Sedimentation in an Active Fold and Thrust Belt, Santa Barbara Basin, California: Spatial and Temporal Evolution of Sedimentation from 1 Ma to Present*

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Abstract

Syntectonic sedimentation in the Santa Barbara basin shows significant changes in sediment rate, volume, and depocenter location in the past 1 Ma as a result of local and regional tectonism and related changes in source to sink sediment distribution. This study provides insight into how rapidly, in space and time, deposition relevant to petroleum reservoir distribution can change within a single basin.

The prolific east-west-trending Santa Barbara basin is part of an active fold and thrust belt within the Western Transverse Ranges province. Isopach maps defined by distinctive sequence boundaries and other stratigraphic reference horizons identified on deep-penetration industry multichannel seismic reflection (MCS) data, and high-resolution MCS and USGS towed chirp data document dramatic shifts in location, shape, and accumulation rate of sedimentary depocenters in Santa Barbara Channel during the last 1 Myr. Horizon ages were assigned based on correlation to well-dated ODP Site 893, a previously recognized 1-Ma horizon derived from industry well logs, and interpolation between dated tephra layers, biostratigraphic markers, and isotope stage transitions identified from recovered cores that sample strata back to ~700 ka. Horizons were interpreted and correlated across the eastern and central basin, extending beyond ODP Site 893, then gridded. Isopach thickness maps were created from the gridded horizons, using a 3D velocity model based on approximately two dozen velocity surveys.

Sedimentation rates were highest between 1 Ma and ~790 ka, but then decreased owing possibly to the initiation of subsidence of the crest of the anticline connecting Anacapa Island to the Santa Monica Mountains, resulting in the initiation of the

Hueneme fan. Since ~710 ka, sedimentation has been focused within a WNW-ESE-trending offshore footwall basin located between the North Channel and Oak Ridge fault systems. Continued uplift across these two bounding fault systems and further development of the structurally complex northern shelf and south-bounding Mid-Channel anticline is reflected in the 3-dimensional geometry and spatial pattern of sedimentation and constriction of the main central trough. Evolution of these depocenters thus reflects the growth history of faults and folds, and related subsidence, while changes in sedimentation rates reflect the diversion of sediment sourced from the Santa Clara River.

Selected Websites

California State Fault Activity Map: State of California Department of Conservation: Web accessed 31 July 2012. http://www.quake.ca.gov/gmaps/FAM/faultactivitymap.html

NOAA National Geophysical Data Center: NGDC Coastal Relief Model: Web accessed 31 July 2012. http://www.ngdc.noaa.gov/mgg/coastal/coastal.html

Sedimentation in an active fold and thrust belt, Santa Barbara Basin, CA:

Spatial and temporal evolution of sedimentation from 1 Ma to present

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Geology CSULB

MSI UCSB

Regional Location Map and Geologic Setting

3 Major Tectonic Regimes

1. Mesozoic-Cenozoic convergence
2. Miocene-Quaternary transrotation
3. **Plio-Quaternary Contraction**

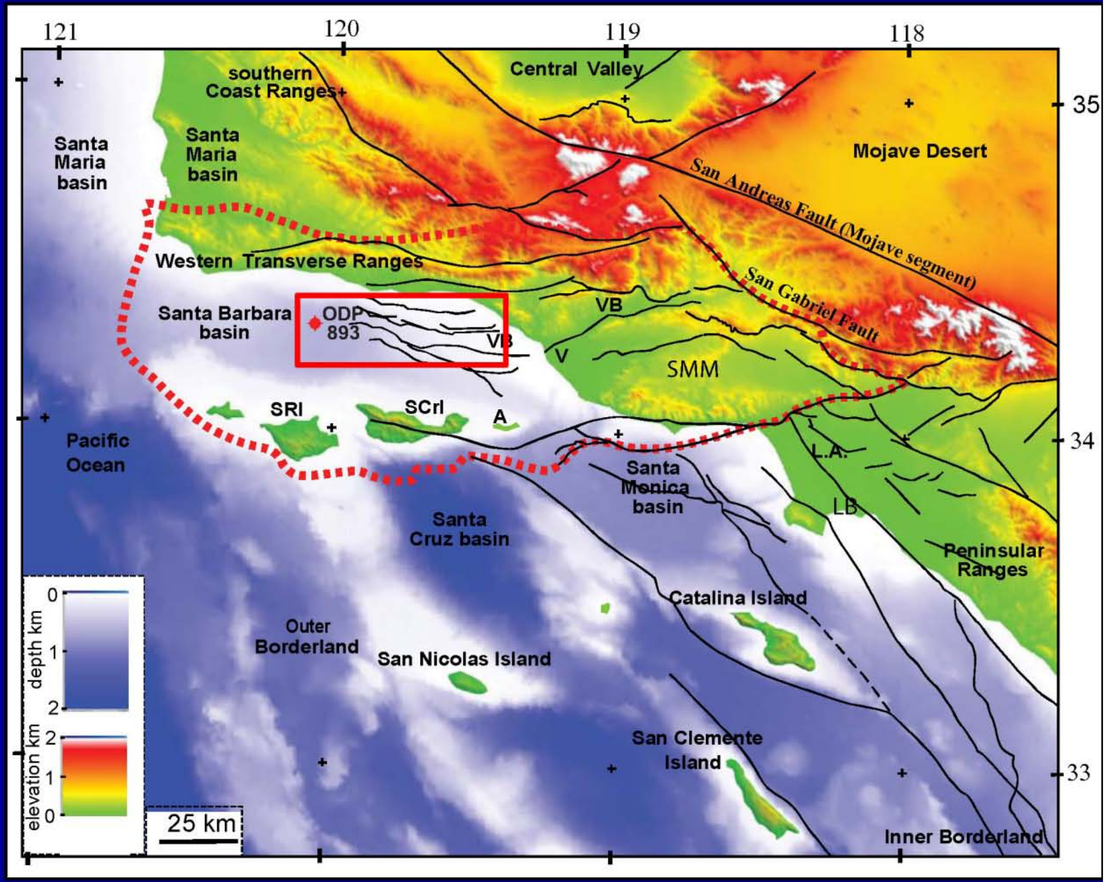
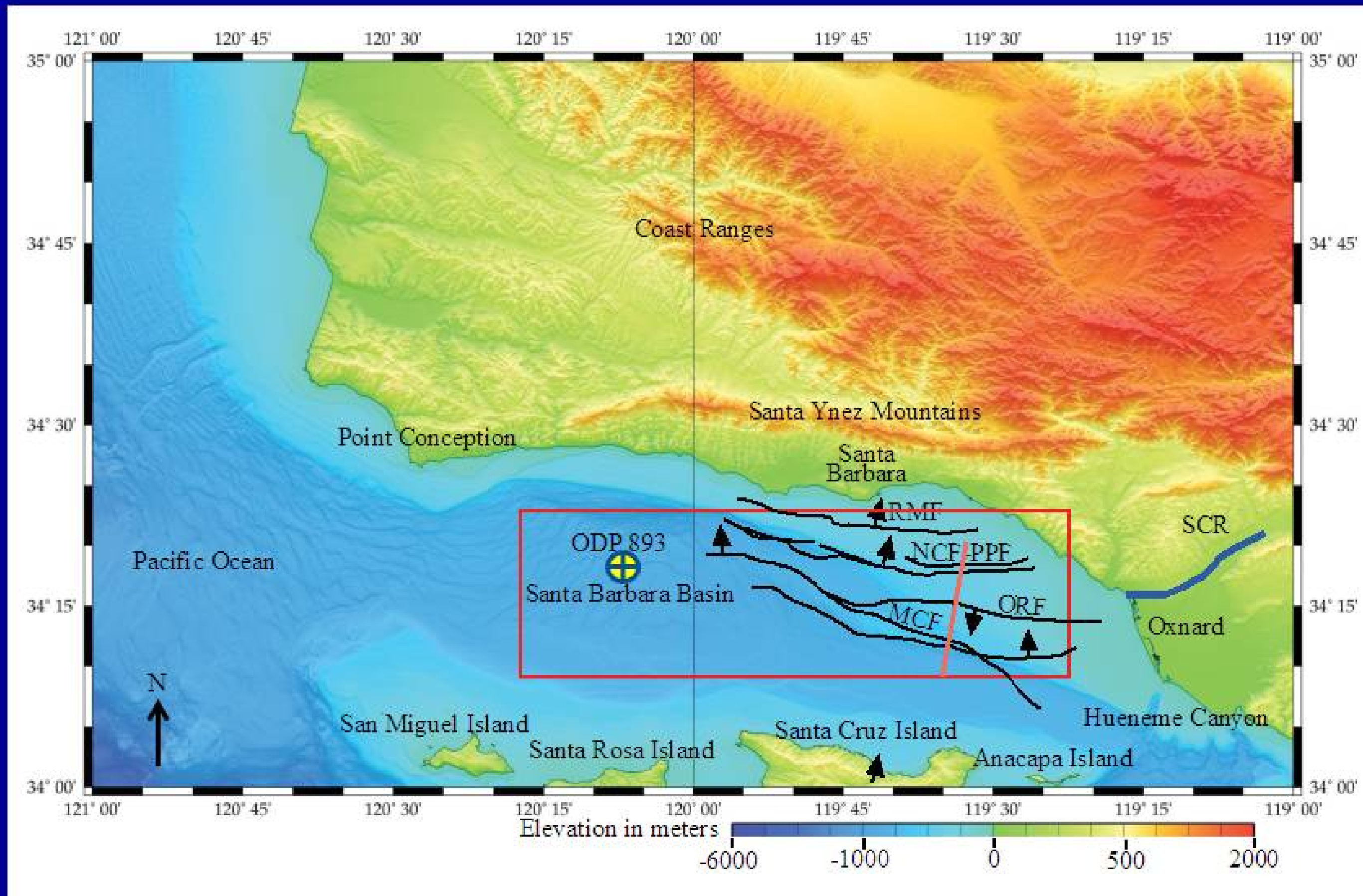


Figure modified from Community fault map, PG&E, and State fault map

Presenter's Notes: The Santa Barbara basin is presently a part of the regional fault and fold belt that makes up the Western Transverse Ranges province, a set of east-west trending anticlinal folds and synclinal basins. The SBB developed within three major tectonic regimes since the Mesozoic: a Mesozoic to early Cenozoic convergent margin subduction regime, large-scale Miocene-Quaternary transrotation, and NNE-SSW Plio-Quaternary contraction due to the initiation of the Big Bend. The NNE-SSW shortening produced rapid localized growth of east-west trending folds, as well as rapid subsidence and sedimentation in the synclinal areas, including the Santa Barbara-Ventura basin.

