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Canada-Russia geotechnical studies of permafrost Bovanenkovo test site Yamal Peninsula, Western Siberia

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P.J. Kurfurst

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CANADA-RUSSIA GEOTECHNICAL STUDIES OF PERMAFROST
BOVANENKOVO TEST SITE
YAMAL PENINSULA, WESTERN SIBERIA

JULY 1991

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July 1992

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1. Introduction (P.J. Kurfurst)

Major oil and gas discoveries in the arctic areas of Canada and Russia have created an urgent need for regional and site specific knowledge of geological, geotechnical and geothermal conditions of these areas. This information is essential especially for the design, construction and maintenance of engineering structures such as pipelines and related facilities. As a part of Canada-USSR Arctic Scientific Exchange, Theme 7.1 "Geological conditions and development of petroleum-bearing regions of the Arctic" a joint Canada-Russia program of extensive geotechnical field studies was carried out on the Yamal Peninsula, Russia in July 1991 in order to compare existing methodology and field techniques and to test new techniques and equipment for detection and delineation of massive ground ice and saline permafrost. Results of the field and laboratory studies provided the basis for detailed geological and permafrost profiles and maps and led to selection and recommendation of effective methods and techniques of geotechnical mapping in different permafrost terrains, required by the oil and gas exploration and construction industries working in the Arctic.

The results of geotechnical studies of the Bovanenkovo oil and gas field on the Yamal Peninsula, Western Siberia are described and documented in this Open File. The selection of the site for detailed field studies was based on evaluation of existing geological and landform maps of the northern Yamal Peninsula. Field studies included geological profiling and mapping, geotechnical drilling and borehole sampling, standard and experimental surface geophysical profiling and mapping, standard and experimental downhole logging, ground probing radar, and topographical surveys.

This investigation, based on preliminary interpretation of field results, produced detailed profiles and maps of the distribution and extent of surficial materials, various bodies of massive ground ice, and zones of saline permafrost.

Laboratory tests of the collected samples included standard physical properties (grain size, Atterberg limits, density, water content), salinity, mineralogy and geochemistry (clay minerals, stable isotopes) of soils, water and ice; results will be used in the final interpretation of the field geotechnical data. Two shells were also recovered and submitted for radiocarbon dating for age determination.

2. Geological setting (P.J. Kurfurst, E.S. Melnikov)

The Yamal Peninsula is located in Western Siberia in the northern part of the West Siberia basin (Fig. 1). The peninsula is 750 km long and 240 km wide and lies between the Obskaya and Baydaratskaya Gulfs of the Kara Sea (Fig. 1 - inset). The West Siberian Basin deepens northward, with several kilometres of sediments beneath the Yamal Peninsula. The sedimentary cover is composed of marine and continental deposits of Jurassic, Cretaceous and Paleocene age. Bovanenkovo oil and gas field, shown in Fig.1, lies within the North-Central Gas District. The surface relief, developed in late Quaternary, consists mainly of the Upper Quaternary and Holocene terraces (Ershov, E.D., 1989). The terraced surface of the region is cut by trough-shaped river valleys. The slopes of these valleys are dissected by short ravines with steep slopes, caused by thermal erosion of ice-rich sediments. Polygon-ridge relief is widespread in the depressions and on the elevated and flat parts of the terraces. The study area is located within two major landscape units, first marine terrace (ImV) and recent river floodplain (OaA). A detailed map of the Bovanenkovo study

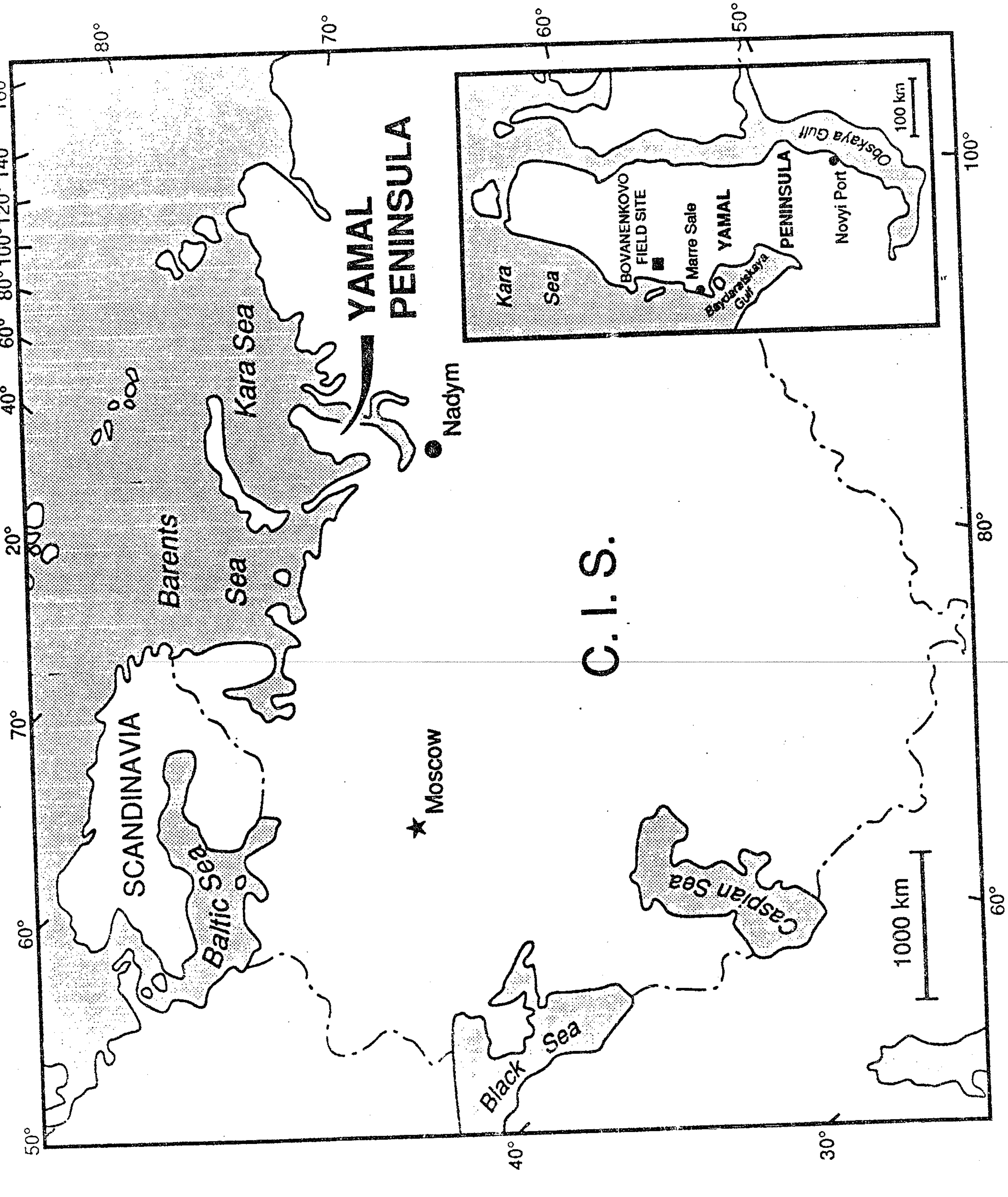

YAMAL PENINSULA
Kara Sea
Barents Sea
Nadym
C. I. S.
Moscow
SCANDINAVIA
Baltic Sea
Black Sea
Caspian Sea
1000 km
Kara Sea
BOVANENKOVO FIELD SITE
Marre Sale
YAMAL PENINSULA
Baydaratskaya Gulf
Novyi Port
Obskaya Gulf
100 km

Figure 1

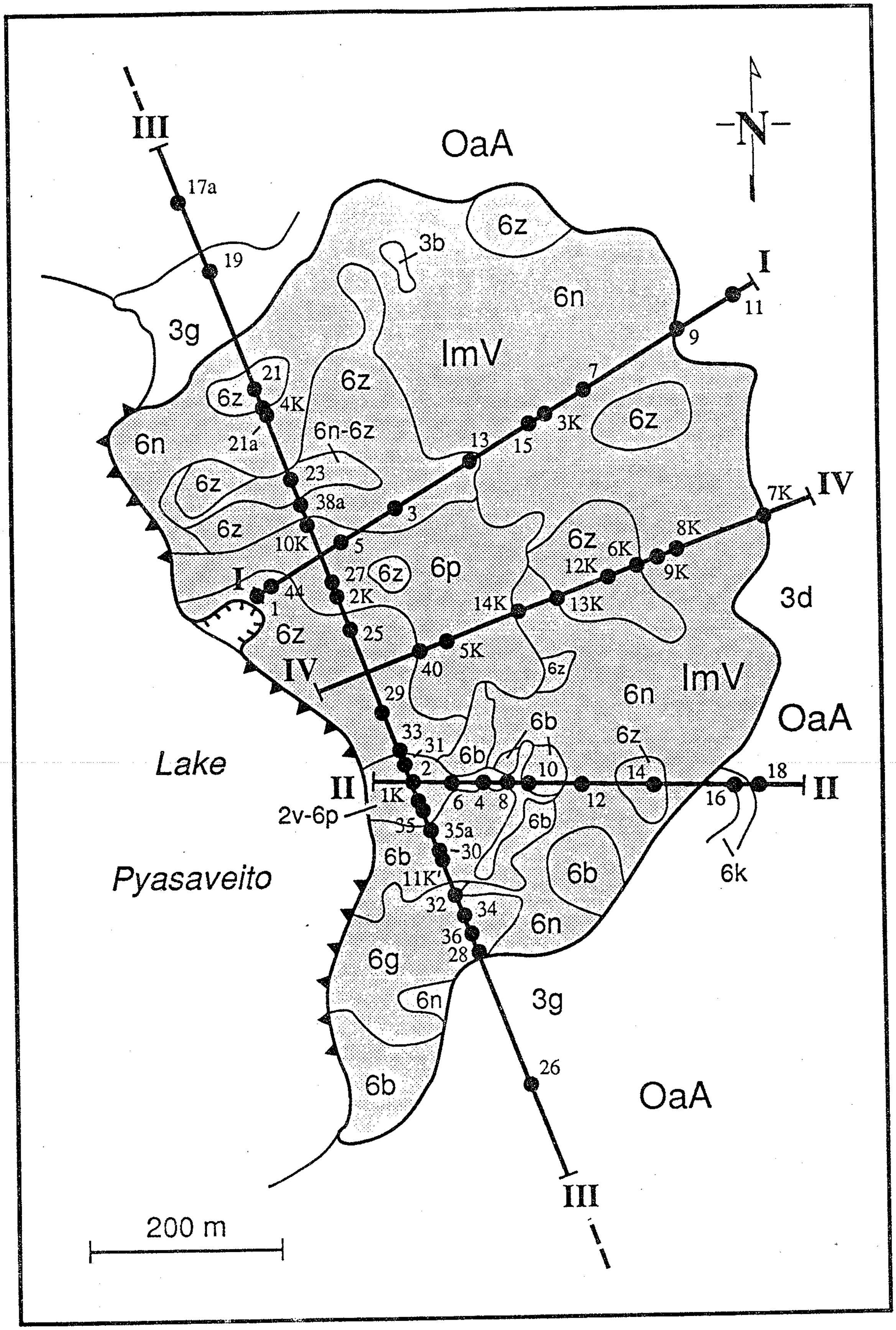
site, showing the landscapes, land units and sub-units present, and the accompanying legend, are presented in Fig. 2.

3. Field studies

The field studies of the Bovanenkovo area were carried out by scientists from the VSEGINGEO Institute in Moscow between 1987 and 1990. Based on preliminary 1:50 000 maps of landscape units and results from drilling, site KU-2-90 was selected for detailed investigations. Results of preliminary mapping and the 1990 drilling along four profiles (Fig. 2 – I to IV) indicated the presence of sediments ranging from clays to sands with various ice contents. The study area also contained large body of massive ice up to 12 metres thick. After studying the available maps and profiles, locations for geotechnical boreholes and geophysical surveys were selected by the scientists from the Geological Survey of Canada (GSC); all field work described in this Open File was conducted by a joint VSEGINGEO/GSC team during July 1991.

3.1 Surface mapping (S.E. Grechischev, E.I. Tschervova

Surface studies included detailed mapping of various surficial sediments and associated vegetation cover within the two major landscape types, viz. first marine terrace (OaA) and recent river floodplain (ImV). Each landscape type is associated with one of two land units (A and V). Seven and three land sub-units respectively were recognized and described within the first marine terrace and recent river flood plain landscape types. The field results were combined into a legend and a landscape map of the study site showing all landscape types, land units and sub-units (Fig. 2). Surface mapping was complemented by



N
OaA
III
I
IV
II
ImV
6n
6z
3b
3g
6n-6z
6p
6b
6g
6k
3d
Lake
Pyasaveito
2v-6p
17a
19
21
21a
4K
23
38a
10K
5
3
13
15
3K
7
9
11
7K
8K
6K
9K
12K
13K
14K
5K
40
27
2K
44
1
25
29
33
31
2
1K
6
4
8
10
12
14
16
18
35
35a
30
11K'
32
34
36
28
26
200 m

Figure 2

LEGEND

I ——— I	geological profiles
● 6K	boreholes
OaA / ImV	boundaries of landscapes
3g / 6n	boundaries of land sub-units
	shore scarps
	gullies

LANDSCAPES

Im	first marine terrace
Oa	recent river flood plain

LAND UNITS

A	lacustrine, bog, flat
V	solifluction / landslides, hilly

LAND SUB-UNITS

First Marine Terrace

2v	ravines, gully
3b	swamps, flat
6b	terraces, polygonal, well drained
6g	terraces, polygonal, poorly drained
6n	terrace slopes
6p	terraces, eroded
6z	terrace slopes, micro-polygonal

Recent River Flood Plain

3d	swamps, polygonal
3g	swamp complex
6k	low area of flood plain

a detailed topographic survey of the study area. Results of this survey, showing elevations and topographic contours, are summarized in Fig. 3.

3.2 Geotechnical drilling and sampling (P.J. Kurfurst, A.M. Tarasov)

Fourteen boreholes (1K-14K) ranging in depth from 10 to 24 m were drilled along profiles I, III and IV in locations where additional information on lithology or massive ice was required or in areas where geophysical anomalies were detected. In addition, two boreholes drilled in 1990 (34 and 36) were reamed out to allow downhole logging using Canadian equipment. Locations of both the 1990 boreholes (1-44) and the 1991 boreholes (1K-14K) are shown in Fig. 2.

A small hand-held portable drill was used to drill 75 mm diameter boreholes and collect continuous soil and ice samples with spoon sampler. A total of 97 samples were collected for future laboratory analyses. All samples were logged for lithology, ice content, cryological structures and borehole temperatures and prepared for shipping. The field borehole logs, showing all relevant information, are summarized in Figs. 4-17. This information was combined into four profiles (I to IV) showing detailed geology and extent of massive ice (Fig. 18).

Borehole bottom temperatures were recorded to provide detailed information on the geothermal region at the study site; these temperatures are also presented in geology/ice profiles in Fig. 18.

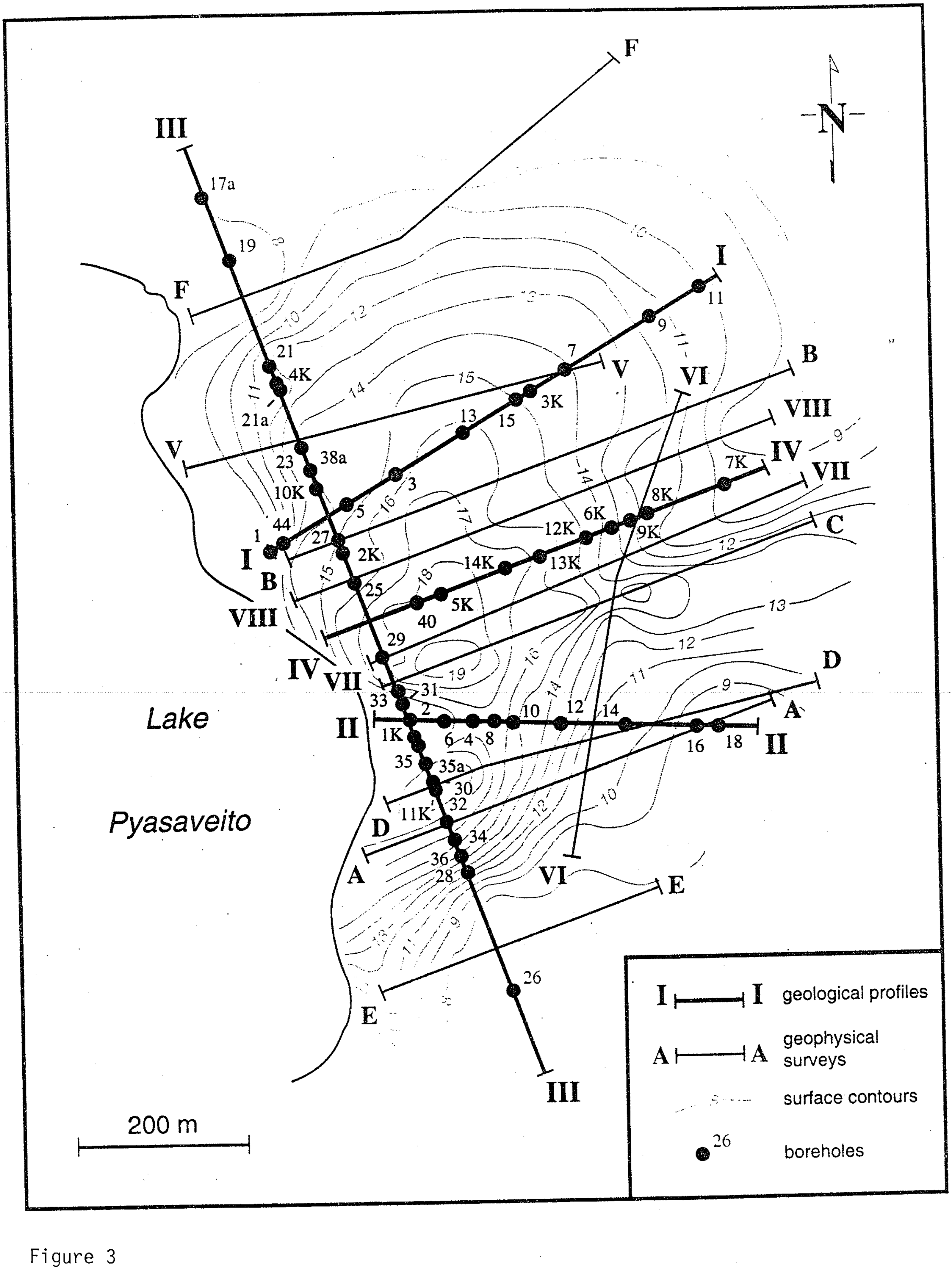

Lake
Pyasaveito
N
I
II
III
IV
V
VI
VII
VIII
A
B
C
D
E
F
200 m
geological profiles
geophysical surveys
surface contours
boreholes

Figure 3

3.3 Surface geophysical surveys (B.J. Todd, V.M. Timofeev, R.A. Burns, A.G. Skvortzov, N.N. Tzarov)

Surface geophysical surveys included standard electromagnetic (EM) surveys (EM-31 and Max-Min I portable EM units) and high frequency electrical profiling (VCHEP). These techniques determine the near-surface distribution of electrical resistivity.

An experimental common depth point (CDP) shallow seismic shear wave reflection technique was also used to determine vertical and horizontal extent of massive ice bodies.

Electromagnetic (EM) surveys (B.J. Todd, V.M. Timofeev)

Electromagnetic (EM) surveys have been used in northern North America for the detection of permafrost and for mapping its horizontal and vertical distribution. EM methods are suitable for subsurface mapping of permafrost because the electrical resistivity of earth materials increases with decreasing temperature as incorporated water is frozen.

The location of the survey lines at Bovanenkovo site is shown in Fig. 19. Data were collected on 14 lines totalling 7.85 km in length. The grid was situated on the eastern shore of Lake Pyyasaveito extending about 1200 m south to north and 700 m west to east over a prominent topographic high surrounded by flat plains. The survey area elevation was between 8 and 20 metres above sea level (Fig. 20). Previous drilling had demonstrated that the hills are ice-cored.

An inductive, frequency-domain EM method was used in this study. Instruments of this type employ a local transmitter coil to generate a time-varying magnetic field that induces small eddy currents in the earth. These eddy currents produce a secondary magnetic field which is detected, along with the primary field, by a receiver coil. This secondary field and its depth of penetration are a function of the intercoil spacing, the operating frequency, and the ground conductivity. Under certain constraints, the ratio of the secondary to the primary magnetic field is linearly proportional to the terrain conductivity.

For shallow permafrost mapping, two portable EM units were used; a Geonics EM-31 and an Apex MaxMin I. These instruments determine the near-surface lateral distribution of electrical resistivity and consequently are used to map the horizontal distribution of shallow permafrost. The station interval used for these surveys was 10 m, though this interval was decreased to 5 m where abrupt lateral changes in readings occurred.

The Geonics EM-31 operates at 9.8 kHz with a fixed intercoil spacing of 3.66 m. Three measurements with the instrument provide three effective depths of exploration. A horizontal dipole at ground level corresponds to 2.1 m effective depth; a horizontal dipole at hip level to 3.7 m; and a vertical dipole at ground level to 4.6 m. The apparent electrical conductivity of the ground is read from the instrument in milli-Siemens per metre (mS/m).

The Apex MaxMin I is a multifrequency horizontal loop EM (HLEM) system which operates at 110, 220, 440, 880, 1760, 3520, 7040 and 14080 Hz. The lowest frequency provides the deepest penetration and the highest frequency provides the shallowest. Readings of in-phase and quadrature components of the secondary magnetic field were made using a coil spacing of 50 m. The effective depth of exploration is approximately 25 m.

The data from the EM-31 survey are shown in Figs. 21a, 21b and 21c, corresponding to effective depths of exploration of 2.1, 3.7 and 4.6 m. The contour interval for all three maps is 5 mS/m. The general distribution of the pattern of apparent conductivity is the same on the three maps: a broad high of >20 mS/m centred over about 100 m east on lines IV and VII (where peak readings reached 60 mS/m) and a smaller area of high values centred over 470 m east on lines B and VIII. These areas of high apparent conductivity correspond with areas of low apparent resistivity mapped by other methods (Fig. 22). The outer zones of the study area show apparent conductivities of 5 mS/m or less.

The broad high conductivity area shown in Fig. 21 is located just north of the highest elevation (Fig. 20). Drilling indicates the clayey silt in this high conductivity area is not underlain by ice. The high values of conductivity suggest either that the active layer is thicker here than elsewhere in the survey area, or that the active layer is of similar thickness as elsewhere but that high salinity groundwater is near the surface. The small conductivity high near the east end of lines B and VIII corresponds to low, moist, thawed ground adjacent to a small lake at the eastern termination of these lines. Low apparent conductivity values in the remaining portions of the study area suggest that shallow permafrost is present to within 1-2 m of the ground surface.

The MaxMin results are shown in Fig. 23a to 23e. Lines I, II, and E (Fig. 23a, 23b and 23e) demonstrate the Horizontal Loop Electromagnetic (HLEM) response over frozen ground. Both the in-phase and quadrature components are essentially flat. Line III (Fig. 23c) shows both an in-phase and quadrature response from 500 to 650 m. Inspection of Fig. 21 shows that this HLEM anomaly corresponds to the region of high apparent conductivity mapped using the EM-31. Similarly, line IV (Fig. 23d) shows a quadrature anomaly from 50-300 m along the line corresponding to the intersection of line IV with the mapped conductivity high (Fig. 21).

Areas of high apparent conductivity were mapped at Bovanenkovo site using two frequency-domain EM instruments. This qualitative analysis demonstrates a relationship between the EM-31 and the MaxMin results. A future quantitative analysis of these data will provide estimates of the depth of unfrozen ground beneath the anomalous areas.

The data presented in this report are available in digital form in ASCII and GEOSOFT format.

Shear wave reflection survey (R.A. Burns, A.G. Skvortzov, N.N. Tzarov)

A CDP shallow seismic shear wave reflection profile was shot along the north-south baseline (0-0) from approximately 600 N to 900 N (Fig. 24). The source was the rod driven into the ground at a 45° angle transverse to the line and hit with a 2 kg sledge hammer. An average of 11 blows (ranged from 10 to 13) were stacked in the seismograph before the rod was withdrawn and reset in the ground angled in the opposite direction. The polarity of recording was then switched in the seismograph and an additional 11 (average) blows were stacked into the original signal. This procedure was used at every source location to attenuate the compressional energy and enhance the shear wave signal.

The shear wave reflection data were recorded as 12-channel records with 2 m spacing between geophones and a 2 m offset between the source and nearest geophone. Single 50 Hz horizontal geophones, oriented transverse to the survey line, were used as the receiver for each channel. The geophones were buried 10-15 cm below the ground surface to improve the ground coupling and minimize the wind noise picked up by the receivers. A rollalong switch was used to roll through a series of 24 geophones planted along the line. Expanded spreads (12-channel records) were collected with a source spacing of 2 m, resulting in a 6-fold CDP data set.

Three example expanded spreads are shown in this report (Figs. 25-27). They show a clear large-amplitude reflection from a clay/ice or clay/sand interface at a time of approximately 60 ms. Records 765 and 768 show the classic hyperbolic moveout on the reflection. Record 778 was shot over an area where the massive ice body was rising steeply to the north, as indicated by the negative moveout observed on the reflection signal on this record.

Six common offset panels that were pulled from the CDP data set are also shown in this report (Fig. 28-33). They correspond to offsets between source and receiver of 4, 6, 8, 10 and 12 m, with the 12 m offset panel being plotted both with and without static corrections. Static corrections have been made for all offsets by aligning the first shear arrivals. The improvement in the coherency of subsurface reflections that results from the application of static corrections is evident in a comparison of the 12 m panels.

The panels corresponding to small offsets (4 and 6 m) show indications of the dipping surface of the massive ice body in the vicinity of borehole 2K (BH2), but the reflection from this interface is muted and indistinct in places. The subsurface structure is much clearer in the 8, 10 and 12 m offset panels. The dipping surface of the massive ice body produces a strong reflection in the vicinity of borehole 2K, while the interface between frozen clayey silt and sand at the south end of the profile is also indicated by a shear wave reflection. At the north end of the profile, the interface between the massive ice and the overlying fine-grained sediments is shallow, and does not produce a reflection that is resolvable from the first arrival refraction event at these offsets.

The shear wave reflection survey showed that this technique has potential as a tool for mapping subsurface structure in this environment. Interfaces between frozen fine-grained sediments and coarser-grained sediments or massive ice appear to be characterized by reflection coefficients that are high enough to produce observable reflections; however, the contrast between massive ice and frozen sand is more subtle, and such boundaries are difficult to observe using this technique.

3.4 Borehole logging (J.A Hunter, V.M. Timofeev, R.A. Burns, A.G. Skvortzov)

Two passive (natural gamma, conductivity) and two active (gamma-gamma, neutron) downhole logs were run in all the 1991 boreholes (1K to 14K) and in available 1990 boreholes (90-34, 90-36). Seismic downhole logging was conducted only in boreholes 1K, 2K, 4K, 10K and 11K. Downhole shear wave VSP surveys were carried out in boreholes 2K, 4K, 10K and 11K.

Natural gamma and conductivity logs

Two passive logs, the natural gamma log and the electrical conductivity log, were run with the Geonics EM-39 system by GSC personnel. Measurements on both logs were made at 2.5 cm intervals in all the 1991 boreholes (1K to 14K) and in two 1990 boreholes (90-34, 90-36).

The natural gamma tool consists of sodium iodide crystal as the detector of gamma radiation. As a general rule gamma count rates in the order of 100-150 cps indicate the presence of silty clay. Count rates in the order of 50-100 cps correlate with silt or silty sand. Count rates below 50 cps are generally consistent with coarse-grained sands and gravels. Count rates approaching 0 cps are indicative of massive ice. All natural gamma logs are shown in Figs. 34-47.

The conductivity tool provides a direct measure of formation conductivity in millisiemens per metre. Since conductivities in ice-bonded permafrost are extremely low, this tool requires careful calibration as well as cooling in the hole before measurements are taken.

Conductivities in most holes were in general less than 10 mS/m indicative of ice-bonding or excess ice in the sediments. Conductivities in the 10-20 mS/m range are indicative of fine-grained sediments with some unfrozen water content. Conductivities above 20 mS/m are probably indicative of substantial unfrozen water content or of saline conditions.

Some conductivity logs show the presence of thin conductive zones. Some of these anomalies may result from intense magnetic storms which occurred during the survey period; however, many of these anomalies were repeatable on the second or third run of the log in the borehole. All electrical conductivity logs are presented in Figs. 48-61.

Gamma-gamma and neutron logs

Two active logs, a gamma-gamma log and a neutron log, were run by VSEGINGEO personnel in 13 1991 boreholes (1K-8K, 10K-14K). The gamma-gamma log is an active tool using an uncollimated radioactive Cesium source. Gamma radiation received in the tool is correlated to density of the formation using a calibration curve. Measurements were made at 25 cm intervals. In general, ice-rich sediment densities are in the 1.3 to 1.6 g/cm^3 range. Massive ice densities are in the range of 0.9-0.93 g/cm^3. Plots of density versus depth are shown in Fig. 62-74.

Estimates of the water content in percent by volume are derived from the neutron log. An uncollimated neutron source (unspecified) was used. The neutron count rate detected at the receiver end of the tool varies inversely with the hydrogen content, and hence can be used as an indicator of water content. A calibration curve was used for conversion to volume percent water content. In general, ice-rich sediments show values in the range of 45-60 % water content. This tool is a good indicator of massive ice where values reach close to 100%. Note also that a formation with high organic content indicates a high apparent water content as a result of the hydrogen contained in hydrocarbons. Figs. 75 to 87 show distribution of volume-percent water content against depth.

Actual field measurements of bulk density and water content in numerical form are summarized in Table 1.

Seismic downhole logs

Seismic downhole logs were run on boreholes 1K, 2K, 4K, 10K and 11K in support of the seismic reflection and refraction surveys done in the area. The logs shown here were obtained using the downhole well-lock three-component geophone belonging to VSEGINGEO, and the GSC seismograph. The source for all experiments was a 2 kg hammer striking a rod at the base of the active layer. Data were recorded at 0.5 metre intervals down the hole for both compressional and shear waves. For shear wave recording, the source direction was polarized (by applying the rod at an angle to the vertical) and the polarity reversal mechanism of the seismograph was used to minimize compressional wave interference.

A running three-point least-squares fit was applied to both compressional and shear wave data for each borehole. The error bars shown on the plots (Figs. 88-92) indicate one

Table 1

GSC-VSEGINGEO FIELD PROGRAM BOVANENKOVO TEST SITE			
Borehole BH-91-1K			
Depth (m)	Bulk density (g/cm^3) from γ-γ log	Water content (%) from neutron log	Natural γ (cps)
1.00	1.48	0.44	29.00
1.25	1.44	0.57	28.00
1.50	1.59	0.48	23.00
1.75	1.83	0.28	22.00
2.00	1.08	0.67	10.00
2.25	0.95	0.88	4.00
2.50	0.95	0.91	2.00
2.75	0.96	0.89	1.00
3.00	0.96	0.83	1.00
3.25	0.96	0.85	1.00
3.50	0.95	0.87	1.00
3.75	0.95	0.86	1.00
4.00	0.95	0.85	1.00
4.25	0.95	0.87	1.00
4.50	0.96	0.83	1.00
4.75	0.96	0.84	1.00
5.00	0.94	0.88	1.00
5.25	0.95	0.87	1.00
5.50	0.97	0.84	1.00
5.75	0.95	0.82	1.00
6.00	0.95	0.82	1.00
6.25	0.96	0.83	1.00
6.50	1.05	0.81	4.00
6.75	1.04	0.87	7.00
7.00	1.00	0.92	6.00
7.25	1.02	0.84	6.00
7.50	0.94	0.90	5.00
7.75	1.02	0.83	6.00
8.00	1.00	0.90	7.00
8.25	1.09	0.78	9.00
8.50	1.02	0.77	6.00
8.75	0.96	0.82	2.00
9.00	0.96	0.80	1.00
9.25	0.96	0.81	1.00
9.50	0.96	0.83	2.00
9.75	1.03	0.79	7.00
10.00	1.06	0.80	11.00

Table 1 cont.

GSC-VSEGINGEO FIELD PROGRAM BOVANENKOVO TEST SITE			
Borehole BH-91-2K			
Depth (m)	Bulk density (g/cm^3) from γ-γ log	Water content (%) from neutron log	Natural γ (cps)
0.75	1.49	0.40	30.00
1.00	1.38	0.53	29.00
1.25	1.21	0.58	29.00
1.50	1.48	0.48	31.00
1.75	1.48	0.47	32.00
2.00	1.56	0.45	34.00
2.25	1.60	0.39	34.00
2.50	1.57	0.43	34.00
2.75	1.54	0.46	33.00
3.00	1.65	0.40	34.00
3.25	1.66	0.37	34.00
3.50	1.66	0.36	33.00
3.75	1.51	0.41	33.00
4.00	1.37	0.52	32.00
4.25	1.41	0.48	33.00
4.50	1.46	0.45	33.00
4.75	1.64	0.39	32.00
5.00	1.57	0.41	35.00
5.25	1.56	0.42	32.00
5.50	1.59	0.45	32.00
5.75	1.64	0.42	34.00
6.00	1.57	0.40	32.00
6.25	1.37	0.57	32.00
6.50	1.44	0.51	32.00
6.75	1.63	0.42	33.00
7.00	1.59	0.42	34.00
7.25	1.49	0.46	32.00
7.50	1.43	0.54	33.00
7.75	1.51	0.47	33.00
8.00	1.63	0.45	36.00
8.25	1.64	0.42	34.00
8.50	1.57	0.45	32.00
8.75	1.37	0.46	32.00
9.00	1.44	0.43	32.00
9.25	1.63	0.40	33.00
9.50	1.59	0.41	34.00
9.75	1.49	0.44	32.00

Table 1 cont.

GSC-VSEGINGEO FIELD PROGRAM BOVANENKOVO TEST SITE			
Borehole BH-91-2K			
Depth (m)	Bulk density (g/cm^3) from γ-γ log	Water content (%) from neutron log	Natural γ (cps)
10.00	1.43	0.48	33.00
10.25	1.51	0.40	33.00
10.50	1.63	0.39	36.00
10.75	1.58	0.41	33.00
11.00	1.53	0.45	32.00
11.25	1.61	0.43	33.00
11.50	1.68	0.38	34.00
11.75	1.61	0.40	33.00
12.00	1.69	0.40	34.00
12.25	1.55	0.40	34.00
12.50	1.55	0.40	32.00
12.75	1.47	0.46	36.00
13.00	1.46	0.46	34.00
13.25	1.56	0.42	34.00
13.50	1.59	0.41	31.00
13.75	1.61	0.40	34.00
14.00	1.58	0.43	34.00
14.25	1.62	0.40	30.00
14.50	1.08	0.63	16.00
14.75	0.97	0.90	5.00
15.00	0.98	0.90	2.00
15.25	0.98	0.92	1.00
15.50	0.98	0.90	1.00
15.75	0.98	0.89	1.00
16.00	0.98	0.91	1.00
16.25	0.99	0.90	1.00
16.50	0.99	0.91	2.00
16.75	0.98	0.92	2.00
17.00	0.98	0.91	5.00
17.25	1.11	0.79	14.00
17.50	1.49	0.60	23.00
17.75	1.67	0.48	20.00
18.00	1.66	0.50	22.00
18.25	1.10	0.78	19.00
18.50	1.41	0.65	22.00
18.75	1.66	0.51	21.00
19.00	1.76	0.46	22.00

GSC-VSEGINGEO FIELD PROGRAM BOVANENKOVO TEST SITE			
Borehole BH-91-3K			
Depth (m)	Bulk density (g/cm^3) from γ-γ log	Water content (%) from neutron log	Natural γ (cps)
1.00	1.30	0.55	26.00
1.25	1.12	0.75	22.00
1.50	1.01	0.80	18.00
1.75	1.08	0.74	20.00
2.00	1.08	0.69	20.00
2.25	1.30	0.68	25.00
2.50	1.40	0.52	30.00
2.75	1.60	0.45	32.00
3.00	1.76	0.34	30.00
3.25	1.47	0.50	31.00
3.50	1.33	0.55	29.00
3.75	1.56	0.50	27.00
4.00	1.75	0.40	25.00
4.25	1.65	0.42	30.00
4.50	1.81	0.37	30.00
4.75	1.69	0.40	31.00
5.00	1.69	0.41	31.00
5.25	1.49	0.48	34.00
5.50	1.51	0.49	31.00
5.75	1.48	0.50	30.00
6.00	1.57	0.46	30.00
6.25	1.63	0.44	31.00
6.50	1.75	0.42	29.00
6.75	1.79	0.38	27.00
7.00	1.78	0.36	27.00
7.25	1.84	0.36	21.00
7.50	1.79	0.38	22.00
7.75	1.82	0.37	23.00
8.00	1.81	0.38	23.00
8.25	1.87	0.38	23.00
8.50	1.86	0.39	24.00
8.75	1.83	0.38	24.00
9.00	1.75	0.44	23.00
9.25	1.81	0.44	22.00
9.50	1.82	0.43	23.00
9.75	1.75	0.47	23.00
10.00	1.57	0.50	22.00
10.25	1.76	0.47	23.00

GSC-VSEGINGEO FIELD PROGRAM BOVANENKOVO TEST SITE			
Borehole BH-91-4K			
Depth (m)	Bulk density (g/cm^3) from γ-γ log	Water content (%) from neutron log	Natural γ (cps)
0.75			27.00
1.00	1.16	0.65	26.00
1.25	1.07	0.76	19.00
1.50	1.05	0.72	18.00
1.75	1.23	0.65	23.00
2.00	1.78	0.40	32.00
2.25	1.73	0.44	32.00
2.50	1.74	0.44	32.00
2.75	1.19	0.65	25.00
3.00	1.34	0.62	27.00
3.25	1.54	0.55	28.00
3.50	1.88	0.39	31.00
3.75	1.71	0.36	30.00
4.00	1.86	0.40	33.00
4.25	1.47	0.60	27.00
4.50	1.56	0.52	23.00
4.75	1.63	0.46	22.00
5.00	1.08	0.76	13.00
5.25	0.95	0.94	4.00
5.50	0.96	0.83	3.00
5.75	0.95	0.90	2.00
6.00	0.95	0.85	2.00
6.25	0.94	0.89	1.00
6.50	0.95	0.89	1.00
6.75	0.94	0.84	1.00
7.00	0.95	0.87	1.00
7.25	0.95	0.86	1.00
7.50	0.95	0.84	1.00
7.75	0.96	0.92	2.00
8.00	0.96	0.87	5.00
8.25	1.10	0.77	12.00
8.50	1.66	0.55	18.00
8.75	1.47	0.56	22.00
9.00	1.65	0.50	21.00
9.25	1.88	0.41	23.00
9.50	1.90	0.40	26.00
9.75	1.81	0.44	25.00
10.00	1.74	0.52	26.00

Table 1 cont.

