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SHALLOW SEISMIC-REFRACTION PROFILING OF THE U.S. COAST GUARD RESERVATION, KODIAK, ALASKA

by

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This report has not been reviewed for technical content (except as noted in text) or for conformity to the editorial standards of DGGS.

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ERRATA

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Please make the following changes to plate 2:

1. The hachured, closed contour at line 4 should be labelled "0".

2. The closed contour at line 1 should be hachured on the interior and labelled "55".

3. The "0" denoting the end of line 20 should read "299" and the "299" denoting the other end of line 20 should read "0".

4. The contour adjacent to line 19 should be labelled "60".

5. The contour labelled "55" is misdrawn where it crosses line 2. Starting at the "55" label nearest line 2, the contour should be drawn crossing line 2, around the "345" end of line 2, and reconnecting with the existing "55" contour near the "55" label.

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ABSTRACT

During 1988, a seismic refraction survey was undertaken at the U.S. Coast Guard Reservation, Kodiak, Alaska, principally to determine the configuration of the bedrock surface in selected areas near known or suspected sites of ground-water contamination. Data from 39 seismic lines were collected, analyzed, and combined with available geologic data to produce a structure contour map of the bedrock surface. Numerous buried troughs, ridges, and other structural features were identified that were previously not known to exist. The complex morphology of the bedrock surface is considered to result from differential erosion that occurred during Pleistocene glaciation and fluvial downcutting. The seismic data was also used to estimate probable thicknesses and compositions of nonlithified deposits. Because of the variability of these deposits, and similar seismic velocities for different types of deposits, completely unambiguous stratigraphy could not be confidently interpreted in some areas.

INTRODUCTION

In cooperation with the U.S. Geological Survey (USGS) Water Resources Division, several geologic studies were undertaken during 1988 by the Alaska Division of Geological and Geophysical Surveys (DGGS) to provide detailed information on bedrock and surficial deposits of the U.S. Coast Guard Reservation, Kodiak, Alaska. The study area is shown in figure 1. This report summarizes results of seismic refraction profiling and geotechnical data compilation, including data from concurrent bedrock (Solie and Reifenstuhl, 1989) and surficial geologic (Combellick, 1989) investigations.

Goals of the seismic study were to: 1) determine the structural configuration of the bedrock surface in areas near known or suspected sites of ground-water contamination; and 2) estimate the thickness and lithology of nonlithified deposits in the same areas.

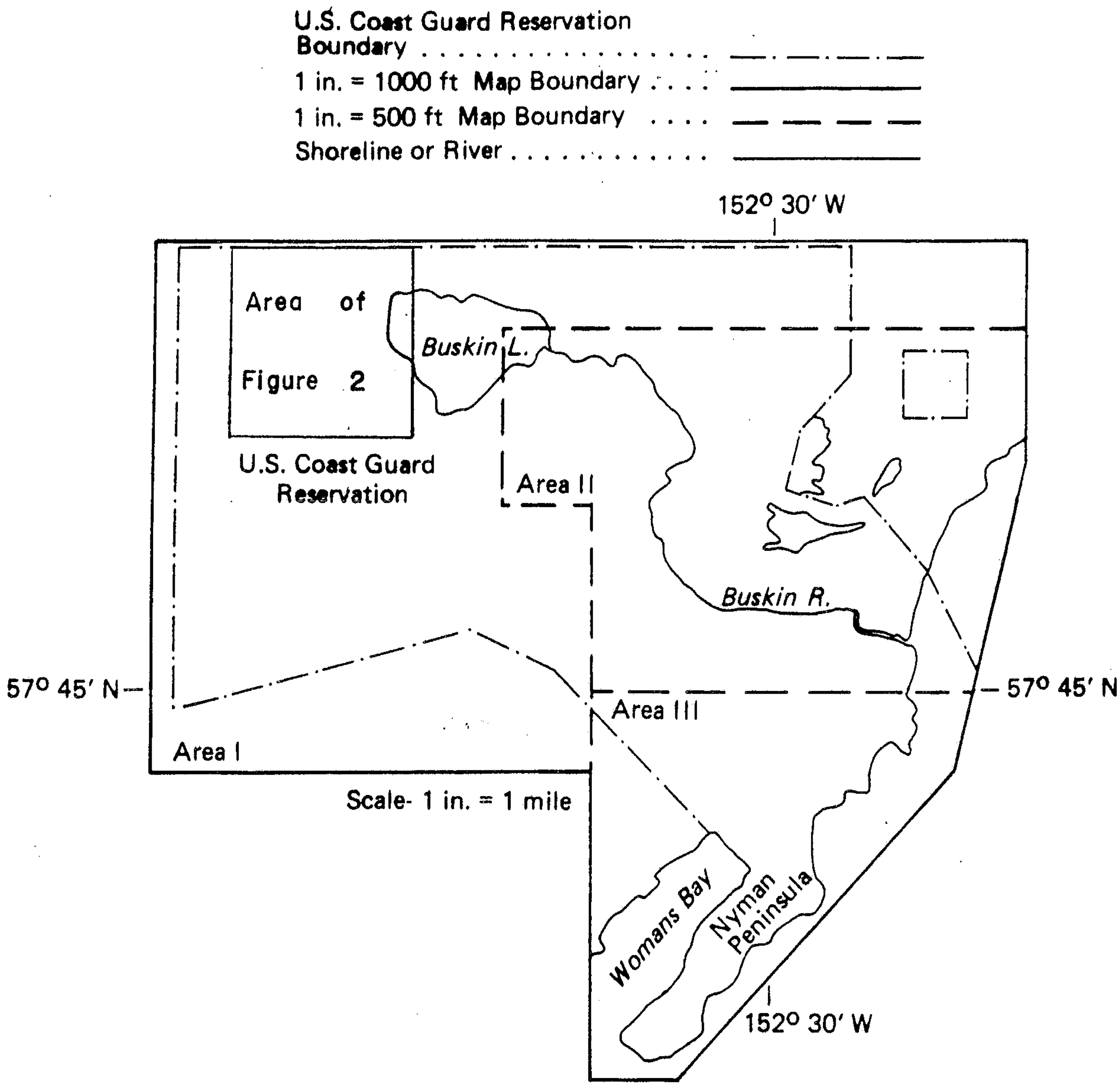


Figure 1. Location map of study area and index of areas shown on plates. Area I includes Areas II and III.

Previous Studies

Previous geologic investigations are comprehensively summarized by Solie and Reifenstuhl (1989) and Combellick (1989). Numerous geotechnical studies have been performed in conjunction with facilities development on the reservation, providing data from boreholes, wells and test pits. Earliest known work by the U.S. Navy in 1938 and the 1950's focused on areas within the support center, around housing developments, on airport grounds, and offshore. Most other work has been carried out since the late 1970's, including geotechnical studies for Coast Guard building sites; studies by the Alaska Department of Transportation and Public Facilities (DOT/PF) near roads and runways; and other miscellaneous studies. In addition, well logs and elevation control data obtained by the USGS are available for over 100 monitoring wells drilled since 1988. The USGS also provided maps showing actual or potentially contaminated sites.

Three previous seismic refraction studies at Kodiak are available. A study by DOWL (1984) used seismic data with electrical resistivity data and borehole data to identify an unconsolidated fill layer with P-wave velocities ranging from 800-1000 ft per second (fps), a "natural soils" layer with velocities from 1200-1600 fps, and a bedrock unit with a velocity range of 11,500-13,200 fps. Harding-Lawson's (1981) study showed velocities of 1000-1400 fps for organic soils and a silty gravelly sand fill, 4800-6050 fps for "weathered slate bedrock", and 12,000-15,000 fps for sound bedrock. In EBASCO Services' (1982) study, short seismic lines were surveyed to determine foundation conditions at thirty-five transmission line tower sites. Although excavation, drilling, and observation noted alluvium, glacial outwash, till, and metasediments as principal lithologies, their seismic layer interpretations lumped these into general categories. Velocities ranging from 1100-2050 fps were designated as overburden, 4300-6075 fps as saturated overburden, and 16,500 fps as rock.

Geologic Setting

The entire study area (fig. 1) is underlain by Cretaceous marine shales, slates, and thin-bedded graywackes of the Kodiak Formation (Moore, 1967 and 1969). Kodiak Formation rocks were deposited as part of a turbidite sequence that is part of the 1,700 km-long belt of Cretaceous turbidite flysch and melange known as the Chugach terrane (Plafker and others, 1977). Turbidite deposits of the Chugach terrane were accreted to older Peninsular terrane rocks as a result of collision between the Pacific and North American plates, probably prior to about 60 m.y. ago (Davies and Moore, 1984). Rocks are typically isoclinally folded and tilted to near vertical. Bedding consistently strikes N. 30^{o} E. to N. 40^{o} E., dipping 75^{o} W. to 90^{o} W., closely paralleled by cleavage planes. Fracture sets perpendicular to bedding were observed (Solie and Reifenstuhl, 1989). Where the buried bedrock surface has been exposed in trench pits, microscale ridges and valleys with up to several feet of relief can be observed. This relief is a result of differential erosion by glacial scour. A review of subsurface geologic data indicates that the bedrock surface in some areas is relatively free of weathered material. In other areas, particularly where bedrock is low-lying, the bedrock surface is indistinct and gradational over distances of several feet. Reported occurrences of fractured shale with silt filled fractures grading upward to silty slate gravels have been observed.

Stratigraphy and geomorphology suggest three major glaciations have occurred on Kodiak Island, separated by long interglacial periods (Karlstrom, 1969; Coulter and others, 1965). Present day topography and surficial geology largely result from the last major glaciation from 30,000 to 10,000 years ago (Karlstrom, 1969; Coulter and others, 1965). Within the study area, ice-scoured bedrock is discontinuously mantled by up to 15 ft of till (Combellick, 1989). A layer of organic-rich loess commonly overlies till and bedrock. Postglacial fluvial processes include stream incision of V-shaped canyons in bedrock highlands, and deposition of alluvial fans and alluvium (silt, sand, and gravel) over till and bedrock in valley lowlands (Combellick, 1989). Although not mapped, marine or glaciomarine deposits may be common in the subsurface in areas where the top of bedrock is below sea level.

The 1912 eruption of Novarupta (Mt. Katmai) blanketed the area with a layer of volcanic ash commonly 1-1.5 ft and occasionally 4 ft thick, which lies just below the present day vegetative mat. A typical complete section of nonlithified deposits outside of current and abandoned floodplains from bottom to top consists of bedrock, till, organic-rich silts (derived from loess and soil development), volcanic ash, and modern soil and vegetative mat (Combellick, 1989). Where till is absent, bedrock may be exposed, or overlain by some combination of overlying units.

Combellick (1989) observed that the rugged drowned coastline of the entire Kodiak archipelago is probably a result of continued periodic subsidence during major megathrust earthquakes. The area around Kodiak and the U.S. Coast Guard Reservation subsided tectonically 5.6 ft as a result of the March 1964 great Alaskan earthquake (Kachadoorian and Plafker, 1967).

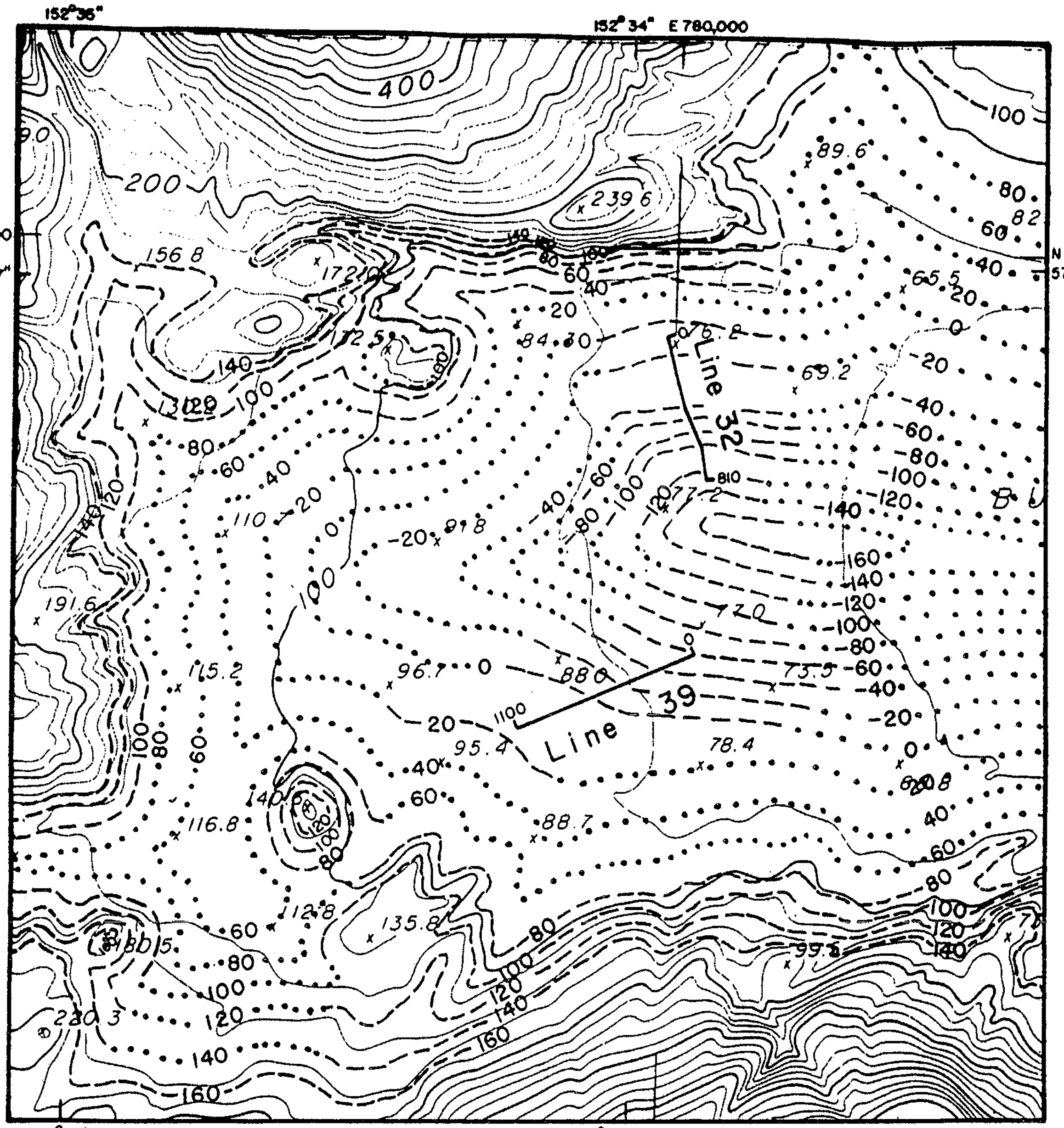
METHODS OF INVESTIGATION

Base Maps, Line Placement, and Equipment

Base maps used for this study were prepared for this project as described by Combellick (1989). High-resolution field maps at a scale of 1:2,400 were obtained for some areas from the U.S. Coast Guard, and a 1:12,000 scale 100-ft contour interval topographic map for the entire reservation was also obtained.

Between May and August, 1988, borehole, well, and test pit data were assembled and plotted on the 1:2,400 and 1:12,000 scale maps. These compilations summarized overburden thicknesses and depths to bedrock, primarily in developed areas and at USGS. monitoring well locations, and identified areas lacking data. Data-deficient areas near known or suspected contaminated areas with reasonably clear straight-line expanses of ground were selected for seismic-refraction evaluation. Fifty potential line locations were initially selected, and 39 lines were eventually surveyed (pls. 1 and 2, fig. 2). In general, lines were oriented over suspected bedrock structures that could influence ground-water or contaminant flow. Near most of these sites, monitoring-well or other data existed, providing lithologic and stratigraphic control.

Field investigations were carried out from August 26 to October 19, 1988. An 11 ft box van was used as a work station for all lines except lines 20, 32, and 39. Seismic record was simultaneously obtained on two 12-channel seismographs, an ES-1210F and an ES-1225, manufactured by EG&G Geometrics. The seismographs were commonly connected to the seismic energy source with a spliced Y-branch trigger cable custom-made by EG&G Geometrics. Each machine was connected to 14-Hz geophones with a 12-geophone takeout cable. On Nyman Peninsula, seismic record initiation using the



Base map prepared photogrammetrically by Walker-Alaska Aerial Surveys, Inc., from aerial photography taken 9-30-88.

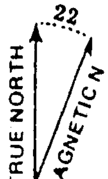
MAP SYMBOLS

Line 32 (0 — 810) Seismic line, with line number and station numbers at ends of line.

– – – -40– – – Bedrock-elevation contour--approximately located. Contour locations where determined from seismic-refraction data unsupported by nearby geologic control, trends in the bedrock surface near areas with depth control, or minimum overburden thicknesses determined by test pits, boreholes, or wells that did not encounter bedrock.

• • • • • -120• • • • • Bedrock-elevation contour--location inferred. Contour locations are unsupported by local control. Based on closest bedrock exposures, subsurface data points, and trends.

Bedrock elevation contour interval 20 ft.



APPROXIMATE MEAN DECLINATION, 1987

SCALE 1:12000

1000 500 0 1000 2000 3000 FEET

CONTOUR INTERVAL 20 FT
DATUM: MEAN LOWER LOW WATER

Figure 2. Structure contour map of the bedrock surface, Buskin Lake area. See figure 1 for location.

hammer switch, sledgehammer, and strike plate worked well, with good time correlation between records from each machine. When the hammer switch was attached to a large weight, and longer shot cable lines used, trigger-time inconsistencies developed. Typically the ES-1225 showed premature record initiation of up to 70 milliseconds (ms), and the ES-1210F was up to 30 ms delayed. This was probably caused by the trigger sensitivity setting for each seismograph not being adjusted to equal threshold voltages. The problem was remedied by providing a common electrical ground between the two machines.

Field Data Acquisition

After refining line locations based on field considerations, lines were staked and measured and geophones were deployed. Elevations at all geophone and shot-point locations were surveyed using vertical control surveyed to USGS monitoring wells, or estimated from the topographic base maps. Typical geophone spacing on the Nyman Peninsula was 15 to 30 ft. For lines where bedrock was deep (up to about 300 ft) string lengths of up to 1750 ft were used.

For an energy source (a "shot") on lines shorter than 500 ft, a 16 lb sledgehammer striking a 1 inch thick aluminum plate was used. Two-component explosive charges of five to eight pounds initiated by electric caps were used for line 38 southeast of Buskin Lake, lines 32 and 39 west of the lake, and lines 20, 33, and 34 (off-the-end shots only). Because explosives were unusable in some areas, a weight drop method was devised as an energy source for some lines longer than 500 ft. A 1000 lb concrete buoy anchor approximately 1 yard square and 1 ft thick was suspended by aircraft chain from a quick-release pelican hook on a steel cross beam. An all-terrain forklift was used to transport and hoist the beam and weight, to which a hammer switch was taped. Dropped from a height of approximately 18 ft onto its flat base, the weight generated P-wave first arrivals which could be detected at distances up to 1800 ft under optimum noise and ground conditions. For long or noisy shots, two or three drops were often stacked for signal enhancement. This method proved to be fast and efficient. For shots next to geophones, weight-drop records were augmented by hammer shots for definitive shot-to-phone distances and velocities. Weight-drop records were correlated with hammer records to remove slight delay effects caused by hammer switch placement atop the weight, and aberrations caused by non-parallel contact of the weight with the ground.

Seismic data were acquired from shots at the ends, off-the-ends (exterior to), and in the interior of the geophone spreads. Seven to fourteen shots were acquired per line, and paper copies of oscillograph wave-form displays were printed for each shot. This sampling pattern satisfied several criteria. First, it allowed bedrock detection beneath the entire string length. Also, first-and intermediate-layer velocities and depths were assessed often enough to detect lateral velocity variations within layers. These variations affect profile modeling efforts. Sufficient intermediate-layer refractor overlap coverage was acquired to allow delay-time layer thicknesses (see Redpath, 1973) to be calculated throughout the spread interior.

Modeling

To deal with the large volume of seismic data acquired, the SIPT program of Scott, Tibbets, and Burdick (1972), Scott (1973), and Scott (1977) was used. Originally developed for mining geology applications in rugged terrain with steeply dipping discordant stratigraphy, this seismic-refraction inverse-modeling program accommodates first arrival data for up to 48 geophones, seven shots per spread, and up to five theoretical layers. The program calculates layer velocities, estimates delay-time thicknesses for each layer, constructs theoretical ray paths from each shot to each geophone, and calculates theoretical ray-path travel times. Theoretical travel times are compared to actual travel times. If they do not agree within a user-specified limit (2 ms for most lines), the model adjusts the refractor interface and ray-path departure point along the interface until the limit is reached or three iterations are completed. Layers are smoothed for the final profile.

To use this program, shot and geophone positions, elevations, raw arrival times, and initial layer assignments of each arrival time are entered. The output file lists input data, calculates a first-layer velocity, calculates datum-corrected arrival times, and constructs an arrival time vs. distance graph. It then calculates refractor velocities, performs inverse-modeling iterations, and constructs a cross-section showing ray-path exit points for each interface unique to each shot, geophone, and ray-path. Model results are considered satisfactory when: 1) modeled ray-path travel times are within 2 ms of field data; 2) calculated ray-path exit points are sufficiently clustered to define interfaces; and 3) modeled layers are reasonably consistent with nearby geologic and geophysical data.

Analysis of each line began with choosing a combination of seven shots. Where bedrock was shallow, the two end shots and five equally spaced interior shots were usually selected. Closely-spaced interior shots were sometimes grouped around a structure in an intermediate refractor for enhanced resolution. Where bedrock was deep, two end shots, one off-the-end shot on each end, and three interior shots worked best. The program had difficulty modeling ends of spreads where bedrock was deep and seismic data did not contain returns from the bedrock surface. The model typically calculated spurious bedrock depths in these areas.

Models were run using initial layer assignments evaluated from paper records, using first arrival apparent-velocity segments. Initial inspection of calculated velocities, arrival time vs. distance graphs, and cross sections resulted in layer assignment amendments and additional model runs. Some lines required trying several 7-shot combinations or changing the number of layers modeled, usually to fewer. After 20 to 40 model runs, acceptable cross sections were usually achieved (see Appendix A). Acceptance was based on close convergence of calculated ray-path exit points into relatively narrow bands that define refractor interfaces and correlation of layer types and thicknesses with nearby geologic data.

GENERAL INTERPRETATIONS

A major use for the seismic refraction method is to assess the hydrogeologic framework and hydrologic boundaries of aquifers. The chief virtue of seismic refraction in hydrologic studies lies in its ability to delineate surfaces of acoustic velocity discontinuity which commonly define aquifer boundaries. Alluvial or glacial materials over bedrock, unsaturated nonlithified deposits underlain by saturated, nonlithified deposits, or other distinctive downward-increasing velocity discontinuities between geologic units are well-suited for refraction methods (Haeni, 1986).

As previously described, seismic data collected at Kodiak were analyzed in conjunction with nearby geologic data. Table 1 presents a generalized correlation of observed seismic velocities with interpreted geologic materials at the locations of the seismic lines. Site-specific velocity-geology correlations are discussed subsequently on a line-by-line basis.

Table 1. Observed velocities and interpreted geologic materials.

Observed velocity range (feet per second)	Interpreted geologic materials
400-2200	Surface or near-surface unsaturated peat, uncompacted to compacted fill and volcanic ash, typically 0-15 ft thick.
2000-5500	Moist to wet volcanic ash; uncompacted to compacted organic silt (loess); silty sandy gravels, fill, alluvium, silt and sand, outwash, and clay. Higher velocities indicate higher degree of compaction and moisture content. Thickness up to 35 ft; may be exposed at the surface or buried.
5300-8000	Till. Heterogeneous mixture of silt, sand, gravel cobbles, and boulders. Commonly dense to very dense and unsaturated to saturated. Commonly <25 ft thick, but up to 270 ft thick. Thick till may be interbedded with glaciomarine or glaciofluvial deposits.
10,000-15,300	Competent bedrock. Alternating near-vertical beds of shale, slate, and graywacke. Velocity transition zones up to several feet thick occur due to fractured and weathered bedrock surface.

Methodological Limitations

The seismic refraction method used in this investigation has inherent limitations that must be evaluated as part of the interpretation. The limitations are:

1) Hidden layers. A low-velocity contrast between two layers can cause refracted energy to reach the surface from a given refracting layer (especially if relatively thin) subsequent to arrivals from an underlying layer with higher velocity contrast. Failure to account for the hidden layer's presence will cause underestimation of depths to underlying interfaces. At Kodiak, the hidden-

layer problem is significant because thin till underlying alluvium is susceptible to being obscured by this effect.

2) Thin intermediate layers. The resolution limit for detection of an intermediate refractor is a function of layer thickness, depth and geophone interval. Where geophone spacing is significantly greater than the thickness of an intermediate layer, even where the layer is quite shallow, very few or no returns may be detected. The SIPT program often failed to model refractors which yielded few returns, requiring the data be included with layer assignments of an adjacent unit. Failing to account for a detected unit causes the solution to undercalculate depths to underlying layer interfaces. Using SIPT, more confidence is usually placed on 3- or 4-layer solutions that account for a layer's presence, than comparable 2- or 3-layer solutions that do not.

3) Discontinuous layers. The SIPT program assumes all layers are continuous beneath the spread. Where an intermediate layer is detected by only a few geophones on a line, the SIPT program can incorrectly extrapolate it to both ends of the spread, which requires the layer to be disregarded.

4) Lateral velocity variations. The SIPT seismic analysis program assumes constant velocity for each model layer. Lateral velocity variations within geologic deposits can result in thickness computation errors.

5) Velocity reversals. A downward decrease in acoustic velocity (a velocity reversal) occurs where a lower velocity layer underlies a higher velocity layer. Acoustic energy crossing this interface will refract away from the surface, and will return only after encountering an underlying unit with a velocity higher than any overlying layer. Failure to account for a velocity reversal will cause overestimation of depths to interfaces below the low-velocity layer.

6) Gradational or irregular contact zones. Gradational changes in velocity do not show up as distinct refractors between units with otherwise distinctive velocity contrasts. Resulting velocities observed depend on depth of seismic energy penetration. This effect is common where nonlithified deposits contain loosened and weathered bedrock in the contact zone. Small-scale relief on the bedrock surface can produce a similar effect.

7) Weathered layers. The top layer of intensely to completely weathered material can show velocity and thickness variations which introduce depth calculation errors.

8) Seismic velocities cannot always be uniquely correlated with geologic units. For example, velocities of several types of nonlithified deposits overlap, especially considering different degrees of saturation at different places.

9) The inverse modeling program used to analyze the seismic data does not produce unique solutions. Different combinations of layer numbers, thicknesses, and velocities can yield acceptable results.

10) Field Limitations. Geophone spacing and line length layouts are compromises between depth of seismic penetration and layer resolution. Ambiguities can result by emphasizing one objective at the expense of the other.

Potential Effects of Limitations

In general, the limitations described above did not seriously jeopardize the validity of the results of the seismic survey. General observations relevant to the limitations described above are:

1) Where till is present as an undetected hidden layer (as suspected in at least six lines on Nyman Peninsula) maximum hidden-layer thickness calculations show that actual depth to bedrock may be up to 50% greater than modeled depth to bedrock (from Redpath, 1973, p. 21-23). Even where modeled bedrock depth is in error, however, it is likely that trends are reasonably accurate.

2) Thin or discontinuous acoustic layers and pockets were detected by a few geophones on numerous lines as: a) an intermediate layer between low-velocity surface units and till or bedrock; or b) a till layer between overlying nonlithified deposits and bedrock. Attempts to model these zones were usually unsuccessful, and data from these layers were included in adjacent unit layer assignments.

3) Lateral velocity variations were assessed using the reduced arrival time vs. distance graph display option of SIPT, which removes first layer delay times so that true modeled refractor veloc-

ities can be shown. Some intermediate refractor velocity variations were observed. Although interface depths could probably be affected as much as 20%, comparison of model solutions with geologic control showed that few instances are suspected.

4) Velocity reversals caused by low-velocity peat (V = approximately 500 fps) or loosely consolidated volcanic ash (V = 700-1000 fps) underlying compacted roadbeds (V = 1500-2000 fps) are suspected beneath a few lines on Nyman Peninsula. These layers do not appear to be sufficiently thick to affect depth calculations by more than a few feet.

5) Gradational and irregular contacts of fractured and weathered bedrock have been observed by investigators. Where velocity transition zones several feet thick possess an upward bulk density decrease, high frequency energy from a nearby shot will pass through the gradational contact at a shallower depth and with lower velocity than a distant shot, which will send its lower frequency energy through a deeper, denser level of the zone at higher velocity. This may be the cause of imprecise bedrock interface solutions denoted by clusters of ray-path exit points 5-15 ft thick.

6) Weathering atop nonlithified layers has not been observed to occur to any great extent at Kodiak (Combellick, 1989), and did not appear to have a significant influence on the seismic investigation.

