Petroleum Systems in the World's Richest Petroliferous Basin, Los Angeles, California*

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Other presentations from this session and posted on Search and Discovery are Article #80375 (2014) by Wallace Dow, Article #80385 (2014) by Robert Sterling and Anne Grau, and Article #80387 (2014) by Prasanta Mukhopadhy.

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Abstract

Based on a training set of 112 nonbiodegraded or mildly biodegraded crude oil samples, a chemometric decision tree was constructed which identifies five tribes and 12 genetic oil families in the Los Angeles basin. The decision tree classified more than 50 additional samples that were affected by severe thermal maturation or biodegradation. The families occur in different parts of the basin and exhibit different bulk properties, such as API gravity, sulfur and metal content. Unlike previous publications, which propose that these differences result from maturation or biodegradation of similar oil, this work shows that these properties are largely controlled by different source rock organofacies. The character of the source rock was inferred from the geochemistry of each family and their distinct stratigraphic occurrence. Carbon isotope ratios for saturate and aromatic fractions indicate marine Neogene source rocks. Tribes 1–2 consist of five oil families found mainly east of the Newport-Inglewood Fault Zone (NIFZ). These oils show evidence of proximal, clay-rich source rock deposited under suboxic conditions with more higher-plant and especially angiosperm input than Tribes 3–6 (e.g., elevated C_{19} tricyclic terpane, oleanane/hopane, C_{31}R/hopane, and C_{24}/C_{23} tricyclic terpane ratios). Tribes 1–2 originated from upper Miocene (Delmontian) shale in the Central Trough. Tribes 3–6 originated from distal, clay-poor source rock deposited under anoxic conditions with less angiosperm input. Tribes 3–6 also show elevated bisnorhopane/hopane, supporting anoxic conditions. Tribe 3 consists of three families generated

from upper Miocene (Middle-Upper Puente) marl source rock west of the NIFZ. These oils occur from Torrance in the north to the giant Wilmington and Huntington Beach fields in the south. Tribe 4 consists of two families west of the NIFZ that likely originated from middle-upper Miocene (Mohnian) marl source rock. The oils range from Playa del Rey in the north to Wilmington field in the south. Tribe 5 occurs southwest of the NIFZ mainly in the Wilmington and Huntington Beach fields and originated from middle-upper Miocene (Lower Puente) nodular shale with significant higher-plant plant input. Tribe 6 occurs northwest of the NIFZ from Beverly Hills in the north to the El Segundo field in the south. These oils were generated from middle-upper Miocene (Lower Modelo) nodular shale equivalent with significant higher-plant plant input.

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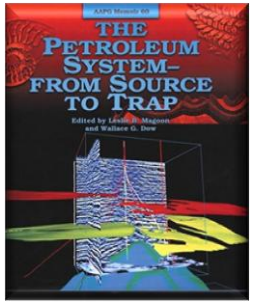
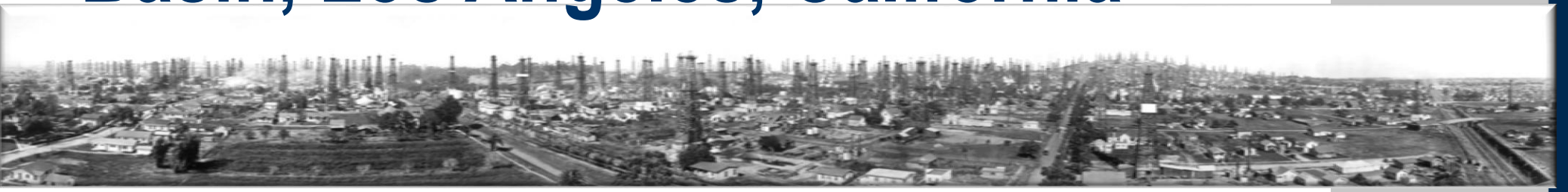


Petroleum Geochemistry and Source Rock Characterization:
Honoring 50 Years of Wallace Dow's Contributions

APRIL 8, 2014
HOUSTON, TX

Petroleum Systems in the World's Richest Petroliferous Basin, Los Angeles, California



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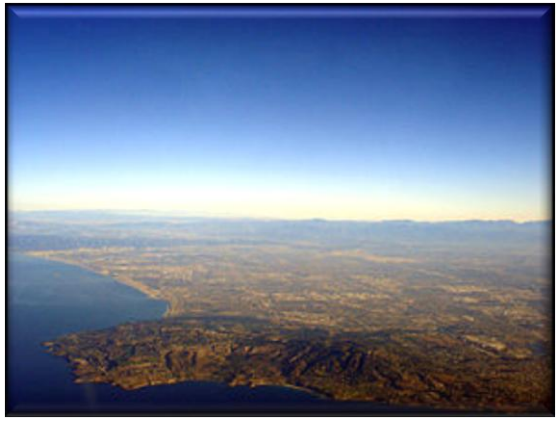
- *Les Magoon (general discussions)*

Signal Hill, California, c 1923

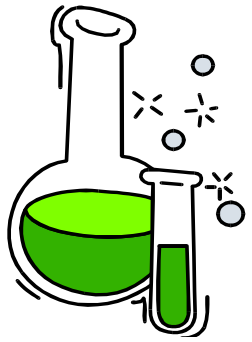
Significant Characteristics of the Los Angeles Basin

- **World's richest basin; classic transform-margin basin.**
- **Since 1880, ~67 fields were discovered, e.g., supergiant Wilmington, Long Beach, and Huntington Beach fields.**
- **Little exploration since the early 1970's; significant potential remains in deep, especially offshore areas.**
- **Current Paradigm – Variations in oil quality are caused by differing *maturity, migration, and/or source oxicity, not by different organic matter* (Jeffrey et al., 1991).**

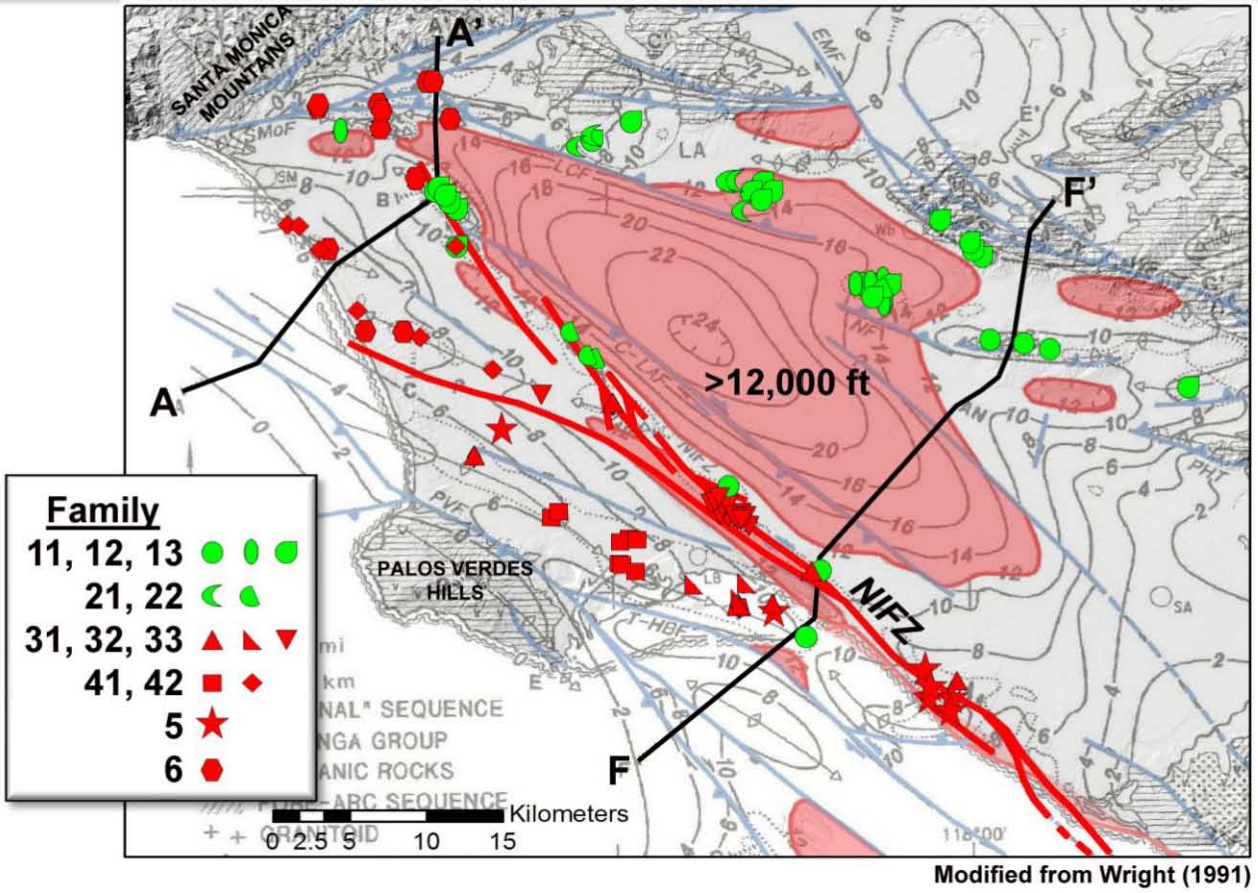


Purpose of the Los Angeles Basin Study

- **Measure biomarker and isotope ratios for ~150 crude oil samples from the basin to evaluate genetic relationships.**
- **Assess the extent of biodegradation for each sample to identify a "training set" where source-related biomarker or isotope ratios are unaffected.**
- **Identify oil families; create a chemometric (multivariate statistics) decision tree to classify new samples.**
- **Map the distribution of oil families; use biomarker and isotope ratios to infer their source-rock organofacies.**



Map Shows Families and Base Mohnian (~14 Ma) >12,000 Ft.



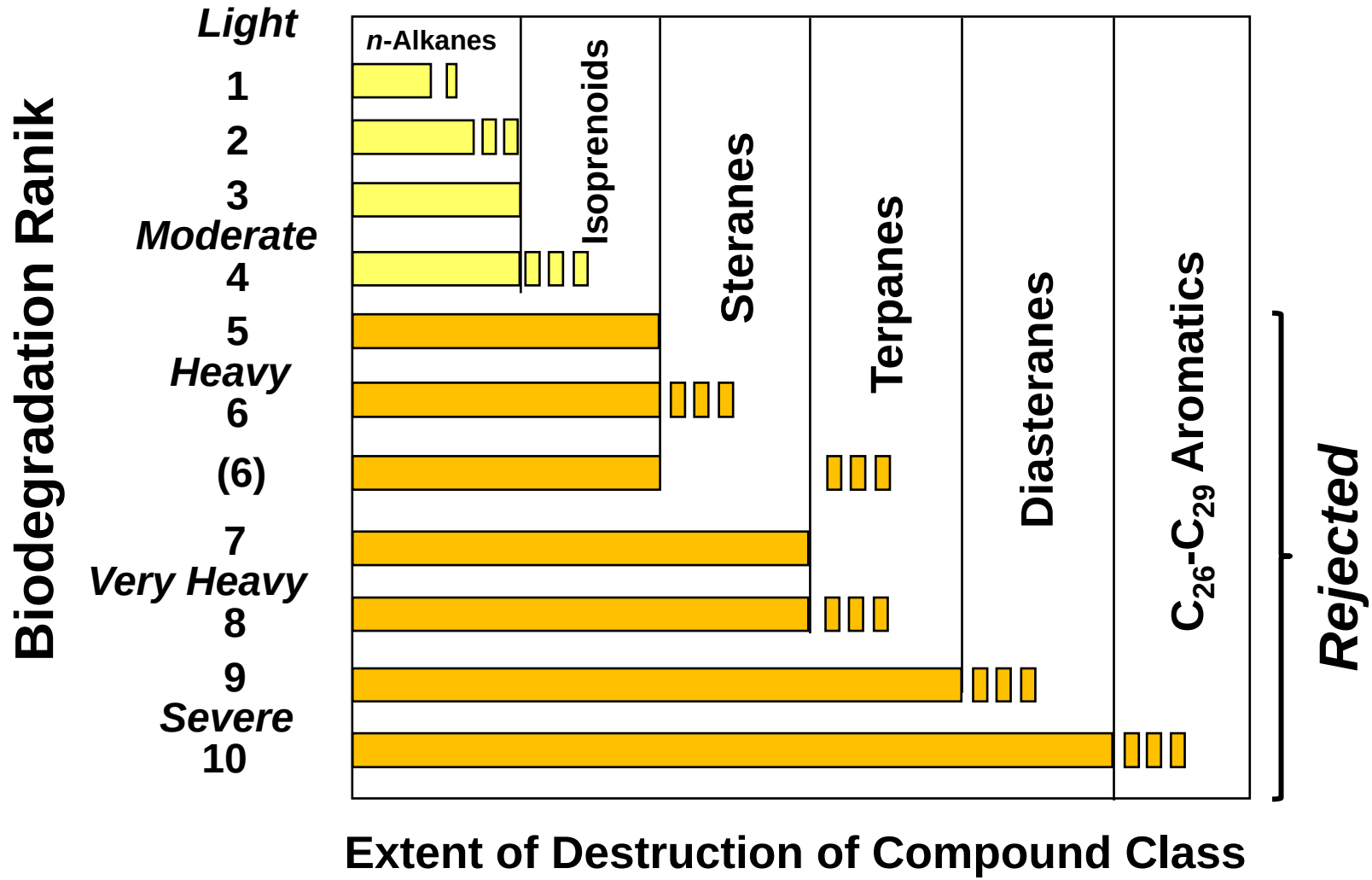
Presenter's notes: Base Mohnian is a late middle Miocene horizon; NIFZ = Newport-Inglewood Fault Zone

