PS Evaluating the Thermal History of the Los Angeles Basin through 3D Basin and Petroleum System Modeling*

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Abstract

The Los Angeles Basin presents a valuable opportunity for 3D basin and petroleum system modeling due to its impressively high hydrocarbon productivity relative to sediment volume, high source rock TOC, and the geochemical diversity of the produced oils. A 3D Earth model of the Los Angeles Basin was constructed from basement to ground surface to examine the various factors impacting heat flow through the basin's history. The basement surface is defined by the SCEC Community Velocity Model supplemented by well penetrations on the basin flanks. Overlying sedimentary strata are mapped from well logs, to include top Pico, Repetto and Monterey (Puente) formations, as well as several chronostratigraphic surfaces, including top Miocene, Oligocene, Eocene and Paleocene. The Miocene Puente Formation is additionally subdivided into several subunits, including the organic-rich Nodular Shale source rock unit.

The chief aim of this model is to better understand the impacts of the basin's complex geologic history, resulting in a number of often conflicting thermal effects, which overlap through geologic time, on the thermics of the basin. The relative impacts and magnitudes of the various thermal effects are explored from a basin modeling perspective through scenario testing and comparison with calibration data and mapped source rock maturity trends, buttressed by new custom bulk kinetics of the nodular shale phosphatic source rock. We examine the following successive tectonic episodes having conflicting thermal effects: (a) pre-basinal subduction of the Farallon Plate through the Paleogene resulting in early depression of isotherms, (b) subsequent subduction of the East Pacific Ridge and transition to a transform plate boundary, associated with volcanism, schist upwelling and increased heat flow, and (c) rapid subsidence of the basin initiated in the Middle to Late Miocene, producing in turn a cooling effect through the thermal blanketing effects of deposited sediments and the lateral heat loss through steep basin margins. This new model of the Los Angeles Basin will provide for a more comprehensive understanding of this basin's unique petroleum system.

Evaluating the Thermal History of the Los Angeles Basin Through 3-D Basin and Petroleum System Modeling

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Abstract

The Los Angeles Basin presents a valuable opportunity for 3D basin and petroleum system modeling due to its impressively high hydrocarbon productivity relative to sediment volume, high source rock total organic carbon (TOC), and the geochemical diversity of the produced oils. A 3D Earth model of the Los Angeles Basin was constructed from basement to ground surface to examine the various factors impacting heat flow through the basin's history. The basement surface is defined by the Southern California Earthquake Center (SCEC) Community Velocity Model, supplemented by well penetrations on the basin flanks. Overlying sedimentary strata are mapped from well logs, to include top Pico, Repetto and Monterey (Puente) formations, as well as several chronostratigraphic surfaces, including top Miocene, Oligocene, Eocene and Paleocene. The Miocene Monterey Formation is additionally subdivided into several subunits, including the organic-rich Nodular Shale source rock unit.

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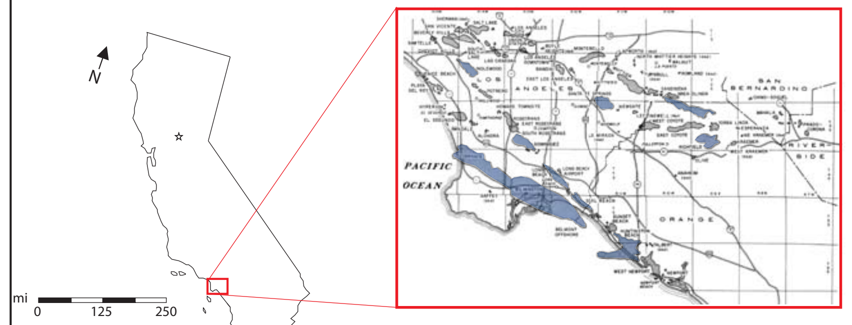
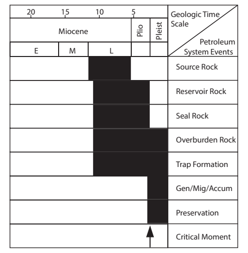
Background



