Case Study: 25 Years of Historic Hydrocarbon Seep Studies in Santa Maria Basin, Offshore California Using Seismic and Stratigraphic Data (1995 through 2020)*

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Search and Discovery Article #11346 (2020)**
Posted August 24, 2020

*Adapted from oral presentation prepared for the 2020 AAPG Pacific Section Convention, 2020 Vision: Producing the Future, Mandalay Beach, Oxnard, California, April 4-8, 2020 (Cancelled)
 DOI:10.1306/11346Saenz2020

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Abstract

Historic seismic and stratigraphic records were used to understand the relative effects of active tectonics on hydrocarbon seeps in the Santa Maria Basin (SMB), offshore California. The study confirms that hydrocarbon seeps are associated with the Hosgri-Purisuma-Lompoc Fault zones tapping into a single major reservoir, the Monterey Formation. In the northern and central areas, these Monterey reservoirs occur in growing anticlinal folds that are faulted and fractured by the Hosgri Fault zone, acting as a major conduit for gas and oil seeps. In the southern area, heavy oil migrating up-dip in the Monterey Formation is found near (or at) the seafloor in the hanging-wall of the Santa Barbara Basin along North Channel Fault. The stratigraphy of the offshore SMB is known from seismic surveys, cores, electric logs, and 73 mud logs within the basin.

More than 60 multi-sensor, shallow drilling hazard and deep seismic reports provided data sets of seeps, seafloor features, and geologic structure. We find an abundance of evidence to suggest continuous or episodic upward movement of fluids as migrating gas plumes from deeper sediments into surface sediments. The analysis shows that bright spots on the seismic reflection profiles are gas-plumes, linked to the highest geothermal gradients and controlled by active tectonics. Gas, deeply sourced in the Monterey Formation, migrates upward along faults, anticlinal folds, and steeply dipping beds into shallow sediment. Gas chromatographic analysis from mud logs samples in wells near gas plumes show the highest concentrations of methane, ethane, propane, and butane. Temperature changes induced by geothermal heating during burial caused in-reservoir thermal cracking of the oil to lighter-end hydrocarbon gases that migrate as gas plumes into shallow burial depths.

Records indicate that Monterey Formation API oil gravities range from 3° to 35°. Oil gravities are related to zones of shallow gas-charged sediments, and variable geothermal gradients ranging from 1.7°F/100 ft to 3°F/100 ft, with downhole temperatures ranging from 118°F to 248°F. Within close proximity to the Hosgri Fault zone, lithologic analysis revealed three areas where siliceous Monterey rocks have been

diagenetically altered to glassy cherts related to high geothermal gradients and reservoir pressures (2115 psig to 3385 psig). Active tectonics has fractured these brittle reservoir rocks, forming migration pathways that serve as conduits for seafloor hydrocarbon seeps.

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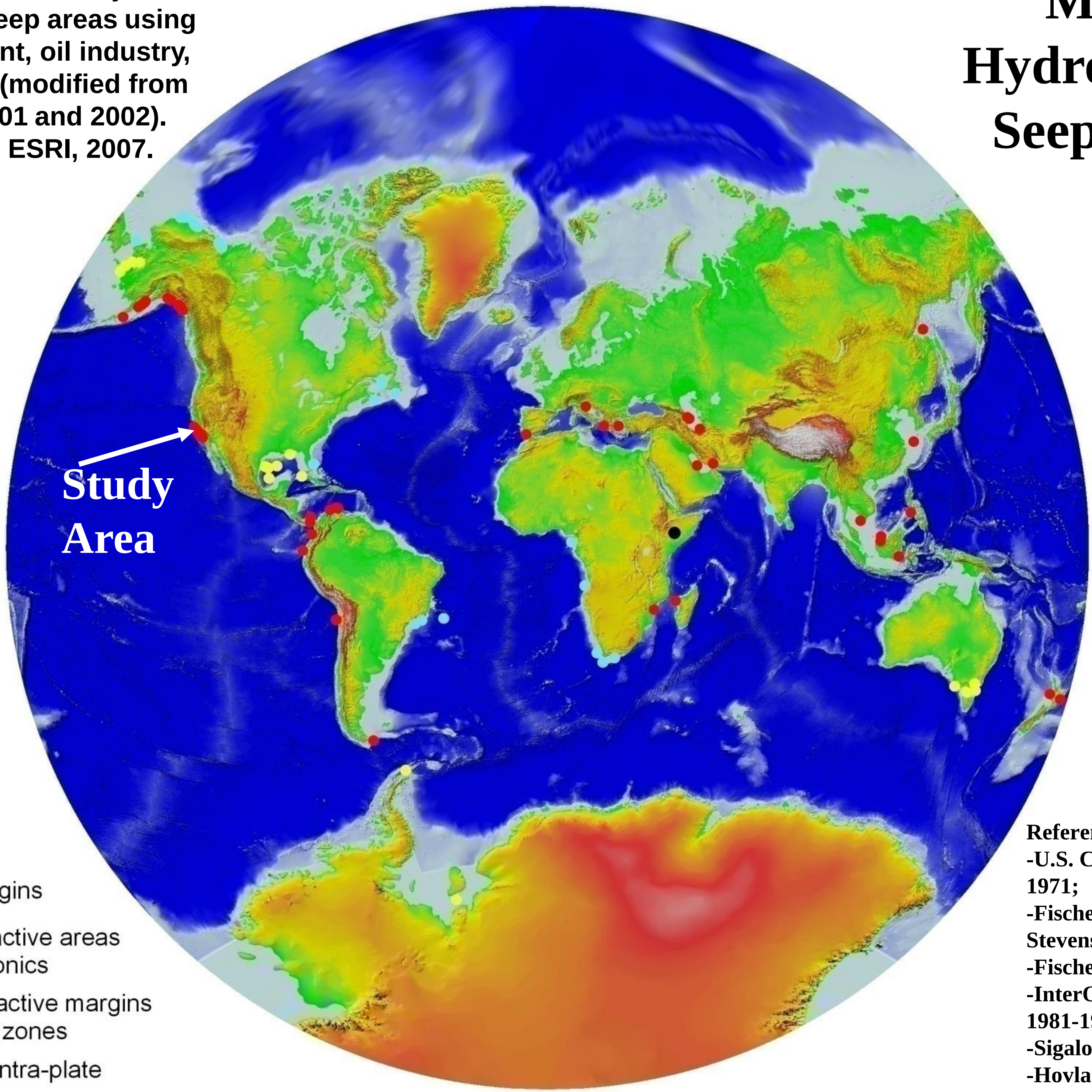
Acknowledgements

- Peter J. Fischer*, Ph.D., California State University, Northridge, Professor Emeritus
- Gerry Simila*, Ph.D., California State University, Northridge, Professor
- Dan Francis*, Ph.D., California State University, Long Beach, Professor
- Fred Piltz*, Ph.D., U.S. Minerals Management Service, Pacific OCS Region
- James Vernon, Ph.D., GEO III – Research Vessel
- Mark Legg, Ph.D., Legg Geophysical, Inc.
- Satish Pullammanappallil, Ph.D., University of Nevada, Reno, Seismological Laboratory
- Rick Behl, Ph.D., California State University, Long Beach
- Tom O'Neil of Oxnard College
- Jim Ceasar formerly of Clean Seas
- U.S. Minerals Management Service, D. Mayerson, J. Grant, H. Syms, B. Bosserman, S. Drewry, S. Wolfson, M. Brickey, T. Dunaway, C. Ogawa, F. Victor, K. Piper, and G. Shackell, and others
- U.S. Department of the Navy, D. B. Chan, Ph.D, K. Zaiger, Ph.D., R. Nordahl, and others
- U.S. Coast Guard, Commander Bill Drelling, LT Commander Michael Hunt, and others
- U.S. Drug Enforcement Administration, T. Gorshe and others
- U.S. Geological Survey, Tom Lorenson and Janet Watt
- Combined Joint Task Force Horn of Africa, Admiral Richard Hunt, Admiral Moon, CDR Paul Vandenberg, Major Tim Collier, and others

Major Hydrocarbon Seep Areas

Worldwide review of major hydrocarbon seep areas using U.S. Government, oil industry, and other data (modified from Saenz, 1995-2001 and 2002). Base map from ESRI, 2007.



- Passive margins
- Seismically active areas and salt tectonics
- Tectonically active margins and collision zones
- Continental Intra-plate rift margins

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Background
U.S. Minerals Management Service
1982 to 2010

Formed in December 1982
Dissolved in June 2010

Agency existed for 28 years.

MMS Focus Facility Inspection Team, Pacific Outer Continental Shelf Region - 1999

Deep Water Horizon Explosion
April 20, 2010

American Society of Mechanical Engineers, September 2011

Under President Obama's Administration:

Due to perceived conflict of interest and poor regulatory oversight following the Deepwater Horizon oil spill and Inspector General investigations, the Secretary of the Interior Ken Salazar issued a secretarial order on May 19, 2010 splitting MMS into three new federal agencies:

1) the Bureau of Ocean Energy Management (BOEM),
2) the Bureau of Safety and Environmental Enforcement (BSSE), and
3) the Office of Natural Resources Revenue.

Formed	January 19, 1982
Dissolved	October 1, 2011

Background:

In 1995, the U.S. Coast Guard requested a hydrocarbon seep map of the Santa Maria Basin, offshore California from the U.S. Minerals Management Service, Operations Section.

No hydrocarbon seep maps existed for the SMB, Offshore California.

Several maps were generated upon the U.S. Coast Guard's request.

Eventually, this seven year effort lead to my Masters Thesis obtained from CSUN in 2002.

Data Set Used in this Investigation

- Seafloor features (hydrocarbon seeps, pockmarks, mass movement deposits, buried channels, and seafloor mounds, rubble, and hummocks) mapped from multi-sensor, high-resolution geophysical surveys from over 60 Lease Blocks, well and core data.

- SNIFFER data (Sigalove, 1985; and Ocean Engineering International, 1985).

- Mesozoic and Cenozoic Formation thickness from 73 offshore exploratory wells interpreted from mud logs, electric logs, dip meter logs, unpublished micropaleontological analyses, well correlations, and other data.

- A structural synthesis (anticlines, synclines) and a brief assessment of recent fault activity from multi-sensor, high-resolution geophysical surveys and other sources.

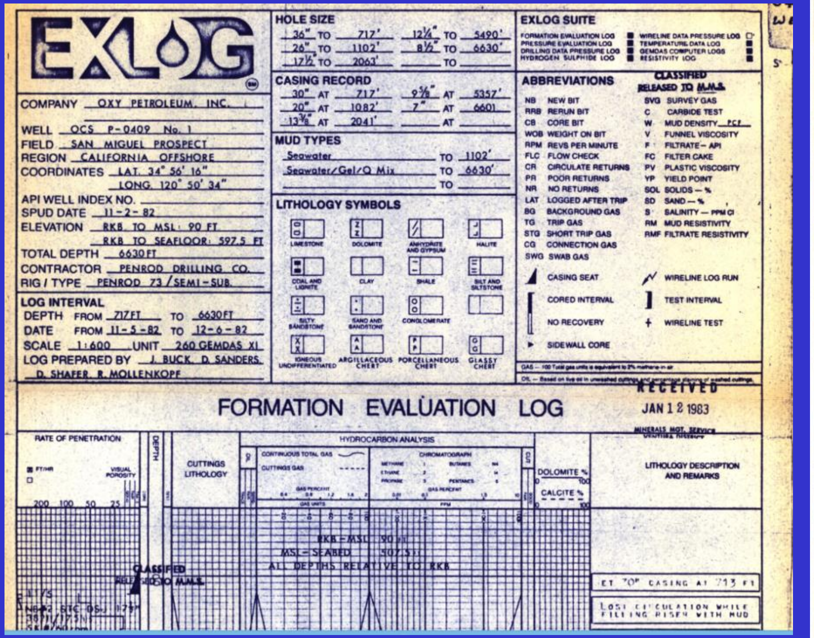
- Assessments of API oil gravity, geothermal gradient, and average temperatures, and distribution of chert types based upon 73 offshore exploratory wells.

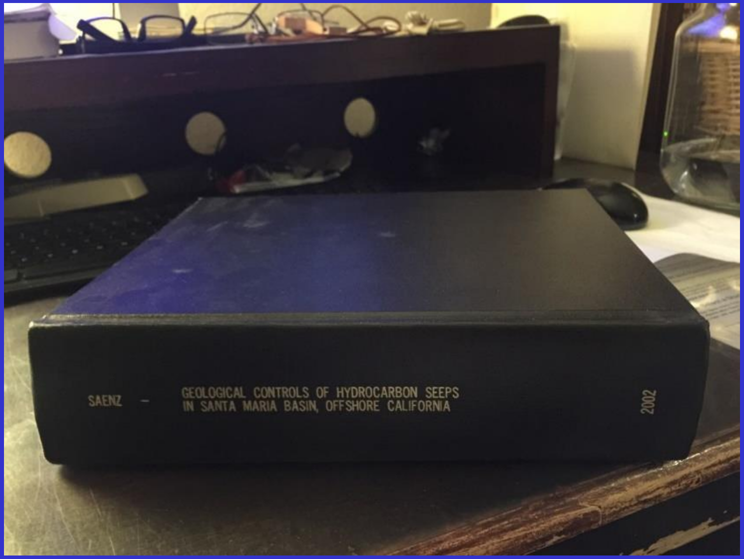
- An assessment of glauconite and phosphate in Quaternary and Neogene Formations.

- An assessment of seismic activity in the region (e.g.: November 4, 1927 M 7.3 Lompoc Earthquake)

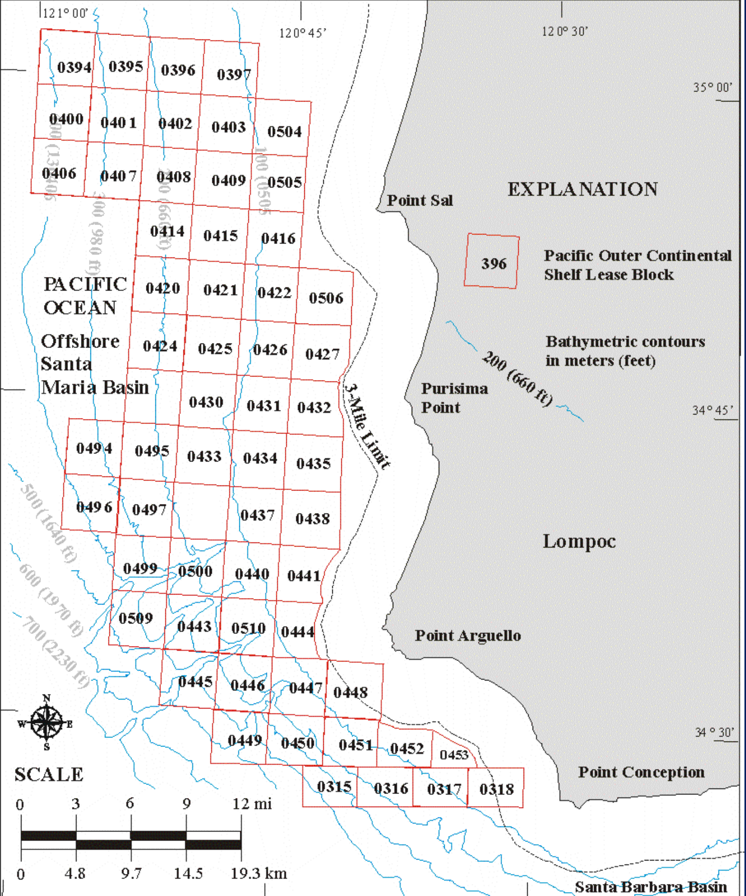
Data Set Used in this Investigation

- Mud Logs
- Temperature Logs
- Dual induction Logs
- Compensated Neutron Formation Density Logs
- Micro-later Log / Micro Logs
- Natural gamma ray tool Logs
- SP Logs
- Borehole compensation sonic Logs
- Neutron litho-density Logs
- Computer processed Logs
- Sonic waveform Logs
- High Resolution Continuous Dip-meter Logs
- Drill Stem Tests
- Completion reports / Daily reports





