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Scientific Investigations Map 3302
Sheet 11 of 12
Pamphlet accompanies map

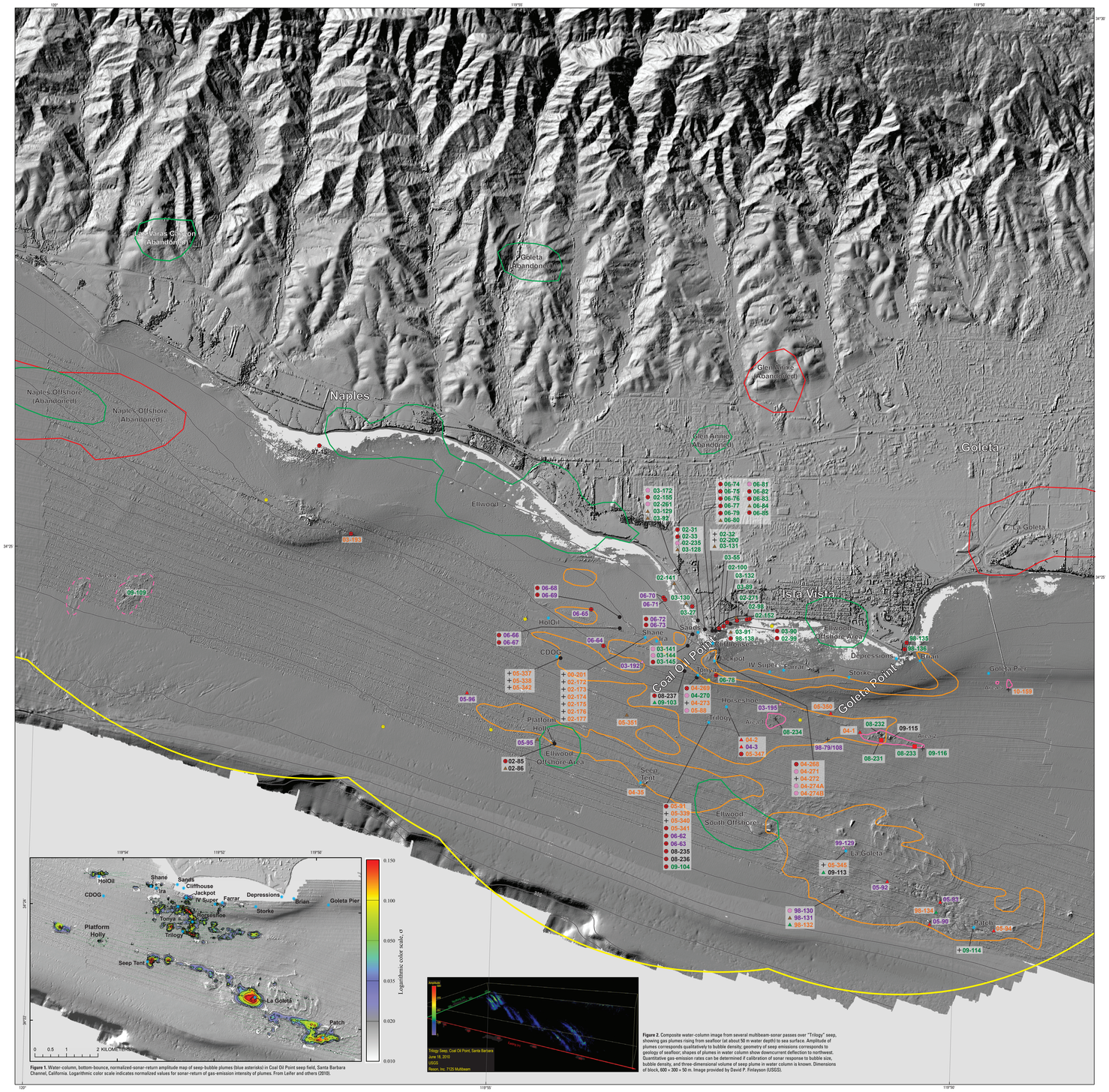

Figure 1. Water-column, bottom-bounce, normalized-sonar-return amplitude map of seep-bubble plumes (blue asterisks) in Coal Oil Point seep field, Santa Barbara Channel, California. Logarithmic color scale indicates normalized values for sonar-return of gas-emission intensity of plumes. From Leifer and others (2010).