Study Location

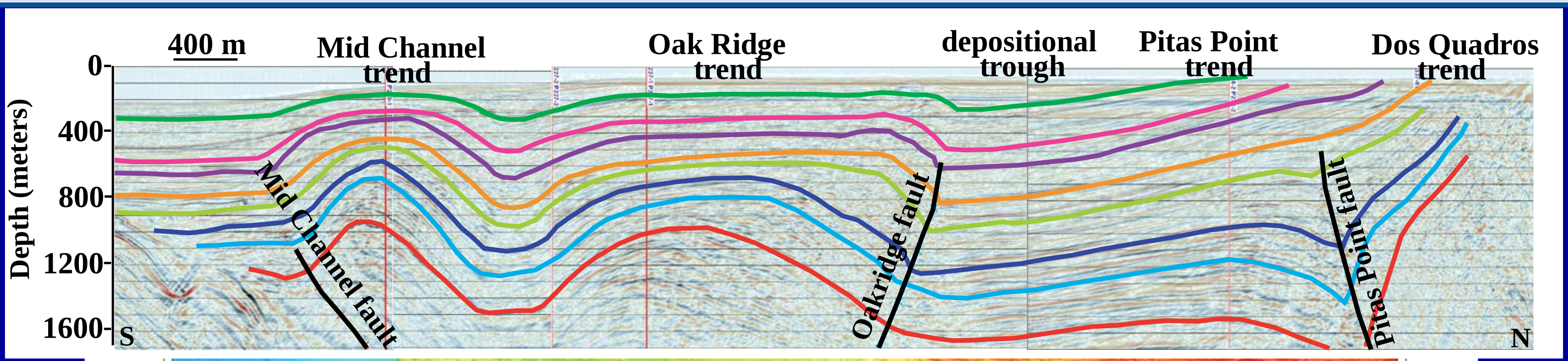


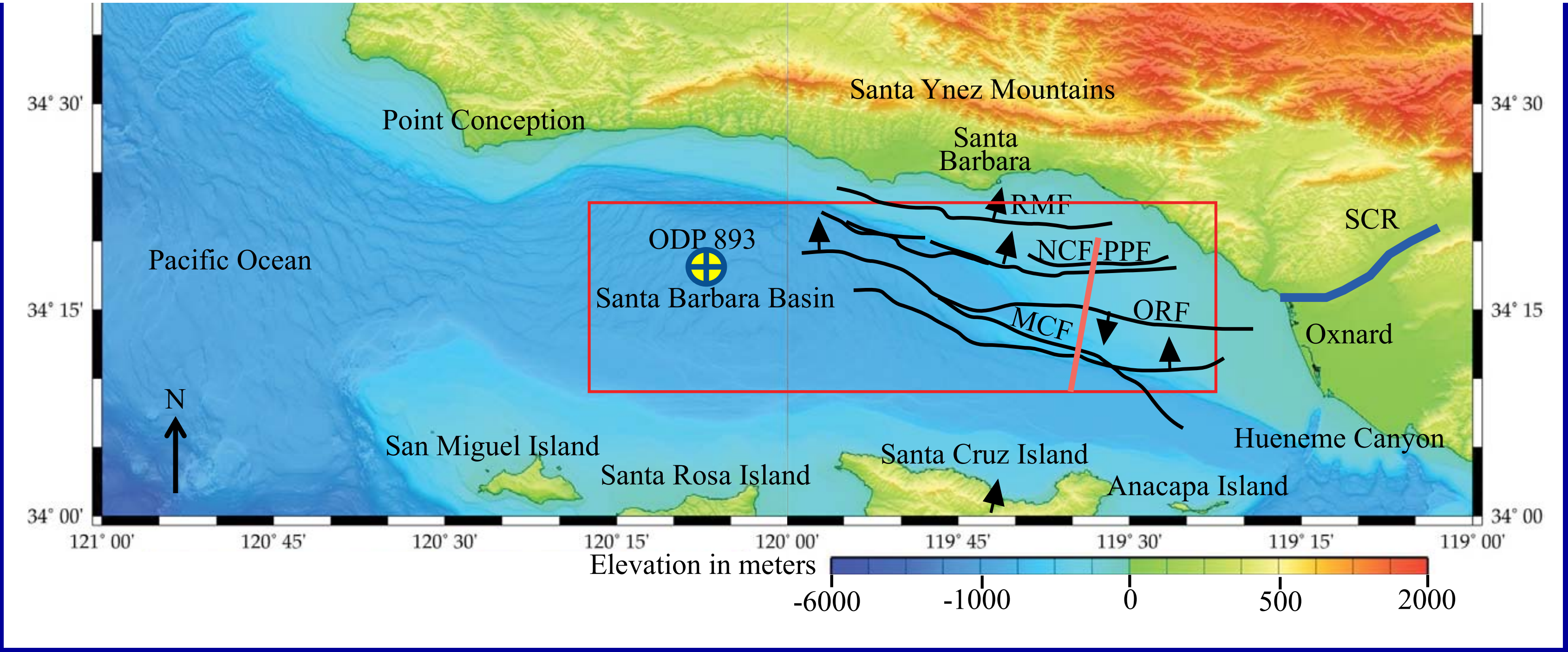
Modified from NOAA National Geophysical Data Center, NGDC Coastal Relief Model

Presenter's Notes: The Santa Barbara Channel covers the modern marine area between the mainland coast and the northern Channel Islands. My study location the main central trough of the offshore Ventura basin, is an east-west trending asymmetric basin bounded by the Mid Channel and Oak Ridge Trend related to the Oak Ridge fault in the south and the Dos Quadros and Pitas Point trends related to the Pitas Point-North Channel-Red Mountain fault system in the north. The narrow, east-west trending depositional trough broadens westward, near ODP 893, where the modern Santa Barbara bathymetric basin is located.

The bounding structures shape the SBB into a silled basin, with hemipelagic sedimentation being the primary type of late Quaternary deposition. The Santa Clara River (SCR) is the largest present-day source of sediment providing 95% of sediment into the basin. The lower watershed of the Santa Clara River is characterized by the highest uplift rates in South California.

Study Location





Modified from NOAA National Geophysical Data Center, NGDC Coastal Relief Model

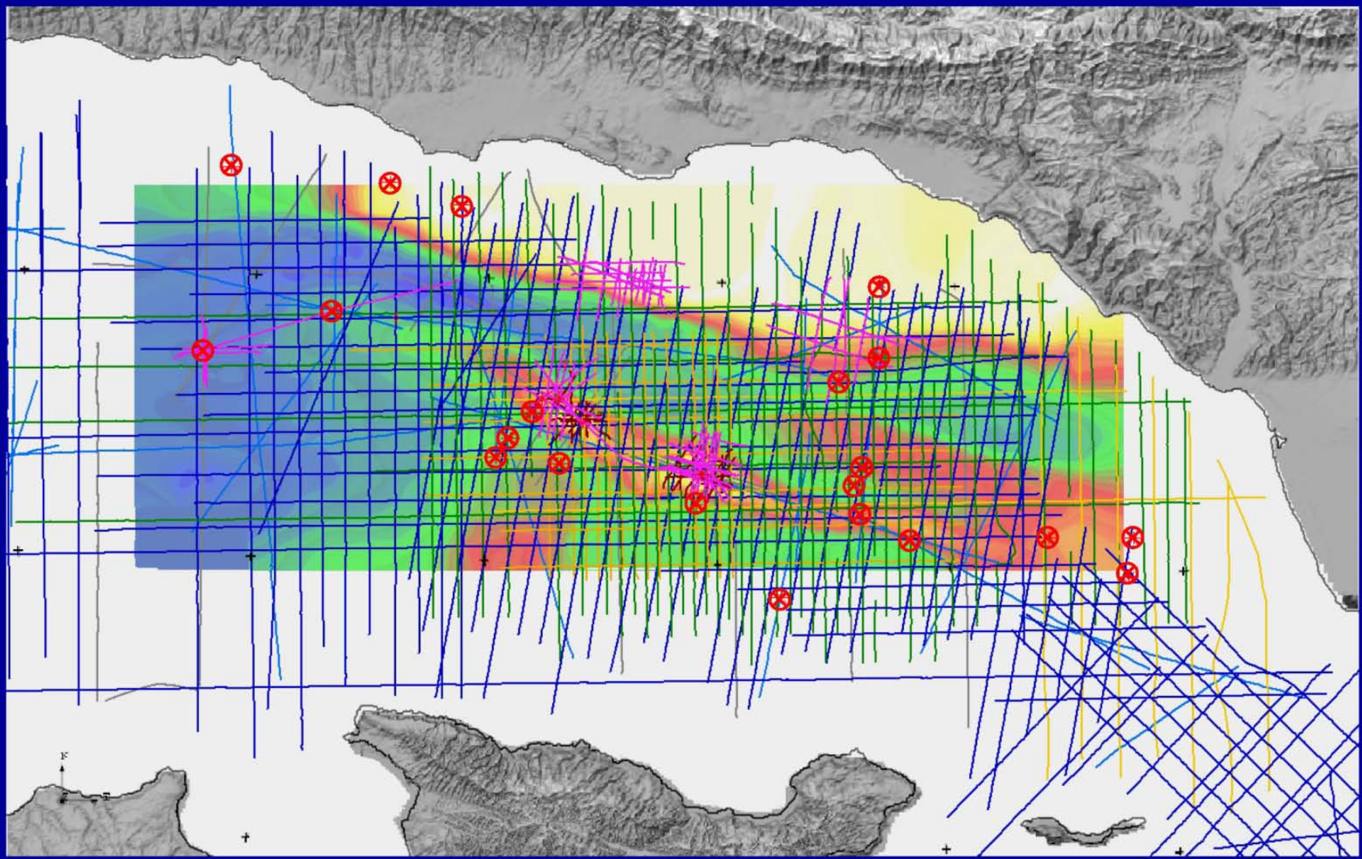
Objectives

- To determine the spatial and temporal distribution of sediment from 1 Ma to present
- Identify and outline distinct stratigraphic packages
- To identify trends and shifts in the sediment accumulation and distribution

Hypotheses

- Even though this time period had dramatic swings in glacial-sea level, the rate (mm/yr) of total sediment accumulation is primarily controlled by the tectonic influence on sediment supply in the past 1 Ma.
- The sequence stratigraphic structure of the sedimentary accumulation within horizon-bound intervals is primarily controlled by changes in accommodation space and location
- The growth of basin-bounding, active faults and folds has controlled the size and location of primary depocenters