GSC-VSEGINGEO FIELD PROGRAM BOVANENKOVO TEST SITE			
Borehole BH-91-5K			
Depth (m)	Bulk density (g/cm^3) from γ-γ log	Water content (%) from neutron log	Natural γ (cps)
1.00	1.63	0.44	33.00
1.25	1.61	0.42	32.00
1.50	1.66	0.42	32.00
1.75	1.67	0.46	33.00
2.00	1.61	0.44	34.00
2.25	1.74	0.44	36.00
2.50	1.74	0.41	34.00
2.75	1.74	0.40	35.00
3.00	1.78	0.39	35.00
3.25	1.77	0.39	34.00
3.50	1.72	0.38	35.00
3.75	1.75	0.42	36.00
4.00	1.74	0.41	34.00
4.25	1.66	0.44	33.00
4.50	1.63	0.45	35.00
4.75	1.69	0.44	33.00
5.00	1.80	0.37	32.00
5.25	1.77	0.37	35.00
5.50	1.74	0.40	35.00
5.75	1.57	0.47	32.00
6.00	1.67	0.42	35.00
6.25	1.57	0.46	33.00
6.50	1.62	0.41	32.00
6.75	1.74	0.35	33.00
7.00	1.68	0.38	32.00
7.25	1.66	0.41	35.00
7.50	1.56	0.43	33.00
7.75	1.59	0.44	33.00
8.00	1.64	0.39	32.00
8.25	1.62	0.39	34.00
8.50	1.68	0.38	34.00
8.75	1.69	0.38	34.00
9.00	1.66	0.39	34.00
9.25	1.69	0.37	34.00
9.50	1.76	0.34	35.00
9.75	1.69	0.38	34.00
10.00	1.52	0.42	34.00

Table 1 cont.

GSC-VSEGINGEO FIELD PROGRAM BOVANENKOVO TEST SITE			
Borehole BH-91-5K			
Depth (m)	Bulk density (g/cm^3) from γ-γ log	Water content (%) from neutron log	Natural γ (cps)
10.50	1.64	0.42	33.00
11.00	1.69	0.39	35.00
11.50	1.48	0.49	34.00
12.00	1.48	0.49	35.00
12.50	1.56	0.46	34.00
13.00	1.56	0.46	35.00
13.50	1.49	0.52	36.00
14.00	1.69	0.40	36.00
14.50	1.60	0.44	37.00
15.00	1.72	0.38	35.00
15.50	1.42	0.51	34.00
16.00	1.61	0.44	33.00
16.50	1.69	0.38	36.00
17.00	1.55	0.44	35.00
17.50	1.60	0.41	33.00
18.00	1.62	0.40	35.00
18.50	1.73	0.38	34.00
19.00	1.74	0.39	37.00
19.50	1.65	0.43	33.00
20.00	1.71	0.37	34.00
20.50	1.56	0.44	32.00
21.00	1.59	0.43	32.00
22.00	1.45	0.49	20.00
22.50	1.05	0.82	9.00
23.00	1.17	0.85	12.00
23.35	1.89	0.43	21.00

Table 1 cont.

GSC-VSEGINGEO FIELD PROGRAM BOVANENKOVO TEST SITE			
Borehole BH-91-6K			
Depth (m)	Bulk density (g/cm^3) from γ-γ log	Water content (%) from neutron log	Natural γ (cps)
0.75			22.00
1.00	1.12	0.59	23.00
1.25	1.55	0.57	22.00
1.50	1.83	0.39	20.00
1.75	1.64	0.40	21.00
2.00	1.65	0.49	20.00
2.25	1.79	0.41	21.00
2.50	1.76	0.44	22.00
2.75	1.83	0.39	25.00
3.00	1.77	0.43	22.00
3.25	1.67	0.42	19.00
3.50	1.72	0.40	17.00
3.75	1.00	0.78	9.00
4.00	0.93	0.87	3.00
4.25	0.94	0.91	2.00
4.50	0.94	0.90	1.00
4.75	0.93	0.83	1.00
5.00	0.94	0.81	1.00
5.25	0.94	0.81	1.00
5.50	0.94	0.82	1.00
5.75	0.94	0.84	1.00
6.00	0.95	0.81	1.00
6.25	0.93	0.88	1.00
6.50	0.94	0.83	1.00
6.75	0.95	0.87	1.00
7.00	0.94	0.93	1.00
7.25	0.94	0.90	1.00
7.50	0.94	0.91	1.00
7.75	0.94	0.89	2.00
8.00	0.94	0.89	2.00
8.25	0.93	0.91	2.00
8.50	0.96	0.93	5.00

Table 1 cont.

GSC-VSEGINGEO FIELD PROGRAM BOVANENKOVO TEST SITE			
Borehole BH-91-6K			
Depth (m)	Bulk density (g/cm^3) from γ-γ log	Water content (%) from neutron log	Natural γ (cps)
8.75	1.22	0.74	15.00
9.00	1.69	0.51	24.00
9.25	1.59	0.45	24.00
9.50	1.49	0.49	21.00
9.75	1.07	0.81	13.00
10.00	1.20	0.76	15.00
10.25	1.61	0.57	20.00
10.50	1.74	0.50	24.00
10.75	1.68	0.53	21.00

Table 1 cont.

GSC-VSEGINGEO FIELD PROGRAM BOVANENKOVO TEST SITE			
Borehole BH-91-7K			
Depth (m)	Bulk density (g/cm^3) from γ-γ log	Water content (%) from neutron log	Natural γ (cps)
1.00	1.60	0.59	31.00
1.25	1.82	0.44	29.00
1.50	1.35	0.56	25.00
1.75	1.20	0.77	22.00
2.00	1.38	0.64	24.00
2.25	1.12	0.66	17.00
2.50	1.35	0.67	19.00
2.75	1.15	0.71	21.00
3.00	1.30	0.65	23.00
3.25	1.47	0.62	26.00
3.50	1.50	0.53	27.00
3.75	1.75	0.47	29.00
4.00	1.56	0.49	27.00
4.25	1.19	0.70	23.00
4.50	1.46	0.55	27.00
4.75	1.42	0.55	26.00
5.00	1.33	0.64	26.00
5.25	1.64	0.50	29.00
5.50	1.79	0.42	30.00
5.75	1.73	0.48	29.00
6.00	1.88	0.41	28.00
6.25	1.75	0.46	29.00
6.50	1.76	0.45	29.00
6.75	1.76	0.43	27.00
7.00	1.59	0.49	26.00
7.25	1.52	0.51	27.00
7.50	1.68	0.47	27.00
7.75	1.69	0.47	24.00
8.00	1.64	0.49	26.00
8.25	1.56	0.49	28.00
8.50	1.61	0.46	29.00
8.75	1.52	0.44	24.00
9.00	1.22	0.67	22.00
9.25	1.15	0.66	15.00

Table 1 cont.

GSC-VSEGINGEO FIELD PROGRAM BOVANENKOVO TEST SITE			
Borehole BH-91-8K			
Depth (m)	Bulk density (g/cm^3) from γ-γ log	Water content (%) from neutron log	Natural γ (cps)
0.75			28.00
1.00	1.39	0.59	30.00
1.25	1.57	0.50	34.00
1.50	1.26	0.54	29.00
1.75	1.59	0.60	31.00
2.00	1.71	0.43	34.00
2.25	1.29	0.53	27.00
2.50	1.12	0.70	21.00
2.75	1.24	0.67	20.00
3.00	1.23	0.69	19.00
3.25	1.19	0.73	21.00
3.50	1.25	0.68	22.00
3.75	1.27	0.68	25.00
4.00	1.47	0.64	26.00
4.25	1.76	0.42	31.00
4.50	1.28	0.55	25.00
4.75	1.10	0.68	26.00
5.00	1.76	0.39	30.00
5.25	1.70	0.41	34.00
5.50	1.69	0.46	31.00
5.75	1.41	0.56	26.00
6.00	1.10	0.73	22.00
6.25	1.33	0.59	24.00
6.50	1.65	0.49	30.00
6.75	1.82	0.39	34.00
7.00	1.70	0.44	31.00
7.25	1.64	0.47	28.00
7.50	1.20	0.61	23.00
7.75	1.21	0.66	24.00
8.00	1.15	0.74	26.00
8.25	1.39	0.59	31.00
8.50	1.39	0.55	29.00

Table 1 cont.

GSC-VSEGINGEO FIELD PROGRAM BOVANENKOVO TEST SITE			
Borehole BH-91-8K			
Depth (m)	Bulk density (g/cm^3) from γ-γ log	Water content (%) from neutron log	Natural γ (cps)
8.75	1.55	0.56	30.00
9.00	1.71	0.46	34.00
9.25	1.62	0.48	33.00
9.50	1.50	0.50	33.00
9.75	1.43	0.52	29.00
10.00	1.32	0.57	29.00
10.25	1.51	0.51	28.00
10.50	1.71	0.48	30.00
10.75	1.88	0.38	23.00
11.00	1.84	0.40	24.00
11.25	1.90	0.39	27.00
11.50	1.89	0.41	25.00

Table 1 cont.

GSC-VSEGINGEO FIELD PROGRAM BOVANENKOVO TEST SITE			
Borehole BH-91-10K			
Depth (m)	Bulk density (g/cm^3) from γ-γ log	Water content (%) from neutron log	Natural γ (cps)
1.00	1.54	0.49	33.00
1.50	1.59	0.47	34.00
2.00	1.56	0.49	32.00
2.50	1.68	0.42	34.00
3.00	1.54	0.47	32.00
3.50	1.57	0.45	35.00
4.00	1.56	0.43	33.00
4.50	1.54	0.44	31.00
5.00	1.22	0.69	18.00
5.50	0.98	1.06	2.00
6.00	0.97	0.91	1.00
6.50	0.96	0.90	2.00
7.00	0.97	0.91	1.00
7.50	0.98	0.91	1.00
8.00	0.97	0.91	1.00
8.50	0.96	0.91	1.00
9.00	0.98	0.89	2.00
9.50	0.97	0.91	1.00
10.00	0.98	0.91	3.00
10.50	1.07	0.84	10.00
11.00	1.46	0.58	19.00
11.50	1.79	0.41	26.00
12.00	1.67	0.50	24.00
12.50	1.11	0.79	19.00
13.00	1.53	0.52	21.00
13.50	1.44	0.66	22.00
13.75	1.53	0.50	24.00

Table 1 cont.

GSC-VSEGINGEO FIELD PROGRAM BOVANENKOVO TEST SITE			
Borehole BH-91-11K			
Depth (m)	Bulk density (g/cm^3) from γ-γ log	Water content (%) from neutron log	Natural γ (cps)
1.00			19.00
1.25	0.94	0.79	8.00
1.50	0.94	0.84	3.00
1.75	0.93	0.90	2.00
2.00	0.94	0.88	2.00
2.25	0.93	0.85	2.00
2.50	0.95	0.84	2.00
2.75	0.95	0.84	2.00
3.00	0.95	0.85	2.00
3.25	0.95	0.82	1.00
3.50	0.95	0.82	2.00
3.75	0.95	0.84	1.00
4.00	0.95	0.80	2.00
4.25	0.94	0.85	2.00
4.50	0.94	0.85	1.00
4.75	0.95	0.88	1.00
5.00	0.94	0.89	1.00
5.25	0.94	0.84	1.00
5.50	0.94	0.84	1.00
5.75	0.94	0.81	1.00
6.00	0.94	0.86	1.00
6.25	0.97	0.82	1.00
6.50	0.98	0.86	1.00
6.75	0.96	0.89	1.00
7.00	0.98	0.88	1.00
7.25	0.98	0.83	1.00
7.50	0.98	0.83	1.00
7.75	0.98	0.82	2.00
8.00	0.97	0.81	2.00
8.25	0.99	0.84	2.00
8.50	0.98	0.88	2.00
8.75	0.98	0.95	1.00
9.00	0.96	0.92	2.00
9.25	0.96	0.91	1.00
9.50	0.96	0.93	1.00
9.75	0.97	0.92	1.00
10.00	0.98	0.91	1.00

Table 1 cont.

GSC-VSEGINGEO FIELD PROGRAM BOVANENKOVO TEST SITE			
Borehole BH-91-11K			
Depth (m)	Bulk density (g/cm^3) from γ-γ log	Water content (%) from neutron log	Natural γ (cps)
10.25	0.97	0.89	1.00
10.50	0.97	0.90	1.00
10.75	0.97	0.84	1.00
11.00	0.97	0.82	1.00
11.25	0.96	0.87	2.00
11.50	1.00	0.90	2.00
11.75	1.01	0.85	3.00
12.00	0.99	0.88	3.00
12.25	1.01	0.85	3.00
12.50	0.97	0.92	2.00
12.75	0.98	0.92	3.00
13.00	1.00	0.89	5.00
13.25	1.37	0.69	13.00
13.50	1.41	0.57	21.00
13.75	1.42	0.67	30.00
14.00	1.85	0.42	24.00
14.25	1.89	0.40	24.00
14.50	1.81	0.41	25.00
14.75	1.50	0.59	23.00
14.90	1.53	0.48	24.00

Table 1 cont.

GSC-VSEGINGEO FIELD PROGRAM BOVANENKOVO TEST SITE			
Borehole BH-91-12K			
Depth (m)	Bulk density (g/cm^3) from γ-γ log	Water content (%) from neutron log	Natural γ (cps)
1.00	1.57	0.47	34.00
1.50	1.20	0.67	27.00
2.00	1.55	0.46	32.00
2.50	1.84	0.46	33.00
3.00	1.56	0.46	32.00
3.50	1.51	0.46	30.00
4.00	1.16	0.62	20.00
4.50	0.97	0.88	2.00
5.00	0.98	0.86	7.00
5.50	1.38	0.48	29.00
6.00	0.96	0.82	7.00
6.50	0.98	0.88	1.00
7.00	0.97	0.91	1.00
7.50	0.98	0.92	1.00
8.00	0.98	0.90	0.00
8.50	0.97	0.92	0.00
9.00	0.97	0.90	1.00
9.50	0.97	0.90	1.00
10.00	0.98	0.88	1.00
10.50	0.98	0.88	1.00
11.00	0.97	0.89	1.00
11.50	0.97	0.89	1.00
12.00	0.97	0.92	1.00
12.50	0.97	0.91	1.00
13.00	0.98	0.92	1.00
13.50	0.98	0.90	1.00
14.00	0.98	0.88	1.00
14.50	0.99	0.93	2.00
15.00	1.02	0.89	4.00
15.50	1.03	0.93	8.00
16.00	1.04	0.82	8.00
16.50	1.34	0.73	21.00

Table 1 cont.

GSC-VSEGINGEO FIELD PROGRAM BOVANENKOVO TEST SITE			
Borehole BH-91-12K			
Depth (m)	Bulk density (g/cm^3) from γ-γ log	Water content (%) from neutron log	Natural γ (cps)
16.75	1.26	0.53	19.00
17.00	1.06	0.86	15.00
17.25	1.35	0.55	18.00
17.50	1.23	0.74	24.00
17.75	1.72	0.48	22.00
18.00	1.78	0.40	23.00
18.25	1.67	0.54	25.00

Table 1 cont.

GSC-VSEGINGEO FIELD PROGRAM BOVANENKOVO TEST SITE			
Borehole BH-91-13K			
Depth (m)	Bulk density (g/cm^3) from γ-γ log	Water content (%) from neutron log	Natural γ (cps)
1.50	1.26	0.64	26.00
2.00	1.35	0.52	30.00
2.50	1.67	0.40	32.00
3.00	1.87	0.41	35.00
3.50	1.56	0.43	33.00
4.00	1.46	0.48	34.00
4.50	1.52	0.43	32.00
5.00	1.69	0.37	33.00
5.50	1.58	0.41	34.00
6.00	1.64	0.38	33.00
6.50	1.56	0.43	34.00
7.00	1.64	0.40	34.00
7.50	1.73	0.37	34.00
8.00	1.61	0.40	32.00
8.50	1.49	0.45	33.00
9.00	1.55	0.46	30.00
9.50	0.95	0.86	4.00
10.00	0.97	0.94	1.00
10.50	0.96	0.89	1.00
11.00	0.97	0.88	1.00
11.50	0.98	0.89	1.00
12.00	0.97	0.91	1.00
12.50	0.96	0.91	1.00
13.00	0.99	0.90	2.00
13.50	0.98	0.89	1.00
14.00	0.98	0.91	1.00
14.50	0.98	0.95	1.00
15.00	0.98	0.93	1.00
15.50	0.99	0.94	0.00
16.00	0.99	0.93	1.00
16.50	0.98	0.91	1.00
17.00	0.98	0.98	0.00

Table 1 cont.

GSC-VSEGINGEO FIELD PROGRAM BOVANENKOVO TEST SITE			
Borehole BH-91-13K			
Depth (m)	Bulk density (g/cm^3) from γ-γ log	Water content (%) from neutron log	Natural γ (cps)
17.50	0.99	0.96	1.00
18.00	0.99	0.94	1.00
18.50	1.06	0.78	7.00
19.00	1.02	0.90	4.00
19.50	1.03	0.90	5.00
19.75	1.02	0.92	8.00
20.00	1.68	0.47	19.00
20.25	1.48	0.55	21.00
20.50	1.70	0.54	23.00
20.60	1.67	0.54	20.00

Table 1 cont.

GSC-VSEGINGEO FIELD PROGRAM BOVANENKOVO TEST SITE			
Borehole BH-91-14K			
Depth (m)	Bulk density (g/cm^3) from γ-γ log	Water content (%) from neutron log	Natural γ (cps)
1.00	1.63	0.45	26.00
1.50	1.54	0.50	32.00
2.00	1.44	0.50	27.00
2.50	1.50	0.49	30.00
3.00	1.93	0.41	33.00
3.50	1.59	0.43	33.00
4.00	1.61	0.42	32.00
4.50	1.70	0.40	34.00
5.00	1.63	0.42	35.00
5.50	1.70	0.41	33.00
6.00	1.61	0.44	34.00
6.50	1.81	0.35	34.00
7.00	1.64	0.41	36.00
7.50	1.57	0.43	34.00
8.00	1.62	0.40	33.00
8.50	1.67	0.39	35.00
9.00	1.61	0.40	33.00
9.50	1.08	0.62	15.00
10.00	0.98	0.88	2.00
10.50	0.98	0.84	1.00
11.00	0.98	0.84	1.00
11.50	0.98	0.88	1.00
12.00	0.99	0.90	1.00
12.50	0.99	0.94	1.00
13.00	0.98	0.92	1.00
13.50	0.98	0.93	1.00
14.00	0.99	0.92	1.00
14.0	0.99	0.92	1.00
15.00	0.98	0.93	1.00
15.50	0.98	0.92	1.00
16.00	0.99	0.93	0.00
16.50	0.98	0.91	1.00

Table 1 cont.

GSC-VSEGINGEO FIELD PROGRAM BOVANENKOVO TEST SITE			
Borehole BH-91-14K			
Depth (m)	Bulk density (g/cm^3) from γ-γ log	Water content (%) from neutron log	Natural γ (cps)
17.00	0.97	0.90	1.00
17.50	0.99	0.91	1.00
18.00	0.98	0.85	1.00
18.50	0.99	0.91	4.00
19.00	1.02	0.91	9.00
19.25	1.71	0.44	16.00
19.50	1.72	0.49	20.00
19.75	1.77	0.48	17.00
19.90	1.81	0.49	15.00

standard deviation of the fit at each location (68% confidence level); however, with only three points, such error bars should only be used in a qualitative sense.

Compressional wave velocities are in excess of 2000 m/s for all materials. Ice-rich materials and massive ice show velocities well in excess of 3000 m/s.

Shear wave velocity variation correlates well with the compressional wave curves. Velocities in the 800-1000 m/s range are associated with the upper portions of the holes containing fine grained sediments. Velocities in the range of 1000-2000 m/s are associated with high ice-content materials and massive ice.

The combined compressional and shear wave velocity data were analyzed to produce plots of Poisson's ratio vs depth for all boreholes tested (Figs. 93-97). From the geological logs, the values of Poisson's ratio for the upper clayey silt, the massive ice, and the lower icy sand were collated. The data were plotted in histogram form (Figs. 98-100) and arithmetic mean values of Poisson's ratio were calculated for each of the three stratigraphic units, viz. clayey silt, icy sand and massive ice. Because of the paucity of data for icy sand, the mean value calculated for this unit may not be statistically reliable. However, all three units demonstrate differing mean values of Poisson's ratio.

Additional compressional wave logs were run using the GSC 12-channel hydrophone array in boreholes 1K, 2K and 4K and a hammer source on surface. The array was moved down the hole in 0.5 m steps such that a multiplicity of overlapping hydrophone positions were recorded. The first arrival refraction data were analyzed using in-house GSC software. The logs shown (Figs. 101-103) are for a three-point running least-squares fit of the data. This form of array shooting and data analysis is independent of start time of recording, hence removing any effect of trigger errors.

Downhole shear wave VSP

The downhole shear wave vertical seismic profiling (VSP) surveys were carried out in four boreholes (2K, 4K, 10K and 11K). The survey used a combination of VSEGINGEO and GSC equipment; VSEGINGEO provided the seismic source, the downhole three-component well-locked geophone, and the surface cables and rollalong switch, while GSC provided the recording instrument (EG&G Geometrics ES-2401 engineering seismograph), and the surface 50 Hz horizontal geophones (Mark Products). The survey was conducted by lowering the three-component well-locked geophone down the borehole in 0.5 m increments, and at each location recording the three components of motion generated by the signal from a seismic source at the surface. A series of records were recorded at each borehole, corresponding to different source offsets from the borehole, and/or different orientations of the source.

The seismic source used for the first VSP survey (borehole 2K) was a steel tube (approximately 10 cm in diameter and 0.9 m in length) which was driven into the ground at an angle of 45°, so that the bottom of the tube was in firm contact with frozen ground beneath the active layer. A 16 lb sledge hammer was then used to hammer on the top of the tube, and so generate a seismic signal in the ground with some horizontal component of motion.

The tube and the 16 lb hammer were abandoned as a shear wave reflection source after the first VSP survey, because it was found that the tube tended to freeze into the permafrost after it was hammered several times. Dislodging the tube was then difficult and time consuming. The rest of the VSP surveys and the shear wave reflection line were recorded using a rod (E rod approximately 1.5 m in length) instead of the tube. As with the tube, the rod was driven into the ground at an angle of 45°, until the bottom was in firm contact with frozen ground, and then hammered at the top with a 2 kg sledge hammer. This source seemed to work well as a high frequency shear wave reflection source, was easy to remove from the ground, and left virtually no surface disturbance.

Each downhole VSP record is presented here as a suite of six plots consisting of unfiltered and digitally filtered vertical, horizontal 1 and horizontal 2 components. Most of the records show a clear reflection from the top of the buried massive ground ice; however, the reflection from the bottom of the ice body was in general poorly defined. The records obtained with the source located close to the top of the borehole were analyzed to produce downhole velocity logs.

Borehole 2K

The first downhole shear wave VSP survey was carried out in borehole 2K, using a steel tube and 16 lb sledge hammer as the source. The source was moved out along the surface both north and south of the borehole; records were obtained with at least two orientations of the source at 24, 11, and 5 m north of the borehole, and with one orientation of the source at 0.3 m north, 12 and 26 m south of the borehole. The only signal enhancement during data acquisition was the stacking (summing) of signals recorded from several hammer blows.

The records (Figs. 104-161) show a strong reflection from the top of massive ice at a depth of approximately 15 m below ground surface. This interface is a contact between fine-grained sediments (clayey-silt) and ice. The reflection from the bottom of the ice (17 m below surface), which is a contact between ice and coarser-grained sediment (silty-sand,

sand), is not clearly resolvable on these records. This is partly due to the thickness of the ice body in this location (2 m), which is very small relative to the wavelength of the seismic signal (on the order of 10 m), resulting in interference between the signals reflected from the top and bottom of the ice. It may also be partly due to a lower reflection coefficient from the ice/sand interface.

The surface topography in the vicinity of borehole 2K, combined with the extreme slope on the surface of the massive ice at this site, results in a complicated series of ray paths, especially when shooting from the north (down the slope of the ice body).

Borehole 4K

Borehole 4K, located at the north end of the seismic reflection profile, intersects the massive ice body between 5 and 8.5 m below surface. VSP data were collected using the rod and 2 kg hammer as the source; several blows of the hammer were stacked (summed) to produce the recorded signal. Only the set of data collected with the source close to the borehole (0.2 m east of the borehole) are presented here (Figs. 162-167), as the data do not show any coherent reflections from either the top or bottom of the ice body. This could be partly due to the complicated subsurface structure in the vicinity of this borehole (topography on the surface of the ice, and the presence of several lithologic units in the upper 5 m), and partly due to the fact that the ice is only in contact with coarse-grained sediments (sand) at this site.

Borehole 10K

The downhole VSP survey in borehole 10K was carried out using the rod and 2 kg hammer as the source. Records were obtained with the steel rod angled away from the borehole at 1.8 m south of the borehole, and at 0.2, 1.5, 3.8 and 7.6 m north of the borehole.

The records (Figs. 168-197) clearly indicate an increase in velocity associated with the massive ice body as compared to the fine-grained sediments (clayey silt) above it. Many of the records also show a clear reflection from the top of the massive ice at a depth of 5 m below surface. However, the reflection from the bottom of the ice is poorly defined at best. Since topography on the surface and subsurface structures is minimal at this site, the poor definition of the reflection from the bottom of the massive ice is attributed to a low density/velocity contrast at the ice/frozen sand interface.

Borehole 11K

Borehole 11K is located south of the seismic reflection line, and intersects a different massive ice body from that sampled in boreholes 2K, 4K and 10K. This ice body is overlain by frozen sand rather than fine-grained sediments. Borehole 11K was drilled through an ice wedge, so that ice was encountered in the borehole from a depth of only 1.5 m below surface. The main body of massive ice occurs between depths of 7 and 13 m below the ground surface.

The downhole VSP survey in borehole 11K was carried out using the rod and 2 kg hammer as the source. Records (Figs. 198-236) were obtained with the rod angled away from the borehole at 7.8, 3.8 and 1.8 m north of the borehole, and at 0.3, 1.8 and 3.8 m south of the borehole.

The dominant frequency of the downhole shear wave VSP data obtained in this borehole is on the order of 1000 Hz, which differs markedly from that obtained in boreholes 2K, 4K and 10K (on the order of several hundred Hz). This may be due to the proximity of massive ice to the source, or to the difference in the material in which the source was planted (frozen sand at borehole 11K; frozen clayey silt at boreholes 2K, 4K and 10K).

Some of the records obtained at borehole 11K show a weak reflection from the bottom of the massive ice (ice/sand interface) at a depth of 13 m.

3.5 Ground temperature measurements (A.S. Judge, E. Shesin)

Ground temperature measurements to depths of 10m were made in nine boreholes (1K-4K, 7K, 8K, 10K, 11K, 34). The results are summarized in graphical and tabular form in Figs. 237-245. Each of the measurements were made at least two days after the completion of the drilling by suspending a 10-sensor multithermistor cable in the borehole for a period of at least four hours or, in several cases, overnight. Since the boreholes were air-filled, with the exception of borehole 7K which contained unfrozen saline water in its lower half, there was some concern about their overall thermal stability. In short-term tests the boreholes proved stable if the surface casing was plugged to prevent air exchange with the atmosphere. A brief test of the effect of a plugged borehole versus an open borehole showed differences of temperature of 0.2°C at 0.5m depth but no change in the measured temperature below a depth of 2m. Measurements in air-filled boreholes are standard practice in Russia. The cable used for these measurements was of Canadian manufacture [M-Squared Instruments] using YSI 44033 sensors and a 5-digit Fluke for resistance measurements. Comparisons were made between a Russian-manufactured digital multimeter and the Fluke unit, showing agreement to within 0.01°C. The temperature results demonstrate that, although this area is in continuous permafrost and arctic tundra, ground temperatures even at 10m depth vary by several degrees Celsius between different locations. Figures 246, 247 and 248 present the grouped borehole temperatures based on measurements by Podborny (1990). Locations are divided into interfluve deposits with sandy or clayey soils at the surface, and floodplain deposits. The clustering of temperature in three groups is readily apparent; the interfluvial uplands are colder than the sites located at the lower elevations.

Figure 249 shows the spatial variation of temperatures at a depth of 10m. The two sites on the sandy upland area (11K, 34) record -6.9°C, the three sites on the silty clay uplands (2K, 4K, 10K) range from -5.3 to -6.0°C whereas the sites in wetlands bordering the lake to the east (3K, 7K, 8K) are much warmer (between -2.3 and -2.7°C). The temperatures at 2m depth reflecting summer conditions are somewhat different as shown in Fig. 250. While the wetlands area remains the warmest at -1.7 to -2.3°C, the trend in sandy and clayey uplands is reversed; the clay areas are the coldest at -4.0 to -5.1°C while the temperatures in sandy areas range from -3.1 to -3.5°C. The implication is that while the sandy areas support the lowest mean annual ground temperatures, they also undergo the largest yearly variation of surface temperature.

Figures 251 and 252 summarise the depth of seasonal thaw in late July, as interpolated from borehole temperatures. Unfortunately lack of time did not permit a more extensive survey between boreholes using the thermistor-tipped steel rod. However, the results obtained ranged from 45 to 110 cms and seem to be dependant on soil type and landform present. All of the data, except from sites 2K and 34, indicated a depth to the 0°C isotherm between 0.5 and 1.0m; at site 2K the depth was less than 0.5m and at site 34 it was greater than 1.0m. At the completion of the survey, a 1.5m active layer probe was installed close to borehole 10K. An 8-channel data logger [Branker logger Model #XL-800] was attached to the probe for unattended year-round readings of near-surface ground temperature. Similarly, a 15m long multithermistor cable was installed in borehole 11K for further observation of ground temperature in the interfluvial sediments containing icy sand.

Podborny (1990) summarises ground temperatures in the region as being in the range of -1.5 to -6.2°C, warmer in the floodplain and cooler on the interfluve. Our results are in general agreement with his conclusions while in contrast with the -5°C mean ground temperature attributed to Devyatkin as reported by Duchkov and Devyatkin (1992). No meteorological station is operated at the Bovanenkovo site but the mean annual air temperature at Marre Sale, some 100 km to the west and located on the sea coast, is -8.0°C.

3.6 Ground penetrating radar (A.S. Judge)

Several kilometers of line along profiles III, IV, A and D (Fig. 3) were surveyed using a pulseEKKO 4 ground penetrating radar system (GPR). The system is a light weight, fully digital radar developed in Canada by Sensors and Software Ltd. for the Geological Survey of Canada. The test surveys were carried out to evaluate GPR as a sounding method in the complex surficial geology conditions of the Bovanenkovo area. GPR system, which has a high resolution in the range of 10 to 30 cm and a depth penetration in the range of 10 to 30m, was considered potentially a most suitable tool for characterization of contrasting lithology and for detection of zones of saline permafrost and massive ice.

The surveys were carried out using three different frequencies (50MHz, 100MHz and 200MHz). Two types of survey were used, that of transmitter and receiver at a constant separation of 1 to 2m moved progressively along the line and that of increasing separation between transmitter and receiver. The former was the standard sounding mode while the latter was used to determine near surface signal velocity.

Survey lines were selected to cover the transition between sands and clays, and icy clays in contrast with non-icy clays, saline frozen soils and massive ice bodies within the sand sequence. Figure 253 shows the location of the individual survey lines, primarily along the baseline (LINE 3) and on cross-lines between 200N and 600N and to the east of the baseline (LINE 2 and LINE 4). The complete data profiles along lines 2, 3 and 4 are shown in Figs. 254, 255 and 256 respectively. Each of the individual profiles is shown with lateral distance along the horizontal axis and the two-way travel time for the returning radar signal on the vertical axis. Each of the lines has been reformatted to create a single continuous profile rather than to present the lines as they were carried out in the field. Positioning along the line was made with reference to pickets 24, 28 and 31, shown on Fig. 253. Using these points, the lateral distance along the radar lines is marked with the picket numbers 25m apart. A depth axis is given for a single set but typical velocity in order to give a general idea of the depth of individual horizons.

Several short lengths of profile are included to demonstrate the value of the GPR surveys in recognizing contrasting types of lithology, in detecting zones of saline permafrost and in indicating the presence of massive ground ice in sediments of various types. Figure 257 shows a section in which the sediments in the left side of the section are saline; the salinity is believed to decrease to the right with a corresponding increase in the depth of penetration of the radar signal. Figure 258 shows a transition between icy and non-icy sediments within the clay sequence. Figure 259 shows a body of massive ice within the sands, with the top of ice rising close to the surface. Figure 260 shows the change in lithology from a clay sequence to a sand sequence across the 5m-deep gully between pickets 28 and 31.

At the completion of the Bovanenkovo surveys, a short study was carried out in Nadym at one of the local factories. Settlement was taking place at several locations along one wall of the large factory building. The interest was to see if the radar could detect any anomalous conditions in the sands providing the foundation for the building. The results of the short (100m) survey are shown in Fig. 261. Fig. 262 shows a brief extract of the profile, where the problem areas are indicated by an apparent low ground wave velocity. This low velocity could be associated with lower density (i.e. low compaction) of the sands or with a higher local moisture content. Field sampling would be necessary to determine the actual cause of the anomalous zones but the GPR was able to detect near-surface anomalies which warrant more detailed geotechnical evaluation.

In summary, the GPR method was able to discriminate between different lithologies, to detect the presence of massive ice in various sediment types, and to outline zones of saline permafrost.

4. Laboratory studies

Laboratory tests of soil, ice, water and fossil samples collected from the Bovanenkovo field site were carried out both by the VSEGINGEO and GSC laboratories. The measurements included determination of physical properties (grain size, Atterberg limits, water content, density, salinity), geochemistry (mineralogy, ion content, stable isotopes) and age determination (radiocarbon dating).

4.1 Physical properties (P.J. Kurfurst, A.M. Tarasov)

Detailed study of the physical properties was carried out to further delineate the stratigraphic and lithological boundaries of the sediments which had been tentatively established on the basis of detailed core logging in the field. Once measurements of the density, water content and Atterberg limits were complete, salinity of the pore waters were determined by measuring the conductivity. The remainder of the sample was then used for grain size analysis.

The water content for all samples ranged from as low as 18% in some silts and sands to nearly 100% in massive ice; the average value, excluding those of massive ice, was 42%. Values of bulk density varied between 0.76 g/cm^3 for samples with high content of organic material to 1.77 g/cm^3 with average value 1.30 g/cm^3.

