Impact of Local Accommodation on the Architecture and Stacking Patterns of Three Capistrano Formation Slope Channel Outcrops: Point Fermin, Dana Point, and San Clemente, California*

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Abstract

The stratigraphy of deep-water reservoirs is partially related to local accommodation at the time of deposition. Three outcrops of the upper Miocene-Pliocene (‘Delmontian’ stage) Capistrano Formation provide the opportunity to document contrasting channelized slope depositional systems and the effects of local accommodation on slope-channel architecture and stacking patterns. Stratigraphic columns, paleocurrent, photomosaic and LIDAR data were collected to address the stratigraphy and evolution of each depositional system. The three slope-channel systems studied are incised into slope mudstone of the middle to upper Miocene Monterey Formation. The three channel systems contain similar lithofacies types although their proportions and distributions vary by location. The architectural elements are also similar at each exposure but vary in their dimensions, geometries, and stacking patterns. The Point Fermin exposure contains a 45-m-thick, 500-m-wide half graben syn-depositionally filled with Capistrano channel deposits. These deposits represent a proximal slope setting with poorly confined sedimentation from a nearby uplift (within 2 kilometers). The strata vary, both upward and laterally toward the steep side of the half-graben, from mass-transport-complex-dominated to channel-dominated. This architecture reflects high differential accommodation that varies laterally. The Dana Point Harbor exposure contains a 30-m-thick, 900-m-wide, conduit-filling channel complex set, formed by three laterally accreting and two vertically stacking channel complexes. The accommodation is low to moderate, influenced by laterally variable internal basal channel cut topography and is locally impacted by sand volcanoes formed at the base of the early channel complex cut. The conduit, which confines the Capistrano Formation at Dana Point, was cut into upper slope mudstones and fed sediments from 7 to 25 kilometers to the east. The San Clemente exposure contains a 20-m-thick, 500-m-wide, mainly laterally accreting, meandering slope channel complex composed of ten non-amalgamated and amalgamated channel deposits. The amount of confinement and stacking patterns indicate a low accommodation at the time of deposition. The lower slope channel complex at San Clemente was fed sediments from the Peninsular Ranges 10 to 30 kilometers to the east.

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From the Mountains to the Abyss

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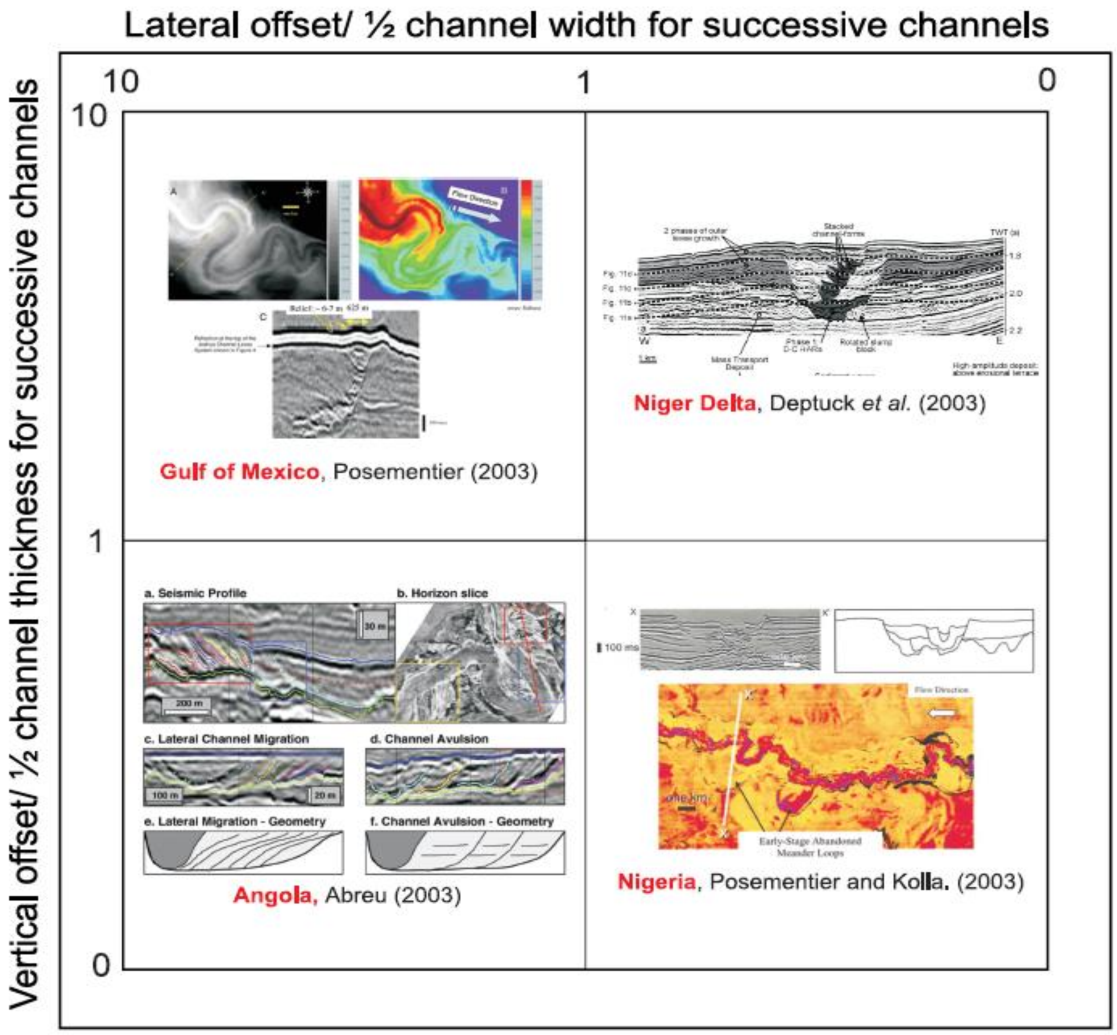
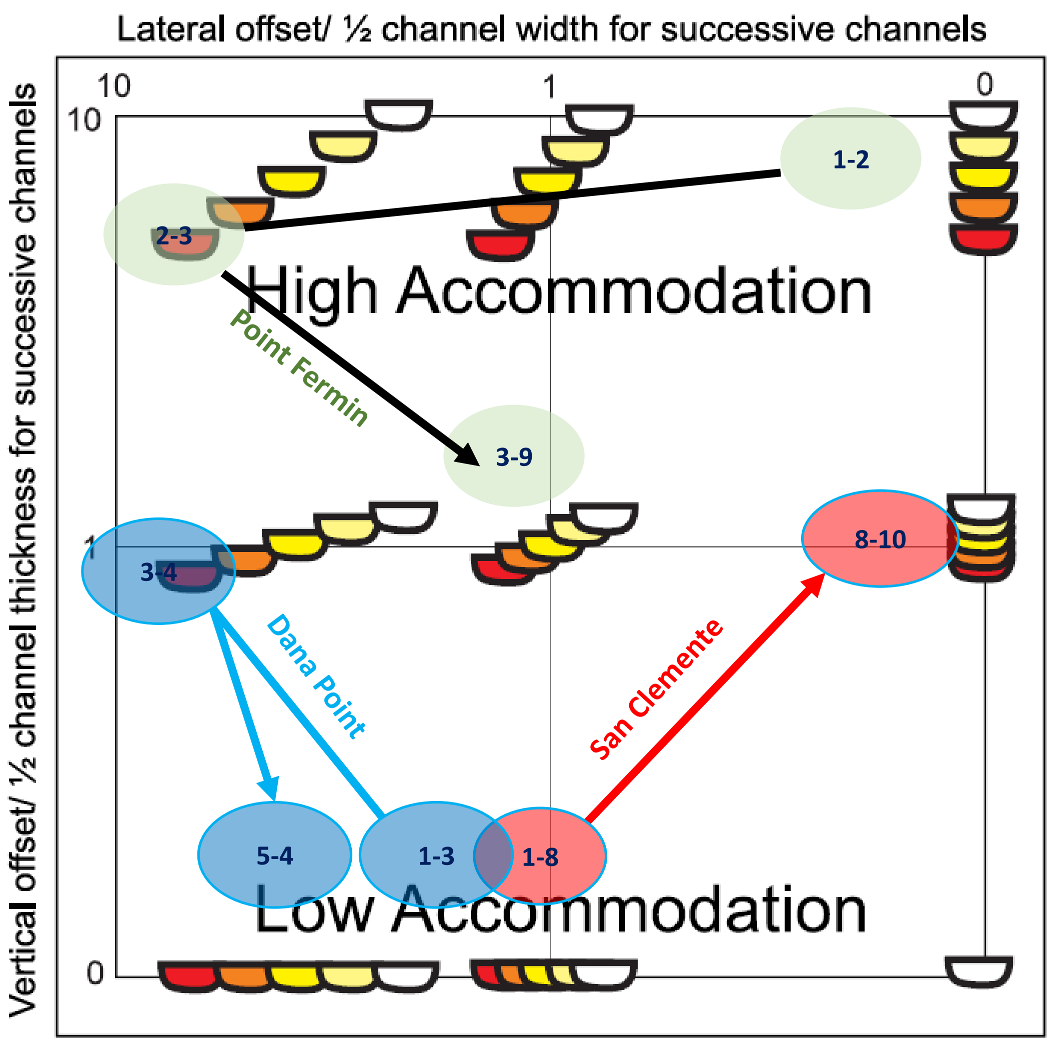
V/L diagrams illustrate the relationship between channel stacking pattern and reservoir characteristics within deep-water channel complexes



Examples of published channel complexes are shown for each quadrant of the V/L diagram.