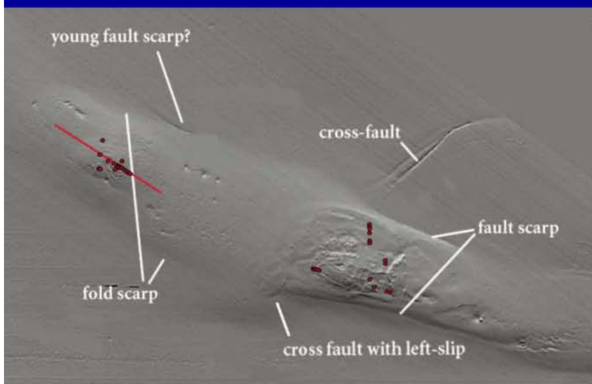
Seismic Base Map



- Western Geophysical deep penetration TWTT seismic data (shown as blue)
- High resolution multichannel seismic airgun and towed chirp data (shown as hot pink)
- Various Mineral Management Services well data
-ODP-893 (Ocean Drilling Program)

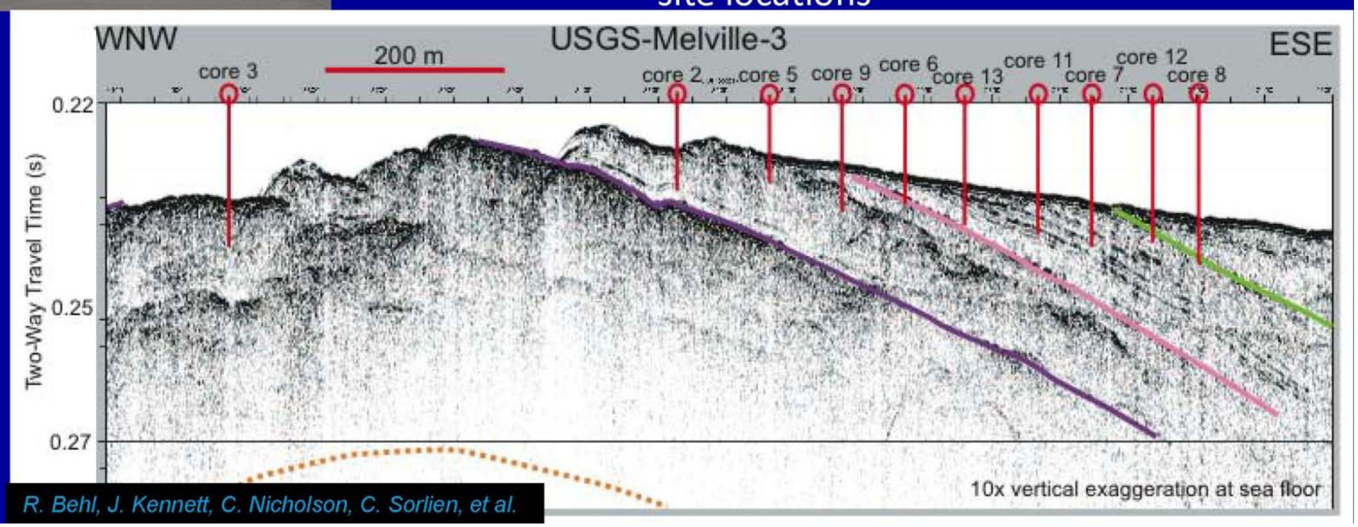
Presenter's Notes: ODP-893 provided the uppermost subsurface horizon at 120 ka. A mapped 1-Ma time horizon, the use of the MIS stage-level climate transitions and constant sedimentation rate near ODP 893 provided interpolation of ages of five previously mapped horizons, and three newly identified sequence stratigraphic horizons.

Seismic Tie to Piston Core Locations



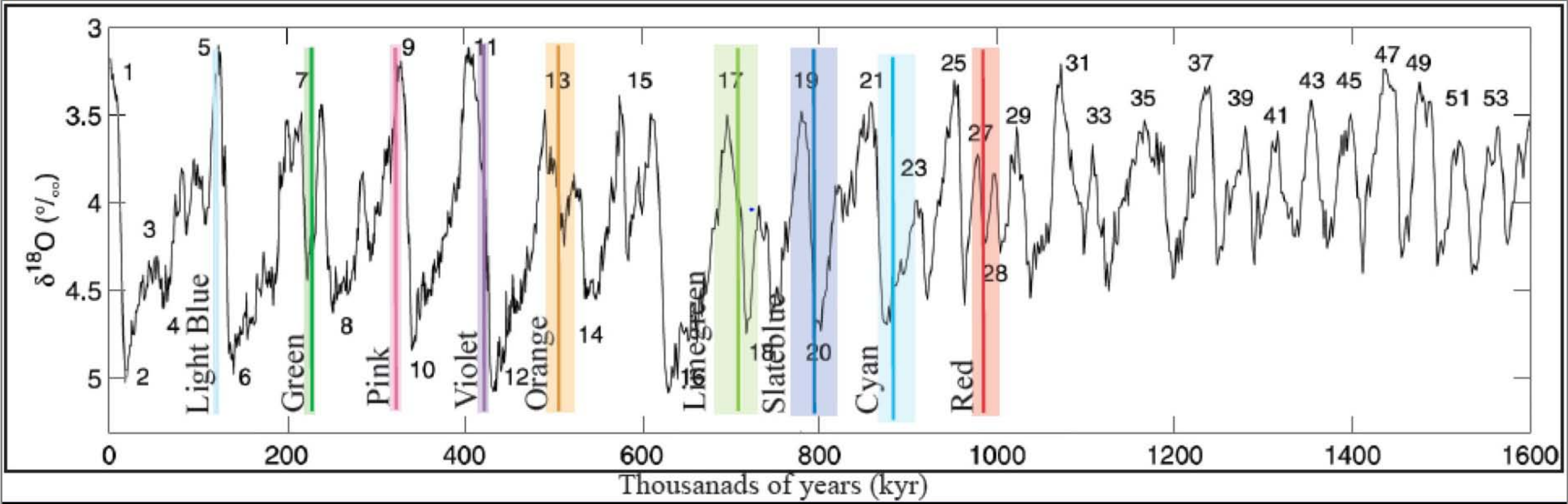
MBARI bathymetry of the Mid Channel trend with piston core locations

High-resolution chirp record over Mid-Channel Trend showing dipping outcrop of older late-Quaternary strata and core site locations



Presenter's Notes: This shows an example of the high quality, high-resolution chirp data we were able to acquire, interpret, and use to pick core site locations. The record clearly shows how older late-Quaternary strata (that in this case extend in age from about 150 to 450 thousand years) crop out along the seafloor. By judicious sampling with piston core, as we did at these marked locations, we could systematically recover each of these older stratigraphic sequences. Eventually, 32 piston cores were successfully recovered over the Mid-Channel Trend, with typical core penetration ranging from 3 to 5.5 m.

Horizon Ages Refined Using Piston Core Data:



1. 30 Piston Cores (red) correlated relative to seismic stratigraphic position and δO18 value relative to LR04 curve (grey) down to ~700 ka.

2. Biostratigraphic, climatic, and/or chronostratigraphic constraint provided additonal age refinement.

3. 1 Ma time-horizon used for interpolation of horizons older than ~700 ka.

Presenter's Notes: Individual core range in age from Holocene to ~700 ka, as shown on the chart to the right. The seismic stratigraphic position relative to cores provided biostratigraphic, climatic, and/or chronostratigraphic constraint. The top chart shows the age of the horizons with respect to the MIS stage-level climate transition curve. The lighter band represents range in error of these horizons. Therefore, for the horizons Limegreen, Slateblue, and Cyan that were deeper than the core depths, the range in error increases to ~+/- 30 ka.

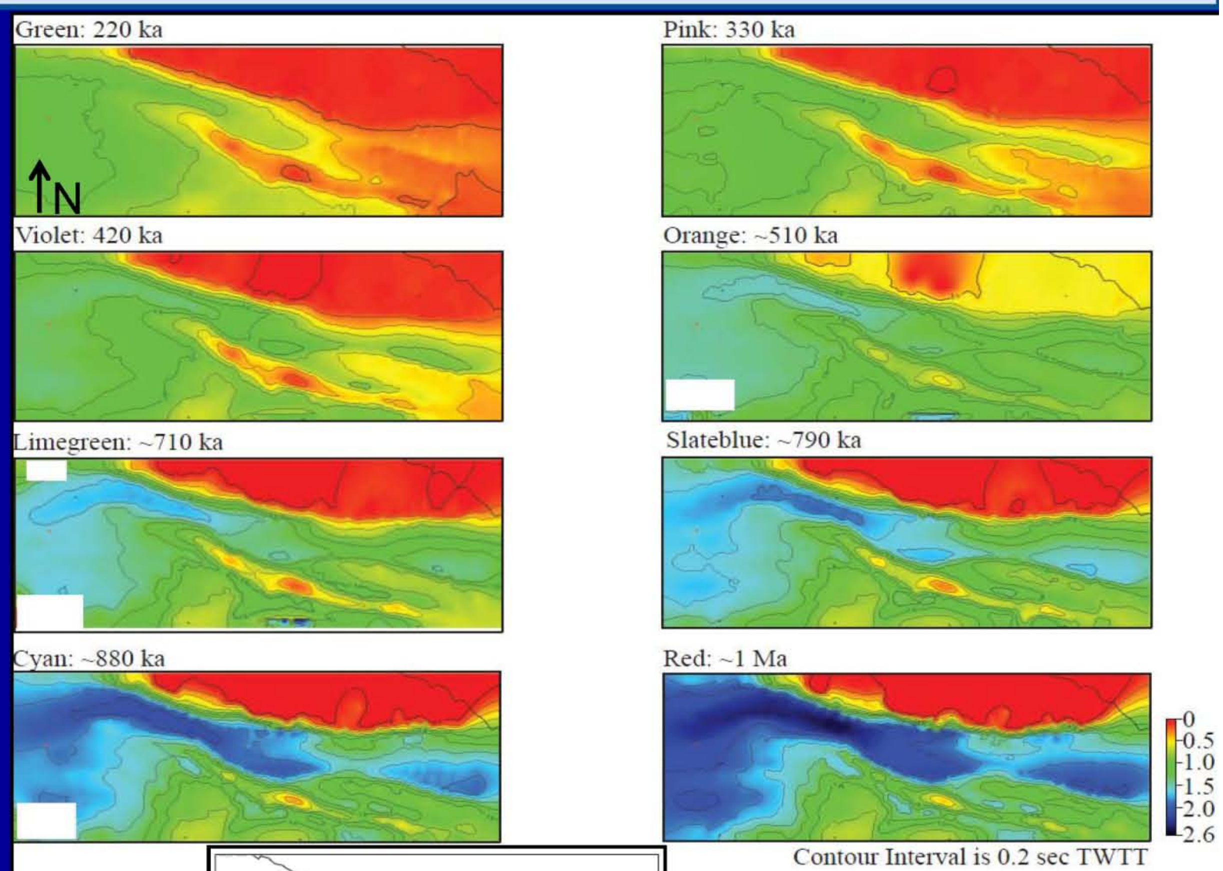
TWTT Structure Contour Maps of each horizon

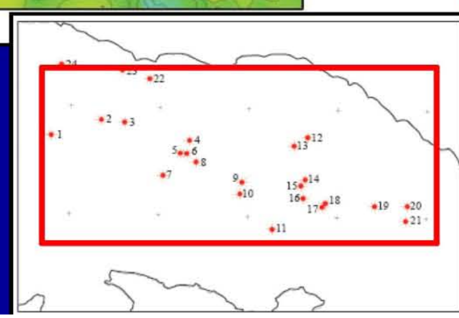
-24 wells used to create TD charts and velocity model of each gridded surface.