Figure 2. Composite water-column image from several multibeam-sonar passes over "Trilogy" seep, showing gas plumes rising from seafloor (at about 50 m water depth) to sea surface. Amplitude of plumes corresponds qualitatively to bubble density; geometry of seep emissions corresponds to geology of seafloor; shapes of plumes in water column show downcurrent deflection to northwest. Quantitative gas-emission rates can be determined if calibration of sonar response to bubble size, bubble density, and three-dimensional volume of seep plume in water column is known. Dimensions of block, 600 × 300 × 50 m. Image provided by David P. Finlayson (USGS).

Onshore elevation data from NOAA Coastal Services Center (data collected by EarthData International in 2002-2003 and from U.S. Army Corps of Engineers (data collected by Fugro Pelagos in 2009). California's State Waters limit from NOAA Office of Coast Survey

Universal Transverse Mercator projection, Zone 11N

NOT INTENDED FOR NAVIGATIONAL USE

APPROXIMATE MEAN DECLINATION, 2014

SCALE 1:24 000

1 0 1 MILE
1/2 0
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 0 1 KILOMETER

BATHYMETRIC CONTOUR INTERVALS 10 AND 50 METERS
ONE MILE = 0.869 NAUTICAL MILES

MAP LOCATION

Hydrocarbon seepages and tarball accumulations mapped by Thomas D. Lorenson and others, 2001-2011. Bathymetric contours by Andrew C. Ritchie, 2011

GIS database and digital cartography by Florence L. Wong

Edited by Taryn A. Lindquist

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Natural Offshore Hydrocarbon Seepage and Related Tarball Accumulation, Offshore of Coal Oil Point Map Area, California

By

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EXPLANATION

Type of sample—Indicated by color of sample-number label

05-530 **Seep**—Surface-oil sample associated with active underlying seepage

02-62 **Unlocated seep (surface-oil sample)**

05-10 **Oil**

97-56 **Tarball or asphalt**

Model groups (oil tribes and families)—Oil families determined by suite of biomarkers. Symbols within transparent white boxes have been offset from their collection localities for clarity

Tribe 1 sample localities—Source rock inferred to be clayey, siliceous-rich shale of the Monterey Formation, with significant higher plant-organic matter input, deposited under suboxic conditions

- **Family 11**
- **Family 12**
- **Family 13**
- **Family 14**

Tribe 2 sample localities—Source rock inferred to be carbonaceous marl, deposited in hemipelagic setting under suboxic to anoxic conditions

- **Family 211**
- **Family 212**
- **Family 22**

Tribe 3 sample localities—Source rock inferred to be clay-poor, calcareous-siliceous carbonate, deposited under anoxic conditions and dominated by pelagic organic matter

- **Family 31**

Unclassified group—Too weathered and biodegraded to classify

- **Family 0**

Previously located seeps

- **Seeps (informally named)**—Confirmed by Leifer and others (2010)
- **Offshore seeps**—Unconfirmed (Wilkinson 1971, 1972)

Hydrocarbon fields

- **Oil field**—From California Division of Oil, Gas, and Geothermal Resources (2001)
- **Gas field**—From California Division of Oil, Gas, and Geothermal Resources (2001)
- **Gas-vent field**—From Hornafius and others (1999)
- **Asphalt-mound field**—Dashed where boundary is uncertain

DISCUSSION

Ongoing natural hydrocarbon seepage in the Offshore of Coal Oil Point map area has fascinated humans for centuries. The native Chumash tribe used the asphalt (tar), which is biodegraded and weathered oil, found in the map area for a variety of purposes, including waterproofing boats and gluing arrowheads to shafts (Galloway, 1998). Hydrocarbon emissions, all sourced from the Miocene Monterey Formation and the Rincon Shale, range from viscous biodegraded asphalt or oil drops to methane-rich gas bubbles. Some of these emissions impact the shoreline by the deposition of tarballs and the local atmosphere by the release of hydrocarbon gases such as methane and ethane.