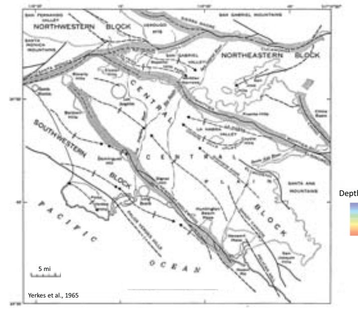
Field	Discovery Year	Oil (EUR in MMBO)	Gas (EUR in BCFG)
Wilmington-Belmont	1932	2857	1235
Huntington Beach	1920	1138	861
Long Beach	1921	945	1088
Santa Fe Springs	1919	634	839
Brea-Olinda	1880	430	482
Inglewood	1924	400	285
Dominguez Hills	1923	277	387
Torrance	1922	246	158
Seal Beach	1924	216	225
Richfield	1919	203	173

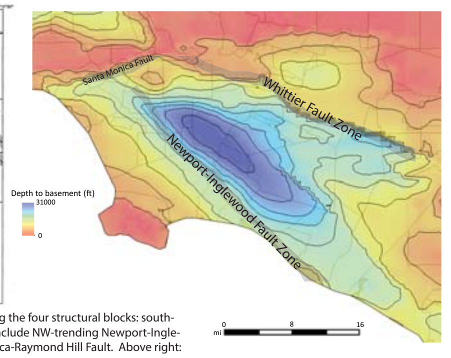
Table above plots discovery year and estimated ultimate recovery of oil and gas for the 10 largest accumulations in the Los Angeles Basin province. Data from 1995 National Oil and Gas Assessment (Beyer, 1995). Map to the left plots all oil fields in the basin, with the 10 largest highlighted in blue (CA DOGGR, 1992).

-Los Angeles Basin is a Neogene pull-apart basin located on the coast of southern California, USA
-Most petroliferous basin in the world relative to sediment volume (Biddle, 1991)
-Cumulative reserves estimated at over 10 BBOE, including 3 fields over 1 BBOE (Wilmington, Huntington Beach, Long Beach) (Beyer, 1995)
-Basement structure defined by deep NW-trending trough in central block of basin with over 9000m (30000 ft) overlying sedimentary strata
-Major fault zones (Newport-Inglewood, Whittier-Elsinore, Santa Monica) divide basin into structural blocks



Generalized petroleum system events chart for LA Basin petroleum systems after Magoon and Dow, 1994.

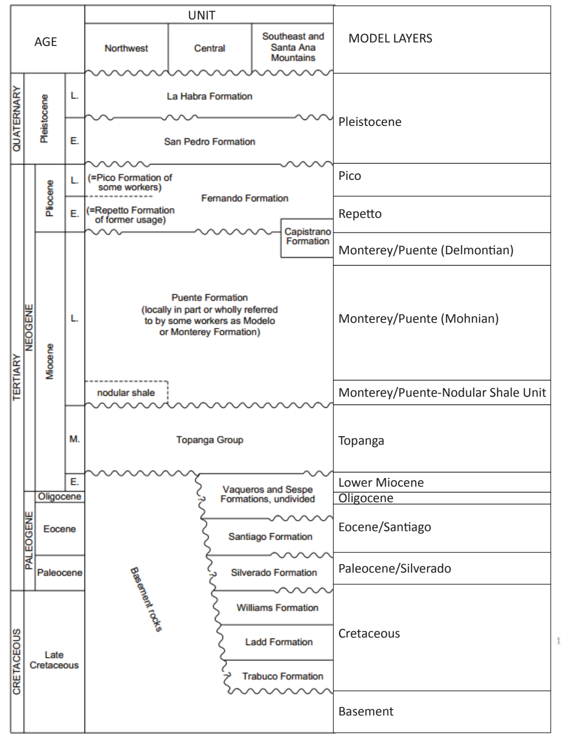




Above left: Major structural features of the Los Angeles Basin, including the four structural blocks: southwestern, central, northeastern, and northwestern. Major fault zones include NW-trending Newport-Inglewood and Whittier-Elsinore fault zones, and E-NE trending Santa Monica-Raymond Hill Fault. Above right: structural relief of basement.