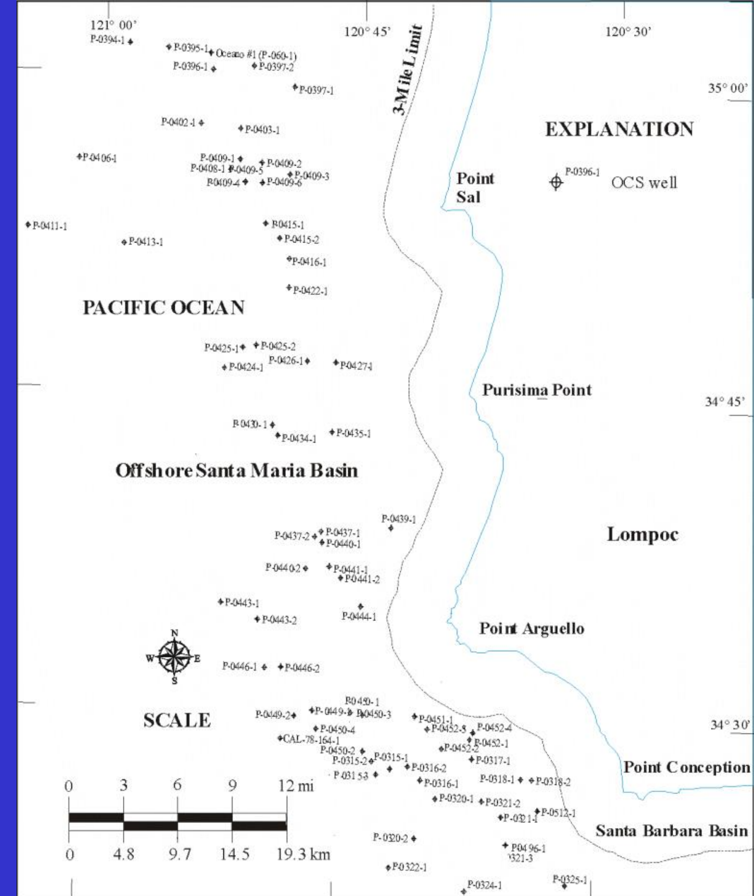
Shallow Hazard Seismic Surveys



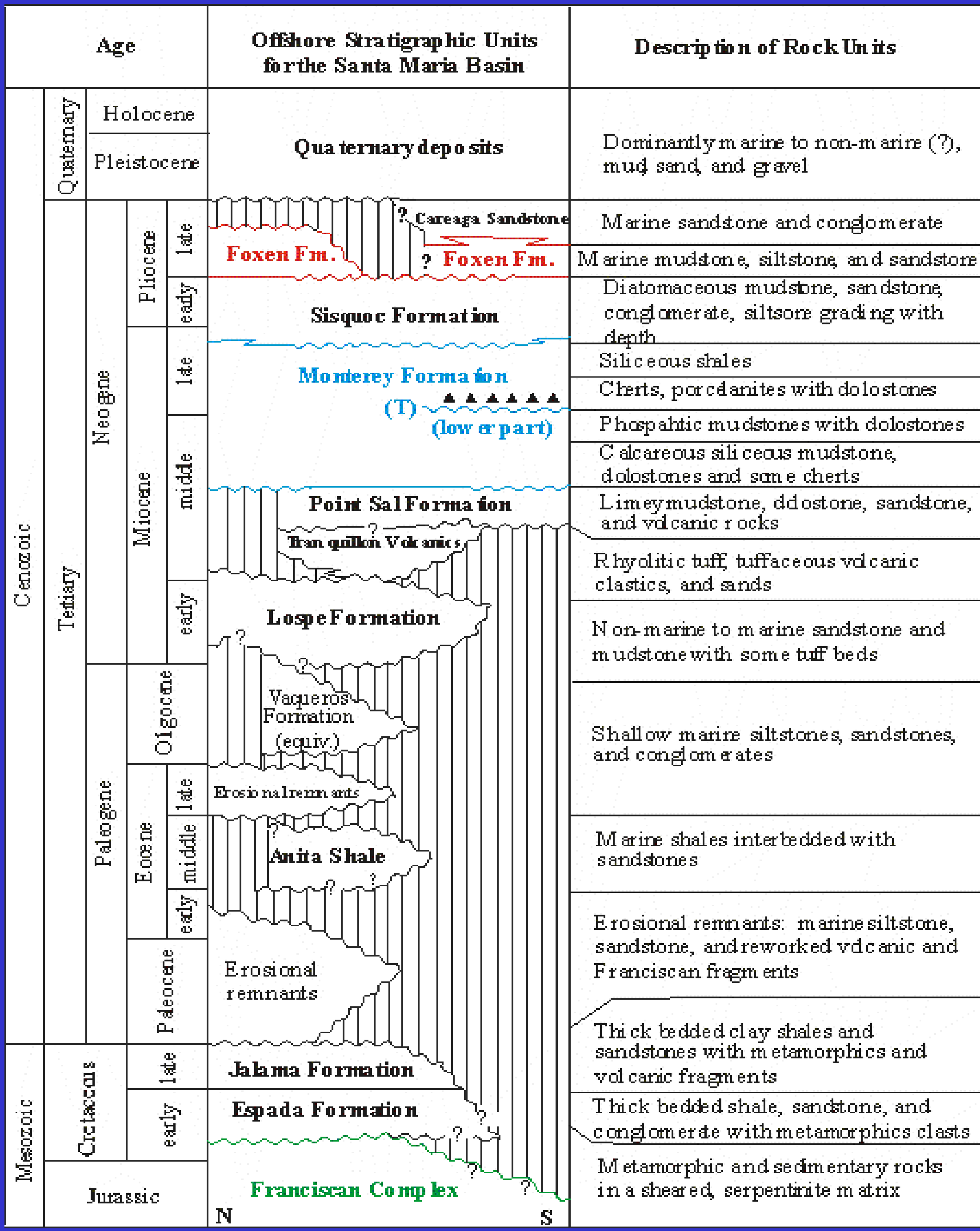
Pacific Outer Continental Shelf Lease Blocks and Bathymetry of the Offshore SMB Study Area

Geologic structures, rock stratigraphy, and seafloor features were identified and confirmed from high resolution geophysical survey data collected within the POCS lease blocks. Blocks with lease numbers were surveyed by industry consultants and are listed in unpublished reports in Saenz 2001 and 2002.

Offshore Exploratory Wells



- Locations of the 73 offshore exploratory wells in the offshore SMB study area.
- Exploratory wells were drilled from 1965 through 1989. Geophysical logs, mud logs, micropaleontology controls and other data that were used to define the stratigraphy of the offshore SMB study area.
- Mud log data are the most abundant geochemical data available. In general, they are an adequate representation of vertical variations of light gases and fluorescing compounds. Showing orders of magnitude of changes in a few feet to tens of feet, and rapid compositional shift of light compounds to heavier compounds
- High values are related to the occurrence of mature source rocks, top of over pressured zones, faults, and reservoirs (Saenz et al, 2005).



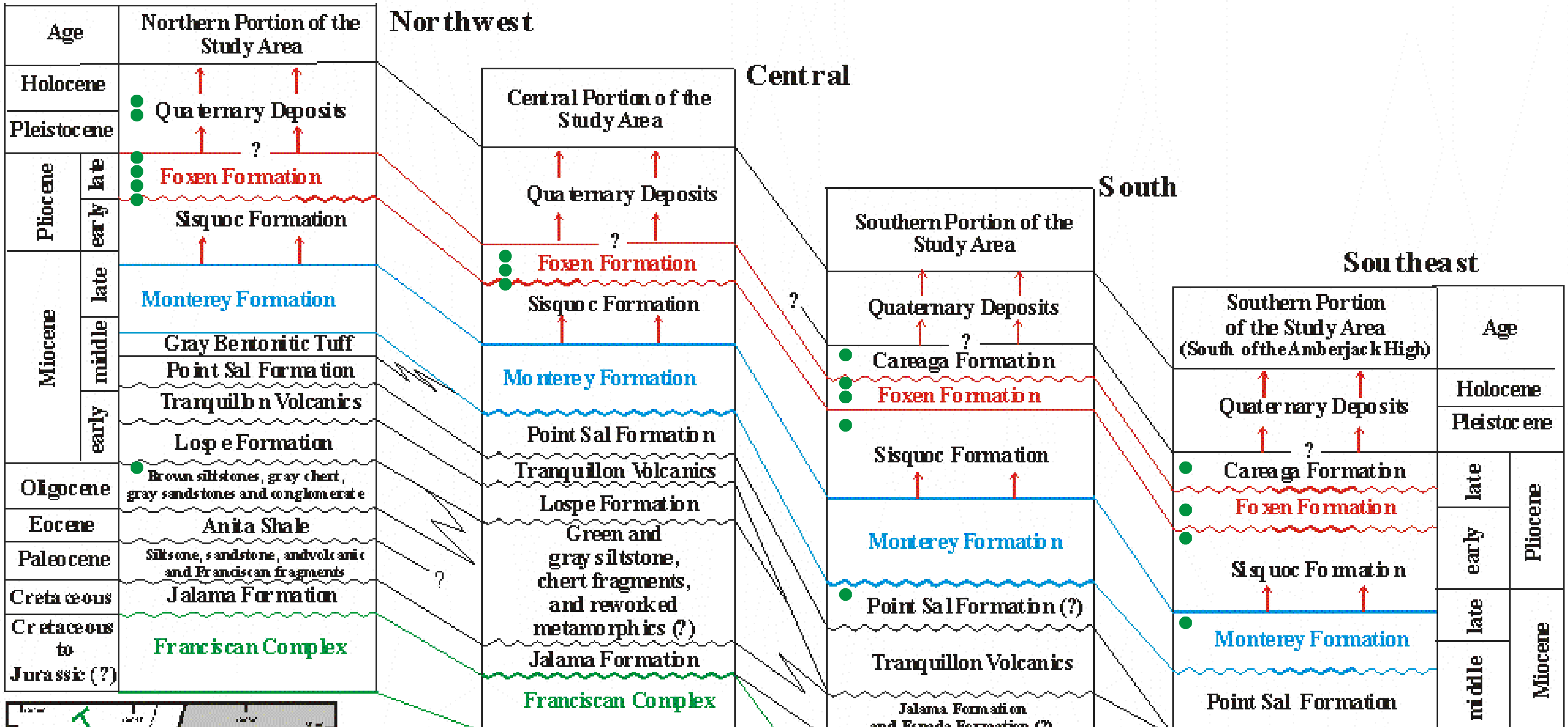
Generalized stratigraphic column

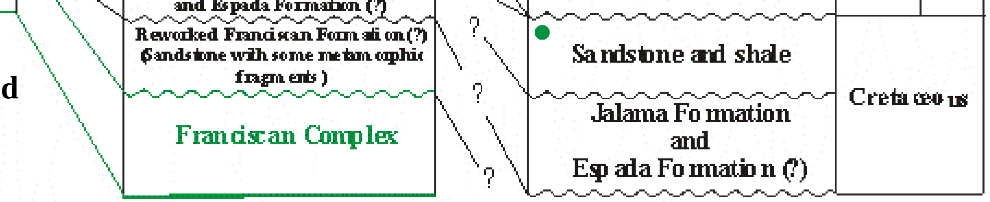
•Stratigraphy of the offshore SMB study area, generalized from offshore well data (Appendix B of Saenz, 2002) (Note; the top of the "lower part" of the Monterey Formation (T) is the mapped horizon of Figure 2 (Saenz, 2002).

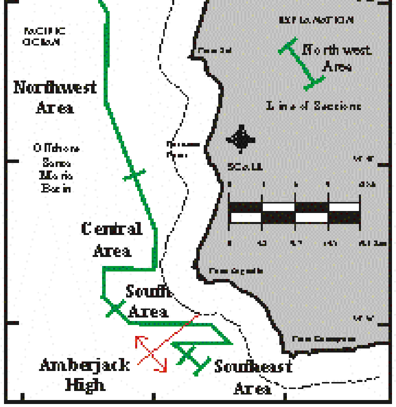
Holocene 0.010 Ma to 0 Ma (10,000 yrs. ago to 0 yrs. ago)
Pleistocene 2.6 Ma to 0.010 Ma (10,000 yrs. ago)
Pliocene 5.3 Ma to 2.6 Ma
Miocene 23 Ma to 5.3 Ma
Oligocene 33.9 Ma to 23 Ma
Eocene 56 Ma to 33.9 Ma
Paleocene 66 Ma to 56 Ma
Cretaceous 145 Ma to 66 Ma
Jurassic 201 Ma to 145 Ma
Triassic 252 Ma to 201 Ma

Note: Times Picks from GSA Geologic Time Scale v. 4, 2012

Stratigraphic Correlation and Migration Pathways for Hydrocarbon Gases Originating from Monterey Formation Source Rocks

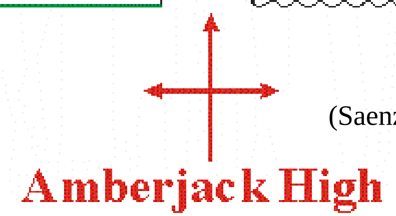






● Assessment of Glauconite and phosphate in Formations

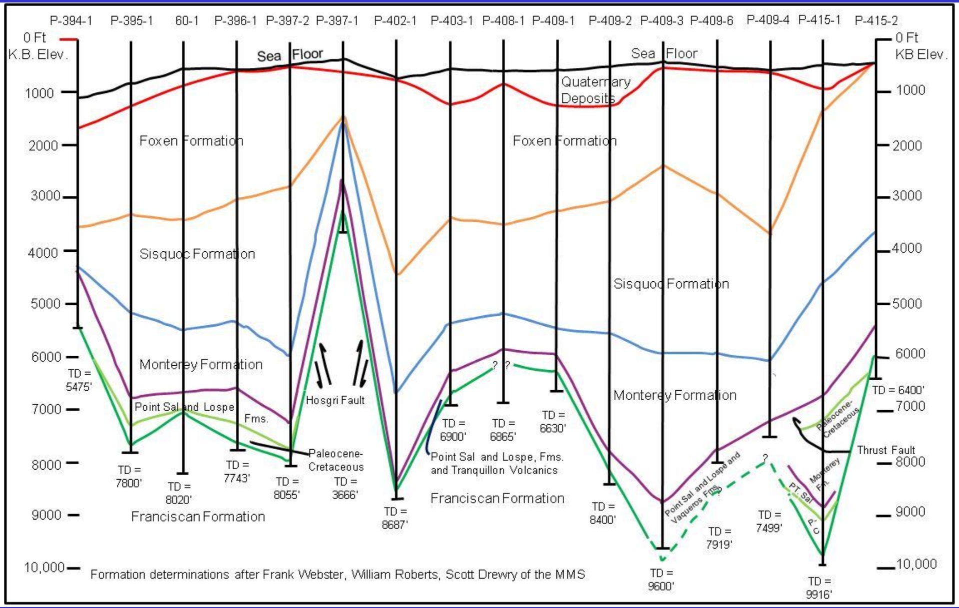
Index map showing locations of stratigraphic columns for the northwest, central, south, and southeast portions of the study area.



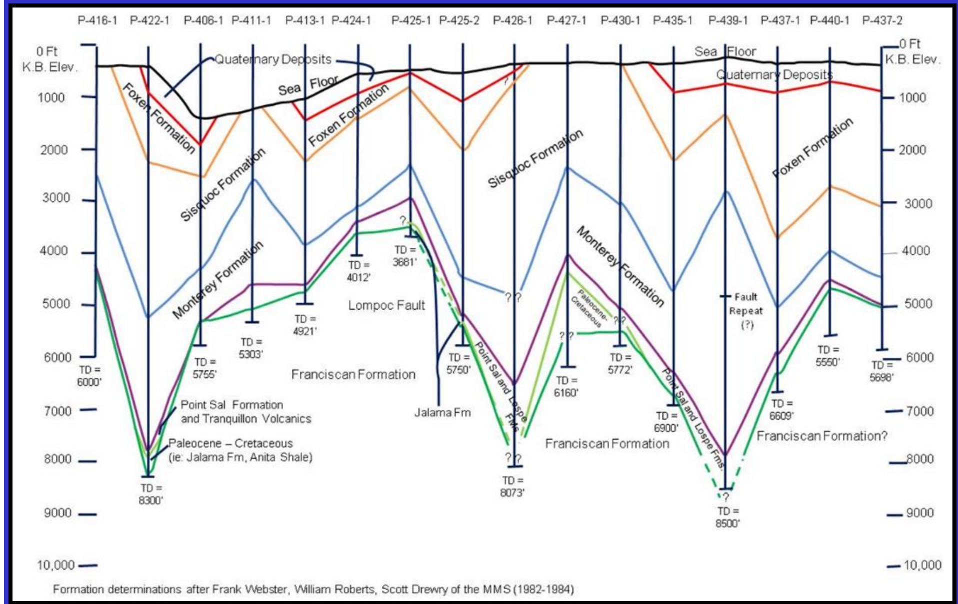
(Saenz, 2002; and Saenz et al, 2005)

Stratigraphic Correlations - Fence Diagrams

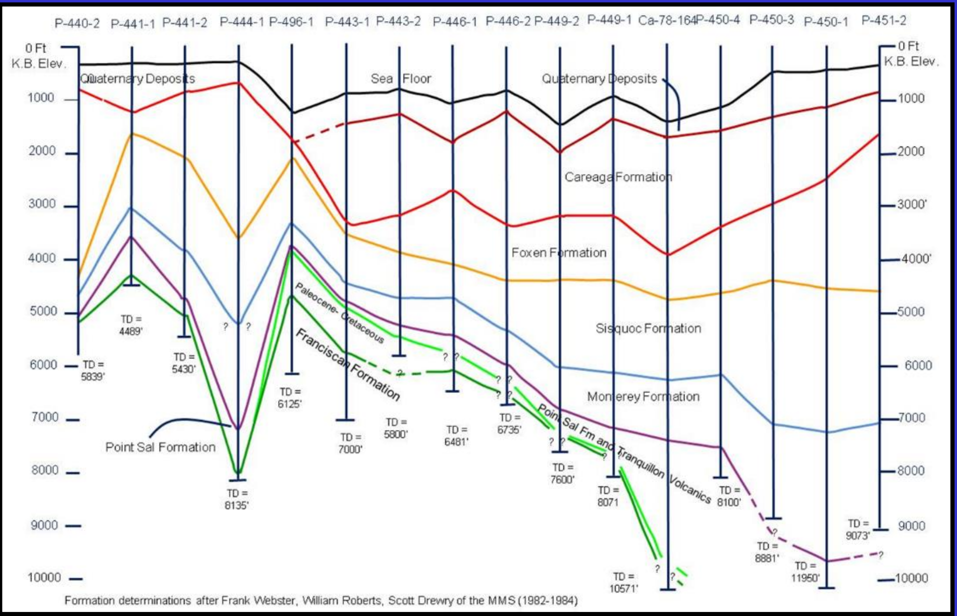
Northern Area



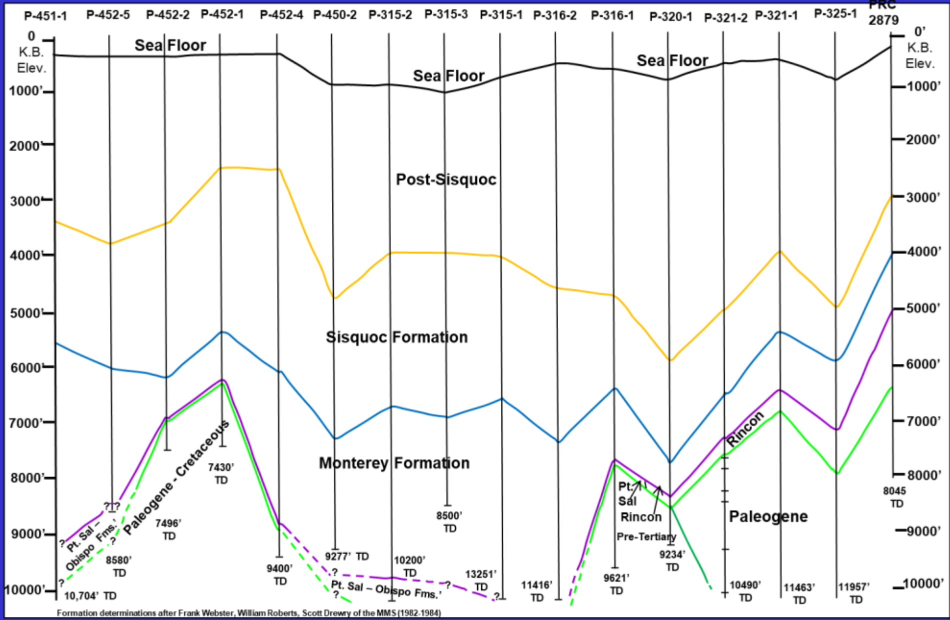
Central Area

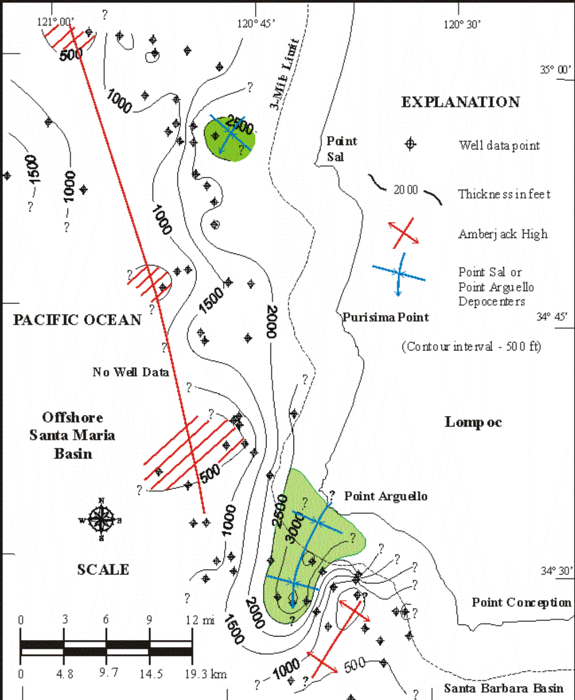


Southern Area



Southern-Most Area





Isochore Map of the Monterey Formation

•Offshore SMB rapidly subsided from Oligocene (?) into late Miocene time.

