USGS-OFR-97-687 USGS-OFR-97-687

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

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

By

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Open-File Report 97-687

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1997

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 Vp (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 ρ (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 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 (μs/ft) as a function of depth in feet down the well. For the gamma-gamma density logs, we picked bulk density in g/cm^3 as a function of depth in feet down the well. For the neutron density porosity logs, we converted the logged density porosity (ϕ) back to formation density (ρ_{fd}) using $\rho_{fd} = \rho_m + (\rho_f - \rho_m)\phi$, where the matrix density $\rho_m = 2.65$ g/cm^3, and the fluid density $\rho_f = 1.0$ g/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/Hunnicutt & 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 Vp (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 Vp (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 ρ (g/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 g/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. 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 Vp/Vs 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 Vp/Vs ratios in Tertiary sedimentary units. Ohta et al. [1977] published Vs and Vp 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.

ACKNOWLEDGEMENTS

We are grateful to Leslie Klinchurch and Karen Hedrick, Chevron USA, for providing several sonic and density logs, and to Donald Lewis, formerly Chief Geologist, Chevron USA, for arranging access to these and additional data. Rick Stanley, USGS, made many useful suggestions for acquiring well logs for the Bay area, and gave us the sonic log from Butano Ridge in San Mateo County (Santa Cruz Lumber/Champlain Petroleum). Zenon Valin, USGS, kindly performed a search of a digital database providing well locations and other well information. Larry Beyer, USGS, made many useful suggestions on an earlier draft of this manuscript.

This work was supported by the National Earthquake Hazards Reduction Program and Pacific Gas and Electric Company through a Cooperative Research Agreement (CRADA).

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ABBREVIATIONS USED IN TABLE 1:

BHC - Borehole Compensated Sonic Log
CNFD - Compensated Neutron Formation Density*
CFD gg - 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	1	5		DUNNIGAN HILLS	38.7368	-121.8919	9897	3017	219	67	1961	T3R1R		SP		UK 2774 m to TD?
RICE JOHN	1	CLAREMONT ENERGY	N	6	W	8	21		COTATI	38.3474	-122.7527	1220	372	205	63	1983		CNF (ds)	Cal., GR		
H D PETERSON ET AL	556-25	STANDARD OIL OF AMERICA	N	5	W	1	25	SW	WILDCAT	38.2478	-121.9222	1789	545	25	8	1973	BHC		Cal., SP	Eo.,Pal., Danian to TD	
H D PETERSON ET AL	558-25	STANDARD OIL OF AMERICA	N	5	W	1	25	SW	DENVERTON	38.2478	-121.9222	6000	1829	30	9	1973	BHC T3R2R	CNFD	Cal., GR	Eo.,Pal., Danian to 671 m	UK 671 m to TD
H D PETERSON ET AL	556-35	STANDARD OIL OF AMERICA	N	5	W	1	25	SW	DENVERTON	38.2478	-121.9222	508	155	30	9	1973	BHC		Cal., SP	No ages	
FILLIPPINI	1	GENERAL CRUDE OIL CO.	N	4	W	5	1		WILDCAT	38.2251	-122.3558	7263	2214	50	15	1965	T2R3R		Cal., SP		
KIRBY COMMUNITY	12	CHEVRON USA	N	4	W	1	13		KIRBY HILL	38.1896	-121.9219	3823	1166	111	34	1989		CNFD	Cal., GR	Eocene 640-951 m	UK 55-640 m
MANGEL	2	CHAMBERLAIN/ C H	N	4	W	6	24		TUBBS ISLAND	38.182	-122.4642	1750	534	164	50	1961	3' Span		Cal., SP		
ELK-TUBBS	1	ELK EXPLORATION	N	4	W	5	33			38.14360	-122.4243	8150	2485	7	2	1963	T3R3R		Cal., SP		
SUISUN COMMUNITY	15	STANDARD OIL OF AMERICA	N	3	W	1	5		SUISUN BAY	38.14	-121.9938	7937	2420	19	6	1974	T3R1R		Cal., SP	Paleocene to 2390 m	UK 2390 m to TD
UNITED CALIFORNIA	1	CHEVRON USA	N	3	W	1	24		HONKER BAY	38.0827	-121.9187	7600	2317	20	6	1980	BHC		Cal., SP	All Eocene	
NIXON/ L	1	CHEVRON USA	N	3	W	2	26			38.0689	-122.046	5523	1684	12	4	1967	BHC T3R2R	CFD gg	Cal., GR, SP	Eocene/Paleocene	
PERRY	1	CHEVRON USA	N	2	W	1	8		LOS MEDANOS	38.0343	-121.9945	4053	1236	187	57	1980	BHC		Cal., SP	Eocene/Paleocene	
NEELEY	1	CHEVRON USA	N	2	W	1	8		LOS MEDANOS	38.0312	-121.9901	4350	1326	183	56	1984	BHC		Cal., SP	All Eocene	
SEENO-SCOTT	2	CHEVRON USA	N	2	W	1	16		WILLOW PASS	38.0135	-121.9717	5445	1660	402	123	1986	BHC	CNFD	Cal., GR, SP	Eocene to 915 m	UK 915 m to TD
BOYLAN UNIT	2	CHEVRON USA	N	2	W	2	24		CONCORD	38.0044	-122.02780	2250	686	178	54	1963	T3R1R		Cal., SP		
BOYLAN	1	CHEVRON USA	N	2	W	2	24		CONCORD	38.003	-122.025	2500	762	168	51	1964	T3R3R		Cal., SP		
HOFFMAN ET AL	1	CHEVRON USA	N	2	W	2	24		CONCORD	38.0013	-122.0244	2625	800	100	30	1963	T3R3R		SP	Eocene to 561 m	UK 561 m to TD
BETHLEHEM	2	CHEVRON USA	N	2	W	4	19		PINOLE POINT	37.9991	-122.3391	6372	1943	38	12	1969	BHC T3R2R		Cal., SP		
BETHLEHEM	1	CHEVRON USA	N	2	W	4	19		PINOLE POINT	37.9994	-122.3391	9997	3048	39	12	1969	BHC T3R2R	CFD gg	Cal., GR, SP	Miocene	
HANS NIELSON ET UX	1	EXXON CORP.	S	2	E	1	9		WILDCAT	37.7789	-121.8622	13230	4034	637	194	1966	BHC T3R2R		Cal., SP	Eocene	
GUMPERT A	1	CITIES SERVICE OIL	S	2	E	1	7		WILDCAT	37.7756	-121.8965	17432	5315	645	197	1973	BHC T3R2R	CFD gg	Cal., GR, SP		
DYER	1	MICHIGAN OIL	S	2	E	3	17		ALTAMONT	37.7627	-121.6748	3332	1016	812	248	1964	T3R1R		Cal., GR		
GUMPERT/ E	1	CHEVRON USA	S	2	E	1	17		SAN RAMON	37.761	-121.8937	8081	2464	539	164	1964		CFD gg	Cal., GR	Miocene/Pliocene	
CASTELLO	1-13	SUPERIOR OIL	S	2	E	3	13		WEST TRACY	37.7558	-121.5913	6004	1830	376	115	1964	T3R3R		Cal., SP		
GARVANTA	68-22	CHOWCHILLA GAS	S	2	E	2	22		LIVERMORE	37.7388	-121.7381	2573	784	642	196	1968	BHC T3R2R		Cal., SP		
CITY OF LIVERMORE	1	BUTTES GAS & OIL	S	2	E	2	27	SE	LIVERMORE	37.7297	-121.7336	3837	1170	530	162	1968		CFD gg	Cal., GR		
GOMES	1	BRAZOS OIL & GAS	S	2	E	3	35		ALTAMONT	37.71	-121.6131	4012	1223	591	180	1962	T3R1R		Cal., SP		
SPRR	1	CAPITAL OIL CORP.	S	3	E	2	1		LIVERMORE	37.7081	-121.7042	4500	1372	575	175	1967	BHC T3R2R		Cal., SP		
MCCULLOCH GUIDOTTI	1	MCCULLOCH OIL	S	3	E	3	6		LIVERMORE	37.7062	-121.6902	4715	1438	652	199	1968	BHC T3R2R	CFD gg	Cal., SP		
KENNEDY/ GERTRUDE	1	SUNRAY DX OIL	S	3	E	5	5		W CARBONA AREA	37.7	-121.4376	9500	2896	152	46	1967	T3R3R		Cal., GR		
MCCULLOCH-MARIDON	1	MCCULLOCH OIL	S	3	E	5	6		SW TRACY AREA	37.6979	-121.45880	8398	2560	179	55	1964	T3R1R		Cal., SP		
ALTAMONT	1	IREX CORP.	S	3	E	3	1		WILDCAT	37.6969	-121.5876	3340	1018	739	225	1982		CNFD	Cal., GR		
MILLER-RICHARDS	1-1	HERSHEY OIL	S	3	E	2	1		LIVERMORE	37.6961	-121.697	6313	1925	623	190	1981	BHC		Cal., SP		
NISSEN	3	MCCULLOCH OIL	S	3	E	3	7	NE	LIVERMORE	37.6933	-121.6831	6819	2079	693	211	1967		CFD gg	Cal., GR	Tesla	UK 1555 m to TD
NISSEN	6	MCCULLOCH OIL	S	3	E	3	7	NE	LIVERMORE	37.6924	-121.68420	3055	931	685	209	1969	BHC T3R2R		Cal., SP		
MCCULLOCH-COYNE	1	MCCULLOCH OIL	S	3	E	4	10	NW	SW TRACY	37.687	-121.5236	5302	1616	919	280	1964	T3R1R		SP		
LUPIN	5	BROWN/ E C	S	3	E	3	8	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	5	14		TRACY AREA	37.6785	-121.3922	5000	1524	117	36	1960	T3R3R		SP		
TESLA	1	MCBURNEY/ R W	S	3	E	3	16		LIVERMORE	37.6763	-121.6584	4864	1483	1020	311	1967	BHC T3R2R		SP	Miocene/Pliocene	UK 1119 m to TD
PETERSON FEE	43-17	DIAMOND SHAMROCK	S	3	E	5	17		WILDCAT	37.6735	-121.4342	10075	3072	221	67	1982	BHC	CFD gg	Cal., GR, SP		
WISNER UNIT ONE	3	CASTLE MINERALS	S	3	E	3	18		LIVERMORE	37.6673	-121.6825	3091	942	787	240	1983		CNFD	Cal., GR		
WISNER UNIT ONE	2	CASTLE MINERALS	S	3	E	3	19	NW	LIVERMORE			2613	797	775	236	1983		CNFD	Cal., GR		
STEELE	47-19	STEELE, HORACE	S	3	E	5	19		TRACY AREA	37.6555	-121.4615	5954	1815	563	172	1968	BHC T3R2R		Cal., SP		
YOUNG UNIT 1	1	RESERVE OIL & GAS	S	3	E	5	24		VERNALIS	37.6654	-121.36250	7238	2207	118	36	1963	BHC T3R1R		SP		
WISNER UNIT	1-1	HUNNICUTT & CAMP	S	3	E	3	19	NE	WILDCAT	37.6611	-121.6829	3416	1041	772	235	1972	BHC T3R2R		Cal., SP		
MULQUEENY	1	TRICO OIL & GAS	S	3	E	3	24		LIVERMORE	37.652	-121.5921	5020	1530	1537	469	1967	BHC	CFD gg	Cal., GR, SP		K 448 m to TD
KCY-GNESA ETAL	44-25	KERN COUNTY LAND	S	4	E	6	25			37.5592	-121.26	5243	1598	202	62	1959	3' Span		SP	Miocene to 823 m	UK 1018 m to TD
SOUZA	18-1	TRIDENT OIL & GAS	S	7	W	4	18		LA HONDA	37.3204	-122.3313	3153	961	272	83	1985		CNFD	Cal., GR		
SANTA CRUZ LUMBER	12-18	CHAMPLIN PETROLEUM	S	8	W	3	18		WILDCAT	37.2392	-122.24	11052	3370	2136	651	1984	BHC		Cal., GR, SP	Eocene	
GULF-JAMES W REA	2	GULF OIL	S	12	E	3	1		SARGENT	36.9246	-121.585	4749	1448	817	249	1980		CNFD	Cal., GR		

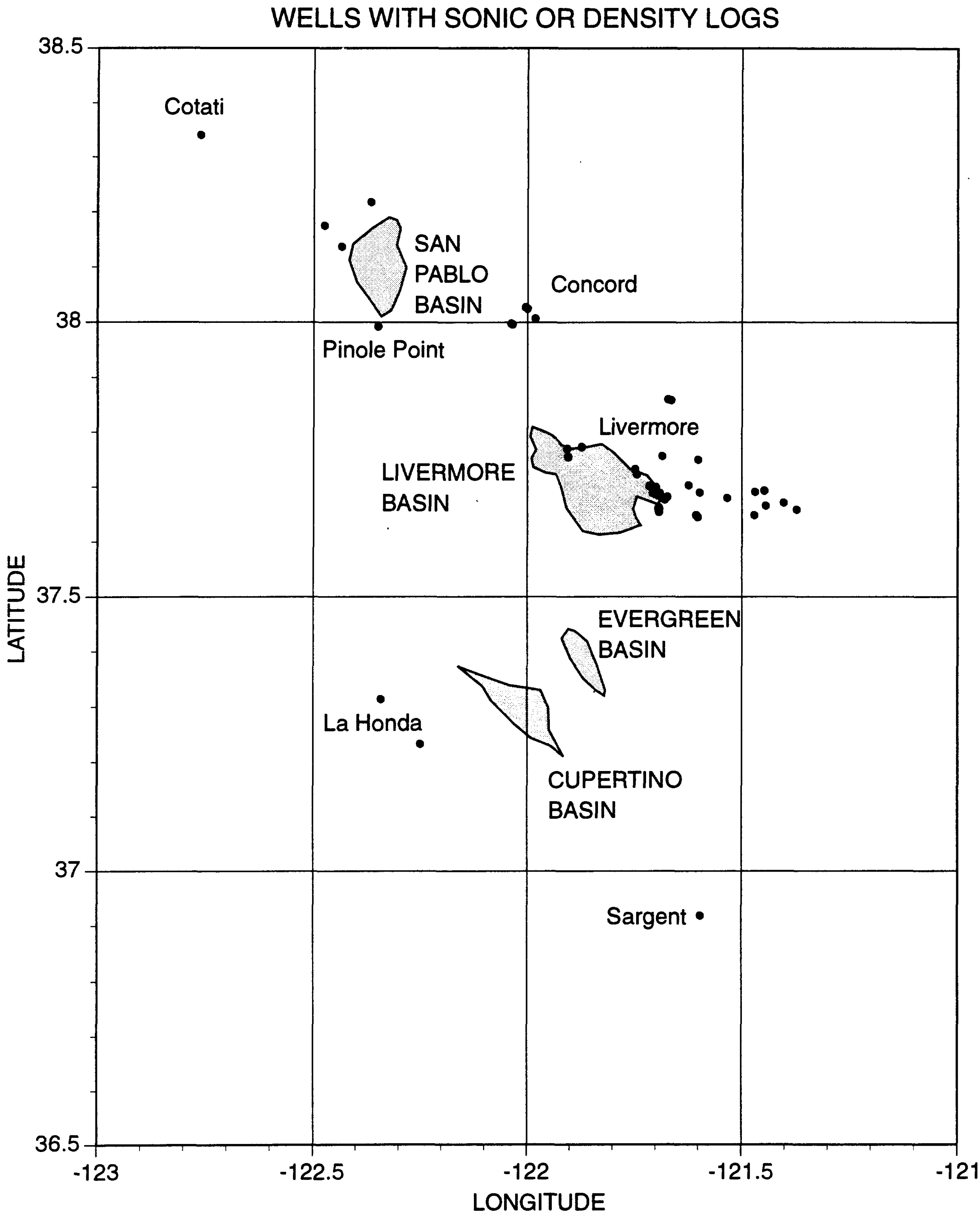


Figure 1. Map showing locations of wells having sonic or density logs analyzed in this report. Shaded regions show selected Cenozoic basins inferred from inversion of gravity data [Jachens et al., 1995]. Selected oil fields are labeled (Cotati, Concord, Livermore, La Honda, and Sargent fields).

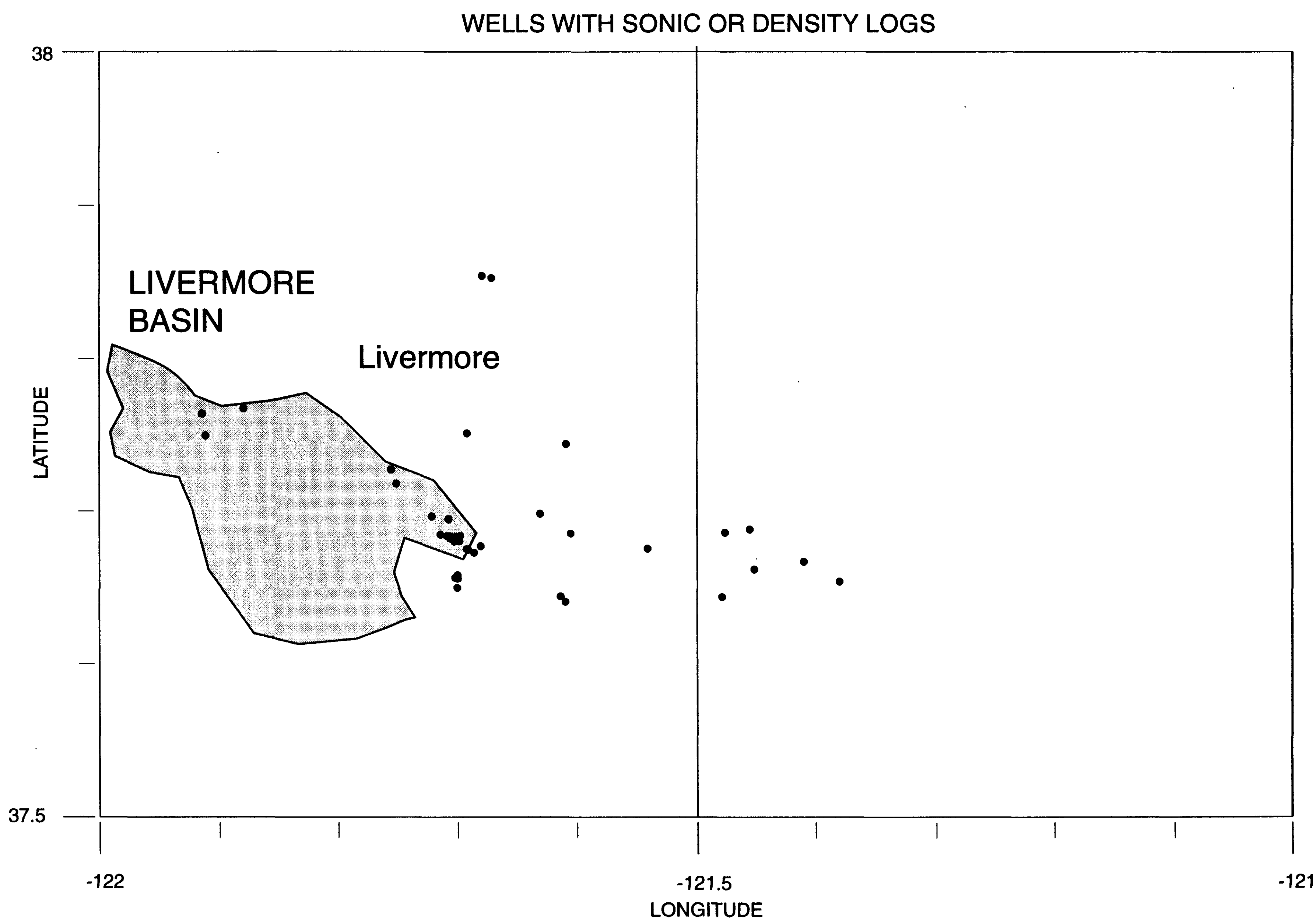


Figure 2. Map showing locations of wells in the vicinity of Livermore having sonic or density logs analyzed in this report. Shaded region shows the geometry of Livermore basin inferred from inversion of gravity data [Jachens et al., 1995].

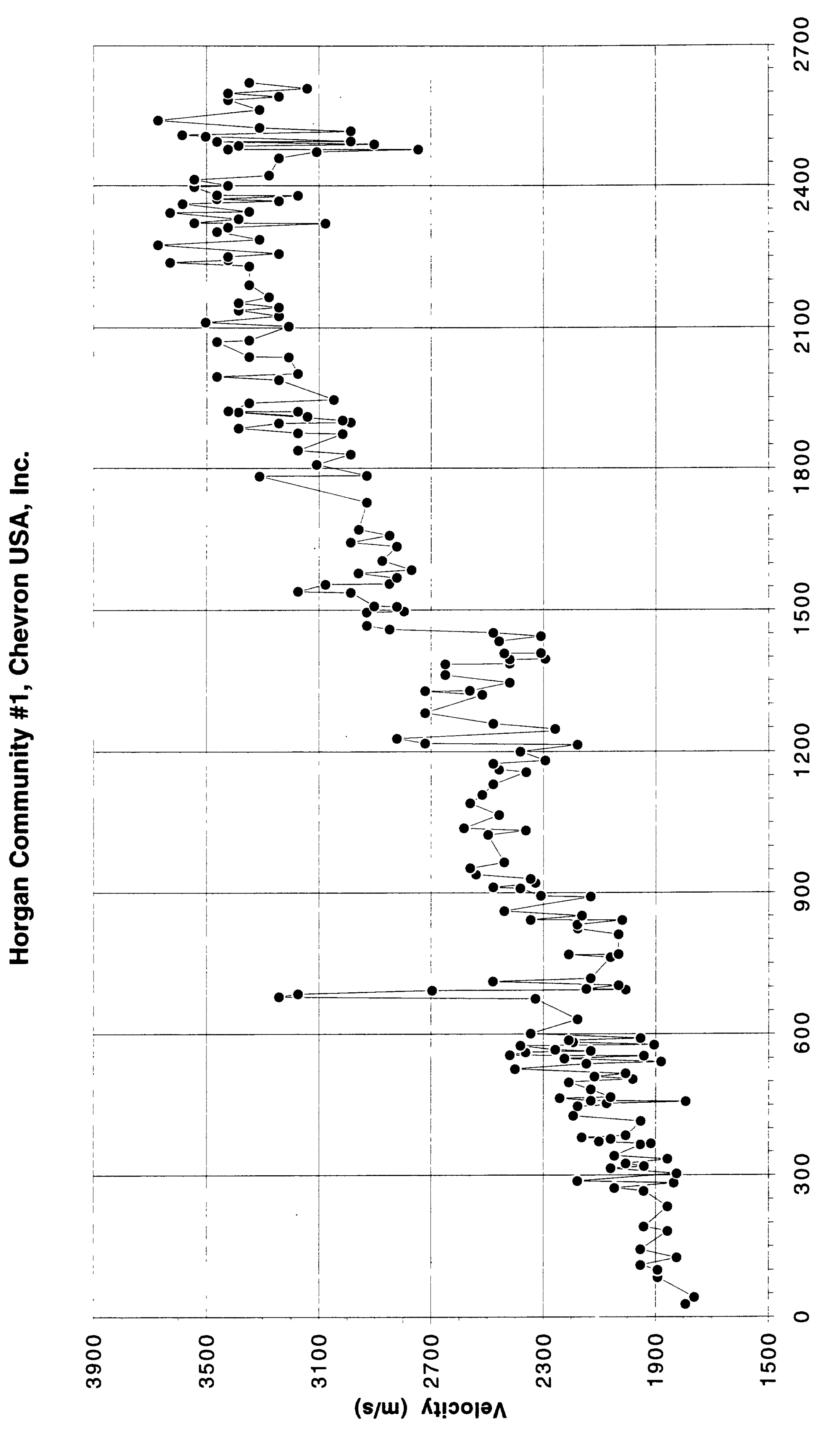

Horgan Community #1, Chevron USA, Inc.
Velocity (m/s)
Depth (m)
3900
3500
3100
2700
2300
1900
1500
0
300
600
900
1200
1500
1800
2100
2400
2700

Figure 3.

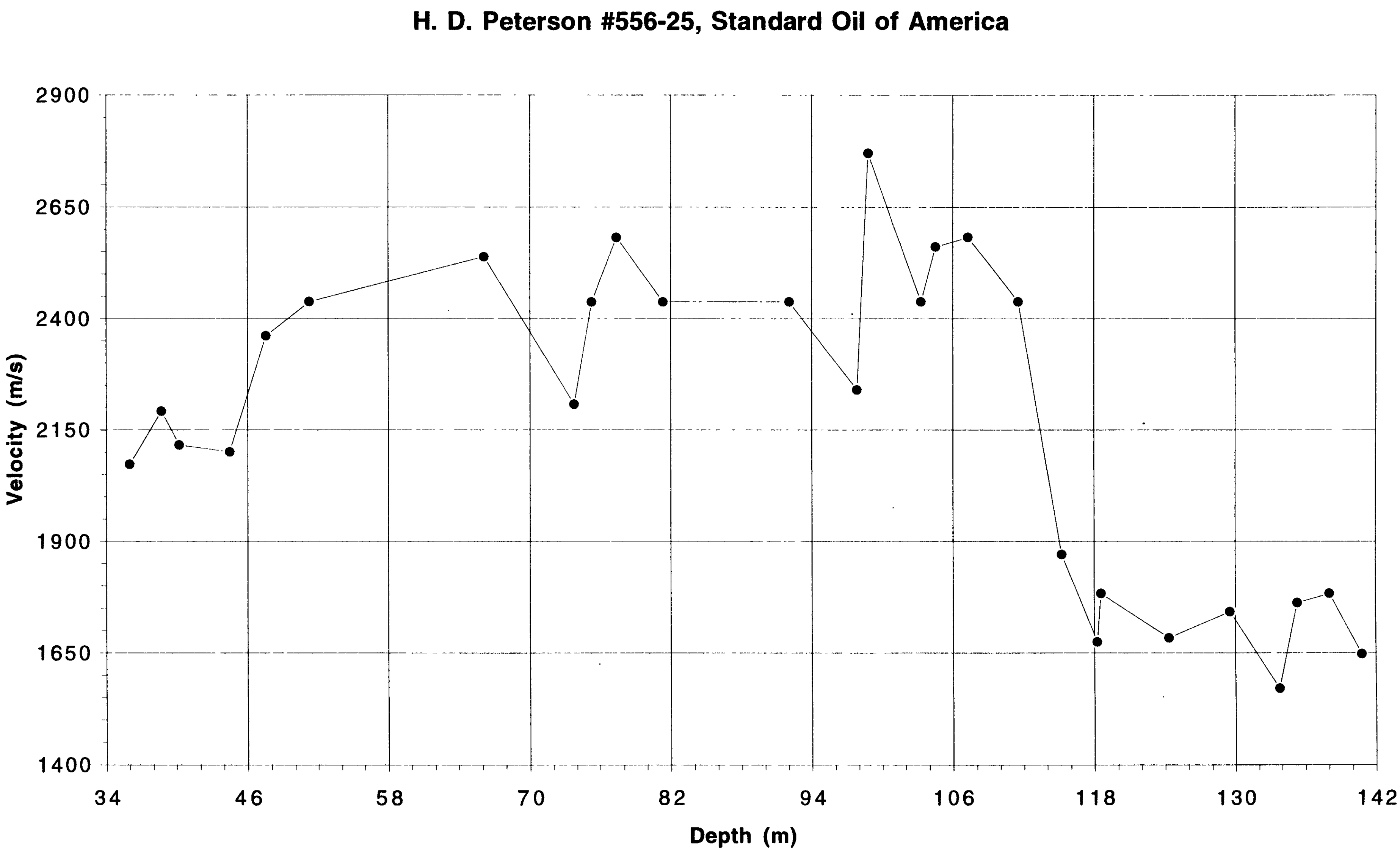

H. D. Peterson #556-25, Standard Oil of America
Velocity (m/s)
2900
2650
2400
2150
1900
1650
1400
34
46
58
70
82
94
106
118
130
142
Depth (m)

Figure 4.

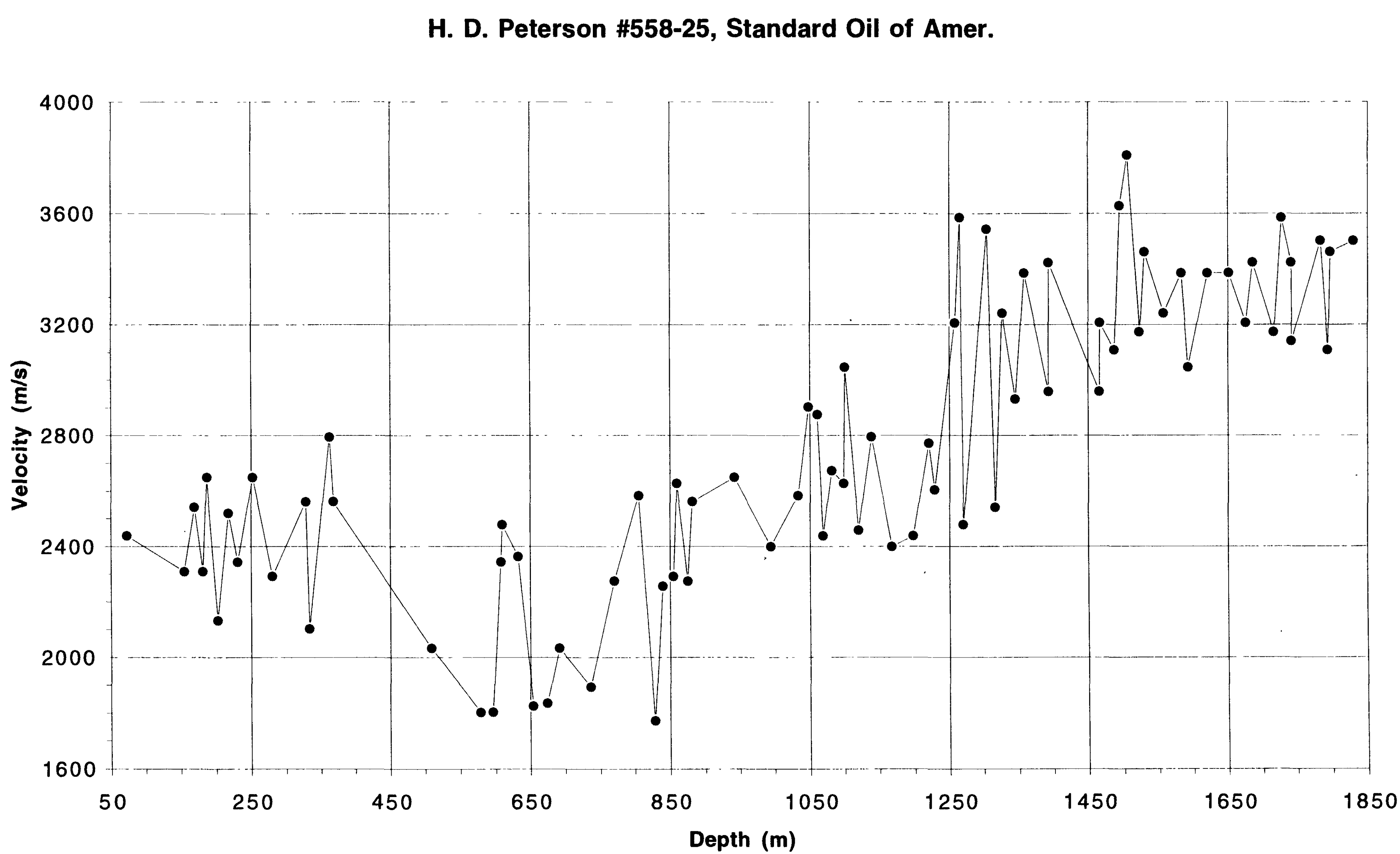

H. D. Peterson #558-25, Standard Oil of Amer.
Velocity (m/s)
4000
3600
3200
2800
2400
2000
1600
50
250
450
650
850
1050
1250
1450
1650
1850
Depth (m)

Figure 5.