-Depth structure grids created.

-Isopach maps created for each horizon interval with dip maps.

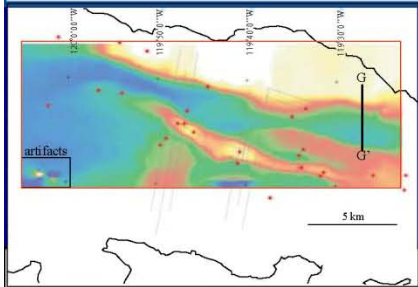
-Sedimentation rate maps used for analysis

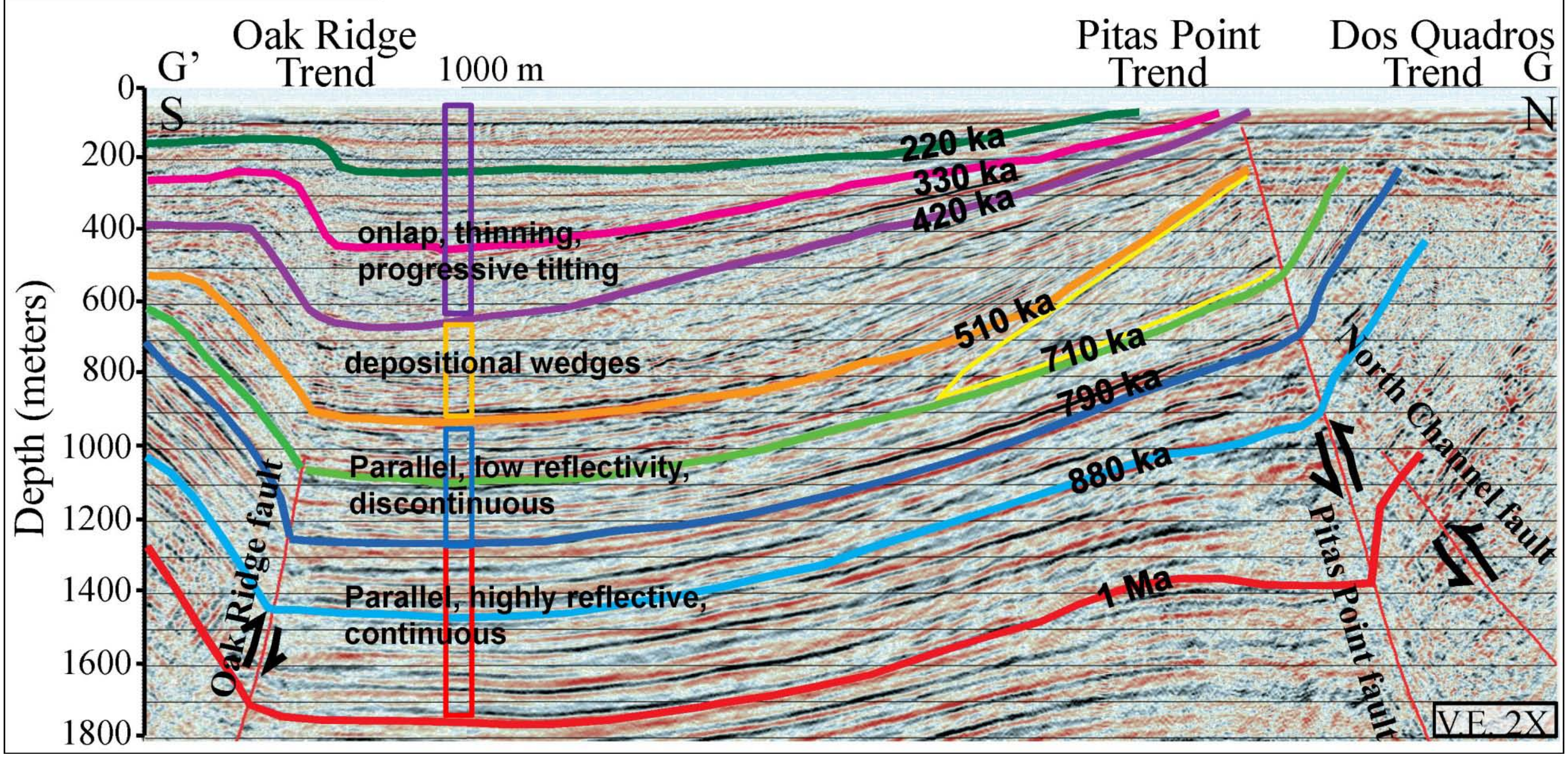




Presenter's Notes: Each interpreted horizon was then gridded in TWTT. To get an understanding of the study location for future figures, 1 is the northern shelf, 2 is the Mid Channel Trend, 3, is the Oak Ridge Trend, and 4 is the depositional trough on each figure.

Seismic Stratigraphic Packages

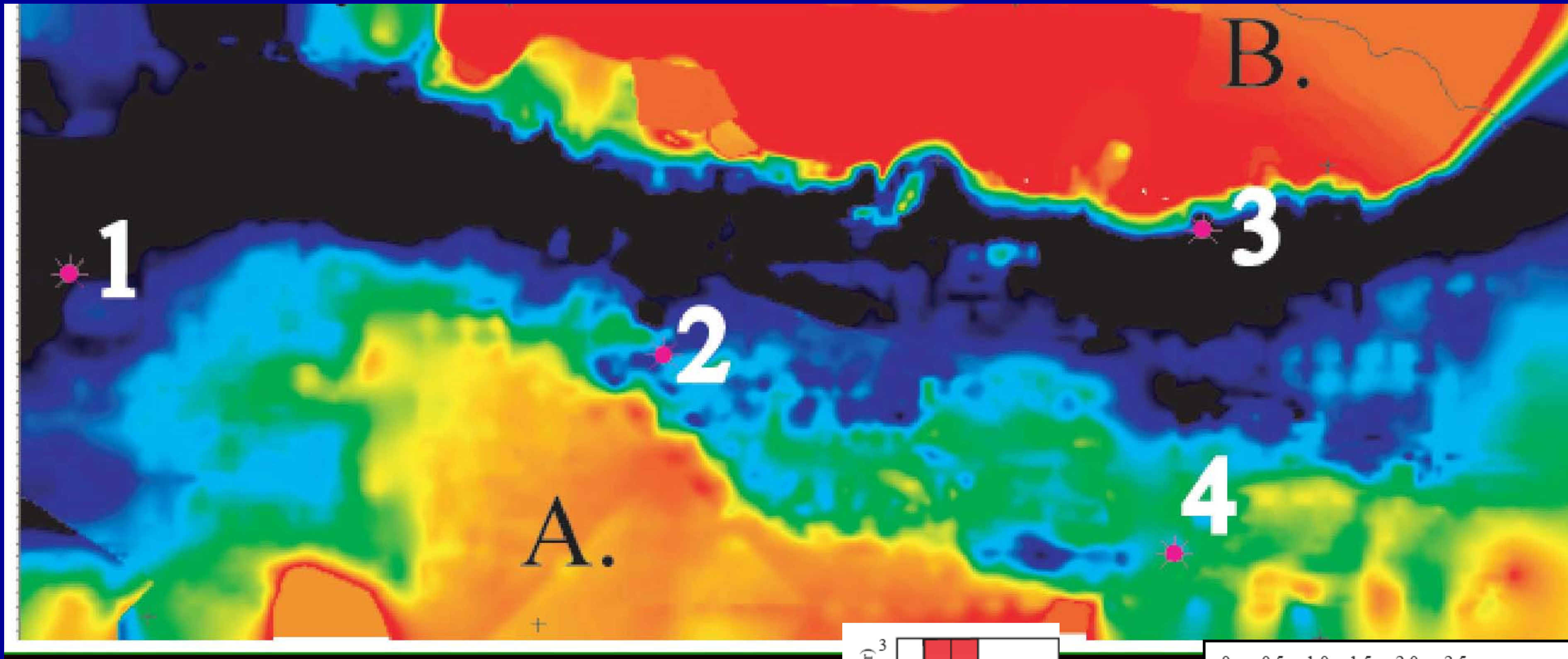


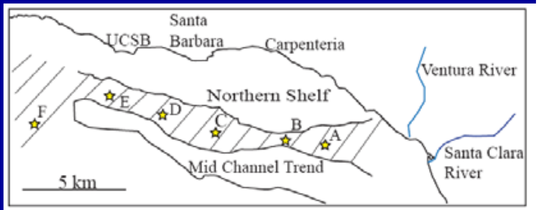


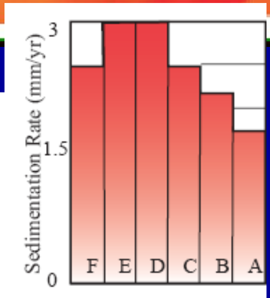
Presenter's Notes: Cross-section G'-G is a dip line located in the eastern SBB. You can see the Oak Ridge, Pitas Point, and Dos Quadros Trend as well as the fault locations. Continuing with the 4-phase sediment distribution, you can actually analyze the seismic stratigraphic character and identify different packages. From 1 Ma to 790 ka (Red, Cyan to Slateblue), you can see relatively parallel, *(notes continued on next slide)*

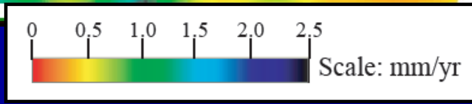
highly reflective, continuous horizons. On the isopach map this was when sedimentation rates were high, and uniform across the depositional trough over a broader area, typical of high discharge volumes of sediment depositing rapidly (very much like turbidites). From 790 ka to 510 ka (Limegreen to Orange), the reflections have low reflectivity, and are parallel but relatively discontinuous. On the isopach map, sediment distribution was still uniform, but sedimentation rate at declined dramatically, and you could start seeing the growth of the southern and northern-bounding structures. The low reflectivity could be a result of the waning of sediment volume into the depositional trough during this time. Also note the interval thickening approaching the Pitas Point fault, and a very restricted, steeply dipping, progradational depositional wedge is present (yellow border). This wedge is truncated by the Pitas Point fault to the north. From 510 ka to 420 ka, the eastern Santa Barbara Channel acquired a thick section of sediment, deposited as a series of depositional wedges. These wedges are only evident in the eastern SBB, in proximity to the source of sediment. The interval isopach map displayed sediment accumulation being restricted to the eastern SBB. From 420 ka to present, you can see evidence of progressive tilting, resulting in onlap and thinning without onlap, as the eastern Santa Barbara Channel fills and sediment progrades into the western Santa Barbara Channel. The next slide is an expanded display of the black box.

