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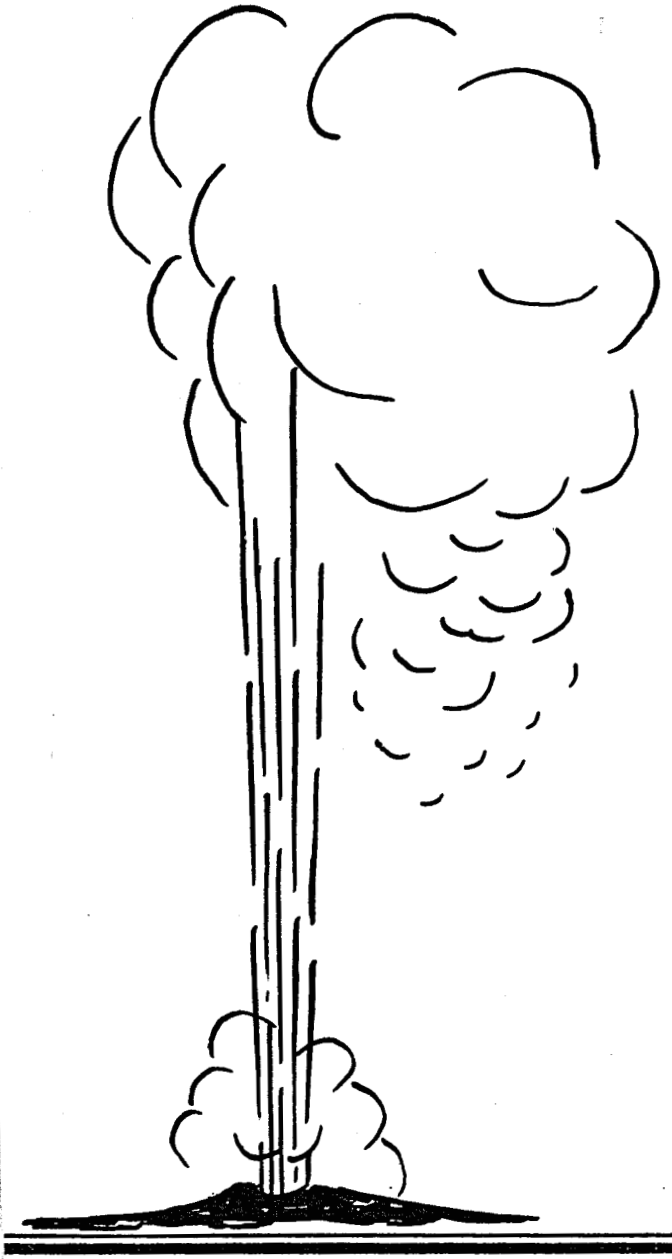

IDENTIFICATION OF GEOPRESSURED OCCURRENCES OUTSIDE OF THE GULF COAST

Final Report. Phase II

By
Oscar Strongin

March 5, 1981

Work Performed Under Contract No. AC08-80NV10133

Science Applications, Inc.
McLean, Virginia

U. S. DEPARTMENT OF ENERGY
Geothermal Energy

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FINAL REPORT
PHASE II

IDENTIFICATION OF GEOPRESSURED OCCURRENCES OUTSIDE OF THE GULF COAST

Prepared by:

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Prepared for:

The U. S. Department of Energy
Nevada Operations Office
Las Vegas, Nevada 89114

Under Contract

No. DE-AC08-80NV10133

March 5, 1981

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ABSTRACT

The work on Phase II of this project focused on the occurrences of geopressures in Appalachia and selected California basins. In the former region, where geopressures have been observed, the pressure gradients for the most part were only slightly above normal as in the case of the Oriskany formation of Devonian age; this unit was also characterized by extremely high salinity. The one notable exception was in the Rome trough of West Virginia where Cambrian beds at depths below 10,000 feet display very high geopressures, approaching the lithostatic gradient, and the waters are only moderately saline. Though the geothermal gradient throughout Appalachian is relatively low, even in the Rome trough, the pressure, temperature and salinity values in this area indicate that the methane content of the Cambrian formation waters is in the range of 30-35 SCF/barrel.

The two California areas researched included the contiguous Sacramento and San Joaquin Valleys. In the first, geopressures have been principally encountered in the Forbes formation of Cretaceous age, often at very shallow depths. Further the formation waters are invariably characterized by very low salinity, far below the salinity of normal sea water, while the geothermal gradient is apparently higher in geopressured than in normally pressured zones. In the San Joaquin Valley, geopressures are particularly noteworthy in at least two formations of Miocene age at depths generally greater than those of the Forbes. The formation waters are likewise low in salinity; however, the geothermal gradient, especially in the geopressured zones on the west side of the valley, can be extremely high, up to twice as much as the normal temperature gradient. In view of these conditions, it is estimated that in the western San Joaquin Valley the methane content of geopressured formation waters will range from 30 to 40 SCF/barrel while in the Sacremento Valley, the methane content is estimated to be 20-25 SCF/barrel.

1. INTRODUCTION

The work in Phase I amply demonstrated that the occurrence of geopressures is not an isolated phenomenon confined strictly to the Gulf Coast, but rather can be found in numerous onshore and offshore sedimentary basins throughout the United States. This bodes well for the extension of current development efforts in the Gulf Coast to other areas since the occurrence of methane in formation waters is, in part, a function of pressure. It has long been recognized, according to Weeks (1958), "One fact which requires little contemplation to appreciate is the truly immense quantity of hydrocarbons that abound in the sedimentary basins in the form of gas dissolved in water outside the accumulation in gas pools, gas caps over oil pools, and dissolved in the oil of oil pools themselves (and) there seems to be no reason to assume that formation waters of basins generally over the world carry less gas per barrel than the average of the many areas and sands investigated by the authors." From a practical standpoint, the quantity of methane dissolved in formation waters is directly related to pressure and temperature and inversely related to the salinity of such waters. Thus, there may be situations in overpressured oil and gas zones where there is little or no formation water, but where present, they will assuredly contain varying quantities of dissolved methane.

In view of the results attained in the Phase I work, it was decided that the Phase II project should focus on two areas, namely California and Appalachia. The former was chosen since conditions in several basins were favorable (at least from a preliminary basis) for the occurrence of dissolved methane based on high pressures, relatively high temperatures, and significantly low salinities. The latter region was selected for study for geographic balance, proximity to markets and the potential for important quantities of dissolved methane in formation waters of deep Cambrian sediments.

As there is a paucity of readily available written material on geopressures in either of these two regions, the major effort during this phase was focused on obtaining additional published papers together with documents, reports, and well descriptions from state geological agencies, private companies, and individuals. The following individuals and organizations were particularly cooperative:

California Division of Oil and Gas

John Sullivan, Woodland Office
Vic Van Matre, Coalinga Office
A.L. Lorshbaugh, Bakersfield Office

Tenneco Exploration, Bakersfield

Wes Franklin
Dan Mandel

Texaco, U.S.A., Los Angeles

Norris Saunders

Seaward Resources, Inc., Denver

Charles Lee

U.S. Geological Survey, Menlo Park

Y. Kharaka

Columbia Gas Transmission Corporation, Charleston, WV

Porter Brown

Peoples Gas Company, Pittsburgh

D. Tatlock

Ashtola Production Company, Pittsburgh

Dana Kelley

Consolidated Gas Supply Corporation, Clarksburg, WV

Richard Cross

2. APPALACHIA

2.1 GENERAL

The Appalachian basin has classically been considered to be composed of those Paleozoic sediments lying between the Blue Ridge Mountains on the east and the crests of the Cincinnati-Findley arches and Nashville dome on the west extending from the Canadian border southward to Alabama where it is overlapped by Cretaceous rocks. However, seismic work conducted a few years ago indicates that the Appalachian province should be extended 60-100 miles eastward, an area termed the Eastern Overthrust Belt, in which the older Blue Ridge crystalline rocks are overlying younger Paleozoic formations. Current drilling activities in the eastern panhandle of West Virginia and elsewhere tend to confirm the existence of the overthrust area.

The stratigraphic sequence of sediments in terms of the major oil/gas producing zones which will be cited in this discussion are listed in Table 1.

2.2 CHARACTERISTICS OF GEOPRESSURING

For the most part, the sediments of the Appalachian basin aside from several noteworthy exceptions, tend to be either normally pressured or abnormally underpressured. As shown in Table 2, overpressuring was only noted in the Oriskany and Huntersville (primarily of lower Devonian age) and the Onondaga (of middle Devonian age). One reason advanced for the abnormally low pressures is that lenticular reservoirs closely associated with shales have undergone erosion which caused a reduction in the fluid pressure in the pore space of shales that was transmitted to the closely associated reservoir beds (Russell, 1972).

The occurrence of abnormally high pressures indicates the presence of permeability barriers between the outcrop of the reservoir and the

TABLE 1
PRINCIPAL OIL– AND GAS–PRODUCING PAY ZONES IN THE APPALACHIAN BASIN (1)

System	Series	Southern New York	Pennsylvania	Southeastern Ohio	West Virginia	Virginia	Central and eastern Kentucky	Tennessee
PERMIAN	Upper	(No production)	Murphy sd Little Dunkard sd Big Dunkard sd	Carroll sd Goose Run sd Mitchell sd Wolf Creek sd Pecker sd First Cow Run sd Buell Run sd Macksburg 500-foot sd	Carroll sd Sewickley coal Pittsburgh coal Minshall sd Murphy sd Moundsville sd First Cow Run sd Big Dunkard sd			
PENNSYLVANIAN	Middle		Freeport sd Kittanning sd Clarion sd "First Salt" sd "Second Salt" sd	Second Cow Run sd Macksburg 500-foot sd Macksburg 700-foot sd Germantown sd Scheem sd "First Salt" sd "Second Salt" sd Brill sd	Burning Springs sd "Pecker" sd- Second Cow Run sd Horsneck sd "First Salt" sd "Second Salt" sd	Salt sd	Beaver sd Horton sd Pike sd "First Salt" sd "Second Salt" sd "Third Salt" sd	
	Lower		"Maxton" sd	"Maxton" sd	"Maxton" sd			
MISSISSIPPIAN	Upper		"Big Lime" (Greenbrier Ls)	"Big Lime" Lime sd	Princeton sd Ravencliff sd Maxton sd "Big Lime"	Ravencliff sd Maxton sd Greenbrier Ls ("Big Lime") Little Valley Ls (sds)	Maxton or "Maxon" sd Clirkin ("Gasper") Fm Ste. Genevieve Ls St. Louis Ls Warsaw Ls	Unnamed sds Glen Dean Ls "Gasper" Fm St. Louis Ls Warsaw Ls
	Lower		Lime sd Big Injun sd Squaw sd Second sd Berea Ss Murrysville- Thirty Foot sd	Keener sd Big Injun sd Squaw sd Hamden sd Weir sd Berea Ss "Second Berea" ss Cussewago Ss	Keener sd Big Injun sd Squaw sd Weir sd Berea Ss Murrysville sd	Berea Ss	Keener sd- Fort Payne Chert Red Injun sd Big Injun sd Weir sd Sunbury Sh Berea Ss Beaver sd-Beaver Creek sd Borden sd	Fort Payne Chert Borden sd
DEVONIAN	Upper	Bradford First sd Sugar Run sd Chipmunk sd Bradford Second sd Harrisburg Run sd Richburg sd	Gantz sd Hundred foot- First Venango sd Nineveh sds Red Valley sd Thirty foot- Second Venango sd Snee sd Knox Third sd Knox Fourth sd Gordon Stray sd Gordon-Third Venango sd McDonald Fourth sd McDonald Fifth sd Bayard sd Elizabeth sd Warren First sd Warren Second sd Bradford First-Glade- Ocean-Eighty ft sds Clarendon sd Speechley sd Tiona sds Bradford Second sd Cooper sd Bradford Third sd Kane sds Haskill sds Onondaga Ls	Ohio Sh	Gantz sd (now gas storage) Fifty foot sd Thirty foot sd Gordon Stray sd Gordon sd McDonald Fourth sd McDonald Fifth sd Sixth-Bayard sd Seventh-Elizabeth sd Warren First sd Burnside sd Warren Second sd Clarendon sd Speechley (Tiona) sd Balltown-Cheery Grove sd Riley sd Benson sd Elk-Porter sd "Kane" sd "Childress zone" sd		Brown sh (Black sh)	Chattanooga Sh

(1) Miller, 1975

TABLE 1
PRINCIPAL OIL– AND GAS–PRODUCING PAY ZONES IN THE APPALACHIAN BASIN – CONTINUED

System	Series	Southern New York	Pennsylvania	Southeastern Ohio	West Virginia	Virginia	Central and eastern Kentucky	Tennessee
DEVONIAN	Middle	Hamilton Fm Onondaga Ls	Onondaga Ls		"Brown" sh Hamilton Fm			
	Lower	Oriskany Ss	Huntersville Chert Oriskany Ss	Oriskany Ss	Huntersville Chert Oriskany Ss Healing Springs Ss Mbr of New Scotland Ls	Oriskany Ss	"Onondaga" Ls (Irvine sd)	
SILURIAN	Upper	Salina Gp	Salina Fm	Salina Gp Newburg Dol	Unnamed dol Williamsport sd Newberg sd		Salina Fm Peebles sd	
	Middle	Lockport Dol	"Lockport" Dol	"Lockport" Dol "Packer Shell-Little Lime"	"Lockport" Dol Big Six sd (Keefer Ss)		"Lockport" Dol Big Six sd	"Lockport" Dol
	Lower	"Gray Medina" sd "Red Medina" sd "White Medina" sd	"Red Medina" sd "White Medina" sd	Stray Clinton sd Red Clinton sd (Albion Sd) White Clinton sd Medina sd	Clinton sd (Tuscarora Ss)		Clinton sd Brassfield Ls	
ORDOVICIAN	Upper				Juniata Fm		Liepers Ls	
	Middle	Ls of Trenton Gp		Trenton Dol Black River Ls Glenwood Fm St. Peter Ss	Trenton Dol Black River Ls	Trenton Ls "Black River" (Witten) Ls Moccasin Ls	Sunnybrook sd-Granville sd "Black River" Ls "St. Peter" Ss	
	Lower	Beekmantown Dol	Beekmantown Dol	Beekmantown Dol			"Beekmantown" Dol (Knox Dol)	Knox Gp
CAMBRIAN	Upper	Potadam Ss	Gatesburg Fm	Copper Ridge Dol (Trempealeau Dol) Mount Simon Ss				
	Middle	(No production)						
	Lower				Rome Fm		Rome Fm "Basal" sd	

TABLE 2

Pressure-Depth Ratios of Selected Lenticular Appalachian Reservoirs[1]

Overpressured Occurrences	Pressure Gradient (psi/ft) Mean	Std Error of Mean	Number of Determinations
Oriskany sandstone, lower Devonian, slightly deformed, NY	0.491	0.023	17
Oriskany sandstone and Onondaga chert, lower and middle Devonian, slightly deformed, PA	0.491	0.069	11
Oriskany sandstone and Onondaga chert, lower and middle Devonian, strongly deformed, PA	0.550	0.069	79
Oriskany sandstone and Huntersville chert, lower and middle Devonian, WV	0.418	.020	28
Underpressured Occurrences			
Greenbrier limestone, middle Mississippian, WV	0.305	0.023	14
Big Injun sandstone and limestone, lower and middle Mississippian, WV	0.242	0.016	12
All Mississippian sandstones, excluding Big Injun, WV	0.222	0.019	13
Upper Devonian sandstones, exclusive of "Brown shale", WV	0.358	0.021	16
"Brown shale", Devonian, WV	0.152	0.016	19
Newburg sandstone, upper Silurian, WV	0.412	0.019	6
Lower Silurian sandstones, NY	0.299	0.019	15
Lower Silurian sandstones, Ohio	0.293	0.013	22
Lower Silurian sandstones, PA	0.298	0.014	16
Lower Silurian sandstones, WV	0.534	0.021	6

(1) Russell, 1972

location of the high fluid pressures. This phenomenon is buttressed by the fact that the Oriskany formation, in both West Virginia and Pennsylvania, is characterized by very high salinities and only rare instances of low salinities as shown in Tables 3 and 4. (It should be noted that Tables 3 and 4 have been prepared without reference to overpressuring, but as described elsewhere in this report, known overpressured Oriskany zones, with only one exception, are likewise marked by extremely high salinities.) Evidently, these barriers have severely limited the invasion of fresh meteoric waters. In fact, since many of the salinity values are considerably higher than sea water (35,000 ppm), it strongly suggests that these Devonian beds have received significant quantities of saline water from the underlying Silurian salt beds.

It should also be noted, as set forth in Table 3, that the geothermal gradient is relatively low in the Oriskany formation in the Appalachian basin. Aside from an occasional extremely high and/or very low gradient the bulk of the readings are in the range of 1.5 to 1.7°F/100'. Similar values obtained for deep wells into the Cambrian (described further in this part of the report) confirm the general low temperature regime of the region.

As indicated in Table 2, there is an apparent correlation between the deformation the rocks have undergone and the pressure gradient. For example, in the Oriskany-Onondaga sequence in the strongly folded areas of north and north-central Pennsylvania, the pressure gradient is 0.050 higher than in nearby relatively deformed regions to the west. Of the many determinations in the former, 20 were above 0.6, 6 above 0.7 and 1 above 0.8 while in the slightly deformed area, only 3 were above 0.6 and none were higher than 0.7 (Russell, 1972).

2.3 SPECIFIC OCCURRENCES

The following section comprises a description of various specific occurrences and their salient characteristics in various formations of

TABLE 3

ANALYSES OF ORISKANY FORMATION WATERS IN WEST VIRGINIA

Series A[1]

County	District	Depth Data: Top of Sand (ft)	Depth Data: Depth to Brine (ft)	Temperature (°F)	Temp. Gradient (°F/100')	Total Dissolved Solids (ppm)
Braxton	Otter	6277	6281	79	1.26	250,000
Hancock	Clay	4768	4771	69	1.65	1,530
Jackson	Ravenswood	5068	5071	79	1.56	269,000
"	"	4995	4996	79	1.58	264,500
"	"	5355	5393	81	1.50	271,800
"	"	5151	5179	85	1.64	251,000
"	"	5200	5238	85	1.62	246,400
"	"	5302	5340	88	1.65	242,500
"	Ripley	5222	5222	75	1.44	274,000
"	"	5088	5120	79	1.51	268,490
"	"	4958	4960	77	1.55	137,848
"	Washington	5440	5444	83	1.52	274,400
"	"	5494	5502-12	88	1.60	273,464
"	"	5003	5025	81	1.62	178,000
"	"	5060	5082	86	1.69	271,000
"	"	5267	5281	77	1.46	274,425
"	"	5186	5215	79	1.51	272,000
"	"	5037	5061	86	1.70	238,000
"	"	5103	5103	81	1.59	265,000
Kanawha	Elk	4998	4998	83	1.66	271,340
"	"	5198	5205	83	1.59	272,000
"	Poca	5014	5120	77	1.50	260,000
"	Union	5101	5120	81	1.58	264,166
"	"	5136	5149	81	1.57	268,306
"	"	4847	4850	81	1.67	261,150

TABLE 3

ANALYSES OF ORISKANY FORMATION WATERS IN WEST VIRGINIA (Cont'd)

Series A[1]

County	District	Depth Data: Top of Sand (ft)	Depth Data: Depth to Brine (ft)	Temperature (°F)	Temp. Gradient (°F/100')	Total Dissolved Solids (ppm)
Putnam	Union	5019	5074	86	1.69	266,700
Randolph	Valley Bend	1597	1640-53	83	5.04	112,000
Roane	Geary	5972	5977	73	1.22	226,000
"	Harper	5057	5065	84	1.66	278,000
"	Geary	5972	5977	73	1.47	226,000
Wayne	Butler	3036	3043	81	2.66	123,410
Wirt	Burning Springs	4851	4882	73	1.49	284,000
"	Spring Creek	5654	5656	79	1.40	263,800
Garrett (Maryland)	Accident Twp	8085	8097	81	1.00	256,900

Series B[2]

Kanawha	Big Sandy	5763	5777	77	1.33	267,000
"	Elk	NA	NA	72	—	6,700
"	"	5020	5032-35	76	1.51	29,200
"	Malden	5067	5089-89	76	1.49	240,300
"	"	5249	5249	74	1.41	235,100
Roane	Geary	5972	5978	71	1.19	223,900
Wirt	Spring Creek	4899	4901-3	75	1.53	280,000
"	"	4899	4901-3	72	1.47	270,000

(1) Hoskins, H.A., 1947
(2) Price, P.H., et al, 1937

TABLE 4

Selected Analyses of Waters from Deep Oriskany Wells in Pennsylvania*

County	Quadrangle	Total Depth (ft)	Sample Depth (ft)	Total Dissolved Solids (ppm)
Armstrong	Elders Ridge	7751	7707-7723	303,654
Bedford	Clearville	4810	4599-4790	159,797
"	"	4810	4714	297,592
"	"	5095	4970	139,277
Cambria	Johnstown	8950	8847-8950	312,823
Cameron	Benzette	6641	6607-6640	325,009
Clearfield	DuBois	7297	7260-7297	338,440
"	"	7242	7211-7241	325,054
"	"	7270	7263	250,203
"	Houtzdale	8151	8006-80026	253,770
"	"	8151	8053	330,389
"	Penfield	7292	7267-7291	248,511
"	"	7600	7534	274,763
"	"	7191	7183-7191	324,112
"	"	7272	7238-7271	77,578
"	"	7320	7258-7289	123,237
"	"	7368	?	103,810
"	"	6829	?	240,329
"	"	7437	7404-7435	274,977
"	"	7344	7314-7343	87,590
"	"	7270	7240-7269	190,401
"	"	7249	7234-7249	325,408
"	"	7227	7198-7226	122,915
"	"	7447	7411-7439	274,542
"	"	7183	7175-7183	330,058

*Kelley,D.R., et al, 1973.

Note: Brackets indicate analyses from the same well.

TABLE 4 (Cont'd)

County	Quadrangle	Total Depth (ft)	Sample Depth (ft)	Total Dissolved Solids (ppm)
Clinton	Renovo West	6040	6040	375,000
Elk	Benzette	6860	6853-6854	268,721
"	Penfield	7211	7180-7210	232,255
"	Ridgeway	7384	7352-7383	191,311
Erie	Erie	2005	1997-2005	272,518
Indiana	Punxatawney	7650	7567	279,698
"	Smicksburg	7710	7621-7642	297,265
Jefferson	DuBois	7298	7260-7287	338,440
"	"	7458	7488	328,338
"	"	7458	7255	336,042
"	"	7289	7257-7286	316,299
Mercer	Shenango	3225	3205-3220	332,297
"	Stoneboro	5690	4000-4045	330,382
Somerset	Somerset	8450	8417	127,477
"	"	8625	8509-8550	154,357
"	"	8642	8615-8642	173,401
"	"	8650	8580-8650	250,199
"	"	8650	8460-8560	281,474
"	"	8625	8533-8625	220,885
"	"	8133	8053-8133	63,570
"	"	8133	8053-8133	124,060
"	Donegal	8205	8102-8205	94,306
"	"	8205	8103-8205	122,695
Tioga	Elkland	4376	4347-4367	595
"	Tioga	4322	4315	276,234
"	"	4322	4315	278,048
Warren	Tidioute	5818	4334-4349	317,560
Washington	Burgettstown	7248	6260-6315	264,835
Westmoreland	Donegal	7435	7337-7435	272,298
"	"	7478	7407	302,000
"	"	7384	7335	315,328
"	"	7854	7819-7848	308,131

TABLE 4 (Cont'd)

County	Quadrangle	Total Depth (ft)	Sample Depth (ft)	Total Dissolved Solids (ppm)
Westmoreland	Donegal	8330	8330	317,284
"	"	8330	8330	321,308
"	Latrobe	7701	7659-7701	181,610
"	New Florence	7586	7541-7586	277,677

Paleozoic age in the Appalachian basin. The location, on a county basis is shown in the accompanying state maps.

2.3.1 Pennsylvania (Figure 1)

One of the noteworthy gas fields in Appalachia that is characterized by very high pressures is the Leidy field in Clinton County, Pennsylvania. Discovered in the early 1950's, this field and the nearby South Leidy field, both of which produced from the Oriskany formation, have been depleted and are currently used for gas storage by Consolidated Gas Supply Corporation. The pressure gradient in virtually all of the wells listed below, for which data was available, exceeds the normal pressure gradient in the area.

Pressure Gradient of Selected Wells in the Oriskany Formation in the Leidy Field*

Township	Quadrangle	Depth to Oriskany Fmt. (ft)	Initial Reservoir Pressure (psi)	Pressure Gradient (psi/ft)
Leidy	Hammersly Fork	5659	4200	.742
		6172	3950	.640
		5823	3180	.546
		5804	4100	.706
		5658-78	4075	.718-.720
		5695	3900	.685
		5600	3180	.563
		5925	3950	.667
		5676	3975	.700
		5587	3100	.555
		5899	3450	.585
		5842	3600	.616
		5810	3950	.680
		5607	2660	.474
		6422	1000(?)	.156
		6028	2100(?)	.348
	Tamarack	6086(?)	4100	.674
		6335	3650	.576

*Enright and Ingham, 1951

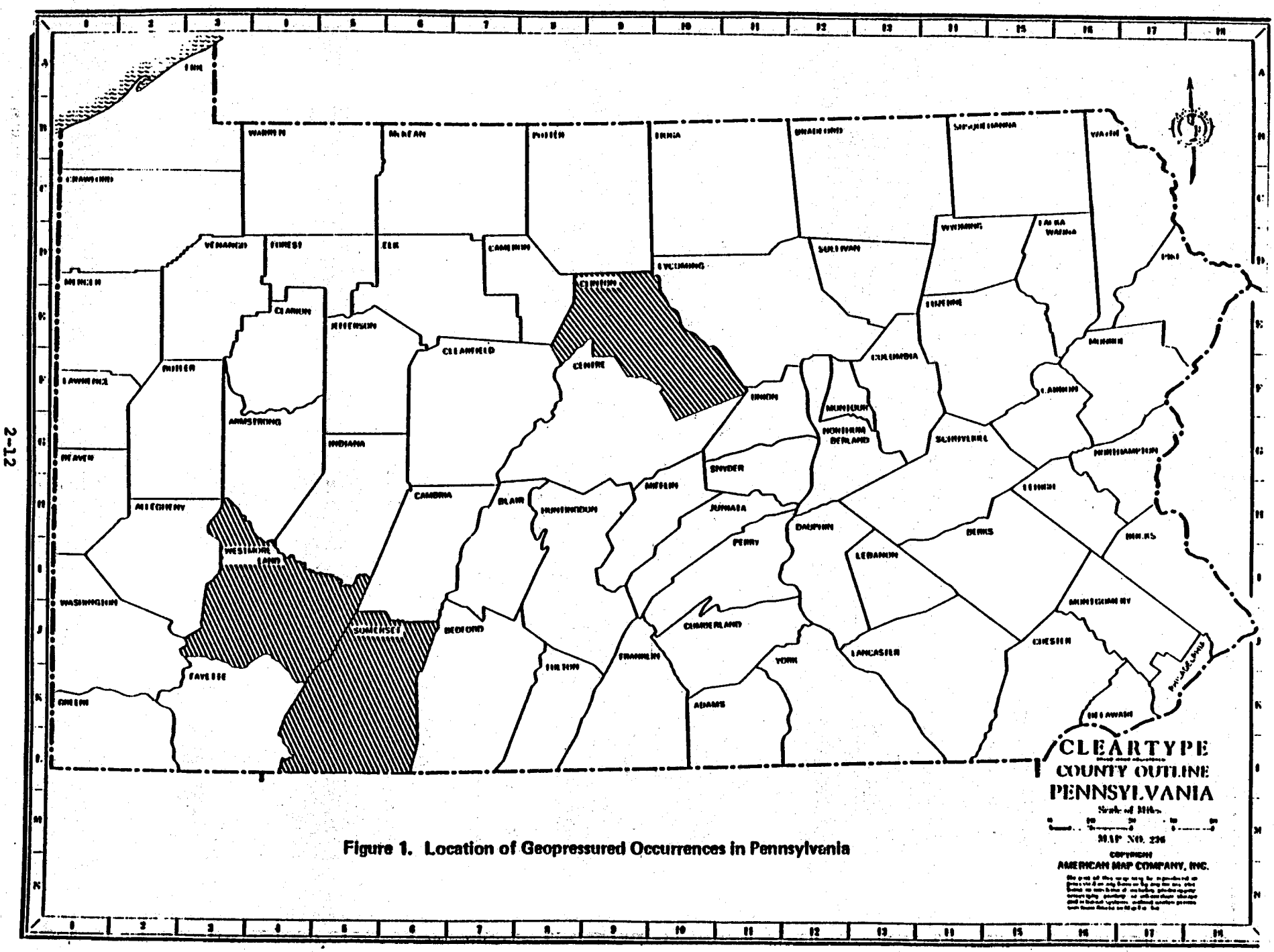


Figure 1. Location of Geopressured Occurrences in Pennsylvania

The salinity of the Oriskany in the Leidy field is apparently rather low in contrast to the analyses of this formation elsewhere in the state as shown in Table 4. The following tabulation of Oriskany waters from the Leidy area is derived from data furnished by Consolidated Gas Supply Corporation (Cross, 1980).

Water Analyses from Wells in the Leidy Field Area

Locations	Cations (mg/l)	Anions (mg/l)	Total Dissolved Solids (mg/l)
Leidy South	3720	6500	10200
"	13100	21000	34100
"	466	809	1280
Leidy North	351	626	977
"	398	687	1080

The Leidy /South Leidy fields located in north central Pennsylvania, where the formations are relatively more deformed than those farther west, essentially confirms the relationship between deformation and high fluid pressure gradients. The low salinities present are anomalous by contrast to those normally found in the Oriskany, but it is probable that the folding in the region had permitted the introduction of meteoric waters and a consequent freshening.

Several wells drilled to a depth of 7000-9000' in western Pennsylvania encountered overpressuring in the Oriskany formation. In five (5) wells drilled by Peoples Gas Company in Westmoreland County, the results were as follows (Tatlock, 1980) :

Well #	Depth (ft)	Pressure (psi)	Gradient (psi/ft)	Total Solids in ppm*
4736	7899	4347	.550	149,769
4387	7933	4250	.536	144,829
4388	7701	4350	.552	181,019
4365	7739	4372	.565	154,783
4092	7476	4100	.548	323,253

(*A complete chemical analysis is available for each listed well)

The pressure gradients found here are within the range anticipated for the slightly deformed area of Pennsylvania.

Numerous Oriskany wells have been recently drilled in Somerset County through a joint effort of UGI and Amoco. Several selected wells show slight overpressuring, with pressure gradients ranging from 0.456 to 0.493 psi/ft. None of these wells initially produced water but it is anticipated, based in part on experience, that formation water incursion will shortly occur (Kelley, 1980).

2.3.2 New York (Figure 2)

Slight to notable overpressuring has been reported from several wells in New York as set forth in the tabulation below. Aside from the occurrence in Cayuga County, all of them are localized in the extreme western part of the state and,other than in Cattaraugus County, are found in either Silurian or Ordovician formations or both. The lithostatic-plus pressure in the Chautauqua County well is extremely unusual given the rather shallow depth and may reflect a measurement or reporting error.

