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COMPILATION OF 59 SONIC AND DENSITY LOGS FROM 51 OIL TEST WELLS IN THE  
SAN FRANCISCO BAY AREA, CALIFORNIA

By

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## ABSTRACT

Several relatively thick (>3 km deep) Cenozoic basins, including the Cupertino, Evergreen, Livermore, and San Pablo basins, may locally enhance strong ground motions in the San Francisco Bay area, California. As part of a crustal-scale, three-dimensional seismic velocity and density model for the Bay area, we have compiled data from sonic and density logs from oil test wells in the Bay area to better understand strong motion resonances generated by these basins. We have compiled the velocities and densities of sediments and rocks within these Cenozoic basins using 59 sonic and density logs from 51 oil test wells. The well data are primarily from the Livermore, Concord, and Los Medanos oil fields, and the Sacramento-San Joaquin delta, and provide measurements from the surface to as much as 5.3 km subsurface. Only a few logs from the South Bay are included in this compilation. The logs were hand digitized at non-uniform intervals between 3 and 30 m to capture the significant variations of the logs with depth for frequencies up to 2 Hz. Linear regression through 41 sonic logs yields  $V_p$  (km/s) =  $2.24 + 0.599Z$ , where  $Z$  is depth in km. Shallow borehole data, generally from the South Bay, and from less than 30 m deep, indicate that the average surficial P-wave velocity at 10 holes in weathered Tertiary sedimentary units ranges from 2.21 and 2.32 km/s and is in close agreement with extrapolated P-wave velocities inferred from the oil test wells. A sonic log for Eocene sediments from Butano Ridge in San Mateo County shows that at a given depth, velocities are approximately 0.5 km/s higher than those near Livermore. The higher P-wave velocities for the Tertiary sedimentary rocks at Butano Ridge probably result from a combination of dense volcanic clasts in conglomerates plus very tight compaction of the sandstones. Density logs in Cenozoic sedimentary rocks show higher scatter. Linear regression of 18 density logs yield  $\rho$  ( $\text{g/cm}^3$ ) =  $2.25 + 0.065Z$ . Average densities of weathered Tertiary sedimentary rocks measured on core samples from 5 shallow boreholes in the South Bay lie between 2.20 and 2.25  $\text{g/cm}^3$ , in close agreement with the surficial density inferred from linear regression of oil well data. This report presents the locations, elevations, depths, stratigraphic and other information about the oil test wells, provides plots showing the density and sonic velocities as a function of depth for each well log, and compiles all data to better understand the velocities and densities of Cenozoic sedimentary rocks in the Bay area.

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## INTRODUCTION

Several relatively thick (>3 km deep) Cenozoic basins in the San Francisco Bay area, California, including the Cupertino, Evergreen, Livermore, and San Pablo basins (Fig. 1), are defined by inversion of gravity anomalies, seismic reflection and refraction profiles, and borehole control [Meltzer et al., 1987; Smith, 1992; Wright and Smith, 1992; Jachens et al., 1995]. Observations of strong ground motion data from earthquakes in southern California and synthetic seismograms calculated from three-dimensional velocity models suggest that these thick basins may locally enhance strong ground motions in the Bay area [e.g., Frankel and Vidale, 1992]. We have compiled sonic and density logs from oil test wells in the Bay area as part of a crustal-scale three-dimensional seismic velocity and density model for the Bay area being developed to better understand strong motion resonances generated by these basins [Brocher et al., 1997]. Previous compilations of check shot P-wave velocity data from oil test wells within Tertiary sedimentary units in California were made for the southern San Joaquin valley, near Bakersfield [Hafner, 1941; Haskell, 1941; Wells, 1949].

We present data from 59 sonic and density logs from 51 oil test wells in the Bay area to categorize the velocities and densities of these Cenozoic sedimentary basins. The geometries of these basins are inferred from inversion of gravity data [Jachens et al., 1995]. The well data are primarily from the Livermore, Concord, and Los Medanos oil fields, and the Sacramento-San Joaquin delta (Figures 1 and 2), and provide measurements from the surface to as deep as 5.3 km subsurface. Well logs from eighteen additional wells in these fields are available, but were not analyzed because they would not substantively improve upon the spatial distribution and depth coverage of the logs summarized here. Locations, elevations, and depths of the oil test wells, as well as the lease name, well number, operator, name of the oil field, and completion year are presented in Table 1. In this table the wells are ordered by latitude, from north to south. This information is taken from the Well History Control System (WHCS) One-line File, an on-line digital well-log database leased from Petroleum Information by the USGS Office of Energy

Resources at Denver. Table 1 also provides information on the lithologies and stratigraphy encountered in the holes, taken from the compilation of Bay area wells by Powell et al. [1997]. Age control is available for 20 of the 51 wells. Finally, because the logs were run over a 30-year interval between 1959 and 1989, Table 1 provides information on the type of sonic and density tool used to make the log, as well as the other tools which were run simultaneously with these tools (normally caliper, spontaneous potential, and gamma-ray). Many of the sonic logs were made with older, short tools, with short spans between the source and receivers.

### WELL LOG ANALYSIS

Sonic and density logs were hand digitized at non-uniform intervals between 3 and 30 m to capture the significant variations of the logs with depth for frequencies up to 2 Hz. The sampling fit the average linear trends in the data over these intervals. We note that our sampling interval was not intended and is not sufficiently dense for the calculation of high-frequency (say >10 Hz) synthetic seismograms. For higher-frequency synthetics, it will be necessary to redigitize the logs with a finer sampling interval.

For the 41 sonic logs, we picked transit times ( $\mu\text{s}/\text{ft}$ ) as a function of depth in feet down the well. For the gamma-gamma density logs, we picked bulk density in  $\text{g}/\text{cm}^3$  as a function of depth in feet down the well. For the neutron density porosity logs, we converted the logged density porosity ( $\phi$ ) back to formation density ( $\rho_{fd}$ ) using  $\rho_{fd} = \rho_m + (\rho_f - \rho_m)\phi$ , where the matrix density  $\rho_m = 2.65 \text{ g}/\text{cm}^3$ , and the fluid density  $\rho_f = 1.0 \text{ g}/\text{cm}^3$  [Ellis, 1987]. Almost all of the logs analyzed here are plotted at a scale of 100 feet = 2 inches. Depths are measured from an arbitrary reference datum, normally the K.B., located 12 feet (3.65 m) above ground level. The downhole depths reported here have not been corrected for this small upward shift. Cased intervals of the wells and sections identified on the logs as having cycle skipping problems were not digitized. In some cases data from the logs were ignored: these data were associated with washouts, thick mudcake, invasion of drill fluids or large deviations from the general trend of density and sonic values having very limited depth extent, generally less than a few tens of feet [Ellis, 1987]. Using

Excel spreadsheets, the digitized sonic log data were converted from transit times to velocities (m/s) and depths from feet to meters for both the sonic and density logs. Plots showing seismic velocities and densities as a function of depth for each well are presented in Figures 2 to 60. Although we digitized all repeated passes of tools in sections of the wells, we do not show these redundant passes in Figures 3 to 61.

Oil test wells having the longest sonic logs include: Horgan Community #1/Chevron USA (Fig. 3), H D Peterson et al #558-25/Standard Oil of America (Fig. 5), Elk-Tubbs #1/Elk Exploration (Fig. 8), United California Bank #1/Chevron USA (Fig. 11), L Nixon #1/Chevron USA (Fig. 12), Bethlehem #1/Chevron USA, Perry #1/Chevron USA (Fig. 13), Hans Nielson et al #1/Exxon Corp. (Fig. 21), A Gumpert #1/Cities Service Oil (Fig. 22), and Santa Cruz Lumber #12-18/Champlin Petroleum (Fig. 43). The longest density logs are from the following wells: Bethlehem #1/Chevron USA (Fig. 49), E Gumpert #1/Chevron USA (Fig. 50), A Gumpert #1/Cities Service Oil (Fig. 51), and Peterson Fee #43-17/Diamond Shamrock Oil (Fig. 56).

Typically, these and the other logs compiled here provide evidence for a monotonic increase in sonic velocity and density with depth, with little evidence for significant reversals in sonic velocity or density. The Wisner Unit #1-1/Hunnicut & Camp Drilling encountered a thick sequence of Franciscan rocks beneath 625 m depth (Fig. 40). This Wisner well is the only known penetration of Franciscan rocks in this compilation of Bay area wells, and shows considerable variation in sonic velocity for the 450 m of Franciscan rocks sampled in the well.

## **INTERPRETATION OF WELL LOG DATA**

To estimate average P-wave velocity and density gradients for the Cenozoic sedimentary units in the Bay area, we have plotted all the well data in separate scatter plots for sonic velocity and density (Figs. 62 and 63). For this purpose we have eliminated data from Franciscan assemblage rocks, but we have retained data corresponding to Cretaceous members of the Great Valley sequence. The latter data were retained because they comprise a relatively small fraction of the database and because we found no obvious break in velocity or density in the wells where the

depth of the Tertiary/Great Valley contact is known (see Table 1). The absence of a distinct break at the Tertiary/Cretaceous boundary is consistent with the depositional nature of this contact and the absence of a distinctive lithologic contrast across it [Bartow and Nilsen, 1990].

Linear regression through all the P-wave velocity data for 41 sonic logs yields  $V_p$  (km/s) =  $2.24 + 0.599Z$  for the Cenozoic (predominately Tertiary) sedimentary units, where  $Z$  is depth in km (Fig. 62). The  $R^2$  for this regression is 0.633. Shallow ( $\leq 30$  m) borehole data, from the South Bay, indicate that the average surficial P-wave velocity of weathered Tertiary sedimentary units at 10 holes lies between 2.21 and 2.32 km/s [Gibbs et al., 1975, 1976, 1992, 1993, 1994; Fumal et al., 1982; Thiel and Schneider, 1993], in close agreement with the surficial velocities extrapolated from the oil test wells. A published compilation of check shot data from 62 wells in the southern San Joaquin Valley yielded  $V_p$  (km/s) =  $2.01 + 0.464Z$  [Hafner, 1940]. The lower surficial P-wave velocity and P-wave velocity gradient in the southern San Joaquin Valley may reflect a number of causes, including different provenance, abundance of organic matter, and the presence of finer grained sediments near the center of the Great Valley than more proximal facies in the Bay area. Applying previous compilations of check shot P-wave velocity data from oil test wells within Tertiary sedimentary units in California were made for the southern San Joaquin valley, near Bakersfield [Hafner, 1941; Haskell, 1941; Wells, 1949], to the Bay area, may therefore result in the underestimation of P-wave velocity with depth.

One sonic log from Butano Ridge in San Mateo County (Santa Cruz Lumber #12-18/Champlain Petroleum) shows that at a given depth, velocities in the Eocene Butano sandstone are approximately 0.5 km/s higher than those in Cenozoic (primarily Tertiary) sedimentary rocks near Livermore (Fig. 43). The higher velocities at Butano Ridge are probably a combination of dense volcanic clasts in conglomerates and very tight compaction and cementation of the Butano sandstone, perhaps reflecting a different burial history, not addressed in our compilation.

Another limitation of our compilation is that it is largely based on wells from the East Bay (Figs. 1 and 2). The apparent scarcity of oil test well logs from San Mateo and Santa Clara



Counties means that the P-wave velocities and densities of Tertiary sedimentary rocks there are much less known than those in the East Bay.

Density logs for the Cenozoic sedimentary units show higher scatter than do the P-wave velocities. Linear regression of data from 18 density logs yield  $\rho$  ( $\text{g}/\text{cm}^3$ ) =  $2.25 + 0.065Z$ , where  $Z$  is depth in km (Fig. 63). The  $R^2$  for this regression is 0.301. Average densities of weathered Tertiary sedimentary rocks measured on core samples from 5 shallow ( $\leq 30$  m deep) South Bay boreholes lie between 2.20 and 2.25  $\text{g}/\text{cm}^3$  [Gibbs et al., 1975, 1976], in close agreement with the surficial density inferred from our linear regression of the test well density log data.

### **DATA AVAILABILITY**

The picks of density and seismic velocity shown in Figures 3 to 61 are available in Excel4 and Excel5 spreadsheets using anonymous ftp. The anonymous ftp address is: [eratos.wr.usgs.gov](ftp://eratos.wr.usgs.gov). Change the directory (cd) to `/sfbay/welllogs`. The files are named `SFBay.sonic.xl4.bin` and `SFBay.density.xl4.bin` (Excel4) and `SFBay.sonic.xl5.bin` and `SFBay.density.xl5.bin` (Excel5), in Mac Binary II format. Table 1 of this report is also in this ftp site, labeled as Table 1.

### **DISCUSSION**

Ultimately, S-wave as well as P-wave velocities are needed for the calculation of strong ground motions in the San Francisco Bay area. Average  $V_p/V_s$  ratios in weathered Tertiary sedimentary units from shallow (30-m) boreholes from 10 holes in the South Bay range from 2.8 to 4.0 [Gibbs et al., 1975, 1976, 1992, 1993, 1994; Fumal et al., 1982; Thiel and Schneider, 1993]. Sonic and density logs from the oil test wells do not directly provide S-wave velocities at greater depth. However, published compilations of S-wave data for sedimentary rocks provide some guidance for typical  $V_p/V_s$  ratios in Tertiary sedimentary units. Ohta et al. [1977] published  $V_s$  and  $V_p$  in two deep holes sampling Tertiary sediments in Japan. Hamilton [1979] compiled

these and similar measurements in Russia to obtain Vp/Vs ratios in the uppermost 1 km of section within Tertiary sedimentary units. Finally, Castagna et al. [1985] compiled Vs and Vp data from S-wave and P-wave logging and other measurements to obtain Vp/Vs for a variety of clastic silicate rocks. Castagna et al. [1985] suggest that Vp/Vs ratios in sandstones reach an average value near 1.7 beginning at depths of about 2 km, whereas the Vp/Vs in noncalcareous shales reach an average value of about 2 at depths near 3 km. Based on the shallow (30-m) borehole data, Hamilton [1979], and Castagna et al. [1985], we propose the following function for Vp/Vs in the Tertiary sedimentary rocks in the San Francisco Bay area:  $Vp/Vs = 4.0 - 1.504Z$  for  $Z \leq 1.33$  km, and  $Vp/Vs = 2.0$  for  $Z > 1.33$  km.

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ABBREVIATIONS USED IN TABLE 1:

BHC - Borehole Compensated Sonic Log

CNFD - Compensated Neutron Formation Density\*

CFD  $\gamma\gamma$  - Compensated Formation Density (gamma-gamma)\*

CNF (ds) - Compensated Neutron Formation Density (Dual Spaced)\*

Cal. - Caliper

SP - Spontaneous Potential

GR - Gamma Ray

T3R3R - Sonic tool spacing (in feet) between transmitter (T) and receivers (R)

\*All density logging tools employ the backscattered gamma-ray technique, commonly called "gamma-gamma". The different names used here are either from different vendors or from different generations (having different trademark names).

Table 1. Oil Test Well Data

LEASENAME	No.	OPERATOR	T	R	S	FIELD	Latitude	Longitude	DEPTH (FT)	DEPTH (M)	ELEV (FT)	ELEV (M)	YR COMP.	Sonic	Density	Other Logs	Tertiary Units	Cretaceous
HORGAN COMMUNITY	1	CHEVRON USA	N	10	E	DUNNIGAN HILLS	38.7368	-121.8919	9897	3017	219	67	1961	T3R1R	CNF (ds)	SP		UK 2774 m to TD?
RICE JOHN	1	CLAREMONT ENERGY	N	6	W	COTATI	38.3474	-122.7527	1220	372	205	63	1983			Cal., GR		
H D PETERSON ET AL	556-25	STANDARD OIL OF AMERICA	N	5	W	SW WILDCAT	38.2478	-121.9222	1789	545	25	8	1973	BHC	CNF	Cal., SP	EO. Pal., Danian to TD	
H D PETERSON ET AL	558-25	STANDARD OIL OF AMERICA	N	5	W	SW DENVERTON	38.2478	-121.9222	6000	1829	30	9	1973	BHC T3R2R	CNF	Cal., GR	EO. Pal., Danian to 671 m	
H D PETERSON ET AL	556-35	STANDARD OIL OF AMERICA	N	5	W	SW DENVERTON	38.2478	-121.9222	508	155	30	9	1973	BHC	CNF	Cal., SP	No ages	
FILLIPPINI	1	GENERAL CRUDE OIL CO.	N	4	W	WILDCAT	38.2251	-122.5558	7263	2214	50	15	1965	T3R3R	CNF	Cal., GR	Eocene 640-951 m	
KIRBY COMMUNITY	12	CHEVRON USA	N	4	W	KIRBY HILL	38.1896	-121.9219	3823	1166	111	34	1989			Cal., GR		
MANGEL	2	CHAMBERLAIN/C/H	N	4	W	TUBBS ISLAND	38.182	-122.4642	1750	534	164	50	1961	3' Span		Cal., SP		
ELK-TUBBS	1	ELK EXPLORATION	N	4	W	533	38.14360	-122.4283	8150	2485	7	2	1983	T3R3R		Cal., SP		
SUISUN COMMUNITY	15	STANDARD OIL OF AMERICA	N	3	W	SUISUN BAY	38.14	-121.9938	7937	2420	19	6	1974	T3R1R		Cal., SP	Paleocene to 2390 m	
UNITED CALIFORNIA	1	CHEVRON USA	N	3	W	HONKER BAY	38.0827	-121.9187	7600	2317	20	6	1980	BHC	CNF	Cal., SP	All Eocene	
NIXON/ L	1	CHEVRON USA	N	3	W	LOS MEDANOS	38.0689	-122.046	5523	1684	12	4	1967	BHC T3R2R	CFD	Cal., GR, SP	Eocene/Paleocene	
PERRY	1	CHEVRON USA	N	2	W	LOS MEDANOS	38.0343	-121.9945	4053	1236	187	57	1980	BHC		Cal., SP	Eocene/Paleocene	
NEBLEY	1	CHEVRON USA	N	2	W	LOS MEDANOS	38.0312	-121.9901	4350	1326	183	56	1984	BHC		Cal., SP	All Eocene	
SEENO-SCOTT	2	CHEVRON USA	N	2	W	WILLOW PASS	38.0135	-121.9717	4540	1660	402	123	1986	BHC	CNF	Cal., GR, SP	Eocene to 915 m	
BOYLAN UNIT	2	CHEVRON USA	N	2	W	CONCORD	38.0044	-122.02780	2250	686	178	54	1963	T3R1R		Cal., SP		
BOYLAN	1	CHEVRON USA	N	2	W	CONCORD	38.003	-122.025	2500	762	168	51	1964	T3R3R		Cal., SP		
HOFFMAN ET AL	1	CHEVRON USA	N	2	W	CONCORD	38.0013	-122.0244	2625	800	100	30	1963	T3R3R		SP		
BETHLEHEM	2	CHEVRON USA	N	2	W	PINOLE POINT	37.9991	-122.3391	6372	1943	38	12	1969	BHC T3R2R		Cal., SP		
BETHLEHEM	1	CHEVRON USA	N	2	W	PINOLE POINT	37.9994	-122.3391	9997	3048	39	12	1969	BHC T3R2R	CFD	Cal., GR, SP		UK 561 m to TD
HANS NIELSON ET UX	1	EXXON CORP.	S	2	E	WILDCAT	37.7789	-121.8622	13240	4034	637	194	1966	BHC T3R2R		Cal., SP		
GUMPERT A	1	CITIES SERVICE OIL	S	2	E	WILDCAT	37.7756	-121.8965	17432	5315	645	197	1973	BHC T3R2R	CFD	Cal., GR, SP		
DYER	1	MICHIGAN OIL	S	2	E	ALTAMONT	37.7627	-121.6748	3332	1016	812	248	1964	T3R1R		Cal., GR		
GUMPERT/E	1	CHEVRON USA	S	2	E	SAN RAMON	37.761	-121.8937	8081	2464	539	164	1964		CFD	Cal., GR		
CARSTELLO	1-13	SUPERIOR OIL	S	2	E	WEST TRACY	37.7558	-121.5913	6004	1830	376	115	1964	T3R3R		Cal., SP		
GARVANTA	68-22	CHOWCHILLA GAS	S	2	E	LIVERMORE	37.7388	-121.7381	2573	784	642	196	1968	BHC T3R2R		Cal., SP		
CITY OF LIVERMORE	1	BUTTES GAS & OIL	S	2	E	LIVERMORE	37.7297	-121.7336	3837	1170	530	162	1968		CFD	Cal., GR		
GOMES	1	BRAZOS OIL & GAS	S	2	E	ALTAMONT	37.71	-121.6131	4012	1223	591	180	1962	T3R1R		Cal., SP		
SPRR	1	CAPITAL OIL CORP.	S	3	E	LIVERMORE	37.7081	-121.7042	4500	1372	575	175	1967	BHC T3R2R		Cal., SP		
MCCULLOCH GUIDOTTI	1	MCCULLOCH OIL	S	3	E	LIVERMORE	37.7062	-121.6902	4715	1438	652	199	1968	BHC T3R2R		Cal., SP		
KENNEDY/GERTRUDE	1	SUNRAY DX OIL	S	3	E	W CARBONA AREA	37.7	-121.4376	9500	2896	152	46	1967	T3R3R		Cal., GR		
MCCULLOCH-MARIDON	1	MCCULLOCH OIL	S	3	E	SW TRACY AREA	37.6979	-121.45880	8398	2560	179	55	1964	T3R1R		Cal., SP		
ALTAMONT	1	IREX CORP.	S	3	E	WILDCAT	37.6969	-121.5876	3340	1018	739	225	1982		CNF	Cal., GR		
MILLER-RICHARDS	1-1	HERSHEY OIL	S	3	E	LIVERMORE	37.6961	-121.697	6313	1925	623	190	1981	BHC		Cal., SP		
NISSIN	3	MCCULLOCH OIL	S	3	E	LIVERMORE	37.6933	-121.6831	6819	2079	693	211	1967		CFD	Cal., GR		UK 1555 m to TD
NISSIN	6	MCCULLOCH OIL	S	3	E	LIVERMORE	37.6924	-121.68420	3055	931	685	209	1969	BHC T3R2R		Cal., SP		
MCCULLOCH-COYNE	1	MCCULLOCH OIL	S	3	E	NW SW TRACY	37.687	-121.5236	5302	1616	919	280	1964	T3R1R		SP		
LUPIN	5	BROWN/E/C	S	3	E	SW LIVERMORE	37.6865	-121.675	4821	1470	782	238	1968	BHC T3R2R		Cal., SP		UK at 854 m
GERLACH	22-14	YOUNG/ JOHN M	S	3	E	TRACY AREA	37.6785	-121.3922	5000	1524	117	36	1960	T3R3R		SP		
PETERSON FEE	1	MCBURNIE/ R/W	S	3	E	LIVERMORE	37.6763	-121.6584	4664	1483	1020	311	1967	BHC T3R2R		SP		UK 1119 m to TD
WISNER UNIT ONE	3	CASTLE MINERALS	S	3	E	WILDCAT	37.6735	-121.4342	10075	3072	221	67	1982	BHC		Cal., GR		
WISNER UNIT ONE	2	CASTLE MINERALS	S	3	E	LIVERMORE	37.6673	-121.6825	3091	942	787	240	1983		CNF	Cal., GR		
STEELE	47-19	STEELE HORACE	S	3	E	LIVERMORE	37.6555	-121.4615	5954	1815	563	172	1968	BHC T3R2R		Cal., SP		
YOUNG UNIT 1	1	RESERVE OIL & GAS	S	3	E	TRACY AREA	37.6654	-121.56250	7238	2207	118	36	1963	BHC T3R1R		SP		
WISNER UNIT	1-1	HUNNICUTT & CAMP	S	3	E	VERNALIS	37.6611	-121.6829	3416	1041	772	235	1972	BHC T3R2R		Cal., SP		K 448 m to TD
MULQUEENY	1	TRICO OIL & GAS	S	3	E	LIVERMORE	37.652	-121.5921	5020	1530	1537	469	1967	BHC	CFD	Cal., GR, SP		UK 1018 m to TD
KCY-GNESEA ETAL	44-25	KERN COUNTY LAND	S	4	E	LIVERMORE	37.5592	-121.26	5243	1598	202	62	1959	3' Span		SP		
SOUZA	18-1	TRIDENT OIL & GAS	S	7	W	LA HONDA	37.3204	-122.3313	3153	961	272	83	1985	BHC	CNF	Cal., GR		
SANTA CRUZ LUMBER	12-18	CHAMPLIN PETROLEUM	S	8	W	WILDCAT	37.2392	-122.24	11052	3370	2136	651	1984		CNF	Cal., GR		
GULF-JAMES W REA	2	GULF OIL	S	12	E	SARGENT	36.9246	-121.585	4749	1448	817	249	1980		CNF	Cal., GR		

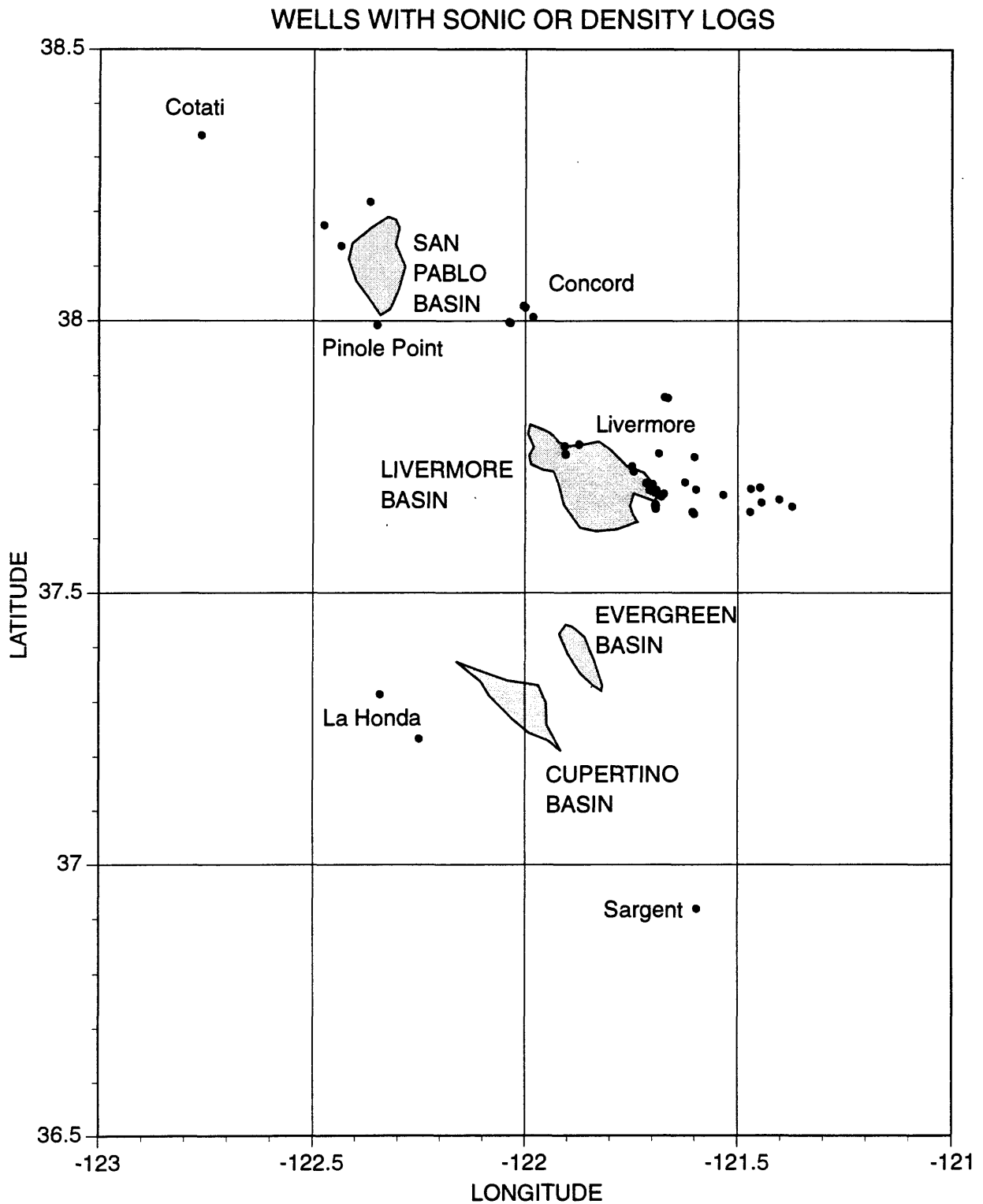


Figure 1. Map showing locations of wells having sonic or density logs analyzed in this report. Shaded regions show selected Cenozoic basins inferred from inversion of gravity data [Jachens et al., 1995]. Selected oil fields are labeled (Cotati, Concord, Livermore, La Honda, and Sargent fields).

WELLS WITH SONIC OR DENSITY LOGS

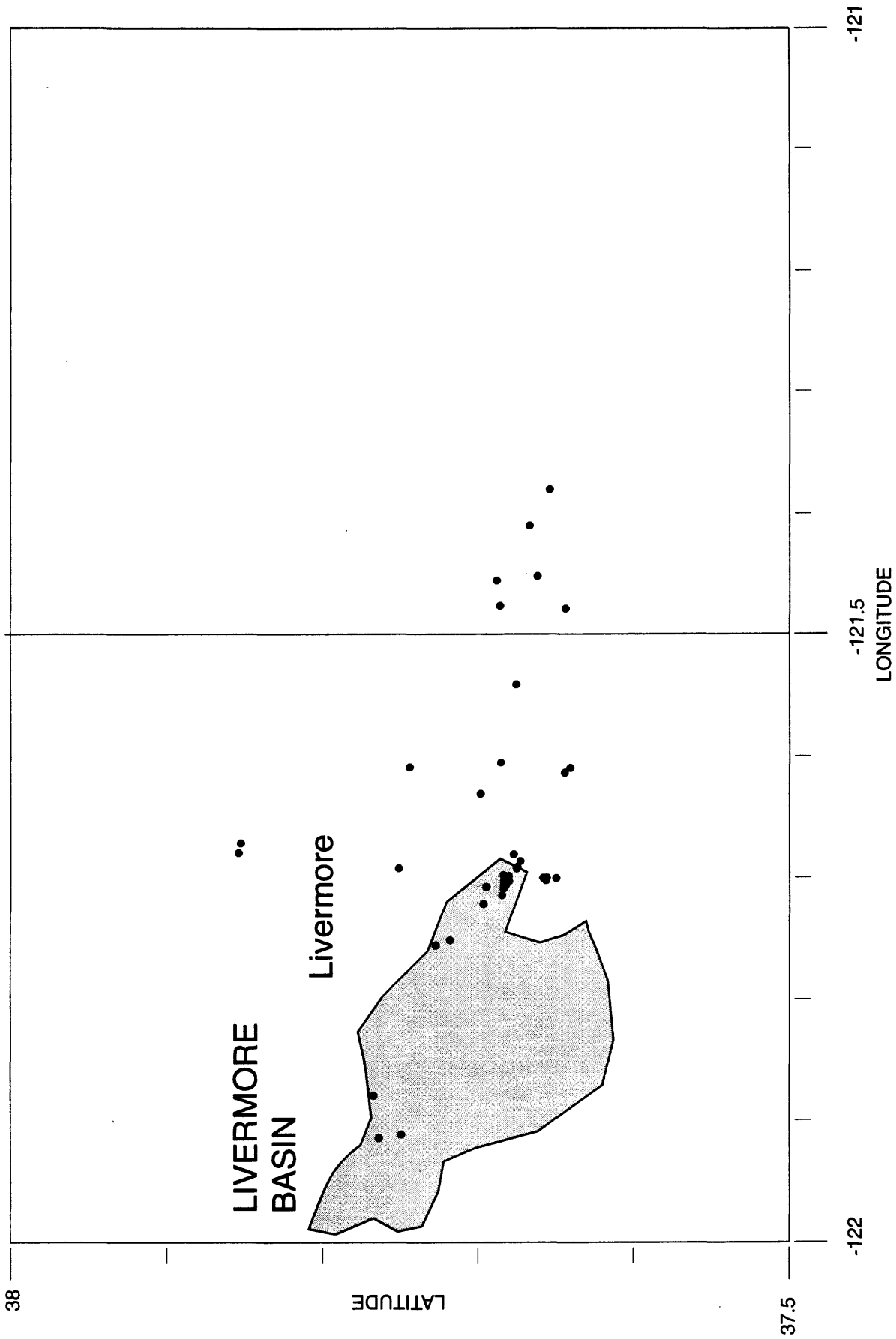


Figure 2. Map showing locations of wells in the vicinity of Livermore having sonic or density logs analyzed in this report. Shaded region shows the geometry of Livermore basin inferred from inversion of gravity data [Jachens et al., 1995].