7) Non-unique solutions for acoustic velocity layers present some unresolvable lithologic identification ambiguities for nonlithified deposits. A sufficiently large velocity discontinuity between bedrock and overlying deposits generally allowed clear delineation of the interface.

8) In order to select the most acceptable model result, correlations were made between different shot arrays, crossing seismic lines, and nearby geologic data.

9) The wide acoustic velocity range of the aeolian, glacial and alluvial materials at Kodiak is a result of widely varying composition, degrees of compaction, and moisture content. Although lithologies were often identifiable from geotechnical data or geologic setting, variable compaction and saturation levels were harder to assess. Within some layers, gradual velocity increases rather than sharp interfaces were observed on several geophones, suggesting downward

increases in moisture content or compaction. In general, these intra-unit variations were too thin or indistinct to model as layers, even with relatively close geophone spacing. Very tight geophone spacing (3 ft interval) would be necessary to detect thin discrete layers, but such a survey is not consistent with the objectives of this investigation.

As previously described, optimum model results were usually selected on the basis of multiple model runs with different configurations of shot points and layer assignments. Model results were evaluated by comparison with nearby geologic and geophysical data. Where depth to bedrock discrepancies could not be resolved, preference for the purpose of drawing contours (pls. 1 and 2, and fig. 2) was given to: 1) nearby borehole data; 2) model results with more detailed layer resolution; or 3) model results with sharply defined layer interfaces. Where no clear bedrock elevation can be determined, contours were drawn to represent an average of the principal options. The differences between bedrock elevations shown in the Appendix A and elevations mapped on plates 1 and 2 and figure 2 are generally less than about 10 ft.

LINE-BY-LINE INTERPRETATIONS

This section presents interpretations of the seismic data, and discussion of lines surveyed as they pertain to site-specific hydrogeologic conditions. Lines are treated in order of location, generally from southwest to northeast, starting at the tip of Nyman Peninsula. Line locations are shown in plates 1 and 2 and figure 2, and locations of boreholes used in the analyses are given in Combellick (1989, pls. 2 and 3). All depths mentioned are relative to ground surface. All elevations are relative to mean lower low water (MLLW).

Southwest Nyman Peninsula

Line 9 at station 103 crosses line 13 at station 182. Data collected at Line 13 yielded a 3-layer solution. The upper layer velocity is inferred to represent the visually observed clayey sandy silt surface materials. The intermediate layer overlies what appear to be small channels in an irregular bedrock surface. Line 9 shows the bedrock surface dipping seaward in a two-layer solution. Because of differences in deposit continuity or geophone spacing, insufficient intermediate layer returns were acquired on line 9 to facilitate modeling of an intermediate layer. For this reason, the line 13 model is inferred to be more accurate. Bedrock surface elevations derived from line 9 are about 5-6 ft higher than elevations derived from line 13 where the lines intersect. Bedrock surface elevation contours beneath line 9 (pl. 2) are drawn 5-6 ft lower than elevations shown on the line 9 cross section.

Lines 12 and 21 were modeled as two-layer solutions. Line 12 at station 35 crosses line 21 at station 471. At their intersection, the bedrock surface modeled on line 21 is about 4 ft higher than on line 12. Well A50 is located 36 ft east of station 63 of line 12. The log of well A50 noted gravelly fill from 0-11 ft, no drilling returns from 11-12 ft (suspected to be clayey till), and a static water level near 6 ft. Line 12 at station 63 shows a bedrock depth of only 9 ft. This may be higher than the actual bedrock surface by several feet as a result of a hidden-layer effect caused by the saturated layer. Bedrock elevations contours (pl. 2) are drawn on the basis of elevations 3-6 ft lower than elevations shown on the line 12 and line 21 cross sections.

At line 6 a high-velocity first layer inferred to represent compacted roadbed overlies an intermediate acoustic layer between stations 125-345. Nearby test pits indicate the bedrock surface may be shallower than modeled, as does the secondary bedrock interface denoted by question marks and shot N interface ray-path exit points on the cross-section (dashed line). This could be a result of a velocity reversal created by compacted roadbed materials overlying slower volcanic ash and soil layers (observed in nearby test pits). The dashed bedrock interface line matches bedrock depths derived from line 7 data, supporting this hypothesis. Bedrock elevation contours (pl. 2) are drawn on the basis of elevations 2-3 ft higher than elevations shown on the line 6 cross section.

The first layer at line 7 is inferred to represent natural soil horizons, volcanic ash, or uncompacted fill and is modeled only where geophones were placed in natural soils rather than directly into the roadbed. Nearby test pits (Shannon & Wilson, 1988) encountered unweathered till at a depth of 4-6 ft, which indicates that the layer 2 velocity may be unrealistically low. If a hidden layer of till is present, bedrock may be deeper than shown on the cross section.

Line 5 at station 6 crosses line 7 at station 545. Layer one is inferred to represent fill, volcanic ash, and the pre-1912 soil horizon. Line 7 does not register a significant thickness of layer 1 from stations 375 to 550, presumably due to greater geophone spacings. Interpreted bedrock depths at the intersection of lines 5 and 7 agree within 2 ft.

At the southeast of line 5, station 123 of line 3 is 16 ft from the end of station 345. Well A54 is located about 16 ft northeast of station 331 of line 5, and about 30 ft northwest of station 116 of line 3. The well log noted silty fill, 0-2 ft; volcanic ash, 2-4 ft; silty clay with organics, 4-6 ft; and silty sandy gravel (till?) from 6-13 ft, with a static water level at 4.8 ft. Model layer 2 is inferred (based in part on velocity) to represent saturated fill, silty clay, and gravels observed in well A54.

The layer 1 velocity of line 3 is relatively high, and is inferred to represent compacted fill, volcanic ash, and silty clay logged in well A54, which are probably wet in the lower portion. The second model layer has a high velocity inferred to represent till noted in the log of well A54. Till was apparently absent, hidden or too thin to model beneath line 5.

Well A52, located about 54 ft north of station 82 of line 10, penetrated gravelly silt fill from 0-3 ft; organic soil, 3-5 ft; loam, 5-8 ft; gravel, 8-9 ft; and till from 9-19 ft, with a water level 6.7 ft deep. On line 10, model layer 1 is inferred to represent the unsaturated portion of the fill, soil, loam, and gravel deposits logged in well A52. Model layer 2 is inferred to represent the till. The top few feet of model layer 2 may consist of saturated nonlithified deposits overlying the till.

The line 11 model yields a two-layer solution. Layer 1 is inferred to represent primarily fill, which is present at the land surface. Other nonlithified deposits logged in well A52 may also be present. A few intermediate velocity returns which could not be modeled suggest these deposits are saturated in their lower portion. Data from line 10 suggest that undetected till may be present at depth. The till could be a hidden layer, causing the modeled bedrock surface to be 2-4 ft shallower than the true surface. Bedrock elevation contours (pl. 2) are drawn on the basis of elevations about 4 ft lower than elevations shown on the line 11 cross section.

As inferred from well logs, layer 1 of line 4 probably consists of road surfacing, fill, and unsaturated till on the northeast end near well A56, and unsaturated soil, volcanic ash, and till on the southwest end near well A55. Well A56 is 25 ft northwest of station O and well A55 is 25 ft northwest of station 345. As inferred from wells A55 and A56, layer 2 may represent wet till with cobble gravel interbeds a few feet thick. Dense till may be present at depth, creating the potential for a hidden-layer problem. Theoretical hidden-layer calculations indicate that the total thickness of the detected layer 2 and the hidden layer could be as much as 25% greater than layer 2 model thickness, with 48% of the combined thickness as till. Bedrock could be 2-6 ft deeper than modeled.

Central Nyman Peninsula

Line 1 is located near wells A59 (about 16 ft northwest of station 280) and B8 (50 ft southeast of station 130). Well B8 shows 3 ft of unsaturated gravel overlying 0.5 ft of wet volcanic ash and soil. Well A59 penetrated soil and gravel (probably fill) from 0-3 ft, peat from 3-5 ft, and sandy clay from 5-8 ft, encountering water at 8 ft. These unsaturated materials are inferred to represent the first layer of the model. Peat, volcanic ash, and soil noted in the logs may act as a low-velocity layer beneath compacted roadbed. Well A59 penetrated cobbles and clayey sand from 8-11 ft, and dense clay (till?) from 11-14 ft. Model layer 2 is inferred to represent these deposits. Well B8, however, penetrated gravelly clay and till from 4-8 ft, and encountered weathered bedrock at 8 ft. Along the northeast half of the spread, well B8 and several test pits consistently show bedrock elevations at 50-55 ft, compared to the modeled bedrock interface from 33-40 ft. This suggests that the second model layer may not be accurate. This may be a result of an overlying velocity reversal or the effects of weathered or fractured bedrock under part of the spread. Geophones between stations 90 and 285 recorded data indicative of velocities of 6500-9300 fps above bedrock that could not be adequately modeled. These returns may be indicative of a significant thickness of weathered or fractured bedrock under parts of the spread. Because of these problems, bedrock surface contours are drawn (pl. 2) principally from geological control as shown by the dashed line on the cross section.

Line 14 is located near well A84, which lies about 50 ft southeast of station 205. The first model layer is inferred to represent the unsaturated portion of deposits of volcanic ash, soil, and peat logged in well A84 from 0-8 ft (static water level was at 3.3 ft). Well A84 shows clay (till?) from 8-11 ft and till from 11-14 ft, which is inferred to be represented by the upper portion of model layer 2. Near station 165, test pit data (Crittenden, 1953) records "loose slate" at a 5 ft depth where the model puts bedrock depth at 35 ft. The test pit data are considered questionable because of uncertain test pit locations and the possibility that "loose slate" refers to cobbles and boulders within the fill.

Line 15 was a short 3-ft-geophone-interval line sited perpendicular to line 14 to define top of till or detect the possible presence of shallow bedrock. The model shows the top of layer 2 at a depth of 5-6 ft, in good agreement with line 14. Although the layer 2 velocity of 8181 fps is relatively high for till, it may be clast-supported with high densities of cobbles or boulders. Although a velocity of 8181 fps could represent weathered or fractured bedrock, it is not likely because well A84 (located 12 ft southwest of station 18 of line 15) did not encounter bedrock within the drilled depth of 14 ft. Time-intercept calculations yield theoretical minimum undetected fresh bedrock (V = 14,770 fps) depths of 30 ft on both ends of the line. Where line 15 at station 69 crosses line 14 at station 197, line 14 models bedrock depth at 32 ft.

Station 0 of line 16 coincides with station 345 of line 14. Well A85 is located 27 ft southeast of station 302 of line 16. Well A85 penetrated gravel fill from 0-3 ft and peaty soil from 3-7 ft, which is inferred to be represented by model layer 1. The well log shows gravel with some clay from 7-17.5 ft, till from 17.5-19 ft, and a water level at 11.1 ft. The top portion of model layer 2 is inferred to represent the unsaturated gravels; the lower portion of layer 2 is inferred to represent the saturated clays, gravels, and underlying till. Where lines 14 and 16 intersect, modeled bedrock depths agree to within 1 ft.

Line 8 was oriented perpendicular to the peninsular axis to determine dip on the bedrock surface. The line was located 38 ft northeast of well A61 at station 172, 45 ft southwest of well A62 at station 315, and 59 ft northeast of well A85 at station 430. Logs of wells A61 and A62 record fill, peaty soil, and volcanic ash from 0-5 ft. The upper portion of model layer 1 is inferred to represent these deposits. Well A61 penetrated till from 5-14 ft and clay (till?) from 14 to 17 ft, with a water level at 14.2 ft; well A62 encountered clay (till?) from 5-9 ft, and till from 9-11 ft, with a static water level at 6.6 ft. Data from these units could not be modeled as a separate intermediate layer, causing a potential hidden-layer problem. Where line 8 (at station 460) crosses line 16 (at station 370) bedrock as determined from the line 8 cross section is about 6 ft higher than it is on the line 16 cross section. A maximum possible hidden-layer calculation shows that actual nonlithified deposit thickness may be up to 40 percent greater than shown on the line 8 cross section, with as much as the bottom 44 percent being composed of material such as dense till.

Line 2 yielded a 3-layer model. Well A67, located 4 ft from station O, penetrated gravelly soils, volcanic ash, and unsaturated clay from 0-6 ft. Model layer 1 is inferred to represent these deposits. Clay, cobbles, clayey sand, and till were logged from 6-12 ft, with a water level at 7.1 ft. Model layer 2 is inferred to represent these deposits. At well A66A, located 14 ft from station 291, fill, volcanic ash, and soil logged from 0-3 ft are inferred to be represented by layer 1. Clayey, pebbly sand from 3-13 ft, and clay (till?) from 13-14 ft were also logged in well A66A, with a water level at 8.5 ft. The upper portion of layer 2 is inferred to represent these materials. The lower portion of layer 2 may represent till, causing actual depths to bedrock to be somewhat greater than shown on the line 2 cross section, because of hidden-layer considerations.

Northeast Nyman Peninsula

Data from lines 17 and 18 yielded 3-layer and 4-layer models, respectively. Line 17 at station 229 intersects line 18 at station 129. Well A71, located 54 ft from the south end of line 17, penetrated uncompacted silty clay and gravel fill from 0-4 ft and silty clay from 4-8 ft. The first and second layers of line 18 and the first layer of line 17 are inferred to represent these deposits. The second layer of line 17 is inferred to represent unsaturated gravels logged from 8-17 ft and dense silty sand (till) logged from 17-20 ft at well A71.

The first model layer of line 18 does not extend the full length of the line. It probably represents uncompacted fill which could not be separately modeled on line 17. Eighteen feet from station 0 of line 18, unsaturated gravel fill is logged from 0-15 ft in well A73. The second model layer of line 18 is inferred to represent these deposits. The third layer is inferred to represent clay, volcanic ash, and thin till encountered between depths of 15-29 ft in well A73. Bedrock elevations observed at well A73 and modeled at line station 0 of line 18 agree within 1 ft. Where lines 17 and 18 intersect, modeled bedrock elevations are identical.

Line 19, located on artificial fill, was modeled with a two-layer solution. Well A30, located 68 ft southwest of station 27, penetrated soil and peat from 0-3 ft, till from 3-19 ft, and no bedrock. A coarse gravel layer from 10-14.5 ft produced water at 13 ft with a static water level at 9.4 ft. Boring A31, located 95 ft northeast of station 268, penetrated volcanic ash and peat from 0-2.5 ft, till and clay from 2.5-6 ft, and bedrock at 6 ft. Although some seismic data indicated the presence of an intermediate layer, they were insufficiently numerous to model. Because of the possible presence of saturated fill or till and the low velocity of layer 1, a hidden layer may be present. The hidden layer may cause the modeled bedrock surface to be too shallow by as much as several feet as compared to the true bedrock surface.

Borehole A31 is located about 68 ft southwest of station 179 of line 20. At the station 299 shot hole, 2 ft of as soil and volcanic ash were logged. 2.5 ft of soil and ash were also observed in the station 0 shot hole. According to borehole A31, the lower reaches of the thicker portion of layer 1 may contain clay and till. A bedrock high with 10 ft of relief separates two lows which define shallow bedrock trenches that slope northeast toward the beach.

Line 37 is a long line surveyed to define anticipated deep bedrock. Geophones 1-16 were located atop artificial fill; the remainder just above the cobble beach on marshy ground near the high tidal limit. Well A43 is located of 11 ft northwest of station 135, and well A42 is located 61 ft northwest of station 567. Model layer 1 is inferred to represent fill (sandy gravel, coarse silty sand, clayey silt and sand), cobbles, and sandy pebbly clay observed in the well logs. The lower few feet of layer 1 probably represent saturated deposits. Layer two is inferred to represent saturated marine or glaciomarine deposits.

Head of Womens Bay

Boreholes along the dike at the head of Women's Bay (Shannon & Wilson, 1964) encountered 12-16 ft of hydraulic fill (pumped in from Women's Bay) overlying 1-2 ft of volcanic ash, which delineates the 1912 nearshore bottom. Below the ash, slate-derived gravelly sand and gravel layers with some clay and silt become cohesive, then "till-like" within a few feet. The log of well A18, located 33 ft southeast of station 0 of line 35 correlates well, recording 25 ft of "gray fill". Drilling ceased at the 25 ft depth on top of dense material, probably till or marine deposits. The well is screened from 18-23 ft, with a June 1988 water level 13.4 ft below land surface, or 4.8 ft elevation. The fill was not logged as water-bearing, but is probably saturated below the observed static well level. The fairly uniform thickness of model layer 1 suggests that the layer 1-layer 2 interface is related to a fairly flat (slightly sloping) water table or contact at the base of the fill, or both. Because the geophone spacing was selected to identify deep bedrock structure, data are insufficiently dense to resolve detailed stratigraphy in the upper 25 ft of the section.

Data collected at line 36 presented modeling difficulties. First arrival time graphs typically showed gradual slope changes rather than discrete layer breaks. This indicates the existence of gradational velocity increase with depth. Also no geologic data were available for depths below the first model layer. The location of this line suggests that nonlithified deposits under the line may be extensively heterogeneous, possibly consisting of fill, volcanic ash, peaty soil, loess, sandy gravelly or cobbly alluvium or beach deposits, till, or clayey and silty marine deposits. As a result, the line 36 model shows a fairly poor convergence of ray-path exit points on the bedrock surface, and a layer 1-layer 2 interface that cannot be clearly correlated with any known or hypothesized discrete geologic boundary.

Kodiak Airport

Well A16, located on the northwest side of line 29 15 ft from station 43, penetrated soil (0-3.5 ft), volcanic ash (3.5-4.5 ft), and peat (4.5-9 ft), which are represented by layer 1. The peat may cause a layer 1 thickness overcalculation of 1-2 ft. These units thin northeast of the spread, becoming 4 ft thick at wells A82 located 203 ft from station 970 on the southwest side of the line and A17 (see line 31 description). In well A16, alternating coarse and clayey medium gravel units (alluvium) are logged from 9-29.5 ft, with saturation below 23.4 ft, and bedrock at 29.5 ft. These gravels are represented by model layer 2. At station 43, the bedrock surface elevation is modeled to be 17.5 ft MLLW, about 5 ft lower than is logged in well A16 (22.6 ft MLLW). This may be a result of a peat-caused velocity reversal and layer 2 thickness overcalculation.

Most stations between stations 240-880 of line 29 yielded data to indicate the presence of a third nonlithified layer directly overlying bedrock. Though too sparse to model, these data yielded time-distance curve segments with apparent velocities ranging from 5,555-9,615 fps. A hidden-layer analysis using an averaged velocity of 7,304 fps showed that a composite layer (consisting both of model layer 2 and a hidden layer) up to 33% thicker than model layer 2 could exist, with up to 40% of the composite layer being the maximum theoretical hidden-layer thickness. This third layer, interpreted to represent till, is detected below the northeastern majority of the line, and may be up to 13 ft thick. Bedrock beneath the northeastern portion of the line may be up to 8 ft deeper than modeled.

Wells A16, A17, and A82 all encountered similar stratigraphy. Well A17 penetrated a sequence of alternating coarse and fine gravel layers from 4-33 ft, gravelly clay (till?) from 33-36 ft, and a static water level at 30.3 ft. Well A82 indicated alternating coarse and fine and occasionally sandy gravel and some cobble layers from 4-38 ft, till at 38 ft, and no water. These wells indicate that the sequence of alluvial gravel deposits thickens both down valley and toward the valley center. Similar trends are also observed in the line 30 and 31 model results.

Well A17 is located on the southwest side of line 31 about 188 ft from station 121. From well A17 stratigraphy, layer 1 at the northwest end may represent a thin sequence of unsaturated soil, volcanic ash, and peat. To the southeast, where layer 1 is more than 3 or 4 ft thick, it may represent principally uncompacted and compacted fill. Model layer 2 is inferred to represent the deposits of sandy fine to coarse gravels, cobbles, and sand logged from 4-33 ft in well A17. The bottom few feet of the layer may represent saturated conditions.

At station 120, the top of layer 3 is modeled about 35 ft deep, which matches the gravelly clay (till?) logged in well A17 from 33-36 ft. Based on the well data, the line location, its depth, thickness, and velocity, layer 3 is inferred to represent till or other dense glacial or glaciomarine deposits.

Sand and sandy silt with some gravel were observed on the ground surface at line 30. Model layer 1 has low velocity, and is inferred to represent uncompacted fill. Materials such as volcanic ash and natural soil may be represented in its lower portion.

The upper portion of model layer 2 of line 30 is inferred to represent lithologies similar to those represented by layer 2 of line 31. The bottom of this layer was difficult to model because data sufficient to model a third layer were obtained only from stations 0-360. However, returns corresponding to a third layer with apparent-velocity segments ranging from 5084-8823 fps were observed as far east as station 630. Because these first arrivals (from stations between 360 and 630) could not be modeled separately, they were incorporated with bedrock returns. The bedrock profile shown between stations 360 and 855 should be regarded as a highly simplified and imprecise representation of the true bedrock surface.

A hidden-layer analysis revealed that the second and hidden third layers together could be 36% thicker than the modeled second layer alone (east of station 360), with the hidden third layer composing 33% of the composite thickness. From station 360-855, a hidden third layer 12-28 ft thick could exist, and bedrock may theoretically be 9-22 ft deeper than shown.

A comparison of model results from lines 29, 30, and 31 shows significant variation. A thick third layer modeled in line 31 does not appear in lines 29 and 30. As previously discussed, however, a third layer probably does exist as a hidden layer in the portions of those lines nearest line 31, and correlates with the third layer of line 31. This unit appears to thicken towards the center of the Buskin River valley.

Lines 22 and 28 are sited in the interior of the eastern triangular area formed by runway intersections at Kodiak airport. Line 22 at station 40 crosses line 28 at station 245. These lines show a low-velocity first layer 3-9 ft thick, representing fill (probably silty sands and gravels), with possible natural soils, volcanic ash, or loose alluvial sandy gravels and silty sands. Excavation for utilities between lines 22 and 31 encountered cobble gravels to a depth of at least 20 ft. (K. Skaflestad, DOT/PF, oral commun., 1988). Boreholes along the E-W runway near line 28 logged silty sandy gravel, gravels, and some sands to depths of 15-25 ft, with the bottom 7 ft in the 25-ft deep hole noted as "damp" (Stanley and Pavey, 1981). Based on this evidence and acoustic velocities, model layer 2 is inferred to represent sandy and gravelly alluvium, probably saturated near its base.

From velocities and stratigraphic position, the third model layer is inferred to represent till or glaciomarine deposits. At the intersection of lines 28 and 22, line 28 models the bedrock interface at an elevation of about -145 ft compared to the line 22 model result of -110 ft. The line 28 model is considered more accurate because off-the-end shots could not be obtained at line 22, preventing the acquisition of a complete suite of data. Only stations 450-750 at line 22 had seismic returns that travelled through bedrock from both directions.

The first layer at line 23 is inferred to represent materials similar to materials represented by the first layers in lines 22 and 28. Model layer 2 has a slightly lower velocity than layer 2 of lines 22 and 28, but is inferred to represent similar deposits, with possible minor differences in compaction, moisture content, or lithology. A hidden-layer analysis using a velocity of 3913 fps to represent a possible undetected saturated alluvial layer shows that the combined layer 2-hidden layer thickness may be up to 24% greater than the modeled second layer, with 55% of their combined thicknesses being the saturated hidden layer.

Although the second layer is modeled to directly overlie bedrock, a few intermediate-velocity (4000-7000 fps) returns that could not be modeled were detected above bedrock between stations 480-920. These returns indicate the possible presence of a hidden layer composed of till under the northern part of the line. Using a velocity of 7000 fps, a hidden-layer calculation showed that the combined layer 2-hidden layer thickness could sum to 34% thicker than the model layer 2, with 36% of the combined layer being the hidden layer. In the model, intermediate-velocity returns were included with data assigned to the bedrock layer, so that true bedrock may be 8-10 ft deeper than is shown on the cross section.

USGS well A13, located westward of line 27 and 27 ft from station 98, penetrated soil from 0-4 ft, and alternating layers of peaty clay and cobble-gravel from 4 to 26 ft, with saturated conditions below 15.5 ft. The northern part of model layer 1 of line 27 is inferred to represent unsaturated deposits logged at well A13. To the south, away from Buskin River, these clays and gravels probably grade into inter-channel silts, silty sands, and sandy gravels, overlain by compacted artificial fill (silty sands and gravels). These materials, where unsaturated, are represented by model layer 1 of line 25 and the southern part of model layer 1 of line 27.

Model layer 2 of line 25 and 27 is inferred to represent mostly till because of its velocity and location. The top 5-10 ft of this layer may consist of saturated alluvium, although it is too thin to model separately because of the wide geophone spacings used. The upper boundary of layer 2 on line 27 could be the water table, because it is relatively flat (except for a depression between stations 112 and 250), slopes gradually northward toward Buskin River, and is close to river and sea level at the north end. A more pronounced depression is evident in the top of layer 2 in line 25. These depressions may represent a predevelopment stream course of Devil's Creek cut into glacial deposits, or a travel-time slowdown due to buried utilities in the vicinity.

Lines 25 and 27 defined the deepest bedrock of any lines in this study. On line 27, only one off-the-end shot 295 ft north of station 0 detected first arrivals from the bedrock surface. Ray-path exit points from the third model layer from this shot ($) are evident from stations -200 to +196 on the cross-section. From stations 196 to 644, the bedrock surface trend is extrapolated. Although its exact depth and relief could not be modeled at line 27, the projected bedrock depth is in agreement with the line 25 solution, which had complete bedrock first-arrival coverage.

Line 24 at station 592 crosses line 26 at station 1172. USGS well A12A is located on the northeast side of line 26 85 ft from station 71. Well A12 is located on the northeast side of line 26 288 ft from station 862 and on the northwest side of line 24 250 ft from station 248. Well A12 penetrated fill from 0-3 ft, sandy gravel with clay from 3-25 ft, and coarse gravel with cobbles from 25-27 ft. An open interval from 17-27 ft produced a static water level 12 ft below land surface. Well A12A penetrated sandy cobble gravel from 0-5 ft, coarse gravel from 5-15 ft, and gravelly sand from 15-26 ft, with a static water level at 17 ft. Model layer 1 of lines 24 and 26 is inferred to represent the unsaturated portion of these alluvial deposits.

Model layer 2 of lines 24 and 26 has velocities characteristic of till, and is inferred to represent mainly till possibly with some glaciomarine or glaciofluvial deposits. At least the top 5-10 ft of this layer probably represents saturated alluvium that was too thin to model. In both models, the top of layer 2 probably represents the water table.

Contouring of data collected at lines 22-28 using available geologic data and reported shallow depth to bedrock in the western triangular area formed by principal runway and taxiway intersections (K. Skaflestad, DOT/PF, oral commun., 1988) has resulted in the identification of major bedrock troughs beneath the airport and lower Buskin River valley (pl. 1). The trough underlying the main east-west runway closely follows the predevelopment course of Devil's Creek as shown in a circa-1937 aerial-photo collage on display in the U.S. Coast Guard administration building. Nonlithified deposits beneath the airport probably represent a combination of glacial drift, glaciomarine, and alluvial deposits of both Buskin River and Devil's Creek, and volcanic ash, loess, peat, and fill.

Sanitary Landfill

Lines 33 and 34 cross atop a landfill located west of Catherine Lake. Line 33 at station 515 crosses line 34 at station 230. USGS well A10A is located 542 ft from station 810 of line 33 on a bearing of E. 14^{O} S. Stratigraphy logged at the well were peat 0-4 ft, sand 4-13 ft, and till at 13 ft, with a water level at 2 ft. A 3-ft-deep shot hole dug at station 0 of line 33 penetrated rock fragment fill from 0-2.5 ft, and volcanic ash from 2.5-3 ft.

Both lines yielded two-layer solutions, modeling a single low-velocity layer 10-48 ft thick overlying bedrock. However, on all shot data, apparent-velocity segments for the upper layer exhibited progressive velocity increases with increasing depth up to 1785-2870 fps. These higher-velocity returns could not be separately modeled, so were included with other data assigned to layer 1. These pervasive velocity variations attest to a probable downward increase in compaction or moisture content within the nonlithified materials overlying bedrock. The upper portion of this modeled layer probably represents uncompacted artificial fill containing refuse; the lower portions may represent relatively wetter and more compacted fill or natural deposits.

The seismic data also exhibited significant velocity variations within the uppermost layer along the line of section. This is interpreted to represent significant lateral irregularities within the landfill deposits. The irregular profile of the bedrock surface modeled at line 24 may be a result of these irregularities, rather than real relief on the bedrock surface.

A hidden-layer analysis applicable to both lines shows that the combined thicknesses of layer 1 and a hidden layer with an acoustic velocity of 2,870 fps may be up to 41% greater than the modeled upper layer, with 54% of that combined thickness being the hidden layer. This means bedrock could be 4-20 ft deeper beneath a hidden layer 2-10 ft thick. If these deposits are saturated at the base, using a potential hidden-layer velocity of 5000 fps, the unsaturated plus saturated zones could be 43% thicker than modeled, with 40% of the total thickness being saturated. This equates to a total nonlithified section thickness 4-20 ft greater than shown, with a saturated zone 2-8 ft thick.