Red to Cyan (1 Ma – 880 ka) 236.3 km^3

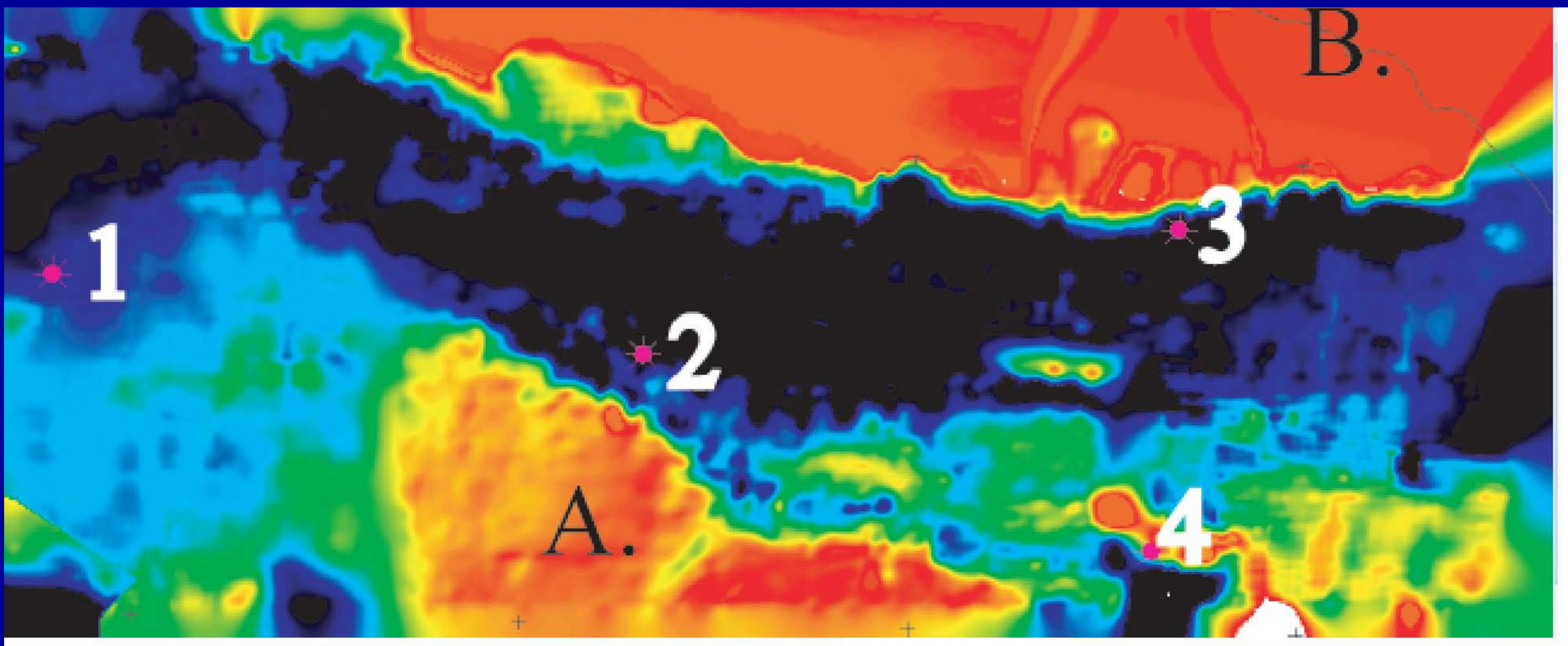


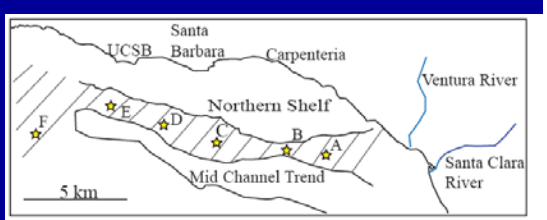


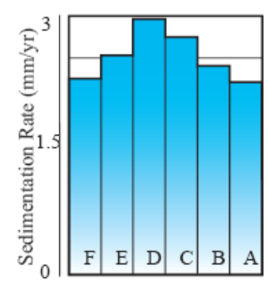


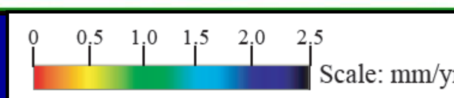


Cyan to Slateblue (880 ka – 790 ka) 197.1 km^3

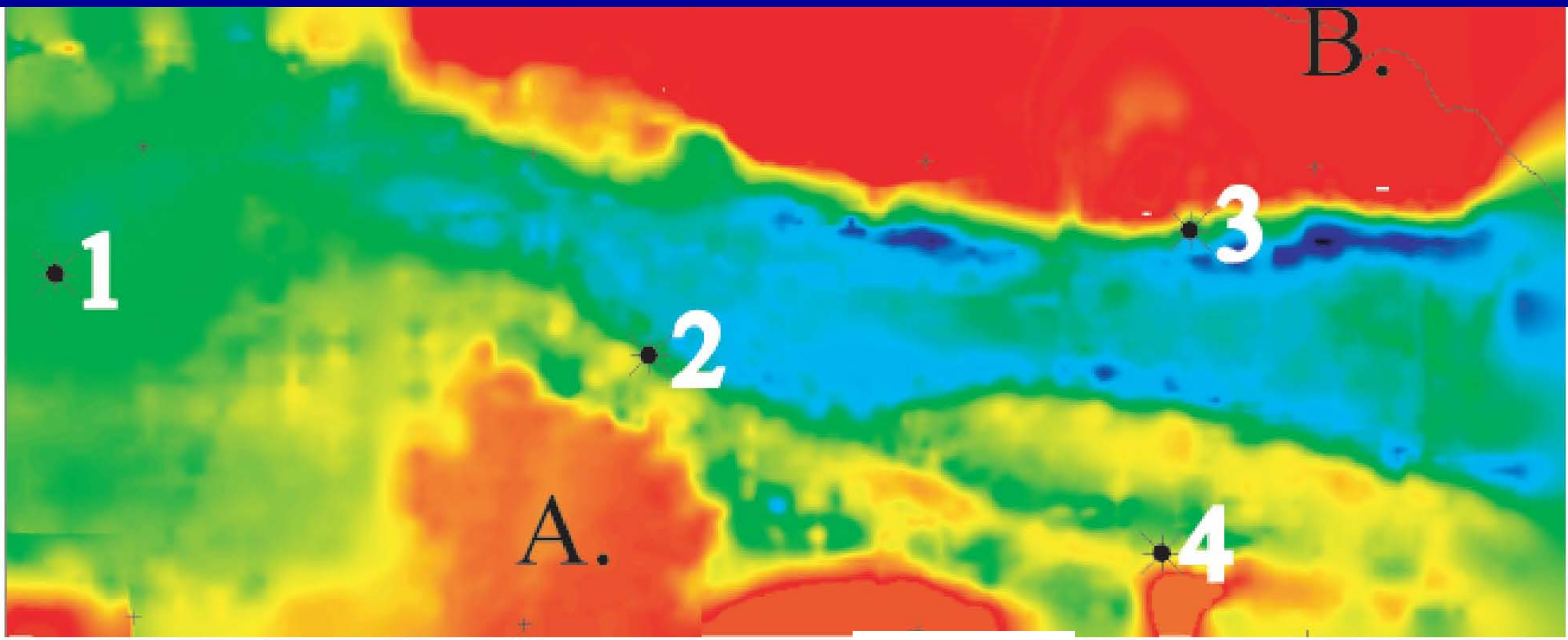


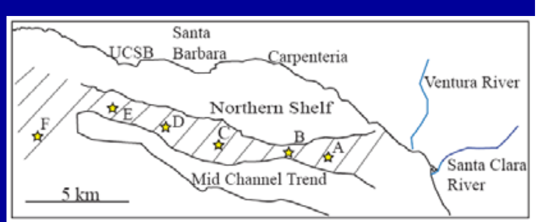


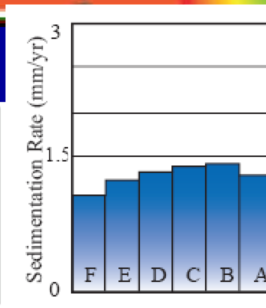


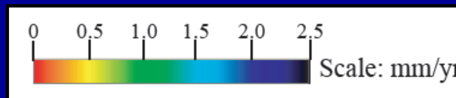


Slateblue to Orange (790 ka – 510 ka) 306.6 km^3

