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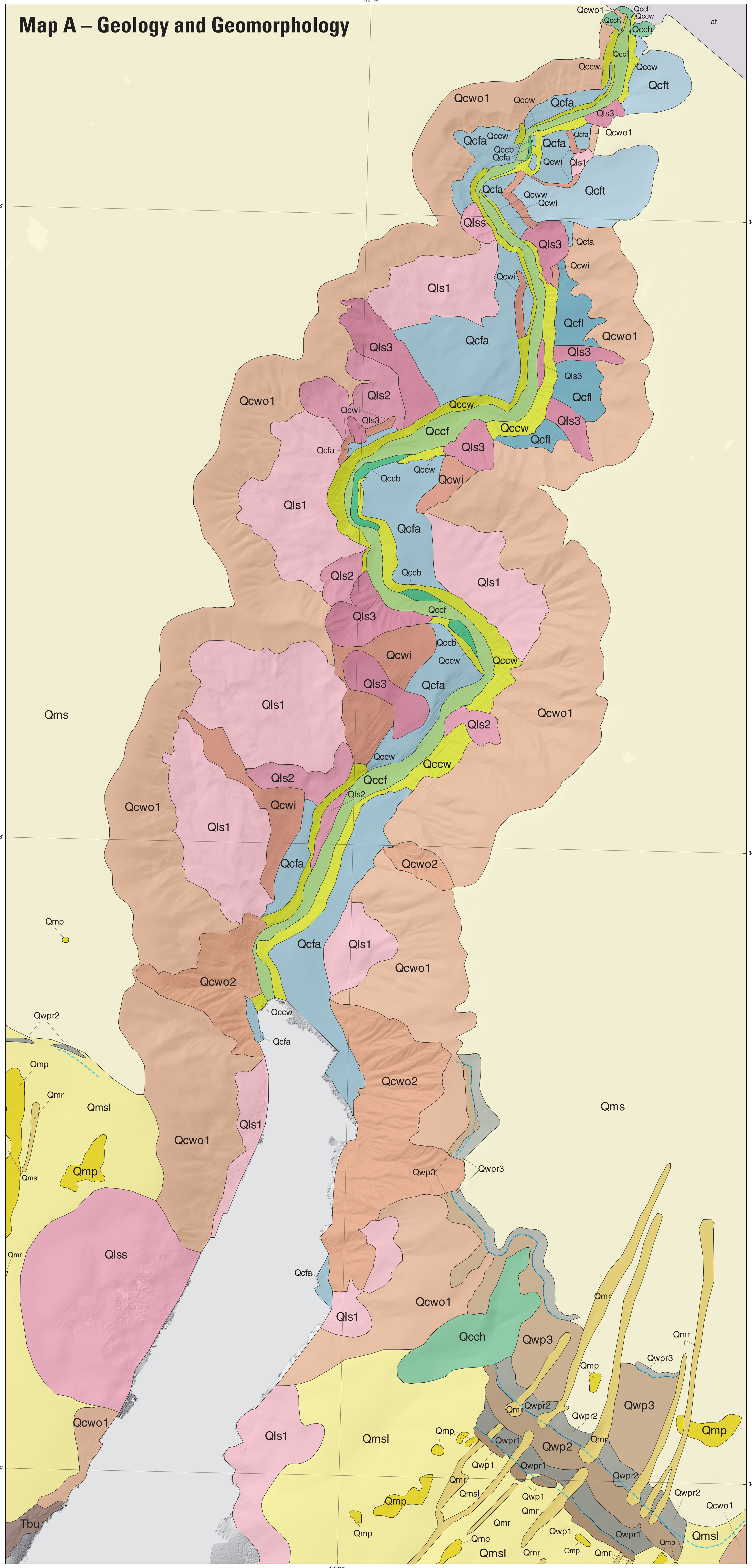
U.S. Department of the Interior
U.S. Geological Survey

Scientific Investigations Map 3225
Sheet 11 of 12
Pamphlet accompanies map

Map A – Geology and Geomorphology



Offshore shaded-relief bathymetry from map on sheet 2, this report
Universal Transverse Mercator projection, Zone 11N