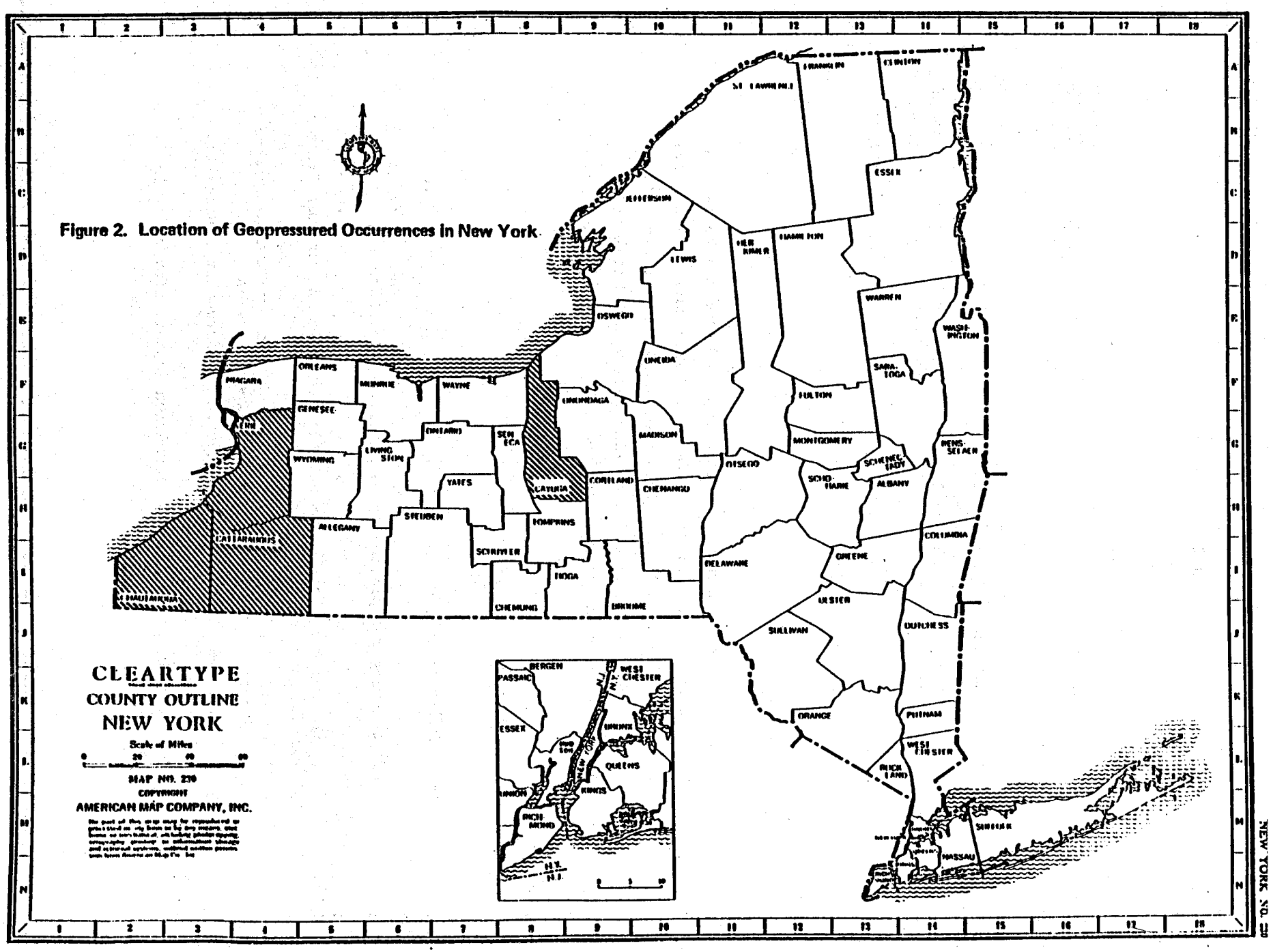


Figure 2. Location of Geopressured Occurrences in New York

Overpressured Wells in New York*

County	Township	Formation	Depth (ft)	Pressure (psig)	Pressure Gradient (psi/ft)
Cattaraugus	Hinsdale	Oriskany (Dev)	3813-23	1831	.481
Cayuga	Cato	Trenton (Ord)	2640-2953	1519	.575-.514
Chautauqua	Sheridan	Medina (Sil)-Queenstown (Ord)	1688-1828	1950	1.15-1.07
Erie	Alden	Medina (Sil)	1073-1158	535	.499-.462
Erie	Brant	Medina (Sil)-Queenstown (Ord)	1807-1924	884	.489-.459
Erie	Hamburg	Medina (Sil)	1420-21	700	.493

*Kreider, W.H.., et al, 1972

2.3.3 Tennessee

One area of overpressuring has been reported from the eastern part of the state where the Petroleum Development Corporation drilled several shallow wells (1700-1800' depths) into the Fort Payne limestone (upper Mississippian) and encountered oil-bearing zones, with little or no water, that have pressure gradients ranging from .510 to .620 psi/ft (Jenkins, 1980).

2.3.4 West Virginia (Figure 3)

2.3.4.1 Previous Citations

Overpressuring has previously been reported in Phase I in the following areas:

- In the Oriskany in the Sissonville Gas field in Kanawha, Jackson Putnam Counties
- In Cambrian formations in deep wells in the Rome trough drilled in Calhoun, Jackson, Lincoln, and Mingo Counties
- In a test well in Devonian shales at Morgantown in Monongalia County
- In Reedsville/Utica/Trenton formation (upper Ordovician) in southern West Virginia

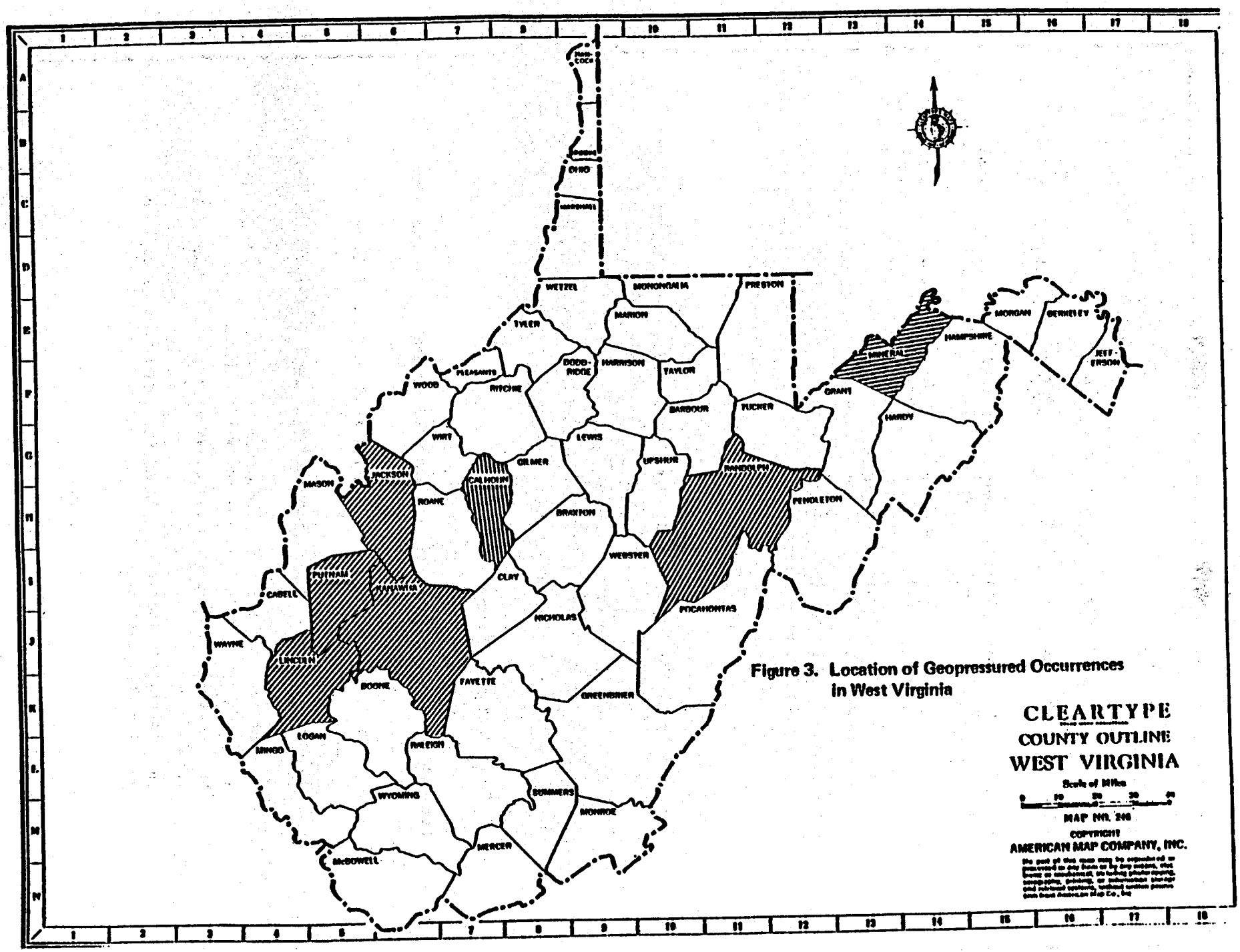


Figure 3. Location of Geopressured Occurrences in West Virginia

- In the Eastern Overthrust Belt in Ordovician formations in Mineral County, slight overpressuring encountered at a depth of about 12,000' - believed to reflect relict overpresurring associated with thrust faulting
- In the Oriskany in the Glady field in Randolph and Pocahontas Counties.

2.3.4.2 Rome Trough

Abnormally high pressures such as those found in California and the Gulf Coast have only been observed in the Appalachian basin in the Cambrian formations of the Rome trough. The latter is a subsurface graben-like depression which extends from eastern Kentucky-southern West Virginia into southwestern Pennsylvania. The configuration of this basin is indicated in Figure 4,an isopachous map which indicates a thickness of over 8000' of the lower Cambrian section. The general stratigraphic sequence of Silurian and older formations is shown in Figure 5. A description of the various wells, all of which were drilled during the mid-1970's, is presented below.

o McCoy #1 Well, Jackson County, WV (Brown, 1980)

This well reached a total depth of 17,689' and encountered high overpressuring in the Upper Elbrook section of the Rome formation. The shut-in pressures and pressure gradients for several drill stem tests are as follows:

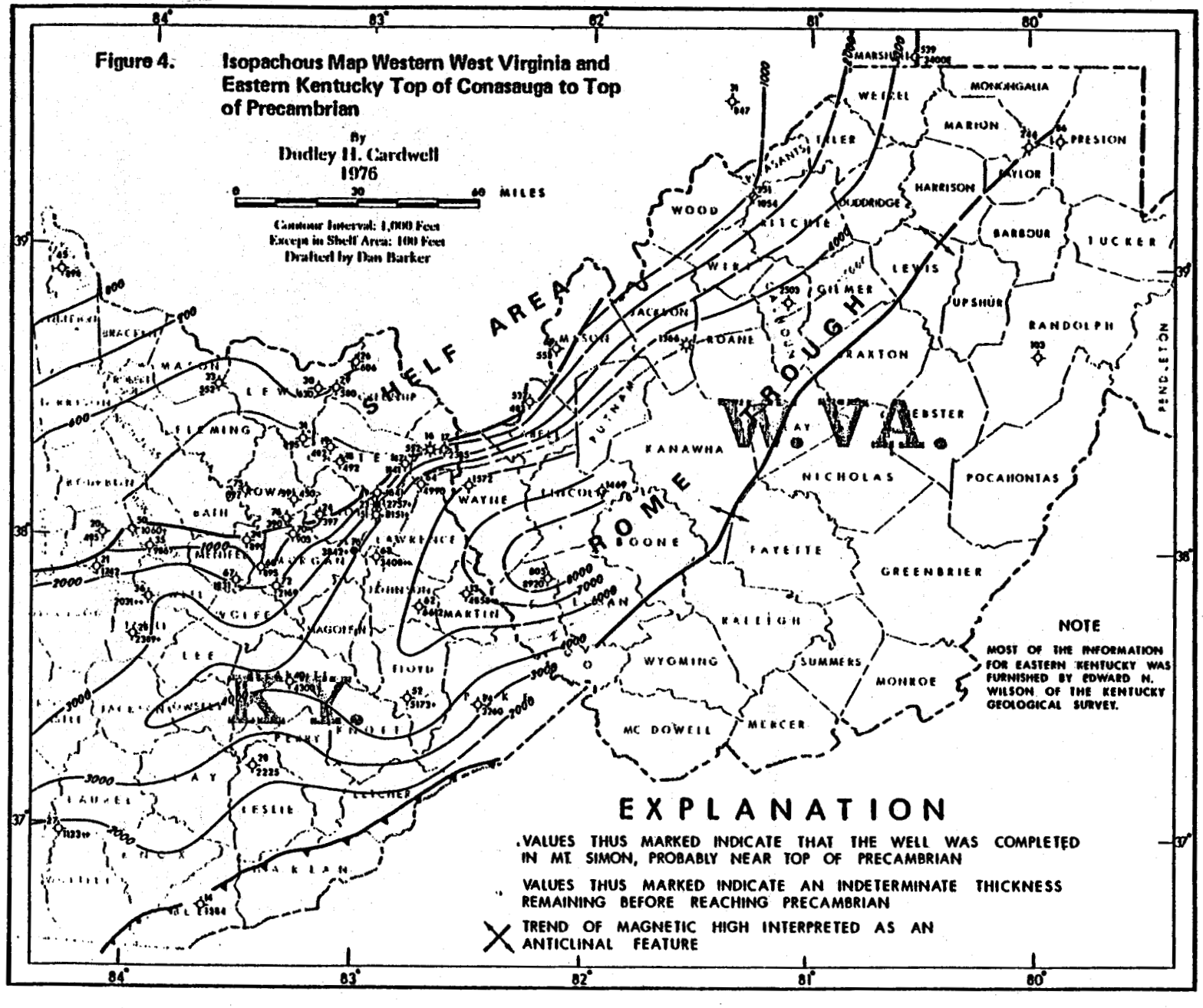


Figure 4. Isopachous Map Western West Virginia and Eastern Kentucky Top of Conasauga to Top of Precambrian
By
Dudley H. Cardwell
1976
0 30 60 MILES
Contour Interval: 1,000 Feet
Except in Shelf Area: 100 Feet
Drafted by Dan Barker
SHELF AREA
ROME TROUGH
W.VA.
84°
83°
82°
81°
80°
39°
38°
37°
MARSHALL
WETZEL
MONONGALIA
MARION
PRESTON
TYLER
WOOD
HARRISON
TAYLOR
DODDRIDGE
BARBOUR
TUCKER
LEWIS
GILMER
UPSHUR
RANDOLPH
JACKSON
ROANE
CALHOUN
BRAXTON
WEBSTER
PENDLETON
PUTNAM
KANAWHA
NICHOLAS
POCAHONTAS
BOONE
FAYETTE
GREENBRIER
RALEIGH
WYOMING
SUMMERS
MONROE
MC DOWELL
MERCER
MARTIN
FLOYD
PERRY
LAUREL
LESLIE
LETCHER
NOTE
MOST OF THE INFORMATION FOR EASTERN KENTUCKY WAS FURNISHED BY EDWARD N. WILSON OF THE KENTUCKY GEOLOGICAL SURVEY.
EXPLANATION
. VALUES THUS MARKED INDICATE THAT THE WELL WAS COMPLETED IN MT. SIMON, PROBABLY NEAR TOP OF PRECAMBRIAN
VALUES THUS MARKED INDICATE AN INDETERMINATE THICKNESS REMAINING BEFORE REACHING PRECAMBRIAN
TREND OF MAGNETIC HIGH INTERPRETED AS AN ANTICLINAL FEATURE

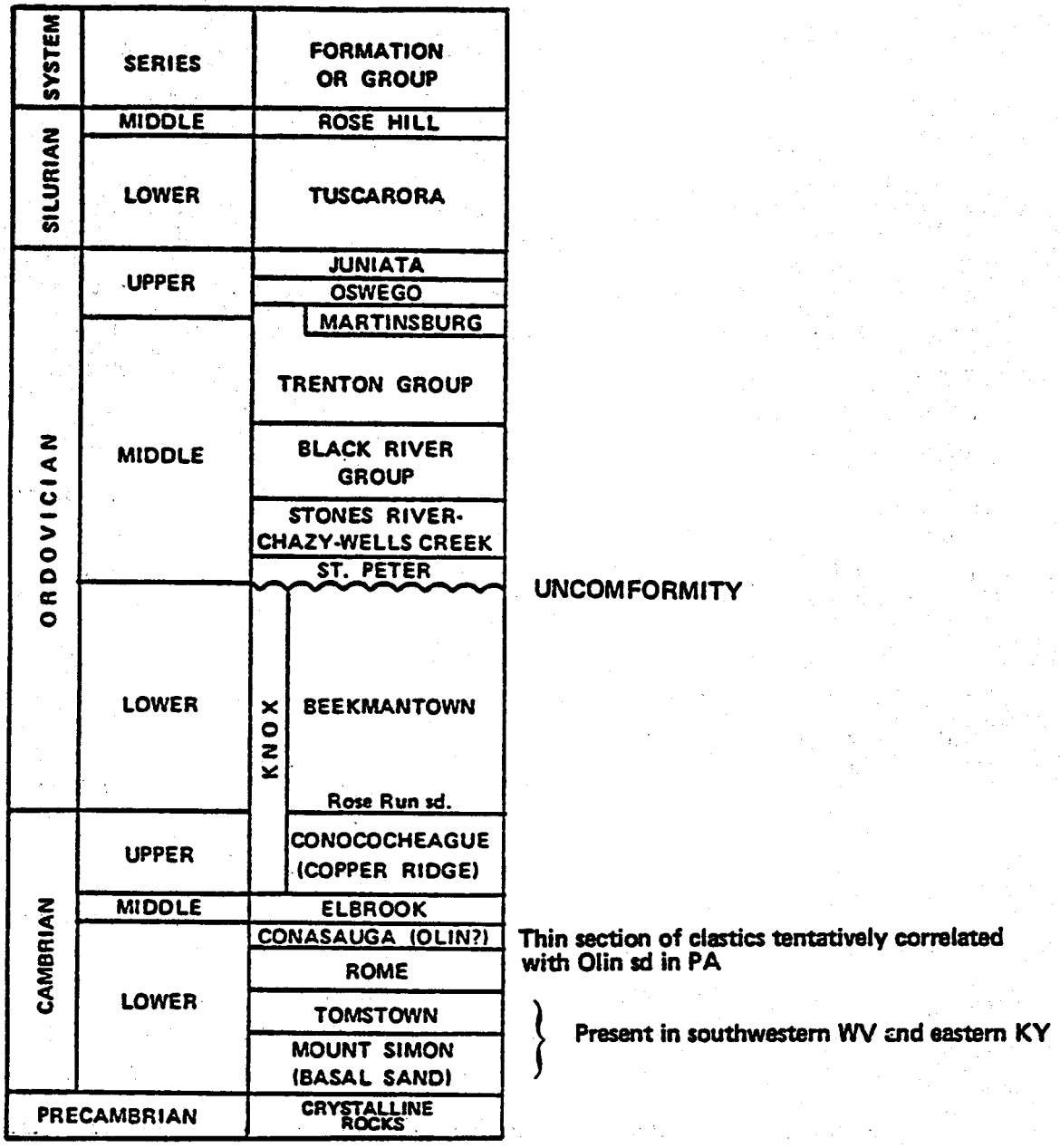


Figure 5 Generalized Stratigraphic Section of Lower Paleozoic Formations in Western West Virginia (Including area of Rome Trough)

(1) After Cardwell, 1977

Depth (ft)	Shut-In Pressure (psi)	Pressure Gradient (psi/ft)
14158	11658	.823
14162	11591	.818
14170	11688	.825
14174	11662	.823
14230	11666	.820
14234	11641	.818

This well produced water and gas for a limited period from a pay zone at 14380-14384'. The water from this zone, which occurred above the gas, is characterized by relatively low salinity, i.e. 53,000 ppm of total dissolved solids. The initial output on a test basis was 5000 Mcf/day together with considerable water, but a cutback in gas production did not result in a reduction in water output. It was never determined whether or not this was free gas or gas dissolved in water. The well was plugged shortly after these tests were conducted.

o McCormick well drilled in Lincoln County, WV in 1974 encountered overpressuring in the Rome formation as indicated by the change in mud weights, as follows (Brown, 1980).

Depth of	12,091'	- mud weight increased from 9.9 to 11.2 to 13.0 ppg
	12,124'	- increase from 13.3 to 13.5 to 13.7 ppg
	12,900'	- increase of mud weight to 16.9-17.0 ppg
	13,300'	- increase of 18.0 ppg
	13,600'	- mud weight remained at 18.0 ppg
	19,124 (TD)	- mud weight remained at 18.0 ppg

Two drill stem tests were performed - zone at 12,184' indicated a flow of 100 Mcf/day of gas and water, the latter with a salinity of 27,000 ppm of total dissolved solids; a second test at 19,124' had a flow of 3000 Mcf/day of gas but without water.

- Well 9674-T, Mingo County, WV (Brown, 1980)

This well drilled into basement rock, encountered at 19,527', penetrated the top of the Rome formation at 10,840'. A seismic survey made before drilling indicated two abnormally high pressure zones at 10,900 to 11,300' and from 16,900 to 19,600'. A plot of the calibrated velocity log also indicated abnormal pressure at 10,800 and possibly in three other zones at 10,500 to 12,700'; 14,250 to 15,000'; and 16,500 to 19537'. Abnormal pressure was encountered during drilling at 13,057' where a mud weight of 18.1 ppg was employed, i.e. equivalent to a pressure gradient of 0.94 psi/ft as compared to a normal gradient of 0.465. One of the drill stem tests was from 13,057 and below and had non-commercial shows of gas and accompanying water, the latter with a relatively low salinity of 45,000 ppm total dissolved solids.

The Ordovician and Cambrian section encounted in this well was as follows (Cardwell, 1977):

Elevation	958'	Total Depth 19,600'
Depth to Top of		
Martinsburg	-4427	
Trenton	-5005	
Black River	-5650	
Wells Creek	-6802	Ordovician
St. Peter	-7536	
Beekmontown	-7564	
Rose Run	-8342	
Copper Ridge	-8492	
Rome	-9692	Cambrian
Mount Simon	-18292	
Pre-Cambrian	-18612	

- The Gainer-Lee well drilled in Calhoun County to a total depth of 20,222 into the Pre-Cambrian is reported to have encountered overpressuring in Ordovician and Cambrian formations similar to that found in the Mingo County well. The salinity of Cambrian formation waters was approximately 53,000 ppm total dissolved solids.

- The bottom hole temperatures in these deep Cambrian wells ranged from 258°F in the Mingo County well to 270°F in the Jackson County well for a temperature gradient of 1.6 to 1.8°F/100'. This is fairly representative of the relatively low temperature conditions in the Appalachian basin (Brown, 1980).

- A fourth well drilled in the Kentucky part of the Rome Trough encountered the Rome formation at a depth of about 10,000' but no further information was available.

- In 1981, a new well in Jackson County offsetting the McCoy well is planned (Brown, 1980) and in view of the interesting results of the original, this would be an excellent well for future monitoring and study.

2.3.4.3 Extension of Rome Trough

Based on work by Wagner (1976) it is highly likely that the Rome trough extends further northward into western Pennsylvania and western New York. In this region, an upper Cambrian sandstone called the Olin sandstone (as much as 300' thick and more) has been deposited in an elongated basin some 50 miles wide. This entire section is characterized by various stratigraphic changes which strongly suggests that contemporaneous or growth faulting was active along the western edge of the depression throughout the Cambrian. A structure contour map, Figure 6, indicating the form, depth and position of the basin in southwestern Pennsylvania strongly suggests that this basin is apparently the northward extension of the Rome trough. Further, the Olin sandstone appears to be correlative with the Conasauga and part of the upper Rome formation in West Virginia (Cardwell, 1977).

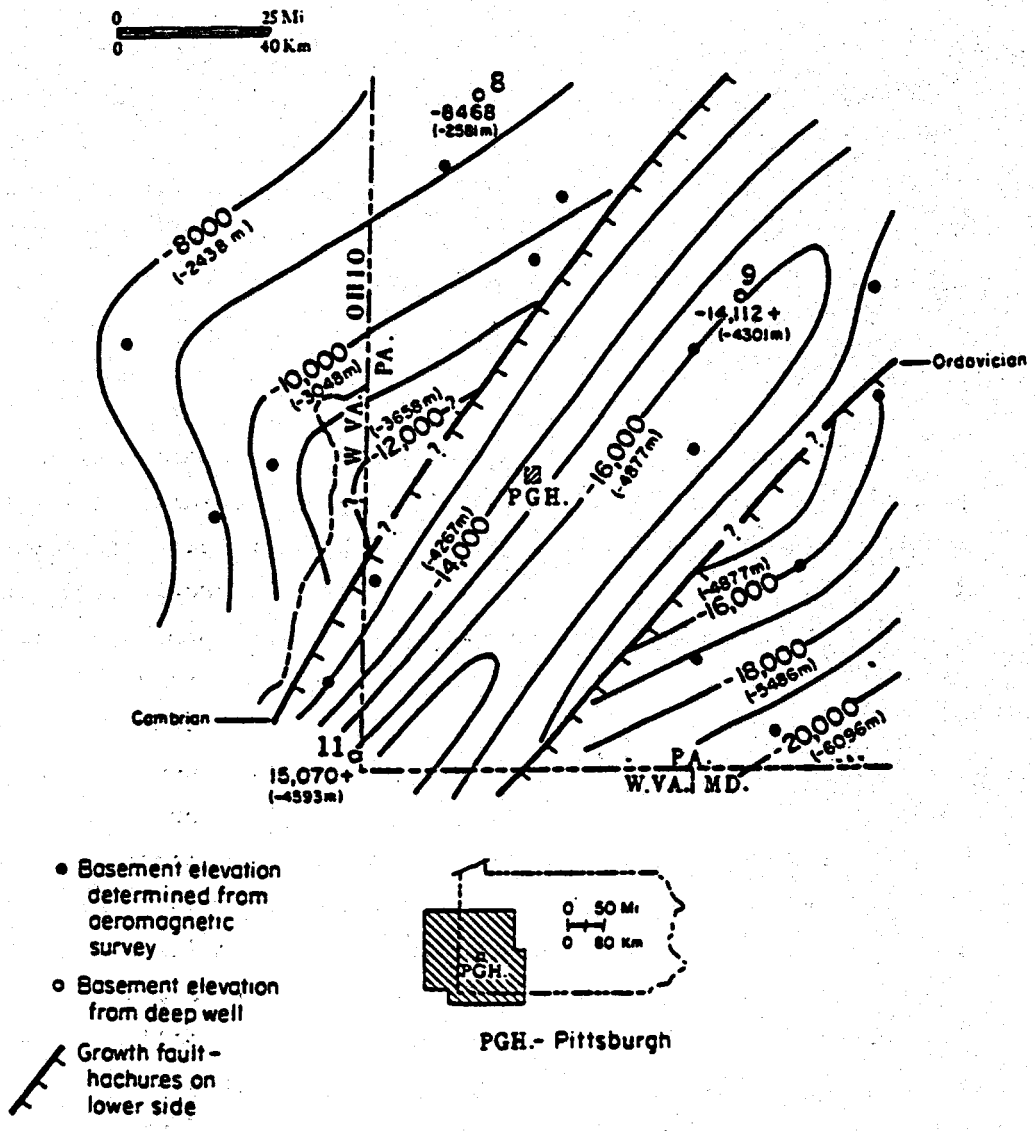


Figure 6. Structure Contours on Precambrian Basement in Southwestern Pennsylvania Indicating the Projection of Growth Faults to Basement (Wagner, 1980)

There was no pressure data available for the Cambrian wells in western Pennsylvania but given the general association of growth faults and abnormally high pressures and the occurrence of the latter in the Rome trough in West Virginia, it is highly probable that future deep drilling will likewise encounter overpressuring.

2.4 SUMMARY

It is apparent from the foregoing that the Appalachian basin is generally an area of normal to abnormally low pressures. Even where abnormally high pressures and even superpressures are encountered, as in the Oriskany (Devonian) and Rome (Cambrian) formations, respectively, the salinities are generally too high (as in the former) or the temperatures are too low (as in the latter) to expect significant quantities of dissolved methane in the formation waters. Moreover, it is not uncommon in either case to encounter high pressure gas zones with little or no water. The only area in the Appalachian basin which holds any promise insofar as the recovery of methane from geopressured waters is concerned, would be the Rome trough. Operating on the premise that dissolved methane is present and based on the solubility relationship as a function of temperature and pressure (Culberson and McKetta, 1951) and subsequently modified by others to account for salinity, it can be estimated that the methane content of these Cambrian waters is approximately 30-35 standard cubic feet (SCF) per barrel of water.

It is accordingly suggested that future drilling in this area be closely monitored, and should a given well (such as the proposed Columbia well previously mentioned) provide meaningful results, then consideration ought to be given to testing under DOE's Wells of Opportunity Program. The monitoring of recently planned drilling activities in the Appalachian basins through the various state geological agencies and selected private monitoring groups does not indicate the contemplation of any other deep wells in the region.

3. CALIFORNIA

3.1 Great Valley

Geopressures have been previously reported in Phase I in various parts of the state, the Great Valley including the Sacramento and San Joaquin Valleys, Coast Ranges,and the Ventura, Santa Barbara, Los Angeles and Eel River basins and their offshore extensions. For the most part, the occurrences outside the Great Valley are isolated and lack consistency. Therefore, for purposes of this report, the principal focus will be on the Sacramento and San Joaquin Valleys though limited data on these other areas, in addition to that cited in the earlier work, will be presented.

From a geologic perspective, the Great Valley with an average width of about 50 miles, occupies the central part of the state extending from near the Oregon border to Bakersfield, a distance of approximately 450 miles. As shown in the geologic map of central and northern California, Figure 7, the floor of the valley is underlain by Tertiary-Quaternary sediments flanked on the west by a thick assemblage of older Jurassic-Cretaceous sediments; these in turn underlie the valley floor. Further west are the Coast Ranges comprised of a complex of Franciscian rocks while to the east, the valley is flanked by a suite of Jurassic-Cretaceous intrusive rocks comprising the Sierra Nevadas. The latter highland area is believed to be the major source of detritus for the relatively thick accumulation of sediments in the valley.