Oil Families: 24 *Source-Related* Biomarker & Isotope Ratios

Oil Sample	Biodegradation*	Terpanes																Steranes				Isotopes		
		C_{19}/C_{23}	C_{22}/C_{21}	C_{24}/C_{23}	C_{26}/C_{25}	C_{26}/Ts	Tet/C_{23}	$C_{27}T/C_{27}$	C_{28}/H	C_{29}/H	X/H	Ol/H	$C_{31}R/H$	Ga/31R	$C_{35}S/C_{34}S$	$C_{27}Ts/Tm$	$C_{29}Ts/Tm$	S/H	$\%C_{27}$	$\%C_{28}$	$\%C_{29}$	S1/S6	$\delta^{13}C_{sat}$	$\delta^{13}C_{aro}$	CV
ElS5	0	0.0350	0.2470	0.7517	0.7903	1.8274	0.1190	0.0378	0.3835	0.5460	0.0192	0.1162	0.2847	0.1006	0.9857	0.4668	0.2008	1.7745	31.1369	41.6277	27.2354	0.1793	-25.02	-23.68	-0.92
LB6	4	0.0332	0.1781	0.6544	1.1647	2.6412	0.1335	0.0590	0.4458	0.5961	0.0167	0.1319	0.2269	0.6705	0.8730	0.3510	0.1628	1.8849	29.7768	44.5270	25.6962	0.1514	-23.88	-22.94	-2.16
BvH7	3	0.0263	0.2458	0.9474	0.8300	2.6974	0.1033	0.0329	0.2743	0.5091	0.0256	0.1405	0.2452	0.2843	0.9021	0.5314	0.2110	1.6759	30.0511	43.9406	26.0083	0.2100	-23.87	-23.16	-2.67
BvH26	0	0.0202	0.2926	0.7979	0.8203	2.0286	0.1268	0.0560	0.3661	0.5678	0.0151	0.1439	0.2741	0.2774	0.9107	0.4159	0.1811	1.3432	31.9467	39.9842	28.0690	0.0125	-25.06	-23.67	-0.80
CvH2	0	0.0237	0.2735	0.8494	0.9053	2.0887	0.1302	0.0499	0.1838	0.5275	0.0216	0.1478	0.2242	0.4121	0.6551	0.5258	0.1826	1.2655	30.6225	39.4825	29.8950	0.1942	-24.95	-23.64	-1.01
SwN28	1	0.0202	0.2647	0.7878	0.8106	2.0852	0.1262	0.0559	0.3621	0.5702	0.0139	0.1472	0.2723	0.4088	0.9618	0.3826	0.1758	1.5505	30.6532	40.9345	28.4122	0.1608	-25.04	-23.73	-0.98
Wht42	4	0.0555	0.2478	0.8727	1.0259	2.8864	0.0908	0.0815	0.2331	0.4251	0.0319	0.2837	0.1736	0.6051	0.6676	0.7019	0.2142	1.3942	32.0455	40.8963	27.0582	0.2966	-23.68	-23.05	-2.91
Wil78	5	0.0169	0.2394	0.7959	0.7684	3.8077	0.0926	0.0514	0.4284	0.7302	0.0286	0.1976	0.3393	0.5113	0.9033	0.3726	0.1649	0.7196	32.7066	41.3216	25.9717	1.1362	-23.66	-22.96	-2.76
Wil79	4	0.0166	0.2464	0.8045	0.7615	3.6745	0.0908	0.0573	0.3370	0.6352	0.0256	0.1622	0.2890	0.5523	0.9238	0.4197	0.1587	1.0619	33.0806	40.7143	26.2051	0.4414	-23.59	-22.91	-2.83

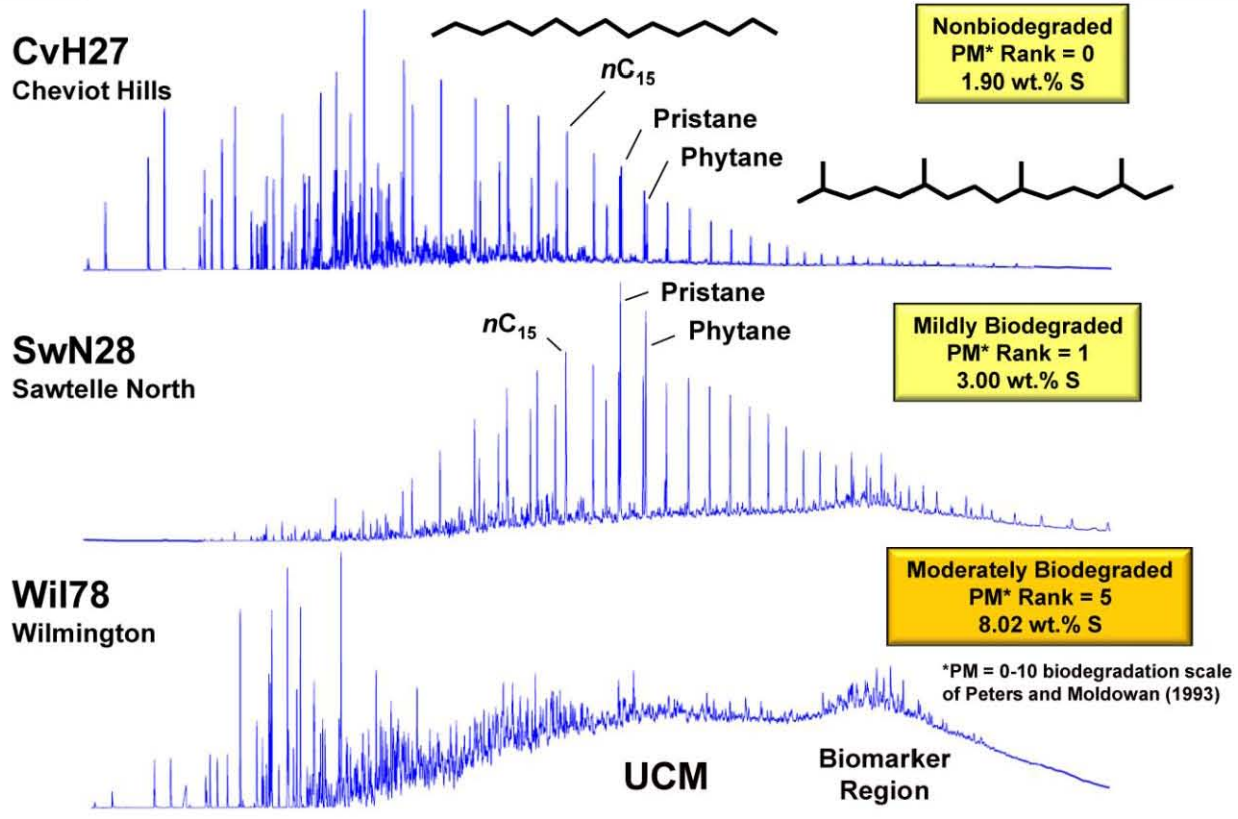
*0-10 biodegradation scale of Peters and Moldowan (1993)

Training Set: No Biodegradation of Steranes or Terpanes



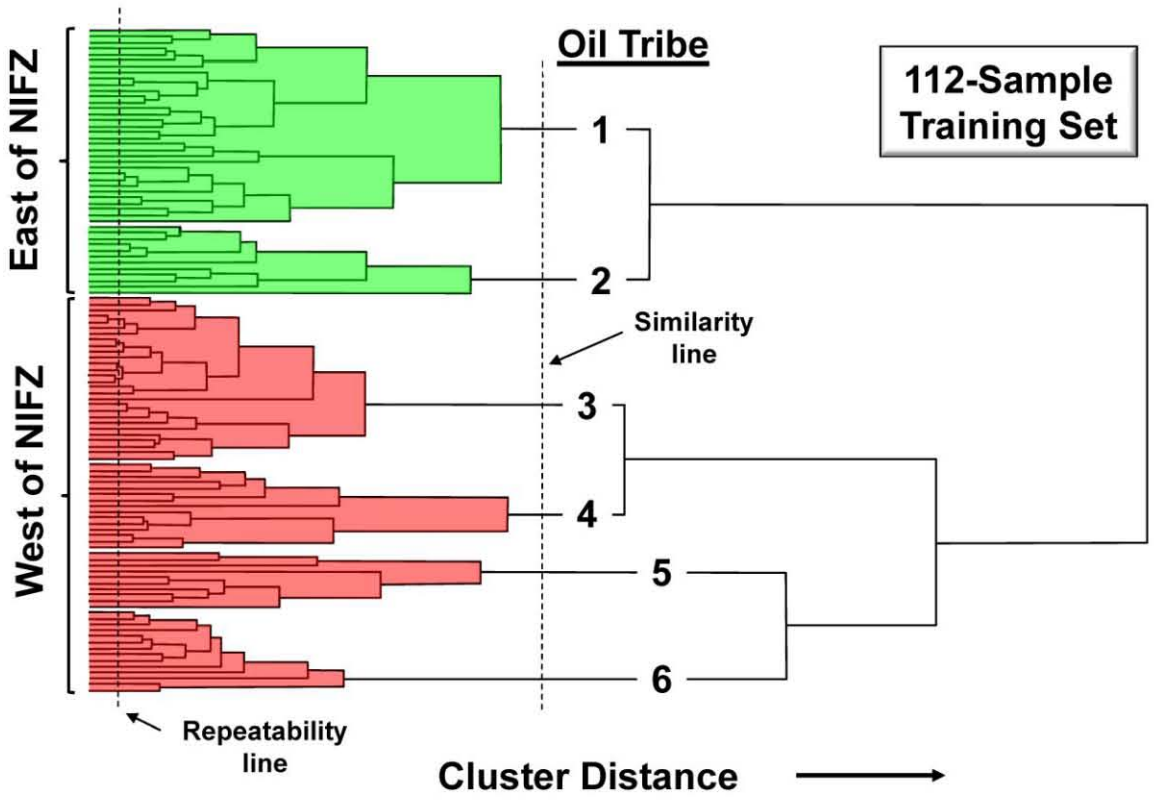
Peters and Moldowan (1993)