Salinity values of massive ice and soil samples were very low (less than 3 ppt), with the exception of samples of clay from horizons between 3.8 and 4.1 m in boreholes 2K and 10K, which were 18 and 20 ppt respectively. A sample of water seepage, collected from borehole 7K, had an exceptionally high salinity value of 61 ppt. Borehole profiles with summaries of the physical properties are shown in Figs. 263 to 276. The physical properties data are also listed in Table 2.

4.2 Geochemistry and mineralogy (P.J. Kurfurst, A.M. Tarasov)

Detailed chemical and mineralogical analysis of the samples was carried out to complement the results of the physical properties tests. They included determination of clay mineralogy, ion content and stable isotopes.

After completion of grain size analysis, particles smaller than 0.001 mm were separated for detailed clay mineralogy tests. The X-ray diffraction technique was used on 53 samples from eleven boreholes. Major clay minerals present included smectite, illite, kaolinite and chlorite. Smectite was the most frequently present clay mineral (from 29 to 75%), followed by illite (from 23 to 45%). Combined content of kaolinite and chlorite varied between 11 and 22%. All samples also contained traces of quartz and feldspar.

Thirteen samples from several boreholes were selected for detailed studies using the X-ray diffraction technique to analyze the unoriented powder samples of soils and of fractions larger than 0.1 mm. All diffractograms of powder samples had the same character. Although the diffractograms of fractions larger than 0.1mm displayed similar character, traces of iron oxides were detected. The results of these analyses of mineral content confirmed that various soil types (sands, clays and aleurits) are of same origin, i.e. their source is from same area, and their conditions of deposition were similar.

Water extracted from 63 samples was tested for pH and ion content (HCO_3^-, Cl^-, SO_4, Ca^+, Mg^+, $Na^+ + K^+$); detailed results are presented in Table 3.

Samples from all the 1991 boreholes had pH values between 7.15 and 7.85, with the exception of samples from borehole 7K, where pH varied between 5.15 and 7.05.

The results showed that water samples from clayey soils deposited above the massive ice contained mainly ions Cl^- and Na^+. Samples of sandy soils, both from above and below the massive ice, showed the predominant presence of ions HCO^-_3, Na^+ and Ca^{++}, while mainly ions HCO^-_3, Mg^{++} and Na^+ were present in samples from the active layer.

Table 2

			GSC - VSEGINGEO FIELD PROGRAM						
			BOVANENKOVO TEST SITE						
			PHYSICAL PROPERTIES						
		GRAIN SIZE							
BOREHOLE NUMBER	DEPTH (cm)	% SAND	% SILT	% CLAY	WATER CONTENT (%)	LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	BULK DENSITY (g/cm3)
1K	64-80	44.07	33.60	22.33	21.63	30.80	17.58	13.22	1.26
1K	110-120	22.60	47.87	29.53	23.81	31.50	20.86	10.64	1.42
1K	151-164	51.98	36.26	11.76	19.04				1.39
1K	175-190	62.87	25.80	11.33	14.02	16.20			1.77
1K	660-675	22.28	65.06	12.66	21.06	26.05			1.56
1K	820-830	18.06	69.61	12.33	23.25	24.25			1.49
1K	1020-1030	74.43	22.46	3.11	18.20				1.39
2K	390-410	0.00	32.47	67.53	38.92	74.60	30.04	44.56	0.96
2K	530	2.40	37.70	59.90		53.00	28.00	25.00	2.71*
2K	790-800	0.00	44.89	55.11	31.22	65.00	28.90	36.10	1.18
2K	1200-1210	0.33	46.77	52.90	28.26	59.80	29.78	30.02	1.27
2K	1732-1745	1.44	81.60	16.96	32.03	30.15	25.93	4.22	1.21
2K	1780-1795	67.27	27.75	4.96	18.69				1.36

Table 3

GSC-VSEGINGEO FIELD PROGRAM BOVANENKOVO TEST SITE CHEMICAL ANALYSIS OF EXTRACTED WATER								
			Ion content (%)					
Borehole	**Depth (cm)**	**pH**	**HCO^-_3**	**Cl^-**	**SO^-_4**	**Ca^{++}**	**Mg^{++}**	**Na^++K^+**
2K	510-530	7.80	0.038	0.629	0.044	0.003	0.006	0.434
2K	1760-1800	7.55	0.027	0.003	0.015	0.006	0.001	0.010
3K	580-610	7.50	0.033	0.068	0.005	0.002	0.001	0.055
3K	720-750	7.15	0.013	0.008	0.010	0.001	0.001	0.024
4K	35-50	7.15	0.023	0.015	0.017	0.002	0.001	0.022
4K	880-897	7.45	0.018	0.003	0.008	0.004	0.001	0.001
4K	1000-1010	7.35	0.020	0.003	0.006	0.005	0.001	0.005
5K	5-25	7.85	0.073	0.017	0.044	0.003	0.003	0.051
5K	25-40	8.13	0.131	0.026	0.044	0.003	0.038	0.012
5K	60-70	7.75	0.076	0.137	0.050	0.003	0.008	0.125
5K	85-100	7.70	0.054	0.391	0.120	0.003	0.006	0.320
5K	100-110	7.85	0.058	0.386	0.076	0.003	0.008	0.294
5K	110-120	7.60	0.058	0.033	0.044	0.003	0.006	0.378
5K	135-145	7.75	0.051	0.518	0.006	0.005	0.005	0.347
5K	150-190	7.70	0.039	0.690	0.056	0.006	0.008	0.473
5K	165-180	7.88	0.045	0.748	0	0.003	0.010	0.470
5K	190-200	7.80	0.041	0.591	0.015	0.003	0.008	0.393
5K	260-290	7.85	0.033	0.607	0.012	0.005	0.006	0.399
5K	430-470	7.70	0.030	0.642	0.085	0.005	0.008	0.452
5K	550-570	7.77	0.039	0.690	0.070	0.008	0.008	0.477
5K	650-750	7.60	0.038	0.624	0.082	0.005	0.009	0.440
5K	750-770	7.65	0.028	0.636	0.099	0.005	0.009	0.452
5K	850-875	7.65	0.031	0.714	0.076	0.006	0.009	0.493
5K	940-950	7.50	0.044	0.558	0.063	0.005	0.016	0.377

Table 3 cont.

GSC-VSEGINGEO FIELD PROGRAM BOVANENKOVO TEST SITE CHEMICAL ANALYSIS OF EXTRACTED WATER									
			Ion content (%)						
Borehole	Depth (cm)	pH	HCO_3^-	Cl^-	SO_4^-	Ca^{++}	Mg^{++}	$Na^+ + K^+$
5K	1250-1300	7.65	0.045	0.505	0.006	0.003	0.008	0.334
5K	2300-2360	7.40	0.028	0.015	0.004	0.006	0.001	0.013
6K	165-185	7.30	0.017	0.007	0.010	0.001	0.001	0.012
6K	320-350	6.85	0.009	0.010	0.002	0.002	0.001	0.006
6K	920-935	7.20	0.014	0.007	0.001	0.003	0.001	0.004
6K	1025-1040	7.70	0.027	0.008	0.002	0.007	0.002	0.005
7K	115-140	5.15	0.029	0.007	0.002	0.008	0.011	-
7K	355-380	6.85	0.020	0.010	0.010	0.002	0.003	0.012
7K	480-500	6.15	0.020	0.043	0.064	0.008	0.004	0.050
7K	530-550	7.05	0.013	0.041	0.008	0.003	0.004	0.025
7K	640-670	6.20	0.007	0.128	0.002	0.018	0.019	0.032
7K	770-810	5.10	0.007	0.610	0.005	0.064	0.055	0.227
7K	1000-1030	7.05	0.020	0.315	0.013	0.005	0.004	0.207
8K	50-80	7.80	0.034	0.009	0.005	0.002	0.001	0.671
8K	260-280	7.70	0.040	0.010	0.010	0.002	0.003	0.020
8K	795-830	7.60	0.037	0.009	0.008	0.004	0.001	0.016
8K	950-970	7.70	0.027	0.022	0.008	0.001	0.003	0.022
8K	1070-1100	7.40	0.016	0.010	0.002	0.002	0.002	0.008
9K	80-110	7.65	0.027	0.005	-	0.001	0.002	0.009
9K	525-555	7.20	0.013	0.007	0.008	0.001	0.001	0.011
9K	790-815	7.40	0.023	0.012	0.005	0.003	0.001	0.013
9K	830-870	7.60	0.017	0.007	0.005	0.003	0.002	0.006
10K	180-200	7.8	0.047	0.648	0.046	0.003	0.006	0.450
10K	300-320	7.95	0.037	0.672	0.041	0.003	0.008	0.456

Table 3 cont.

GSC-VSEGINGEO FIELD PROGRAM BOVANENKOVO TEST SITE CHEMICAL ANALYSIS OF EXTRACTED WATER								
			Ion content (%)					
Borehole	**Depth (cm)**	**pH**	**HCO^-_3**	**Cl^-**	**SO^-_4**	**Ca^{++}**	**Mg^{++}**	**Na^++K^+**
10K	380-405	7.9	0.041	0.813	0.038	0.005	0.010	0.543
10K	465-485	7.9	0.048	0.694	0.071	0.005	0.010	0.483
10K	1100-1140	7.65	0.020	0.003	0.005	0.004	0.001	0.005
10K	1280-1390	7.65	0.023	0.003	0.010	0.005	0.001	0.007
11K	1380-1430	7.80	0.026	0.003	0.005	0.005	0.001	0.006
12K	110-130	2.05	0.101	0.026	0.050	0.003	0.018	0.034
12K	225-250	8.05	0.076	0.215	0.102	0.003	0.014	0.188
12K	400-1650	7.21	0.022	0.003	0.003	0.005	0.001	0.007
12K	525-580	7.85	0.044	0.508	0.038	0.003	0.005	0.357
12K	1650-1700	7.60	0.016	0.003	0.005	0.005	0.001	0.004
12K	1770-1800	7.55	0.038	0.007	0.009	0.010	0.002	0.008
12K	1800-1825	7.82	0.028	0.005	0	0.007	0.001	0.004
12K	1840-1850	7.42	0.047	0.010	0.005	0.011	0.002	0.010
14K	40-60	7.50	0.045	0.009	0.008	0.003	0.006	0.012
14K	260-300	7.76	0.048	0.601	0.021	0.003	0.008	0.405

Results of the chemical analysis of water from borehole 7K showed very high content of ions Na^+ and Cl^- and presence of elements such as Br, I and others (see Table 4), typical of a marine environment.

Table 4

GSC - VSEGINGEO FIELD PROGRAM						
BOVANENKOVO TEST SITE						
CHEMICAL ANALYSIS OF SALINE WATER (g/cm^3) – Borehole 7K, depth 10.0 m						
pH	**HCO_3^-**	**Cl^-**	**SO_4^-**			
4.8	0.459	31.009	–			
Na^+	**K^+**	**Ca^{++}**	**Mg^{++}**	**NH_4^+**	**Fe^{++}**	
8.870	0.043	3.051	3.456	0.400	3.487	
Br	**I**	**B**	**Li**	**Sr**		
0.101	0.0076	0.0076	0.00008	0.030		

Over 100 samples of massive ice and of ice from the underlying and overlying sediments from boreholes 27, 32, 35, 1K, 2K, 3K, 4K, 6K, 10K and 11K and two samples of water seepage from borehole 7K were tested for isotope content (oxygen ^{18}O and hydrogen D). Values of $\delta^{18}O$ and δD for massive ice range from -17.11 to -20.5 SMOW, and from -134.0 to -152.0 SMOW respectively, showing little variation with depth. The average values of $\delta^{18}O$ and δD of massive ice from various boreholes were similar and ranged from -18.2 to -19.5 SMOW and from -138.9 to -147.5 SMOW respectively. Values of $\delta^{18}O$ and δD of ice samples from deposits below and above massive ice show almost no difference from those of massive ice, with the exception of samples from ice and clay at shallow depths in borehole 2K where values of $\delta^{18}O$ and δD are very high and similar to those of sea water. Two independant measurements of the seepage water produced $\delta^{18}O$ values of -14.1 and -14.9 SMOW and δD values of -102.5 and -79.0 SMOW. For comparison, samples of precipitation (rain, snow), lake and sea water were also tested. A summary of the results is present in Table 5.

Table 5

GSC - VSEGINGEO FIELD PROGRAM				
BOVANENKOVO TEST SITE				
SALINITY/STABLE ISOTOPES				
SAMPLE LOCATION/ BOREHOLE	DEPTH (cm)	SALINITY (ppt)	$\delta^{18}O$ (SMOW)	δD (SMOW)
1K	110-120	0/00	-15.80	-123.40
1K	255-270	0/00	-17.79	-139.40
1K	430-470	0/00	-18.40	-144.80
1K	660-665	5/00	-19.06	-145.50
1K	820-830	2/00	-19.00	-156.20
1K	1020-1030	1/00	-17.95	-133.90
2K	125-130		-18.60	
2K	150-160		-19.00	
2K	180-190		-18.80	
2K	215-220		-18.80	
2K	250-260		-18.90	
2K	300		-19.10	
2K	350		-18.90	
2K	390-410	18/00	-2.75	-17.10
2K	400		-19.00	
2K	450		-19.10	

Table 5 cont.

GSC - VSEGINGEO FIELD PROGRAM				
BOVANENKOVO TEST SITE				
SALINITY/STABLE ISOTOPES				
SAMPLE LOCATION/ BOREHOLE	DEPTH (cm)	SALINITY (ppt)	$\delta^{18}O$ (SMOW)	δD (SMOW)
2K	500		-18.90	
2K	550		-18.90	
2K	600		-19.10	
2K	650		-18.90	
2K	700		-18.80	
2K	750		-19.00	
2K	800		-18.80	
2K	820-830	3/00	-19.85	-148.30
2K	850		-19.10	
2K	900		-18.60	
2K	950		-18.50	
2K	1000		-18.60	
2K	1060		-18.90	
2K	1100		-19.30	
2K	1150		-19.10	
2K	1200		-18.90	
2K	1240		-19.30	
2K	1300		-18.80	
2K	1325		-18.10	
2K	1360-1380		-17.70	
2K	1470		-17.60	
2K	1470-1550	0/00	-19.11	-141.70
2K	1735-1745	0/00	-19.98	-152.00

Table 5 cont.

GSC - VSEGINGEO FIELD PROGRAM				
BOVANENKOVO TEST SITE				
SALINITY/STABLE ISOTOPES				
SAMPLE LOCATION/ BOREHOLE	DEPTH (cm)	SALINITY (ppt)	$\delta^{18}O$ (SMOW)	δD (SMOW)
2K	1780-1795	0/00	-19.84	-153.40
3K	90-104	1/00	-16.39	-122.50
3K	250-265	4/00	-14.25	-109.90
4K	110-130	0/00	-12.84	-98.80
4K	160-170	0/00	-13.11	-104.80
4K	475-485	2/00	-14.28	-107.50
4K	485-495	0/00	-14.66	-109.90
4K	505-660	0/00	-18.31	-150.00
4K	660-750	0/00	-18.84	-145.10
4K	835-845	0/00	-17.70	-133.40
4K	845-855	0/00	-17.19	-129.70
6K	780-880	0/00	-18.57	-142.40
7K	WATER SEEPAGE		-14.10	-102.50
10K	360-380	20/00	-3.58	
10K	505-725	0/00	-18.20	-138.90
10K	1045-1060	0/00	-17.19	-134.40
11K	220-400	0/00	-18.28	-141.20
Marre-Sale 1		0/00	-23.39	-179.70
Marre-Sale 2		0/00	-16.30	-115.20
Marre-Sale 3		0/00	-15.58	-112.00
Lake Chalevto 1		0/00	-23.22	-172.70
Lake Chalevto 2		0/00	-20.58	-156.40
Lake Chalevto 3		0/00	-20.25	-153.20

Table 5 cont.

GSC - VSEGINGEO FIELD PROGRAM				
BOVANENKOVO TEST SITE				
SALINITY/STABLE ISOTOPES				
SAMPLE LOCATION/ BOREHOLE	DEPTH (cm)	SALINITY (ppt)	$\delta^{18}O$ (SMOW)	δD (SMOW)
27	1360		-18.80	
27	1400		-19.60	
27	1410		-18.70	
27	1430		-19.30	
27	1450		-19.50	
27	1470		-18.60	
27	1480		-18.80	
27	1490		-18.80	
27	1510		-19.20	
27	1520		-19.30	
27	1530		-20.00	
27	1540		-19.10	
27	1550		-19.30	
27	1560		-18.90	
27	1570		-19.20	
27	1580		-18.90	
27	1590		-18.00	
27	1610		-19.00	
27	1620		-18.70	
27	1630		-18.90	
27	1650		-18.80	
27	1680-1700		-19.20	
27	1700-1720		-20.1	

Table 5 cont.

GSC - VSEGINGEO FIELD PROGRAM				
BOVANENKOVO TEST SITE				
SALINITY/STABLE ISOTOPES				
SAMPLE LOCATION/ BOREHOLE	DEPTH (cm)	SALINITY (ppt)	$\delta^{18}O$ (SMOW)	δD (SMOW)
32	250		-19.20	
32	300		-18.80	
32	350		-20.60	
32	400		-18.30	
32	500		-19.10	
32	550		-18.60	
32	700		-17.60	
32	900		-18.70	
32	950		-18.80	
32	1000		-19.00	
32	1050		-18.80	
32	1070-1090		-15.30	
32	1110-1140		-14.60	
35	150-170		-16.10	
35	180		-18.70	
35	250		-18.60	
35	300		-18.80	
35	400		-19.00	
35	450		-19.90	
35	550		-19.40	
35	570		-18.70	
35	590-610		-19.20	
35	720		-20.50	

Table 5 cont.

GSC - VSEGINGEO FIELD PROGRAM				
BOVANENKOVO TEST SITE				
SALINITY/STABLE ISOTOPES				
SAMPLE LOCATION/ BOREHOLE	DEPTH (cm)	SALINITY (ppt)	$\delta^{18}O$ (SMOW)	δD (SMOW)
35	750		-18.50	
35	1000		-17.00	
SPECIAL CONDITIONS				
CONDITION	DATE/PLACE	DEPTH(cm)	$\delta^{18}O$ (SMOW)	δD (SMOW)
SNOW	12/91	0.00	-20.10	
SNOW	01/92	0.00	-24.10	-187.00
RAIN	08/90	0.00	-12.40	
RAIN	08/91	0.00	-11.46	-79.00
WATER	LAKE PYASAVEITO	-12.00		
WATER SEEPAGE/	7K	900-1000	-14.70	-79.00
WATER	KARA SEA	0.00	-6.40	-43.00

4.3 Radiocarbon dating (P.J. Kurfurst)

Two fossils were collected from core samples in boreholes 2K (18.6 m depth) and 10K (4.7 m depth) respectively. The shells were submitted to the Accelerator Mass Spectrometry Facility for their age determination. However, only the specimen from borehole 2K was large enough for correct testing procedure. The fossil was identified as *Clinocardium ciliatum (?)*. The sample age, of 44 720 ± 1050 years BP, is an uncalibrated conventional radiocarbon date in years before present, using the Libby ^{14}C mean half life of 8033 years.

Acknowledgments

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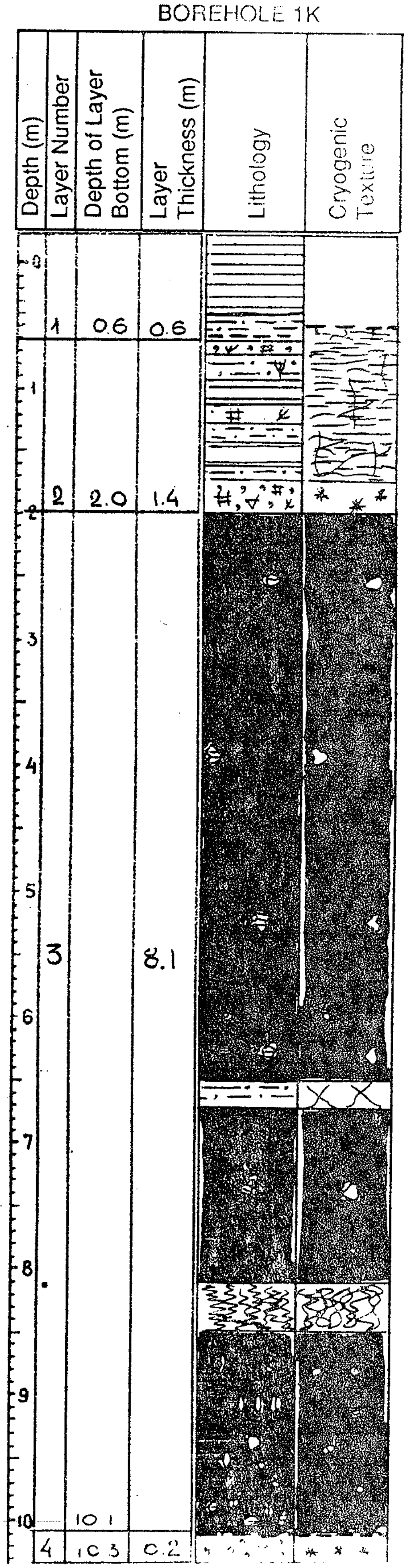

BOREHOLE 1K
Depth (m)
Layer Number
Depth of Layer Bottom (m)
Layer Thickness (m)
Lithology
Cryogenic Texture
0
1
2
3
4
5
6
7
8
9
10
1
0.6
0.6
2
2.0
1.4
3
8.1
10.1
4
10.3
0.2

Figure 4

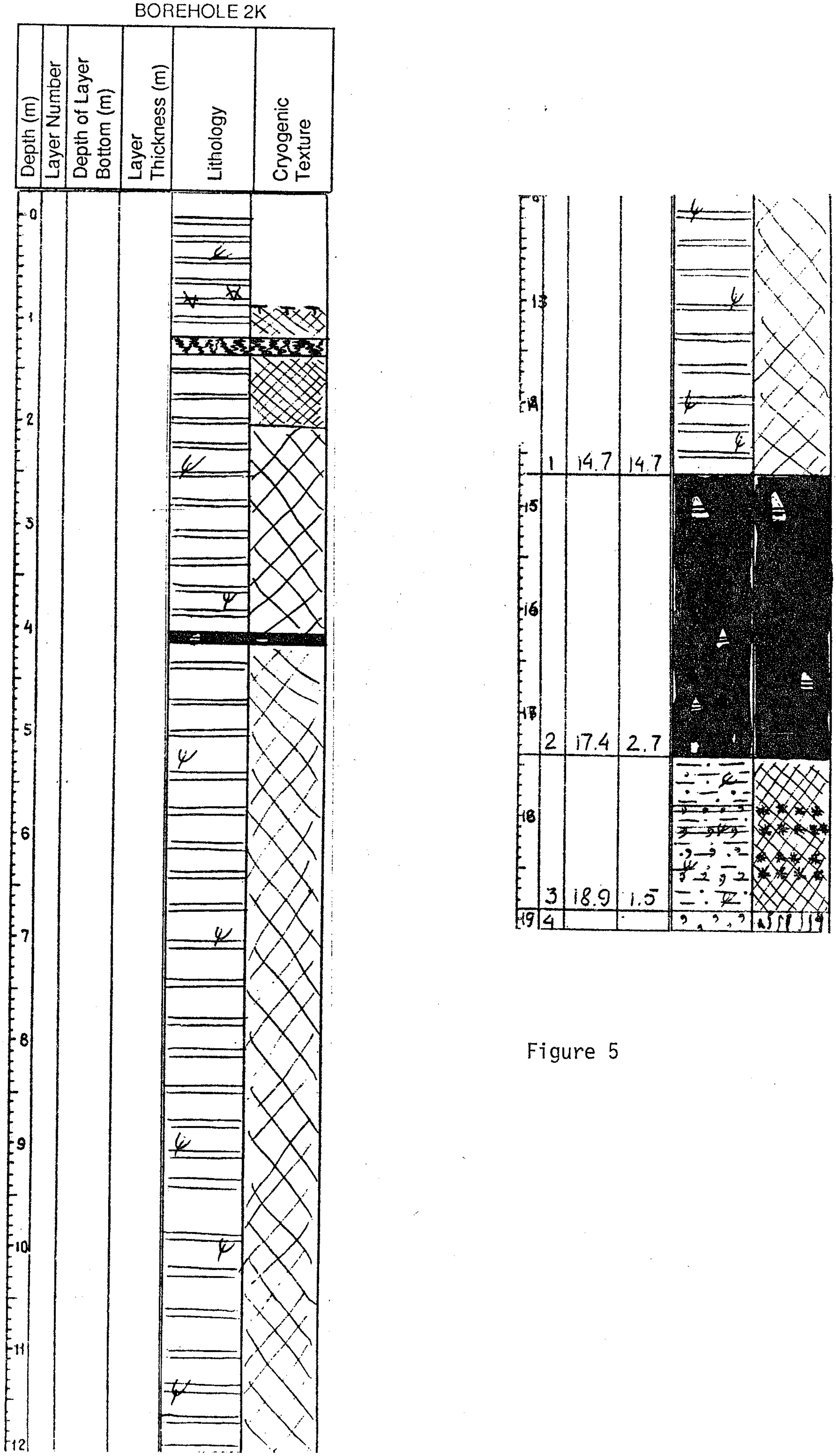

BOREHOLE 2K
Depth (m)
Layer Number
Depth of Layer Bottom (m)
Layer Thickness (m)
Lithology
Cryogenic Texture
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
1 14.7 14.7
2 17.4 2.7
3 18.9 1.5
4

Figure 5

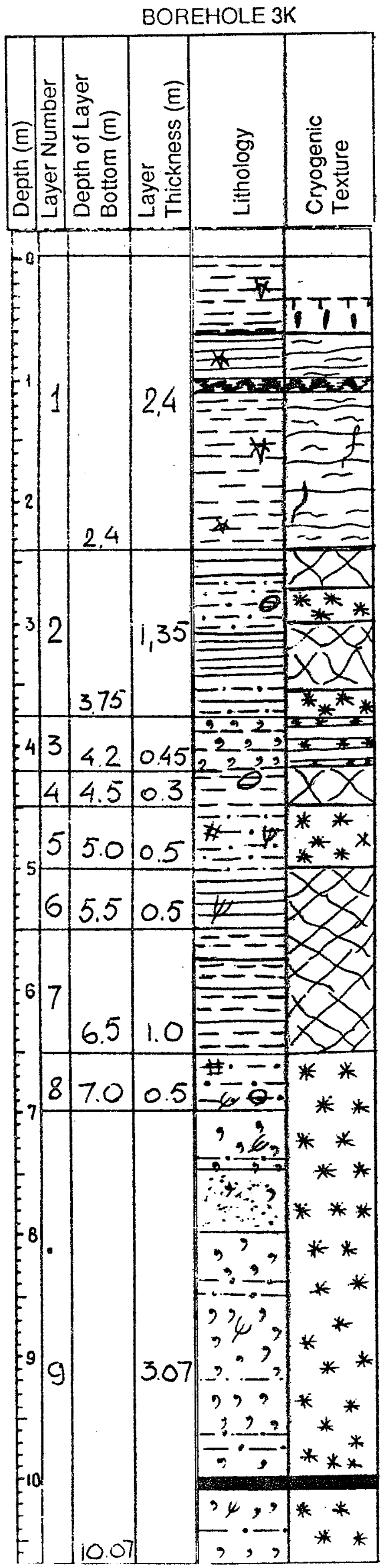

BOREHOLE 3K
Depth (m)
Layer Number
Depth of Layer Bottom (m)
Layer Thickness (m)
Lithology
Cryogenic Texture
0
1
2
3
4
5
6
7
8
9
10
1
2
3
4
5
6
7
8
9
2.4
3.75
4.2
4.5
5.0
5.5
6.5
7.0
10.07
2,4
1,35
0.45
0.3
0.5
0.5
1.0
0.5
3.07

Figure 6

BOREHOLE 4K

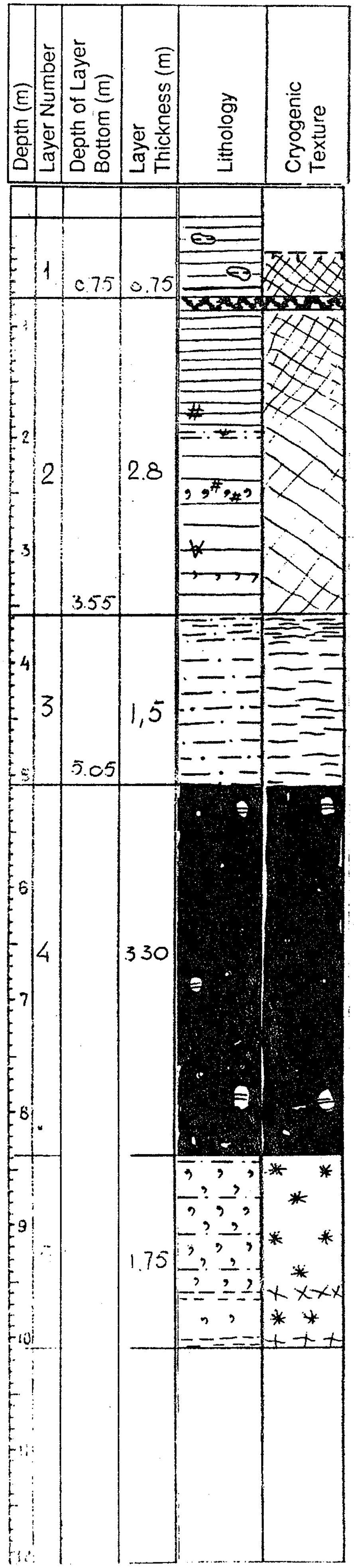


Figure 7

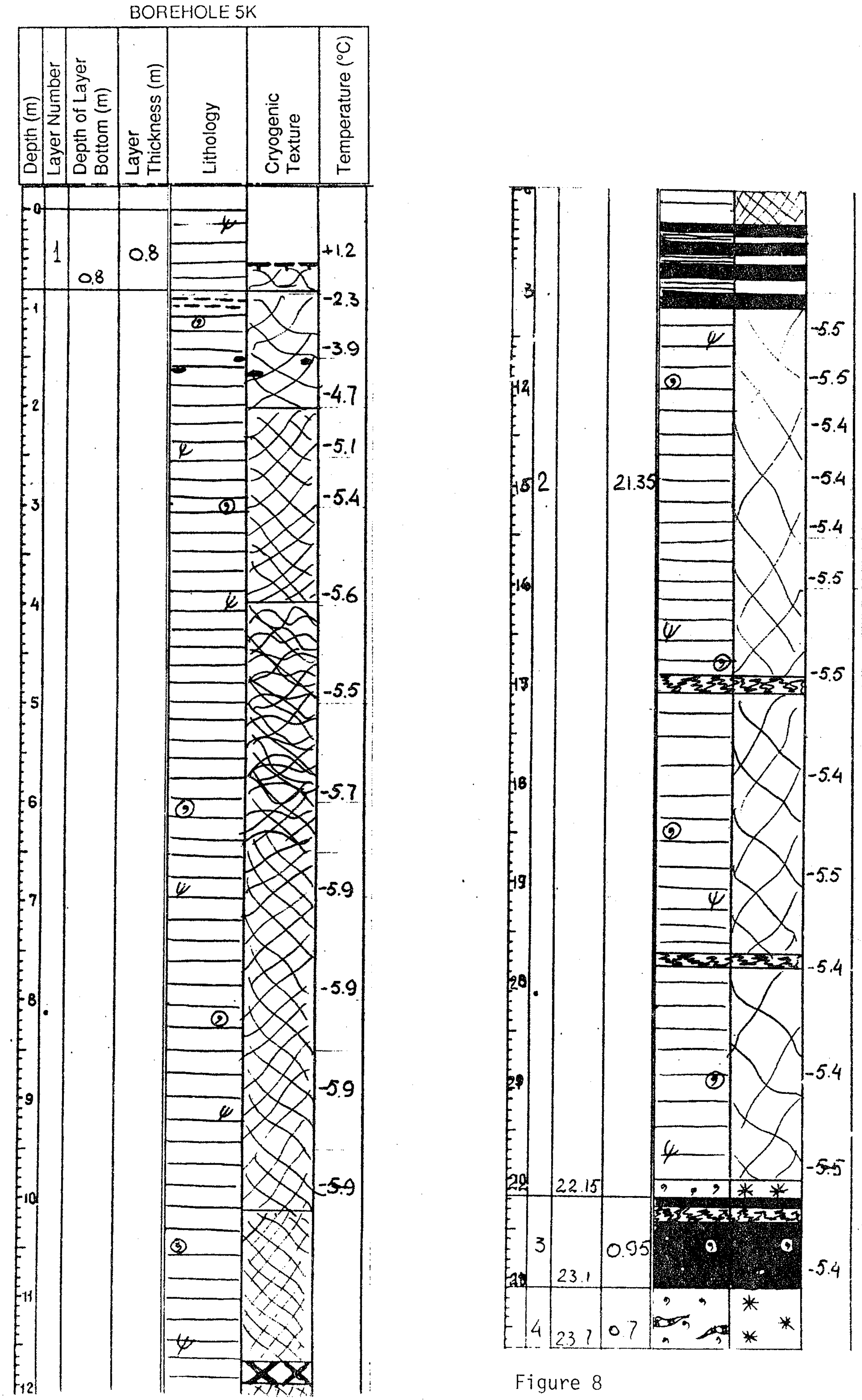

BOREHOLE 5K
Depth (m)
Layer Number
Depth of Layer Bottom (m)
Layer Thickness (m)
Lithology
Cryogenic Texture
Temperature (°C)
1
0.8
0.8
+1.2
-2.3
-3.9
-4.7
-5.1
-5.4
-5.6
-5.5
-5.7
-5.9
-5.9
-5.9
-5.9
2
21.35
-5.5
-5.5
-5.4
-5.4
-5.4
-5.5
-5.5
-5.4
-5.5
-5.4
-5.4
-5.5
22.15
3
0.95
23.1
-5.4
4
23.7
0.7

Figure 8

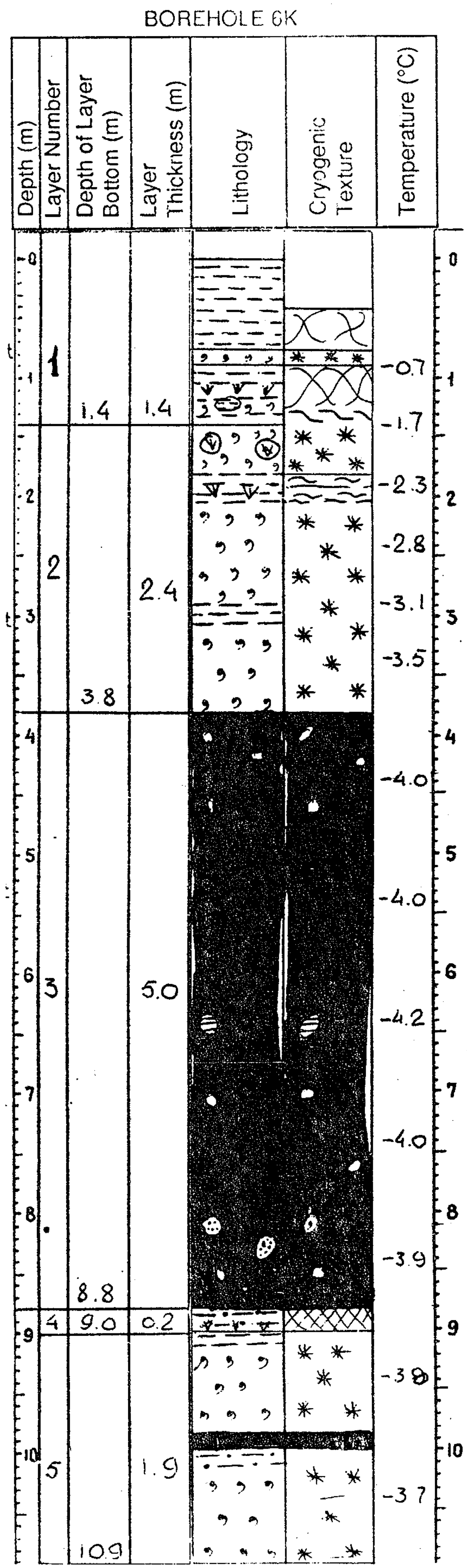

BOREHOLE 6K
Depth (m)
Layer Number
Depth of Layer Bottom (m)
Layer Thickness (m)
Lithology
Cryogenic Texture
Temperature (°C)
1
1.4
1.4
2
3.8
2.4
3
8.8
5.0
4
9.0
0.2
5
10.9
1.9
-0.7
-1.7
-2.3
-2.8
-3.1
-3.5
-4.0
-4.0
-4.2
-4.0
-3.9
-3.8
-3.7
0
1
2
3
4
5
6
7
8
9
10

Figure 9

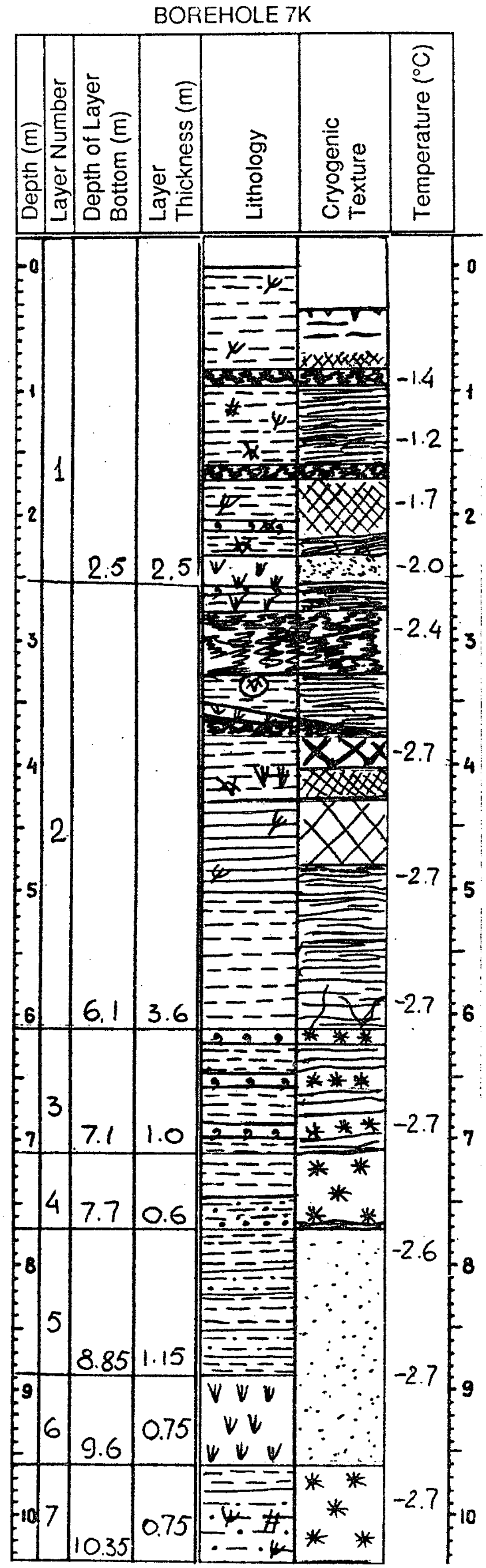

BOREHOLE 7K
Depth (m)
Layer Number
Depth of Layer Bottom (m)
Layer Thickness (m)
Lithology
Cryogenic Texture
Temperature (°C)
0
1
2
3
4
5
6
7
8
9
10
1
2.5
2.5
2
6.1
3.6
3
7.1
1.0
4
7.7
0.6
5
8.85
1.15
6
9.6
0.75
7
10.35
0.75
-1.4
-1.2
-1.7
-2.0
-2.4
-2.7
-2.7
-2.7
-2.7
-2.6
-2.7
-2.7

Figure 10

Table 2 cont.