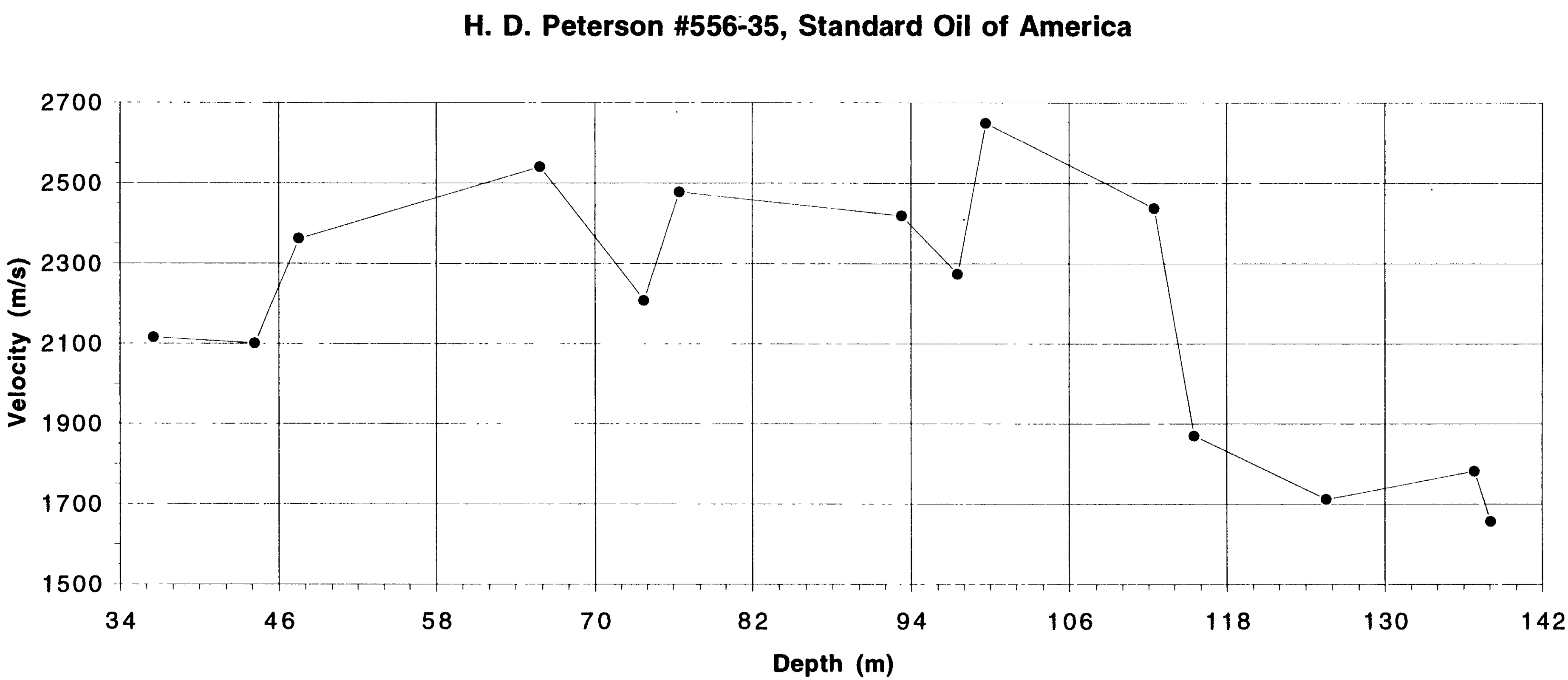

H. D. Peterson #556-35, Standard Oil of America
2700
2500
2300
2100
1900
1700
1500
Velocity (m/s)
34
46
58
70
82
94
106
118
130
142
Depth (m)

Figure 6.

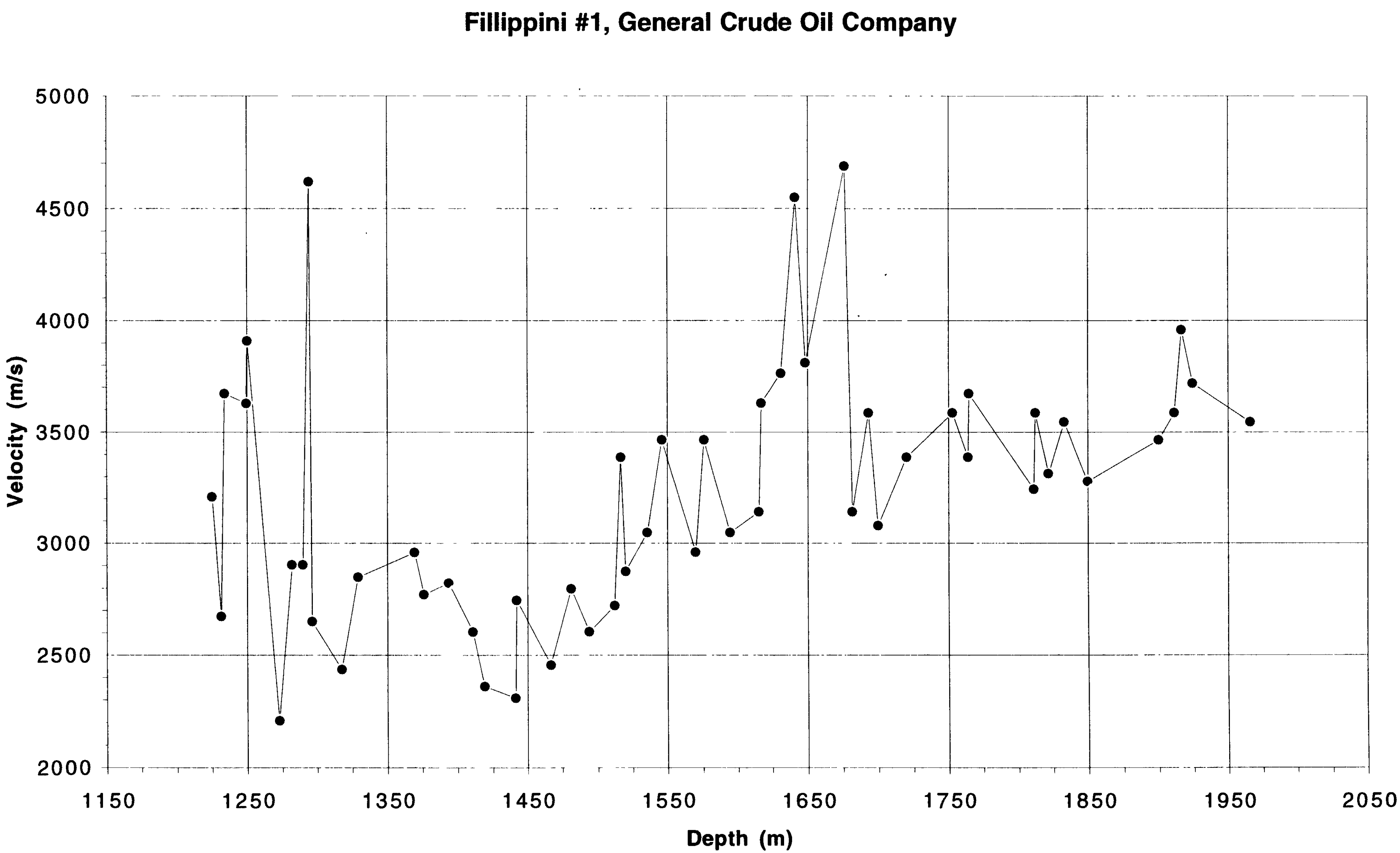

Fillippini #1, General Crude Oil Company
Velocity (m/s)
5000
4500
4000
3500
3000
2500
2000
1150
1250
1350
1450
1550
1650
1750
1850
1950
2050
Depth (m)

Figure 7.

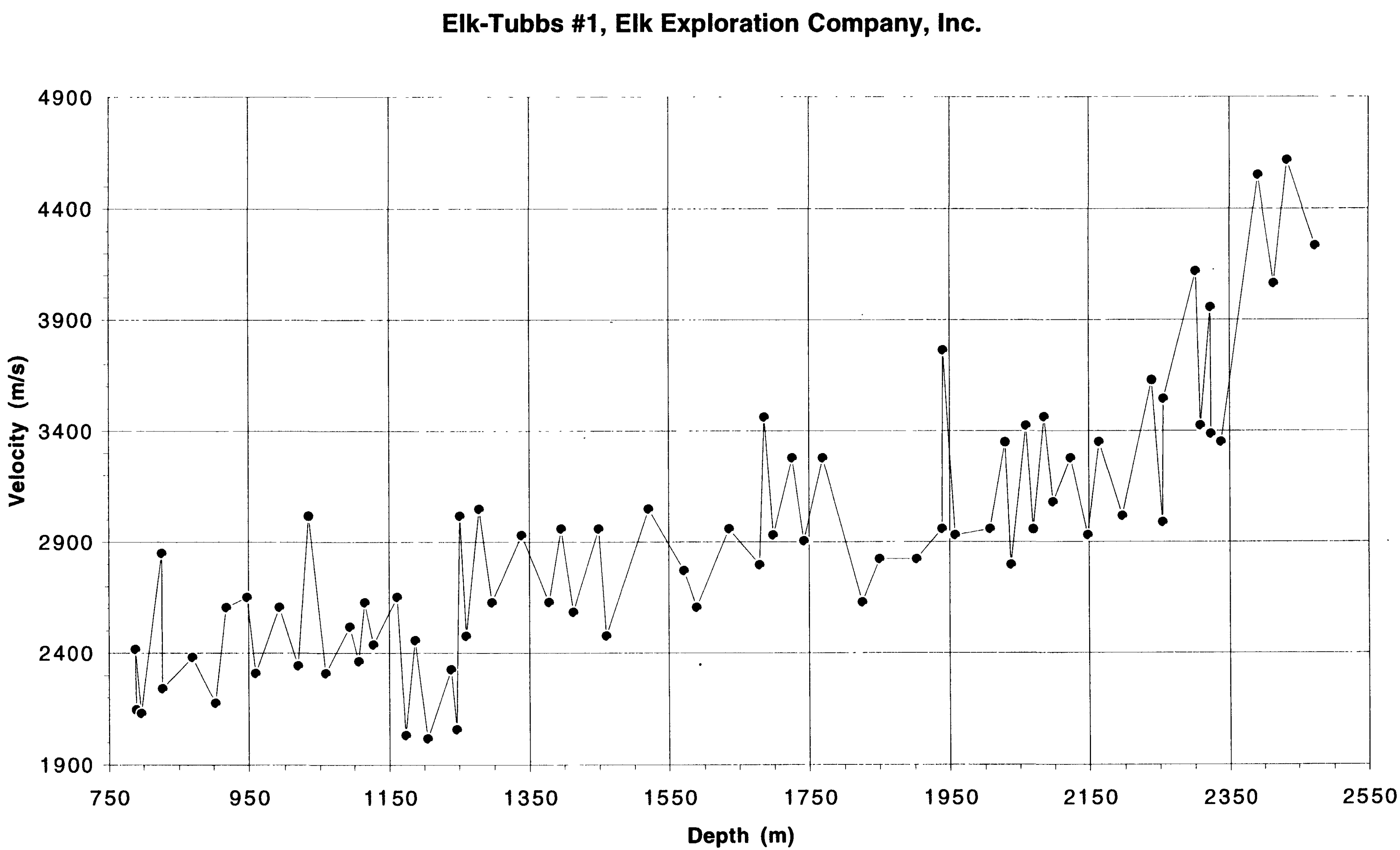

Elk-Tubbs #1, Elk Exploration Company, Inc.
Velocity (m/s)
1900
2400
2900
3400
3900
4400
4900
Depth (m)
750
950
1150
1350
1550
1750
1950
2150
2350
2550

Figure 8.

Mangel #2, C. H. Chamberlain

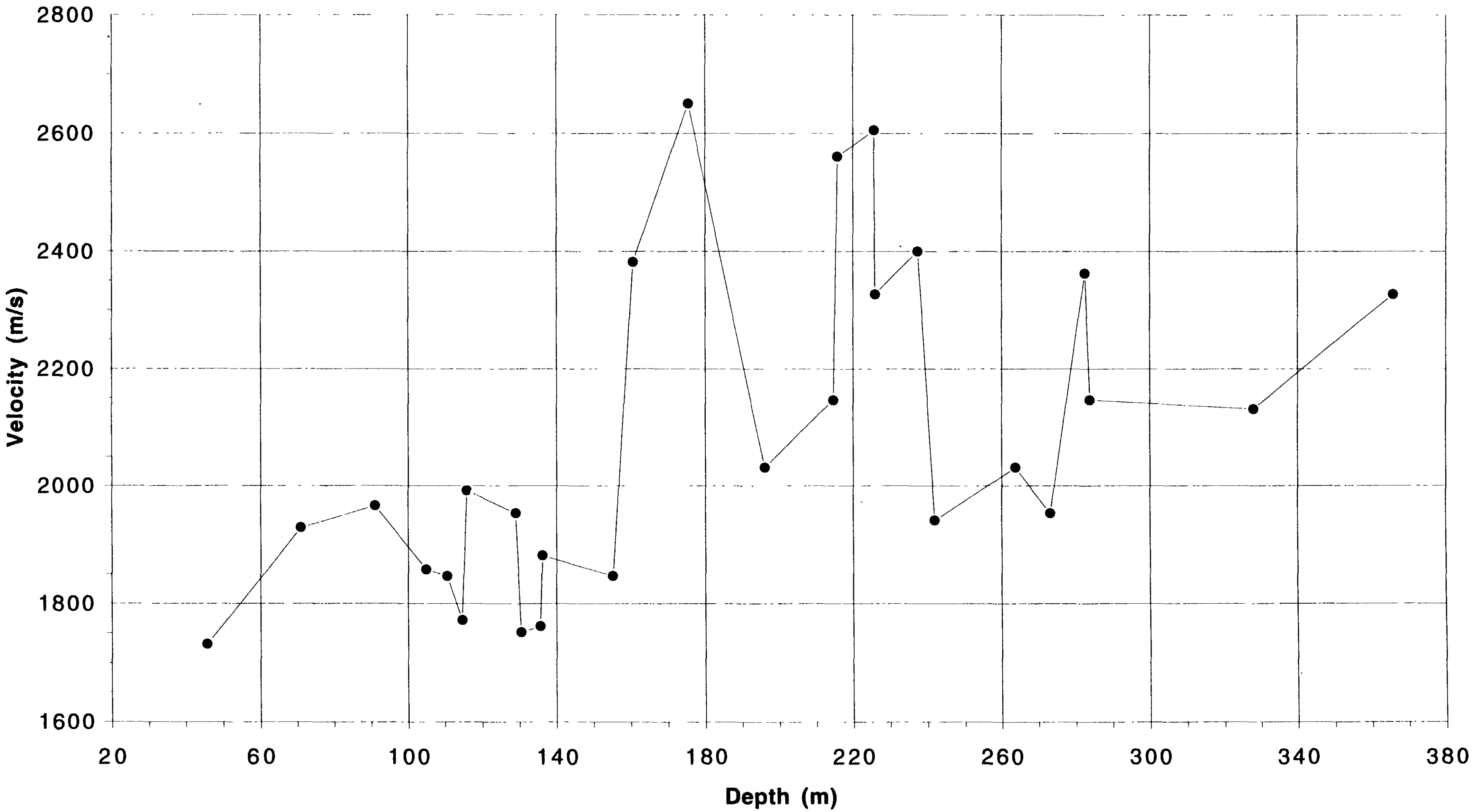


Figure 9.

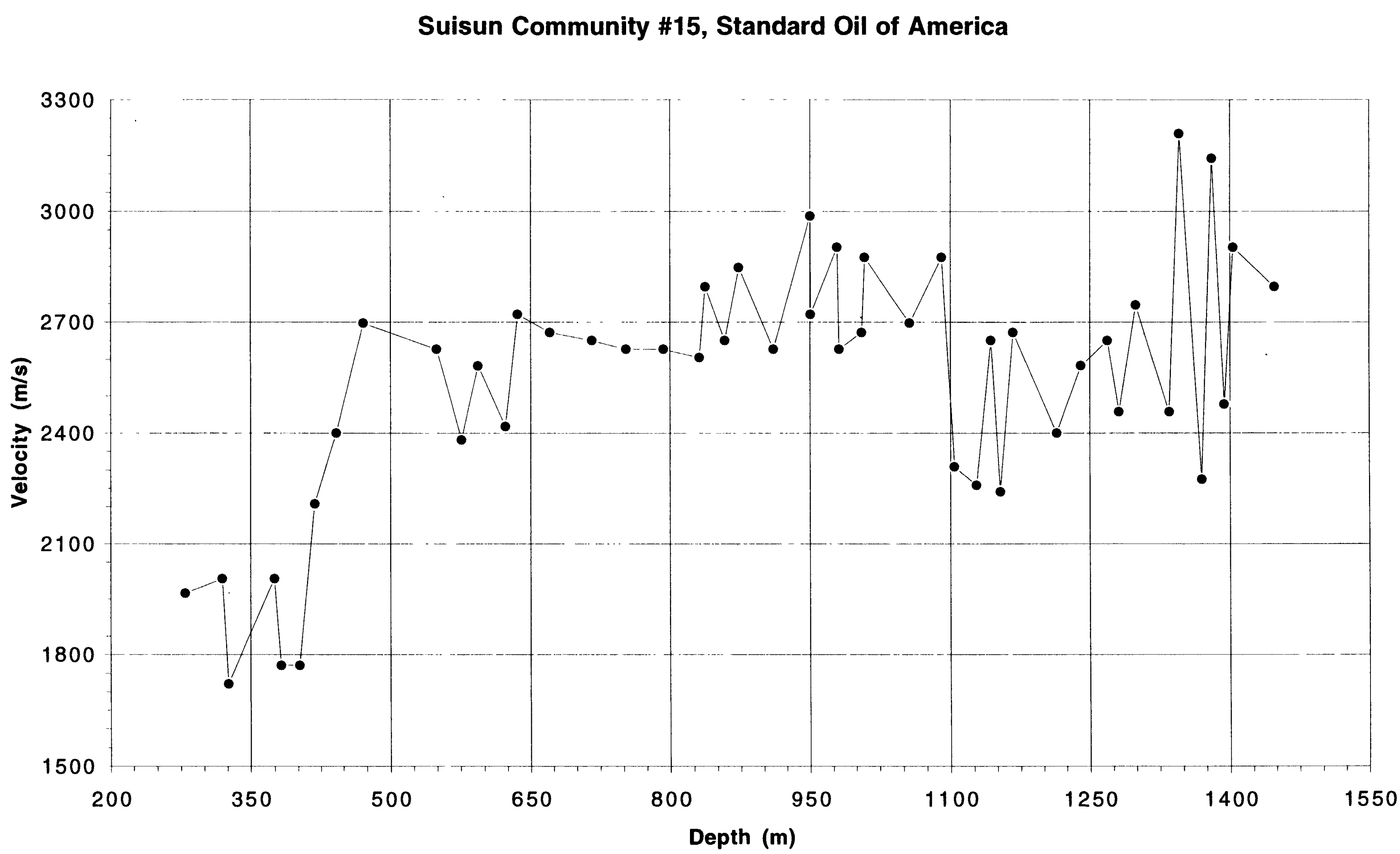

Suisun Community #15, Standard Oil of America
3300
3000
2700
2400
2100
1800
1500
Velocity (m/s)
200
350
500
650
800
950
1100
1250
1400
1550
Depth (m)

Figure 10.

United California Bank #1, Chevron USA, Inc.

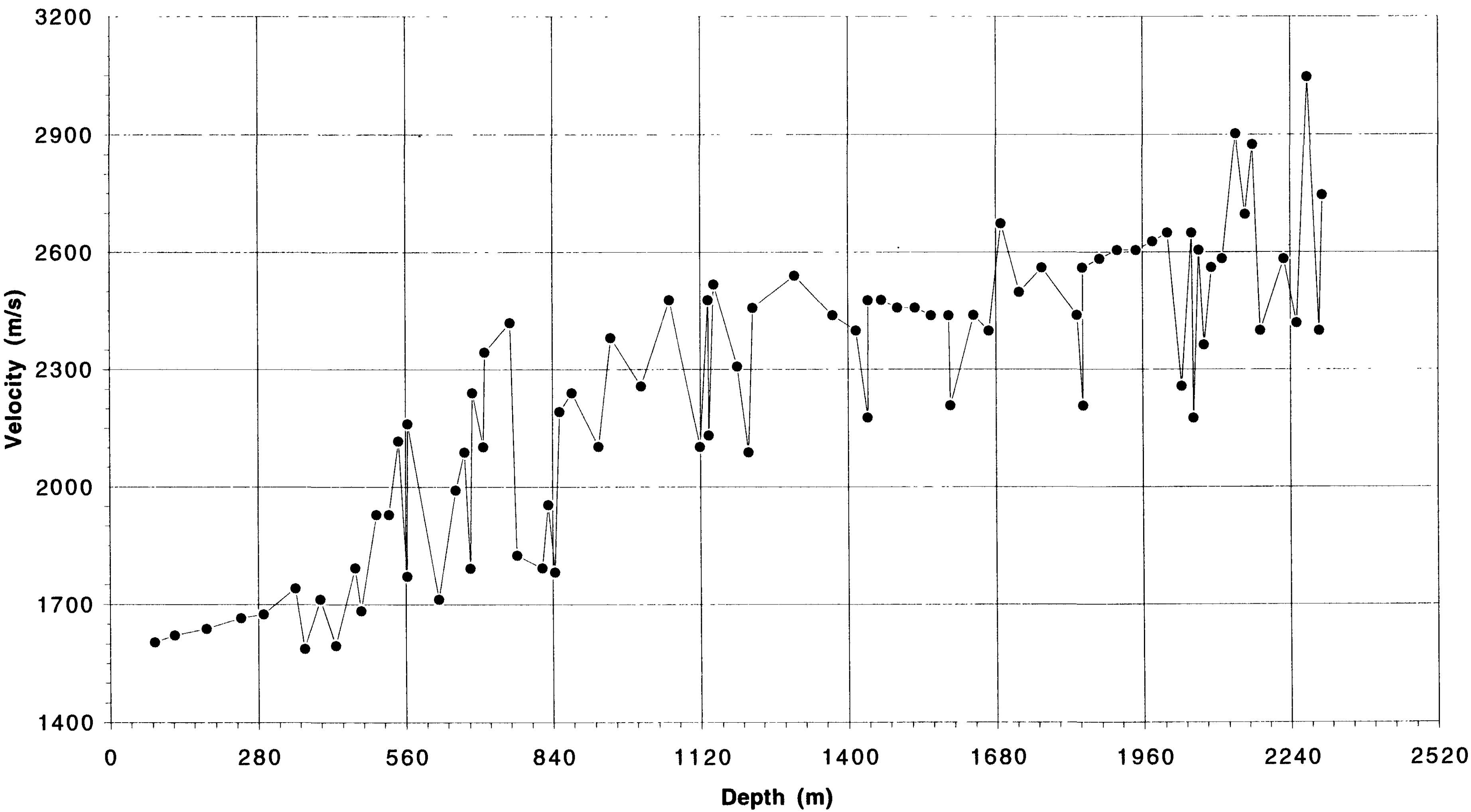


Figure 11.

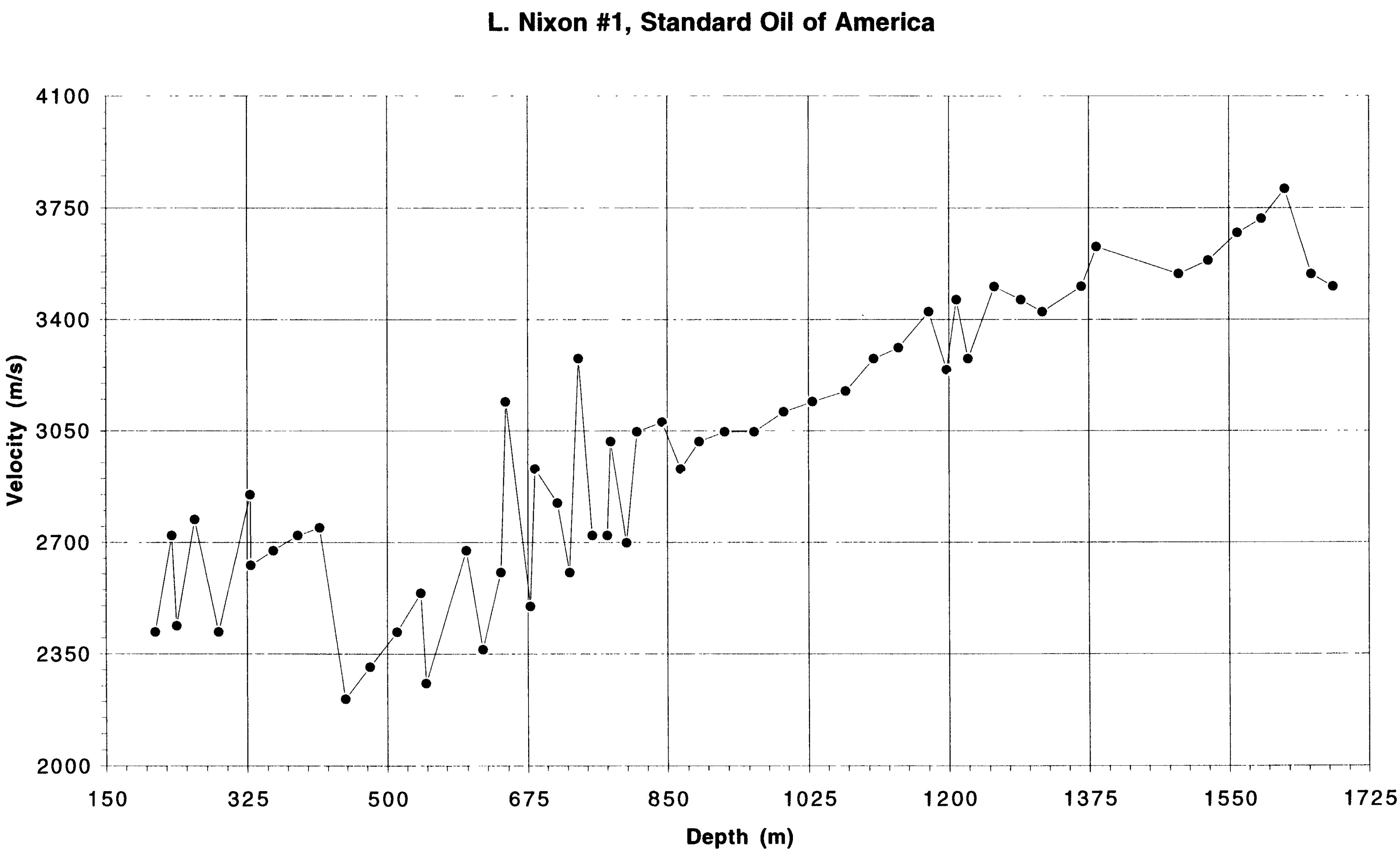

L. Nixon #1, Standard Oil of America
Velocity (m/s)
4100
3750
3400
3050
2700
2350
2000
150
325
500
675
850
1025
1200
1375
1550
1725
Depth (m)

Figure 12.

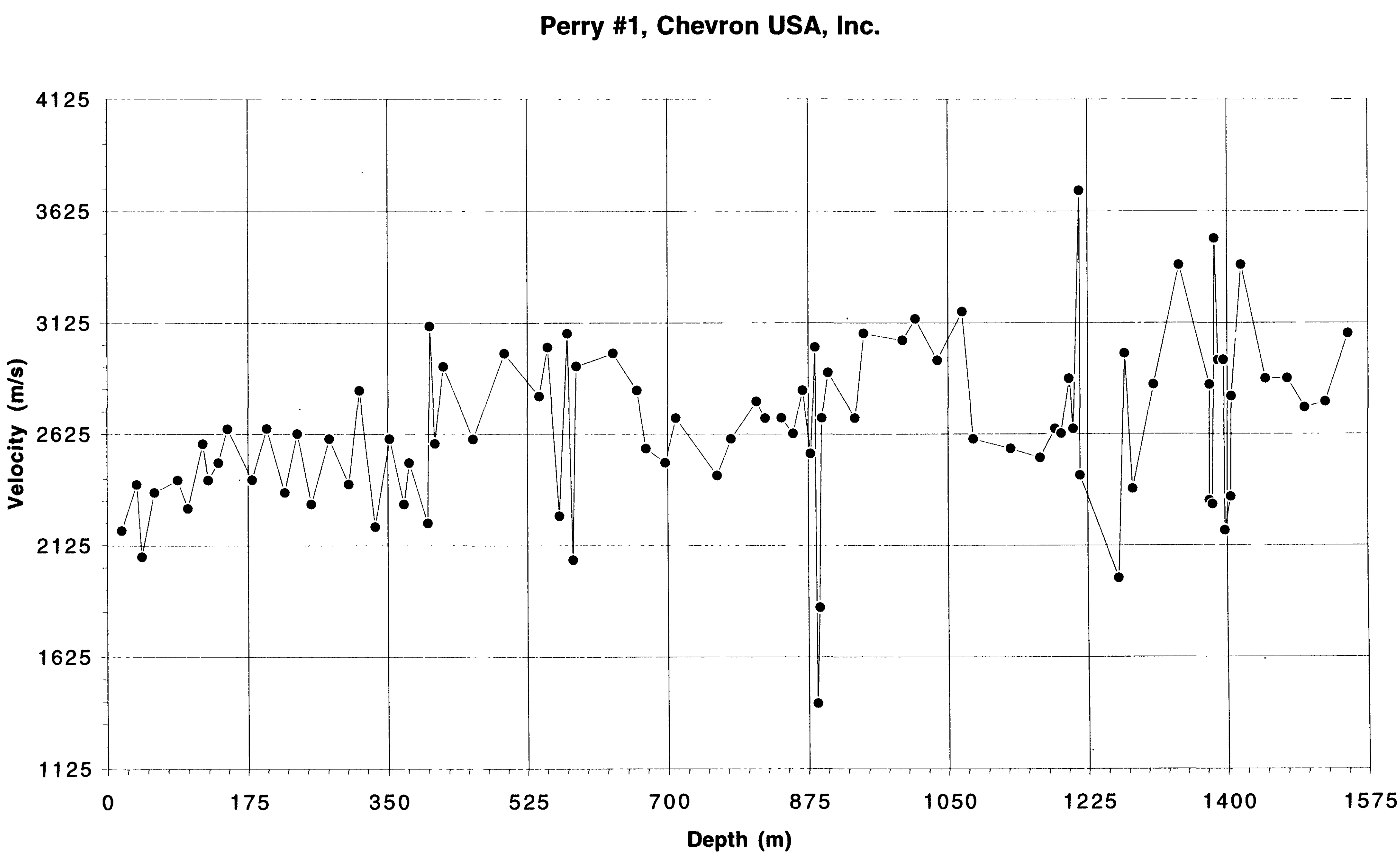

Perry #1, Chevron USA, Inc.
Velocity (m/s)
4125
3625
3125
2625
2125
1625
1125
Depth (m)
0
175
350
525
700
875
1050
1225
1400
1575

Figure 13.

Neeley #1, Chevron USA, Inc.

