Monterey Formation Overview and Context for New Research

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Abstract

The Miocene Monterey Formation of California provides a potentially unsurpassed archive of Neogene paloeoclimatic and paleoceanographic evolution as its deposition spans the Miocene Climatic Optimum and the Miocene Climatic transition. It is an important reservoir of organic carbon, potentially large enough to have influenced the global transition from greenhouse to icehouse conditions, as well as being the major source rock for petroleum in California. Highly biosiliceous, it is the best-studied of the world’s Neogene diatomaceous deposits that developed along oceanic upwelling margins in the Miocene. It accumulated in numerous new and rejuvenated sedimentary basins that developed with the transition from convergent to transform geometry along the Pacific-North American plate margin. The bathymetry of these basins intercepted open-ocean oxygen minimum zones or created restricted, silled basins that helped preserve organic matter and minimized bioturbation and degradation of a detailed sedimentary record. Although the member-scale compositional lithostratigraphic succession is similar between basins – reflecting the climatic/oceanographic stages of the Miocene – local bathymetric gradients and local exposure to deep bottom-scouring currents, created large lateral variation in environment, sediment thickness and composition. These lateral variations are critical controls of reservoir and source-rock properties, and also provide challenges and opportunities for generating quantitative histories of biogeochemical fluxes and paleoceanographic conditions.

References


Doris, N.; Behl, R.J.; 2014. 3D Subsurface Model of Monterey-Related Sediments and the Syntectonic Distribution of Clastic and Biogenic Facies, Offshore Santa Maria Basin, California, Pacific Section AAPG/SEPM meeting, Bakersfield, CA.

Erbele, H.; Behl, R.J.; 2015. Lateral Variation of Siliceous Sedimentary Lithofacies in the Upper Monterey Formation, South Belridge-Lost Hills Fields, Kern County, California; Pacific Section AAPG/SEPM Conference, Oxnard, CA, Search and Discovery Article #51103.


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Monterey Formation Overview & Context for New Research

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Miocene Monterey Formation

- Important link to past climate change
- Important storehouse of carbon
- Major source & reservoir of oil in California

- Characteristics
  - Fine-grained (mudstone)
  - Siliceous (diatom silica-rich)
  - Organic matter-rich
  - Thin-bedded, laminated

- Age: approximately ~17-6 Ma
- Related deposits span the Pacific Rim
Circum-Pacific
“Monterey”
diatomaceous facies
Bio-Siliceous Sediments are Common Along Neogene Continental Margins

Modified from Hein & Parrish (1987) and other authors
Oceanic Production of Organic Matter by Photosynthesis (mostly diatoms) is similar to the Neogene Siliceous Deposits. Production at surface doesn’t necessarily mean preservation in the sediment.
The Monterey records the Cenozoic Climate Transition from “Greenhouse” to “Icehouse”

Miller et al. (1987)
Mid-Miocene tectonic shift from convergent to transform margin formed numerous restricted and silled basins.
Basins formed as the Farallon plate split apart

Blake et al. (1978)
Key:
Faults:
SAF - San Andreas Fault
GF - Garlock Fault
HCF - Hayward-Calaveras Fault
MFZ - Mendocino Fracture Zone
Basins:
  a. Livermore
  b. La Honda
  c. Pismo, Huasna, Cuyama
  d. Ridge
  e. Soledad
  f. Santa Monica, San Pedro
  g. Los Angeles
  h. San Diego
Neogene Basinal Stratigraphy

Generalized Basinal Facies of the Monterey Formation

Generalized Upper Tertiary Facies, Coast Ranges, California

Generalized Basinal Facies of the Monterey Formation

Facies of the Monterey Formation, Santa Barbara, California

Facies of the Monterey Formation, San Joaquin Basin, California

Nonmarine Facies

Shallow Marine Facies

Basinal Facies

Shallow Marine Facies

Nonmarine Facies

(Pisciotto and Garrison, 1981)

Siliceous Facies

Phosphatic Facies

Calcareous Facies

Sisquoc Formation

Clayey and calcareous siliceous member

Carbonaceous marl member

Calcereous siliceous member

Rincon Shale

(Isaacs, 1983)

Etchegoin + Santa Margarita Formation

Reef Ridge

Antelope

McLure Member undifferentiated

Devilwater

Devilwater/Gould undifferentiated

Gould

Temblor Formation

(Isaacs, 1983)

(Graham and Williams, 1985)
Irregular depositional surface & lateral changes in thickness

Santa Maria Basin

Dunham et al. (1991)
Tilted Fault Blocks of the Offshore Santa Maria Basin

Doris & Behl, 2014

Sorlien et al., 1999
Plio-Pleistocene inversion & deformation of thick Miocene depocenters formed oil fields

Nelson Doris (2013)
Most California oil fields are in young, recently formed anticlinal folds.
Main Sedimentary Components

• Silica
• Carbonate
• Organic matter
• Phosphate
• Detritus (clay, silt & sand)

High diagenetic potential of silica, carbonate, phosphate & organic matter
Calcareaous Microfossils
Detritus & Diatom fragments
Organic Matter, Phosphate & Calcite
Disseminated Dolomite

Concentrated with favorable chemistry or enough time
Compositional data of Isaacs (1985) for the Monterey Formation.

