TETRA TECH RPS ENERGY | TRAINING

# N364: Fracture Architecture, Sedimentology and Diagenesis of Organic-rich Mudstones of Ancient Upwelling Zones with Application to Naturally Fractured Reservoirs *(California, USA)*

Instructor(s): Richard Behl and Jon Schwalbach / Michael Gross

**Format and Duration**

Field - 5 Days
Moderate Physical Demand

## Summary

This course uses the Monterey Formation as a natural laboratory to understand the origin, distribution and physical properties of biogenic, organic-rich mudstones as well as the relationship between mechanical stratigraphy and fracture distribution in layered rocks.

Business Impact: Application of the learnings of this course will empower participants to better distinguish types of siliceous, calcareous/dolomitic, phosphatic and organic-rich rocks and understand relationships between composition, diagenesis, bedding and fracture architecture to enhance prediction of reservoir properties.

## Learning Outcomes

Participants will learn to:

1. Judge factors that contribute to a successful unconventional resource play in thin-bedded, brittle, fine-grained rocks.
2. Distinguish cherts, porcelanites, siliceous shales, diatomites, dolomites, calcareous and phosphatic mudstones.
3. Evaluate depositional setting, sequence stratigraphic and facies relationships of hemipelagic/pelagic sediments and their paleoceanographic and paleogeographic controls.
4. Characterize key sedimentary structures of mudstones from different depositional environments.
5. Formulate interpretations of biogenic mudstones and predict changes in physical properties that occur with diagenesis.
6. Identify components of an active petroleum system, including source rocks, migration pathways, carrier beds and reservoir rocks.
7. Synthesize stratal stacking, sediment composition and diagenetic stage to predict mechanical stratigraphy and potential fracture networks.
8. Recognize the component elements of mechanical stratigraphy and evaluate their impact on fracture development in a variety of structural settings.
9. Conduct surveys of fault and fracture networks in order to evaluate fracture scaling and fracture connectivity, and to design potential landing zones and trends for horizontal laterals in fractured reservoirs.
10. Design conceptual models of a fractured reservoir that incorporate aspects of lithology, mechanical stratigraphy, fracture attributes and structural position.

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## Training Method

This is a field course, supported by classroom sessions in a 60:40 ratio. Classroom sessions will comprise presentations, case studies, exercises, and reviews of the fieldwork.

## Physical Demand

The physical demands for this class are MODERATE according to the Nautilus Training Alliance field course grading system. The field area is at sea level in central and southern California, where summer temperatures range from cool, damp and foggy to warm and sunny. There will be walks of up to 3.2 km (2 miles), with some wading through shallow water on sandy or rocky beaches required to visit some outcrops. Much field time will be spent on uneven, possibly slippery surfaces of wave-cut beach platforms. The greatest ascent is about 30 m (100 ft) up steep, sandy slopes that will require the use of hands and a rope to aid participants in pulling themselves up the slope. The course will include some long drives of 1-2 hours on mostly paved roads. Transportation by coach.

## Who Should Attend

The course is aimed at exploration, development and production geoscientists whose focus is on unconventional resources. However, engineers and asset managers who are engaged in production from shale, chert or other unconventional resources and/or conventional fractured reservoirs should also benefit from this course.

## Course Content

The course uses spectacular, classic outcrops of different facies of the Miocene Monterey Formation exposed along the coast in southern and central California to train participants in the sedimentology, depositional systems, and climatic and oceanographic control of facies in clastic-poor, biogenic fine-grained deposits. The great heterogeneity of the Monterey Formation permits investigation of siliceous, calcareous, phosphatic and carbonaceous mudrocks. Position along an active tectonic margin has generated tectonic structures with pervasive brittle deformation in the form of faults and fractures.

Participants will learn to characterize lithology, stratal architecture, depositional setting, diagenetic state, mechanical stratigraphy and fracture networks. Field investigation and exercises will be complemented by classroom lectures, sample examination and core description.

These concepts will be applied to the evaluation of naturally and artificially fractured reservoirs and hydrocarbon production.

The following itinerary may change due to weather or accessibility:

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**Day 0:** Arrival and Introduction

- Arrive at Santa Barbara Airport.
- Introductory lecture in the evening.
- Overnight in Santa Barbara.

**Day 1:** Coastal Outcrops at Santa Barbara and Carpinteria State Beach

- Half-day field excursion to examine the Monterey in both relatively undeformed (Santa Barbara Point) and highly deformed states (Carpenteria State Beach), the petroleum system and hydrocarbon migration and seeps along a fault zone and adjacent fractured "damage zone".
- Half-day classroom lecture/workshop.
- Overnight in Santa Barbara.