Geologically and structurally, as shown in Figure 8, the Great Valley may be considered an elongated northwest-trending asymmetric structural trough which has accumulated an enormous thickness of sediments ranging in age from the Jurassic to the Recent. This

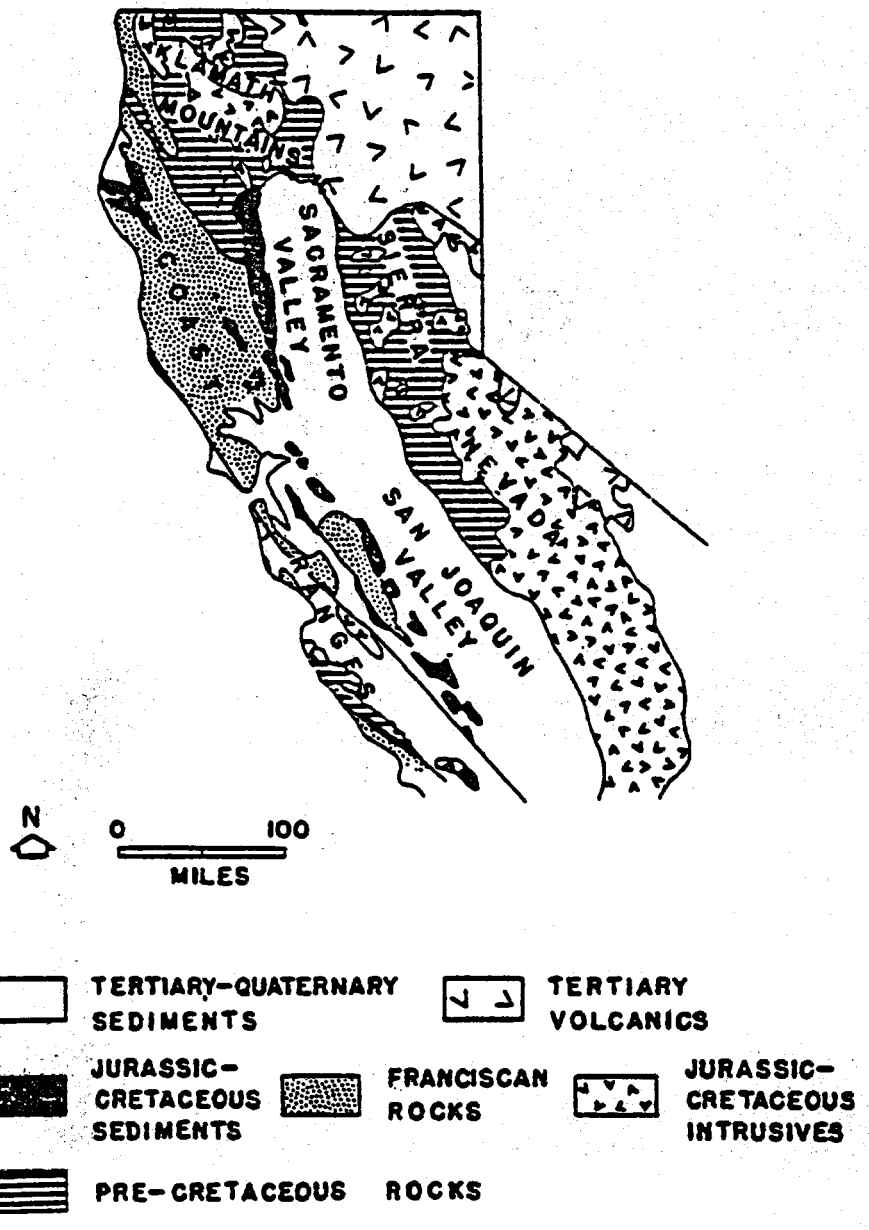


Figure 7. Generalized Geologic Map of Northern and Central California (Chuber, 1962)

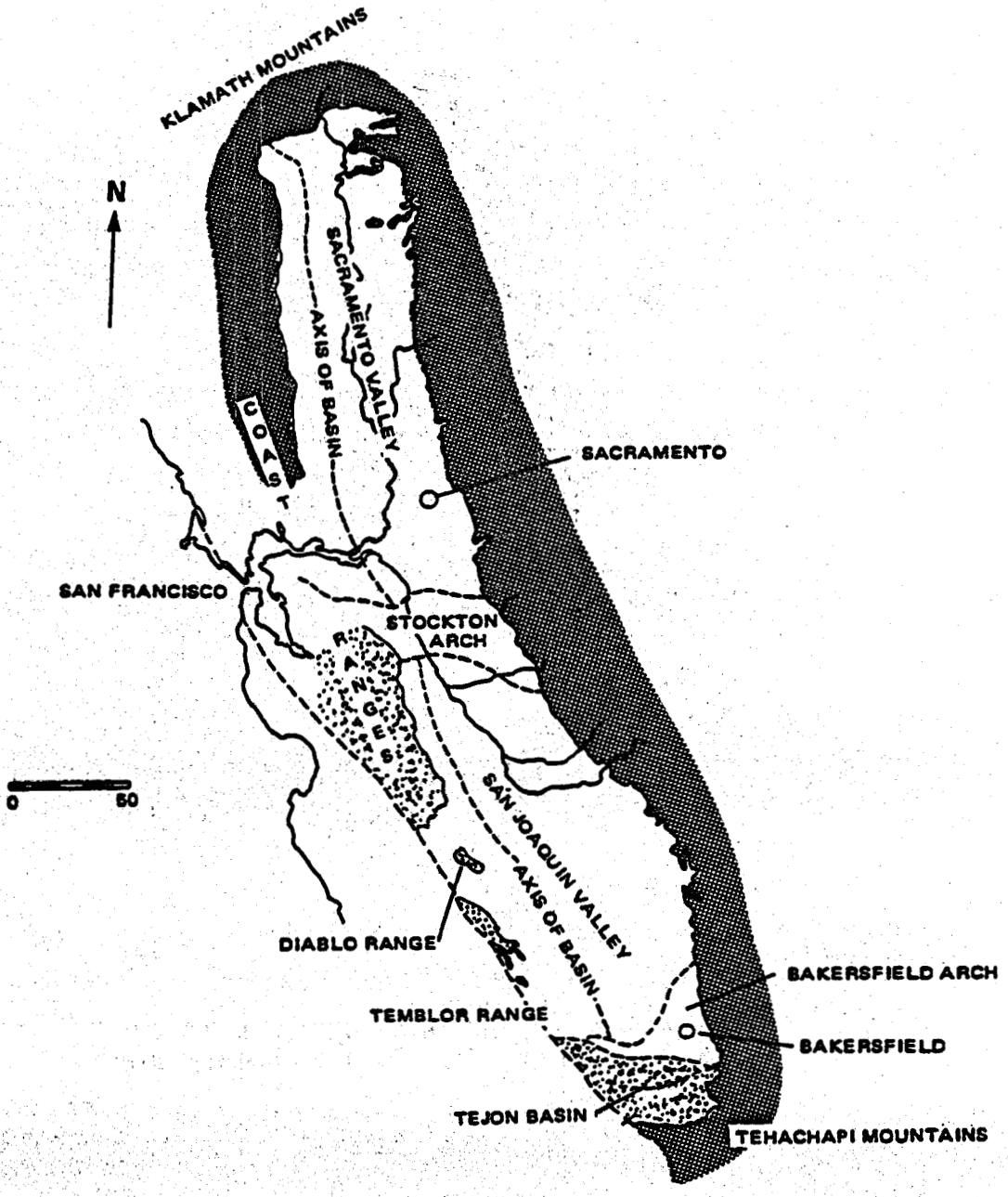


Figure 8. Regional Tectonic Elements of the Great Valley of California

asymmetric geosyncline, with the axis along the western flank, is bounded on the east by the long relatively stable shelf of the Sierra Nevada and on the west by an abbreviated flank in which the basin sediments have been upturned. The basin has a regional southward tilt and the Stockton arch is generally considered to be the boundary between the Sacramento Valley and the San Joaquin Valley.

In terms of stratigraphy, the rock sequences in the two valleys are quite different. The Sacramento Valley is characterized by a thick section of Mesozoic rocks, topped by a relatively thin layer of Paleocene and Eocene sediments. The Mesozoic sequence is thickest along the west side of the Sacramento Valley suggesting that the maximum deposition, believed to be 60,000' at a minimum (Hackel, 1966) occurred somewhat west of the present structural trough. By contrast, the San Joaquin Valley is underlain by a relatively thinner assemblage of Mesozoic sediments which is overlain by a relatively thick sequence of Tertiary sediments (of Paleocene to Pliocene in age) approximately 15-20,000' thick north of the Bakersfield arch and about 30,000' thick south of the arch. The thickest accumulation was along the western edge of the southern part of the San Joaquin basin, close to the present position of the structural low. The relationship between the two basins in terms of type and accumulation of sediments is shown in Figure 9, an isopachous map depicting the thickness of the Mesozoic and Cenozoic sediments in the Great Valley.

3.2 Other Occurrences Outside Great Valley

Other fields outside the Great Valley have isolated reports of geopressures. In addition to the Ventura Avenue Oil field in the Ventura basin and occurrences in the Coast Ranges and elsewhere (including the offshore) which were cited in Phase I, the following overpressured occurrences have been noted.

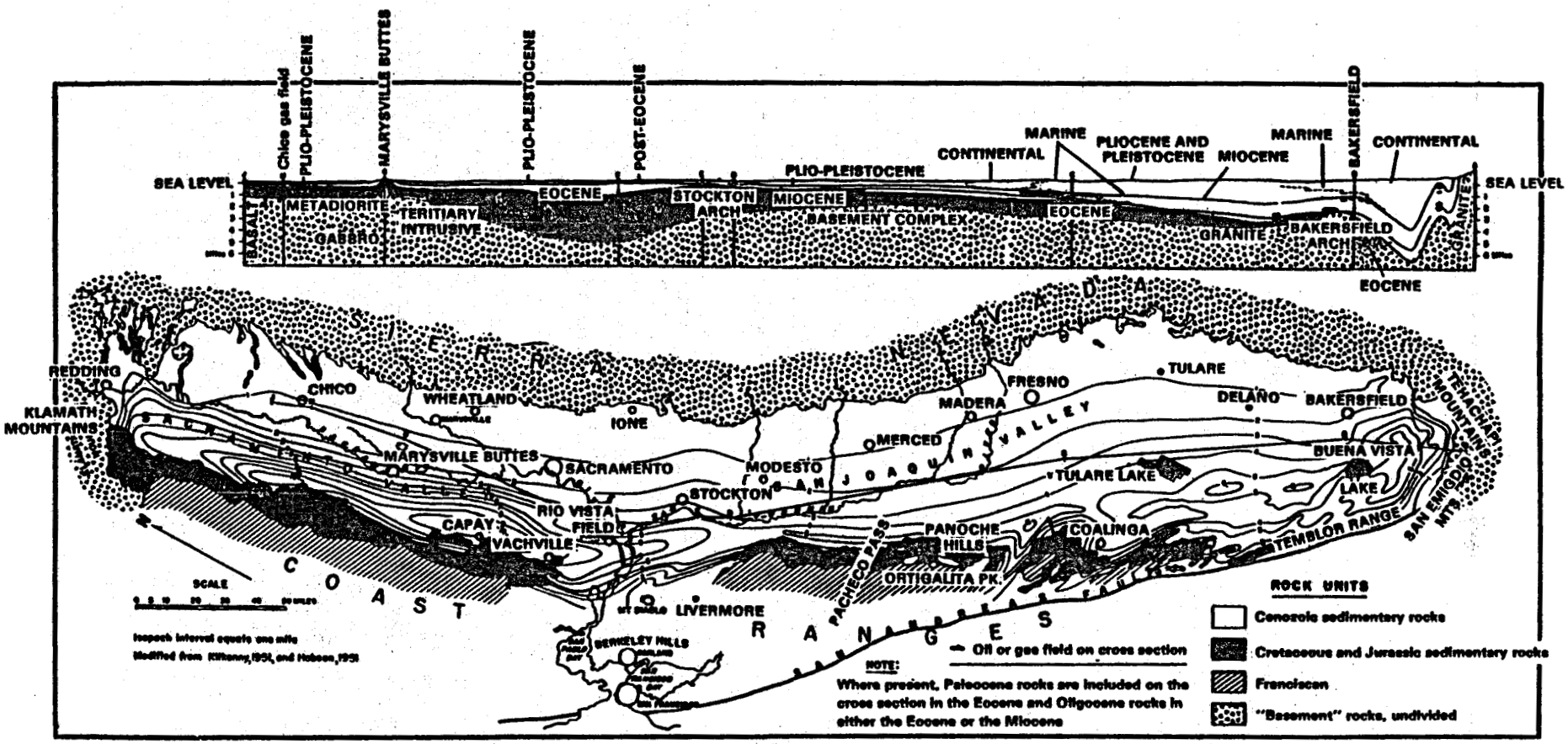


Figure 9. Map of Central California Showing Thickness of Sedimentary Rocks in the Great Valley (Repenning, 1960)

1) Goleta Gas Field, Santa Barbara County (Cal. Div. Oil & Gas Vol. II, 1973)

The Vaqueros formation (lower Miocene) at a depth of 3950' had an original pressure of 1910 psi (.483 psi/ft. pressure gradient) and salinity of 342-5135ppm.

2) San Ardo Oil Field, Main Area Monterey County (Cal. Div. Oil & Gas, Vol. II, 1973)

The Santa Margarita formation (above the Monterey formation) at depths of 1500-2000' has sand pressures that exceed normal hydrostatic pressure.

3) Long Beach Oil Field, Los Angeles County (Ingram, 1968)

During the early stages of development, gas under very high pressure in the lower Wilbur zone (top of lower Pliocene Repetto formation) at an average depth of 2500' and fairly limited in areal extent,was the apparent cause of several spectacular blowouts.

4) Pimental Canyon Gas Area of Vallecitos Oil Field, San Benito County (Cal. Div. Oil & Gas, 1973)

Yokut formation (lower Eocene) at a depth of 2500' displays a salinity of 1113 ppm and a pressure of 1200 psi for a pressure gradient of .480 psi/ft.

5) Tompkins Hill Oil Field, Humboldt County (R1E, T3N)

This field, with productive intervals in the Pico-Repetto formation (Pliocene) is characterized by numerous high pressure gas zones. The following is a list of pressures and salinities for selected wells (Saunders, 1980):

Well		Prod. Interval (ft)	Total Dissolved Solids (ppm)	Orig. Shut-In Pressure (psi)	Calc. Pressure Gradient (psi/ft)
Holmes-Eureka	#2	3622-5101	19023	2550	.704-.500
	3	3951-4511	-	2000	.506-.443
	4	2910-4420	-	2150	.738-.486
	5	4204-5099	19743	2600	.618-.510
	8	4331-5046	15327	2300	.531-.456
	10	3083-4700	14494	1500	.487-.319
	11	3897-4630	12912	1900	.488-.410
	14	4088-4721	13217	2000	.489-.424
	15	4228-5309	14077	3700	.875-.699
	16	3662-5360	-	3500	.956-.653
Fortuna	#1	4508-4980	-	2400	.532-.482
Eddy	#1	4713-5154	-	2100	.446-.407
Little A	#1	5385-5795	14709	2500	.464-.431

3.3 Sacramento Valley

3.3.1 General

In order to track the various formations and their relative age and juxtaposition as they will be discussed in this report, the stratigraphic column for this region is depicted in Figure 10. The locations of the various fields in the Sacramento Valley is shown on two maps - Figure 11A for the northern part and Figure 11B for the southern part.

3.3.2 Geopressure Characteristics

The Sacramento Valley is essentially a dry gas area in which numerous gas fields have been developed for more than fifty years. Fortunately for the purposes of this report, the California Division of Oil and Gas which maintains records on all oil and gas fields in the state, publishes pressure and salinity data in addition to other information, on all gas fields; however, there is no formalized system for

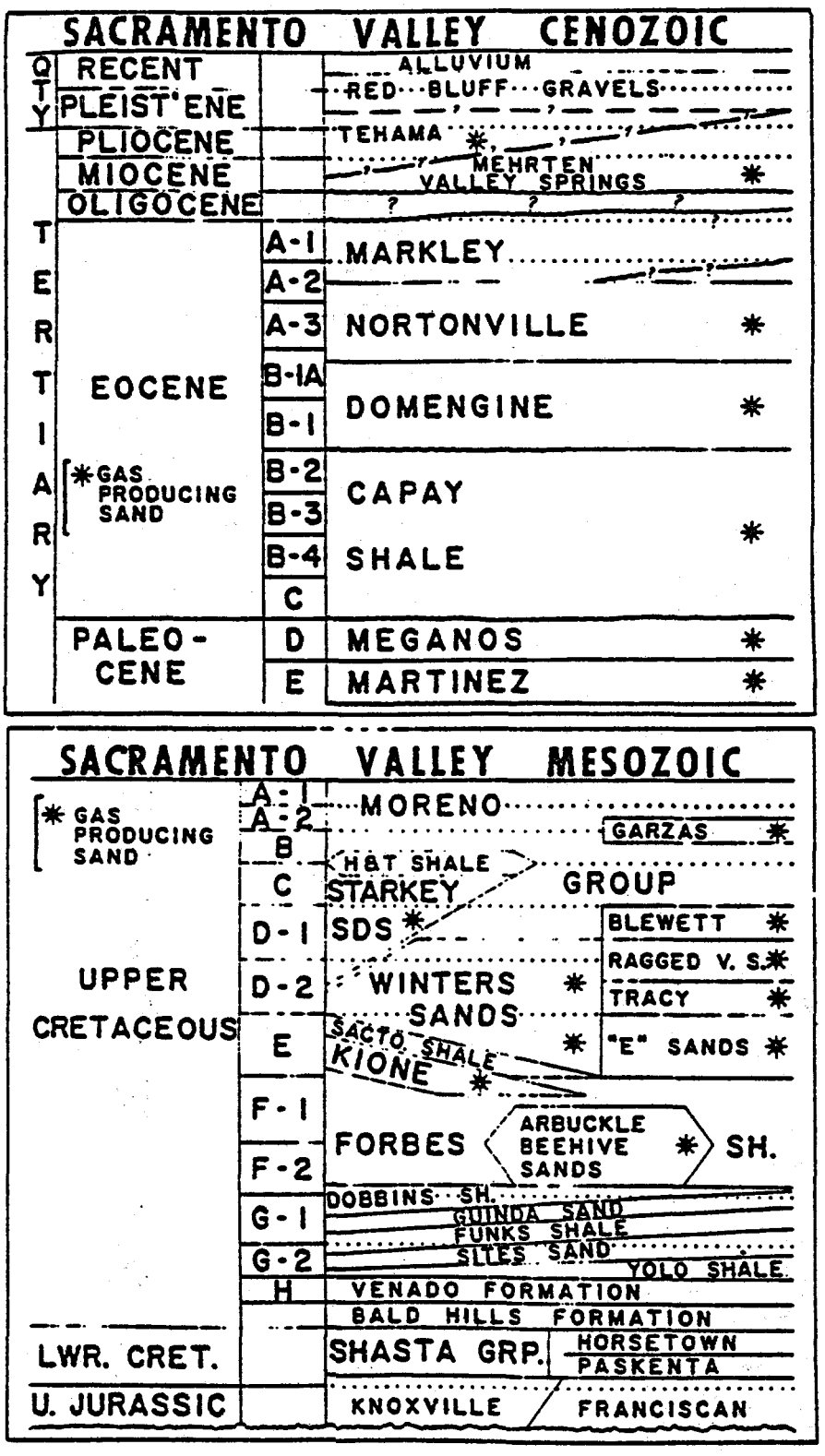


Figure 10. Stratigraphic Column – Sacramento Valley

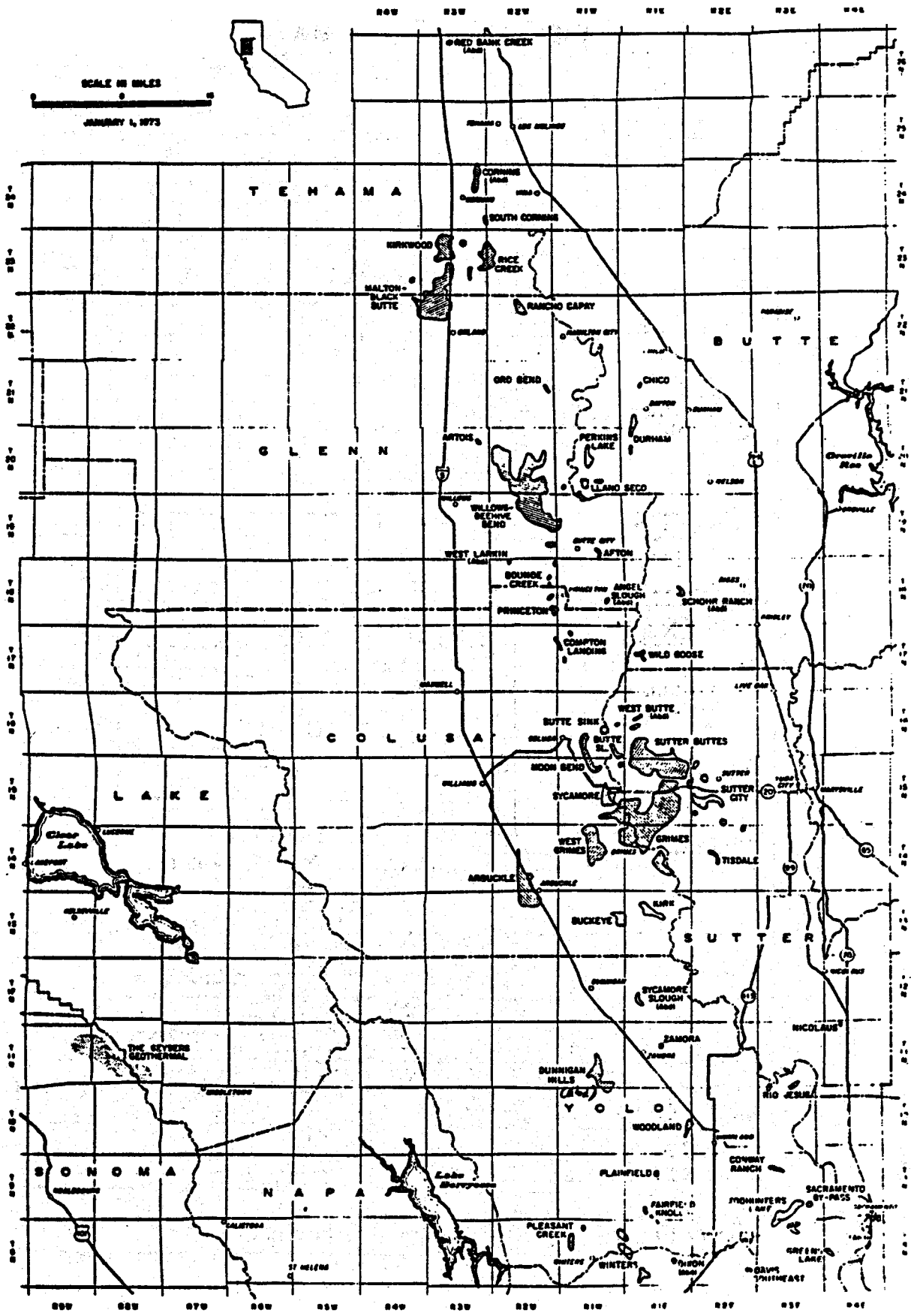


Figure 11A. Location of Fields in Northern Part of Sacramento Valley

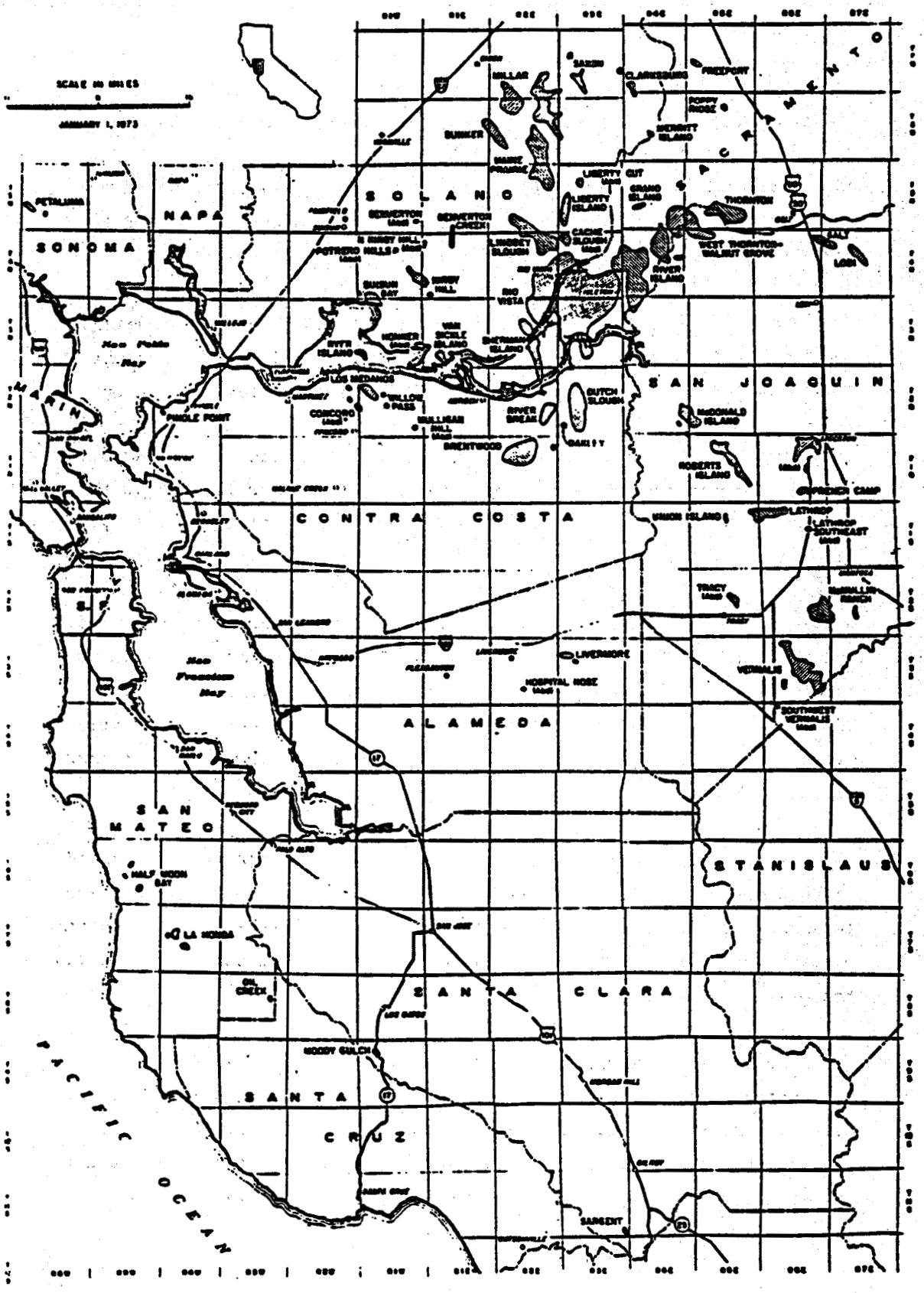


Figure 11B. Location of Fields in Southern Part of Sacramento Valley

reporting pressure data for oil fields even though many of them produce gas. Consequently, there was no difficulty in determining which fields and formations in the Sacramento Valley were overpressured, unlike the San Joaquin Valley, essentially an oil province, where pressure data needs to be obtained from a variety of sources.

Table 5 indicates the geopressured field and formations therein, together with salinity values, depths, ages, and calculated pressure gradients for the Sacramento Valley and northern San Joaquin Valley.

From a review of Table 5, it is apparent that the Forbes formation is ubiquitously overpressured and often superpressured throughout the Sacramento Valley unrelated to depth. For example, a) in the Malton Black Butte field, at a depth of 3250', the pressure gradient in the formation is .486 psi/ft; b) in the Moon Bend field, at 3270', the gradient is .795 psi/ft; and c) in Sutter Buttes field, at 2100', the gradient is .714. The overlying upper Cretaceous formations, such as the Kione, are only rarely overpressured, usually not in excess of .550 psi/ft. Similarly, the Paleocene and Eocene formations are only overpressured to a limited degree, rarely attaining the superpressures of the Forbes.

Geopressures in the Sacramento Valley are geographically oriented in that the abnormally high pressures/superpressures in the Forbes are generally localized along the west side of the valley while the moderate overpressures of the overlying younger formations are to be found along the eastern flank.

The Forbes formation is thickest on the western flank of the Sacramento Valley, e.g. 3000-5500' in the Grimes field, whereas to the east, it thins markedly, in part due to overlap. The Forbes, where productive, generally consists of interbedded dark gray claystones and siltstones and fine grained, gray, friable and lenticular sandstones.

TABLE 5

Geopressured Gas Fields and Formations
Sacramento Valley/Northern San Joaquin Valley[1]

Field	County	Prod. Zone	Avg. Depth (ft)	Geologic Age	Geologic Fmt	Salinity of Zone Waters[2] (ppm)	Orig. Zone Pres. (psi)	Pres. Grad.[5] (psi/ft)
Arbuckle	Colusa	USS[3]	4430-7150	U. Cret.	Forbes	8901-21398	2200-4800	.497-.671
Artois	Glenn	USS	5885	U. Cret.	Forbes	17118	3870	.658
Bounde Creek	Colusa, Glenn	McGowan	4590	U. Cret.	Forbes	7960	3600	.721
		Poster	5450	"	"	9415	3810-4905	.699-.907
		G	6965	"	Guinda	NA	5450	.782
Brentwood (Oil Field)[6]	Contra Costa	Overpressures reported from below 4500'						
Buckeye	Colusa	USS	7850-8510	U. Cret	Forbes	15406	4120-5950	.525-.699
Butte Slough	Colusa, Sutter	USS	5700-7270	U. Cret	Forbes	2311-22253	3250-5000	.570-.688
West Butte (abd)	Sutter	USS	4260-6500	U. Cret	Forbes	NA	1930-4380	.453-.673
Compton Landing	Colusa	USS	6260	U. Cret	Forbes	12000	4450	.710
Concord (abd)	Contra Costa	Nortonville	1650	Eoc.	Nortonville	NA	825	.500
		Domengine	1900	Eoc.	Domengine	2910	1240	.649
		USS	2208	U. Cret	UMS[4]	11810	1200	.543
Conway Ranch	Yolo	Unnamed	2900	Eoc.-Pako.	Meganos-Martinez	NA	1390	.479
		"	3000	"	"	NA	1340	.447
		S-1	3600	U. Cret	Starkey	"	1720	.478
Crossroads	Yolo	S-3	4150	U. Cret	Starkey	NA	2050	.494
		Unnamed	4985	"	Winters	NA	2440	.489
Denverton (abd)	Solano	Martinez	1425	Paleo	Martinez	3081	873	.613
Denverton Creek	Solano	Denverton (Heidorn)	8930	Paleo	Martinez	4128-34064	4680	.524
		Unnamed	9890	U. Cret	Starkey	9928	4800	.485
Dunnigan Hills (abd)	Yolo	Lederer	8400	U. Cret	Forbes	NA	5005	.596

TABLE 5 (Cont'd)

Field	County	Prod. Zone	Avg. Depth (ft)	Geologic Age	Geologic Fmt	Salinity of Zone Waters (ppm)	Orig. Zone Pres. (psi)	Pres. Grad. (psi/ft)
French Camp	San Joaquin	Lathrop	6925	U. Cret	Panoche	24136	4990	.720
Grimes	Colusa, Sutter	USS	4900-8800	U. Cret	Forbes	6847-22250	2780-6000	.567-.682
West Grimes	Colusa	USS	6050-7850	U. Cret	Forbes	16177-25335	3055-5425	.505-.691
Honker (abd)	Solano	Domengine	6500	Eoc.	Domengine	12325	3200	.492
Kirby Hill	Solano	Nortonville	1250-2250	Eoc.	Nortonville	1969-14122	1160	.928-.516
		Domengine	1550-2850	Eoc.	Domengine	941-16776	1195	.771-419
		Martinez	2850-5400	Paleo	Martinez	7703-14721	2205	.774-.408
		USS	5450	U. Cret	UMS	4208-6847	3915	.722
West Larkin (abd)	Glenn	Unnamed	5933	U. Cret	Forbes	NA	3040	.512
North Kirby Hill	Solano	Meganos	3510	Eoc.	Meganos	5478	1695	.482
Kirk	Colusa, Sutter	USS	7330-8710	U. Cret	Forbes	11212-17974	3750-5750	.512-.660
Kirkwood	Tehama	Forbes	4200	U. Cret	Forbes	NA	1970	.490
Lathrop	San Joaquin	Azevedo	3950	U. Cret	Moreno	16947	1920	.486
		U. Tracy	4727	"	Panoche	NA	2240	.474
		L. Tracy	6295	"	"	NA	2810	.446
		3600 lb.	6906	"	"	14037	3610	.527
		3700 lb.	7194	"	"	20542	3730	.518
		3800 lb.	7651	"	"	24308	3850	.503
		3900 lb.	7948	"	"	19172	3940	.496
		4000 lb.	8090	"	"	25934	4040	.499
		4200 lb.	8341	"	"	15663	4210	.505
		4300 lb.	8422	"	"	10699	4240	.503
Southeast Lathrop	San Juaquin	Lathrop	7110	U. Cret	Panoche	1530	3670	.516
Llano Seco	Butte, Glenn	Estes	3300	U. Cret	Kione	4108	1762	.534
		USS	4550-5200	"	Forbes	8217	2086-2686	.458-.516
Los Medanos	Contra Costa	U. Cret	2800	U. Cret	UMS	NA	1570	.561
Maine Prairie	Solano	Bunker	5740	Paleo	Martinez	68	2860	.498
Malton-Black Butte	Glenn, Tehama	USS	3250-4950	U. Cret	Forbes	21569	1580-2940	.486-.594

TABLE 5 (Cont'd)

Field	County	Prod. Zone	Avg. Depth (ft)	Geologic Age	Geologic Fmt	Salinity of Zone Waters (ppm)	Orig. Zone Pres. (psi)	Pres. Grad. (psi/ft)
McMullen Ranch	San Joaquin	Blewett	4525	U. Cret	Panoche	10271	2415	.533
		Tracy	6005	"	"	7874	2900	.483
		E	7200	"	"	11983-23280	4120	.572
Moon Bend	Colusa	USS	2100	U. Cret	Kione/Forbes	45362	1440	.680
		USSS	3270-6850	"	Forbes	13694-18830	2600-4350	.795-.635
Oakley	Contra Costa	2nd Massive	7447	Paleo	Martinez	20028	3515	.472
Perkins Lake	Butte	Perkins Lake	3400	Eoc.	Princeton Gorge fill	4280	1575-1600	.463-.470
Rancho Capay	Glenn	USS	4540-5000	U. Cret	Forbes	NA	2405-2705	.530-.541
Red Bank Creek (abd)	Tehama	Unnamed	4158	U. Cret	Forbes	NA	2040	.491
Rice Creek	Tehama	USS	2000-2660	U. Cret	Kione	10100	970-1270	.485-.477
		USS	4250-5500	U. Cret	Forbes	16.600-23800	2260-3140	.532-.571
Rio Jesus	Yolo	Unnamed	2470	Eoc.-Paleo	Meganos-Martinez	NA	1275	.516
Rio Vista	Contra Costa, Sacramento, Solano	Peterson	9650	U. Cret	Starkey	7703	4860	.504
River Island	Sacramento, San Joaquine	Nortonville	3600	Eoc.	Nortonville	1712-6847	1780	.494
		Domengine	3730	"	Domengine	1712-7018	1860	.499
		Winters	8450	U. Cret	Winters	51-12239	3955	.468
Ryer Island	Solano	Suisun	4470	Eoc.	Nortonville	NA	2410	.539
		Domengine	4750	Eoc.	Domengine	NA	2405	.506
Sacramento Airport	Sacramento, Sutter, Yolo	Moreno	2200	Eoc.-Paleo	Meganos-Martinez	NA	1080	.491
Saxon	Yolo	Glide	7050	U. Cret	Winters	11212	3355	.476
Schor Ranch (abd)	Butte	Schor	2570	U. Cret	Kione	4280	1220	.474
Sherman Island	Contra Costa, Sacramento, Solano	Anderson	6100	Paleo	Martinez	10000	3112	.510
Sutter City, Main Area	Sutter	Kione	1700	U. Cret	Kione	2225	800	.470

TABLE 5 (Cont'd)

Field	County	Prod. Zone	Avg. Depth	Geologic Age	Geologic Fmt	Salinity of Zone Waters	Orig. Zone Pres.	Pres. Grad.
Sutter City, South Area	Sutter	USS	3950-6830	U. Cret	Forbes	2174-22253	2040-3500	.516-.515
		G Zone	6160-6620	"	Dobbins	NA	3210	.521-.485
Sutter Buttes	Sutter	USS	2100-6000	U. Cret	Forbes	3595-31326	1500-4300	.714-.717
Sycamore	Colusa, Sutter	USS	4734-7370	U. Cret	Forbes	18830-33209	2860-5720	.604-.776
West Thornton	Sacramento	Nortonville	2810	Eoc.	Nortonville	5991	1400	.470
Tisdale	Sutter	USS	5800-6300	U. Cret	Forbes	16400-18100	3350	.578-.532
Tracy (abd)	San Joaquin	Tracy	3900	U. Cret	Panoche	6850-8560	1854	.475
Union Island	San Joaquin	USS	9700	U. Cret	Winters	39900	5040	.520
Walnut Grove	San Joaquin	Domengine	2980	Eoc.	Domengine	NA	1390	.483
		USS	7460-8300	U. Cret	Winters	8987-26790	3550-3900	.476-.470
Wild Goose	Butte, Colusa	U. Wild Goose	2500	U. Cret	Kione	30470-55634	1200-1310	.480-.524
		L. Wild Goose	2900	U. Cret	Kione	30812-45363	1345-1500	.472-.517
Willows-Beehive Bend	Glenn	USS	4420-6400	U. Cret	Forbes	1200-17100	2200-4200	.498-.656
		Unnamed	6700	U. Cret	Dobbins	NA	4440	.657
Winters	Solano, Yolo	Unit	4920	U. Cret	Winters	NA	2489	.506

NOTE

1) Unless otherwise indicated, all data is from California Division of Oil and Gas, California Oil and Gas Fields, Northern Area, Vol. 1, 1973 and Supplement, 1979.