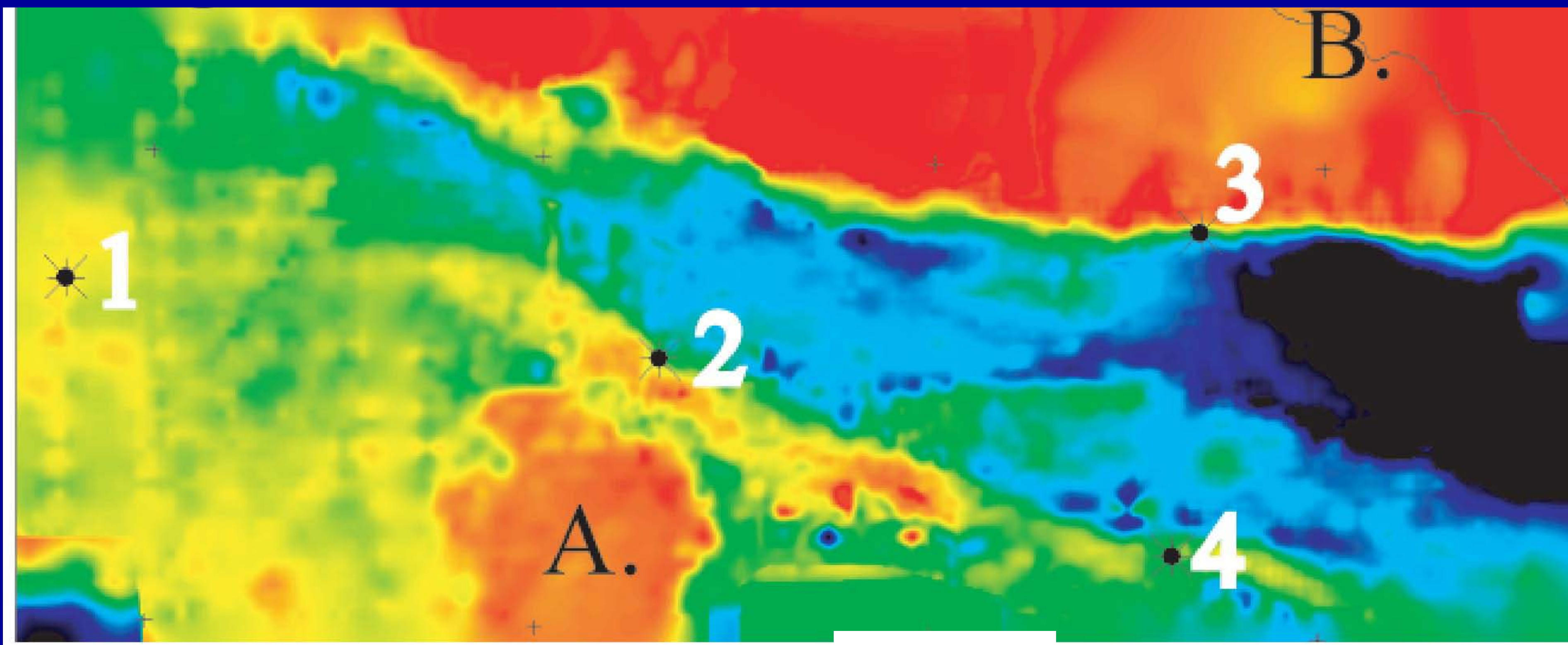


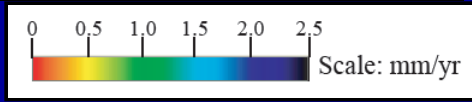


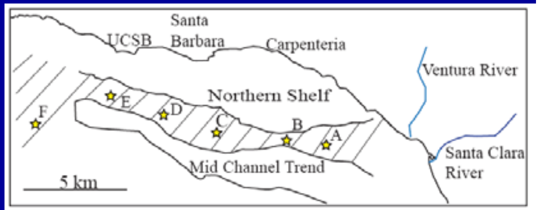


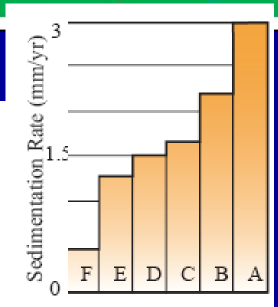


Orange to Violet (510 ka – 420 ka) 122.2 km^3

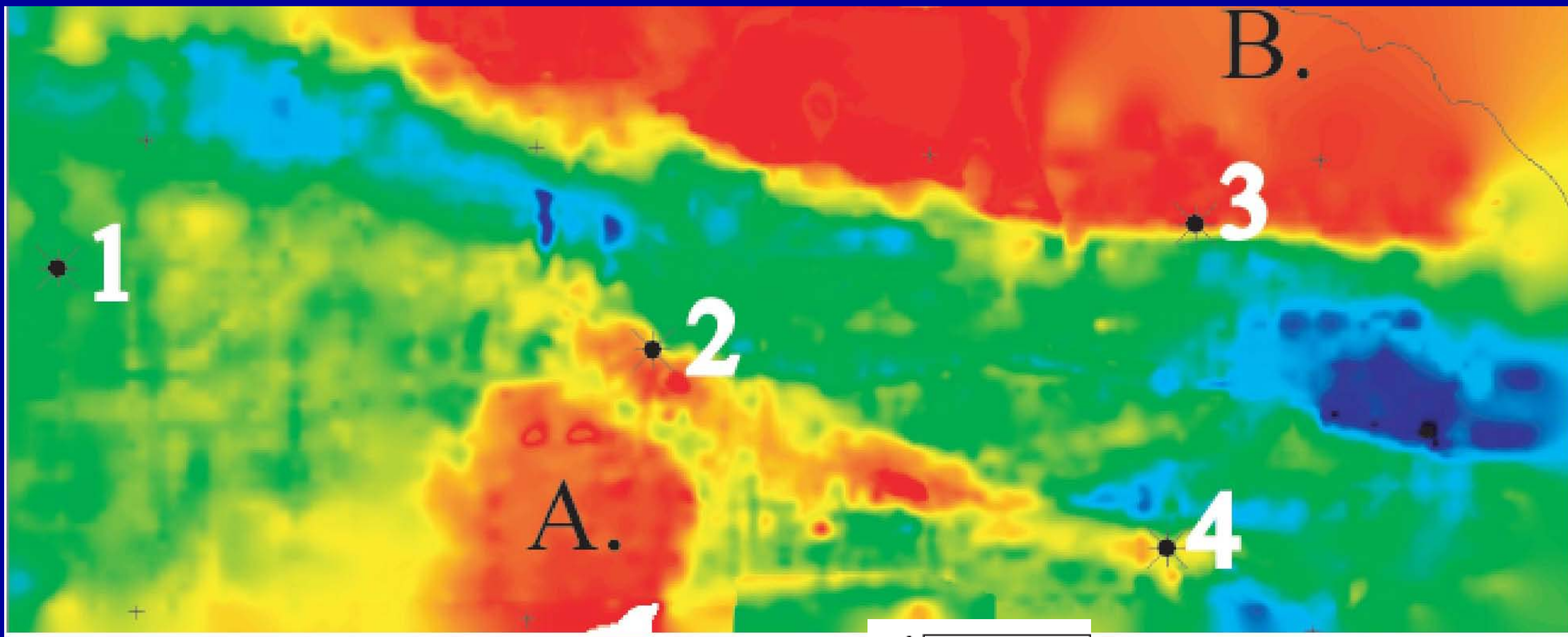


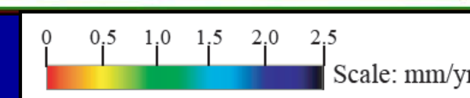


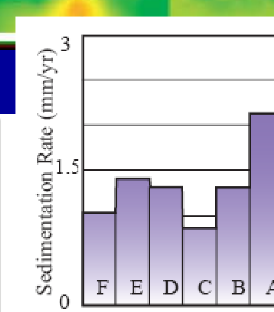




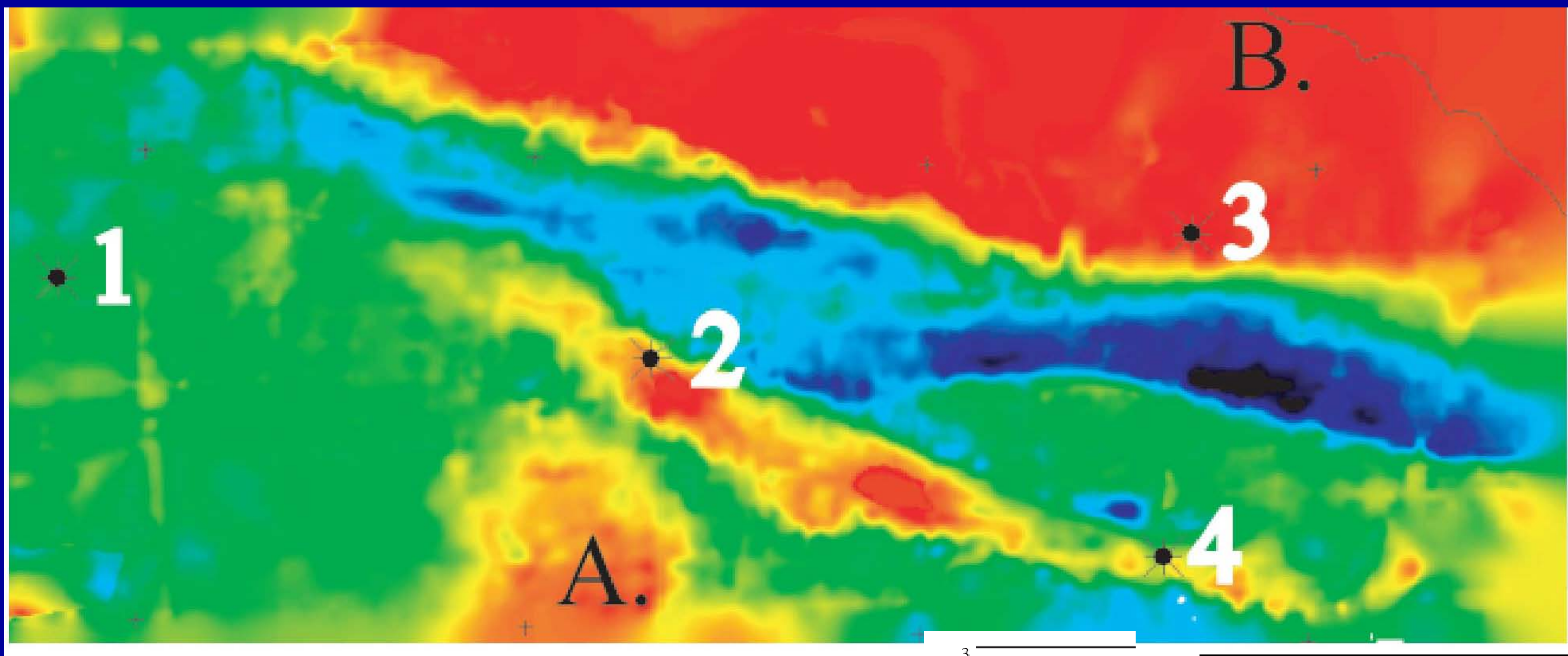
Violet to Pink (420 ka – 330 ka) 97.3 km^3