NOT INTENDED FOR NAVIGATIONAL USE

APPROXIMATE MEAN DECLINATION, 2012

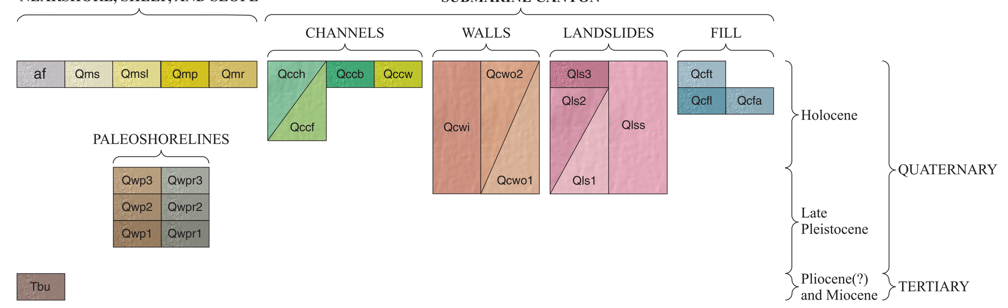
SCALE 1:12 000

ONE MILE = 0.869 NAUTICAL MILES

MAP LOCATION

Geology and geomorphology mapped by Andrew C. Ritchie and Samuel Y. Johnson, 2010-2011
GIS database and digital cartography by Andrew C. Ritchie and Eleyne L. Phillips
Edited by Taryn A. Lindquist
Manuscript approved for publication July 25, 2012

CORRELATION OF MAP UNITS



LIST OF MAP UNITS

[See Description of Map Units (chapter 8, in pamphlet) for complete map-unit descriptions]

NEARSHORE, SHELF, AND SLOPE

- af — **Artificial fill (Holocene)**—Rock, sand, and mud; placed and (or) dredged. Also includes seafloor significantly modified by human activity
- Qms — **Marine shelf deposits (Holocene)**—Predominantly sand; ripple marks common
- Qmsl — **Marine slope deposits (Holocene)**—Sand and mud
- Qmp — **Marine pockmarks (Holocene)**—Sand and mud
- Qmr — **Marine rill (Holocene)**—Probably sand and mud
- Tbu — **Bedrock, undivided (Pliocene? and Miocene)**

PALEOSHORELINES

- Qwp3 — **Submerged wave-cut platform, about 75 to 85 m deep (latest Pleistocene)**—Inferred to be sand and gravel
- Qwpr3 — **Submerged wave-cut platform riser, base about 75 to 85 m deep (latest Pleistocene)**—Inferred to be sand and gravel
- Qwp2 — **Submerged wave-cut platform, about 95 to 100 m deep (latest Pleistocene)**—Inferred to be sand and gravel
- Qwpr2 — **Submerged wave-cut platform riser, base about 95 to 100 m deep (latest Pleistocene)**—Inferred to be sand and gravel
- Qwp1 — **Submerged wave-cut platform, about 120 to 125 m deep (latest Pleistocene)**—Inferred to be sand and gravel
- Qwpr1 — **Submerged wave-cut platform riser, base about 120 to 125 m deep (latest Pleistocene)**—Inferred to be sand and gravel

SUBMARINE CANYON

CHANNELS

- Qcch — **Submarine-canyon channel-head deposits (Holocene)**—Probably sand and gravel(?)
- Qccf — **Submarine-canyon channel-floor deposits (Holocene)**—Inferred to be sand and gravel
- Qccb — **Submarine-canyon channel-flanking bar deposits (Holocene)**—Inferred to be sand, mud, and gravel
- Qccw — **Submarine-canyon channel-wall deposits (Holocene)**—Inferred to be sand, mud, and gravel

WALLS

- Qcwi — **Inner submarine-canyon-wall deposits (Holocene and latest Pleistocene)**—Inferred to be sand, mud, and gravel; slopes mostly more than 12° and commonly more than 20°
- Qcwo2 — **Outer submarine-canyon-wall deposits (Holocene and latest Pleistocene)**—Inferred to be sand, mud, and gravel; slopes mostly more than 30°; erosional and deeply incised
- Qcwo1 — **Outer submarine-canyon-wall deposits (Holocene and latest Pleistocene)**—Inferred to be sand, mud, and gravel; slopes generally more than 18° but rarely more than 30°; smooth and commonly sediment draped