From: Bouroullec & Pyles, 2012

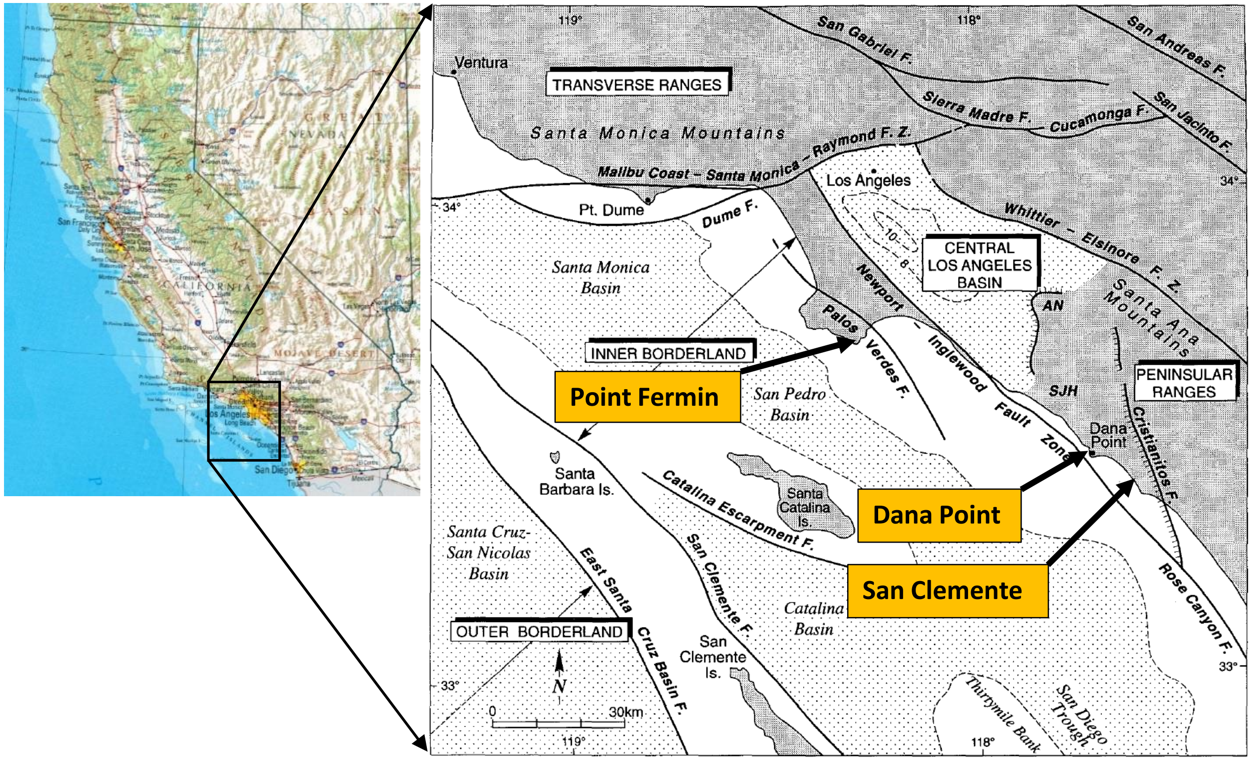
V/L diagrams illustrate the relationship between channel stacking pattern and reservoir characteristics within deep-water channel complexes



Lateral and vertical channel stacking within a channel complex.

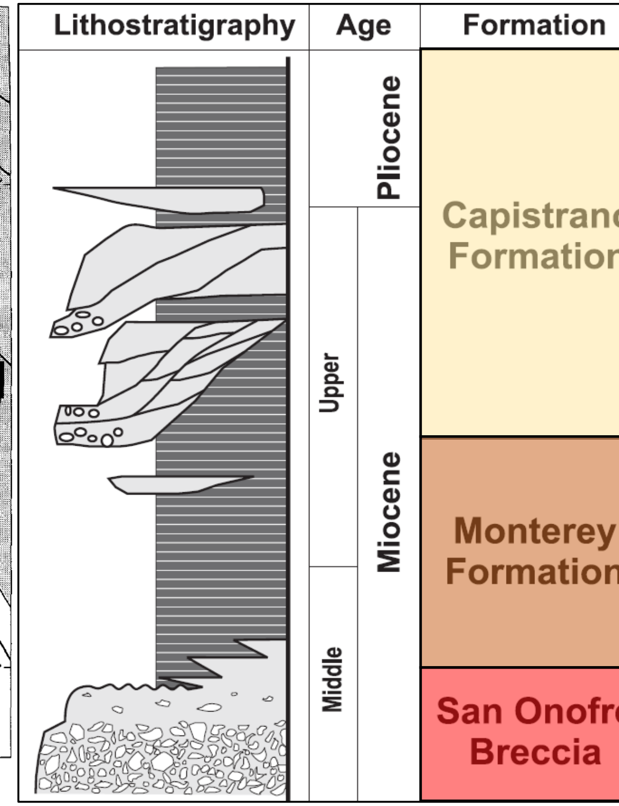
From: Bouroullec & Pyles, 2012

Location and Stratigraphy of the Capistrano Channels in Southern California



Major Faults and Provinces

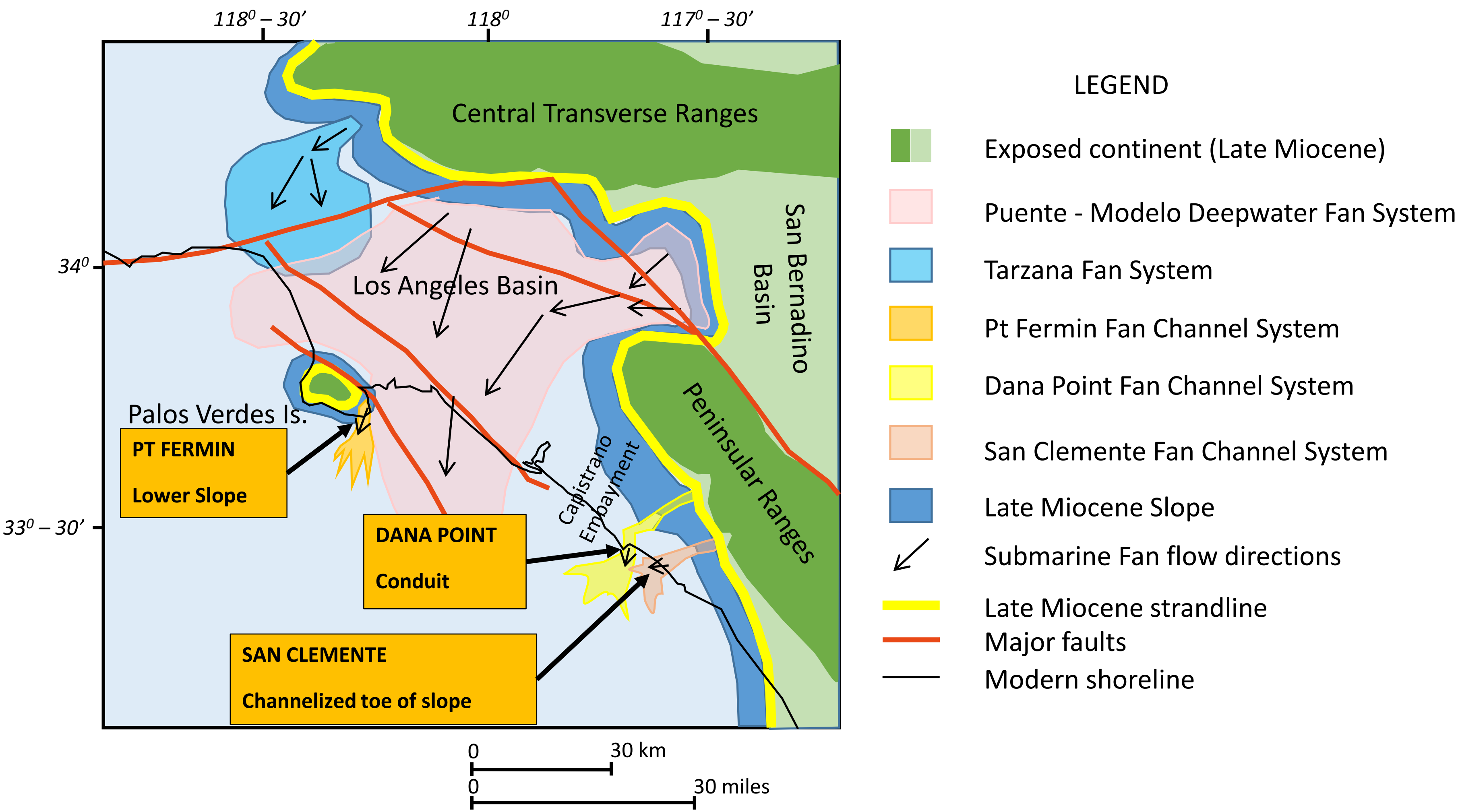
(From Crouch and Suppe, 1993,
modified from Yerkes and others, 1965)



