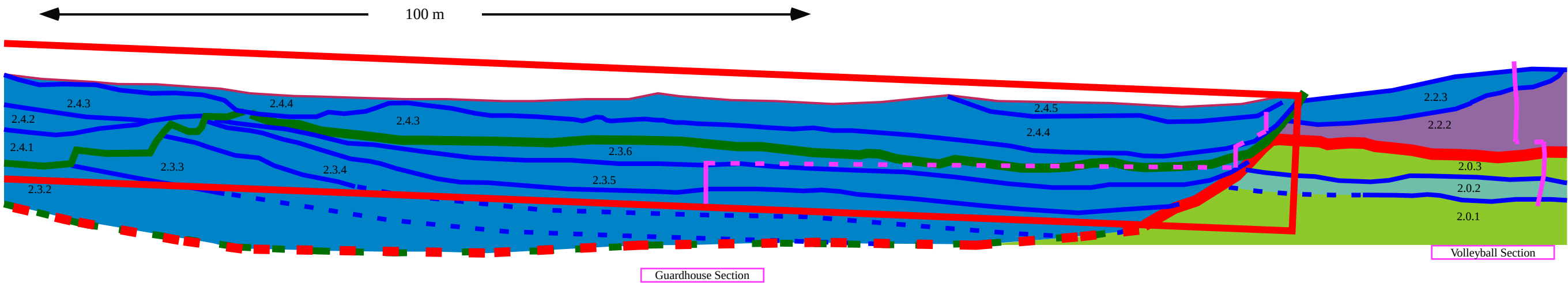


APPENDIX D

OUTCROP INTERPRETATION PANELS

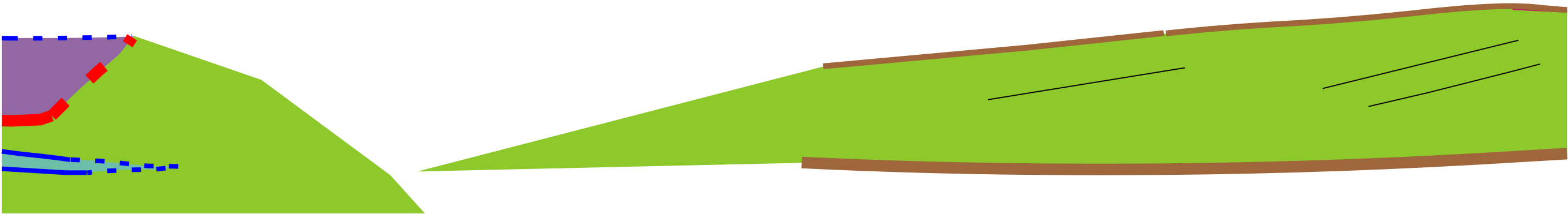






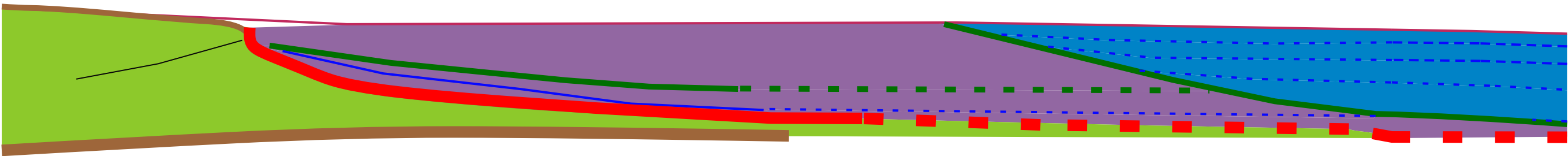