LANDSLIDES

- Qls3 — **Landslide deposits, third generation (Holocene)**—Inferred to be sand and gravel
- Qls2 — **Landslide deposits, second generation (Holocene and latest Pleistocene)**—Inferred to be sand and gravel
- Qls1 — **Landslide deposits, first generation (Holocene and latest Pleistocene)**—Inferred to be sand and gravel
- Qlss — **Slump deposits on canyon walls (Holocene and latest Pleistocene)**—probably sand

FILL

- Qcft — **Tributary-submarine-canyon fill (Holocene)**—Inferred to be sand and gravel
- Qcfl — **Lateral-submarine-canyon fill (Holocene)**—Inferred to be mud, sand, and gravel
- Qcfa — **Axial-submarine-canyon fill (Holocene)**—Inferred to be sand and gravel

EXPLANATION OF MAP SYMBOLS

- **Contact**—Approximately located
- **Inferred former marine shoreline**
- **No data**—Area not mapped owing to insufficient high-resolution seafloor-mapping data

DISCUSSION

This map sheet shows a larger scale (1:12,000) version (Map A – Geology and Geomorphology), centered on Hueneme Canyon, of the geologic map (1:24,000) shown on sheet 10. The purpose is to focus more intensively on the canyon by showing geologic and geomorphic relations in more detail. Additional maps show two parameters, slope (Map B) and curvature (Map C), that inform the geologic-geomorphic mapping. Discussion of geologic units and relations not described below is included on sheet 10 and in pamphlet.

Hueneme Canyon extends about 15 km offshore from its nearshore canyon head. The canyon is relatively deep (about 150 m deep at the California's State Waters limit) and steep (canyon walls as steep as 25° to 30°). Hueneme Canyon is the westernmost of several submarine canyons in the eastern Santa Barbara Channel, and it is the first that intersects the littoral supply of sediment derived from the Santa Ynez Mountains and other mountains of the Transverse Ranges geologic province (Normark and others, 2009). The canyon is thought to have been connected to the Santa Clara River during sea-level lowstand about 21,000 years ago and then maintained its connection with the shoreline by headward erosion during rising sea level.

Geologic-geomorphic mapping in Hueneme Canyon is based on recognition of distinct units that are present either on canyon walls or as channel, landslide, or canyon-fill deposits. The outer walls of Hueneme Canyon extend upward to the shelf edge and vary from smooth (sediment draped) (unit Qcwo1) to deeply incised (unit Qcwo2). Inner canyon walls (unit Qcwi) occupy an intermediate position between the shelf edge and canyon floor. Both outer and inner canyon walls were formed primarily by landsliding. Three different landslide-deposit units are mapped in Hueneme Canyon on the basis of their morphology and relative age, inferred from crosscutting and (or) draping relations: unit Qls1 (oldest), unit Qls2, and unit Qls3 (youngest). The landslide map units commonly include steep erosional scarps paired with hummocky landslide deposits; this genetic pairing (scarps and landslide deposits) distinguishes the internal scarps within landslide units from the head scarps within canyon-wall units. Lower relief, sediment-draped, deep-seated slumps are mapped as a fourth landslide-deposit unit (Qlss).

Channel-head deposits at the mouth of Hueneme Canyon (unit Qcch) are delineated on the basis of their incision into the nearshore, as well as their relatively steep gradients and their V-shaped profiles. These channel heads merge into lower gradient and more flat-bottomed canyon-floor channel deposits (unit Qccf). The Hueneme Canyon channel floor is a zone of active sediment transport characterized by large, asymmetric bedforms (fig. 1) bounded by steep channel walls (unit Qccw). Narrow, elongate channel-flanking bars (unit Qccb) are elevated above, and are morphologically distinct from, the channel floors and, thus, are broken out as separate map units.