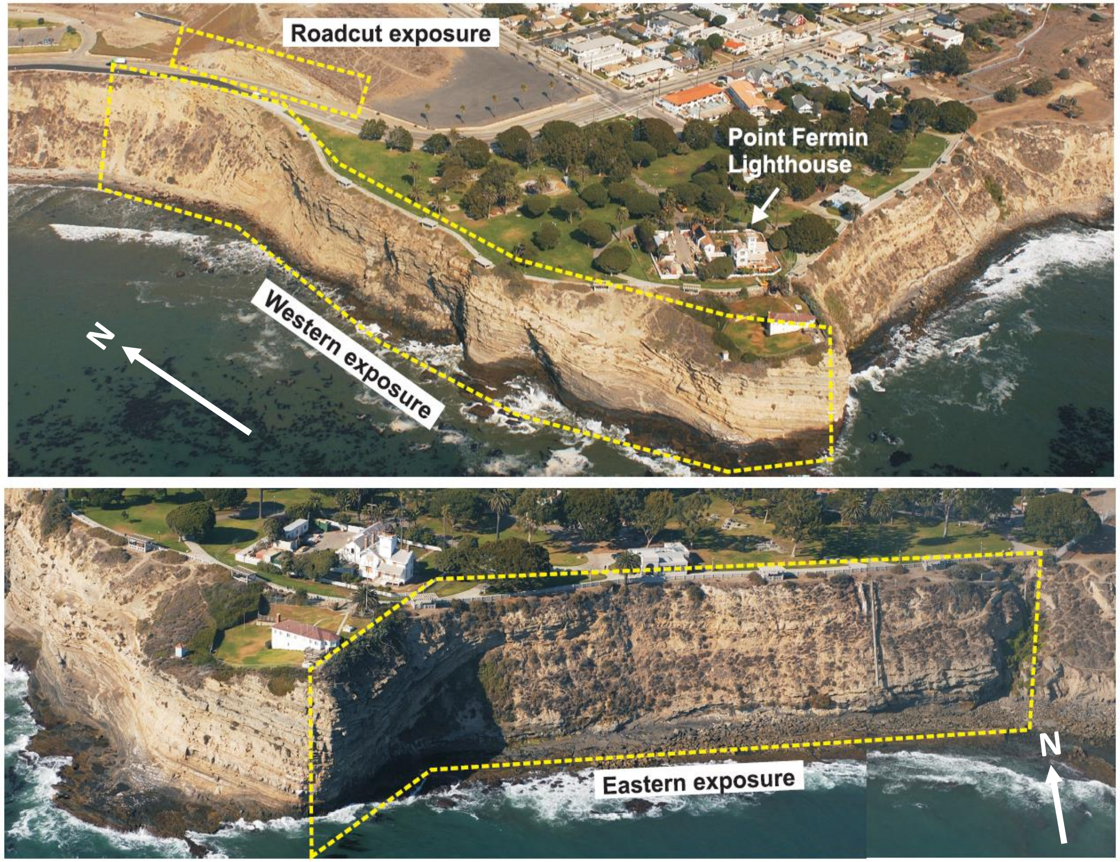
Schematic Lithostratigraphy.

(From Bouroullec & Pyles, 2010)

Distribution of late Miocene to early Pliocene depositional systems in the Los Angeles Basin and Capistrano Embayment

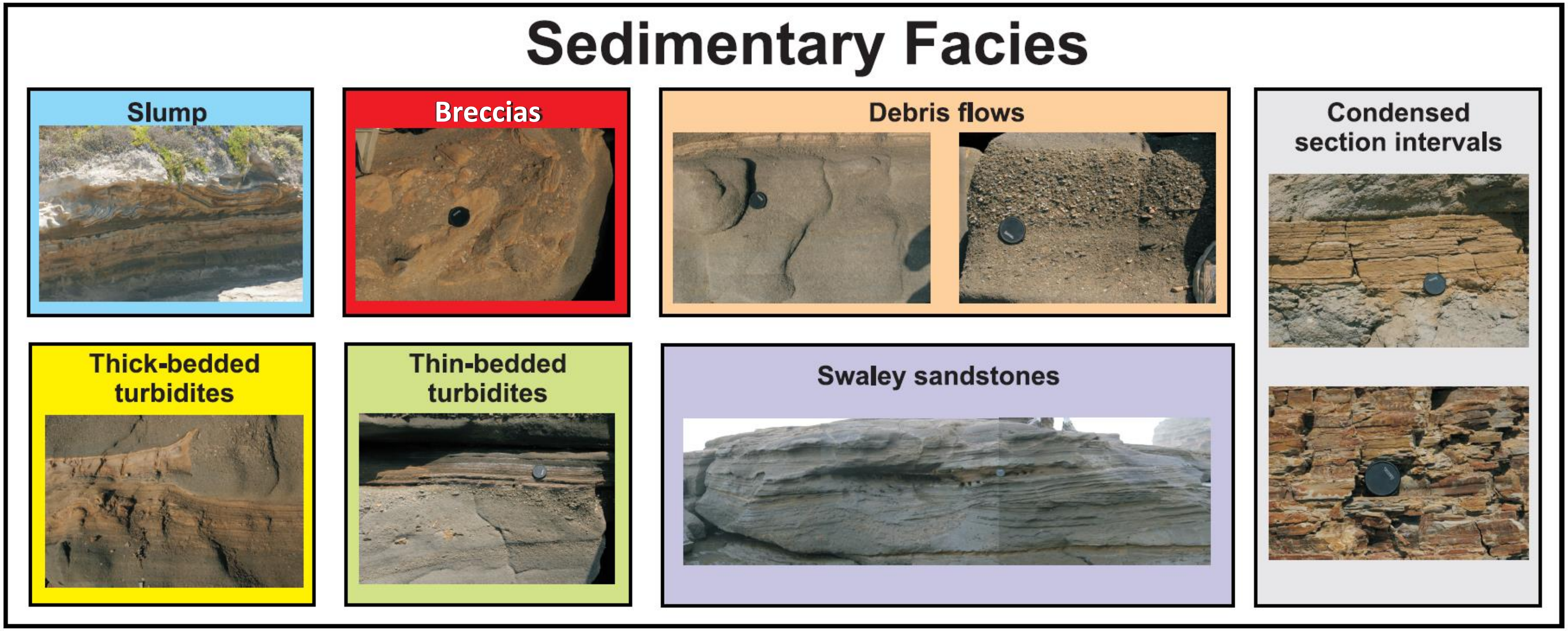


Aerial photographs of Point Fermin

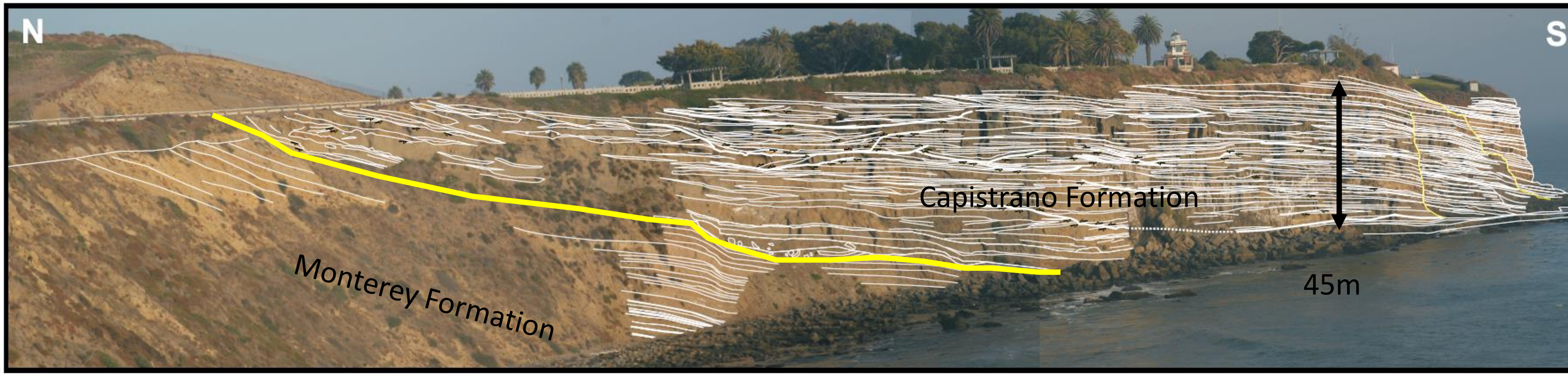


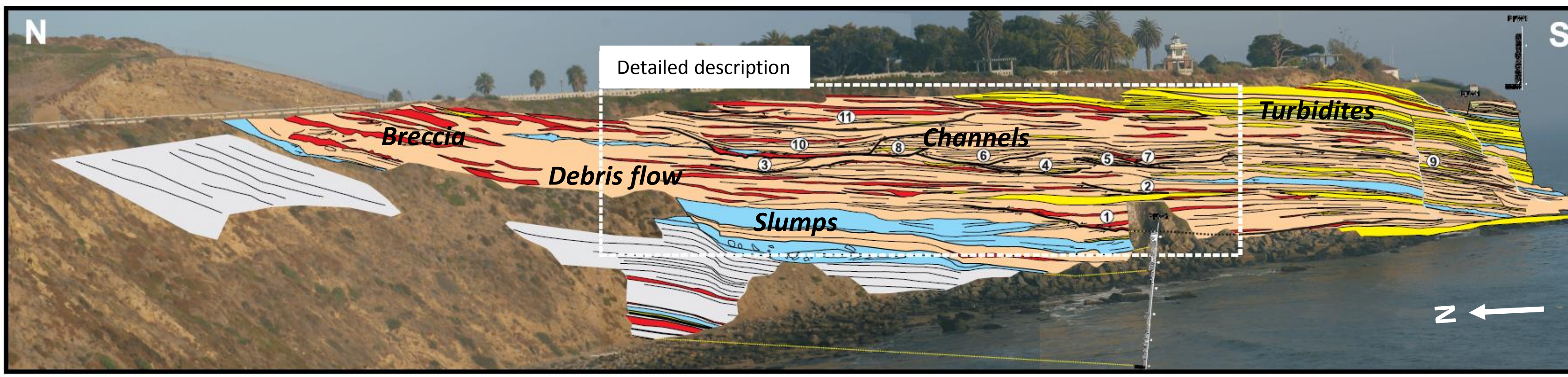
Three exposures have been studied, the Roadcut, Western and Eastern exposures.

