Characterization of Pliocene Repetto Formation Turbidites at Ventura Avenue Field, Ventura, California*

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Abstract

The Pliocene Pico and Repetto Formation turbidites of the Ventura Basin were the subject of some of the early research on deep-water sedimentation. Combinations of cores, subsurface well logs, and outcrop data have been used to characterize the sandstone reservoirs and interpret depositional setting and sand-body geometry. The sandstones deposited in this broad, elongate-trough basin have been recognized as differing from turbidites that make up the lobes of a traditional submarine fan setting. They have been variously described as ribbon or shoestring sands, compensationally stacked elongate-lobe elements, and components of a braided-lobe complex. The majority of the sands are the result of high concentration flows and are poorly sorted. Our study utilizes recently acquired subsurface data from cores and well logs, and new analytical techniques that link these data types, to progress our understanding of depositional environments, facies distributions and rock properties. A key element is a well-log-based petrofacies model that directly ties to lithofacies. This technique enables us to delineate lithofacies stacking patterns and lateral facies variations in wells without core. Well-log correlation, linked with core observations and petrofacies determination helps to define the geometry of stratigraphic elements on the scale of 50-100 feet (15-30 m) and identify key stratigraphic surfaces. Petrofacies also are key for predicting reservoir properties, since porosity and permeability are closely correlated to lithofacies. In the coarsest-grained stratigraphic elements, we identify two lithofacies stacking patterns that likely represent different depositional settings. Both have pebble-to-gravel-sized clasts in a sandy matrix and angular mudstone clasts at their bases. We interpret these elements to have been deposited in axial positions within the depositional system. One element exhibits a fining upward stacking pattern and potentially represents a distributary channel system that eventually migrates or is abandoned. The second coarse-grained element has a blocky stacking pattern and remains coarse-grained nearly to the top of the unit. Overall deposition of the amalgamated sands...
was likely very rapid. This depositional geometry could be consistent with a braided-lobe complex. Thinner-bedded, generally finer-grained sandstones show more variability in stacking pattern and are more difficult to map over larger distances using well-log correlation. The correlation geometry of these stratal elements is generally planar and subparallel, but the individual sands are less continuous or change thickness. The sands are often interbedded with mudstones and sometimes slurry deposits. We interpret these units to represent off-axis or distal deposition. The coarsest-grained bedsets are deposits of high-density turbidites. They are generally amalgamated, poorly sorted sands, with lower matrix porosity and permeability. The tops of graded bedsets, and the thin-bedded sandstones, tend to be finer-grained and better sorted. They usually have higher matrix porosity and permeability.

**Selected References**


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2016 PS SEPM Session: California Borderland, in Honor of Donn Gorsline
Integrating data to improve reservoir characterization

Well logs

Image logs

Core

Thin section and MICP histogram

Geologic Models

Outcrop
• Discovered 1896, First commercial production 1916
• 9 miles long, complexly thrust-faulted anticline with a 10,000 ft of productive column in stacked Pliocene Pico/Repetto turbidites
• Peak production 1954 (76,600 bopd), reached 1 Billion Barrels December 2009
• Waterfloods initiated 1965, current production approx. 13,000 bopd
Transverse Ranges

Approximate Depositional Basin Outline

Pacific Ocean

# Los Angeles

San Gabriel Fault

Ventura Field

# Ventura

Highlands and Sediment Source

Sediment Paths

25 miles

(modified after Schwartz et al., 2007)
Folds and Thrust Faults Dominate

Photo from J. Rotzien
Type Log: Thick Stratigraphic Column

- 1:1 Cross Section with well paths
- Orange and Yellow horizons highlight thrust faults (Shaded Red)
- Green Shading illustrates oil column
Wells (2500+) are the dominant data source
Structure map on DC abandonment surface illustrating core locations and key stratigraphic section

Cores Provide Critical Data for Facies, Dep’t Environment, and Rock Properties
Turbidite Bedsets and Stacking Patterns

Amalgamated, mostly high-density turbidites

- Thicker Beds
- Poorly Sorted
- Lower Porosity
- Higher Net/Gross
- Higher Kv/Kh

Non-Amalgamated, mostly low-density turbidites

- Graded
- Thinner Beds
- Better Sorted
- Higher Porosity
- Lower Net/Gross
- Lower Kv/Kh
Depositional Processes Impact Rock Properties

High Density Turbidites

• *Population II Grains (Pebbles through Medium Sand)*

• *Most deposition from higher-energy, high sediment concentration flows*

• *Particles supported by grain interactions and fluid turbulence*

Low Density Turbidites

• *Population III Grains (Medium Sand and Finer)*

• *Most deposition from lower-energy, lower sediment concentration flows*

• *Particles supported by fluid turbulence*

*Sorting is significantly better in rocks deposited by low density flows.*

(after Lowe, 1982, 2000)
Angular shale rip-up clasts and pebbles in sandy matrix

Pebbles, granules, coarse sand – poorly sorted

Amalgamated, coarsest-grained units

Rapid deposition

Some evidence of local erosion

Occasional S1-S2, typically Ta/S3

Basal Lobe and Axial Position of Distributary or Braid Channels
**Amalgamated Sands**

Granules to medium sand, dominantly “high density” turbidites (Ta/S3)

Occasional pebbles at base of flow units

Some “caps” of fine-medium sands, disrupted bedding common

No shale beds between depositional flow units, thick packages readily correlate

*Rapid Lobe Deposition/Amalgamated Bar forms*

(3’ core strips, plain light)
Non-Amalgamated: Thin-Bedded Turbidites and Mudstones