In addition to landslide and canyon-channel deposits, three additional canyon-fill map units are recognized. Axial-submarine-canyon-fill deposits (unit Qcfa), which form elevated surfaces 20 to 50 m above the floors of Hueneme Canyon and the smaller submarine canyons and which dip gently downcanyon, are composed of well-stratified sediment (sand, mud, gravel?), recognized on the basis of its seismic-reflection data (see sheet 8; high frequency, moderate amplitude, and parallel reflections). Lateral-submarine-canyon-fill deposits (unit Qcfl), located on the east flank of Hueneme Canyon near its head, consist of west-dipping, stratified sediment (recognized on the basis of its seismic-reflection facies; see sheet 8) that probably formed as distributed fluvial input into the canyon in the middle to late Holocene. Tributary-submarine-canyon-fill deposits (unit Qcft) are inferred to have formed as direct fluvial entrants into the canyons in the middle to late Holocene and, subsequently, were partly filled by nearshore and shelf sediment during sea-level rise.

Outside Hueneme Canyon at the shelfbreak, the geology, slope, and curvature maps also highlight submerged paleoshorelines. Sea-level rise (controlled by both eustasy and tectonic land-level change) was not steady during ongoing sea-level rise, leading to development of shorelines during periods of relative sea-level stability that can be preserved by pulses of rapid drowning. These paleoshorelines, characterized by shoreline angles and adjacent submerged wave-cut platforms and risers (Kern, 1977), commonly are buried by shelf sediment. However, their original morphology is at least partly preserved on the outer shelf and upper slope on the east flank of Hueneme Canyon. Three wave-cut platforms (units Qwp1, Qwp2, Qwp3) and risers (units Qwpr1, Qwpr2, Qwpr3) are mapped here, separated by shoreline angles at depths of approximately 75 to 85 m, 95 to 100 m, and 120 to 125 m, respectively (fig. 2).

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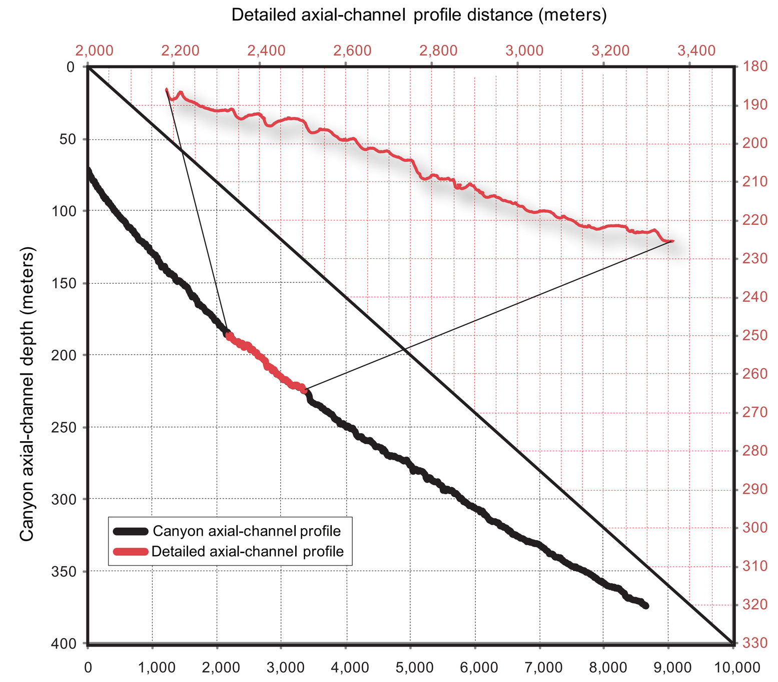


Figure 1. Axial-channel profile and detailed axial-channel profile of Hueneme Canyon (see Map B for locations). Detailed profile illustrates "step-pool" nature of main canyon channel: note that upstream sides of many steps are convex, possibly reflecting presence of upcanyon-migrating bedforms (sediment waves) between nick-point scour pools (Kostic and others, 2010). In this scenario, sediment-rich turbidity currents accelerate until flow becomes supercritical over a step, forming a hydraulic jump and inducing scour at downstream base of step, where energy is lost and deposition occurs.