At their intersection, the line 34 model shows a bedrock elevation of 44 ft, compared to line 33 model result showing a bedrock elevation of 33 ft. This discrepancy is within the bounds of the potential sources of error described above.

Buskin Lake

Line 38 is located southeast of Buskin Lake. USGS well A2 is located southwest of the line, 246 ft from station 1405. Well A2A is located 227 ft from station 1475 on the same side of the line. Well A2 encountered clayey peat from 0-3 ft, gravel and sand from 3-4 ft, moderately sorted clayey gravel, 4-7 ft; pebble-gravel and clay, 7-10 ft, and bedrock at 10 ft. Well A2A encountered peaty soil with volcanic ash from 0-4 ft, wet peaty soil with gravel from 4-6 ft, shale fragments with clay from 6-7 ft, and bedrock from 7-7.5 ft. Although the occurrence of water was noted at 3 ft, no static water level is reported.

Hand-dug shot holes at stations 0, 950, and 1750 encountered (from the surface downward) up to 0.5 ft of organic mat, 0.5-0.8 ft of volcanic ash, and 1.7-3 ft of peat. These materials overlie saturated alluvium 2.8-4.1 ft deep, composed of rounded, elongate phyllite plates 6-8 inches long and 2-3 inches thick, imbricated in a dense clast-supported matrix. At station 1350 (located in a quarry), the shot hole dug in exposed alluvium was damp to a depth of 2.8 ft.

The modeled first layer is inferred to represent organic mat, volcanic ash, some pre-1912 buried soil horizon, and peat. The layer is wet to saturated in its lower portions. The velocity of the second model layer (5,528 fps) is inferred to represent the dense, saturated alluvium observed in the shot holes. Given the geologic setting of this line, however, deposits such as till and glaciofluvial sands and gravels can be expected to occur at depth. The relatively wide band (up to about 30 ft) of ray-path exit points on the modeled cross section suggest that irregularities in the data or modeling effort are present and that the exact position of the bedrock surface is somewhat uncertain in this area.

Lines 32 and 39 are located in the upper Buskin valley (above Buskin Lake). DOT/PF (Erickson and Pavey, 1976) test hole 13 is located on the west side of line 32 60 ft from station 152. The test hole penetrated tan silty sand (ash) from 0-3 ft, with a perched water table at 2 ft; sandy silt, 3-5 ft; gravelly silty sand, 5-6 ft; sandy gravel, 6-7 ft; silty sand with some gravel, 7-13.5 ft; and silty gravelly sand, 13.5-20 ft. Test holes 12, 17, 18, and 19, located 600-860 ft in a general westerly direction from station 0, penetrated 1.5-2 ft of volcanic ash over predominantly sandy gravels to 20 ft total depths. Static water levels between 5 and 9 ft deep were observed in all wells. Shot holes at station 810 and 500 ft due west of station 810 encountered ash from 0-2 ft, brown clayey silt from 2-3 ft, and cobble gravel at 3 ft.

Layer one of the cross-section is inferred to represent road fill, volcanic ash, and sandy silt, which may be saturated in the bottom 1-1.5 ft. Layer two varies from 75-200 ft thick, and is inferred in at least the upper portion to represent saturated alluvium, similar to that observed in the test holes. Velocity increases observed on apparent-velocity segments representing the second layer may be due to lateral or vertical changes in lithology or compaction. If an undetected thickness of till is present, a combined minimum-thickness second layer and a maximum-thickness theoretical hidden layer (velocity = 7000 fps) would add to a total thickness 17% greater than is shown for layer 2 alone. In the maximum case, bedrock would be 13 to 35 ft deeper than shown on the cross section, beneath 50-133 ft of till.

DOT/PF test hole 14 is located on the south side of line 39 170 ft from station 0. The well penetrated volcanic ash from 0-2 ft; gravel and sand from 2-20 ft. DOT/PF test hole 16, located on the south side of line 39 750 ft from station 310 encountered sandy gravel from 0-10 ft, with the water table at 2 ft. USGS well BA-1A, located on the south side of line 39 720 ft from station 770, encountered sod, soil, sand, and ash from 0-3 ft, soil and silty clay (1912 soil horizon) from about 3-3.7 ft, and sandy gravel with some silt and cobble layers from 3.7-15 ft. The water table was encountered at 7 ft. USGS well BA-1, 535 ft S. 20° W. from station 1100 penetrated ash, 0-1 ft; silty clayey sand, 1-3 ft; cobbly gravel, 3-4.5 ft, sand with some gravel, 4.5-6 ft; and sandy gravel from 6-18 ft, with a static water level at about 8 ft.

Shot holes showed some compositional variation, but generally penetrated organic mat, sandy or clayey silt or silty sand, and sandy gravel or cobble gravel. All shot holes were 4.5 ft or less deep.

On the cross section, layer 1 varies from 5-10 ft thick. Its low velocity suggests it to be representative of low-density materials such as were observed above the gravels in the shot holes. The lower parts of model layer 1 probably represent unsaturated sands and sandy gravels. Layer two ranges from about

65-120 ft thick, and is inferred to represent saturated sequences of stratified sandy gravels in at least its top portion. Although intermediate layer returns were not observed, a hidden layer may still be present and the lower portion of layer 2 may represent interbedded glaciofluvial and till deposits. If hidden higher-velocity glacial deposits are present, the summed thicknesses of the maximum hidden layer (velocity = 7000 fps) plus the corresponding minimum theoretical second layer would be 18% greater than the modeled layer 2 thickness. This means that bedrock could be 12 to 22 ft lower beneath 43 to 78 ft of glacial deposits. Figure 2 shows bedrock elevation contours as interpreted from seismic lines 32 and 39, borehole data, and bedrock-controlled side-valley walls.

CONCLUSIONS

Seismic-refraction profiling on the U.S. Coast Guard Reservation at Kodiak has resulted in the characterization of nonlithified deposits and structure contour maps showing the configuration of the buried bedrock surface. Surfaces of high velocity discontinuity that were clearly defined include: volcanic ash and soils over compacted alluvium, unsaturated alluvium over saturated alluvium, alluvium over till, and nonlithified deposits over bedrock. Seismic data were verified, where possible, with geologic and other seismic data, resulting in plausible geologic descriptions of subsurface conditions.

Nonlithified deposits on Nyman Peninsula consist mostly of alluvium and till, ranging in thickness up to about 40 ft. The land surface and bedrock surfaces are irregular on Nyman Peninsula, causing significant lateral thickness variability of nonlithified materials over short distances.

Buried bedrock troughs and depressions up to 280 ft below sea level were seismically detected near the head of Women's Bay, beneath the Kodiak Airport, and near Buskin Lake. These features are inferred to be a result of fluvial or glacial erosion. In the airport area, alluvial deposits within the Devil's Creek and Buskin River drainages overlie till or glaciomarine deposits.

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REFERENCES CITED

Combellick, R.A., 1989, Surficial geology of the U.S. Coast Guard Reservation, Kodiak, Alaska: Alaska Division of Geological and Geophysical Surveys Public Data File 89-8B, 54 p., scales 1:6000 and 1:12,000, 7 sheets.

Coulter, H.W., Hopkins, D.M., Karlstrom, T.N.V., Péwé, T.L., Wahrhaftig, Clyde, and Williams, J.R., 1965, Map showing extent of glaciations in Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-415, scale 1:2,500,000, 1 sheet.

Crittenden, Edwin B., Architect, 1953, Administration building and communication center - Topography, U.S. Naval Station, Kodiak, Alaska: prepared for U.S. Department of Navy Bureau of Yards & Docks, drawing 456056, scale 1:480, 1 sheet.

Davies, D.L., and Moore, J.C., 1984, 60 m.y. intrusive rocks from the Kodiak Islands link the Peninsular, Chugach and Prince William terranes: Geological Society of America Abstracts with Programs, v.16, no. 5, p. 277.

DOWL Engineers, 1984, Subsurface investigation and foundation recommendations--Kodiak Child Care Center: work order D51050 for CCC Architects and Planners, 47 p., scale 1:240, 2 sheets, scale 1:36, 2 sheets.

EBASCO Services, Inc., 1982, Terror Lake hydroelectric project, 138 KV transmission line, geological investigations: document APA 6793-A-541 prepared for the Alaska Power Authority, 113 p.

Erickson, D.R., and Pavey, D.R., 1976, Kodiak runway subsurface soils and material inversigation: Alaska Department of Transportation and Public Facilities, Engineering Geology and Soils Report, 14 p.

Haeni, F.P., 1986, Application of Seismic-refraction techniques to hydrologic studies: U.S. Geological Survey Open File Report 84-746, 144 p.

Harding-Lawson Associates, 1981, Soils investigation--Kodiak Weather Service building, Kodiak, Alaska: Job 5552, 018.80 for USKH Engineers, 25 p.

Kachadoorian, Reuben, and Plafker, George, 1967, Effects of the earthquake of March 27, 1964 on the communities of Kodiak and nearby islands: U.S. Geological Survey Professional Paper 542-F, 41 p.

Karlstrom, T.N.V., 1969, Regional setting and geology, in Karlstrom, T.N.V., and Ball, G.E., eds., The Kodiak Island refugium: Its geology, flora, fauna and history: Toronto, The Ryerson Press, p. 20-54.

Moore, G.W., 1967, Preliminary geologic map of Kodiak Island and vicinity, Alaska: U.S. Geological Survey Open-file Report 271, scale 1:250,000, 1 sheet.

Moore, G.W., 1969, New Formations on Kodiak and adjacent islands, Alaska: U.S. Geological Survey Bulletin 1274-A, p. A27-A35.

Plafker, George, Jones, D.L., and Pessagno, E.A., Jr., 1977, A Cretaceous accretionary flysch and melange terrane along the Gulf of Alaska margin: U.S. Geological Survey Circular 751-B, p. B41-B42.

Redpath, B.B., 1973, Seismic refraction exploration for engineering site investigations: Explosive Excavation Research Laboratory Technical Report E-73-4, Livermore, California. 51 p.

Scott, J.H., 1973, Seismic-refraction modeling by computer: Geophysics, v. 38, no. 2, p. 271-284.

_____, 1977, SIPT - a seismic refraction inverse modeling program for timeshare terminal computer systems: U.S. Geological Survey Open File Report 77-365, 35 p.

Scott, J.H., Tibbetts, B.L., and Burdick, R.G., 1972, Computer analysis of seismic refraction data: U.S. Bureau of Mines, Report of Investigations 7595, 95 p.

Shannon & Wilson, Inc., 1964, Foundation investigation for dike, U.S. Naval Station, Kodiak, Alaska: report J-1014 prepared for Hammond, Collier, and Isaac, Seattle, Washington, 15 p.

_____, 1988, Geotechnical report - ground support equipment building addition, U.S. Coast Guard Support Center, Kodiak, Alaska: report A-293, prepared for U.S. Coast Guard Facilities Design & Construction Center, Seattle, Washington, 27 p.

Solie, D.M., and Reifenstuhl, R.R., 1989, Bedrock geology of the U.S. Coast Guard Reservation, Kodiak, Alaska: Alaska Division of Geological and Geophysical Surveys Public Data File 89-8A, 32 p., scale 1:12,000, 1 sheet, scale 1:6,000, 2 sheets.

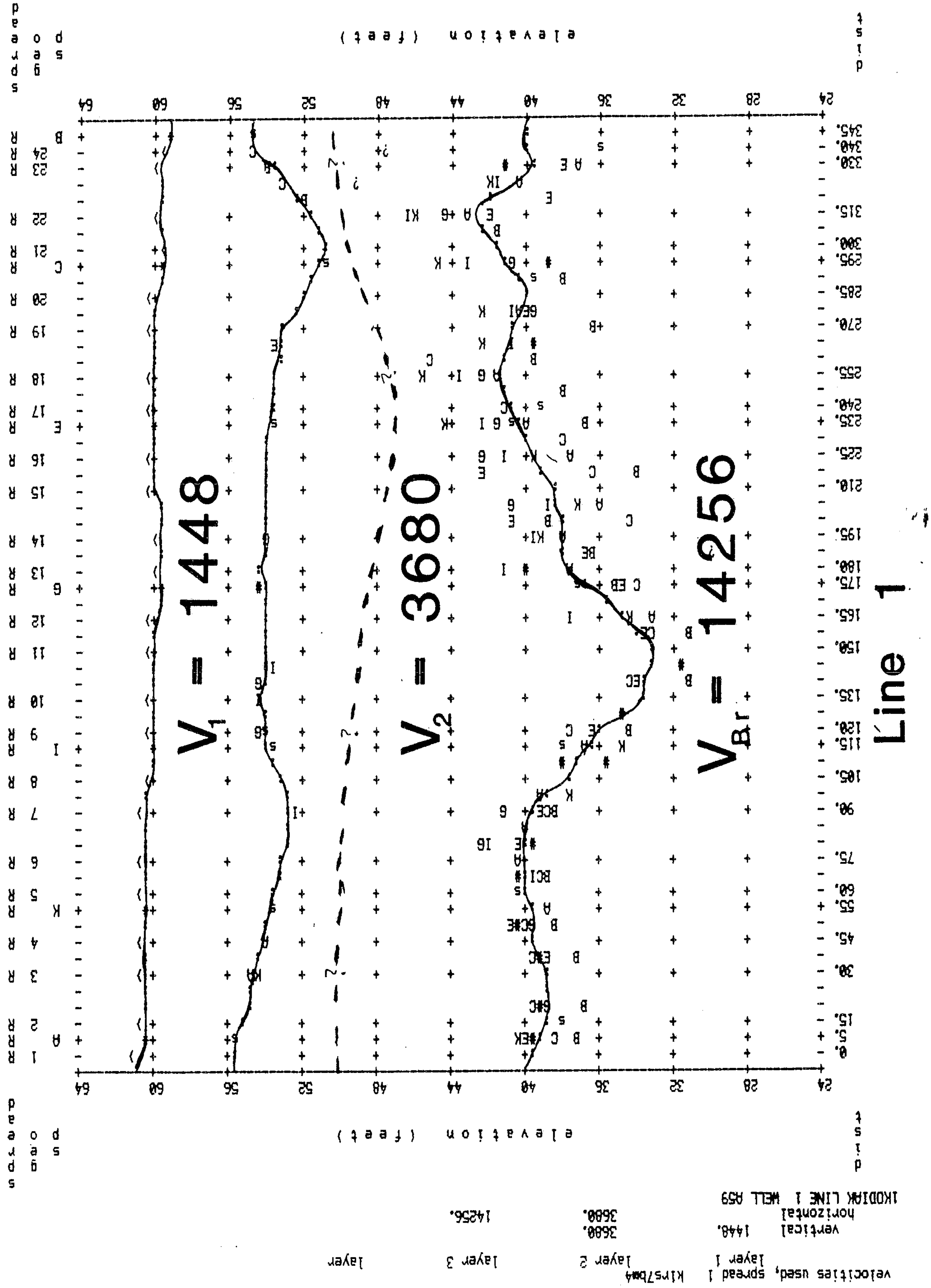
Stanley, D.A., and Pavey, D.R., 1981, Kodiak airport apron expansion and Devil's Creek service road materials investigation: Alaska Department of Transportation and Public Facilities Engineering Geology and Soils Report, 28 p.

APPENDIX A

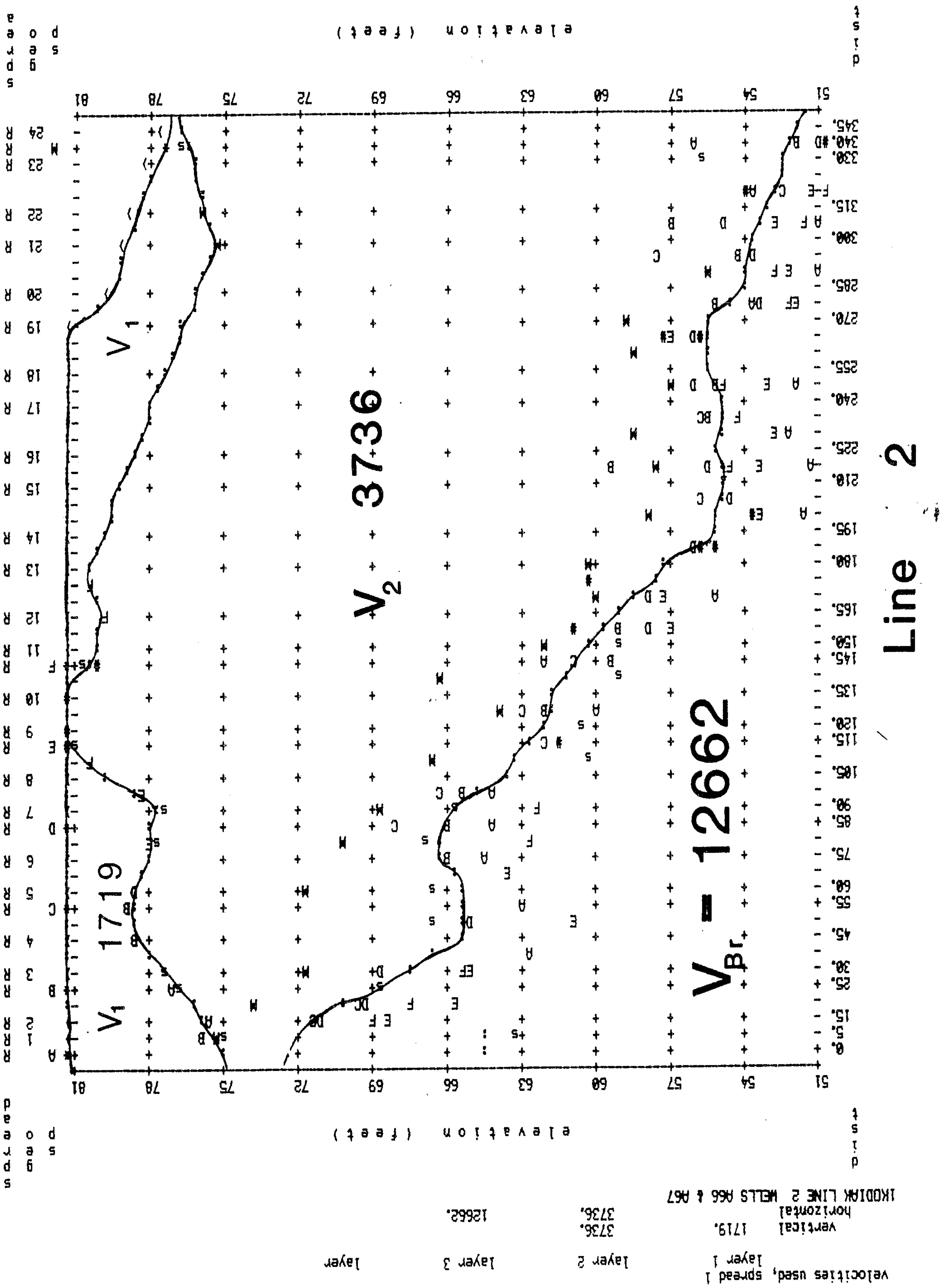
MODEL RESULTS

Explanation

Line station distances in feet are shown along the bottom axis; geophone stations by number are displayed across the top axis. Unequal station spacing results from printer resolution limits. Alphabetical characters below the geophone station numbers denote shot point locations. The vertical axis shows profile elevations in feet above sea level. Ground surface and layer interfaces are delineated by colons (:). Geophone locations (elevation and position) are shown by carats (^), and shot point positions are shown by asterisks (*). Locations of raypath entry points into a refractor from a shot are shown by a small case (s); raypath exit points from a refractor are given by the alphabetical character pertaining to a specific shot. Line 27 also used a dollar sign ($) to denote a shot. Pound signs (#) denote overlaps of alphabetical characters. The program plots colons (:) at the most probable interface locations based on statistical methods; question marks denote raypath exit points occurring outside of statistically prescribed bounds. Lines were manually drawn through the colons for visual clarity. Dashed lines were drawn where model results are ambiguous and more than one interface can be inferred. Vertical dashed lines identify seismic-line intersections.



$V_1 = 1448$
$V_2 = 3680$
$V_{Br} = 14256$
Line 1
elevation (feet)
KODIAK LINE 1 WELL A59
velocities used, spread 1



Line 2
V1
1719
V2
3736
VBr = 12662
elevation (feet)
IKODIAK LINE 2 WELLS A66 & A67
velocities used, spread 1
layer 1
layer 2
layer 3
layer
vertical 1719. 3736.
horizontal 3736. 12662.

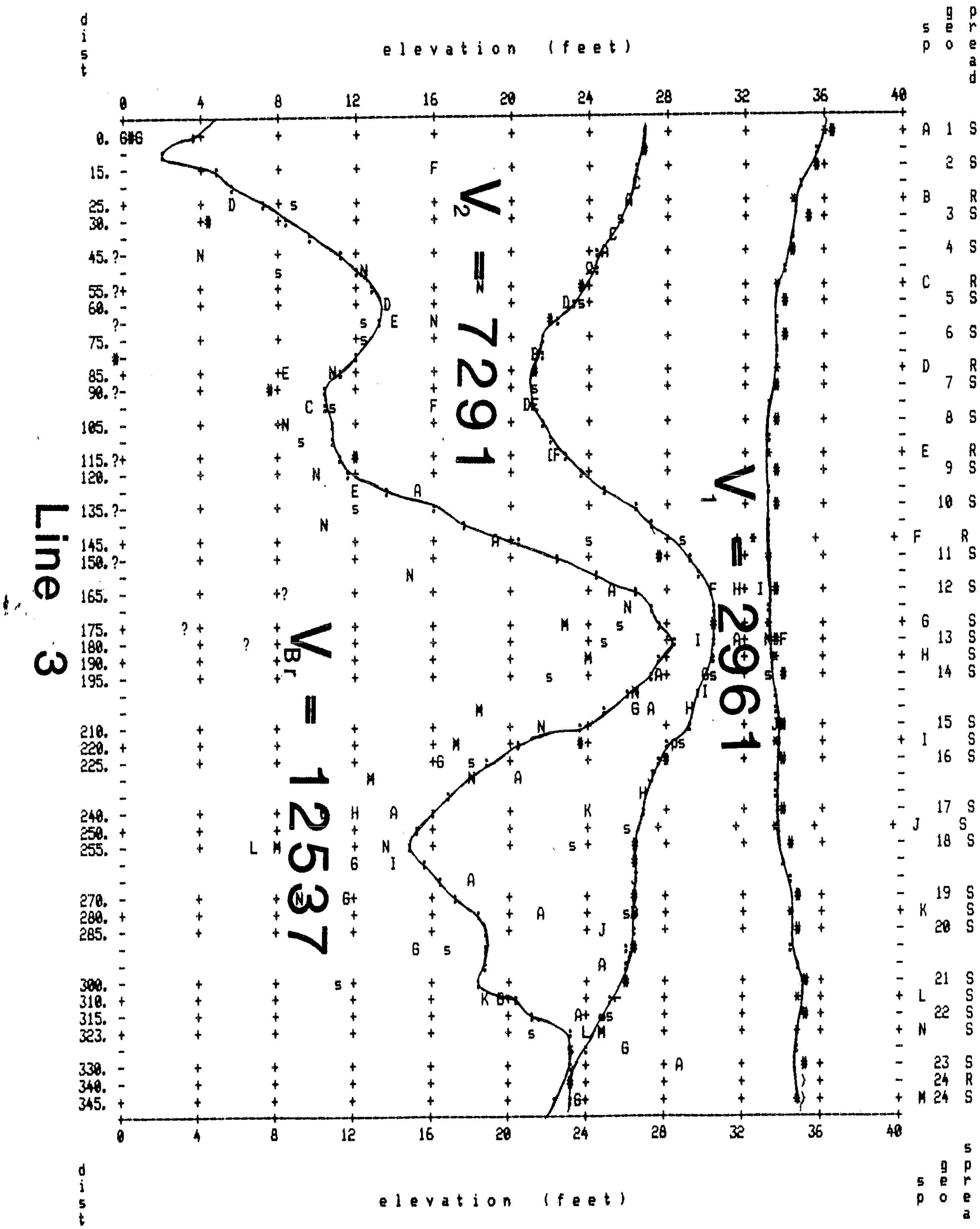
velocities used, spread 1

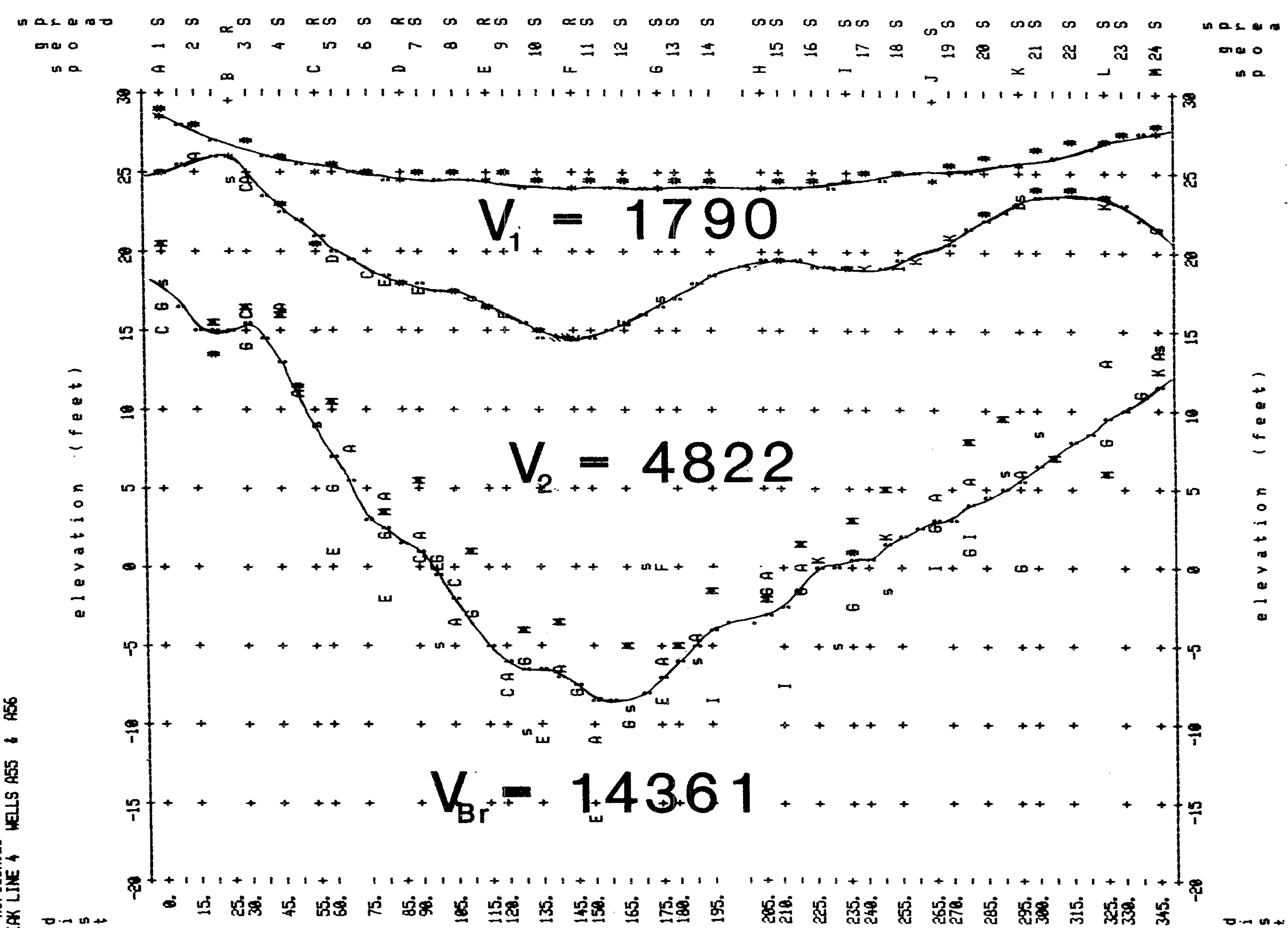
	layer 1	layer 2	layer 3	layer
vertical	2961.	7291.		
horizontal		7291.	12537.	

velocities used, spread 2

	layer 1	layer 2	layer 3	layer
vertical	2961.	7291.		
horizontal		7291.	12537.	