- Biogenic or Diagenetic Silica
  - Chert
  - Diatomite

- Detrital Minerals
  - Porcelainite/Muddy Diatomite
  - Siliceous/Diatom Mudstone
  - Mudstone/Shale

- Carbonates
  - Marl/Marlstone
  - Dolomite/Limestone

Variability of compositional data from Isaacs (1985).
Isaacs (1980, 1983)
Silica Diagenesis

2-step dissolution/reprecipitation:

- Opal-A
- Opal-CT
- Quartz

Time +/- or Temperature

Siever (1983)
Opal-A

- Biogenic silica
  - Diatoms, radiolarians, sponge spicules, silicoflagellates, phytoliths
- Hydrous opaline silica
Inter- and intraparticle porosity infilled by opal-CT silica

Precipitation of opal-CT infilling microfossil void
• Diagenetic silica
  – Complete dissolution of diatoms, etc.
  – Reprecipitation as opal-CT
• Hydrous silica with poorly ordered structure of cristobalite and tridymite
Quartz

- Diagenetic silica
  - Complete dissolution of opal-CT.
  - Reprecipitation as quartz
- Microcrystalline, chalcedonic, megacrystalline
Opal-A diatomite

Opal-CT porcelanite

Up-section
Sedimentation of Hemipelagic Sediments

**Vertical Settling**
- Flocculation
- Fecal pellets
- Marine snow
- Diatom mats and TEP aggregates

**Lateral & downslope transport**
- Surface suspension (hypopyynal flow)
- Nepheloid plumes (hyperpyynal flow)
- Turbidity currents
- Slumps
- Resuspension or reworking by currents
Bathymetric Depositional Patterns

- Uniform thickness/
  Uniform composition

- Basinal thickening/
  Uniform composition

- Basinal thickening/
  Silica-rich basin

- Basinal thickening/
  Detrital-rich basin

Erbele and Behl (2015)
Lateral Variation: Zone E

Thicker sections by focusing of siliceous sediment
Controls of Sediment Distribution

• Seafloor morphology
  – Basin, slope, banktop/shelf

• Proximal or Distal setting
  – Inner or outer basins

• Arid or Humid climate
  – Riverine or eolian supply, or starved for detritus

• Currents
  – Marginal location and water depth
Organic Carbon (TOC)

- Mostly type II kerogen - marine algae
- Mostly between 2% - 6%
- Highest in phosphatic mudstone / carbonaceous marlstone
  - Up to 23% TOC
    - (34% organic matter by weight)
Where the Oxygen Minimum Zone (OMZ) hits the seafloor affects organic carbon preservation

A. OUTER SHELF – UPPER SLOPE

B. ISOLATED BANK TOP

C. AERATED BASIN (BASIN FLOOR AND LOWER SLOPE)

D. ANOXIC BASIN (BASIN FLOOR AND LOWER SLOPE)

Pisciotto & Garrison (1981)
Patchy upwelling leads to uneven distribution of plankton & organic matter.

Red = chlorophyll-rich

CalCOFI (2010)
Semi-enclosed basins can have spatially & seasonally complex upwelling patterns

Red = chlorophyl-rich
Riverine & Eolian detritus (sand, silt, clay…and iron)
Climate Cycles & Lithocyclicity

Thurow et al. (2009)
Environment ➔ Sediment ➔ Diagenesis ➔ Rock Properties ➔ P&P & Def’m Style

A. Forcing Functions

Climate

Oceanography

Depositional Environment

B. Sediment Accumulation

C. Lithologic Variation

Gamma-ray log

D. Stacking Patterns for Single Porcelanite-Shale Cycle

Gamma-ray cycle Varied bed composition Varied shale thickness Varied porcel. thickness

E. Mechanical Stratigraphy & Fractures
Monterey Summary

- Important link to global change & tectonics
- Spans the Pacific Rim
- Organic-rich, highly siliceous, fine-grained
- Vertical and lateral lithofacies variations
  - Global and local controls
- Thin-bedded and cyclic bedding
- High diagenetic potential of silica, carbonate, phosphate & organic matter
- Composition and diagenesis controls physical properties of sediments and mechanical stratigraphy
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- Doris, N.; Behl, R.J.; 2014. 3D Subsurface Model of Monterey-Related Sediments and the Syntectonic Distribution of Clastic and Biogenic Facies, Offshore Santa Maria Basin, California, Pacific Section AAPG/SEPM meeting, Bakersfield, CA.
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