-Pre-basinal tectonic setting = subduction zone until about 30 Ma, including flat-slab phase during Laramide (Ingersoll, 2008)
-Over 90 degrees of block rotation during Miocene from paleomagnetic data (Luyendyk et al., 1980)
-Rapid opening of basin in late Miocene to early Pliocene
-Deep, cold water, restricted circulation and rapid sedimentation resulted in excellent preservation of organic matter in Monterey source rock intervals

Model Building

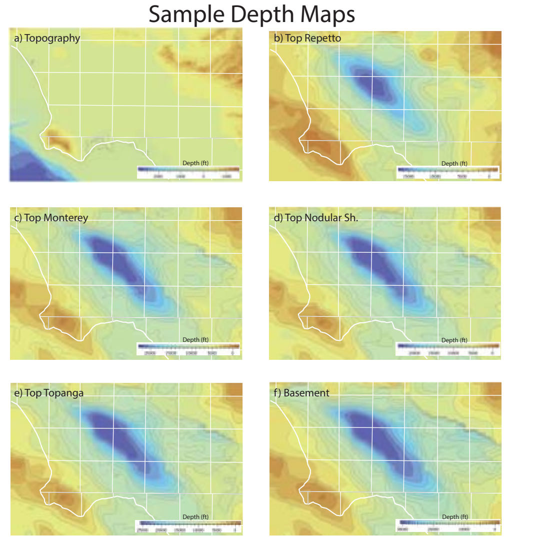


Stratigraphic column for the sedimentary layers of the Los Angeles Basin with corresponding model layers to the right. Major source rock layer is the Monterey, particularly the Nodular Shale Unit, and important reservoir units include the turbidite sandstones of the Pico, Repetto and upper Monterey. Adapted from Beyer, 1995.

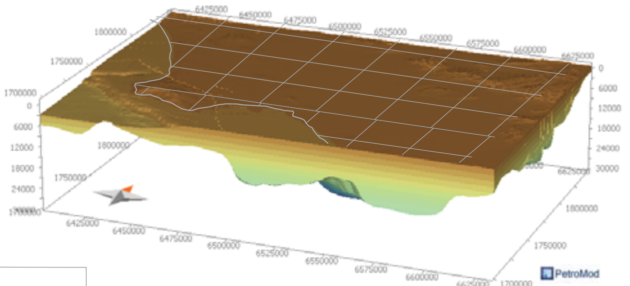
-12 model layers built from well tops and published cross-sections (see map below)
-Topographic surface built from Southern California Coastal Relief Model; Basement surface from SCEC CVM-H

Map above shows cross-sections used for building Pico through Monterey layers. Solid lines for PS-AAPG published cross-sections, dashed lines for CA DOGGR cross-sections. Deeper horizons built from well tops and maps provided by Tom Wright (unpublished).