2) Where listed in grains/gallon, values have been multiplied by 17.118 to obtain values in parts per million (ppm).

3) USS - unnamed sand stringers.

4) UMS - undifferentiated marine strata.

5) Only those fields and formations where the pressure gradient is at least .470 psi/ft have been listed.

6) California Division of Oil and Gas does not report pressures for oil fields; hence, data thereof must be acquired from other sources, namely selected annual reports of the California Division of Oil and Gas.

The Forbes is normally productive from stratigraphically-trapped lenticular sand bodies which are generally considered to be turbidites of a submarine fan facies reflecting deposition in a moderately deep marine environment many miles offshore. Generally, these occurrences are pod-like in shape and oriented in a northwest-southeast direction parallel to the regional tectonic trend. Individual sandstone lenses range in size from that present in a given well to dimensions ranging from 2-3 miles wide to more than 8 miles long. In the Malton field, for example, each lens has an areal extent of about 50 acres with a thickness of 1-40 feet (Hutchinson, 1981). Elsewhere, in the Grimes field, the thickness of indivudual sandstone beds varies between 8 to 60' (Weagant, 1972). The position and sedimentological character of the Forbes is in agreement with paleocurrent studies showing a consistent north to south trend throughout the late Cretaceous which indicates that the source was from the ancestral Klamath Mountains and that deposition was relatively uniform for a protracted time span (Ojakangas, 1968). A model indicating the nature and character of turbidite deposition during this period is depicted in Figure 12.

It has been pointed out by Lee (1980) that commercial gas production in the Forbes appears to be restricted to a particular fluid pressure gradient between .500 to .700 psi/ft. Further, it is apparent that such overpressure trends can be determined to indicate the position of entrapment mechanisms (for gas) in fault zones, stratigraphic pinchouts and other traps. In other words, the pressure can serve as an indicator of the barriers (and hence traps) that have resulted in the persistence of these abnormally high pressures.

The origin of the Forbes overpressures has been a subject of only limited study. It was previously discussed that the Forbes was probably deposited in the outer parts of a submarine fan, an area that generally has been subject to contemporaneous or growth faults caused by slumping that may have been enhanced by the tectonic instability of the region. A rather thick section of late Cretaceous and early Tertiary sediments

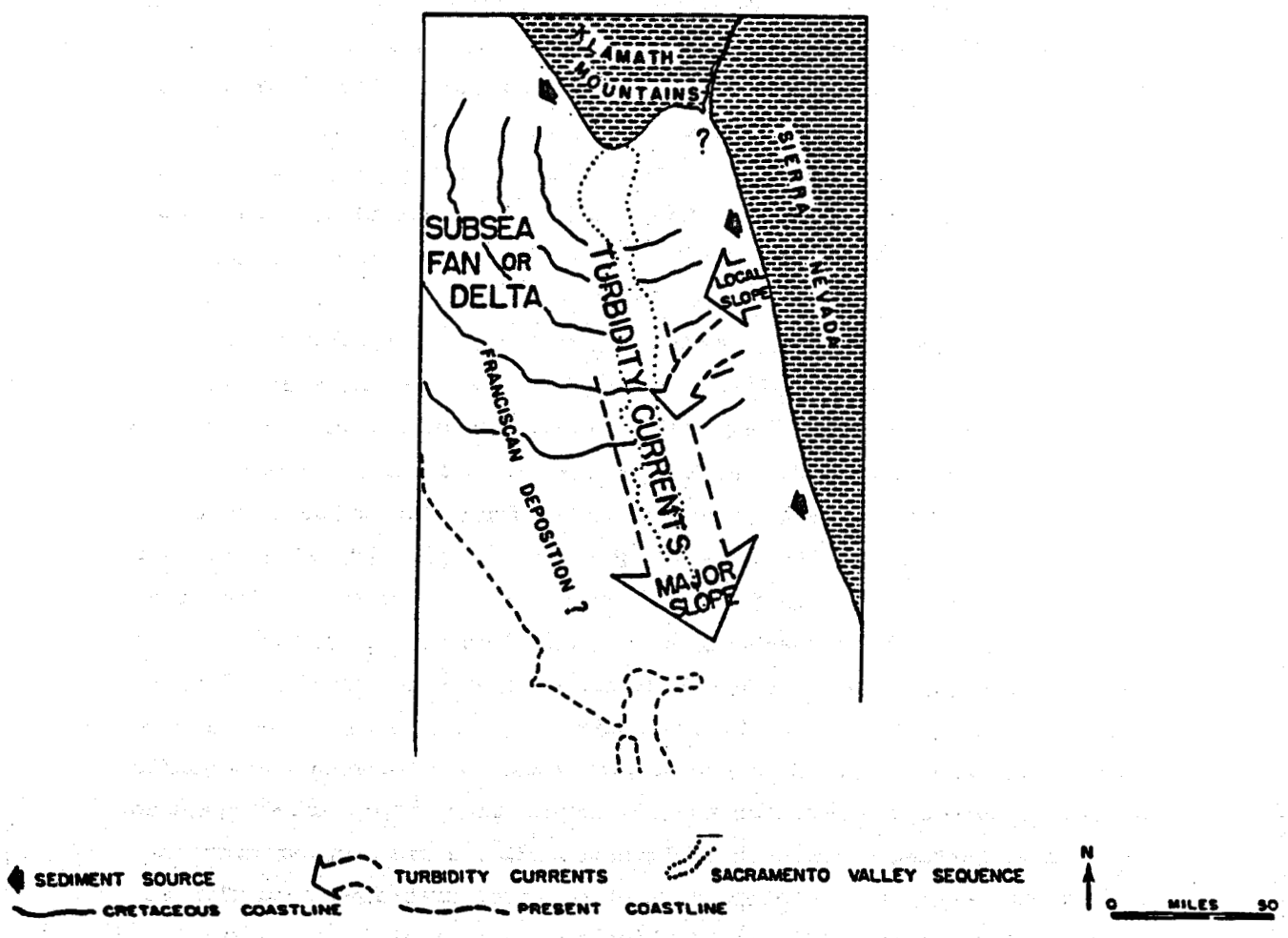
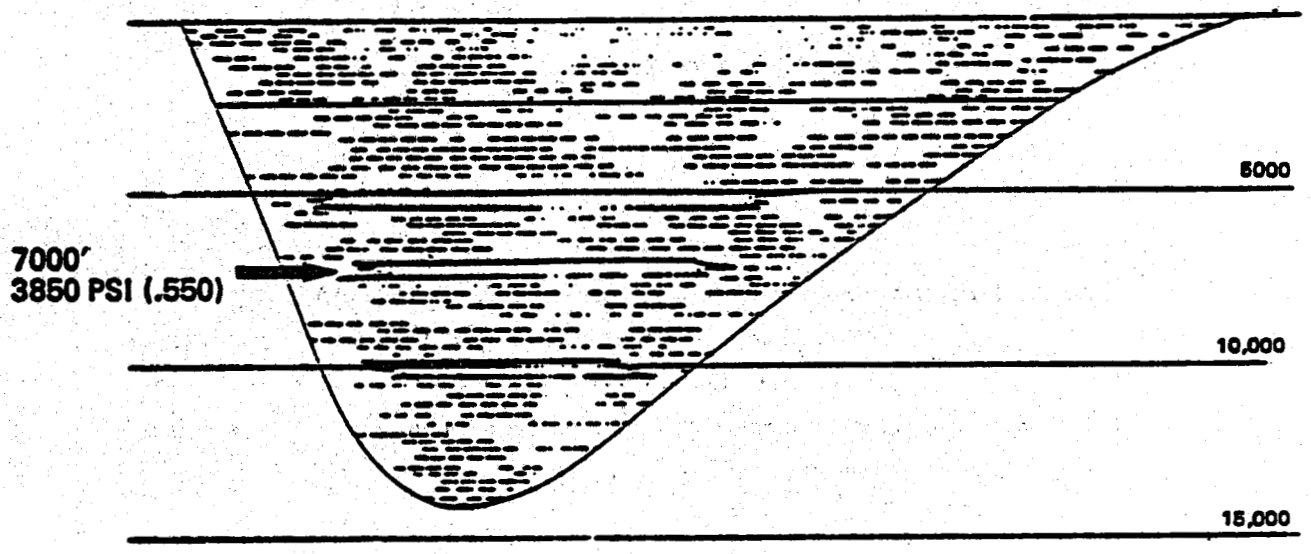


Figure 12. Sedimentation Model for Upper Cretaceous Sediments in Sacramento Valley (Ojakangas, 1968)

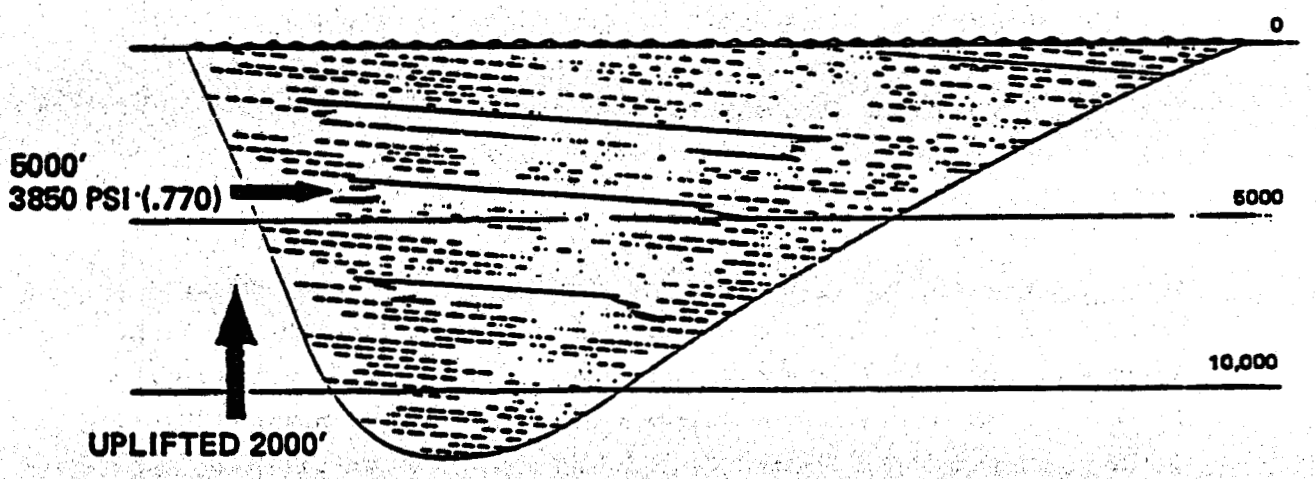
was deposited in the asymmetric Sacramento basin, the axis of which is close to the western margin. As deposition continued, sufficient sediments had accumulated to prevent the ongoing expulsion of water from the Forbes. Thus, the Forbes was now undercompacted and was supporting a part of the overburden. The Forbes at this point was most probably overpressured, but only moderately so. The superpressures noted were seemingly caused when the Sacramento depositional basin was uplifted and later subjected to erosion. Since the Forbes had retained its original pressure but was now at a shallow depth, higher than usual overpressures became the norm. The change from moderate overpressures to superpressures is depicted in Figure 13.

For illustrative purposes, a pressure gradient trend map for the Forbes, Figure 14, was prepared by Charles Lee, for the region between the Buckeye field in the south and the Malton-Black Butte field in the north which is the principal area of Forbes production in the Sacramento Valley. In general, the gradients increase from east to west reflecting the differential intensity of tectonism. It is interesting to note the obvious extremely high pressure (over .800 psi/ft) trend along the west flanks of the Willows-Beehive Bend and West Grimes fields. In the latter areas, gas production is lacking. For example, in the Willows-Beehive Bend field, Figure 15, production from the Forbes is obtained east of the fault where pressure ranges from normal to about .700 psi/ft; however, west of the fault on the downthrown side, where superpressures, in several instances approaching lithostatic, are present, production is lacking. This relationship between overpressures and production is further illustrated in Figure 16 which indicates that in the West Grimes field all commercial production with one exception occurs in the pressure gradient range of .500 to .700 psi/ft.

The detection of overpressures in the Forbes may be determined by various techniques. One involves drill stem tests, though few



STAGE I



STAGE II

Figure 13. Evolution of Superpressures in the Forbes Formation by Undercompaction and Uplift (Lee, 1980)

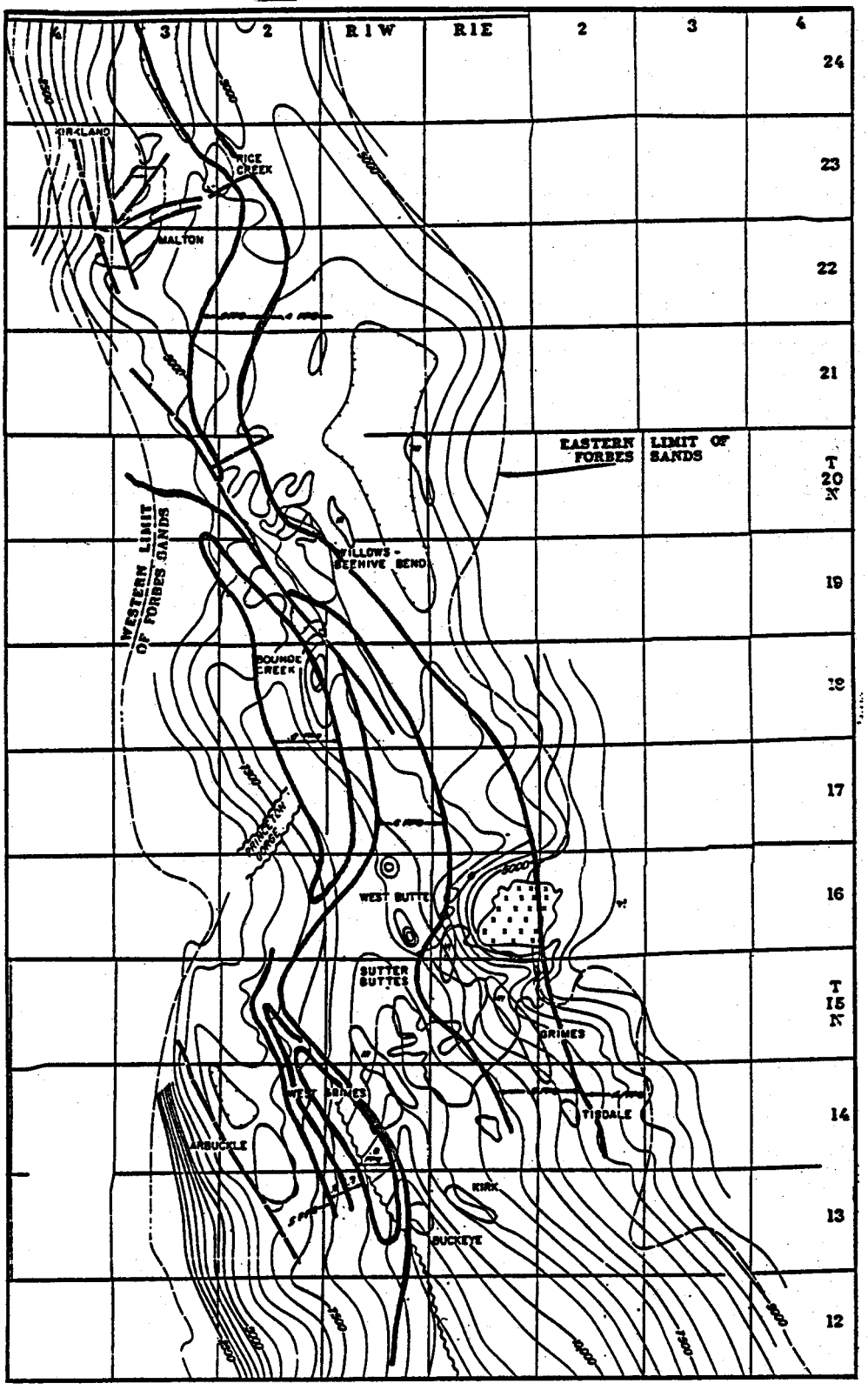


Figure 14. Pressure Gradient Trend Map in the Forbes Formation, Northern Sacramento Valley Showing Fluid Pressure Gradient (FPG) Corridors from .4 to .8 psi/ft. Structure Contours are on the Dobbins Shale (U. Cret.) Below the Forbes. See Figure 11A for Relative Location of Fields in Sacramento Valley (Lee, 1980)

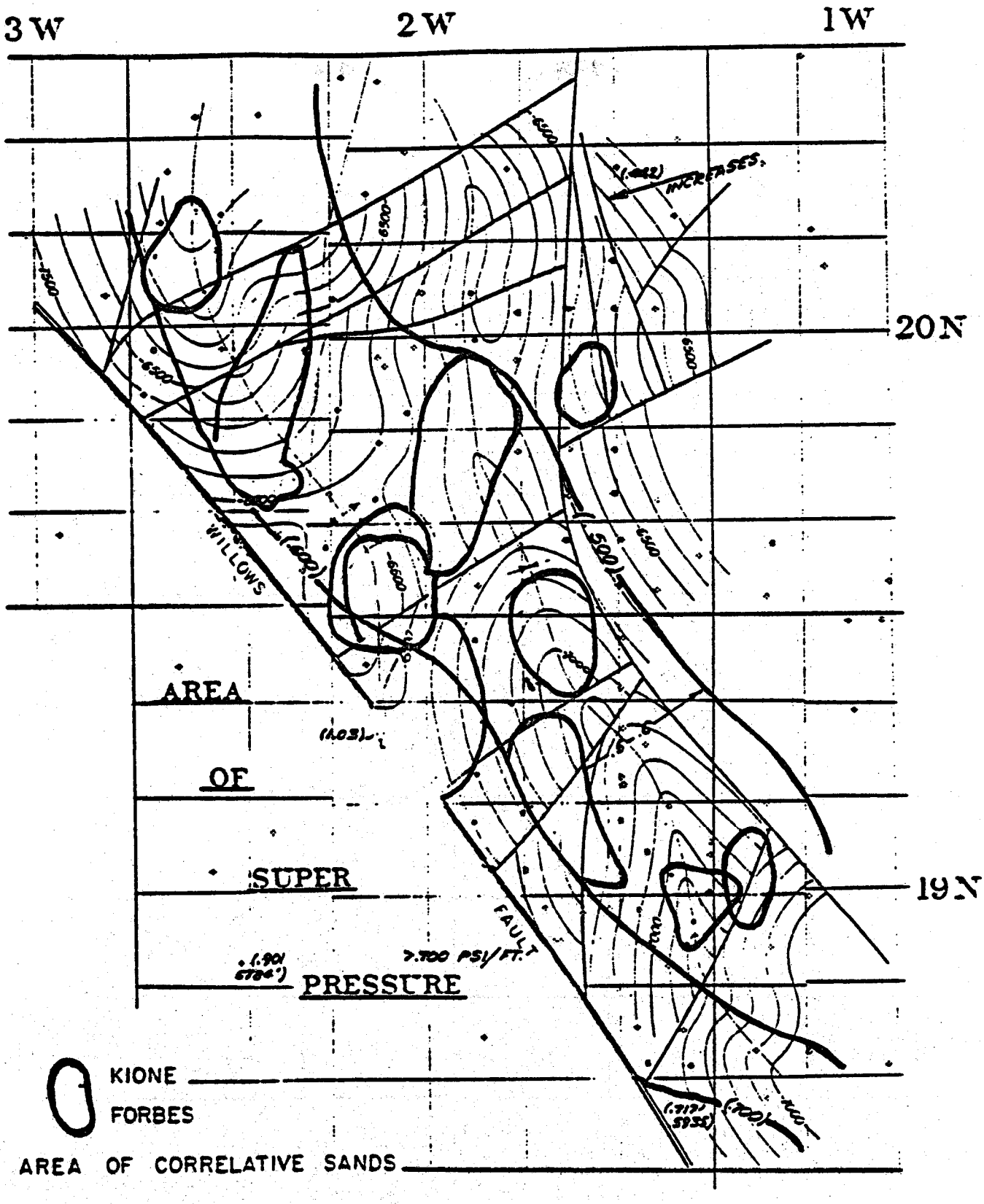


Figure 15. Relation of Production to Superpressures in the Forbes/Kione Formations in the Willows-Beehive Bend Gas Field, Northern Sacramento Valley. Structure Contours are on the Guinda Sand (U. Cret.) Below the Forbes (Lee, 1980)

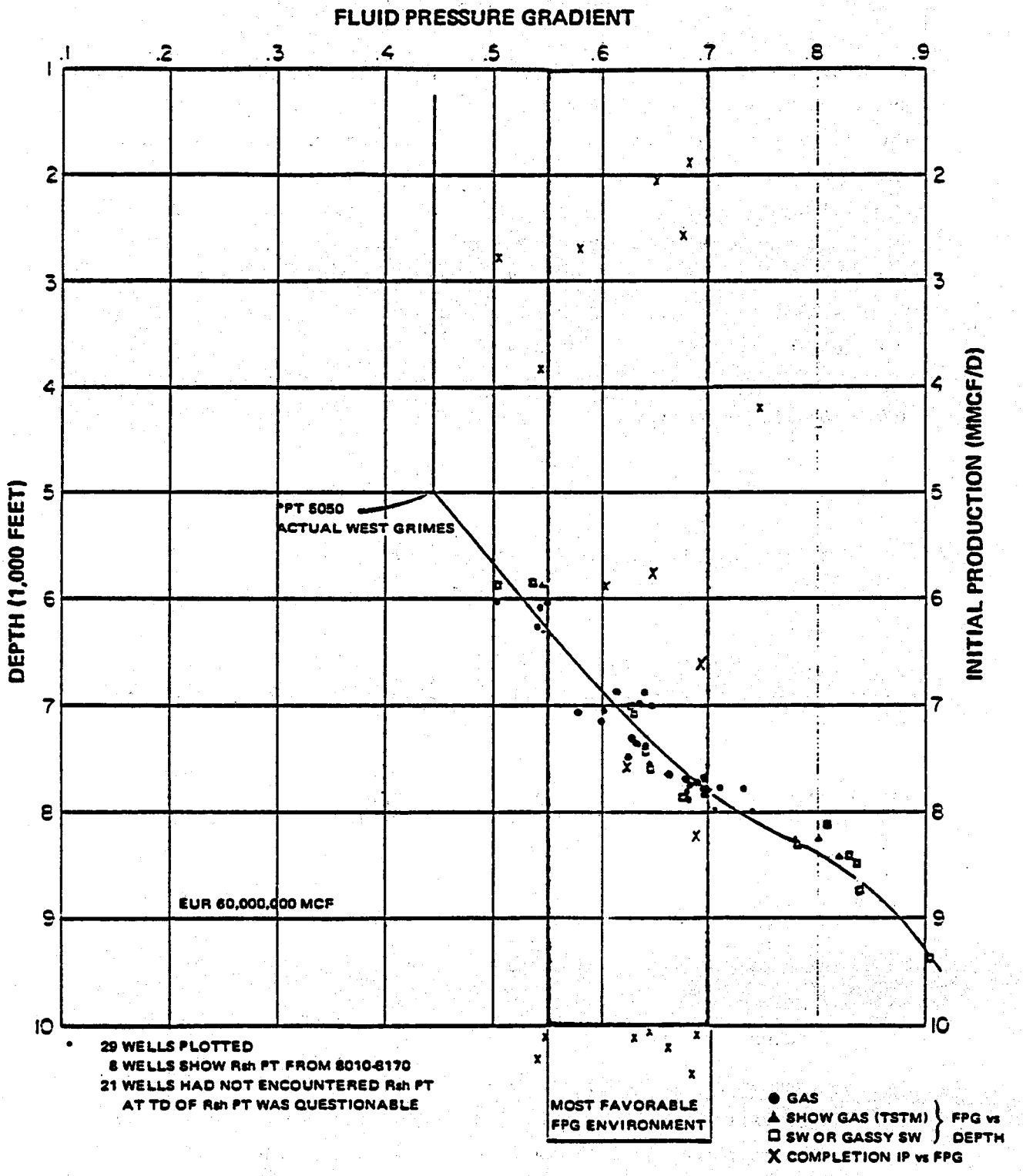


Figure 16. Productivity vs. Pressure Gradient in West Grimes Field (Lee, 1980)

DST's are run in the formation. Static shut-in tubing pressure measurements can be extrapolated to bottom hole shut-in pressure but initial shut-in pressure data is required. A third method involves the use of mud weight data which are generally available, but given the tendency to drill in an overbalanced mode, they must be used with some discretion. It can be presumed that where mud weights greater than 110 lbs/cu.ft. are used, superpressures have undoubtedly been encountered. A final source of pressure information is from electrical logs involving the plotting of shale resistivities.

3.3.3 Specific Occurrences

3.3.3.1 Fields

The following listing indicates the pressure gradients and/or salinities from known fields in the Sacramento Valley.

1) Moon Bend Gas field in Colusa County with production in the Forbes formation exhibits the following pressures (Saunders, 1980):

Well Number	Prod. Internal (ft)	Orig. Shut-In Pres. (psi)	Pressure Gradient (psi/ft)
Colusa UN 1 #1 Upper	4561-4930	2700	.592-.548
UN 1 #1 Lower	5561-5956	3525	.634-.592
Colusa UN 2 #1	4452-4577	2590	.582-.566
UN 2 #2	5184-5266	2600	.502-.594
UN 2 #3	4979-5398	2602	.523-.482
UN 2 #4	5065-5134	2630	.519-.512

2) Colusa County

The attached charts, Figures 17, 18, and 19, are graphical representations of pressure gradients derived from mud weights as compared to drill stem tests for wells drilled into the Forbes formation in the Compton Landing, Arbuckle and Buckeye field.