1KODIAK LINE 3 WELLS A53 - A54





Line 4

velocities used, spread 1

	layer 1	layer 2	layer 3	layer
vertical	1790.	4822.		
horizontal		4822.	14361.	

velocities used, spread 2

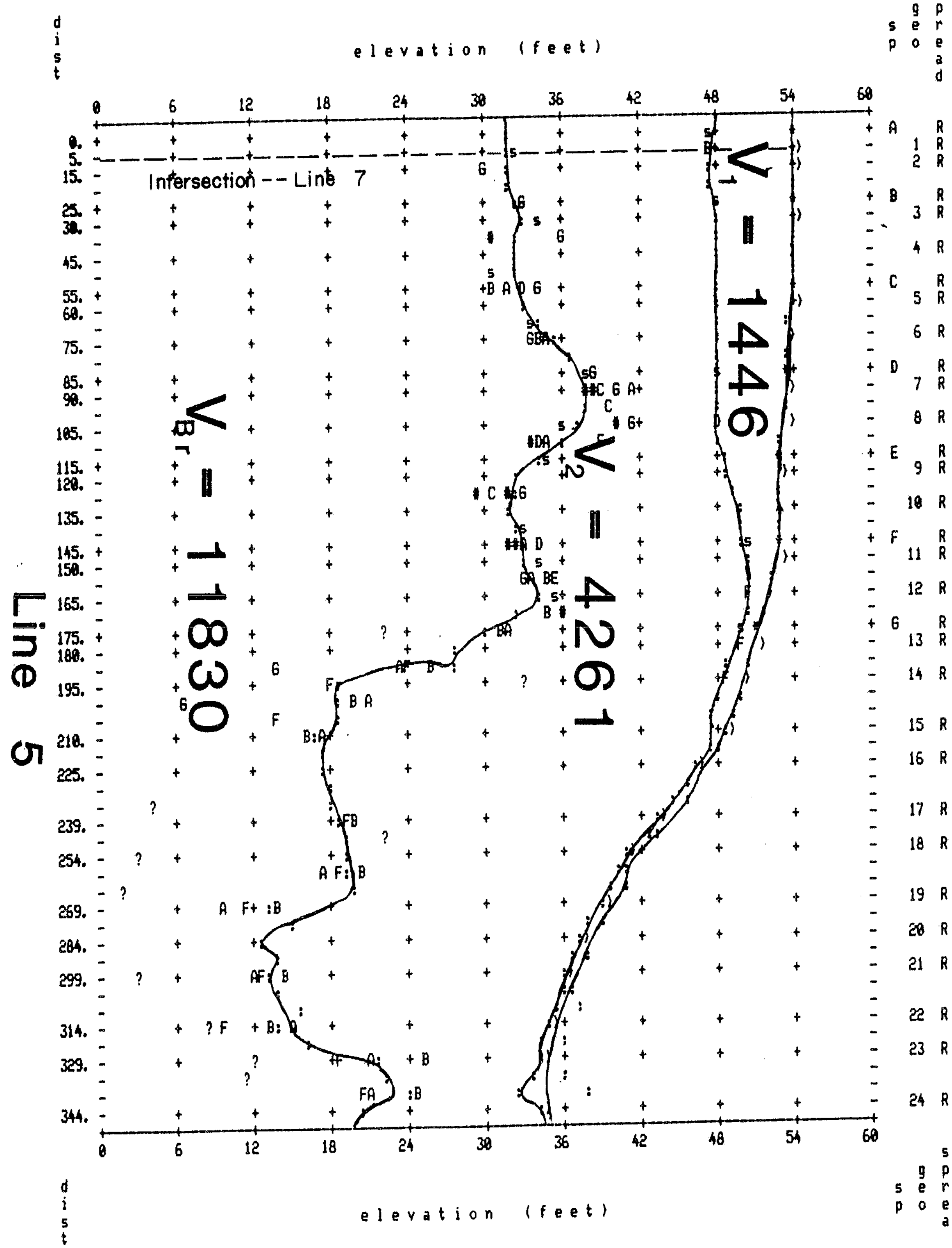
	layer 1	layer 2	layer 3	layer
vertical	1790.	4822.		
horizontal		4822.	14361.	

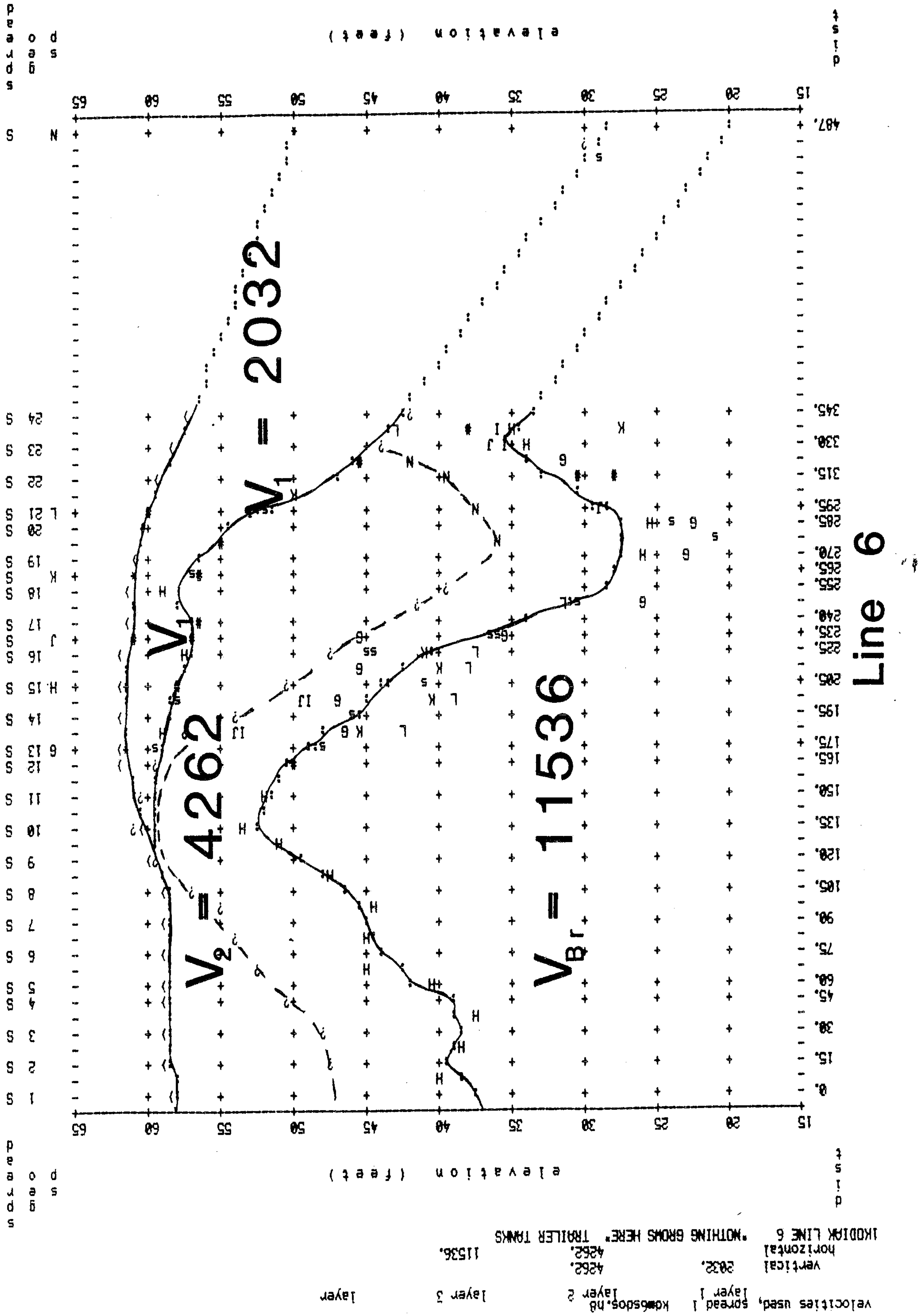
1KODIAK LINE 4 WELLS A55 & A56

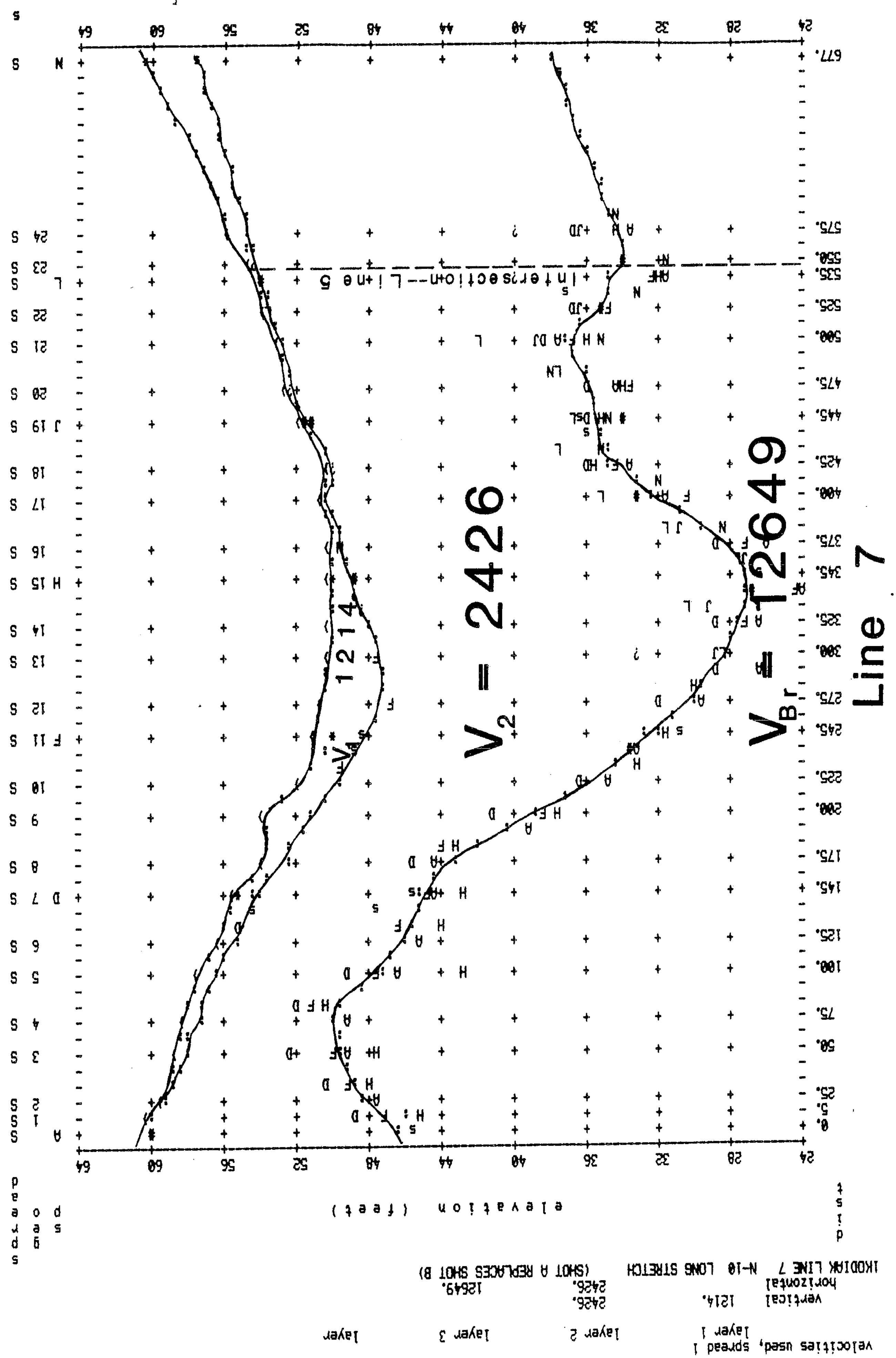
velocities used, spread 1

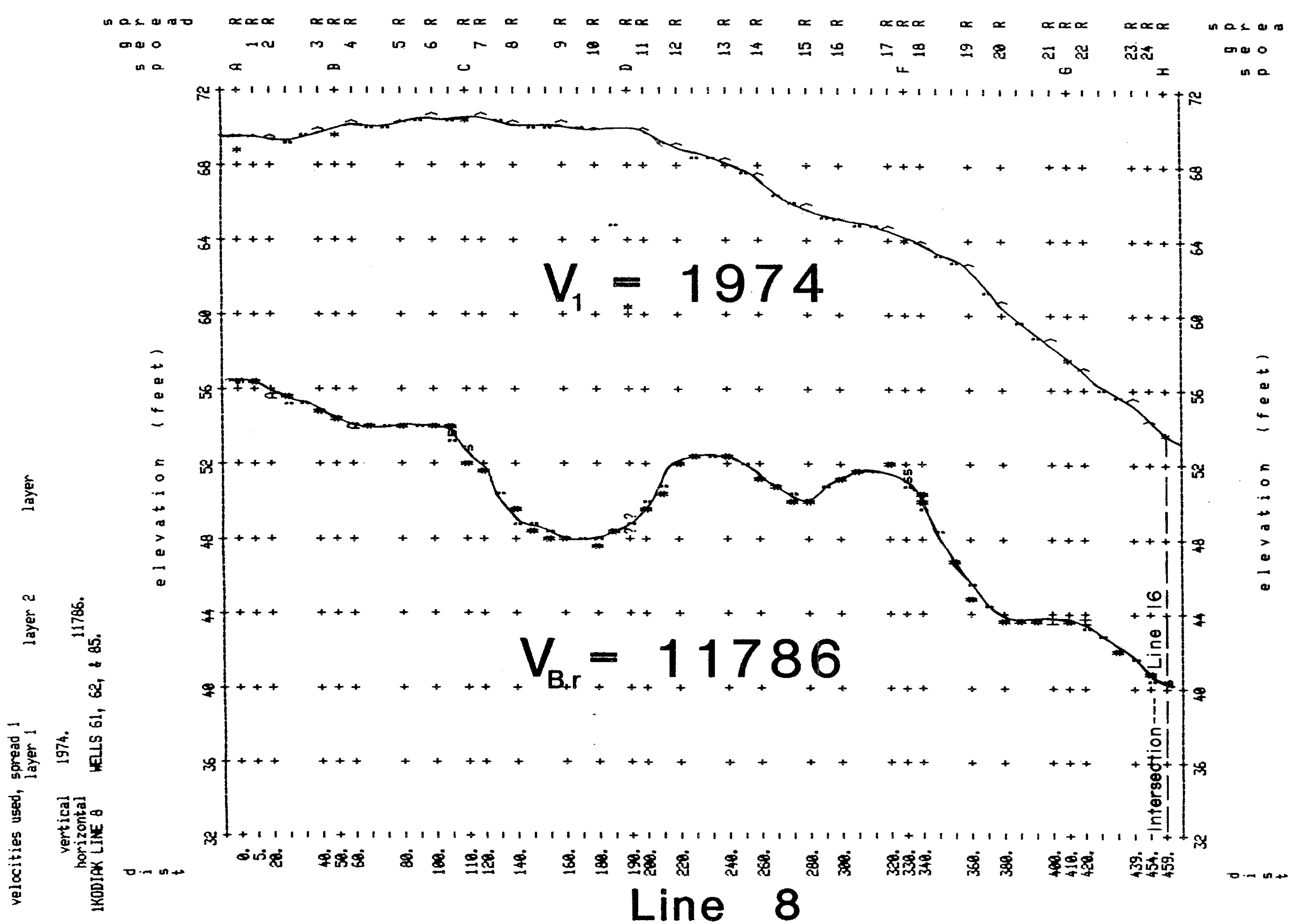
	layer 1	layer 2	layer 3	layer
vertical	1446.	4261.		
horizontal		4261.	11830.	

1KODIAK LINE 5   WELL A54 - TANK N-10   X STRIKE

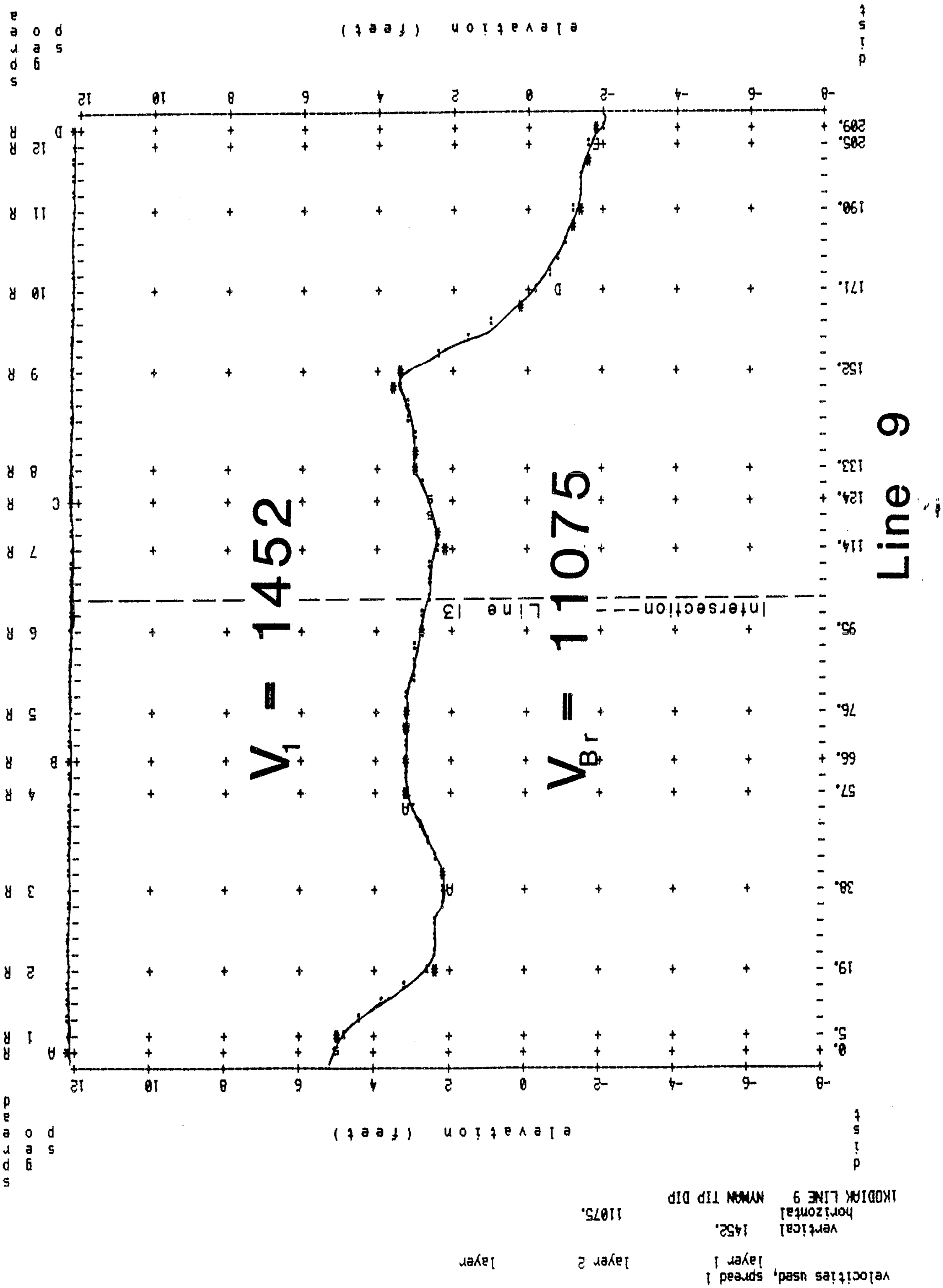


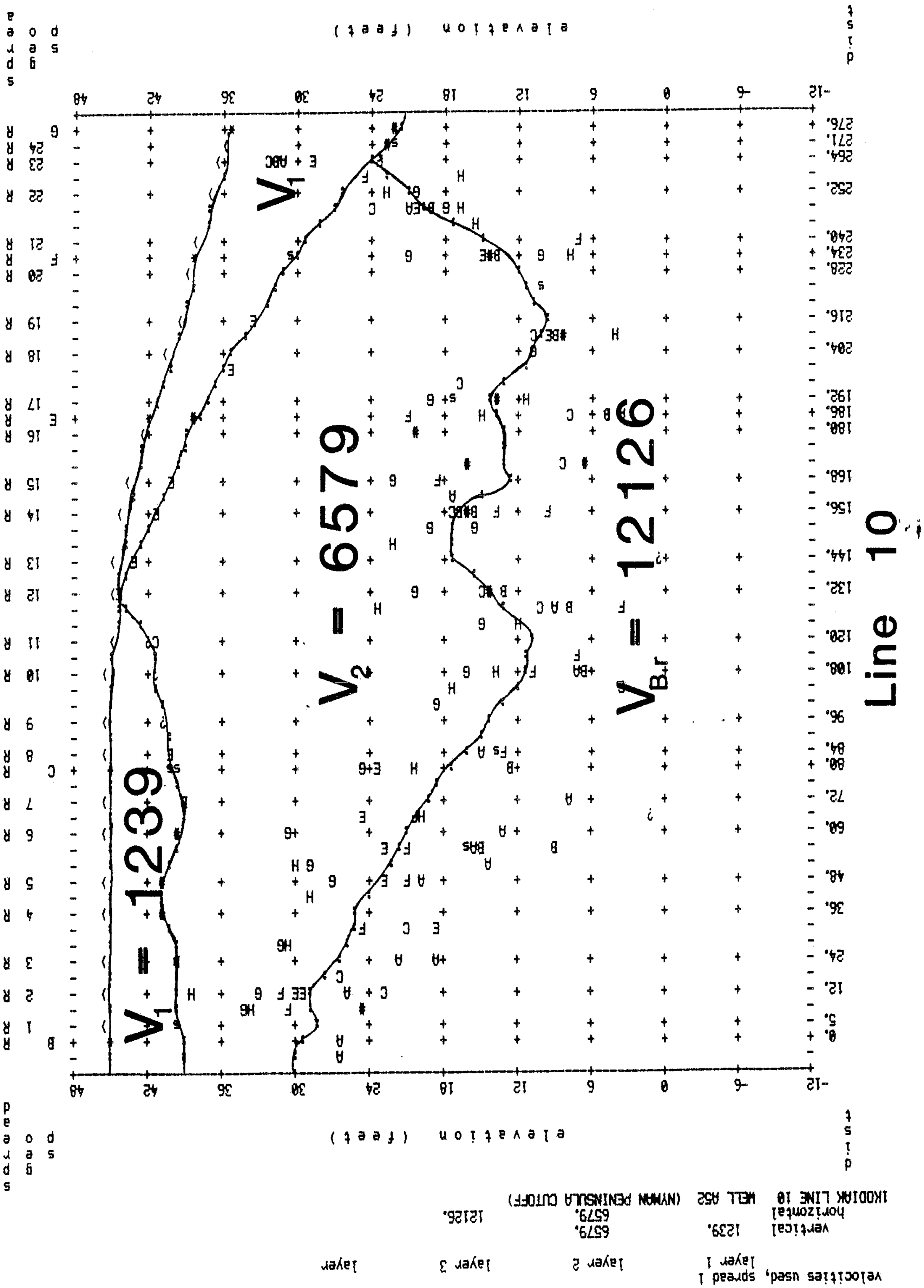

Line 6
V1 = 2032
V2 = 4262
VBr = 11536
elevation (feet)
velocities used, spread 1 kdm6sdos.h8
layer 1 layer 2 layer 3 layer
vertical 2032. 4262.
horizontal 4262. 11536.
IKODIAK LINE 6 "NOTHING GROWS HERE" TRAILER TANKS

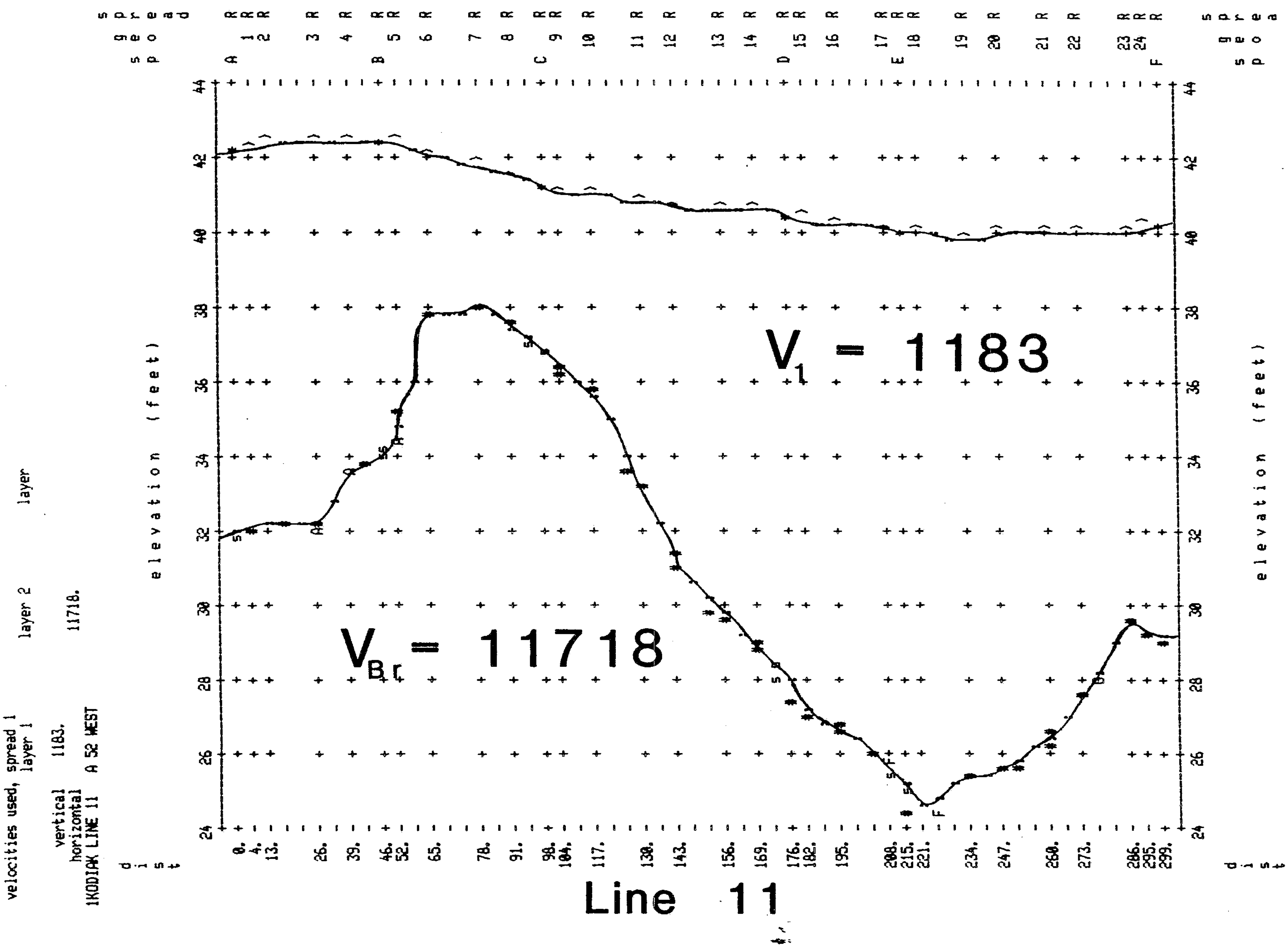

Line 7
V2 = 2426
VBr = 12649
1214
elevation (feet)
IKODIAK LINE 7 N-10 LONG STRETCH (SHOT A REPLACES SHOT B)
velocities used, spread 1
layer 1
layer 2
layer 3
layer
vertical 1214. 2426.
horizontal 2426. 12649.
Intersection--Line 5


V1 = 1974
VB.r = 11786
Intersection---Line 16
elevation (feet)
velocities used, spread 1
layer 1
layer 2
layer
vertical 1974.
horizontal 11786.
1KODIAK LINE 8 WELLS 61, 62, & 85.