100 m



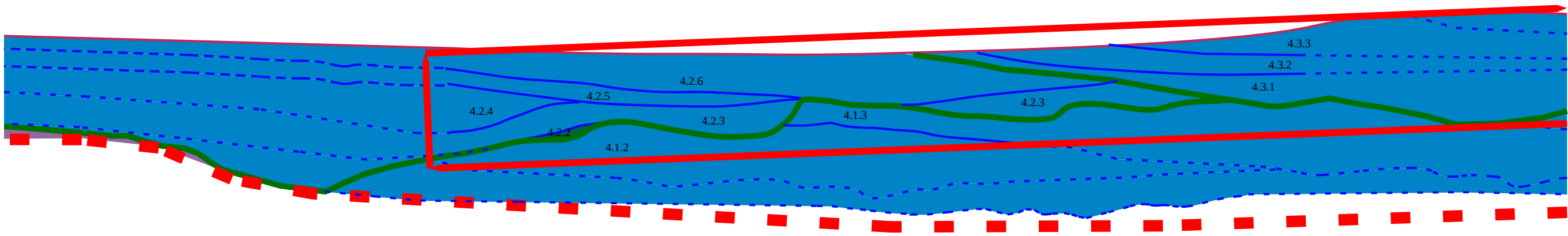


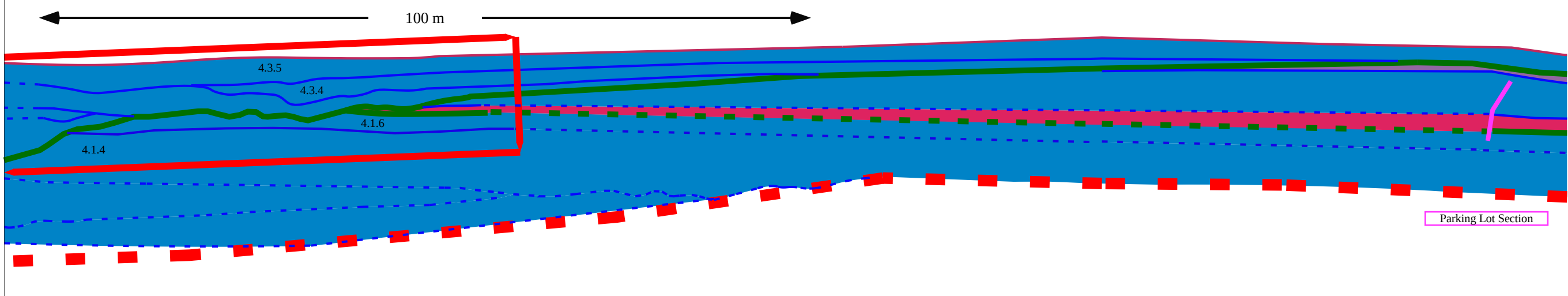
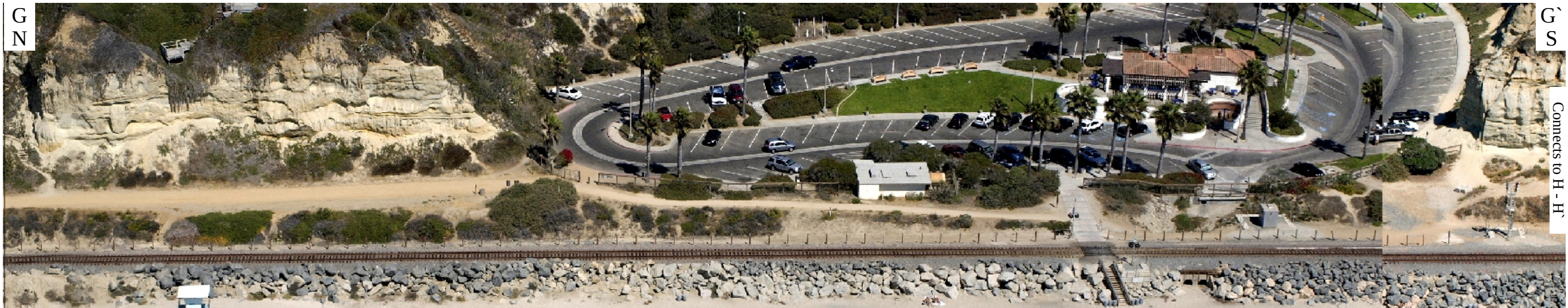
100 m