3K	50-65	7.60	59.76	32.64	20.59	36.40	22.59	13.81	1.46
3K	90-104	2.06	45.52	52.42	30.64	50.10	27.13	22.97	1.21
3K	250-265	1.58	52.06	46.36	30.33	49.95	27.39	22.56	1.19
3K	415-427	9.81	58.16	32.03	25.05	39.55	24.60	14.95	1.30
3K	470-485	19.70	66.61	13.69	38.05				0.70
3K	650-665	30.92	53.31	15.77	23.78	30.50			1.13
3K	850-860	47.69	45.38	6.69	21.98				1.47
3K	980-1000	46.83	46.48	6.69	21.74				1.49
4K	110-130	2.05	56.01	41.94	27.28	46.80	23.29	23.51	1.29
4K	160-170	7.69	50.99	41.32	47.57	62.55	43.68	18.87	0.76
4K	475-485	45.12	41.47	13.41	19.90				1.47
4K	485-495	52.49	34.56	12.95	20.24	19.35			1.60
4K	835-845	42.63	50.48	6.89	18.78				1.28
4K	845-855	85.02	11.67	3.31	20.17				1.33
5K	190	3.50	27.50	69.00		46.00	26.00	20.00	2.70*
5K	290	8.90	32.90	58.20		47.00	23.00	24.00	2.52*
5K	470	4.10	27.60	68.30		45.00	23.00	22.00	2.74*
5K	570	4.80	23.10	72.10		42.00	23.00	19.00	2.72*
5K	770	0.40	29.70	69.90		46.00	28.00	18.00	2.72*
5K	880	11.70	20.50	67.80		50.00	27.00	23.00	2.51*
5K	950	3.20	31.10	65.70		44.00	26.00	18.00	2.72*

Table 2 cont.

8K	80	3.80	35.00	61.20		39.00	21.00	18.00	2.76*
8K	970	3.40	36.70	59.90		43.00	23.00	20.00	2.75*
9K	110	2.60	32.00	65.40		41.00	21.00	20.00	2.75*
10K	200	0.80	21.40	77.80		49.00	27.00	22.00	2.75*
10K	320	0.40	18.90	80.70		49.00	26.00	23.00	2.74*
10K	360-380	1.92	46.32	51.76	33.86	65.00	31.12	33.88	1.10
10K	400	1.00	23.90	75.10		51.00	26.00	25.00	2.76*
10K	480	3.80	25.20	71.00		44.00	23.00	21.00	2.75*
10K	490-505	1.35	45.09	53.56	28.91	64.25	28.35	35.90	1.18
10K	1045-1060	84.12	12.61	3.27	16.72				1.29
10K	1065-1085	52.79	40.66	6.55	16.72				1.28
12K	130	0.90	25.00	74.10		42.00	24.00	18.00	2.77*
12K	250	1.20	25.80	73.00		48.00	26.00	22.00	2.76*
12K	580	3.70	27.30	69.00		47.00	24.00	23.00	2.76*
1	1050-1070	89.60	6.40	4.00	32.00				2.66*
2	870-900	84.80	10.40	4.80	16.00				2.66*
3	1230-1250	75.20	21.60	3.20	39.00				2.68*
7	700-730	76.80	18.40	4.80	35.00				2.68*
7	900-930	86.40	11.20	2.40	24.00				2.67*

Table 2 cont.

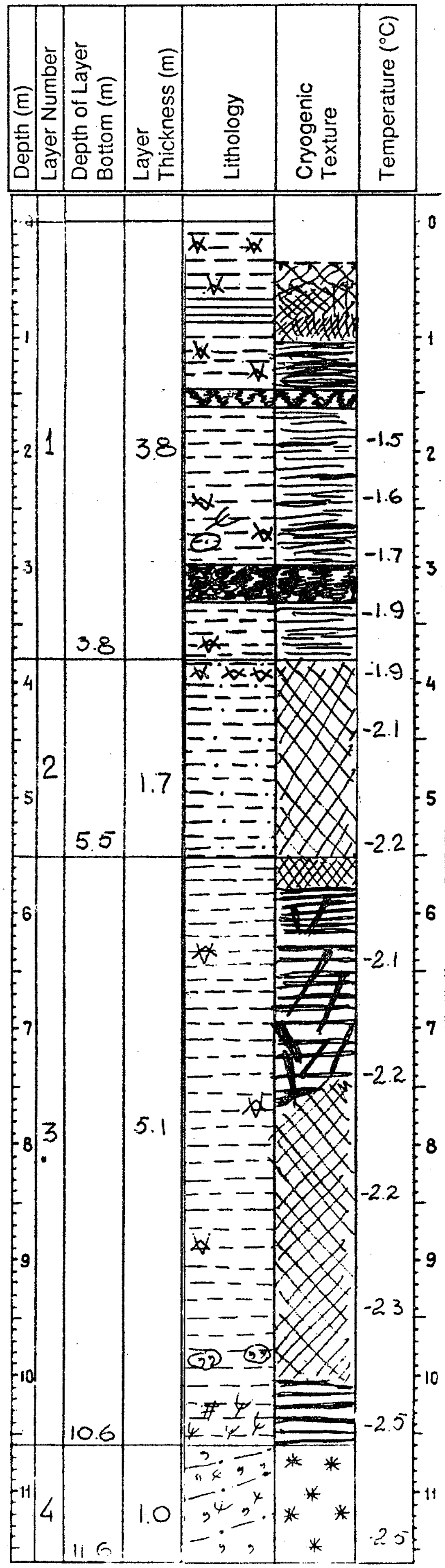
8	150-170	88.00	8.00	4.00	28.00				2.66*
8	1370-1380	80.70	16.10	3.20	32.00				2.67*
9	730-760	77.60	17.60	4.80	30.00				2.68*
9	940-970	63.30	29.50	7.20	50.00	22.10	21.20	0.90	2.70*
11	500-530	88.00	8.80	3.20	22.00				2.68*
11	980-1000	94.40	3.20	2.40	15.00				2.68*
12	150-170	90.40	4.80	4.80	32.00				2.66
12	740-760	92.00	7.20	0.80	14.00				2.67*
12	960-980	78.50	17.50	4.00	37.00				2.70*
14	210-230	87.20	9.60	3.20	26.00				2.68*
14	640-660	87.20	9.60	3.20	26.00				2.68*
15	1000-1020	75.10	18.50	6.40	42.00				2.67*
17	700-720	92.00	5.60	2.40	26.00				2.68*
17	900-920	95.40	3.20	1.60	14.00				2.66*
18	320-340	82.30	14.50	3.20	36.00				2.66*
19	600-620	64.80	29.60	5.60	58.00	23.20	22.40	0.80	2.69*
19	800-820	89.60	7.20	3.20	30.00				2.60*
19	1000-1020	88.80	7.20	4.00	42.00				2.67*
21A	860-880	84.80	12.80	2.40	42.00				2.67*
22	830-850	85.90	9.30	4.80	53.00				2.66*
22	980-1000	80.80	15.20	4.00	26.00				2.68*
24	630-650	79.10	17.70	3.20					2.67*
26	590-610	89.60	6.40	4.00	18.00				2.66*
28	130-140	88.00	7.20	4.80	30.00				2.67*

Table 2 cont.

28	400-430	85.60	12.00	2.40	37.00				2.68*
28	870-890	81.60	14.40	4.00	38.00				2.68*
28	1230-1250	77.40	16.10	6.50	73.00				2.66*
30	320-340	97.60	0.80	1.60	20.00				2.65*
30	450-470	93.60	3.20	3.20	20.00				2.66*
30	1570-1590	75.90	17.70	6.40	68.00				2.68*
31	1800-1850	80.80	15.20	4.00	42.00				2.68*
33	2040-2060	85.50	12.10	2.40	54.00				2.68*
33	2100-2120	83.90	13.70	2.40	55.00				2.68*
34	150-180	90.40	5.60	4.00	39.00				2.67*
34	320-340	90.40	7.20	2.40	40.00				2.67*
34	500-520	71.90	20.10	8.00	84.00	24.40	23.80	0.60	2.68*
34	1000-1020	87.20	9.60	3.20	41.00				2.68*
35	590-610	66.40	27.20	6.40	76.00	22.20	21.40	0.80	2.70*
35	830-850	83.10	11.30	5.60	52.00				2.68*
35	950-970	80.70	13.70	5.60	52.00				2.68*
35A	150-170	91.90	4.80	3.20	40.00				2.67*
35A	300-320	92.80	4.80	2.40	39.00				2.66*
35A	450-470	93.60	4.80	1.60	40.00				2.66*
35A	600-620	92.50	4.80	2.40	36.00				2.67*

*Bulk density of grain particles only

BOREHOLE 8K


Depth (m)
Layer Number
Depth of Layer Bottom (m)
Layer Thickness (m)
Lithology
Cryogenic Texture
Temperature (°C)
1
3.8
3.8
2
5.5
1.7
3
10.6
5.1
4
11.6
1.0
-1.5
-1.6
-1.7
-1.9
-1.9
-2.1
-2.2
-2.1
-2.2
-2.2
-2.3
-2.5
-2.5
0
1
2
3
4
5
6
7
8
9
10
11

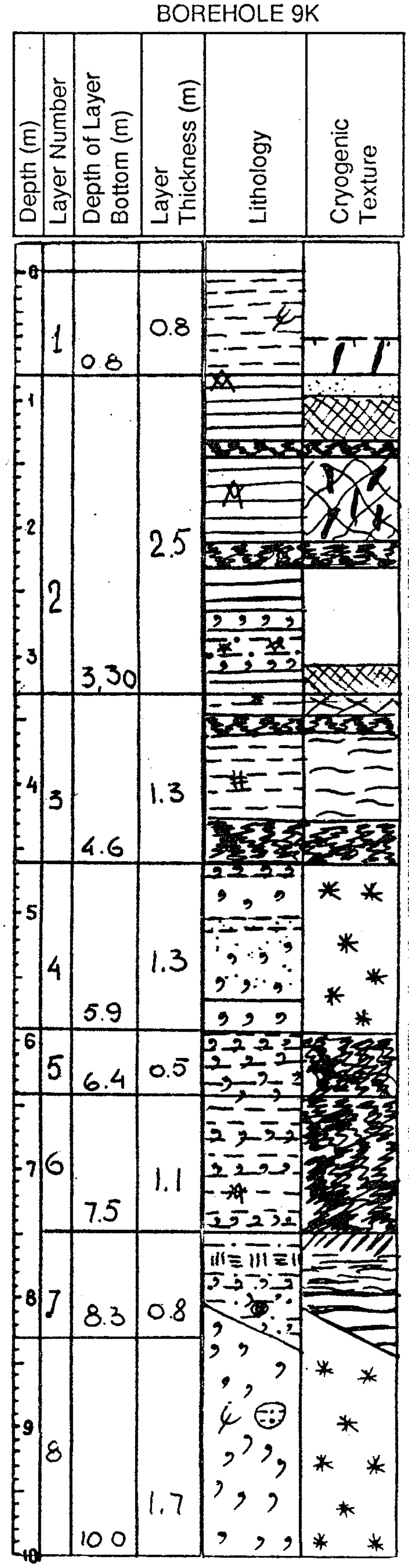

BOREHOLE 9K
Depth (m)
Layer Number
Depth of Layer Bottom (m)
Layer Thickness (m)
Lithology
Cryogenic Texture
0
1
2
3
4
5
6
7
8
9
10
1
0.8
0.8
2
3,30
2.5
3
4.6
1.3
4
5.9
1.3
5
6.4
0.5
6
7.5
1.1
7
8.3
0.8
8
10 0
1.7

Figure 12

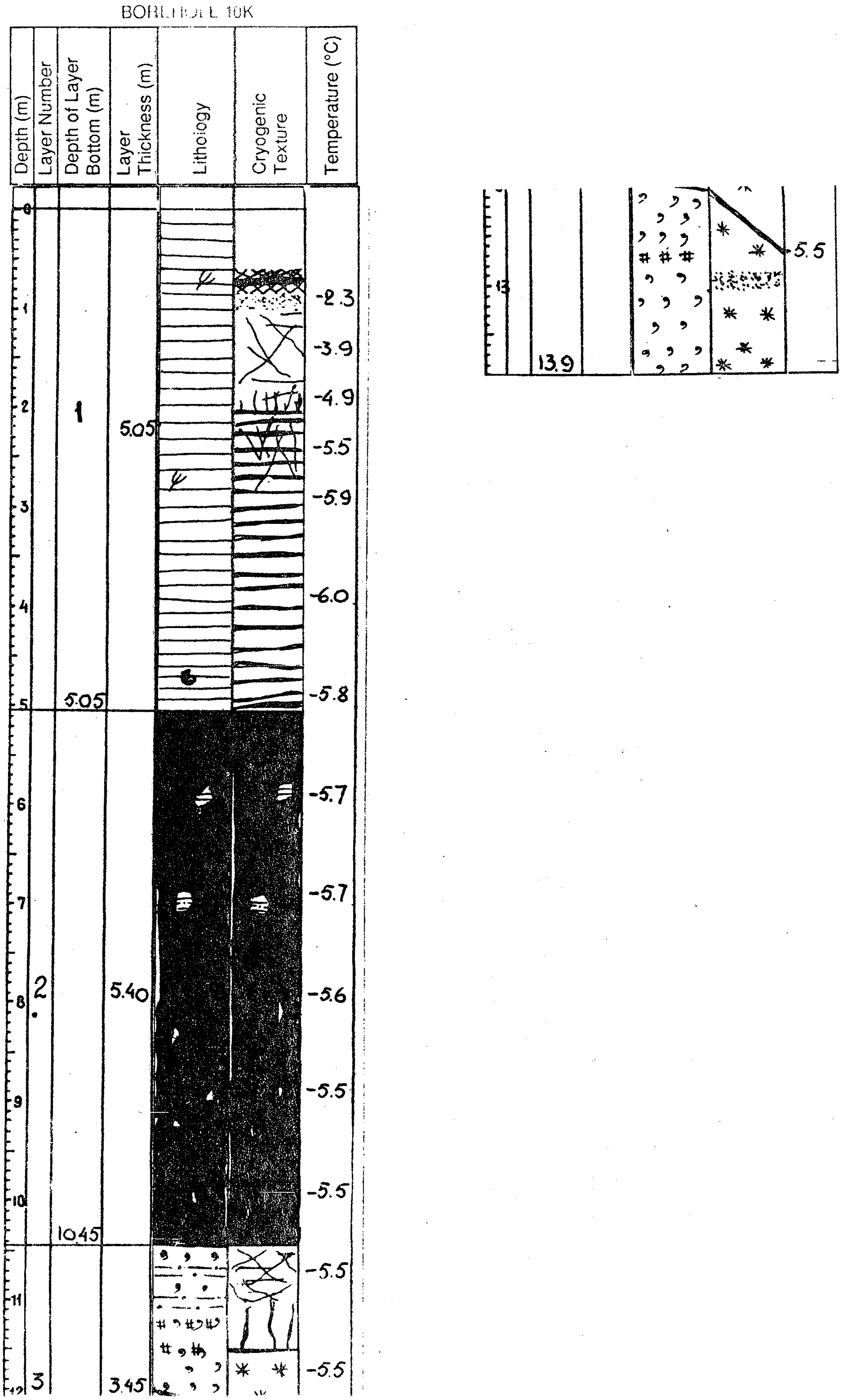
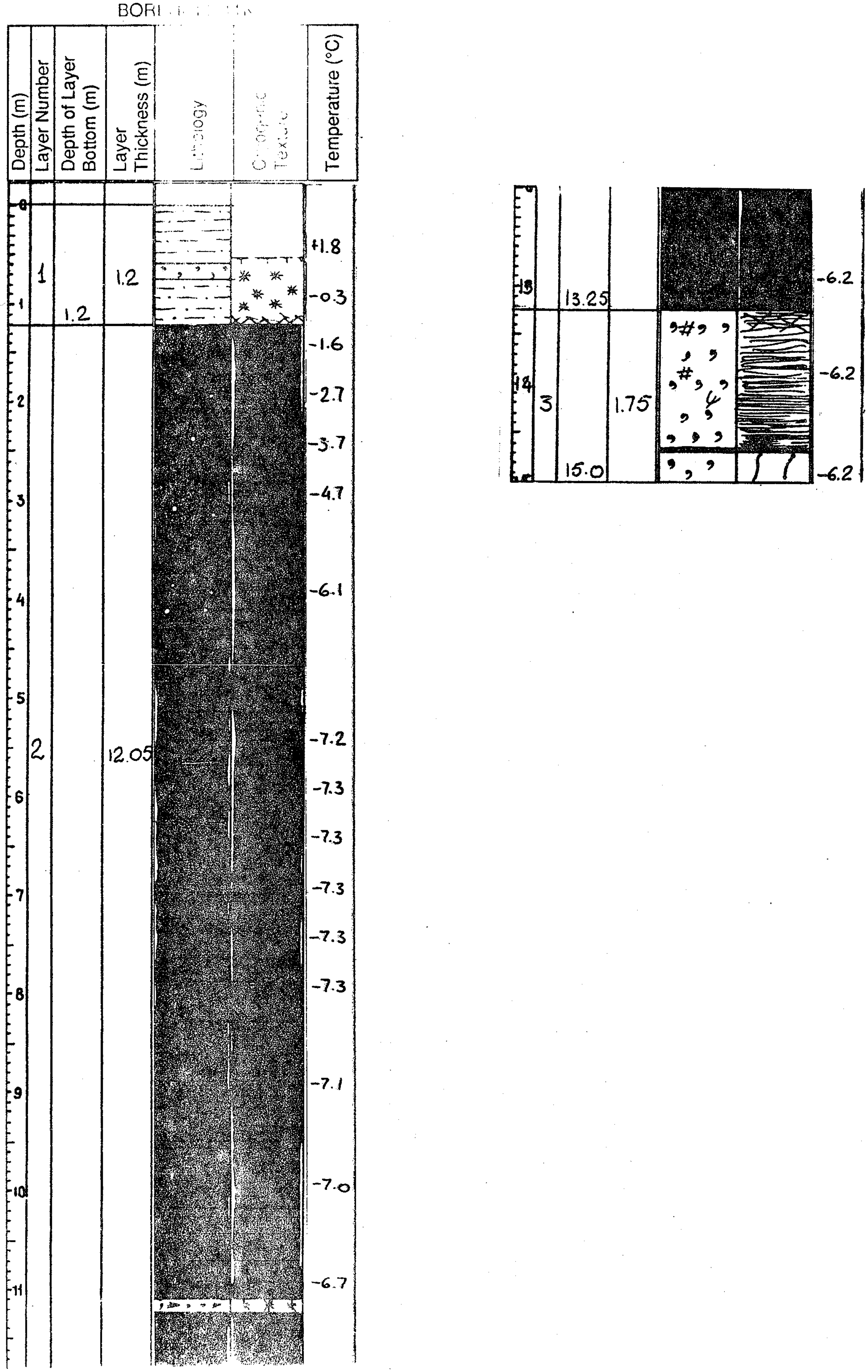
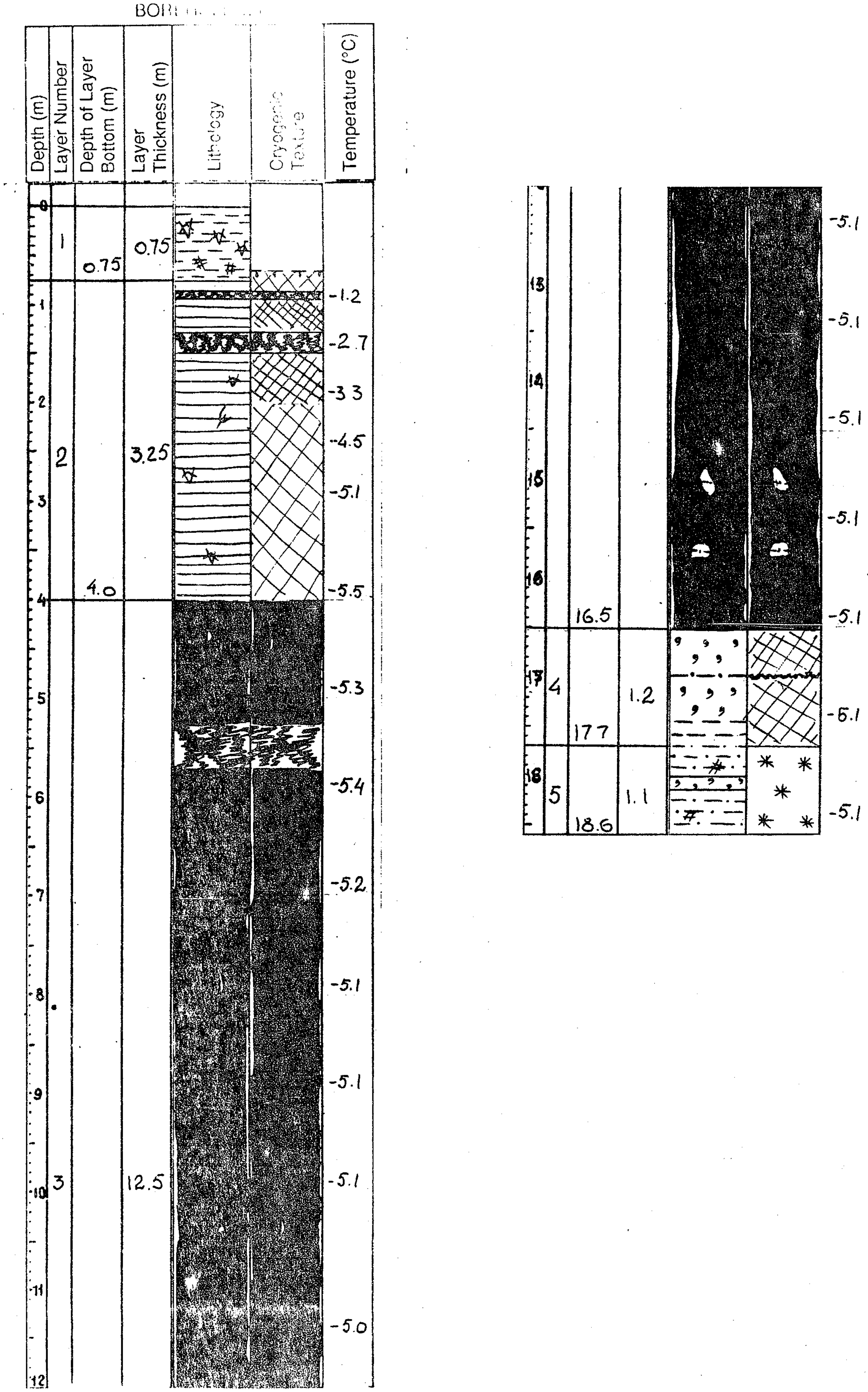

BOREHOLE 10K
Depth (m)
Layer Number
Depth of Layer Bottom (m)
Layer Thickness (m)
Lithology
Cryogenic Texture
Temperature (°C)
1
5.05
5.05
-2.3
-3.9
-4.9
-5.5
-5.9
-6.0
-5.8
2
5.40
10.45
-5.7
-5.7
-5.6
-5.5
-5.5
-5.5
3
3.45
-5.5
13.9
-5.5

Figure 13

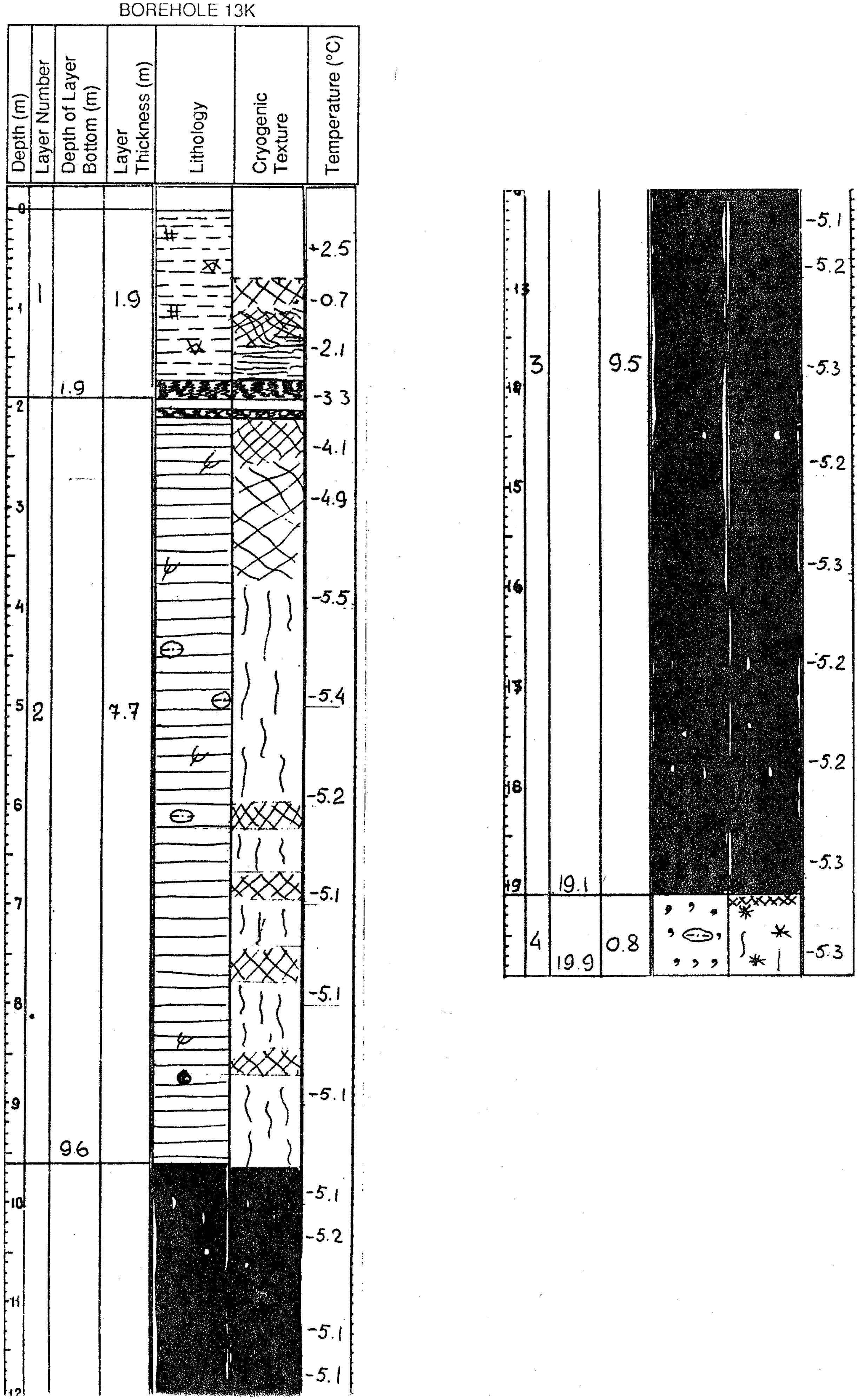


Depth (m)
Layer Number
Depth of Layer Bottom (m)
Layer Thickness (m)
Lithology
Cryogenic Texture
Temperature (°C)
1
1.2
1.2
2
12.05
+1.8
-0.3
-1.6
-2.7
-3.7
-4.7
-6.1
-7.2
-7.3
-7.3
-7.3
-7.3
-7.3
-7.1
-7.0
-6.7
13.25
3
1.75
15.0
-6.2
-6.2
-6.2

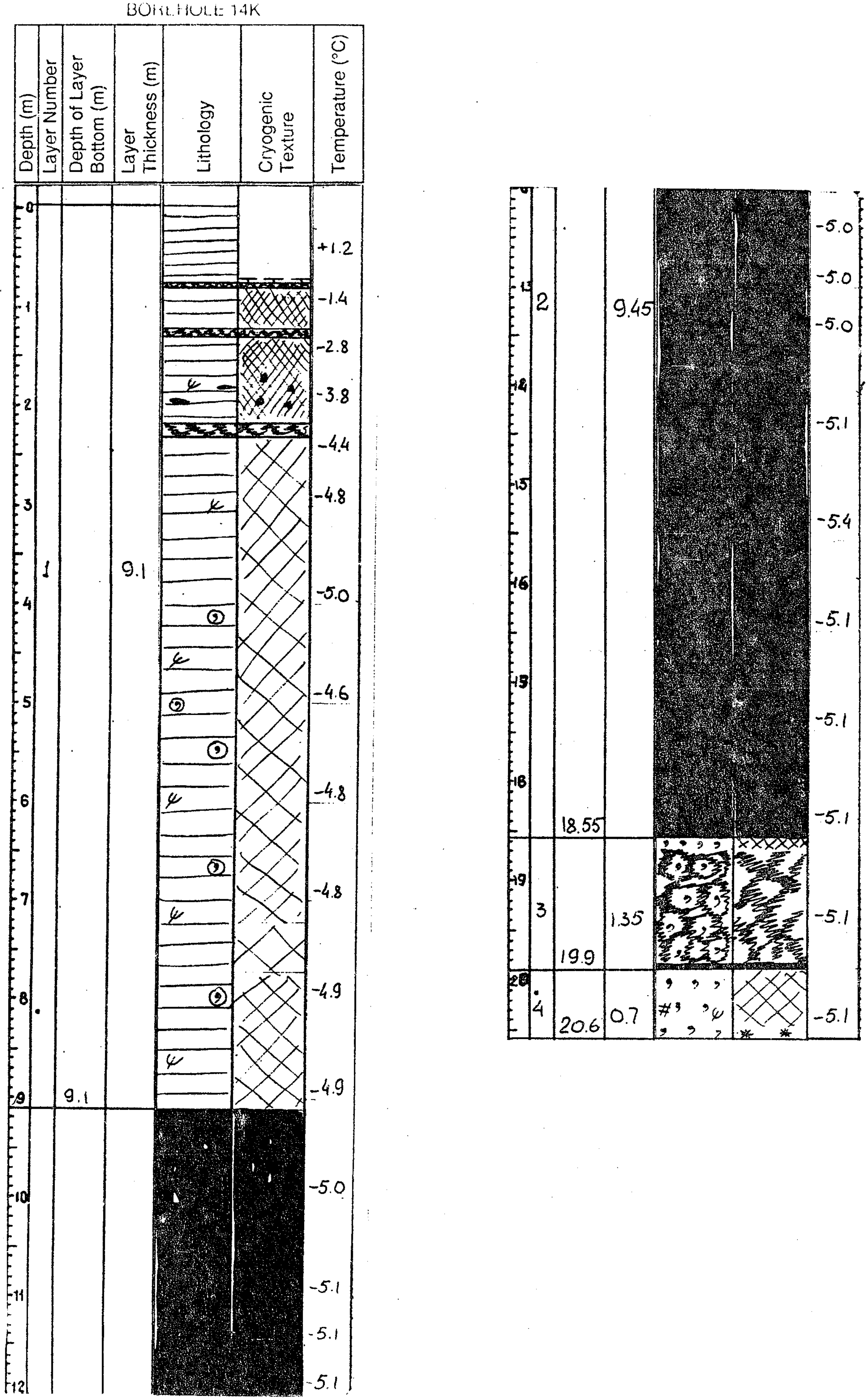
Figure 14


Depth (m)
Layer Number
Depth of Layer Bottom (m)
Layer Thickness (m)
Lithology
Cryogenic Texture
Temperature (°C)
1
0.75
0.75
2
4.0
3.25
3
12.5
16.5
4
17.7
1.2
5
18.6
1.1
-1.2
-2.7
-3.3
-4.5
-5.1
-5.5
-5.3
-5.4
-5.2
-5.1
-5.1
-5.1
-5.0
-5.1
-5.1
-5.1
-5.1
-5.1
-5.1
-5.1

igure 15


BOREHOLE 13K
Depth (m)
Layer Number
Depth of Layer Bottom (m)
Layer Thickness (m)
Lithology
Cryogenic Texture
Temperature (°C)
1
1.9
1.9
+2.5
-0.7
-2.1
-3.3
-4.1
-4.9
-5.5
2
7.7
-5.4
-5.2
-5.1
-5.1
-5.1
9.6
-5.1
-5.2
-5.1
-5.1
-5.1
-5.2
3
9.5
-5.3
-5.2
-5.3
-5.2
-5.2
-5.3
19.1
4
0.8
19.9
-5.3

igure 16


BOREHOLE 14K
Depth (m)
Layer Number
Depth of Layer Bottom (m)
Layer Thickness (m)
Lithology
Cryogenic Texture
Temperature (°C)
0
1
2
3
4
5
6
7
8
9
10
11
12
1
9.1
9.1
+1.2
-1.4
-2.8
-3.8
-4.4
-4.8
-5.0
-4.6
-4.8
-4.8
-4.9
-4.9
-5.0
-5.1
-5.1
-5.1
13
14
15
16
17
18
19
20
2
9.45
18.55
3
1.35
19.9
4
20.6
0.7
-5.0
-5.0
-5.0
-5.1
-5.4
-5.1
-5.1
-5.1
-5.1
-5.1