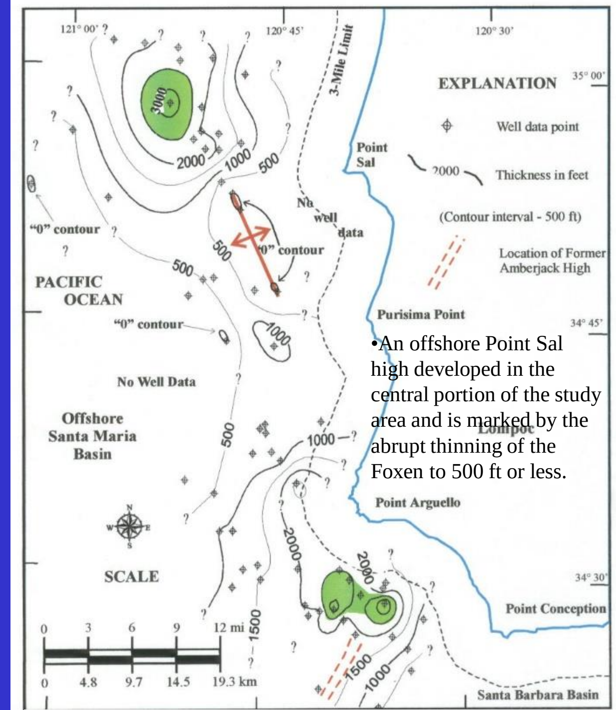
•Accumulations of Monterey Formation, formed in two depocenters where 2900 to 3700 ft of sediment were deposited.

•Monterey Formation thins to the west, a series of highs trend northwest.

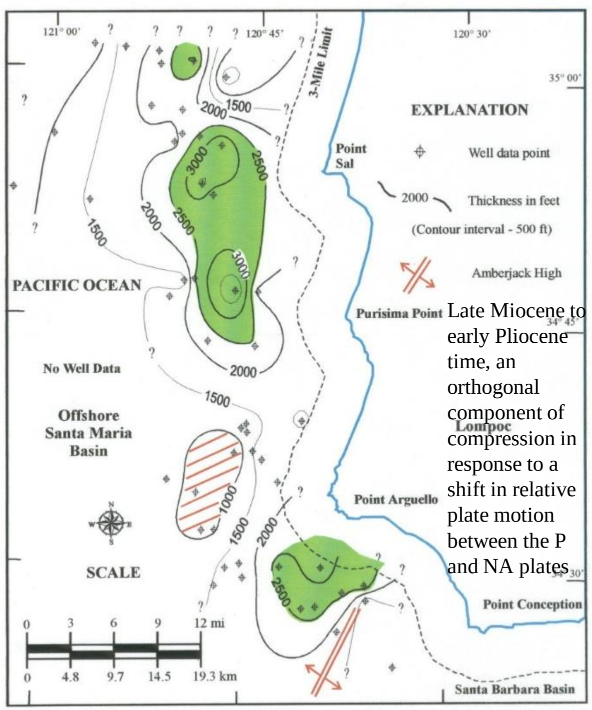
Isochore Map of the Foxen Formation

•A northward migration of the northern depocenter. Basin was filled with over 3400 ft of Foxen Formation.

•The southern depocenter trend becomes elongate and trends NW-SE. It was filled with over 3700 ft of Foxen mudstone



•An offshore Point Sal high developed in the central portion of the study area and is marked by the abrupt thinning of the Foxen to 500 ft or less.



Late Miocene to early Pliocene time, an orthogonal component of compression in response to a shift in relative plate motion between the P and NA plates

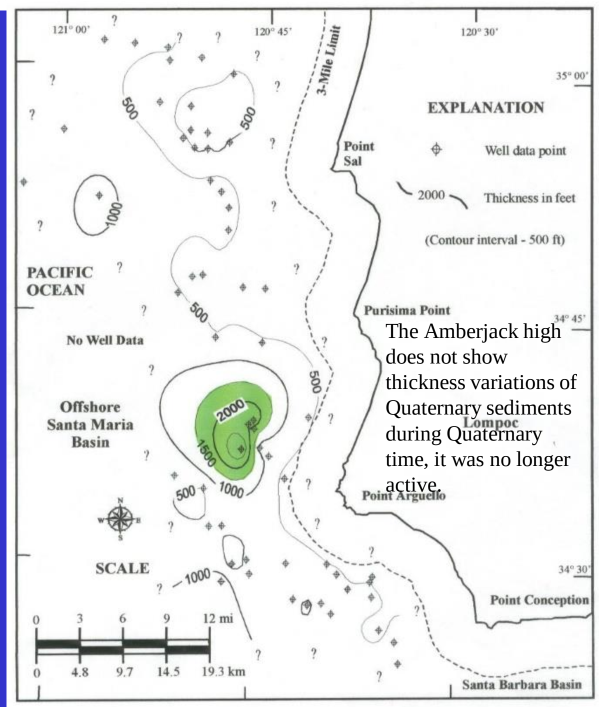
Isochore Map of the Sisquoc Formation

•The northern depocenter became larger and broader, and filling in of the basin trough with more than 4100 ft of sediments.

•The southern depocenter became steeper and narrower; sedimentation was controlled by the Amberjack high; filling up with 3000 ft of sediments.

Isochore Map of the Quaternary Deposits

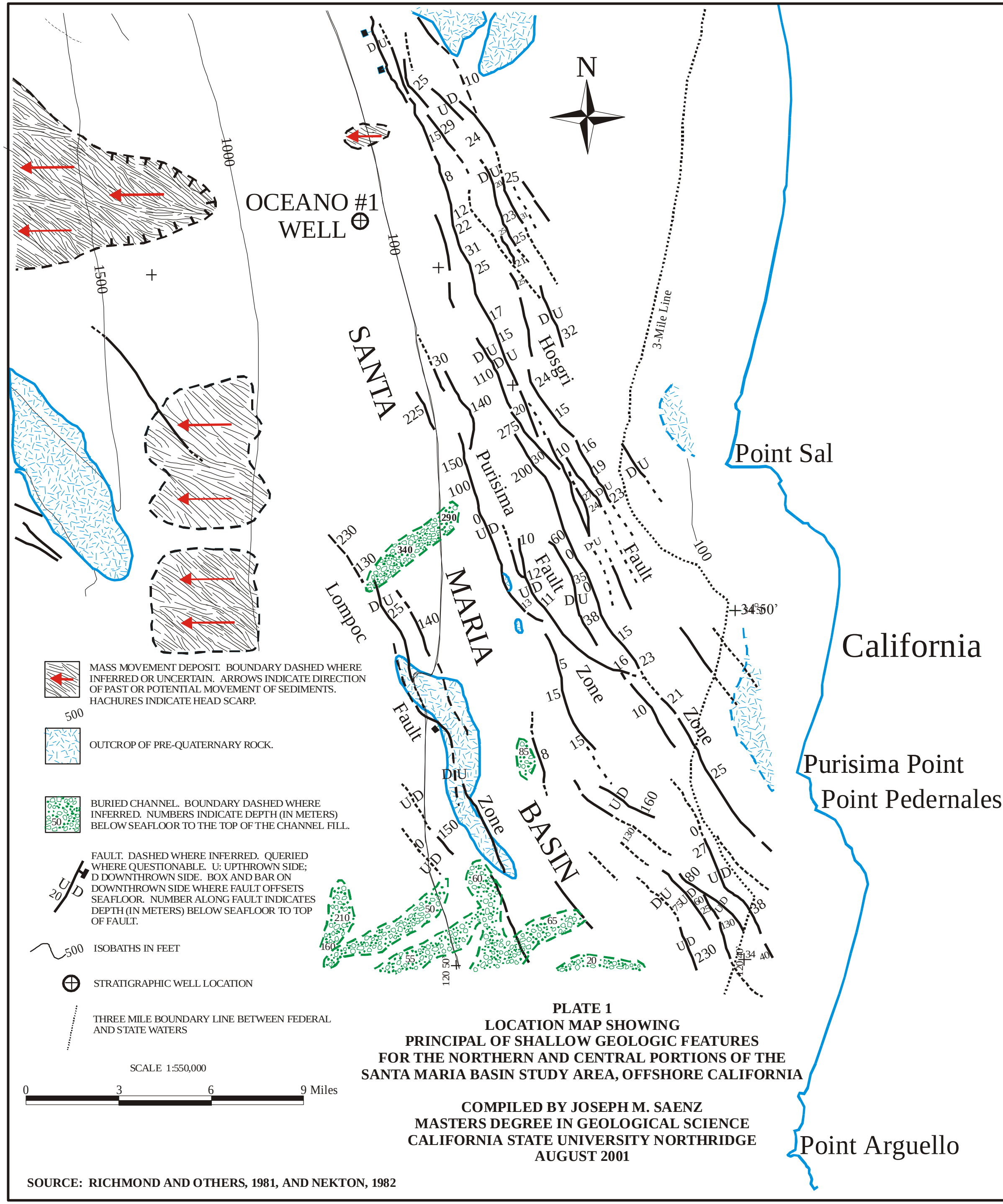
•The northern depocenter shifts westward and the southern depocenter has been filled. A new depocenter to the NW of Point Arguello has formed with 3200 ft of Quaternary deposits.



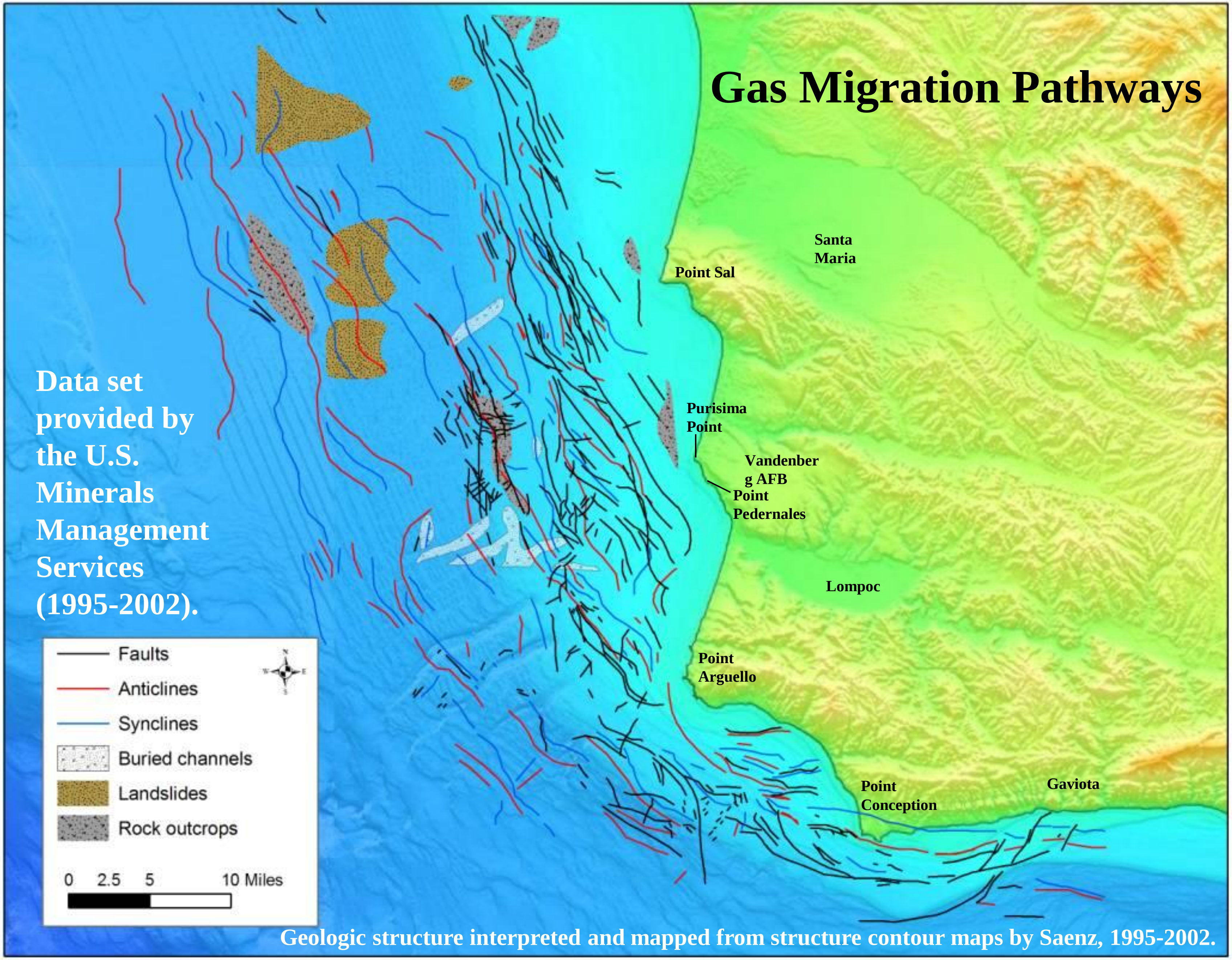
The Amberjack high does not show thickness variations of Quaternary sediments during Quaternary time, it was no longer active.

Gas Migration Pathways: Faults in Shallowest Horizons Offsetting Seafloor and Gas Migration Pathways

Mapped mass movement deposits and seafloor features to include rock outcrop, buried channels, and seafloor offsets due to faulting (Richmond and others, 1981; modified by Saenz, 2002).



Gas Migration Pathways



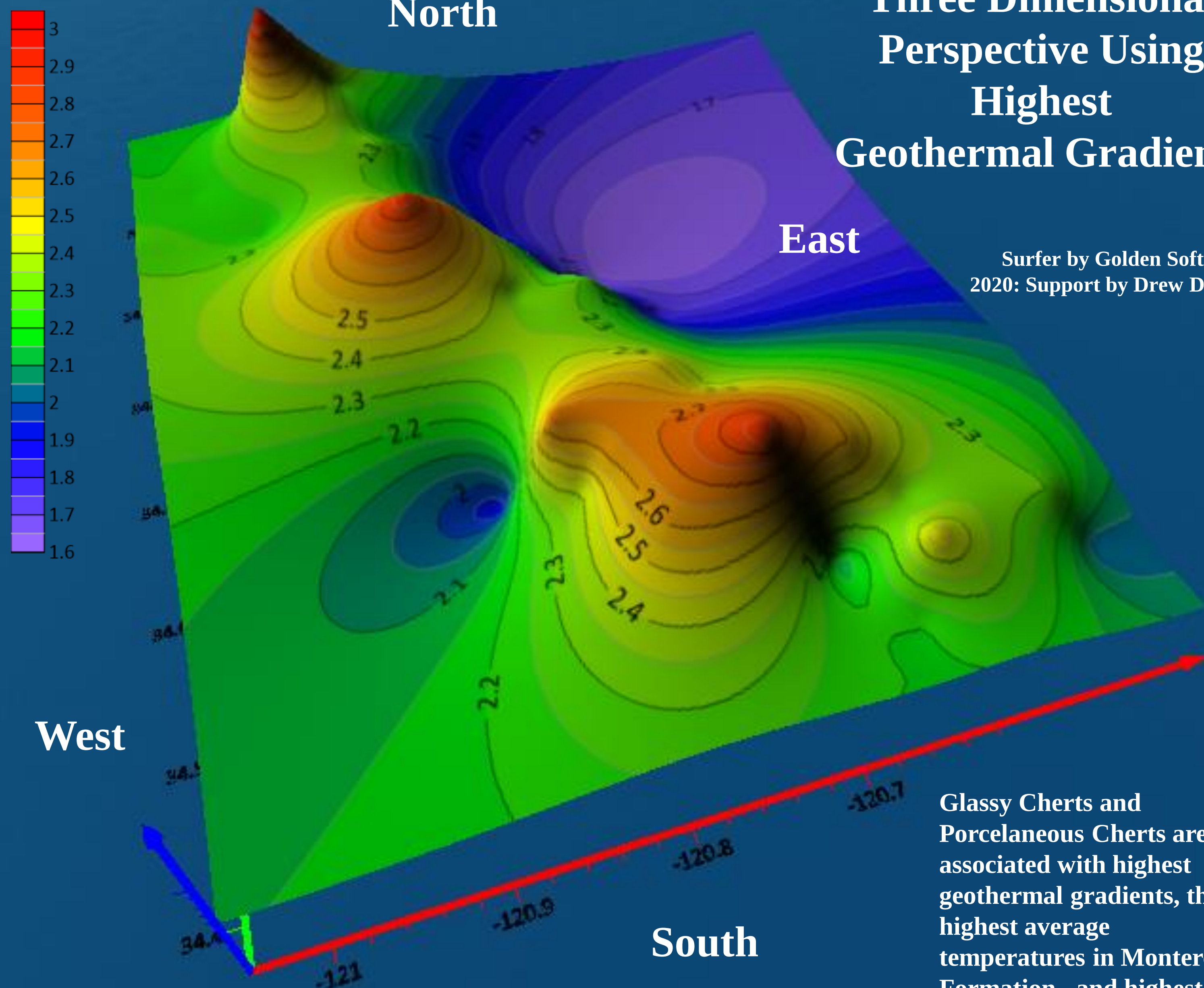
Base Map from National Oceanic Atmospheric Administration National, Geophysical Data Center Coastal Relief Model Vol. 06 Shaded Relief Images.