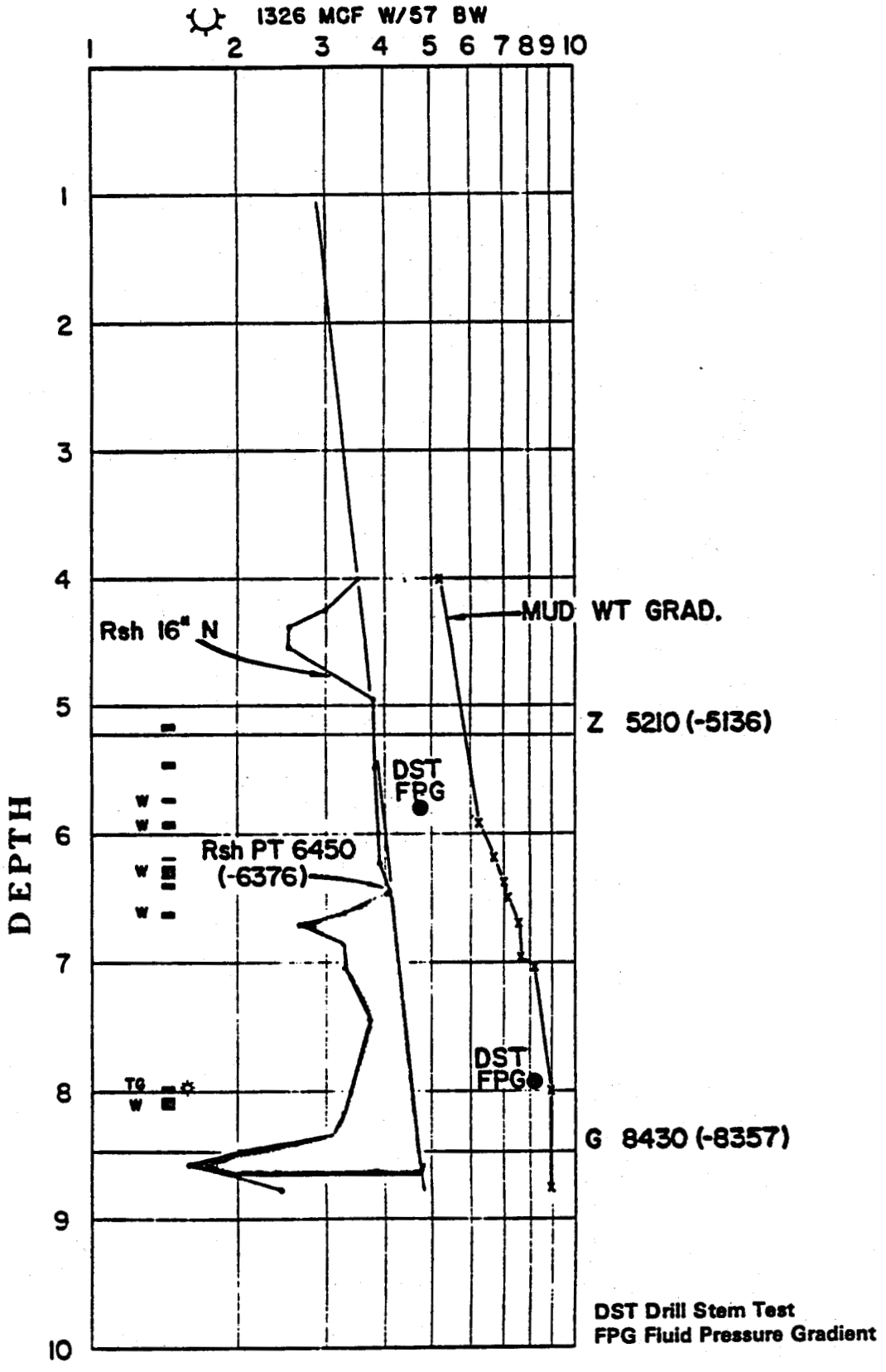


Figure 17. Pressure Gradient Graph for Well in Compton Landing Field
Sec. 29, T17N, R1W
(Lee, 1980)

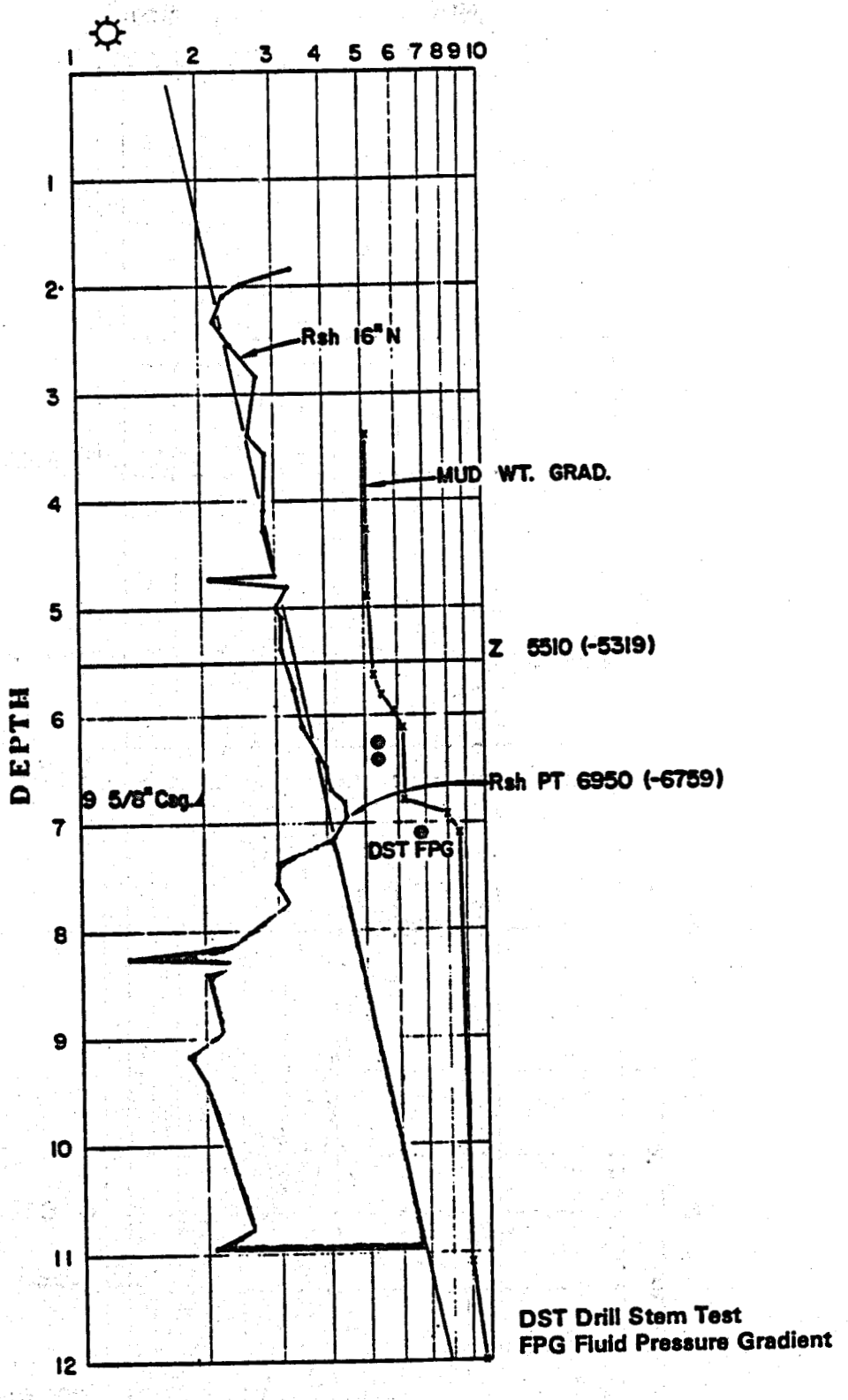


Figure 18. Pressure-Gradient Graph for Well in Arbuckle Field
Sec. 4, T13N, R2W
(Lee, 1980)

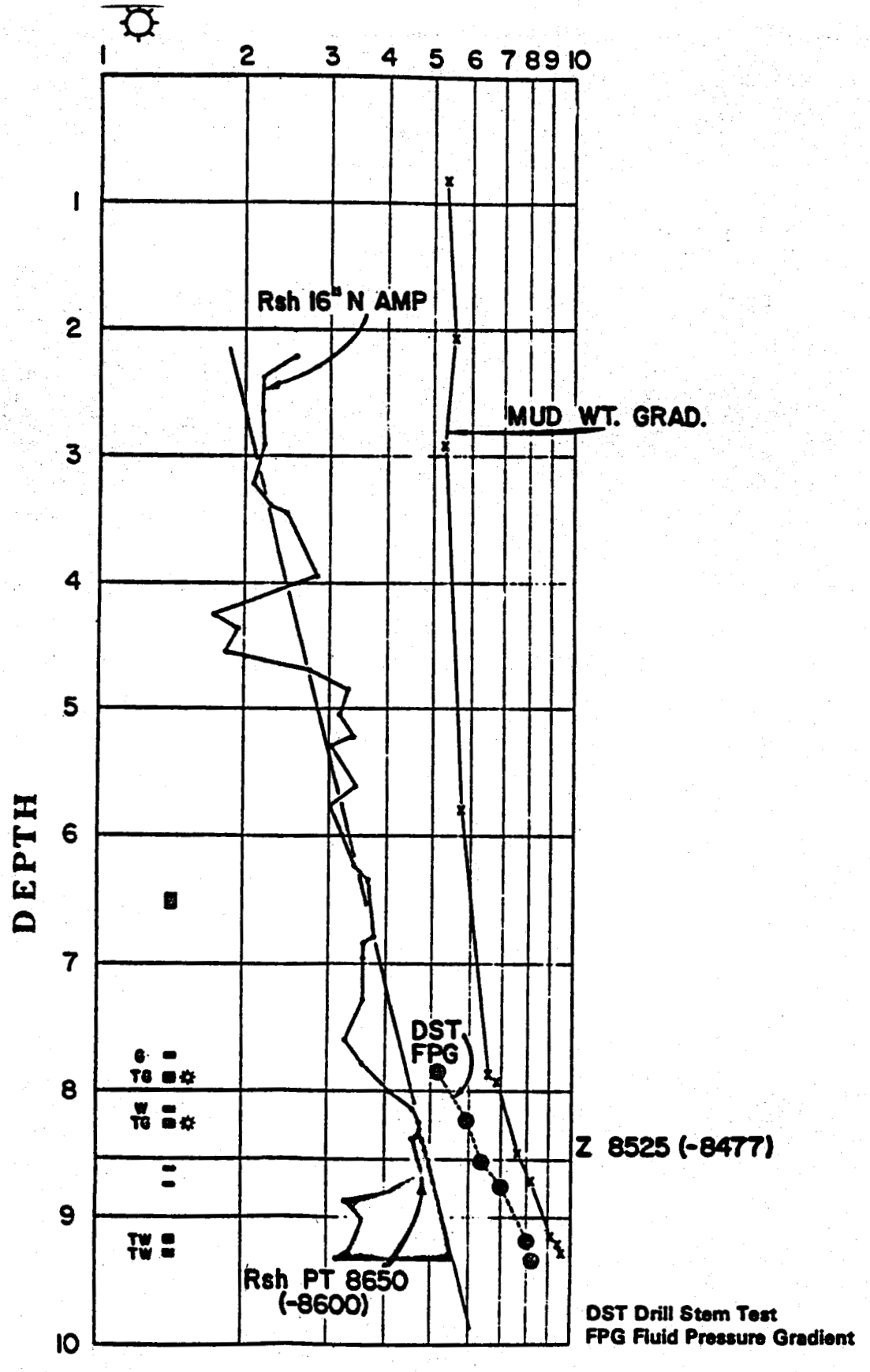


Figure 19. Pressure Gradient Graph for Well in Buckeye Field. Sec. 13, T13N, R1W (Lee, 1980)

Pressure Gradients in Selected Development Wells
from Mud Weights and Drill Stem Tests

Compton Landing field			Arbuckle field			Buckeye field		
	Pres. Grad. Based On			Pres. Grad. Based On			Pres. Grad. Based On	
Depth (ft)	MW (psi/ft)	DST	Depth (ft)	MW (psi/ft)	DST	Depth (ft)	MW (psi/ft)	DST
4000	.440	–	5000	.510	–	5000	.560	–
5800	.620	.480	6000	.590	–	7800	.670	.520
6900	.760	–	6400	.620	.540	8500	.760	.640
7100	.810	–	6900	.800	–	8700	.810	.700
8000	.900	.820	7100	.850	.690	9200	.900	.800

3) Brentwood Field, Contra Costa County (Ditzler and Vaughan, 1968)

The producing reservoirs are characterized by slight overpressuring, e.g. a drill stem test in a well at a depth of 3550-3600' had an initial shut-in pressure of 1695 psi (.477 psi/ft).

3.3.3.2 Wildcat Wells

1) The following listing indicates representative pressure gradients (based on mud weights and/or drill stem tests) and/or salinities from two wildcat wells drilled into the Forbes in the Sacramento Valley (Lee, 1980):

Pressure Gradients (and Salinities) from Mud Weights and Drill Stem Tests in Selected Exploratory Wells in Colusa County

Well in Sec. 3, T14N, R2W (North of Arbuckle field)		Well in Sec. 11, T16N, R1W (NW of W. Butte field)			
	Pres. Grad. Based On		Pres. Grad. Based On		
Depth (ft)	MW (psi/ft)	Depth (ft)	MW (psi/ft)	DST (psi/ft)	Salinity (ppm)
3050	.560	1200	.580	.460	—
5000	.590	3000	.630	.600	—
6000	.620	3700	.700	.670	23000
7400	.700	4000	.760	.720	18000
7600	.820	4400	.770	.680	14000
7900	.980	4900	.800	.600	
		5300	.810	.650	
		7300	.820		

2) Tenneco-Etchepare-Elliott #1 Well, Colusa County (Franklin & Mandel, 1981)

Located in the Maxwell area in Section 19, T17N, R3W, approximately 10 miles west of the Compton Landing Gas field and about 15 miles from the Willows-Beehive Bend Gas field.

This was a dry hole drilled in 1979 to 5300' T.D. designed to test the Forbes and Guinda formations and the total stratigraphic column penetrated was as follows:

	Depth	Subsea Datum
Base of Tehama fm	740' (est)	-578
Top Forbes fm	740' (est)	-578
Mid-Forbes Marker	+2480'	-2318
"G" Marker-base of Forbes	4313'	-4151
Top Guinda fm	4424'	-4262
Top Funks Shale	4962'	-4800

Formation tests indicate notable overpressuring in the Forbes as indicated below:

Depth (ft)	Pressure (psi)	Pressure Gradient (psi/ft)
2180	1345	.617
2209	1392	.630
2243	1445	.644
2268	1487	.656
2504	1713	.684
2792	2475	.886
3787	3178	.839

The mud weights used in the drilling of this well likewise convincingly demonstrated overpressuring in the Forbes as well as an underlying formation though it should be recognized that as a general practice, most operators in the Sacramento Valley tend to use over-balanced mud formulations. Therefore, as a general rule, when determining pressure gradients from mud weights, only those above .550 should be considered overpressured. The actual mud weights, depths and indicated pressure gradients (which are higher than the measured values) are as follows:

Mud Weight (lbs/gal)	Depth (ft)	Indicated Pres. Gradient (psi/ft)
9.5	850	.494
11.0	1300	.572
11.1	1650	.577
11.0	1850	.572
11.2	2050	.582
12.2	2320	.634
13.3	2450	.692
14.0	2720	.728
17.4	2765	.905
18.7	2925	.972
19.8	3350	1.030
19.4	3650	1.009
18.8	3950	.978
19.2	4100	.998
19.0	4700	.988
19.0	5300	.988

A drill stem test at depths of 2714-95'recovered salt water with chloride content of 1500 to 2100 ppm. The bottom hole temperature was 124°F for a temperature gradient of 2.48°F/100 ft.

A nearby well, the West Azevedo #1, some 1½ miles southeast of the Elliott, in Section 29 penetrated a similar section but at about 1100 feet lower; it likewise encountered overpressuring in the Forbes but the maximum gradient was only .780 psi/ft.

3.4 San Joaquin Valley

3.4.1 General

The stratigraphic succession and formation names used in this heavily developed region are shown in Figures 20A and 20B. As there has been extensive drilling into the Miocene and Oligocene beds, there is considerable stratigraphic control and detail available for these younger Tertiary formations for both the east and west side of the valley, in contrast to the underlying rock sequences. The locations of the various fields in the San Joaquin Valley are shown in Figures 21A, 21B, and 21C.

3.4.2 Geopressure Characteristics

Geopressuring in the San Joaquin Valley is essentially present in the fields along the west side of the basin. One major area, previously discussed in Phase I, would be along the trend of the Kettleman Hills, a major structural feature that extends for about 100 miles in a southeasterly direction from the Coalinga region through the Kettleman North Dome, Middle Dome, and South Dome (latter believed continuous with the Lost Hills) and on to the area of the Semitropic and Button-

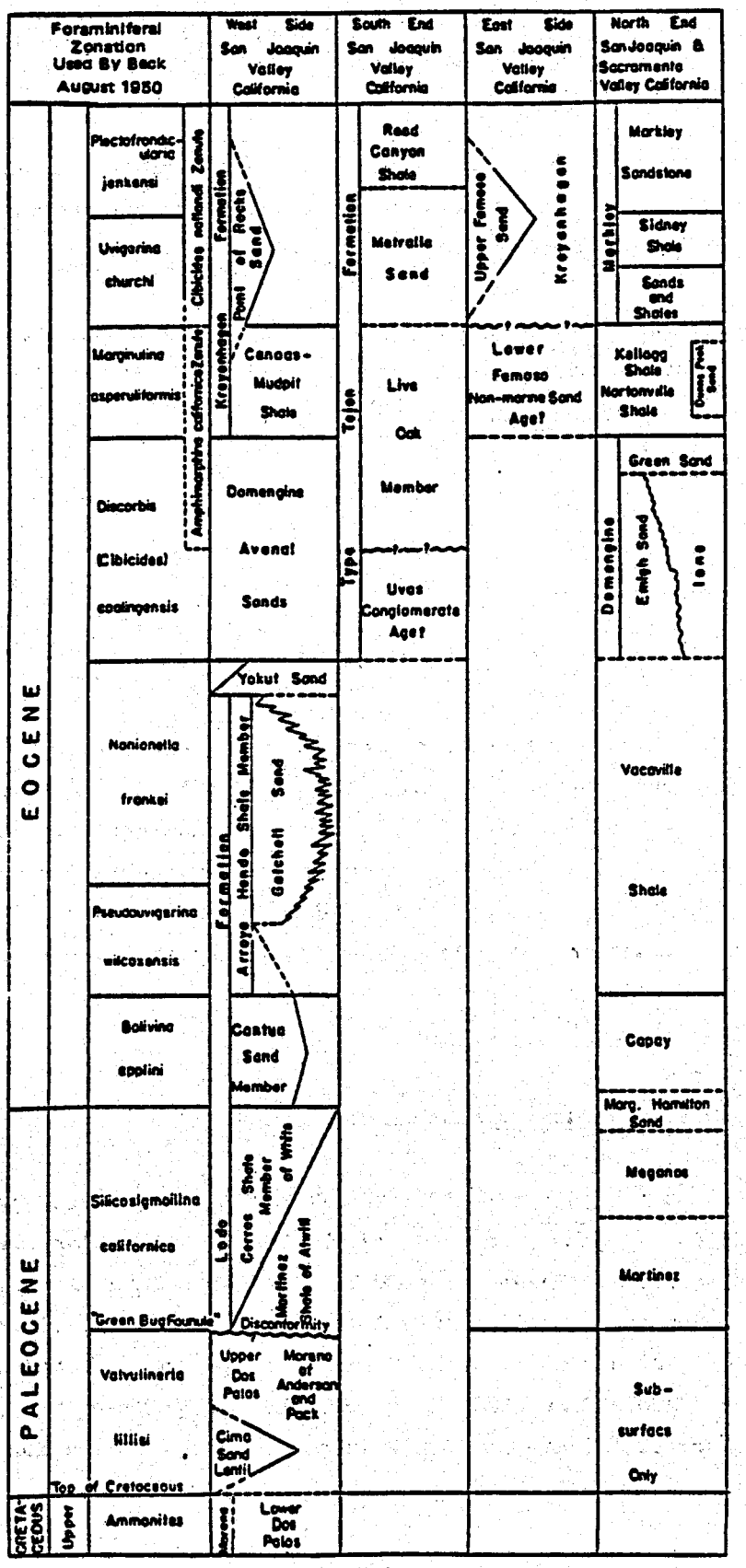


Figure 20A. Stratigraphic Column — San Joaquin Valley, Cretaceous-Eocene

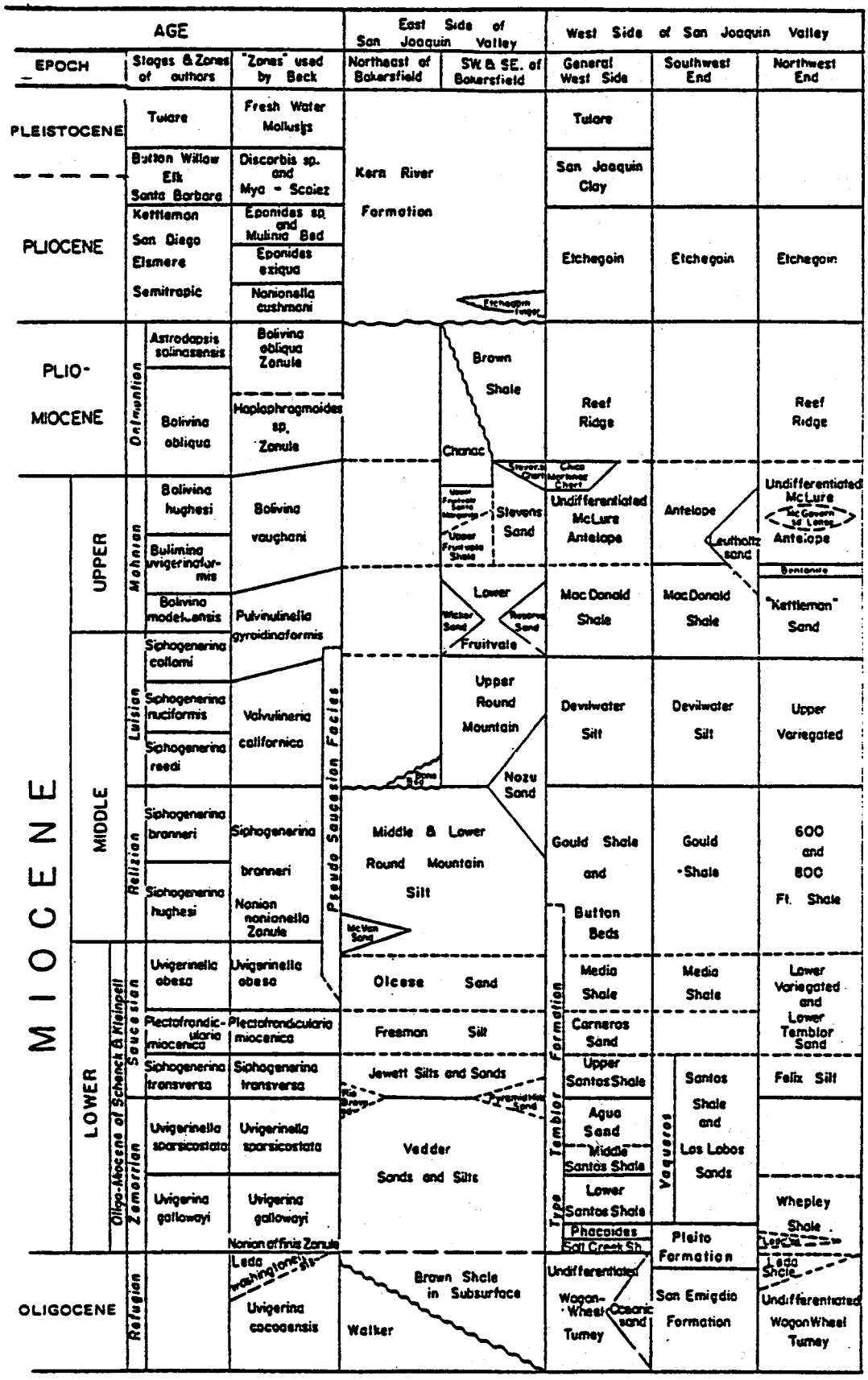


Figure 20B. Stratigraphic Column — San Joaquin Valley, Oligocene-Pleistocene

Source: Pacific Section—Amer. Assoc. Petrol. Geologists

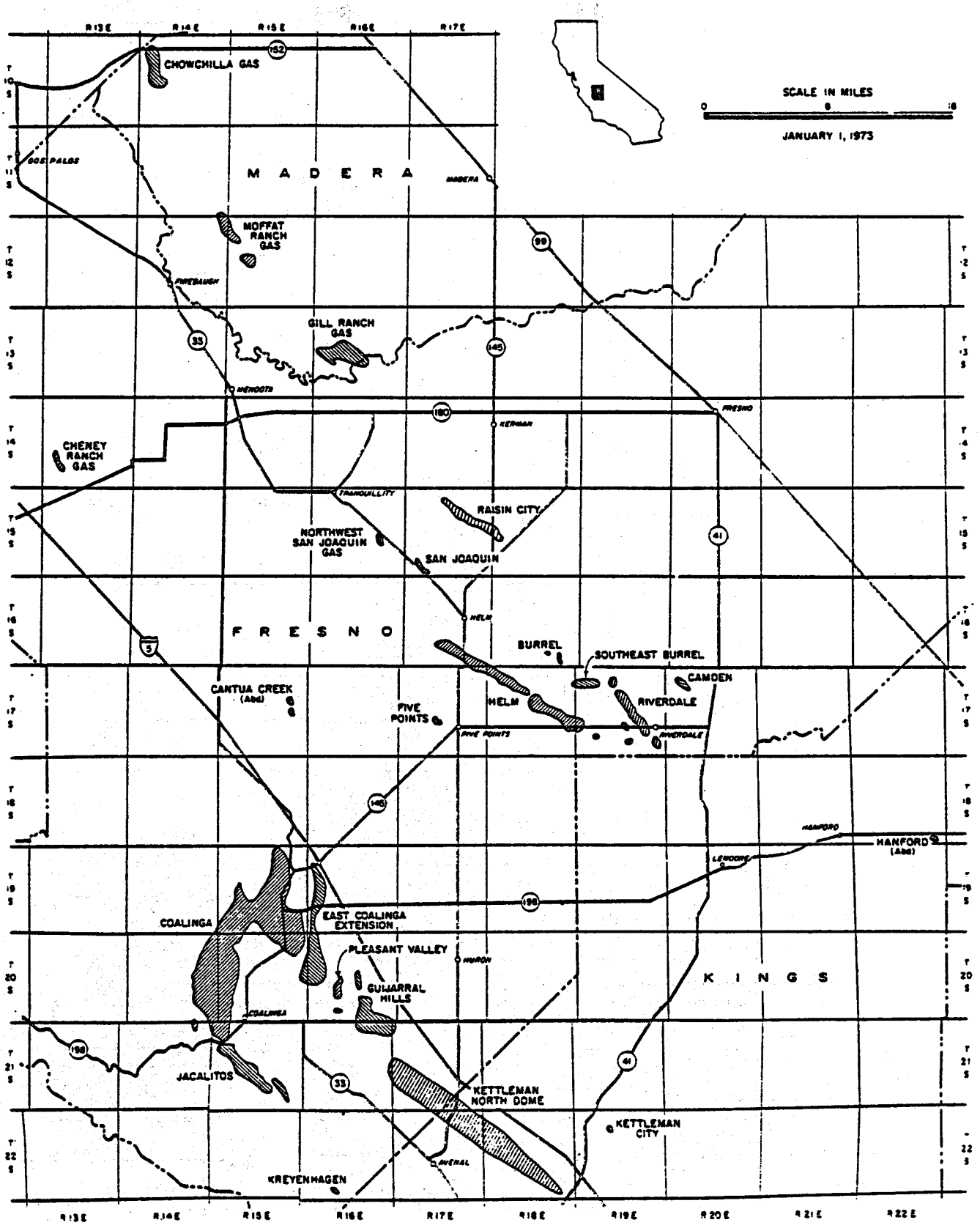


Figure 21A. Location of Fields in Northern San Joaquin Valley

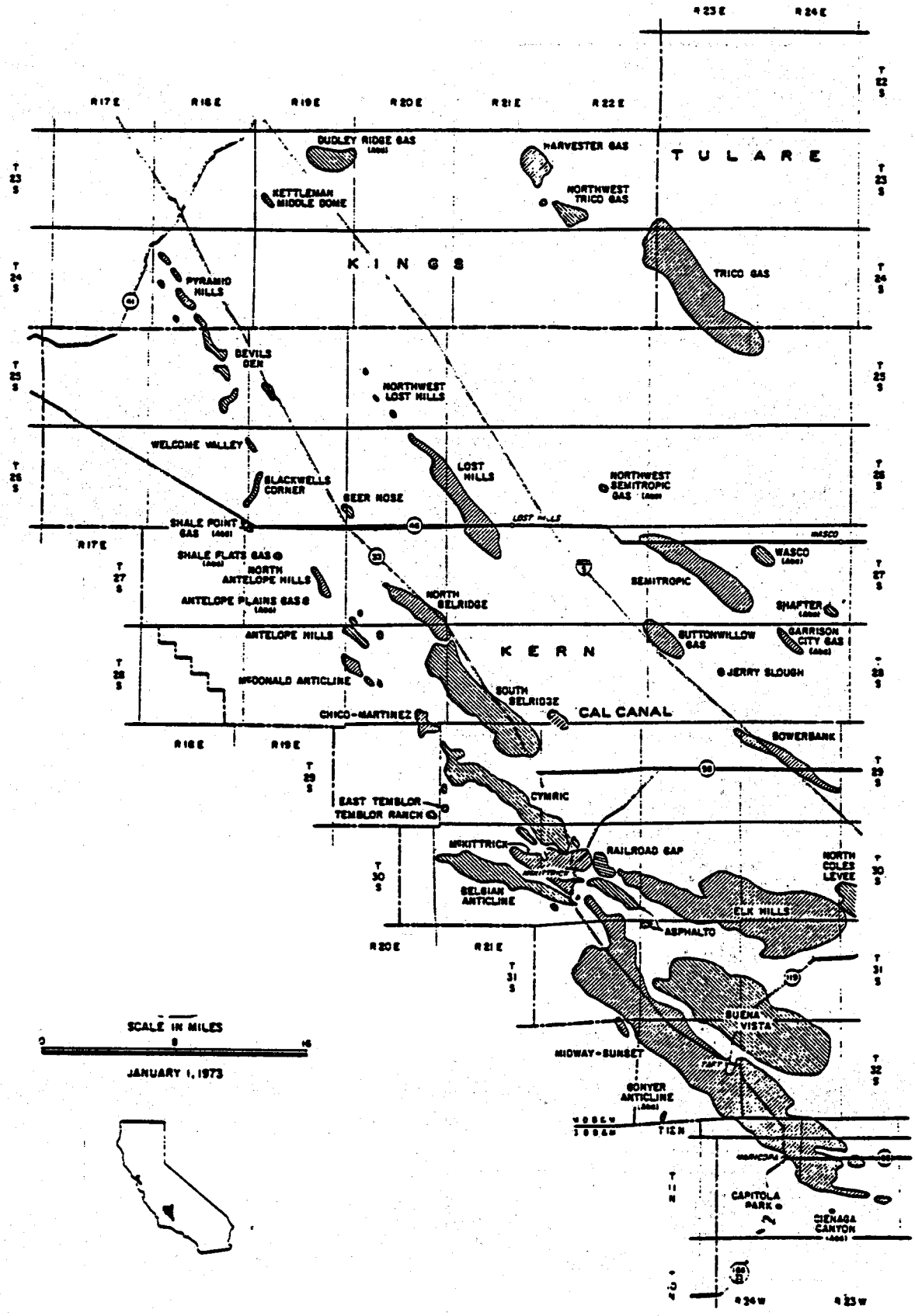


Figure 21B. Location of Fields in Central San Joaquin Valley

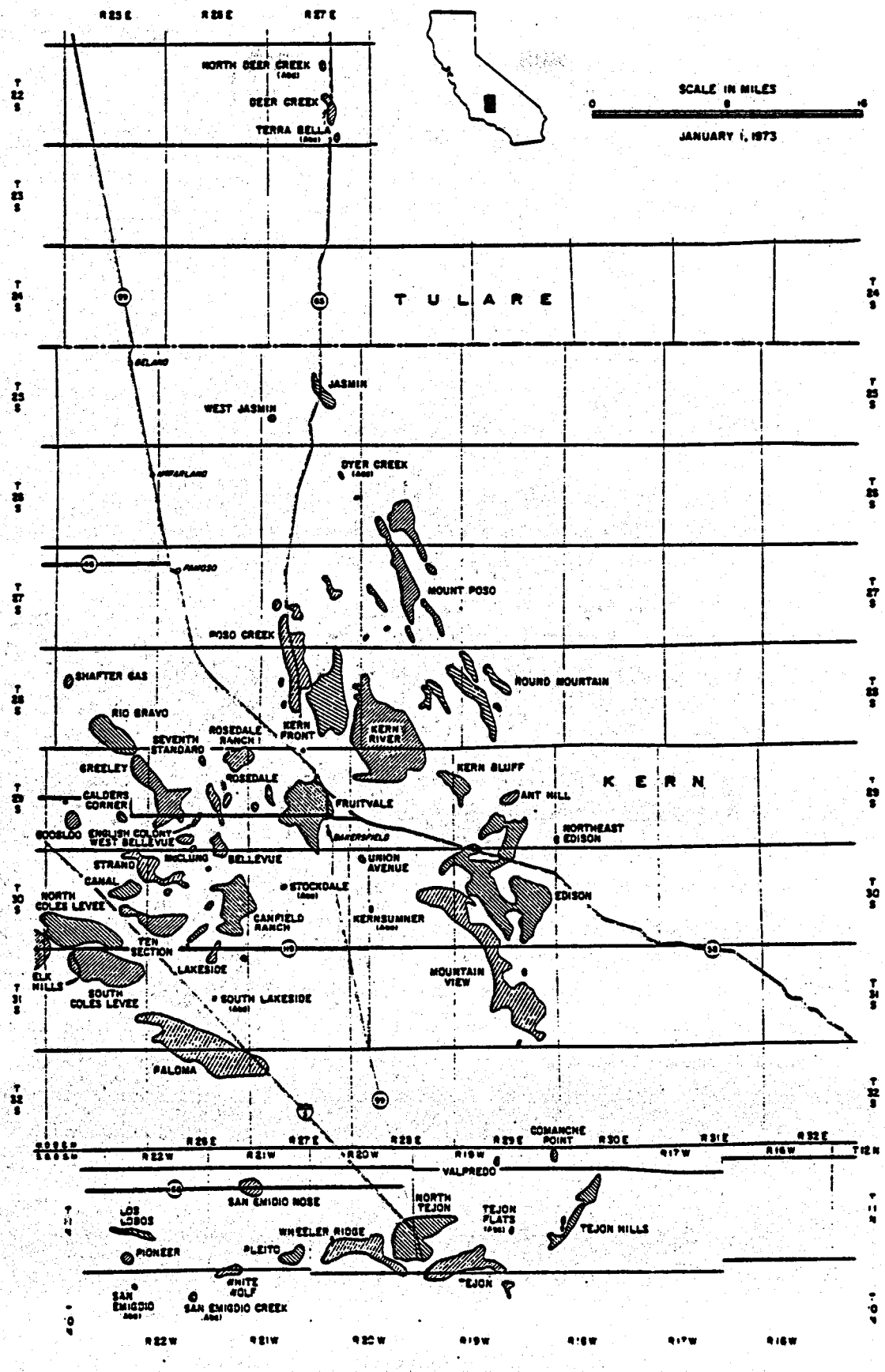


Figure 21C. Location of Fields in Southern San Joaquin Valley

willow fields. Within this belt, geopressures have been noted in upper Cretaceous sediments, the McAdams formation (upper Eocene), Leda sand (Oligocene), Temblor formation (lower Miocene), Stevens formation (upper Miocene), and occasionally in the overlying Etchegoin and San Joaquin sediments (Pliocene).

Slight to moderate geopressures have been reported from fields to the east and southeast such as in the Eocene and Oligocene formations of the Wheeler Ridge field cited in Phase I.

One of the problems associated with obtaining pressure data, whether through direct measurement, use of mud weights, and/or logs is that the California Division of Oil and Gas does not publish this information for oil fields, which predominate in the San Joaquin Valley. Consequently, the only way to acquire this data is to obtain access to the well files maintained by the Division (provided they have not been labled proprietary by the operator involved,which is often the case) or to contact the operator directly for this purpose. In the former instance, the files are not always complete while in the latter case, files were often unavailable for proprietary or other reasons.