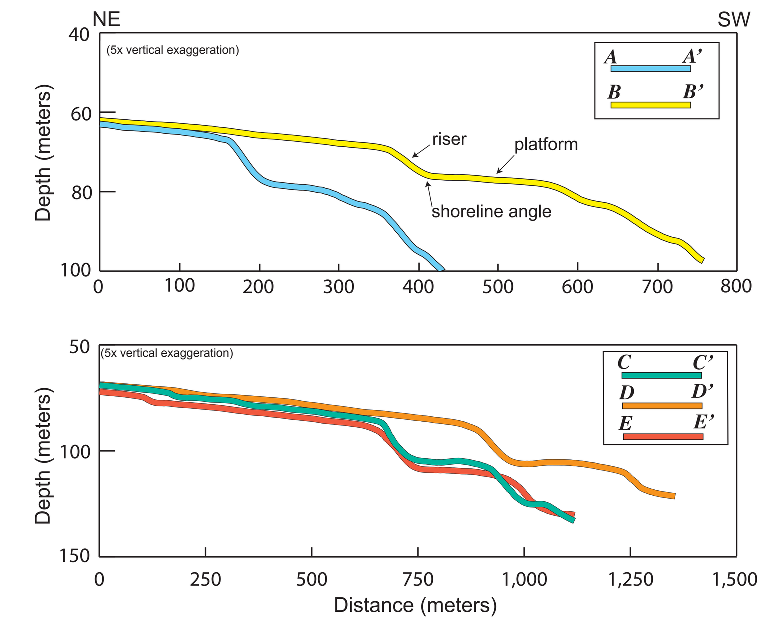
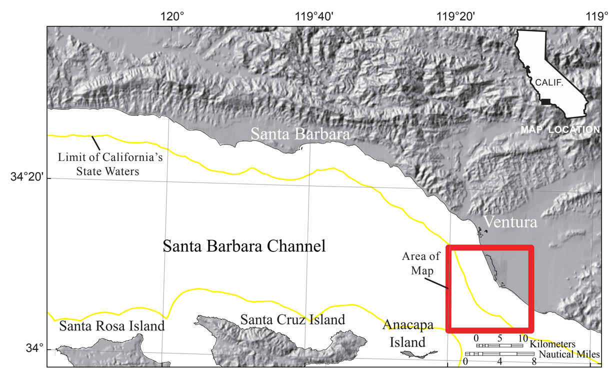