Photographs of the seven sedimentary facies observed at Point Fermin outcrops

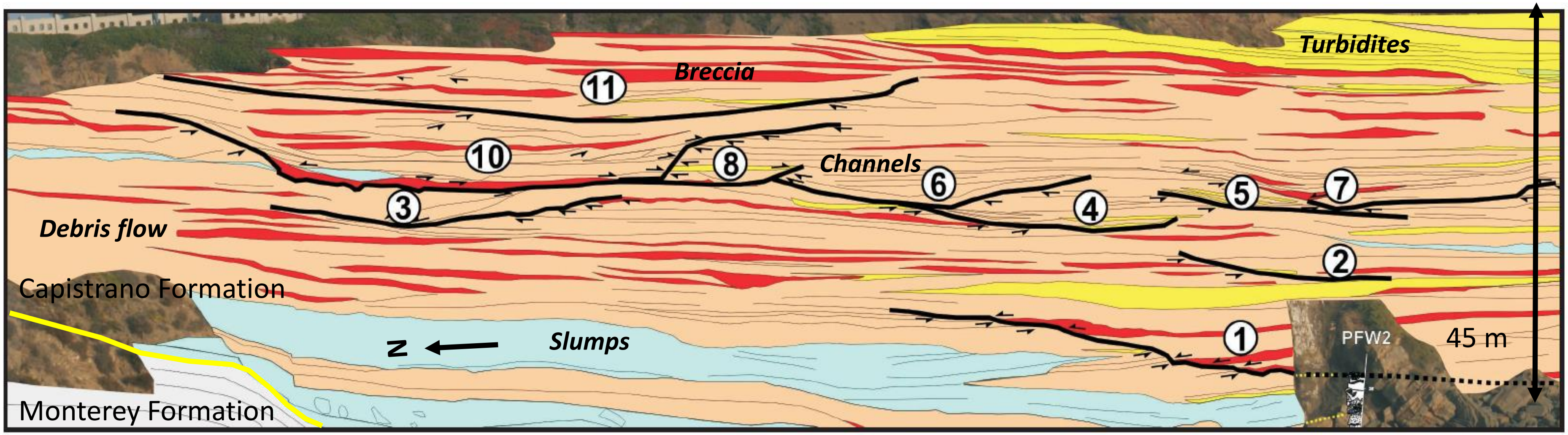


Stratigraphic interpretation of the Capistrano Formation (Malaga Mudstone) at the western exposure of Point Fermin



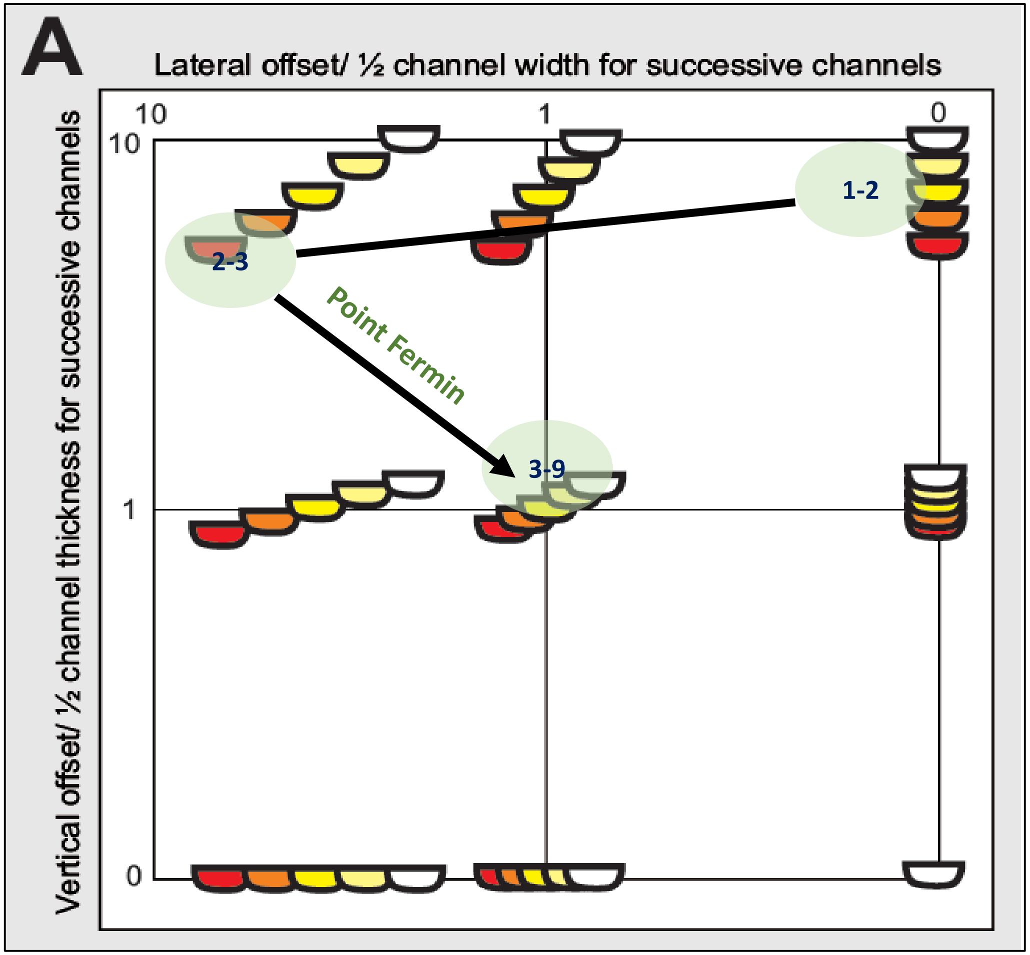


Channel stacking relationships in the Capistrano Formation at Point Fermin, number indicates order of emplacement



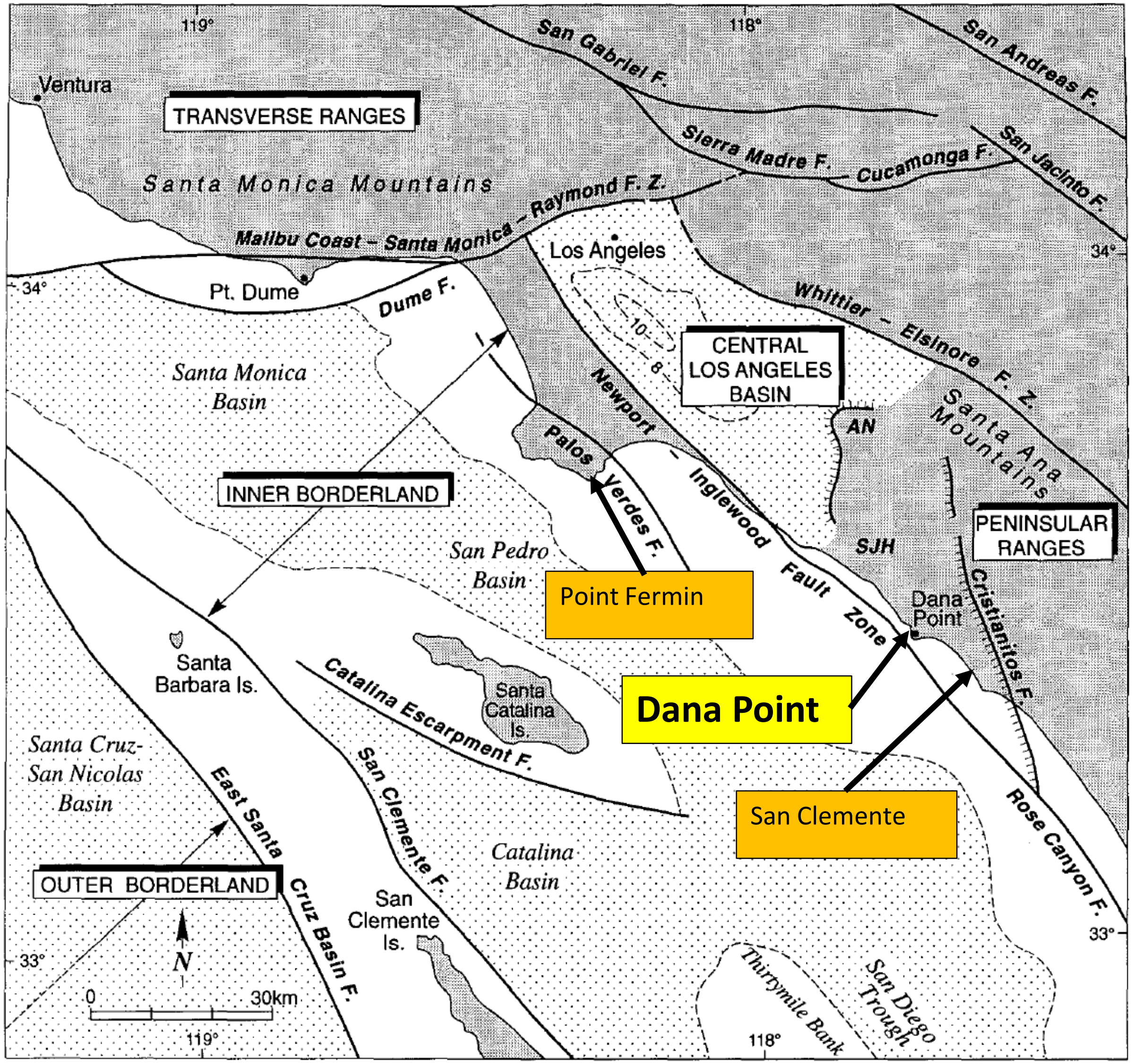
- Detail of channel deposits in the middle of the western exposure showing:
  - erosive bases and vertical (channels 1 and 2) then,
  - lateral channel shifting (channels 3 to 9).
- Channels overly interbedded heterolithic beds of breccia (red) and debris flow (tan) that overlie slump deposits (blue).
- The Monterey can be seen to the lower left (grey).