Within these limitations, considerable data on geopressured occurrences in the San Joaquin Valley has nevertheless been assembled. Table 6 is a listing of selected geopressured occurrences by field based on data, mostly from deep wells, that has been collected by A.L. Lorshbaugh, District Supervisor of the Bakersfield Office of the California Division of Oil and Gas. This list should not be considered complete but in conjunction with the descriptions of other specific occurrences gleaned from published material and other sources, it should provide a fairly comprehensive overview.

The San Joaquin Valley which has been continually subsiding from the mid-Tertiary to the Recent has been the site for the deposition

TABLE 6

Geopressure and Temperature Data for Deep Wells in Selected Fields in San Jouquin Valley*

Field	Geologic Age	Geologic Fmt.	Depth (ft)	Mud Weight (lbs/cu ft)	Temperature (°F)	Indicated Pres. Grad. (psi/ft)	Indicated Temp. Grad. (°F/100°)
Antelope Hills	Cret(?)	----	11,490	79.5	235	.560	1.62
Antelope Plains Gas (abd)	Paleo(?)	----	4,314	86.0	136	.610	1.76
Asphalto	Eoc.	Pt. of Rocks	13,450	85.5	282	.840	1.65
Beer Nose	Eoc.	Pt. of Rocks	11,993	119.0	286	.600	1.63
Belgian Anticline	----	----	10,868	78.0	252	.550	1.77
NW Belgian Anticline	----	----	8,693	80.0	145	.560	.98
Bellevue	U. Mioc.	Stevens	6,611	79.0	180	.560	1.82
S. Bellevue	U. Mioc.(?)	Stevens	9,951	81.5	185	.570	1.26
W. Bellevue	U. Mioc.	L. Stevens	9,672	84.0	173	.590	1.17
N. Belridge	Eoc.(?)	Kreyenhagen	9,691	98.0	266	.690	2.13
S. Belridge	----	----	14,104	82.0	294	.580	2.08
Bowerbank	L. Mioc.	----	15,350	80.0	260	.560	1.30
Buena Vista	----	----	----	96.0	----	.680	1.98

TABLE 6 (Cont'd)

Field	Geologic Age	Geologic Fmt.	Depth (ft)	Mud Weight (lbs/cu ft)	Temperature (°F)	Indicated Pres. Grad. (psi/ft)	Indicated Temp. Grad. (°F/100°)
Calders Corner	L. Mioc.(?)	----	12,735	85.0	200	.600	1.10
Canal	U. Mioc.(?)	Stevens	10,727	86.5	230	.570	1.58
Canfield Ranch	Olig/ Eoc.(?)	----	15,850	88.0	244	.620	1.16
Canfield Ranch-E. Gosford	Olig/ Eoc.(?)	----	14,064	85.0	221	.600	1.14
Canfield Ranch-Old River	U. Mioc.	Stevens	10,980	83.0	190	.580	1.18
Cienega-Canyon (abd)	Cret.(?)	----	12,515	96.0	240	.680	1.44
S. Coles Levee	Cret.(?)	----	16,186	98.0	392	.690	2.05
Cymric	Eoc.	Kreyenhagen	11,945	79.0	240	.560	1.51
Flank Area	Eoc.	Kreyenhagen	11,848	80.0	236	.560	1.49
McKittrick Front	Eoc.	Kreyenhagen	9,507	84.0	265	.590	2.16
1-Y Area	----	----	11,785	79.5	240	.560	1.53
Sheep Spring Area	----	----	10,140	90.0	198	.630	1.36
Devil's Den, Bates Area	Cret.(?)	----	8,266 9,142	98.0 78.0	182 176	.690 .550	1.48 1.27

TABLE 6 (Cont'd)

Field	Geologic Age	Geologic Fmt.	Depth (ft)	Mud Weight (lbs/cu ft)	Temperature (°F)	Indicated Pres. Grad. (psi/ft)	Indicated Temp. Grad. (°F/100°)
Edison	Mioc.	----	5,572	80.0	125	.560	1.17
	----	----	5,673	----	127	----	1.18
	----	----	5,712	----	132	----	1.26
	----	----	5,732	----	133	----	1.27
	----	----	5,755	----	134	----	1.25
	----	----	5,576	----	134	----	1.28
	----	----	6,544	----	130	----	1.07
Edison-	----	----	4,017	78.0	110	.550	1.24
Edison Groves Area	----	----	4,783	----	116	----	1.17
	----	----	5,589	----	130	----	1.75
Edison-	----	----	4,985	82.0	118	.580	1.16
Main Area	----	----	5,529	----	120	----	1.14
Race Track Hill	Olig/	Walker	5,249	79.0	122	.560	1.18
	Eoc.	Walker	5,498	----	124	----	1.16

* Lorshbaugh, 1981

Note: Since most operators in this region tend to overbalance mud formulations, only those pressure gradients of .550 psi/ft. and more are reported in this tabulation.

of thick off-shelf, deep-water marine clastic sediments throughout the Miocene and marine to continental beds since that time. The dominant source region through most of the Tertiary (till Miocene) has been the Sierra Nevada crystalline complex to the east; since late Miocene, the source terranes also included the highlands to the south and west (Webb, 1977). Based on paleontological and sedimentological characteristics, it is likely that most of the Miocene sediments including the Temblor (lower and middle Miocene) and Stevens sands were deposited in water depths in the range of 4000 to 6000'; hence, it is likely that these sands are turbidites.

There have been several recent studies of the Stevens sand, which is one of the major geopressured formations in the region. The most comprehensive study on the subject was authored by MacPherson (1977) and much of the data and analysis presented herein is from his paper.

The Stevens sand (upper Miocene) is a comprehensive nomenclature for over 5000' of deep marine interbedded sands and shales, the extensive lateral extent of which has been ascribed to the action of major coalescing submarine fans that emanated from various source areas. Essentially, four major cycles of turbidite deposition have been recognized in the Stevens, each of which is characterized by a relatively thick sand layer overlain by thinner shale members, the latter indicating periods of little or no sand supply. The turbidites within the Stevens sequence are apparently representative of the mid-fan facies of a submarine fan complex.

Two associated depositional processes have been recognized within this mid-fan area, namely contemporaneous or growth faulting and distributary channel transport. In terms of geopressured occurrences, the former phenomenon is most significant; it is believed to be caused by sedimentation accompanied by syndepositional faulting, in some respects analagous to that of the Gulf Coast. Similarities include a marked expansion of section on the downthrown side, reverse drag

or roll-over, and the presence of antithetic faults. A further similarity is that the growth faults migrate basinward and become progressively younger as new sediment wedges are accumulated. One dissimilarity, however, is that the principal or master fault plane in the Stevens appears to be nearly vertical and only moderately asymptotic to bedding planes with increasing depth.

It is generally held that conditions for growth faulting occur in a marine shelf environment where thick accumulations of sand are rapidly deposited over low-density shales with high water content. The increased pressure causes the formation of a glide plane similar to a slump block that has an arcuate plan shape and a concave upward cross-section. Ongoing lubrication of the glide or fault plane is furnished by the process of shale dewatering that results in a continual process of sliding and slumping. These conditions have apparently occurred in the Stevens, i.e. a thick, rapidly accumulating turbidite section deposited on a comparably thick sequence of underlying shales in which the growth faulting process was probably promoted by the incidence of periodic tremors. Given this set of depositional conditions and the rather recent geologic time frame, it is not surprising that abnormally high pressures have been encountered in many oil fields of the San Joaquin Valley.

3.4.3 Salinity of Formation Waters

3.4.3.1 Northern Section - Fresno, Kings and Madera Counties

The analysis of oil field waters from this part of the San Joaquin is shown in Table 7. It is particularly interesting to note, especially in the Kettleman North Dome field, the differences in salinities between the Miocene and the underlying Eocene zones - the former salinites are considerably higher. This is the reverse of the commonly found condition where the salinity of subsurface waters increases with depth. This

variation is graphically illustrated for this field and the Guijarral Hills field in Figure 22.

This phenomenon in the Kettleman North Dome field has been further investigated by Kharaka and Berry (1974 and 1974A). In this field, the waters in the McAdams formation (Eocene), which has been termed "effluent-type" water by the authors, is believed to be associated with abnormally high pressures where a thick section of shales and siltstones are currently undergoing or have recently been subjected to compaction. The occurrence of this type of water, characterized by certain diagnostic chemical characteristics compared to waters from comparable geologic sections and depths, may be utilized for inferring the presence of geopressuring in underlying or adjacent sediments. This type of water is present in many other fields on the west side of the San Joaquin, as well as the Sacramento Valleys. Accordingly, even where direct pressure measurements are not readily available (e.g. the California Division of Oil and Gas does not record this information for oil fields), or where deeper zones have not yet been penetrated, their occurrence may be inferred from the presence of this type of formation water. Essentially, effluent-type waters, in contrast to other waters, have lower total dissolved solids and Ca/Na ratios and higher Li/Na, NH_3/Na, B/Cl, HCO_3/Cl, I/Cl, I/Br, and F/Cl ratios.

The producing sediments in the Kettleman North Dome field include five zones in the Temblor (Miocene) and two zones in the McAdams, upper and lower. The latter is underlain by a thick sequence of Mesozoic marine shales and siltstones estimated to be about 40,000' thick of which only 4000' has been penetrated. As shown below in Table 8 and illustrated in Figure 23, the original pressures in both the Miocene and Eocene sediments are only slightly above hydrostatic, but they approach lithostatic in the underlying Cretaceous rocks.

TABLE 7
ANALYSES OF OIL AND GAS FIELD ZONE WATERS – NORTHERN SAN JOAQUIN VALLEY*

Field Area Zone	Formation or member	Anions (parts/million)				Cations (parts/million)			Boron (ppm)	Total dissolved solids (ppm)	pH	Resistivity ohms/M at 77°F	Salinity ppm. NaCl	Number of Samples
		Chloride	Sulfate	Carbonate	Bicarbonate	Sodium + Potassium	Calcium	Magnesium						
Burrel														
Miocene	Zilch	24,800	0	0	330	13,170	1,600	660	30	40,690	7.1	--	40,920	1
Burrel, Southeast														
Miocene	Zilch	27,801	0	0	185	15,186	744	1,122	18	45,114	7.5	--	45,872	1
Coalinga														
Eastside														
Etchegoin	Etchegoin	668	2,310	0	390	1,466	24	8	--	5,043	8.1	--	1,100	2
Santa Margerita	Santa Margerita	2,707	59	0	305	3,100	60	13	--	8,244	8.0	--	4,467	2
Eastside, North														
Tumbler	Tumbler	427	315	0	3,095	1,595	300	478	6	5,703	7.8	1.583	704	6
Eastside, Southeast														
Tumbler	Tumbler	1,575	42	2	4,884	2,321	28	20	23	9,407	7.7	1.016	2,596	11
Eastside, Southwest														
Tumbler	Tumbler	511	36	0	2,599	1,283	32	8	6	4,477	7.7	2.626	846	8
Westside														
Etchegoin	Etchegoin	1,605	760	113	1,684	1,875	33	40	15	5,714	7.7	1.366	2,648	6
Westside, North														
Tumbler	Tumbler	980	28	11	2,872	1,707	23	11	18	5,728	8.6	1.465	1,615	12
Westside, Southeast														
Tumbler	Tumbler	1,665	21	0	2,721	2,039	29	25	31	6,516	7.6	1.238	2,712	6
Westside, Southwest														
Tumbler	Tumbler	3,766	8	0	2,918	3,398	32	62	55	10,191	7.7	.711	6,211	7
Coalinga, East, Extension														
Coalinga Nose														
Vaqueros	Vaqueros	8,695	63	--	3,733	6,720	257	60	62	19,566	--	--	14,313	3
Gatchell	Gatchell	209	136	44	1,268	699	9	3	7	2,258	8.6	--	345	8
Northeast														
Gatchell	Gatchell	300	134	32	1,262	728	9	3	--	2,397	7.6	3.390	695	8
Gill Ranch Gas														
Panoche	Panoche	12,600	5	0	98	7,391	660	44	100	20,877	6.8	--	20,741	1
Guijarral Hills														
Main														
Smith	Tumbler	4,810	527	--	669	3,314	241	13	35	9,341	--	--	7,936	17
Allison	Tumbler-Vaqueros	29,363	371	--	399	5,735	11,765	25	--	52,005	6.4	--	48,449	6
Lode	Lode	16,167	23	0	2,814	9,737	1,302	133	76	30,258	6.9	.225	26,661	7
North Lode	Lode	13,632	41	0	2,812	7,868	1,390	141	66	26,225	6.6	.257	21,503	4
McAdams	McAdams	2,943	60	--	1,325	2,509	28	5	--	--	--	--	4,863	1
Bonnel	Gatchell	1,986	43	60	1,626	1,931	26	6	--	5,676	8.2	1.260	3,274	2
Gatchell	Gatchell	1,674	88	0	1,621	1,509	21	1	26	4,513	7.9	1.550	2,633	3
Northwest														
Lode	Lode	14,890	6	0	2,142	8,610	1,315	62	--	27,225	6.9	.364	24,550	1
Polvadero														
Sanger	Tumbler	4,781	532	0	668	--	136	20	27	9,314	7.3	.467	7,889	4
Bourdieu	Gatchell	4,218	19	--	1,054	3,612	31	7	99	9,223	--	--	6,960	3
West														
Lode	Lode	12,457	34	0	2,846	7,908	1,023	99	60	24,618	6.9	.277	20,554	2
Main														
Lemore														
Miocene	Zilch	26,367	19	0	322	14,708	1,332	561	32	44,217	7.8	--	43,487	10
Eocene	Domengine	11,347	35	0	2,501	7,549	549	115	76	22,242	7.8	--	18,707	1
Main														
Miocene	Zilch	22,900	19	0	1,231	13,188	1,250	379	62	39,748	7.3	--	37,785	6
Eocene	Hortonville, Domengine, Wheatville	9,757	28	0	2,032	6,312	963	66	80	18,757	7.3	--	16,090	7
Truman	----------	5,665	19	0	1,402	4,051	64	21	75	11,333	7.8	--	9,365	5
Jacalitos														
Etchegoin	Etchegoin	18,195	2,771	0	55	10,421	2,206	102	--	33,749	7.1	.205	29,996	2
U. Tumbler	Tumbler	3,988	--	0	790	3,676	672	68	27	11,838	7.3	.362	9,874	7
L. Tumbler	Tumbler	3,296	185	0	207	3,318	262	127	61	9,380	7.6	.636	8,733	7
Kettleman Middle Dome														
Etchegoin	Etchegoin	22,736	15	--	403	12,148	1,924	303	--	37,380	--	--	37,514	2
Tumbler	Tumbler	21,224	87	--	1,122	11,715	1,862	131	--	36,243	--	--	35,020	5
Burbank	Burbank	15,832	125	--	533	9,306	862	128	--	26,808	--	--	26,123	2
Vaqueros	Vaqueros	37,549	84	--	342	20,588	3,185	154	--	61,961	--	--	61,956	1
Kreyenhagen	Kreyenhagen	7,621	74	--	1,162	5,306	71	21	--	14,266	--	--	12,575	3
U. McAdams	McAdams	5,358	35	--	513	3,526	85	14	--	9,593	--	--	8,841	4
Kettleman North Dome														
Brown Shale	Reef Ridge-McLure	27,624	86	--	4,618	18,076	912	326	--	52,622	--	--	45,580	4
Tumbler Zone I	Tumbler	20,967	198	--	3,034	12,585	1,742	125	--	38,700	--	--	34,561	3
Tumbler Zone II, North	Tumbler	18,367	449	--	1,063	11,290	1,095	74	--	32,366	--	--	30,305	3
Tumbler Zone II, Middle	Tumbler	18,337	351	--	1,223	10,943	1,451	139	--	33,369	--	--	30,255	2
Tumbler Zone II, South	Tumbler	22,991	150	0	2,185	13,194	1,953	149	--	40,311	6.7	.184	37,925	3
Tumbler Zone II, High Sulfate	Tumbler	17,543	731	--	1,703	10,846	1,180	98	--	32,133	--	--	28,979	2
Tumbler Zone III, North	Tumbler	21,759	130	267	1,911	12,739	1,629	168	24	38,640	9.4	.185	35,895	4
Tumbler Zone III, South	Tumbler	17,898	180	0	1,127	10,125	1,310	139	--	30,986	--	.218	29,321	3
Tumbler Zone III, High Sulfate	Tumbler	3,690	809	33	790	4,217	168	26	40	11,228	8.0	.539	9,056	3
Tumbler Zone IV, North	Tumbler	21,933	397	0	1,517	11,356	2,856	205	--	38,384	6.5	.172	36,178	3
Tumbler Zone IV, Middle	Tumbler	23,813	570	--	1,252	11,839	3,349	131	17	40,508	9.7	.163	37,971	3
Tumbler Zone IV, South	Tumbler	20,457	665	--	1,025	10,304	2,884	85	--	35,627	--	--	33,754	1
Tumbler Zone IV, High Sulfate	Tumbler	11,286	635	--	858	7,252	701	58	--	21,077	--	--	18,630	2
Tumbler Zone V_1, North	Tumbler	22,432	413	--	1,040	9,247	5,161	34	--	38,334	--	--	37,846	3
Tumbler Zone V_1, Middle	Tumbler	19,966	444	0	721	8,350	4,432	43	--	33,962	7.1	.210	32,930	3
Tumbler Zone V_1, South	Tumbler	20,801	434	--	266	5,688	7,267	27	--	34,709	--	--	34,313	3
Tumbler Zone V_1, High Sulfate	Tumbler	10,963	534	--	619	6,157	1,262	28	--	19,667	--	--	18,090	3
Tumbler Zone V_2, North	Tumbler	21,357	384	--	560	7,838	5,398	90	--	35,982	--	--	35,238	4
Tumbler Zone V_2, High Sulfate	Tumbler	17,136	528	0	773	6,823	3,805	99	41	29,365	7.7	.225	28,251	2

TABLE 7—CONTINUED
ANALYSES OF OIL AND GAS FIELD ZONE WATERS—NORTHERN SAN JOAQUIN VALLEY

Field Area Zone	Formation or member	Anions (parts/million)				Cations (parts/million)			Boron (ppm)	Total dissolved solids (ppm)	pH	Resistivity ohms/M at 77°F	Salinity ppm. NaCl	Number of Samples
		Chloride	Sulfate	Carbonate	Bicarbonate	Sodium + Potassium	Calcium	Magnesium						
Kettleman North Dome—Continued														
Tumbler Zone V_3, North...	Tumbler.....	18,800	340	--	768	8,105	3,943	50	--	32,134	--	--	31,020	3
Tumbler Zone V_3, Middle..	Tumbler.....	16,523	381	--	848	7,275	3,411	18	--	28,474	--	--	27,263	1
Tumbler Zone V_3, South...	Tumbler.....	15,672	451	--	330	6,235	3,877	42	--	26,942	--	--	25,859	1
Tumbler Zone V_4, North...	Tumbler.....	20,721	440	--	760	9,228	4,273	38	--	35,571	--	--	34,190	2
Tumbler Zone V_4, Middle..	Tumbler.....	20,707	438	0	731	7,744	5,242	89	36	34,968	6.2	.195	34,137	2
Tumbler Zone V_4, South...	Tumbler.....	26,450	364	--	233	9,396	6,892	126	--	43,660	--	--	43,972	1
Vaqueros.....	Vaqueros.....	17,924	331	10	872	9,211	2,880	84	51	31,871	7.4	.222	29,536	6
Kreyenhagen.....	Kreyenhagen.....	16,091	33	0	2,245	11,061	112	43	26	29,658	6.9	.201	28,539	2
E. McAdams, Northeast....	McAdams.....	1,905	7	0	362	1,321	32	1	21	3,663	7.3	1.556	3,141	3
E. McAdams, Northwest....	McAdams.....	3,723	46	--	1,010	2,741	44	14	--	7,577	--	--	6,143	2
E. McAdams, South.....	McAdams.....	5,603	31	--	647	3,787	76	9	--	10,155	7.5	.601	9,245	5
L. McAdams.....	McAdams.....	4,293	46	16	1,220	3,237	17	8	42	8,856	8.2	.696	7,881	5
Joaquin Ridge.....	Panoche.....	4,675	83	21	345	2,709	343	13	--	8,039	--	--	7,384	1
Pleasant Valley														
Gatchell.....	Gatchell.....	229	104	40	1,101	725	5	3	7	2,456	8.1	3.715	377	4
Pyramid Hills														
Segany														
Er, above thrust.....	Point of Rocks....	3,033	23	--	4,025	3,403	33	22	14	8,695	8.1	.653	4,985	3
Morris														
Er, above thrust.....	Point of Rocks....	3,570	7	--	4,276	3,833	28	22	16	9,774	8.2	.585	5,891	2
Er, below thrust.....	Point of Rocks....	6,230	17	--	517	4,180	48	24	39	10,819	7.8	.540	10,280	2
Avenal.....	Avenal.....	4,270	15	0	545	2,840	73	15	58	7,806	7.6	.760	7,046	1
Westslope														
Er, above thrust.....	Point of Rocks....	3,292	12	--	4,557	4,544	19	25	--	14,448	--	--	5,432	3
Raisin City														
Miocene Tar.....	Zilch.....	29,600	21	--	166	15,683	1,800	802	8	48,[illegible]80	6.7	.125	48,840	1
Miocene.....	Zilch.....	26,809	3	0	277	13,675	1,924	743	8	43,978	7.8	.138	44,219	7
Eocene.....	Nortonville, Domengine.....	13,502	2	0	244	7,827	610	171	25	22,459	7.9	.260	22,247	4
Riverdale														
Miocene.....	Zilch.....	24,347	26	0	4,398	13,851	1,194	531	34	42,712	7.0	.150	40,473	7
Eocene.....	Nortonville, Domengine.....	13,693	46	0	944	8,121	807	138	49	23,880	7.6	--	22,576	3

Note: In some samples the salinity content (ppm) has a higher apparent value than the total dissolved solids content (ppm). This technically is impossible; however, it probably represents the degree of accuracy in determining the various constituents.

*Sullivan, 1971

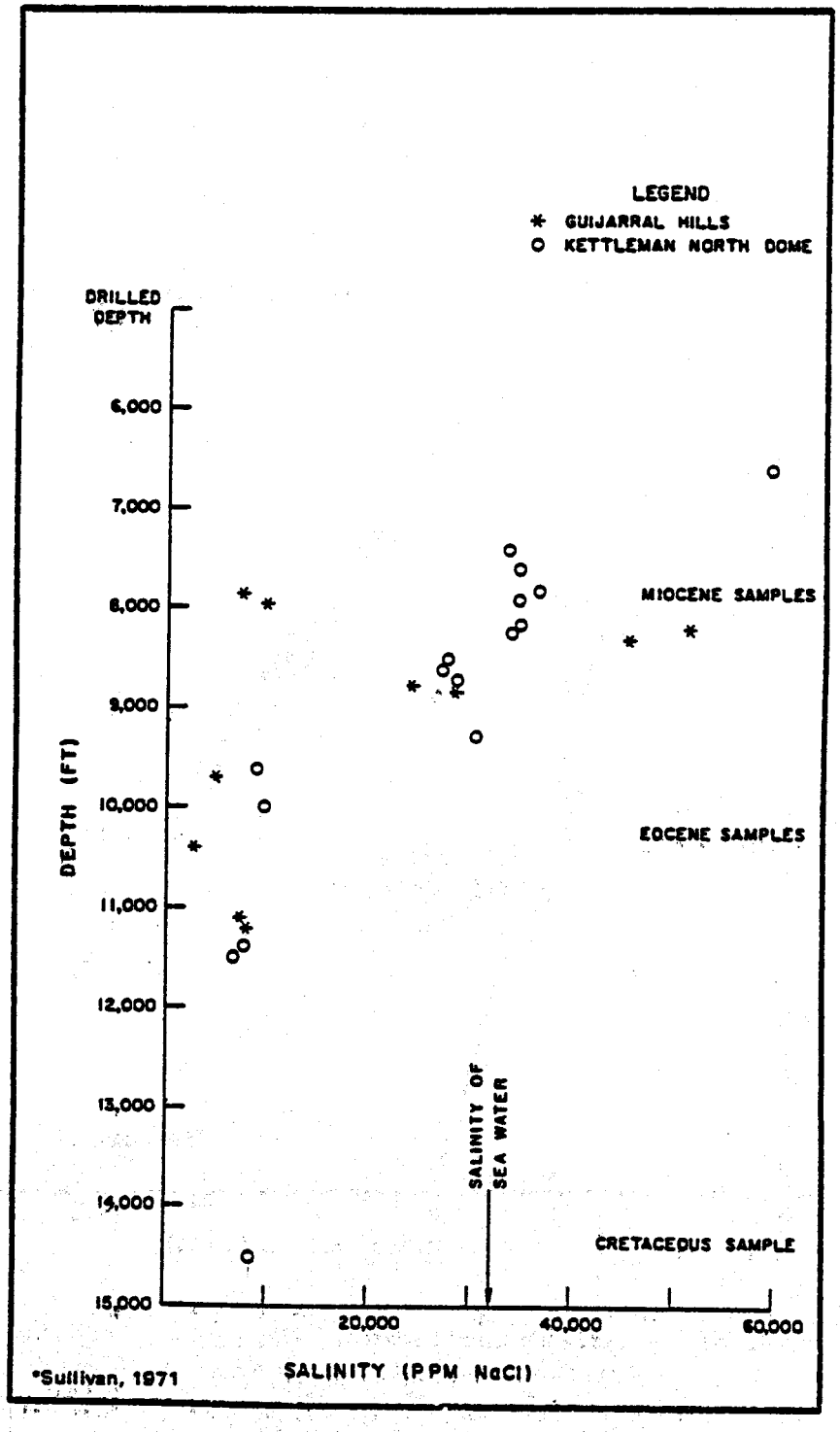


Figure 22. Graph Showing Salinity vs. Depth for Selected Fields in Northern San Joaquin Valley*

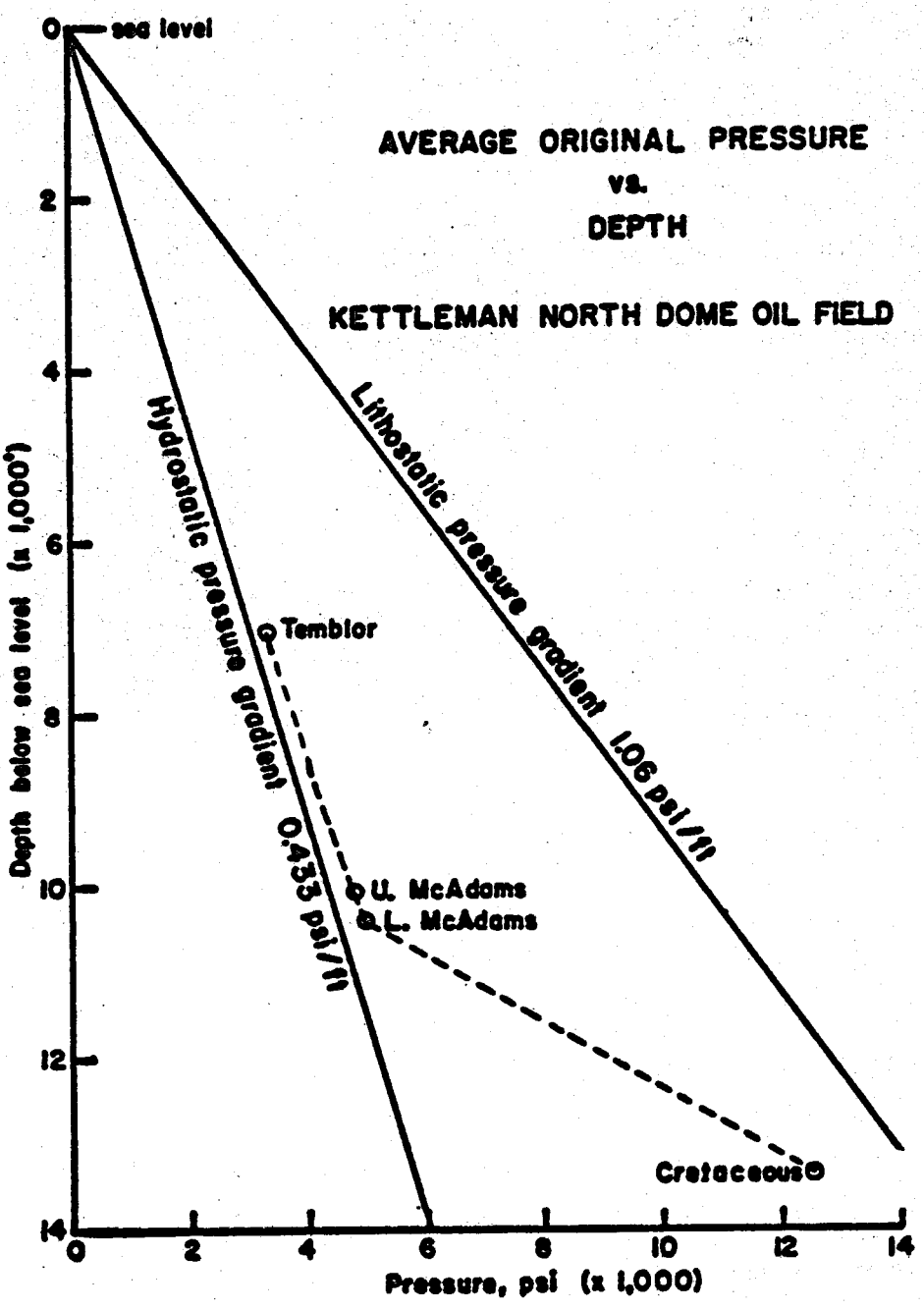


Figure 23. Average Original Pressures Plotted Against Depths Below Sea Level at Kettleman North Dome Oil Field. This Plot Shows a Strong Component of Upward Flow of Water from Cretaceous to McAdams (From Kharaka and Berry, 1974)

PRESSURE, TEMPERATURE, AND SALINITY OF MIOCENE AND EOCENE PRODUCING ZONES IN KETTLEMAN NORTH DOME FIELD, KERN COUNTY

A. Original Temperatures and Pressures at Reservoir Midpoints (1)

Prod. Zone	Depth Res. Midpoint (ft)	Orig. Res Pres. (psi)	Res. Temp (°F)	Pres Grad (psi/ft)
Temblor 1 (Mio)	6250	3110	199	.498
" 2	6690	3230	207	.483
" 3	6960	3310	210	.476
" 4	7060	3340	214	.473
" 5	7330	3420	217	.467
Temblor Pool	7040	3330	212	.473
Vaqueros (Mio)	7700	3525	223	.458
Upper McAdams (Eoc)	10,100	4780	264	.473
Lower McAdams	10,450	5915	270	.470
Cretaceous	beyond 12000' approaches lithostatic gradient			

B. Salinity of Temblor Formation Waters (36 samples) (1)

1.	37109 TDS	13.	7243	25.	12724
2.	6643	14.	7155	26.	17918
3.	24573	15.	6961	27.	23056
4.	3306	16.	7215	28.	159301
5.	31433	17.	6717	29.	33602
6.	28836	18.	7134	30.	32234
7.	26796	19.	15223	31.	29287
8.	36668	20.	38750	32.	2127
9.	40050	21.	20229	33.	22888
10.	7052	22.	21132	34.	34538
11.	6782	23.	31873	35.	34724
12.	6685	24.	30044	36.	25131
			Average		30789

C. Salinity of Upper and Lower McAdams Formation Waters (2)

Upper McAdams		Lower McAdams
1. 11528 TDS		1. 100024 TDS
2. 12209		2. 8994
3. 9769		3. 8074
4. 4851	Average	9030
5. 10179		
6. 10080		
7. 3076		
8. 9033		
9. 10530		
Avg 9028		

1) Kharaka and Berry, 1974

2) Kharaka and Berry, 1974A

Previous discussion in Phase I and in the prior section on the Sacramento Valley indicated the role of tectonism in causing and maintaining these extremely high pressures. This is believed to have similarly occurred along the west side of the San Joaquin Valley which resulted in the squeezing out of large quantities of interstitial water from the Mesozoic shales and siltsones. The primary direction of flow of this water was upward and the first formation encountered in this field was the McAdams - the mixing and flushing of original McAdams water by water derived from the underlying sediments resulted in its total or near-total replacement. It should be noted that the salinity of water from these shaly zones tends to be much lower than sea water due to the high compaction pressure to which they have been subjected and the subsequent expulsion of much of this sea water.