Three Dimensional Perspective Using Highest Geothermal Gradients

Geothermal gradients for the offshore SMB ranges between 3.0 to 1.7 °F per 100 feet.

The highest geothermal gradients for the offshore SMB ranges between 3.0 to 2.2 °F per 100 feet.

Geothermal gradient is a measure of temperature increase with depth. Geothermal gradients are normally 1.0 to 1.7 °F 100 feet. For example: If a well has a surface temperature of 75 °F and bottom hole temperature is 175 °F at a depth of 10,000 feet, the geothermal gradient is 1.0 °F per 100 feet (WellLog, 2003, Resistivity Logging, Revised 05-02-2001, © 2003 - 2011 WELLOG).



Surfer by Golden Software, 2020: Support by Drew Dudley

Glassy Cherts and Porcelaneous Cherts are associated with highest geothermal gradients, the highest average temperatures in Monterey Formation, and highest Methane gas concentrations.

Gas Migration: Three Dimensional Perspective Using Highest Geothermal Gradients, and Gas-Charged Sediments

Well P-0394-1
Average Temperature = 198 °F (92.2 °C)
Geothermal Gradient = 2.2 °F/100'

Methane	Ethane	Propane	Butane
Qt 1,000	NA	NA	NA
Tf 10,000	100	NA	NA
Ts 15,000	150	600	300
Tm +43,000	390	450	70

Well P-0395-1
Average Temperature = 188 °F (86.7 °C)
Geothermal Gradient = 3.0 °F/100'

Methane	Ethane	Propane	Butane
Tf +10,000	NA	NA	NA
Ts +15,000	NA	NA	NA
Tm +32,000	310	400	500

Well P-0424-1
Average Temperature = 143 °F (61.7 °C)
Geothermal Gradient = 2.9 °F/100'

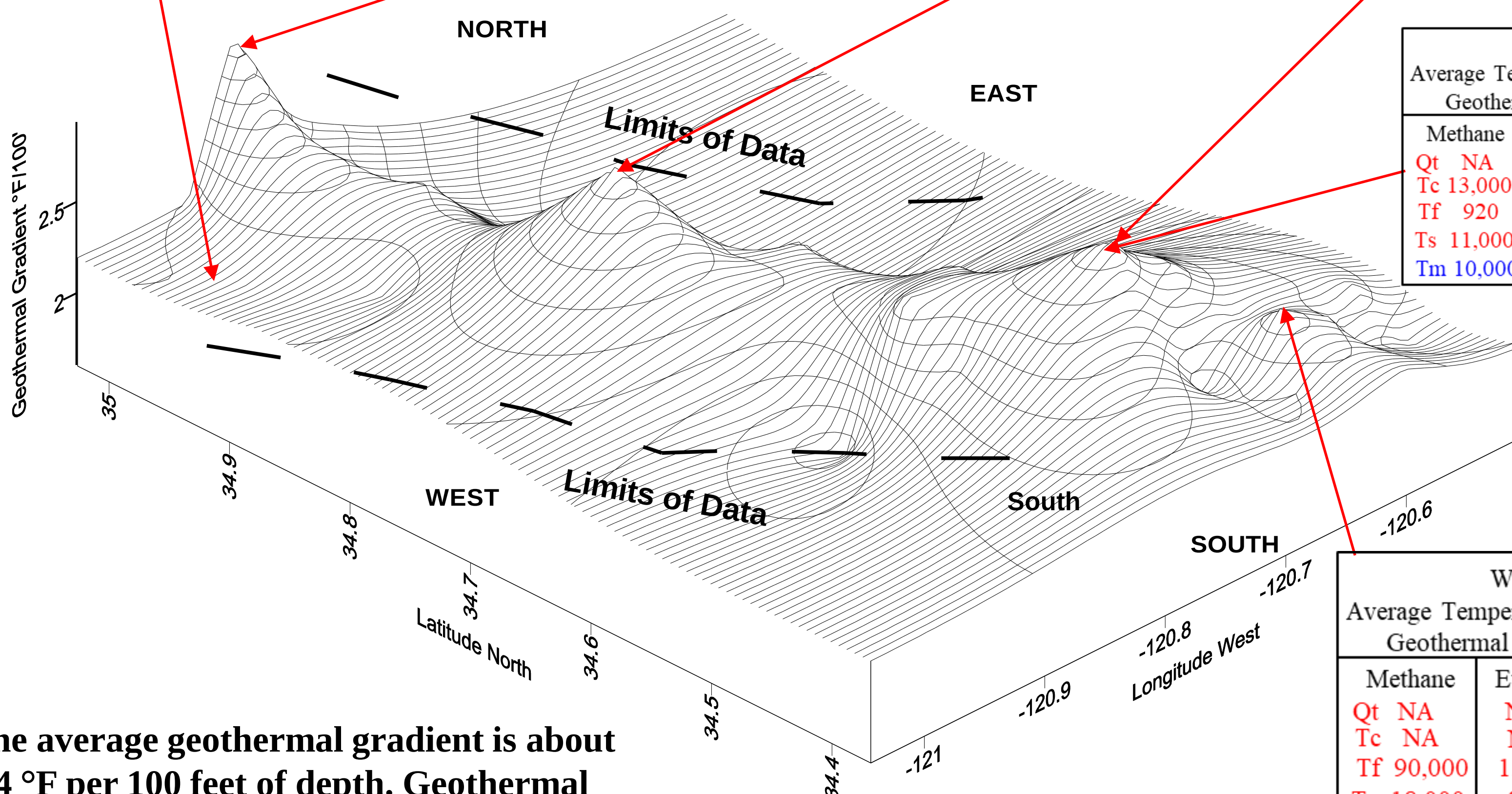
Methane	Ethane	Propane	Butane
Tf 220	NA	NA	NA
Ts 480	NA	NA	NA
Tm 56,800	300	600	800

Well P-0451-1
Average Temperature = 248 °F (107.2 °C)
Geothermal Gradient = 2.6 °F/100'

Methane	Ethane	Propane	Butane
Qt NA	NA	NA	NA
Tc 400	NA	NA	150
Tf 22,000	200	350	10
Ts 3,000	90	65	700
Tm 20,000	825	475	200

Well P-0450-1
Average Temperature = 225 °F (107.2 °C)
Geothermal Gradient = 2.9 °F/100'

Methane	Ethane	Propane	Butane
Qt NA	780	1,000	NA
Tc 13,000	650	700	620
Tf 920	1,050	650	550
Ts 11,000	1,000	850	700
Tm 10,000	1,000	720	630



Well P-0320-1
Average Temperature = 226 °F (107.7 °C)
Geothermal Gradient = 2.5 °F/100'

Methane	Ethane	Propane	Butane
Qt NA	NA	NA	NA
Tc NA	NA	NA	NA
Tf 90,000	1,050	200	150
Ts 18,000	200	150	20
Tm 10,000	700	650	30

The average geothermal gradient is about 1.4 °F per 100 feet of depth. Geothermal gradient are normally 1.0 to 1.7 degrees per 100 feet. (http://www.wellog.com/webinar/interp_p1_p6.htm)

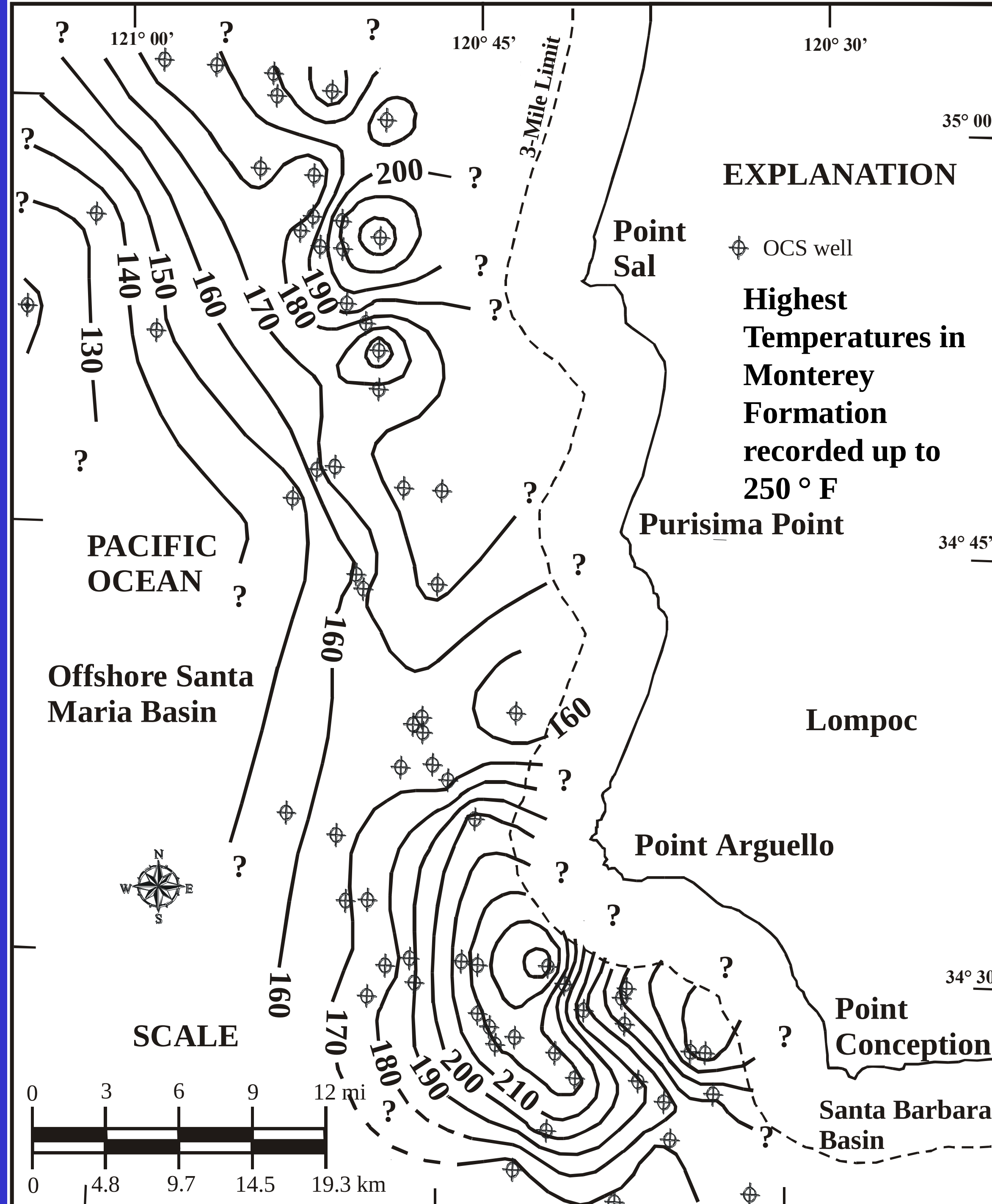
(Saenz, 2002; Saenz et al, 2005; Saenz et al, 2007; Saenz et al, 2020)

(Surfer by Golden Software, 2000)

Gas Migration: Average Temperature in the Monterey Formation: High Heat Flow Volatilizing Hydrocarbon Gases Upward through Fault Zones and Stratigraphic Sections

Map based on temperature logs, dual induction logs, compensated neutron formation density logs, micro-later log / micro logs, natural gamma ray tool logs, SP logs, borehole compensation sonic logs, neutron lithodensity logs, computer processed logs, sonic waveform logs, high resolution continuous dip-meter logs, completion reports, daily reports, and other documents collected from 63 exploratory wells (Saenz, 2002; and Saenz et al, 2005)

The offshore SMB is host to numerous oil and gas fields with average temperatures ranging from 118 °F (47.7 °C) to 248 ° F (120 °C) and reservoir pressure that ranges from 2115 pounds square inch gauge (psig) to 3385 psig. We believe that several of these oil accumulations have undergone in-reservoir thermal cracking, resulting in a lighter, single-phase fluid, together with a pyrobitumen residue in the pore volumes. With several traps at or near their leak-off pressure, the likelihood of top seal failure and gas leakage is prevalent (Saenz, 2007).



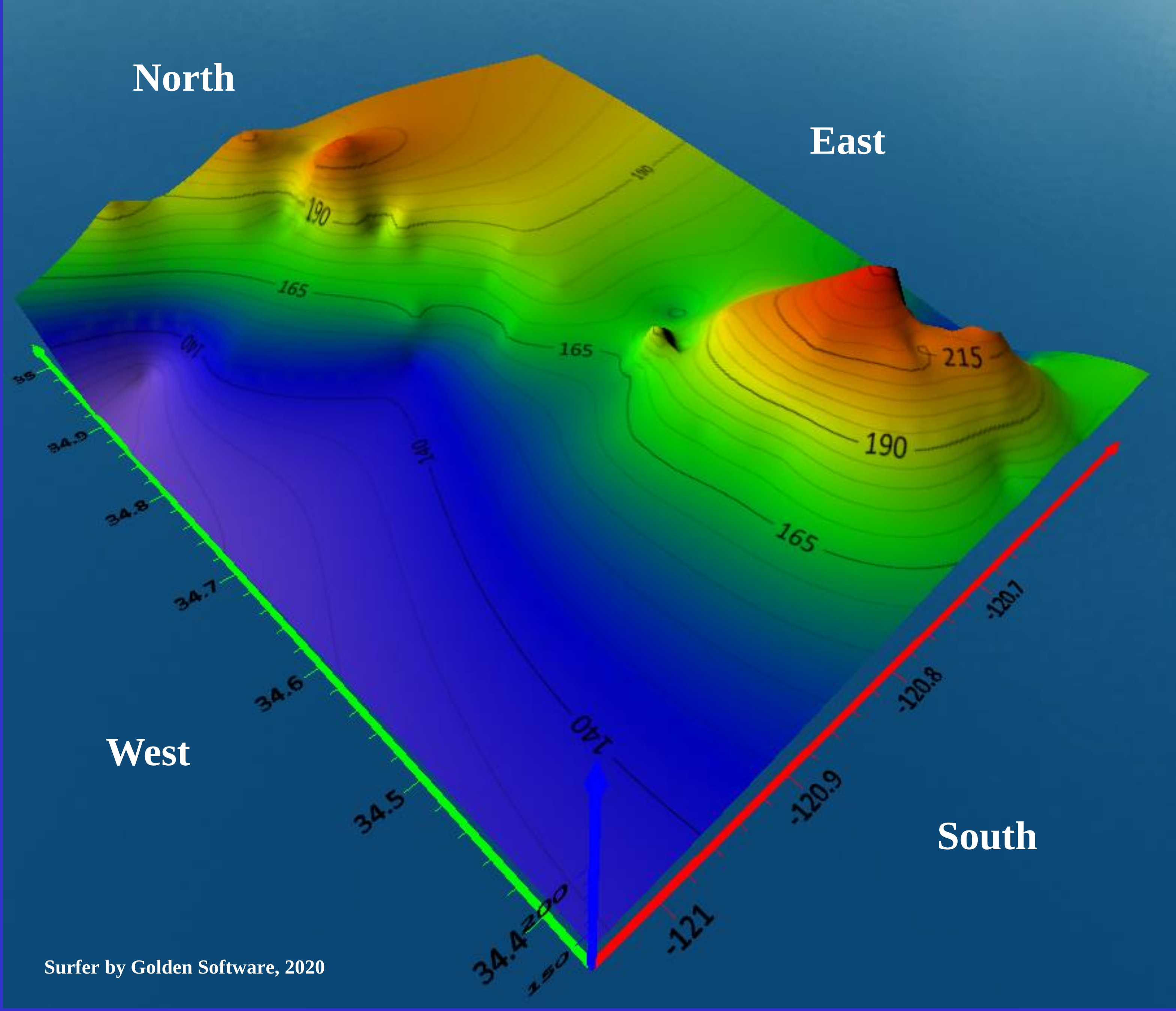
Three Dimensional Perspective of the Average Temperatures in the Monterey Formation

The Glassy Cherts and Porcelaneous Cherts are associated with:

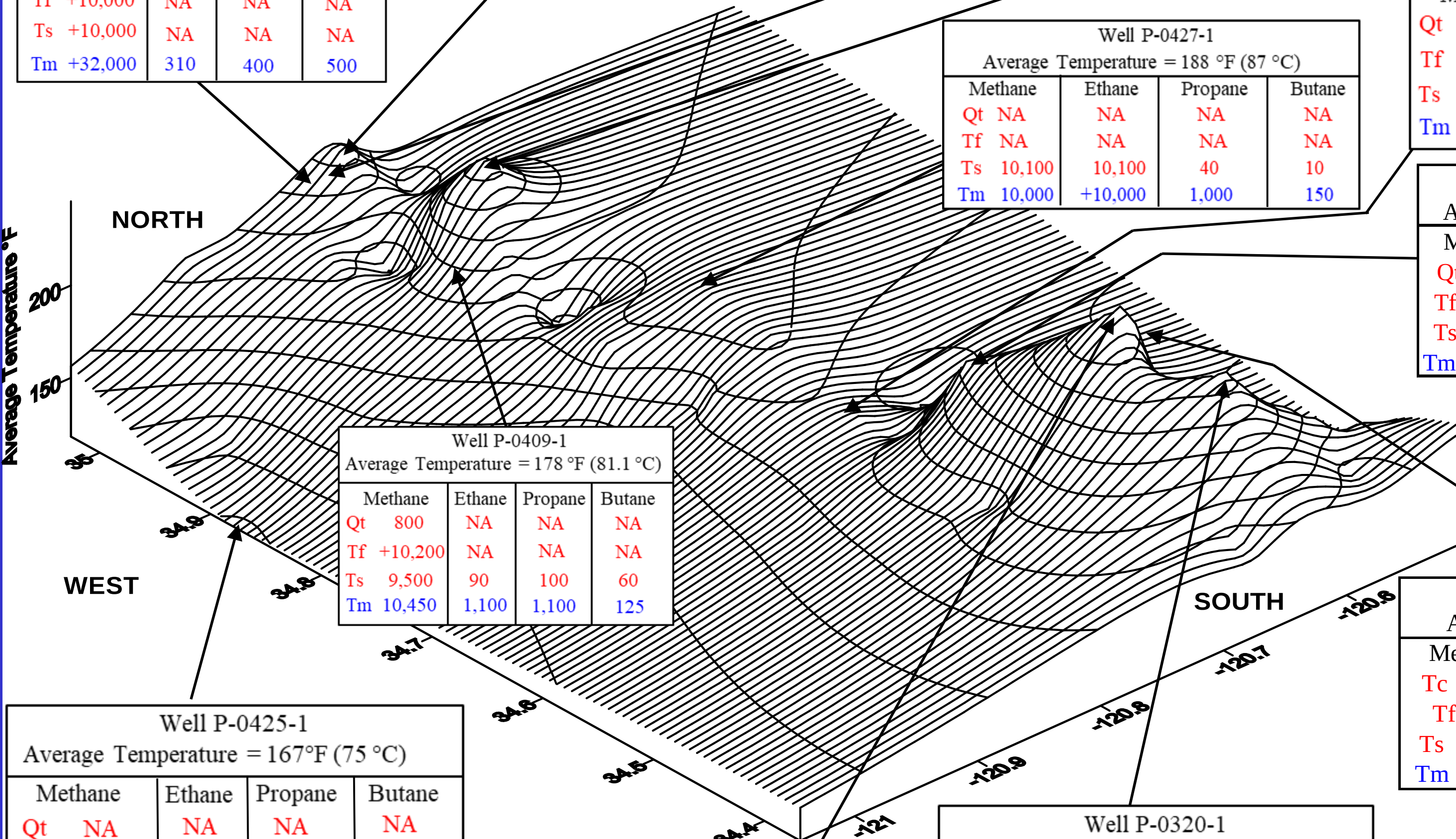
-the highest geothermal gradients,

-the highest average temperatures in Monterey Formation,

-and highest Methane gas concentrations.



Gas Migration: Three Dimensional Perspective of the Average Temperature in the Monterey Formation and Gas Chromatographic Results



Well P-0395-1
Average Temperature = 188 °F (86.7 °C)

	Methane	Ethane	Propane	Butane
Qt	NA	NA	NA	NA
Tf	+10,000	NA	NA	NA
Ts	+10,000	NA	NA	NA
Tm	+32,000	310	400	500

Well P-0397-2
Average Temperature = 218 °F (103.3 °C)

	Methane	Ethane	Propane	Butane
Qt	NA	NA	NA	NA
Tf	+60,000	800	200	NA
Ts	+95,000	2,800	600	NA
Tm	25,000	1,800	1,600	800

Well P-0396-1
Average Temperature = 197 °F (91.7 °C)

	Methane	Ethane	Propane	Butane
Qt	NA	NA	NA	NA
Tf	+40,000	NA	NA	NA
Ts	+100,000	400	90	NA
Tm	+10,000	600	550	200

Well P-0409-3
Average Temperature = 229 °F (109 °C)

	Methane	Ethane	Propane	Butane
Qt	NA	NA	NA	NA
Tf	+18000	NA	NA	NA
Ts	20,000	NA	NA	NA
Tm	5,000	300	500	70

Well P-0437-1
Average Temperature = 167 °F (75 °C)

	Methane	Ethane	Propane	Butane
Qt	NA	NA	NA	NA
Tf	100,000	1,900	4,200	2,200
Ts	4,000	NA	NA	NA
Tm	7,900	350	375	150

Well P-0427-1
Average Temperature = 188 °F (87 °C)

	Methane	Ethane	Propane	Butane
Qt	NA	NA	NA	NA
Tf	NA	NA	NA	NA
Ts	10,100	10,100	40	10
Tm	10,000	+10,000	1,000	150

Well P-0444-1
Average Temperature = 205 °F (96 °C)

	Methane	Ethane	Propane	Butane
Qt	13,000	NA	NA	NA
Tf	12,000	60	45	12,000
Ts	13,000	450	250	20
Tm	100,000	5,500	6,500	1,200

Well P-0409-1
Average Temperature = 178 °F (81.1 °C)

	Methane	Ethane	Propane	Butane
Qt	800	NA	NA	NA
Tf	+10,200	NA	NA	NA
Ts	9,500	90	100	60
Tm	10,450	1,100	1,100	125

Well P-0450-1
Average Temperature = 225 °F (107.2 °C)

	Methane	Ethane	Propane	Butane
Tc	13000	780	1000	620
Tf	920	650	700	550
Ts	11000	1000	850	700
Tm	12000	1000	720	630

Well P-0425-1
Average Temperature = 167°F (75 °C)

	Methane	Ethane	Propane	Butane
Qt	NA	NA	NA	NA
Tf	15,000	900	500	70
Ts	95,000	4,500	2,900	500
Tm	70,000	6,300	3,800	200

Well P-0451-1
Average Temperature = 248 °F (107.2 °C)

	Methane	Ethane	Propane	Butane
Qt	NA	NA	NA	NA
Tc	400	NA	NA	150
Tf	22,000	200	350	10
Ts	3,000	90	65	700
Tm	20,000	825	475	200

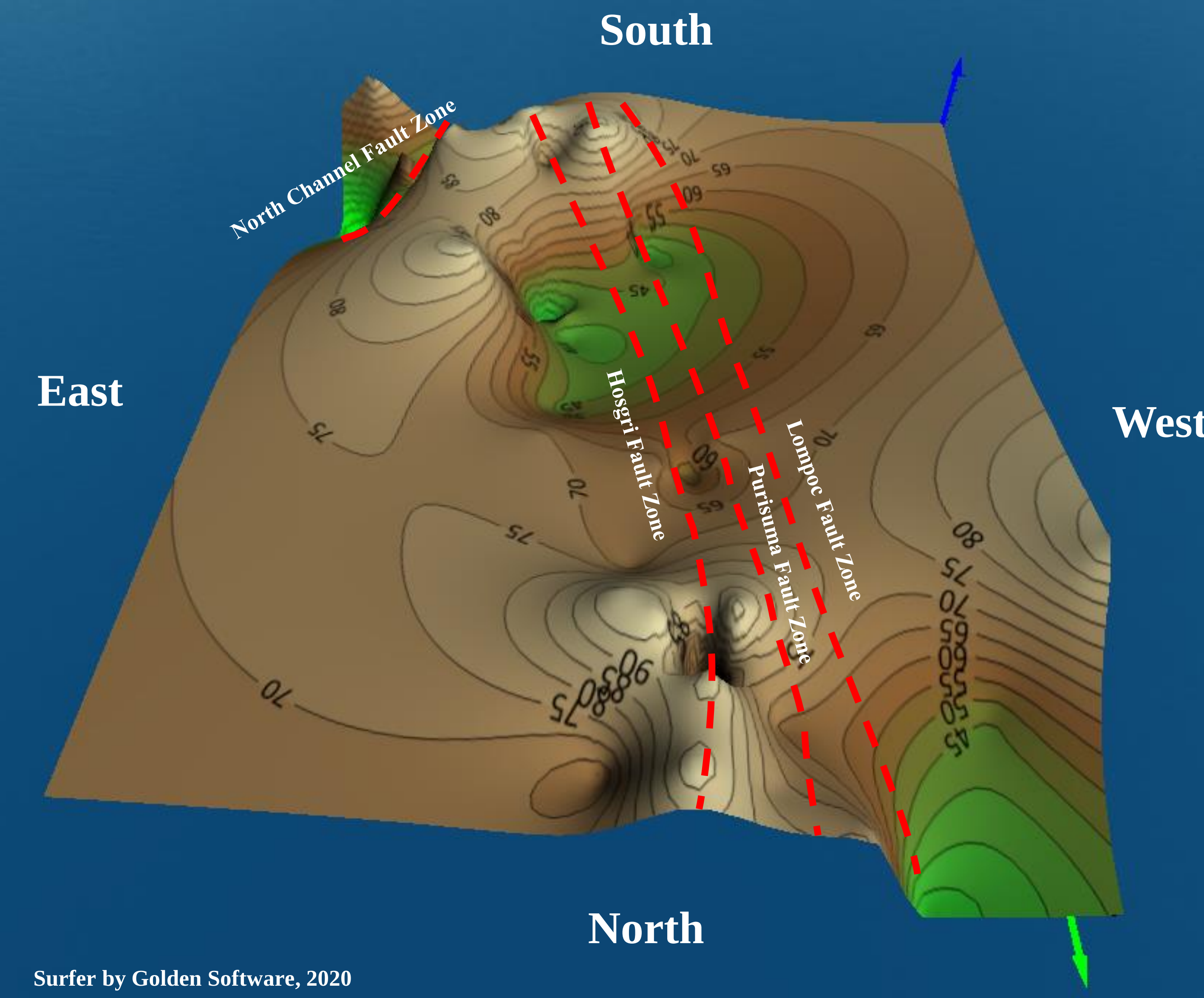
Well P-0320-1
Average Temperature = 226 °F (107.7 °C)

	Methane	Ethane	Propane	Butane
Qt	NA	NA	NA	NA
Tc	400	NA	NA	150
Tf	90,000	1,050	200	150
Ts	18,000	200	150	20
Tm	10,000	700	650	30

(Saenz, 2002; Saenz et al, 2005; 2007, 2009, 2010, 2012, 2018, 2020)

(Surfer by Golden Software, 2000)

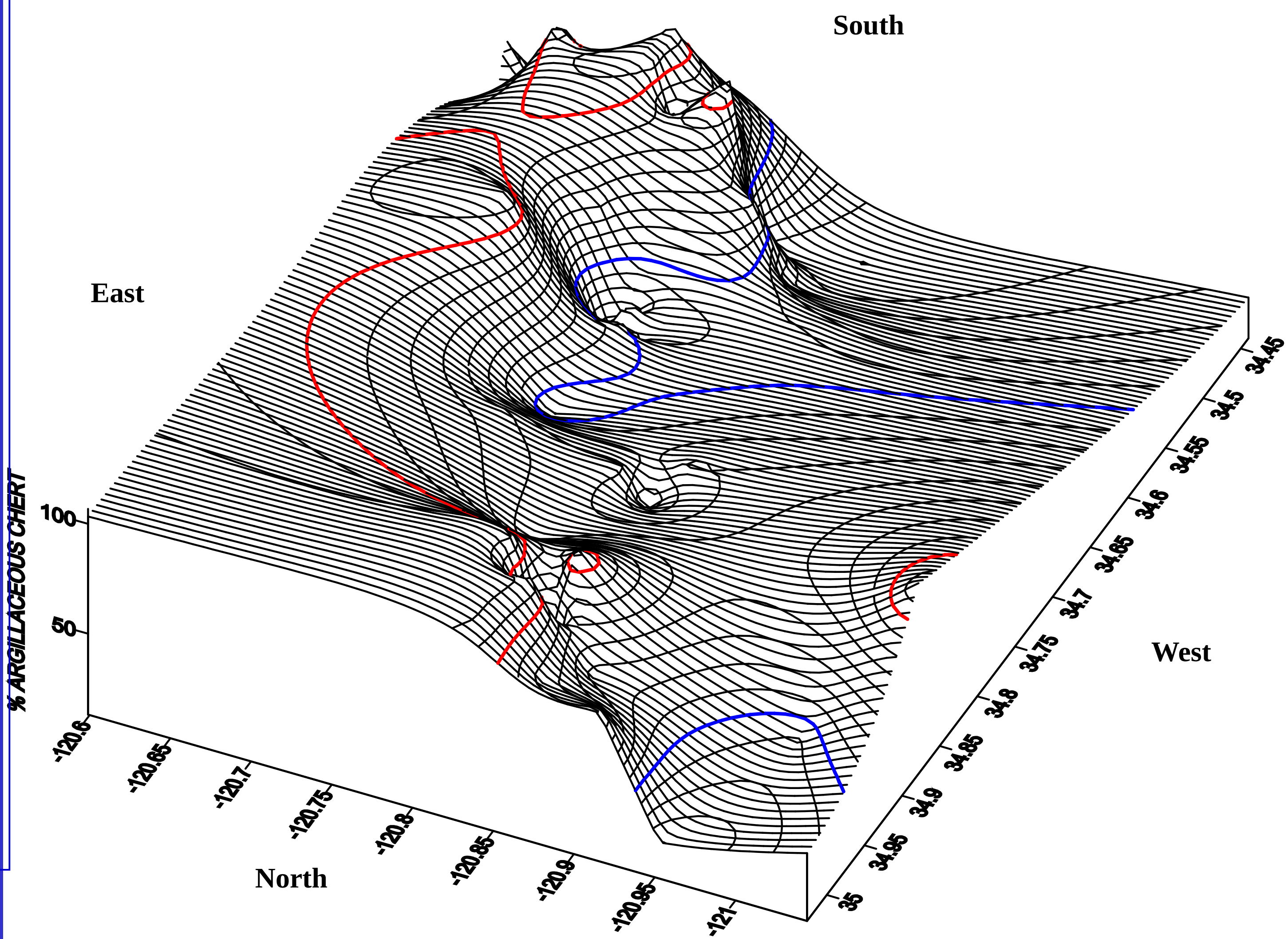
Three Dimensional Perspective of Vertical Distribution of % Argillaceous Chert in Monterey Formation from OCS Wells



Surfer by Golden Software, 2020

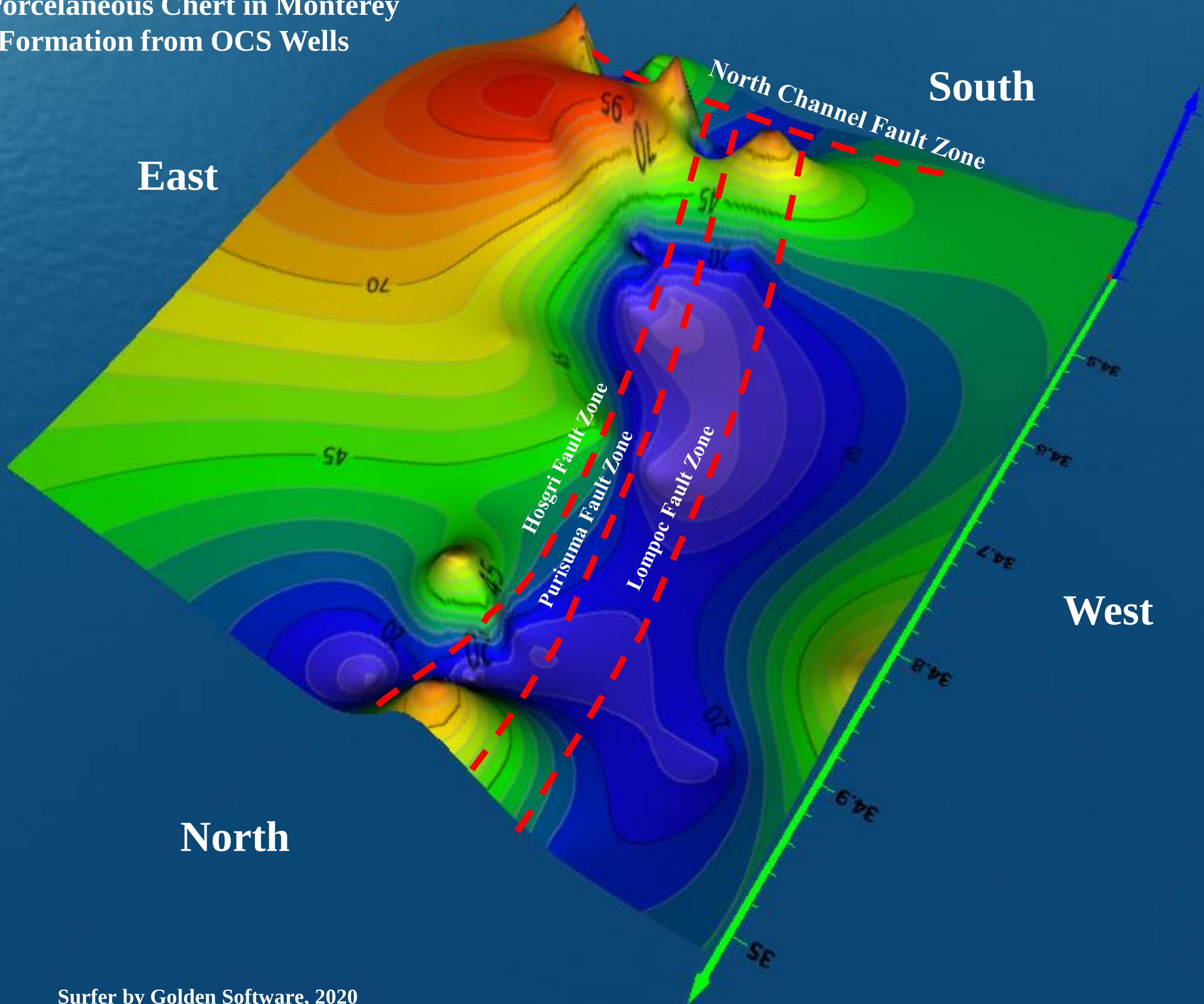
Three Dimensional Perspective of Vertical Distribution of % Argillaceous Chert in Monterey Formation from OCS Wells

MUDLOGS: Argillaceous chert is a hard chert, a less pure chert, with higher amount of clay, and conchoidally fractured. It is vitreous or non waxy in texture. Rock fragments hardness on Mohs scale ranges from 5 to 7. Generally, taken as less pure than porcelaneous chert.