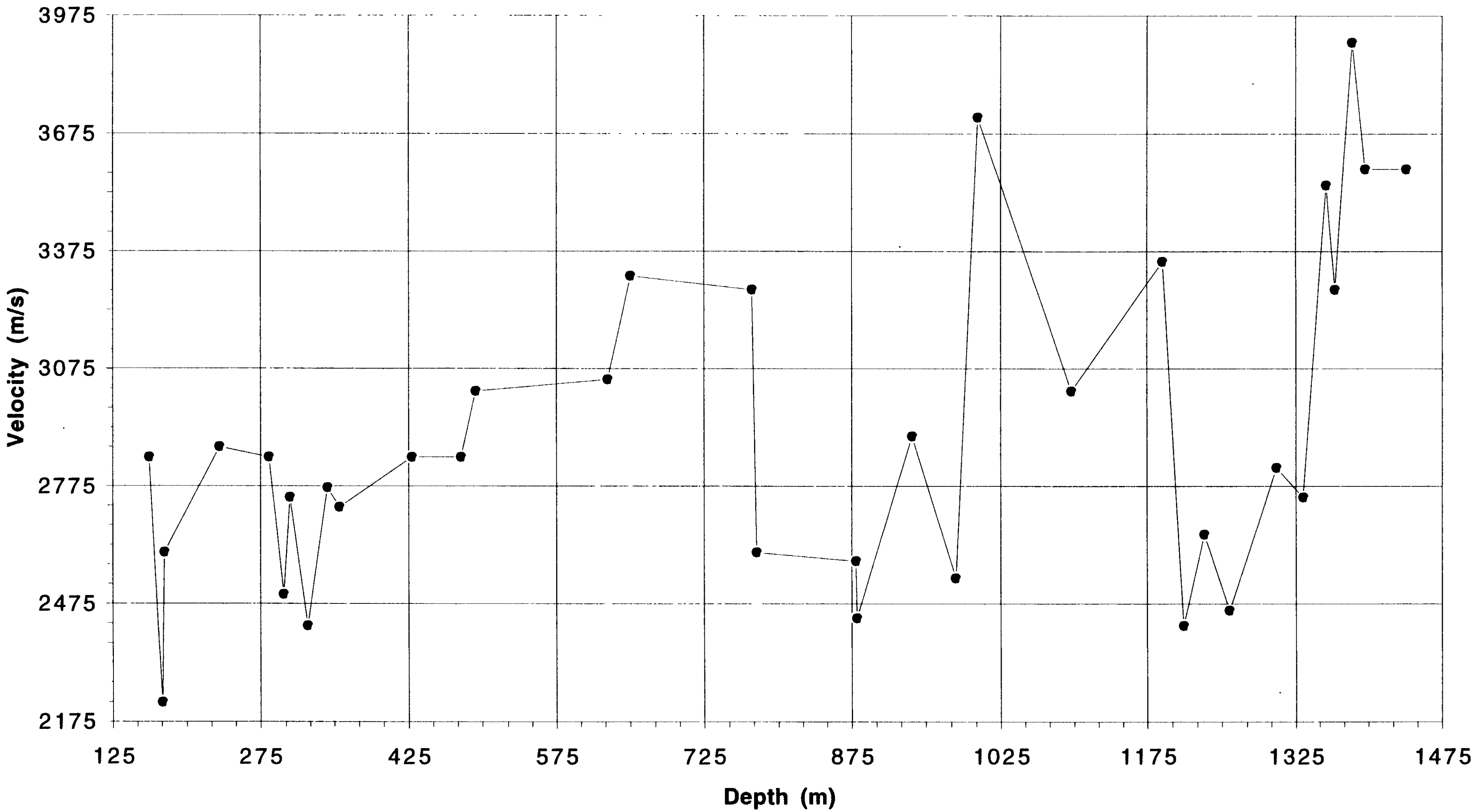


Figure 14.

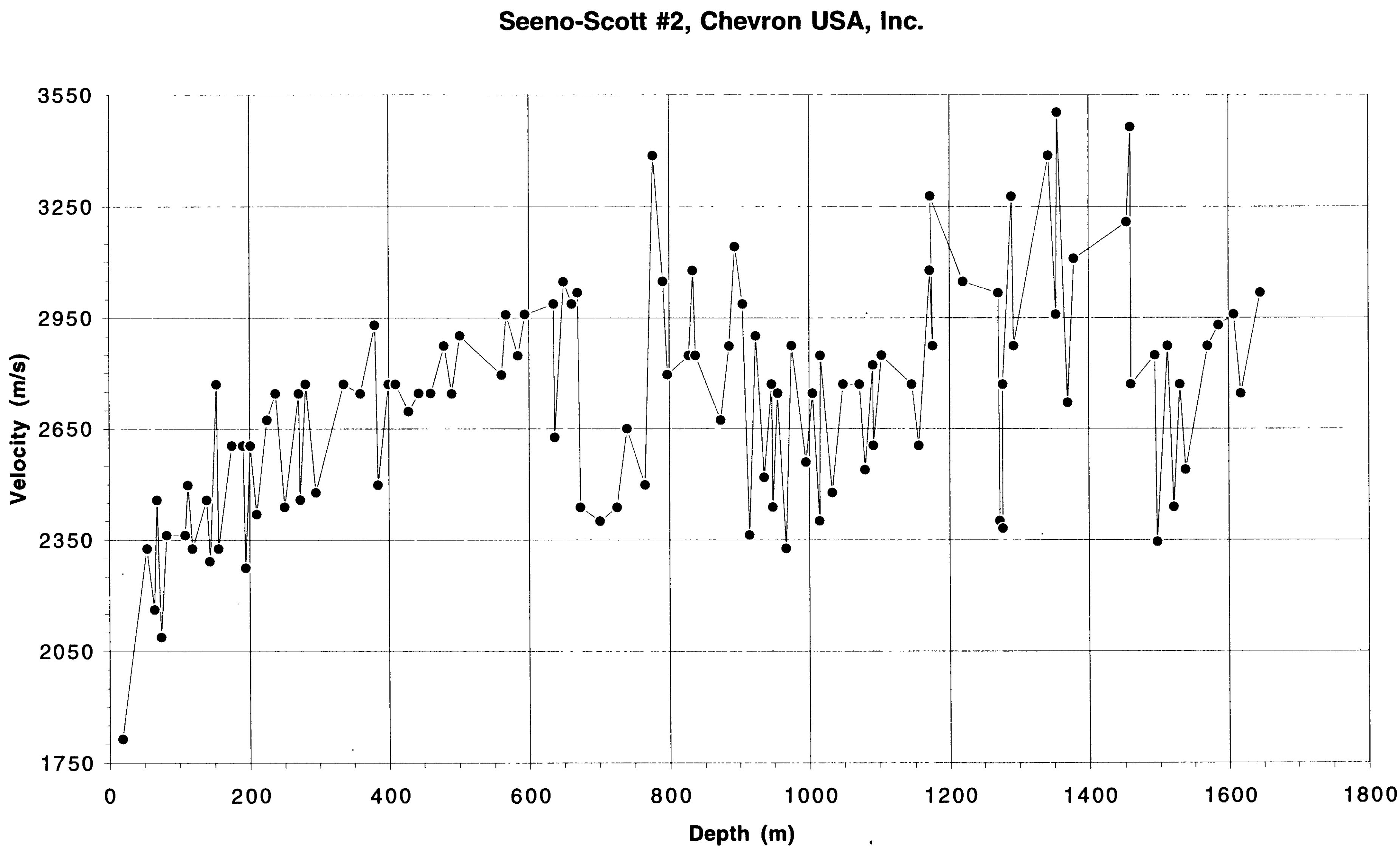

Seeno-Scott #2, Chevron USA, Inc.
Velocity (m/s)
3550
3250
2950
2650
2350
2050
1750
0
200
400
600
800
1000
1200
1400
1600
1800
Depth (m)

Figure 15.

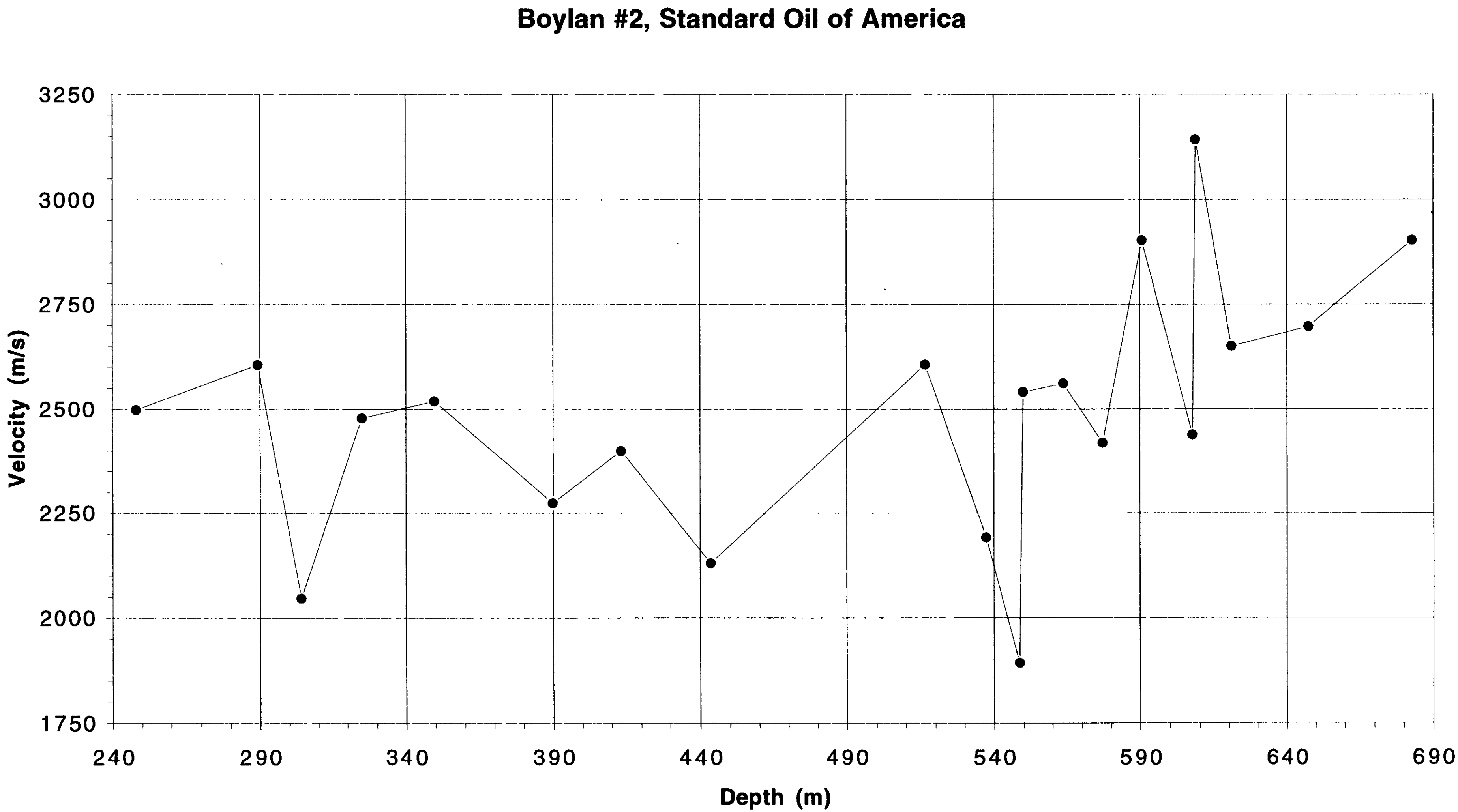

Boylan #2, Standard Oil of America
Velocity (m/s)
3250
3000
2750
2500
2250
2000
1750
240
290
340
390
440
490
540
590
640
690
Depth (m)

Figure 16.

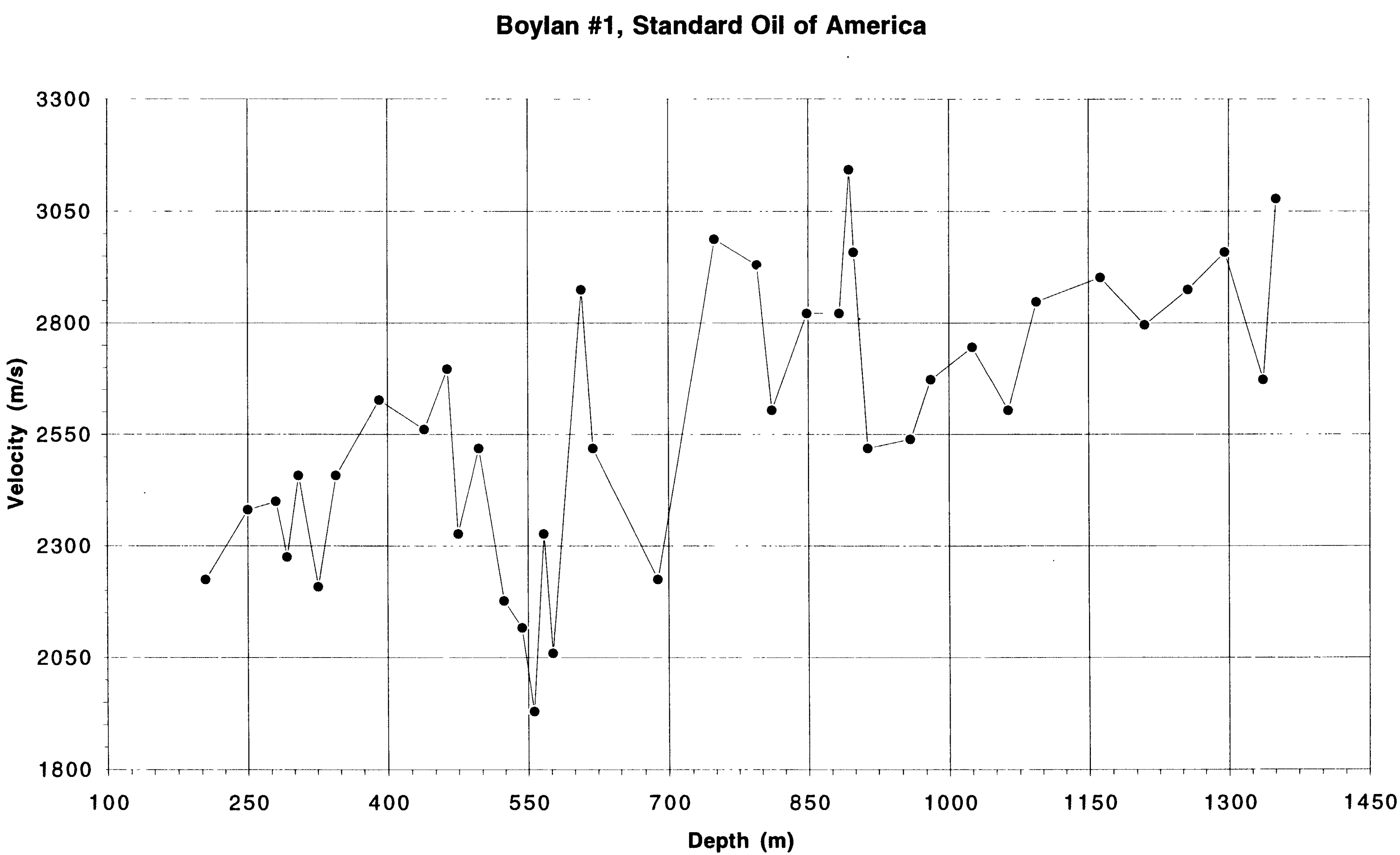
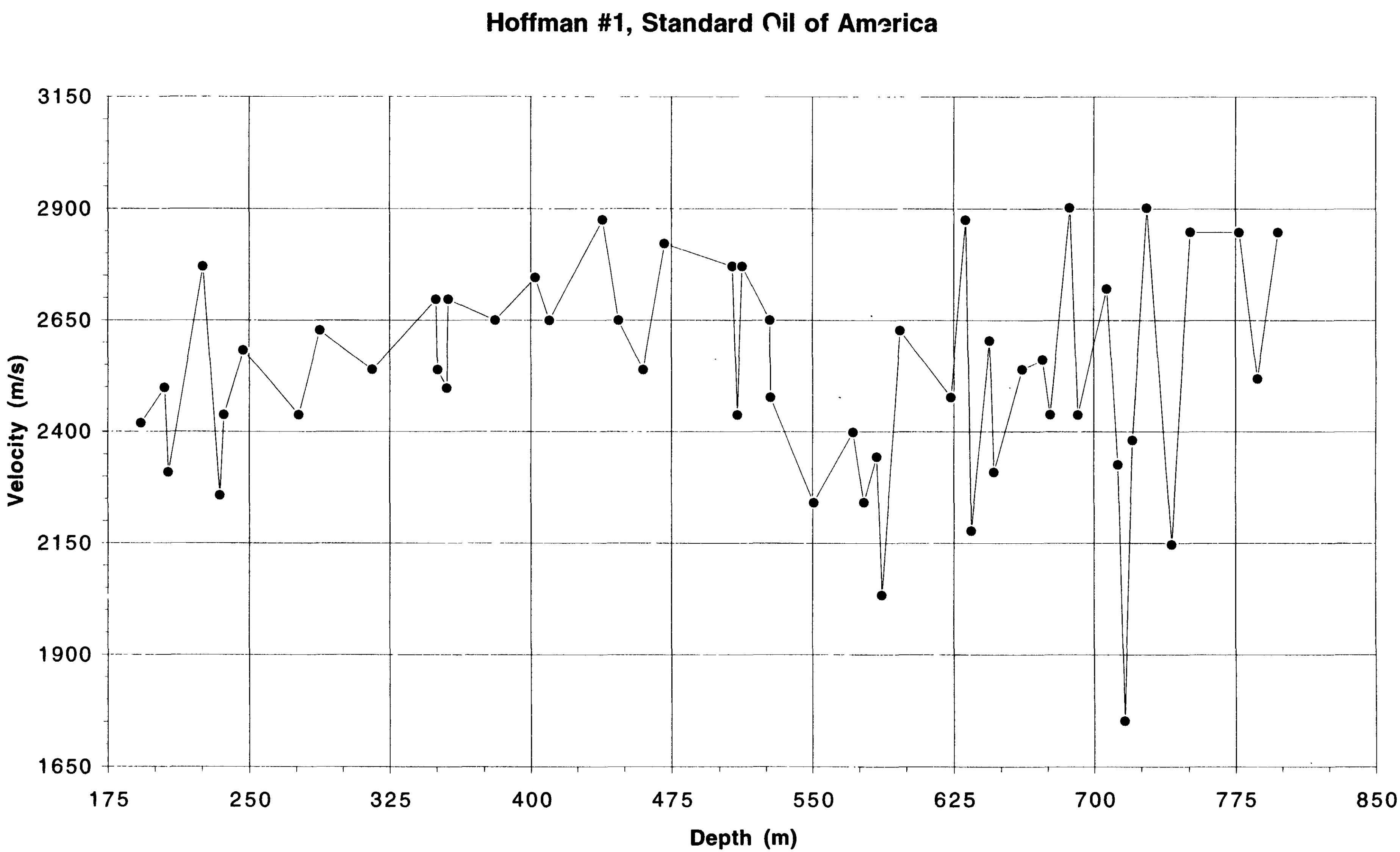

Boylan #1, Standard Oil of America
3300
3050
2800
2550
2300
2050
1800
Velocity (m/s)
100
250
400
550
700
850
1000
1150
1300
1450
Depth (m)

Figure 17.



Hoffman #1, Standard Oil of America
3150
2900
2650
2400
2150
1900
1650
Velocity (m/s)
175
250
325
400
475
550
625
700
775
850
Depth (m)

Figure 18.

Bethlehem #2, Standard Oil of America

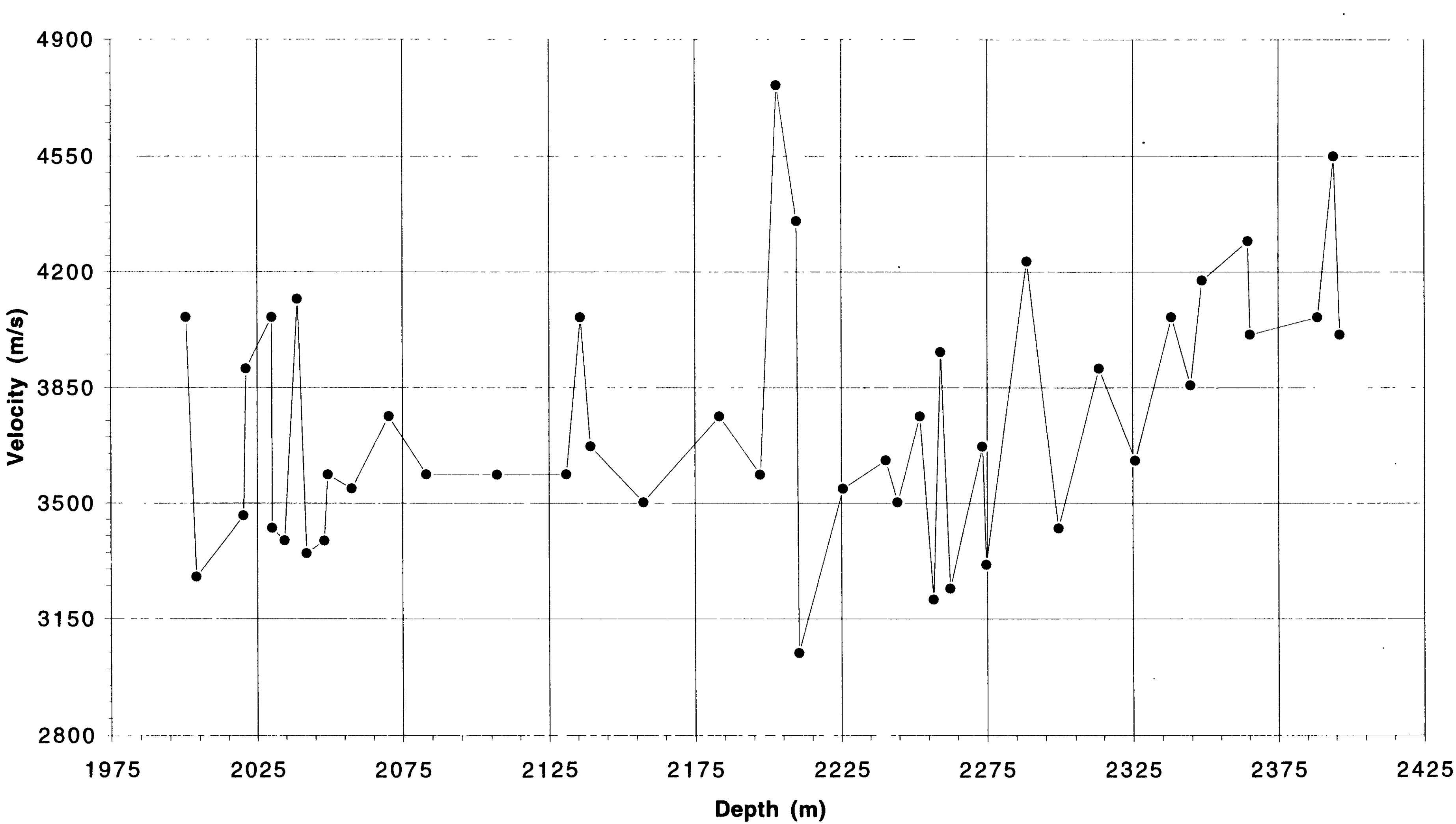


Figure 19.

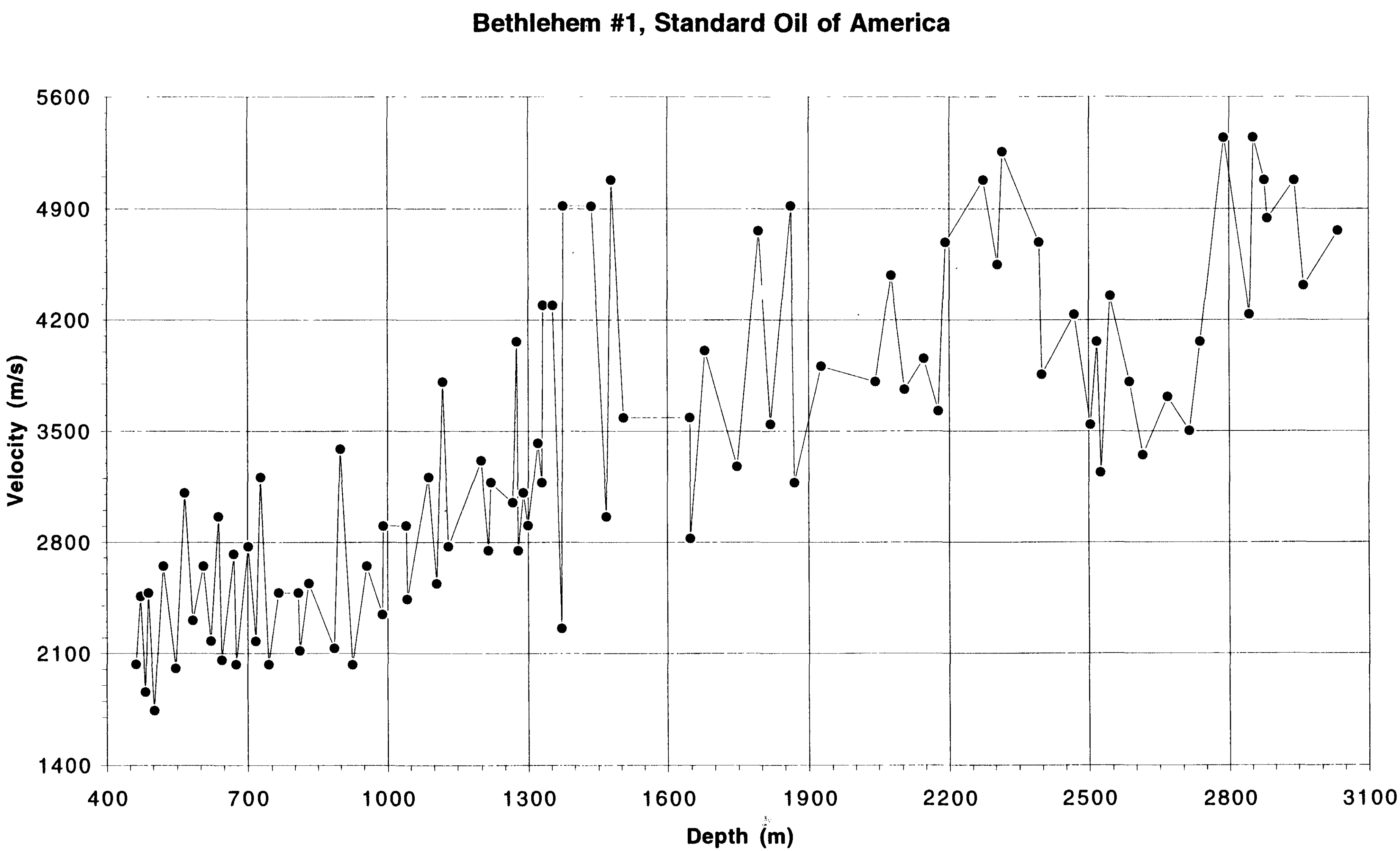

Bethlehem #1, Standard Oil of America
Velocity (m/s)
5600
4900
4200
3500
2800
2100
1400
400
700
1000
1300
1600
1900
2200
2500
2800
3100
Depth (m)

Figure 20.

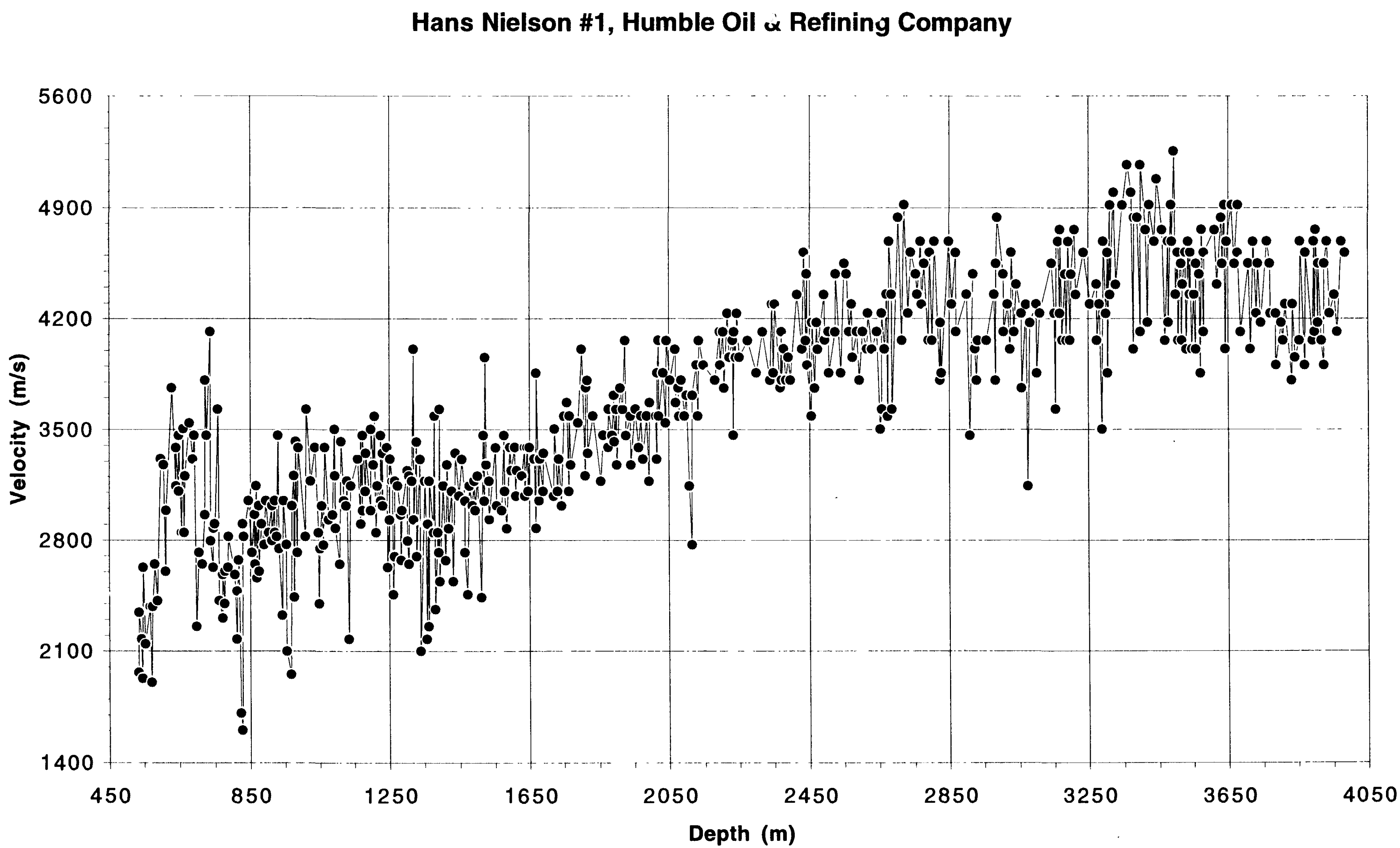

Hans Nielson #1, Humble Oil & Refining Company
Velocity (m/s)
5600
4900
4200
3500
2800
2100
1400
450
850
1250
1650
2050
2450
2850
3250
3650
4050
Depth (m)

Figure 21.

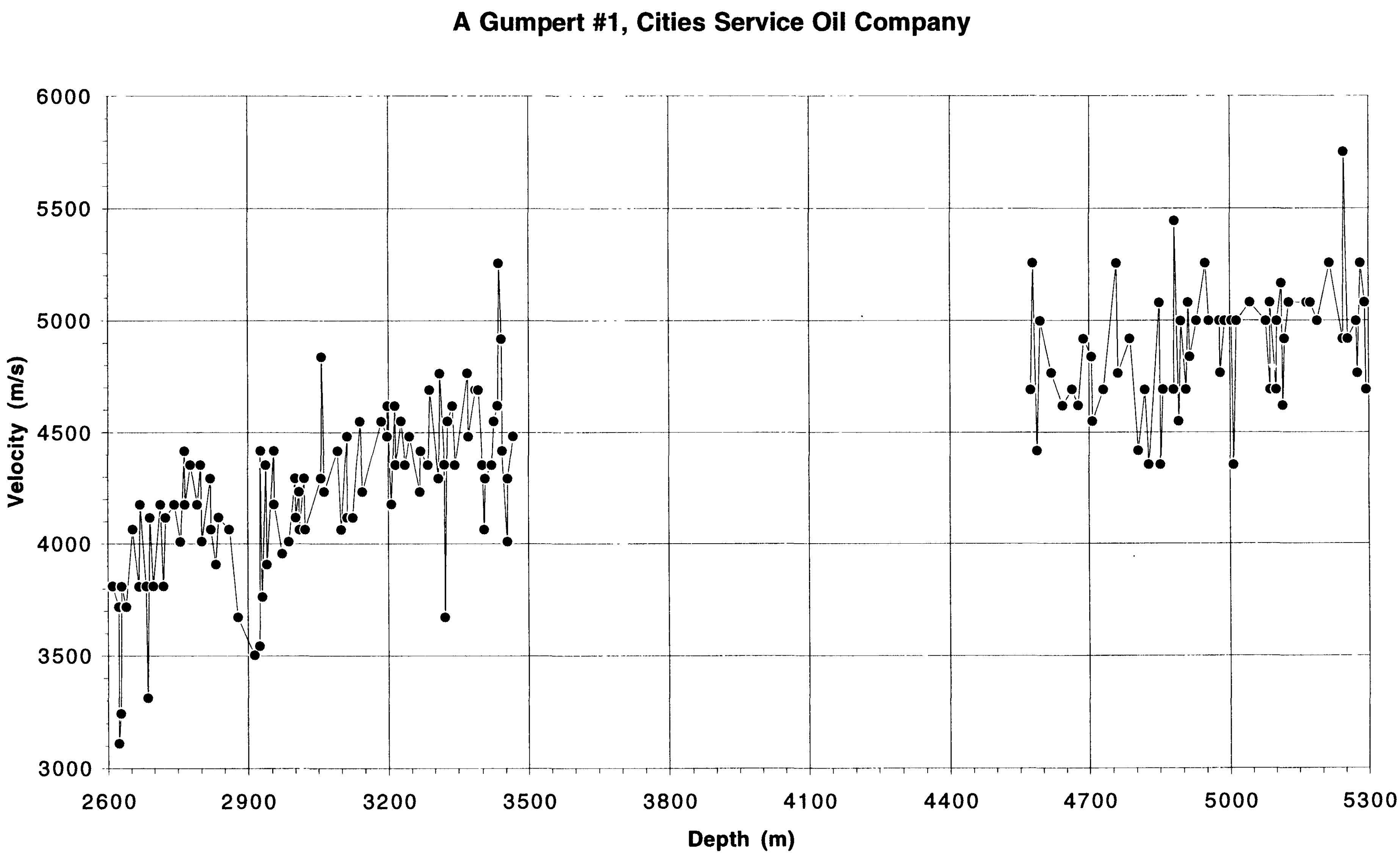

A Gumpert #1, Cities Service Oil Company
6000
5500
5000
4500
4000
3500
3000
Velocity (m/s)
2600
2900
3200
3500
3800
4100
4400
4700
5000
5300
Depth (m)

Figure 22.