Oil Having Biodegradation Rank 5 or More was Rejected



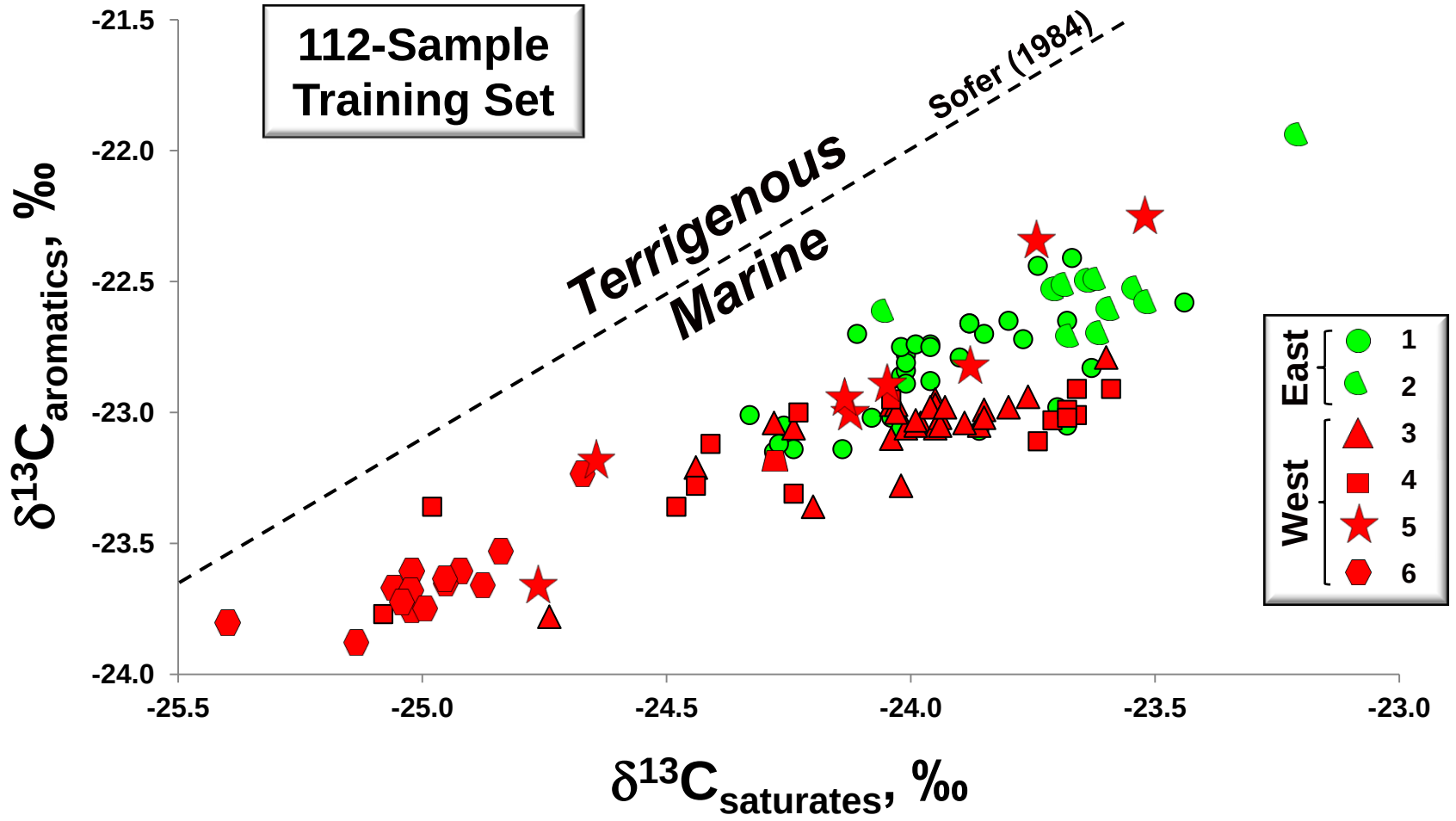
Presenter's notes: CvH27S, SwN28S = family 6 west of Newport-Inglewood Fault Zone
Wil78S = not classified (heavy biodegradation)

6 Tribes: East/West of Newport-Inglewood Fault Zone (NIFZ)



Presenter's notes: Four oils from LB 498, LB499, LB500, and LB501 from different wells, but about the same depth (2518-3060 ft), occur in the middle of Tribe 3 and represent a better assessment of repeatability that four analyses of the same sample.

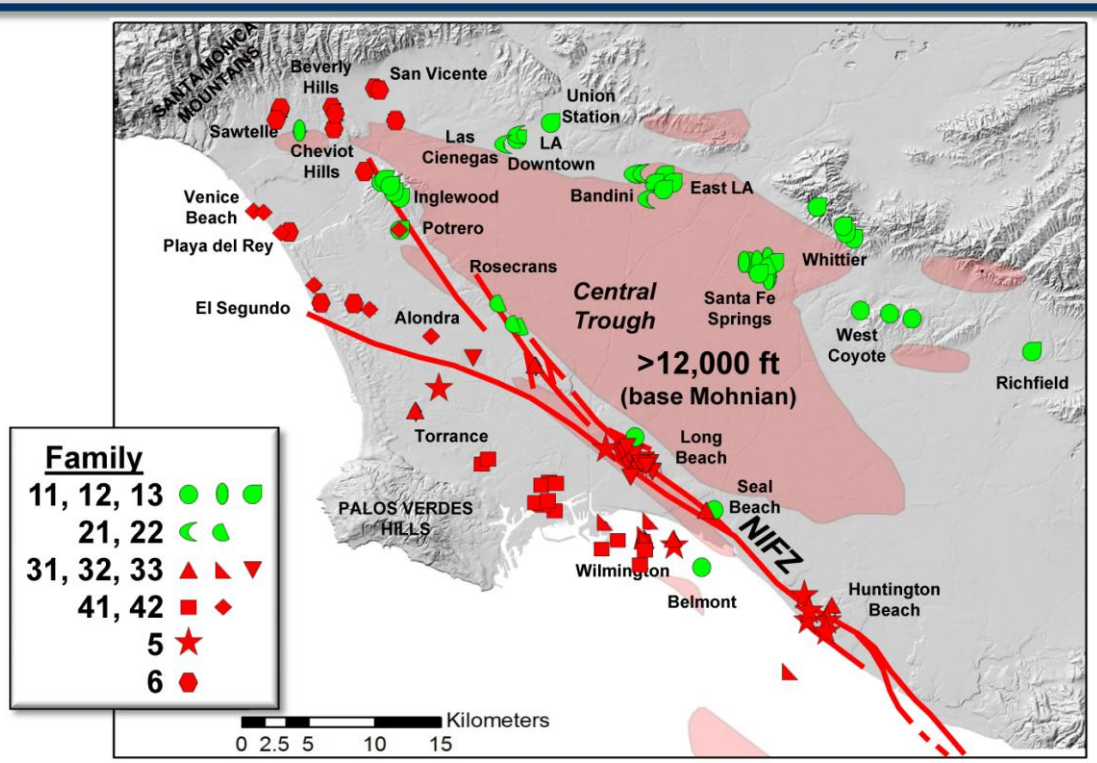
All Samples Have a Miocene Isotopic Signature (^{13}C-Rich)



Tribes 1 and 2 are Enriched in Higher-Plant Biomarkers

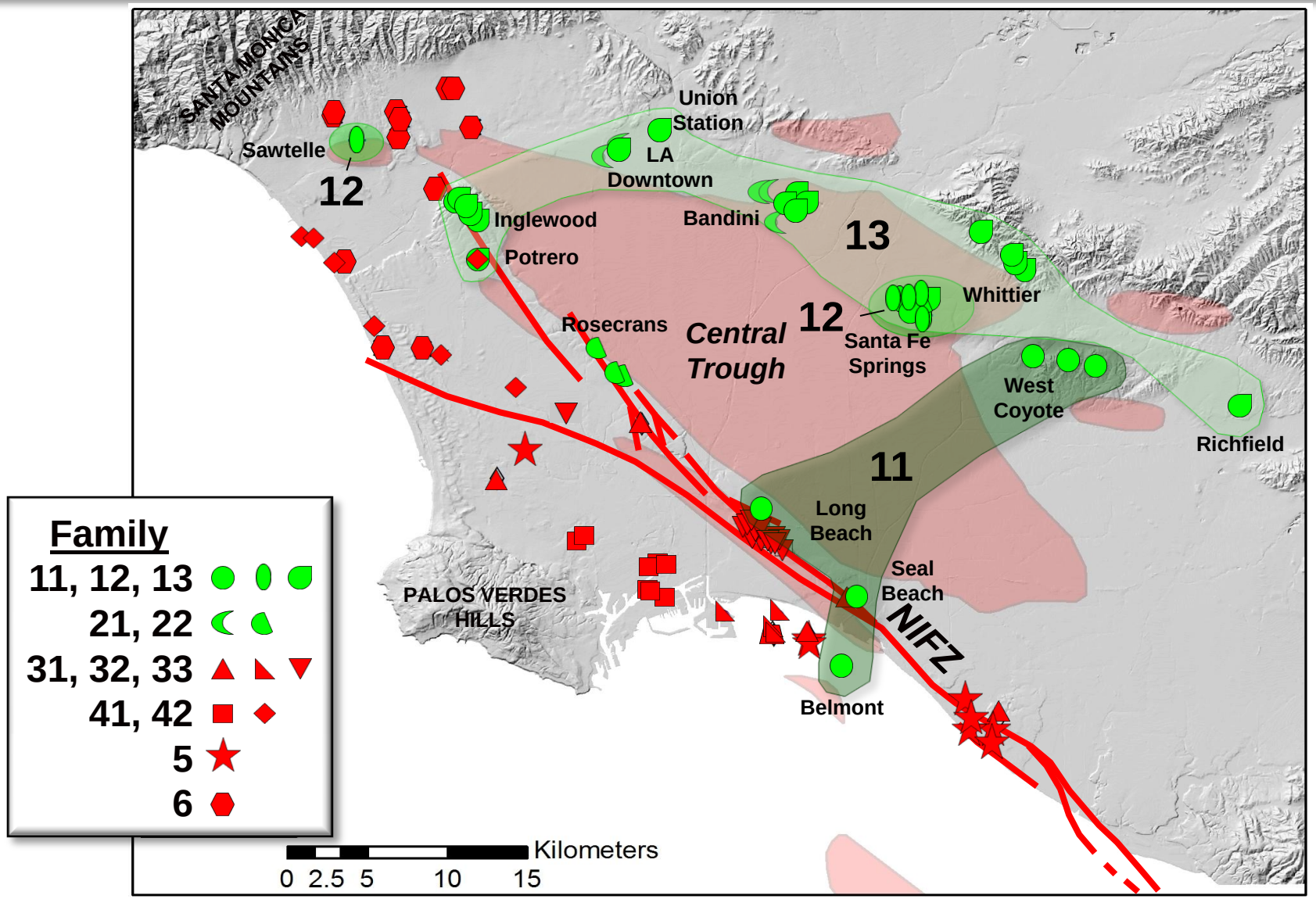
Nerium oleander

Families East/West of Newport-Inglewood Fault Zone (NIFZ)



Presenter's notes: The central trough north of the NIFZ trends N50°W. Maximum width between Dominguez and Santa Fe Springs oil fields is about 8 mi (14 km). The American Petrofina Central Core Hole #1, located 1 mi (3.2 km) northeast of the Rosecrans oil field, reaches Delmontian or lowermost Repetto at TD of 20,700 ft (6311 m). Base of Mohnian from Wright (1991) is late middle Miocene horizon, ca. 14 Ma.