Horgan Community #1, Chevron USA, Inc.

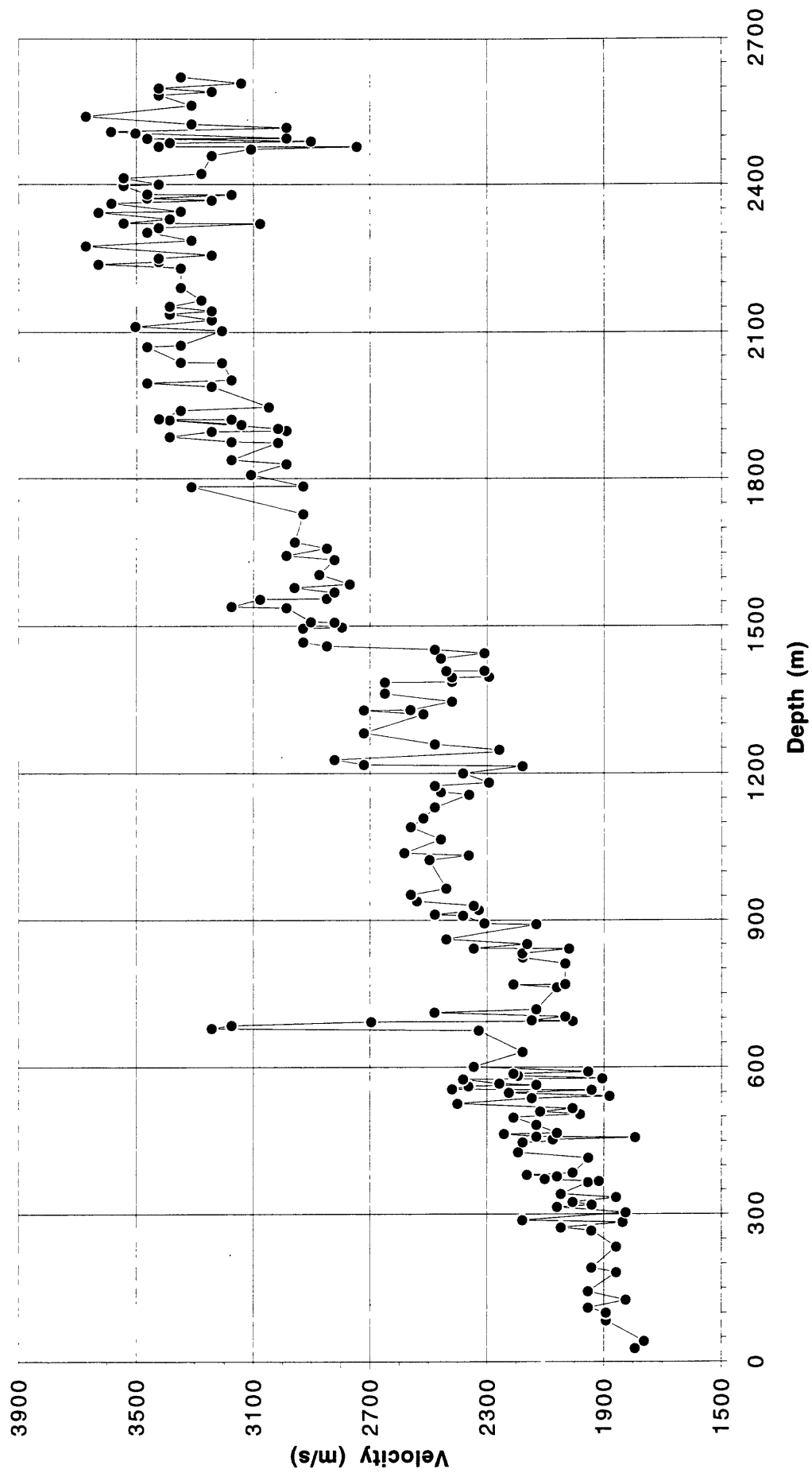


Figure 3.



H. D. Peterson #556-25, Standard Oil of America

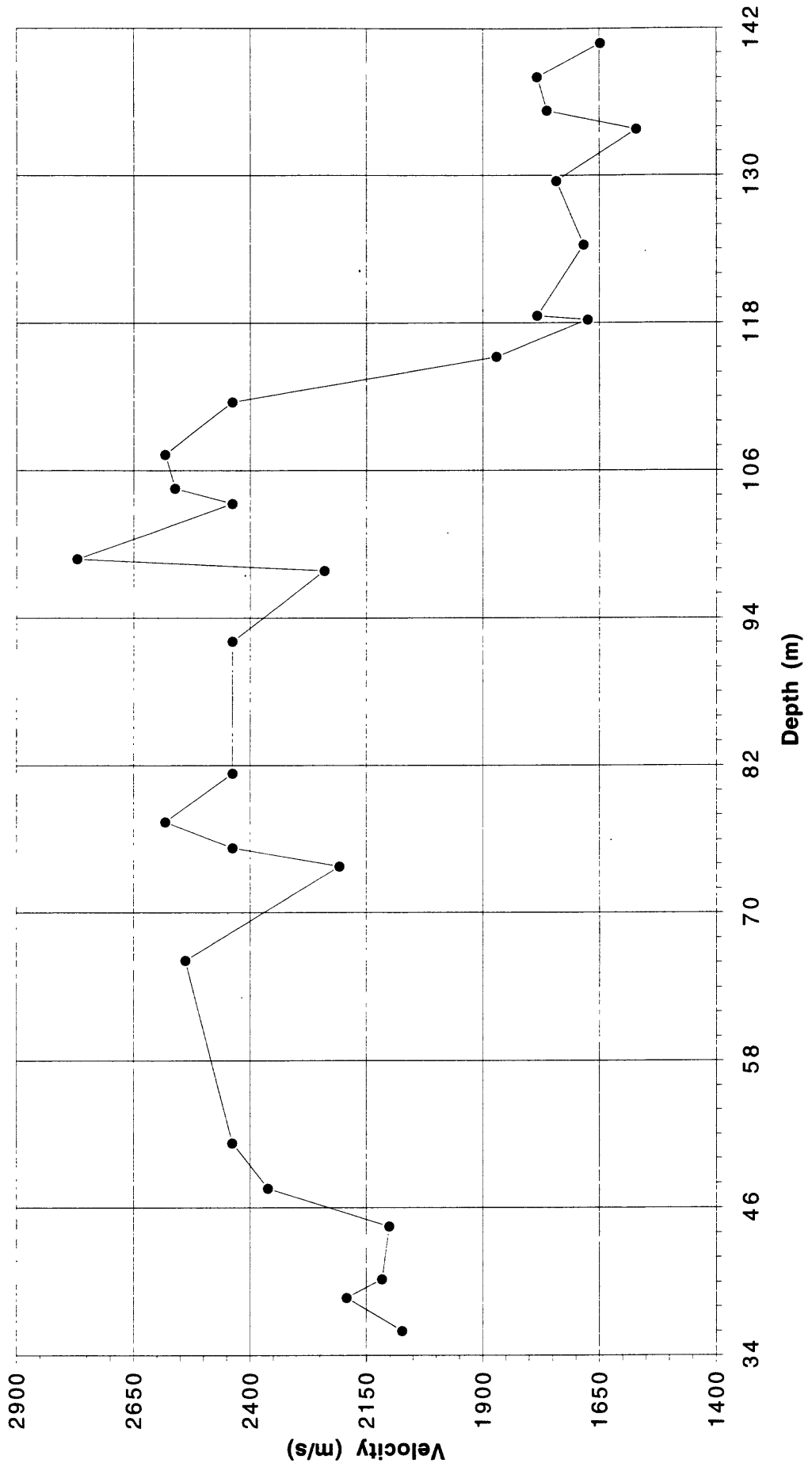


Figure 4.

H. D. Peterson #558-25, Standard Oil of Amer.

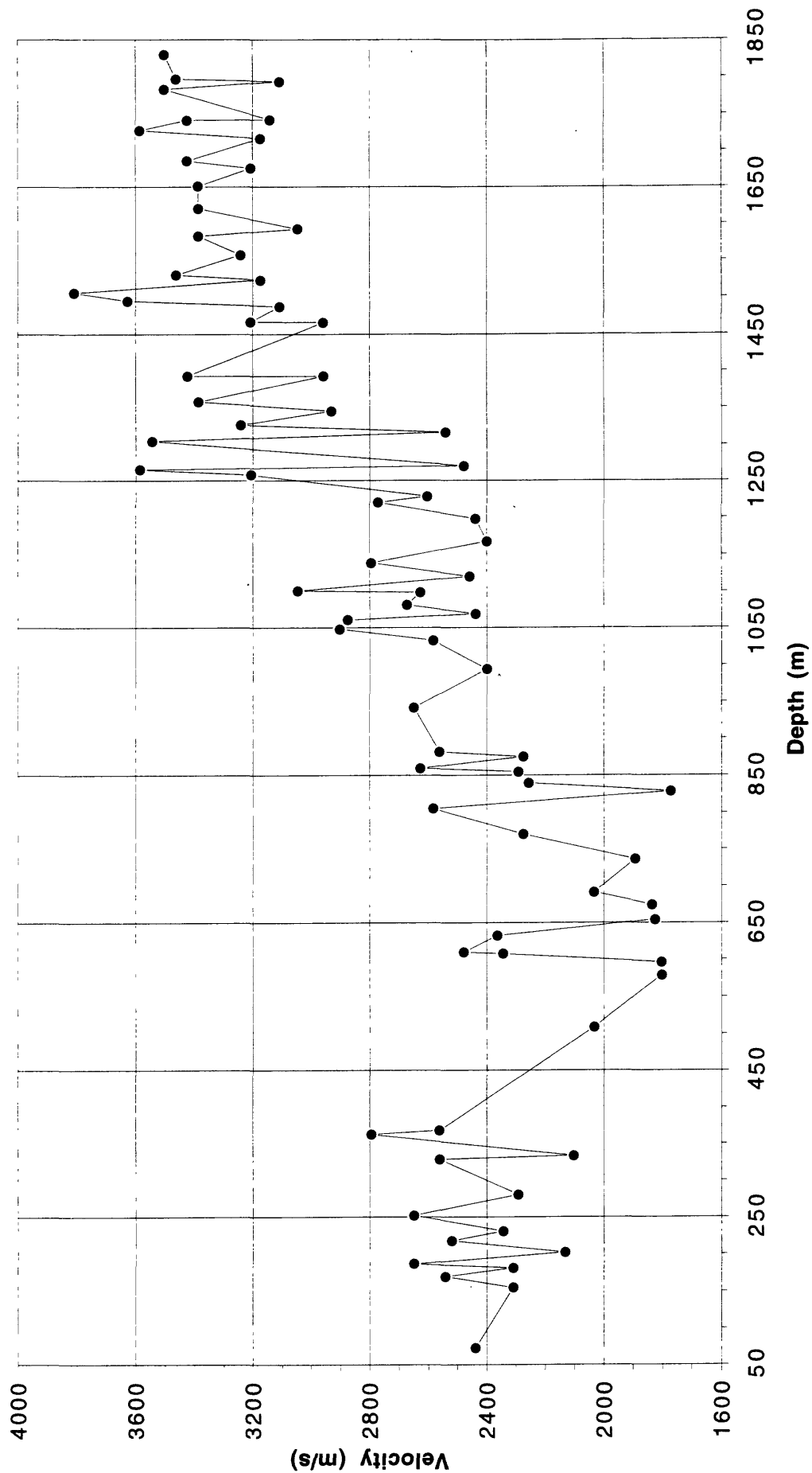


Figure 5.

H. D. Peterson #556-35, Standard Oil of America

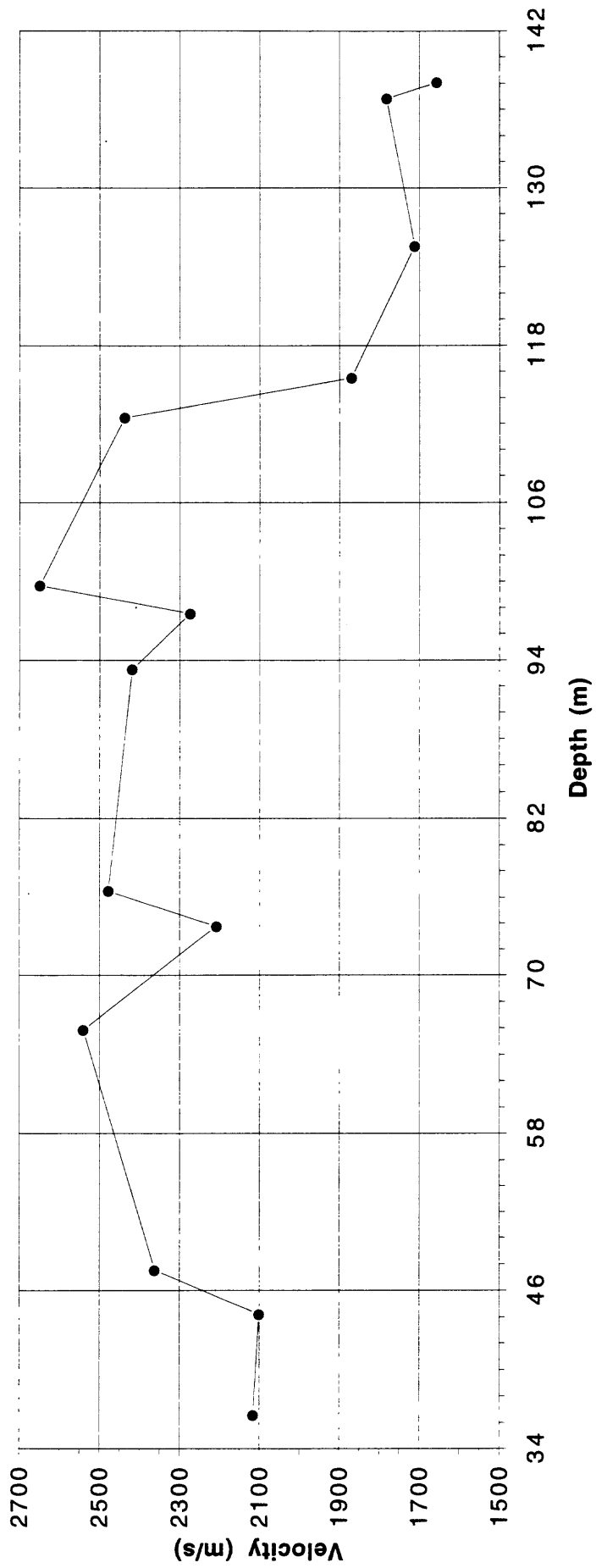


Figure 6.

# Fillippini #1, General Crude Oil Company

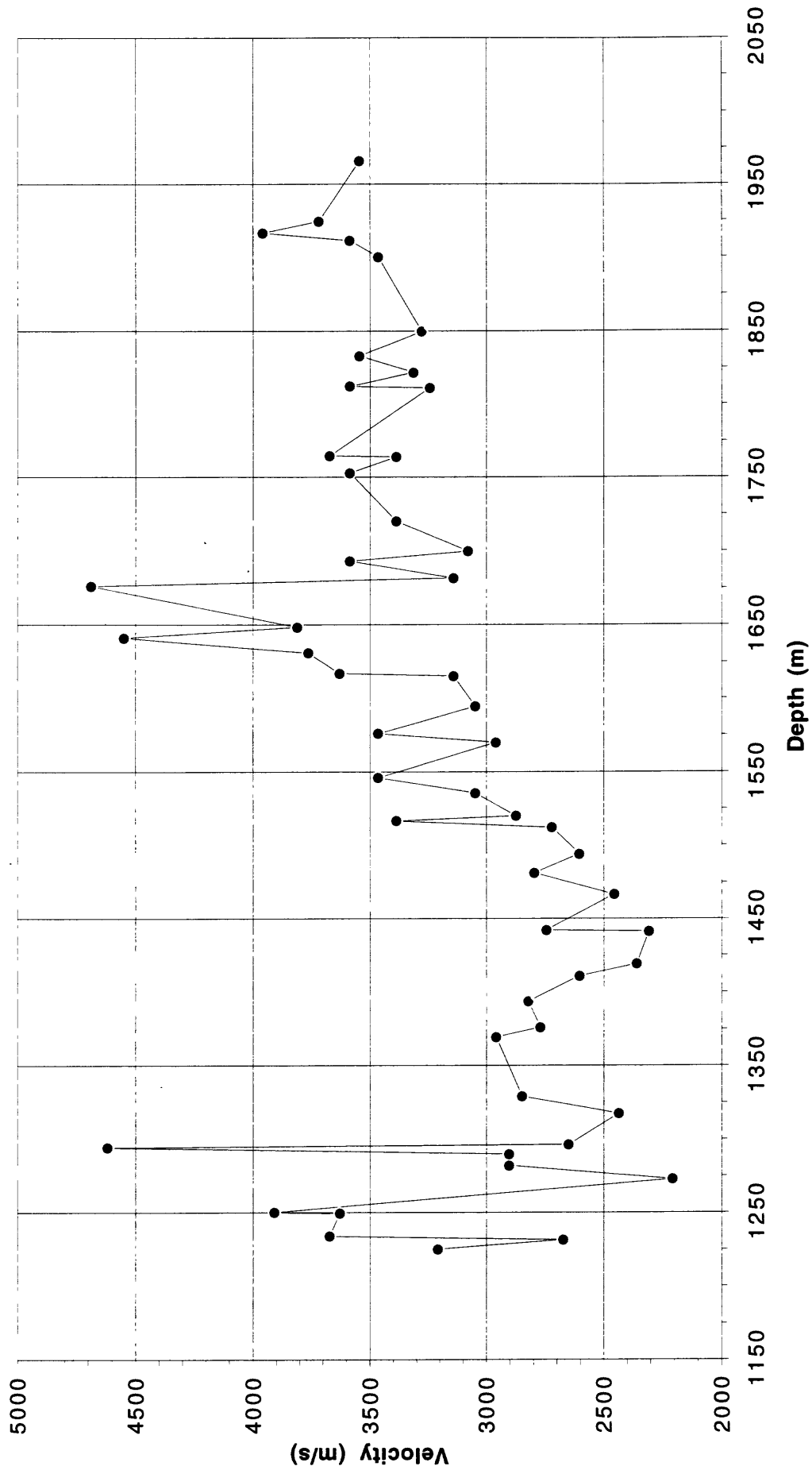


Figure 7.

Elk-Tubbs #1, Elk Exploration Company, Inc.

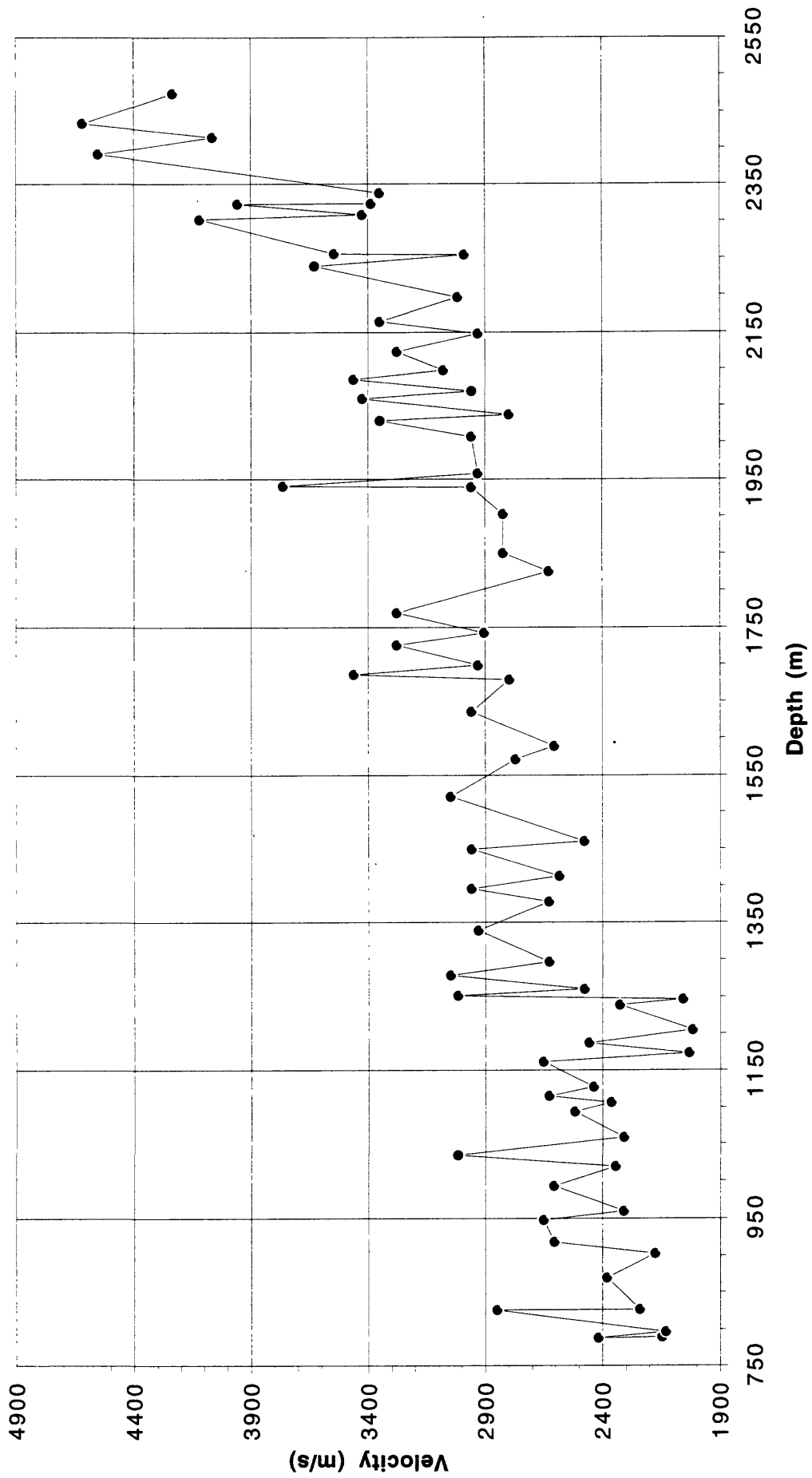


Figure 8.

**Mangel #2, C. H. Chamberlain**

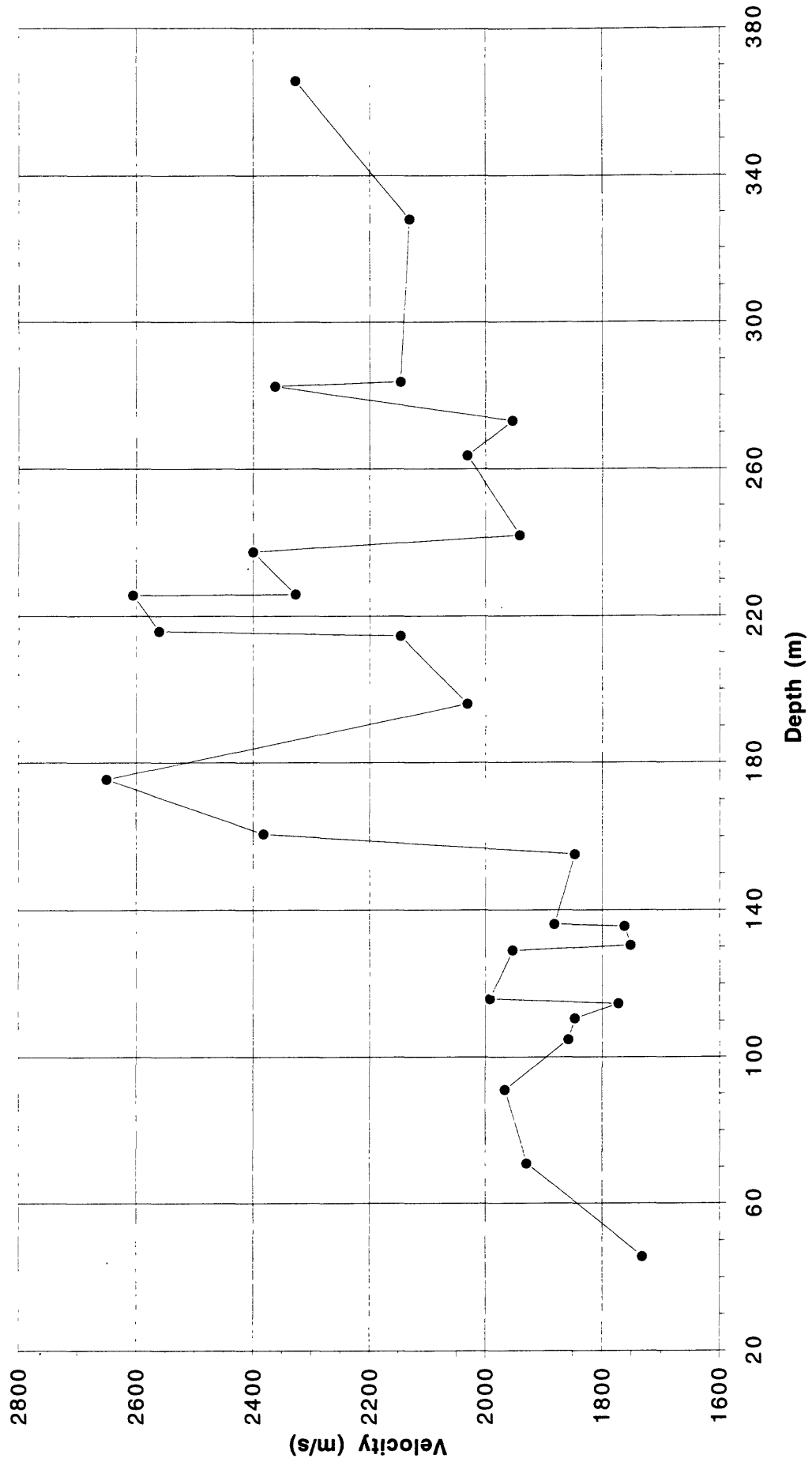


Figure 9.

# Suisun Community #15, Standard Oil of America

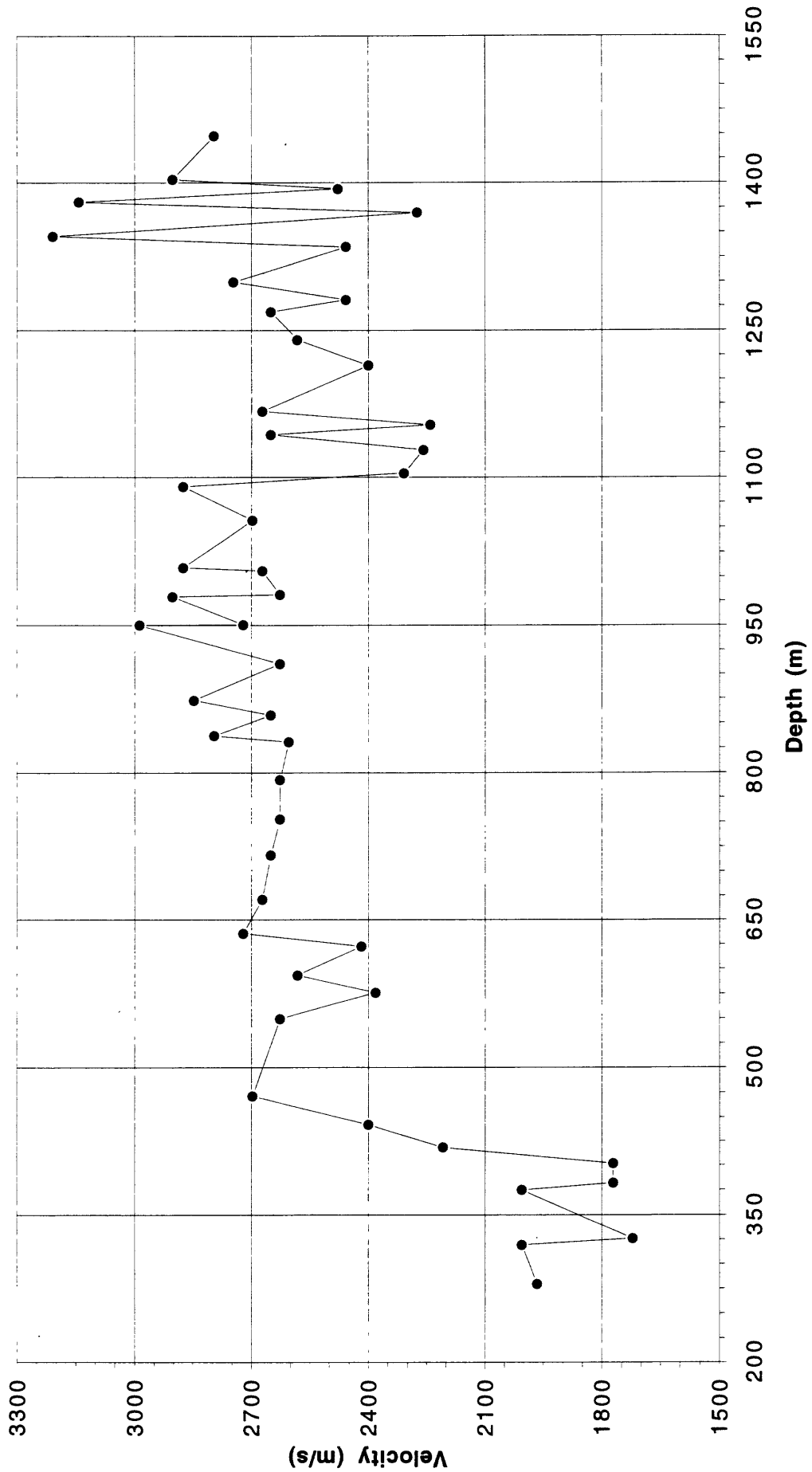


Figure 10.

United California Bank #1, Chevron USA, Inc.

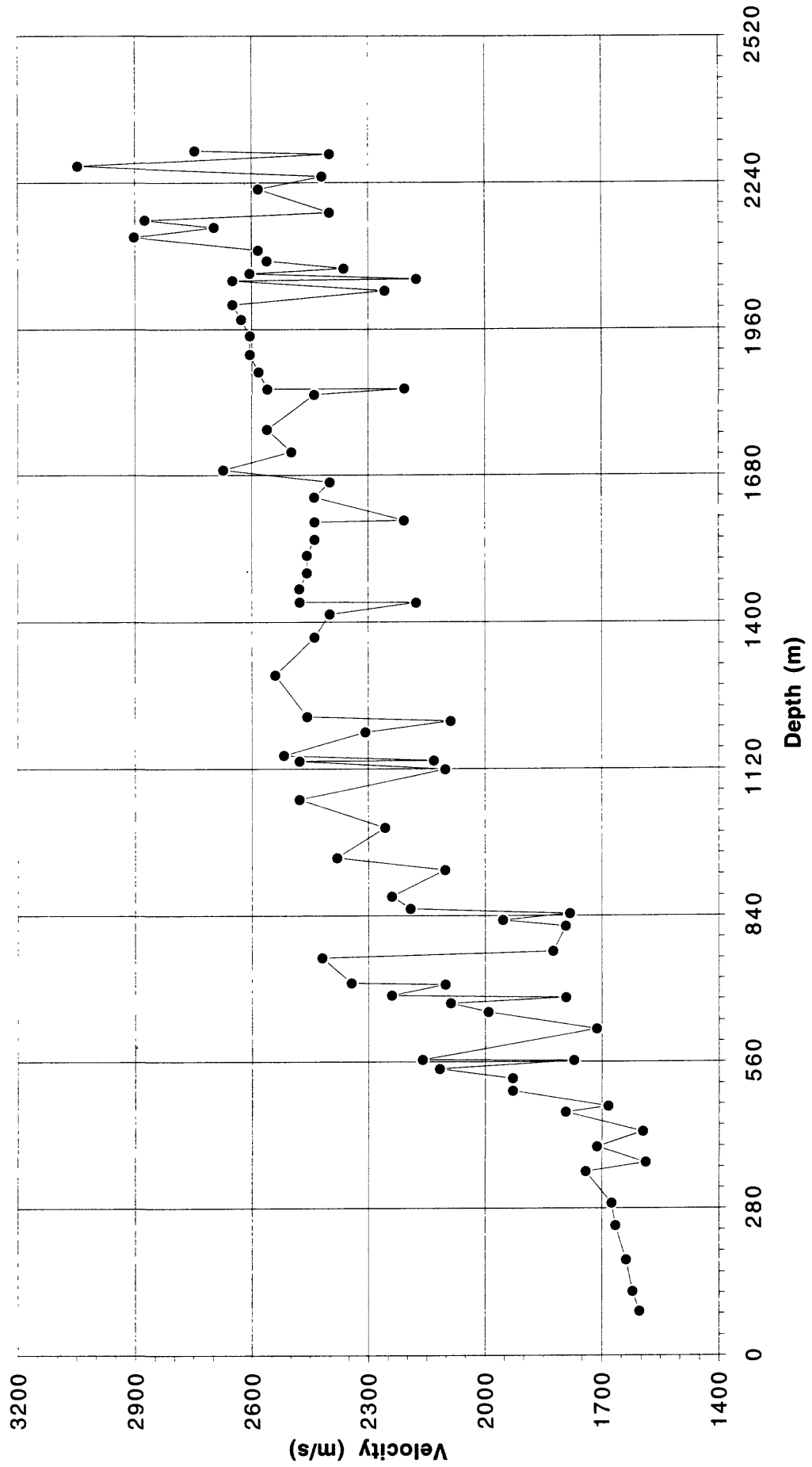


Figure 11.