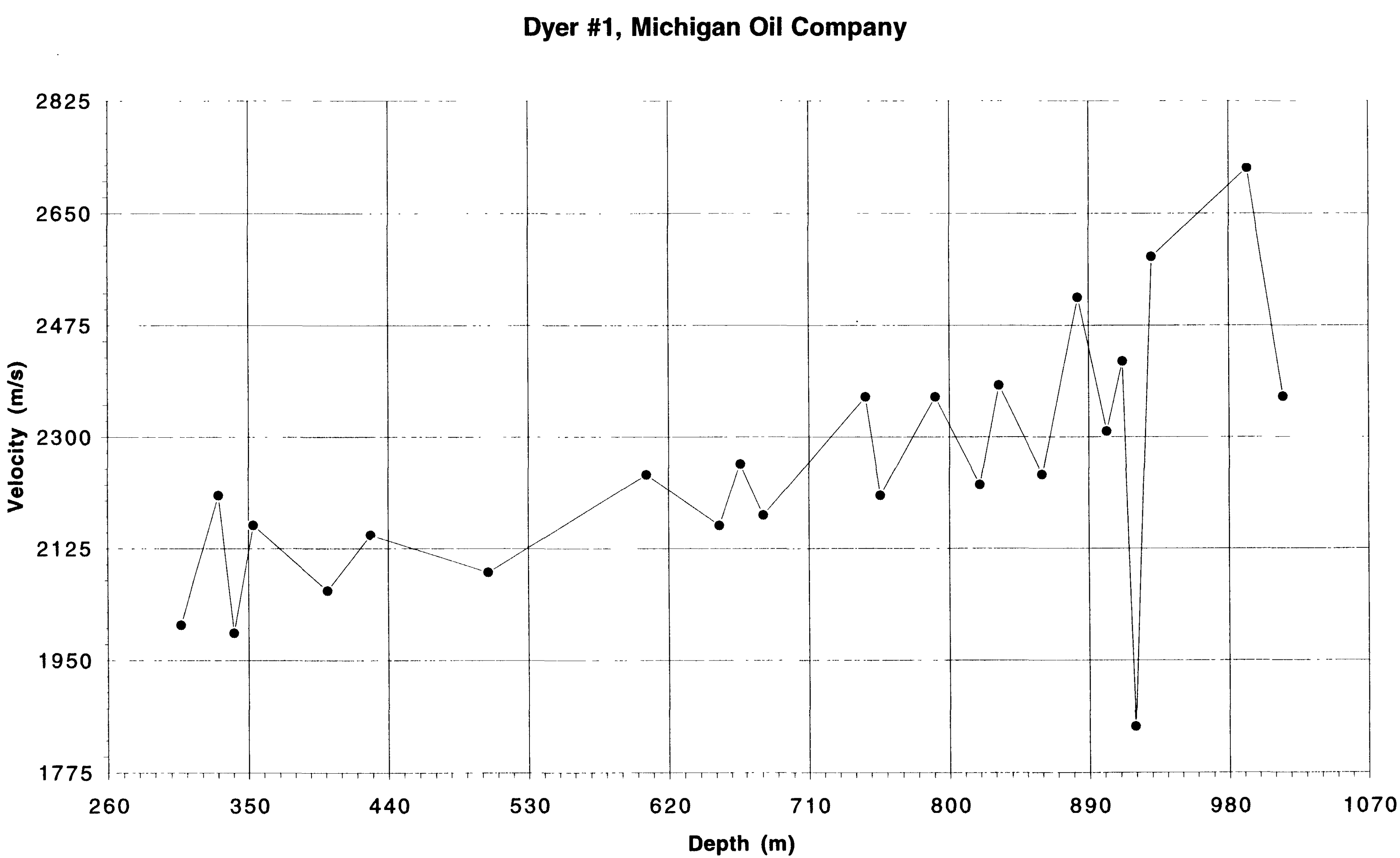

Dyer #1, Michigan Oil Company
Velocity (m/s)
2825
2650
2475
2300
2125
1950
1775
260
350
440
530
620
710
800
890
980
1070
Depth (m)

Figure 23.

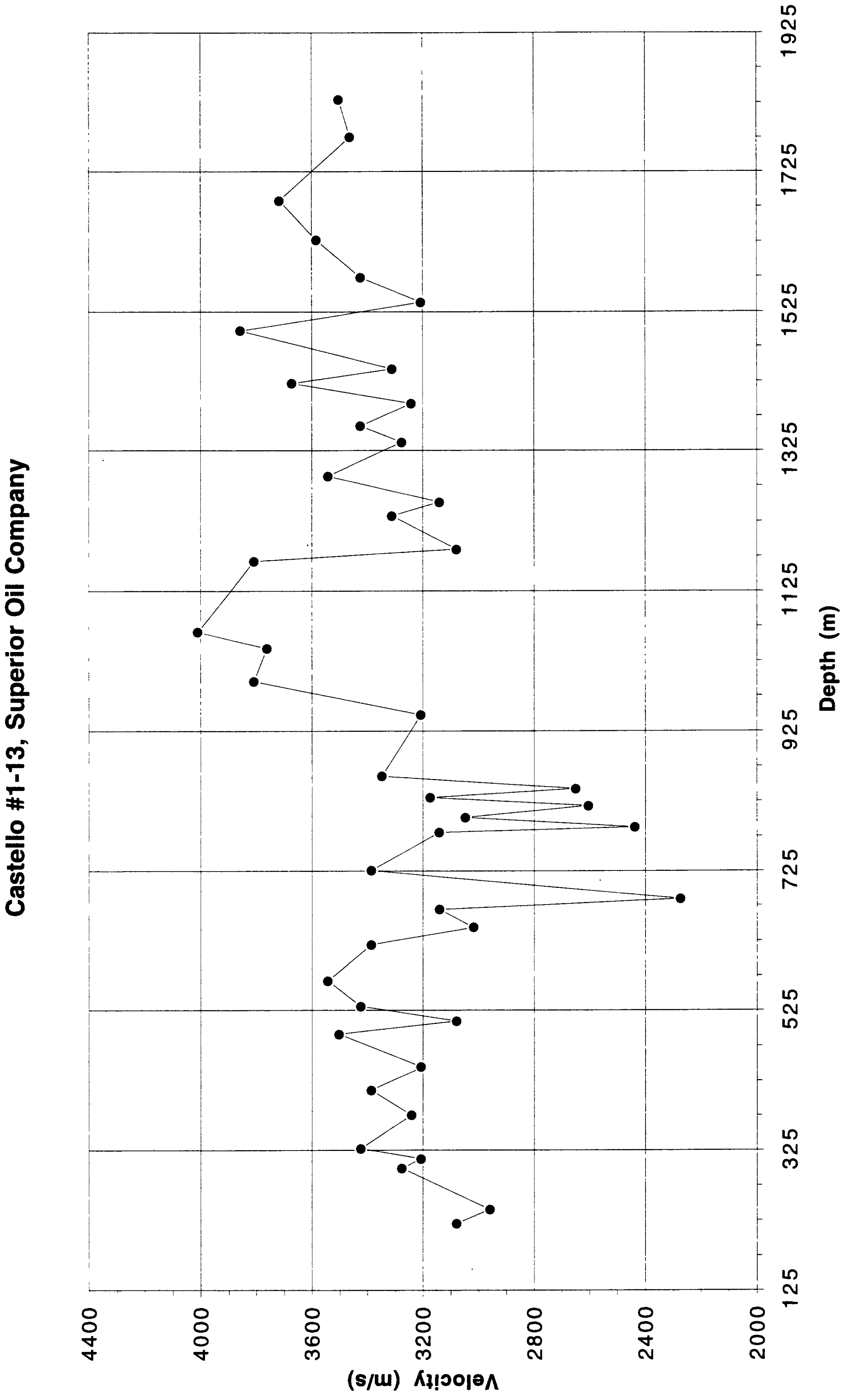

Castello #1-13, Superior Oil Company
Velocity (m/s)
4400
4000
3600
3200
2800
2400
2000
Depth (m)
125
325
525
725
925
1125
1325
1525
1725
1925

Figure 24.

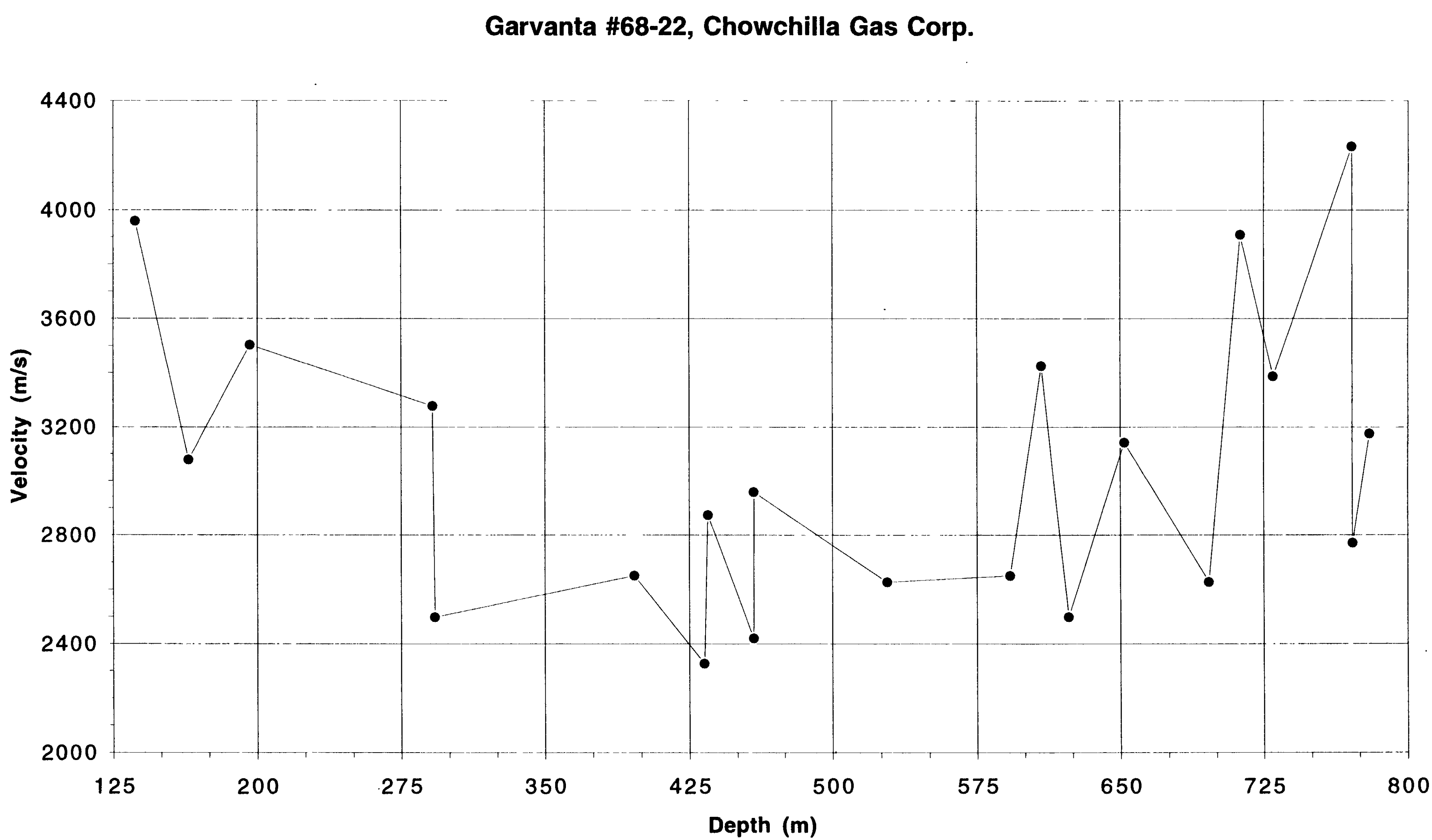

Garvanta #68-22, Chowchilla Gas Corp.
Velocity (m/s)
4400
4000
3600
3200
2800
2400
2000
125
200
275
350
425
500
575
650
725
800
Depth (m)

Figure 25.

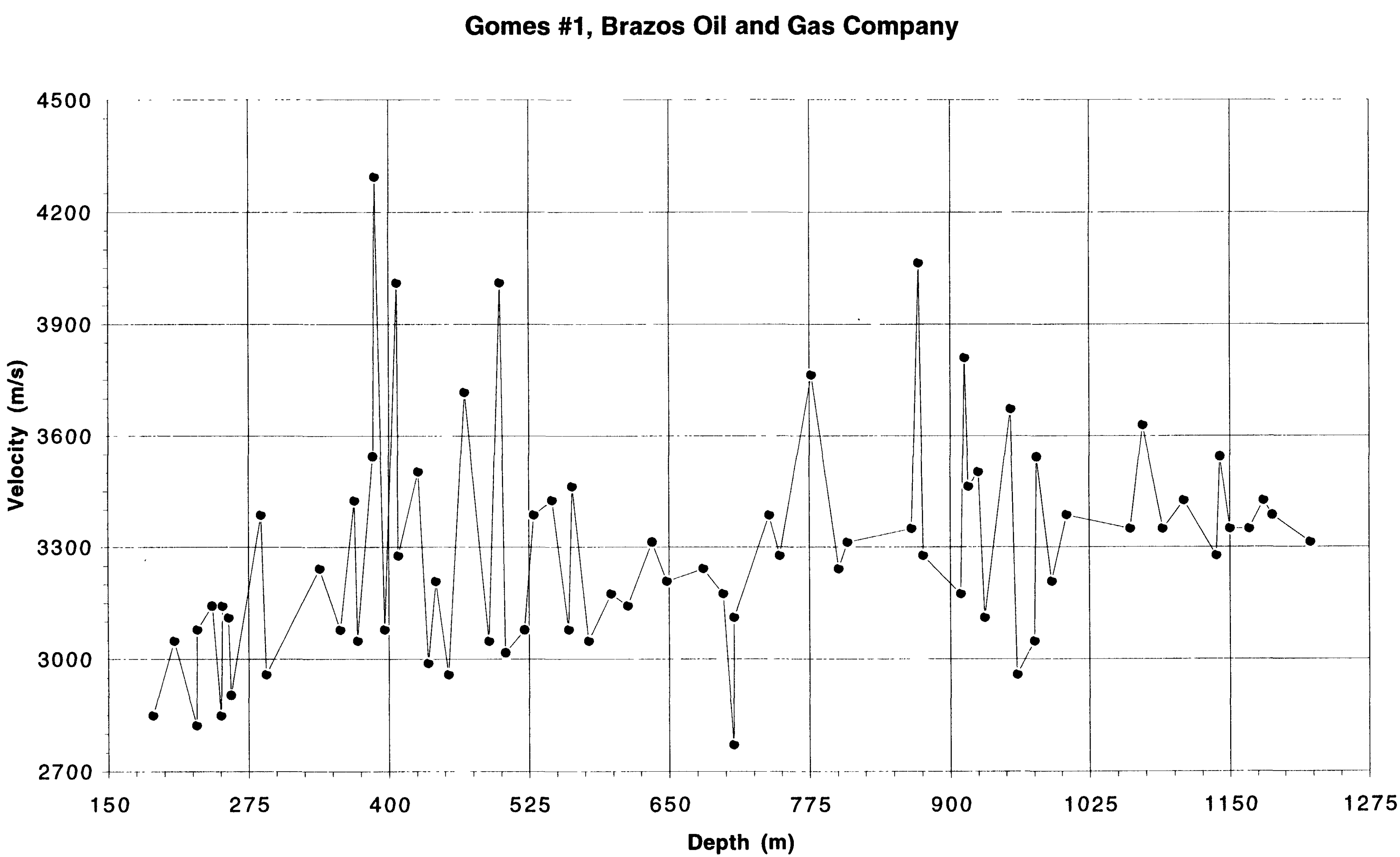

Gomes #1, Brazos Oil and Gas Company
Velocity (m/s)
4500
4200
3900
3600
3300
3000
2700
150
275
400
525
650
775
900
1025
1150
1275
Depth (m)

Figure 26.

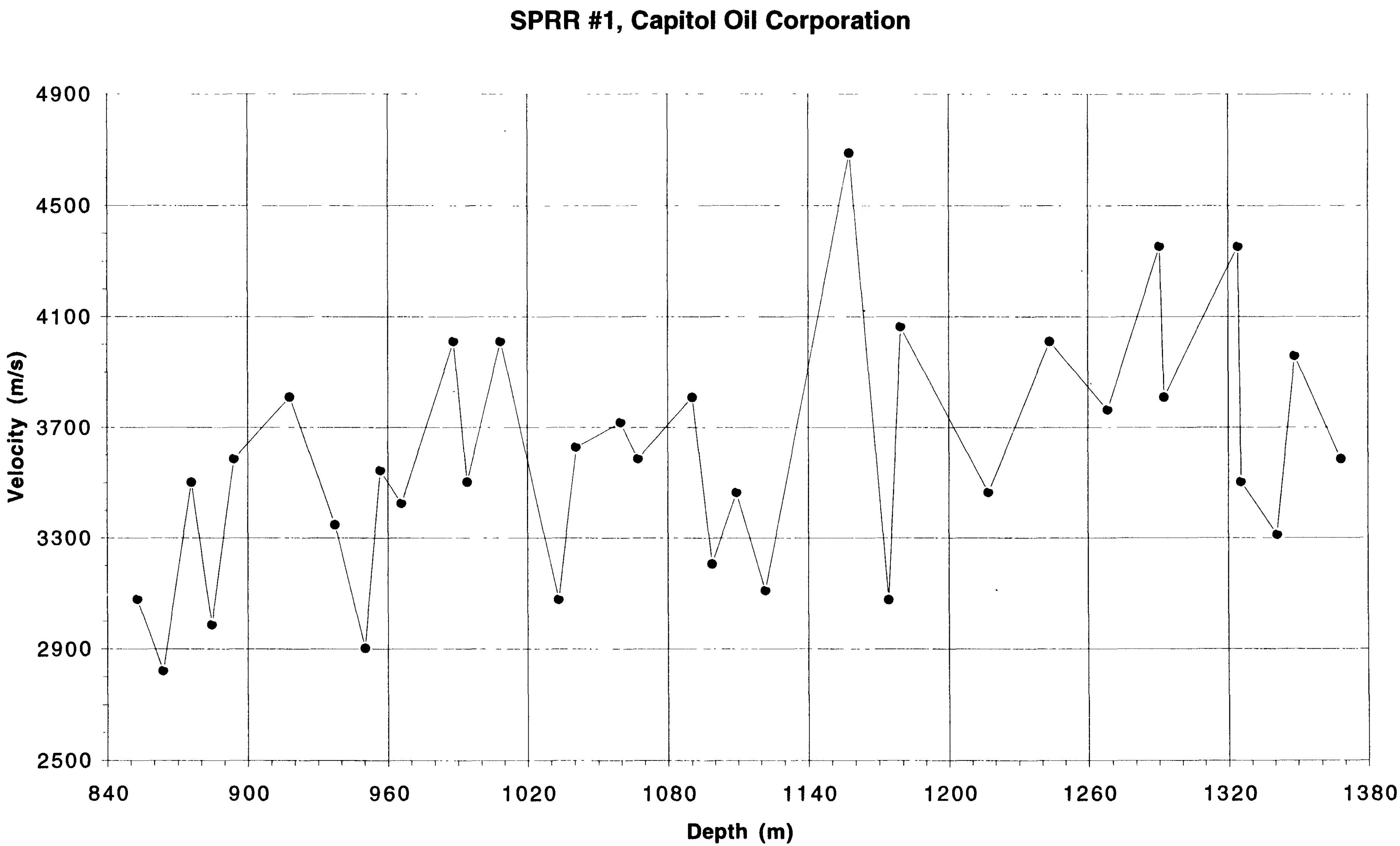

SPRR #1, Capitol Oil Corporation
Velocity (m/s)
4900
4500
4100
3700
3300
2900
2500
840
900
960
1020
1080
1140
1200
1260
1320
1380
Depth (m)

Figure 27.

McCulloch-Guidotti #1, McCulloch Oil of Calif.

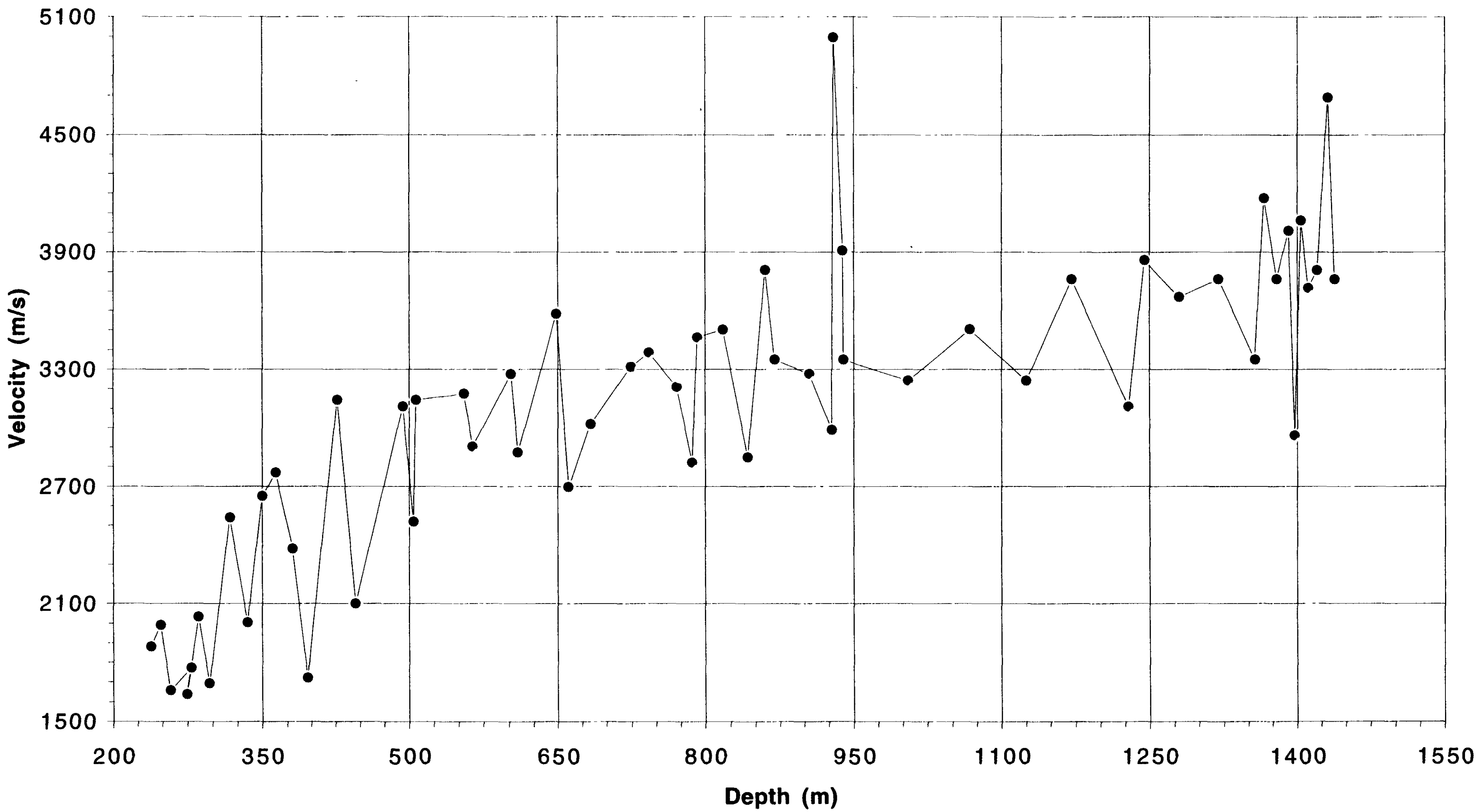


Figure 28.

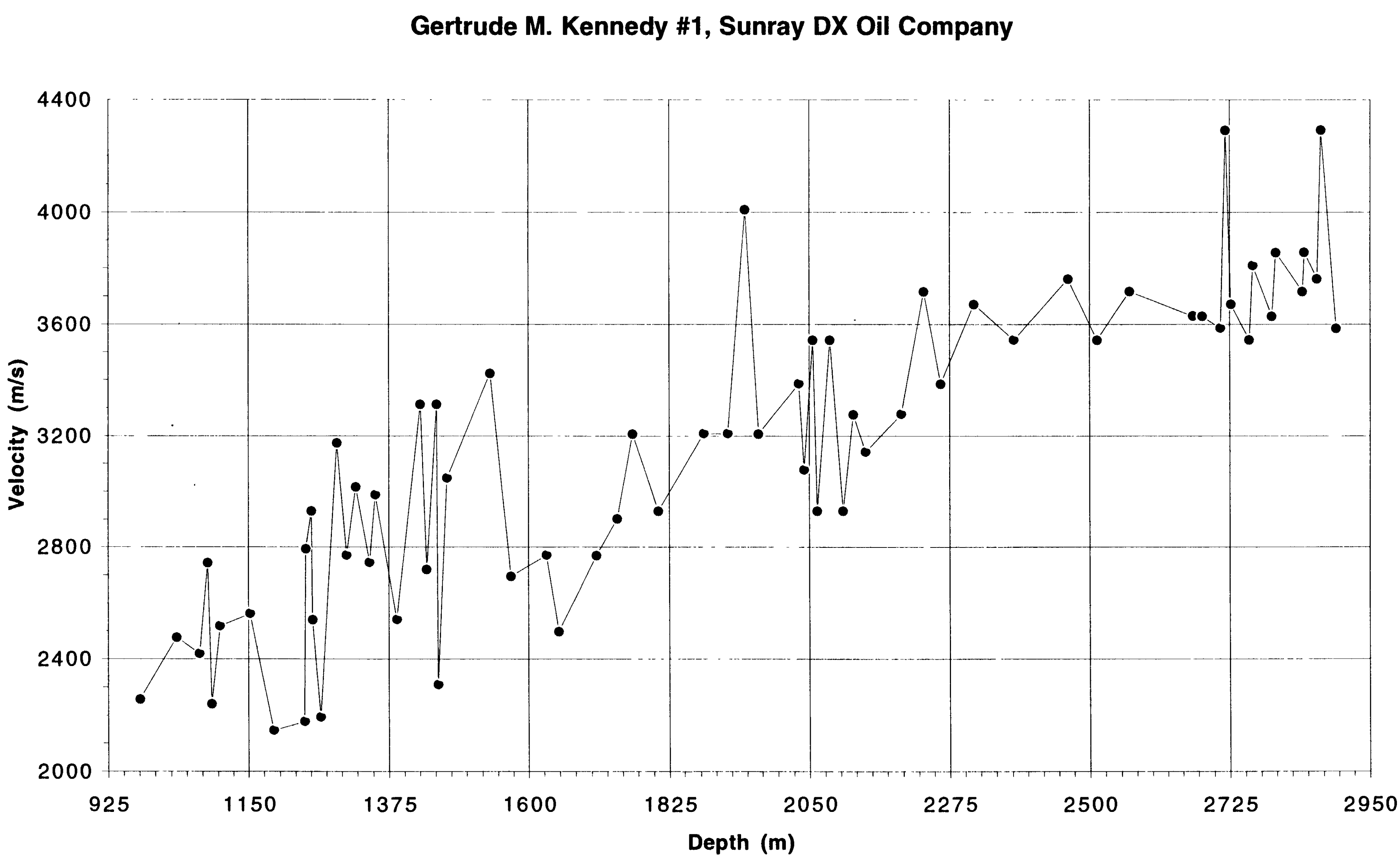

Gertrude M. Kennedy #1, Sunray DX Oil Company
4400
4000
3600
3200
2800
2400
2000
Velocity (m/s)
925
1150
1375
1600
1825
2050
2275
2500
2725
2950
Depth (m)

Figure 29.

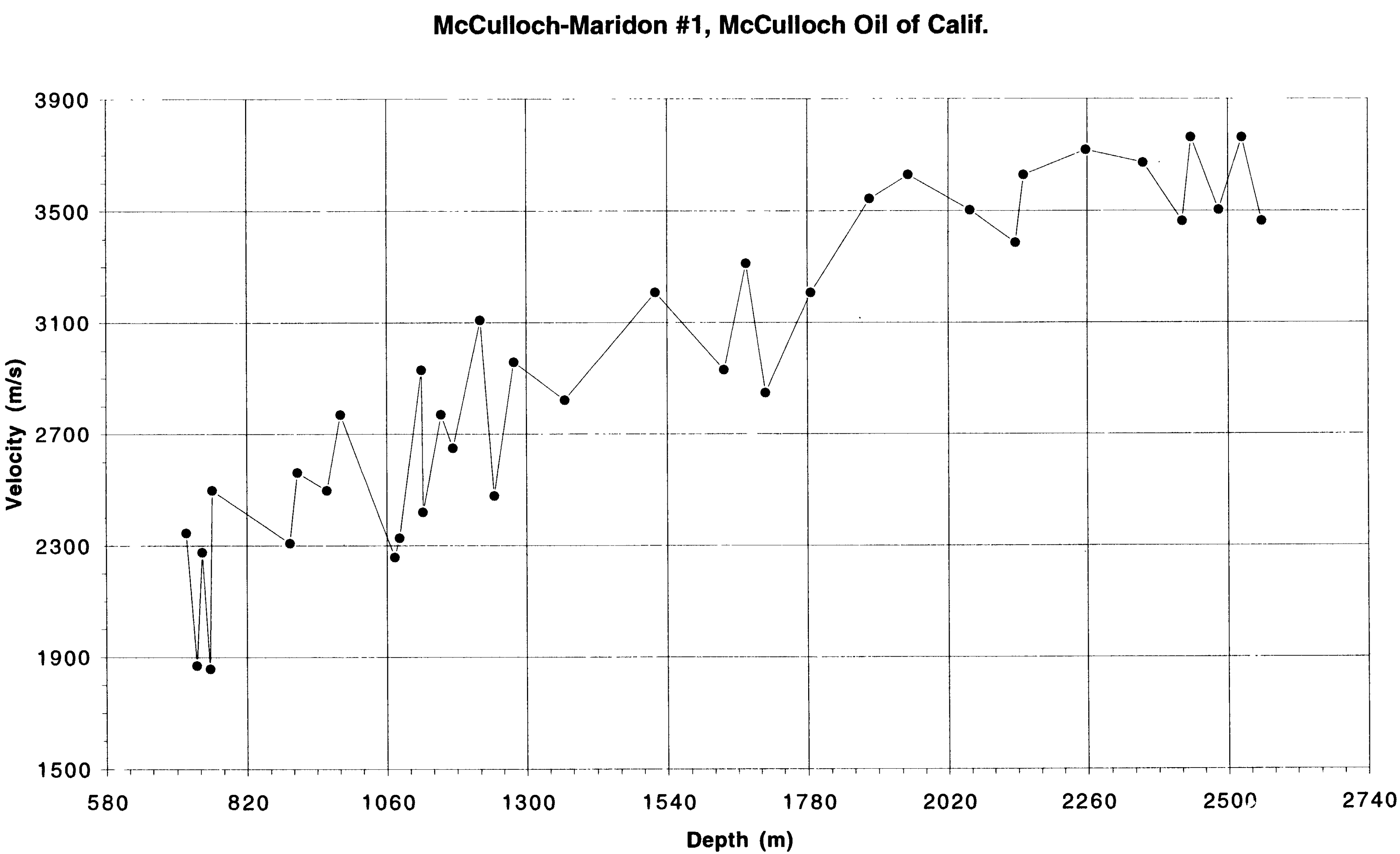

McCulloch-Maridon #1, McCulloch Oil of Calif.
Velocity (m/s)
3900
3500
3100
2700
2300
1900
1500
580
820
1060
1300
1540
1780
2020
2260
2500
2740
Depth (m)

Figure 30.