igure 17

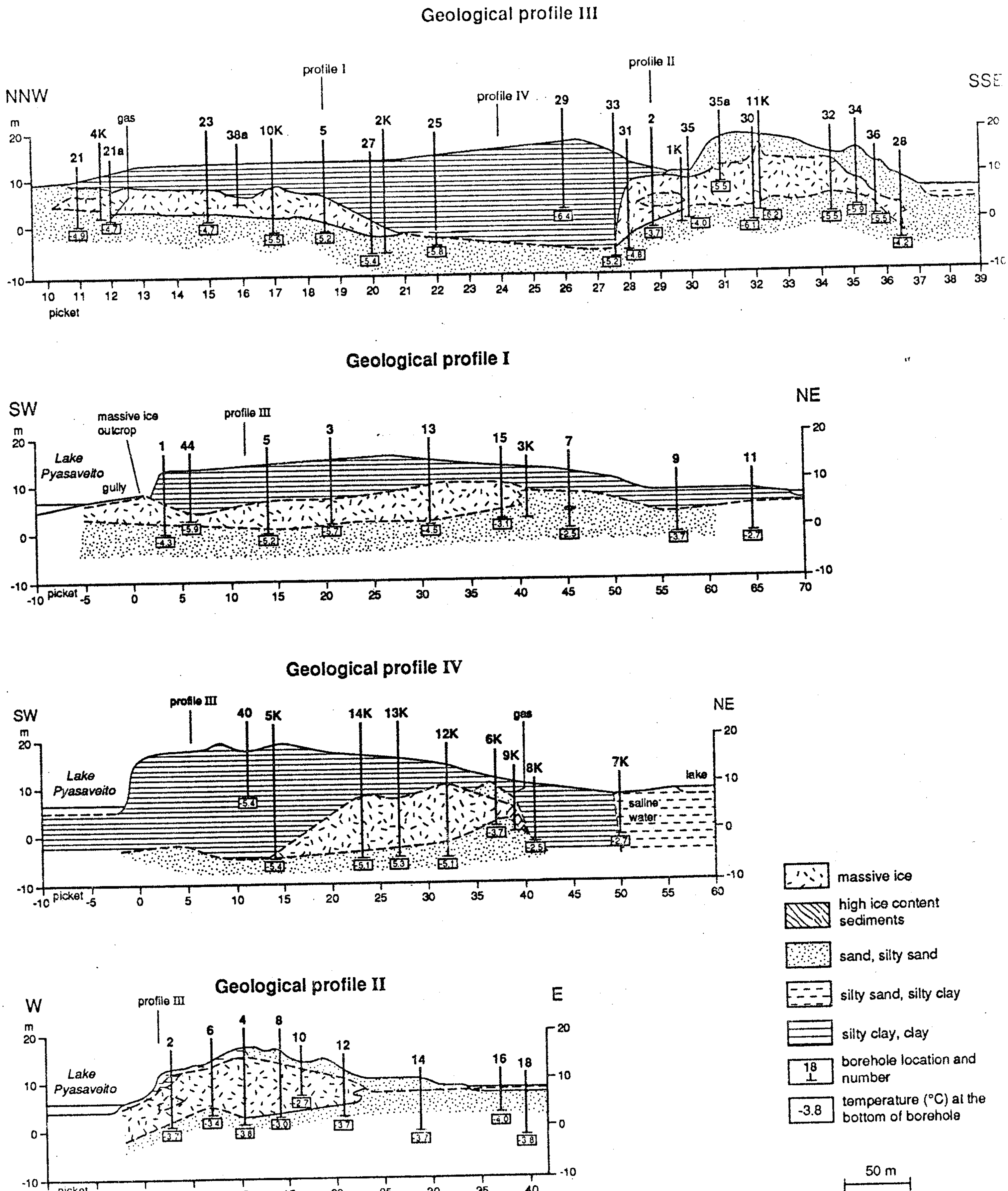
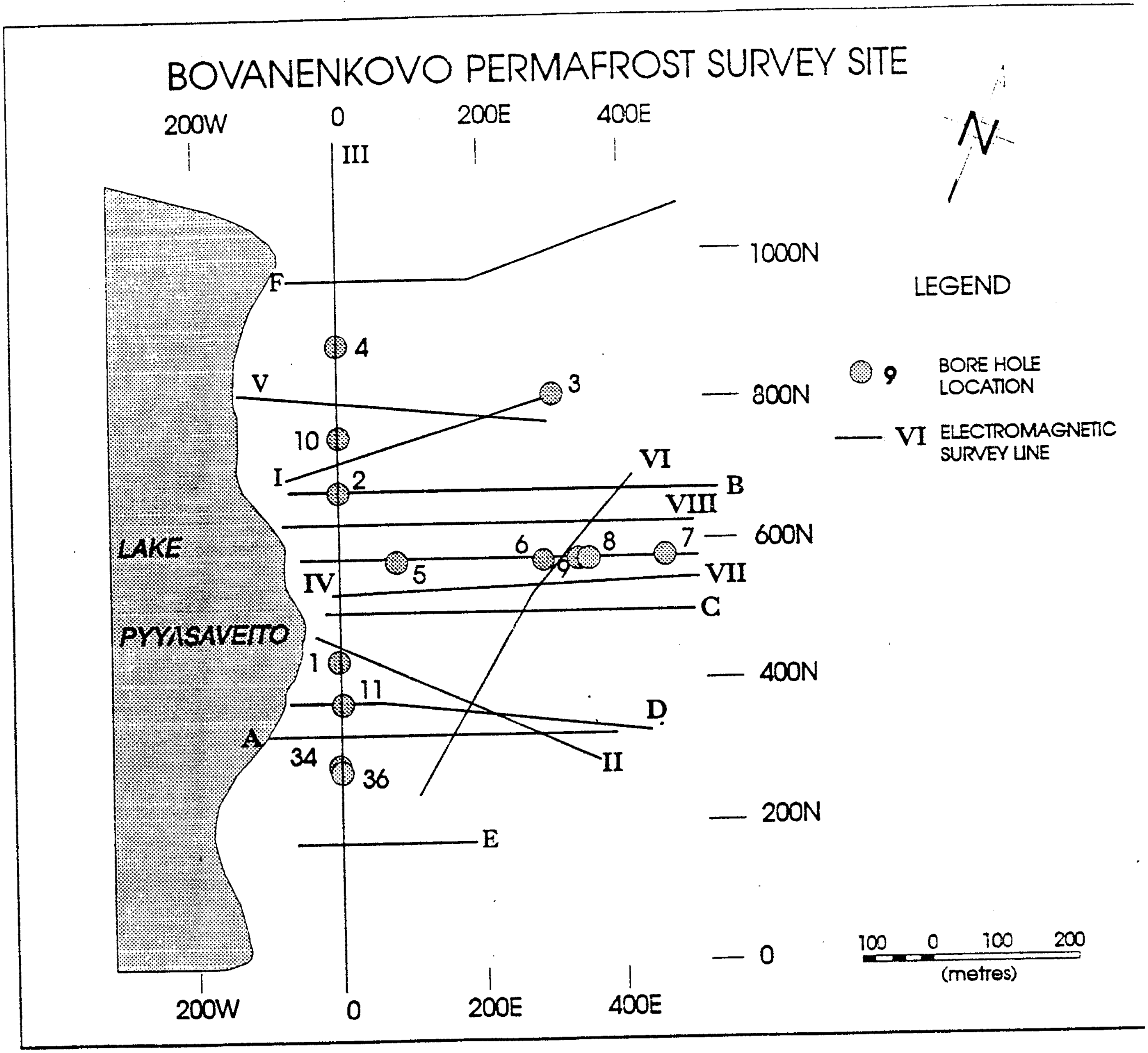

Geological profile III
NNW
SSE
profile I
profile IV
profile II
gas
picket
Geological profile I
SW
NE
massive ice outcrop
profile III
Lake Pyasaveito
gully
picket
Geological profile IV
SW
NE
profile III
gas
Lake Pyasaveito
saline water
lake
picket
Geological profile II
W
E
profile III
Lake Pyasaveito
picket
massive ice
high ice content sediments
sand, silty sand
silty sand, silty clay
silty clay, clay
borehole location and number
temperature (°C) at the bottom of borehole
50 m

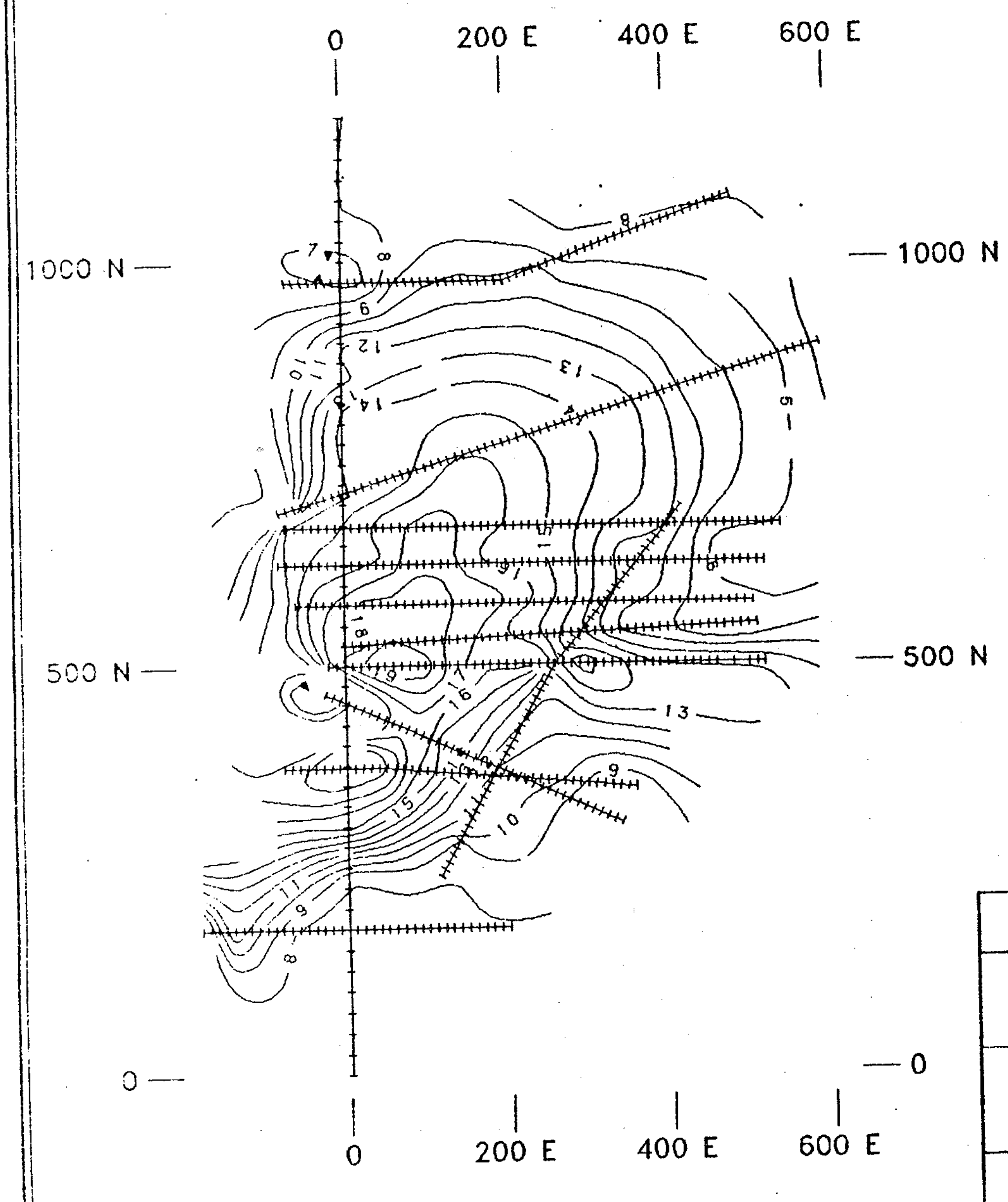
Figure 18

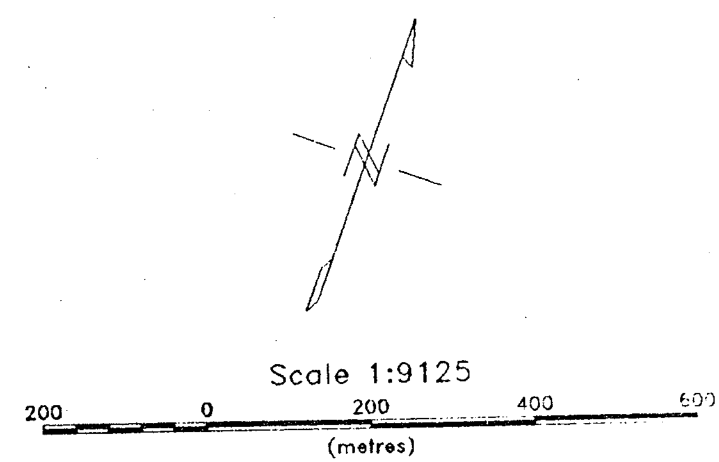


BOVANENKOVO PERMAFROST SURVEY SITE
200W
0
200E
400E
III
N
1000N
F
LEGEND
4
9
BORE HOLE LOCATION
V
3
800N
10
VI
ELECTROMAGNETIC SURVEY LINE
VI
I
2
B
VIII
7
600N
LAKE
6
8
5
9
VII
IV
C
PYYASAVEITO
1
400N
11
D
A
II
34
36
200N
E
0
100
0
100
200
(metres)
200W
0
200E
400E

Figure 19

Figure 20





CANADA / USSR ARCTIC PROJECT

ELEVATION (metres)

BOVANENKOVO SURVEY SITE, JULY, 1991

Topographic Survey
by Dr. Stanislav E. Grechihchev
VSEGINGEO

GSC and VSEGINGEO

Figure 21a

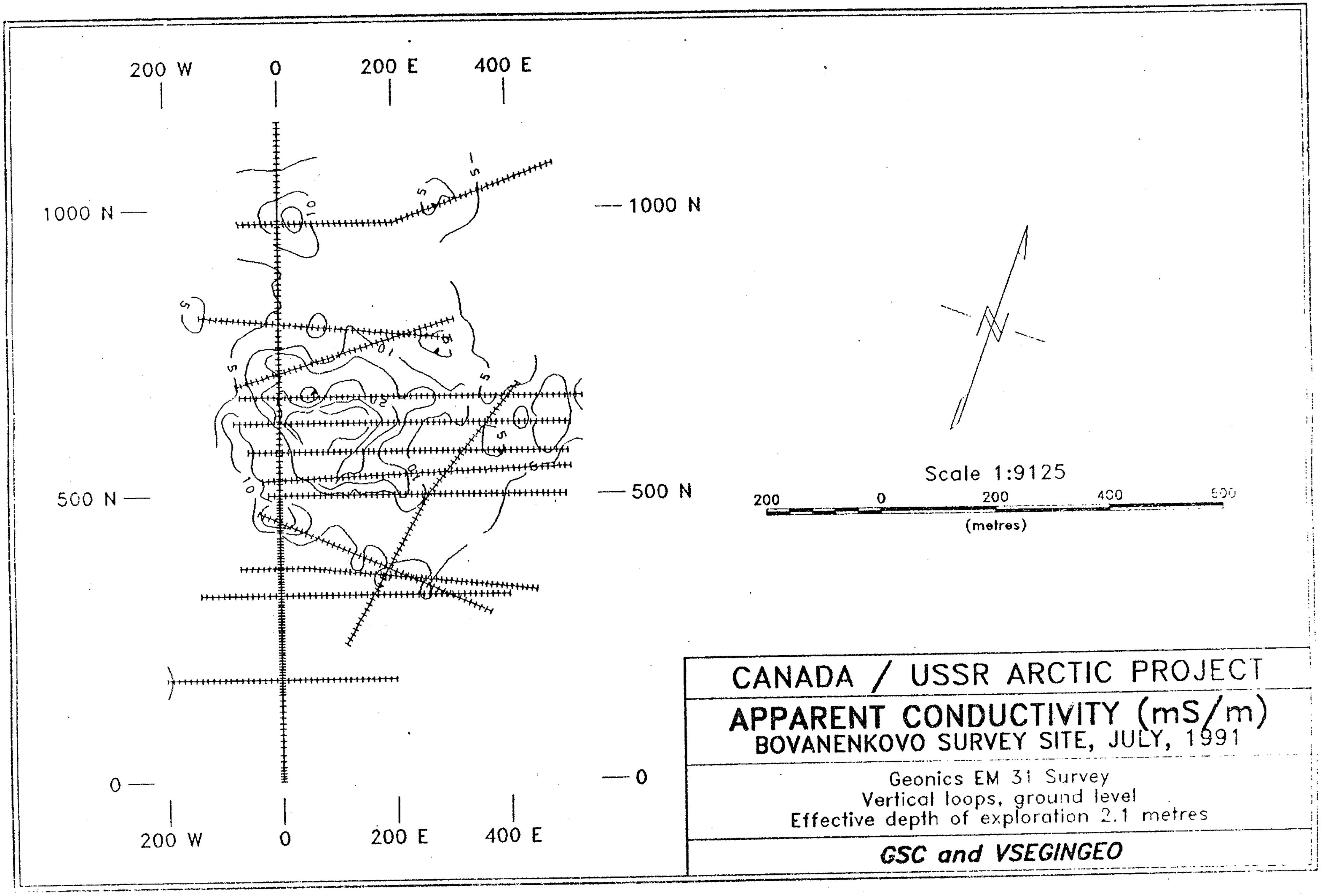

200 W
0
200 E
400 E
1000 N
500 N
0
5
10
Scale 1:9125
200
0
200
400
500
(metres)
CANADA / USSR ARCTIC PROJECT
APPARENT CONDUCTIVITY (mS/m)
BOVANENKOVO SURVEY SITE, JULY, 1991
Geonics EM 31 Survey
Vertical loops, ground level
Effective depth of exploration 2.1 metres
GSC and VSEGINGEO

Figure 21b

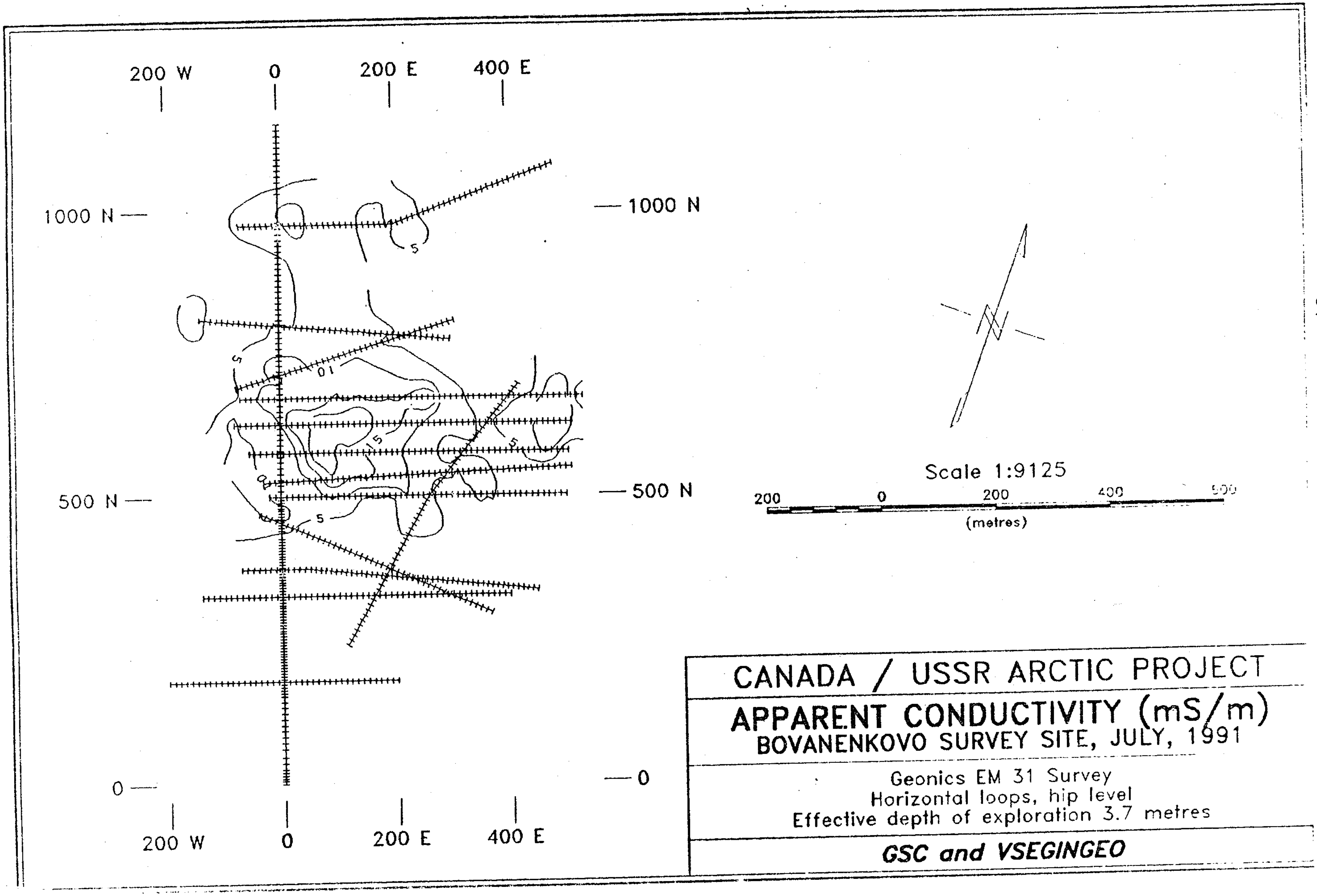

200 W
0
200 E
400 E
1000 N
500 N
0
5
10
Scale 1:9125
200
0
200
400
500
(metres)
CANADA / USSR ARCTIC PROJECT
APPARENT CONDUCTIVITY (mS/m)
BOVANENKOVO SURVEY SITE, JULY, 1991
Geonics EM 31 Survey
Horizontal loops, hip level
Effective depth of exploration 3.7 metres
GSC and VSEGINGEO

Figure 21c

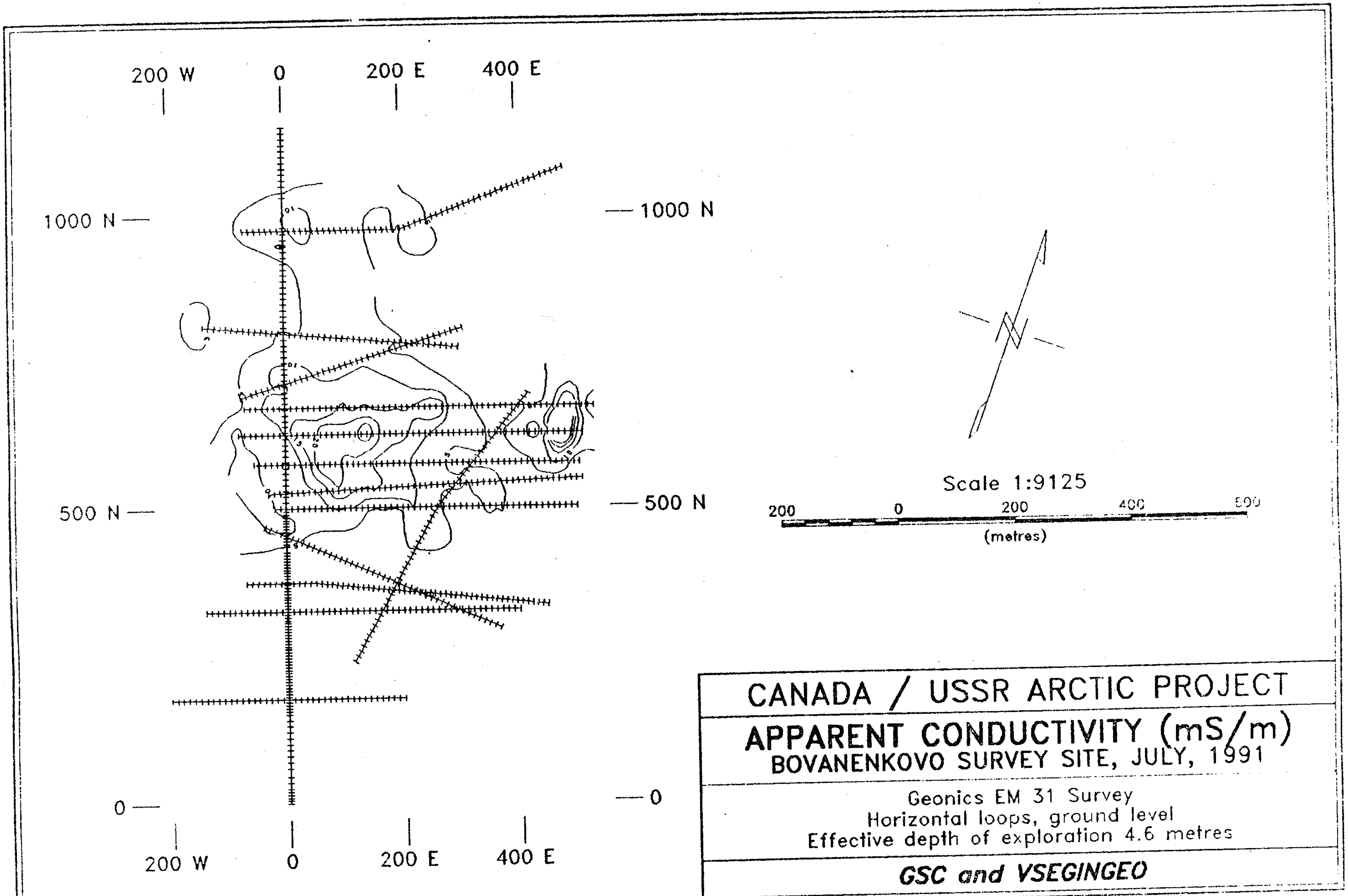
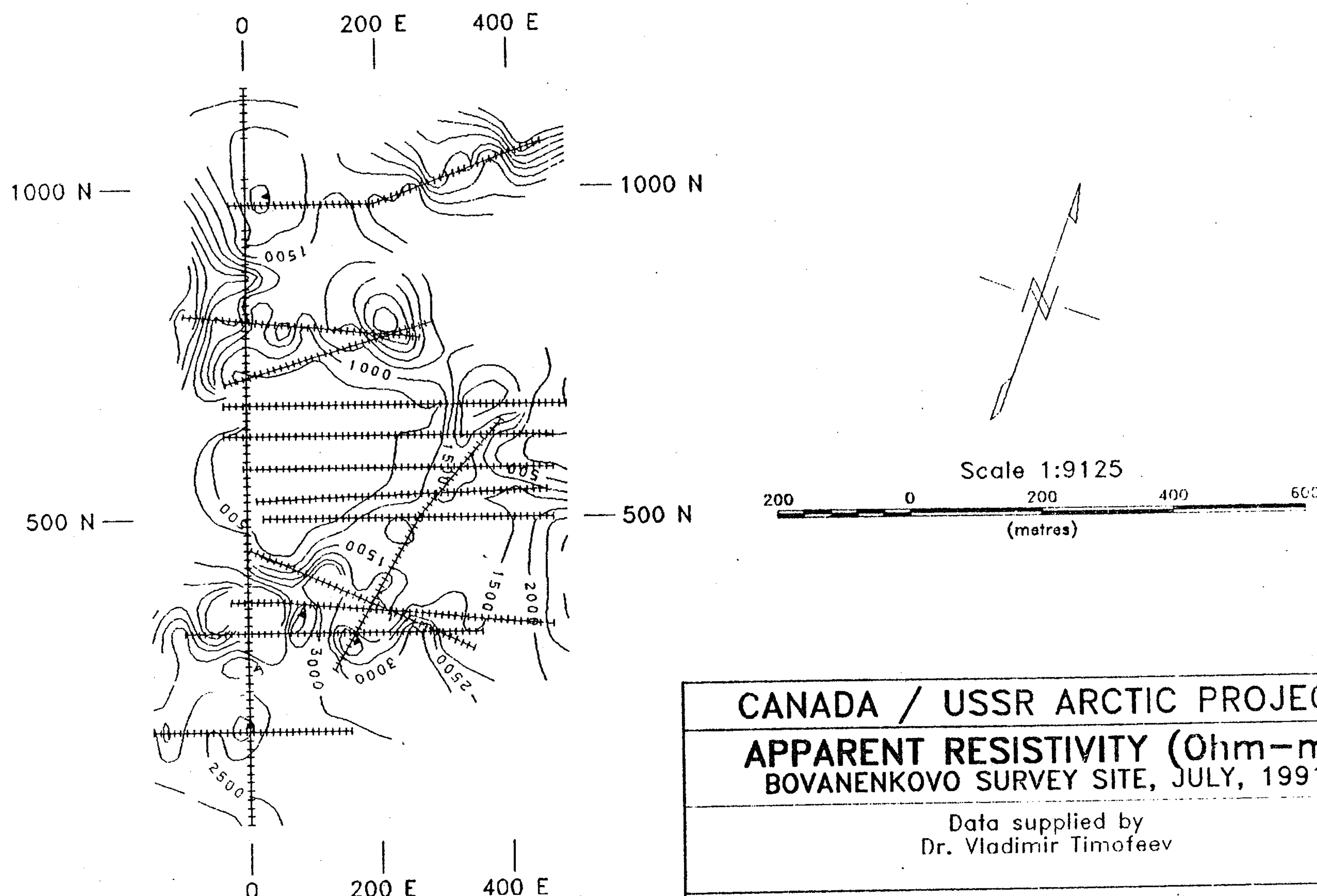

200 W
0
200 E
400 E
1000 N
500 N
0
Scale 1:9125
200
0
200
400
500
(metres)
CANADA / USSR ARCTIC PROJECT
APPARENT CONDUCTIVITY (mS/m)
BOVANENKOVO SURVEY SITE, JULY, 1991
Geonics EM 31 Survey
Horizontal loops, ground level
Effective depth of exploration 4.6 metres
GSC and VSEGINGEO

Figure 22



CANADA / USSR ARCTIC PROJECT

APPARENT RESISTIVITY (Ohm–m)
BOVANENKOVO SURVEY SITE, JULY, 1991

Data supplied by
Dr. Vladimir Timofeev

GSC and VSEGINGEO

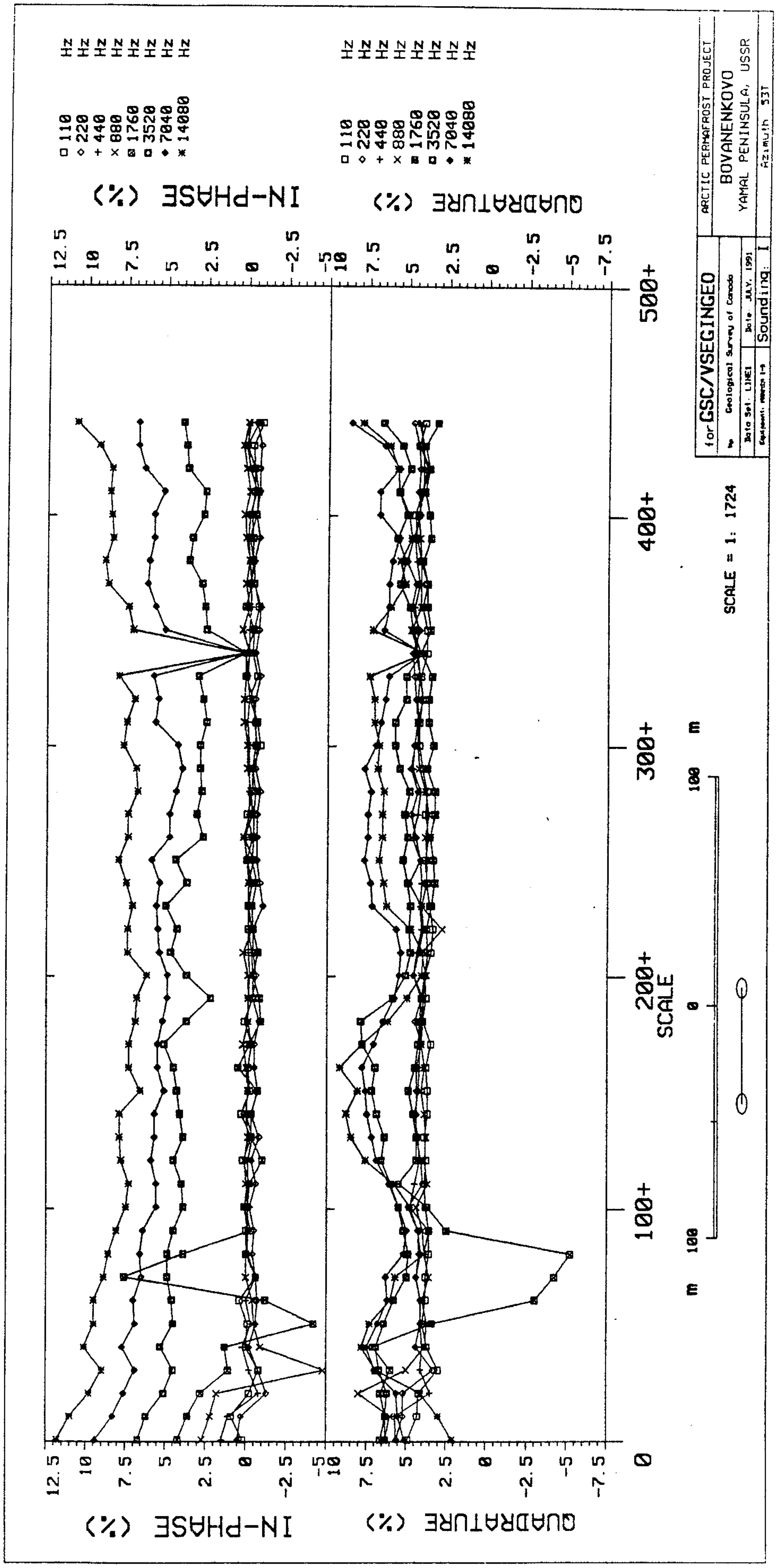

IN-PHASE (%)
QUADRATURE (%)
110 Hz
220 Hz
440 Hz
880 Hz
1760 Hz
3520 Hz
7040 Hz
14080 Hz
ARCTIC PERMAFROST PROJECT
BOVANENKOVO
YAMAL PENINSULA, USSR
for GSC/VSEGINGEO
Geological Survey of Canada
Date: JULY, 1991
Sounding: I
SCALE = 1: 1724
SCALE
0
100+
200+
300+
400+
500+
m 100 0 100 m

Figure 23a

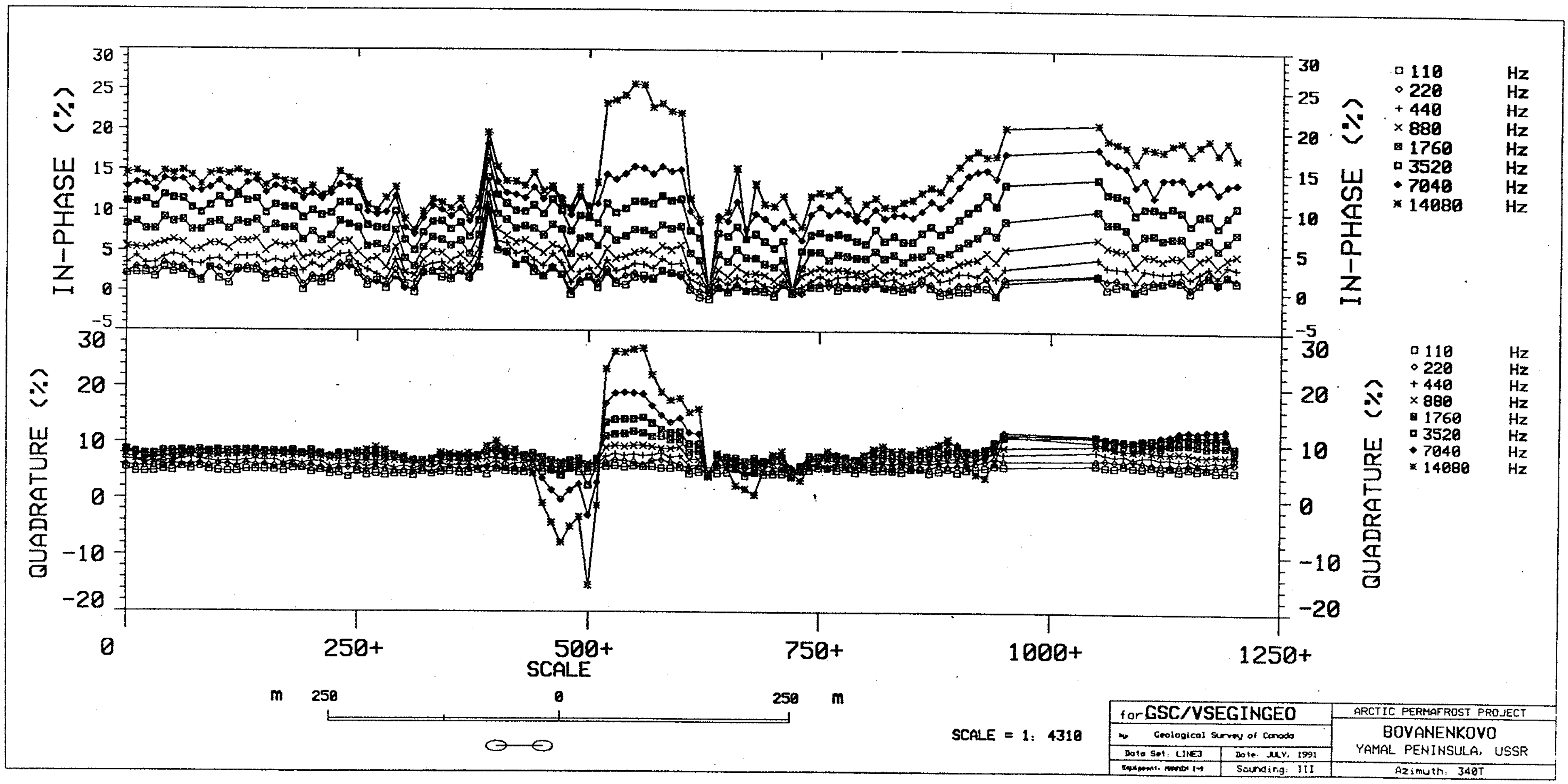

IN-PHASE (%)
QUADRATURE (%)
□ 110 Hz
◇ 220 Hz
+ 440 Hz
× 880 Hz
▣ 1760 Hz
□ 3520 Hz
◆ 7040 Hz
✱ 14080 Hz
0
250+
500+
750+
1000+
1250+
SCALE
m 250 0 250 m
SCALE = 1: 4310
for GSC/VSEGINGEO
Geological Survey of Canada
Data Set: LINE3
Date: JULY, 1991
Sounding: III
ARCTIC PERMAFROST PROJECT
BOVANENKOVO
YAMAL PENINSULA, USSR
Azimuth: 340T