Families in Tribe 1 Originated from Source Rock East of NIFZ



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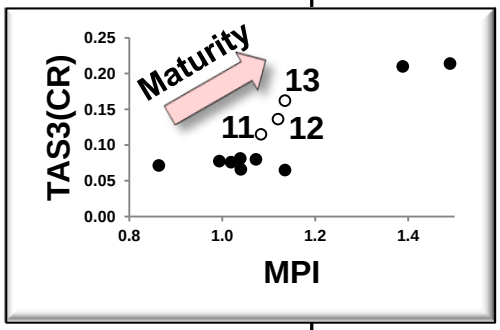
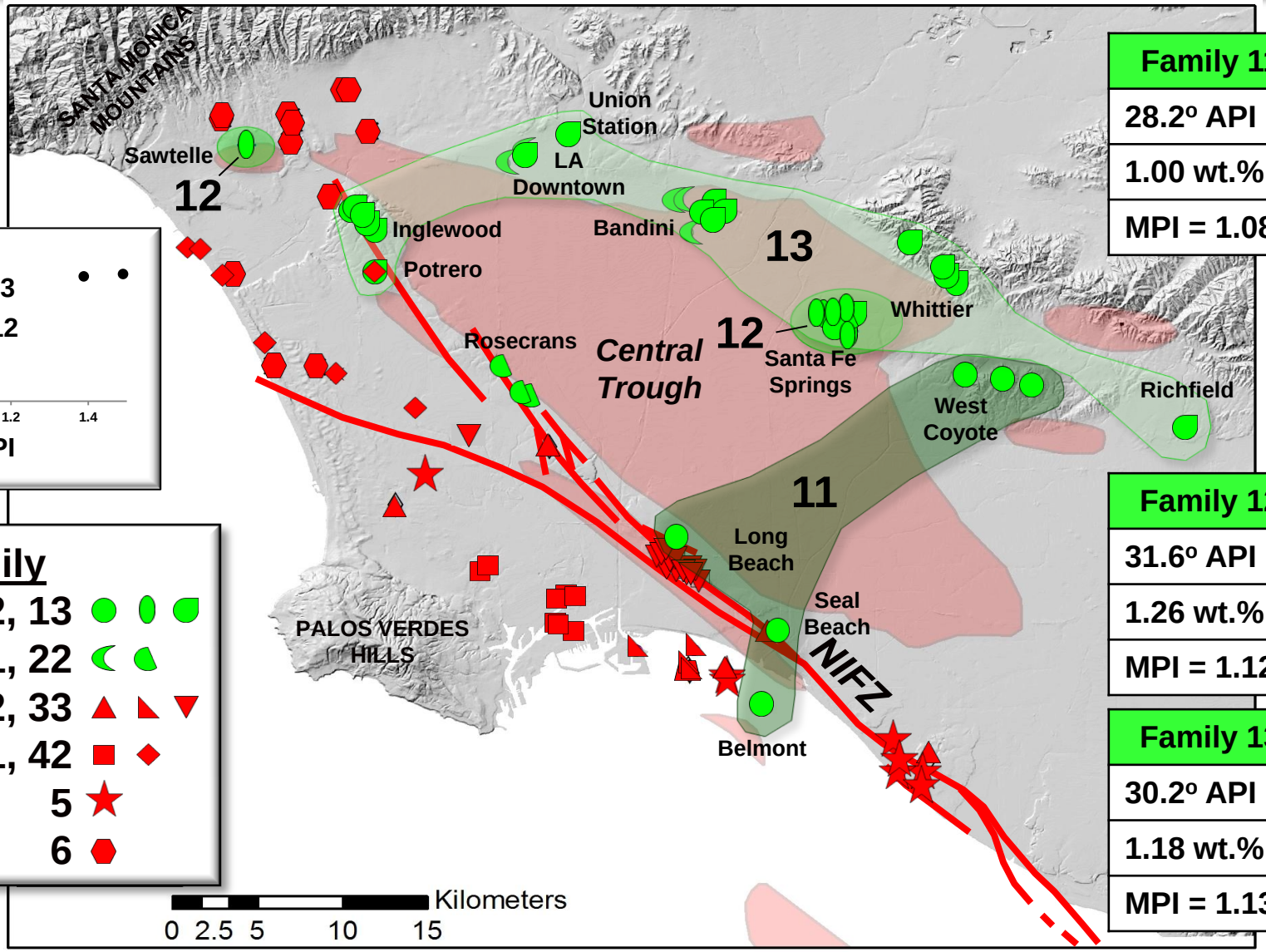


Family

11, 12, 13	● ● ●
21, 22	◐ ◐
31, 32, 33	▲ ◣ ▼
41, 42	■ ◆
5	★
6	⬢

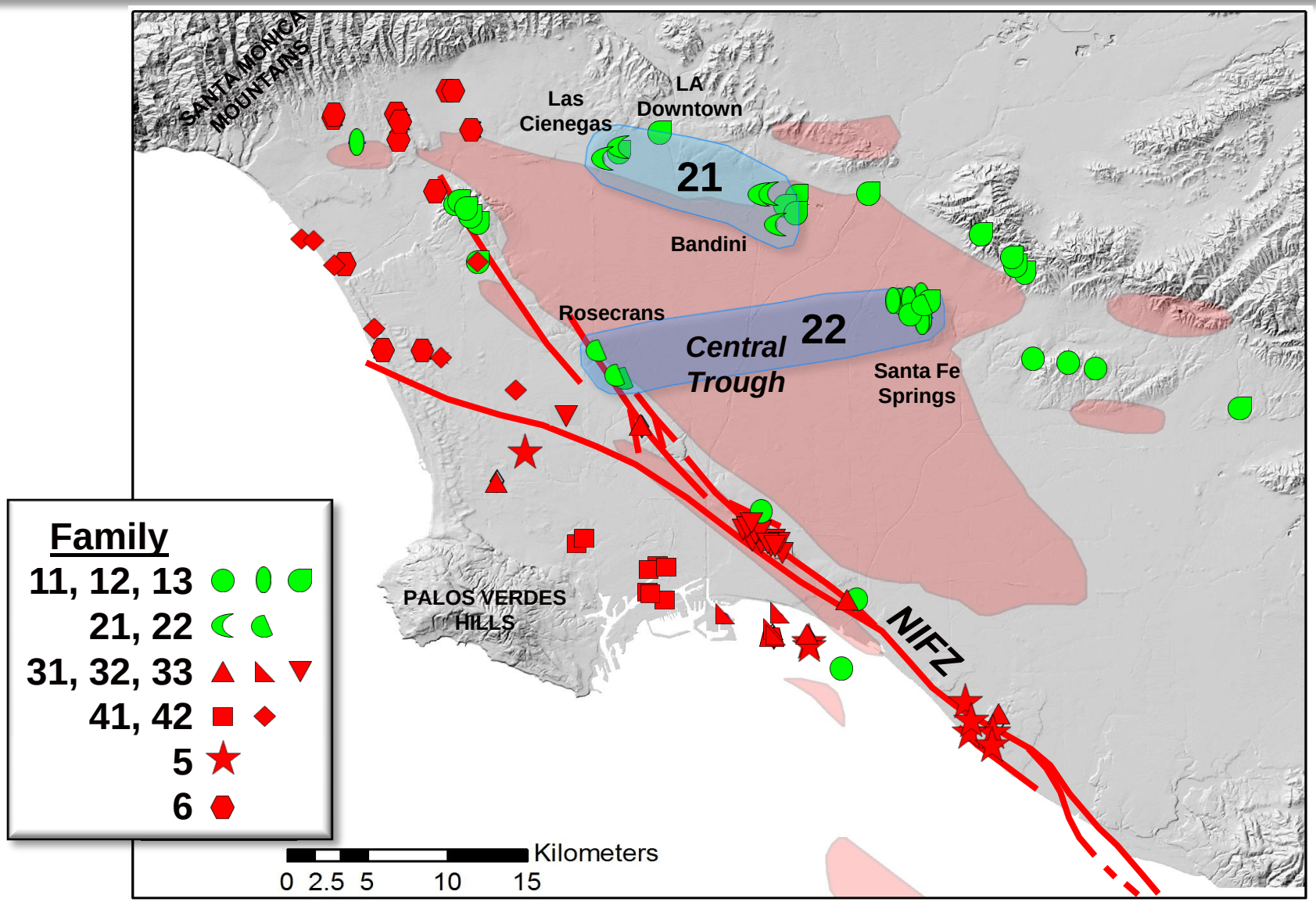


Family 11
28.2° API
1.00 wt.% S
MPI = 1.08

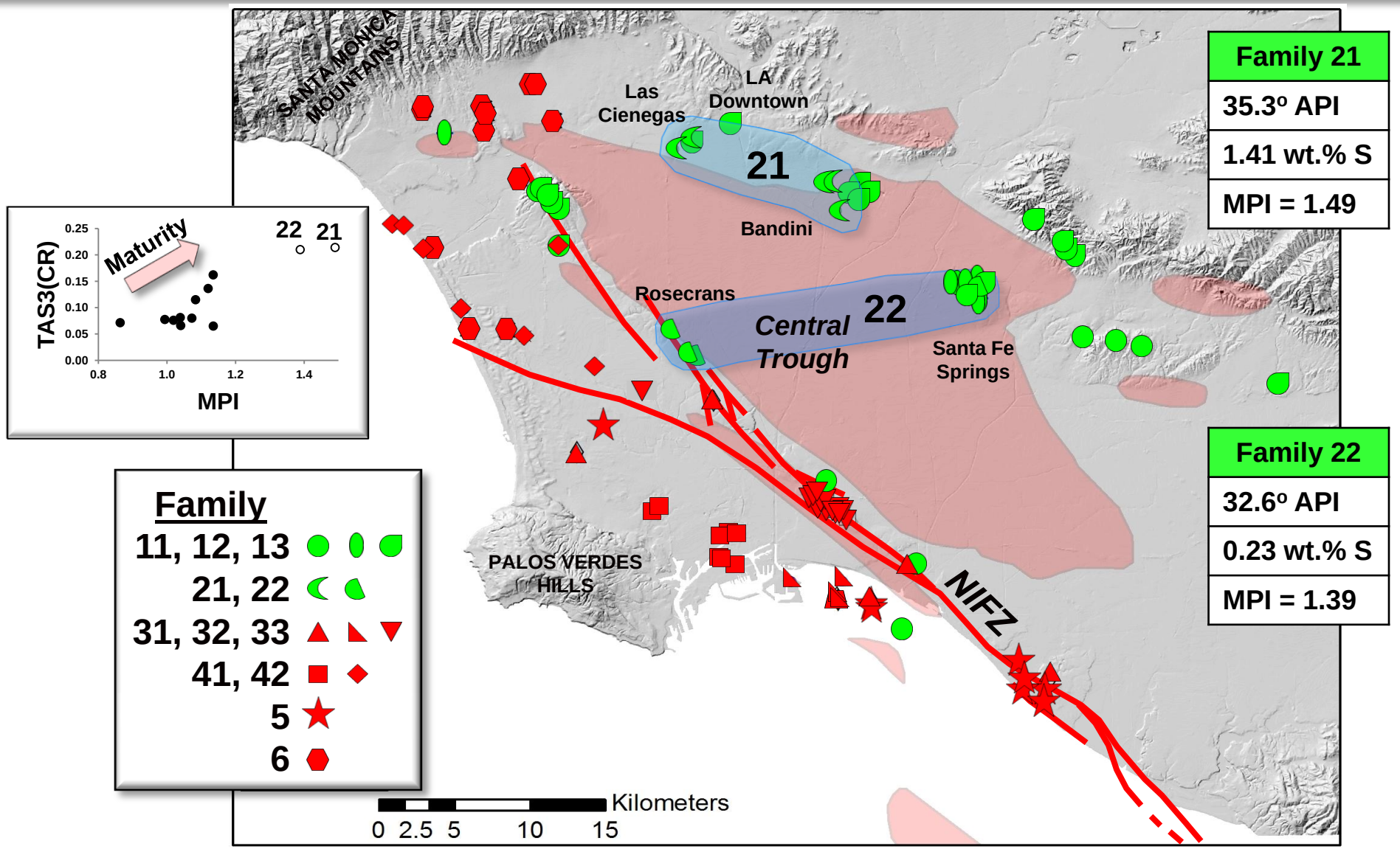
Family 12
31.6° API
1.26 wt.% S
MPI = 1.12

Family 13
30.2° API
1.18 wt.% S
MPI = 1.13

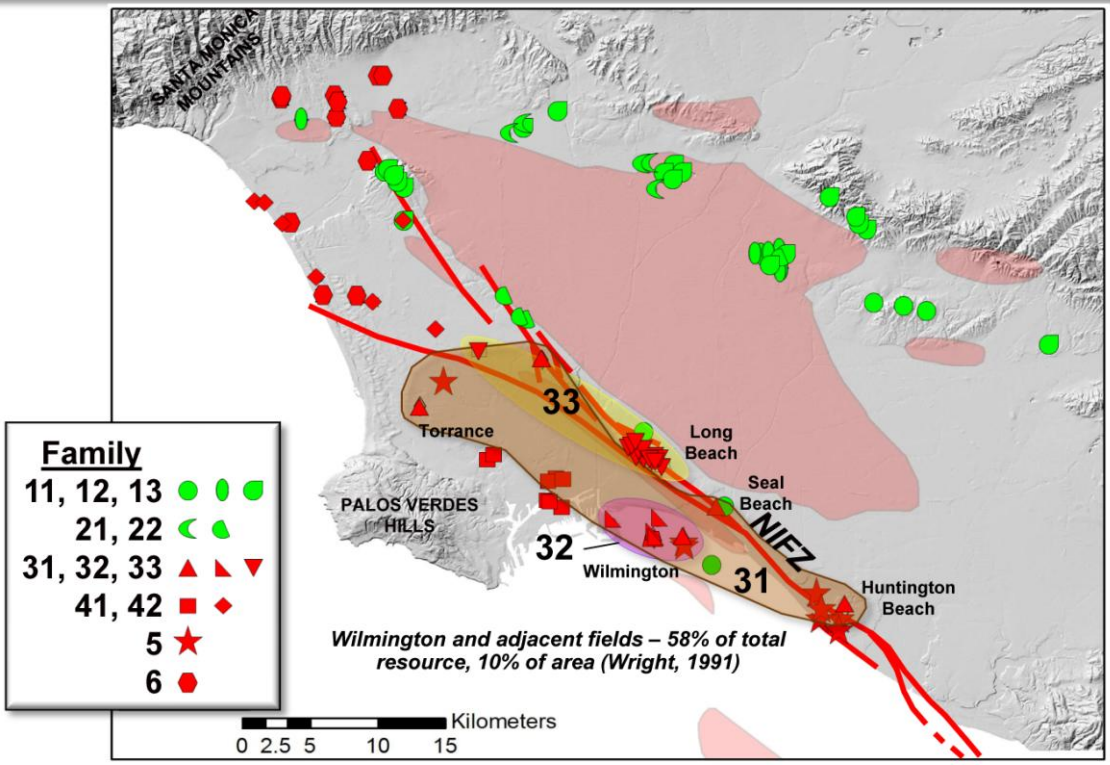
Families in Tribe 2 Originated from Source Rock East of NIFZ