V/L diagram of the lateral and vertical stacking of channels within the Point Fermin channel complex.



- *The stacking pattern for Point Fermin is illustrated in green.*
- *In a high accommodation setting, the channels were first:*
  - *vertically aggraded with low connectivity (channels 1-2), then*
  - *laterally and vertically offset (channel 2-3), with no connectivity between successive channels, and finally*
  - *laterally and slightly vertically offset with higher -connectivity between channels (channels 3-9).*

Location Map, major faults, geomorphic provinces, and principal late Cenozoic basin areas in onshore and offshore southern California.

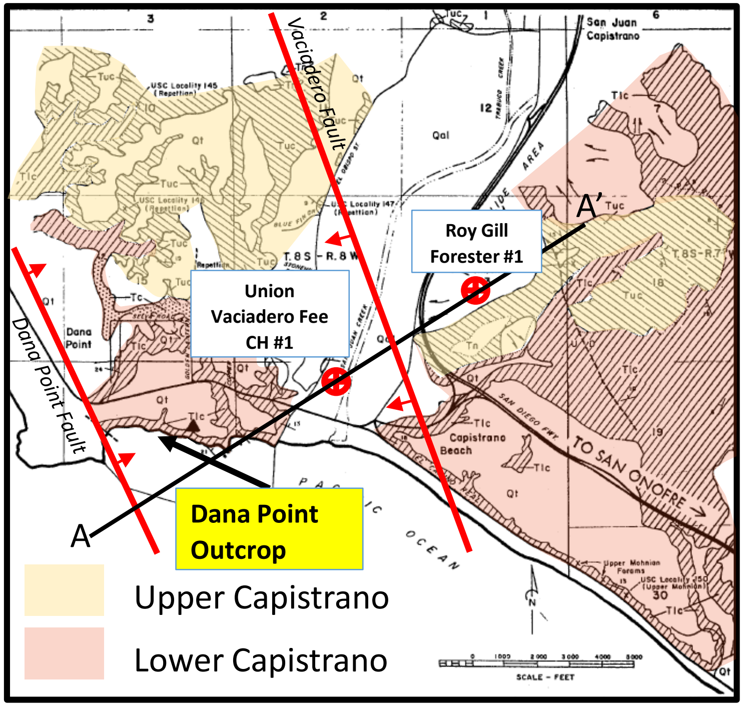


(From Crouch and Suppe, 1993, modified from Yerkes and others, 1965).

Photopanel of western part of the Dana Point Harbor exposure

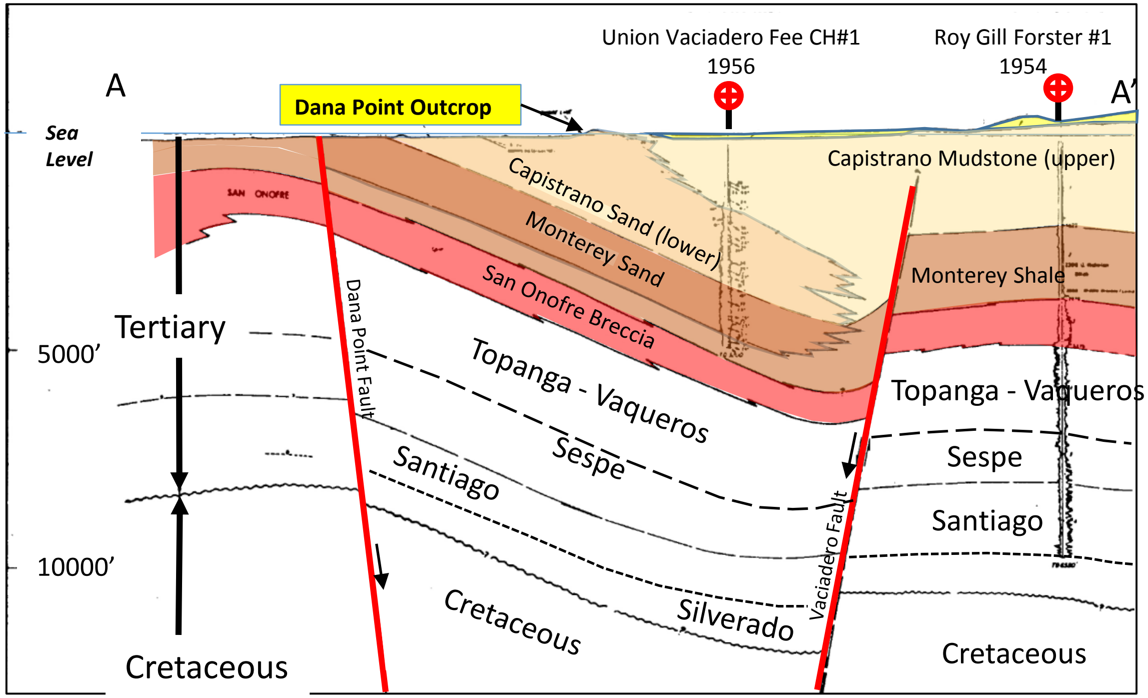
- Monterey and Capistrano Formations are separated by a fault (Dana Point Fault) to the west.
- The Capistrano Formation crops out on the main cliff and is composed of slope channels.

Geologic map of the Dana Point area and structural cross section A-A' from offshore Dana Point east-northeast



Map depicting the location of the cross section connecting the outcrop with two wells drilled to evaluate the Monterey and underlying Formations.

From: Geologic Guidebook, Newport Lagoon to San Clemente, Orange County, California. Pacific Section SEPM Field Trip, October 23, 1971. Adopted from Vedder, Yerkes and Schoellhamer (1957) and White (1956).



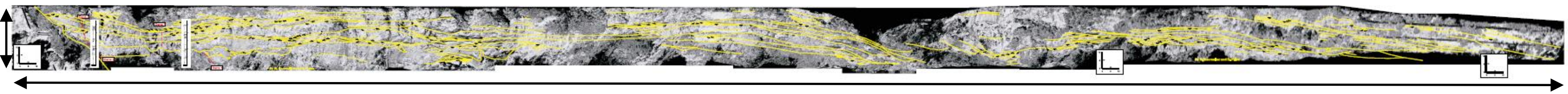
Structural cross section A-A' from offshore Dana Point east-northeast through the Union Vaciadero and Gill Forester wells.

- *The section displays a significant stratigraphic facies change when crossing the Vaciadero Fault.*
- *Monterey Sand and subsequent Capistrano Formation sand was constrained in the graben formed by the fault.*

From: West, 1979: AAPG, SEPM, & SEG – Pacific Section Guidebook.

LIDAR scan and interpretation for the Dana Point Harbor Capistrano Formation exposure

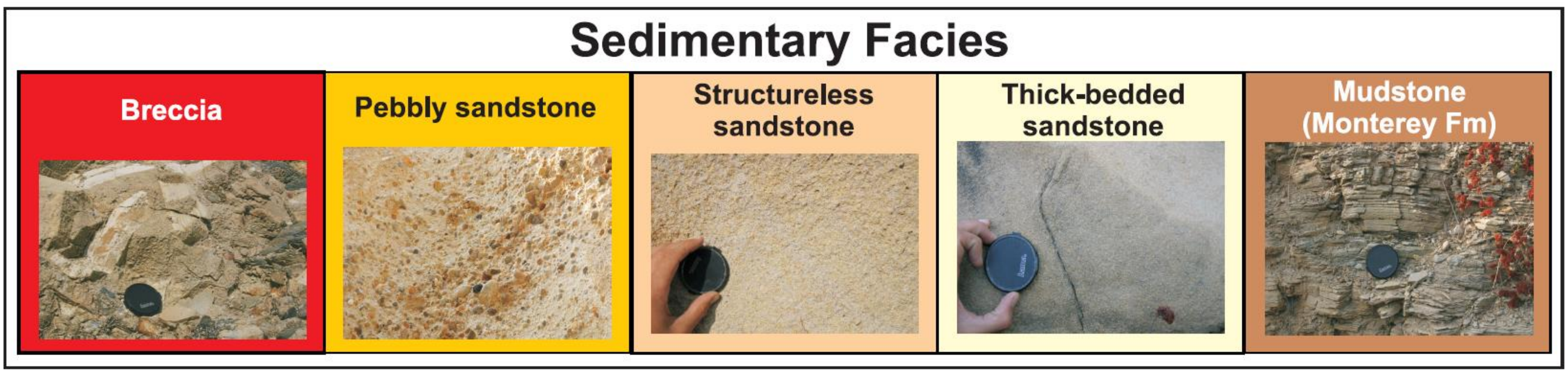
50 meters



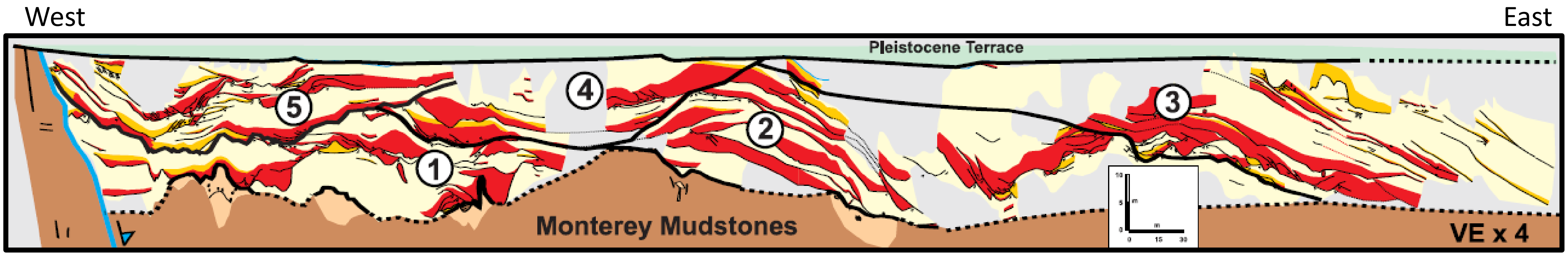
~1600 meters

LIDAR image is a composite of over 50 individual scans of the cliff face from below, to the side, and from above. Bed boundaries are annotated on the image in yellow.