*Classical or “Low Density” Turbidites*

Interbeds of Medium-Fine Sand and Mudstone

Planar-Parallel and Current-Ripple Lamination Common

$T_{b-e}$ dominates, some debrite and slurry flows

*Lobe Fringes, Off-Axis or Inter-Bar Positions, Abandonment Periods*
Outcrops show similar facies and geometry
Taylor 672R1

Bedset Stacking and Porosity Distribution

Non-Amalgamated
Thinner-Bedded
Base: Med. to V. Coarse SS
Caps: Fine SS and Mudstone

- Better Sorting
- Higher Porosity

Amalgamated
Thicker-Bedded
Pebbles to Coarse Sand

- Poorly Sorted
- Lower Porosity
Repetto Formation Core Data: Grain Size vs. Porosity

- **Shale**
- **Fine and Medium ss**
- **Coarse sands to pebbles**
Histograms of Porosity Distribution

Medium Sands (mode=20)

Coarse Sands (mode=16)
Mudstone Interbeds: Sand and Mudstone
Fine to Very Fine Sand
Coarse to Medium Sand
Granules to Very Coarse Sand
Pebbles
Carbonate Concretions

Mudstone with Thin Sand Interbeds

Thick and Thin-Bedded Medium to Fine Sands with Mudstone “Caps”

Medium to Coarse-Grained Amalgamated Sands

Coarse Basal Unit with Mud Rip-up Clasts

Abrupt Change in Stacking

Approx. 120 ft cored interval

Fining Upwards Stacking Pattern

Porosity 30
### HBU-8 Cored Well

#### MICP Histograms

- **10373’**
  - $k_a = 3.07$ md
  - $\Phi = 15.3\%$
- **10393’**
  - $k_a = 30.95$ md
  - $\Phi = 19.7\%$

- Thick-bedded, high density
- Poorly sorted
- Lower Phi, K

- Thin-bedded, low density
- Better sorted
- Higher Phi, K

### Summary

- **Clay, V. Fine SS, Fine SS, Coarse SS, Medium SS, Pebble, Gravel:**
  - DC
  - DC_C64
Integrating Image Logs

High resolution stratigraphic and structural information
- Bedding surfaces, structural orientation
- Rock fabric and facies information
- Quantify sand/mudstone
- Fault locations and orientations
- Fractures

Cored wells provide calibration
- Compare core facies to image log facies
- Extend to areas without core
- Integrates with other log techniques

Detailed Sedimentologic / Facies Interpretation

Lloyd 252 Dynamic Image

Mud cap at top of bed
Pebbles or concretions
Thicker-bedded turbidites
Clay rip-up clasts at base of sand
Loading features at bed boundary
Thin-bedded turbidites, laminated
A key element for subsurface extrapolation is calibrating the cores to the well logs.
Petrofacies Calibration

Core

Petrofacies

GR, N, D

Rhob

Gamma Ray

Nphi
Unique Distributions of Rock Properties Characterize the Lithotypes and Grain Sizes

- Similar to core porosity distributions
- Petrofacies can be used to distribute properties in wells without core
What Criteria Guides Our Correlations?

T788

T228R1

M52

V170

100 feet (30 m)

5 miles
Outcrop and Well Log Observations Provide a Guide for Building the Stratigraphic Framework

- Best surfaces for well-log correlation are regional flooding or abandonment surfaces
- Generally planar parallel geometry on large scale, but bedsets exhibit significant internal geometry
- Some scour and truncation, but it is on the order of 10’s of feet, not 100’s of feet
- Amalgamated sand packages are most correlative and persist over thousands of feet in the E-W (strike) direction
- Individual sands in thin-bedded packages are less continuous
- Stacking patterns of lithofacies are generally consistent, and can be used for correlation
Dominant depositional geometry is planar, mostly parallel.
Lithofacies changes are generally subtle but do occur over distances of hundreds of feet.
Base of thick-bedded amalgamated sands are abrupt and often erosional
Amalgamated sands

Thin sands and mudstone
Mudstone
Poorly-sorted pebble bed
Mudstone
Cobbles and large shale rip-up clasts
Internal geometry of amalgamated sands includes pebble lags and internal scours
Bedsets generally exhibit planar, parallel geometry, with some low-angle truncation and scour.

Base of amalgamated unit
Low-angle scour in thin-bedded units

Approx. 4 feet
Thin-bedded sandstones less continuous than thick-bedded units
Example of Correlations Guided by Stratal Surfaces and Petrofacies Stacking Patterns

Approx. 2000 ft Along Depositional Dip
Approx. 2500+ ft Along Depositional Strike

NW
T478
GR R N GS

Along Depositional Dip

T763
GR ND PF

Along Depositional Strike

T672R1
GR ND GS

DC

DC_C64

25 ft

DC_C40

DF
Correlating DC interval in repeat section of Taylor 786 well

DC T180 Fault Block

Approx. 1000’

DC T410 Fault Block
Correlation based on key stratal surfaces and stacking
Compensational Stacking

True Stratigraphic Thickness Maps of Sand Packages

Background grid boxes are 1000’ by 1000’
Gray solid line is the location of W to E Cross Section
Summary and Conclusions

*Identified and evaluated the critical elements for building a well-based geologic model*

- Cores and outcrops to delineate depositional facies and property distribution
- Petrofacies model extrapolate facies and property distribution away from cored wells
- Outcrop and subsurface observations to identify key stratigraphic surfaces and geometry, helping to establish the stratigraphic framework

*Integrating data of multiple scales, from multiple sources, provides building blocks for a robust geologic model that can be used for development decisions and reservoir simulation*
Example Layers in the Geologic Model

- Amalgamated sands have best continuity
- “Abandonment” mudstone-dominated layers
- Amalgamated and layered sand with limited mudstone
- Amalgamated and layered sand with no continuous mudstone

441 layer VPC
Selected References