L. Nixon #1, Standard Oil of America

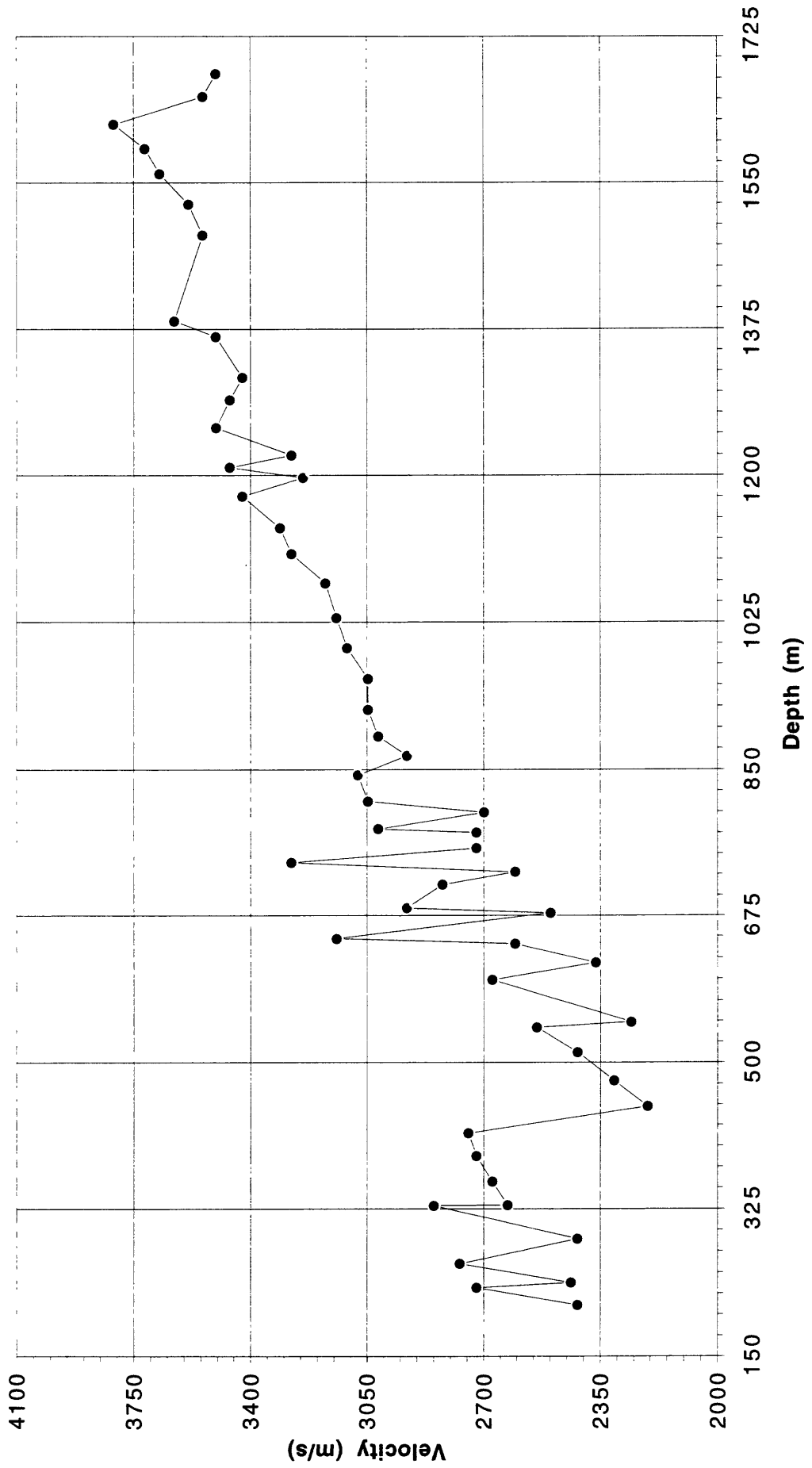


Figure 12.

Perry #1, Chevron USA, Inc.

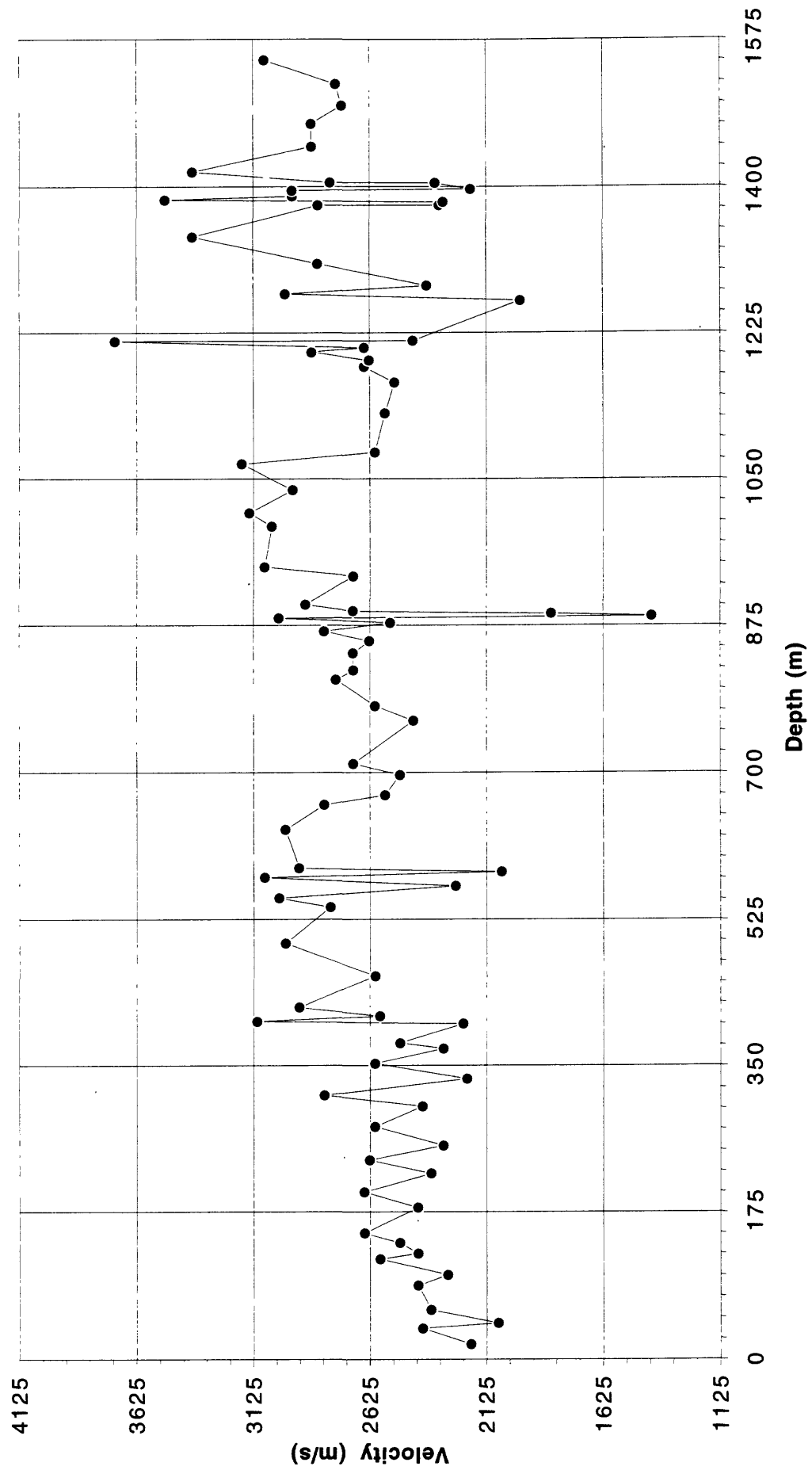


Figure 13.

Neeley #1, Chevron USA, Inc.

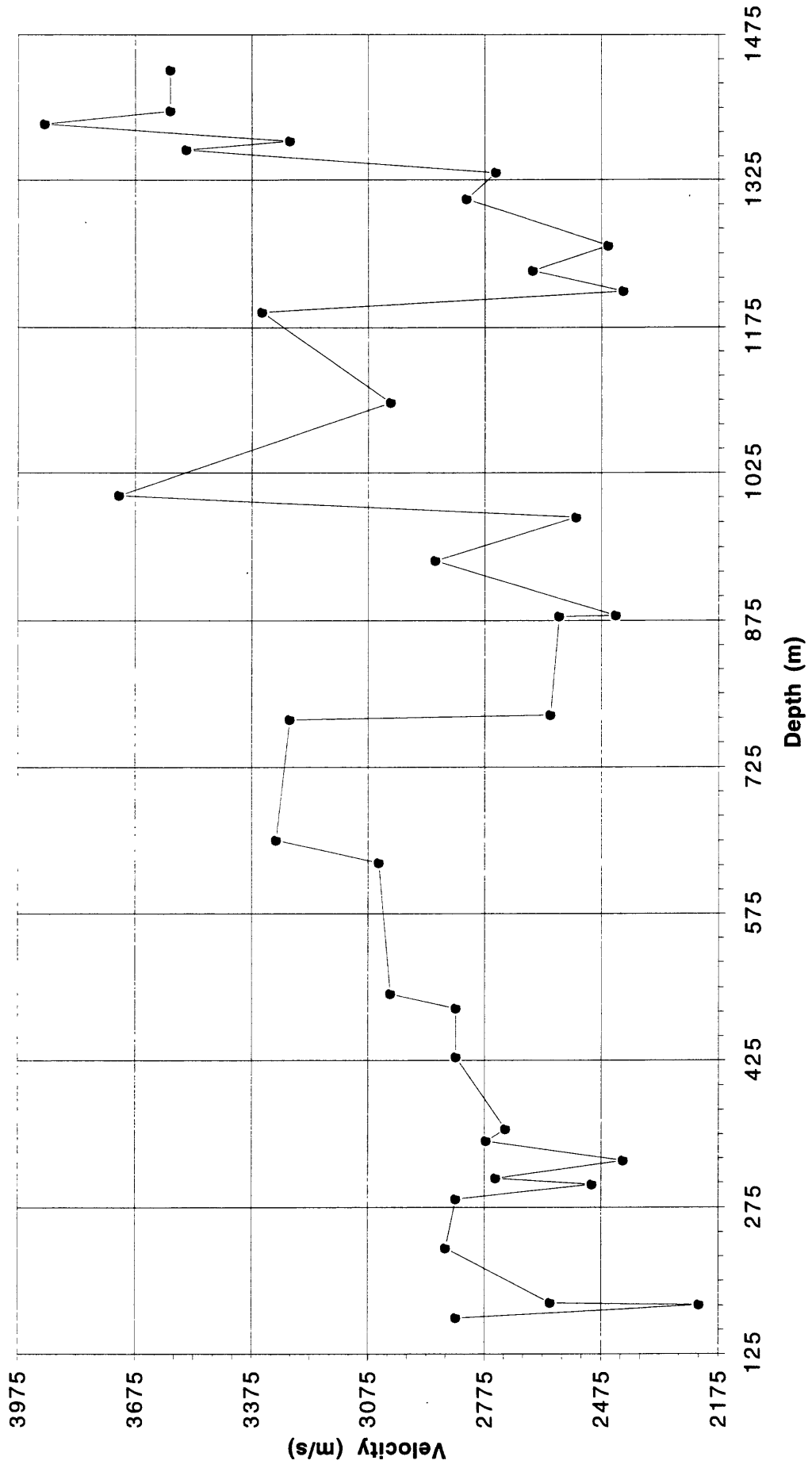


Figure 14.

Seeno-Scott #2, Chevron USA, Inc.

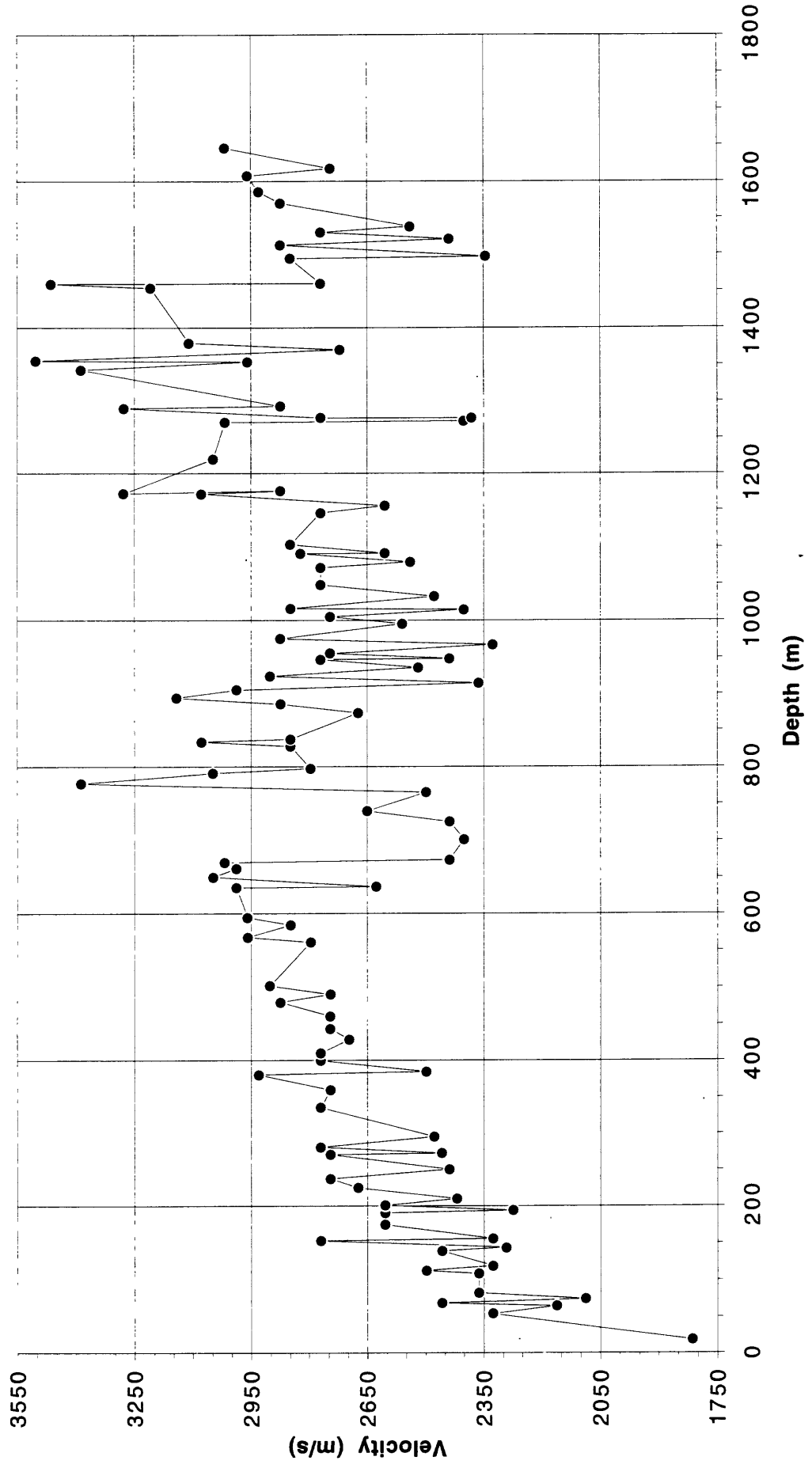


Figure 15.

Boylan #2, Standard Oil of America

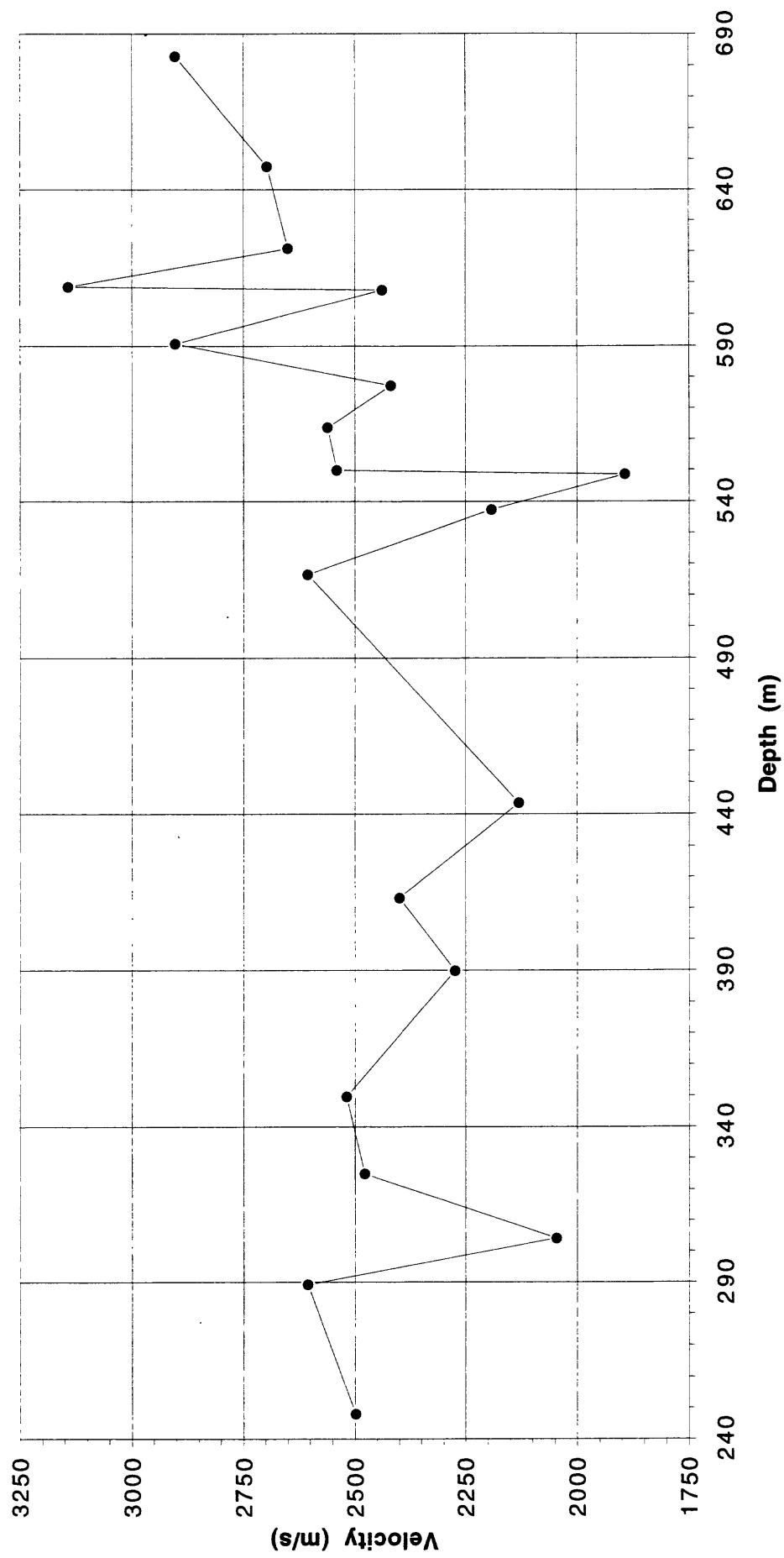


Figure 16.

**Boylan #1, Standard Oil of America**

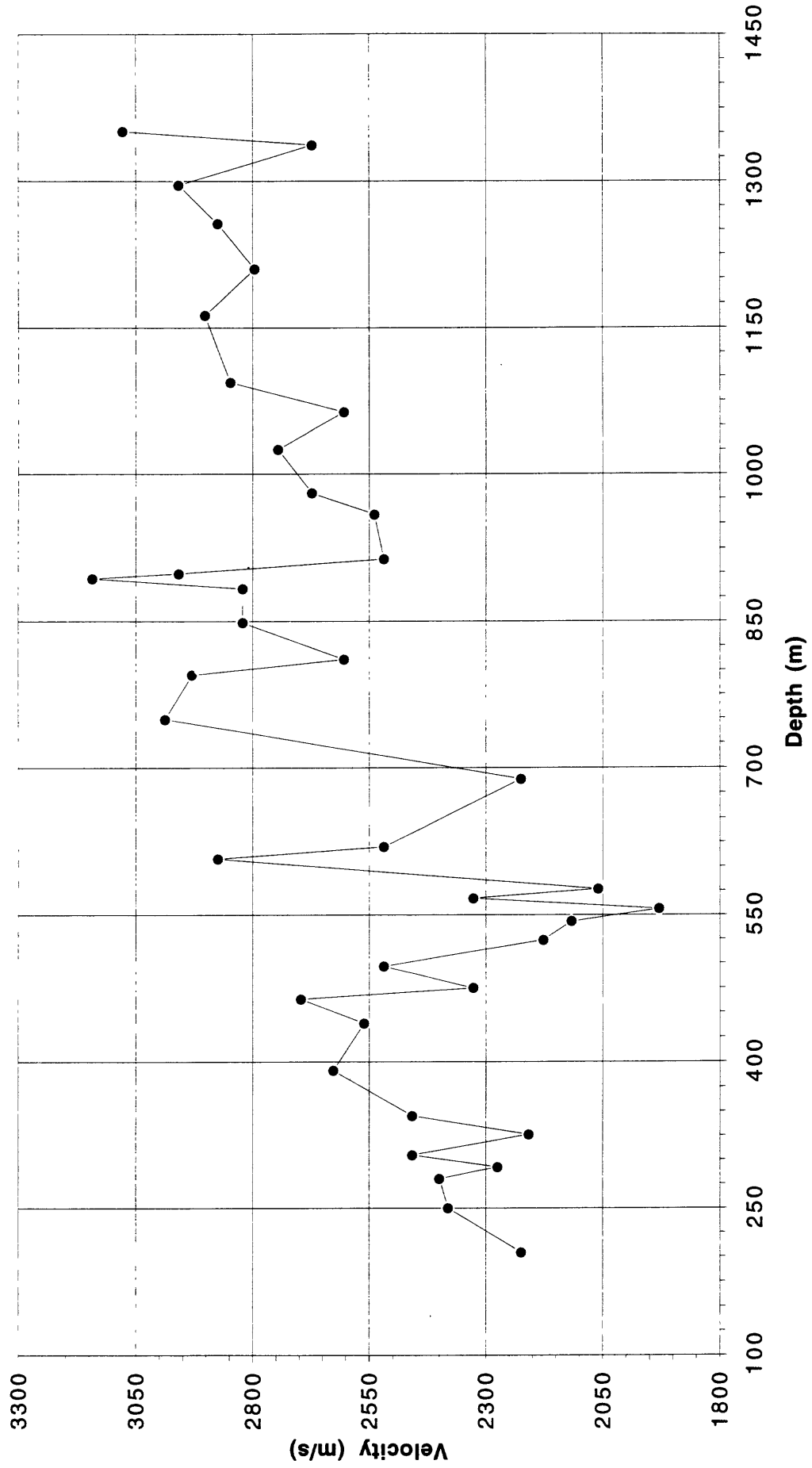


Figure 17.

Hoffman #1, Standard Oil of America

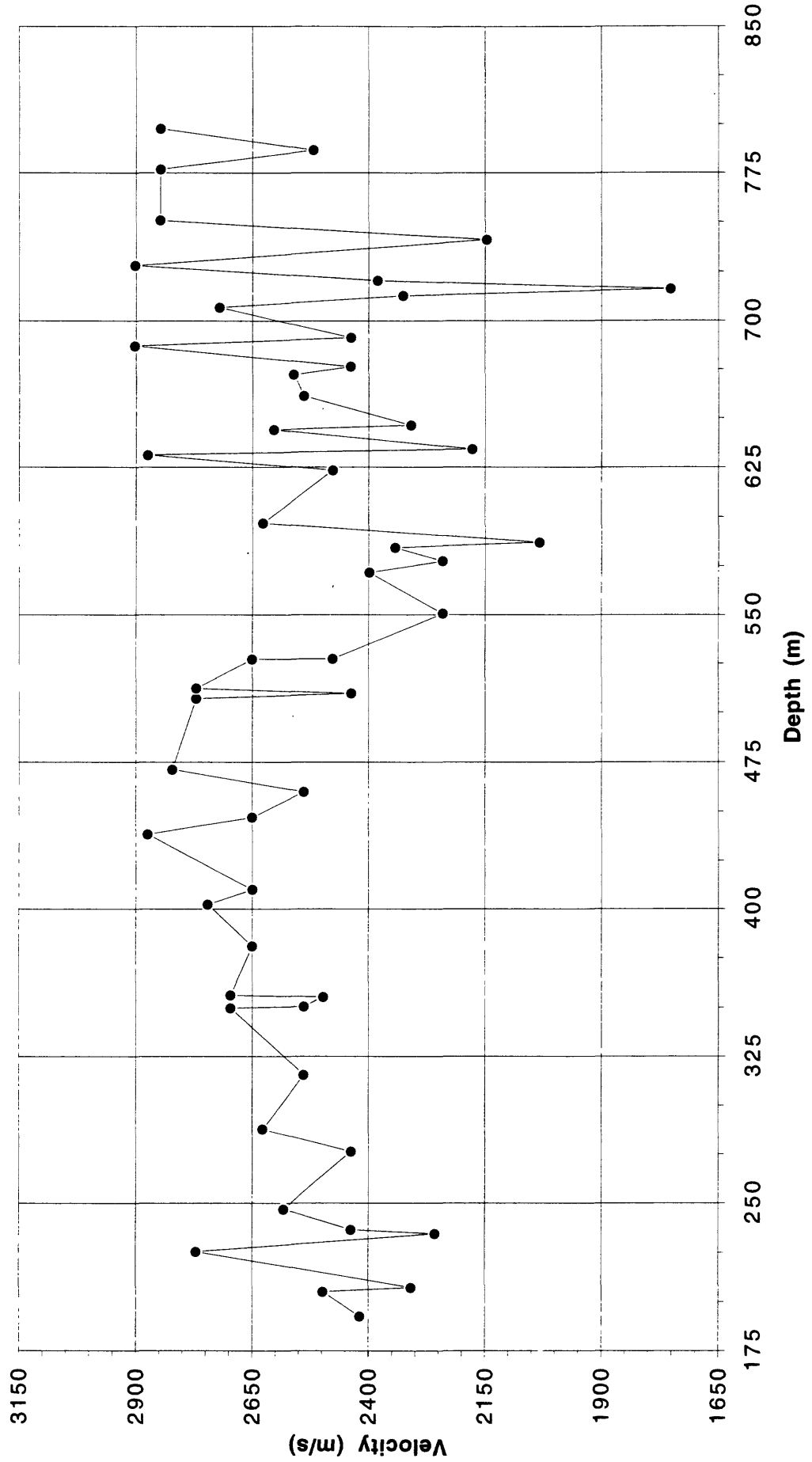


Figure 18.

Bethlehem #2, Standard Oil of America

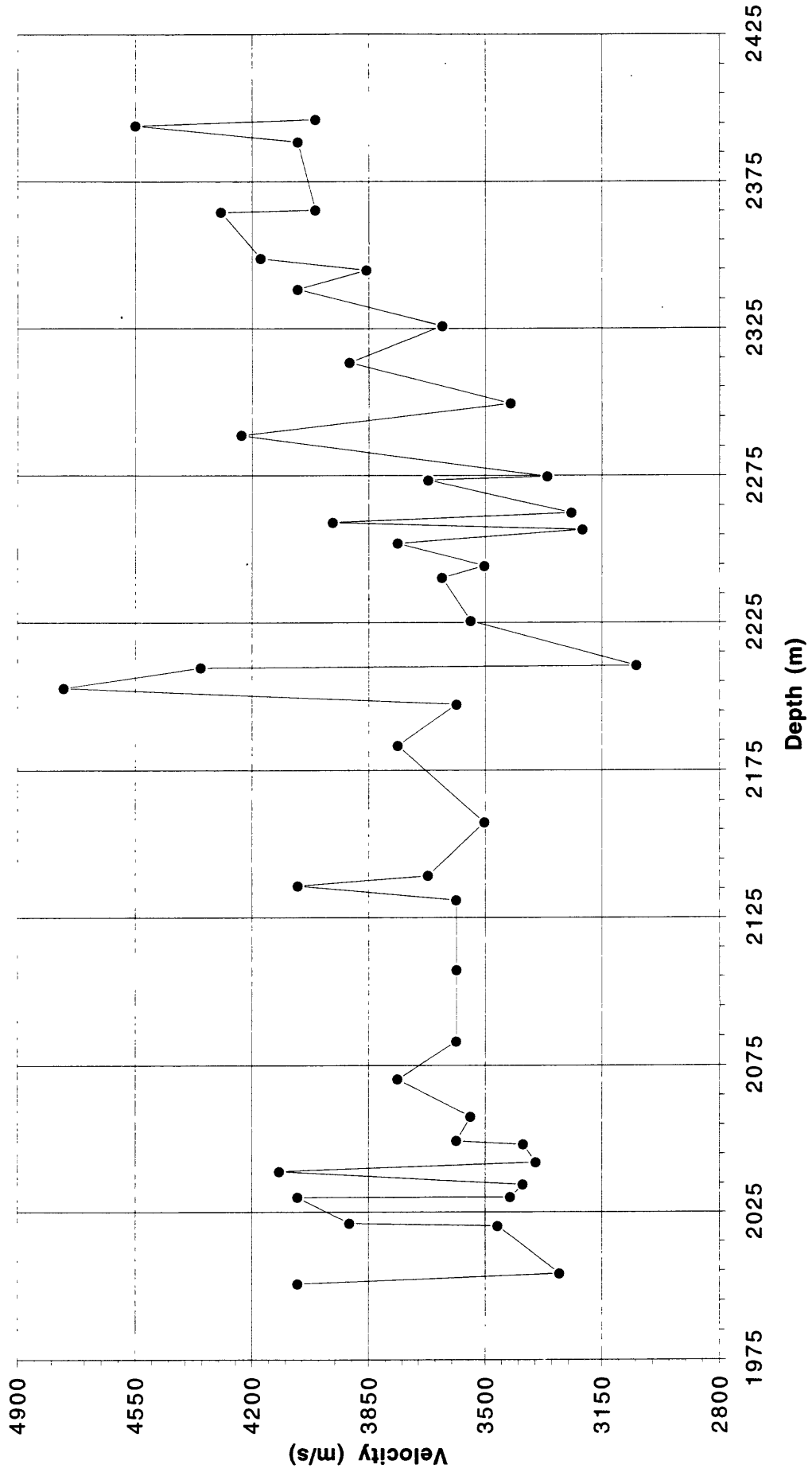


Figure 19.