This map of known hydrocarbon-seepage sites and their oil-source chemical fingerprinting was compiled during a 10-year study that linked beach tarballs to their offshore sources. This study was conducted by the U.S. Geological Survey, in conjunction with the Bureau of Ocean Energy Management (formerly, the Minerals Management Service), the County of Santa Barbara Energy Division, and the University of California, Santa Barbara. The approach was to (1) document the locations of naturally occurring seep oil or tar; (2) collect and geochemically fingerprint samples from these natural occurrences; (3) geochemically fingerprint (with biomarkers) coastal tar residues and potential tar sources in this region, both onshore and offshore; and (4) establish chemical correlations between offshore active seeps and coastal residues, thus linking seep sources and oil residues. The results of this study can be found in Hostettler and others (2004), Peters and others (2008), and Lorenson and others (2009, 2011). Sample numbers displayed on the map are from Lorenson and others (2009, 2011).

Using multivariate statistical techniques (Peters and others, 2008), the oil has been divided into three "tribes" of °C-rich oils, inferred to originate from thermally mature equivalents of three types of strata from the Monterey Formation: (1) clayey-siliceous shale, (2) carbonaceous marl, and (3) calcareous-siliceous carbonate rock. These three tribes have been further subdivided into 13 oil "families." Seven of these families are present in the Offshore of Coal Oil Point map area, with Family 211 being found most frequently, both onshore as tarballs and offshore as seep sources.

Also shown on the map are the onshore and offshore oil (green outline) and gas (red outline) fields in the map area (from California Division of Oil, Gas, and Geothermal Resources, 2011), as well as gas-seepage areas (orange outline), as mapped by Hornafius and others (1999), and asphalt mounds (pink outline). Figure 1 shows a resurvey of normalized sonar return of gas-emission intensity as measured by Leifer and others (2010); figure 2 is a multibeam-sonar image of the water column above the "Trilogy" seep; and figures 3 and 4 show the expression of seeps on the water surface.

The shaded-relief seafloor map shows some of the geologic structure underlying the area. Sampling and imaging of the seafloor and seeps was undertaken with a remotely operated vehicle (ROV; see figs. 5, 6, 7) on three occasions, as guided by seafloor morphology, sea-surface hydrocarbon-seep expression, and dissolved methane in seawater. Figures 8 and 9 show gas seeps; figures 10, 11, and 12 show the morphology and structure of asphalt mounds; and figure 13 shows tarballs transported from these seeps to the shoreline.

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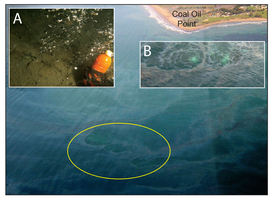

Figure 3. Aerial photograph of Coal Oil Point seep field offshore of Coal Oil Point, showing numerous comingling, naturally occurring oil slicks and also site of "Trilogy" oil and gas seep (yellow outline). Inset photograph "A" shows natural gas bubbling from seafloor vents at "Trilogy" seep, in 50 m water depth; orange bottle contains fluorescein dye used in experiments to measure water-advection rates created by upward movement of seep-bubble emissions; field of "A" view, about 30 × 25 cm. Inset photograph "B" shows localized upwelling (caused by high gas emissions) from "Seep Tent" seep, which can be identified by green water (from fluorescein dye) that surrounds seep next to light-colored areas of gas reaching surface; field of "B" view, about 30 × 25 cm.

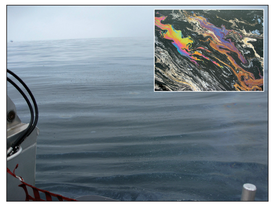

Figure 4. Naturally seeping gas and oil rising to ocean surface above "La Goleta" seep, in Coal Oil Point seep field (sample no. 09-413). Large, visible oil sheens are present on water surface on calm days, and petroleum odor can be strong. Inset photograph shows close-up of oil on water surface above "Trilogy" seep; oil drops and oil-coated natural-gas bubbles rise and burst at surface, then spread out on water surface to create dazzling rainbow of colors, which result from refraction of light through thin oil film of varying thickness; field of view of inset photograph, about 100 × 80 cm.

Figure 5. ROV being prepared for deployment offshore of Coal Oil Point.