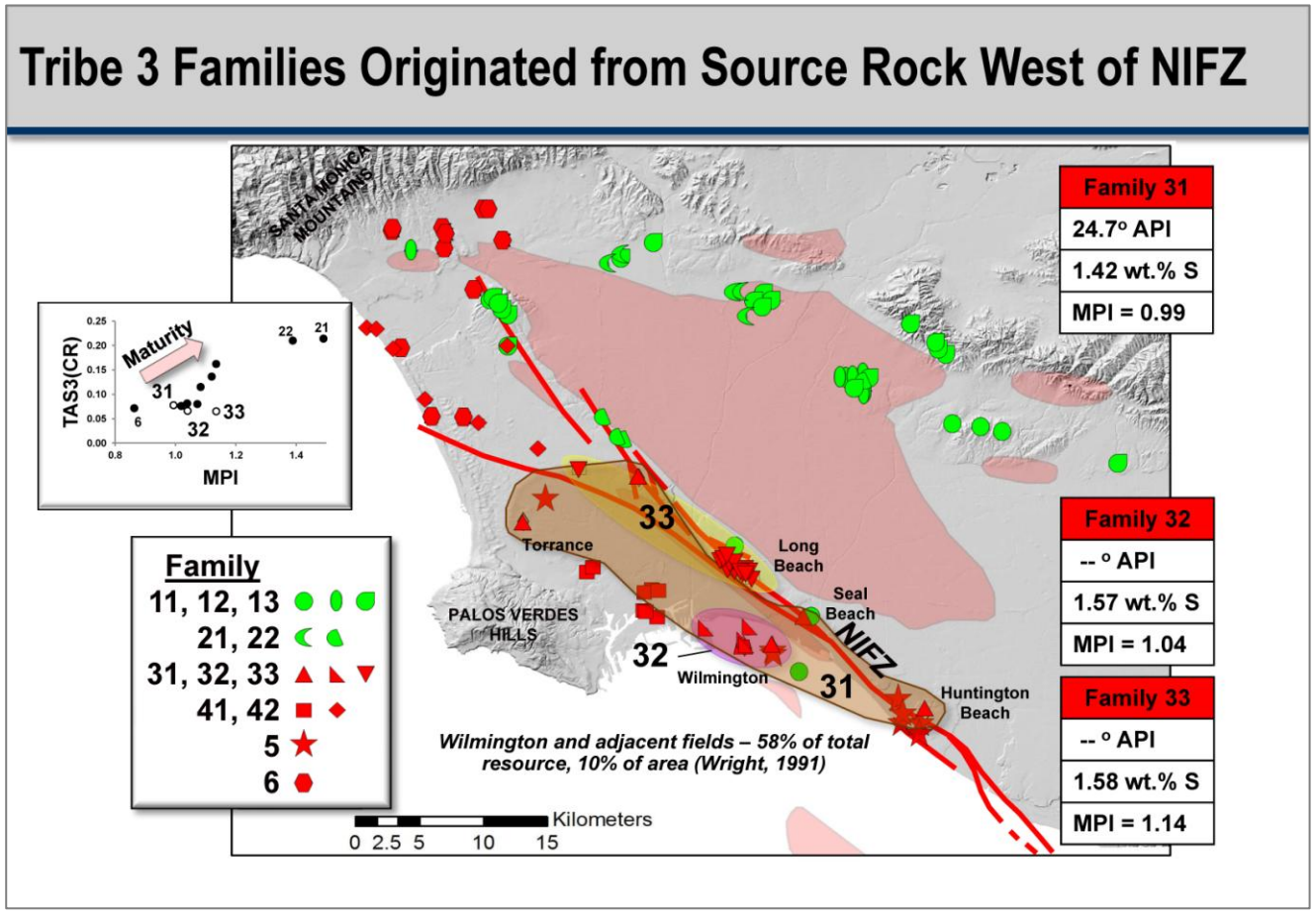
Families in Tribe 2 Originated from Source Rock East of NIFZ



Tribe 3 Families Originated from Source Rock West of NIFZ



Presenter's Notes: "Wilmington and adjacent oil fields – Long Beach, Seal Beach, and Huntington Beach will yield 5.2 GBO, about 58% of the basin's total resource; yet the area encompassed by these fields occupies no more than 10% of the basin. Here all the factors are optimal." Wright (1991). Thick localized Monterey source rock and high geothermal gradient 3.29^{o}F/100 ft (60^{o}C/km) at Wilmington (Beyer, 1988).



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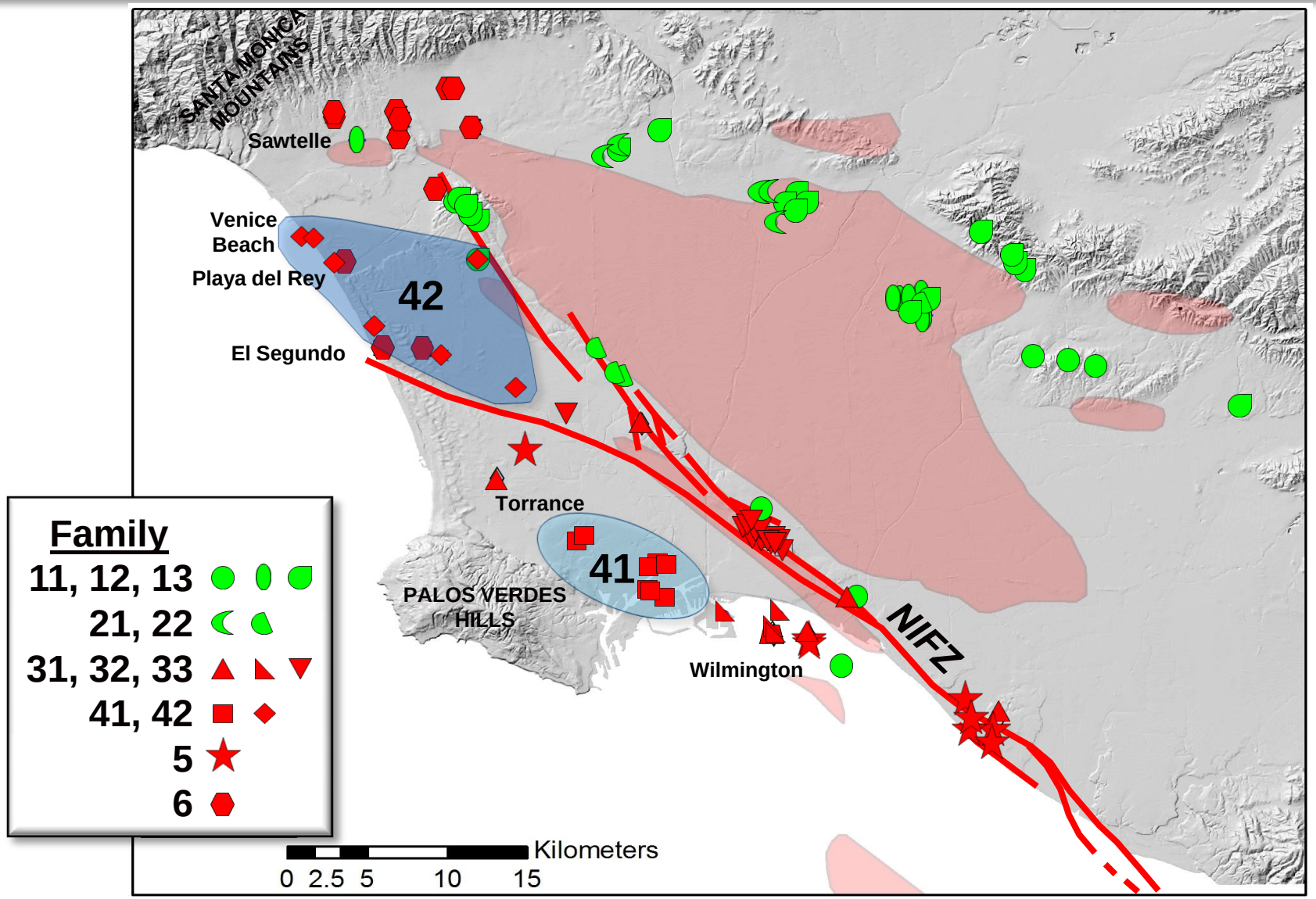
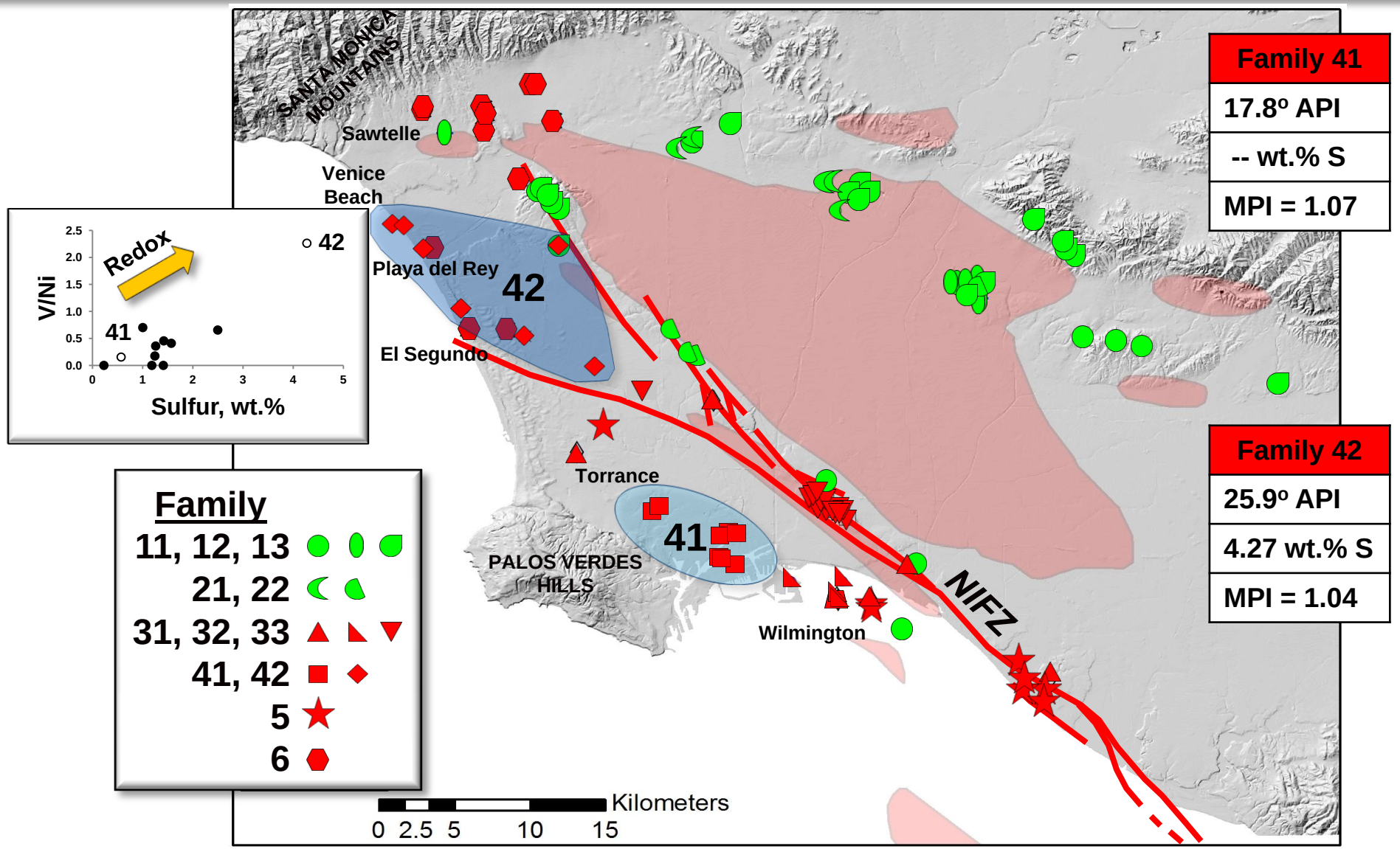
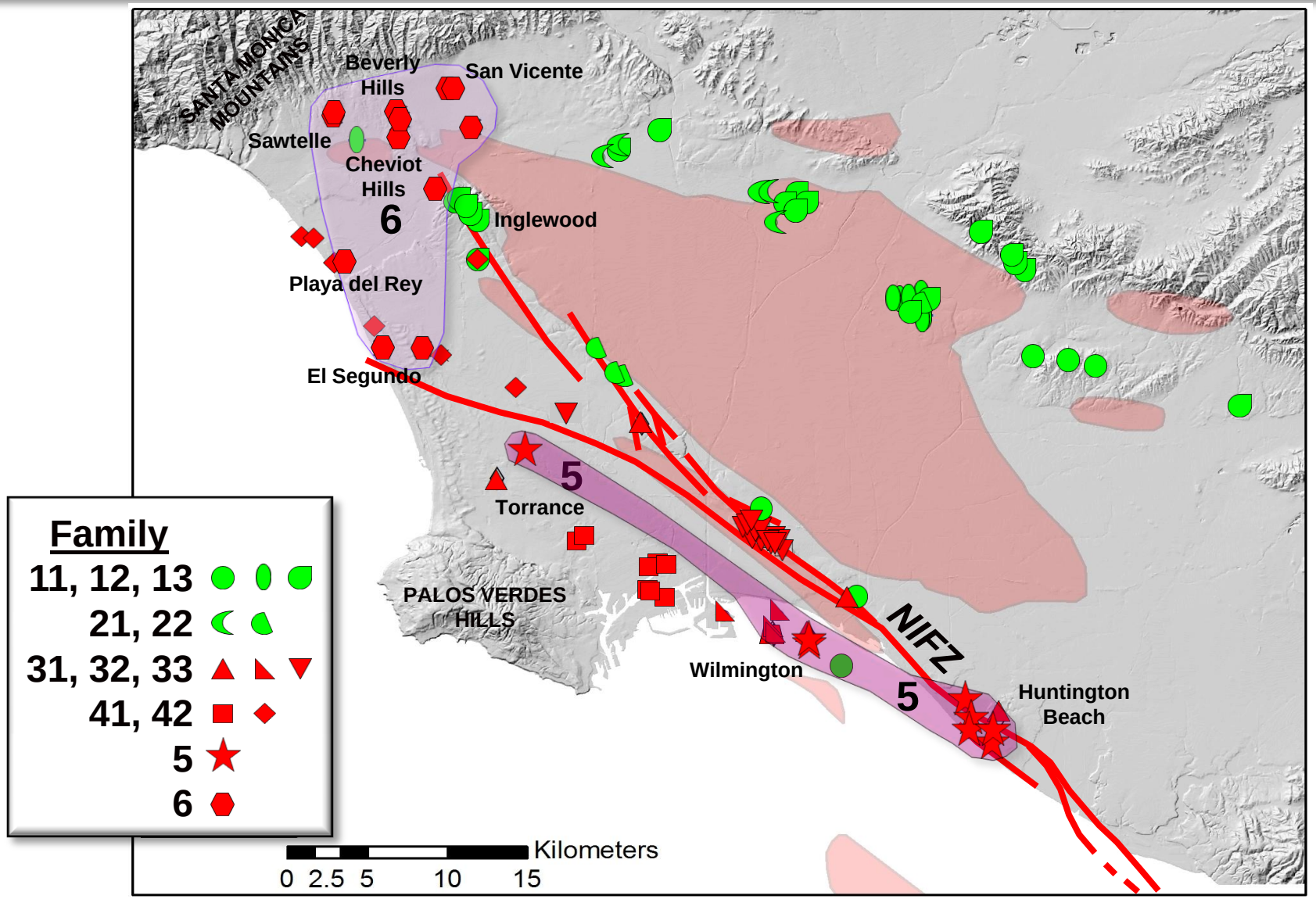
Tribe 4 Families Originated from Source Rock West of NIFZ