**Bethlehem #1, Standard Oil of America**

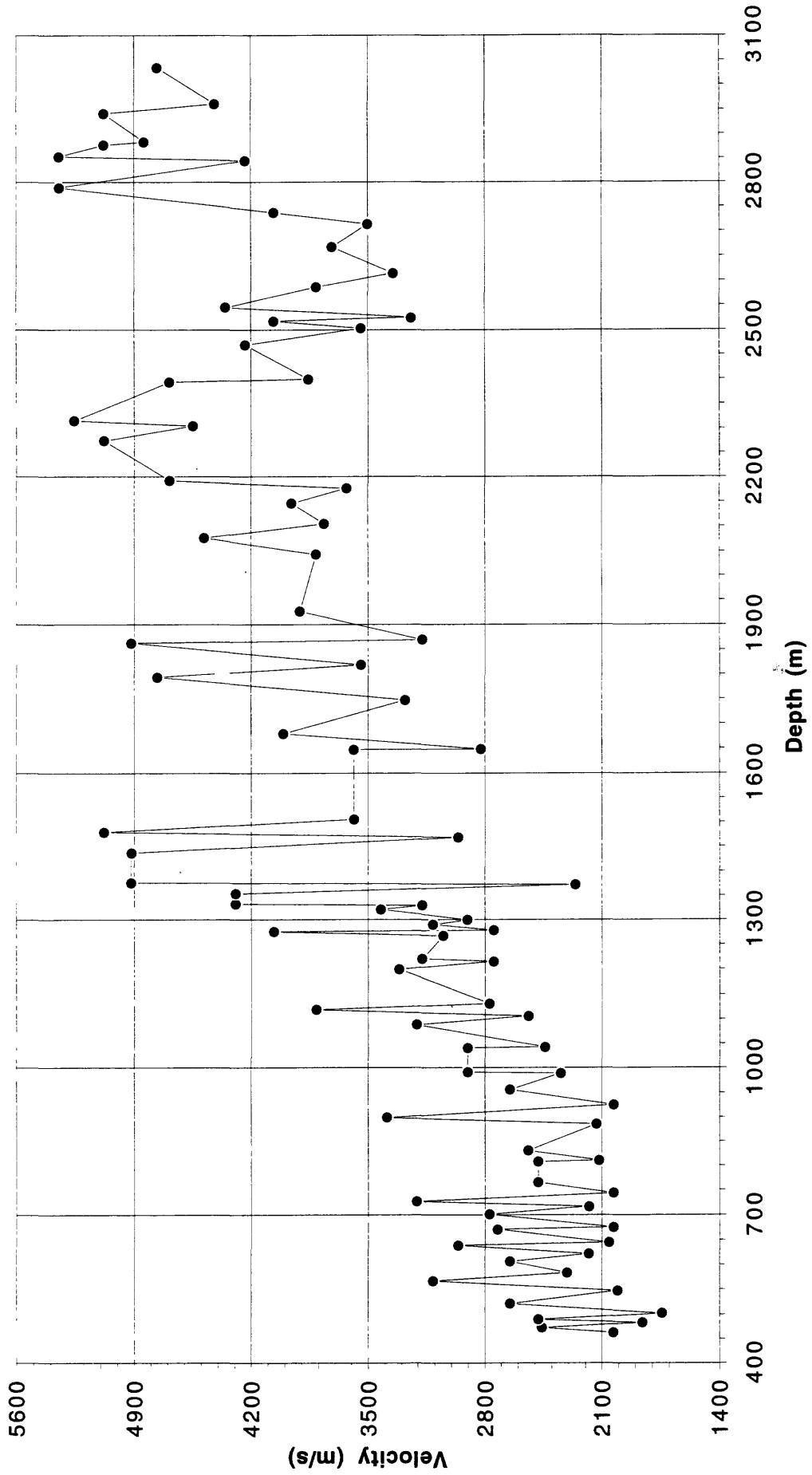


Figure 20.

Hans Nielson #1, Humble Oil & Refining Company

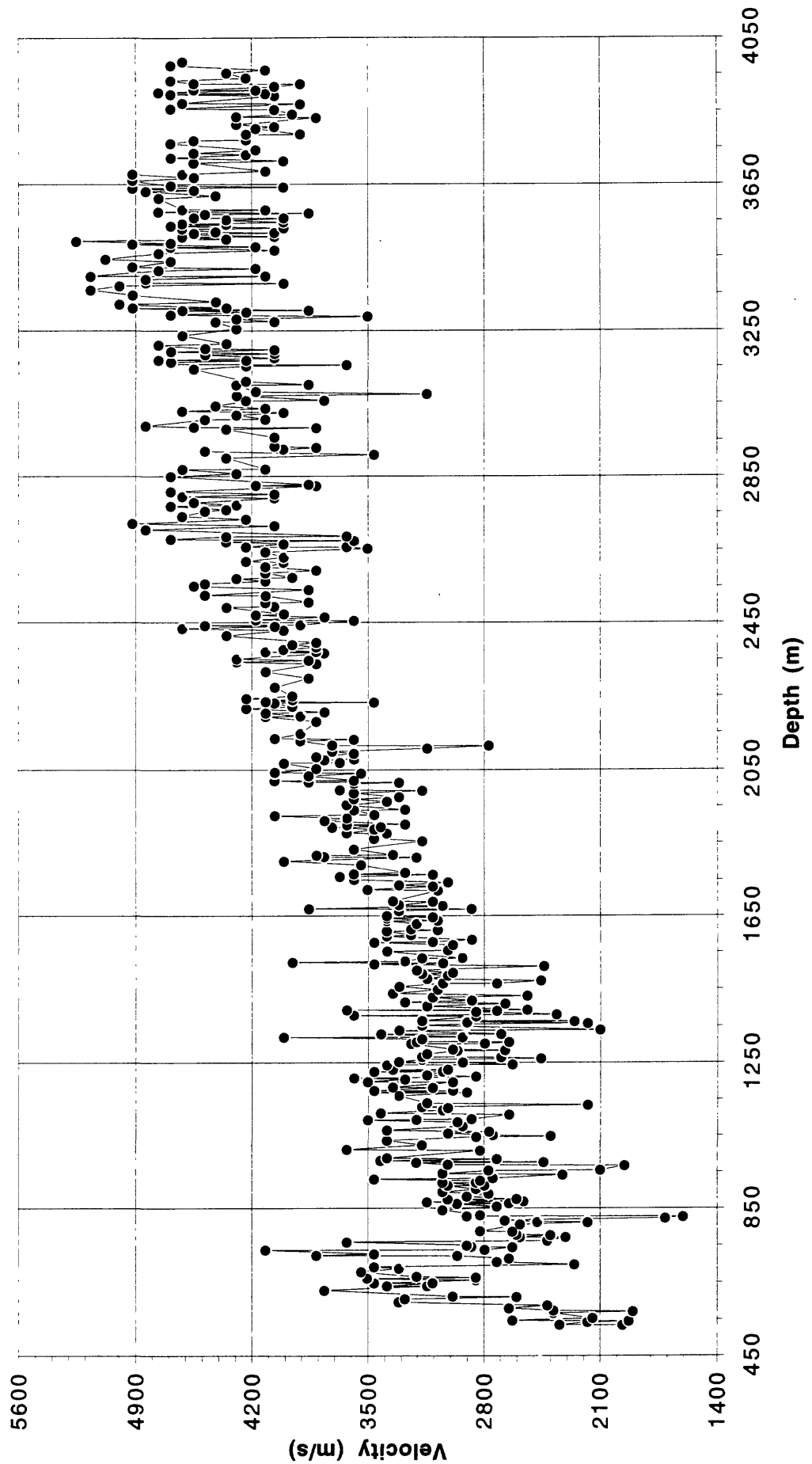


Figure 21.

A Gumpert #1, Cities Service Oil Company

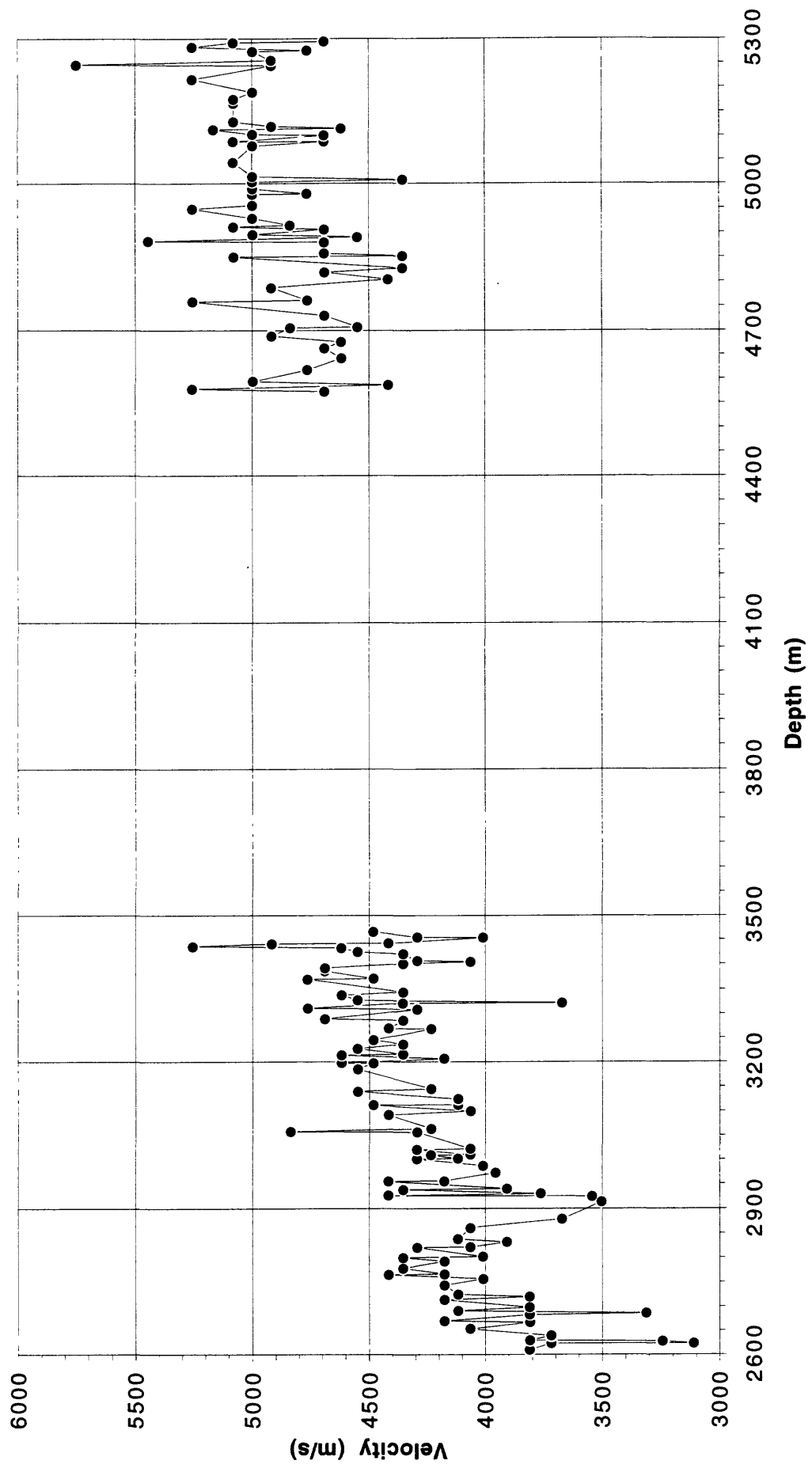


Figure 22.

Dyer #1, Michigan Oil Company

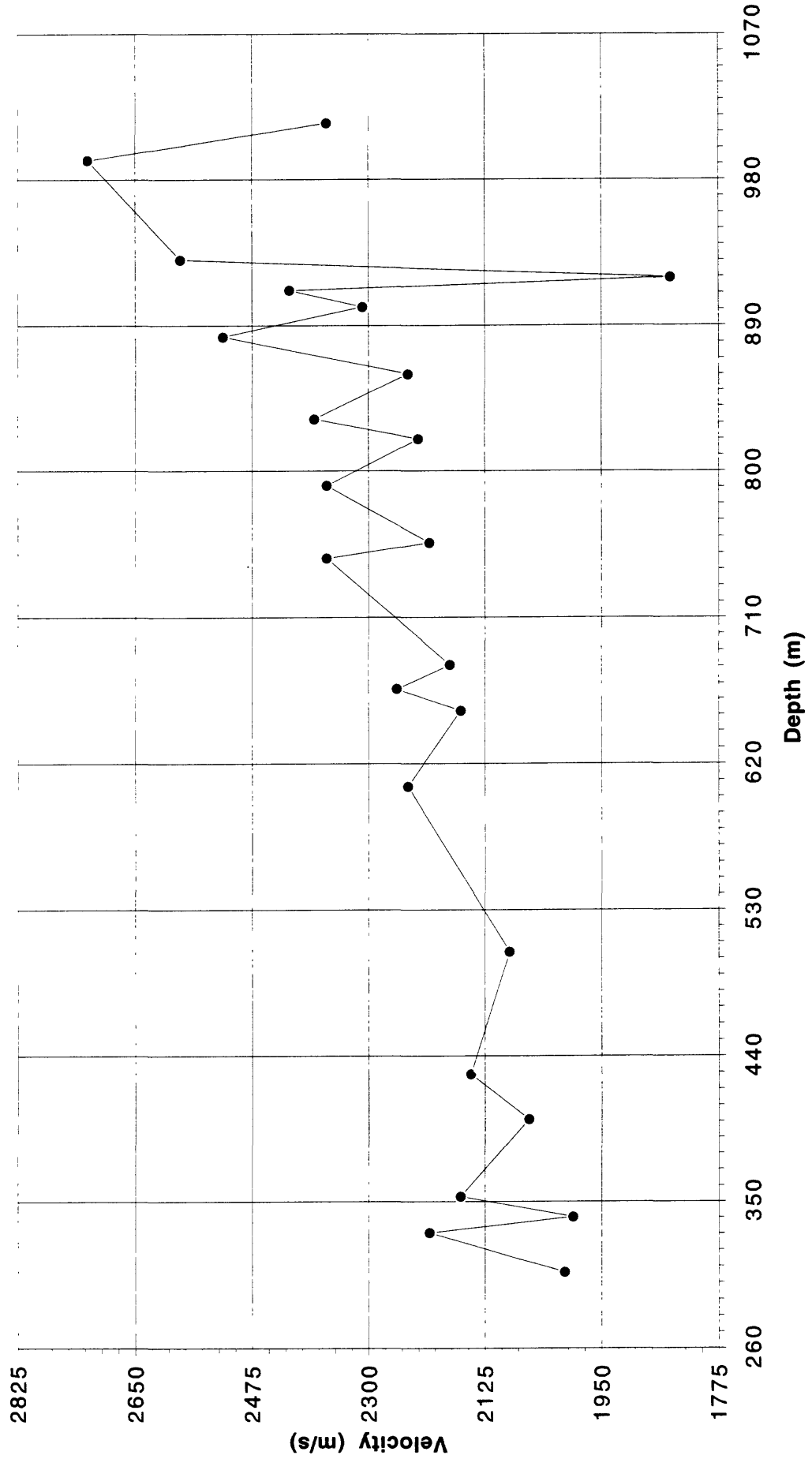


Figure 23.

Castello #1-13, Superior Oil Company

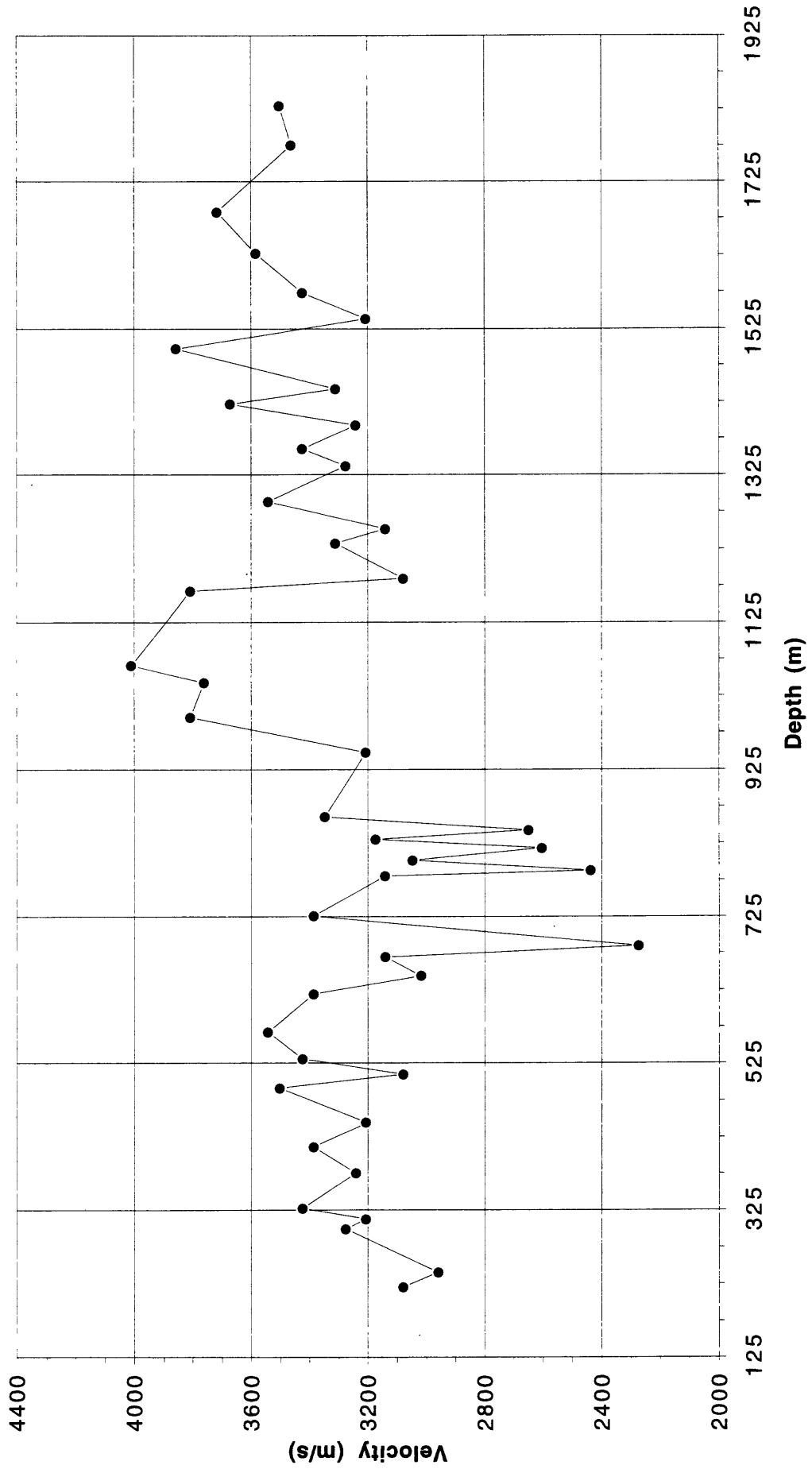


Figure 24.

Garvanta #68-22, Chowchilla Gas Corp.

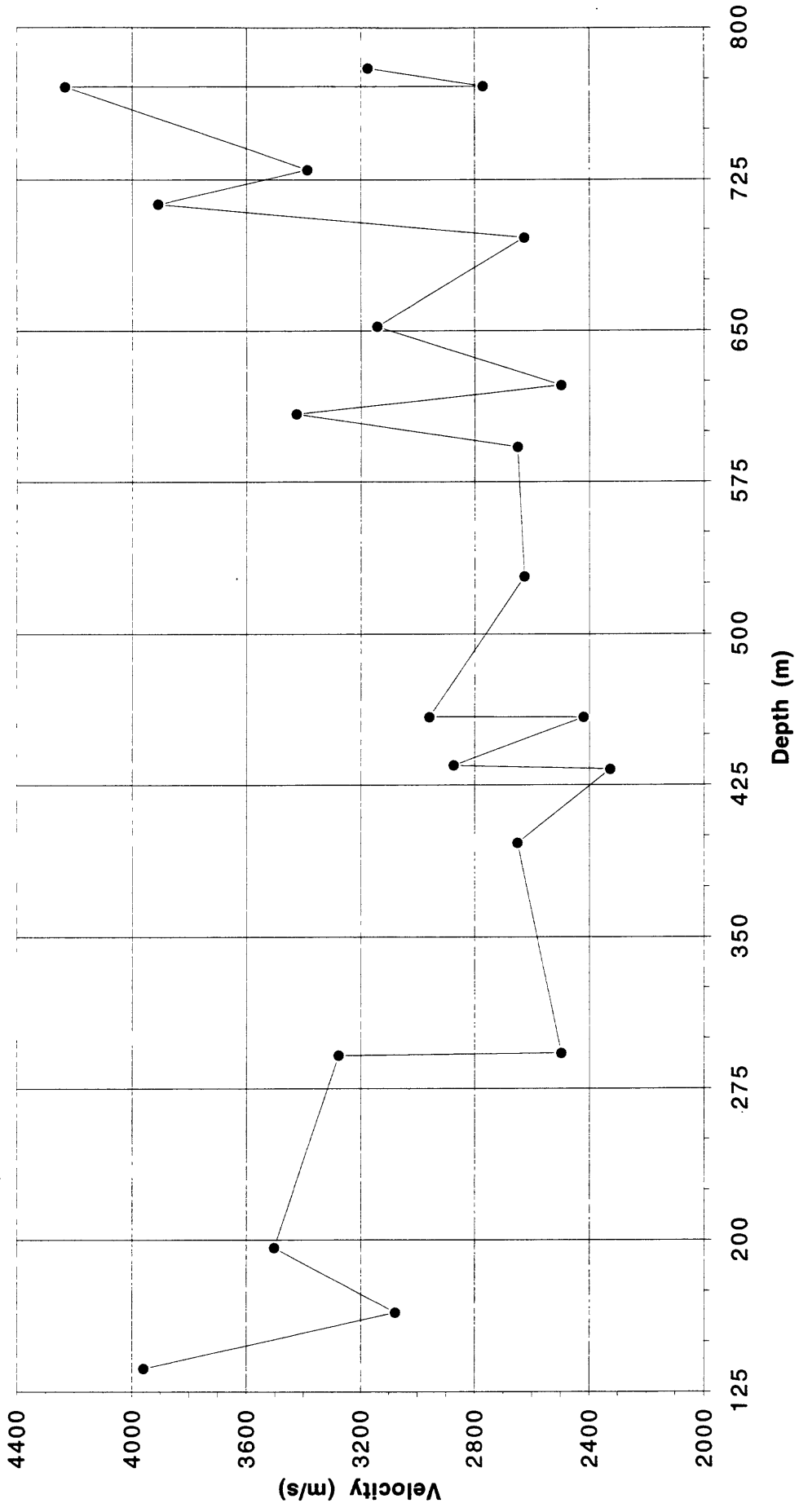


Figure 25.

**Gomes #1, Brazos Oil and Gas Company**

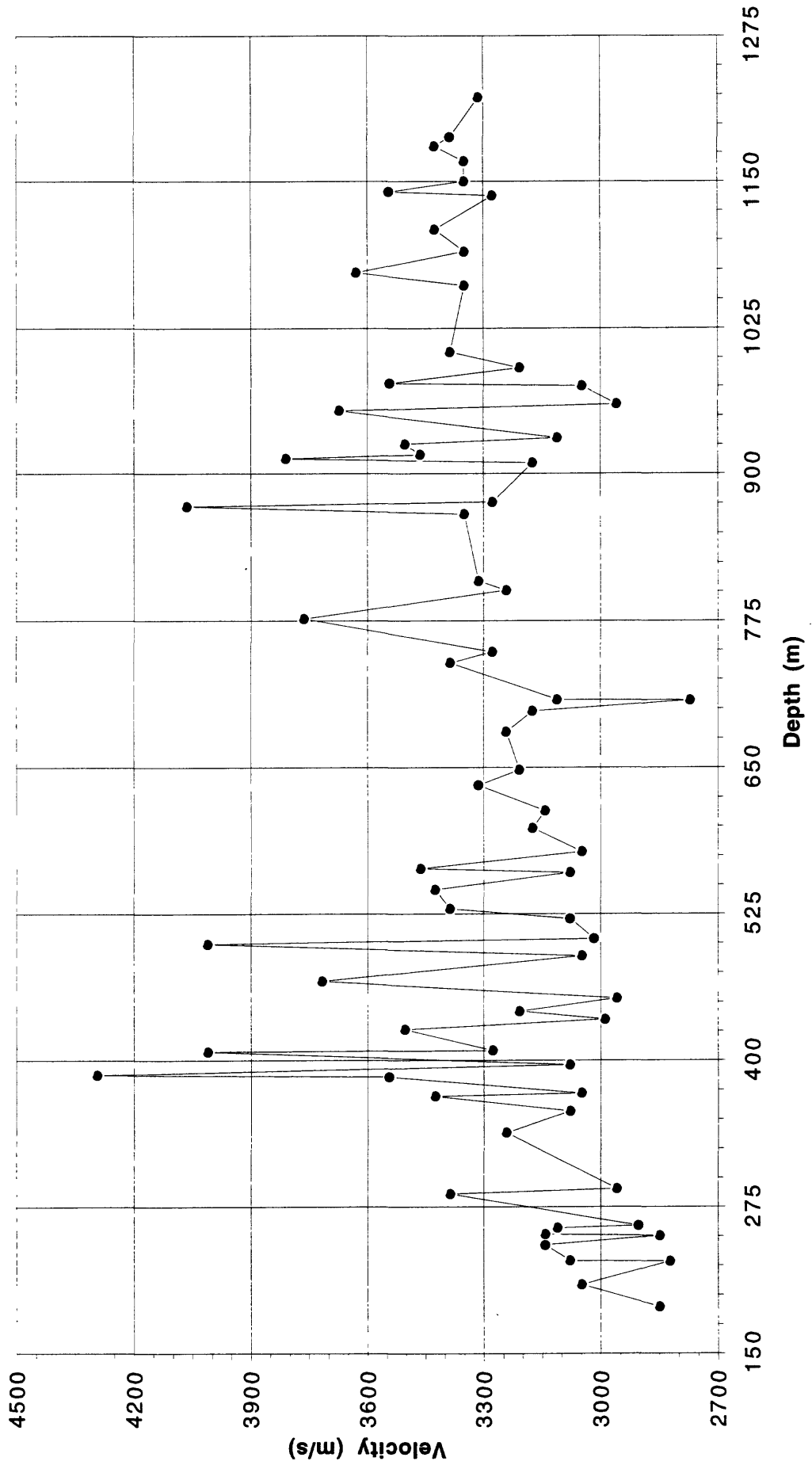


Figure 26.

SPRR #1, Capitol Oil Corporation

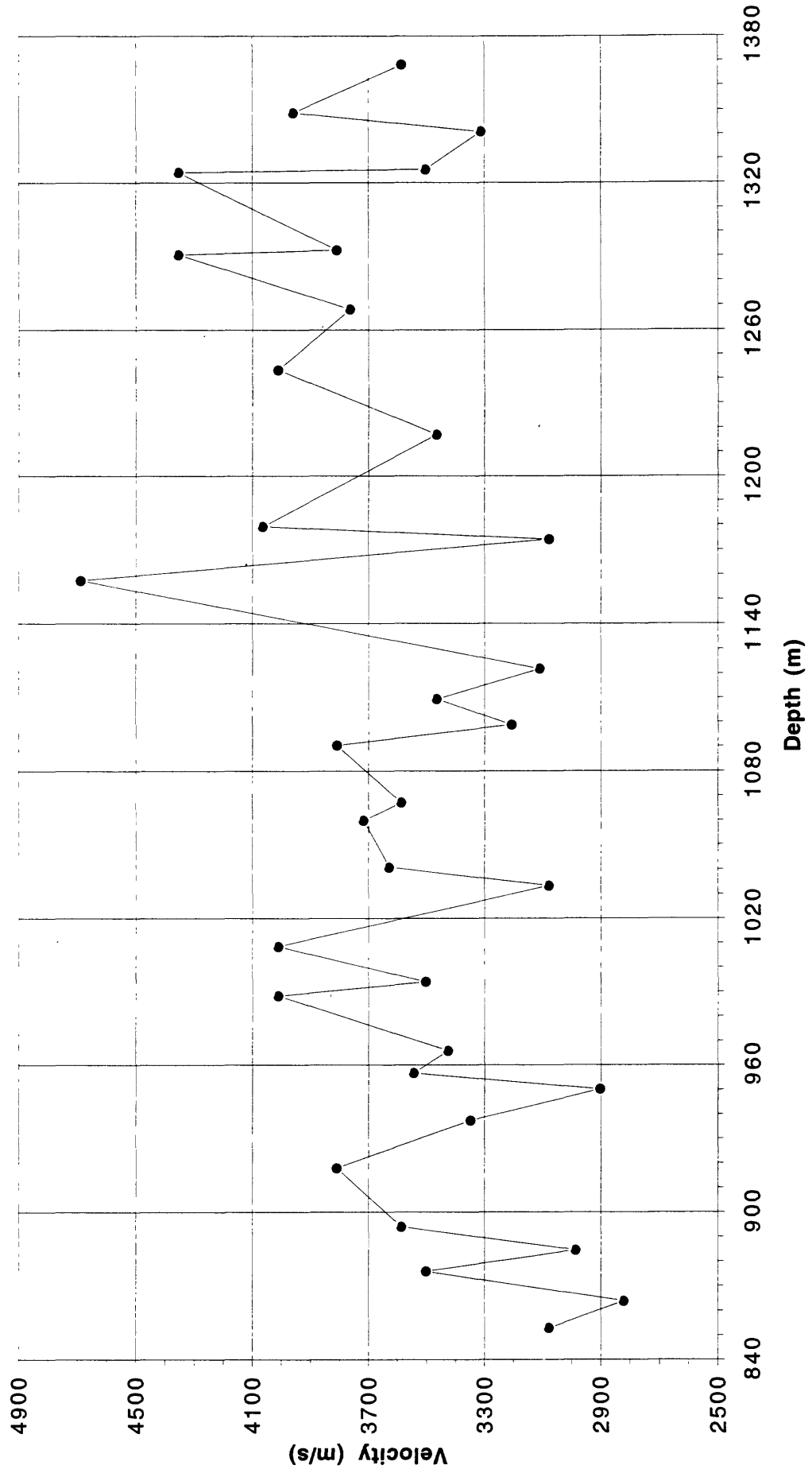


Figure 27.



McCulloch-Guidotti #1, McCulloch Oil of Calif.

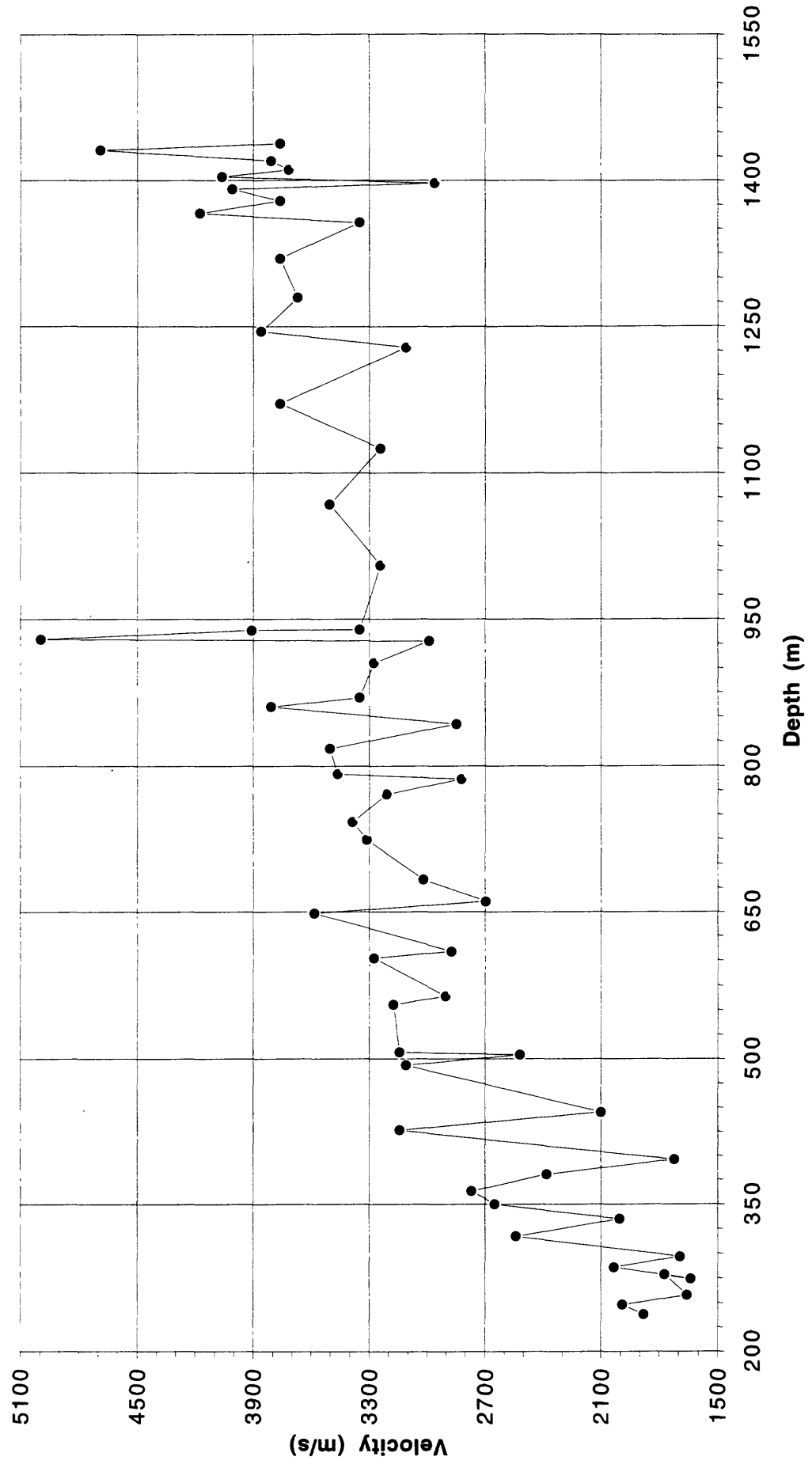


Figure 28.