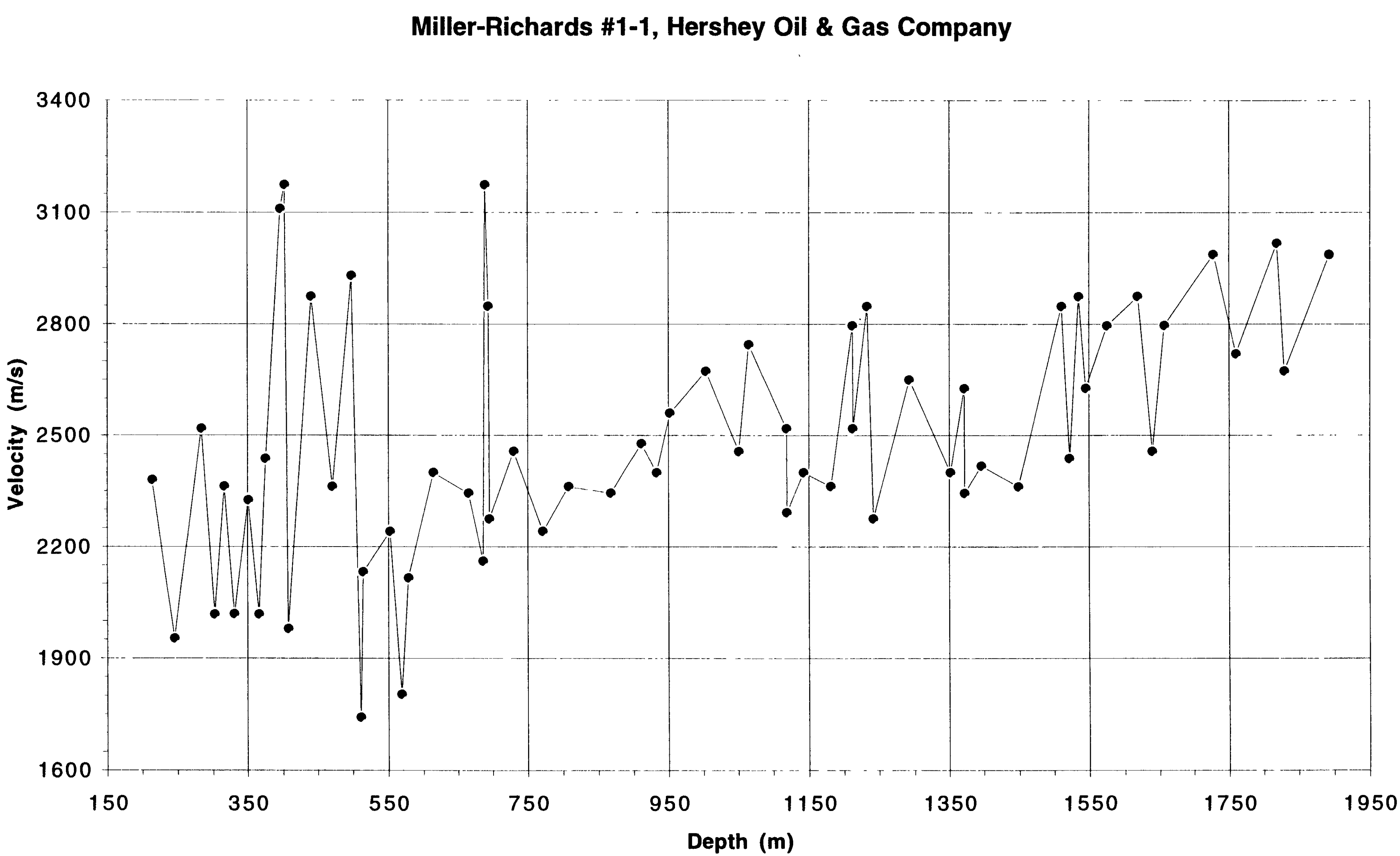
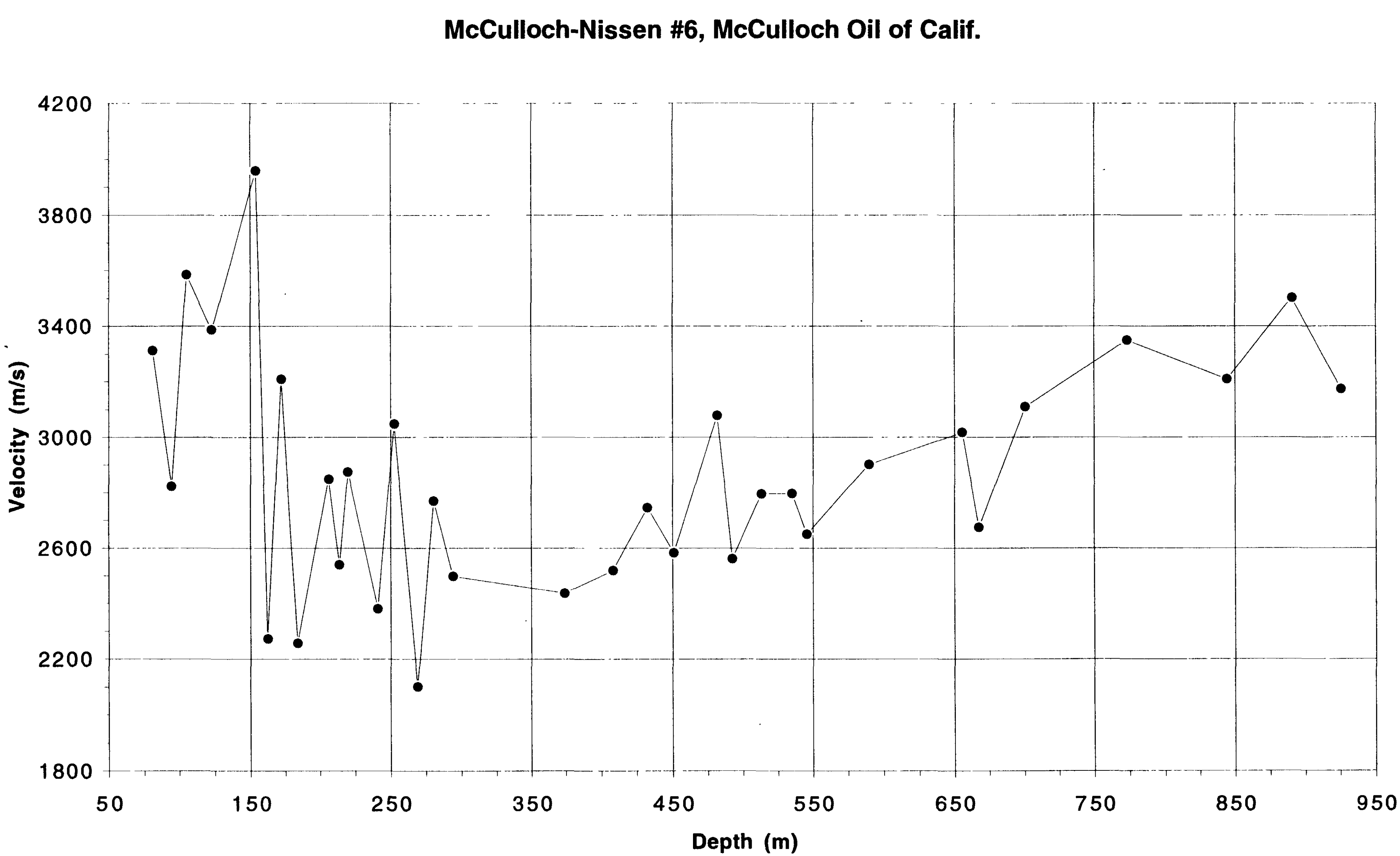

Miller-Richards #1-1, Hershey Oil & Gas Company
3400
3100
2800
2500
2200
1900
1600
Velocity (m/s)
150
350
550
750
950
1150
1350
1550
1750
1950
Depth (m)

Figure 31.



McCulloch-Nissen #6, McCulloch Oil of Calif.
4200
3800
3400
3000
2600
2200
1800
Velocity (m/s)
50
150
250
350
450
550
650
750
850
950
Depth (m)

Figure 32.

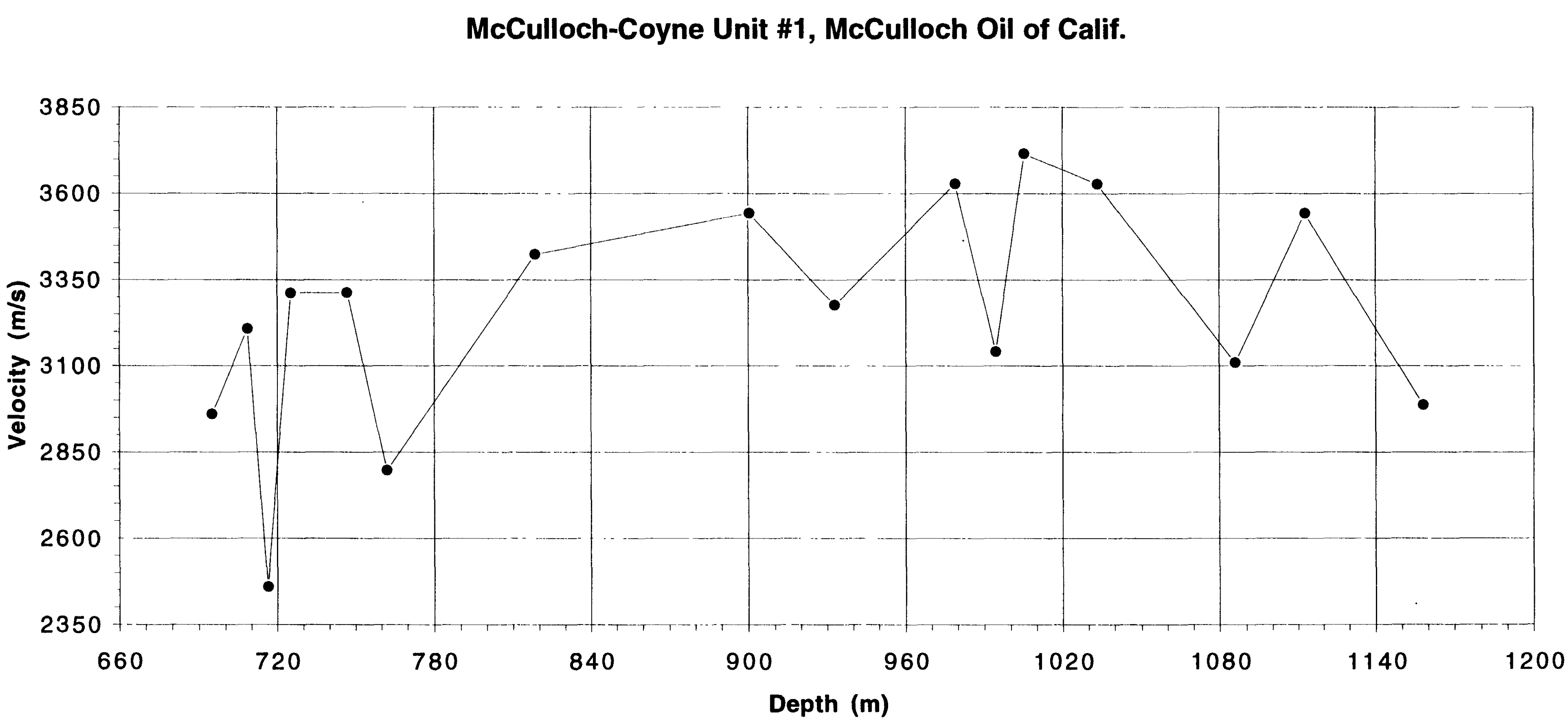

McCulloch-Coyne Unit #1, McCulloch Oil of Calif.
Velocity (m/s)
3850
3600
3350
3100
2850
2600
2350
660
720
780
840
900
960
1020
1080
1140
1200
Depth (m)

Figure 33.

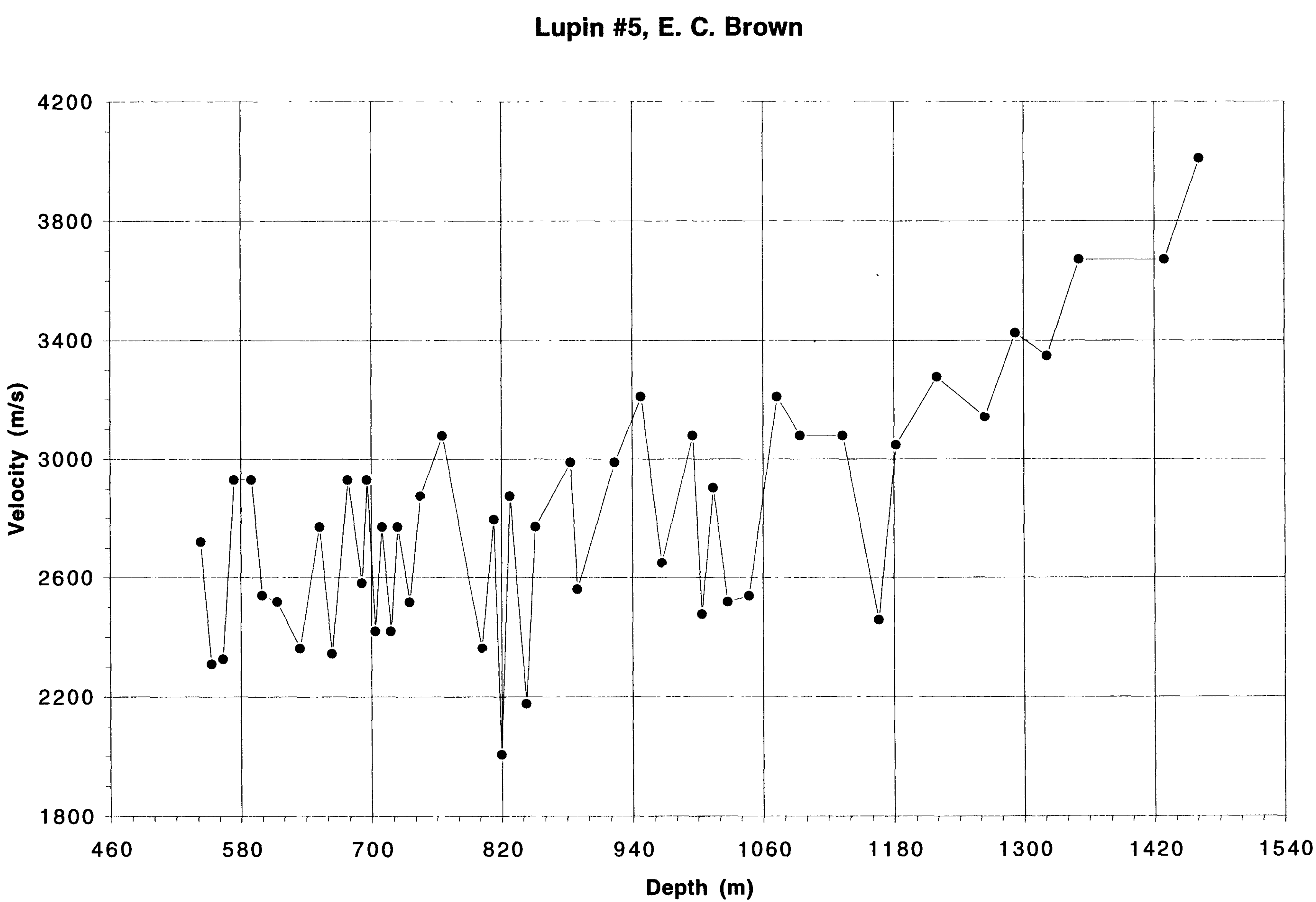
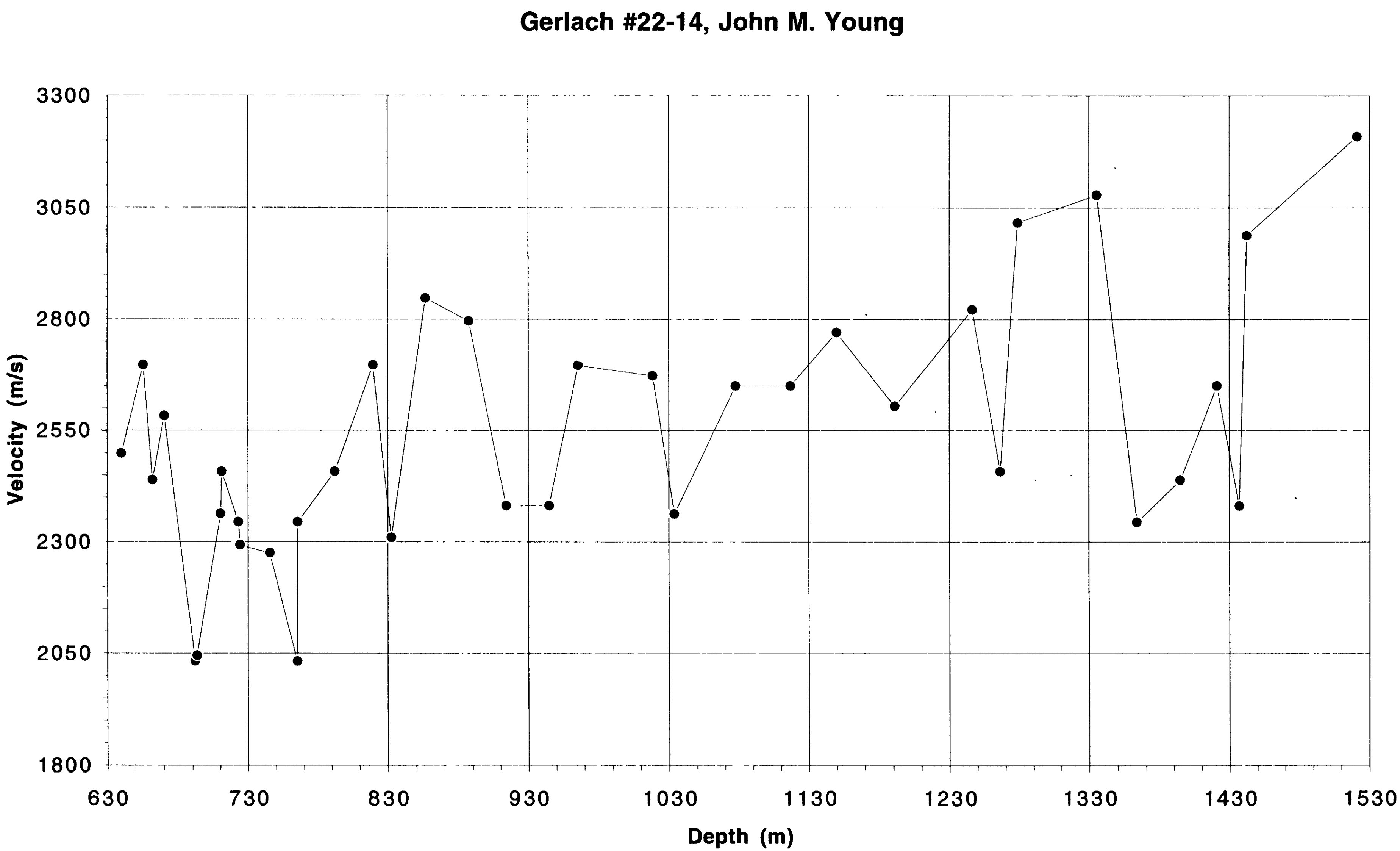

Lupin #5, E. C. Brown
4200
3800
3400
3000
2600
2200
1800
Velocity (m/s)
460
580
700
820
940
1060
1180
1300
1420
1540
Depth (m)

Figure 34.



Gerlach #22-14, John M. Young
Velocity (m/s)
3300
3050
2800
2550
2300
2050
1800
630
730
830
930
1030
1130
1230
1330
1430
1530
Depth (m)

Figure 35.

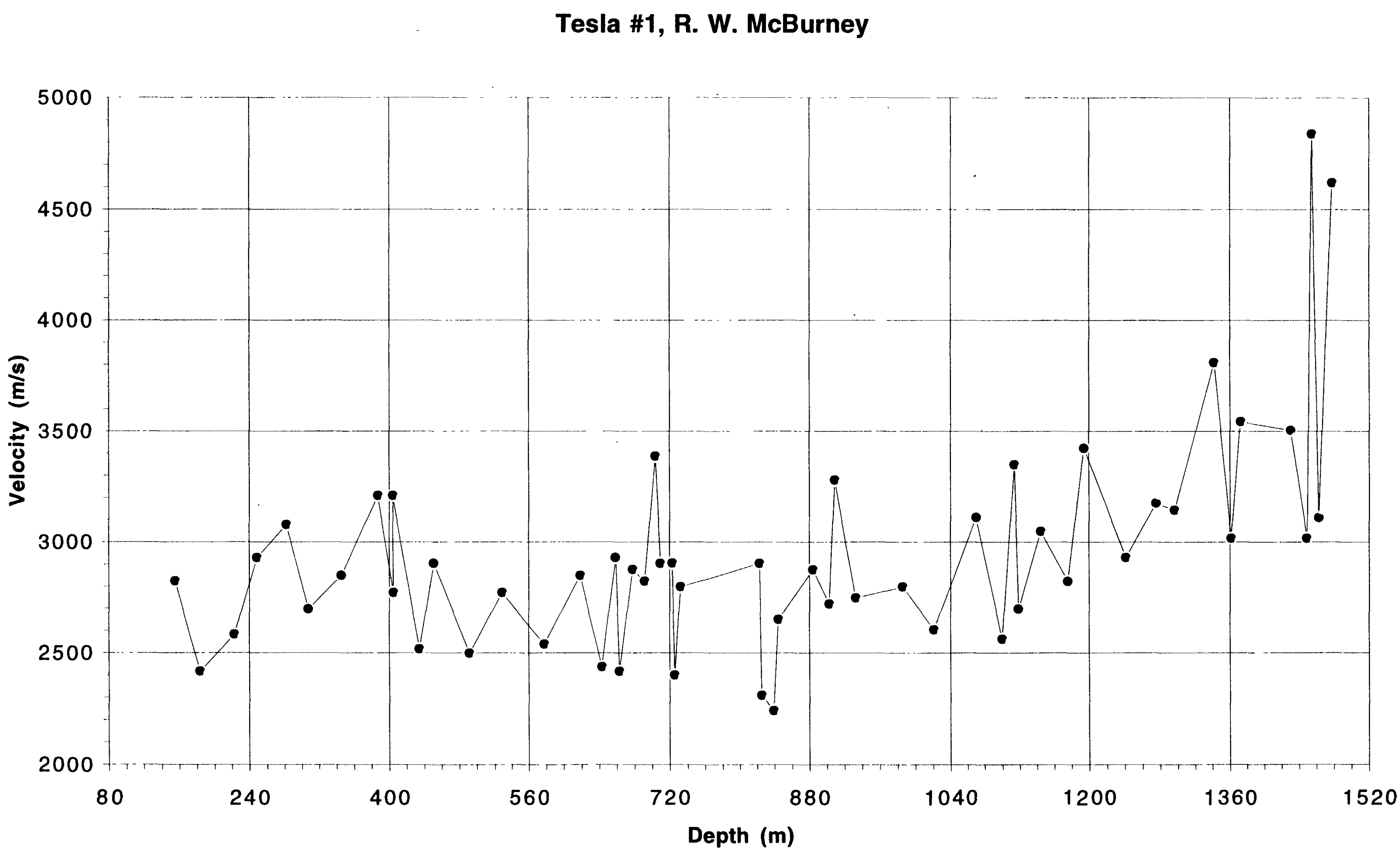

Tesla #1, R. W. McBurney
Velocity (m/s)
5000
4500
4000
3500
3000
2500
2000
80
240
400
560
720
880
1040
1200
1360
1520
Depth (m)

Figure 36.

Peterson Fee #43-17, Diamond Shamrock Corp.

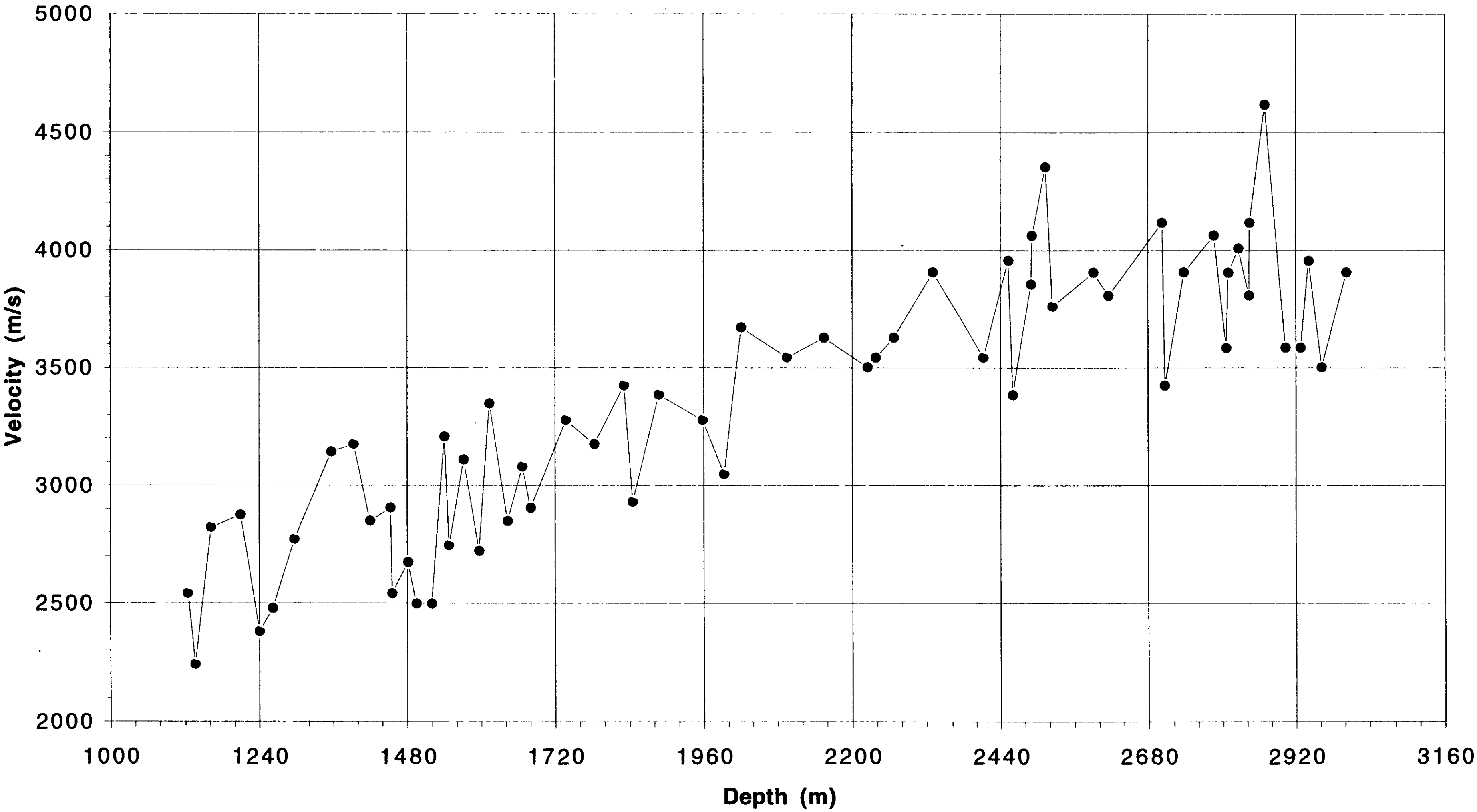
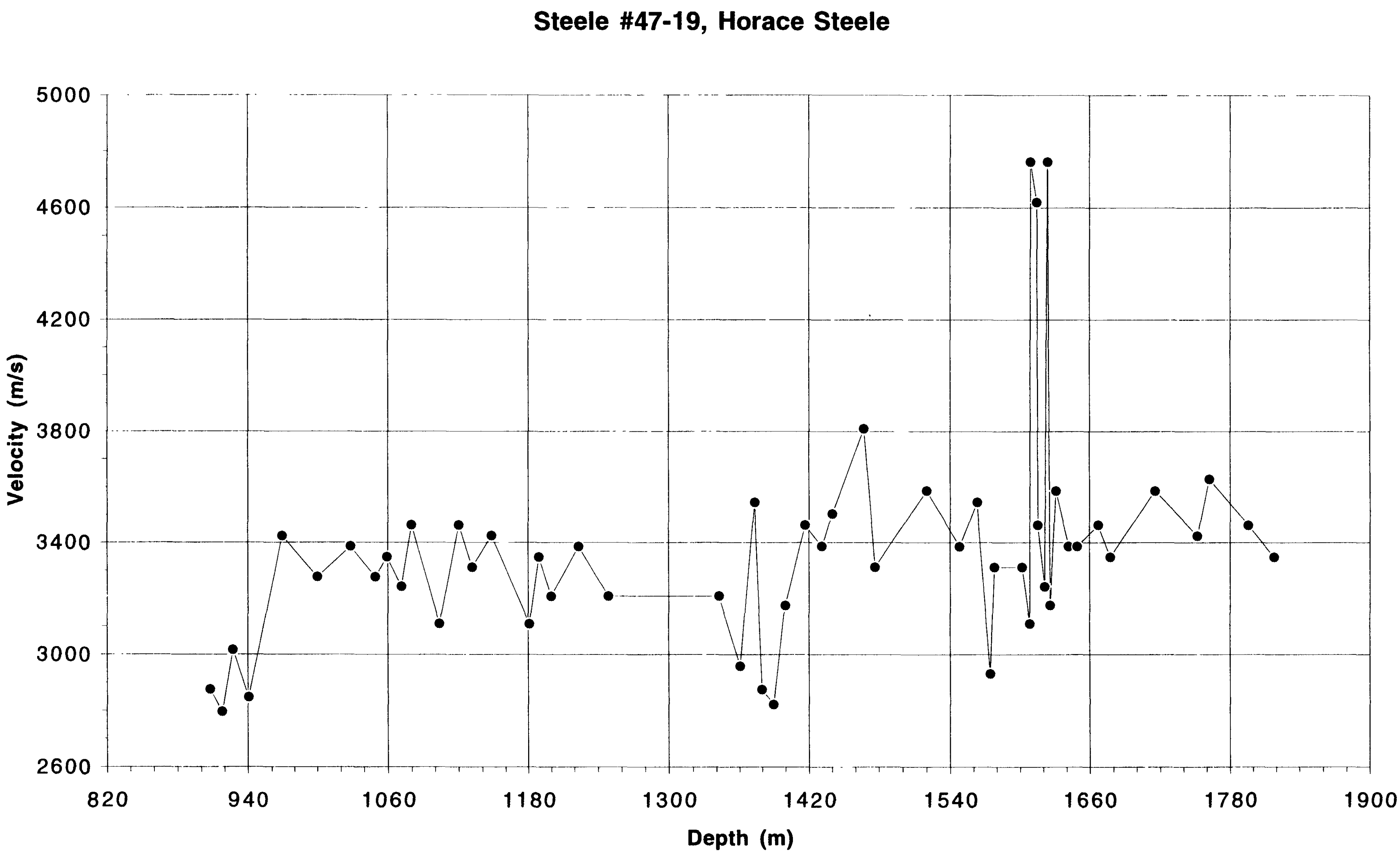


Figure 37.