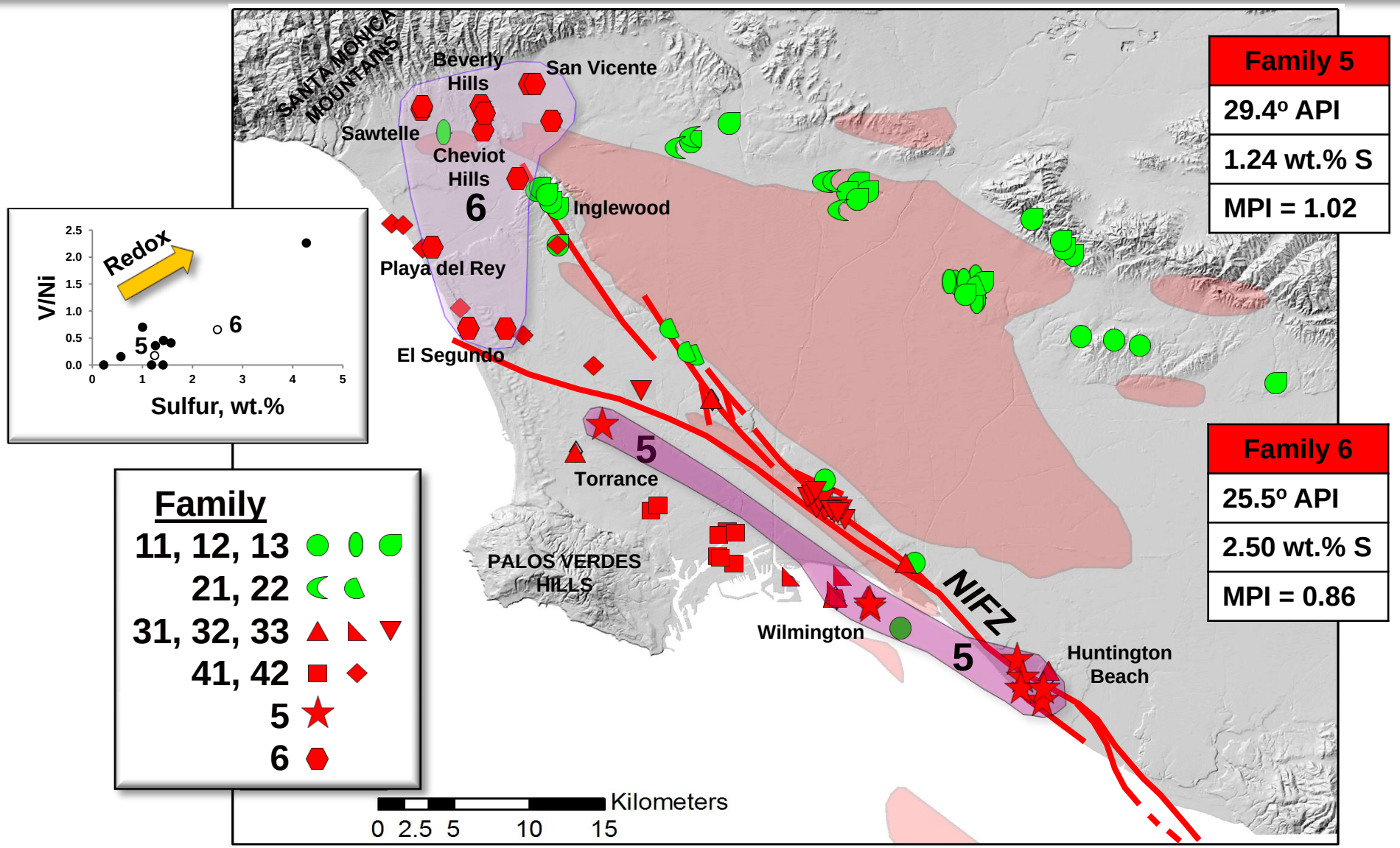
Tribe 4 Families Originated from Source Rock West of NIFZ