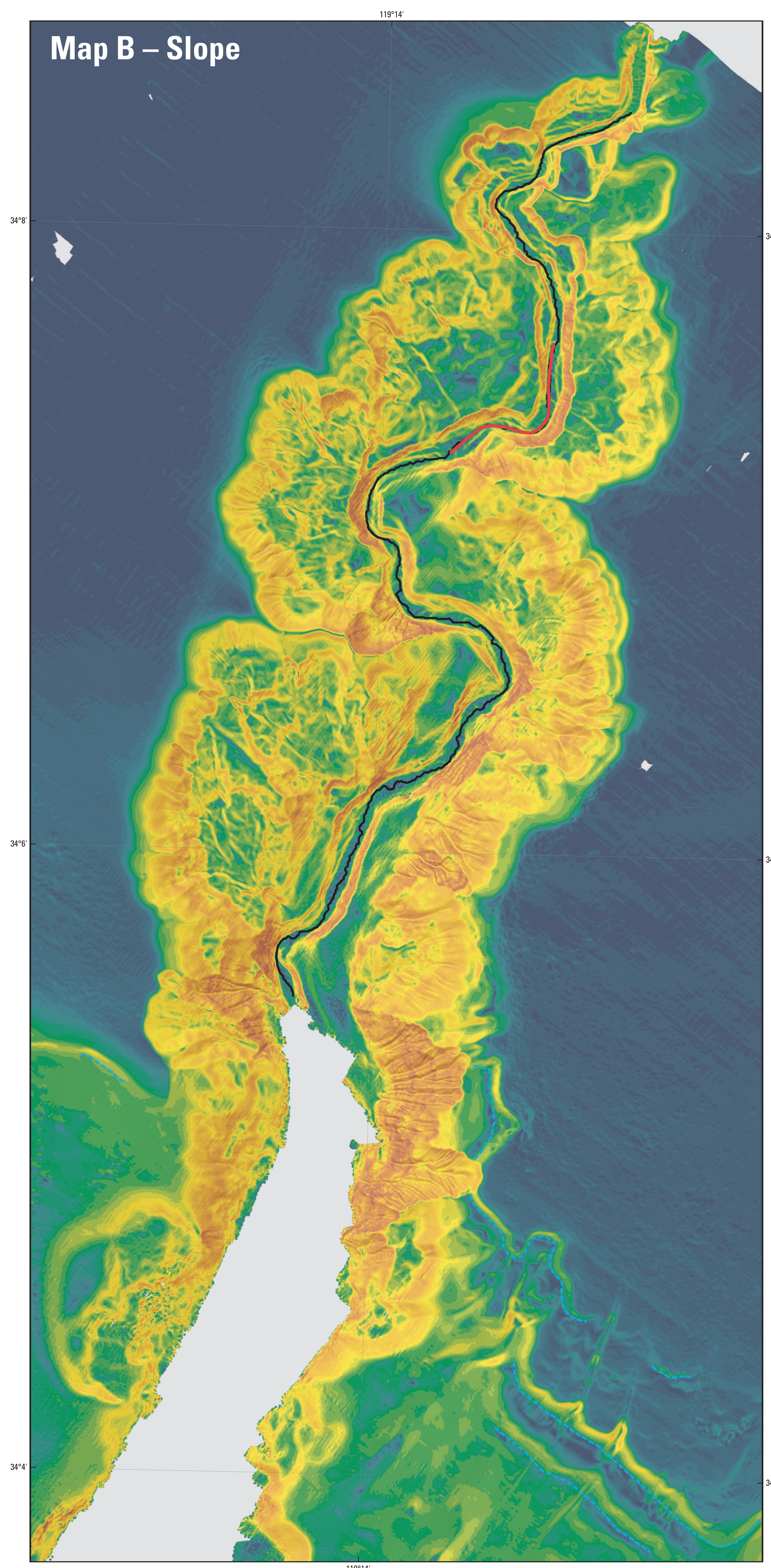