Steele #47-19, Horace Steele
5000
4600
4200
3800
3400
3000
2600
Velocity (m/s)
820
940
1060
1180
1300
1420
1540
1660
1780
1900
Depth (m)

Figure 38.

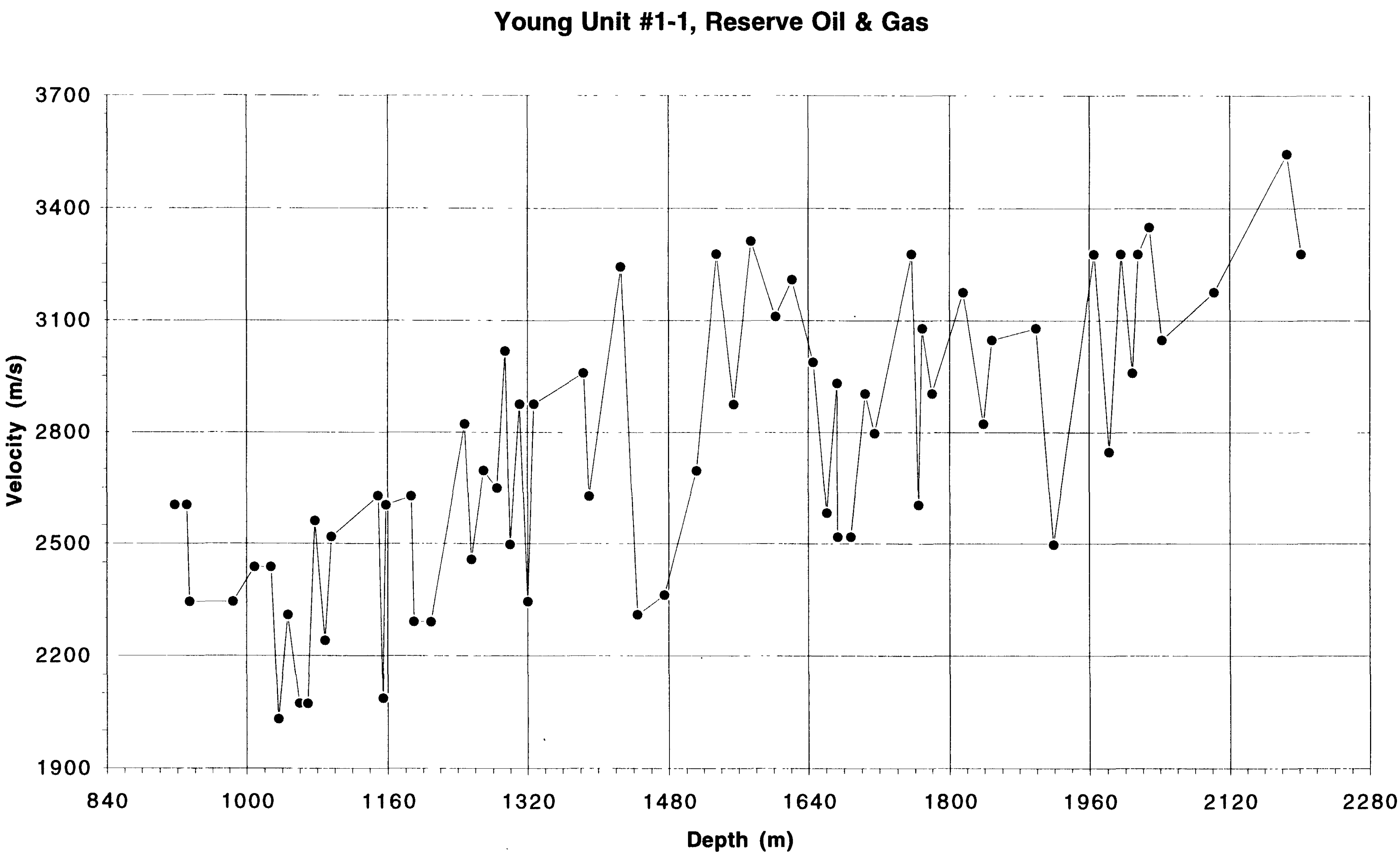
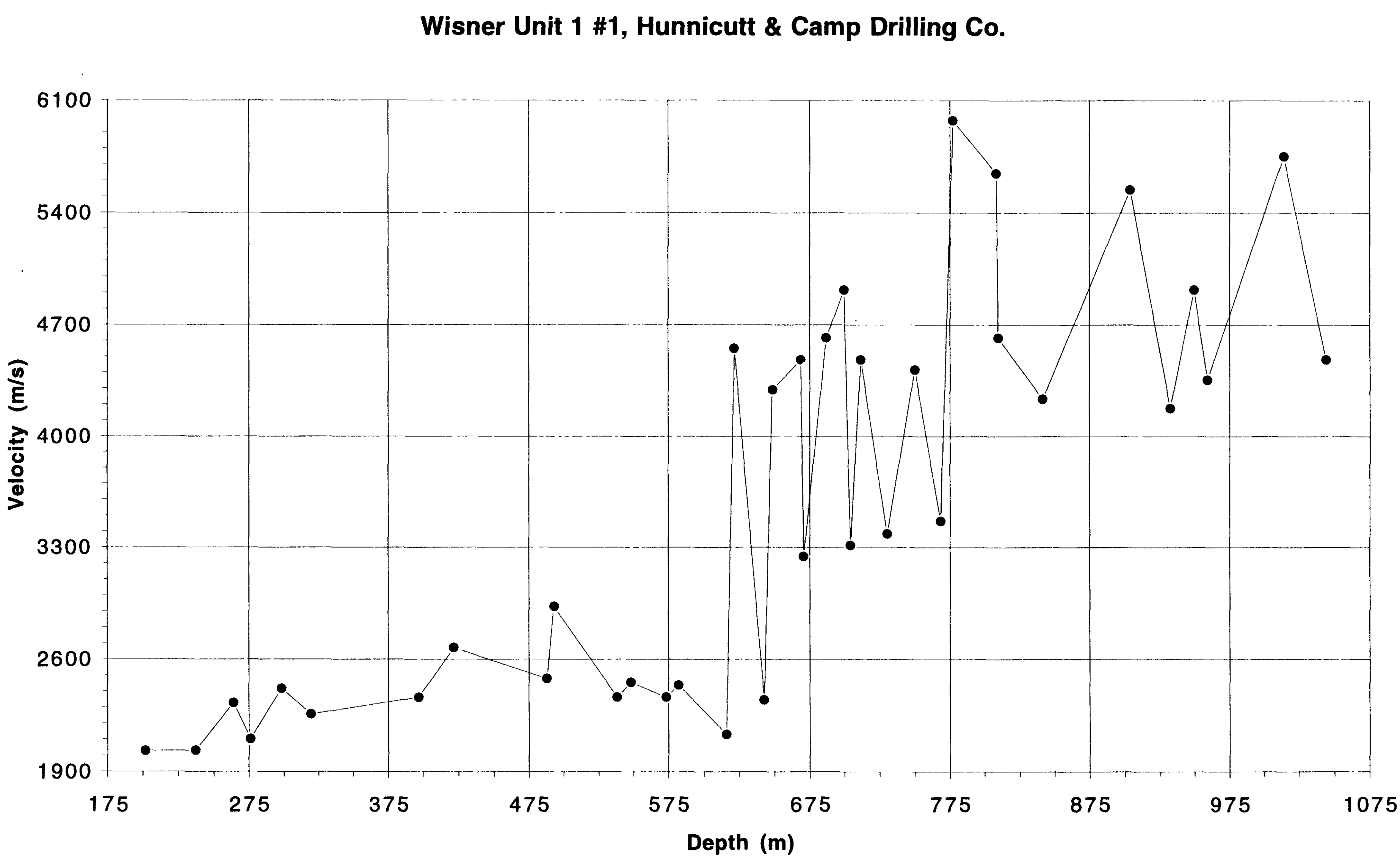

Young Unit #1-1, Reserve Oil & Gas
Velocity (m/s)
3700
3400
3100
2800
2500
2200
1900
840
1000
1160
1320
1480
1640
1800
1960
2120
2280
Depth (m)

Figure 39.



Wisner Unit 1 #1, Hunnicutt & Camp Drilling Co.
Velocity (m/s)
6100
5400
4700
4000
3300
2600
1900
175
275
375
475
575
675
775
875
975
1075
Depth (m)

Figure 40.

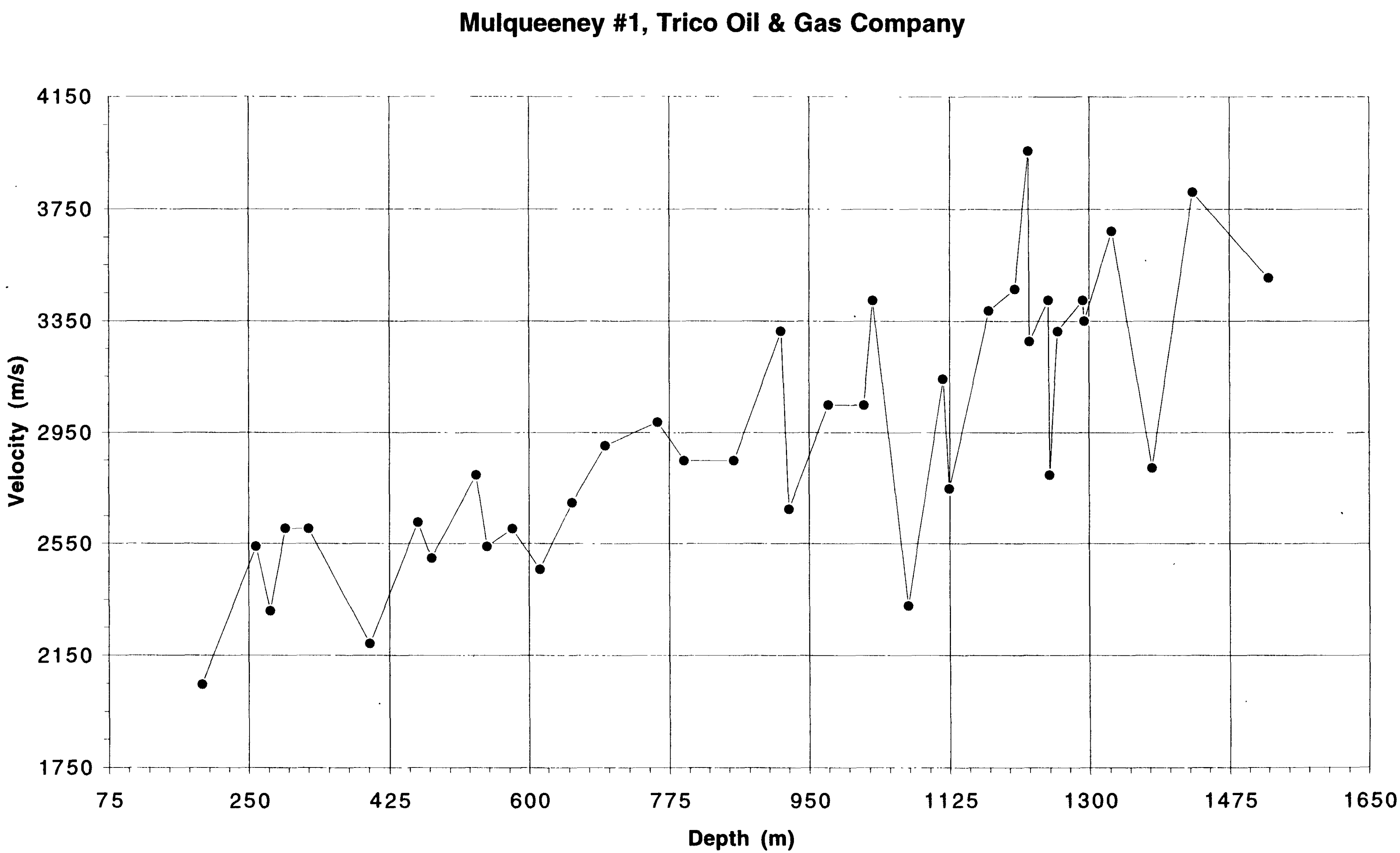

Mulqueeney #1, Trico Oil & Gas Company
4150
3750
3350
2950
2550
2150
1750
Velocity (m/s)
75
250
425
600
775
950
1125
1300
1475
1650
Depth (m)

Figure 41.

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

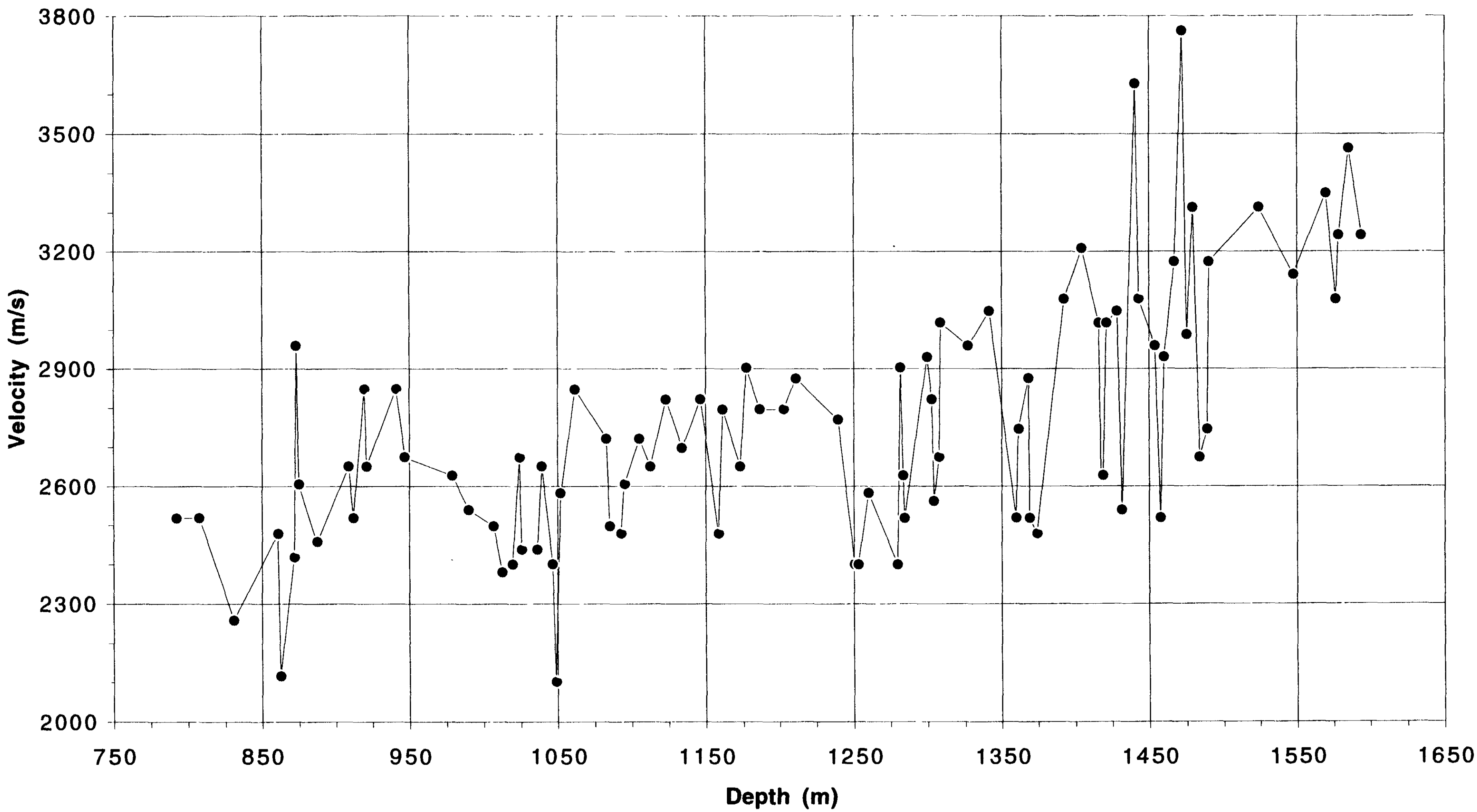


Figure 42.

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

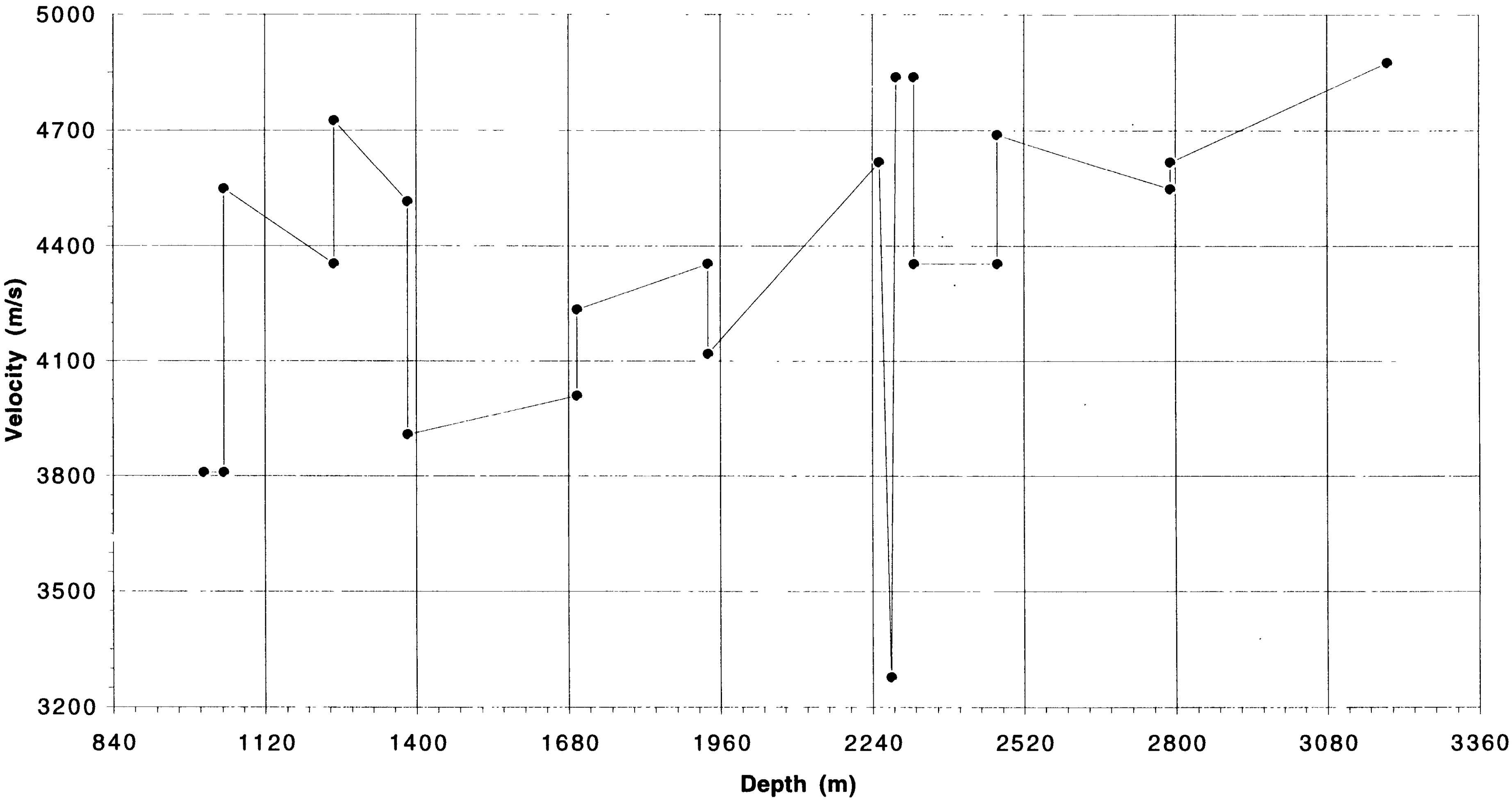


Figure 43.

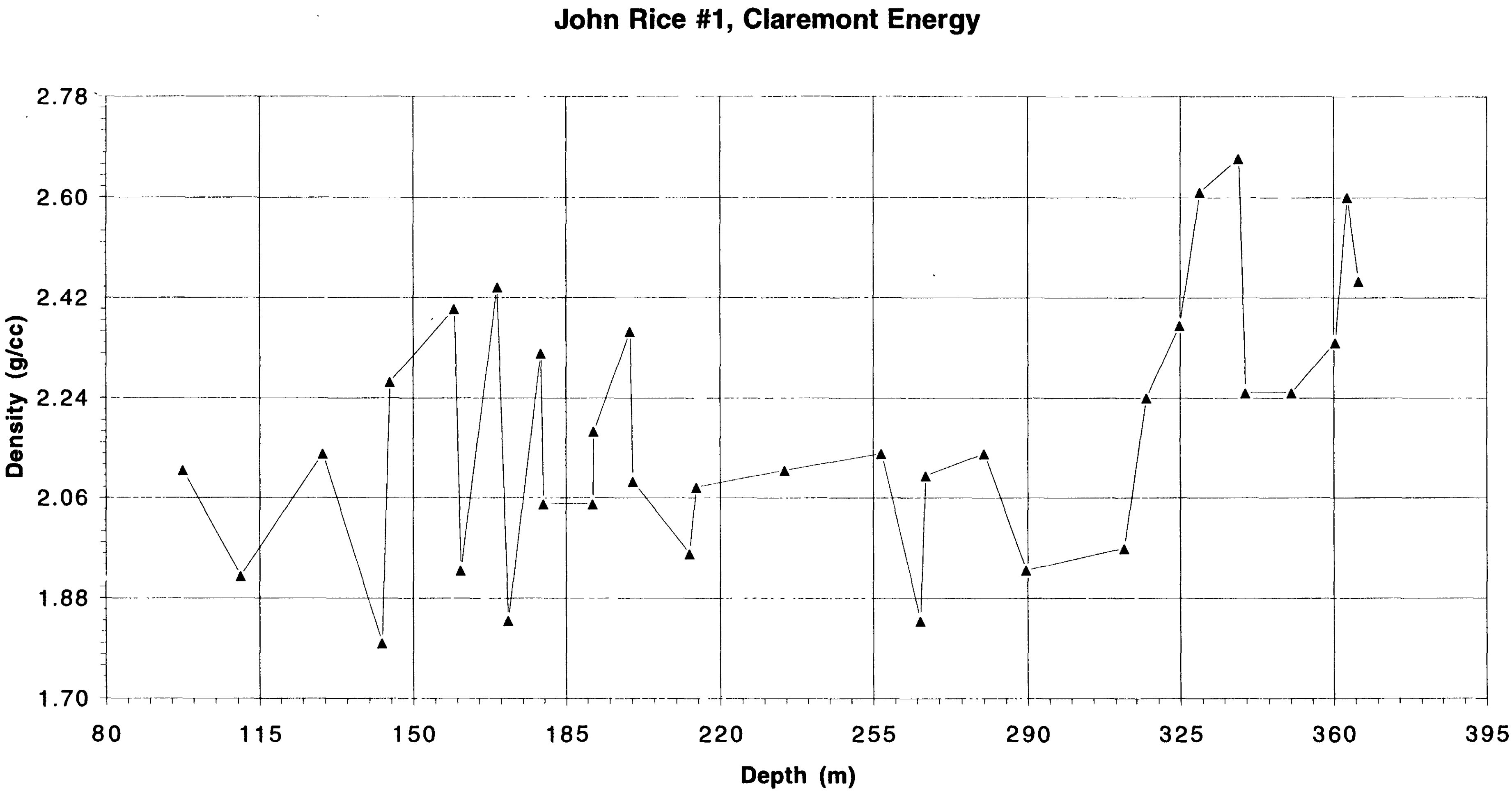

John Rice #1, Claremont Energy
2.78
2.60
2.42
2.24
2.06
1.88
1.70
Density (g/cc)
80
115
150
185
220
255
290
325
360
395
Depth (m)

Figure 44.

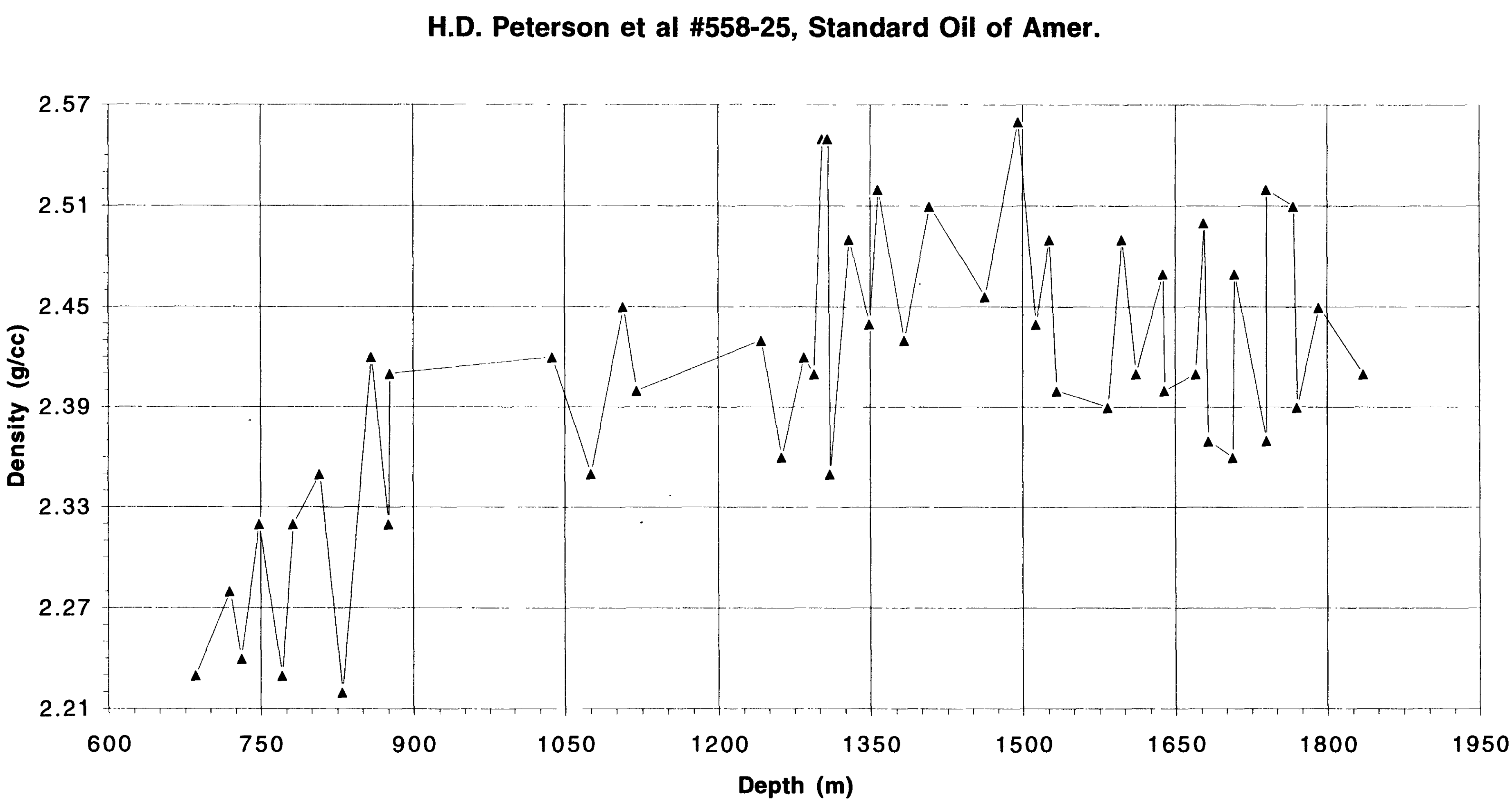

H.D. Peterson et al #558-25, Standard Oil of Amer.
Density (g/cc)
2.57
2.51
2.45
2.39
2.33
2.27
2.21
600
750
900
1050
1200
1350
1500
1650
1800
1950
Depth (m)

Figure 45.

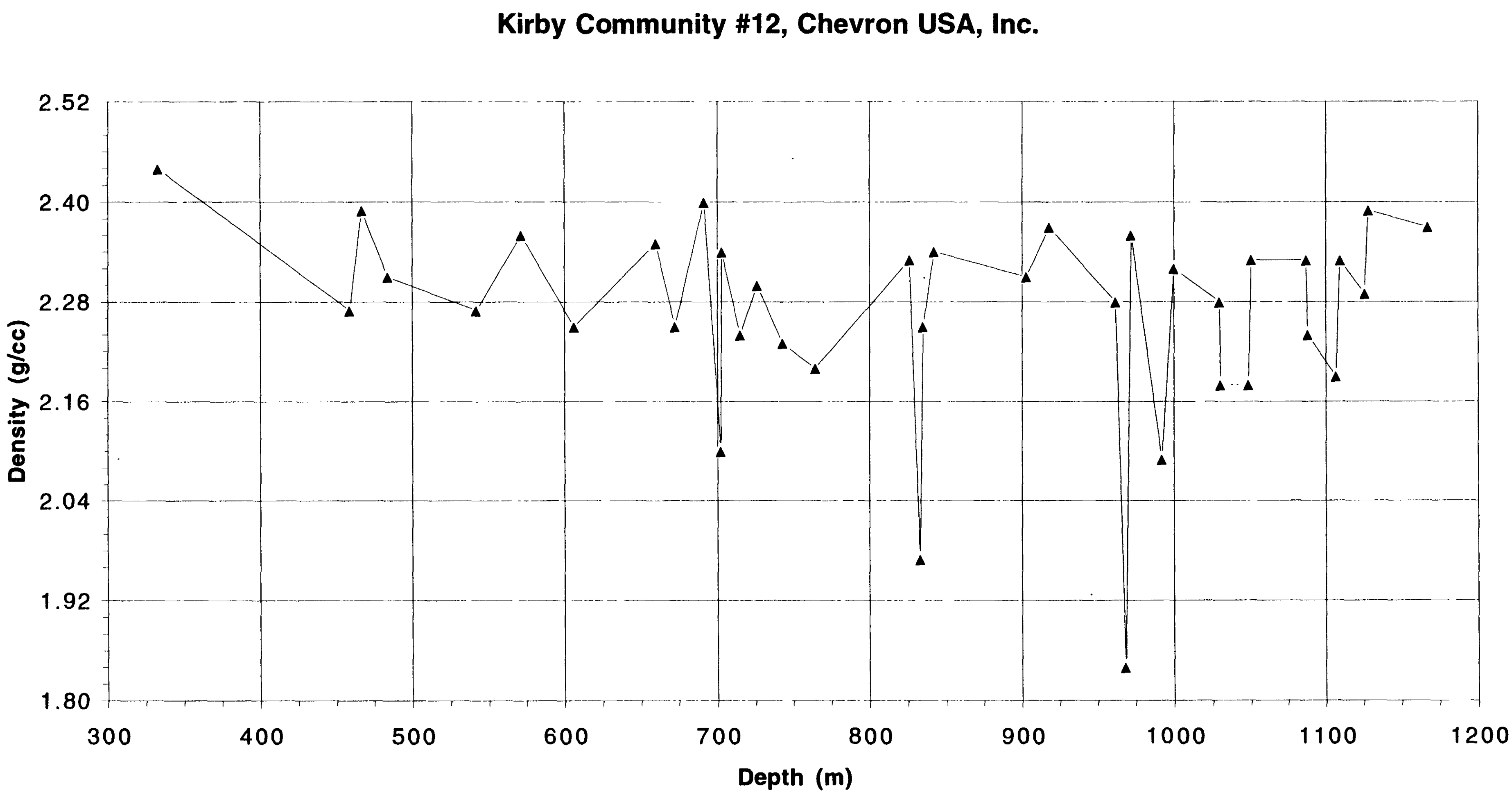

Kirby Community #12, Chevron USA, Inc.
2.52
2.40
2.28
2.16
2.04
1.92
1.80
Density (g/cc)
300
400
500
600
700
800
900
1000
1100
1200
Depth (m)

Figure 46.