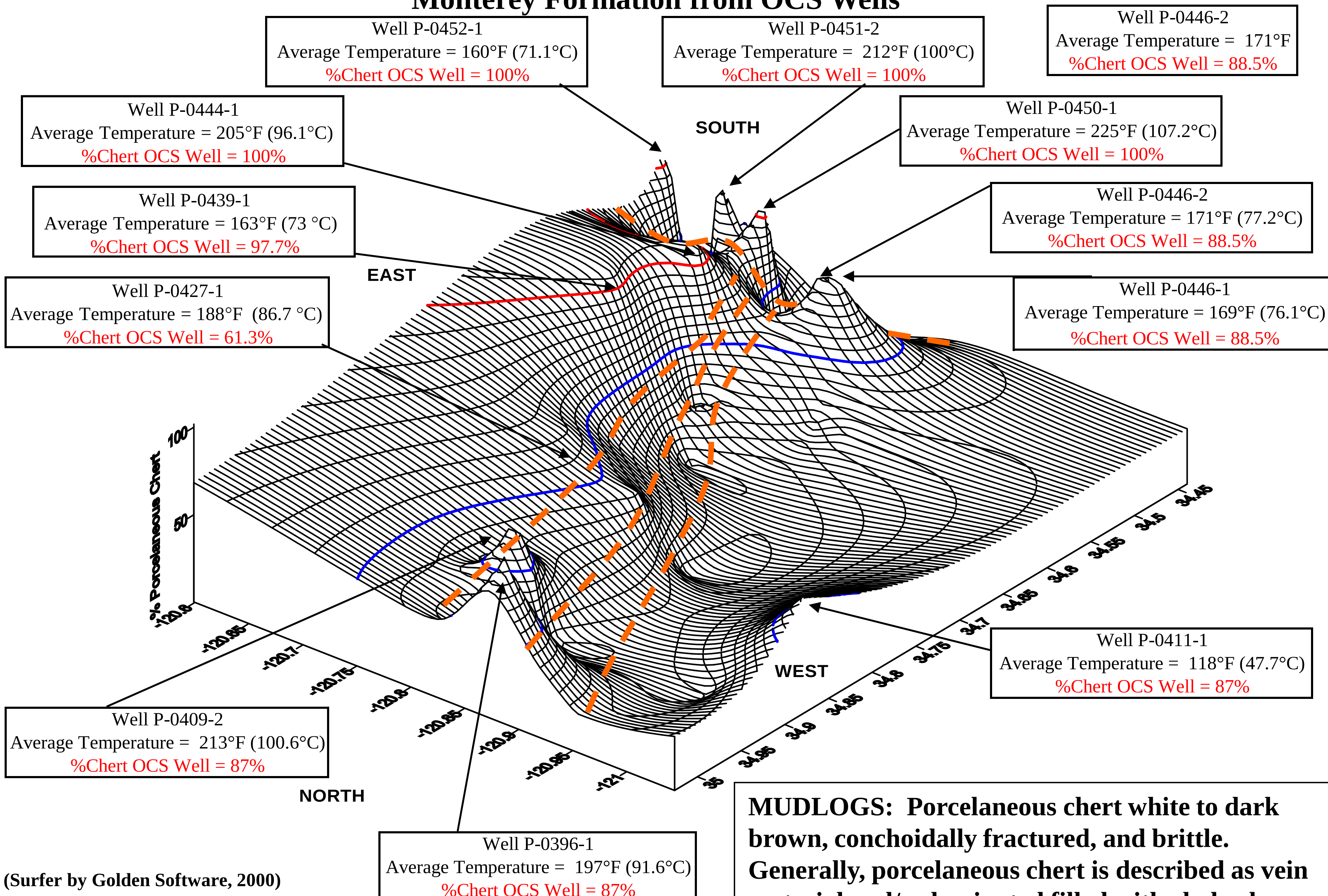
(Surfer by Golden Software, 2000)

Three Dimensional Perspective of Vertical Distribution of Vertical Distribution of % Porcelaneous Chert in Monterey Formation from OCS Wells



Surfer by Golden Software, 2020

Three Dimensional Perspective of Vertical Distribution of % Porcelaneous Chert in Monterey Formation from OCS Wells

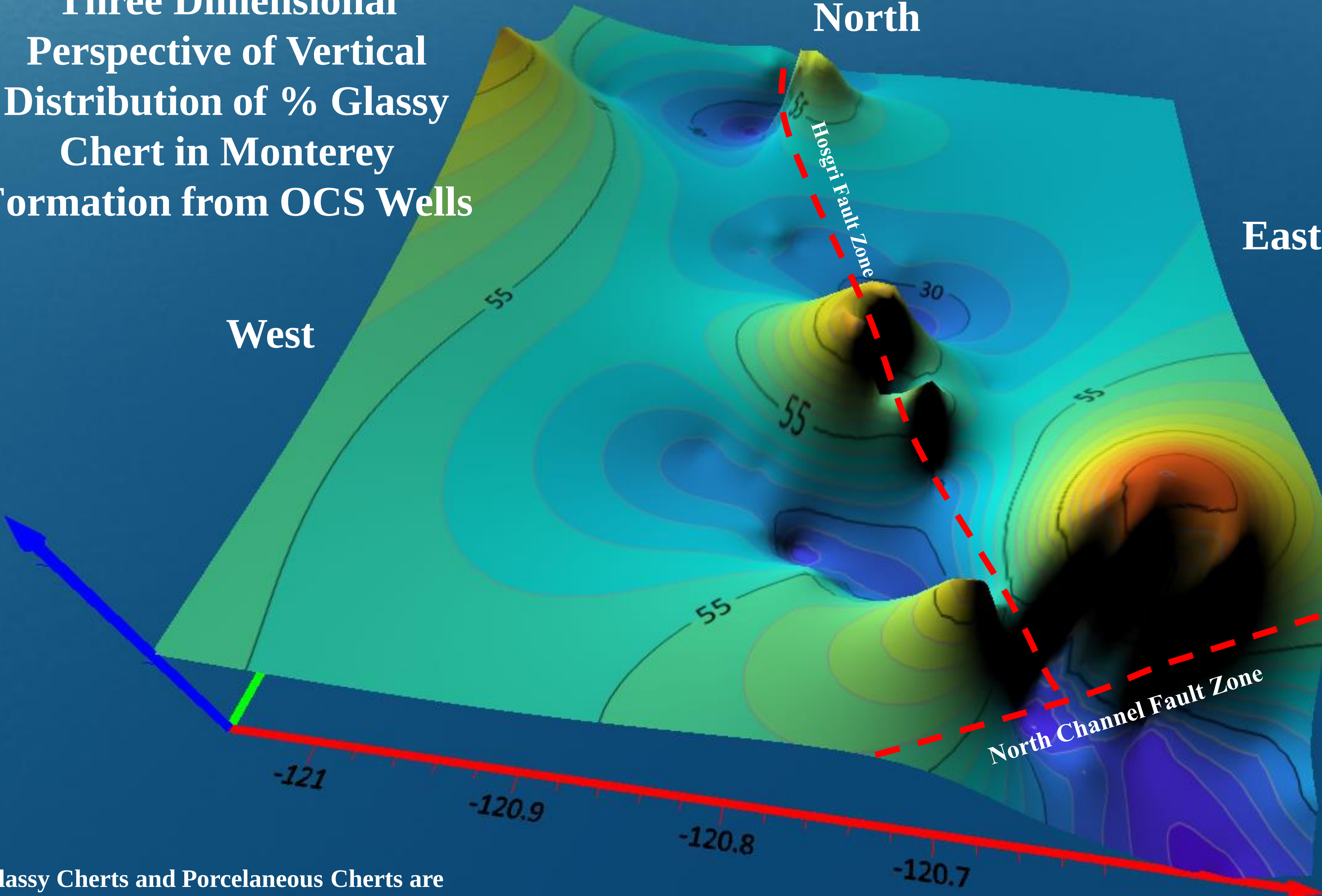


MUDLOGS: Porcelaneous chert white to dark brown, conchoidally fractured, and brittle. Generally, porcelaneous chert is described as vein material and/or laminated filled with chalcedony or quartz.

(Surfer by Golden Software, 2000)

(Saenz, 2002; Saenz et al, 2005; Saenz et al, 2018; and Saenz et al, 2020)

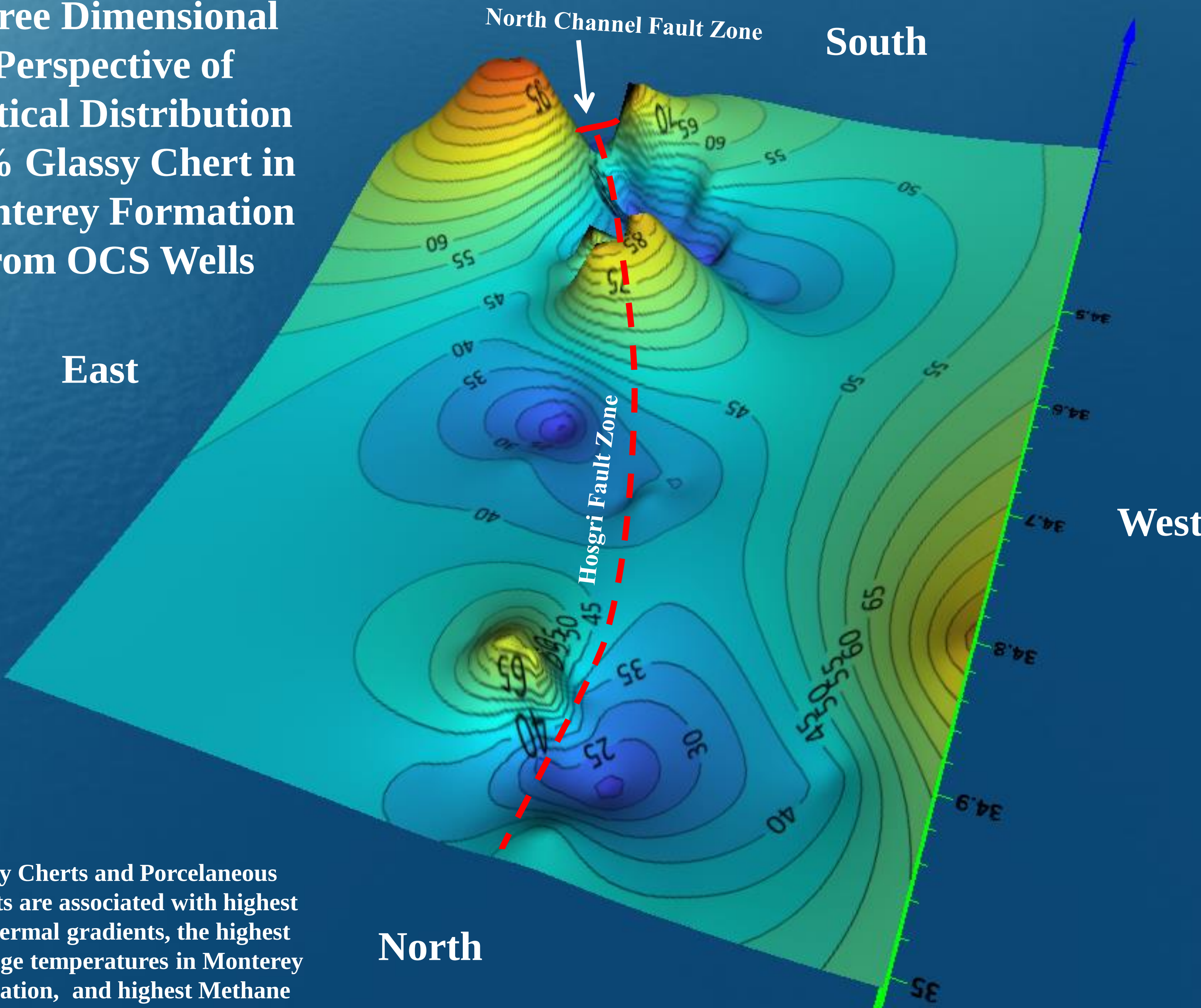
Three Dimensional Perspective of Vertical Distribution of % Glassy Chert in Monterey Formation from OCS Wells



Glassy Cherts and Porcelaneous Cherts are associated with highest geothermal gradients, the highest average temperatures in Monterey Formation, and highest Methane gas concentrations.

Surfer by Golden Software, 2020

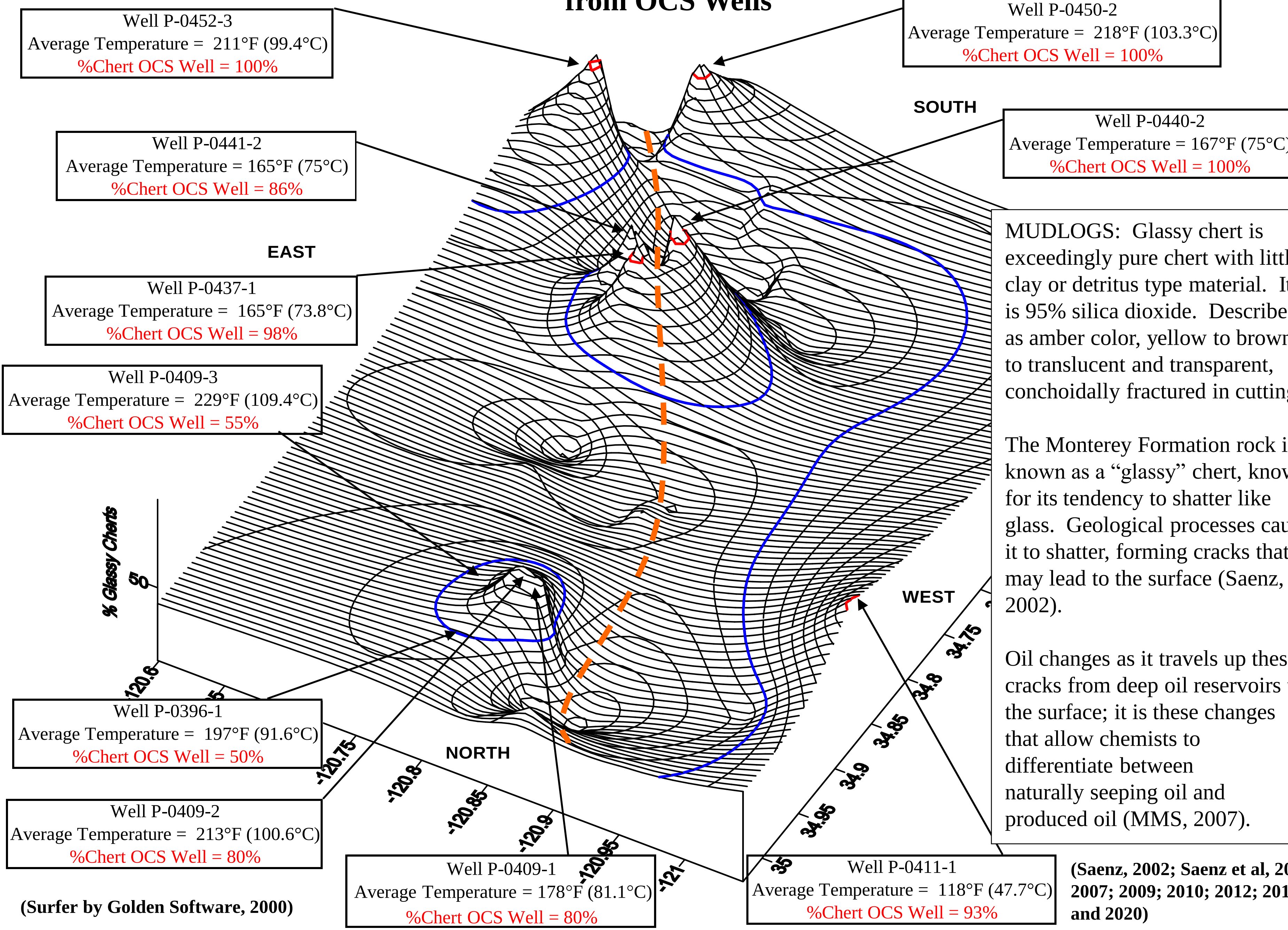
Three Dimensional Perspective of Vertical Distribution of % Glassy Chert in Monterey Formation from OCS Wells



Glassy Cherts and Porcelaneous Cherts are associated with highest geothermal gradients, the highest average temperatures in Monterey Formation, and highest Methane gas concentrations.

Surfer by Golden Software, 2020

Three Dimensional Perspective of Vertical Distribution of % Glassy Chert in Monterey Formation from OCS Wells



(Surfer by Golden Software, 2000)

MUDLOGS: Glassy chert is exceedingly pure chert with little clay or detritus type material. It is 95% silica dioxide. Described as amber color, yellow to brown to translucent and transparent, conchoidally fractured in cuttings.

The Monterey Formation rock is known as a "glassy" chert, known for its tendency to shatter like glass. Geological processes cause it to shatter, forming cracks that may lead to the surface (Saenz, 2002).

Oil changes as it travels up these cracks from deep oil reservoirs to the surface; it is these changes that allow chemists to differentiate between naturally seeping oil and produced oil (MMS, 2007).