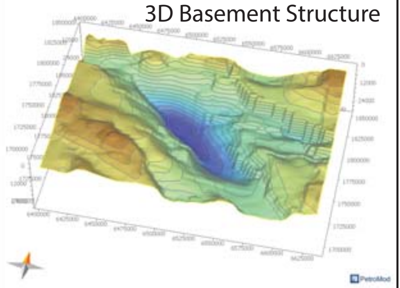
Sample Depth Maps



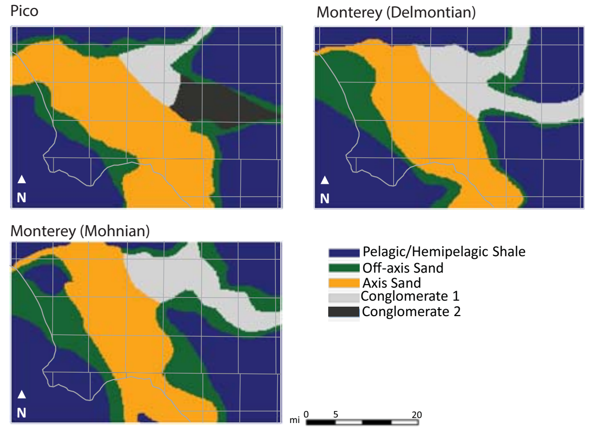
3D Basin Model



3D Basement Structure

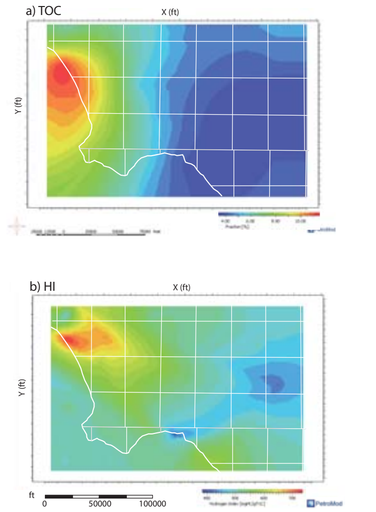


Facies Maps

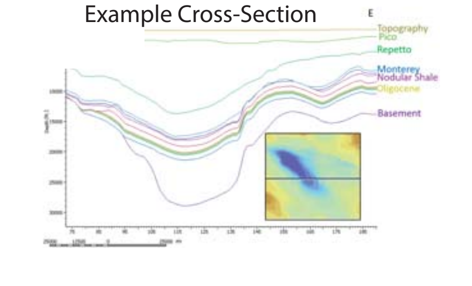


Facies/lithology assigned to layers based on publish stratigraphic columns (see Beyer, 1995 above; Yerkes et al., 1965) and sediment distribution maps, as in maps above (Redin, 1991). Petromod lithology defaults used except where adjustments necessary to fit compaction calibration data.

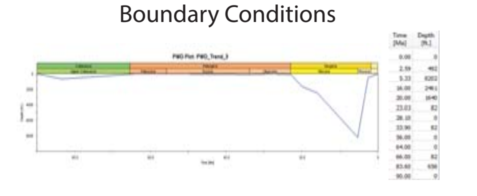
Source Rock Properties



Example Cross-Section



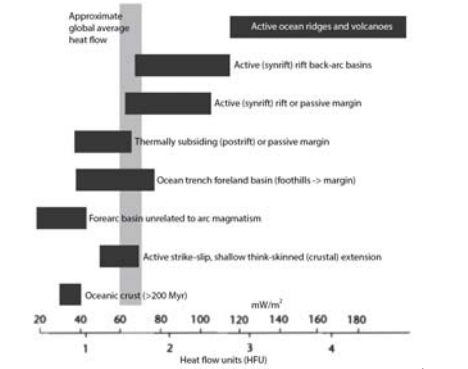
Boundary Conditions



-Map based lithologies assigned for important reservoir layers where resolution of changes in lithology most important to petroleum system (see maps above left)
-Nodular Shale modeled as sole source rock layer- total organic carbon (TOC) and hydrogen index (HI) assigned as maps from well data (see maps above right)
-Custom kinetics from Nodular Shale hand sample used for kinetics modeling (bulk)

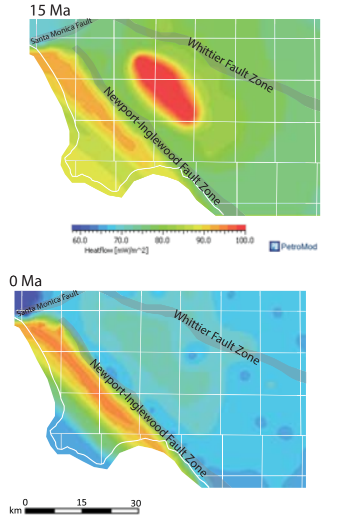
-Paleo-water depth curve generated from benthic foram assemblages (Blake, 1991)
-Sediment-water Interface Temperature (SWIT) assigned using Petromod Auto-SWIT method (Wygrala, 1989)