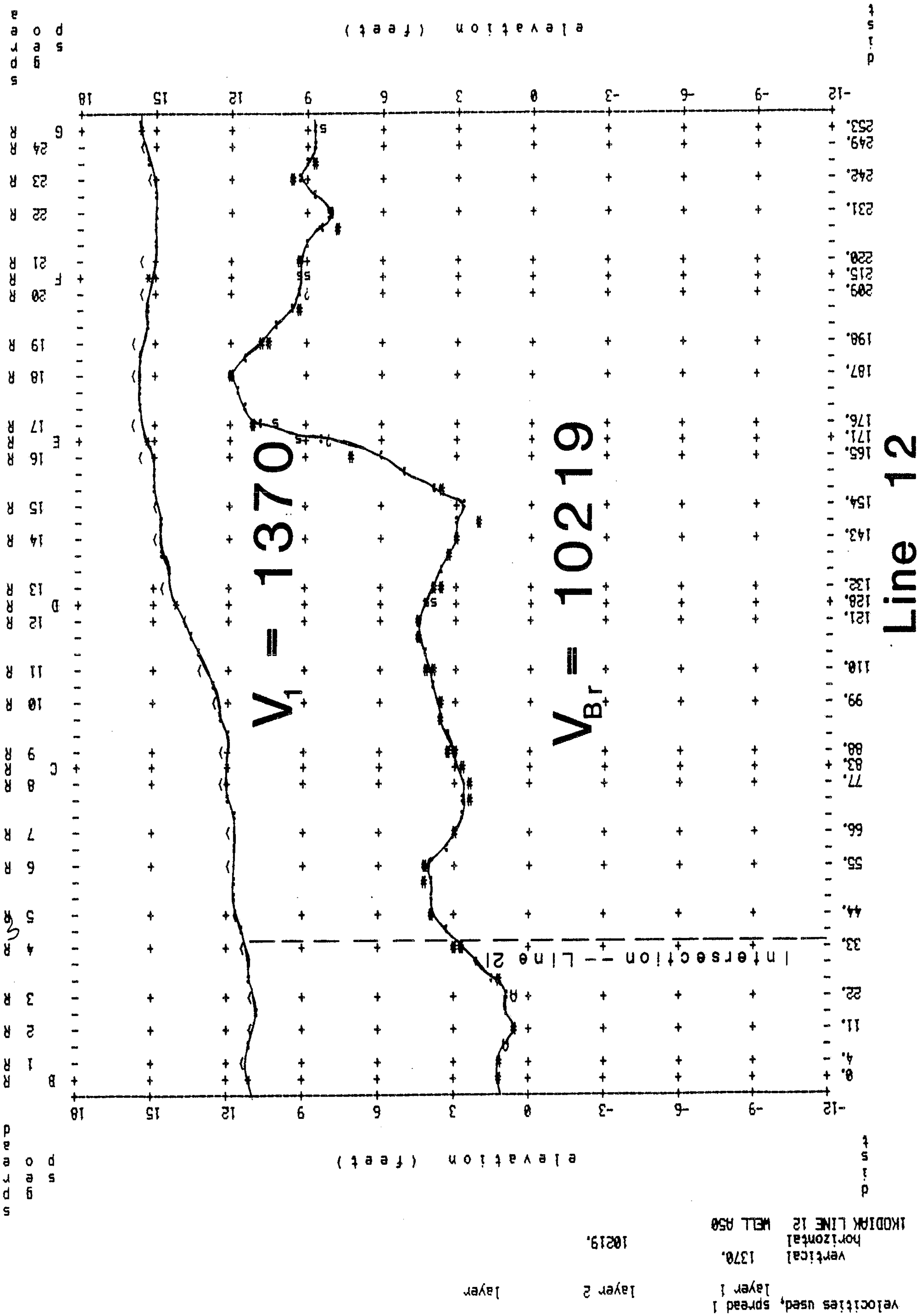
Line 8


Line 9
V1 = 1452
VBr = 11075
Line 13
intersection
elevation (feet)
IKODIAK LINE 9 NYMAN TIP DIP
horizontal 11075.
vertical 1452.
velocities used, spread 1
layer 1
layer 2
layer

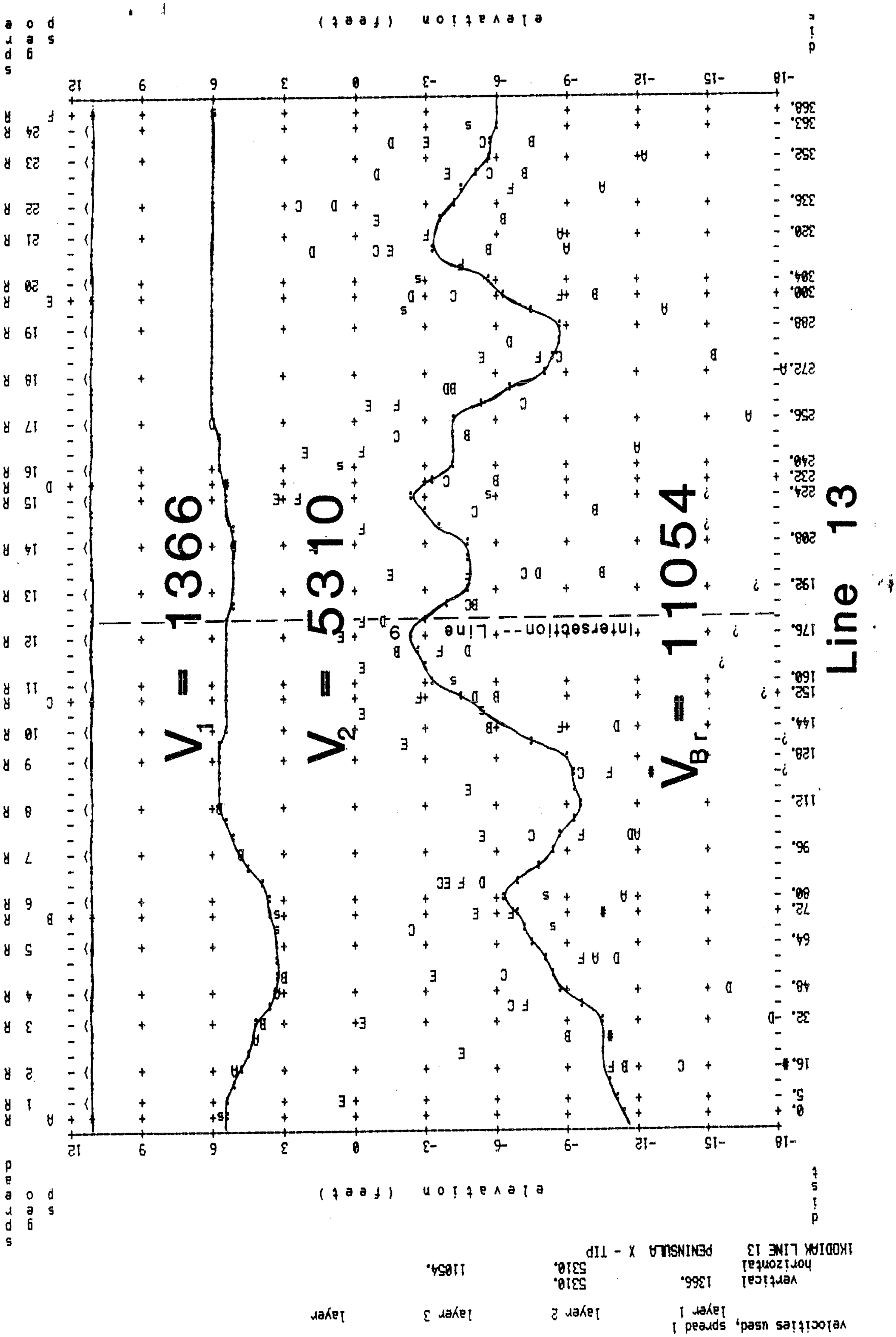

velocities used, spread 1
layer 1
layer 2
layer 3
layer
vertical 1239. 6579. 12126.
horizontal 6579.
1KODIAK LINE 10 WELL A52 (NYMAN PENINSULA CUTOFF)
elevation (feet)
dist
spread
V_1 = 1239
V_1
V_2 = 6579
$V_{B.r}$ = 12126
Line 10



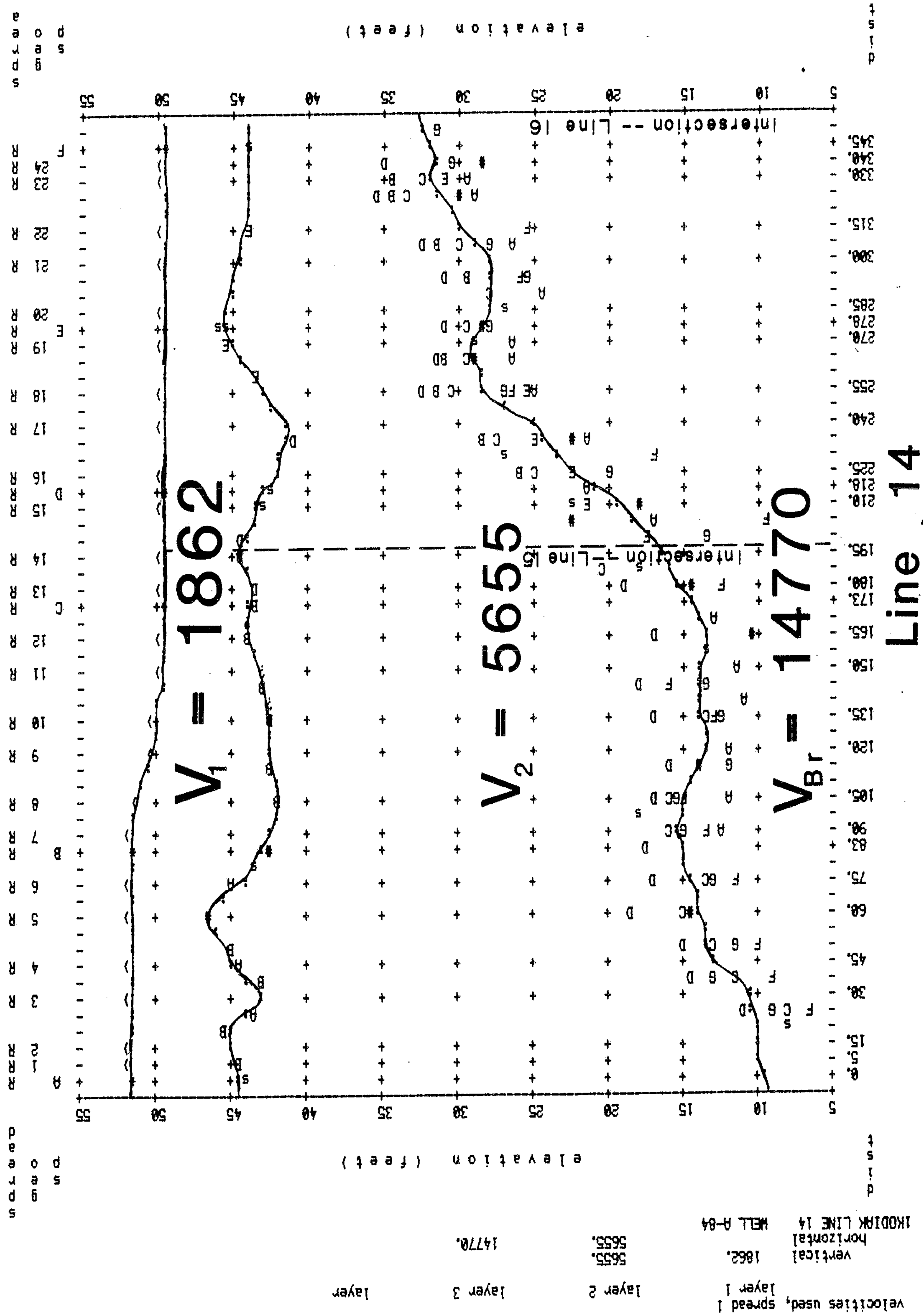
velocities used, spread 1
layer 1
layer 2
layer
vertical 1183.
horizontal 11718.
1KODIAK LINE 11 A 52 WEST
elevation (feet)
dist
geo sp
spread
V1 = 1183
VBr = 11718
Line 11



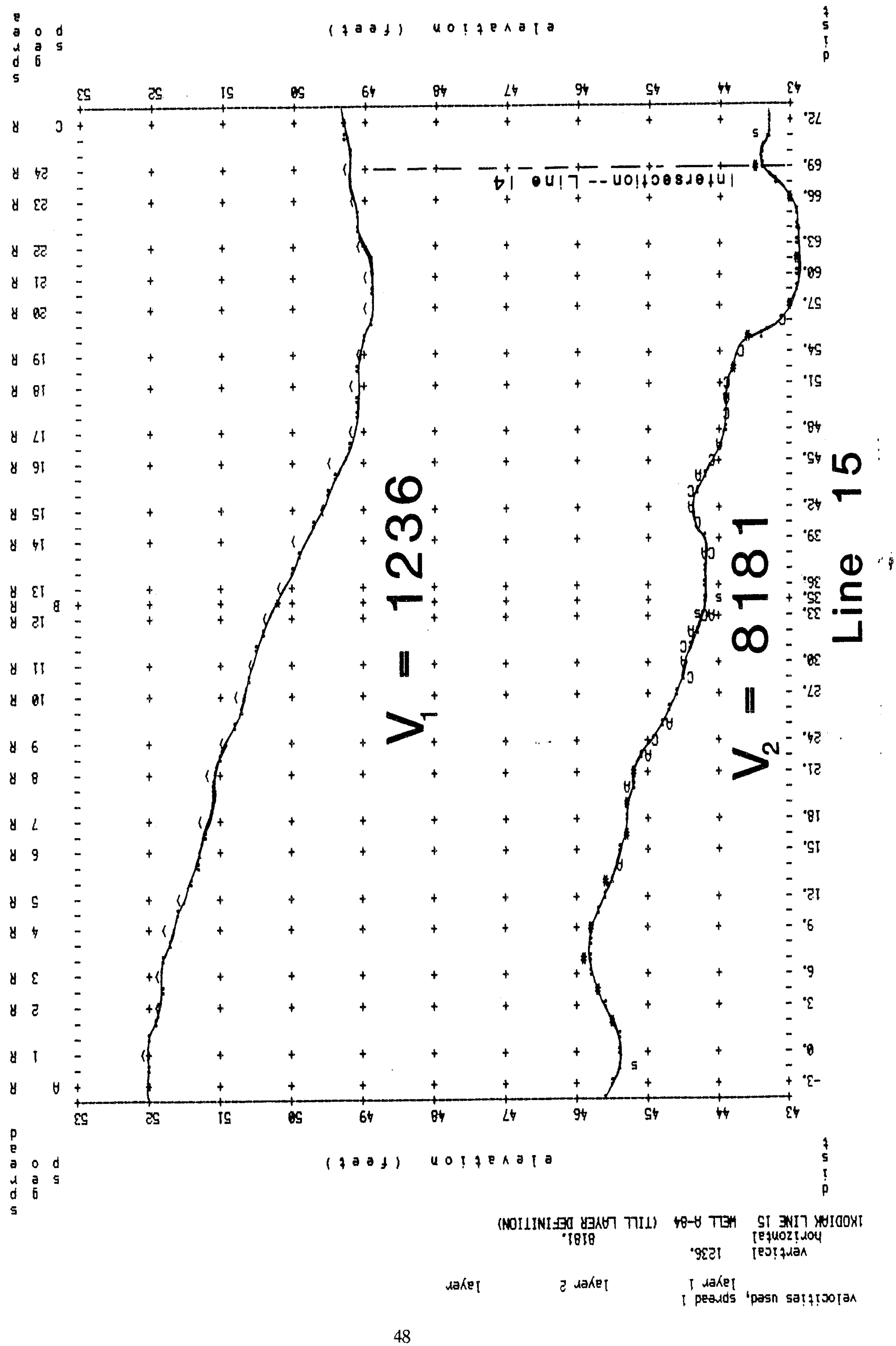
Line 12
V_1 = 1370
V_{Br} = 10219
Intersection -- Line 21
elevation (feet)
dist
spread geo
velocities used, spread 1
layer 1
layer 2
layer
vertical 1370.
horizontal 10219.
IKODIAK LINE 12 WELL A50

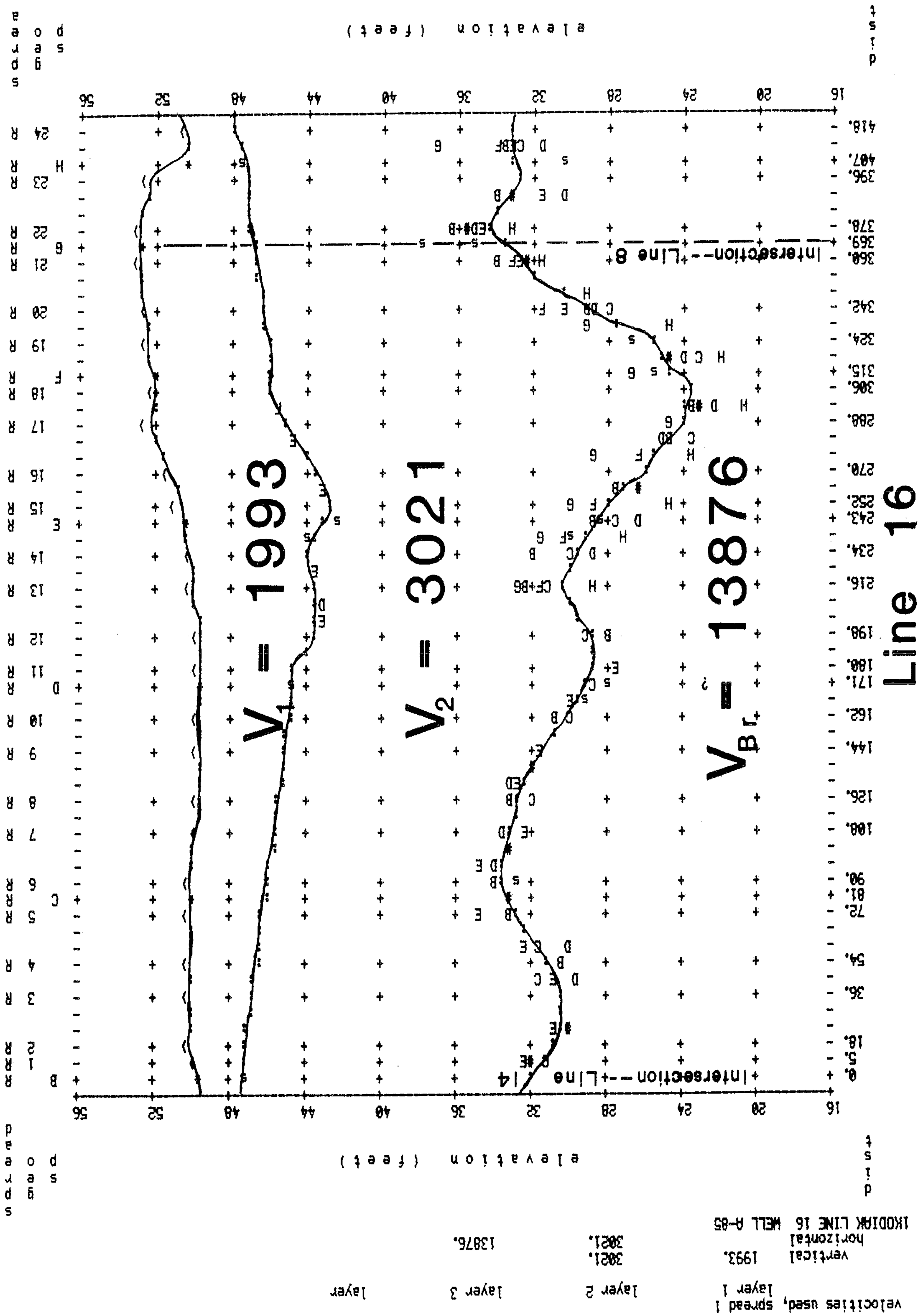


Line 13
V1 = 1366
V2 = 5310
VBr = 11054
Intersection Line 9
elevation (feet)
IKODIAK LINE 13 PENINSULA X - TIP
velocities used, spread 1 layer 1 layer 2 layer 3 layer
horizontal 5310.
vertical 1366. 5310. 11054.

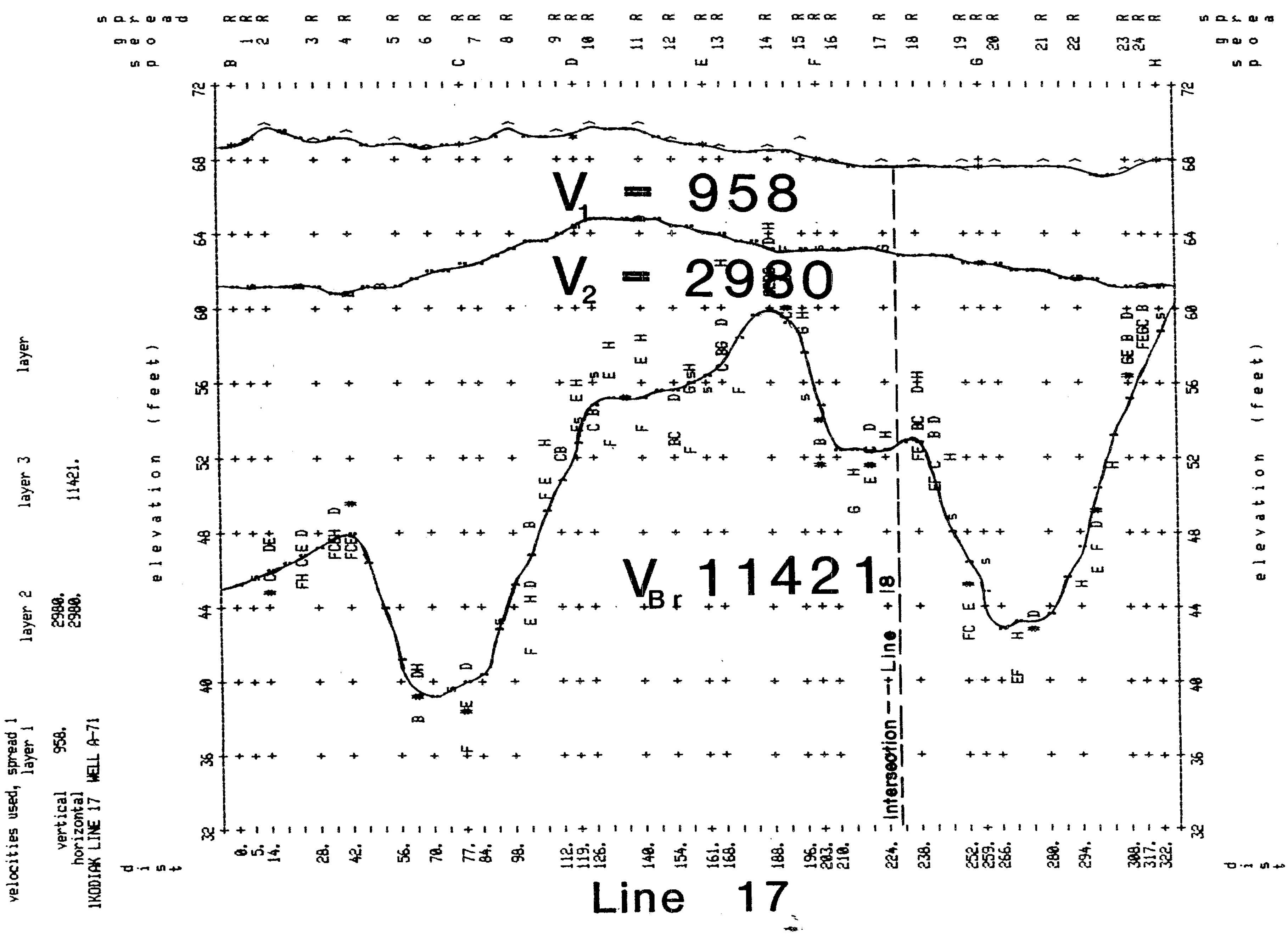


V1 = 1862
V2 = 5655
VBr = 14770
Line 14
Intersection -- Line 16
Intersection -- Line 15
elevation (feet)


Line 15
V_1 = 1236
V_2 = 8181
Intersection -- Line 14
elevation (feet)
KODIAK LINE 15 WELL A-04 (TILL LAYER DEFINITION)
horizontal 8181.
vertical 1236.
velocities used, spread 1
layer 1
layer 2
layer



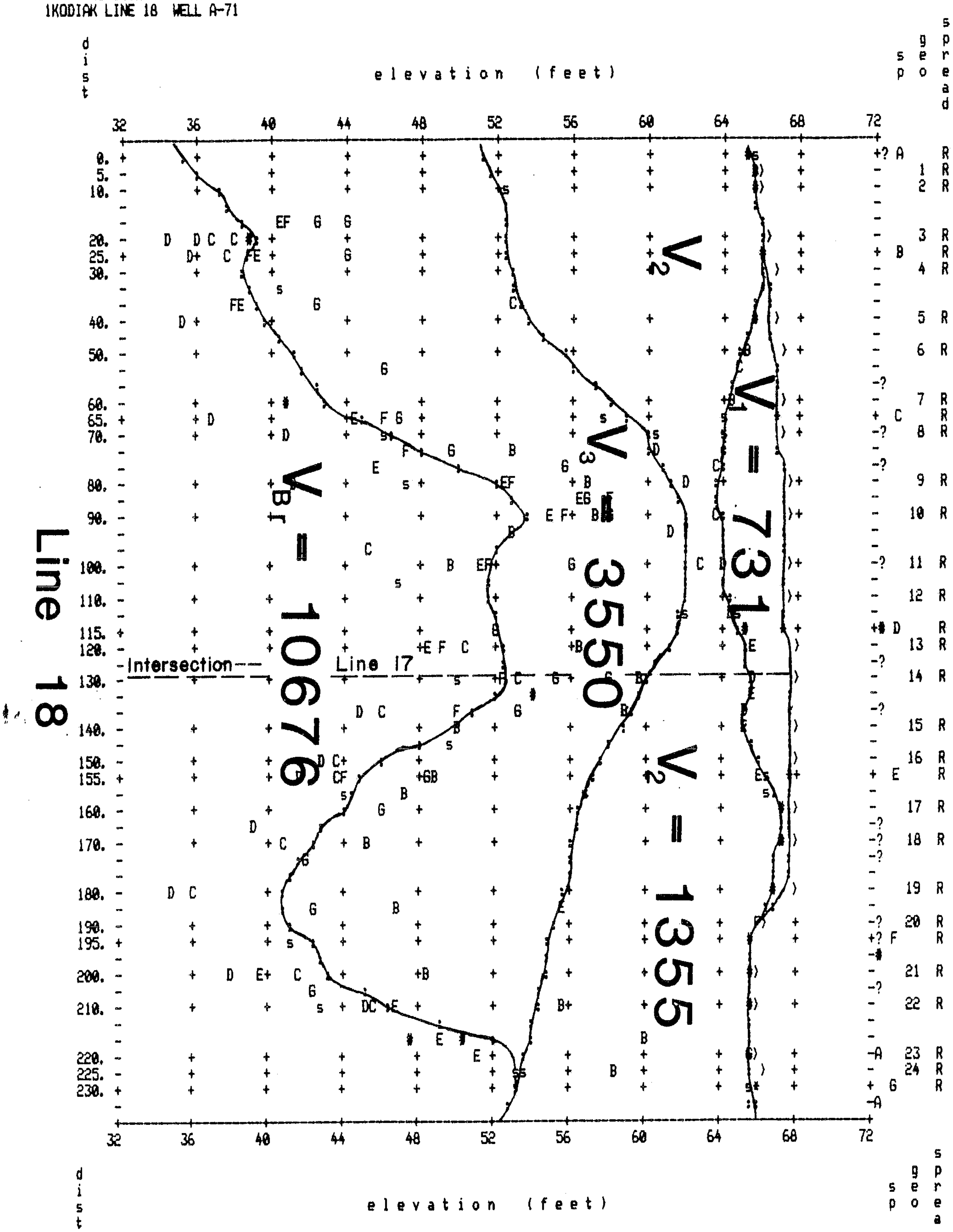
IKODIAK LINE 16 WELL A-85
velocities used, spread 1
layer 1 layer 2 layer 3 layer
horizontal 3021.
vertical 1993. 3021. 13876.
elevation (feet)
Intersection--Line 8
Intersection--Line 14
V1 = 1993
V2 = 3021
VBr = 13876
Line 16