Gertrude M. Kennedy #1, Sunray DX Oil Company

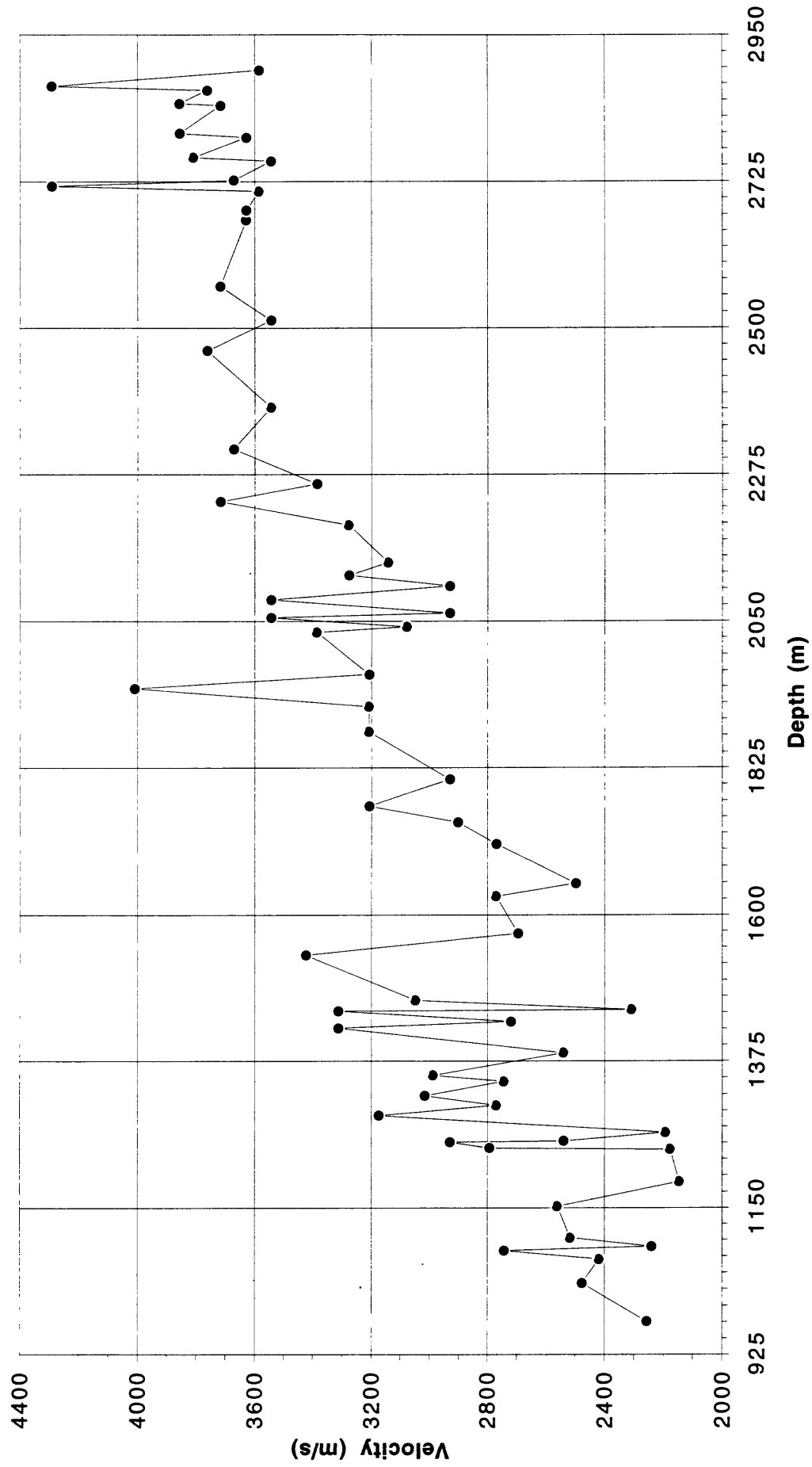


Figure 29.

McCulloch-Maridon #1, McCulloch Oil of Calif.

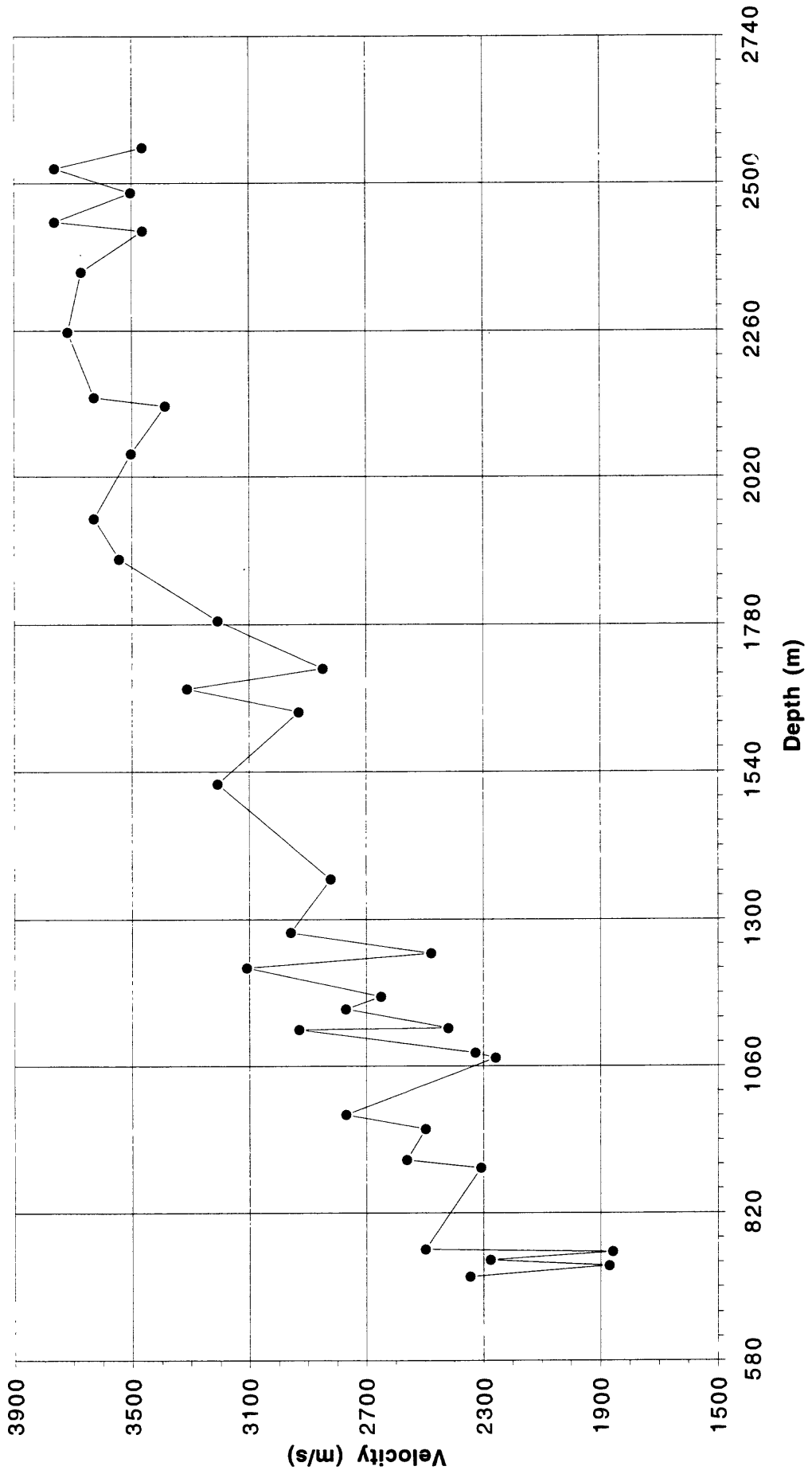


Figure 30.

**Miller-Richards #1-1, Hershey Oil & Gas Company**

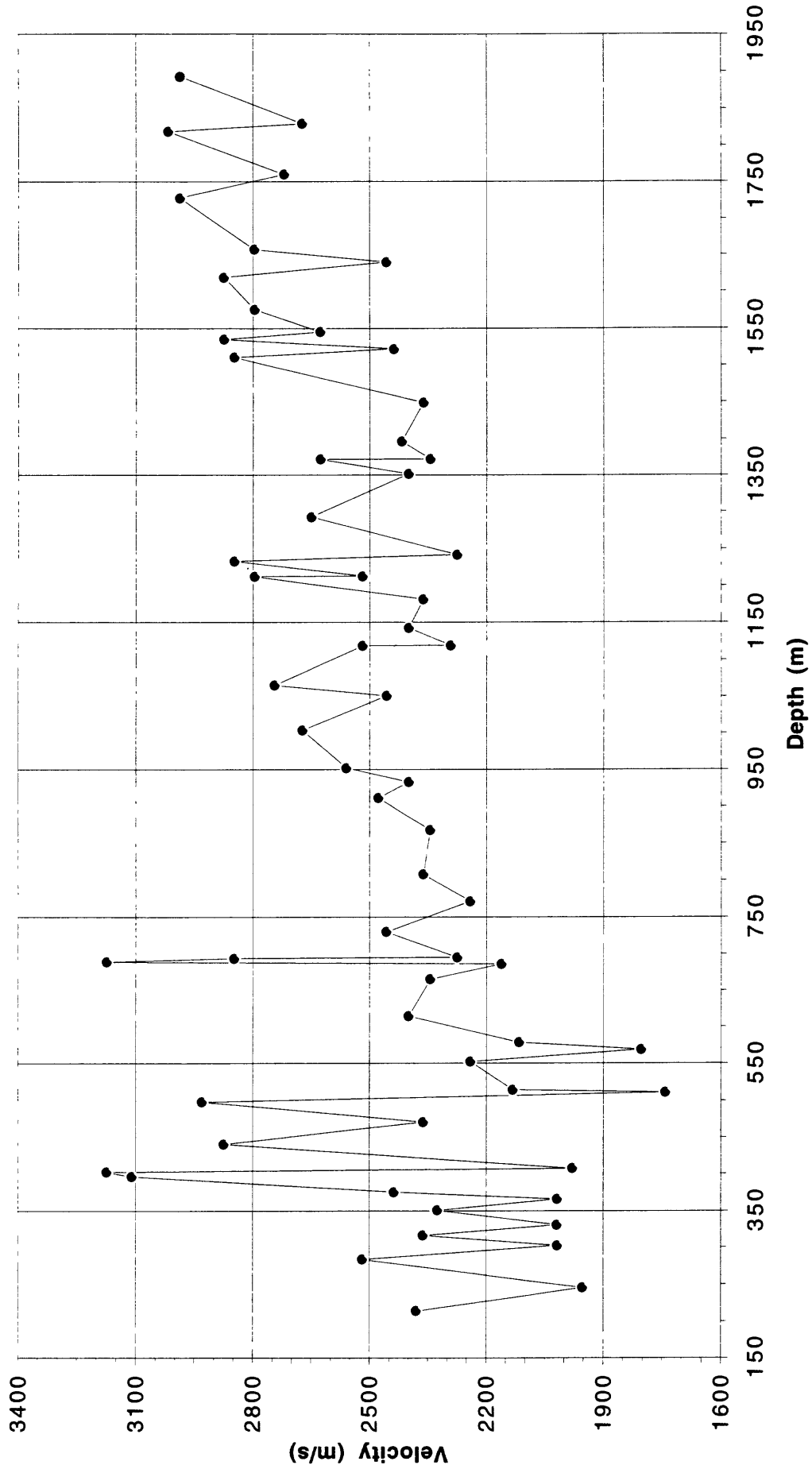


Figure 31.

McCulloch-Nissen #6, McCulloch Oil of Calif.

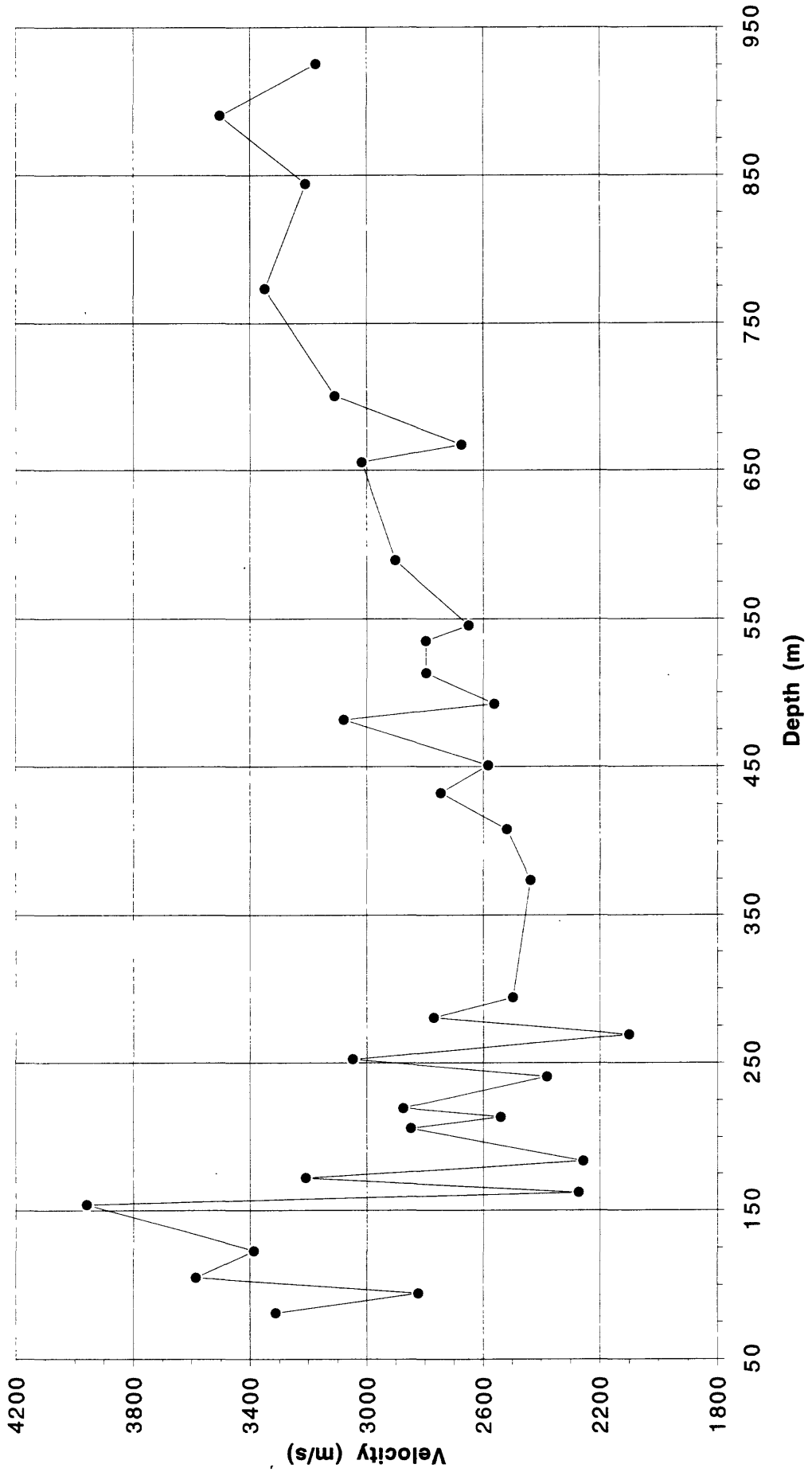


Figure 32.

McCulloch-Coyne Unit #1, McCulloch Oil of Calif.

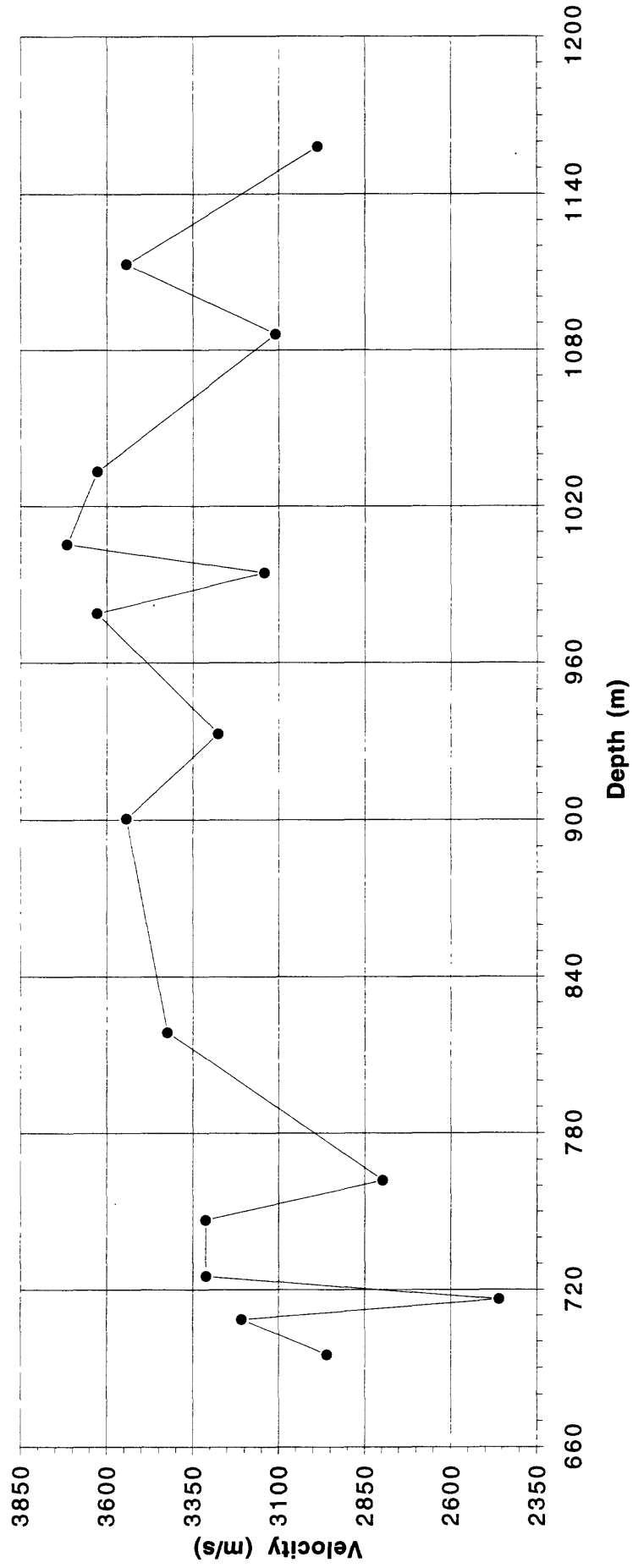


Figure 33.

Lupin #5, E. C. Brown

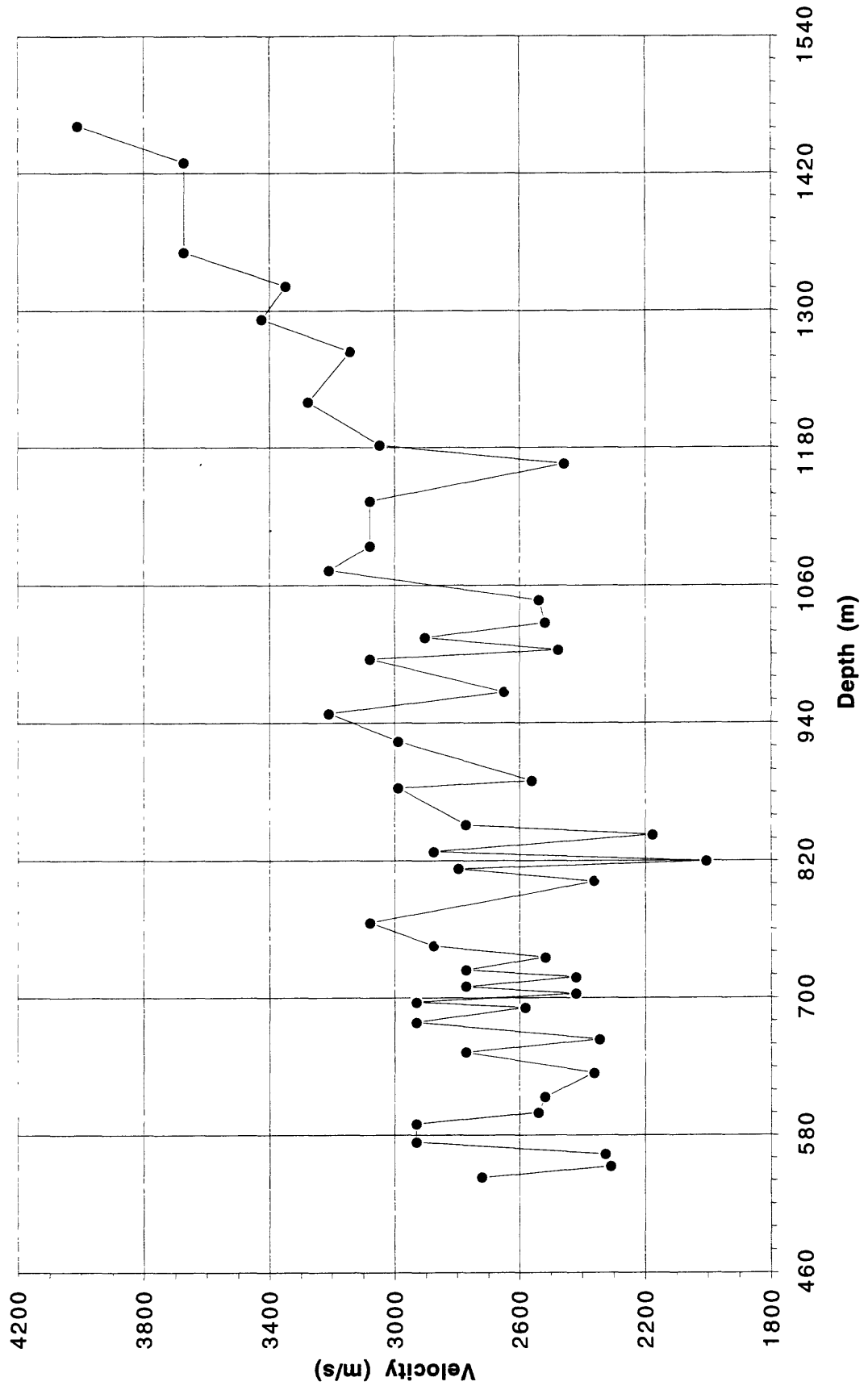


Figure 34.

Gerlach #22-14, John M. Young

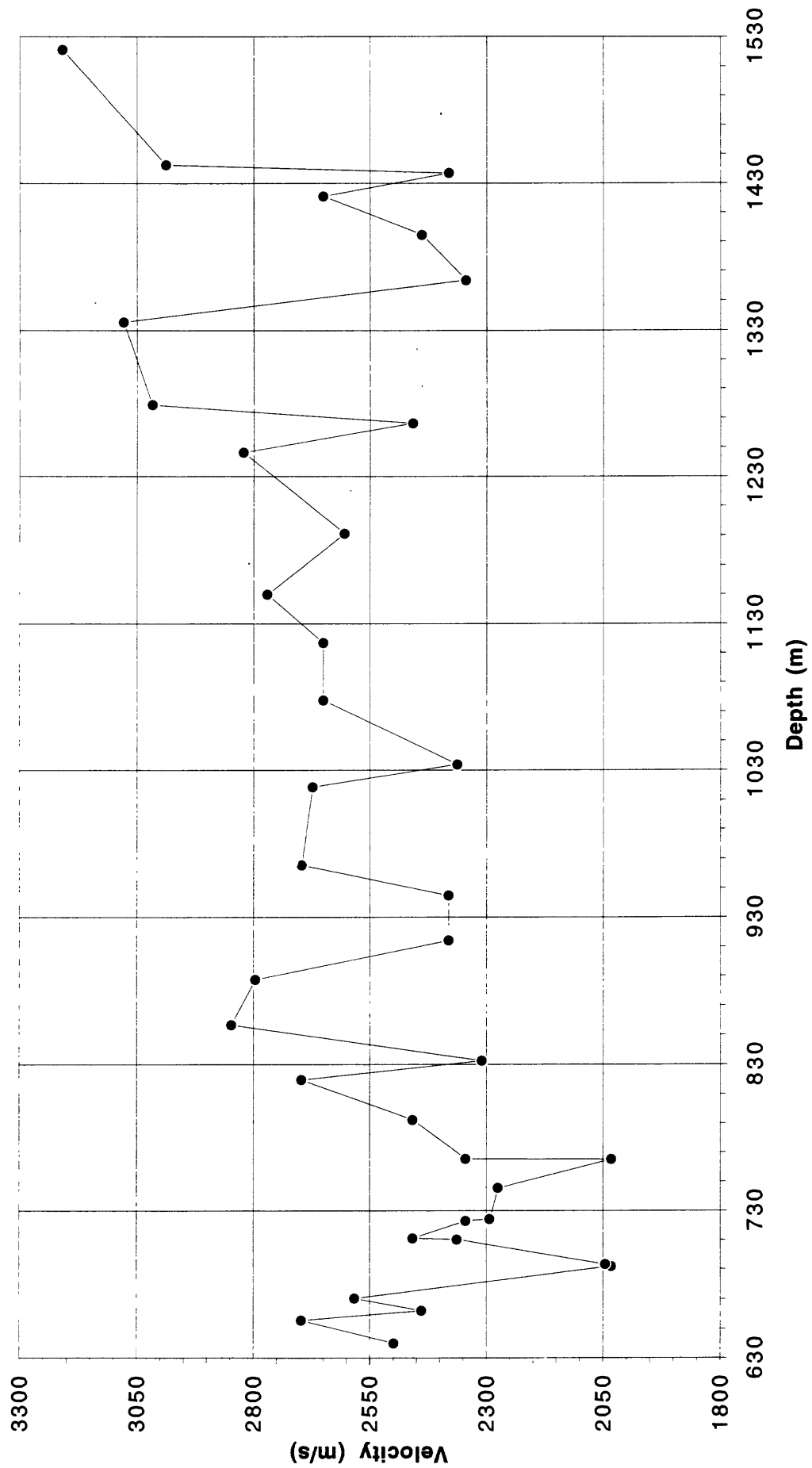


Figure 35.



Tesla #1, R. W. McBurney

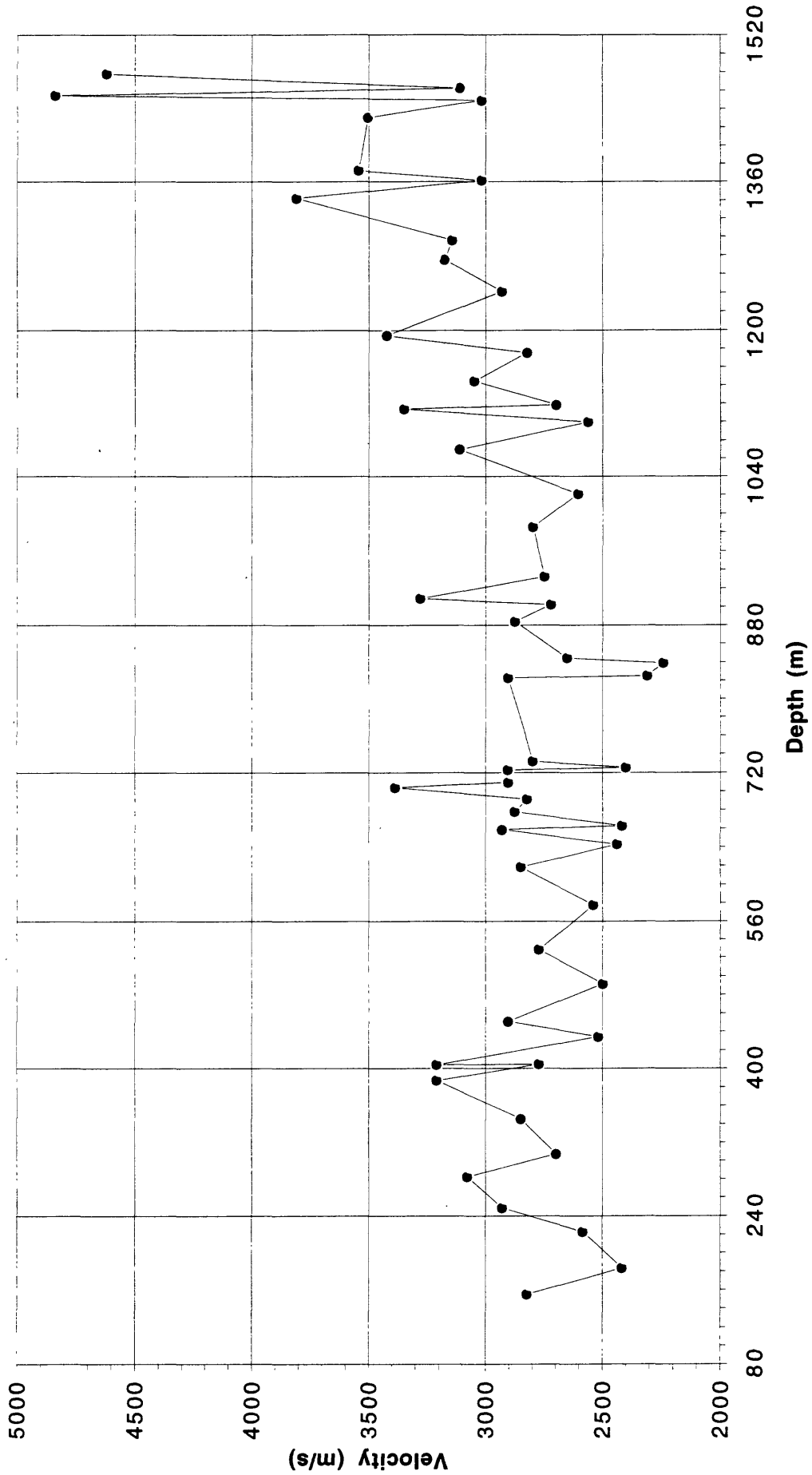


Figure 36.

Peterson Fee #43-17, Diamond Shamrock Corp.