Results

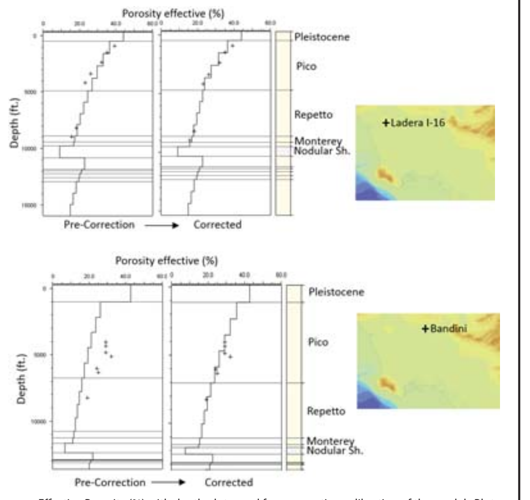


Average heat flow ranges from tectonic settings around the world used to model the LA Basin's past heat flow patterns. Adapted from Allen and Allen, 2013.

-Relatively low heat flow during subduction
phase on order of 42 mW/m^2
-Peak heat flow during basin rifting phase, 90-100+ mW/m^2
-Modeled heat flow rates consistent with observed heat flow ranges from



Modeled heat flow maps for the Los Angeles Basin at 15 Ma (top) and 0 Ma (bottom).



Effective Porosity (%) with depth plots used for compaction calibration of the model. Plots to the left are pre-compaction calibration, and plots to the right show calibrated compaction curves.

-Heat flow regimes bounded laterally by major fault zones, i.e. higher heat flows contained on western side of Newport-Inglewood Fault zone

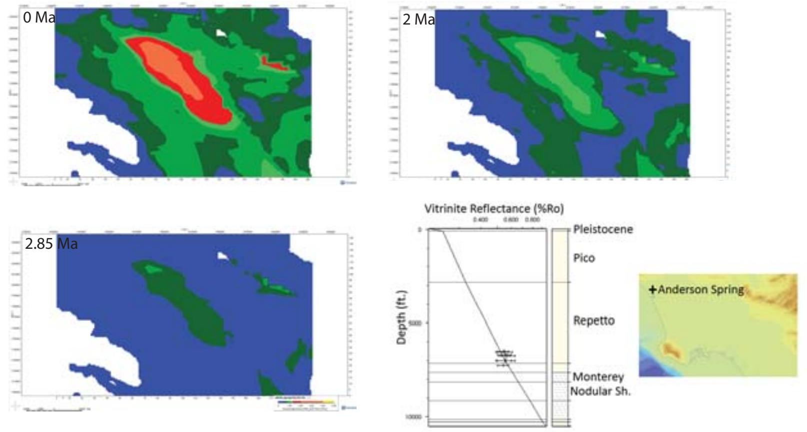
-Recent high heat flows associated with opening of basin in Miocene

-Miocene rifting, volcanics produce high heat flows in central block of basin

-Modeled heat flow maps produce thermal maturity indices consistent with observed data from wells

-Onset of generation just after 3 Ma, basin still contains extensive zones of source rock within the oil window (see maps to the left)

Thermal Maturity



Maps of modeled Nodular Shale source rock maturity using vitrinite reflectance as measure of maturity. Green indicates sediments within the oil window (0.65-1.3). Plot in lower right shows sample well-extraction of vitrinite reflectance with depth plotted with measured well data.

Conclusions

-Los Angeles Basin experienced high heat flows in its recent history of 90-100+ mW/m^2 resulting in recent and rapid maturation of petroleum-producing sediments

-Young petroleum system with onset of generation beginning in the late Pliocene (~2.9 Ma), and all essential petroleum system elements forming in the late Miocene or later

-Modern heat flow patterns demonstrate impacts of basement lithology and structural bounding of faults in producing different heat flow rates

-Full 3-D model of basin will provide valuable framework for future expansion of petroleum system modeling of the Los Angeles Basin

Acknowledgments

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