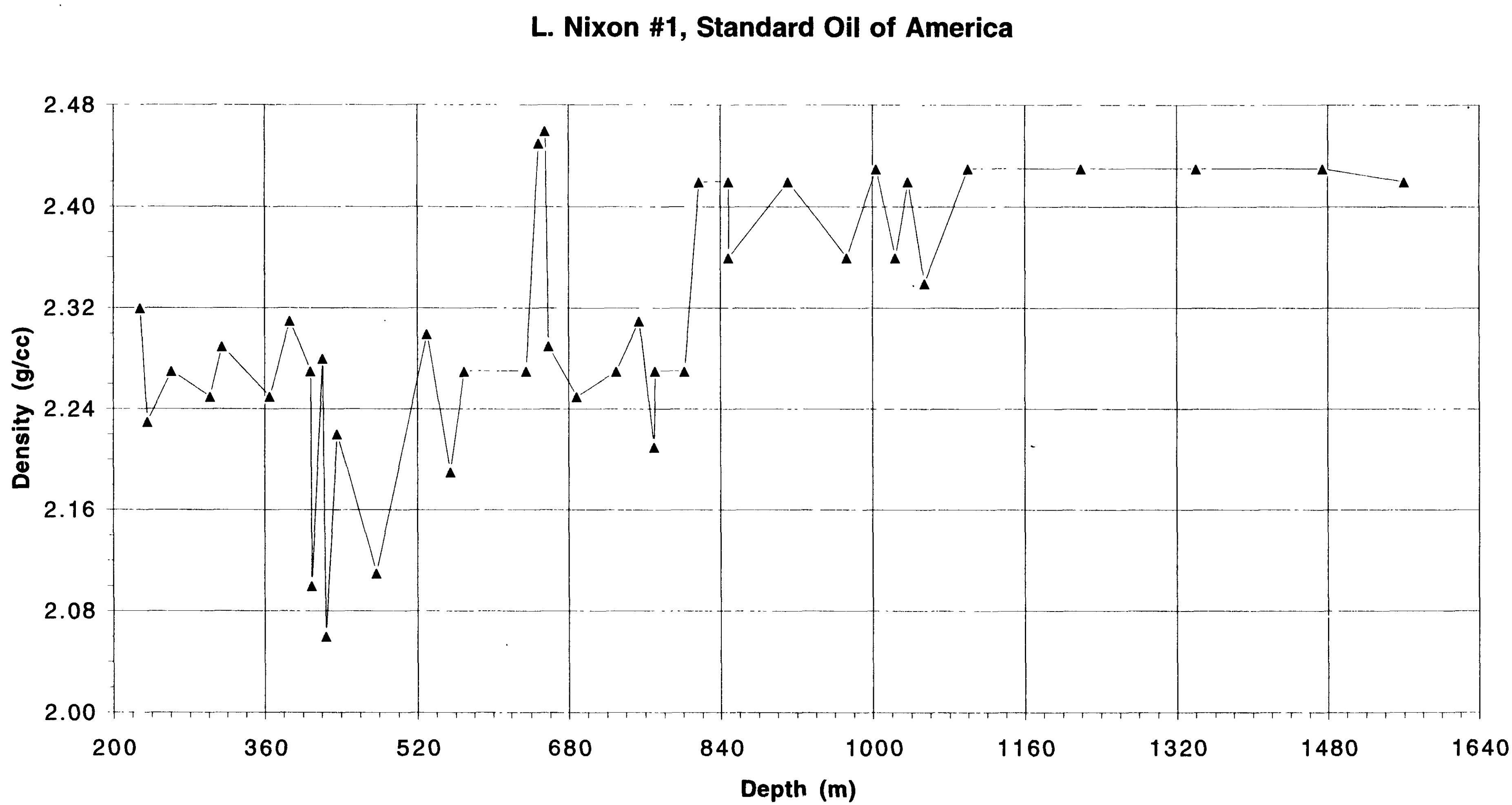

L. Nixon #1, Standard Oil of America
Density (g/cc)
2.48
2.40
2.32
2.24
2.16
2.08
2.00
200
360
520
680
840
1000
1160
1320
1480
1640
Depth (m)

Figure 47.

Seeno-Scott #2, Chevron USA, Inc.

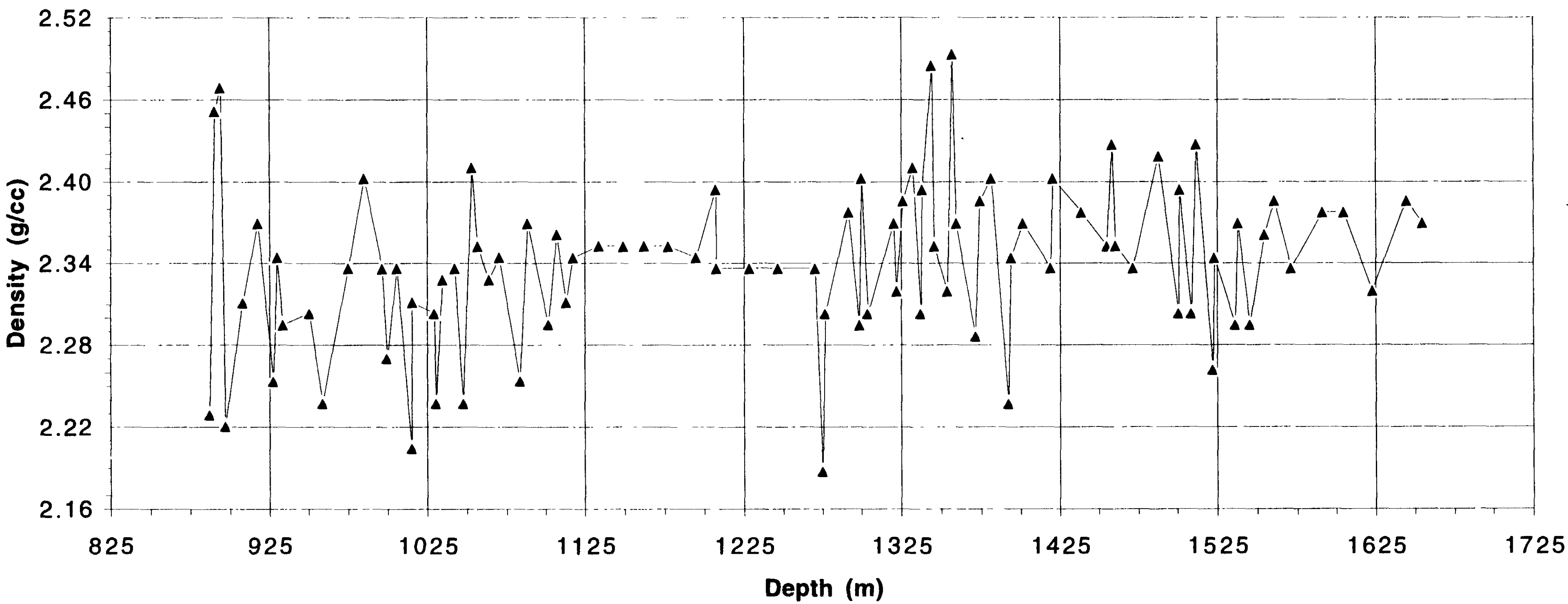


Figure 48.

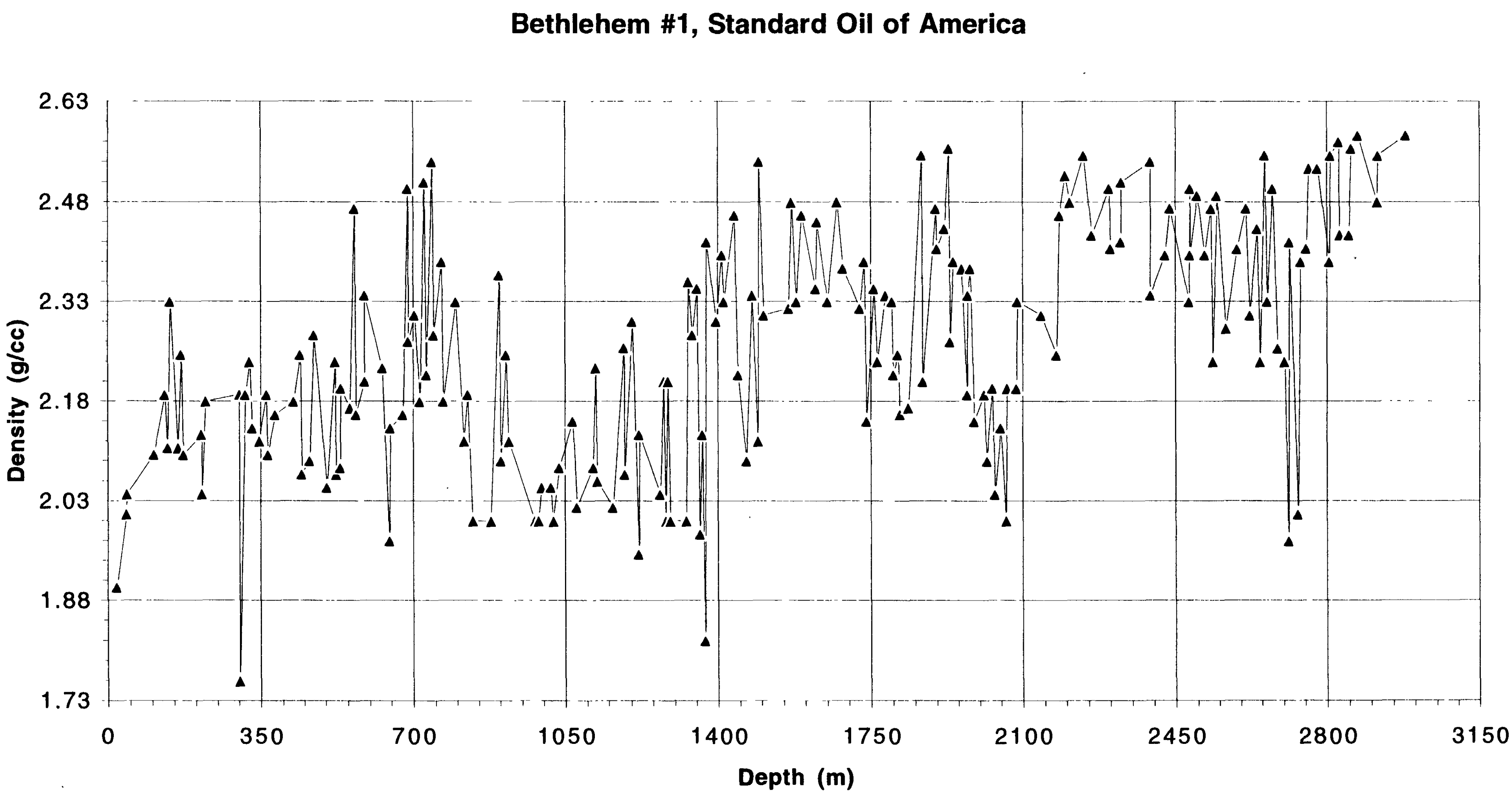

Bethlehem #1, Standard Oil of America
Density (g/cc)
2.63
2.48
2.33
2.18
2.03
1.88
1.73
0
350
700
1050
1400
1750
2100
2450
2800
3150
Depth (m)

Figure 49.

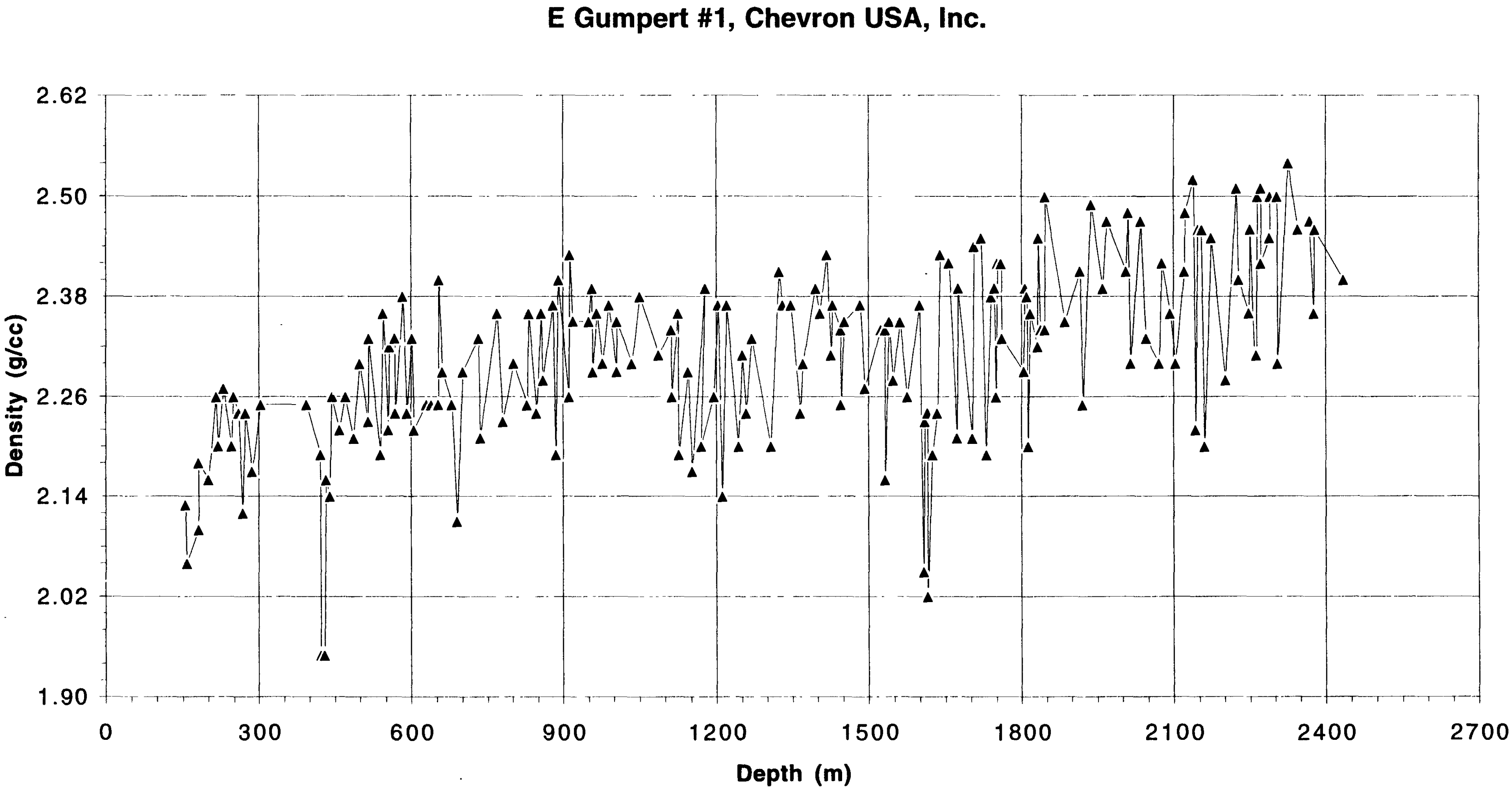

E Gumpert #1, Chevron USA, Inc.
Density (g/cc)
2.62
2.50
2.38
2.26
2.14
2.02
1.90
0
300
600
900
1200
1500
1800
2100
2400
2700
Depth (m)

Figure 50.

A Gumpert #1, Cities Service Oil Company

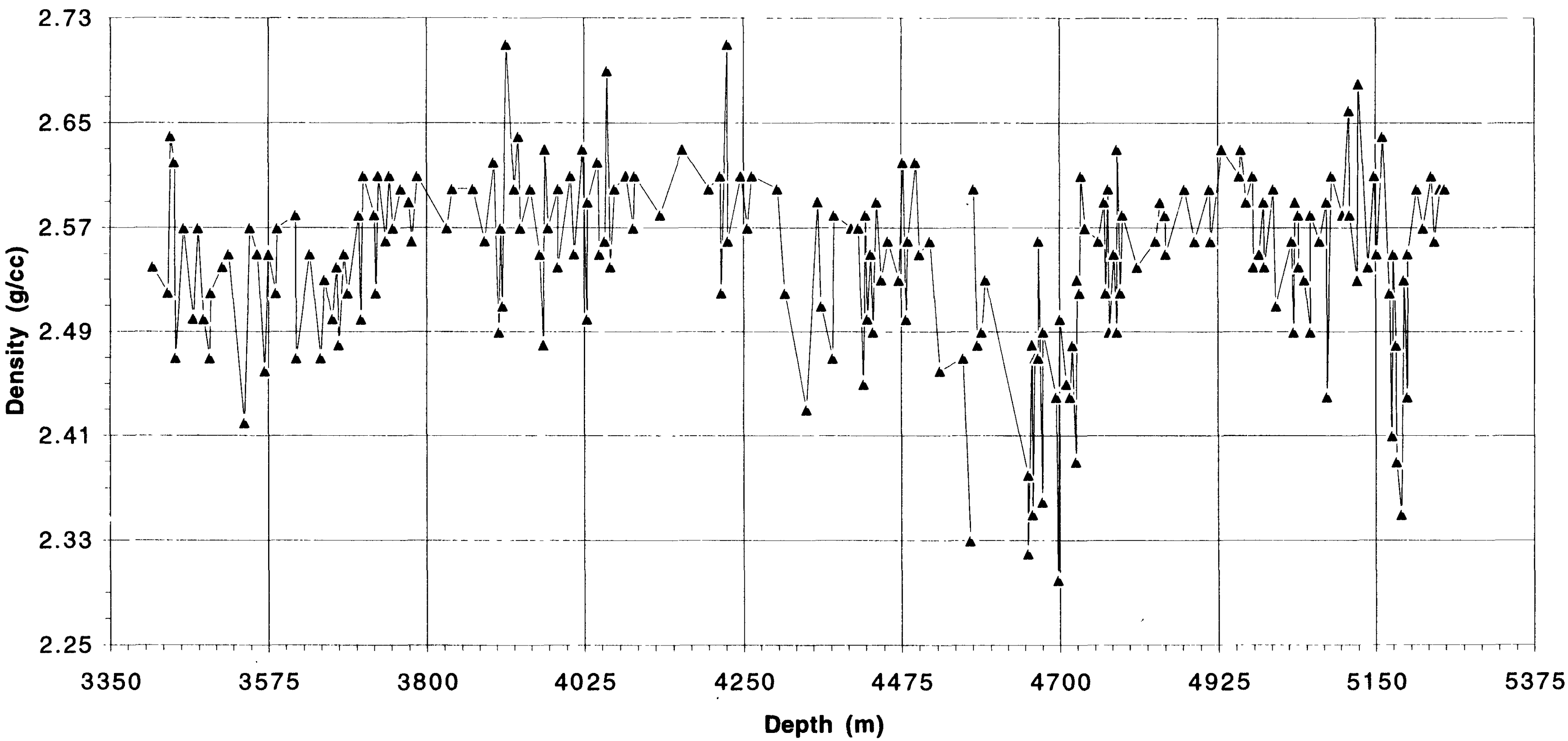


Figure 51.

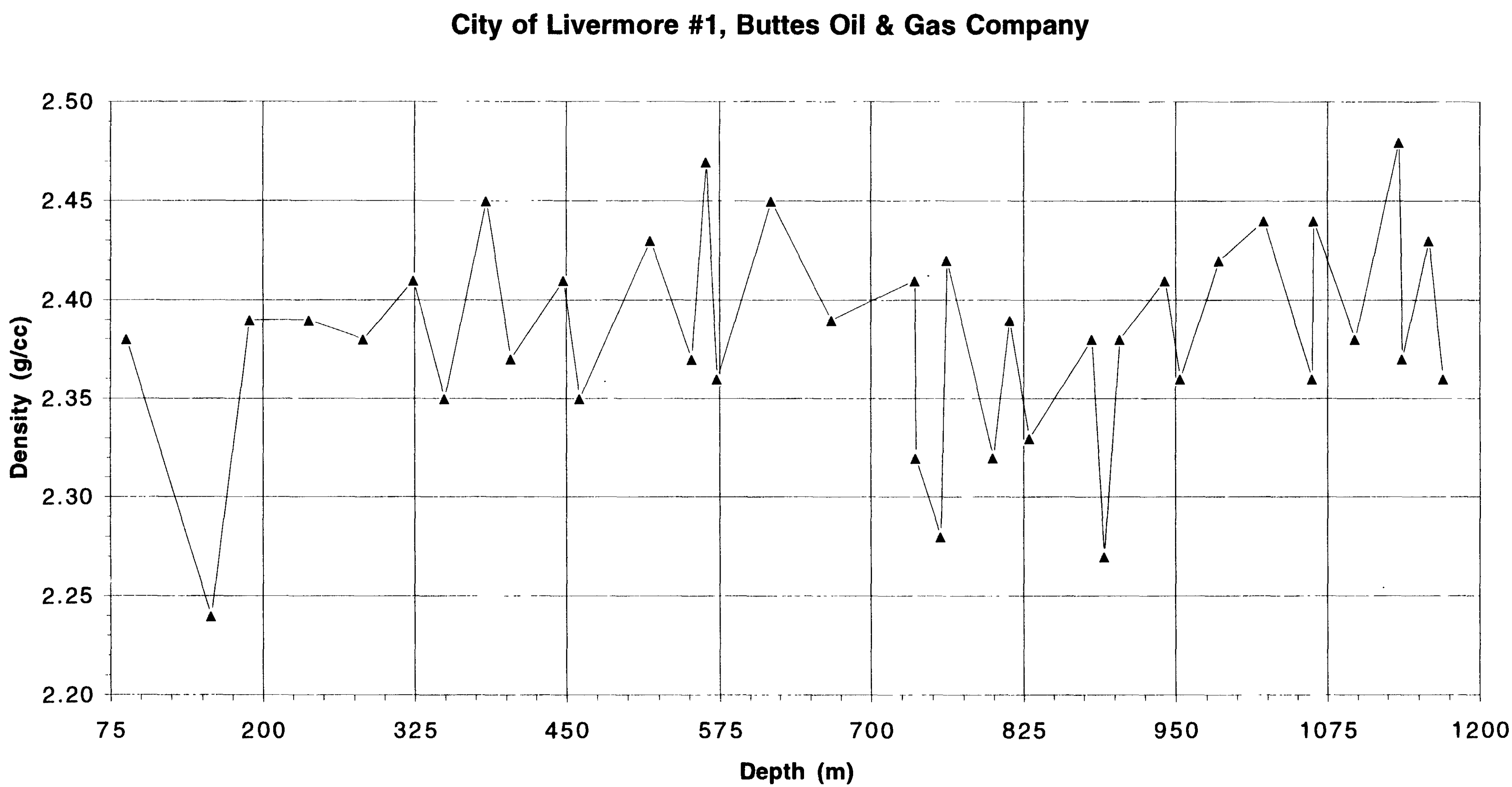

City of Livermore #1, Buttes Oil & Gas Company
Density (g/cc)
2.50
2.45
2.40
2.35
2.30
2.25
2.20
75
200
325
450
575
700
825
950
1075
1200
Depth (m)

Figure 52.

McCulloch-Guidotti #1, McCulloch Oil of Calif.

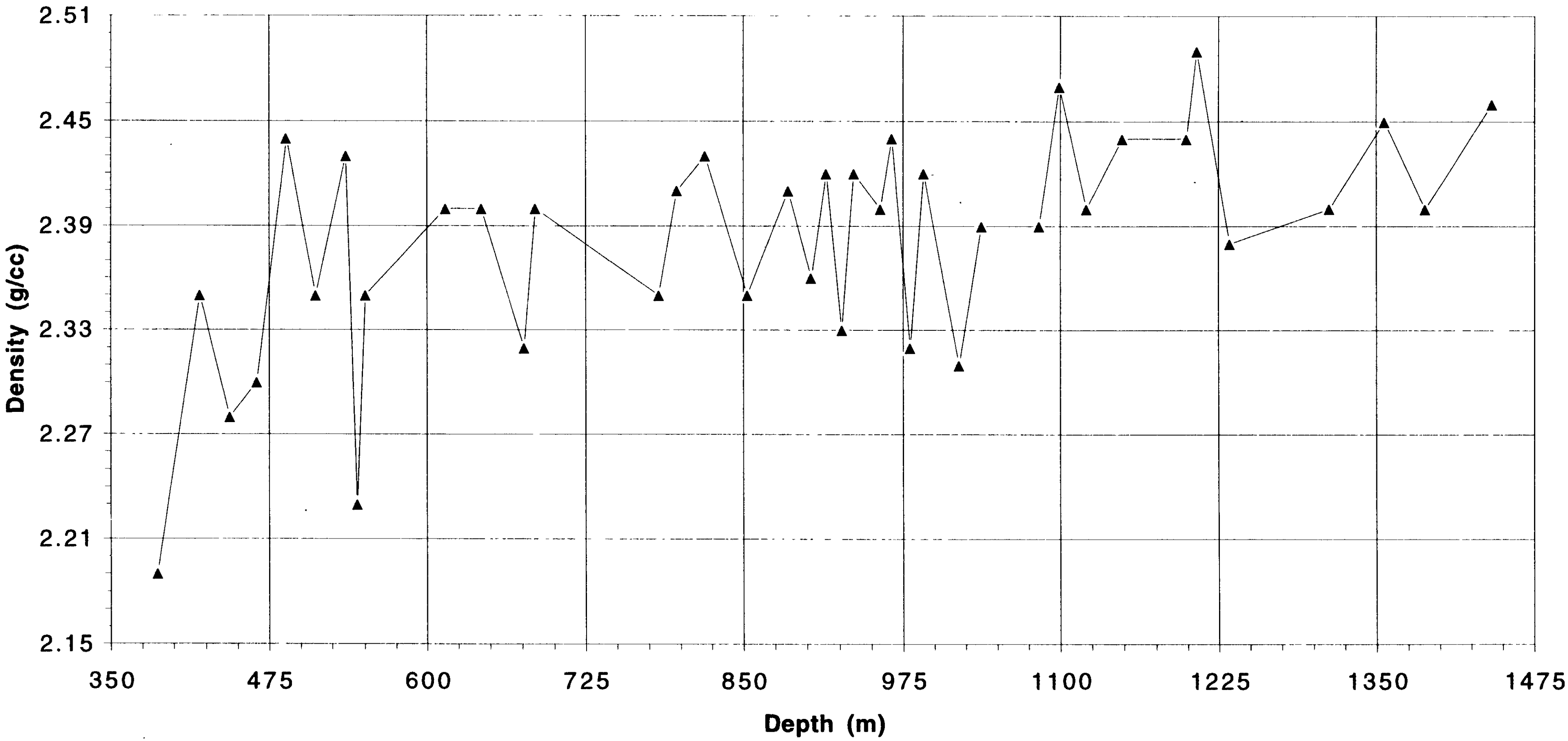


Figure 53.

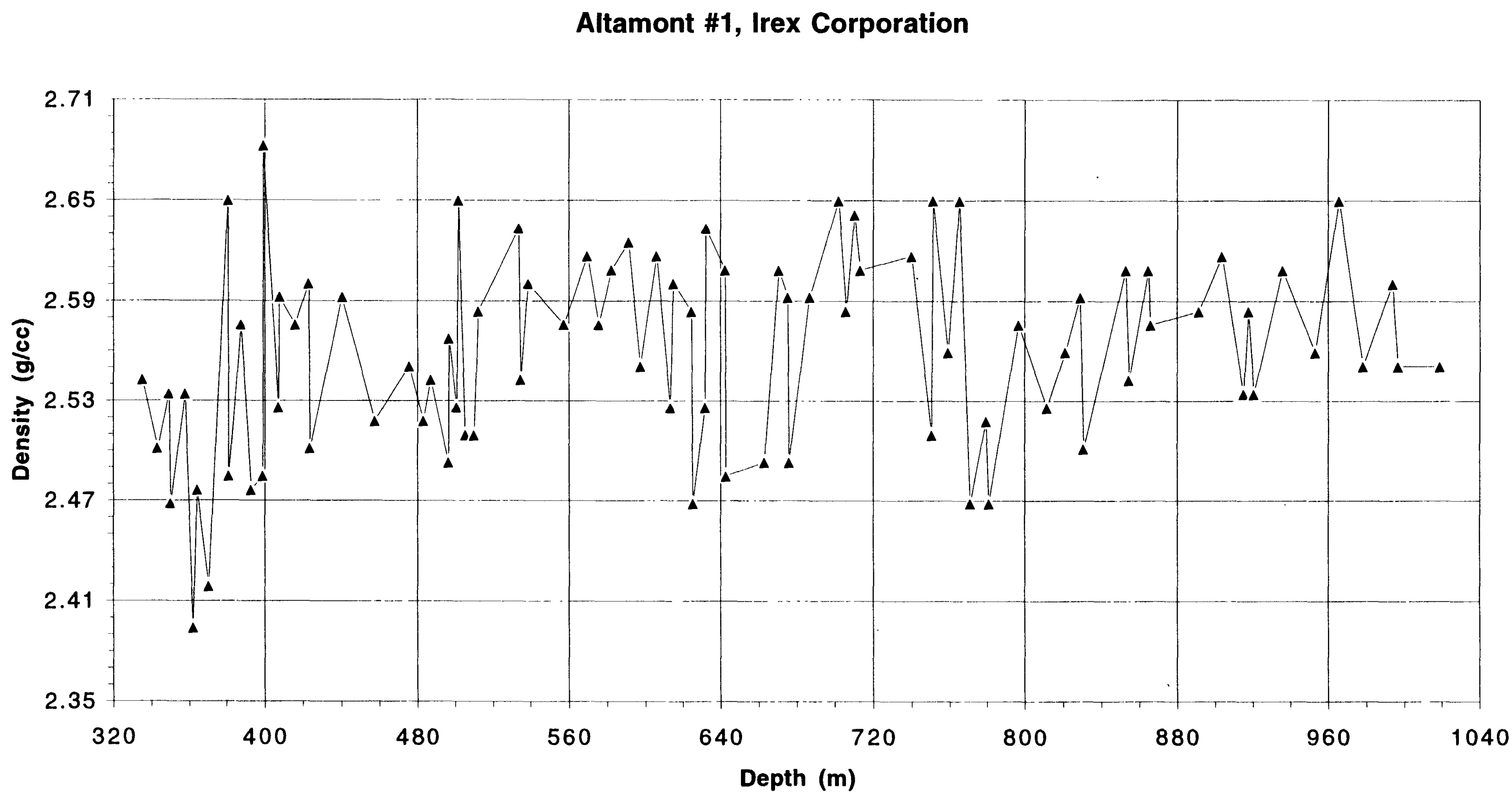

Altamont #1, Irex Corporation
2.71
2.65
2.59
2.53
2.47
2.41
2.35
Density (g/cc)
320
400
480
560
640
720
800
880
960
1040
Depth (m)

Figure 54.

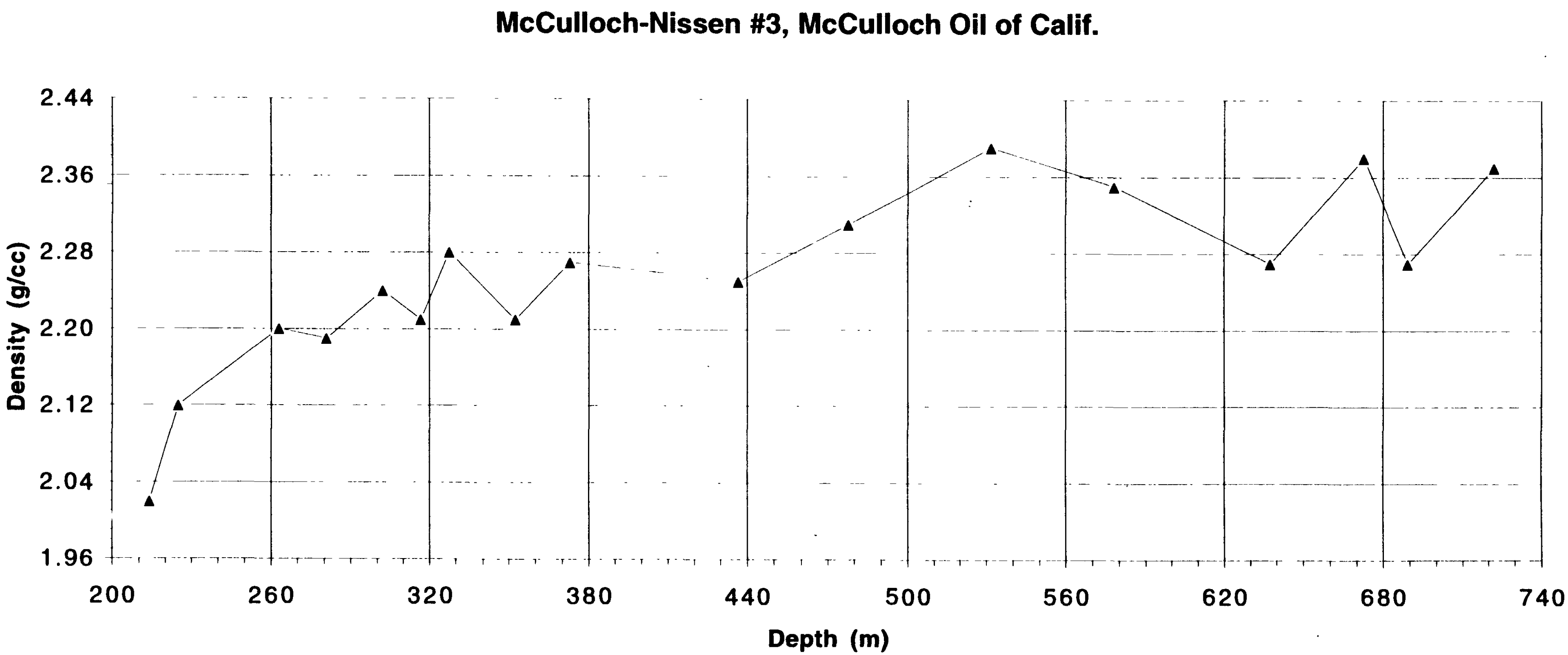

McCulloch-Nissen #3, McCulloch Oil of Calif.
Density (g/cc)
2.44
2.36
2.28
2.20
2.12
2.04
1.96
200
260
320
380
440
500
560
620
680
740
Depth (m)

Figure 55.