Tribes 5 and 6 Originated from Source Rocks West of NIFZ

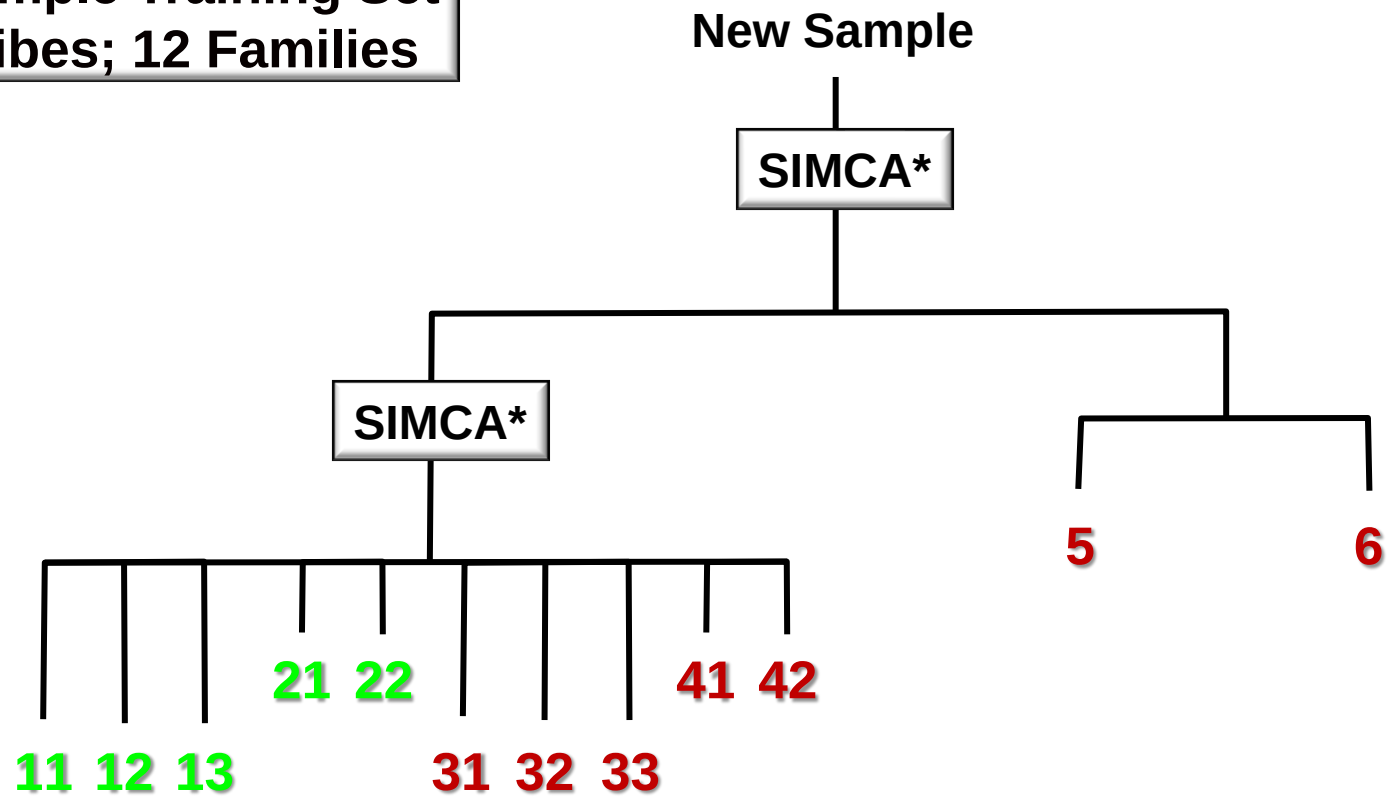


Tribes 5 and 6 Originated from Source Rocks West of NIFZ



Chemometric Decision Tree Classifies New Oil Samples

112-Sample Training Set
Six Tribes; 12 Families



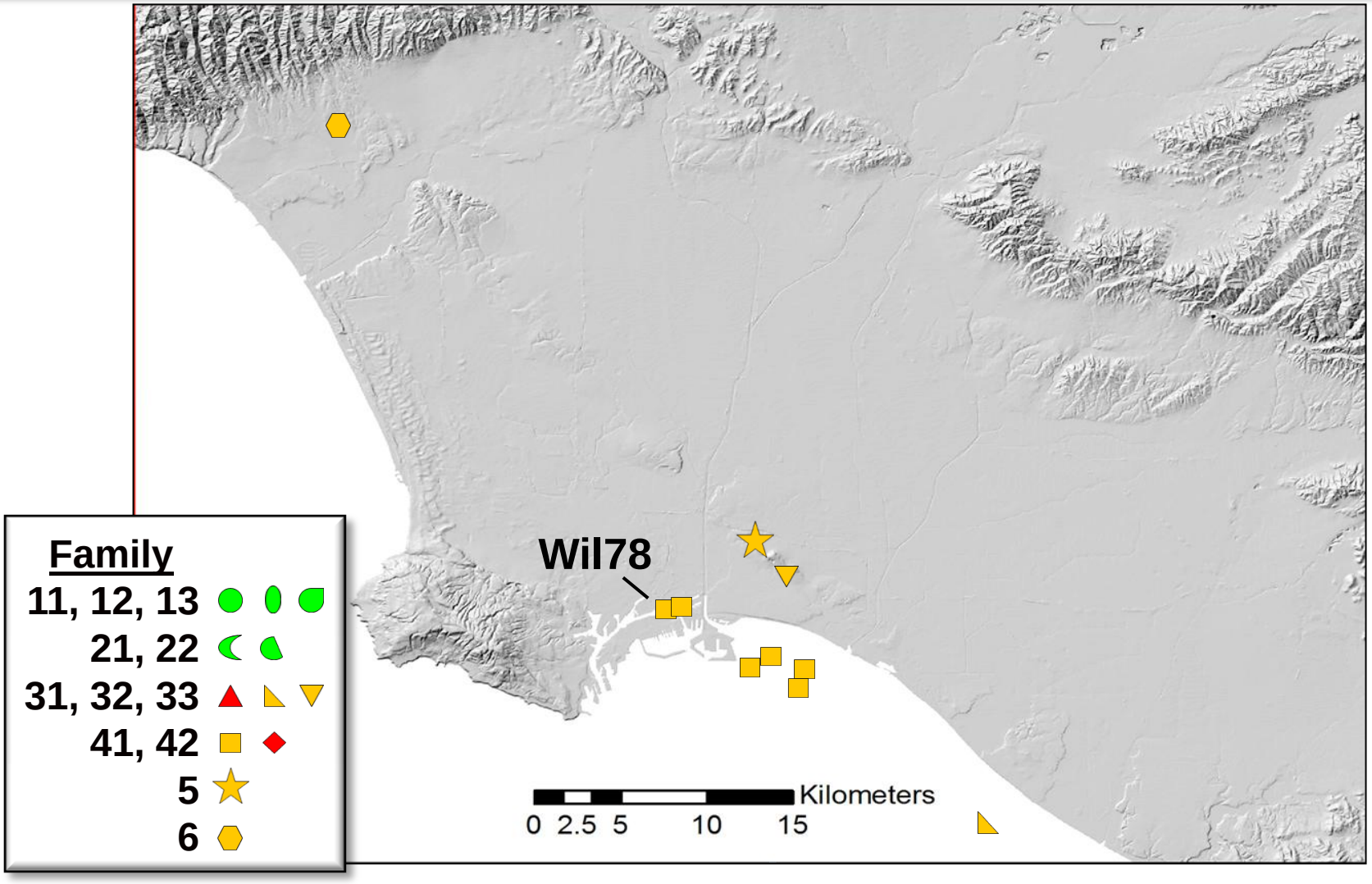
*Soft independent modeling of class analogy

Some Biodegraded or Anomalous Samples Can be Classified

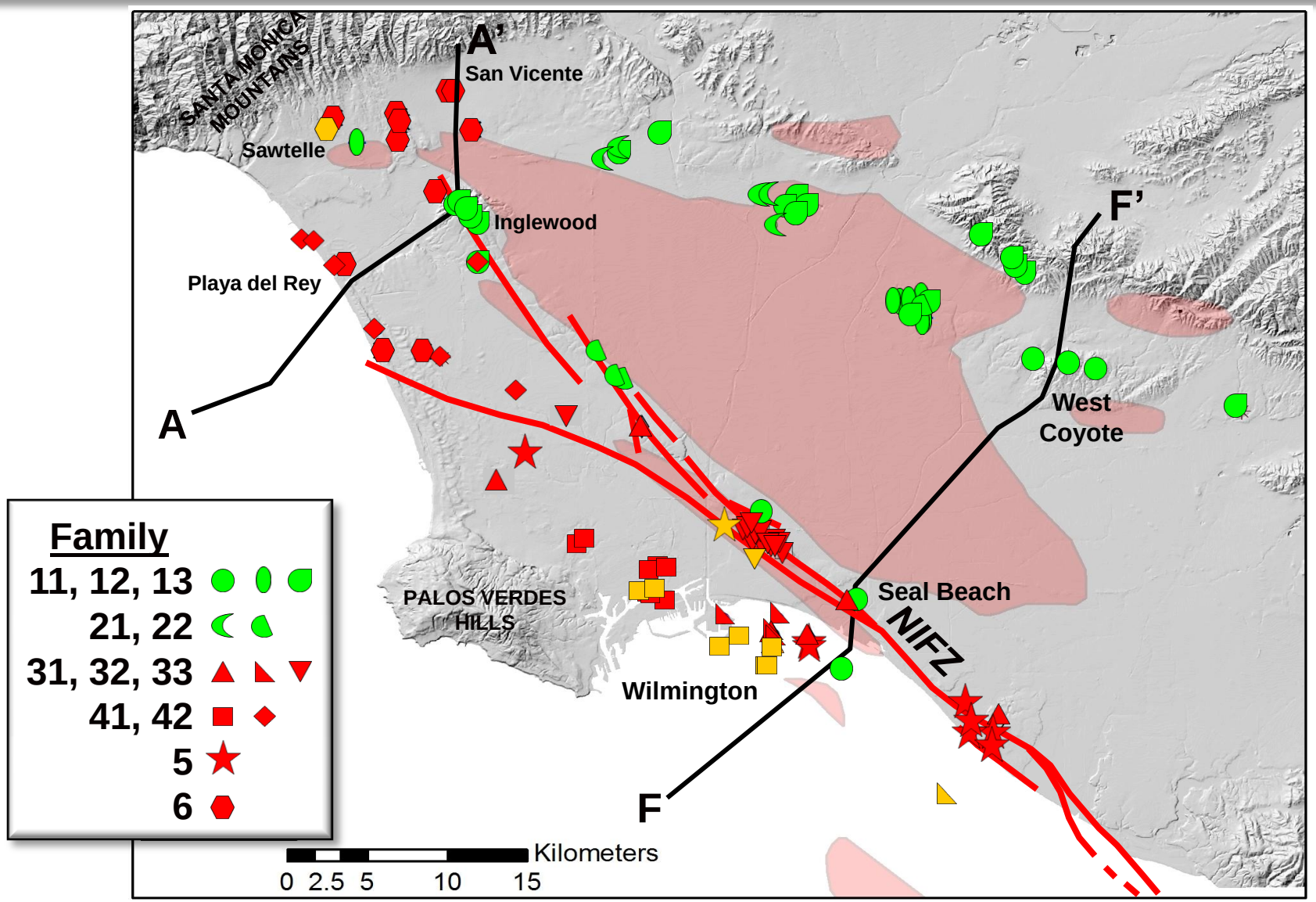
Sample	Longitude	Latitude	Biod. Rank	Family	Confidence*
Saw481	-118.4555	34.05864	6	6	0.814
Wil78	-118.2464	33.78629	5	41	0.987
Wil85	-118.2361	33.78633	5	41	0.935
HB462	-118.044	33.66256	5	32	0.923
Wil531	-118.1796	33.75942	5	41	0.958
Wil532	-118.1625	33.74057	5	41	0.985
Wil533	-118.1624	33.74132	5	41	0.992
Wil536	-118.1942	33.75238	5	41	0.960
Wil592	-118.1577	33.7532	5	41	0.989
LB6	-118.1896	33.82376	4	5	0.971
LB506	-118.1694	33.80556	1	33	0.969

* If the probability cutoff for family membership is set to 0.99, then 99% of samples will be properly predicted.

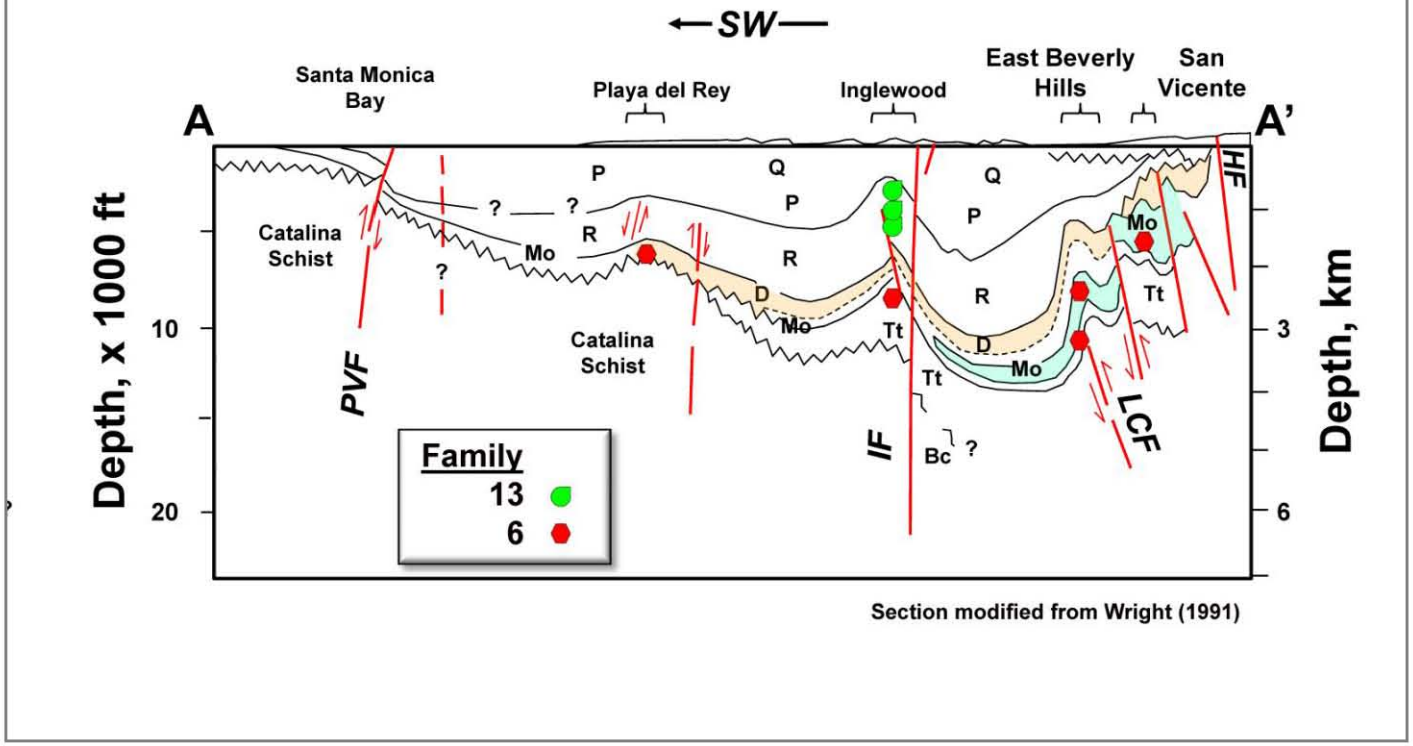
Chemometric Decision Tree Classifies 11 New Oil Samples