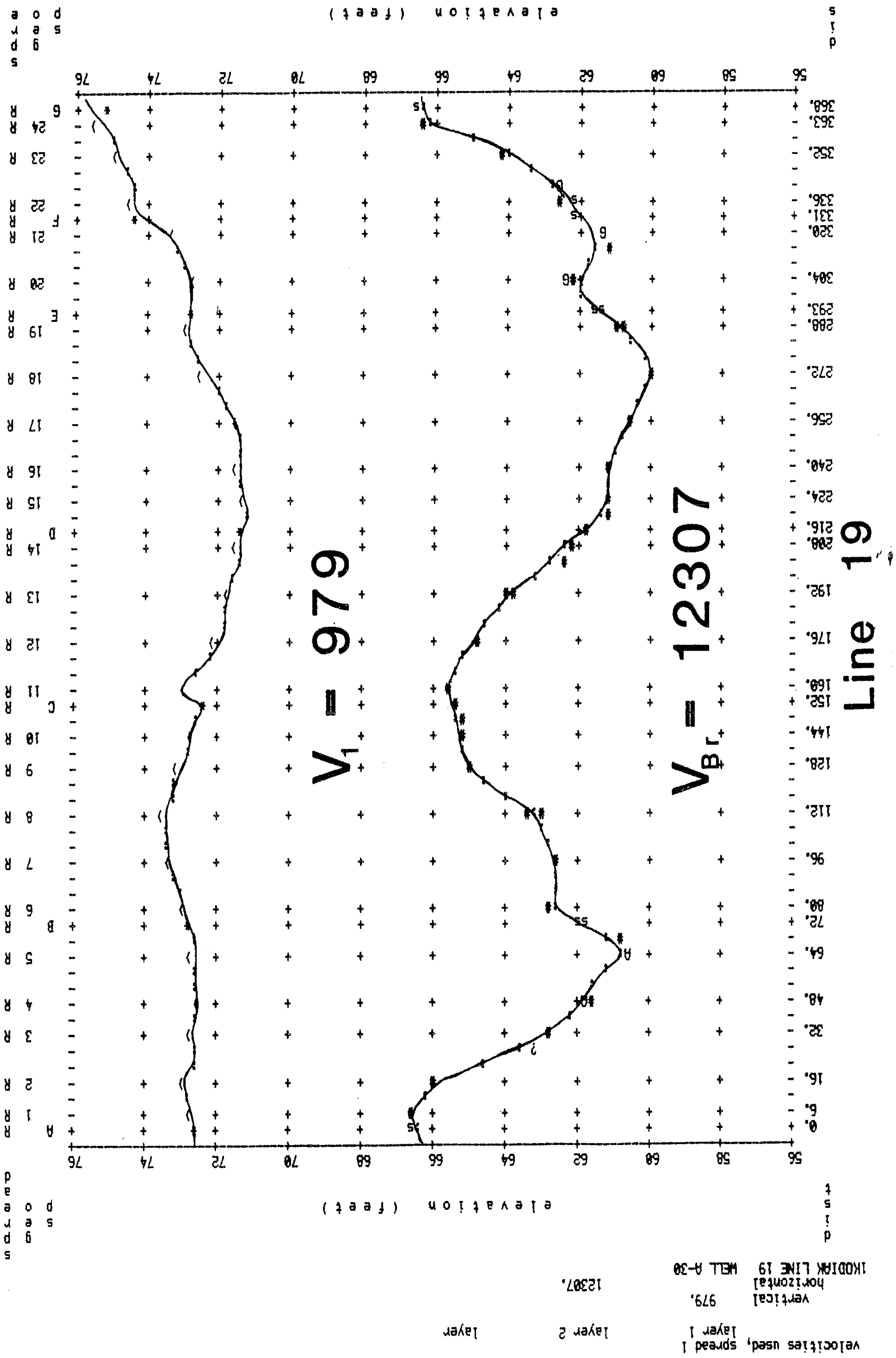

Line 17
V_1 = 958
V_2 = 2980
V_{Br} 11421
Intersection — Line 18
elevation (feet)
dist
velocities used, spread 1
layer 1 layer 2 layer 3 layer
vertical 958. 2980. 11421.
horizontal 2980.
IKODIAK LINE 17 WELL A-71

velocities used, spread 1

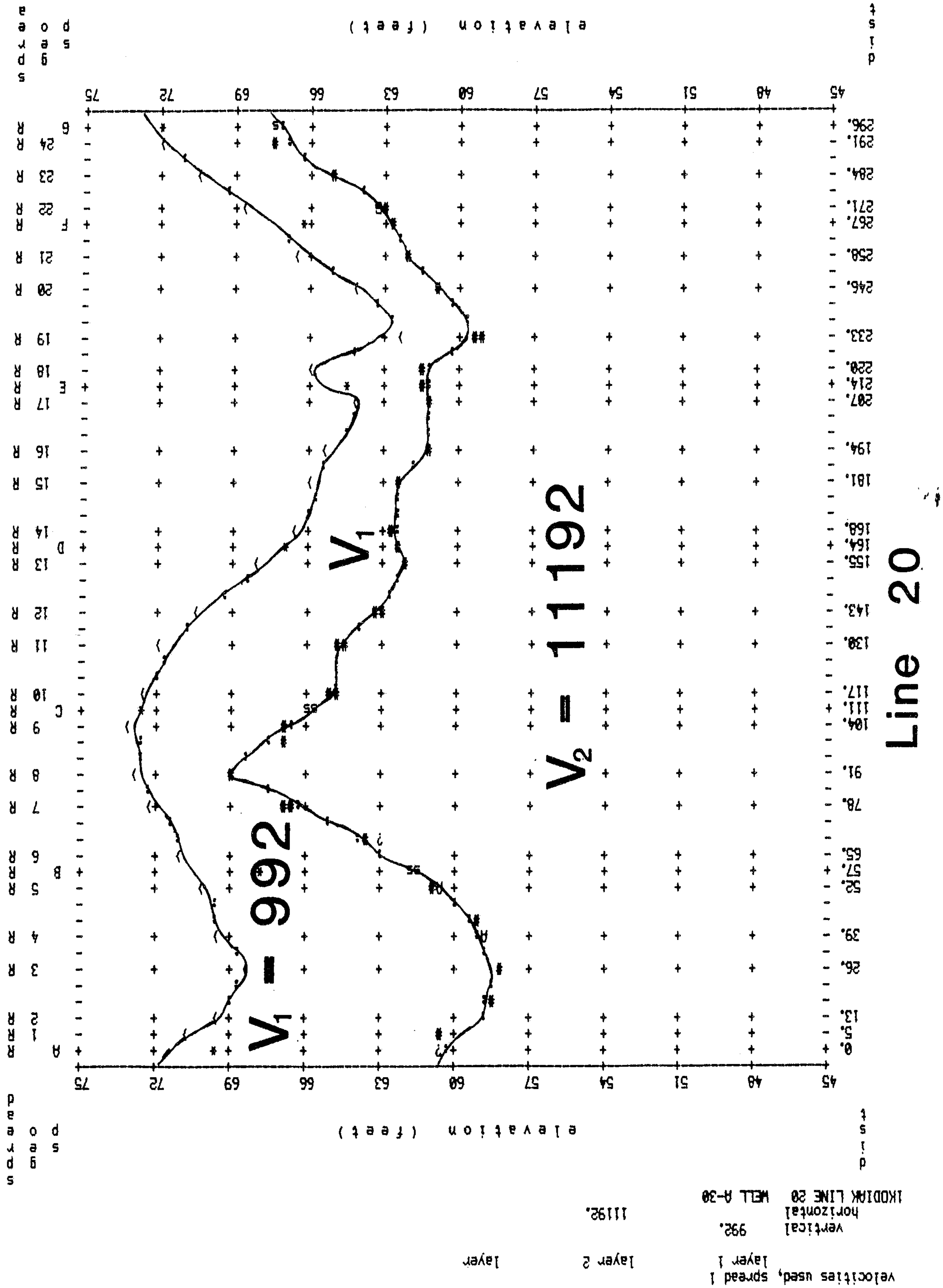
	layer 1	layer 2	layer 3	layer 4	layer
vertical	731.	1355.	3550.		
horizontal		1355.	3550.	10676.	

1KODIAK LINE 18 WELL A-71





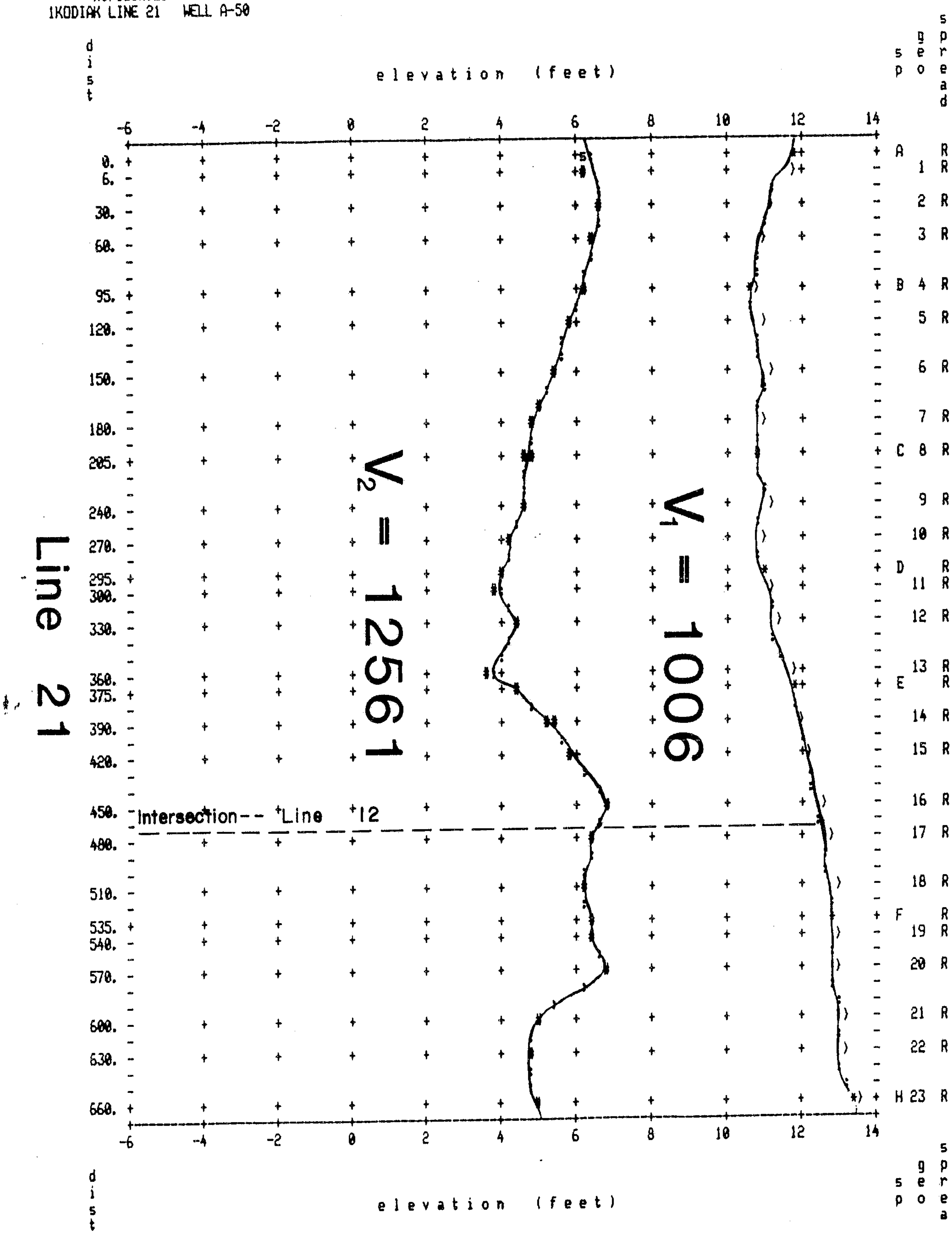
V1 = 979
VBr = 12307
Line 19
elevation (feet)
KODIAK LINE 19 WELL A-30
velocities used, spread 1
layer 1
layer 2
layer
vertical 979.
horizontal 12307.

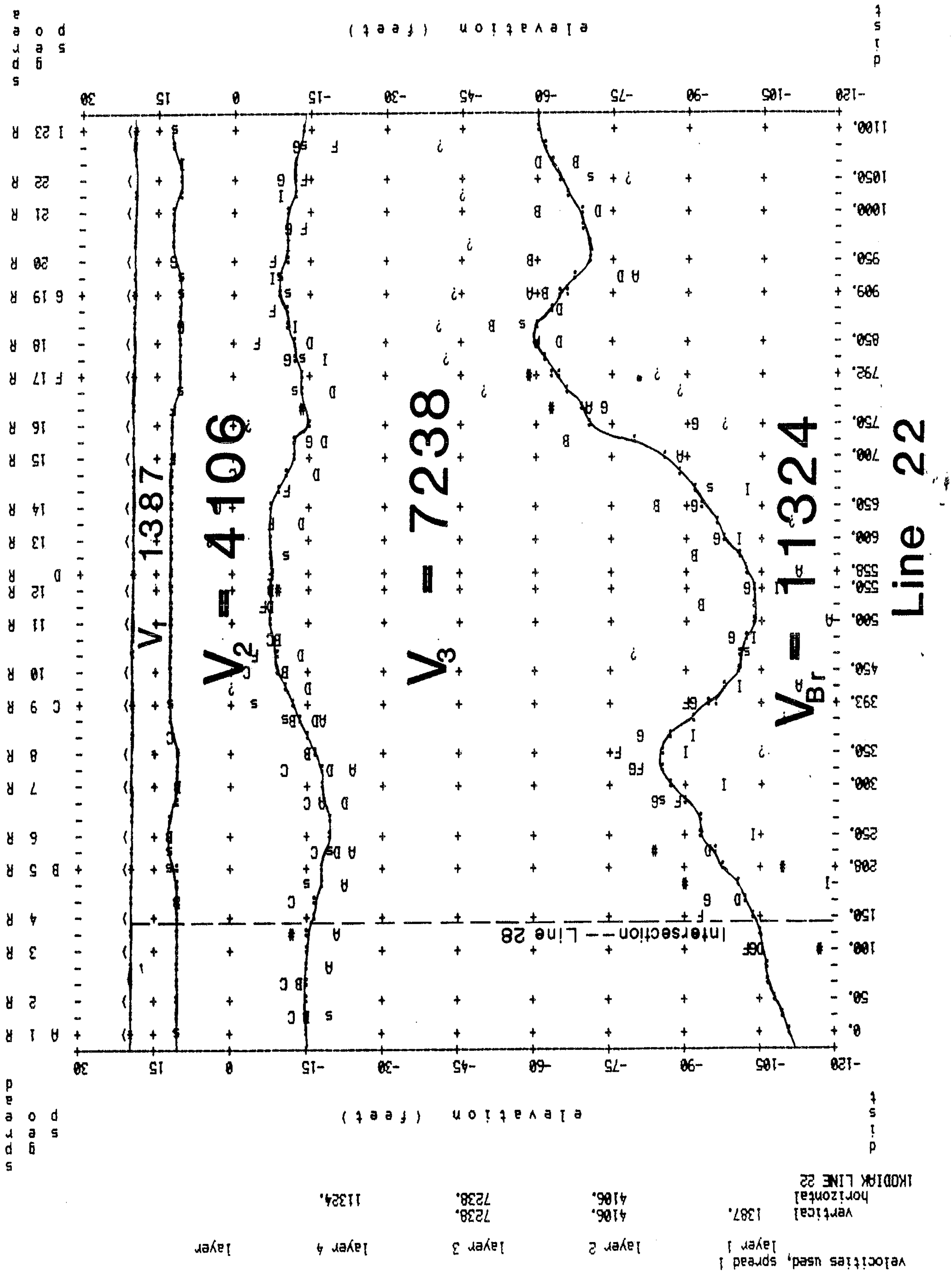

Line 20
V1 = 992
V2 = 11192
V1
elevation (feet)
IKODIAK LINE 20 WELL A-30
horizontal 11192.
vertical 992.
velocities used, spread 1
layer 1
layer 2
layer

velocities used, spread 1

	layer 1	layer 2	layer
vertical	1006.		
horizontal		12561.	

1KODIAK LINE 21   WELL A-50

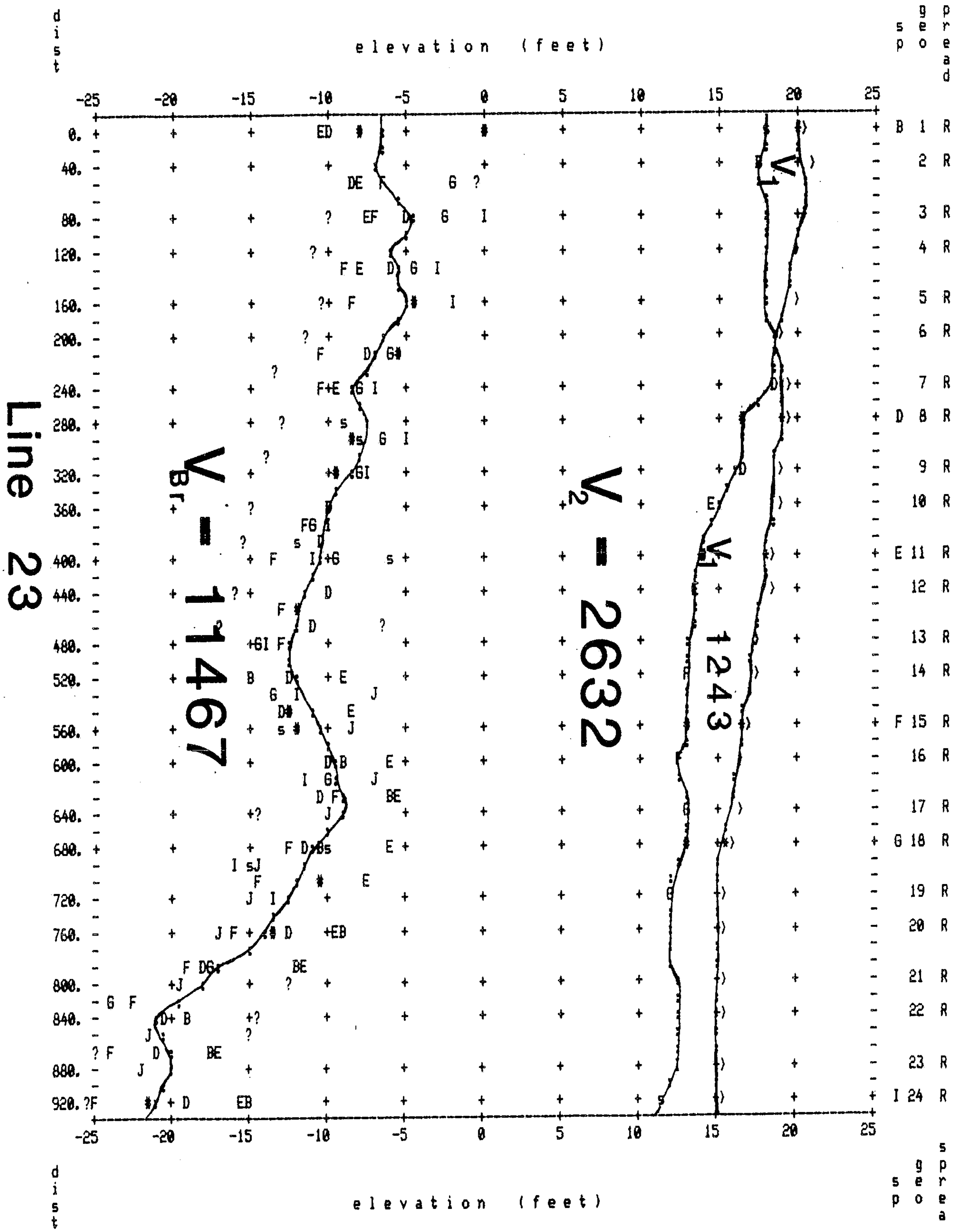




Line 22
V1 = 1387
V2 = 4106
V3 = 7238
VBr = 11324
Intersection -- Line 28

velocities used, spread 1	layer 1	layer 2	layer 3	layer
vertical	1243.	2632.		
horizontal		2632.	11467.	

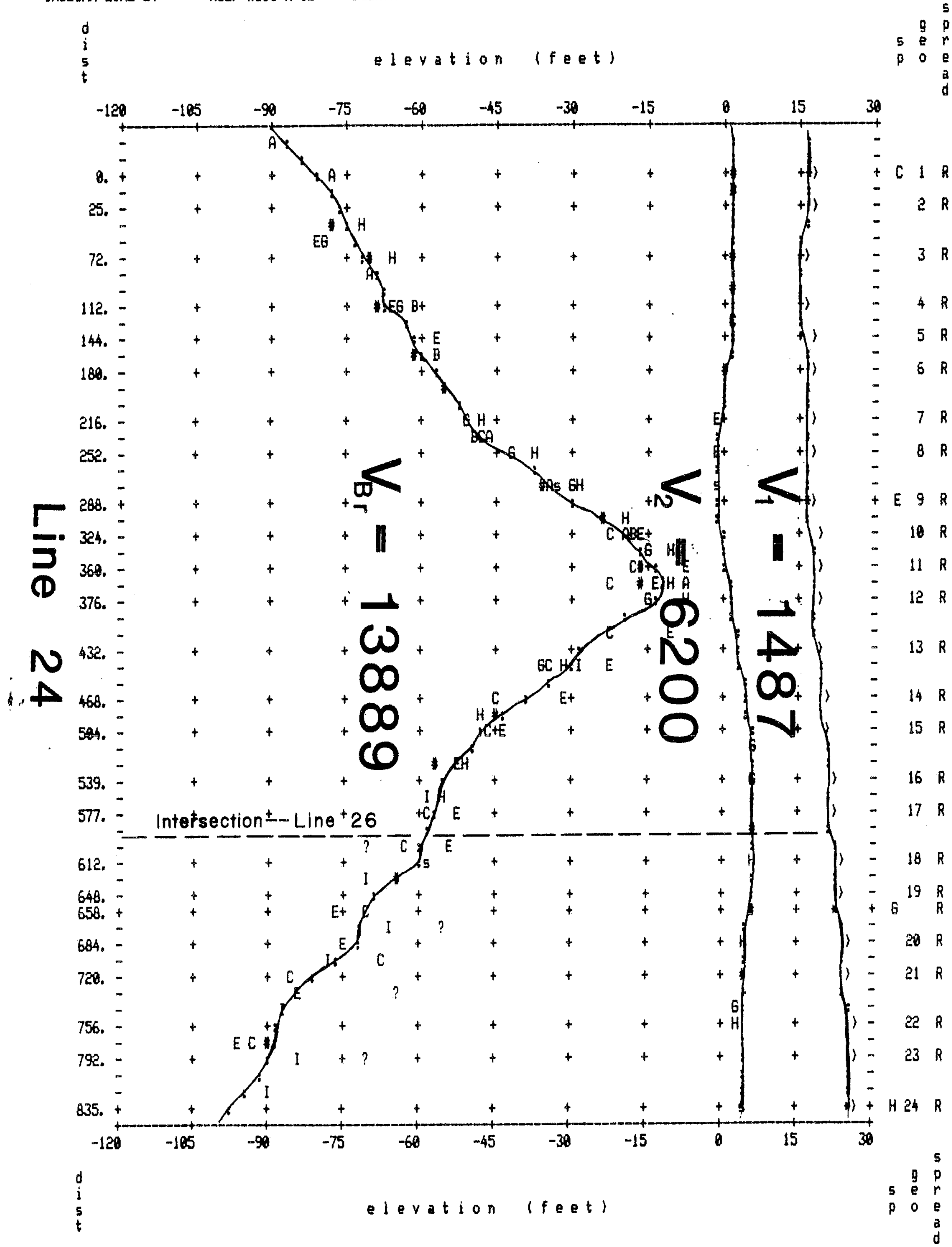
1KODIAK LINE 23 RUNWAY 18-36 between 25,28 turn bays



velocities used, spread 1   k24dfm31.ecf

	layer 1	layer 2	layer 3	layer
vertical	1487.	6200.		
horizontal		6200.	13889.	

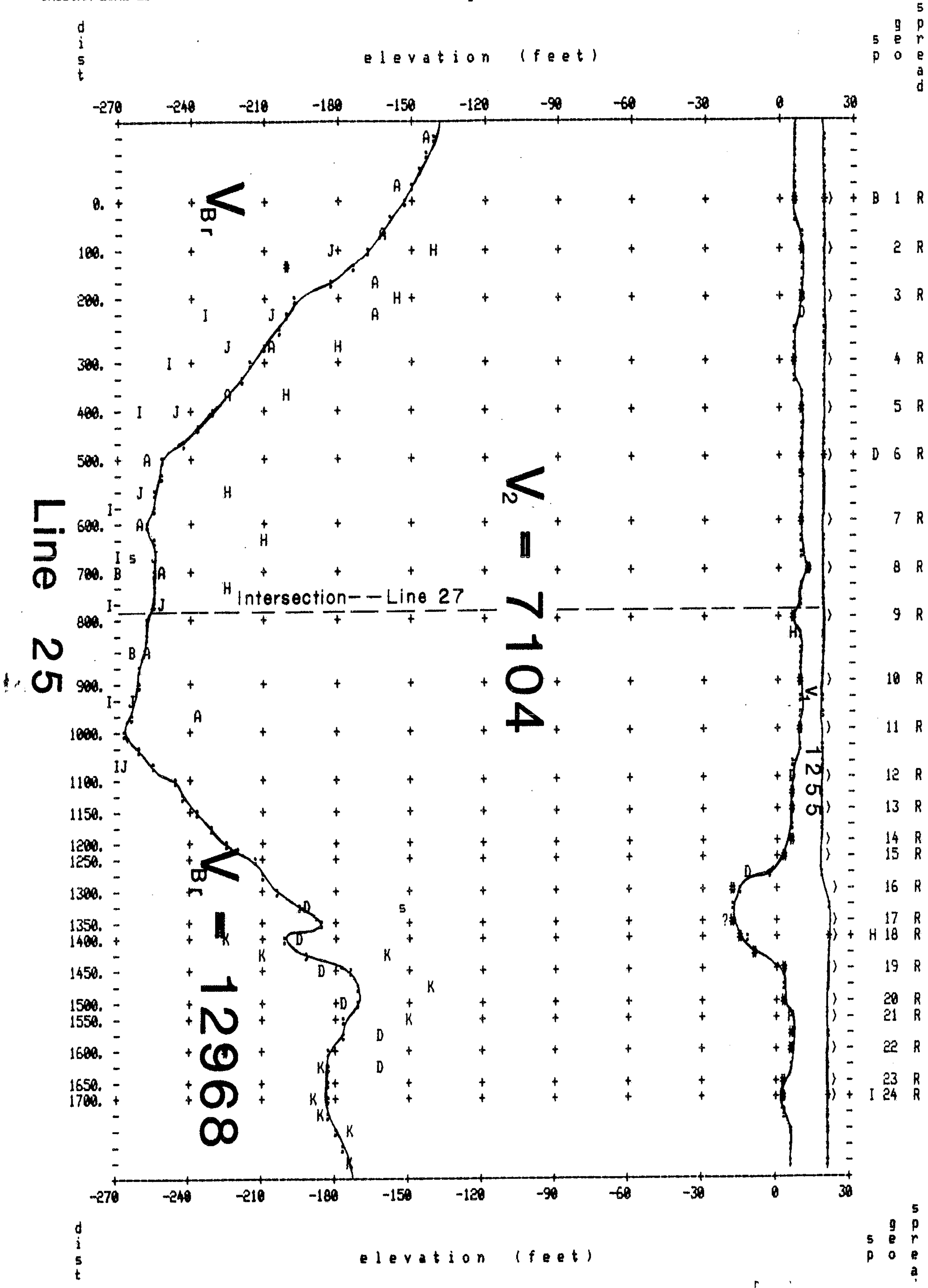
1KODIAK LINE 24   Near well A-12 - - Buskin River Cross-Shot



velocities used, spread 1 P25AM3.XS

	layer 1	layer 2	layer 3	layer
vertical	1255.	7104.		
horizontal		7104.	12968.	

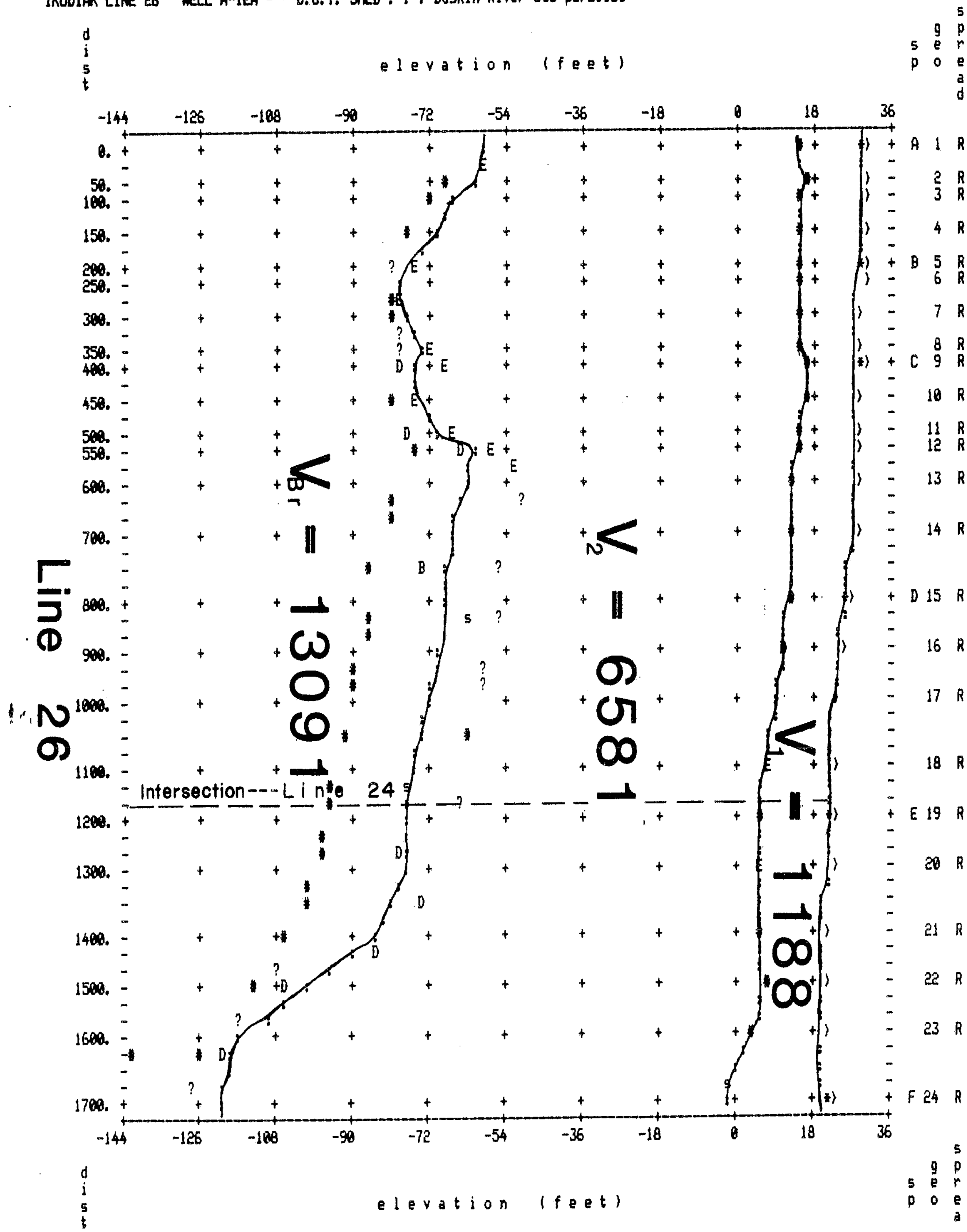
1KODIAK LINE 25 - - Parallel to R 10-28 between Broom Garage and 10-28/7-25 Inter



velocities used, spread 1

	layer 1	layer 2	layer 3	layer
vertical	1188.	6581.		
horizontal		6581.	13091.	