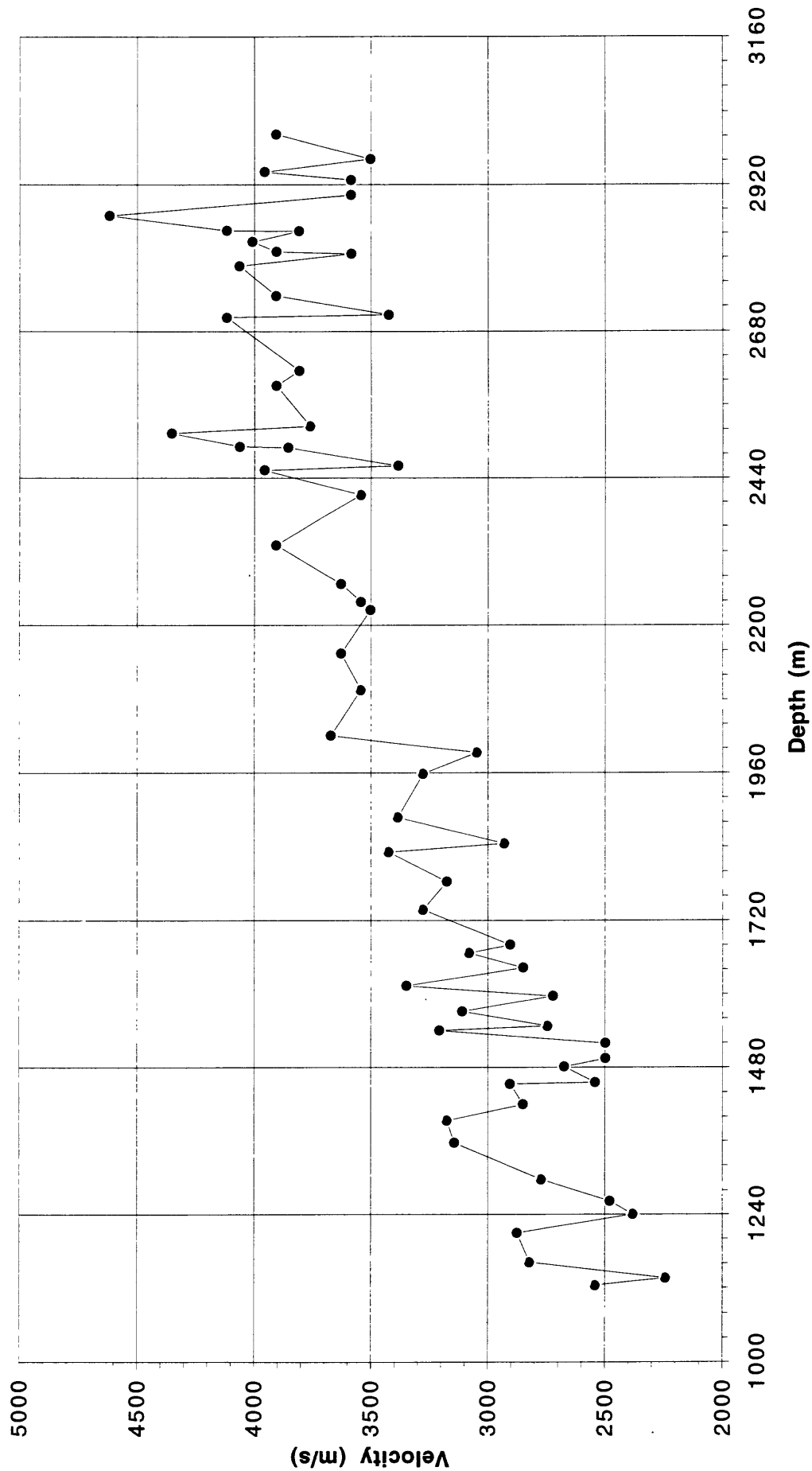


Figure 37.

Steele #47-19, Horace Steele

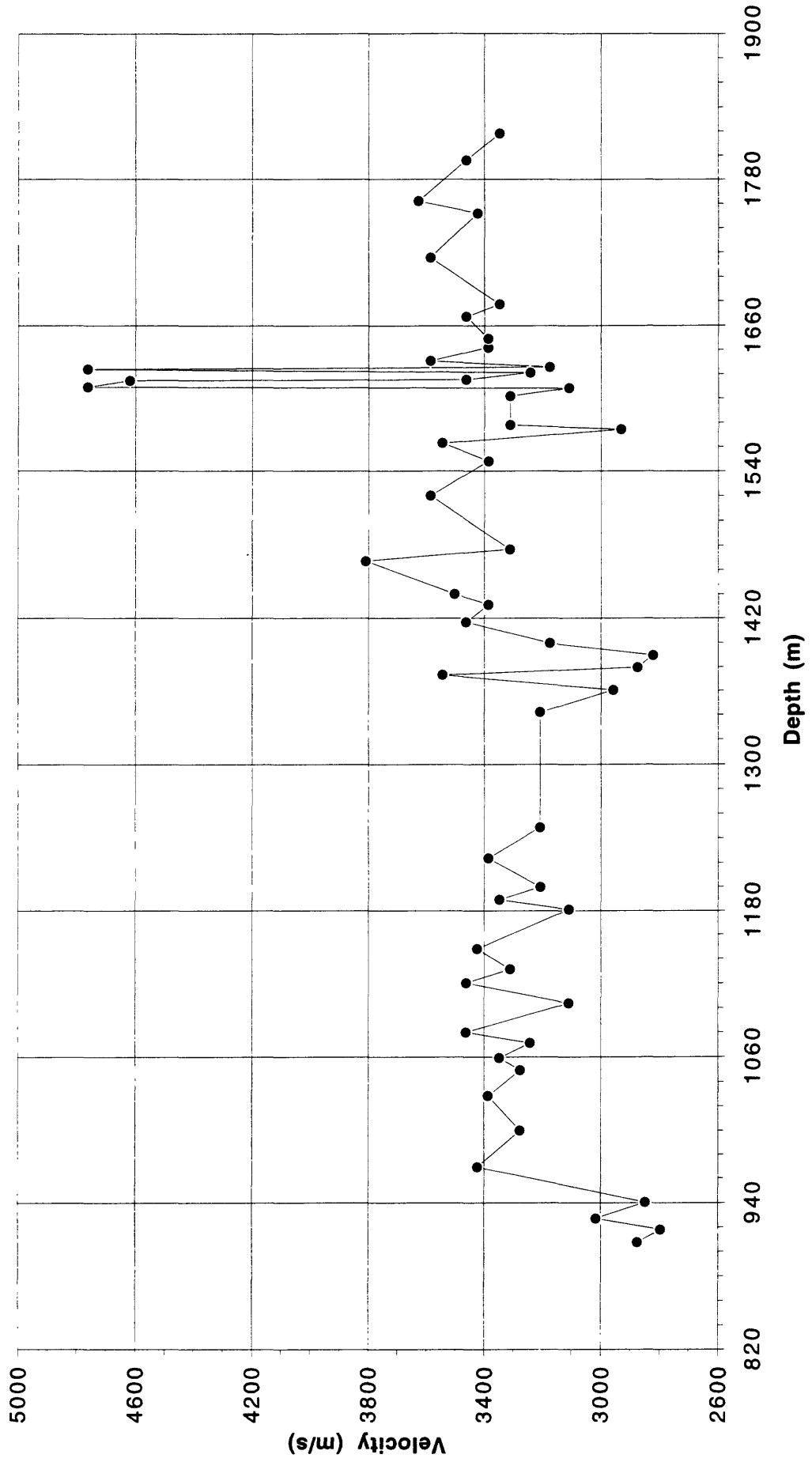


Figure 38.

# Young Unit #1-1, Reserve Oil & Gas

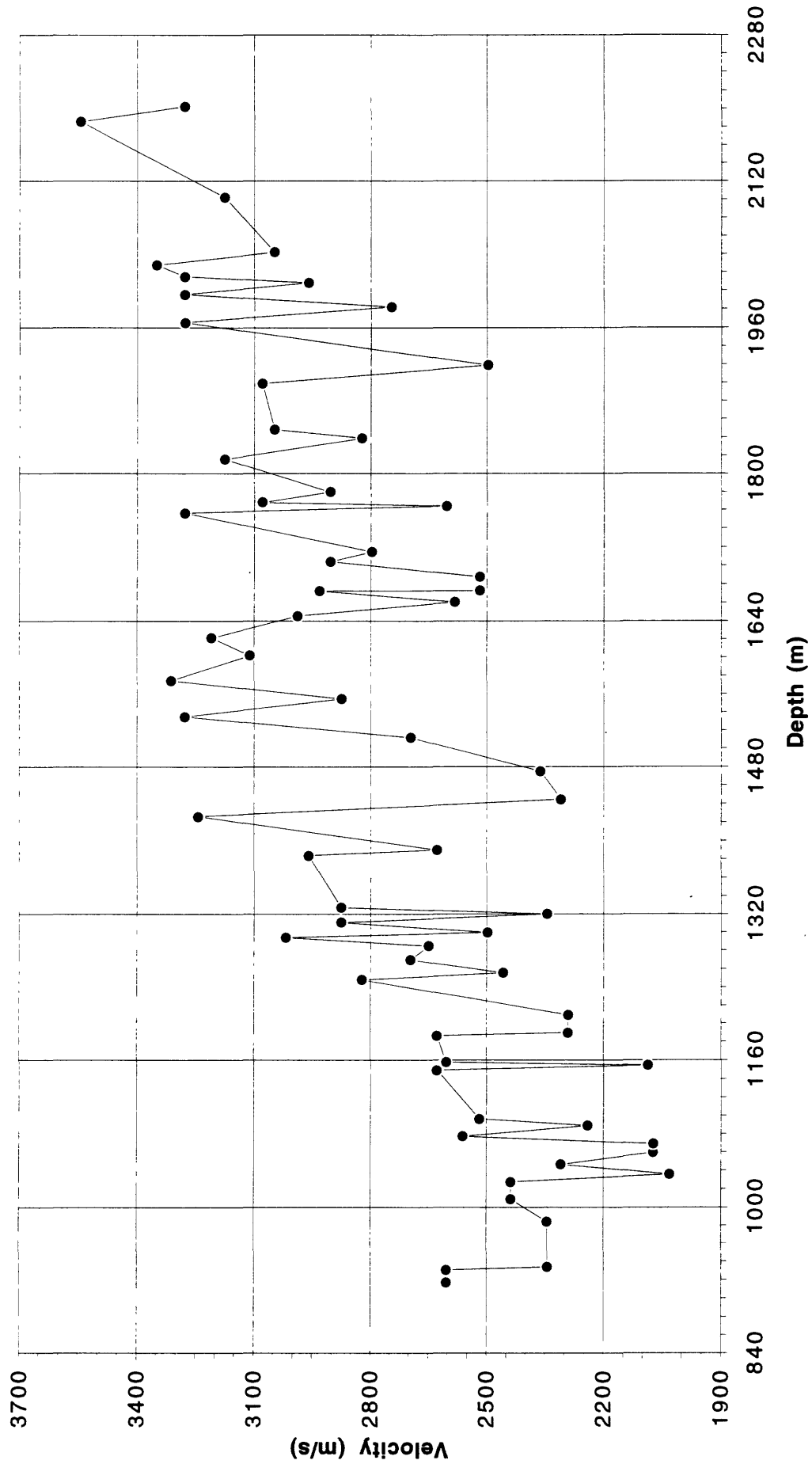


Figure 39.

Wisner Unit 1 #1, Hunnicutt & Camp Drilling Co.

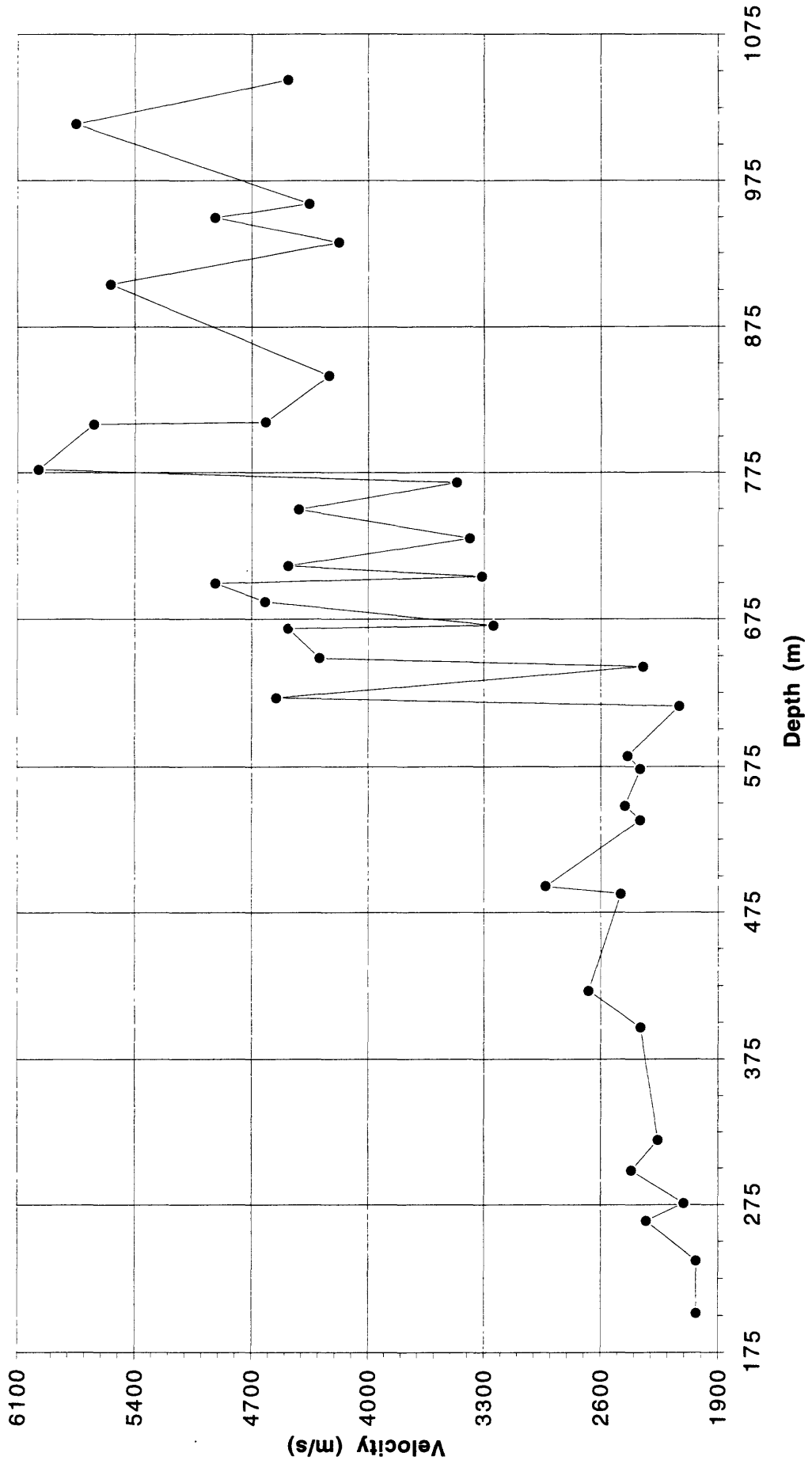


Figure 40.

# Mulqueeneey #1, Trico Oil & Gas Company

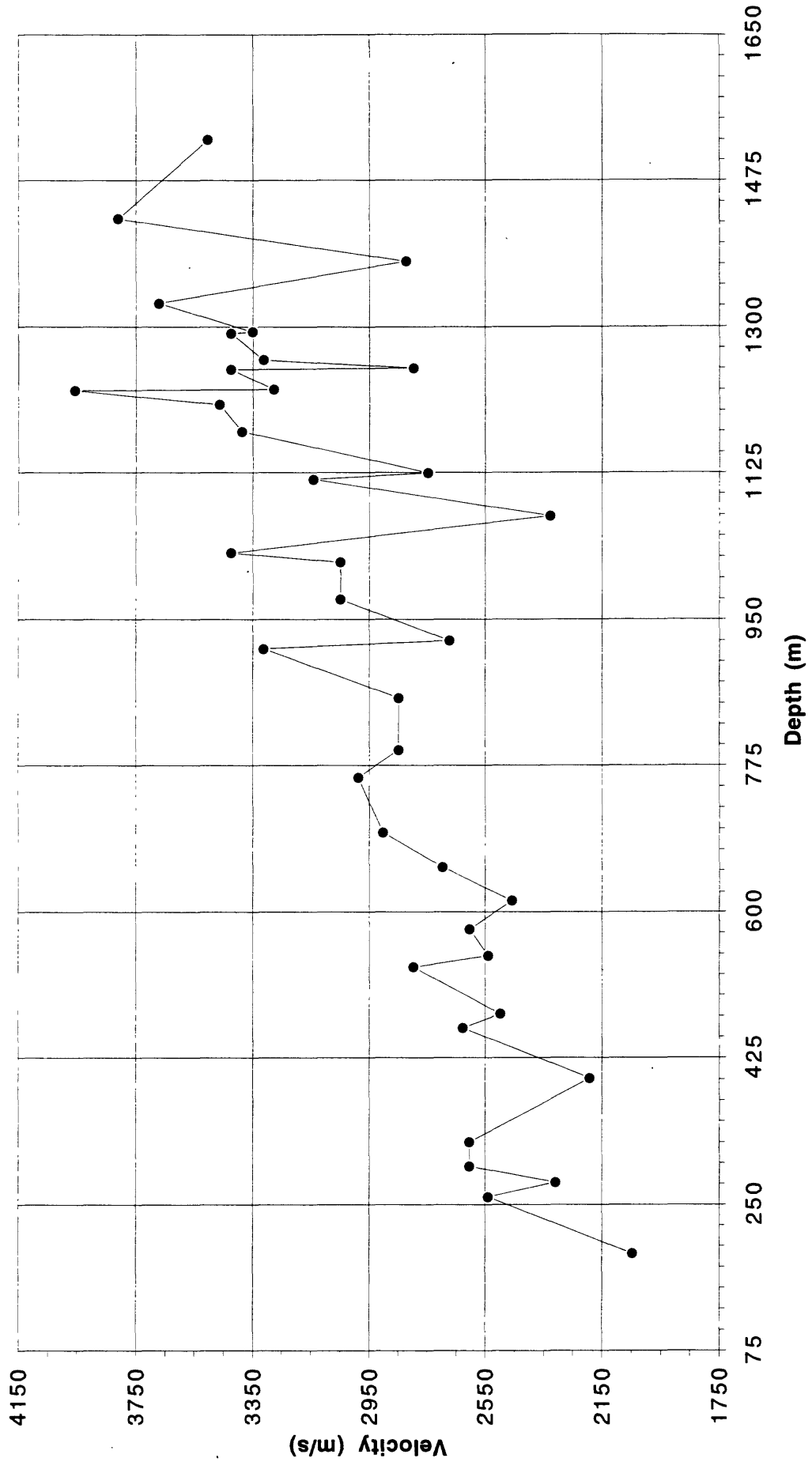


Figure 41.

KCY-GNESA #44-25, Kern County Land Company

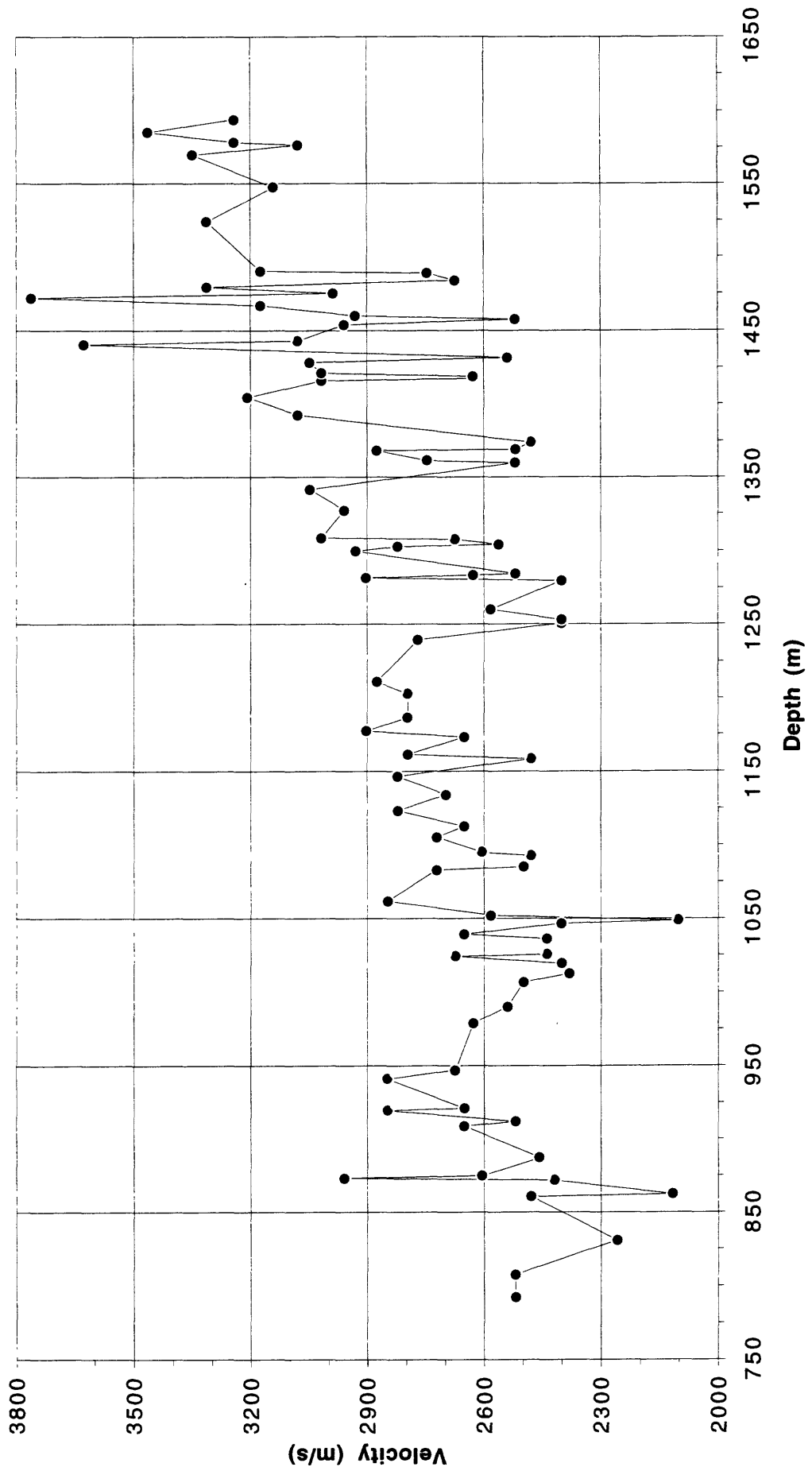


Figure 42.

Santa Cruz Lumber #12-18, Champlin Petroleum Co.

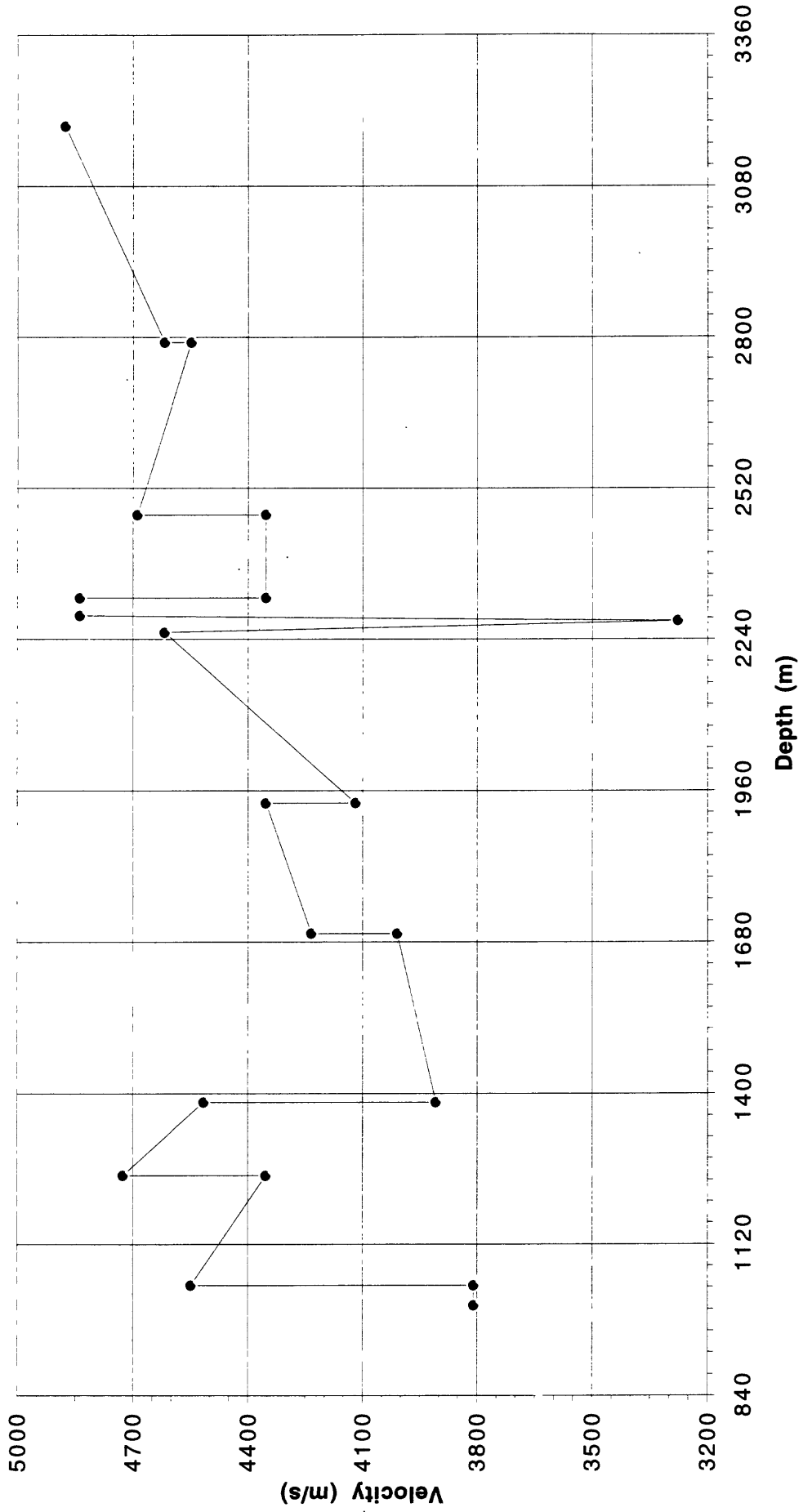


Figure 43.



# John Rice #1, Claremont Energy

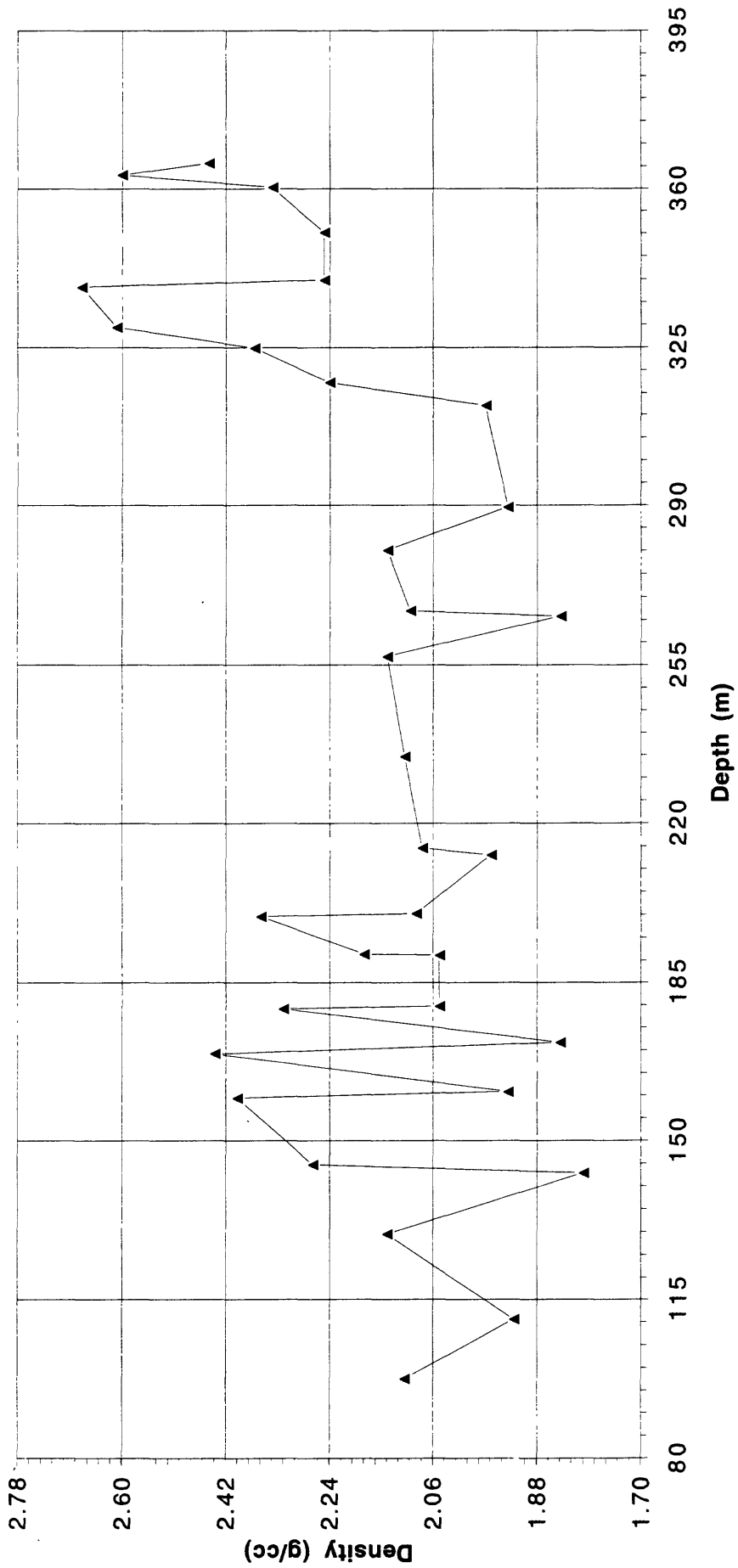
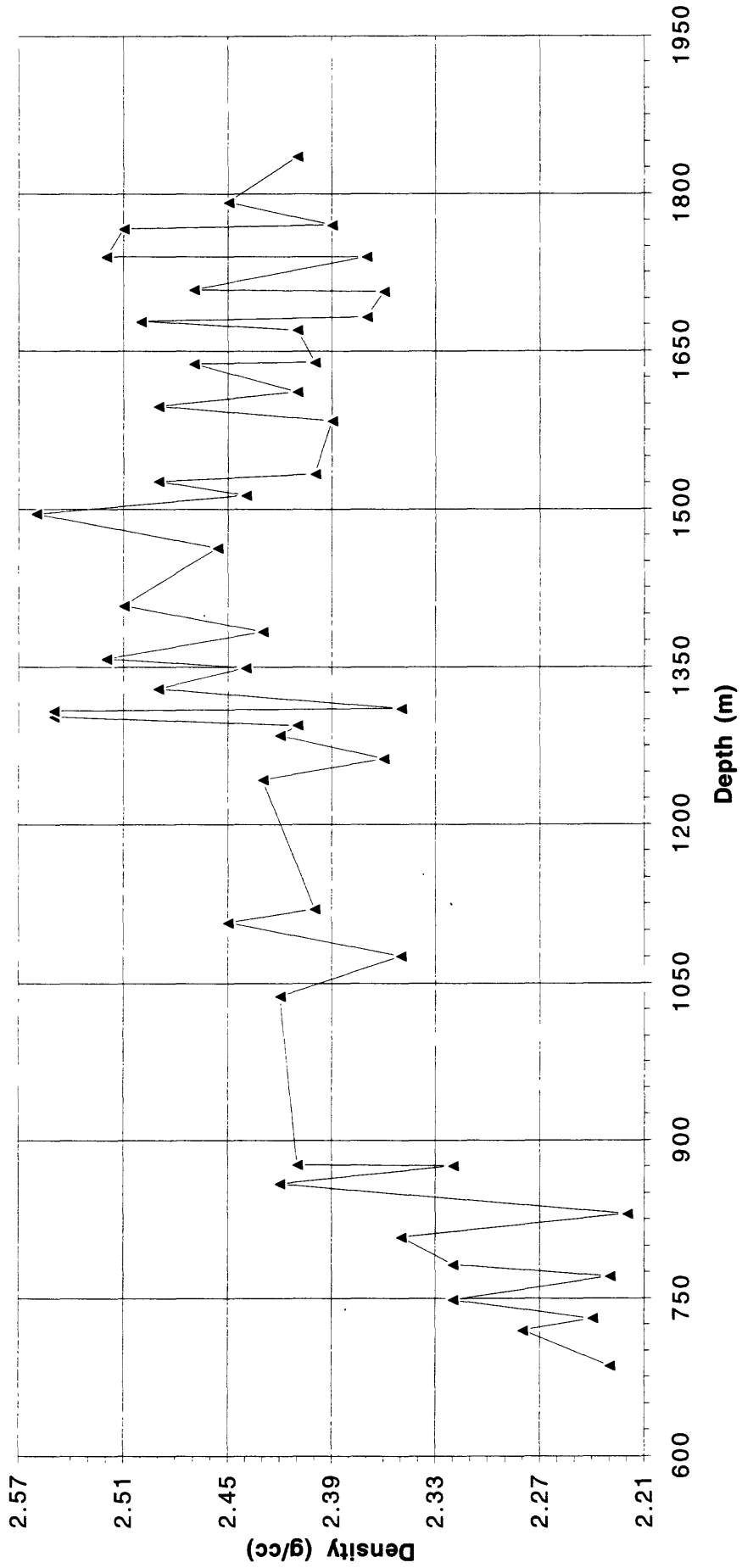
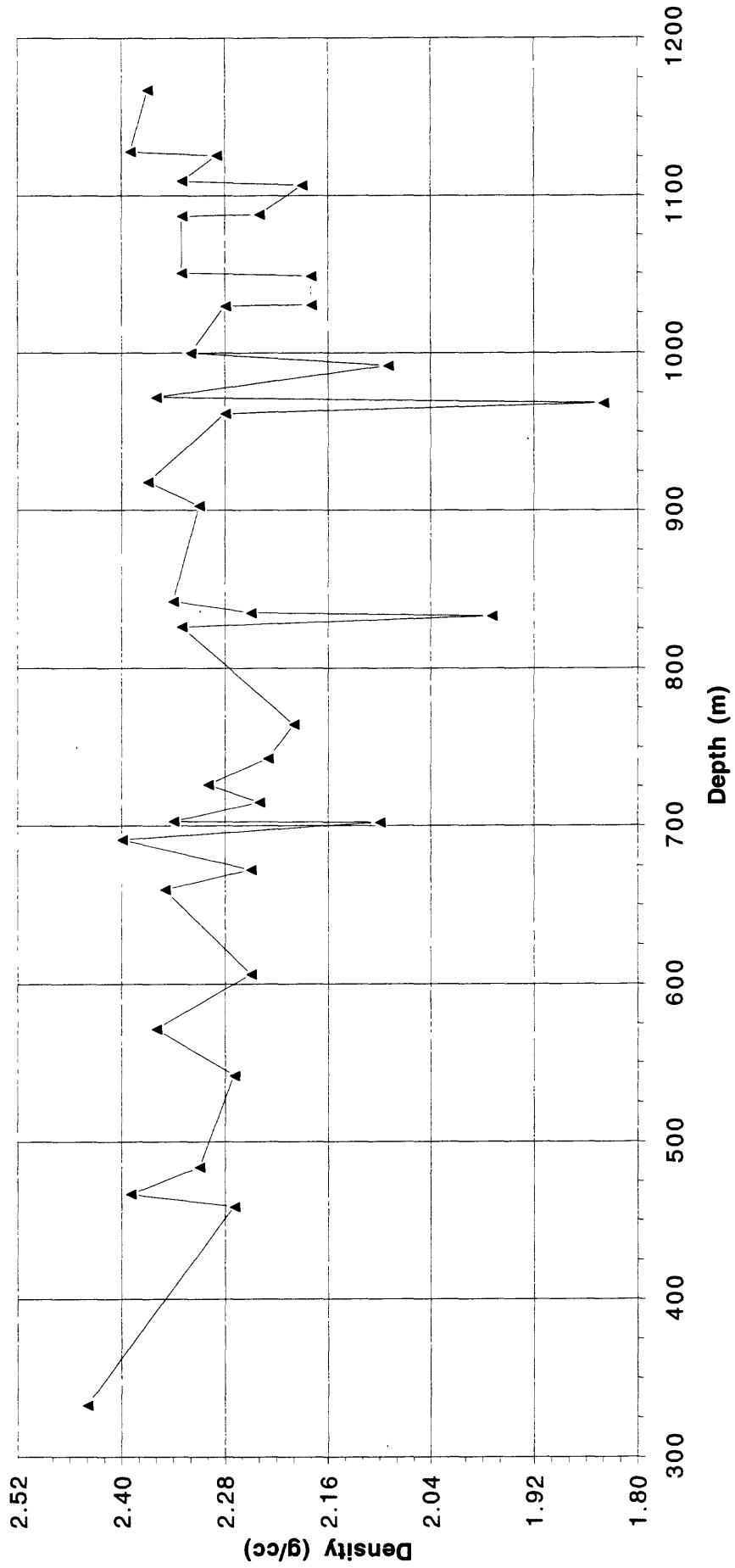


Figure 44.