Cross Sections Reveal Stratigraphy of Some Oil Families

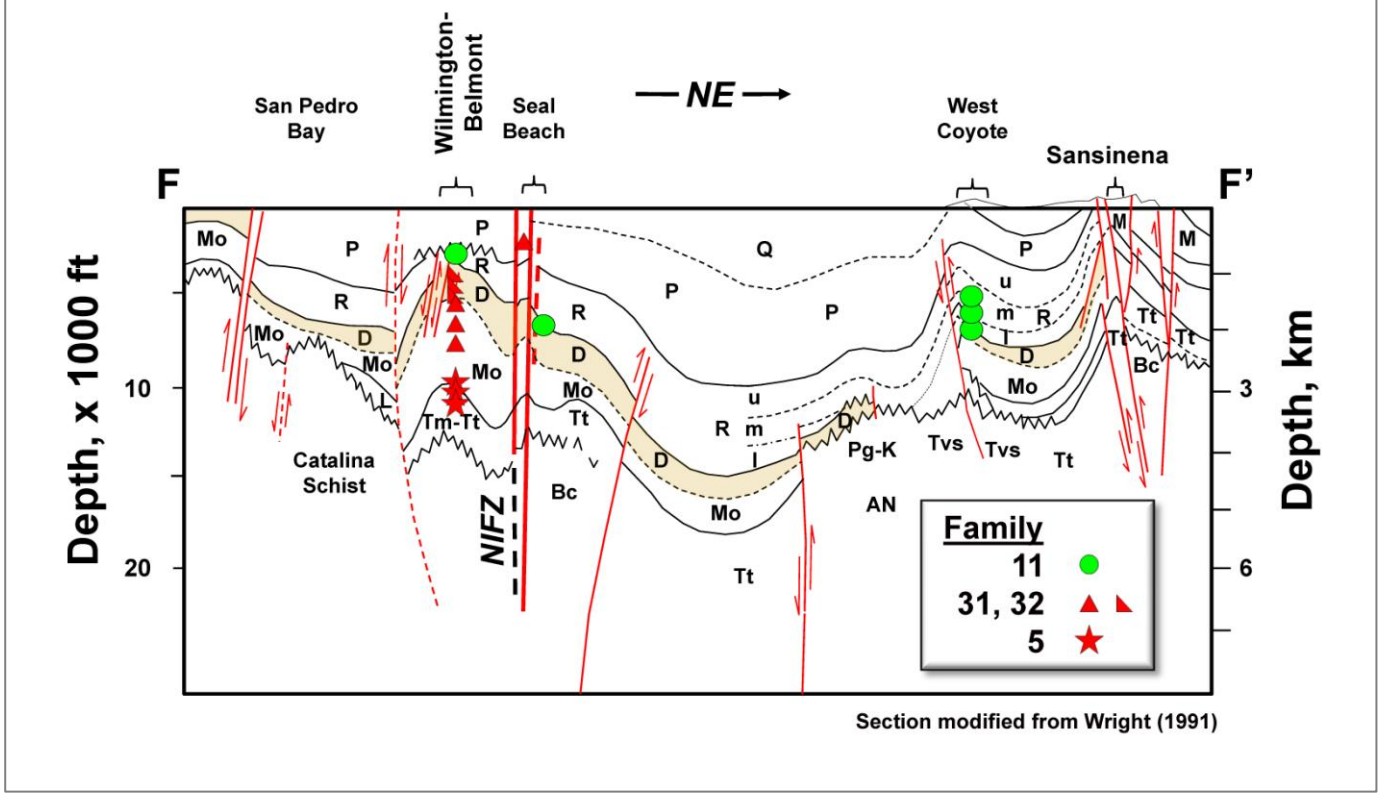


A-A' Section Reveals Stratigraphy of Tribe 6 and Family 13

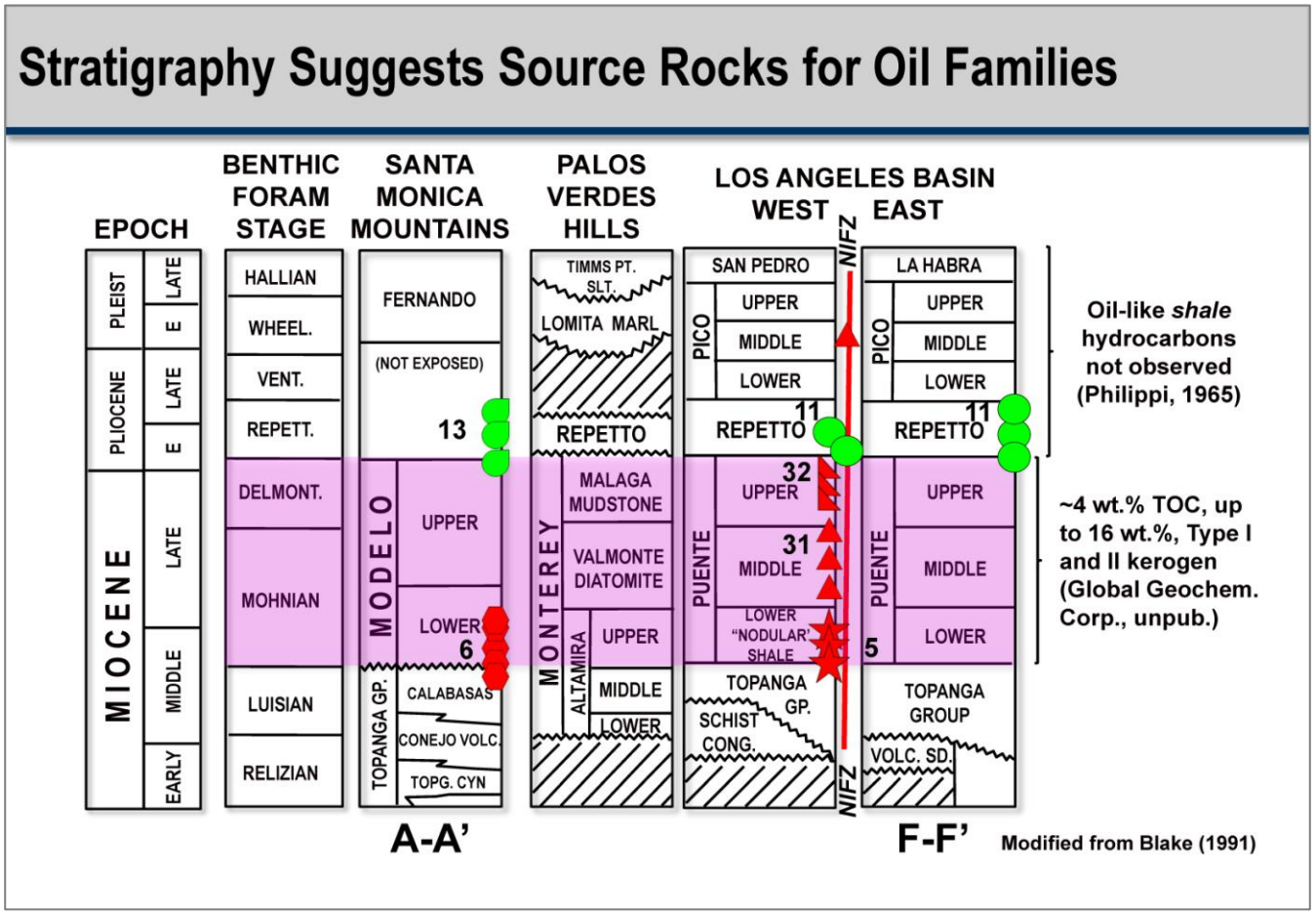


Presenter's notes: P = Pico Formation, R = Repetto Formation, D = Delmontian, Mo = Mohnian, M = undifferentiated Delmontian-Mohnian, Tm = Monterey Formation, L = Luisian, Tt = Topanga Formation, Pg = Paleogene, K = Cretaceous, Bc = undifferentiated metamorphic basement complex; u, m, l = upper, middle, lower; NIFZ = Newport-Inglewood Fault Zone.

F-F' Section Reveals Stratigraphy of Families 5, 11, 31, 32



Presenter's notes: P = Pico Formation, R = Repetto Formation, D = Delmontian, Mo = Mohnian, M = undifferentiated Delmontian-Mohnian, Tm = Monterey Formation, L = Luisian, Tt = Topanga Formation, Pg = Paleogene, K = Cretaceous, Bc = undifferentiated metamorphic basement complex; u, m, l = upper, middle, lower; NIFZ = Newport-Inglewood Fault Zone. Family 11 *west* of NIFZ at Belmont offshore (Bel542S) at 4954 ft.



Presenter's notes: Santa Monica Mountains (NW and NE basin) – Modelo Fm is Mohnian-Delmontian: brown to brownish gray diatomaceous shale with interbedded ss. Phosphatic "nodular shale" contains up to 10 wt.% TOC (Walker et al., 1983); marine, slightly reducing

Monterey Shale (Divisions D and E; i.e., Mohnian-Delmontian) contains 2-18 wt.% TOC with an average of 4 wt.%, marine anoxic conditions – major source (Philippi, 1965). Palos Verdes Hills – Monterey Fm is Topanga-Puente.

Conclusions: Los Angeles Basin Geochemistry

- **At least six Miocene petroleum systems (12 families) occur in different parts of the basin.**
- **The Newport-Inglewood fault separates tribes 1-2 (families 11, 12, 13, 21, 22) to the east from tribes 3-6 (families 31-33, 41-42, 5, 6) to the west.**
- **Biomarkers, isotopes, and stratigraphic occurrence help to identify source rocks for the oil families.**
- ***Source rock samples for oil-source rock correlation and kinetic modeling would be useful.***

Thanks for Your Attention!

Presenter's notes: "Tribute to the Roughnecks" by Cindy Jackson stands atop Signal Hill; Long Beach in distance. Alamitos #1 Signal Hill; photo by Tom Lorenson. Alamitos #1 was completed June 25, 1921, at 3114 ft, flowing 590 bbl of oil/day. EUR is 700,000 bbl. The oilfield still produces 1.5 million bbl each year.

Source Rock Can be Inferred from Stratigraphy-Biomarkers

- **Suboxic Upper Miocene (Delmontian) shale with significant angiosperm input generated Tribes 1-2 at moderate-high maturity in the Central Trough east of NIFZ.**
- **Anoxic Upper Miocene (M.-U. Puente) marl source rock generated Tribe 3 west of NIFZ.**
- **Anoxic Mohnian(?) marl generated Tribe 4 west of NIFZ.**
- **Anoxic M.-U. Miocene (L. Puente “nodular shale”) marl with significant terrigenous plant input generated Tribe 5 southwest of NIFZ.**
- **Anoxic M.-U. Miocene (L. Modelo “nodular shale”) marl with significant terrigenous plant input generated Tribe 6 at low maturity northwest of NIFZ.**

References

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- McCulloh, T.H. et al., 1994, How oil composition relates to kerogen facies in the world's most petroliferous basin: AAPG Search and Discovery Article #90986, AAPG Annual Convention, Denver, CO, June 12-15, 1994.
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Source Rock Character Can be Inferred from Oil Biomarkers

	Family	No.	Shale		Carbonate	Reducing Conditions		Marine	Terrigenous	Angiosperms
			Ts/Tm	C_{24}/C_{23} TT	C_{29}/C_{30}	C_{35}/C_{34}S	BNH/H	C_{26}/Ts	C_{29}/C_{27} St	OI/H
East of NIFZ	11	6	0.50 0.03	0.77 0.03	0.49 0.00	0.81 0.08	0.17 0.01	4.24 0.01	0.75 0.03	0.14 0.01
	12	8	0.55 0.04	0.86 0.03	0.46 0.02	0.71 0.03	0.18 0.01	4.04 0.17	0.77 0.33	0.22 0.01
	13	19	0.63 0.09	0.94 0.08	0.45 0.02	0.76 0.09	0.21 0.04	3.57 0.43	0.80 0.03	0.26 0.07
	21	5	0.83 0.22	0.88 0.05	0.42 0.03	0.64 0.09	0.21 0.08	3.35 0.36	0.83 0.04	0.52 0.12
	22	6	0.59 0.04	0.90 0.03	0.43 0.01	0.61 0.03	0.15 0.02	3.75 0.11	0.78 0.03	0.30 0.01
West of NIFZ	31	8	0.42 0.04	0.74 0.04	0.53 0.03	0.87 0.06	0.32 0.08	3.66 0.38	0.76 0.02	0.13 0.02
	32	5	0.42 0.02	0.72 0.04	0.56 0.01	0.88 0.02	0.34 0.02	3.44 0.18	0.83 0.01	0.14 0.01
	33	15	0.33 0.01	0.70 0.05	0.57 0.02	0.89 0.07	0.28 0.01	4.00 0.19	0.79 0.02	0.12 0.02
	41	8	0.41 0.07	0.85 0.06	0.57 0.07	0.95 0.05	0.32 0.05	3.53 0.19	0.75 0.03	0.14 0.02
	42	8	0.43 0.02	0.98 0.09	0.50 0.03	0.99 0.13	0.32 0.20	3.34 0.37	0.72 0.04	0.14 0.02
	5	10	0.42 0.14	0.74 0.06	0.54 0.04	0.83 0.10	0.55 0.32	2.90 0.18	0.91 0.06	0.17 0.02
	6	14	0.44 0.05	0.78 0.03	0.54 0.02	0.88 0.13	0.32 0.10	2.10 0.25	0.90 0.06	0.14 0.02

Several Petroleum Systems Exist in the Los Angeles Basin

- Four essential elements and two processes and all related petroleum that originated from *one* pod of active source rock

Source rock
Reservoir rock
Seal rock
Overburden rock

Essential Elements

Trap Formation
Generation-Migration-Accumulation

Processes