Figure 23b

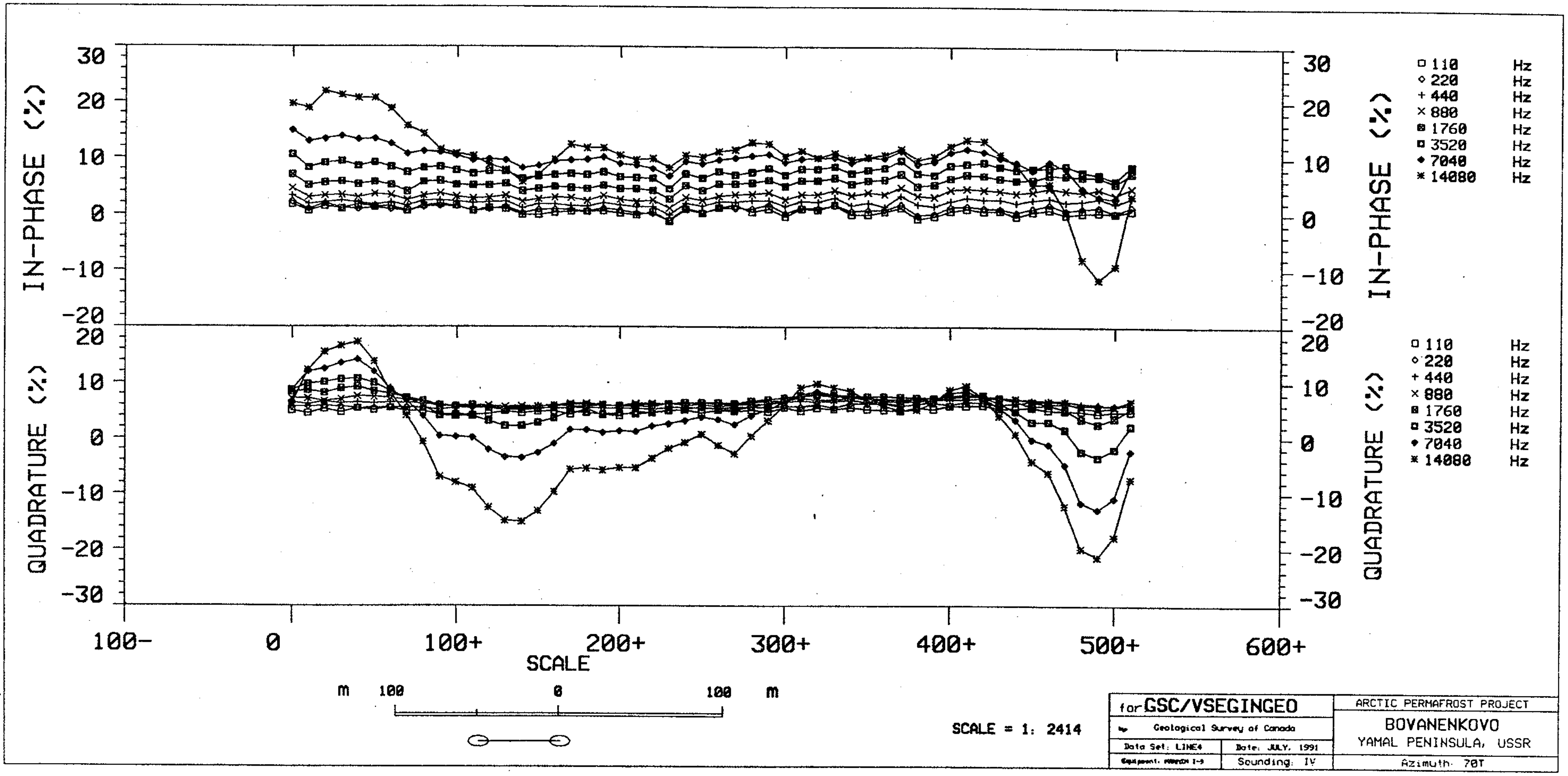

IN-PHASE (%)
QUADRATURE (%)
□ 110 Hz
◇ 220 Hz
+ 440 Hz
× 880 Hz
1760 Hz
3520 Hz
◆ 7040 Hz
✱ 14080 Hz
100- 0 100+ 200+ 300+ 400+ 500+ 600+
SCALE
m 100 0 100 m
SCALE = 1: 2414
for GSC/VSEGINGEO
Geological Survey of Canada
Data Set: LINE4
Date: JULY, 1991
Sounding: IV
ARCTIC PERMAFROST PROJECT
BOVANENKOVO
YAMAL PENINSULA, USSR
Azimuth 70T

Figure 23c

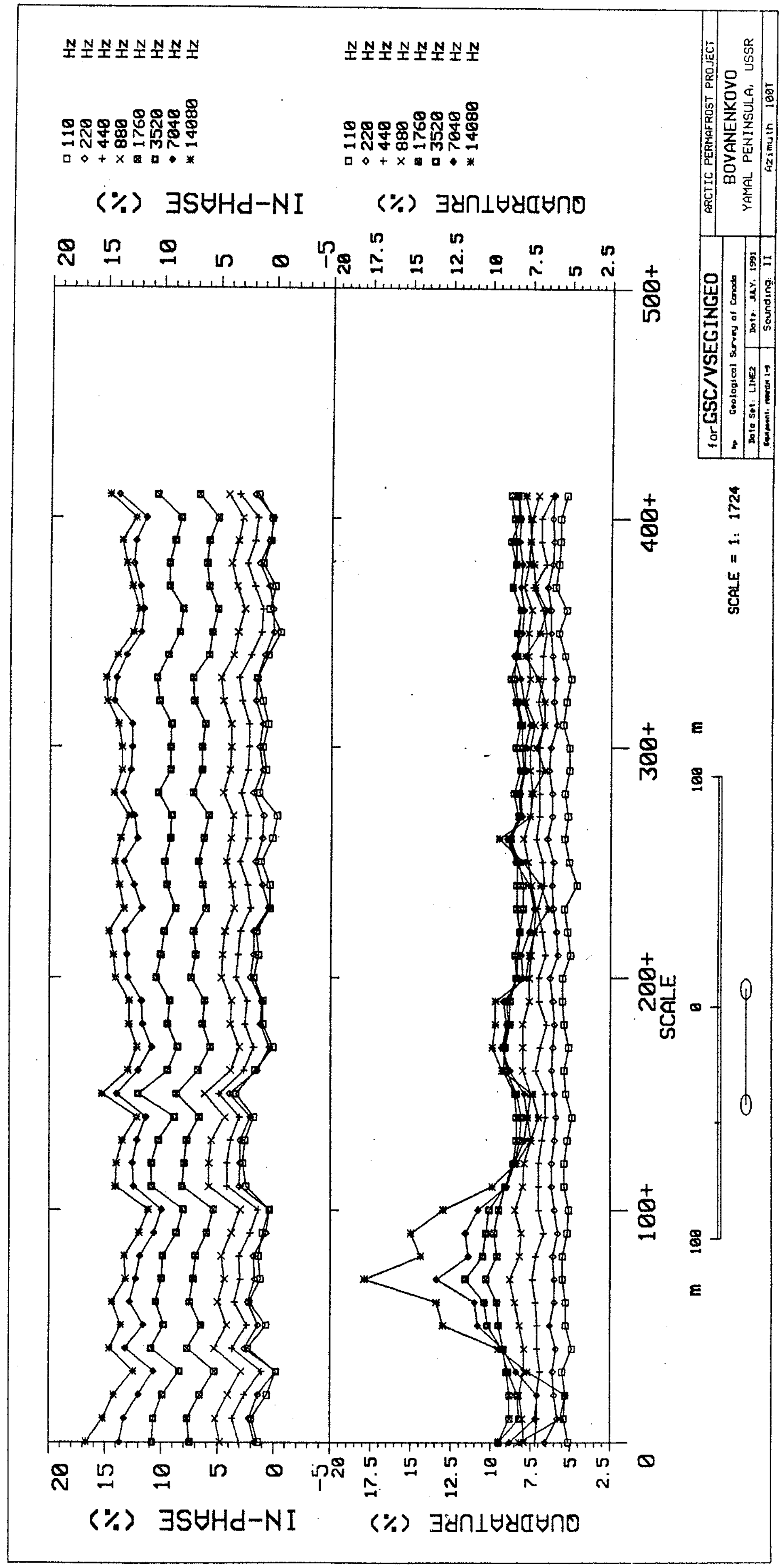

IN-PHASE (%)
QUADRATURE (%)
□ 110 Hz
◇ 220 Hz
+ 440 Hz
× 880 Hz
⊠ 1760 Hz
⊡ 3520 Hz
◆ 7040 Hz
✱ 14080 Hz
ARCTIC PERMAFROST PROJECT
BOVANENKOVO
YAMAL PENINSULA, USSR
Azimuth 100T
for GSC/VSEGINGEO
Geological Survey of Canada
Data Set: LINE2
Date: JULY, 1991
Sounding: II
SCALE = 1: 1724
SCALE
m 100 0 100 m
0
100+
200+
300+
400+
500+

Figure 23d

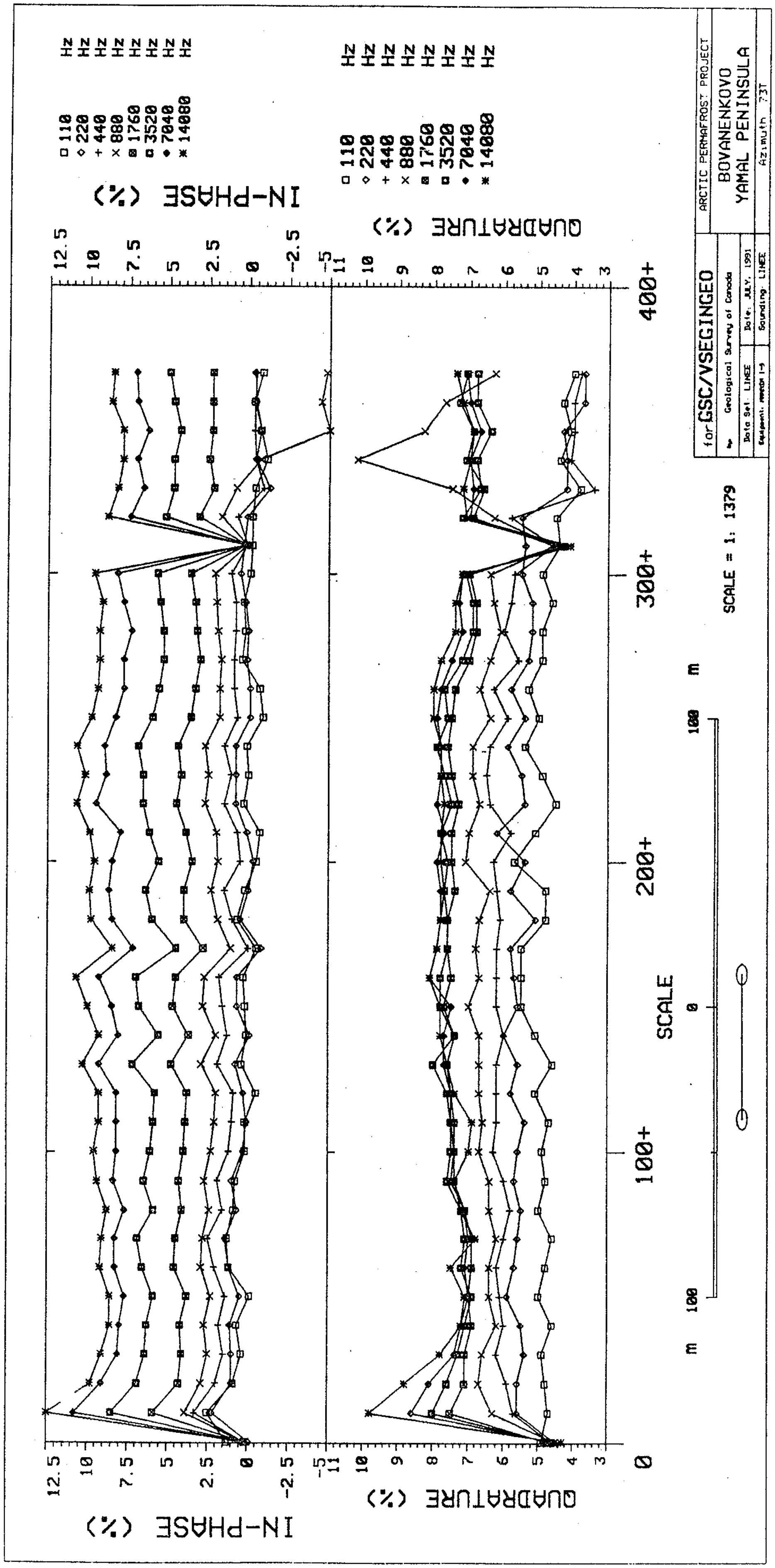

IN-PHASE (%)
QUADRATURE (%)
□ 110 Hz
◇ 220 Hz
+ 440 Hz
× 880 Hz
⊠ 1760 Hz
▣ 3520 Hz
◆ 7040 Hz
✱ 14080 Hz
SCALE
m 100 0 100 m
SCALE = 1: 1379
for GSC/VSEGINGEO
Geological Survey of Canada
ARCTIC PERMAFROST PROJECT
BOVANENKOVO
YAMAL PENINSULA
Date: JULY, 1991
Azimuth 73T

Figure 23e

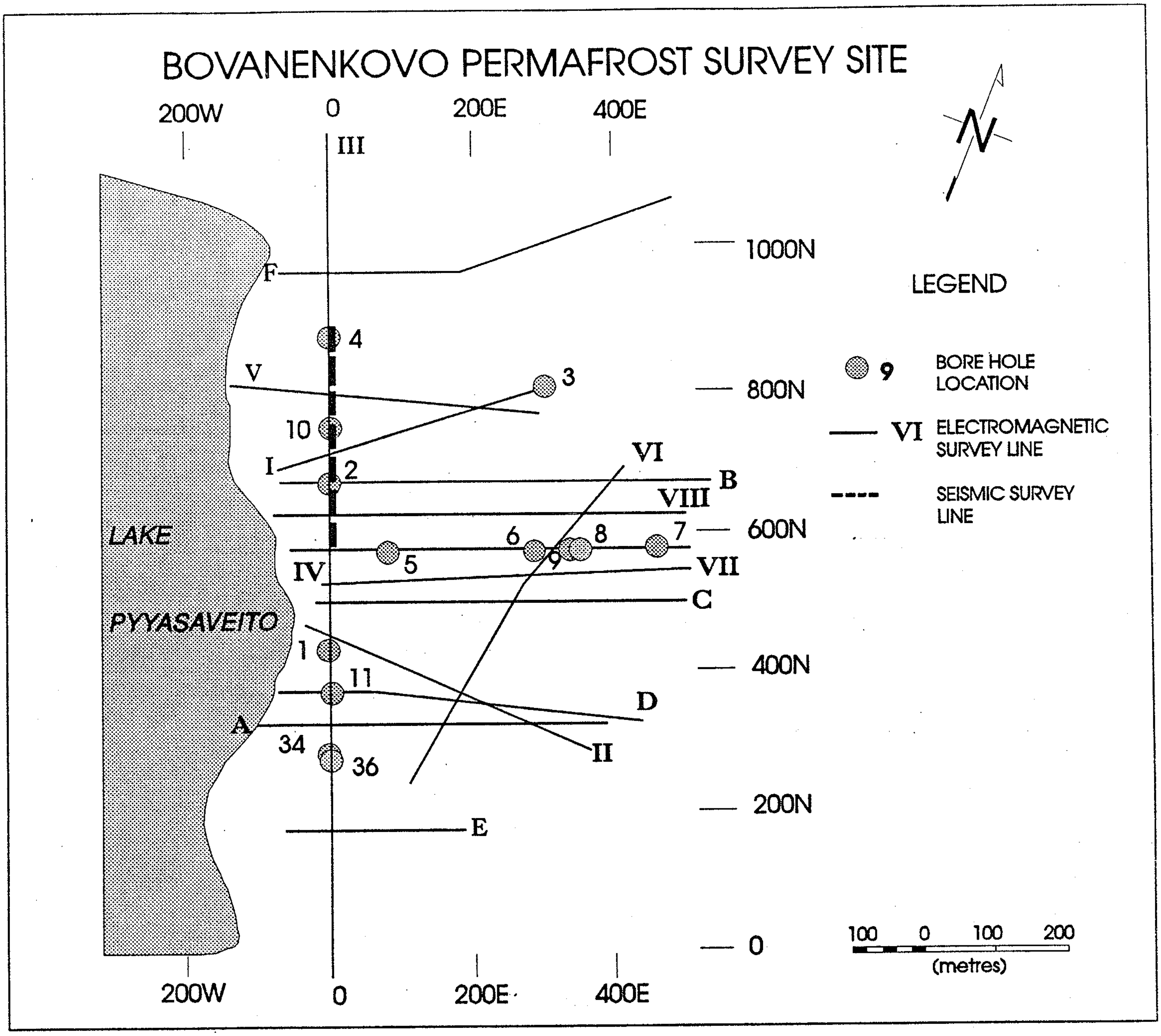

BOVANENKOVO PERMAFROST SURVEY SITE
200W
0
200E
400E
III
1000N
F
LEGEND
4
V
3
800N
9
BORE HOLE LOCATION
10
VI
ELECTROMAGNETIC SURVEY LINE
I
2
B
VIII
SEISMIC SURVEY LINE
LAKE
6
8
7
600N
5
9
IV
VII
C
PYYASAVEITO
1
400N
11
D
A
II
34
36
200N
E
0
100
0
100
200
(metres)
200W
0
200E
400E

Figure 24

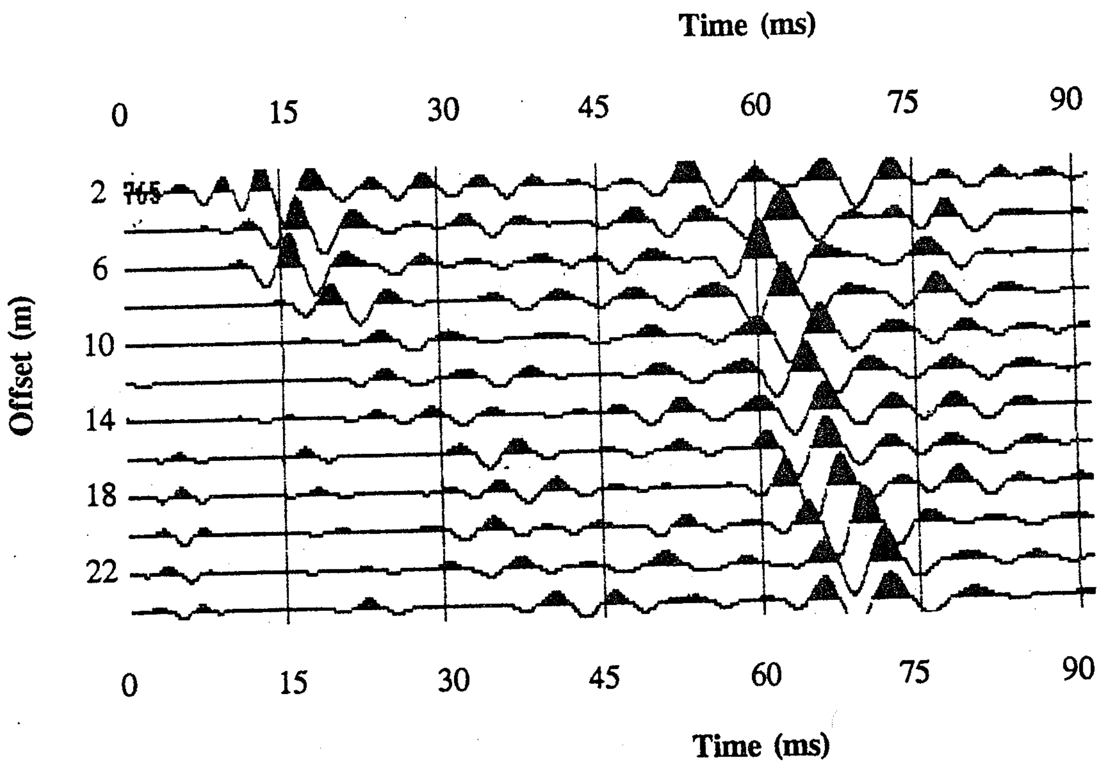
SHEAR WAVE REFLECTION SURVEY

EXAMPLE EXPANDED SPREADS

Figs. 25-27

BOVANENKOVO - SHEAR WAVE REFLECTION SURVEY

EXAMPLE EXPANDED SPREAD - RECORD # 765



Recording Parameters:

Source: Steel rod oriented 45° E/W
Source Depth: 0.5 m
Stack: Equal number of E/W stacks summed with opposite polarities
Source Offset: 2 m from first geophone

Geophones: 50 Hz horizontal geophones oriented transverse to line
Geophone Spacing: 2 m

Sampling Interval: 0.05 ms

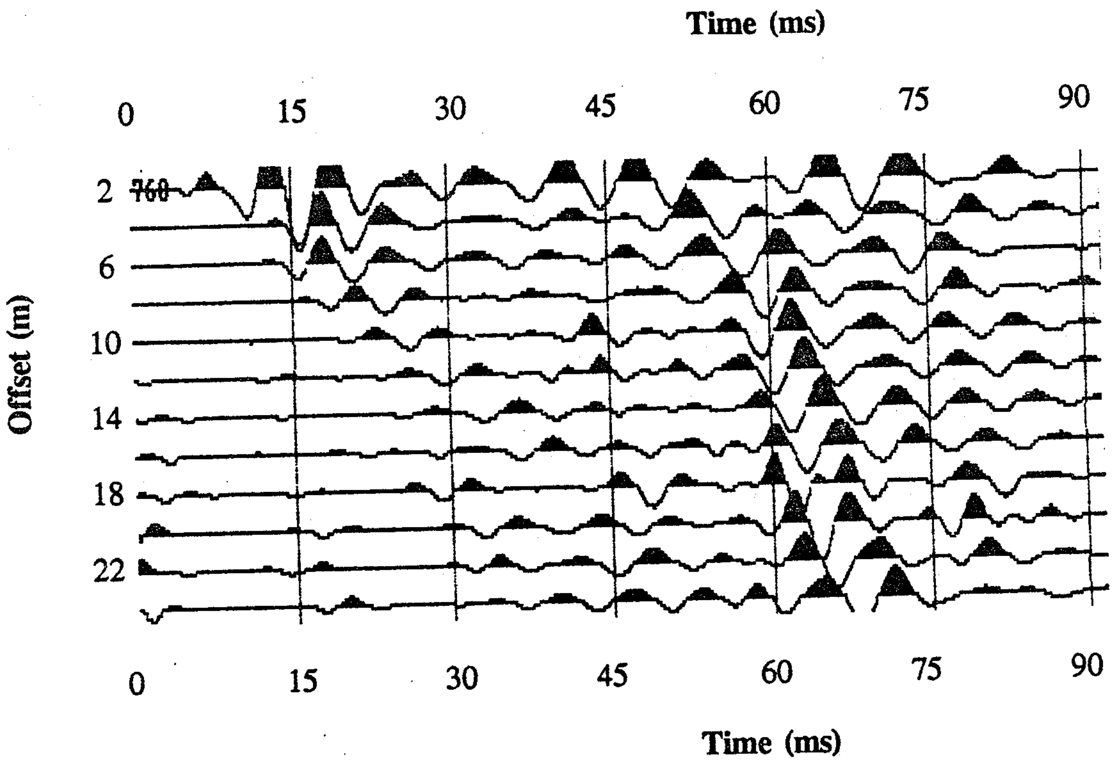
Display Parameters:

AGC Parameters: 400 sample window (centred)
AGC factor = 400
Gain Tapers: 1:0-20 ms / 2:20-40 ms / 2:40-60 ms / 1:60-75 ms / 0.001:75-100 ms
Bandpass Filter: 125-295 Hz (12 db rolloffs)

Figure 25

BOVANENKOVO - SHEAR WAVE REFLECTION SURVEY

EXAMPLE EXPANDED SPREAD - RECORD # 768



Recording Parameters:
Source: Steel rod oriented 45° E/W
Source Depth: 0.5 m
Stack: Equal number of E/W stacks summed with opposite polarities
Source Offset: 2 m from first geophone

Geophones: 50 Hz horizontal geophones oriented transverse to line
Geophone Spacing: 2 m

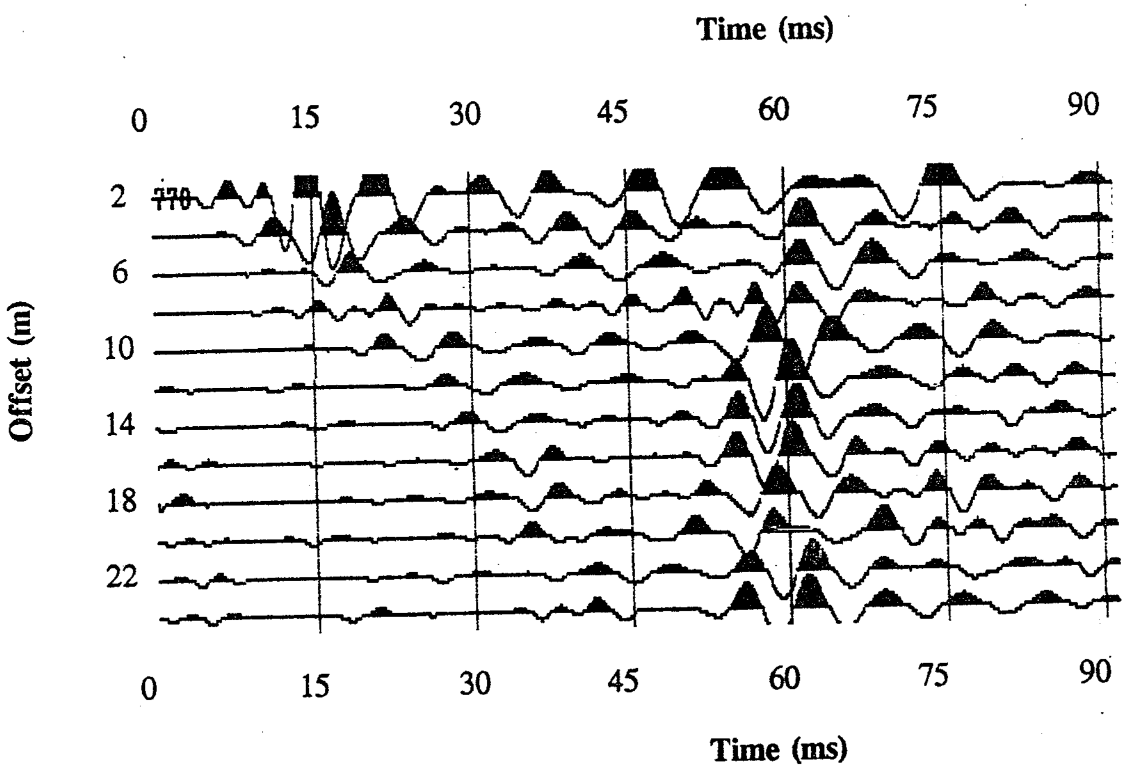
Sampling Interval: 0.05 ms

Display Parameters:
AGC Parameters: 400 sample window (centred)
AGC factor = 400
Gain Tapers: 1:0-20 ms / 2:20-40 ms / 2:40-60 ms / 1:60-75 ms / 0.001:75-100 ms
Bandpass Filter: 125-295 Hz (12 db rolloffs)

Figure 26

BOVANENKOVO - SHEAR WAVE REFLECTION SURVEY

EXAMPLE EXPANDED SPREAD - RECORD # 778



Recording Parameters:
- Source: Steel rod oriented 45° E/W
- Source Depth: 0.5 m
- Stack: Equal number of E/W stacks summed with opposite polarities
- Source Offset: 2 m from first geophone
- Geophones: 50 Hz horizontal geophones oriented transverse to line
- Geophone Spacing: 2 m
- Sampling Interval: 0.05 ms

Display Parameters:
- AGC Parameters: 400 sample window (centred)
  AGC factor = 400
- Gain Tapers: 1:0-20 ms / 2:20-40 ms / 2:40-60 ms / 1:60-75 ms / 0.001:75-100 ms
- Bandpass Filter: 125-295 Hz (12 db rolloffs)

Figure 27

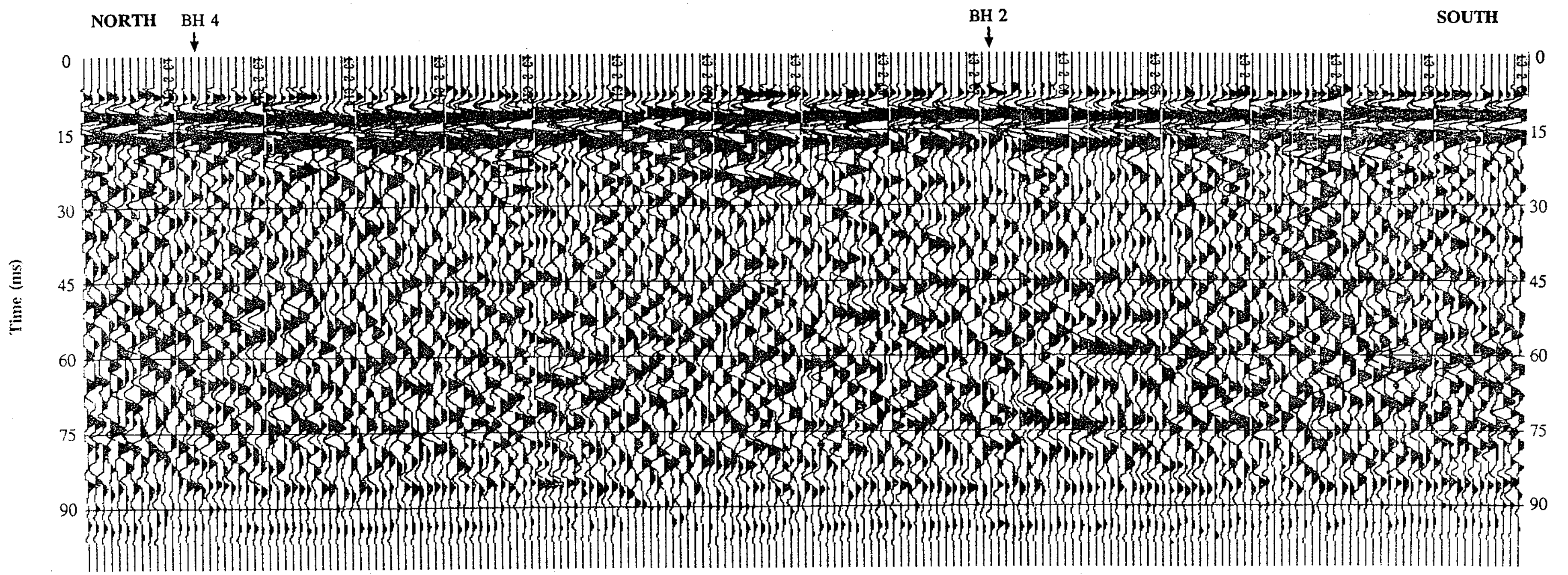
SHEAR WAVE REFLECTION SURVEY

COMMON OFFSET SECTIONS

1. Trace 2 - offset = 4 m
2. Trace 3 - offset = 6 m
3. Trace 4 - offset = 8 m
4. Trace 5 - offset = 10 m
5. Trace 6 - offset = 12 m
6. Trace 6 - offset = 12 m (plotted without static corrections)

BOVANENKOVO - SHEAR WAVE REFLECTION SURVEY

COMMON OFFSET SECTION - TRACE 2 (offset = 4 m)



Recording Parameters:
Source: Steel rod oriented 45° E/W
Source Depth: 0.5 m
Stack: Equal number of E/W stacks summed with opposite polarities
Source-Receiver Offset: 4 m

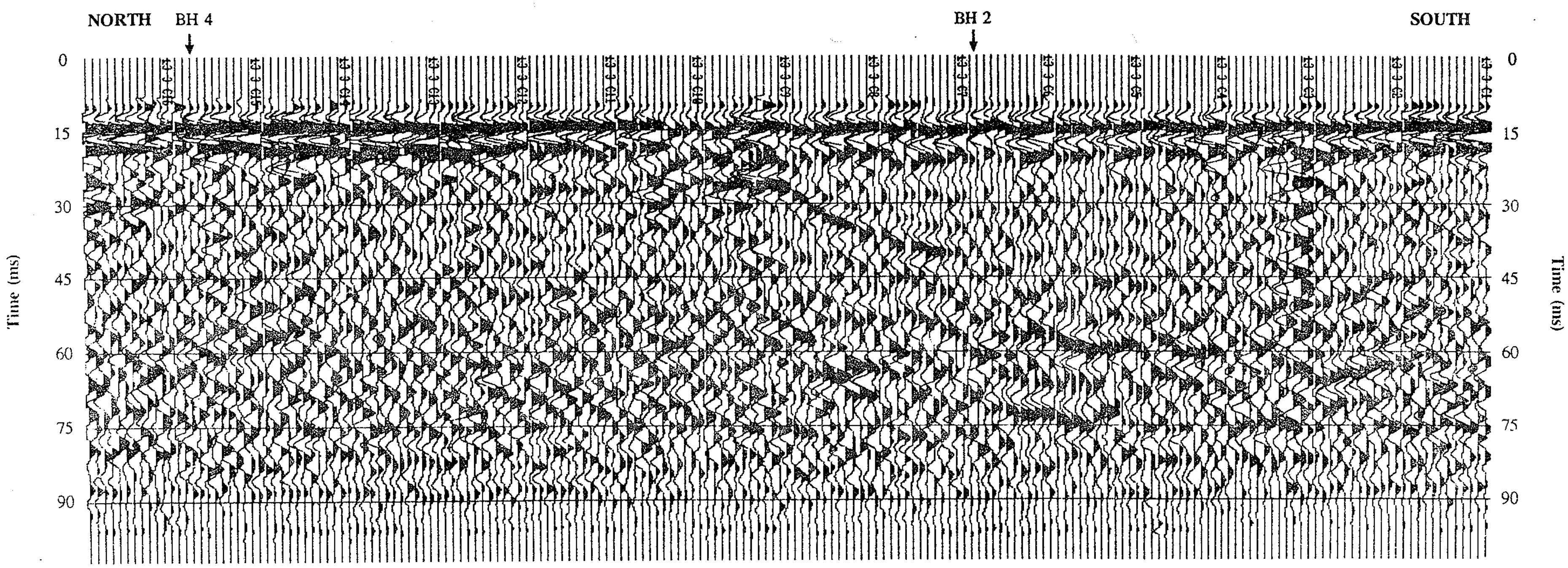
Geophone: 50 Hz horizontal geophones oriented transverse to line
Trace Spacing: 2 m

Sampling Interval: 0.05 ms

Display Parameters:
Static Corrections: Alignment of first arrivals
AGC Parameters: 400 sample window (centred)
AGC factor = 400
Gain Tapers: 1:0-20 ms / 2:20-40 ms / 2:40-60 ms / 1:60-75 ms / 0.001:75-100 ms
Bandpass Filter: 125-295 Hz (12 db rolloffs)

Figure 28

BOVANENKOVO - SHEAR WAVE REFLECTION SURVEY   COMMON OFFSET SECTION - TRACE 3 (offset = 6 m)



Recording Parameters:
Source: Steel rod oriented 45° E/W
Source Depth: 0.5 m
Stack: Equal number of E/W stacks summed with opposite polarities
Source-Receiver Offset: 6 m

Geophones: 50 Hz horizontal geophones oriented transverse to line
Trace Spacing: 2 m