3.4.3.2 Southwestern Section

The salinities for the producing zones in the fields in the southwestern part of the San Joaquin Valley in Kern County essentially represent the structural extension of the fields cited above. Table 9, indicating the salinities for these southwestern fields, shows that the decrease in salinity with depth is likewise operative in this region. This is graphically presented for three fields in Figure 24, e.g. Elk Hills field with a decline in salinity from Pliocene to lower Miocene beds and the North Belridge field with a reduction in total dissolved solids from upper Miocene to Oligocene zones.

3.4.3.3 Southeastern Section

The analyses of formation waters from the southeastern fields of San Joaquin Valley in Kern County is presented in Table 10. Unlike the other analyses, the waters in many of these fields display the more common phenomenon of increased salinity with increasing depth, as depicted in Figure 25 for several representative fields. This is to be anticipated in view of its relative distance from the locus of tectonic activity on the west side of the San Joaquin Valley.

TABLE 9
ANALYSES OF OIL ZONE WATERS – SOUTHWESTERN SAN JOAQUIN VALLEY*

Field / Area / Zone	Formation or member	Anions (parts/million)				Cations (parts/million)			Boron (ppm)	Total solids (ppm)	pH	Resistivity ohms/M at 77°F	Salinity g/g NaCl	Number of samples
		Chloride	Sulfate	Carbonate	Bicarbonate	Sodium+Potassium	Calcium	Magnesium						
Antelope Hills														
Tulare	Tulare	483	66	0	1,093	710	29	8	—	2,394	8.2	3.350	47	1
IA Gas	Devilwater-Gould	4,300	29	174	2,379	2,787	14	15	—	10,699	8.4	—	414	1
Button Bed	Temblor	2,540	95	86	2,498	2,674	22	12	—	7,936	—	—	244	2
Agua	Temblor	1,533	144	195	2,727	2,253	19	7	4	6,500	8.6	1.178	148	7
Antelope Hills, North														
Agua	Temblor	11,207	0	0	2,373	7,892	112	64	48	20,222	7.6	0.306	1,088	2
Asphalto														
Stevens	Stevens	13,145	24	0	3,321	9,863	71	37	114	26,929	7.7	0.263	1,286	15
Belgian Anticline														
Main, B-K, and Telephone Hills Areas														
Phacoides	Temblor	8,036	23	87	1,701	5,775	122	37	84	16,033	8.1	0.291	773	5
Oceanic	Tumey	7,083	30	0	2,179	5,093	245	77	91	14,871	7.9	0.355	682	7
Point of Rocks	Kreyenhagen	999–10,822	7–87	0	307–2,574	655–6,442	88–1,044	9–70	20–225	2,347–18,658	6.7–8.2	3.100–0.328	96–1,063	10
Northwest and Forbes Areas														
Phacoides	Temblor	10,992	3	0	689	6,778	380	88	44	19,078	7.7	0.322	1,089	2
Oceanic	Tumey	10,362	51	0	750	6,363	508	94	70	18,071	7.0	0.335	996	2
Point of Rocks	Kreyenhagen	11,160	75	0	474	6,763	1,256	104	165	19,034	7.0	0.329	1,074	5
Belridge, North														
Fractured Shale	Antelope	22,642	14	0	1,111	14,817	180	66	—	38,845	—	—	2,128	2
Temblor	Button Bed	24,379	737	0	696	14,848	1,111	223	—	41,951	6.5	—	2,347	5
Bloemer	Phacoides	12,855	819	0	685	8,476	356	44	tr.	23,235	—	—	1,239	2
Belridge 64	Phacoides	12,144	824	0	725	7,664	355	87	—	21,790	7.5	—	1,157	12
Y Sand	Oceanic	4,079	9	0	1,227	3,832	70	24	33	10,042	7.3	0.490	494	1
Belridge, South														
Upper Tulare	Tulare	2,719	147	94	1,701	2,277	40	112	—	7,009	8.6	1.062	362	18
Lower Tulare	Tulare	10,328	15	0	2,929	6,986	180	281	64	20,532	6.9	0.398	995	15
Etchegoin	Etchegoin	14,950	8	4	645	9,015	298	262	32	25,590	7.6	0.230	1,452	2
Belridge Diatomite	Monterey	19,518	50	0	5,120	13,093	716	373	—	38,878	7.5	—	1,820	5
Fractured Shale	Monterey	14,940	27	0	7,236	12,192	89	67	—	34,562	7.5	—	1,440	4
Blackwells Corner														
Agua	Te[illegible]	8,191	19	0	2,494	5,877	193	289	—	17,978	7.3	0.410	738	1
Buena Vista														
Front														
Sub-Scalez	San Joaquin	19,729	20	0	343	10,968	1,053	403	35	32,499	7.3	0.201	1,900	12
Mulinia	Etchegoin	21,712	34	0	384	11,706	1,473	480	40	35,780	7.3	0.181	2,091	3
Hills														
Sub-Scalez (Top Oil)	San Joaquin	21,396	11	0	484	11,700	1,122	824	24	35,177	7.1	0.189	2,055	25
Sub-Mulinia	Etchegoin	24,678	89	0	282	12,992	1,691	634	84	40,317	7.3	0.162	2,340	1
Wilhelm-Gusher	Etchegoin	20,489	163	0	240	11,688	1,046	386	82	34,080	7.3	0.190	1,968	4
Calitroleum	Etchegoin	20,055	14	0	690	12,250	512	238	40	33,799	7.3	0.195	1,929	11
99-6D	Etchegoin	16,271	273	0	709	10,144	420	159	—	27,995	7.3	0.230	1,567	9
Basal Etchegoin	Etchegoin	19,062	73	0	2,103	12,278	242	257	113	34,214	7.3	0.183	1,824	8
Stevens	Monterey	14,380	28	0	2,519	10,203	69	41	126	27,430	8.1	0.269	1,386	4
Fractured Shale	Antelope	15,615	12	0	1,586	10,150	232	101	145	27,620	7.8	0.228	1,489	12
Cymric														
Cymric Flank														
Carneros	Temblor	3,723	811	0	2,886	3,612	32	21	—	10,825	7.9	0.642	358	1
McKittrick Front														
Amnicola	Tulare	1,048	40	61	2,167	1,410	43	85	5	4,844	7.8	1.900	101	3
Olig	Reef Ridge	10,938	23	0	4,703	8,173	337	186	—	14,448	—	—	1,053	1
Carneros	Temblor	13,011	12	0	2,897	9,366	52	19	75	25,178	8.1	0.266	1,253	2
Phacoides	Temblor	7,757	84	0	1,800	5,140	100	80	—	14,232	7.2	0.454	699	1
Oceanic	Tumey	6,247	151	0	2,308	4,234	50	27	—	13,668	7.3	0.494	602	1
Salt Creek, Main														
Etchegoin	Etchegoin	11,133	166	—	2,650	7,788	171	112	80	22,721	7.8	0.298	1,072	1
Carneros	Temblor	11,356	8	0	2,246	7,460	397	139	121	21,657	7.8	0.274	1,092	8
Phacoides	Temblor	14,426	15	0	252	7,001	1,798	223	204	23,863	7.3	0.273	1,370	3
Sheep Springs														
Phacoides	Temblor	13,682	73	0	442	7,322	1,045	346	—	22,814	7.2	0.260	1,319	1
Welport														
Tulare	Tulare	3,042	48	0	2,621	2,689	90	101	33	8,598	7.1	0.891	293	3
Amnicola	Tulare	7,928	72	0	3,002	5,512	232	232	65	17,052	7.6	0.411	784	1
Fitzgerald	Etchegoin	12,380	30	0	3,041	8,342	122	173	124	24,573	7.8	0.305	1,192	3
Fractured Shale	Antelope	12,304	6	0	5,050	9,698	100	90	96	27,172	7.7	0.264	1,135	1
Carneros	Temblor	13,316	40	0	2,947	9,469	181	47	79	25,967	7.7	0.259	1,282	3
Agua	Temblor	13,000	46	0	1,485	8,180	462	160	230	23,334	7.4	0.284	1,252	3
Phacoides	Temblor	9,170	44	0	1,550	6,153	245	63	96	17,228	7.5	0.366	883	3
Oceanic	Tumey	11,533	27	0	590	6,917	452	150	150	19,686	7.2	0.323	1,111	4
Point of Rocks	Kreyenhagen	12,778	90	0	186	2,946	3,894	78	—	21,380	6.7	0.328	1,254	10
3-Y Gas														
McKittrick Sand	Reef Ridge	6,238	184	0	2,429	4,197	124	44	62	12,235	7.6	0.585	604	3
Devils Den														
Alferitz														
Point of Rocks	Kreyenhagen	4,970	31	6	1,132	3,320	112	34	—	9,806	7.8	0.601	478	1
Old														
Point of Rocks	Kreyenhagen	4,246	—	—	865	2,813	470	1,243	—	9,637	7.2	—	418	1

TABLE 9 – CONTINUED
ANALYSES OF OIL ZONE WATERS – SOUTHWESTERN SAN JOAQUIN VALLEY

Field / Area / Zone	Formation or member	Anions (parts/million) Chloride	Sulfate	Carbonate	Bicarbonate	Cations (parts/million) Sodium+Potassium	Calcium	Magnesium	Boron (ppm)	Total solids (ppm)	pH	Resistivity ohms/M at 77°F	Salinity g/g NaCl	Number of samples
Elk Hills														
Mya (Gas)	San Joaquin	23,850	12	0	410	14,278	2,134	1,138	12	46,842	6.6	0.136	2,778	3
Above Scales	San Joaquin	21,328	18	0	222	11,188	1,506	552	22	34,824	6.8	0.188	2,053	4
Sub-Scales	San Joaquin	21,365	24	0	338	11,493	1,289	534	25	35,028	7.0	0.187	2,067	34
Mulinia	Etchegoin	19,689	9	0	343	10,644	1,098	532	21	32,347	7.1	0.195	1,896	5
Sub-Mulinia	Etchegoin	20,109	70	0	904	11,205	1,029	581	21	33,939	7.3	0.189	1,936	11
Bittium	Etchegoin	20,742	15	0	1,166	11,709	997	553	24	35,186	8.0	0.192	1,998	1
Wilhelm-Gusher	Etchegoin	17,723	282	0	622	9,931	1,023	375	54	29,872	7.4	0.220	1,706	9
Olig	Reef Ridge	15,686	45	0	5,287	11,104	586	220	110	32,942	6.9	0.218	1,511	1
Stevens	Antelope	11,723	63	0	3,718	8,830	107	40	95	24,500	7.7	0.258	1,127	16
Carneros	Temblor	7,779	67	0	2,971	6,166	24	7	38	17,083	8.0	0.389	749	1
McDonald Anticline														
Theta (2nd Devilwater)	Devilwater	2,653	9	0	2,050	2,278	104	54	8	7,146	7.4	0.800	256	1
Tolco (7th Devilwater)	Devilwater	1,456	22	12	3,302	2,888	60	15	14	7,759	8.4	0.841	140	3
Button Bed	Temblor	244	28	105	3,564	1,707	18	5	2	5,890	8.2	1.457	24	3
Agua	Temblor	259	22	79	3,860	1,773	25	8	12	6,178	8.3	1.585	34	2
Point of Rocks	Kreyenhagen	1,334	30	144	720	1,267	4	1	16	3,500	8.7	2.200	129	1
McKittrick														
Main														
Olig	Reef Ridge	4,635	4	0	2,542	3,959	70	56	33	11,612	7.8	0.850	447	7
Stevens	Antelope	12,515	3	0	5,065	9,810	117	43	111	27,534	7.8	0.251	1,206	3
Northeast														
Amnicola	Tulare	751–4,331	25–58	0	421–3,232	568–4,033	3–56	22–45	—	1,975–11,735	7.6–8.2	0.623–2.260	72–417	3
Antelope	Monterey	14,892	22	0	2,734	10,224	182	162	194	28,213	7.2	0.238	1,434	1
Carneros	Temblor	12,783	18	0	2,985	9,272	99	12	—	25,152	7.5	0.277	1,229	3
Phacoides	Temblor	5,875	24	0	2,519	4,729	46	16	36	13,260	8.1	0.512	566	4
Oceanic	Tumey	7,062	90	0	1,672	5,138	83	10	—	14,056	7.7	0.449	680	1
Point of Rocks	Kreyenhagen	13,827	47	0	420	6,068	2,604	48	—	23,014	6.8	0.283	1,331	1
Midway-Sunset														
Central														
Top Oil	San Joaquin	22,221	6	0	304	11,892	1,378	563	89	36,405	7.6	0.168	2,139	3
Kinsey	Etchegoin	19,100	47	0	358	10,400	962	565	—	31,442	7.4	0.202	1,857	1
Wilhelm	Etchegoin	21,785	24	0	245	11,671	1,478	466	34	35,732	7.6	0.180	2,098	1
Gusher	Etchegoin	14,998	94	0	1,580	8,022	545	274	—	25,514	8.0	0.248	1,444	1
Calitroleum	Etchegoin	21,221	11	0	482	10,297	1,058	389	48	35,183	6.8	0.186	2,043	7
Lakeview	Reef Ridge	17,497	14	0	1,934	10,985	397	338	88	31,108	6.5	0.222	1,675	3
Sub-Lakeview	Reef Ridge	4,514	26	0	3,572	4,209	47	32	88	12,503	7.6	0.589	435	7
Monarch	Antelope	483–14,254	0–94	0–120	1,802–3,897	1,173–10,344	2–248	8–75	33–112	4,074–27,814	7.3–8.3	2.230–0.247	47–1,372	8
Exeter	Antelope	11,495	48	0	1,950	8,074	73	30	104	20,696	7.9	0.292	1,107	1
Globe Anticline														
Tar	Tulare	1,800–7,318	5–152	0	735–5,397	1,441–5,849	20–150	1–189	31–56	4,234–17,845	7.0–7.9	1.470–0.416	174–705	4
Top Oil	San Joaquin	22,400	tr.	0	1,342	12,200	1,184	738	23	38,071	7.1	—	2,155	1
Etchegoin	Etchegoin	16,294	33	0	1,031	8,770	849	302	38	28,010	7.0	0.251	1,568	3
Potter	Reef Ridge	35–3,600	0–355	0–450	246–3,353	391–2,827	12–342	2–313	6–45	1,553–9,438	7.0–8.7	5.460–0.570	3–347	19
Marvic	Reef Ridge	440	835	22	2,457	1,688	21	1	—	5,575	7.7	1.870	43	1
Old Belgian Anticline														
Tulare	Tulare	4,502	441	0	2,861	4,062	41	82	—	11,858	7.6	0.600	424	1
2nd Mya (Tar)	San Joaquin	2,650	7	0	2,695	2,701	60	36	35	8,314	7.7	0.980	256	1
Potter	Reef Ridge	1,794–4,150	5–230	0	242–5,612	1,710–3,626	36–272	2–88	25–44	5,558–10,829	7.6–8.4	1.822–0.503	172–400	5
Republic														
Republic	Antelope	700	23	6	3,930	1,850	14	46	—	6,568	8.4	—	67	1
Santiago														
Metson	Antelope	8,200	tr.	0	2,835	6,215	104	55	50	17,622	7.7	—	789	2
Leutholtz	Antelope	5,761	12	0	2,600	4,334	288	24	44	13,110	7.8	0.518	555	4
Sunset														
Tulare	Tulare	9,877	150	0	4,941	7,825	41	355	118	21,344	7.9	0.338	951	1
Top Oil	San Joaquin	15,459	6	0	1,836	9,448	425	357	47	27,583	7.4	0.243	1,488	5
Kinsey	Etchegoin	15,628	6	0	794	8,096	828	387	—	26,443	7.2	0.243	1,505	2
Wilhelm	Etchegoin	17,780	22	0	355	10,800	870	835	—	30,156	7.1	—	1,710	1
Gusher	Etchegoin	16,350	55	0	2,712	11,106	235	145	—	30,753	—	—	1,575	1
Calitroleum	Etchegoin	16,858	15	0	1,161	10,243	712	175	110	28,967	7.3	0.251	1,624	3
10-10	Antelope	9,396	81	47	1,802	6,802	9	12	71	18,131	—	0.366	905	1
Monarch	Antelope	8,416	171	0	3,595	6,602	160	35	89	18,487	7.8	0.356	810	5
Rass	Antelope	10,105	25	76	1,431	7,077	80	15	123	18,779	8.3	0.343	973	1
Obispo (frac. shale)	Antelope	10,046	37	0	3,697	7,631	132	56	91	21,639	7.4	0.351	967	3
Moco	Antelope	10,187	58	62	3,009	7,672	78	51	55	21,220	7.4	0.400	982	4
Uvigerina C.	Antelope	7,608	14	0	3,728	5,814	131	67	80	17,228	7.5	0.420	733	3
Pacific (frac. shale)	Antelope	6,267	124	4	2,621	4,913	138	27	16	14,091	6.9	0.505	604	3
Leutholtz	Antelope	1,934	34	41	2,571	2,330	32	12	—	7,259	8.1	1.090	186	3
Railroad Gap														
Amnicola	Tulare	2,232	220	0	1,046	1,888	65	26	—	5,578	7.8	1.190	224	2
Olig	Reef Ridge	8,917	63	0	2,350	7,091	127	58	—	19,607	7.4	0.325	855	1
Valv Foraminita	Devilwater	19,009	100	0	8,350	15,301	131	37	—	42,929	7.7	0.183	1,831	1
Carneros	Temblor	15,890	55	0	1,880	10,758	199	28	—	28,809	7.7	0.230	1,530	1
Phacoides	Temblor	3,334	811	0	2,639	3,610	19	4	—	10,165	7.5	0.751	326	3

*Weddle, 1967

TABLE 10
ANALYSES OF OIL AND GAS FIELD ZONE WATERS—SOUTHEASTERN SAN JOAQUIN VALLEY*

Field area zone	Formation or member	Anions (parts/million)				Cations (parts/million)			Boron (ppm)	Total dissolved solids (ppm)	pH	Resistivity ohms/M at 77°F	Salinity NaCl (ppm)	No. of samples
		Chloride	Sulfate	Carbonate	Bicarbonate	Sodium + Potassium	Calcium	Magnesium						
Ant Hill														
Olcese	Olcese	945	43	50	1,379	1,130	19	11	14	3,539	8.3	2.049	1,559	3
Jewett	Jewett	2,766	1	0	131	1,700	110	10	16	4,717	7.9	1.197	4,563	1
Bellevue														
Main														
Stevens	Stevens	20,353	28	0	1,015	13,236	256	36	125	35,081	7.4	.190	33,582	1
South														
Stevens	Stevens	17,993	21	0	4,823	12,541	625	125	-	33,628	7.2	.199	29,688	2
Bellevue, West														
Stevens	Stevens	15,222	37	-	2,318	14,280	687	104	108	38,392	7.1	.160	25,116	1
Buttonwillow Gas														
San Joaquin	San Joaquin	16,386	20	0	416	9,376	959	166	-	27,324	7.4	.231	27,037	1
Calders Corner														
Stevens	Stevens	15,067	75	72	3,023	10,669	530	70	-	29,046	7.4	.189	24,860	1
Canal														
Gas zone	Etchegoin	14,713	19	0	409	8,692	612	143	-	24,639	7.1	.250	24,276	1
Stevens	Stevens	15,371	30	0	4,404	10,804	440	173	-	31,241	7.0	.220	25,362	2
Canfield Ranch														
East														
Stevens	Stevens	13,925	57	0	3,689	10,375	65	13	-	28,134	7.7	.274	22,976	3
South Gosford														
Stevens	Stevens	11,912	35	0	3,450	7,095	575	161	127	24,235	7.2	.280	19,655	2
West Gosford														
Stevens	Stevens	13,806	-	-	-	-	-	-	111	27,688	-	-	22,780	1
Old														
Stevens	Stevens	13,452	2	-	4,575	9,382	582	114	36	28,309	6.8	.240	22,196	1
Coles Levee, North														
Etchegoin(gas)	Etchegoin	6,309	15	0	901	4,111	346	62	22	11,786	7.6	-	10,410	6
Stevens	Stevens	13,368	33	0	3,406	9,316	415	38	104	26,912	7.0	.266	22,057	8
Coles Levee, South														
Etchegoin(gas)	Etchegoin	12,011	20	0	2,093	8,735	701	195	48	25,848	7.3	.269	19,818	3
Stevens	Stevens	12,807	74	-	3,113	8,881	426	77	91	25,392	6.9	.218	21,131	8
Comanche Point														
Santa Margarita	Santa Margarita	163	12	0	421	252	-	2	5	688	7.9	-	269	1
Edison														
Edison Grove														
Olcese	Olcese	7,602	11	0	306	4,450	376	103	34	12,897	7.4	.476	12,543	5
Jeppi														
Jeppi	Chanac	206	133	30	281	286	15	13	-	990	8.8	-	340	1
Jewett	Freeman-Jewett	9,834	54	0	290	5,164	999	107	36	16,455	7.0	.369	16,226	2
Pyramid Hill	Jewett	10,770	21	0	213	5,299	1,428	73	32	17,809	7.2	.347	17,770	3
Vedder	Vedder	6,210	13	20	116	3,008	919	18	25	10,307	7.7	.563	10,246	3
Main														
Kern River	Kern River	41	6	0	980	189	150	19	1	1,389	7.1	-	68	2
Wicker	L. Fruitvale Sh.	100	12	0	584	200	90	18	2	966	7.6	-	165	2
Fractured Schist	Schist basement	98	21	70	907	318	34	32	4	1,536	8.0	-	162	8
Racetrack Hill														
Chanac	Chanac	128	24	0	494	242	29	3	-	920	7.5	-	211	4
Mozu	Round Mountain	98	-	-	-	-	-	-	2	-	7.7	-	162	1
Jewett	Freeman-Jewett	823	6	16	123	574	15	2	10	1,553	8.4	3.400	1,358	4
Pyramid Hill	Jewett	744	13	7	0	522	18	5	5	1,451	8.0	4.000	1,228	3
Vedder	Vedder	320	46	0	220	249	39	9	-	1,110	8.0	-	528	1
West														
Santa Margarita	Santa Margarita	360	2	0	726	475	29	1	4	1,596	7.6	4.400	594	1
Mozu	Round Mountain	541	1	7	675	534	53	8	-	1,819	8.1	3.800	893	1
Vedder	Vedder	2,638	4	0	323	1,684	132	9	30	4,769	7.6	1.139	4,353	1
English Colony														
Stevens	Stevens	16,561	22	0	4,656	12,028	284	79	144	33,726	7.3	.210	27,326	4
Fruitvale														
Calloway														
Chanac	Chanac	2,073	32	0	1,487	1,259	339	15	1	5,337	7.1	1.757	3,420	10
Main														
Fairhaven	Etchegoin	200	-	-	1,236	238	184	78	0.5	1,938	7.4	-	330	4
Chanac	Chanac	84	-	-	2,770	699	202	90	0.2	4,071	7.5	-	138	8
Graley														
Stevens	Stevens	14,260	36	0	3,470	10,247	200	57	62	28,315	7.5	.253	23,529	9
12-21	Jewett	19,800	28	0	340	14,342	832	92	101	36,032	6.4	.191	32,670	5
Rio Bravo-Vedder	Jewett-Vedder	10,193	256	0	1,133	6,959	145	25	36	18,705	7.4	.335	16,818	9
Vedder	Vedder	11,634	341	0	1,030	7,741	251	36	40	21,050	7.5	.296	19,196	9
Jasmin														
Vedder	Vedder	92	88	0	312	212	6	2	1.2	727	7.8	-	152	2
Kern Bluff														
"Transition"	"Transition"	60	178	0	290	224	4	3	-	644	7.8	-	99	1
Santa Margarita	Santa Margarita	122	46	5	335	210	14	2	3.8	648	8.1	-	201	1
Kern Front														
Chanac	Chanac	48	4	-	686	268	25	7	0.5	1,070	7.7	-	79	10
Kern River														
Kern River	Kern River	78	4	0	349	126	34	10	0.2	598	7.4	-	129	24

TABLE 10—CONTINUED
ANALYSES OF OIL AND GAS FIELD ZONE WATERS—SOUTHEASTERN SAN JOAQUIN VALLEY

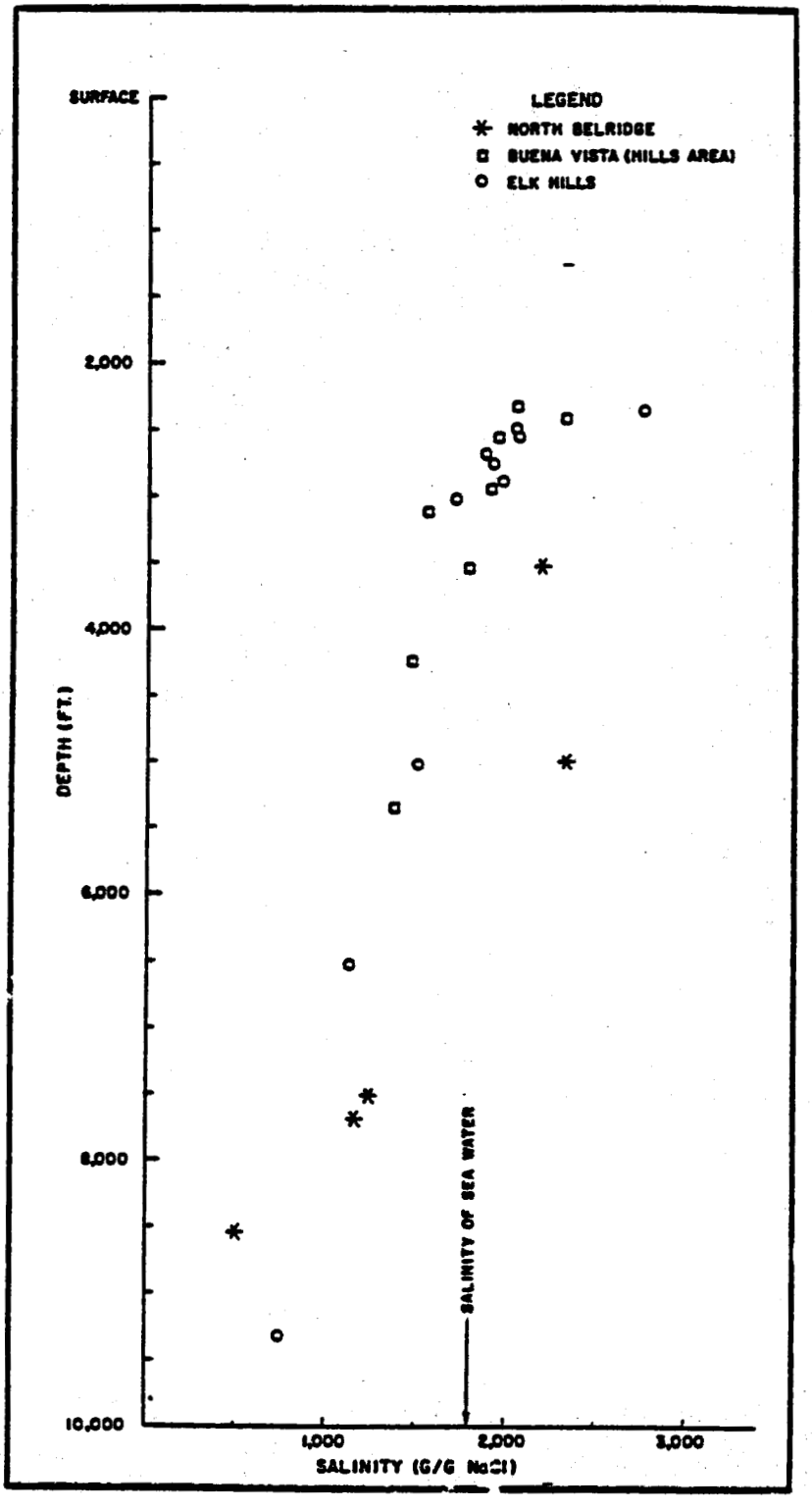
Field area zone	Formation or member	Anions (parts/million) Chloride	Sulfate	Carbonate	Bicarbonate	Cations (parts/million) Sodium + Potassium	Calcium	Magnesium	Boron (ppm)	Total dissolved solids (ppm)	pH	Resistivity ohms/M at 77°F	Salinity NaCl (ppm)	No. of samples
Kern River-Continued														
China	Kern River	44	6	0	416	139	35	10	0.1	645	7.7	-	726	4
Lakeside														
Stevens	Stevens	13,098	0	0	4,423	9,144	430	100	2.3	27,195	7.1	.319	21,612	1
Los Lobos														
Etchegoin	Etchegoin	11,512	16	0	312	7,051	345	78	-	19,324	7.4	.376	18,994	4
Lost Hills														
Etchegoin	Etchegoin	14,287	13	0	3,918	10,189	176	188	145	28,804	7.4	.247	23,574	18
Cahn	McLure	17,515	19	0	3,874	12,664	61	91	133	34,112	7.6	.202	28,900	9
Lost Hills, Northwest														
Overall	Fruitvale or Antelope	21,300	2	0	1,834	14,320	189	206	82	37,852	7.3	.180	35,145	2
Mount Poso														
Granite Canyon														
Vedder	Vedder	114	590	0	301	247	152	22	0.4	1,431	7.2	5,326	188	5
Main														
Vedder	Vedder	615	32	0	325	484	31	7	1.0	1,489	7.7	4.425	1,015	17
Mountain View														
Arvin														
Chanac	Chanac	5,853	22	0	276	3,200	514	64	6	9,930	7.1	.395	9,657	2
Cattani	Chanac	472	20	2	566	486	16	5	8	1,554	8.2	5.901	779	4
Arvin, West														
Chanac	Chanac	1,015	4	25	107	617	87	5	8	1,864	8.7	2.864	1,675	5
Jewett	Freeman-Jewett	7,650	24	0	1,850	4,065	1,391	3	50	14,993	7.4	.436	12,623	1
Main														
Chanac	Chanac	283	14	8	676	421	20	6	6	1,426	8.0	5.566	467	5
Santa Margarita	Santa Margarita	6,459	3	0	358	3,077	820	162	8	10,884	7.1	.574	10,657	2
Nozu	Round Mountain	11,961	18	0	1,949	8,404	53	24	102	22,468	8.0	.295	19,736	3
Vaccaro														
Cattani	Chanac	15,106	389	0	40	3,923	5,256	17	6.3	24,793	6.9	.240	24,925	1
Paloma														
U. Scalez	San Joaquin	4,895	16	0	659	3,067	232	51	4.8	8,920	7.2	.849	8,077	1
5th Mya & R.S.	San Joaquin	12,695	9	0	238	7,048	804	256	22	21,075	6.5	-	20,945	1
Symons	Fruitvale or Antelope	4,580	20	-	3,270	4,114	58	17	-	12,059	7.4	-	7,557	1
Paloma	Fruitvale or Antelope	11,422	79	0	3,169	8,357	188	34	-	2,324	6.6	-	18,846	1
Pioneer														
Pioneer	Media	30,203	194	0	328	10,183	7,796	362	63	49,066	6.8	.141	49,835	7
Pleito														
Ranch														
Chanac	Chanac	5,396	72	0	500	3,262	335	46	43	9,712	7.5	.360	8,903	2
Poso Creek														
McVan														
Basal Etchegoin	Etchegoin	38	-	-	166	80	7	-	0.3	296	7.9	2.280	62	1
Premier														
Basal Etchegoin	Etchegoin	175	6	18	447	281	8	2	1	924	8.1	-	289	4
Chanac	Chanac	234	5	0	733	387	24	9	1	1,400	7.8	6.305	386	17
Rio Bravo														
Gas zone	Etchegoin	23,393	91	0	112	12,358	1,833	411	72	38,328	6.4	.199	38,598	7
Rio Bravo	Jewett	10,389	154	3	1,032	7,033	140	23	30	18,829	7.6	.341	17,141	3
Vedder	Vedder	12,894	456	0	793	8,419	310	46	33	23,056	7.4	.316	21,275	3
Osborne	Vedder	13,568	611	0	988	9,246	202	28	37	24,749	7.2	.348	22,387	2
Helbling	Vedder	7,930	248	0	1,582	5,791	64	12	27	15,680	7.7	.432	13,084	4
Rosedale														
Main														
Stevens	Stevens	17,839	11	0	2,205	12,091	190	108	94	32,094	7.1	.196	29,434	2
North														
Stevens	Stevens	23,430	5	0	122	14,032	688	209	-	38,515	6.3	.200	38,659	1
Rosedale Ranch														
Lerdo	Etchegoin	13,247	16	0	1,252	6,762	940	645	46	22,853	7.0	.294	21,857	15
Chanac	Chanac	17,202	12	0	1,914	9,287	1,279	586	61	30,001	6.9	.222	28,383	6
Round Mountain														
Coffee Canyon														
Pyramid Hill	Jewett	462	12	0	461	455	14	5	4.5	1,410	7.7	4.608	762	1
Vedder	Vedder	773	12	0	178	514	37	10	2.4	1,524	7.5	3.757	1,275	1
Main														
Jewett	Jewett	1,491	8	0	293	1,006	30	20	-	2,712	7.9	2.200	2,460	1
Vedder	Vedder	1,005	22	0	107	578	86	13	-	1,845	7.5	3.400	1,658	2
San Emigdio Creek														
Eocene	Tejon	15,312	15	0	1,180	9,309	824	65	116	26,719	6.6	.239	25,265	2
San Emigdio Nose														
Reef Ridge	Reef Ridge	10,367	234	0	1,005	6,439	939	31	96	18,417	7.4	.355	17,106	3
Semitropic														
San Joaquin	San Joaquin	20,507	52	0	268	10,726	1,376	593	7	33,850	7.4	-	33,836	7
Seventh Standard														
Stevens	Stevens	18,212	4	0	4,961	12,366	951	116	-	36,772	7.3	.202	30,050	2
Strand														
East														
Stevens	Stevens	22,695	42	0	3,410	13,840	581	115	-	38,685	6.8	.181	37,647	3