**Day 2:** Haskell's Beach and Gaviota State Beach

- Half-day field trip to examine multiple lithofacies of organic-rich shale and other biogenic sedimentary rocks at Haskell's Beach and Gaviota State Beach and cross-cutting, oil-charged slope gully sandstone/conglomerate deposit. Regional structure and fracture sets discussed.
- Half-day classroom lecture/workshop.
- Overnight in Pismo Beach.

**Day 3:** Shell Beach and Montana de Oro State Park

- Full field day examining interbedded organic-rich carbonaceous mudstone and fractured chert reservoir rocks and unconformity-related sandstone reservoir at Shell Beach. Examples of parasequence-scale stacking in siliceous mudstones.
- Examine cyclic alternation of thin-bedded siliceous shale and porcelanite facies at Montana de Oro State Park. Investigate primary stratigraphic control of fracture networks and mechanical stratigraphy.
- Overnight in Pismo Beach.

**Day 4:**

- Half-day classroom lecture/workshop.
- Examine diatomaceous and diagenetic-silica-stage siliceous rocks at Sweeney Road.
- Examine detachment folding and faulting at multiple scales in context of regional structure.
- Overnight in Santa Barbara.

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Day 5:

- Lecture, core- and log-based exercises plus field study of mechanical stratigraphy and fracture networks at Arroyo Burro Beach.
- Investigate different modes of brittle failure in adjacent beds of mudstone and porcelanite, and their relationship to fold development.
- Examine evidence for episodic water and oil expulsion from deep basin along fault zones and fracture networks.
- Overnight in Santa Barbara.

Day 6: Travel Day

- Depart from Santa Barbara Airport.

### Exercises Included

This course integrates practical exercises to complement theoretical learning. You will:

1. Measure and interpret fracture orientations at Gaviota Beach:
    - Outcrop exposures of bed-bounded and multi-layer features enable observation of fracture sets related to regional fracture systems and the influence of local stress fields.
    - Measure the orientation of opening-mode fractures, shear fractures, and injectites with respect to bedding and fold orientation.
    - Interpret geometric and genetic relationships within strain fields.
2. Draw and analyze bedding traces and large-scale fractures at Montana de Oro State Park (MDO) Overview:
    - Observations of multi-layer features and their relation to large-scale folding.
    - Draw bedding traces, assess consistency, and estimate strike and dip.
    - Sketch large-scale fractures, estimate lengths, and analyze orientation using rose diagrams.
    - Answer questions about fracture sets, orientation, spatial distribution, displacement mode, and permeability.
3. Assess mechanical stratigraphy and fracture architecture using field observations and diagrams at MDO Platform:
    - Assess the relation between multi-layer and bed-bounded fractures.

- Test concepts of mechanical stratigraphy.
- Work with diagrams and field observations related to the Monterey Formation's structure.
- Answer detailed questions about mechanical stratigraphy, fracture architecture, and tectonic impacts.
- Focus on bed-confined and meso-scale fractures, quantify fracture distribution.
- Use these observations to build a conceptual reservoir model.

4. Study fracture patterns and mechanical deformation at Arroyo Burro Beach:

   - Summary exercise that ties together concepts and observations from the week, enabling reservoir-scale characterization within an active hydrocarbon system.
   - Focus on studying fracture patterns in mudstones and porcelanites and their relationship to fold and fault systems.
   - Describe fracture morphologies and examine mechanical deformation in the

5. Analyze core lithology with handheld XRF data from an offshore Monterey well:

   - Reinforce concepts from outcrop observations with subsurface examples.
   - Illustrate techniques to integrate core and outcrop observations for reservoir characterization and well targeting.
   - Analyze lithology in core using handheld XRF data.
   - Characterize major element oxides in different facies, including clayey siliceous shale, siliceous shale/porcelanite, and phosphatic calcareous mudstone.

6. Describe core fractures and build reservoir models based on observations from McKittrick 418 Core:

   - Reinforce concepts from outcrop observations with subsurface examples.
   - Illustrate techniques to integrate core and outcrop observations for reservoir characterization and well targeting.
   - Describe core fractures over specified depths in a chert-mudstone-diatomite succession.
   - Sketch reservoir models based on core observations, mechanical stratigraphy, and fracture distribution.

These hands-on activities will enhance your understanding and application of sedimentology, depositional systems, and fracture analysis in clastic-poor, biogenic fine-grained sediments.