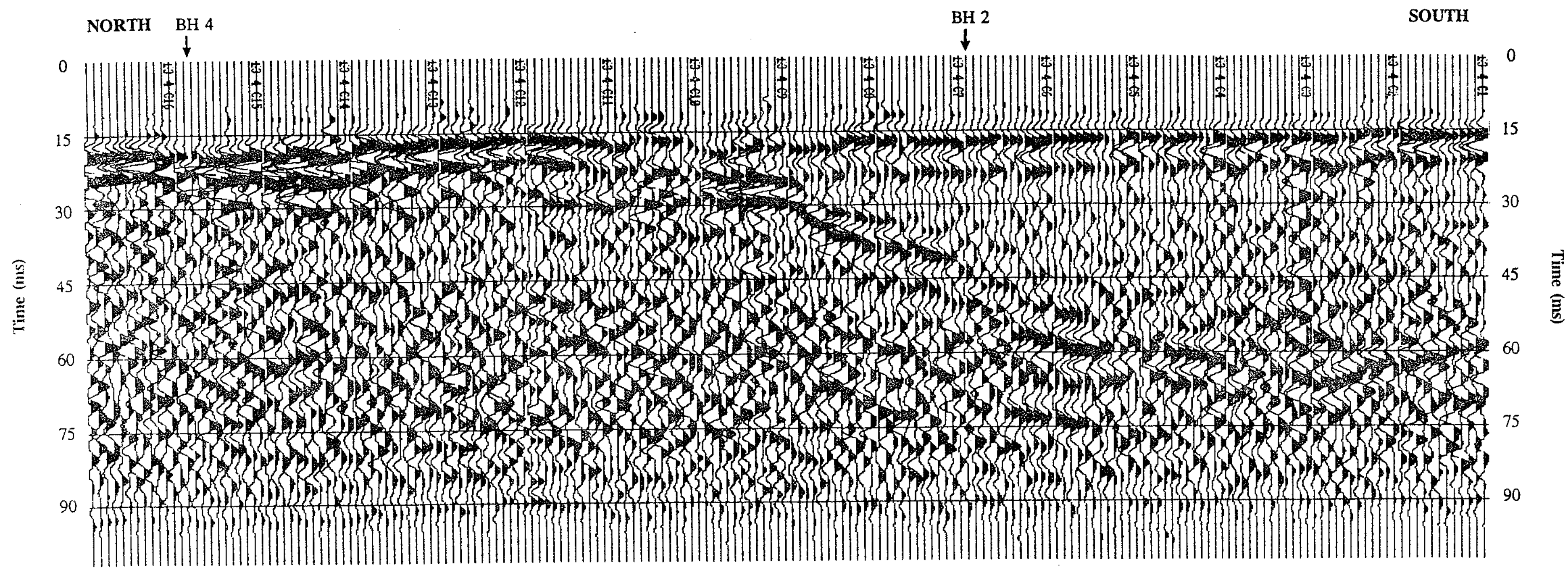
Sampling Interval: 0.05 ms

Display Parameters:
Static Corrections: Alignment of first arrivals
AGC Parameters: 400 sample window (centred)
AGC factor = 400
Gain Tapers: 1:0-20 ms / 2:20-40 ms / 2:40-60 ms / 1:60-75 ms / 0.001:75-100 ms
Bandpass Filter: 125-295 Hz (12 db rolloffs)

Figure 29

BOVANENKOVO - SHEAR WAVE REFLECTION SURVEY

COMMON OFFSET SECTION - TRACE 4 (offset = 8 m)



Recording Parameters:
Source: Steel rod oriented 45° E/W
Source Depth: 0.5 m
Stack: Equal number of E/W stacks summed with opposite polarities
Source-Receiver Offset: 8 m

Geophones: 50 Hz horizontal geophones oriented transverse to line
Trace Spacing: 2 m

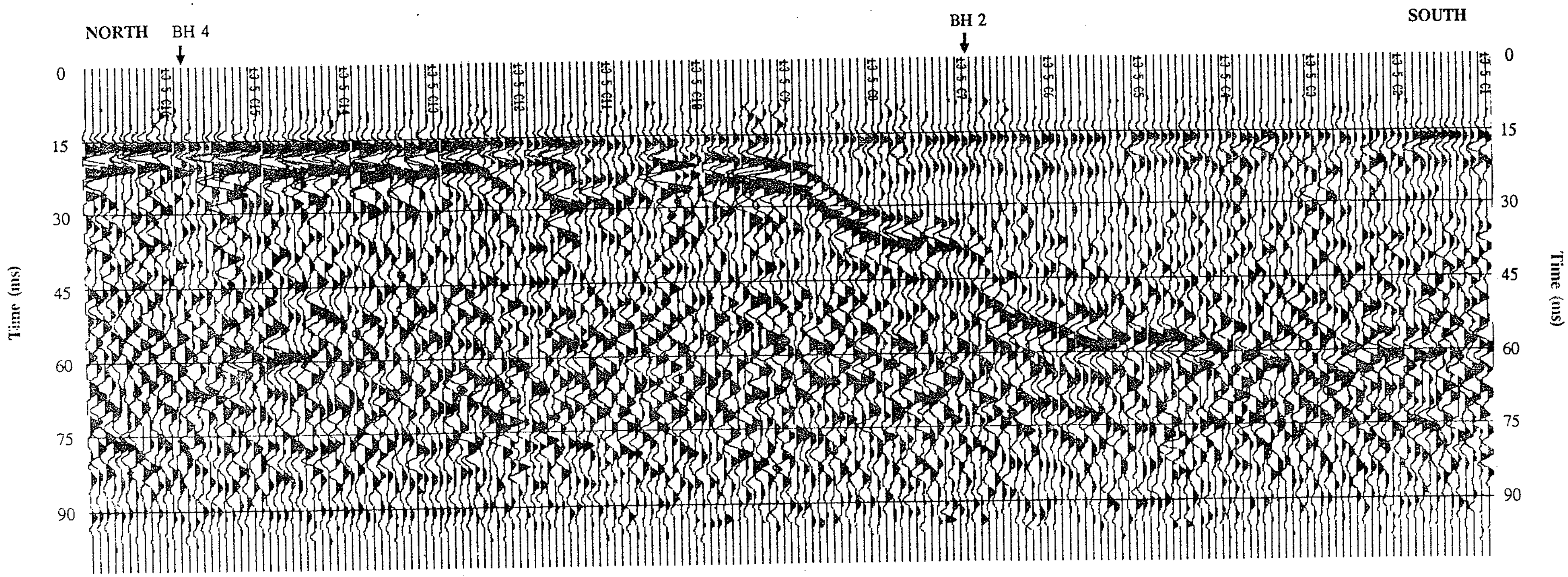
Sampling Interval: 0.05 ms

Display Parameters:
Static Corrections: Alignment of first arrivals
AGC Parameters: 400 sample window (centred)
AGC factor = 400
Gain Tapers: 1:0-20 ms / 2:20-40 ms / 2:40-60 ms / 1:60-75 ms / 0.001:75-100 ms.
Bandpass Filter: 125-295 Hz (12 db rolloffs)

Figure 30

BOVANENKOVO - SHEAR WAVE REFLECTION SURVEY

COMMON OFFSET SECTION - TRACE 5 (offset = 10 m)



Recording Parameters:
Source: Steel rod oriented 45° E/W
Source Depth: 0.5 m
Stack: Equal number of E/W stacks summed with opposite polarities
Source-Receiver Offset: 10 m

Geophones: 50 Hz horizontal geophones oriented transverse to line
Trace Spacing: 2 m

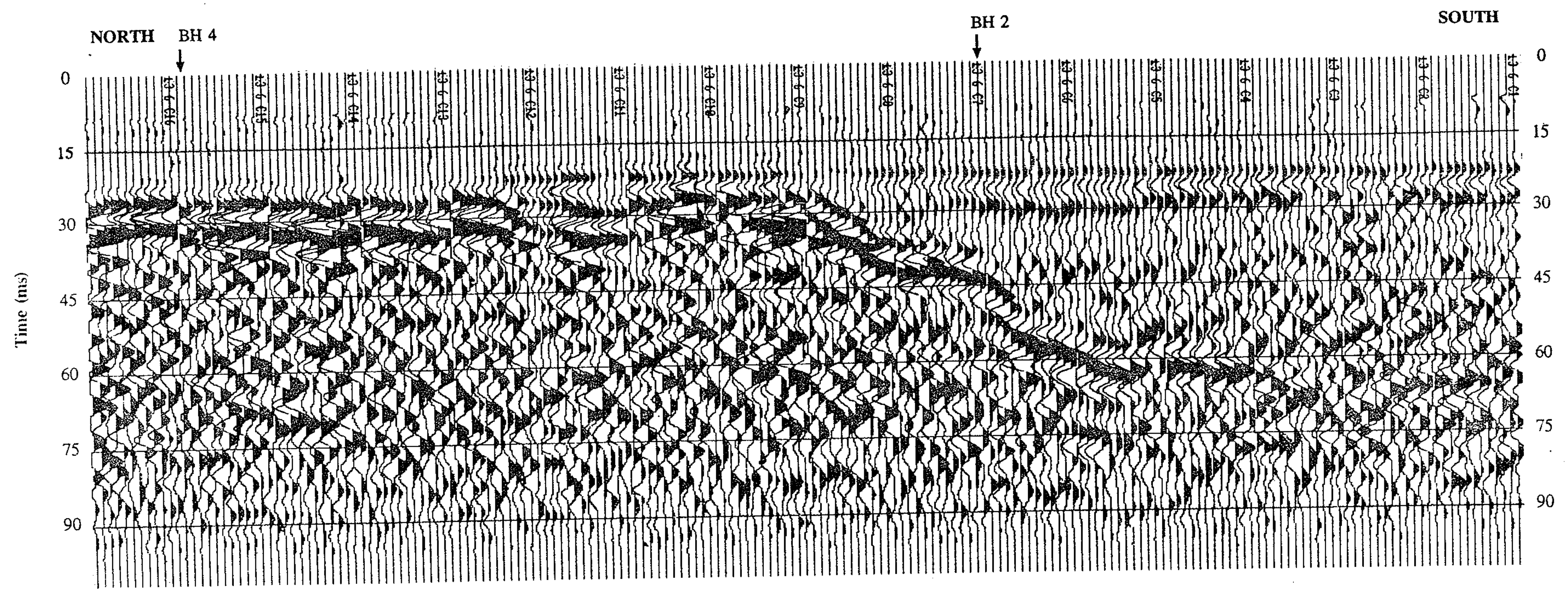
Sampling Interval: 0.05 ms

Display Parameters:
Static Corrections: Alignment of first arrivals
AGC Parameters: 400 sample window (centred)
AGC factor = 400
Gain Tapers: 1:0-20 ms / 2:20-40 ms / 2:40-60 ms / 1:60-75 ms / 0.001:75-100 ms
Bandpass Filter: 125-295 Hz (12 db rolloffs)

Figure 31

BOVANENKOVO - SHEAR WAVE REFLECTION SURVEY

COMMON OFFSET SECTION - TRACE 6 (offset = 12 m)



Recording Parameters:
Source: Steel rod oriented 45° E/W
Source Depth: 0.5 m
Stack: Equal number of E/W stacks summed with opposite polarities
Source-Receiver Offset: 12 m

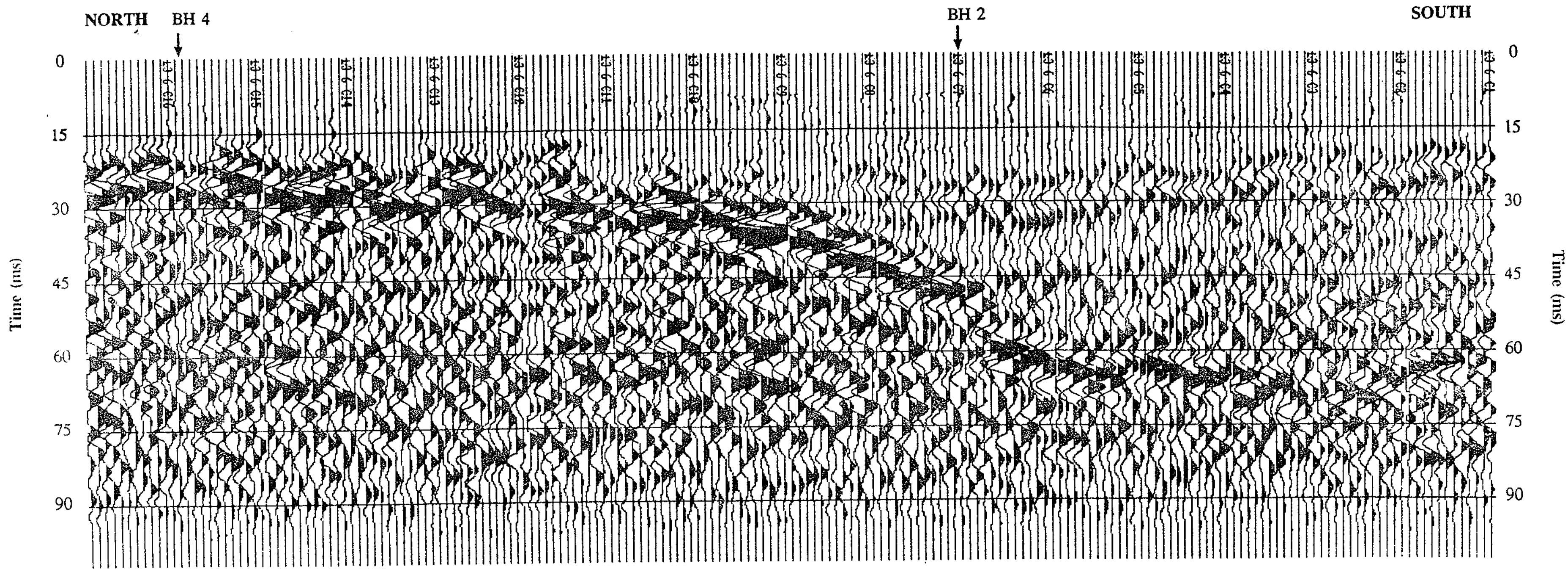
Geophones: 50 Hz horizontal geophones oriented transverse to line
Trace Spacing: 2 m

Sampling Interval: 0.05 ms

Display Parameters:
Static Corrections: Alignment of first arrivals
AGC Parameters: 400 sample window (centred)
AGC factor = 400
Gain Tapers: 1:0-20 ms / 2:20-40 ms / 2:40-60 ms / 1:60-75 ms / 0.001:75-100 ms
Bandpass Filter: 125-295 Hz (12 db rolloffs)

Figure 32

BOVANENKOVO - SHEAR WAVE REFLECTION SURVEY   COMMON OFFSET SECTION - TRACE 6 (offset = 12 m)



Recording Parameters:
Source: Steel rod oriented 45° E/W
Source Depth: 0.5 m
Stack: Equal number of E/W stacks summed with opposite polarities
Source-Receiver Offset: 12 m

Geophones: 50 Hz horizontal geophones oriented transverse to line
Trace Spacing: 2 m

Sampling Interval: 0.05 ms

Display Parameters:
Static Corrections: N/A
AGC Parameters: 400 sample window (centred)
AGC factor = 400
Gain Tapers: 1:0-20 ms / 2:20-40 ms / 2:40-60 ms / 1:60-75 ms / 0.001:75-100 ms
Bandpass Filter: 125-295 Hz (12 db rolloffs)

Figure 33

EM-39 LOGGING SYSTEM

NATURAL GAMMA LOGS

Figs. 34-47

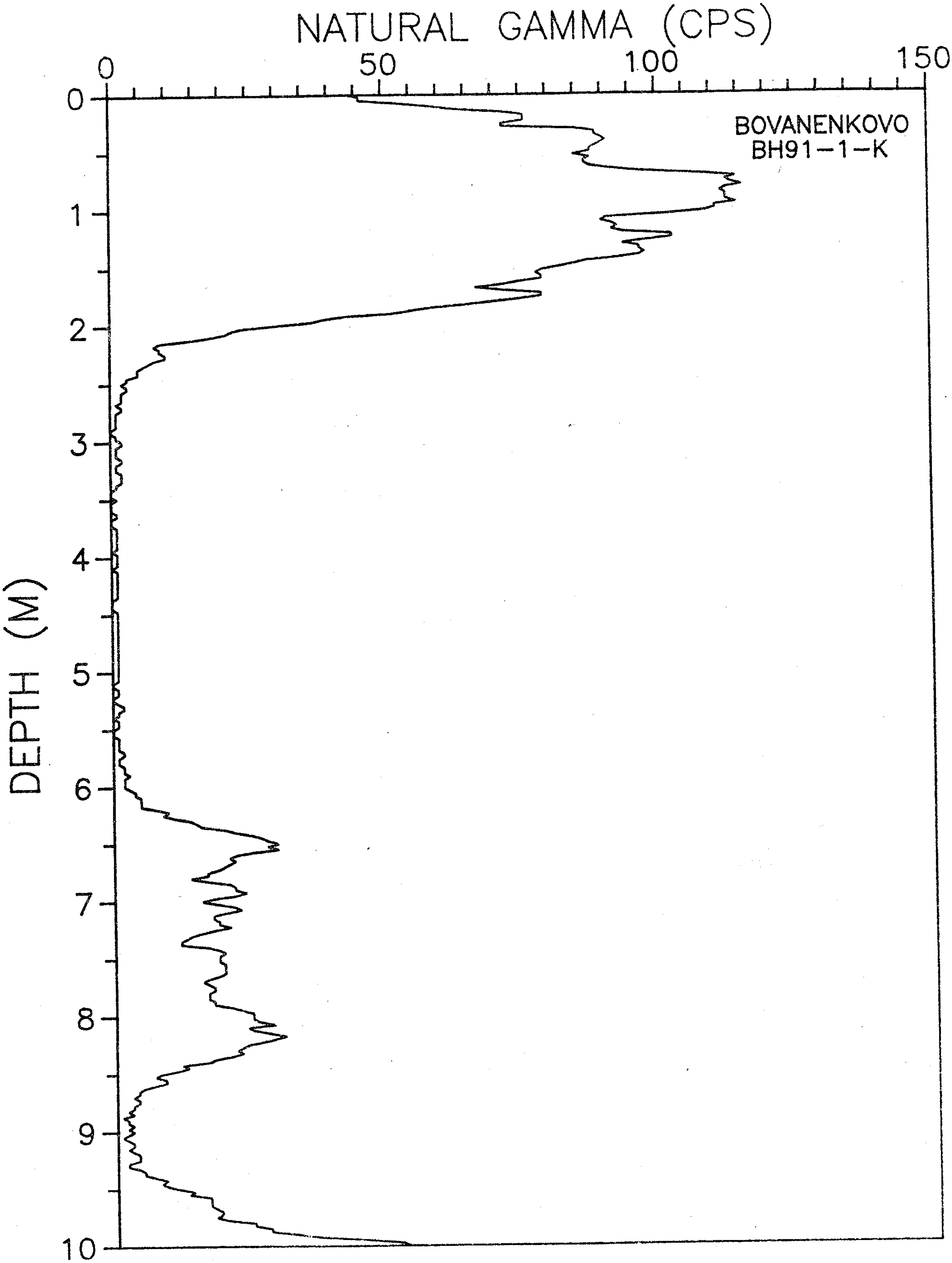
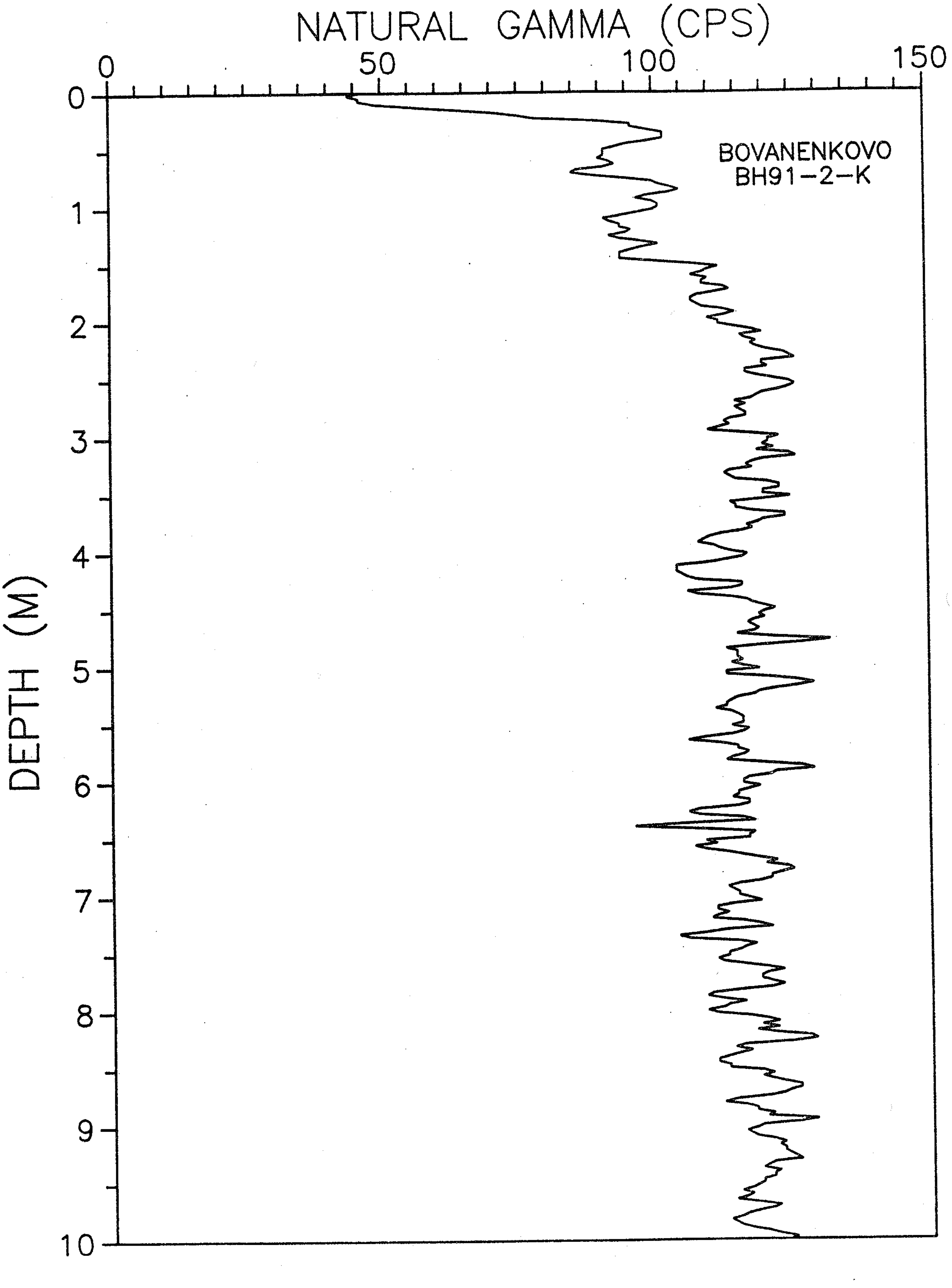

NATURAL GAMMA (CPS)
0
50
100
150
BOVANENKOVO
BH91-1-K
DEPTH (M)
0
1
2
3
4
5
6
7
8
9
10

Figure 34



NATURAL GAMMA (CPS)
0
50
100
150
0
1
2
3
4
5
6
7
8
9
10
DEPTH (M)
BOVANENKOVO
BH91-2-K

Figure 35

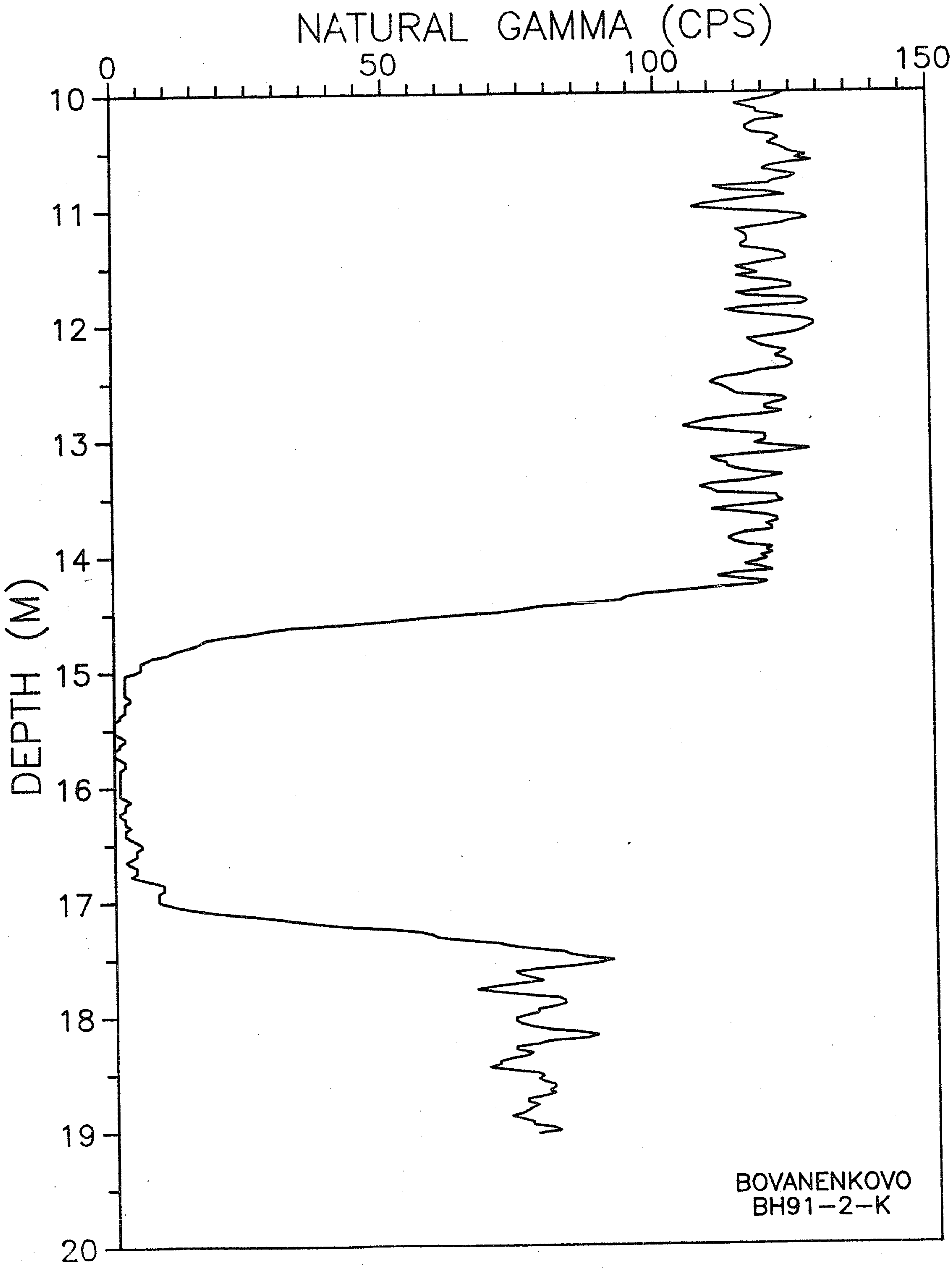


Figure 35 cont.

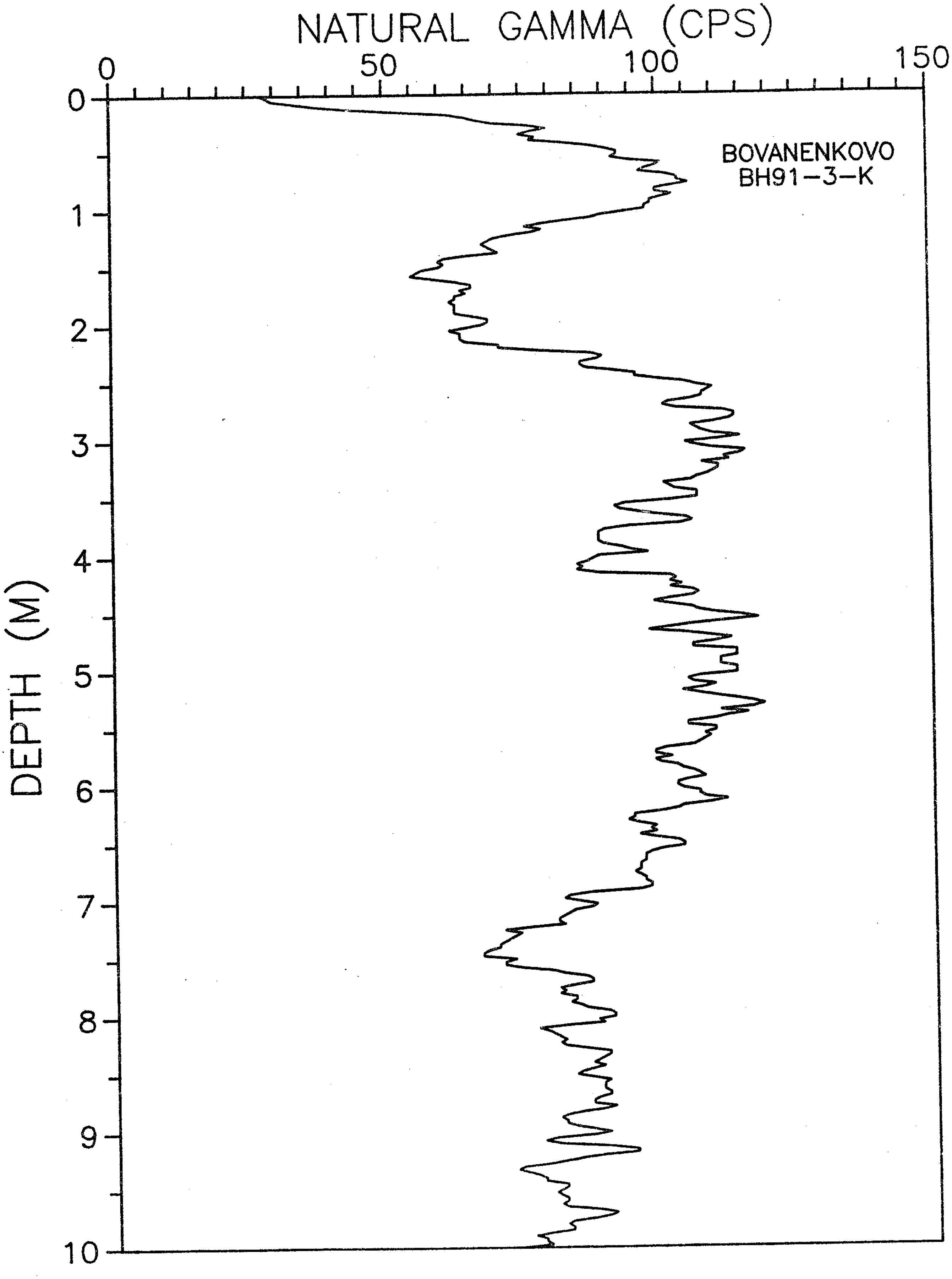

NATURAL GAMMA (CPS)
0
50
100
150
0
1
2
3
4
5
6
7
8
9
10
DEPTH (M)
BOVANENKOVO
BH91-3-K

Figure 36

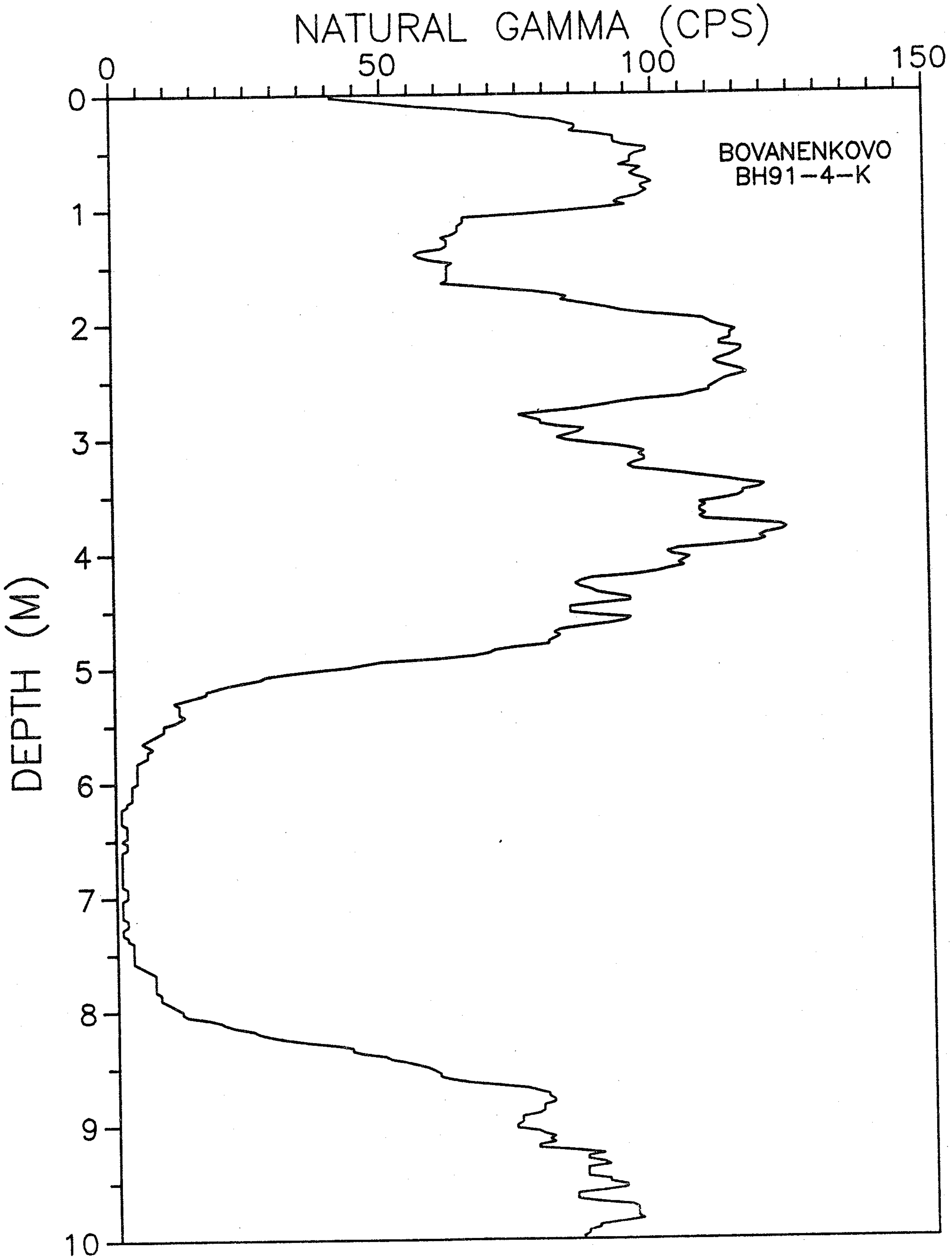

NATURAL GAMMA (CPS)
0
50
100
150
0
1
2
3
4
5
6
7
8
9
10
DEPTH (M)
BOVANENKOVO
BH91-4-K

Figure 37

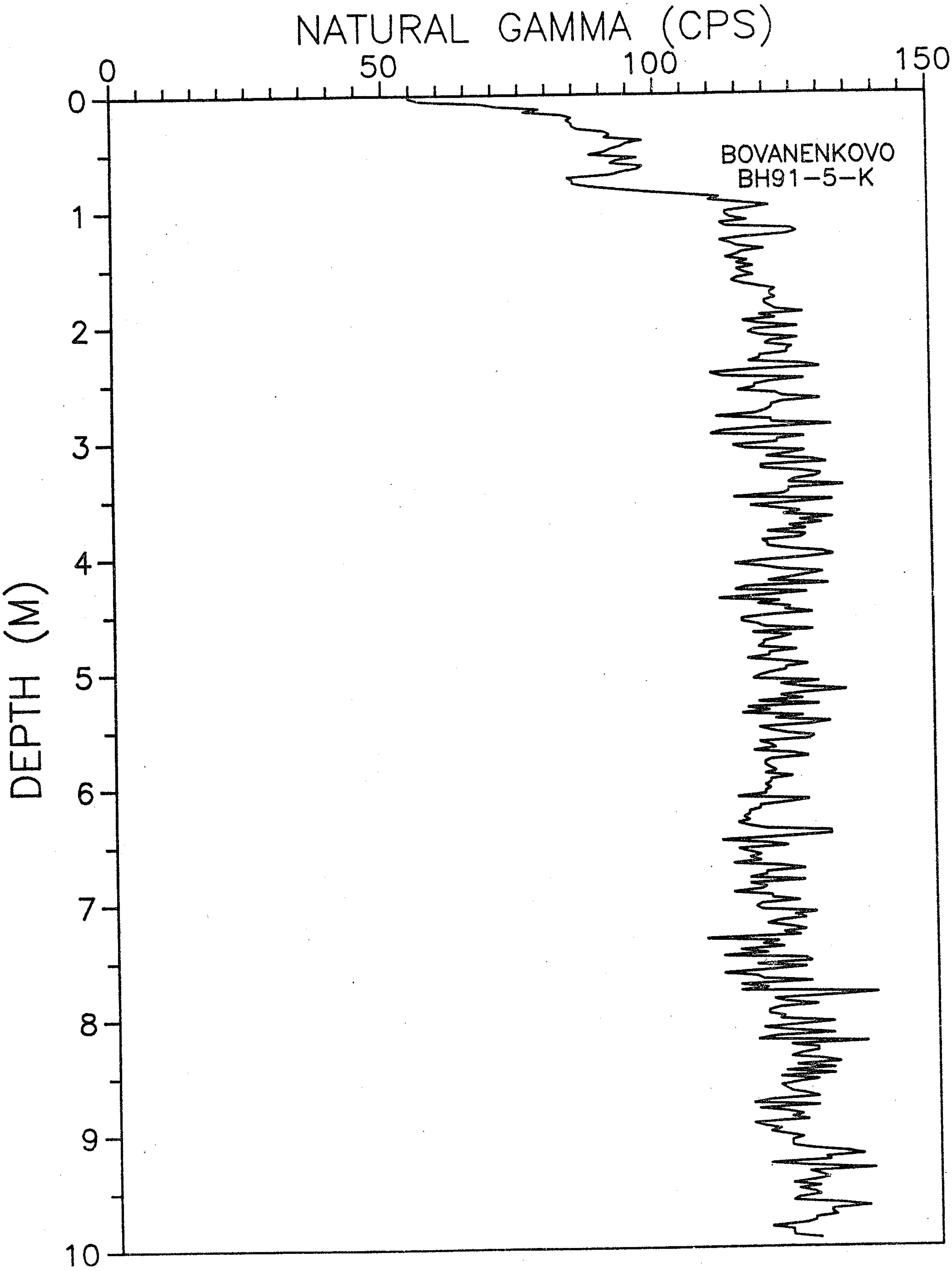
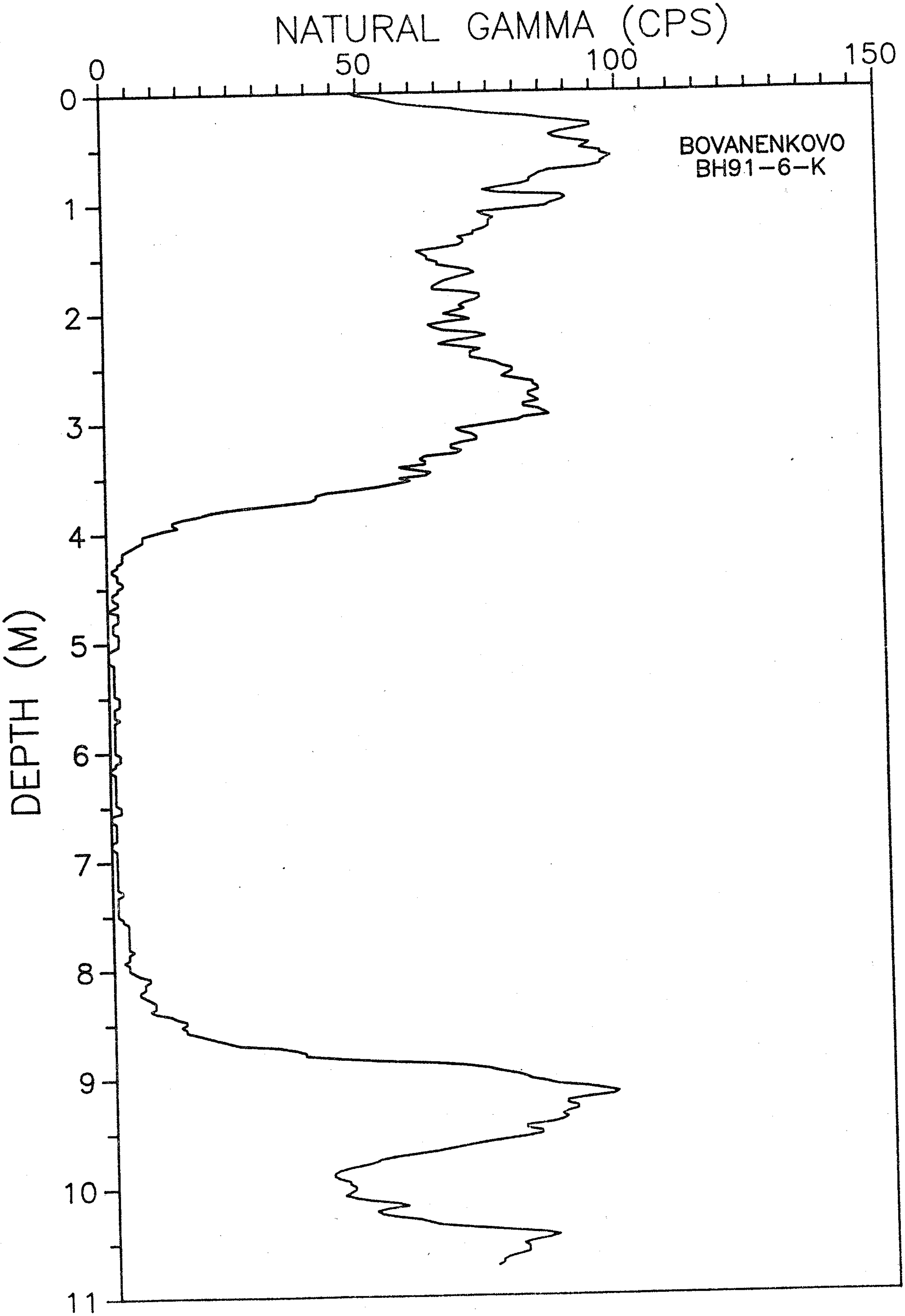