Sedimentary facies annotation on the LIDAR scan of the Dana Point Harbor Capistrano Formation exposure. Facies correspond to sedimentary facies described previously.



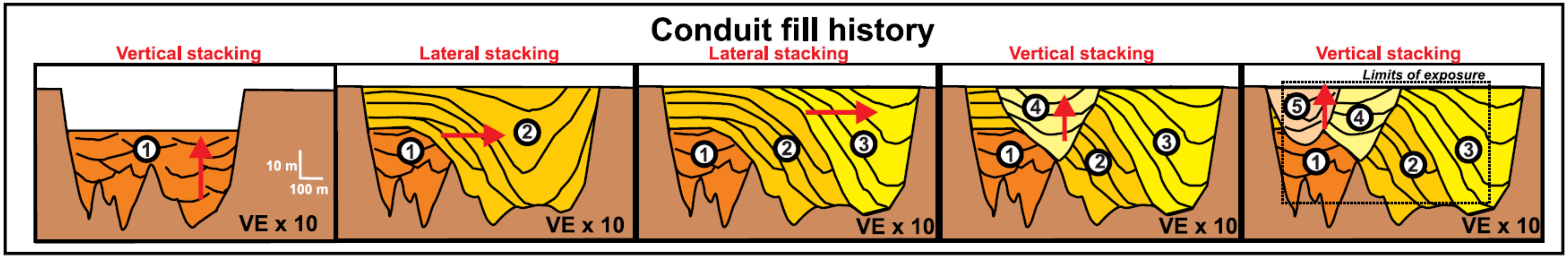
Interpreted cross section from Dana Point Harbor exposure, numbers indicate order of emplacement



- *Channel units are identified on the basis of stacking patterns and erosional boundaries.*
- *The irregular nature of the base of the conduit is defined by the vertical and lateral occurrence of Monterey Formation mudstones above the lowest channel thalweg.*
- *Lateral offsets of channels 1 to 3 to the east; vertical then lateral offset of channels 4 and 5 back to the west.*

Vertical exaggeration 4x. (Bouroullec and Pyles, 2010)

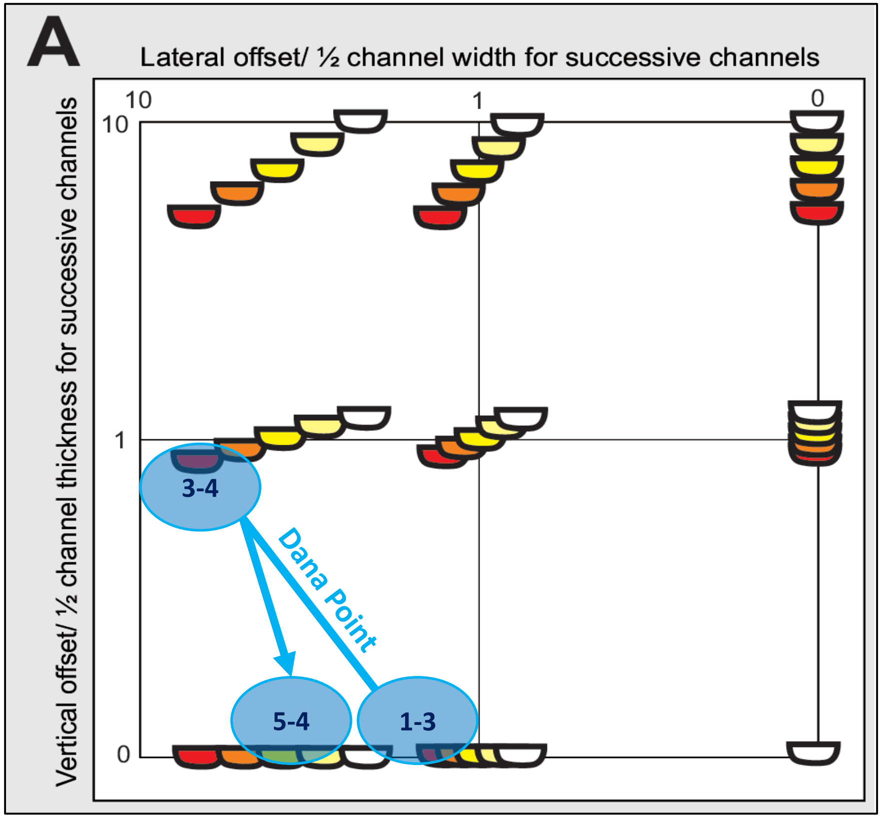
Schematic model of the stratigraphic evolution of the Capistrano Formation channel complex at Dana Point Harbor exposure



- *The conduit was cut into Monterey Formation mudstone with an irregular base.*
- *Several channel deposits filled the conduit in a vertical stacking pattern (Complex 1).*
- *The conduit was further widened and subsequently filled with sandy channel complex deposits via southward shifting lateral moves (Complexes 2 and 3).*
- *This was followed by vertical stacking and northward shifting of the channel cuts and subsequent channel complex deposits (Complexes 4 and 5).*

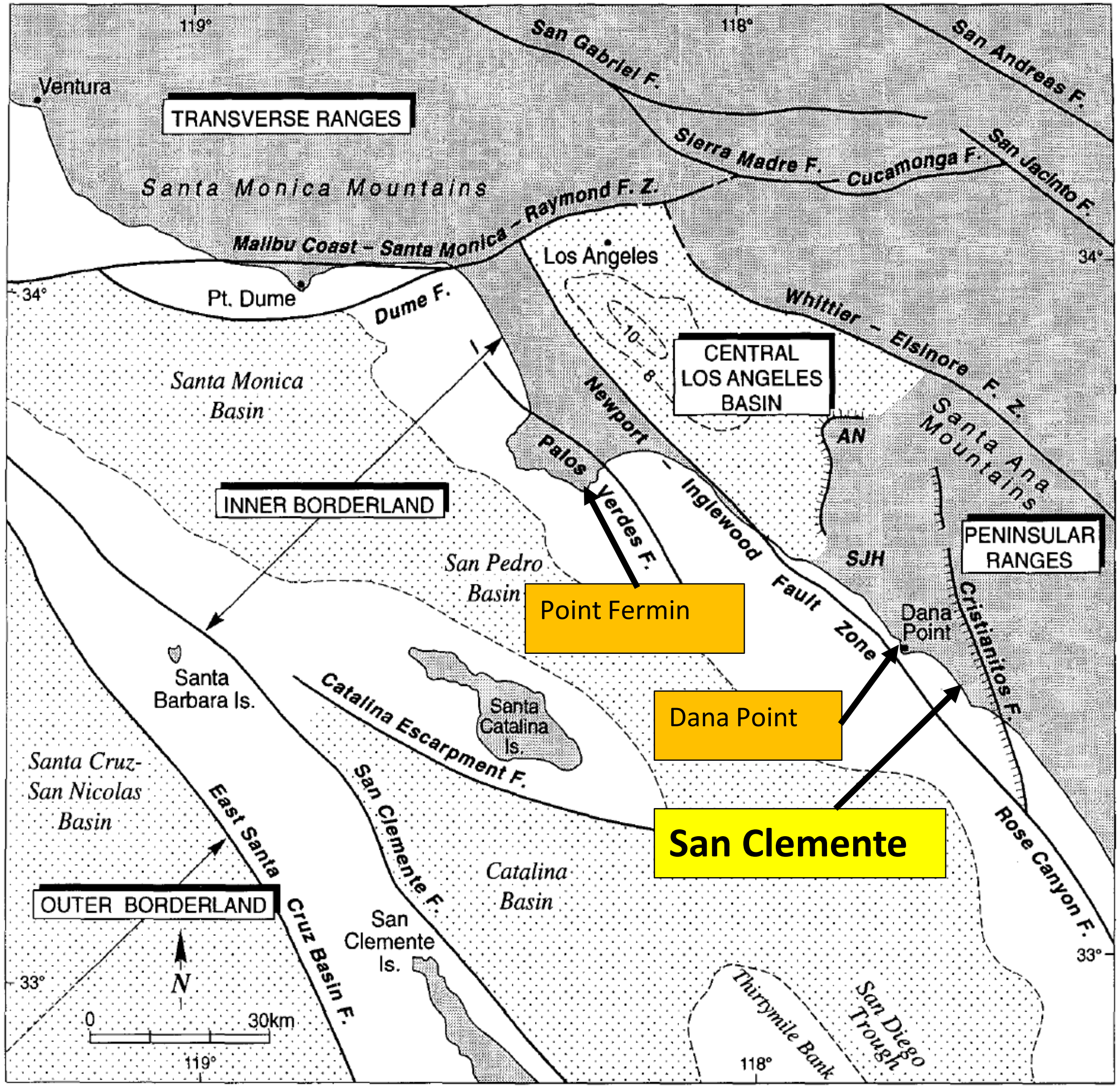
Vertical Exaggeration 10x. (Bouroullec and Pyles, 2010)