TABLE 10—CONTINUED
ANALYSES OF OIL AND GAS FIELD ZONE WATERS—SOUTHEASTERN SAN JOAQUIN VALLEY

Field area zone	Formation or member	Anions (parts/million) Chloride	Sulfate	Carbonate	Bicarbonate	Cations (parts/million) Sodium + Potassium	Calcium	Magnesium	Boron (ppm)	Total dissolved solids (ppm)	pH	Resistivity ohms/M at 77°F	Salinity NaCl (ppm)	No. of samples
Strand-Continued														
Main														
Etchegoin	Etchegoin	20,336	6	0	367	10,725	1,618	395	-	33,447	7.2	.199	33,554	1
Stevens	Stevens	21,264	30	0	878	13,478	860	126	-	39,464	6.9	.175	35,085	5
Vedder	Vedder	9,125	100	0	488	5,800	201	19	55	15,167	7.1	.386	15,056	1
Northwest														
Stevens	Stevens	20,366	33	0	2,629	13,672	346	76	-	37,122	7.1	.187	33,604	3
Tejon														
Central														
"Transition" & Santa Margarita	"Transition" & Santa Margarita	146	2	46	1,353	591	24	12	0.21	2,185	8.1	3.879	341	1
Reserve & Valv	Fruitvale & Round Mountain	2,602	8	0	1,933	1,992	221	95	5	6,923	7.4	.970	4,295	1
JV	Freeman-Jewett	3,695	218	0	350	2,453	142	11	9.2	7,040	7.5	.814	6,097	1
Eastern														
"Transition" & Santa Margarita	"Transition" & Santa Margarita	274	0	22	372	316	17	1	1	942	8.3	-	452	2
Tejon Hills														
Santa Margarita	Santa Margarita	35	2	0	690	233	32	7	4.7	999	7.5	-	58	7
Valv	Round Mountain	57	3	3	230	117	4	2	3.8	418	7.9	-	94	2
Tejon, North														
Main														
Oligocene	Oligocene	19,222	8	0	418	11,138	975	207	68	31,750	7.5	.175	31,716	1
South														
JV	Freeman-Jewett	15,476	66	0	1,376	6,772	3,065	160	31	26,678	7.8	.273	25,535	2
Vedder	Vedder	20,083	106	16	1,214	6,766	5,917	12	52	34,012	7.1	.216	33,136	6
Ten Section														
Etchegoin	Etchegoin	17,736	2	0	103	9,552	1,429	186	-	29,003	7.4	.216	29,264	2
Stevens	Stevens	14,682	23	0	1,377	9,843	731	97	51	26,415	7.4	.260	24,225	6
Trico														
First Mya	San Joaquin	19,450	16	0	373	9,800	1,22	820	5.8	31,702	5.7	.173	32,092	6
Atwell Island	San Joaquin	27,348	9	0	259	13,561	2,046	1,086	6.0	44,530	6.7	.150	45,454	4
Wasco														
Fractured Shale	Etchegoin	16,717	47	0	5,585	12,621	185	73	-	35,243	7.1	-	27,583	3
Vedder	Vedder	12,667	1,300	0	679	8,654	361	54	-	23,914	7.3	-	20,900	2
Eocene	Kreyenhagen	11,829	1,276	0	891	8,188	316	16	16	22,538	7.3	.151	19,317	2
Wheeler Ridge														
Central														
Santa Margarita	Santa Margarita	3,460	15	0	1,615	2,128	496	102	10	7,931	7.6	.790	5,710	1
Main	Fruitvale	4,567	4	0	1,006	2,805	235	137	15	8,834	7.5	.678	7,535	3
Oligocene	Oligocene	12,213	-	8	2,072	7,976	444	129	32	22,995	7.4	.425	20,151	3
Vedder	Vedder	27,200	37	0	1,400	11,340	5,760	87	43	46,139	7.2	.179	44,880	1
Tejon	Tejon	23,225	111	-	1,174	8,403	6,140	61	0	39,147	6.6	.230	38,321	2
Northeast														
FA-2	Fruitvale Shale	4,418	8	0	487	2,528	265	111	16	7,762	7.5	.911	7,289	4
Telegraph Canyon														
Tejon	Tejon	18,900	51	0	1,301	7,799	3,952	131	74	32,530	6.8	.247	31,185	2
Windgap														
Reserve	Fruitvale	13,600	4	0	537	8,692	168	5	27	22,893	7.2	.465	22,110	1
Oligocene	Oligocene	2,100	4	0	1,171	13,660	344	4	62	36,296	7.4	.296	3,665	1
White Wolf														
Reef Ridge	Reef Ridge	8,353	22	17	576	4,440	360	495	3	14,663	7.9	.370	14,112	1

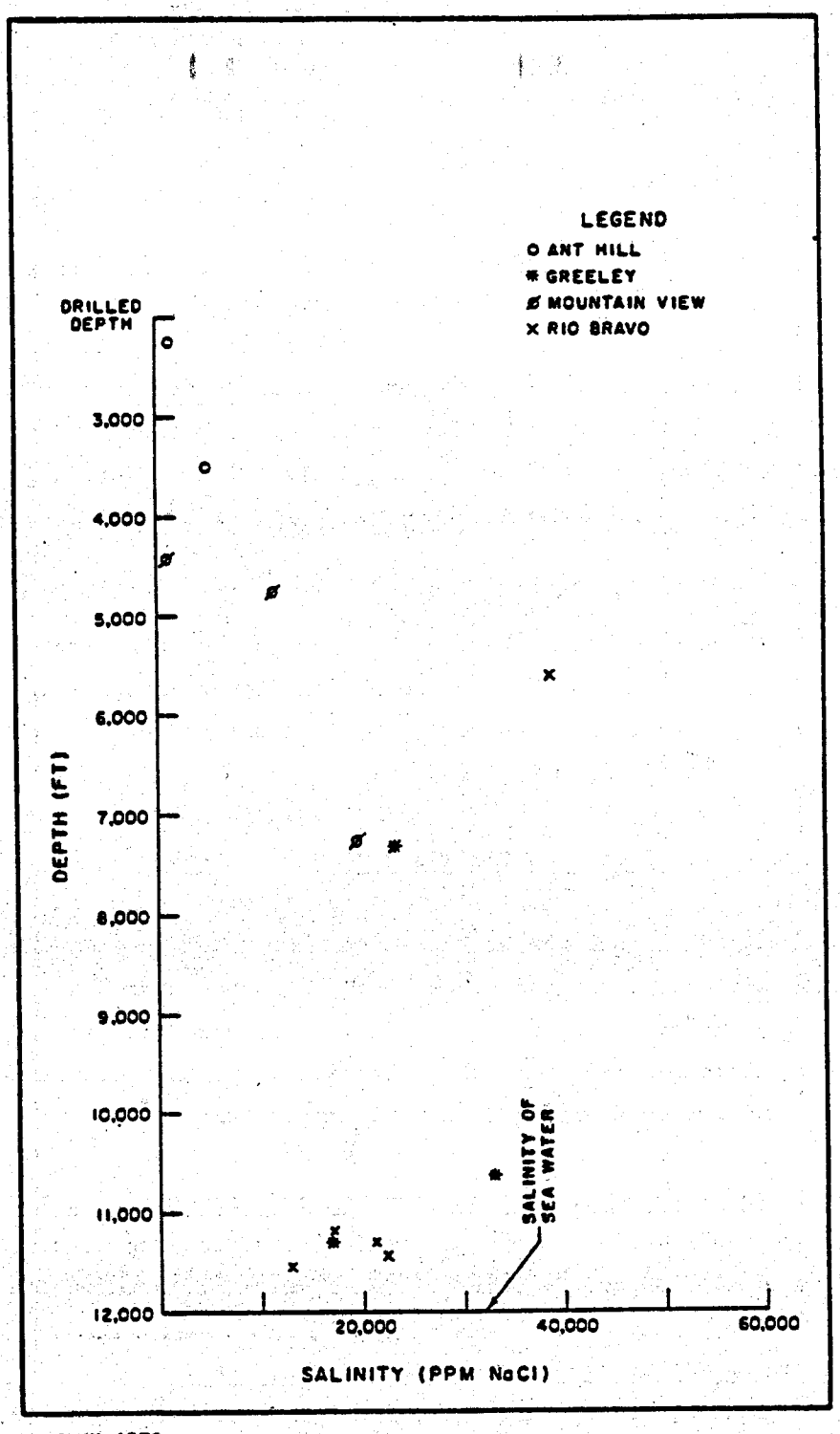
NOTE: In some samples the salinity content (ppm) has a higher apparent value than the total dissolved solids content (ppm). This technically is impossible; however, it probably represents the degree of accuracy in determining the various constituents.

*Hill, 1972



*Weddle, 1967

Figure 24. Graph Showing Salinity vs. Depth for Selected Fields in Southwestern San Joaquin Valley



*Hill, 1972

Figure 25. Graph Showing Salinity vs. Depth for Selected Fields in Southeastern San Joaquin Valley

3.4.4 Specific Occurrences

3.4.4.1 Fields

Cal Canal Field (Pac. Petrol. Newsletter, 1977; Lorshbaugh, 1981)
Discovered in 1977, this field with productive intervals in the Stevens sands at depths of 11863'-12046' had an initial reservoir pressure of 7350 psi and initial reservoir temperature of 290°F for a pressure gradient of .619-.610 psi/ft. and a fairly high geothermal gradient of 2.44-2.41°F/100'. The salinity in one well producing from the Stevens zone at 11863-12046' was 22200 ppm.

Coalinga Oil Field (Kaplow, 1945)
High pressure gas zones have been reported from early-drilled wells penetrating the Temblor formation (lower Miocene) at depths ranging from 3000-4000'. The salinities were varied - ranging from 5133 ppm to 14,943 ppm.

East Coalinga Extension Oil Field (Kaplow, 1942)
The pressure in the Gatchell oil sands (lower Eocene) in the Gatchell Area (Coalinga Nose or Southeast Coalinga) were reportedly quite high, presumably in excess of the normal hydrostatic pressure. The average mid-sand pressure in this area was 3450 psi and the temperature was 198°F; in the Amerada Area to the northeast, the mid-sand pressure was 3740 psi and temperature 210°F.

South Coles Levee Oil Field, Kern County (Cal. Div. Oil & Gas, 1962)
The Steven at an average depth of 8800' is also overpressured, about .470-.500 psi/ft., but there is very little formation water.

Elk Hills Field, Kern County (Lorshbaugh, 1981)
The producing zones below the Carneros, i.e. below 9500' are super-pressured, to the extent that in some cases it exceeds the litho-static pressure.

Garrison City Gas Field, Kern County (Cal. Div. of Oil & Gas, 1973)

In this field, the Mulina zone of the Etchegoin formation (Pliocene) had an original shut-in pressure of 2240 psi at an average depth of 4500', for a pressure gradient of .498 psi/ft.

Gill Ranch Gas Field, Fresno County (Kharaka, 1980)

A well drilled in this field at Sec 16, T13S, R16E is reported to have encounterd overpressures but no specific details are available.

Jerry Slough Oil Field, Kern County (Lorshbaugh, 1981)

This is a one-well field which attained a depth of 13,732 in the Stevens sands (upper Miocene) and production is from fractured shales within this zone at an average depth of 11,250'. The shut-in pressure at a depth of 11,700' was estimated to be 13,050 psi for a pressure gradient in excess of lithostatic, e.g. 1.12 psi/ft. Two water analyses from the interval 12,799-13,731' indicate the following salinities:

Cations (ppm)	Anions (ppm)	Total Dissolved Solids (ppm)
12220.1	17167.0	33840.3
24557.1	27879.4	56927.2

Lost Hills Field, Kern County (Lorshbaugh, 1981

A representative well completed in 1949 at the north end of the field penetrated the following formations:

Depth to Top of	Formation
820'	Etchegoin
2450	Reef Ridge Shale
3400	Main Cherts
5485	Temblor
6047	Nonian-Nonionella Facies
7512	Aqua Sand
9130	Kreyenhagen
9632	Belridge Sand
10386	Point of Rocks Sand

The mud weights used, depths, and indicated pressure gradients are as follows:

Depth (ft)	Mud Weight (lb/cu.ft)	Indicated Pres. Grad. (psi/ft)
5000	105	.729
6000	106	.736
7700	107	.743
8000	106	.736
9000	106	.736
9100	108	.750

A formation test at the 5848-5888' interval had a shut-in pressure of 3700 psi for a pressure gradient of .633 psi/ft. (further demonstrating the tendency of operators to use over-balanced mud formulations in drilling activities in this region). The temperature ranged between 182-189°F at a depth of 4800' and 202-203°F at 5800' for an extremely high geothermal gradient of about 3.7°F/100'. The salinity of the formation waters at 5868-78' was 45,844 ppm total dissolved solids including a relatively high boron content of 62.1 ppm.

McKittrick Field, Kern County (Roger, 1917)

The waters in the sands immediately underlying the oil-bearing zones were reported to be under considerable pressure and at elevated temperatures.

Midway-Sunset Field, Kern County (Roger, 1917)

At depths of less than 100' below the oil zones, abundant supplies of heated water under very high pressure (presumably in excess of hydrostatic pressure) were reported. The temperature of several of these waters in the vicinity of oil sands in various fields along the west side of the San Joaquin Valley was 120-130°F at a depth of 3000-4000'.

Raisin City Oil Field, Fresno County (Cal. Div. Oil & Gas, 1954)
Specific data on pressures and depths are unavailable, but it has been reported that pressures are sufficiently high to necessitate the use of blowout prevention equipment.

Riverdale Oil Field, Fresno County, (Cal. Div. Oil & Gas, 1954)
The Zilch formation (middle Miocene), the continental equivalent of the marine Temblor, is considered to be slightly overpressured in which mud weights of 73 lbs/cu.ft. are considered appropriate.

Rosedale Oil Field, Kern County (Cal. Div. Oil & Gas, 1954)
The Stevens zone (upper Miocene) can likewise be considered to be slightly overpressured requiring the use of mud weights up to 75 lbs/cu.ft. The average temperature of the zone is 153°F.

Semitropic Field, Kern County (Lorshbaugh, 1981)
A well drilled in 1965 in Sec 24, T27S, R23E to a depth of 7700' was completed in the Randolph zone of the lower Etchegoin formation (lower Pliocene). The top of the zone was encountered at a depth of 7412'. The well was completed as an oil producer through four series of perforations between 7373-7600'. The shut-in pressure at 7450' was 7574 psi for a pressure gradient in excess of lithostatic, i.e. 1.017 psi/ft.; it was still building up at the time the well was completed. The geothermal gradient was high, i.e. 2.7°F/100'.

Tule Elk Oil Field, Kern County (Kohlbush, 1977)
Located on the west side of the southern San Joaquin Valley, a 1966 well blew out in the San Joaquin formation at a depth of 3241' necessitating an increase in mud weight to 81 lbs/cu.ft. (equivalent to a pressure gradient of about .560 psi/ft.). The principal productive reservoir is the Stevens sand, at least 2000' of which has been penetrated. The formation is notably

overpressured and in some cases superpressured, in part believed to be due to gas entry from the overlying Reef Ridge shale; thus in some wells it is necessary to increase the mud weight from 85 lbs. to 122 lbs/cu.ft. (.847 psi/ft. gradient). The reservoir temperature at subsea datum of 8300' is 250°F.

Yowlumne Field, Kern County (Griffin, 1981)

Geopressured salt water zones have been encountered in the Reef Ridge formation overlying the Stevens sands.

3.4.4.2 Wildcat Wells

1) American Quasar Bravo #1-31 well in Sec. 31, T23S, R20E, in Kings County, 4-5 miles southeast of the abandoned Dudley Ridge Gas field (Van Matre, 1981)

This well, which was spudded in during 1977 and abandoned about two years later, was a deep test targeted for the Vaqueros formation at 18,300'. The deeper sediments penetrated in this well, which reached a total depth of 20,068' were as follows:

Depth to Top of	Formation
13,375	McClure (upper Miocene)
15,214	Temblor (middle and lower Miocene)
17,890	Vaqueros (lower Miocene)
18,730	Tumey (Oligocene)
18,820	Kreyenhagen (upper Eocene)

The representative mud weights at various depths were as follows:

Depth	Mud Weight (ppg)	Equiv. Pres. Grad, (psi/ft)
6425	9.3	.467
13505	10.3	.517
15576	13.9	.697
17752	14.2	.713
18000	14.2	.713
18562	16.0	.803
18722	18.5	.929
18861	18.5	.929
19986	18.7	.939
20068 (TD)	18.8	.944

2) Great Basins Well #31X-10, Kern County located in the area of the North Buttonwillow field in Sec 10, T27S, R22E, (Franklin and Mandel, 1981). This was a dry hole drilled in 1972 to 21640' TD, the deepest well thus far drilled in California designed to test various formations. The total stratigraphic column penetrated was as follows:

Depth to Top of Formation	Formation
2945	San Joaquin clay
3275	First Mya sand
6095	Etchegoin shale
11970	Reef Ridge shale
13300	McClure shale (N marker)
14190	McDonald shale
15420	Round Mountain silt
16300	Olcese sand
17690	Upper Santos shale
18203	Vedder/Aqua sands
18668	Lower Santos shale
18772	Phacoides sand
19190	Salt Creek shale
19650	Tumey shale
20050	Kreyenhagen shale
20610	Point of Rocks sand
20955	Middle Eocene/Paleocene sands

Based on obtained pressure data (e.g. 12,300 psi at 15,000' and recorded kick at 16086' with a pressure gradient of .905 psi), a sonic log pressure analysis indicated the following gradients in relation to the equivalent and actual mud weights (the latter indicative of the scope of overbalancing generally employed).

Depth	Computed Bottom-Hole Pressure (lbs)	Pressure Gradient (psi/ft)	Equivalent Mud Weights (lbs/cu.ft.)	Actual Mud Weights (lbs/cu.ft.)
6000	3000	.500	70	81
6500	3400	.524	75	80
7000	3600	.520	73	81
7500	4200	.560	82	83
8000	4500	.564	83	83
8500	5000	.610	87	83
9000	5500	.615	89	83
9500	6100	.640	92	87
10000	6500	.650	93	89
10500	7300	.695	100	91
11000	7900	.730	105	94
11500	8400	.730	105	96
12000	8500	.715	103	96
12500	8900	.712	103	96
13000	9200	.706	102	96
13500	10000	.744	106	96
14000	10700	.765	110	96
14500	11300	.778	112	124
15000	12300	.820	118	125
15500	13400	.865	125	124
16000	14200	.890	127	125
16500	14900	.905	130	137
17000	15400	.905	130	136
17500	15900	.910	131	136
18000	16400	.910	131	136

In the depth range to 6000', the actual mud weights employed ranged from 74 to 78 lbs/cu.ft. while from 18000' to TD, they were approximately 132-134 lbs/cu.ft. The salinities throughout the section ranged from about 600 grains/gallon (10270ppm) to 200 g/g (4280ppm) in the first 15000' and declined to as low as 125g/g (2440 ppm) for the

balance of the column. The temperature readings which were recorded as shown below indicate an apparent declining temperature gradient with depth.

Depth	Temperature (°F)	Temp. Gradeint (°F/100')
5260	130	2.47
8215	140	1.70
10330	157	1.52
11930	160	1.34

3.5 SUMMARY

From the viewpoint of presumed methane content, the San Joaquin Valley is probably a more promising target area. Based on the relationship between methane solubility and temperature and pressure, and disregarding salinity which in this region is very low, the methane content in the Forbes formation in selected overpressured gas fields (such as the Grimes, West Grimes, Arbuckle, and Buckeye where the unit is at a depth of 7000-8000') is estimated to be about 20-25 SCF/barrel. The principal reason for these relatively low values is that geopressures in this formation occur at relatively shallow depths and thus, the absolute pressures are relatively low. Similarly, the geothermal gradient rarely exceeds 2.0°F/100' and the absolute temperatures at these depths are likewise relatively low.

By contrast, various fields on the west side of the San Joaquin Valley (such as Lost Hills, Kettleman Dome, Cal Canal, Belridge, Semitropic, and Jerry Slough) display comparable salinities and geopressured gradients, but much higher geothermal gradients, often over 2.5°F/100' and up to 3.7°F/100'. Under these conditions and the somewhat greater depths of occurrence of the overpressured Miocene formations, it is estimated that the methane content in this area will be between 30 to 40 SCF/barrel.

4. DEEP WELLS IN GREAT VALLEY

The Munger Oilogram which is published several times a week provides detailed information on current California drilling activities. For the two-month period ending January 31, 1981, issues of this publication were examined and a listing made of all completed, planned, abandoned, proposed, and ongoing wells in the Sacramento and San Joaquin Valley. Listed in Table 11 are all of the above wells, 8000' or more in depth, by county, field, operator, well designation, depth, and status. The 8000' depth was selected since it indicated those wells which are most apt to penetrate moderately to highly geopressured zones though it is recognized that, as in the case of the Forbes formation in the Sacramento Valley, overpressures may be encountered at much shallower depths.

TABLE 11

Deep Wells in Great Valley Recently Completed, Planned, Abandoned, or in Progress as of End of January, 1981*

SACRAMENTO VALLEY

County	Field	Operator	Well Desig.	Depth Planned or Reached	Status
Colusa	College City	Chevron	CC-3A	8920	Dlg
	S. Compton Landing	"	B&K 1	8000	Dlg
	"	"	Thompson 1	8003	Dlg
	Grimes	Buttes Res	Poundstone 29-1	9185	Test
	"	Coastal	S. Syc 3	8503	Compl
	"	Chevron	Arbuckle 5	9250	Compl
	"	"	Arbuckle 6	9153	Compl
	Sycamore	Coastal	Meridian 1	8010	Compl
	"	"	DFU 2-1	8000	Abd
Contra Costa	Brentwood	Aminoil	Dianda 1	8150	Abd
	Oakley	Atlantic	Loo 1	9100	Loc
	S. Oakley	Depco	McLeod 77-7	8515	Compl
	"	W. Cont'l	NCG-N2	8500	Compl
Sacramento	Sherman Island	Atlantic	Upham 4	9400	Loc
	"	N&W	LS-1	8595	Abd
	Stone Lake	Argo	ER 36-37	9000	Abd
San Joaquin	Lone Tree Creek	Nareco	Cookson 1	10500	Loc
	McMullin Ranch	Great Basins	CL 33-24	8803	Compl (old well)
	Stockton	Hamilton	Eilers 1-32	8175	Susp
	Tracy	Shell	Edwards 1-23	13500	Test
Solano	Lindsey Slough	ARCO	PE 2-22	9615	Compl
	"	ARCO	PE 1-22	9280	Stdg
	"	Cities Svc	Persic A-1	11500	Dlg
	"	McCulloch	HR 5-22	12805	Compl
	"	Aminoil	PE 12	10600	Compl
	"	McCOR	HR 5-21	10735	Dlg
	Millar	Hamilton	Belleair 1-9	8370	Compl
	Rio Vista	Amer-Hess	Serpa 4	11842	Compl
	"	Quintana	Neil 1	9500	Loc
	"	"	Hagen 1	9502	Dlg

TABLE 11 (Cont'd)

SACRAMENTO VALLEY

County	Field	Operator	Well Desig.	Depth Planned or Reached	Status
Sutter	SW Sutter Butte	Tenneco	C-B 1	8800	Compl
Yolo	Merritt Island	Anchor	Hudson 1	8100	Compl
	Mound	Aminoil	YR-3	8300	Abd

SAN JOAQUIN VALLEY

Fresno	Cantua Creek	Home	Griffin 20-1	8657	Abd
	Coalinga, East Ext.	Union	#71-1	8000±	Dlg
	Helm	Anchor	Brix 1	8104	Test
	"	Transam-Wilson	TW 1	8200	Loc
	W. Helm	Energy P&S	McD 1	9500	Loc
	Kettleman North Dome	Flynn	Bravo 1	15000	Planned
	"	"	Bravo 1-11	14000	Dlg
	Mendota	H. Steele	M-S1	8000±	Abd
	Turk Anticline	Hamilton	H-Bravo 1-21	9200	Abd
Kern	Bellevue	Atlantic	Karpe 1	9057	Test
	W. Bellevue	Challenger	KM23X-33	9722	Stdg
	"	"	Williams	9712	Compl
	S. Belridge	Mobil	Belridge III	11500	Planned
	"	Kernridge	#21X-33	15000	Loc
	"	"	#26	15035	Subcom'l
	S. Buttonwillow	Britton	Big Bend	16000	Dlg
	Buena Vista	Cities Svc	B&N Min A-1	13000	Planned
	Cal Canal	Texaco	Bloemhof 1	16000	Dlg
	Canfield Ranch	McFarland	Coulter 73-25	10933	Compl
	N. Coles Levee	ARCO	CL-A-487-29	9260	Stdg
	S. Coles Levee	Marathon	SCLU 36-11	9973	Compl
	"	"	SCLU 83-11	10075	Compl
	"	"	SCLU 85-11	9507	Dlg
	Elk Hills	UONPR	#326-9G	9902	Dlg
	Greeley	Chevron	KCL 11-42	11482	Svc well

TABLE 11 (Cont'd)

SAN JOAQUIN VALLEY

County	Field	Operator	Well Desig.	Depth Planned or Reached	Status
Kern	Los Lobos Creek	Tenneco	LLC 52X-15	9500	Test
	Los Padres	"	LP 87X-29	14000	Dlg
	Lost Hills	Shell	#71X-22	Deep Test	Planned
	Mountain View	N. Mich. Expl.	Mott 1	8076	Dlg
	"	Hamilton	Dewitt 1-25	12500	Loc
	Paloma	Tenneco	#414-10	12500	Test
	Pleito	"	PR 6-25	12020	Prod
	"	"	PR 7-25	11330	Test
	Rio Viejo	Chevron	Chev-Con 27X-35	13964	Dlg
	"	"	Tenn-Chev 27X-35	14952	Stdg
	Sand Hills	McCCR	MC 1-32	18000	Dlg
	Strand	Challenger	Bravo 57X-31	10118	Abd
	Tule Elk	UONPR	#1 (367-7R)	9487	Compl
	"	"	#1 (375-7R)	8725	Compl
	Yowlumne	Texaco	Y37X-14	11993	Dlg
	"	"	Y22X-14	12201	Compl
Kings	Kettleman City	Bennett	APl-Tadco 4-4	13400	Dlg
	Kettleman North Dome	Sumpf-Williams	D-USL 2-12	10500	Loc
	Leemore	Seaward	Myrick 1-1	9250	Loc
	Westhaven	Koch	Haven 44X-6	13517	Redlg old well

*Record of wells completed, abandomed in progress, etc. that are deeper than 8000' based on daily issues of the Munger Oilogram, Los Angeles, for December, 1980 and January, 1981.

5. CONCLUSIONS AND RECOMMENDATIONS

From the vantage point of pressure, temperature, and salinity, the Forbes formation in the Sacramento Valley and the Stevens and Temblor formations in the San Joaquin Valley, all appear to be likely candidates for further study in terms of their potential for development of dissolved methane. In certain respects, these sediments, especially the geopressured Miocene formations in the San Joaquin Valley, compare as favorably or even more favorably than the reservoirs currently being studied and tested on the Gulf Coast, for the following reasons:

- The salinities of all three formations are much lower than those in the Gulf Coast, usually less than 20,000 ppm and often less than 10,000 ppm, whereas the Gulf Coast is characterized by salinities that range from 20,000 to over 200,000 ppm (Kharaka and Berry, 1980).
- The temperature gradients in the normally pressured zones of the Great Valley range from 1.0-1.5^{o}F/100' up to 2.5^{o}F/100', and up to twice as much in the geopressured zones, most notably on the west side of the San Joaquin Valley (Kharaka and Berry, 1980).
- In the formations cited, the Forbes is invariably overpressured, in cases exceeding lithostatic, especially in those fields on the west side of the Sacramento Valley. The other two formations where overpressured, particularly on the west side of the San Joaquin Valley, have comparably high pressure gradients to be of considerable interest in view of the greater depth of occurrence of geopressuring.
- In terms of depth, geopressured zones are noted in the Forbes, at depths as shallow as 2100' and extremely high pressure gradients are noted at depths in the 6000-8000' range. Geopressured zones in the San Joaquin Valley are also found at the latter depth and slightly deeper. By contrast, geopressured

zones can generally be anticipated in the Gulf Coast only at depths in excess of 10,000'.

The overriding issues of geopressured methane development that need to be resolved are that of methane content and reservoir producibility and longevity. These questions are currently being addressed by the several design wells being drilled and tested in Texas and Louisiana under DOE sponsorship and funding. In terms of methane content, it appears that in California, the San Joaquin Valley holds more promise than the Sacramento Valley, 1.5-2 times as much, but in neither case were any analyses available. It has been suggested that growth faulting has sharlpy limited the potential reservoir boundaries of the Tertiary sediments of the Gulf Coast and that similarly, the depositional nature of the California formations cited, i.e. turbidites deposited under deep-sea fan conditions, accompanied at times by similar contemporaneous faults, suggests that such (geopressured methane) reservoirs are likewise bound to be of limited extent. However, this cannot be determined at this time without much more detailed work involving the investigation of hundreds, if not thousands of logs, available cores, and drilling records to determine the lateral extent of these potential reservoirs and other salient characteristics.

In view of the favorable parameters attendant upon these California geopressured occurrences, particularly the western San Joaquin Valley, it is recommended that a study of the magnitude described be undertaken, similar to the work performed for the Gulf Coast to identify and pinpoint favorable "fairways" and site locations. Certainly, as a first step, there are many deep wells currently being drilled in the Great Valley (as shown in Table 11) and it would be useful if further specific data relevant to known geopressured fields and areas could be obtained.

In addition to the development of these geopressured waters for the recovery of methane (and secondarily for direct heating utilization or

possibly for exectricity generation) there are two other potential applications that merit further study:

a) Given the low salinity of the California geopressured formation waters, in many cases approaching potability, and the inordinately high cost of irrigation water, consideration should be given to the feasibility of producing these waters, extracting the methane, and desalinating (and removing such objectionable elements as boron), the energy source for such operations might well be furnished by the recovered methane.

b) These geopressured waters in California (as well as those of the Gulf Coast and elsewhere) might well have application as a source of heated waters in waterflooding operations in abandoned, depleted, or near-depleted fields and reservoirs with low to mid-gravity crude oil.

In the Appalachian basin, the only formation that holds any promise insofar as geopressured methane is concerned would be the upper Cambrian sediments in the Rome trough of western West Virginia, eastern Kentucky, and western Pennsylvania. The Oriskany formations can be essentially disregarded for this purpose in view of the slight to moderate overpressuring displayed, prevailing low geothermal gradient, and the general very high salinities. The upper Cambrian zones, on the other hand, are characterized by very high pressure gradients, close to lithostatic in cases, and relatively low salinities. The one negative factor, is the relatively low geothermal gradient. At this time, only a handful of wells have been drilled into this zone and the control is accordingly limited for assessing its areal extent. Therefore, as an initial step, it is recommended that more detailed studies be made of the data from the few Rome trough wells that have been drilled and to closely monitor the planned well that Columbia Gas will drill later this year.

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