H.D. Peterson et al #558-25, Standard Oil of Amer.



Kirby Community #12, Chevron USA, Inc.



L. Nixon #1, Standard Oil of America

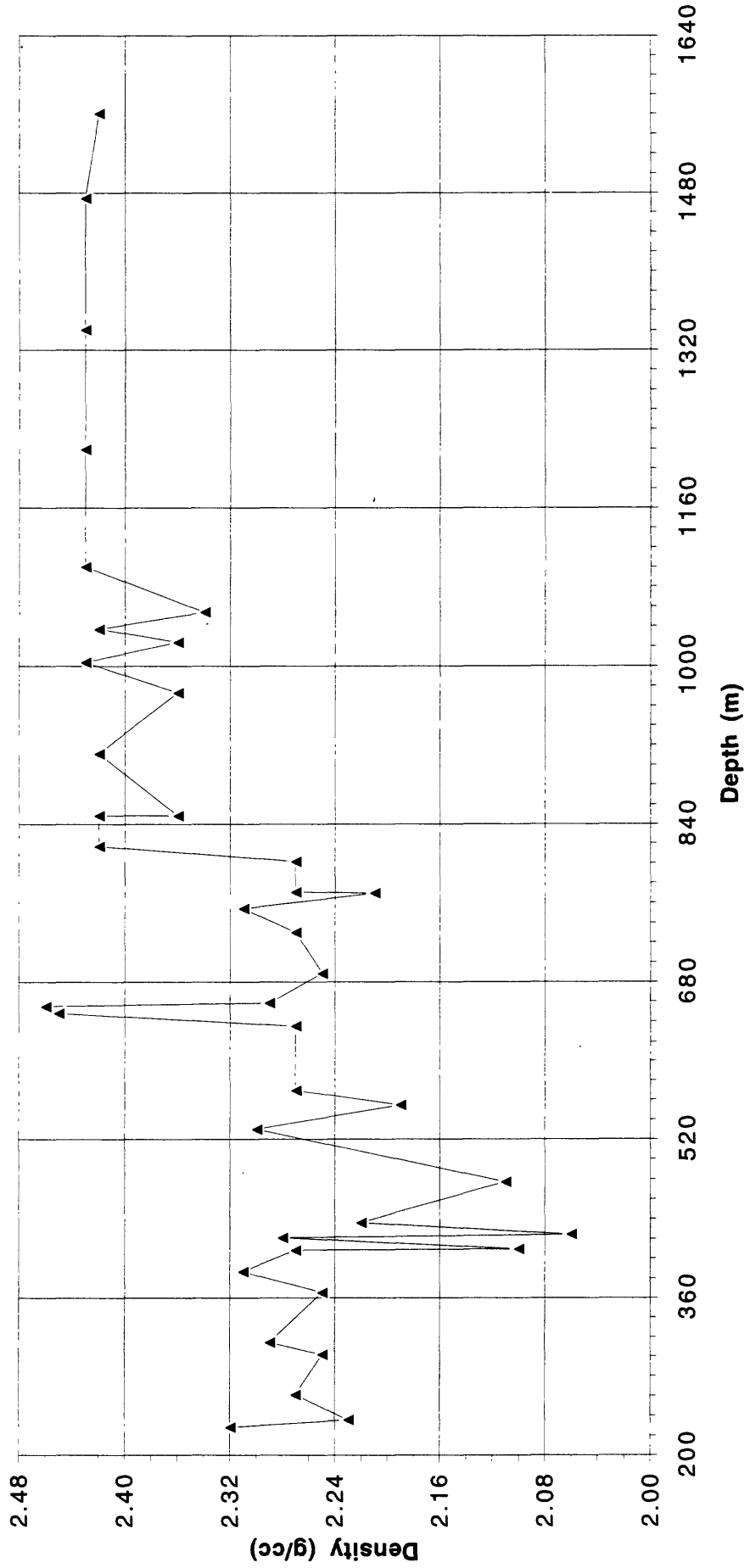


Figure 47.

Seeno-Scott #2, Chevron USA, Inc.

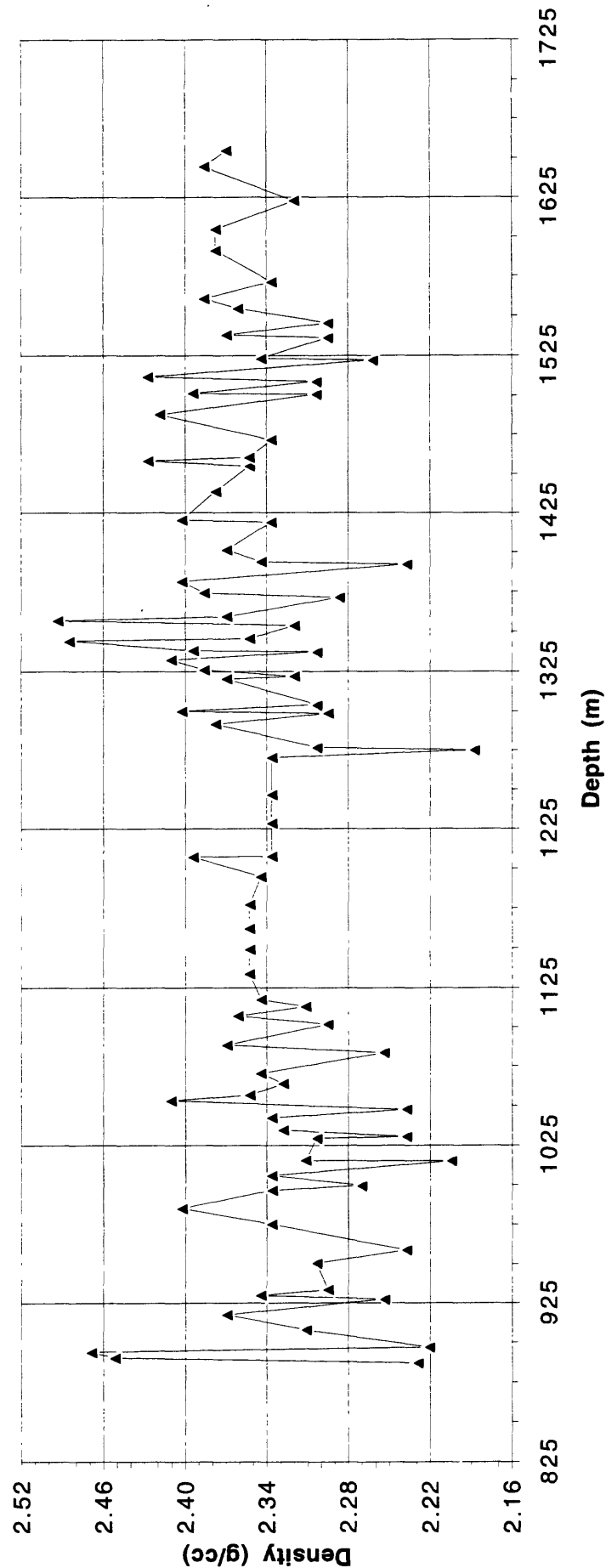


Figure 48.

# Bethlehem #1, Standard Oil of America

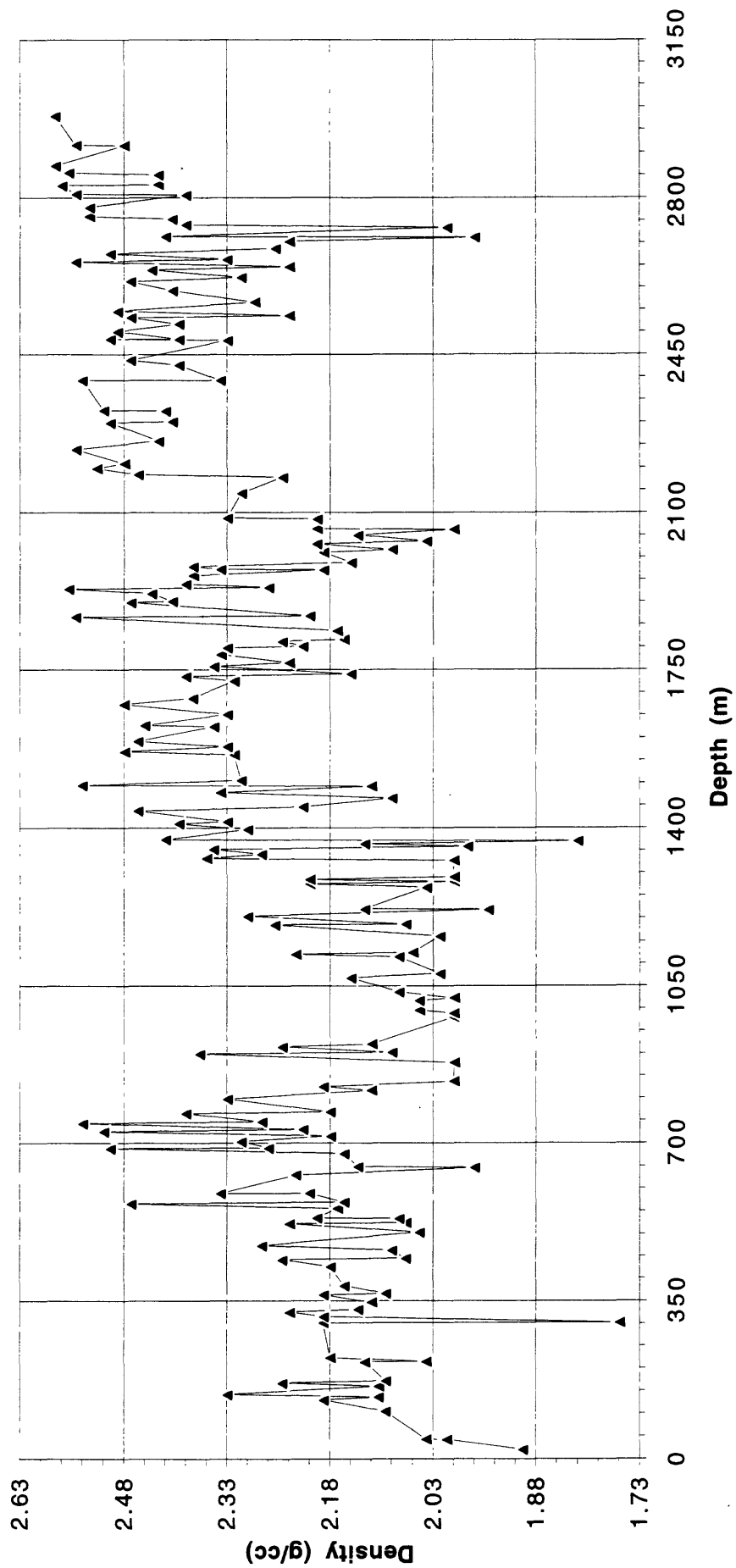


Figure 49.

**E Gumpert #1, Chevron USA, Inc.**

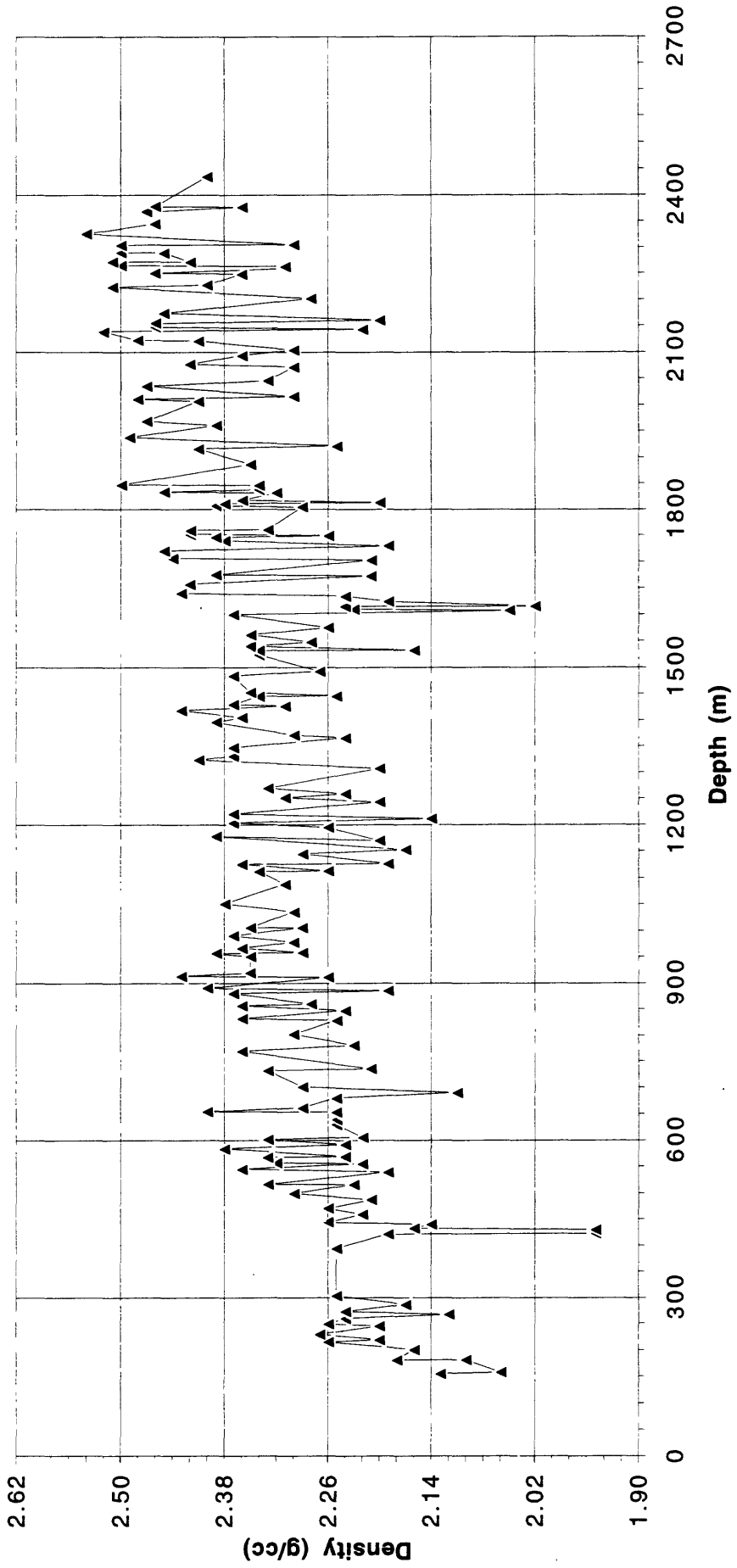


Figure 50.

**A Gumpert #1, Cities Service Oil Company**

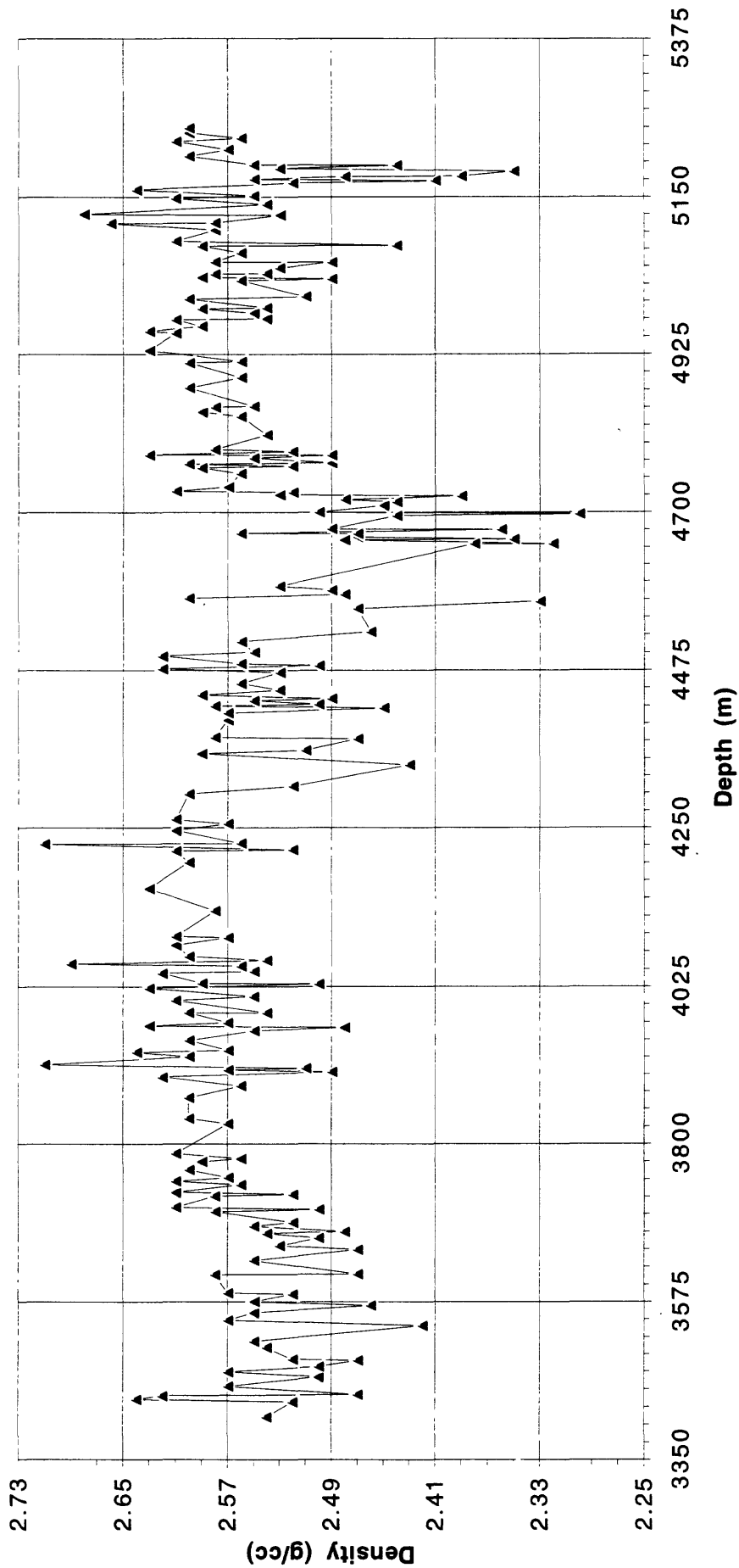


Figure 51.



City of Livermore #1, Buttes Oil & Gas Company

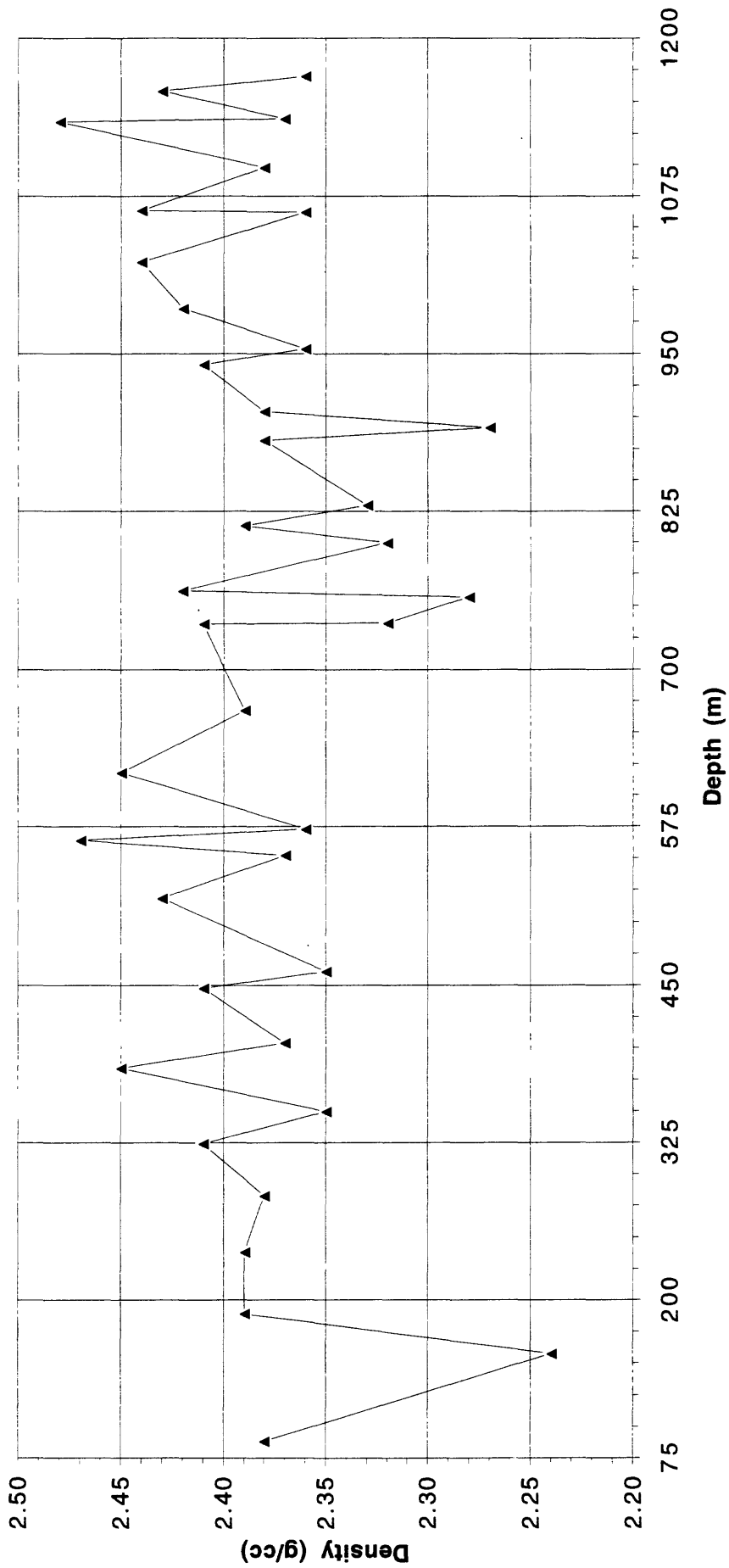


Figure 52.

**McCulloch-Guidotti #1, McCulloch Oil of Calif.**

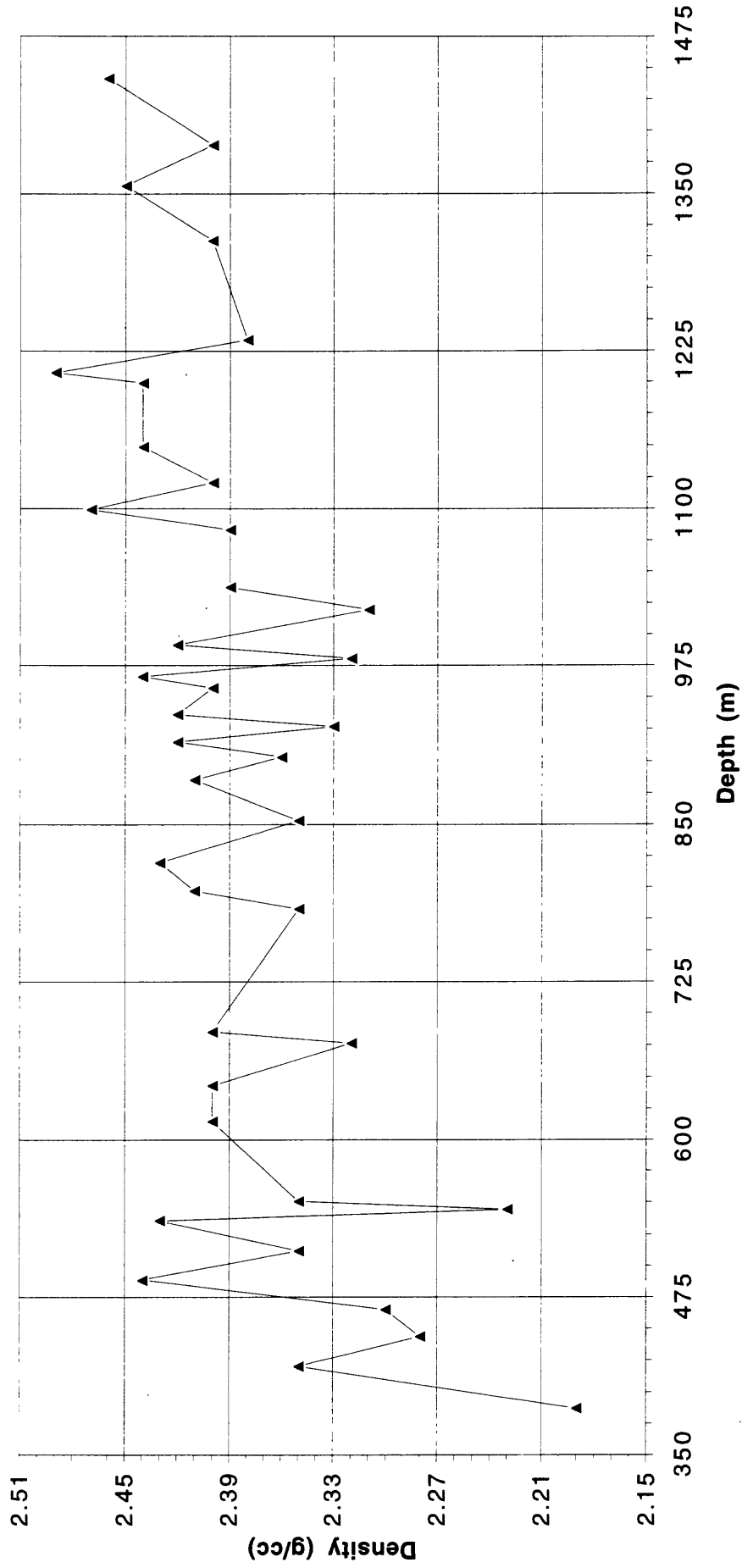


Figure 53.

**Altamont #1, Irex Corporation**

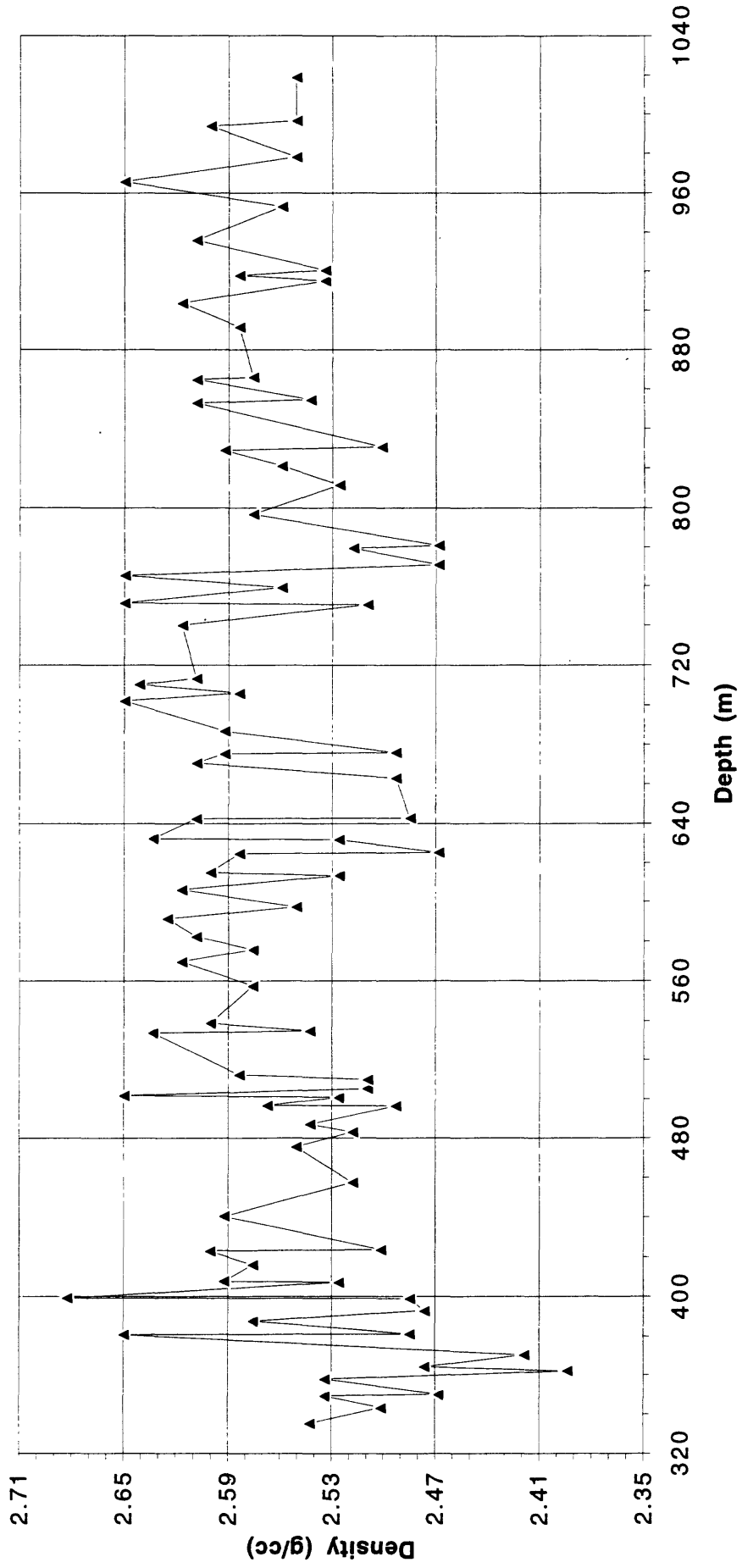


Figure 54.