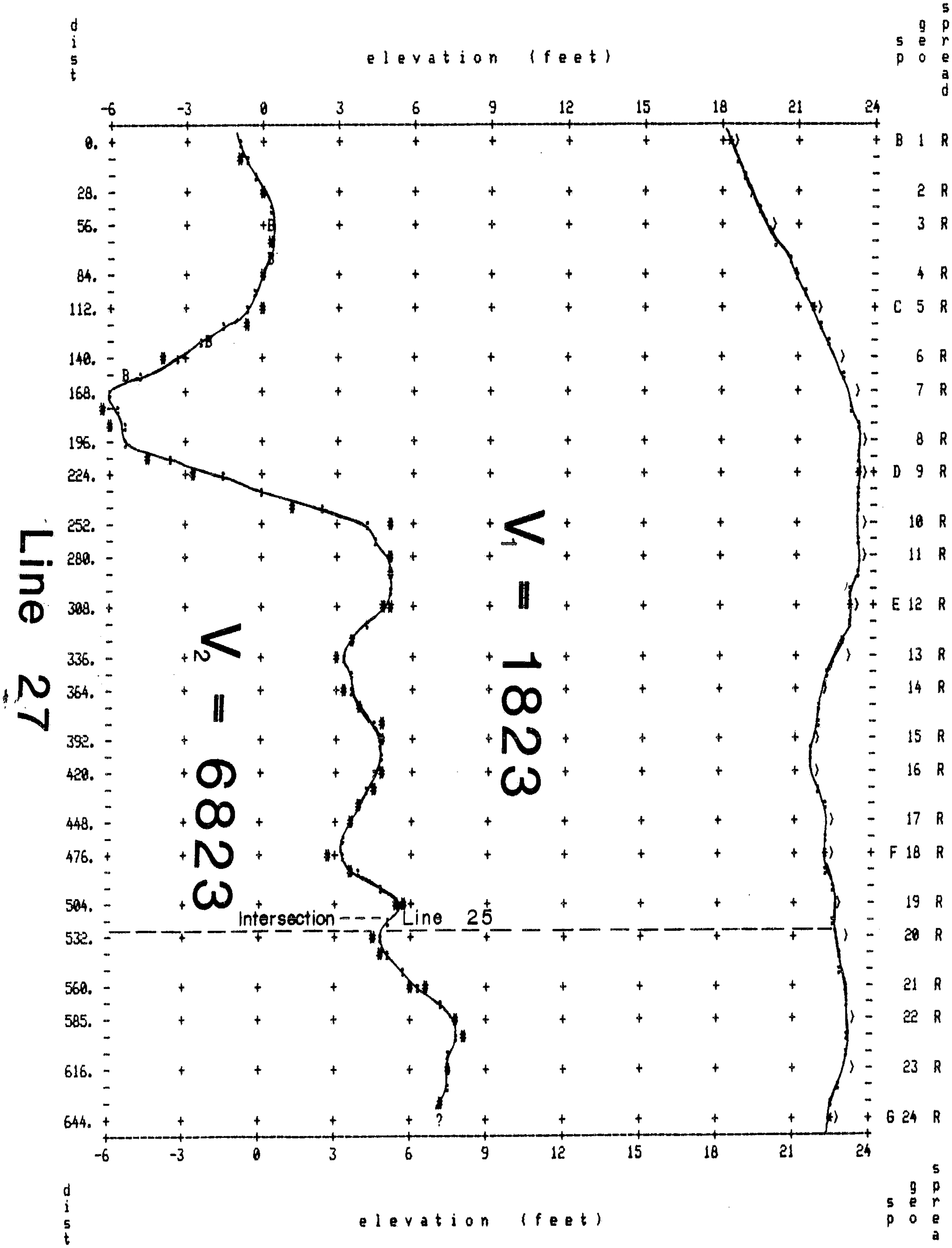
1KODIAK LINE 26 WELL A-12A - - D.O.T. SHED . . . Buskin River Sub-parallel



velocities used, spread 1
layer 1 layer 2 layer

vertical 1823.
horizontal 6823.

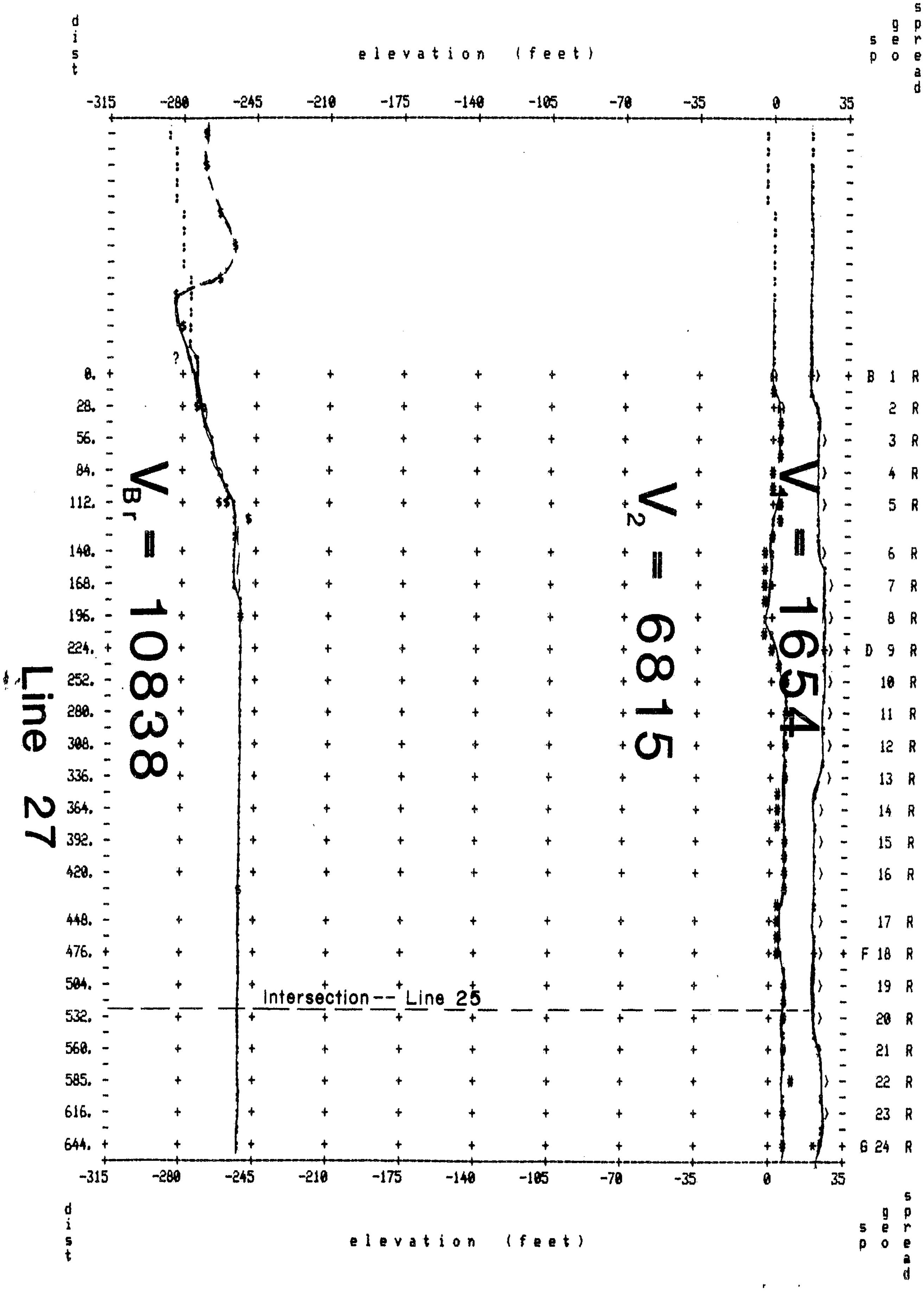
1KODIAK LINE 27 A-13 Access Road - - Transverse Buskin River Shot



velocities used, spread 1 K2/ce3m3.134

	layer 1	layer 2	layer 3	layer
vertical	1654.	6815.		
horizontal		6815.	10838.	

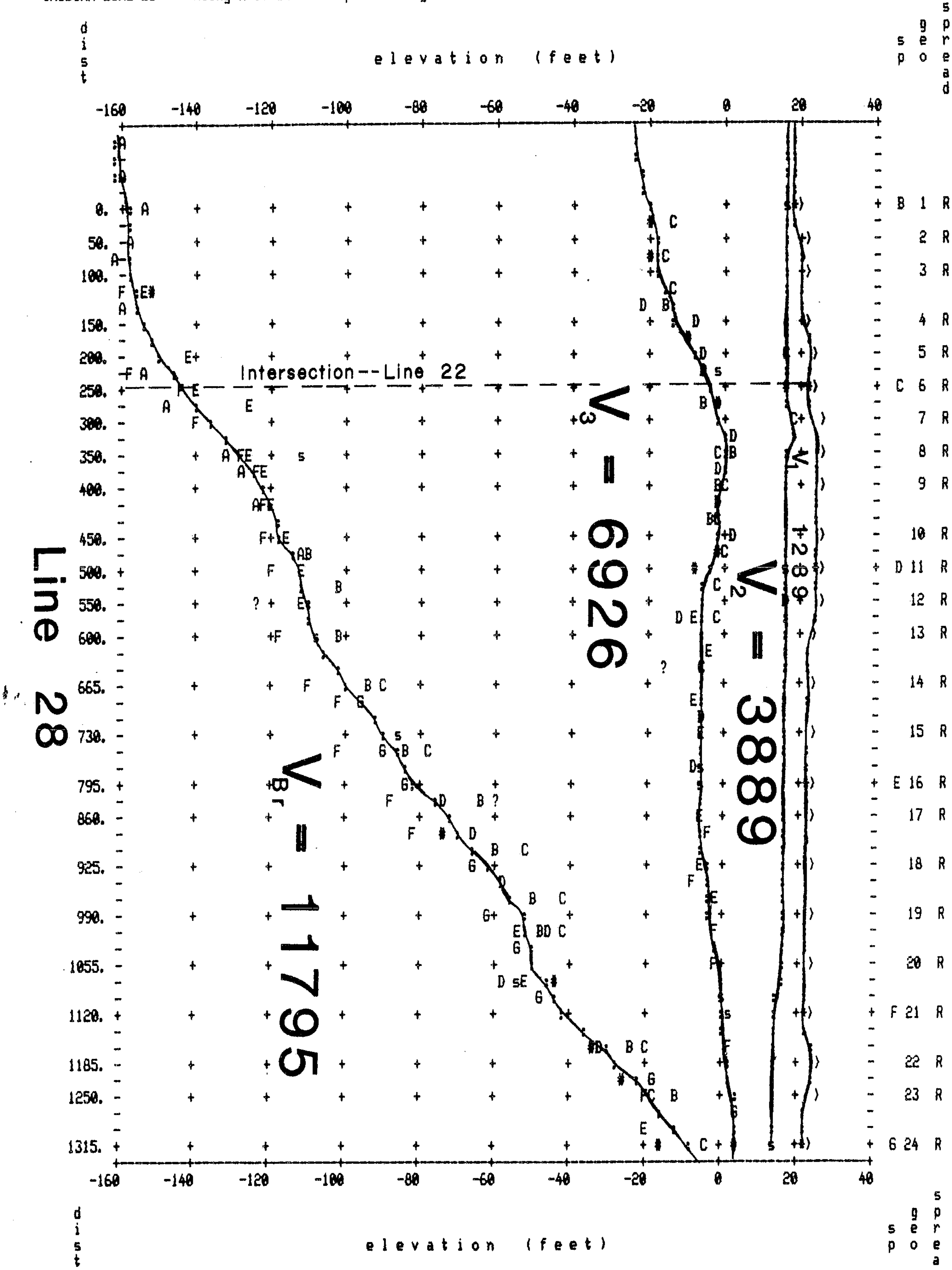
1KODIAK LINE 27 A-13 Access Road - - Transverse Buskin River Shot



velocities used, spread 1

	layer 1	layer 2	layer 3	layer 4	layer
vertical	1239.	3889.	6926.		
horizontal		3889.	6926.	11795.	

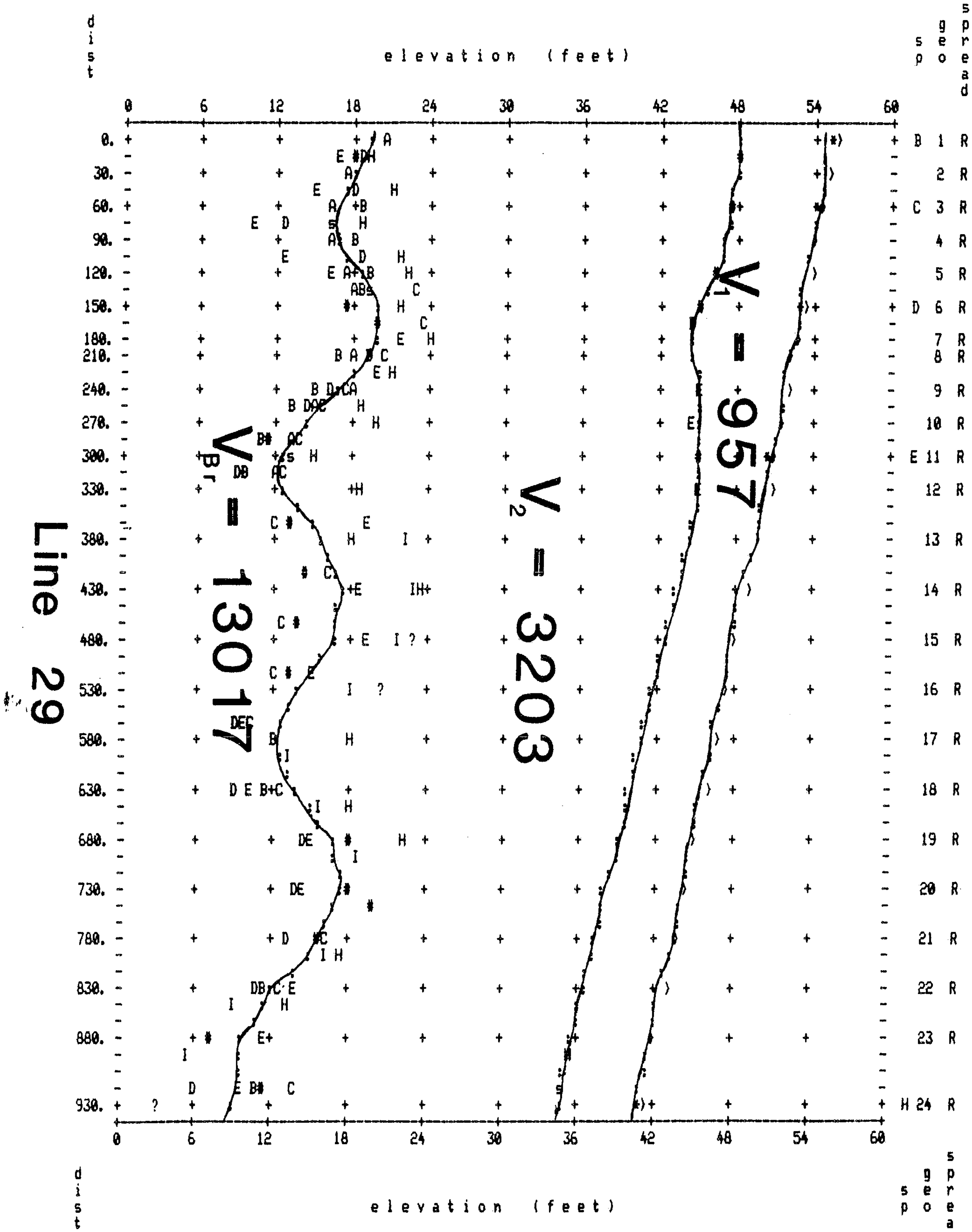
1KODIAK LINE 28 - - Along R 17-25 in compass triangle



velocities used, spread 1

	layer 1	layer 2	layer 3	layer
vertical	957.	3203.		
horizontal		3203.	13017.	

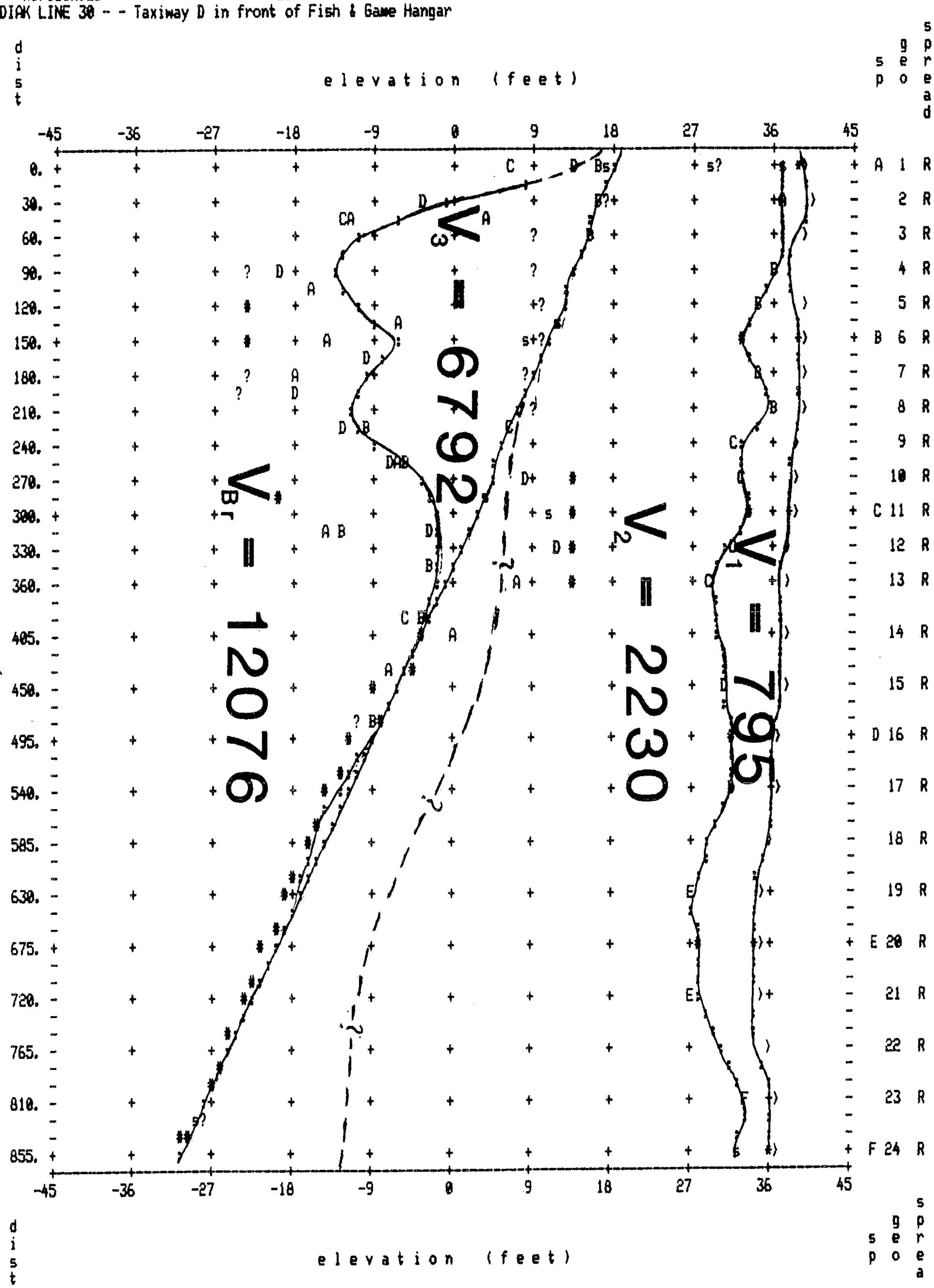
1KODIAK LINE 29 - - Elementary School Road / Well A-16



velocities used, spread 1

	layer 1	layer 2	layer 3	layer 4	layer
vertical	795.	2230.	6792.		
horizontal		2230.	6792.	12076.	

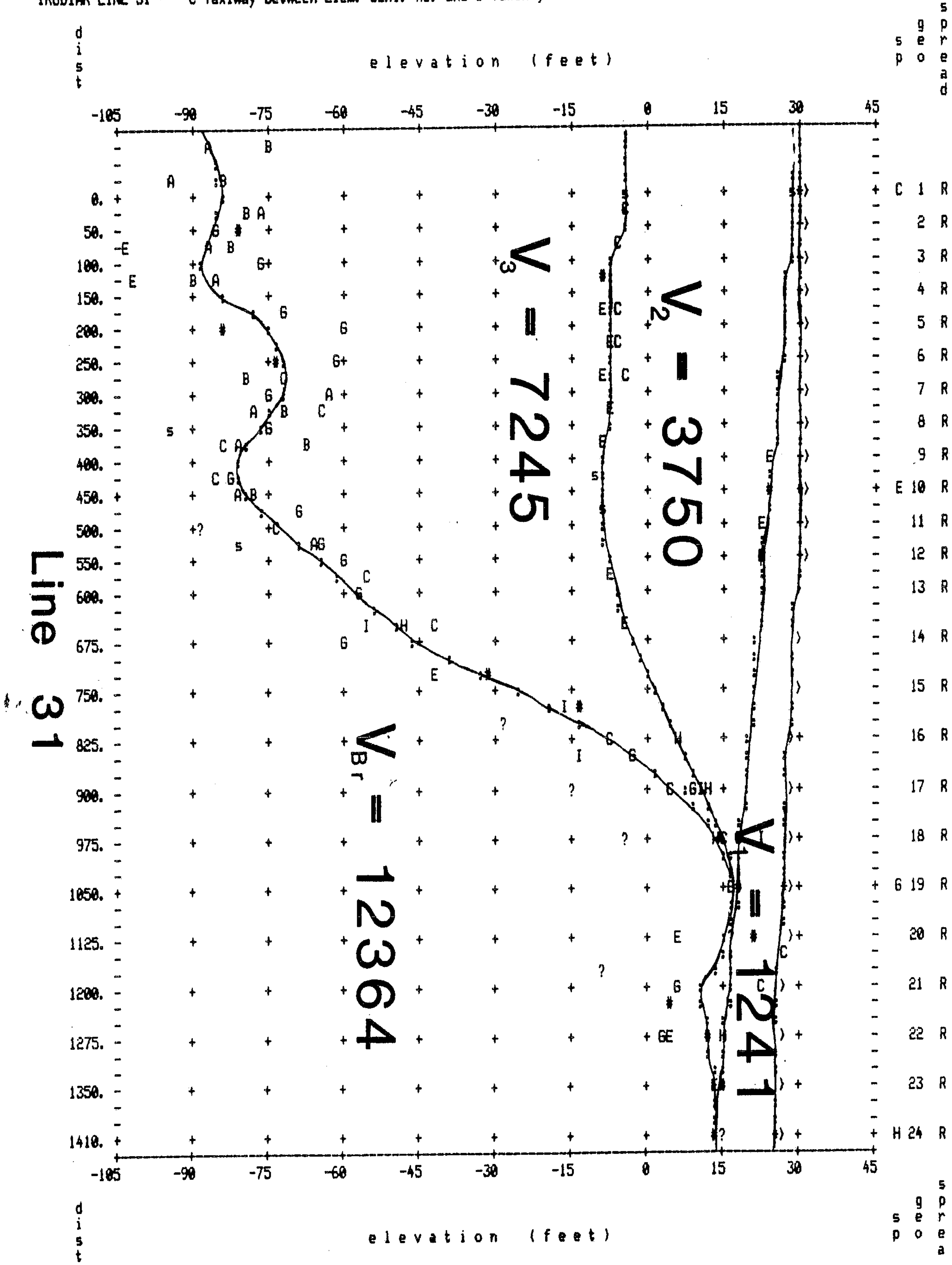
1KODIAK LINE 30 - - Taxiway D in front of Fish & Game Hangar

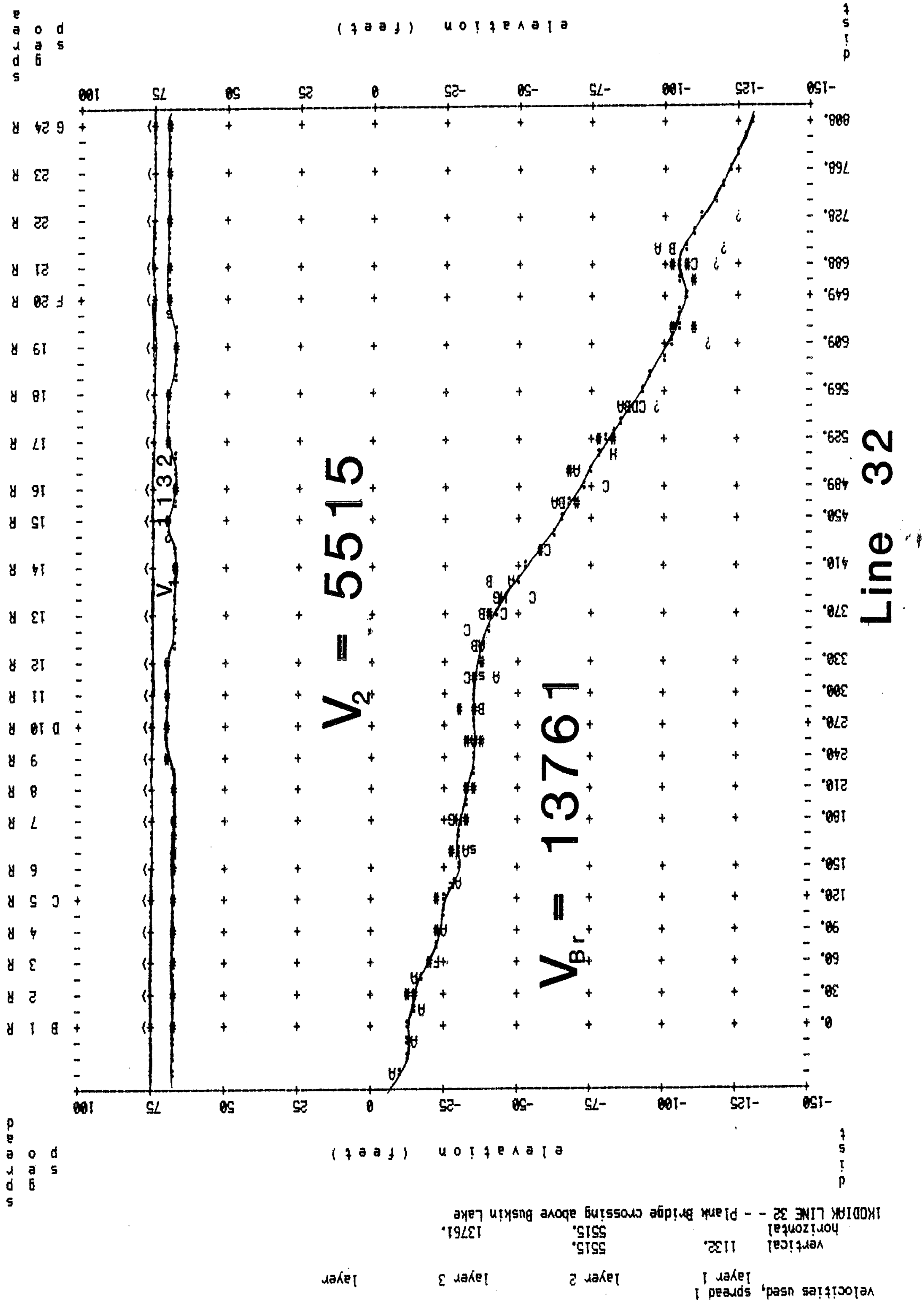


velocities used, spread 1

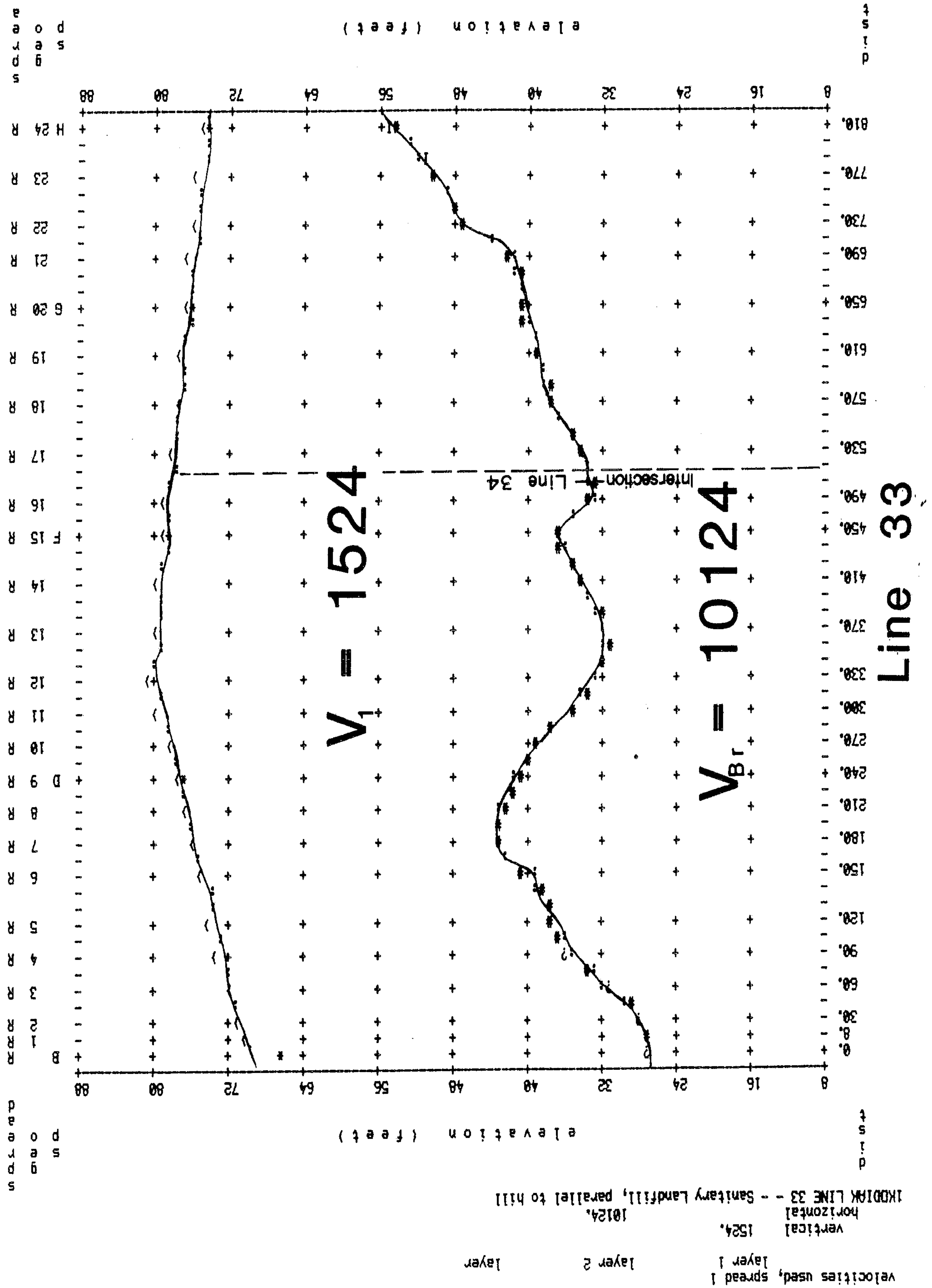
	layer 1	layer 2	layer 3	layer 4	layer
vertical	1241.	3750.	7245.		
horizontal		3750.	7245.	12364.	