V/L diagram illustrating the lateral and vertical stacking of channels within the Dana Point channel complex



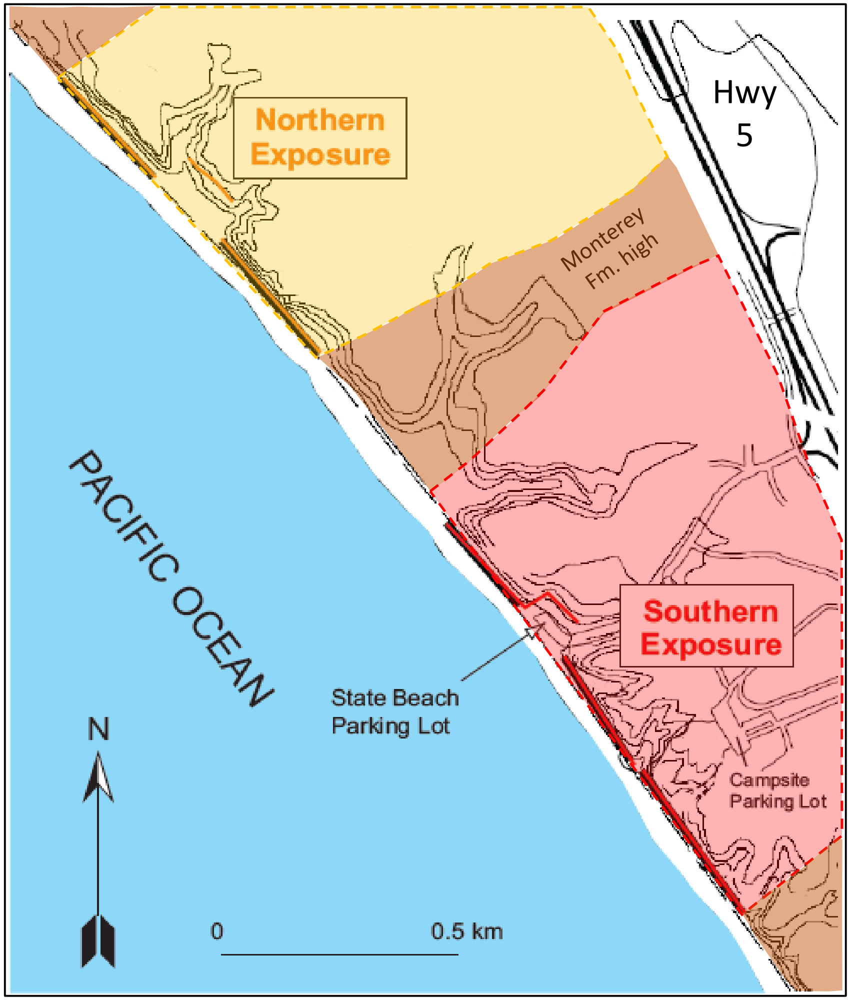
- *The stacking pattern for Dana Point is illustrated in blue.*
- *In a low to moderate accommodation setting, the channels first were:*
  - *Laterally offset and have good connectivity (channels 1-3), then*
  - *Vertically offset (channel 3-4), with good connectivity between successive channels, and finally*
  - *Laterally offset with higher-connectivity between channels (channels 5-4).*
  - *Connectivity is influenced by the breccia at the base of the channel sets.*

Location Map, major faults, geomorphic provinces, and principal late Cenozoic basin areas in onshore and offshore southern California



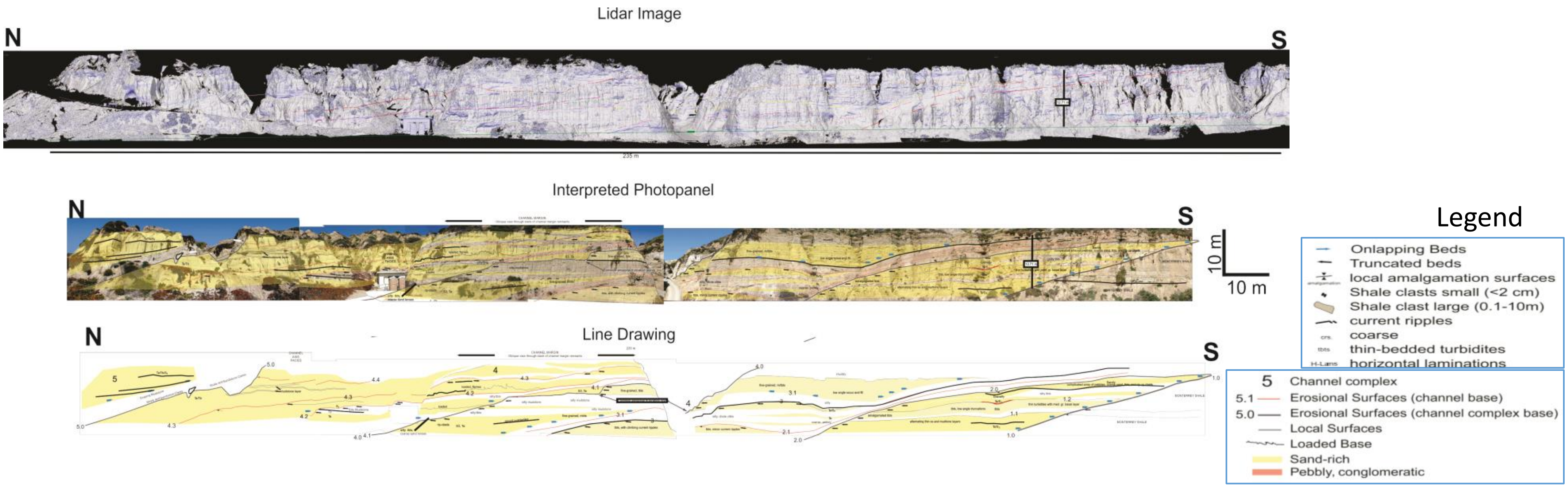
(From Crouch and Suppe, 1993, modified from Yerkes and others, 1965).

Topographic map of the San Clemente State Beach area



- The Capistrano Formation crops out at two exposures along the State Beach.
- The Northern (orange) and Southern (red) exposures are separated by a Monterey Formation mudstone high and incise into Monterey mudstone to the south and north (brown).

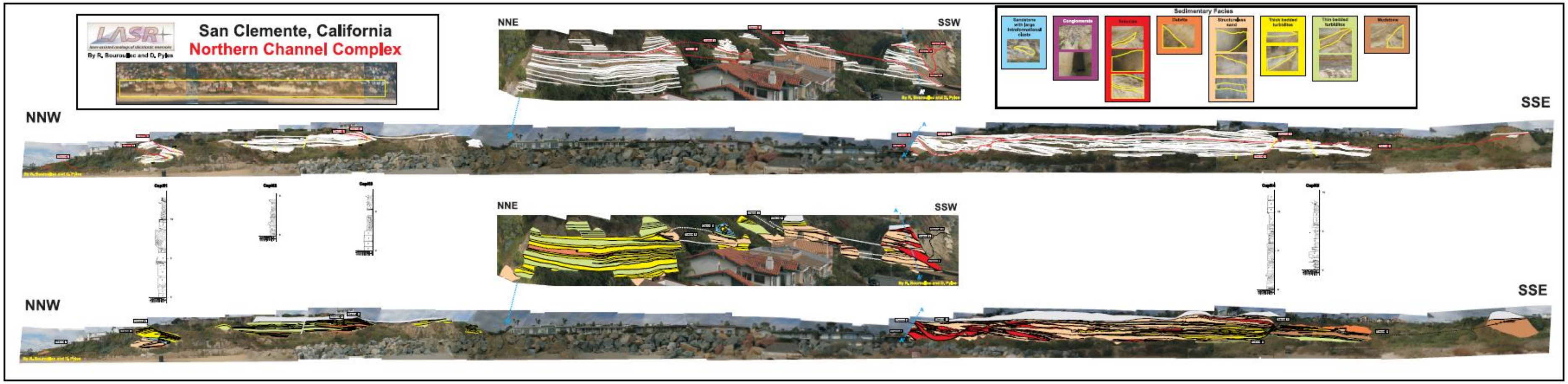
Southern part of the Southern Exposure of the Capistrano Formation at San Clemente State Beach



The panel provides comparative images of LIDAR, a photo mosaic with interpretation, and an annotated interpretation of the lithologic elements of the first four channel fill sequences.