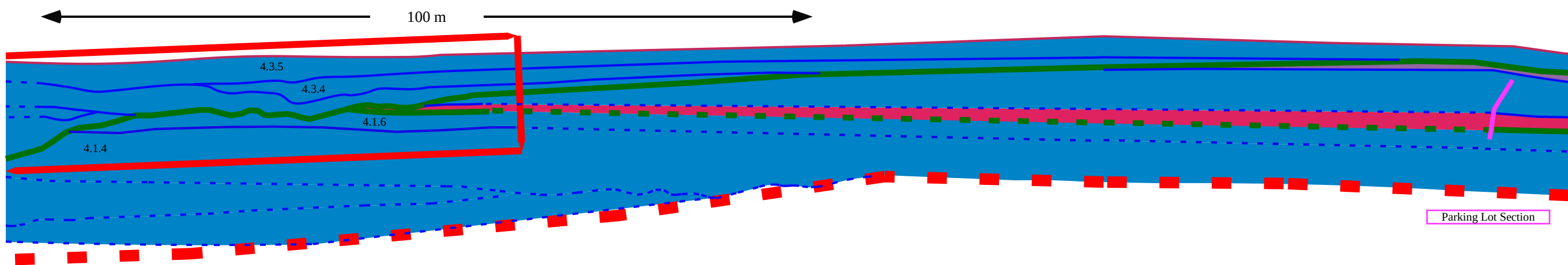




← 100 m →





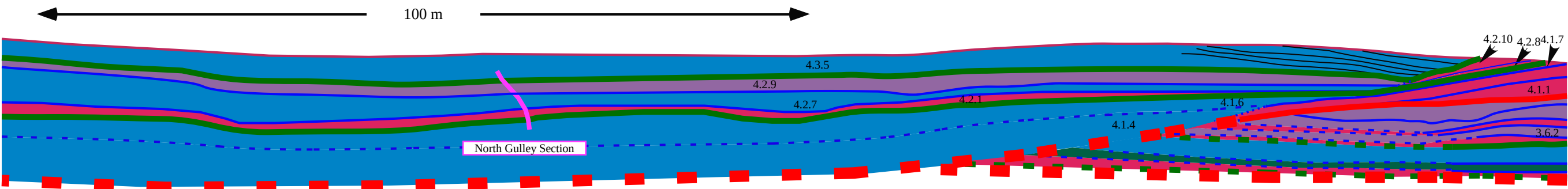