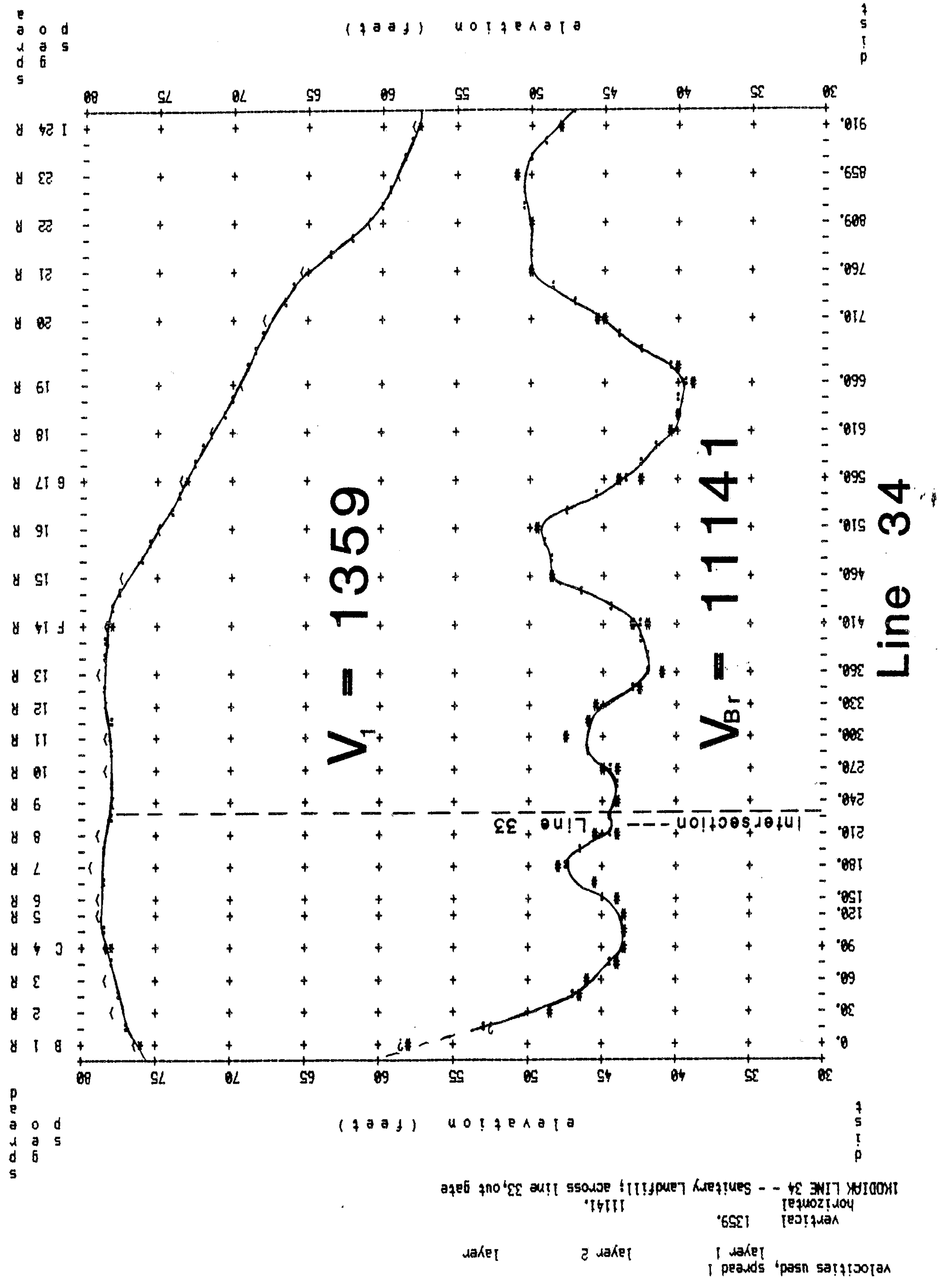
1KODIAK LINE 31 - - C Taxiway between Elem. Schl. Rd. and B Taxiway





Line 32
V1 = 1132
V2 = 5515
VBr = 13761
elevation (feet)
velocities used, spread 1
layer 1 layer 2 layer 3 layer
vertical 1132. 5515.
horizontal 5515. 13761.
IKODIAK LINE 32 - - Plank Bridge crossing above Buskin Lake


Line 33
V_1 = 1524
V_{Br} = 10124
Intersection — Line 34
elevation (feet)
dist
spread geo
velocities used, spread 1
layer 1 layer 2 layer
vertical 1524.
horizontal 10124.
IKODIAK LINE 33 -- Sanitary Landfill, parallel to hill

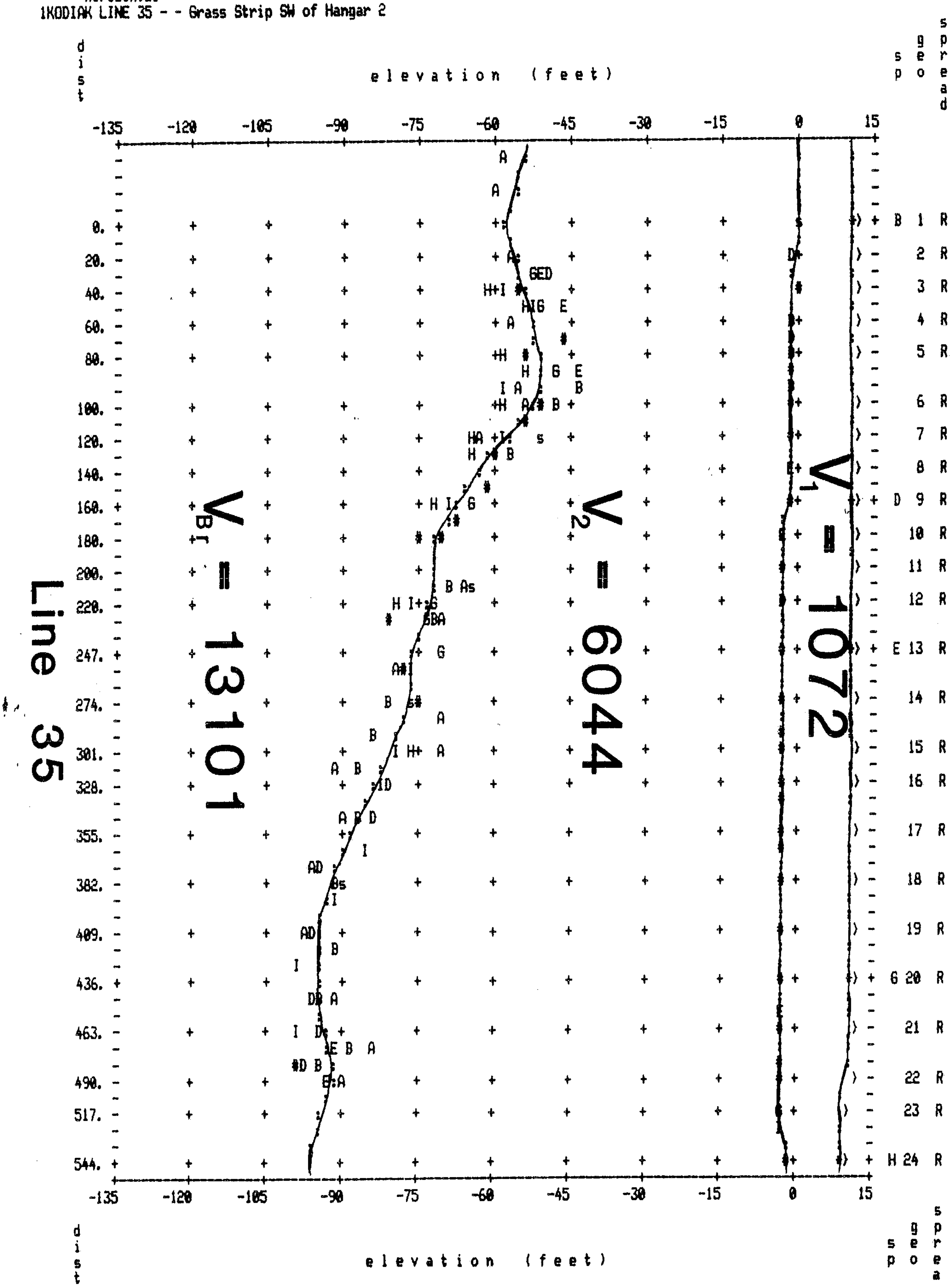


Line 34
V1 = 1359
VBr = 11141
Intersection --- Line 33
elevation (feet)
dist
spread
geo
KODIAK LINE 34 - - Sanitary Landfill; across line 33,out gate
horizontal 11141.
vertical 1359.
layer 1 layer 2 layer
velocities used, spread 1

velocities used, spread 1

	layer 1	layer 2	layer 3	layer
vertical	1072.	6044.		
horizontal		6044.	13101.	

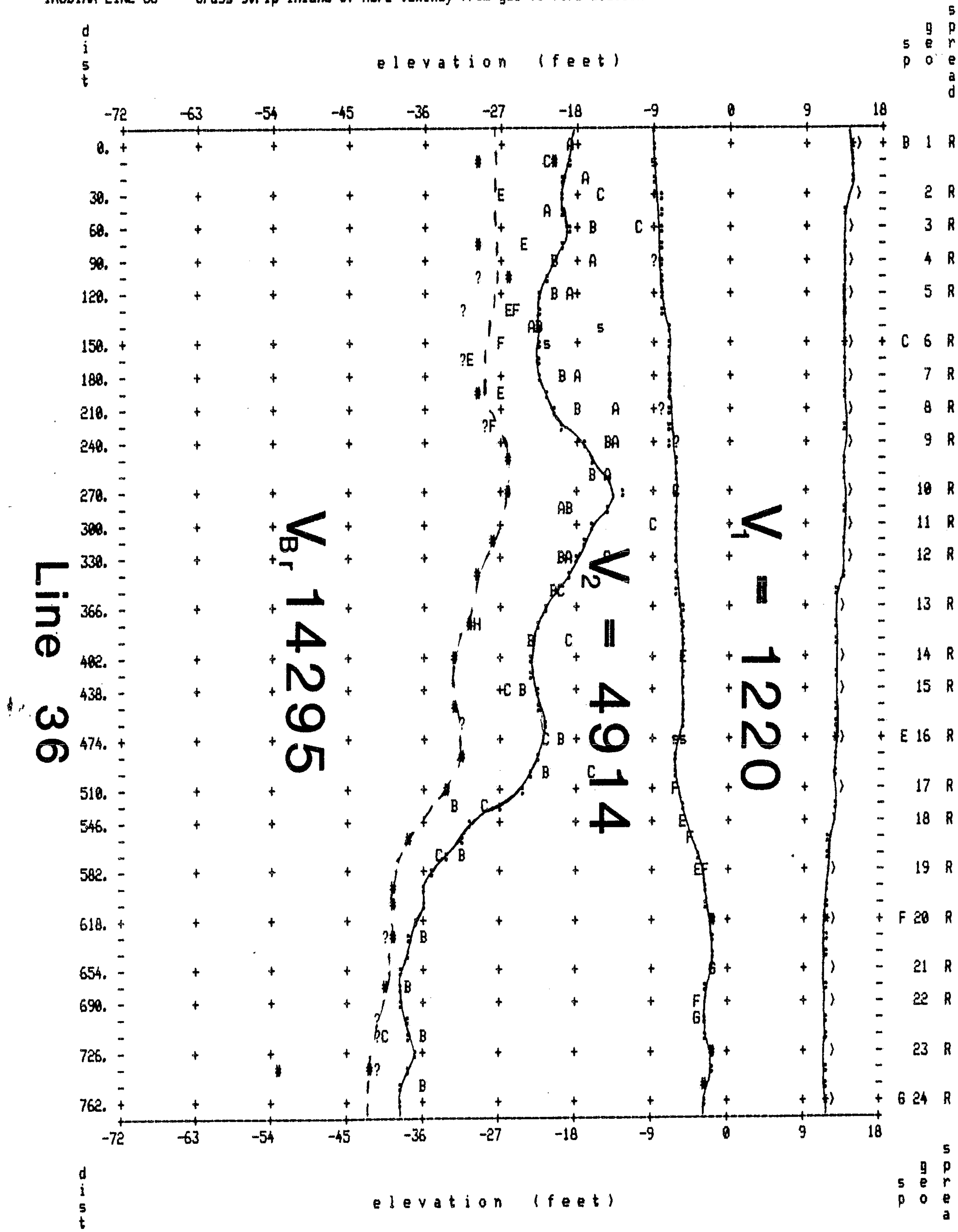
1KODIAK LINE 35 - - Grass Strip SW of Hangar 2

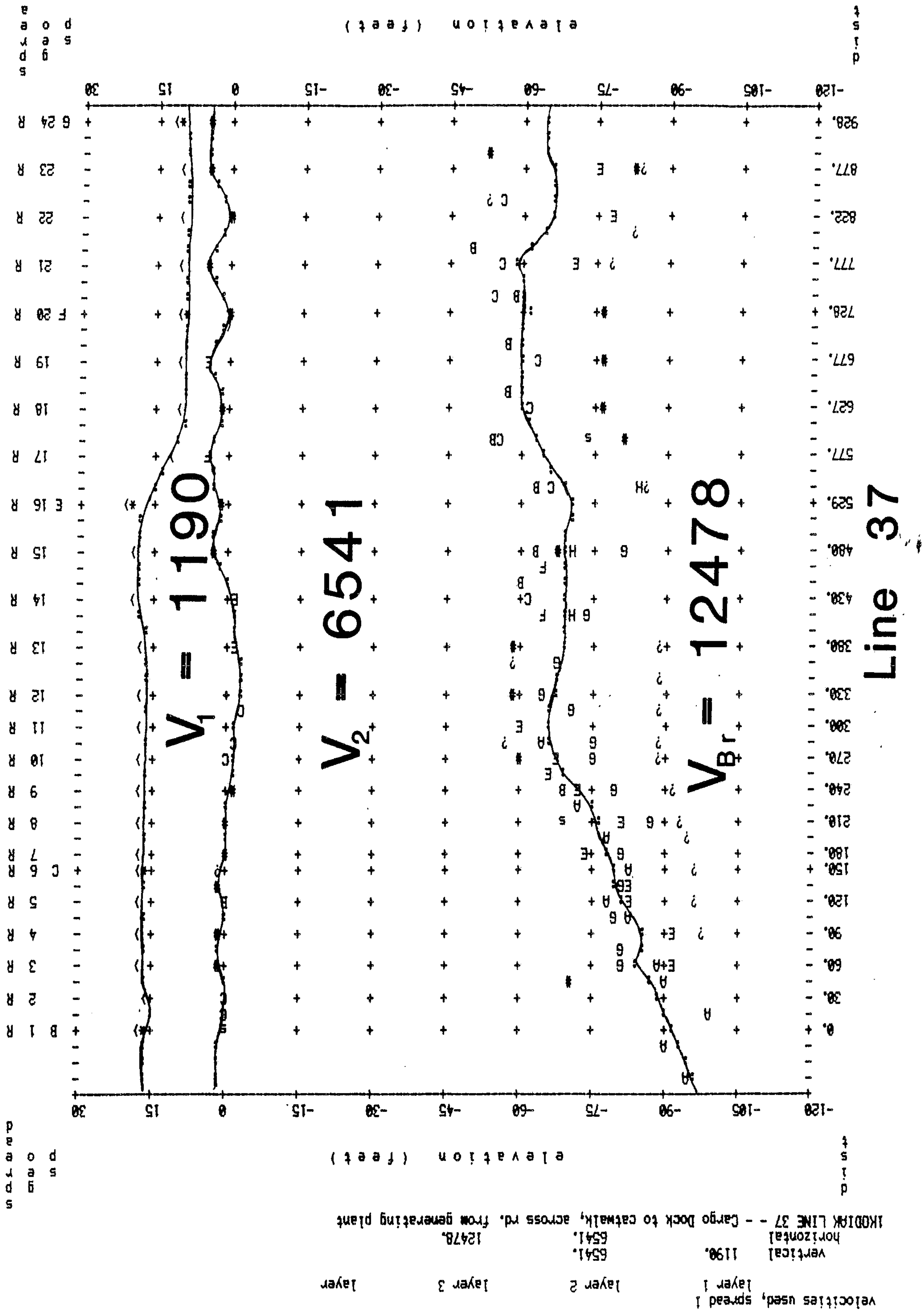


velocities used, spread 1

	layer 1	layer 2	layer 3	layer
vertical	1220.	4914.		
horizontal		4914.	14295.	

1KODIAK LINE 36 - - Grass strip inland of Herc taxiway from gas to fire station

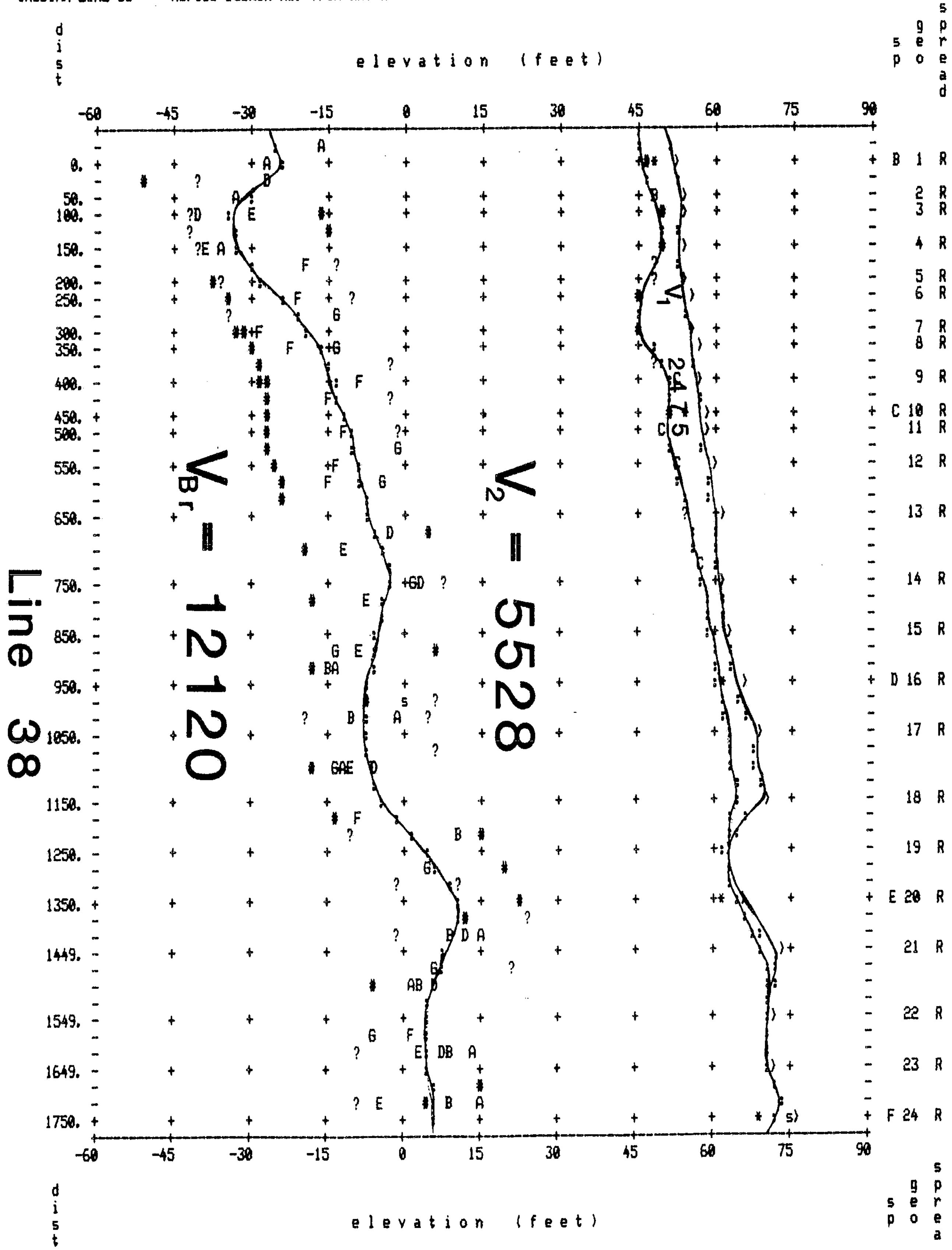


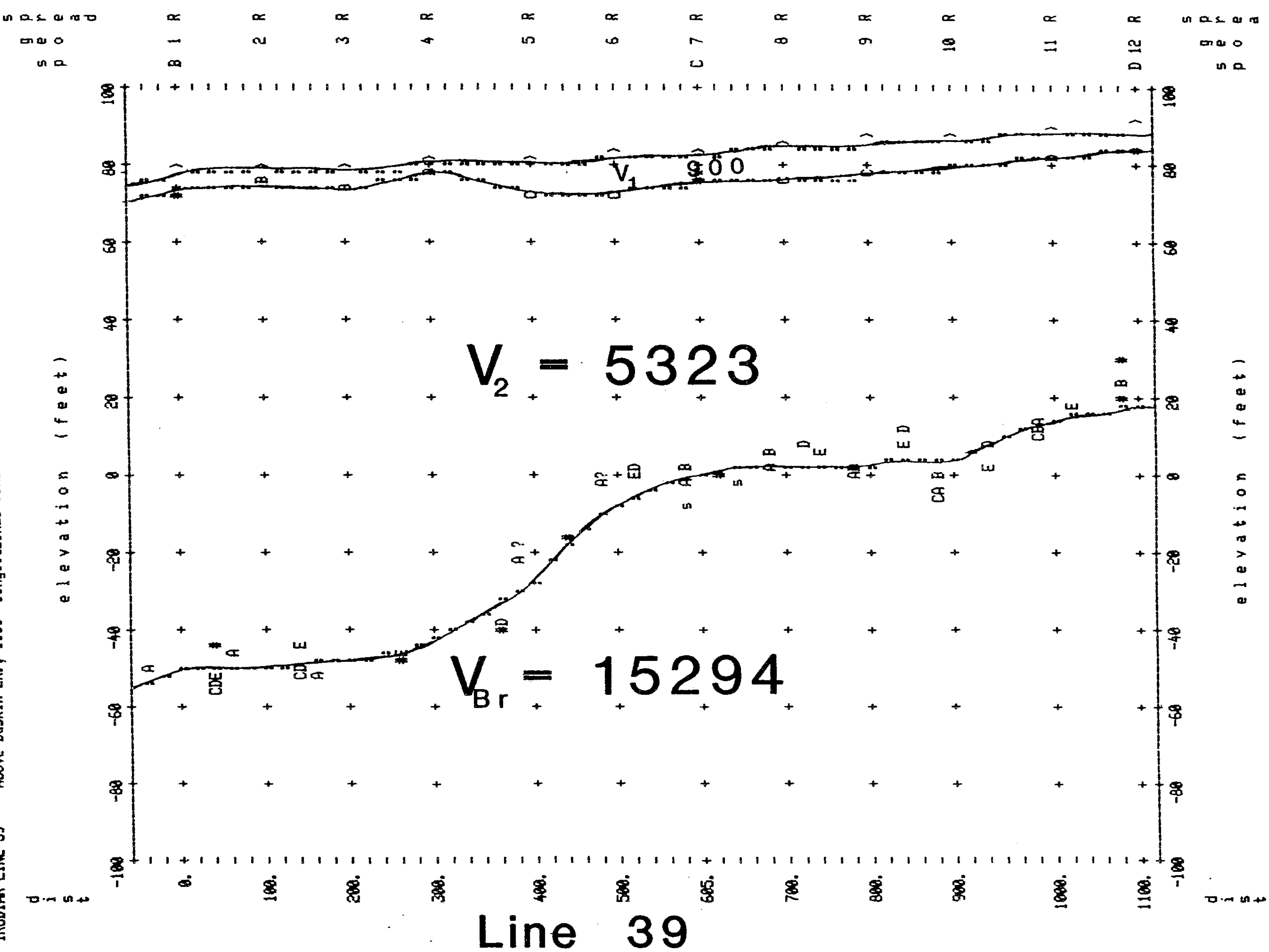

Line 37
V_1 = 1190
V_2 = 6541
V_{Br} = 12478
elevation (feet)
IKODIAK LINE 37 - - Cargo Dock to catwalk, across rd. from generating plant
velocities used, spread 1
layer 1 layer 2 layer 3 layer
vertical 1190. 6541.
horizontal 6541. 12478.

velocities used, spread 1

	layer 1	layer 2	layer 3	layer
vertical	2475.	5528.		
horizontal		5528.	12120.	

1KODIAK LINE 38 - - Across Buskin Rd. from antenna farm





velocities used, spread 1

	layer 1	layer 2	layer 3	layer
vertical	900.	5323.		
horizontal		5323.	15294.	

1KODIAK LINE 39 - - Above Buskin Lk.; 1100' longitudinal line