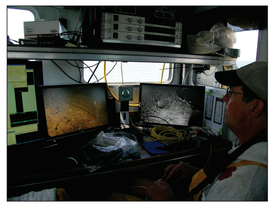

Figure 6. ROV pilot maneuvering ROV along seafloor. Twin monitors display live images from two video cameras mounted on ROV.

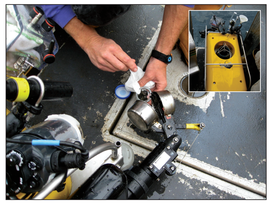

Figure 7. Asphalt (tar) sample being retrieved from ROV claw. Inset photograph shows ROV used to sample natural seeps; ROV is equipped with 10-megapixel digital still camera and high-definition (1,080 × 1,920 pixel resolution) video camera, as well as gas- and oil-sampling equipment.

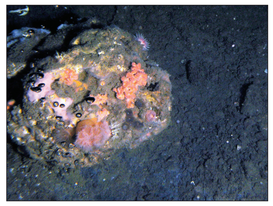

Figure 8. Naturally seeping, oil-coated gas bubbles rising from seafloor at "La Goleta" seep, in area next to sample locality 09-113. Anenome- and bryozoan-encrusted rock overlies dark, rubbly sediment that contains dark iron sulfides and colonies of white, sulfate-reducing microbes. Field of view, about 30 × 40 cm.

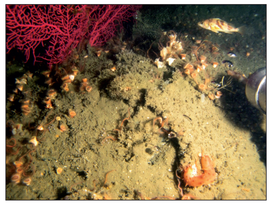

Figure 9. Gas seep issuing from sediment-covered, invertebrate-colonized asphalt mound just east of map area; water depth, 75 m. Here, asphalt mounds coalesce into features as much as 80 m in diameter and 3 m in relief. Larger mounds are found elsewhere in Santa Barbara Channel offshore of Point Conception (west of map area) and on Mid-Channel high (southeast of map area). Size of gorgonian coral and multitude of solitary cup corals implies feature is decades old. Field of view, about 50 × 40 cm.

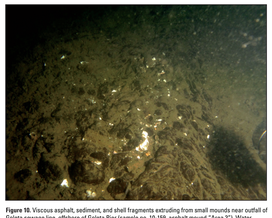

Figure 10. Viscous asphalt, sediment, and shell fragments extruding from small mounds near outfall of Goleta sewage line, offshore of Goleta Pier (sample no. 10-159, asphalt mound "Area 3"). Water depth, about 40 m; field of view, about 30 × 25 cm.

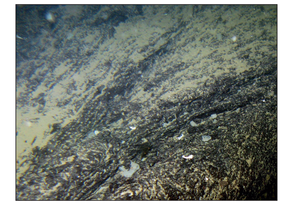

Figure 11. Flowing asphalt southeast of Coal Oil Point (sample no. 09-115, asphalt mound "Area 1"). Field of view, about 20 × 30 cm.

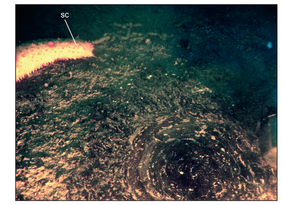

Figure 12. Active, small, viscous asphalt mound offshore of Naples (sample no. 09-109). Also shown is sea cucumber (sc). Field of view, about 30 × 40 cm.

Figure 13. View to west of beach at Coal Oil Point, showing substantial tarball stranding in June 2003 during period of unusual tarball accumulation; tarballs can be seen on several wave strand lines. Tarballs result from nearby naturally occurring oil seepage and subsequent stranding on beach; previous studies (Del Sontro and others, 2007; Lorenson and others, 2009) showed that significant order-of-magnitude seasonal variations of beach tar accumulation can occur. Inset photograph shows close-up of nascent tarballs, which are releasing light film of oil; more commonly, tarballs are less frequent, more weathered, and do not emit oily sheen.

This map was printed on an electronic plotter directly from digital files. Dimensional calibration may vary between electronic plotters and between X and Y directions on the same plotter, and paper may change size due to atmospheric conditions; therefore, scale and proportions may not be true on plots of this map.

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