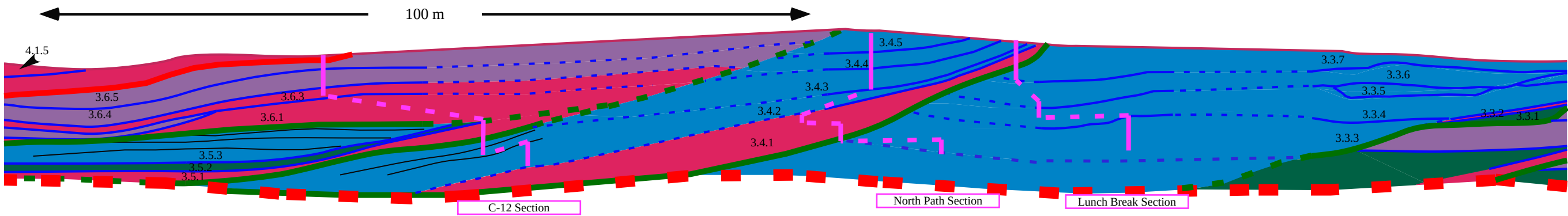
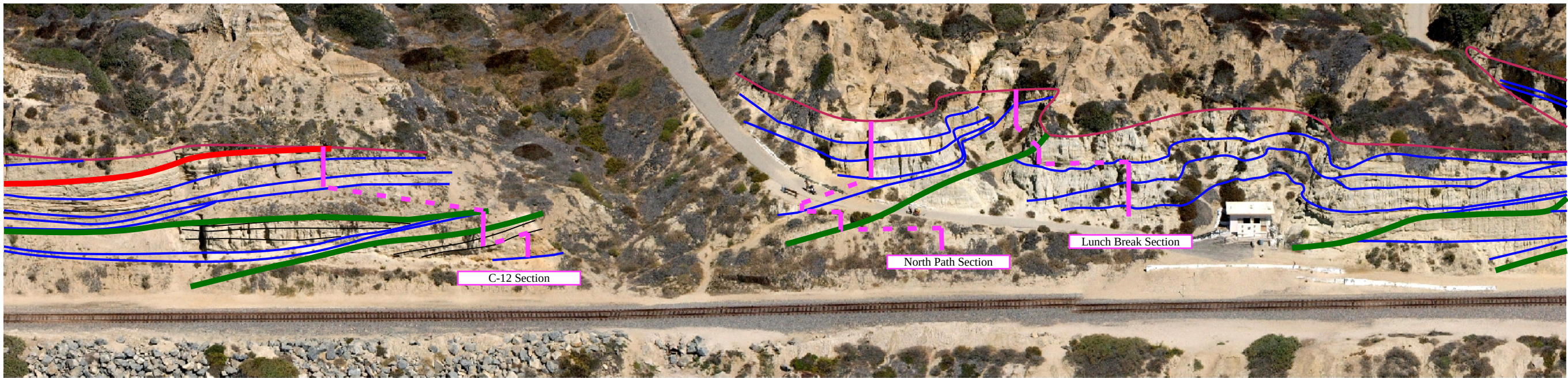
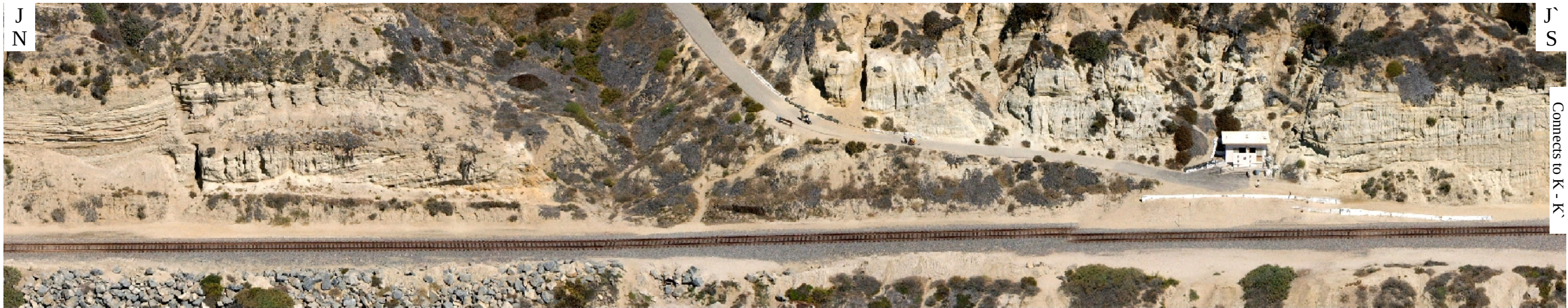