(Saenz, 2002; Saenz et al, 2005; 2007; 2009; 2010; 2012; 2018; and 2020)

Oil Isopleths Showing °API Gravity Related to Thermal Degradation of Monterey Formation Crude Oil (Saenz, 2002)

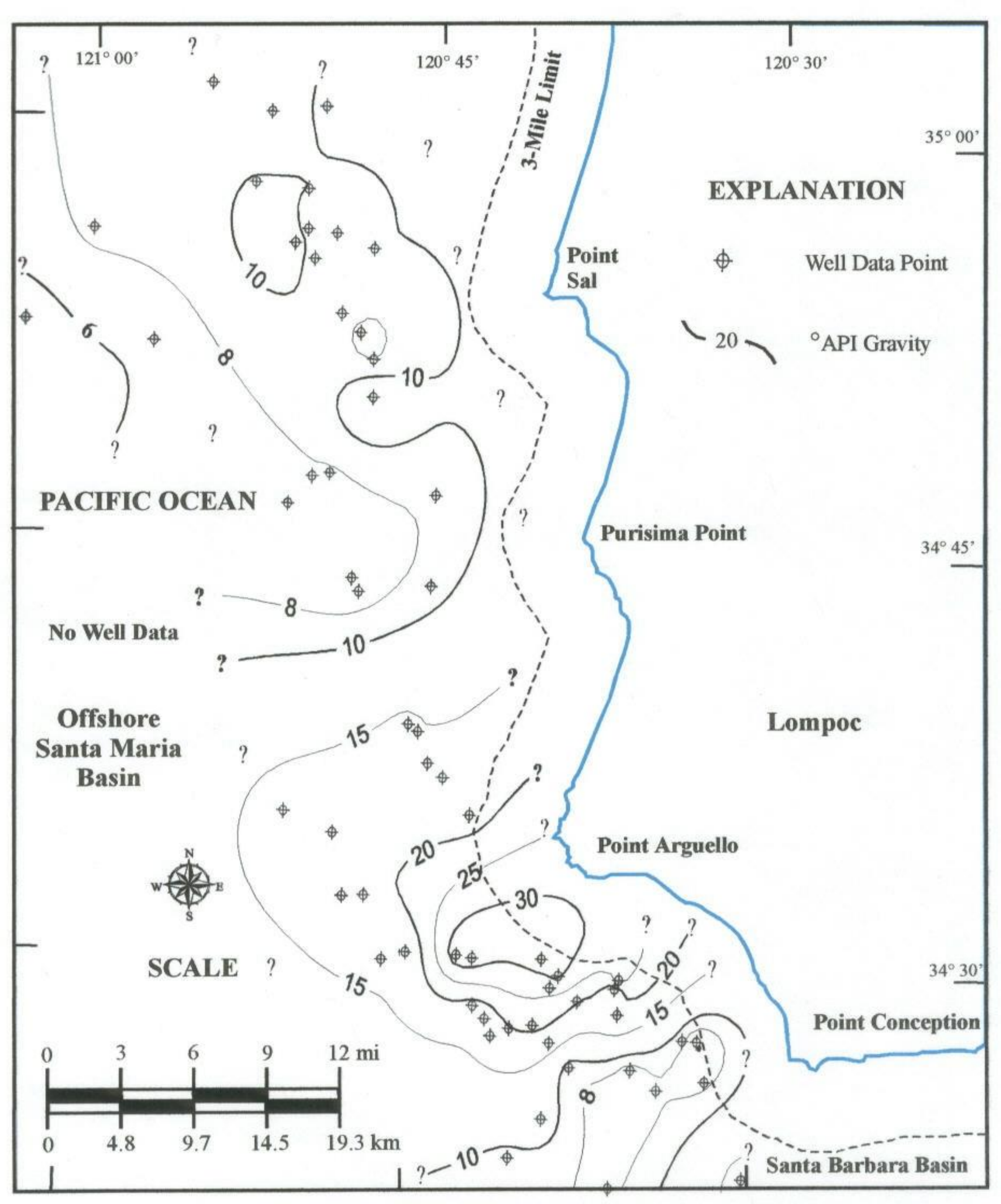
•Degree API (°API) gravity crude oil collected from drill stem tests from 60 exploratory wells of the SMB study area.

•As shown in the Figure, the isopleths of °API gravity oil decrease to the northwest of Point Arguello.

•In Federal Waters, about 20-25 miles (32-40 km) between Purisima Point and Point Sal are the lowest gravities in the study area. Area N-1 is located in this area of minimum API gravity area.

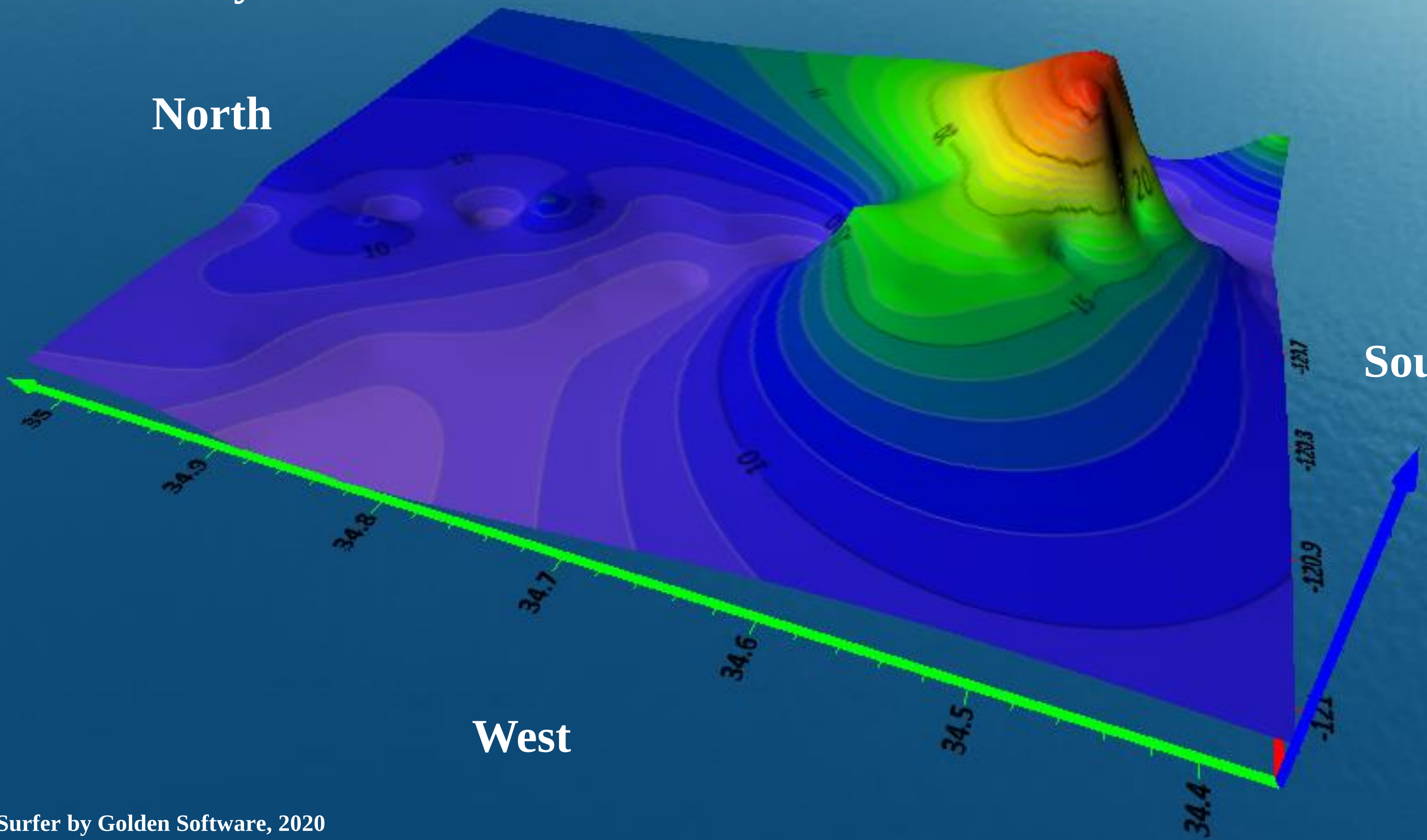
•Heavy oil is (low API gravity) due to escape of volatiles during migration from predominantly thermogenic degradation in the northern and central areas, but in the southern area due to microbial action. Microbial action is also responsible for the high sulfur content of heavy oils. Some conditions must be met to carry out sub-surface biodegradation. Meteoric waters, which contain oxygen and bring bacteria to the oil to aid biodegradation are important. Degradation is less where meteoric water circulation is limited by shale seals. Waters that induce degradation must contain dissolved oxygen at least at 8 ppm in order to maintain aerobic bacteria.

The waters must contain nutrients and the reservoir temperature must not exceed 80°C in order for the bacteria to survive. Hydrogen sulfide, which kills them, should not be present. The breaking up of heavy oil molecules into lighter fractions by the use of high temperature without the aid of catalysts.



Three Dimensional Perspective

Showing three dimensional perspective of °API Gravity for Monterey Formation

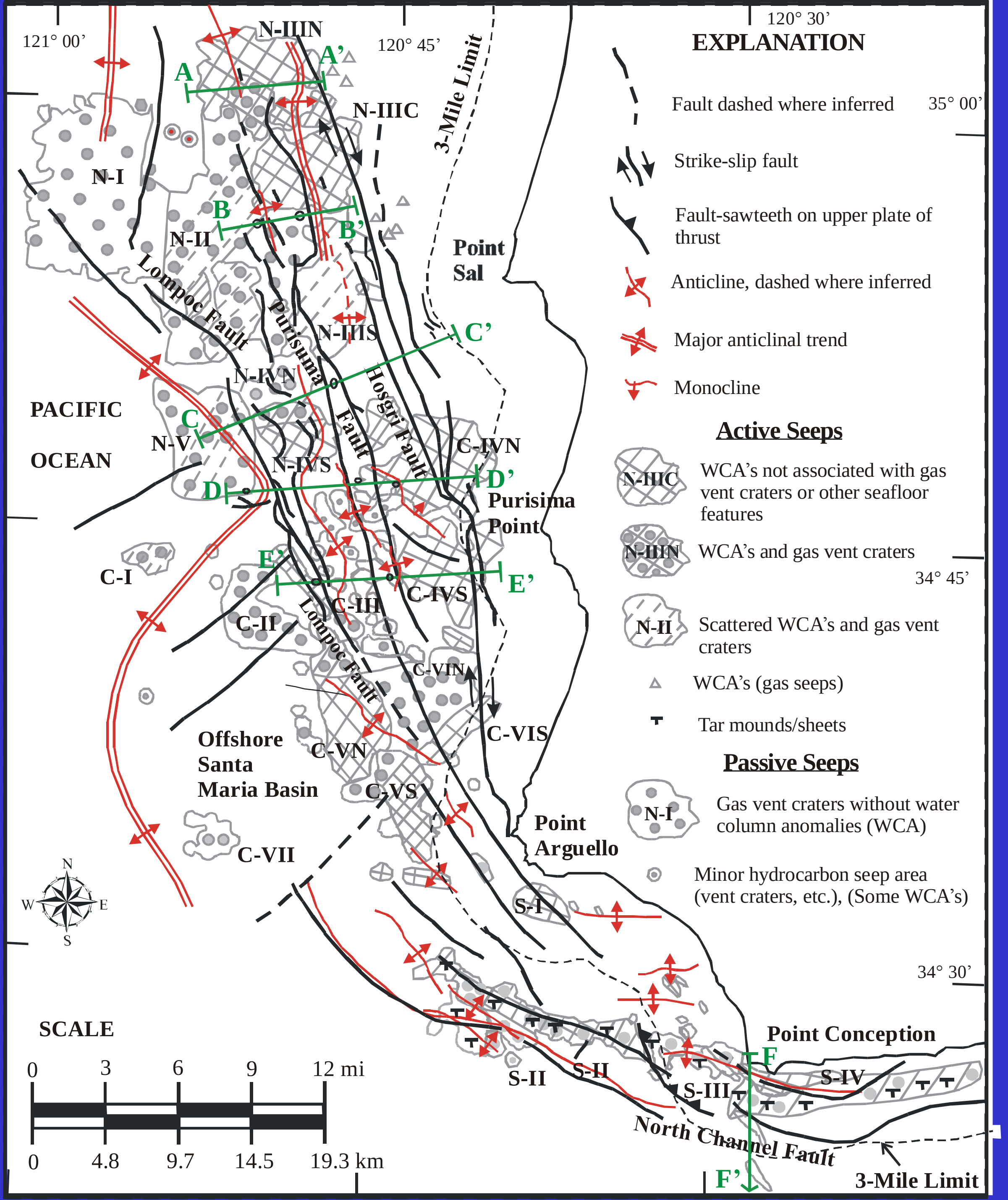


Surfer by Golden Software, 2020

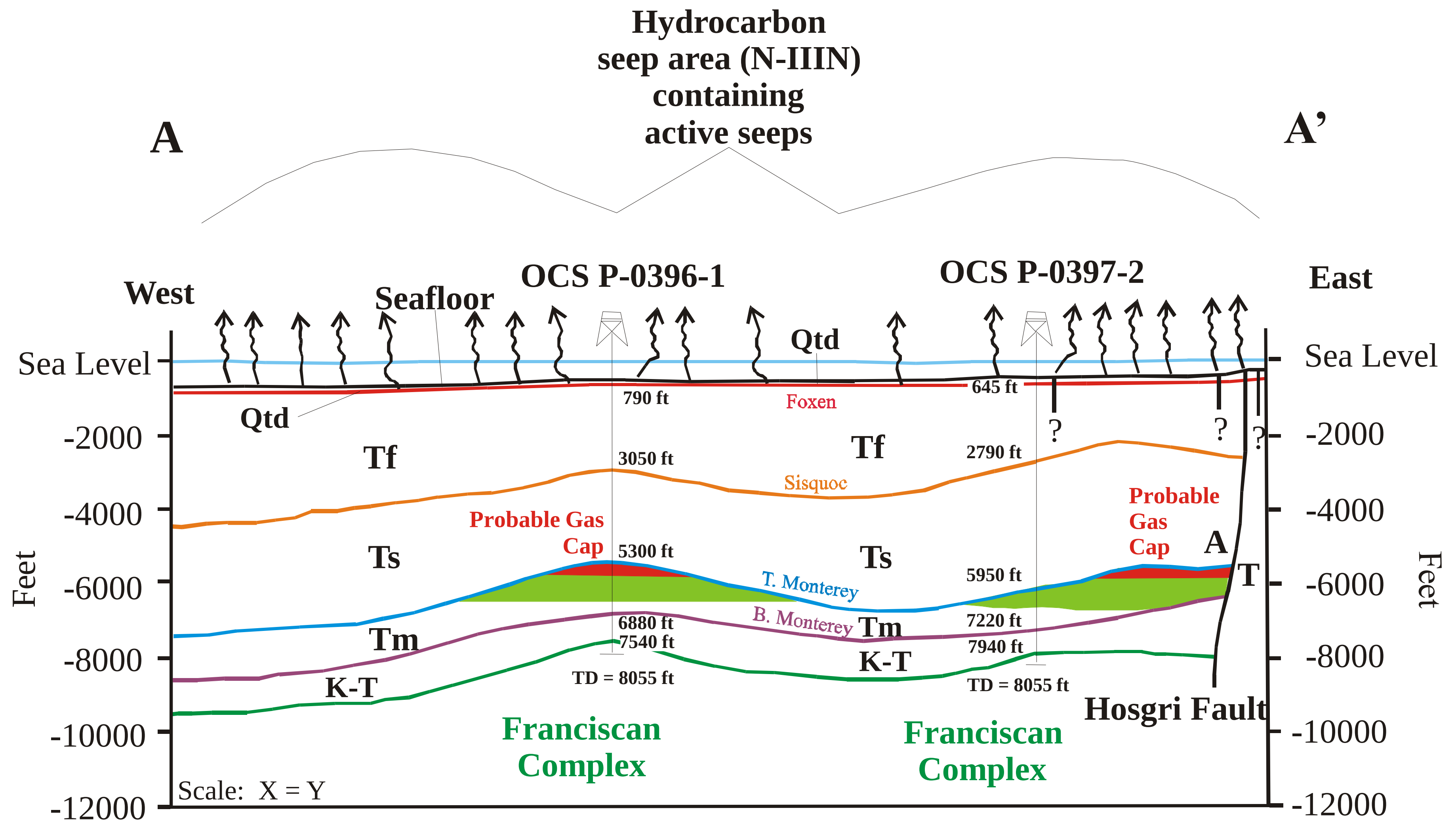
Differences among seeps and seep features are related to the difference in tectonic regimes of Santa Maria and Santa Barbara Basins

•In the northern and central study area, strike-slip tectonics of the Hosgri, Purisima, and Lompoc fault zones are associated with numerous active and episodic gas vent craters.

•In the southern-most portion of the study area, compressional tectonics of the North Channel Fault zone are associated with heavy oil-tar seeps.