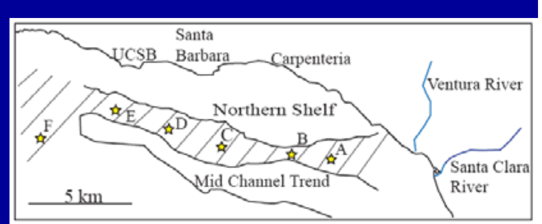


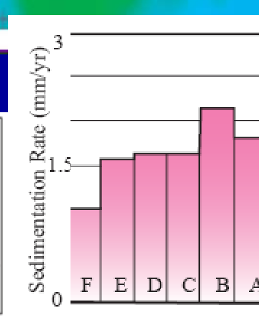




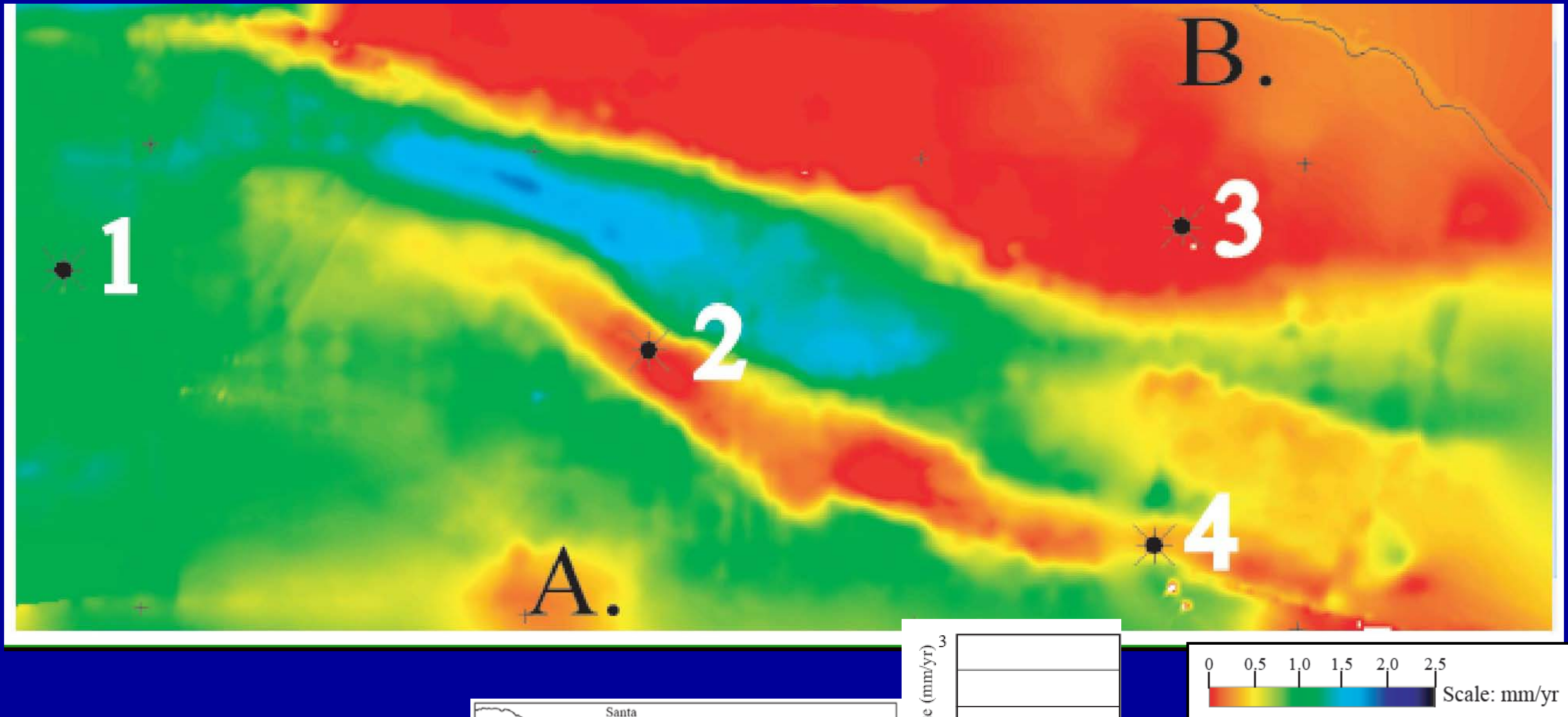
Pink to Green (330 ka – 220 ka) 134.8 km^3

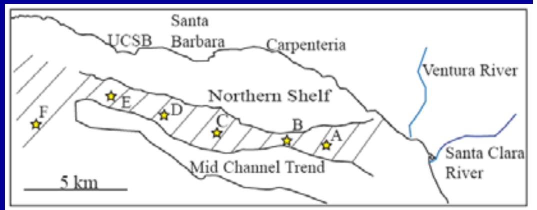


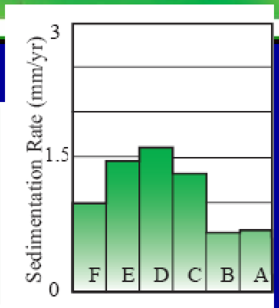




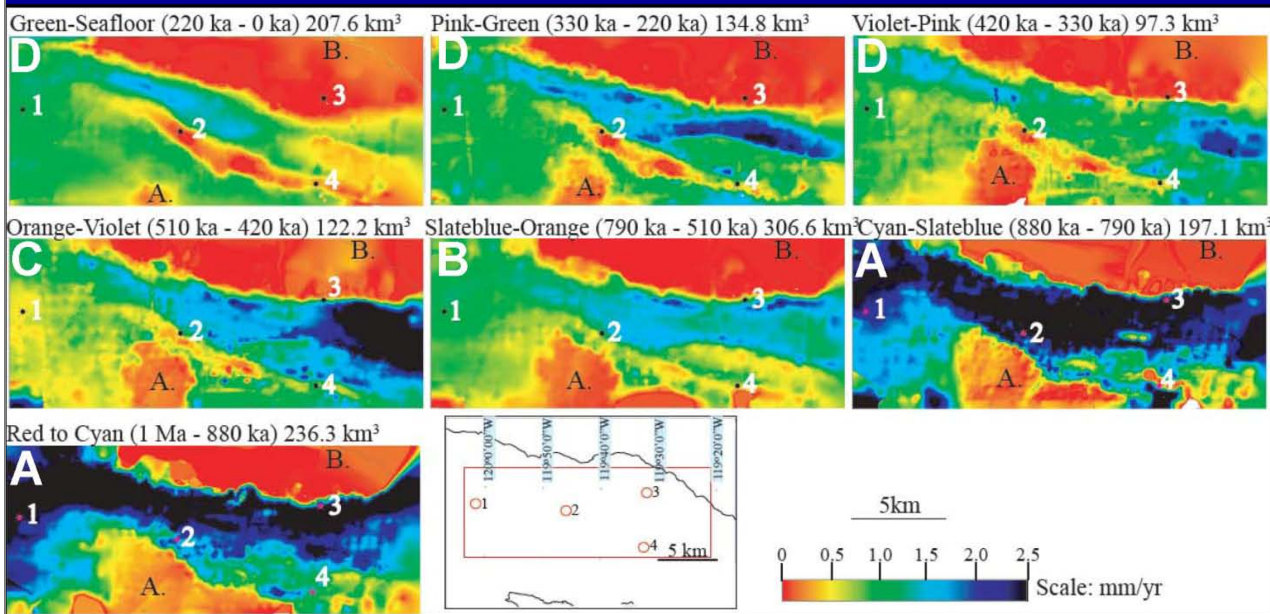
Green to Seafloor (220 ka – 0 ka) 207.6 km^3







Four Phase Sediment Accumulation



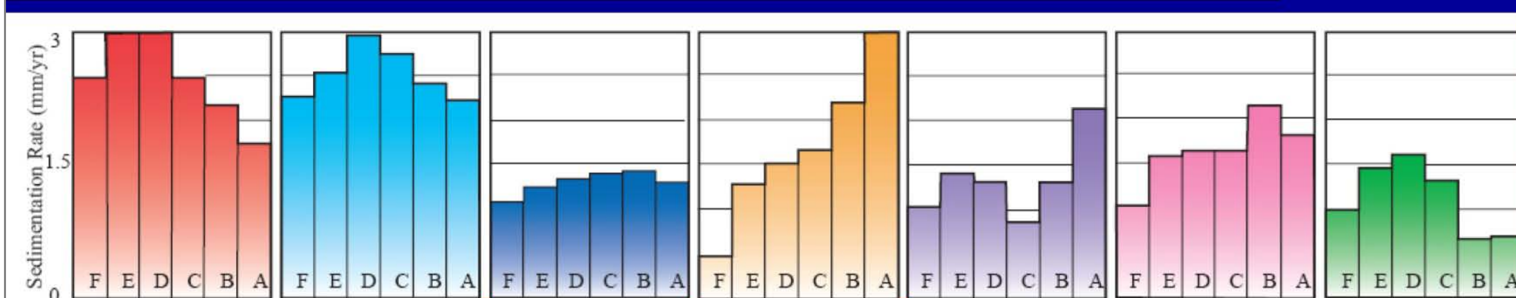
4 step sediment evolution:

A. 1 Ma to 790 ka

B. 790ka to 510 ka

C. 510 ka to 420 ka

D. 420 ka to 0 ka



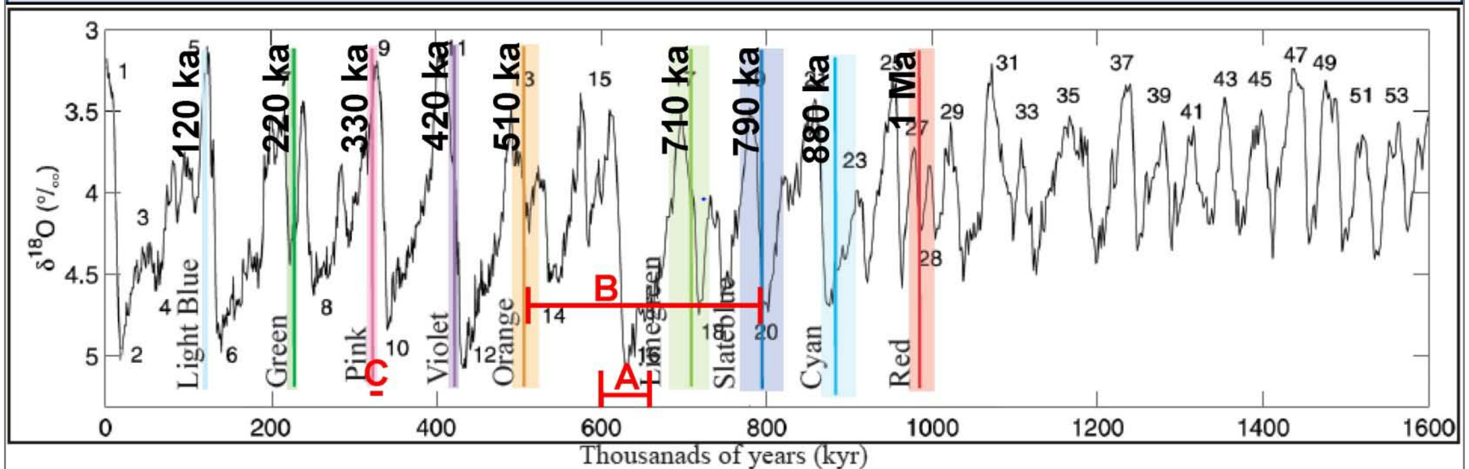
1Ma-880ka | 880ka-790ka | 790ka-510ka | 510ka-420ka | 420ka-330ka | 330ka-220ka | 220ka-now

Presenter's Notes: Here are the interval sedimentation rate maps. Above the maps, you can see the horizons and ages, as well as the total volume of sediment accumulated during that time period. Well locations 1-4 are labeled on each map in order to get an understanding of the lateral change in location of the depositional trough. In addition, keep in mind the scale bar is uniformly scaled from 0 to 2.5 mm/yr. *(notes continued on next slide)*

This does NOT mean that max sedimentation rate is 2.5 on any of these maps. In the lower right hand corner, I give max sed rates for each interval. The 4 phases of sediment distribution include from 1 Ma to 790 ka, when sed rates were relatively uniform across the entire basin, and consistently high. From 790 to 510 ka, sediment continued to be distributed overall uniformly across much of the basin, but sediment accumulated at a markedly slower rate. From 510 to 220 ka, sediment accumulation rates were more variable east-west across the depositional basin, being primarily focused in the eastern SBB. From 220 to present, sediment accumulation rates dramatically decreased in the eastern SBB, and sediment refocused to the western SBB.