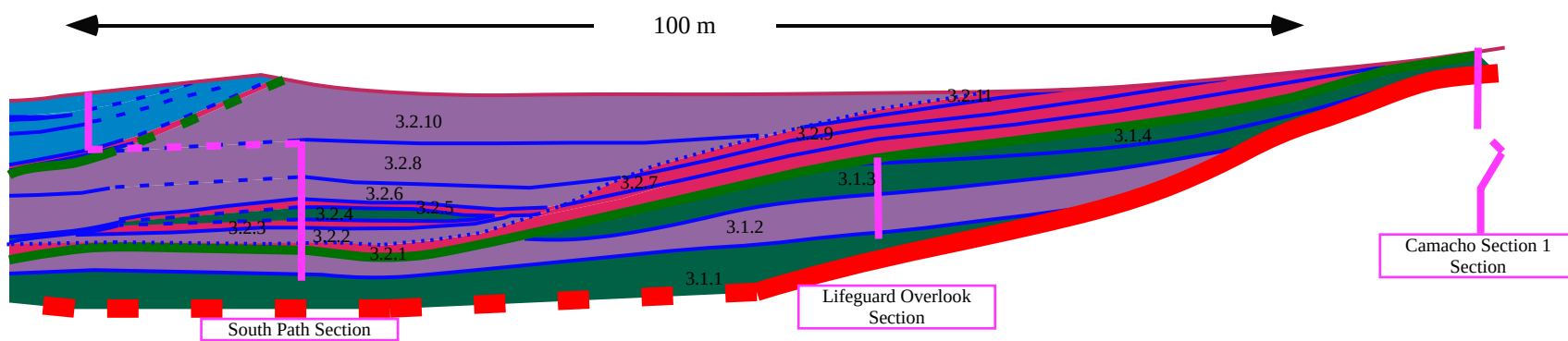
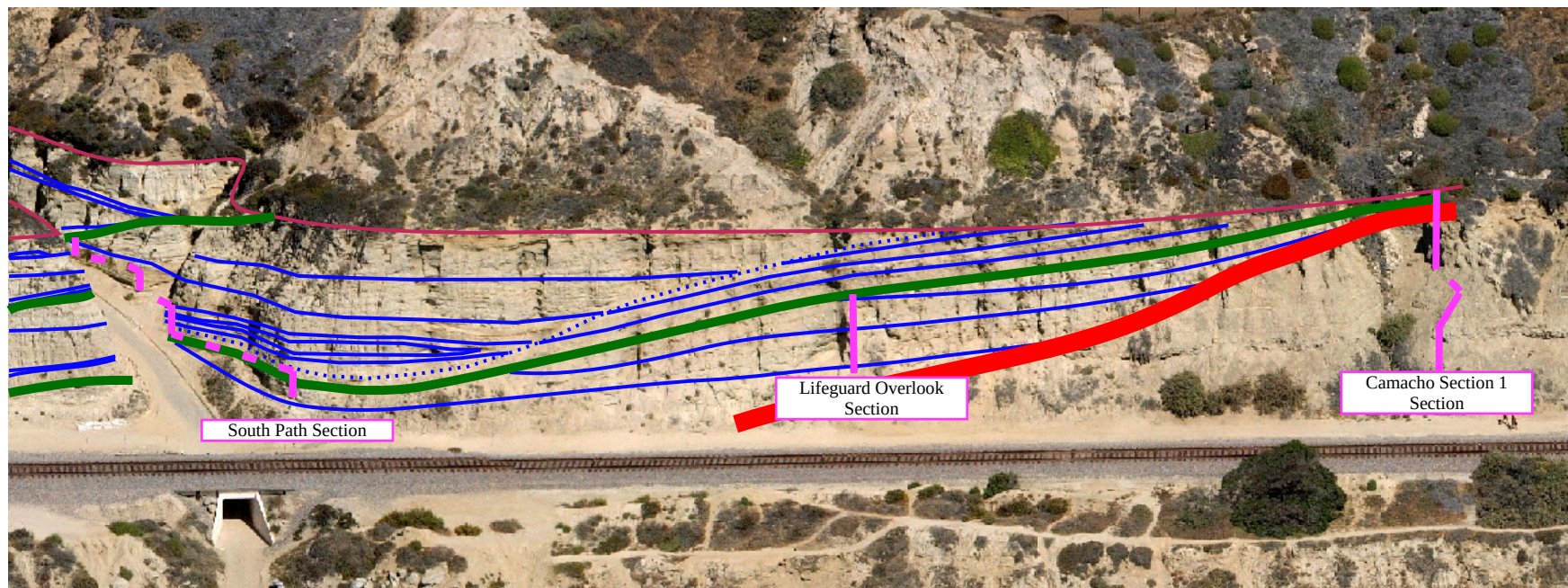
Connects to J - J'



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- | | |
|-----------------------------|--------------------|
| — Channel Complex | — Bedding |
| — Composite Channel | — Measured Section |
| — Elementary Body | |
| ■ Active Channelform Body | ■ Wedgeform Body |
| ■ Inactive Channelform Body | ■ Drape Body |
| ■ Remnant Channelform Body | ■ Modern Landslide |