Figure 2. Shore-perpendicular bathymetric cross sections of outer shelf and shelfbreak just east of Hueneme Canyon (see Map C for locations), showing paleoshorelines at depths of about 80 m (sections *A–A′*, *B–B′*), 100 m (sections *C–C′*, *D–D′*, *E–E′*), and 120 m (sections *C–C′*, *E–E′*). Submerged paleoshorelines develop and are preserved during periods of relative sea-level stability and (or) rapid drowning, controlled primarily by eustasy and, to lesser degree, tectonics. Deepest paleoshoreline (about 120 m deep) corresponds approximately to sea level during final phases of last sea-level lowstand about 21,000 years ago; most shallow paleoshoreline (about 80 m deep) is compatible with pulse of rapid sea-level rise during meltwater pulse 1a, about 14,000 years ago (Peltier, 2005; Gornitz, 2009).



Map B – Slope

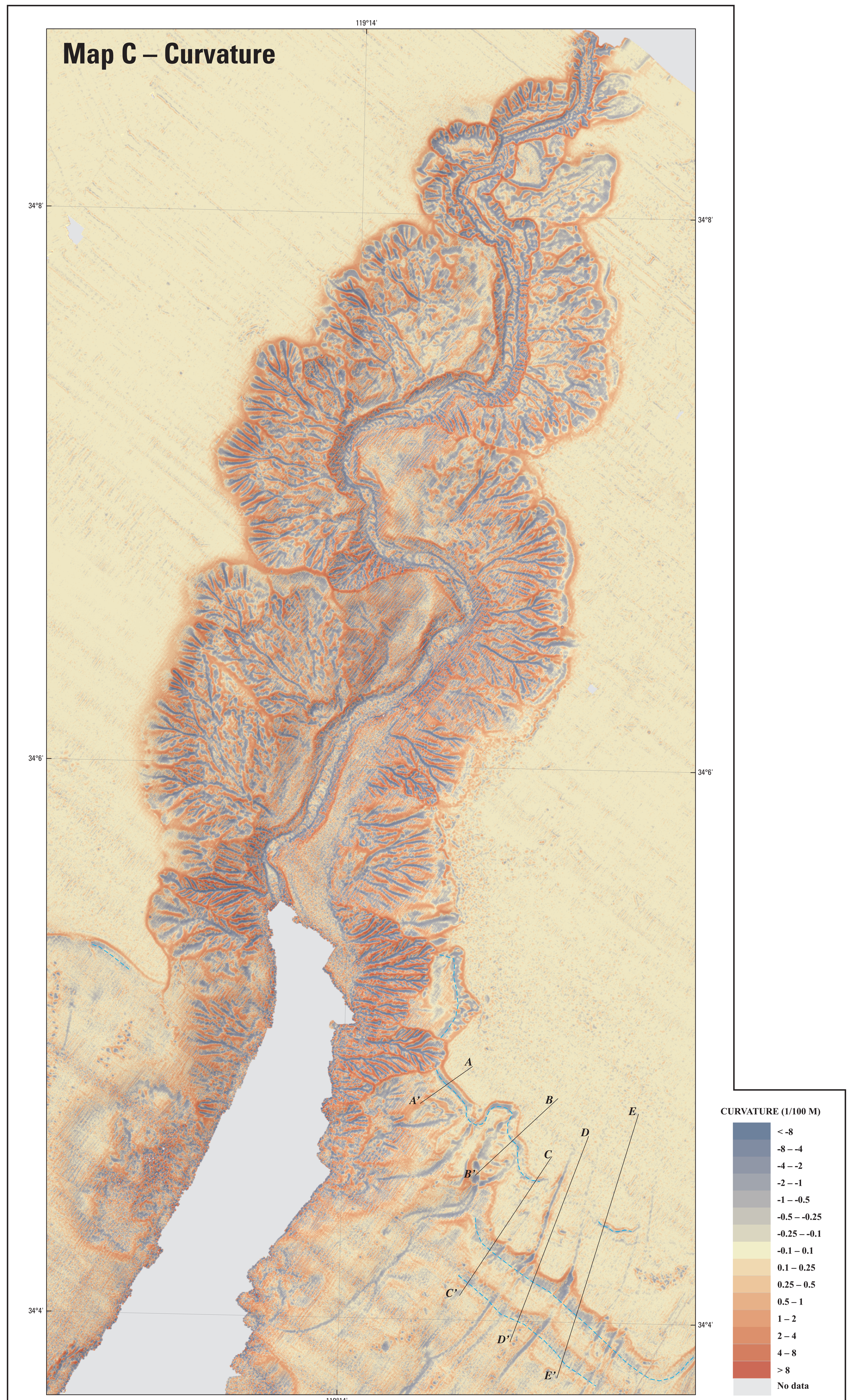


SCALE 1:18 000

ONE MILE = 0.869 NAUTICAL MILES

Map B. Slope map of Hueneme Canyon. Note that ranges of slope values (in degrees) represented by each discrete color increases with increasing slope: colors represent 0.5° intervals between 0° and 4° slope; 1° intervals, between 4° and 6° slope; and 3° intervals, between 6° and 45° slope. Slope values were used to help distinguish units on geology-geomorphology map (Map A; see also, sheet 10). Black line in canyon shows trace of axial-channel profile depicted in figure 1; red line in canyon indicates location of detailed profile shown in figure 1. Dashed blue lines indicate traces of inferred former marine shorelines.

Map C – Curvature



SCALE 1:18 000

ONE MILE = 0.869 NAUTICAL MILES

Map C. Curvature map of Hueneme Canyon, also showing locations of cross sections depicted in figure 2. Curvature values (in 1/100 m) are second-derivative values of elevation surface (in other words, slope of slope, calculated using methods of Zeverbergen and Thorne, 1987): positive (red) values are convex; zero (yellow) values are flat; negative (blue) values are concave. Note that ranges of curvature values represented by each color decreases as values (positive or negative) approach zero. Total curvature values (as shown here), in addition to plan and profile curvature values, were used to help distinguish units on geology-geomorphology map (Map A; see also, sheet 10). Dashed blue lines indicate traces of inferred former marine shorelines.

Detailed Geology and Geomorphology, Hueneme Canyon, California

By

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2012

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