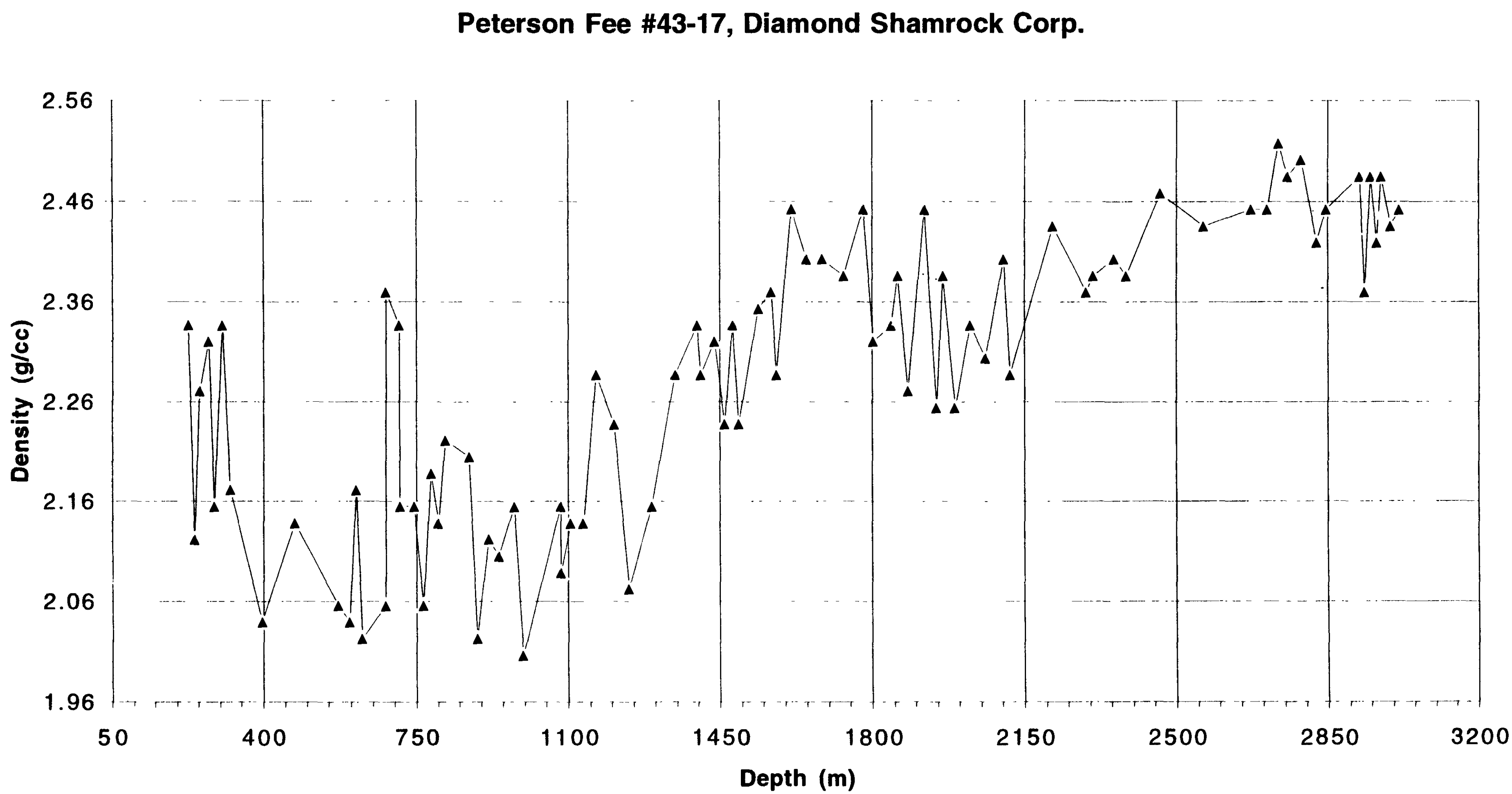
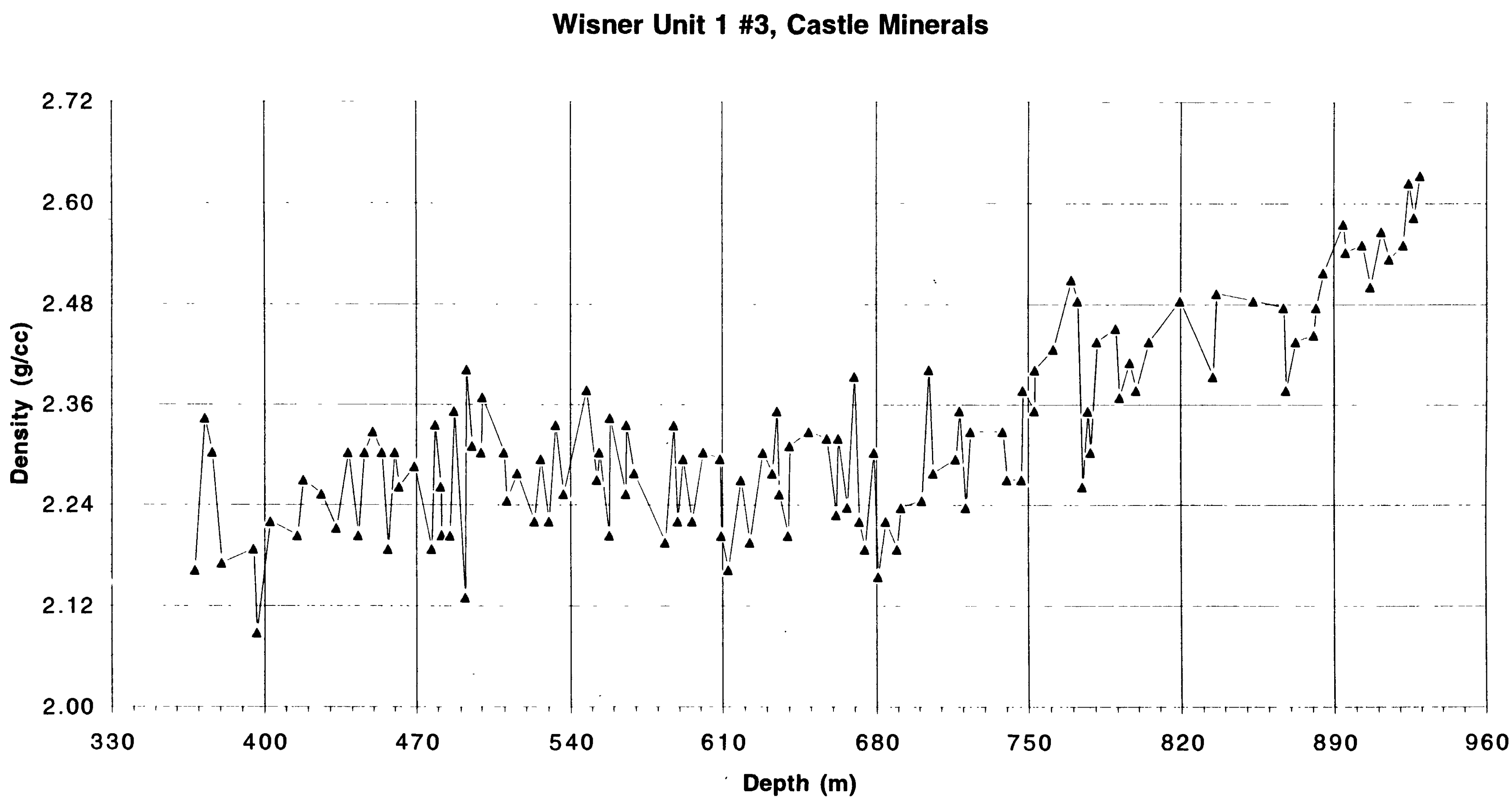

Peterson Fee #43-17, Diamond Shamrock Corp.
Density (g/cc)
2.56
2.46
2.36
2.26
2.16
2.06
1.96
50
400
750
1100
1450
1800
2150
2500
2850
3200
Depth (m)

Figure 56.



Wisner Unit 1 #3, Castle Minerals
2.72
2.60
2.48
2.36
2.24
2.12
2.00
Density (g/cc)
330
400
470
540
610
680
750
820
890
960
Depth (m)

Figure 57.

Wisner Unit 1 #2, Castle Minerals

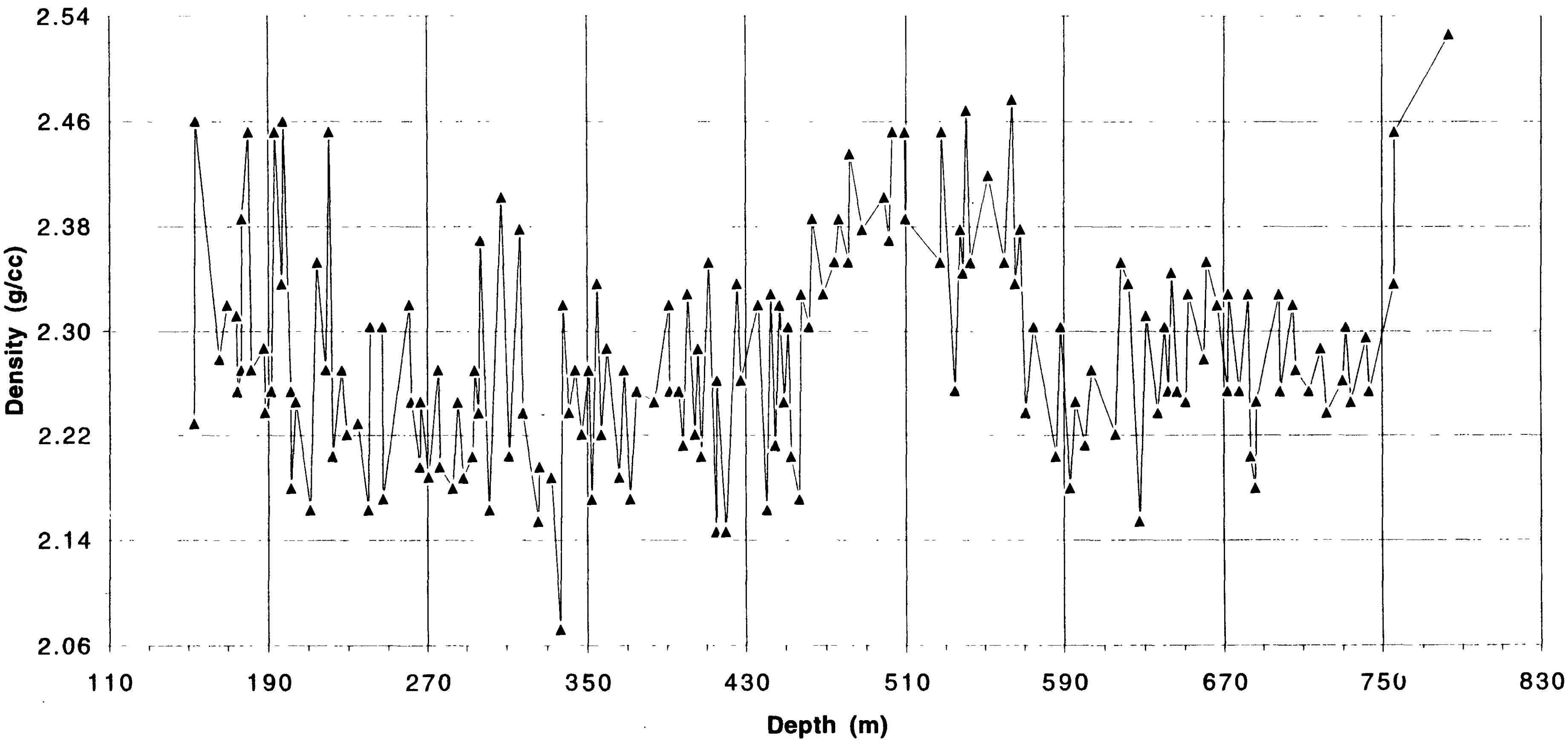


Figure 58.

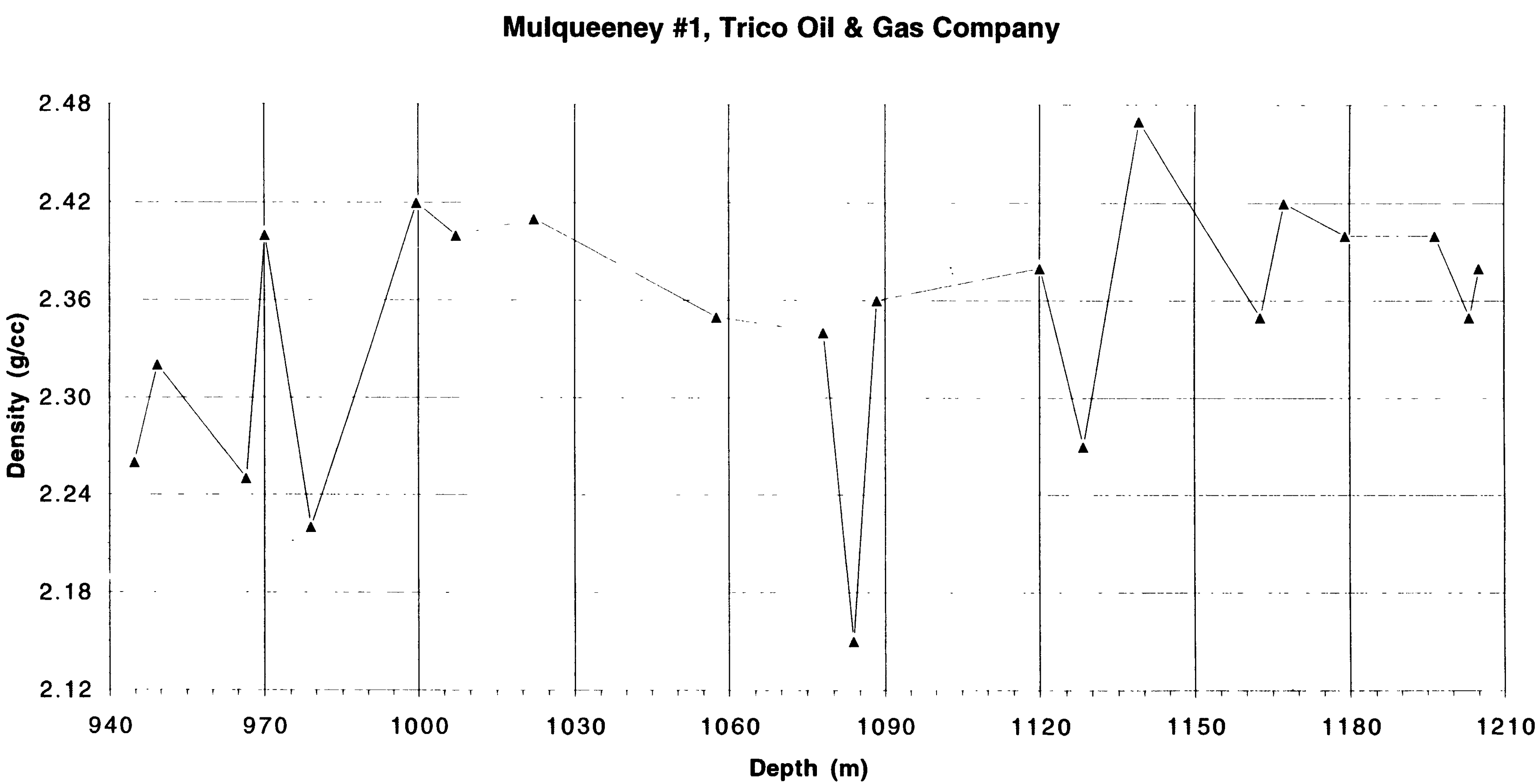

Mulqueeney #1, Trico Oil & Gas Company
Density (g/cc)
2.48
2.42
2.36
2.30
2.24
2.18
2.12
940
970
1000
1030
1060
1090
1120
1150
1180
1210
Depth (m)

Figure 59.

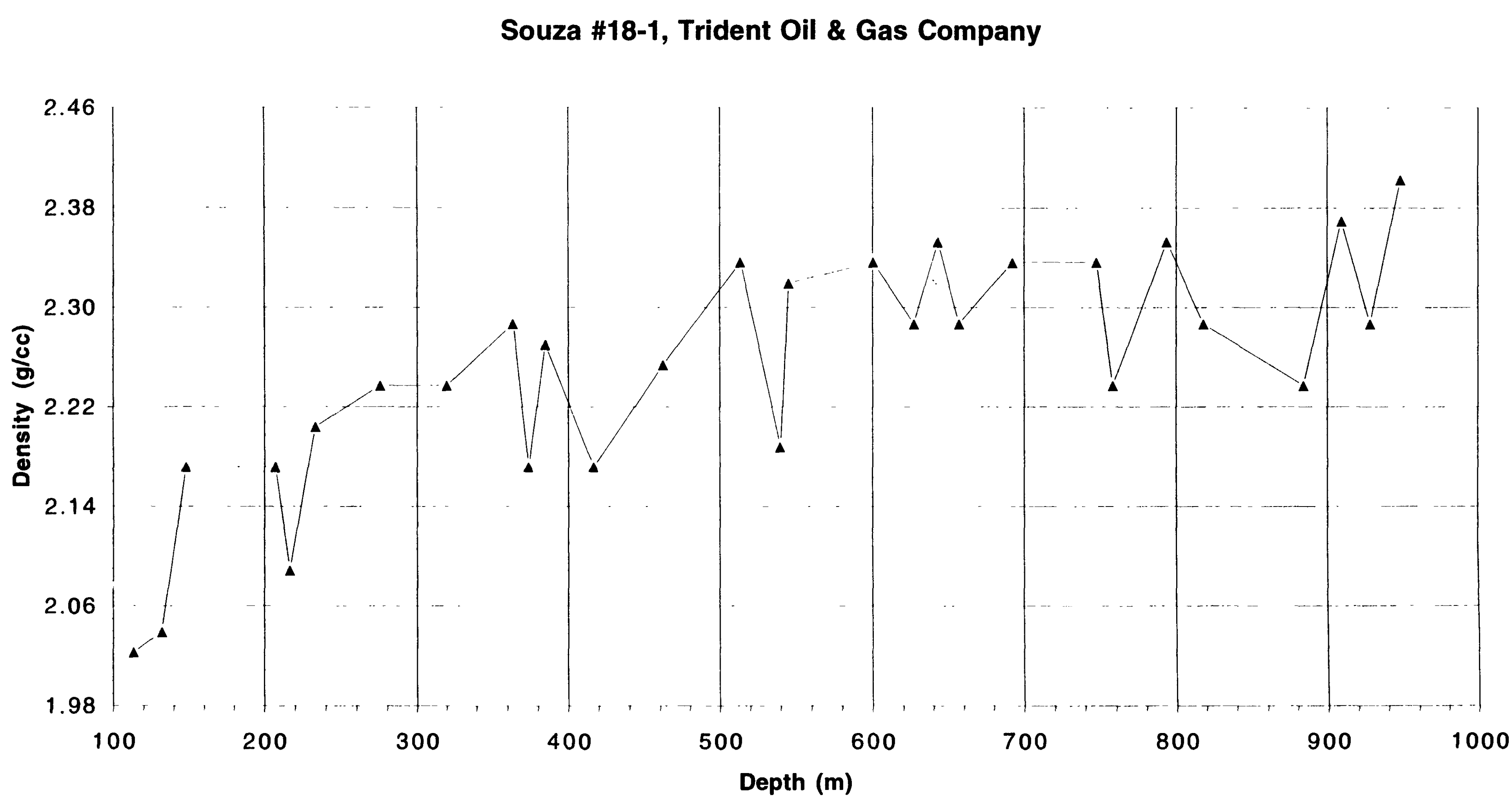

Souza #18-1, Trident Oil & Gas Company
2.46
2.38
2.30
2.22
2.14
2.06
1.98
Density (g/cc)
100
200
300
400
500
600
700
800
900
1000
Depth (m)

Figure 60.

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

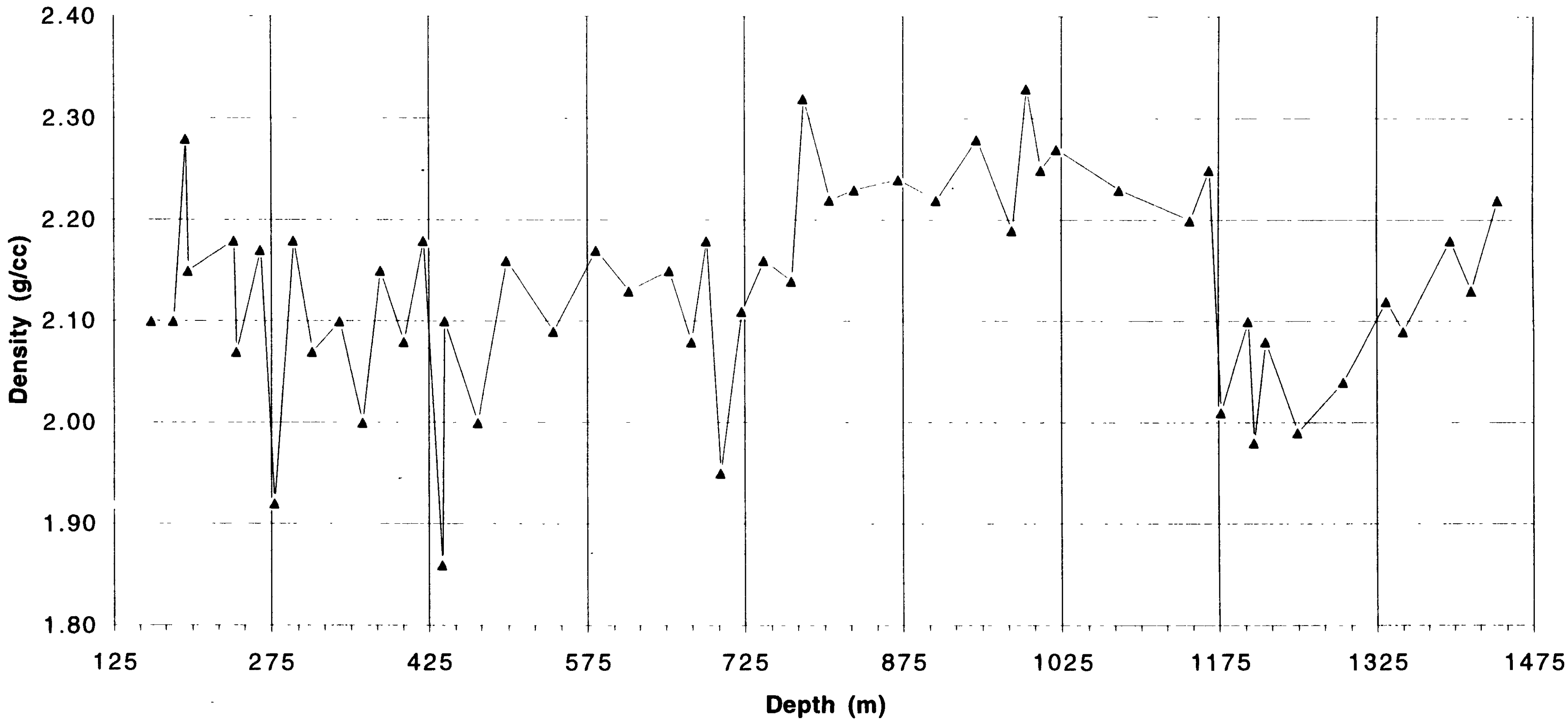


Figure 61.

San Francisco Bay Area Sonic Velocity Regression

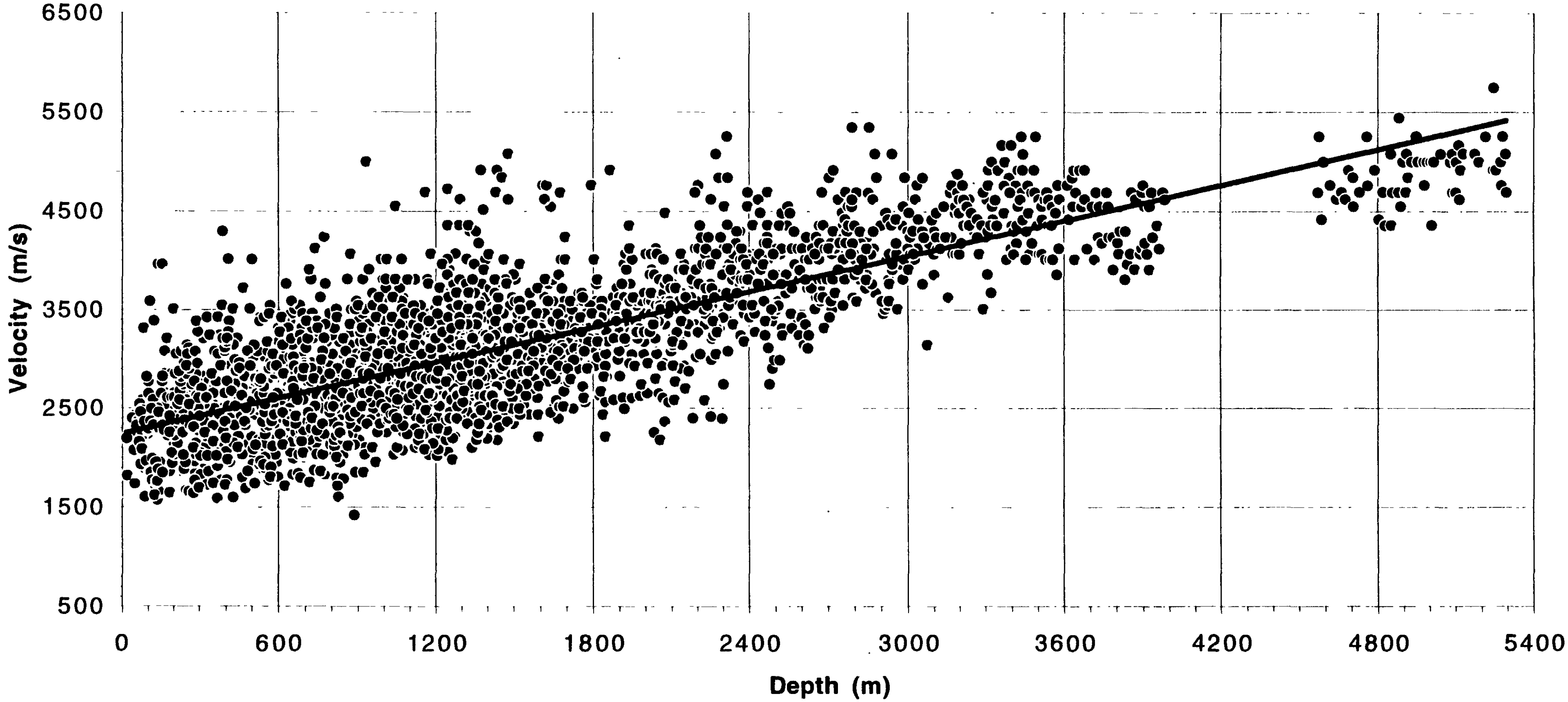


Figure 62.

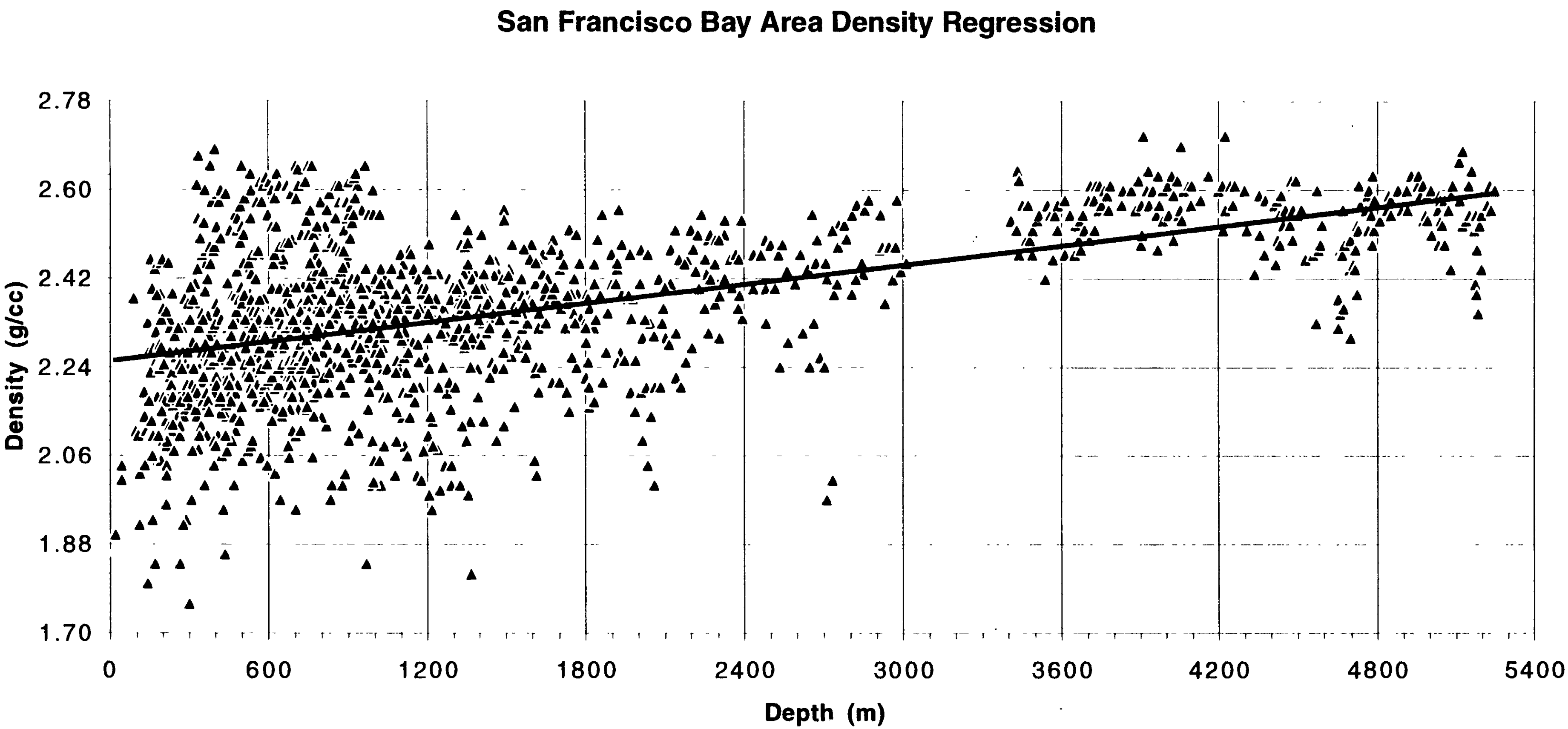

San Francisco Bay Area Density Regression
Density (g/cc)
2.78
2.60
2.42
2.24
2.06
1.88
1.70
Depth (m)
0
600
1200
1800
2400
3000
3600
4200
4800
5400

Figure 63.