**McCulloch-Nissen #3, McCulloch Oil of Calif.**

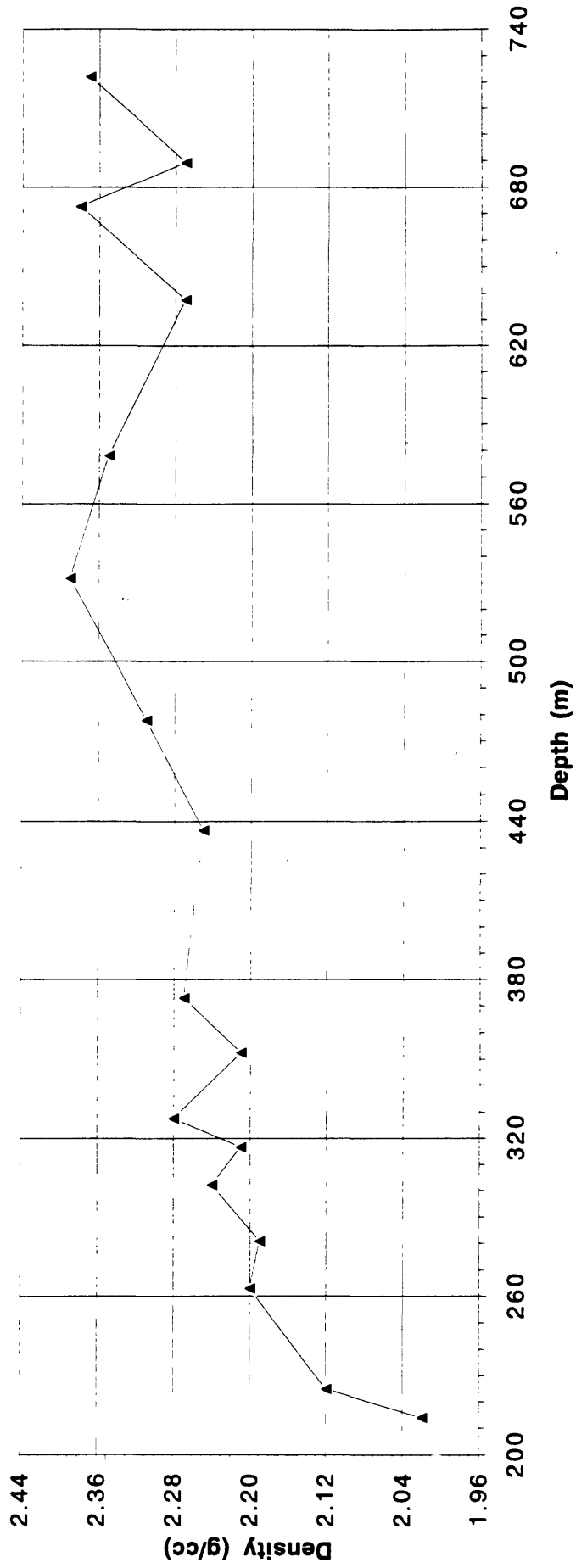


Figure 55.

**Peterson Fee #43-17, Diamond Shamrock Corp.**

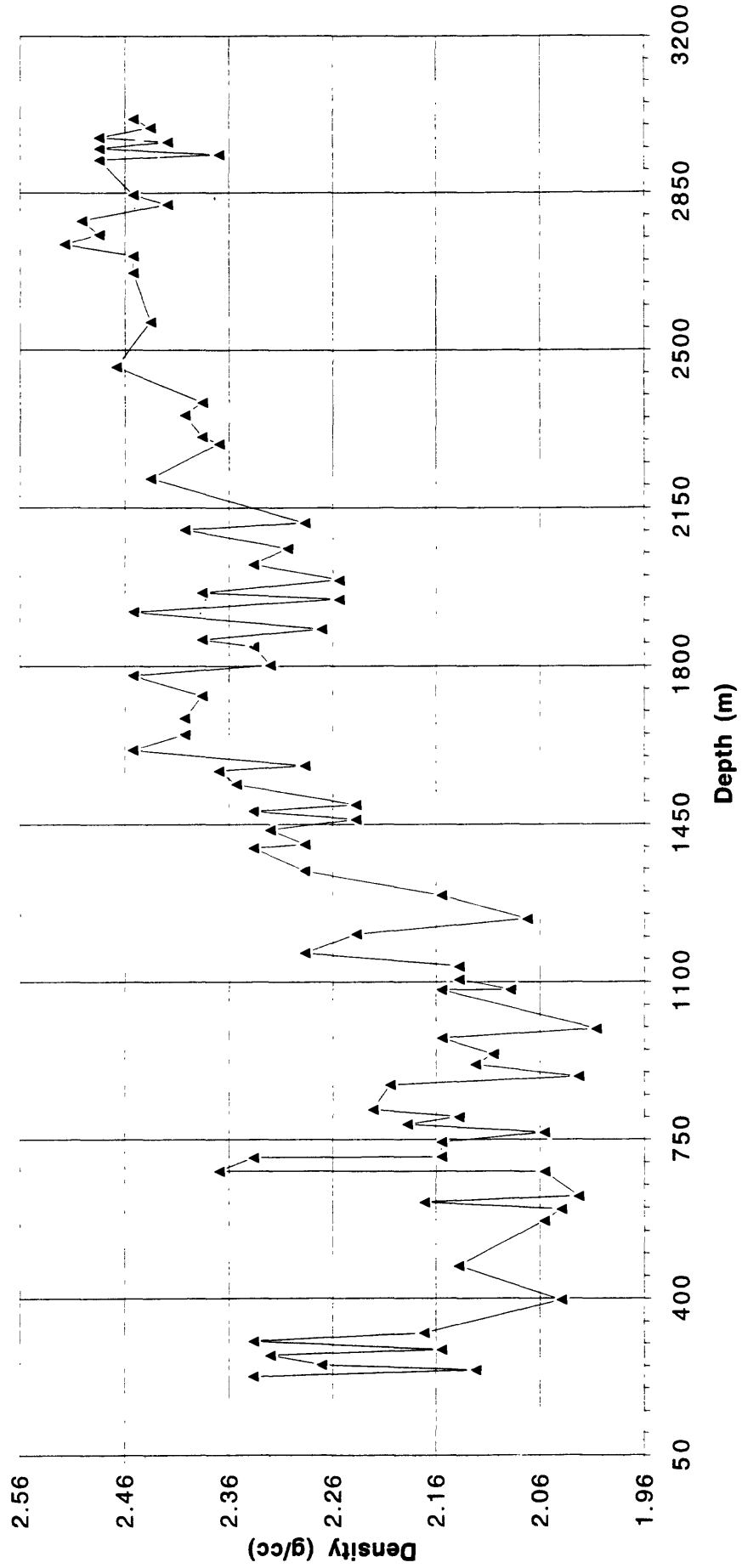


Figure 56.

Wisner Unit 1 #3, Castle Minerals

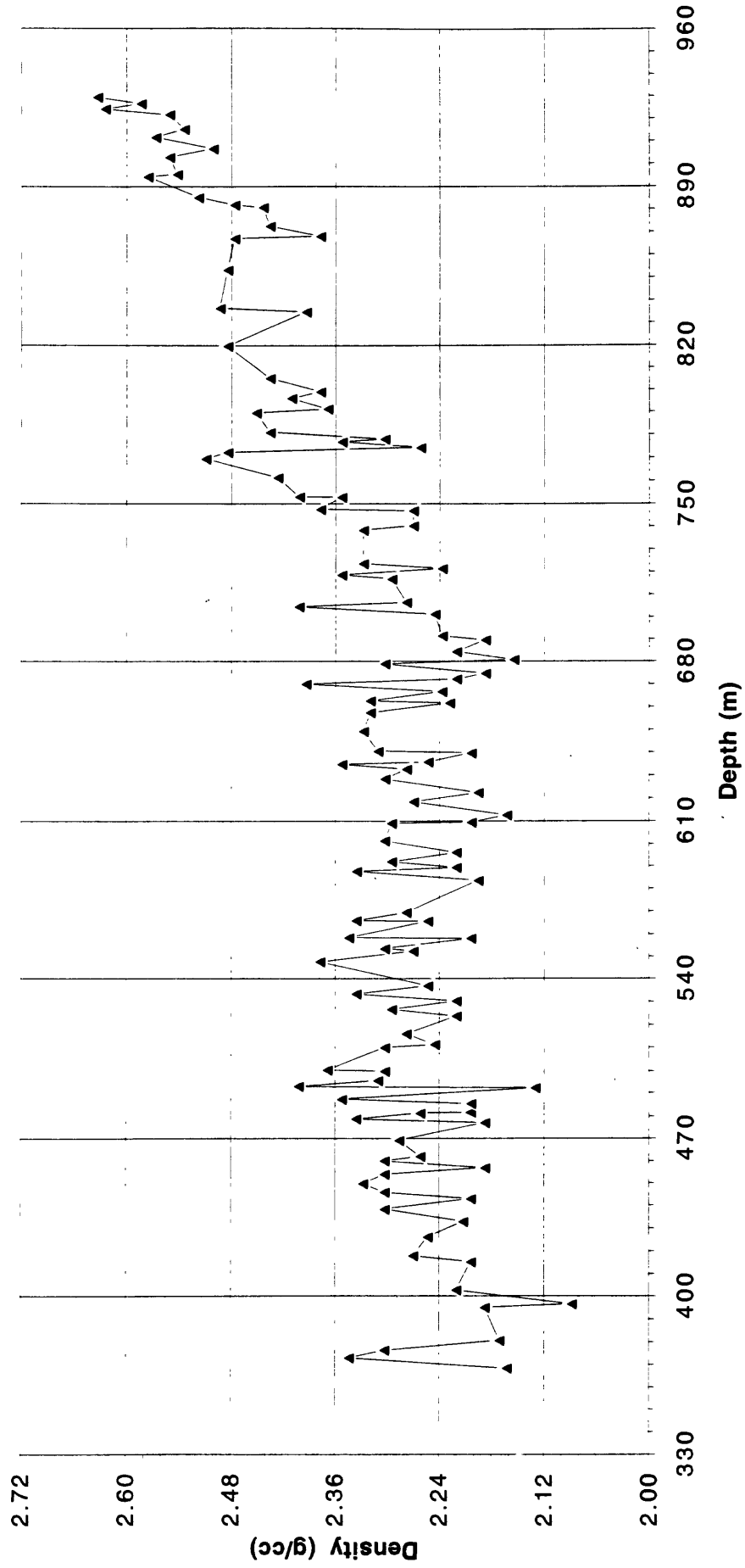


Figure 57.

**Wisner Unit 1 #2, Castle Minerals**

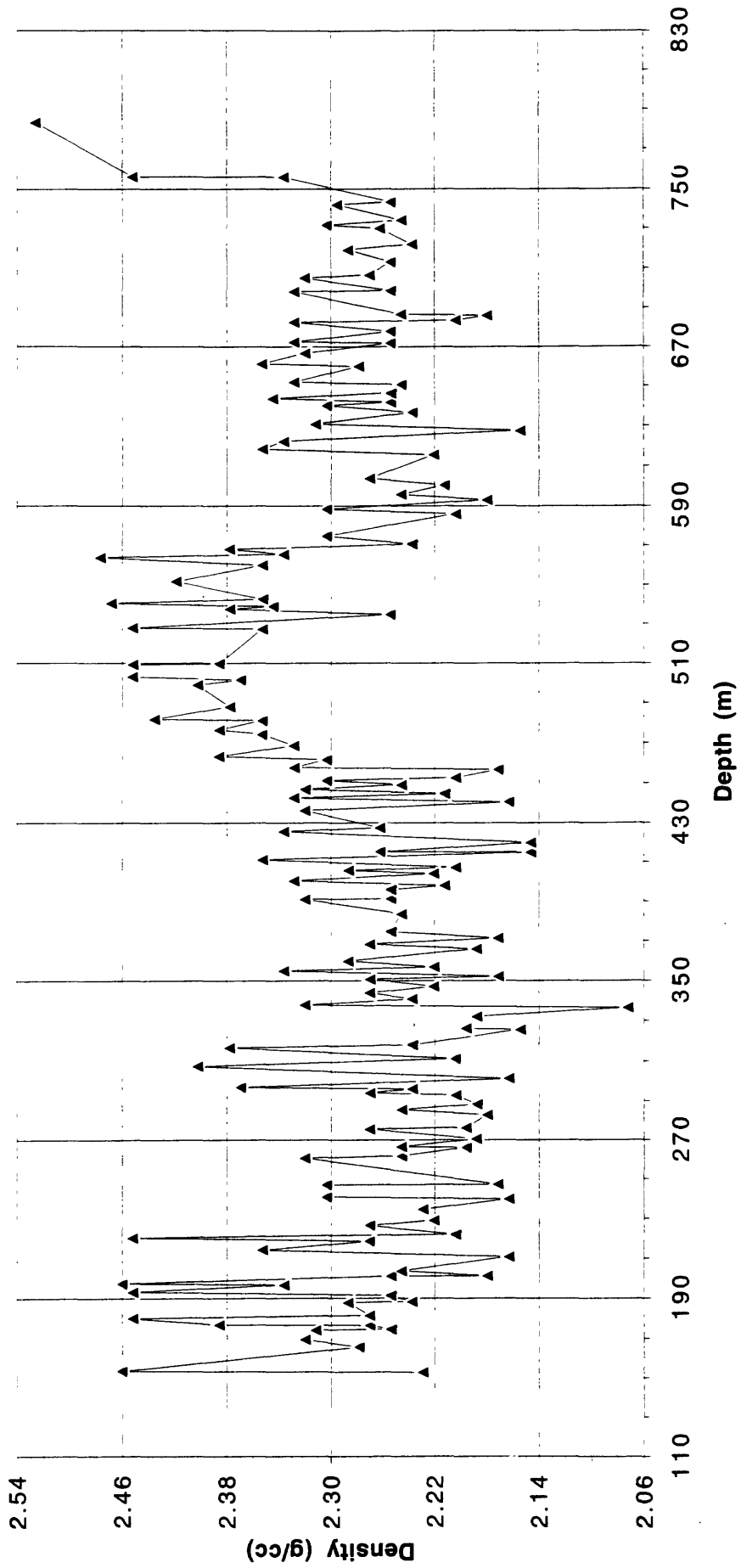


Figure 58.

Mulqueoney #1, Trico Oil & Gas Company

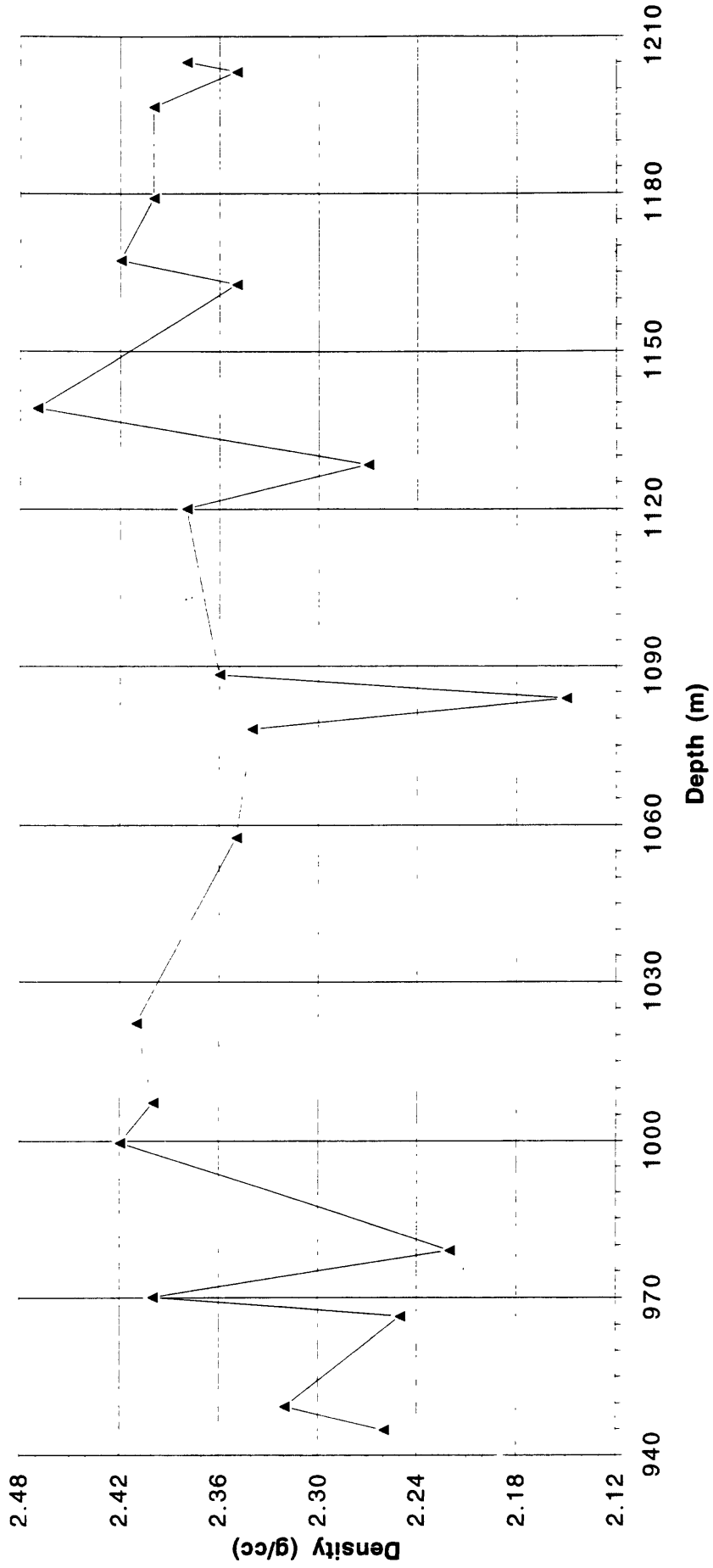


Figure 59.



**Souza #18-1, Trident Oil & Gas Company**

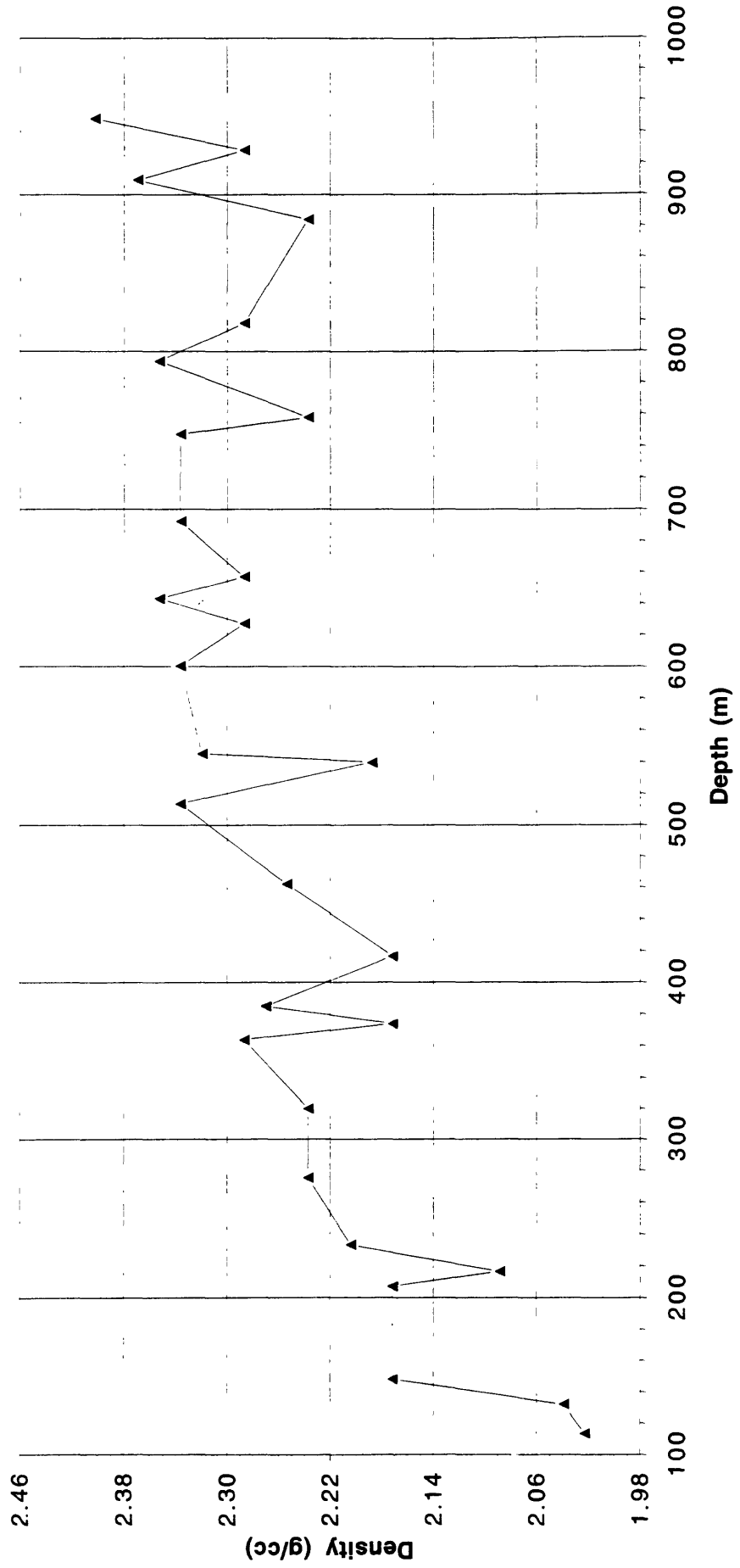
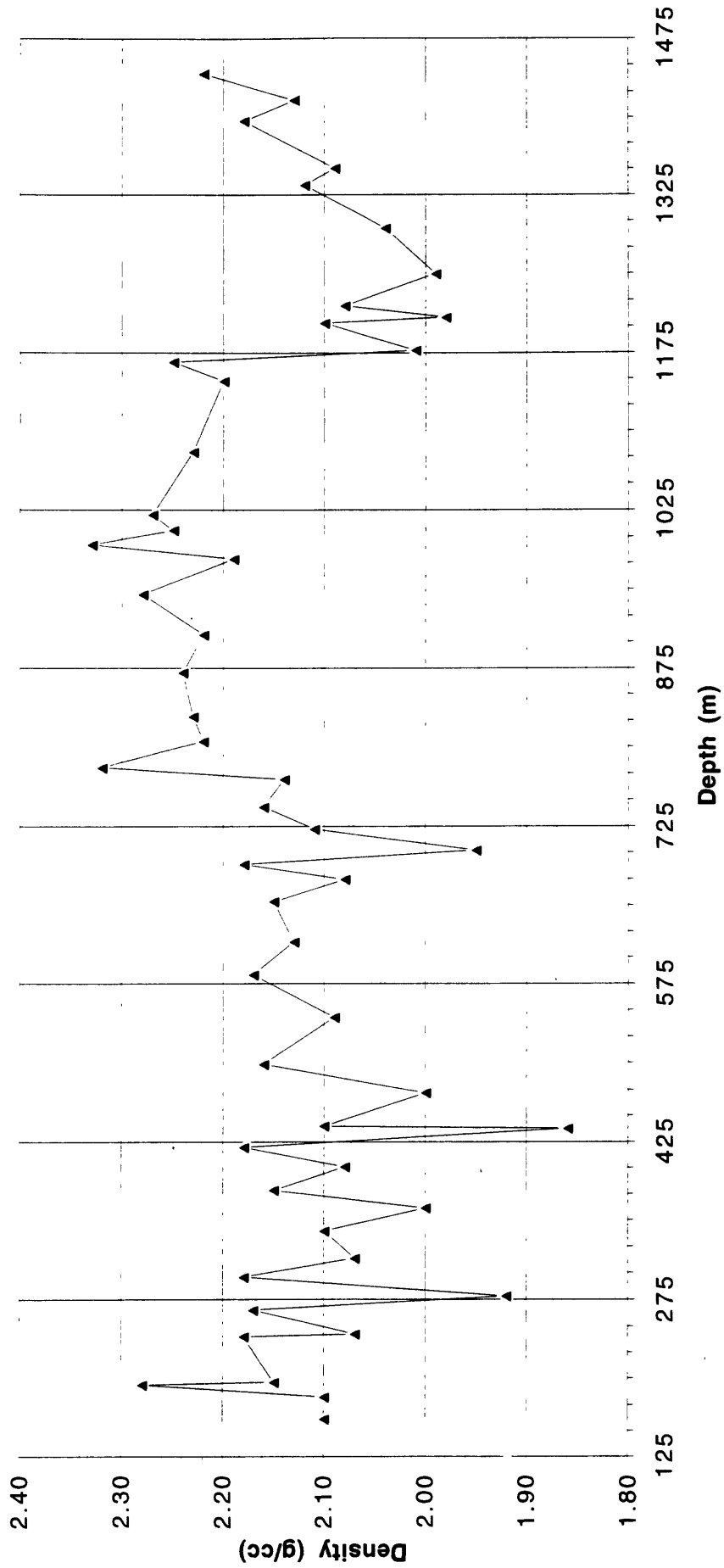


Figure 60.

**James W. Rea Jr. #2, Gulf Oil Corp.**



### San Francisco Bay Area Sonic Velocity Regression

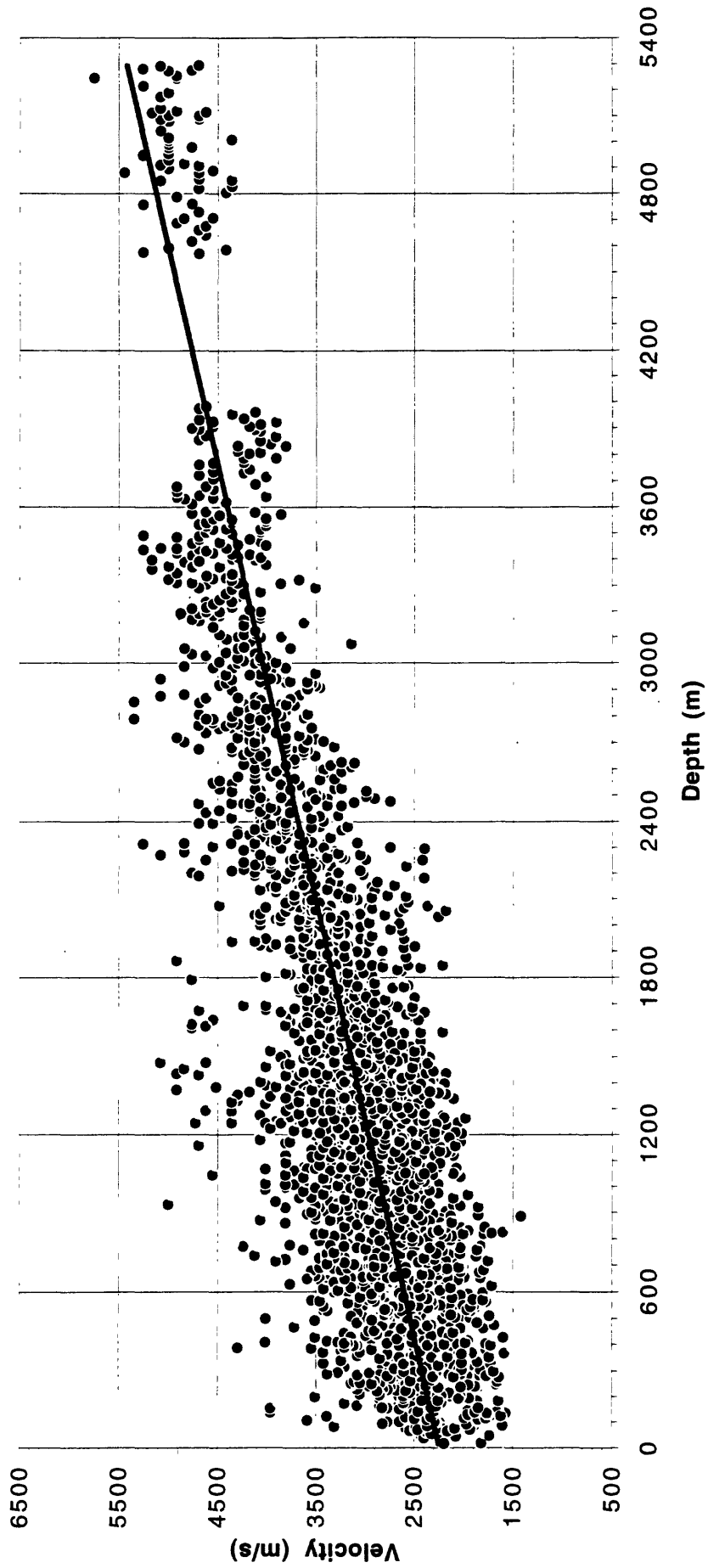


Figure 62.

### San Francisco Bay Area Density Regression

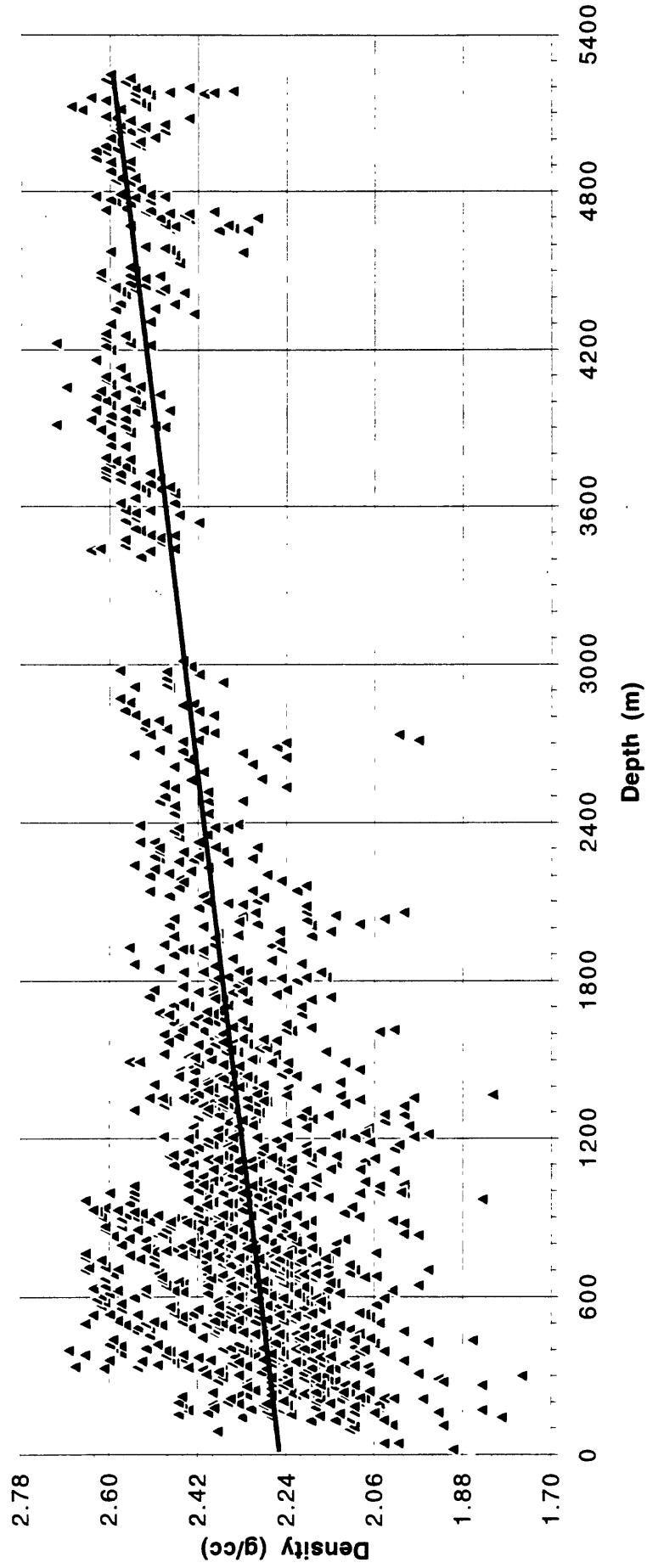


Figure 63.