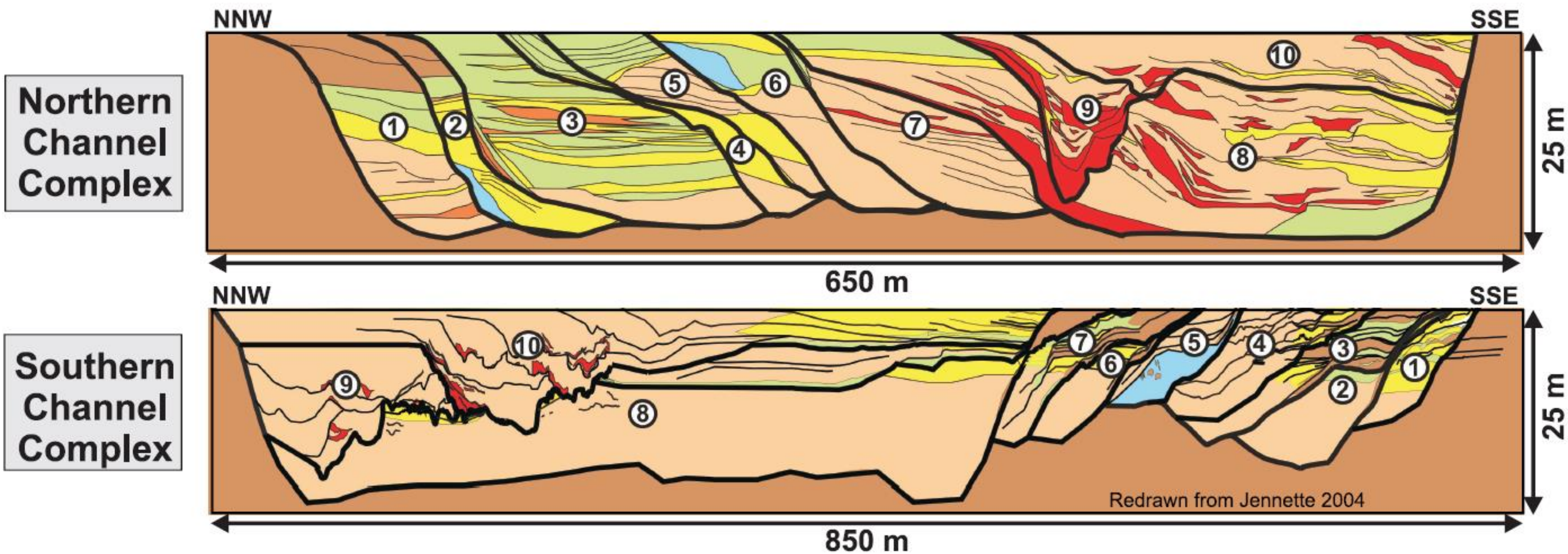
- The first deposit onto the erosive Monterey Formation flank represents Channel 1 (on right).
- Subsequent channel complex units are deposited in a left (northward) stepping succession.
- Mud drapes separate Channel 1 from Channel 2, and Channel 4 from Channel 5.

Composite photograph display of Northern Channel Complex at San Clemente Beach



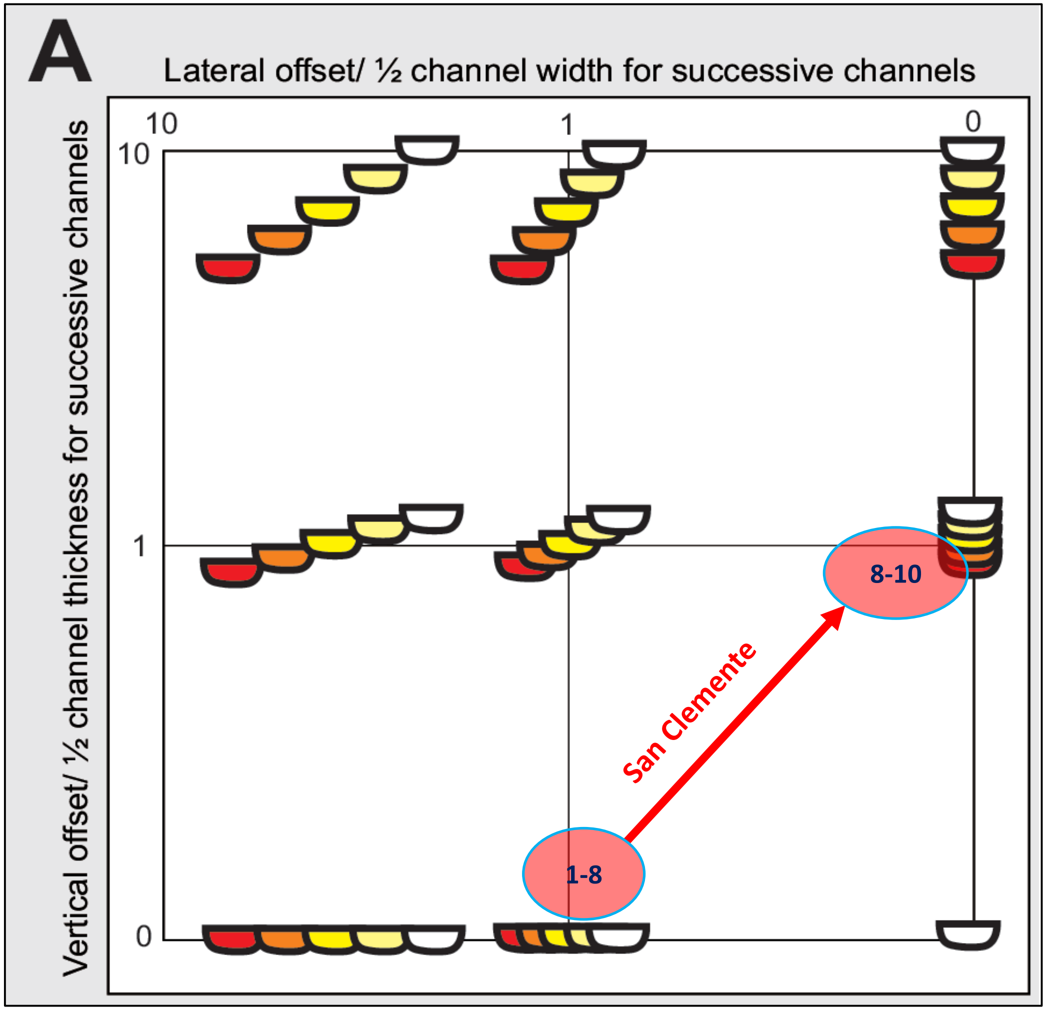
- Upper panel: bed boundaries on the photographs, while
- Lower panel: color fill representing sedimentary facies observed in outcrop and visualized in the Sedimentary Facies display.

Stratigraphic architecture of the channel complexes cropping out at the San Clemente State Beach



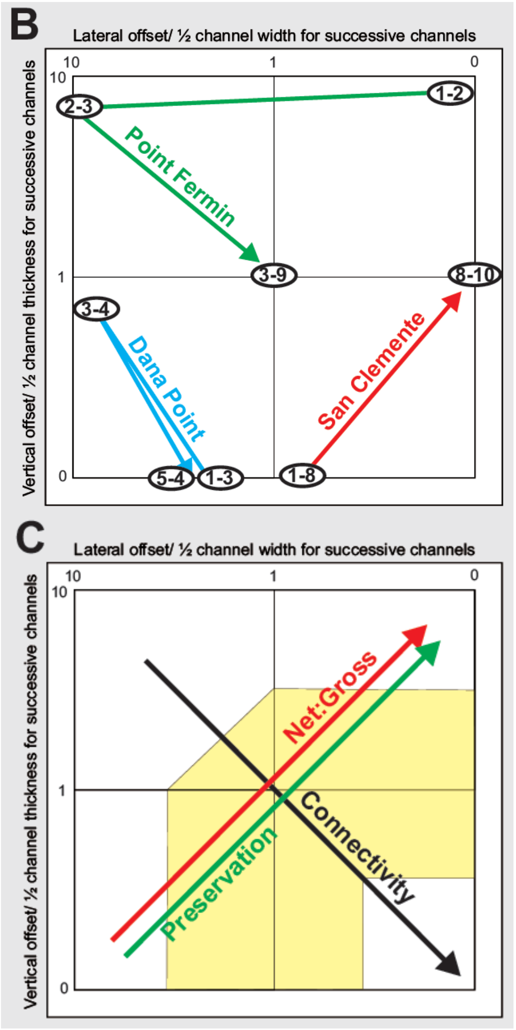
- **For both channel complexes, channels 1-8 are laterally offset and channels 9 and 10 are vertically offset.**
- **The overall net:gross of the channel complex is low but net:gross increases in the younger channels and the connectivity between channels also increases.**
- **Shale drapes seen in the South are not present in the North.**
- **Channel bases are not visible at either complex and are therefore speculative.**
- **The northern margin of channel 1 in the northern complex and the northern margin of channels 8, 9, and 10 in the southern complex are speculative.**

V/L diagram illustrating the lateral and vertical stacking of channels within the San Clemente channel complexes



- *The stacking pattern for San Clemente is illustrated in red.*
- *In a low accommodation setting, the channels first were:*
  - *laterally offset and have variable connectivity (channels 1-8) because the occurrence/preservation of shale drapes is not consistent. Then,*
  - *channels vertically offset (channel 8-10), with good connectivity between successive channels thru eroded surfaces.*

Conclusions



Variable lateral and vertical channel stacking in the three Capistrano channel complexes.

- **Point Fermin** has vertically aggrading channels with low connectivity (1-2), then laterally and vertically offset with limited connectivity (2-3), and laterally / vertically offset channels with good connectivity (3-9).
- **Dana Point** conduit channels mainly laterally offset (except some vertical motion between channel 3 and 4), with good connectivity.
- **San Clemente** high connectivity in laterally offset (1-8) then vertically offset channels (8-10). Shale drape extent will impact connectivity.

Stratigraphic analysis of the three channel complexes concerning the relationship between channel stacking pattern within a channel complex and key reservoir characteristics:

- Connectivity increases with decrease vertical and lateral channel offset.
- Net : Gross and sand facies preservation increases with increase channel vertical offset and decrease channel lateral offset.
- The yellow zone indicative of the most favorable zone for good reservoir characteristics.