You can also see that the location of well #3 was once an area of deposition, where it is presently an area of non-deposition/erosion. The same occurs for wells 2 and 4. Also, note the growth of the MCT starts in the eastern basin, and appears to propagate to the west. This is characteristic of the MCT. I am now going to show you some dip lines, and you can start to see that the 4-phase sediment distribution can also be seen in the seismic data.

Why did sediment volume decrease by 44% ~790 ka to ~510 ka?



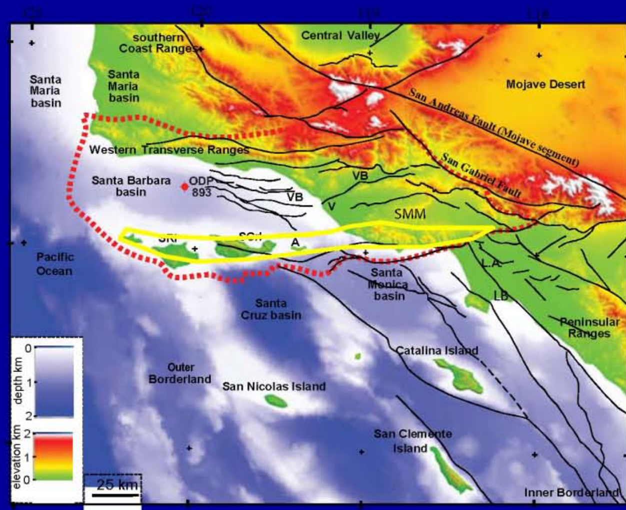
A. ~650 ka – 600 ka, the first low sea level after Mid-Pleistocene Transition occurred.

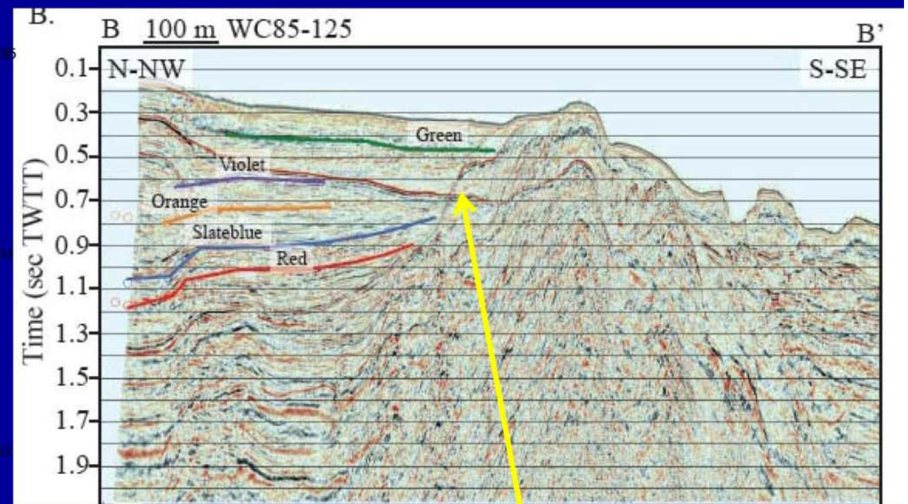
B. During this time interval, the Santa Susanna Mtns were reportedly uplifting, providing additional erosional area and relief for drainage to the Santa Clara River.

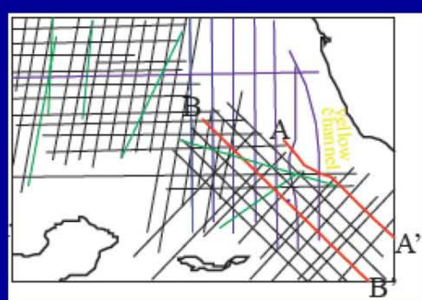
C. Bill Normark proposed that at MIS 10 (~320 ka), this low-stand caused the initiation of the Hueneme Fan located between the SBB and the Santa Monica basin, diverting nearly all sediment into the neighboring Santa Monica basin.

Presenter's Notes: ~650-600 ka, the first occurrence of the very high delta O18 and low sea level in the Cenozoic occurred after the Mid-Pleistocene transition. However, deep-water sedimentation tends to increase during low-stands, rather than slowing as it does here. Taken alone, the narrowing of the offshore SBB from 790 ka to 510 ka would have decrease total accommodation space resulting in higher sedimentation rates across a smaller area, and that is not seen either. During the time interval from 790 ka to 510 ka, Treiman and Saul report the Santa Susanna Mtn's were uplifting, which created an additional erosional area and relief for drainage to the SCR. By itself, additional catchment area would further increase sediment supply, and increase sedimentation rate to the offshore SBB, but the opposite is seen. The reason there is less sediment accumulation in the eastern SBB during that time (Pink to Green) is not a result sediment diversion, but the filling and progradation of sediment into the western SBB. There are seismic lines that cross Anacapa Ridge.

Santa Monica Mountain-Channel Island Anticlinorium and Anacapa Ridge



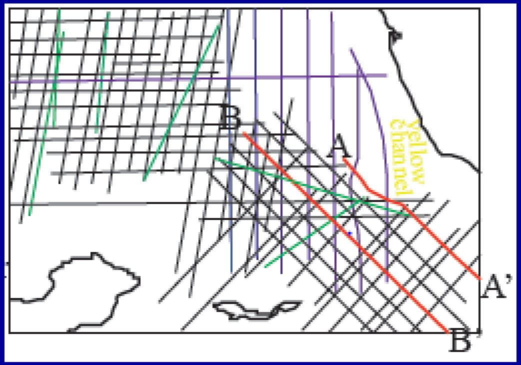


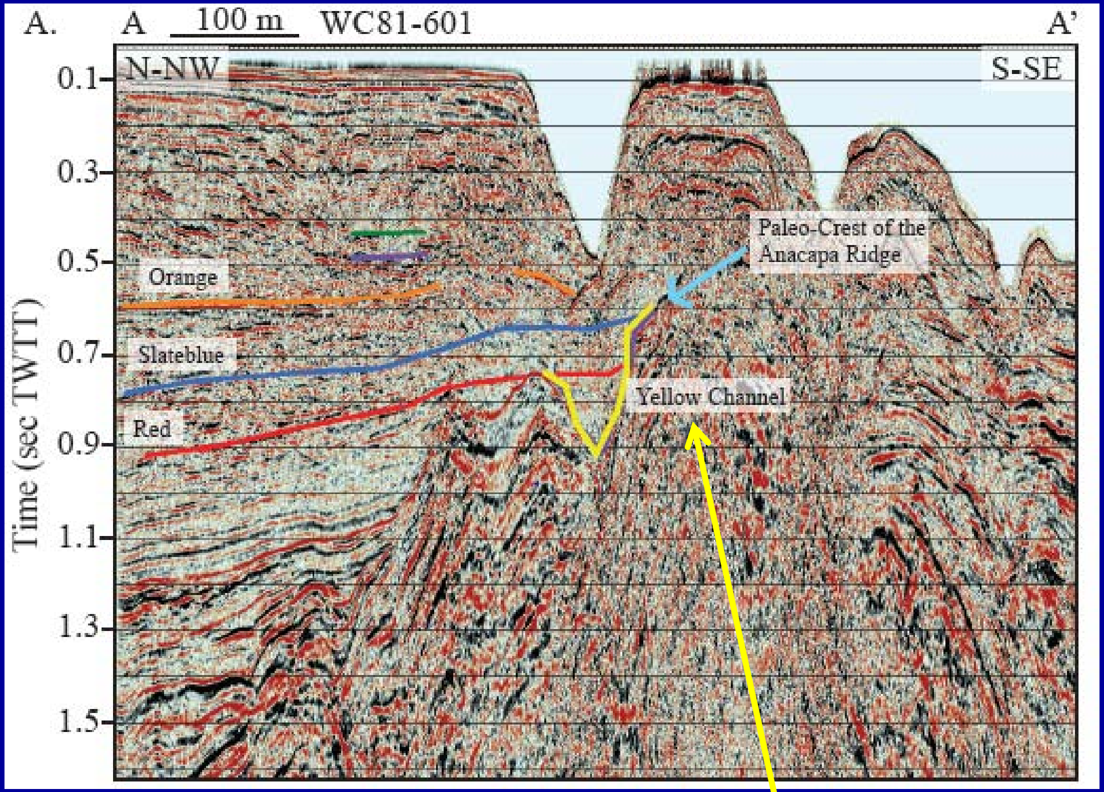


horizons onlap onto the flank of the Anacapa Ridge

Presenter's Notes: Regionally, the Santa Monica Mountain-Channel Islands anticlinorium extends from the Santa Monica Mountains westward to the northern Channel Islands, and in the past acted as a topographic high and bounding structure between the SBB and SMB. It has been reported in previous studies that the northern limb of the anticline decreased in its rate of northward tilting around 1 Ma. When this tilting stopped, the rate of folding decreased/stopped, and the crest of the anticline was able to subside. It is then that sediment might have been able to prograde across earlier than first reported, initiating the Hueneme Fan before Normark had initially proposed. The first major low-stand may have helped incise and entrench channelized transport as well.

Santa Monica Mountain-Channel Island Anticlinorium and Anacapa Ridge





Slateblue (790 ka) and younger horizons reach the paleo-crest of Anacapa Ridge.

Conclusions

- ~790 ka, the growth of the bounding faults and folds both narrowed the Santa Barbara depositional trough, and controlled the size and location of primary depocenters.

- ~510 ka, increased uplift and related subsidence trapped all sediment accumulation to the eastern basin.

- Between ~790 ka and 510 ka, decreased uplift of the Anacapa Ridge, as well as the first major low-stand in sea-level allowed sediment to onlap and breach the crest of the Ridge, initiating the Hueneme Fan prior to previously thought.