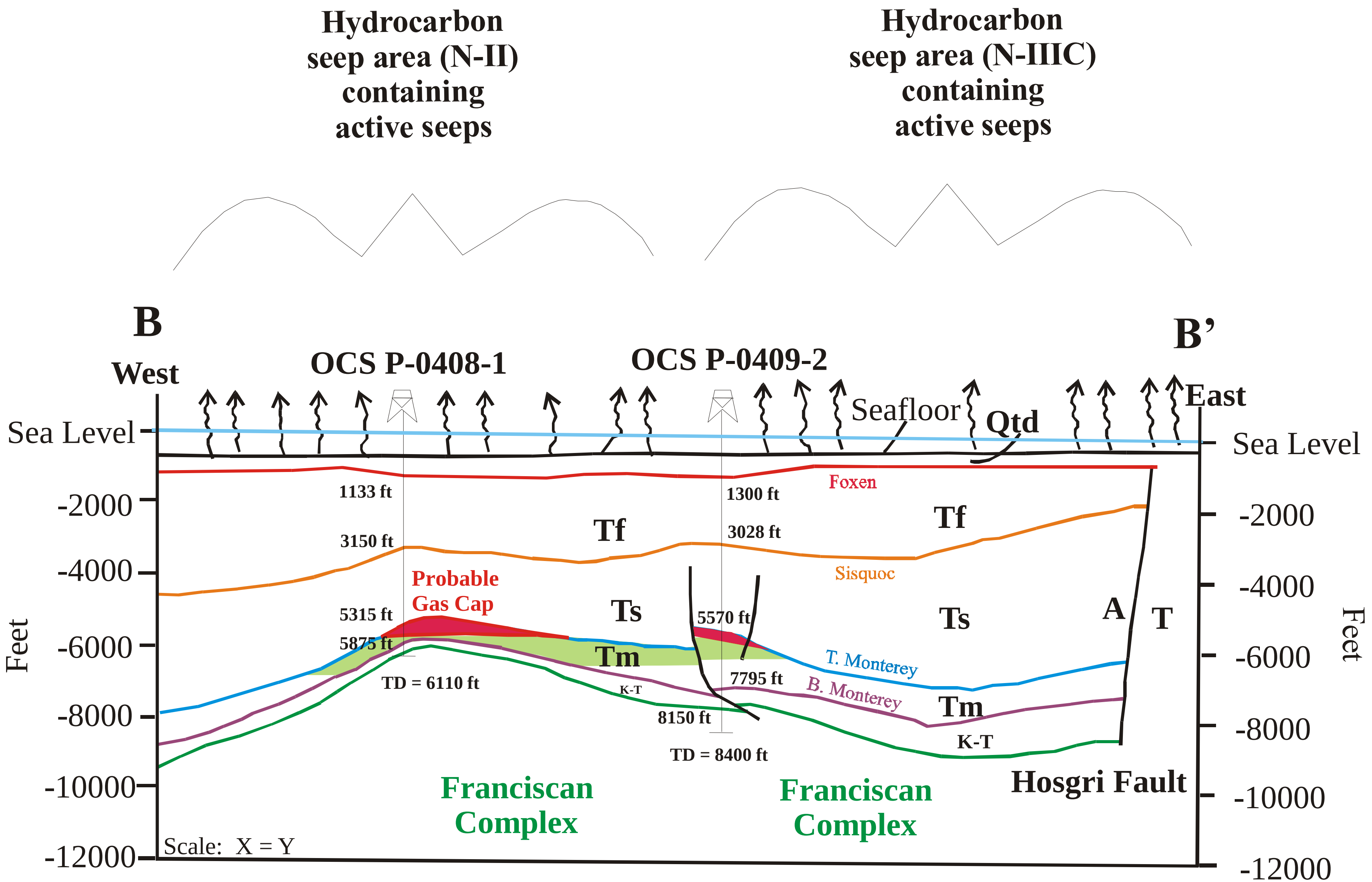


Strike-slip Tectonics
Cross Section A-A'



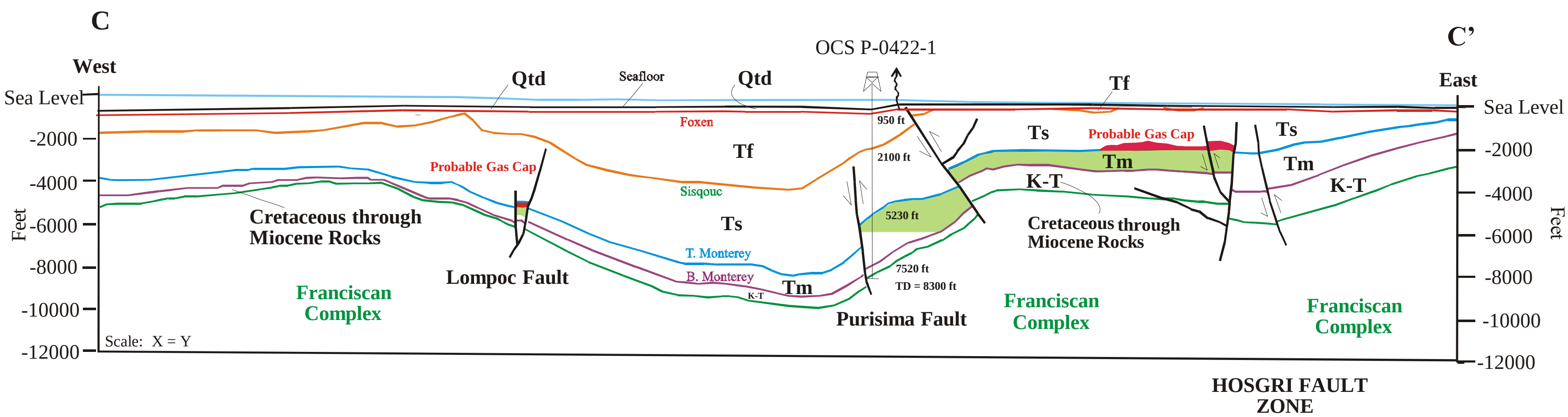
(Saenz, 2002)

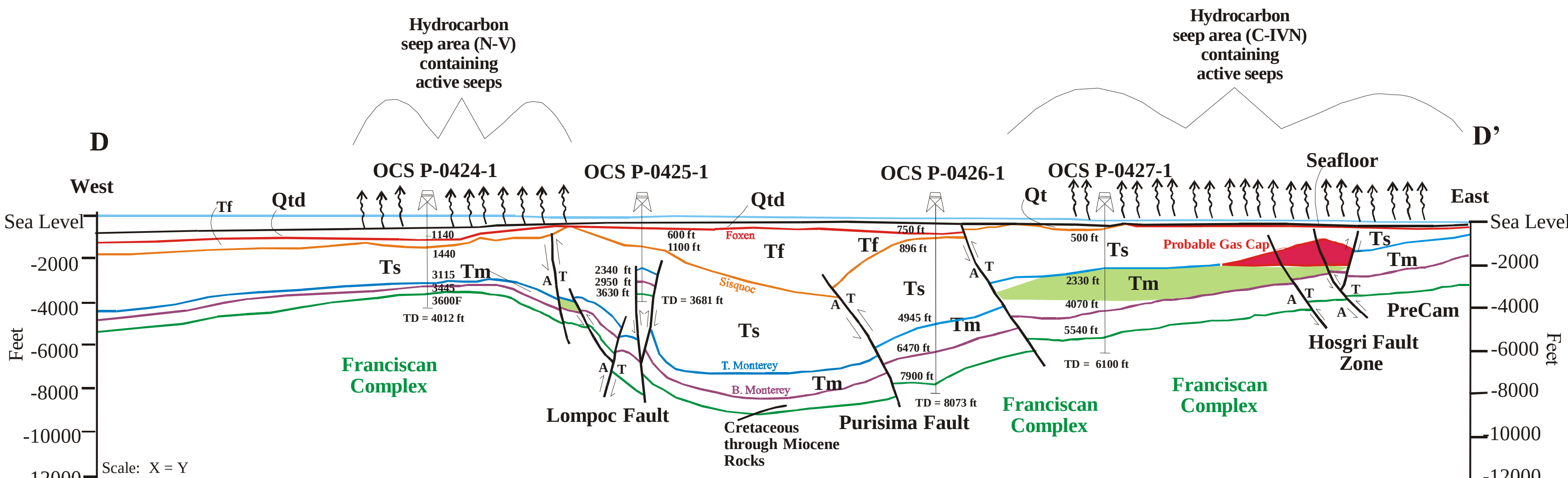
Strike-slip Tectonics
Cross Section B-B'



(Saenz, 2002)

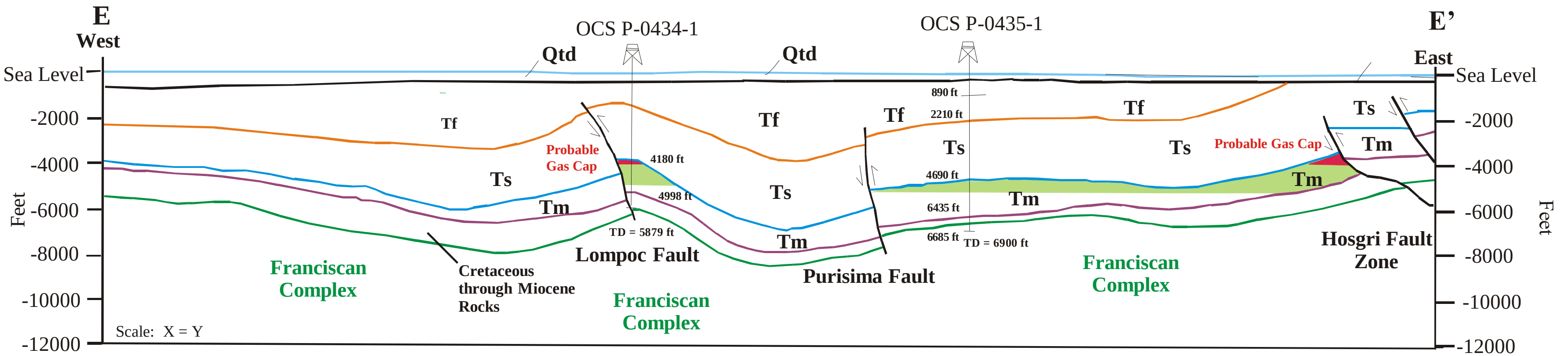
Strike-slip Tectonics
Cross Section C-C’ and Cross Section D-D’





(Saenz, 2002)

Strike-slip Tectonics
Cross Section E-E'



(Saenz, 2002)

Compressional Tectonics

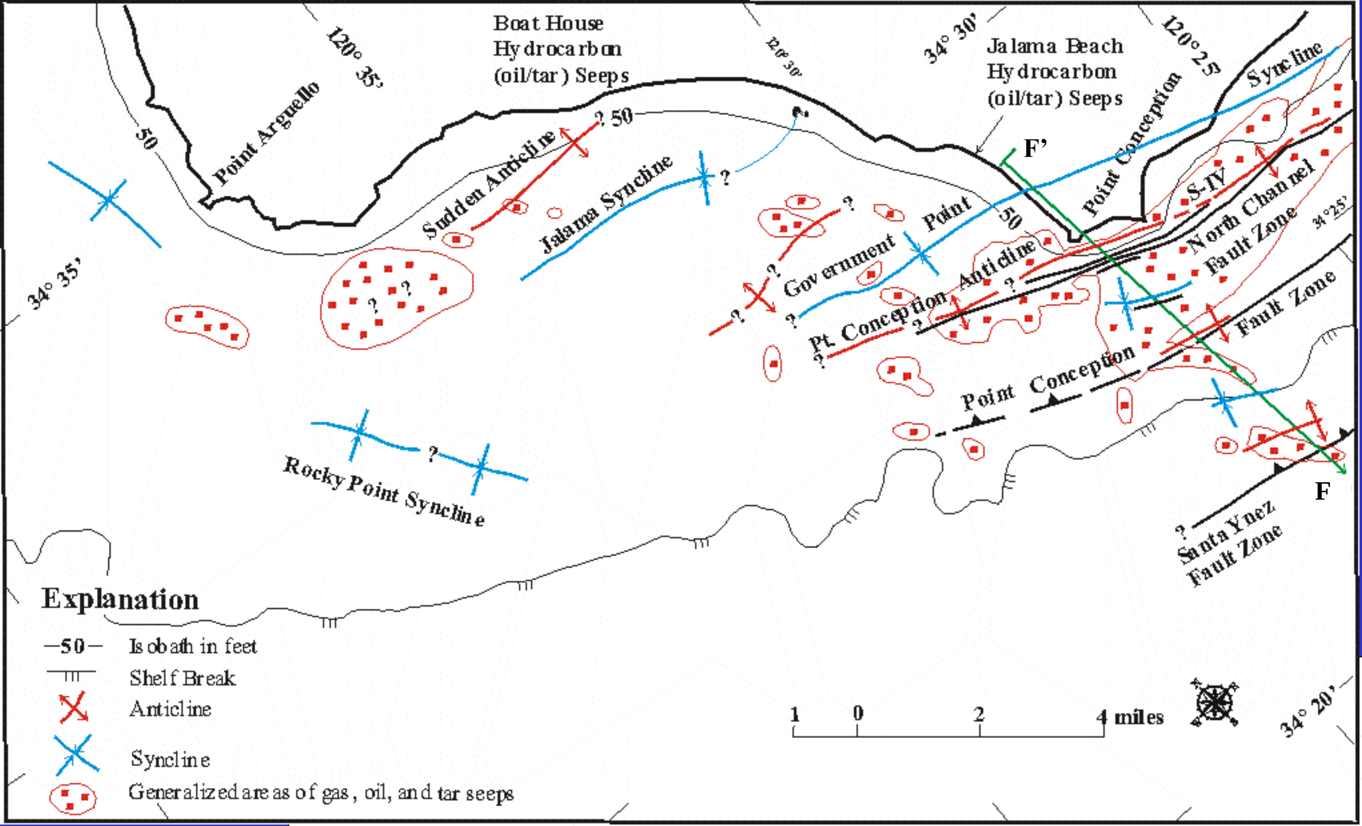
- In the southern-most portion of the study area, compressional tectonics of the North Channel Fault zone, bring the Monterey Formation to the surface resulting in a loss of volatiles and biodegradation of the oil to tar at the surface. The heavy oil-tar seeps form tar sheets and growing tar mounds.

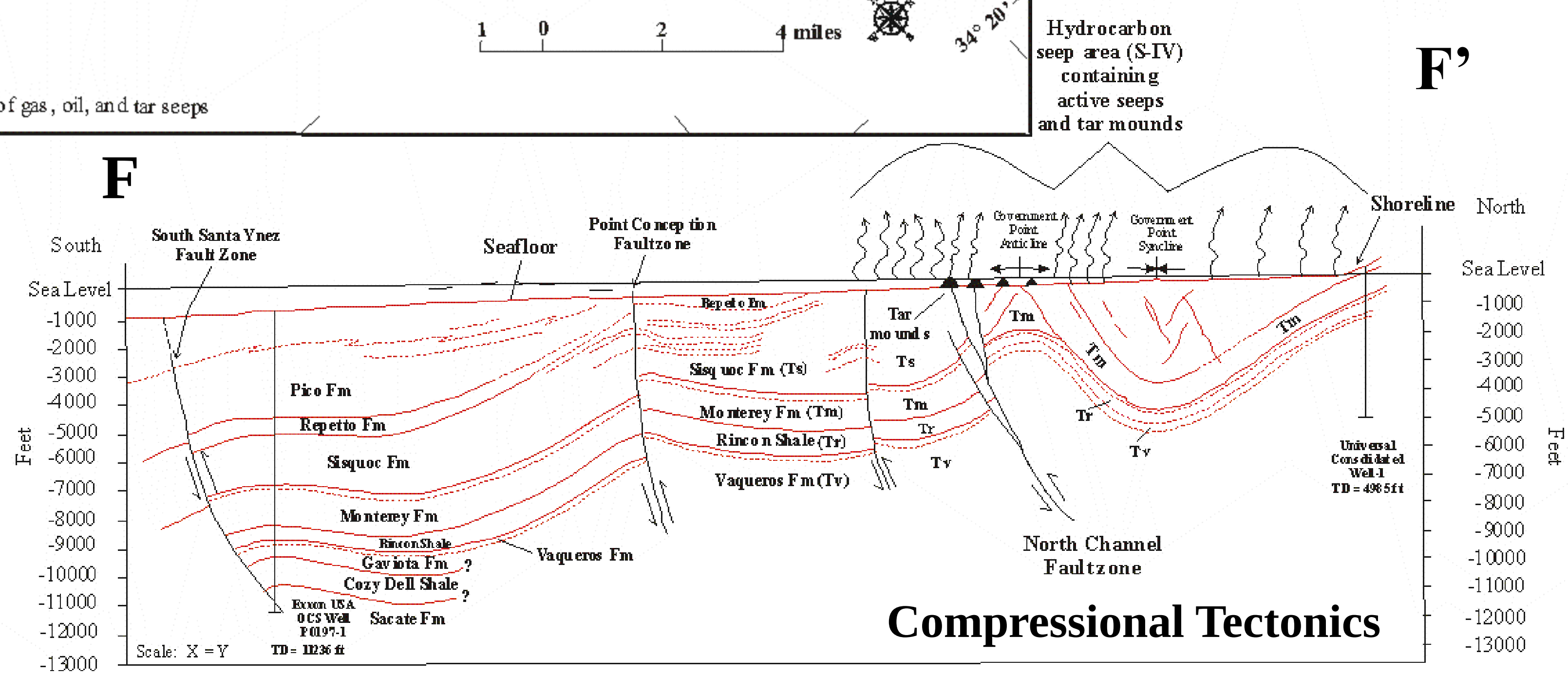
- The hydrocarbon seeps in the SBB along the North Channel fault and east-west trending fold trends have tapped into various reservoir rocks; including the Monterey, Vaqueros, Sespe, and Sacate Formations.

- The compressional tectonics of the North Channel Fault zone, brings the Monterey Formation to the surface resulting in a loss of volatiles and biodegradation of the oil to tar at the surface in the southern area. The occurrence of these features is generally limited to the Arguello Slope. The heavy oil-tar seeps form tar sheets and growing tar mounds found near the seep vent structures, and in one case associated with Beggiatoa, a chemosynthetic bacterium that metabolizes petroleum was found near a seep in area S-II.

Cross section (F-F') showing structure, and hydrocarbon seeps for the southern portion of the offshore SMB study area (Saenz, 2002).

Location of this section is south of Point Conception.





Compressional Tectonics

(Saenz, 2002)

Case Study - Conclusions

•The mechanism for thermal degradation of Monterey Formation oil are associated with the highest Geothermal Gradients (3°F/100 ft), and high Monterey Formation temperatures (250 F°)

•Glassy Chert's and Porcelaneous Chert's are associated with highest geothermal gradients, the highest average temperatures in Monterey Formation, and highest Methane gas concentrations.

•Presence of thermogenic hydrocarbons at depth results in the vertical migration of gas in major fault zones to the seafloor (high resolution seismic surveys, mud logs-gas chromatograph trends, well cores, and SNIFFER surveys.

•Loss of volatiles or lighter–end fractions (C1–C8) have resulted from thermal cracking in the northern and central areas and correlate to low °API gravities in Monterey Formation oil, highest gas concentrations in shallow horizons (0-3000 ft subsea), and highest # of gas vent craters on the seafloor (+1500).

•Differences among seeps and seep features are related to the difference in tectonic regimes of Santa Maria and Santa Barbara Basins.

•The primary seep controls are the northwest-trending active faults of the Hosgri system (strike-slip tectonics), including the Purisima and Lompoc faults all tapping into one major reservoir rock.

•In the southern-most portion of the study area, the North Channel Fault zone (compressional tectonics) is the primary seep control tapping into several major reservoir rocks.

•Tar mounds/sheets or seeping oil on seafloor may be inhibiting the upward migration of hydrocarbons acting as a "secondary seal" in the North Channel Fault zone. Leading to slower gas-seepage rates and higher °API gravities in Monterey Formation oil. Low concentrations of craters are located in the southern area and are associated with tar mounds/sheets.