NATURAL GAMMA (CPS)
0
50
100
150
0
1
2
3
4
5
6
7
8
9
10
DEPTH (M)
BOVANENKOVO
BH91-5-K

Figure 38



NATURAL GAMMA (CPS)
0
50
100
150
DEPTH (M)
0
1
2
3
4
5
6
7
8
9
10
11
BOVANENKOVO
BH91-6-K

Figure 39

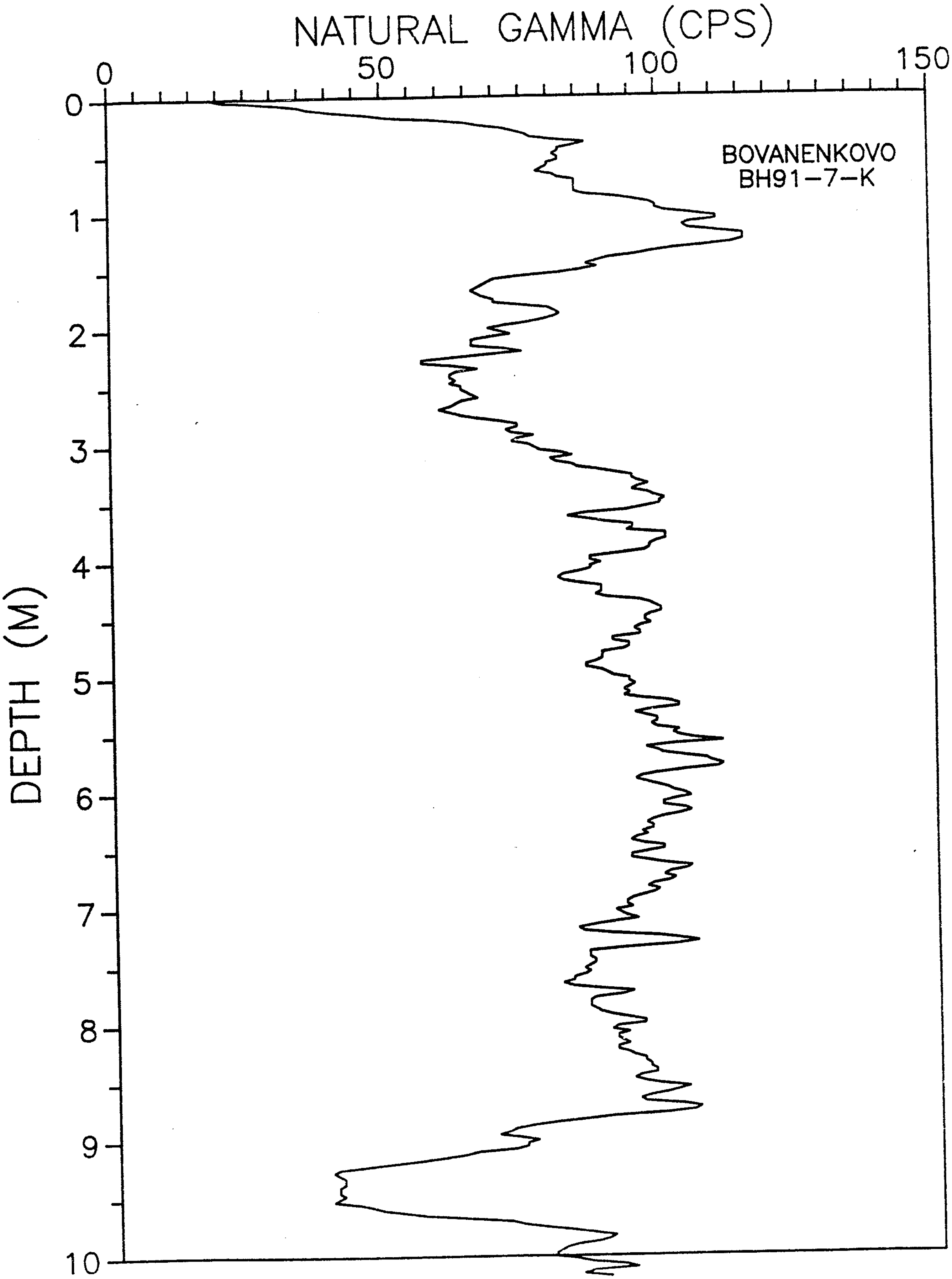

NATURAL GAMMA (CPS)
0
50
100
150
BOVANENKOVO
BH91-7-K
DEPTH (M)
0
1
2
3
4
5
6
7
8
9
10

Figure 40

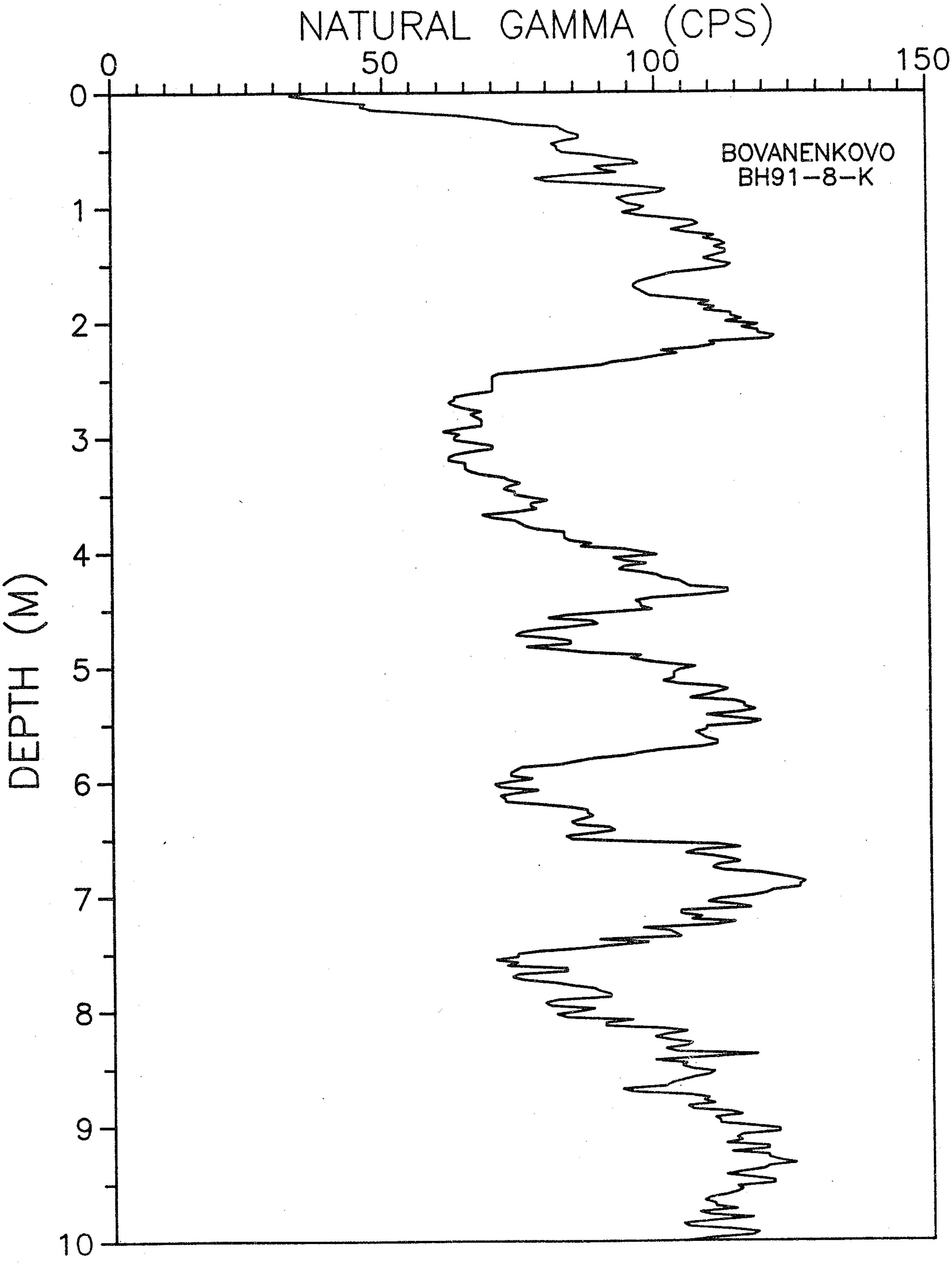

NATURAL GAMMA (CPS)
0
50
100
150
0
1
2
3
4
5
6
7
8
9
10
DEPTH (M)
BOVANENKOVO
BH91-8-K

Figure 41

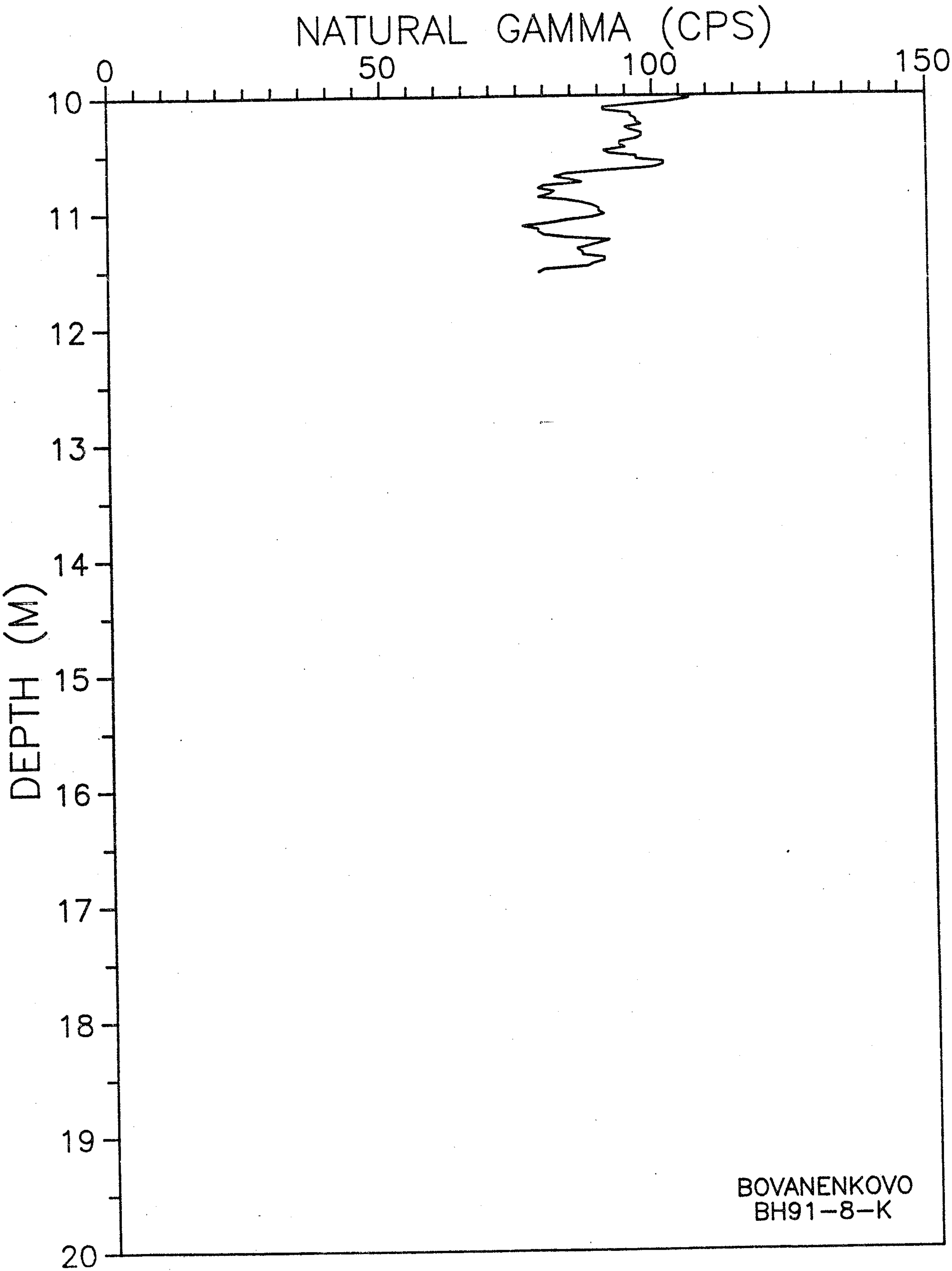


Figure 41 cont.

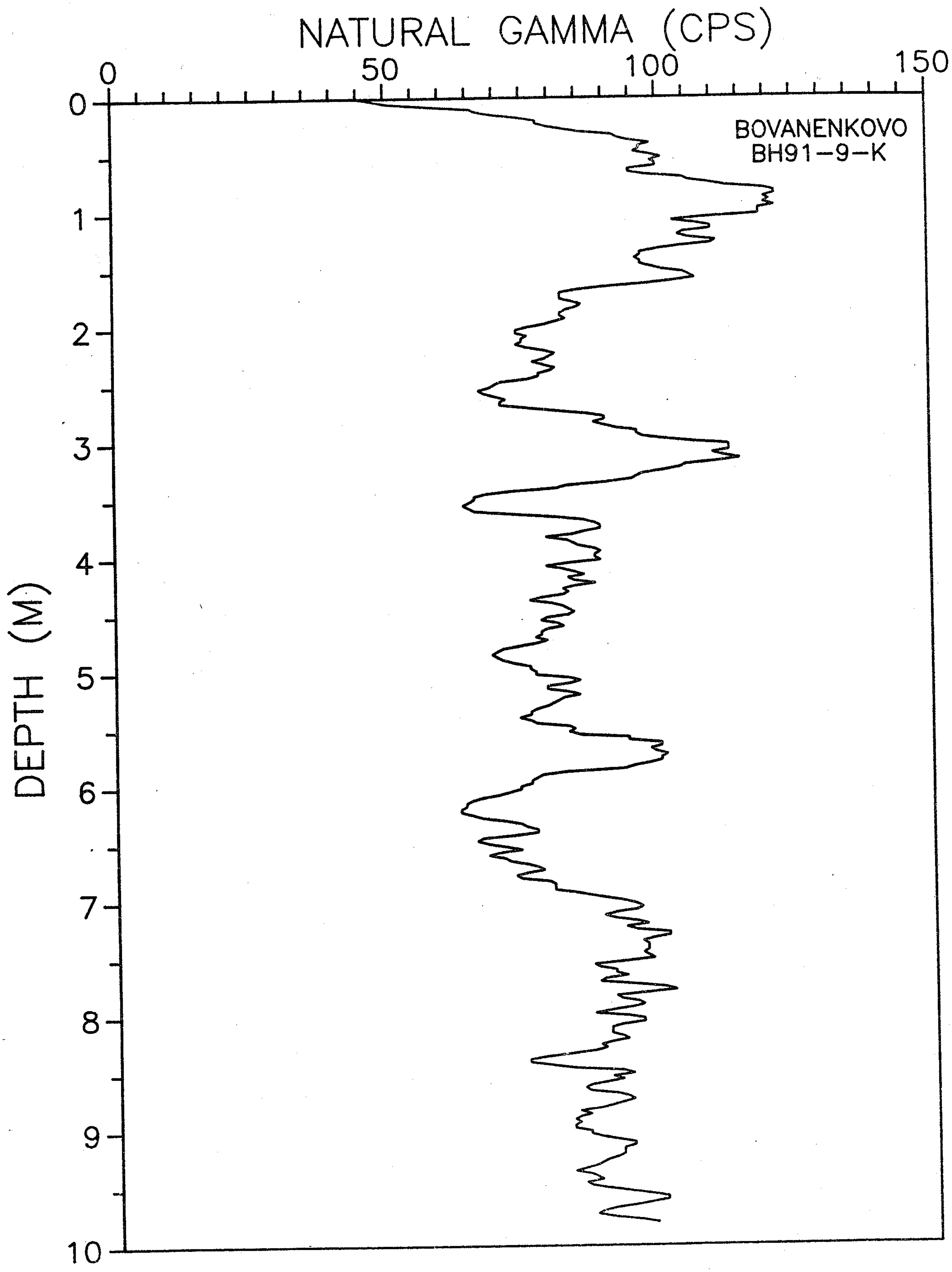

NATURAL GAMMA (CPS)
0
50
100
150
BOVANENKOVO
BH91-9-K
DEPTH (M)
0
1
2
3
4
5
6
7
8
9
10

Figure 42

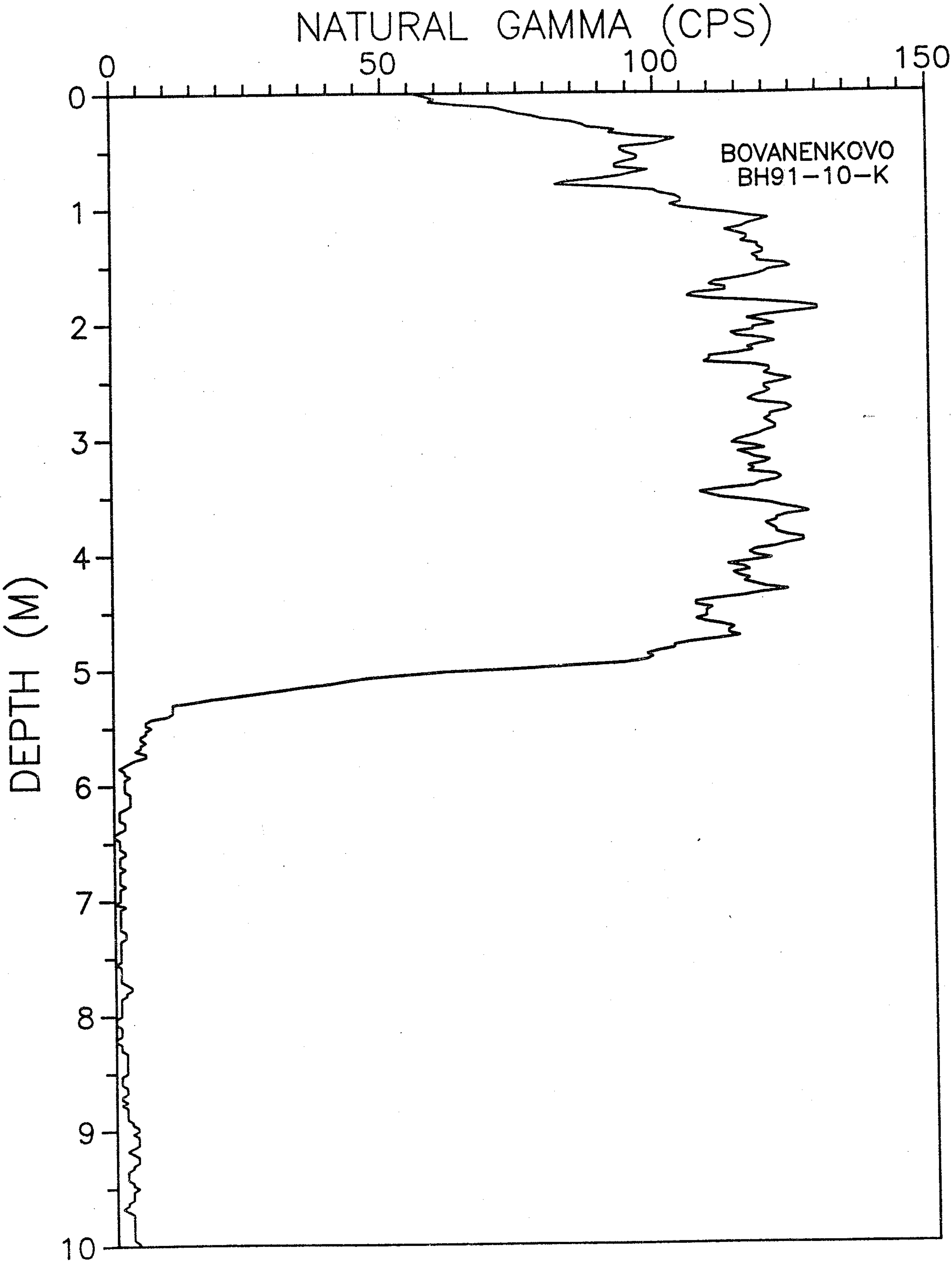

NATURAL GAMMA (CPS)
0
50
100
150
0
1
2
3
4
5
6
7
8
9
10
DEPTH (M)
BOVANENKOVO
BH91-10-K

Figure 43

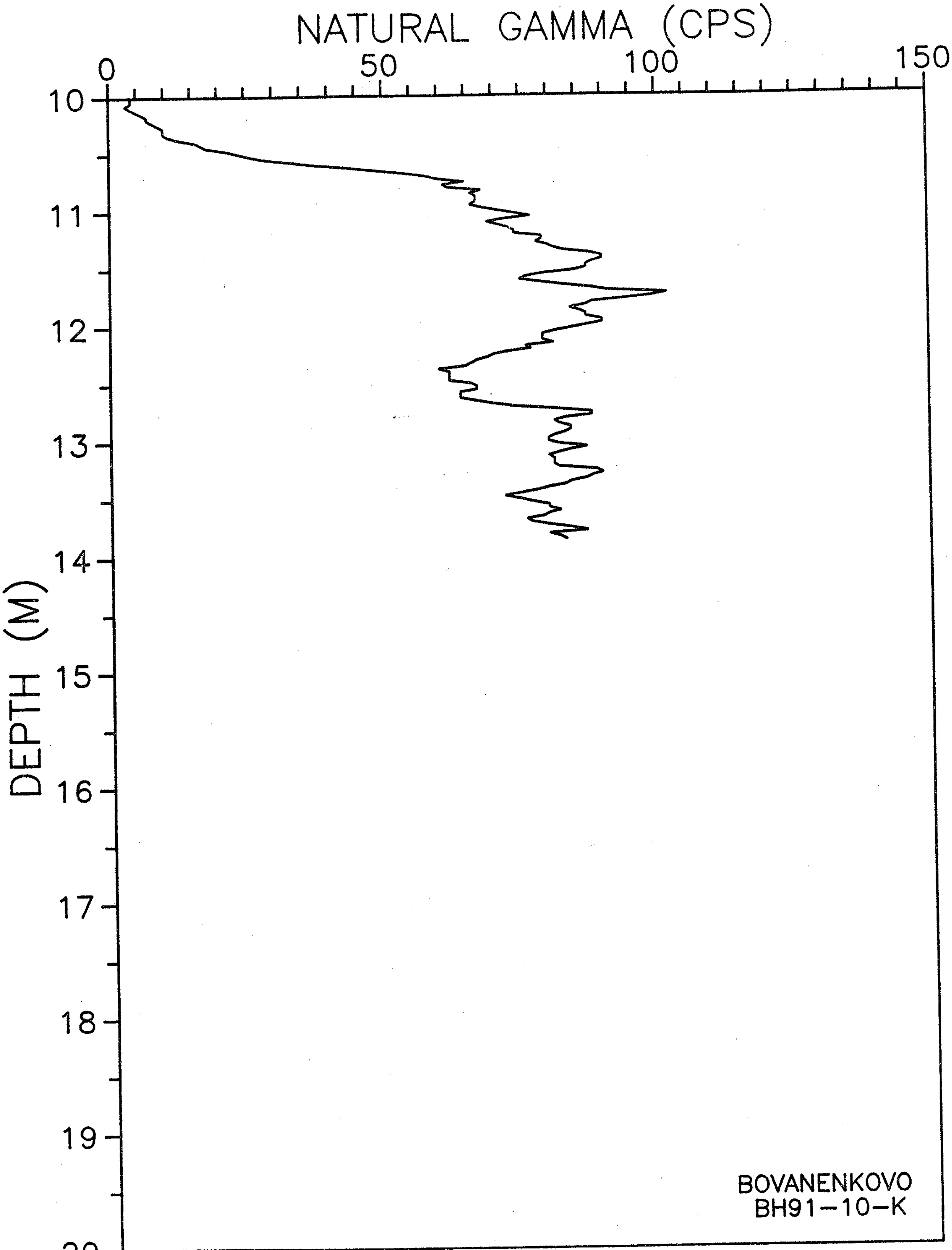


Figure 43 cont.

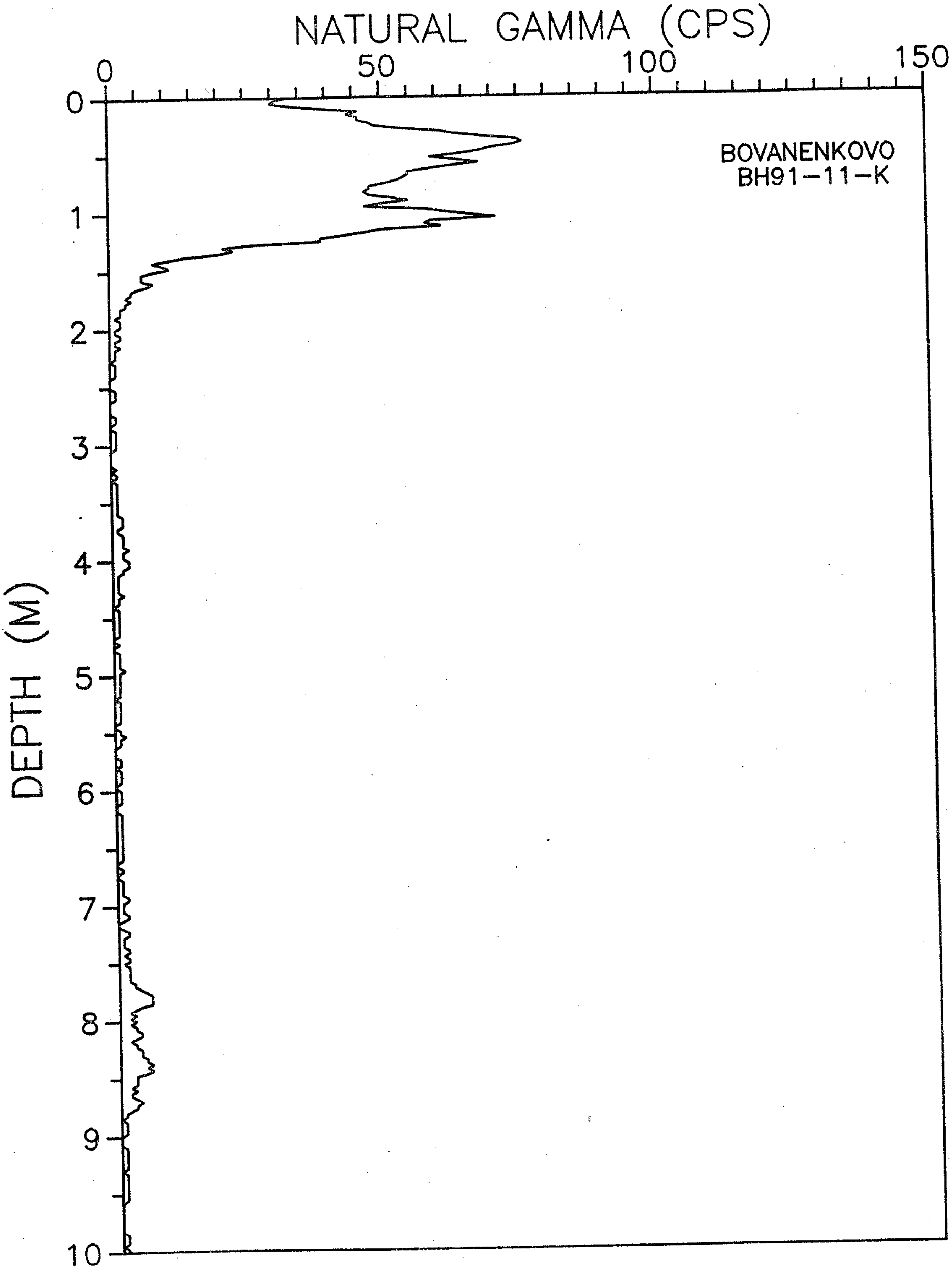

NATURAL GAMMA (CPS)
0
50
100
150
0
1
2
3
4
5
6
7
8
9
10
DEPTH (M)
BOVANENKOVO
BH91-11-K

Figure 44

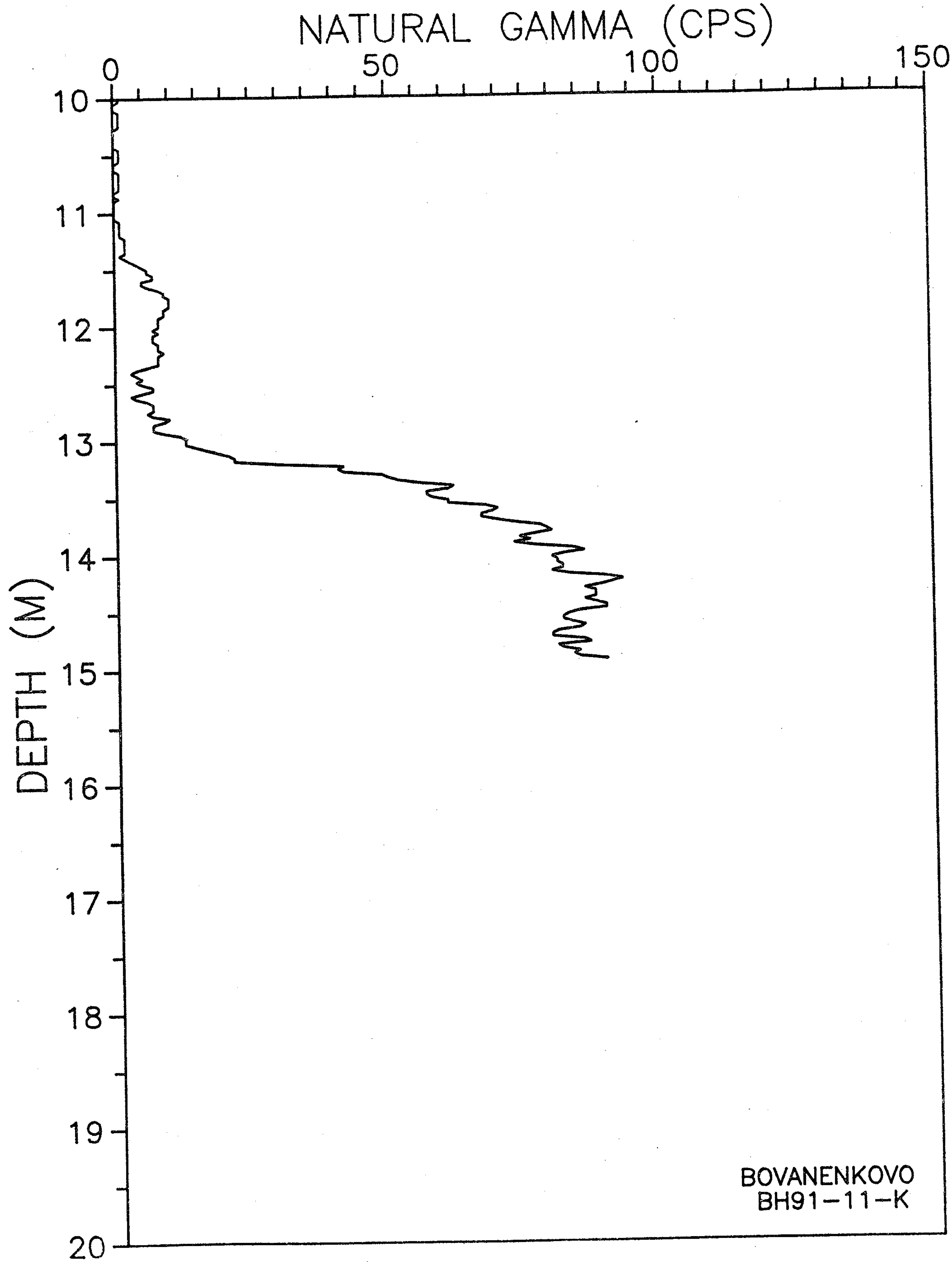


Figure 44 cont.

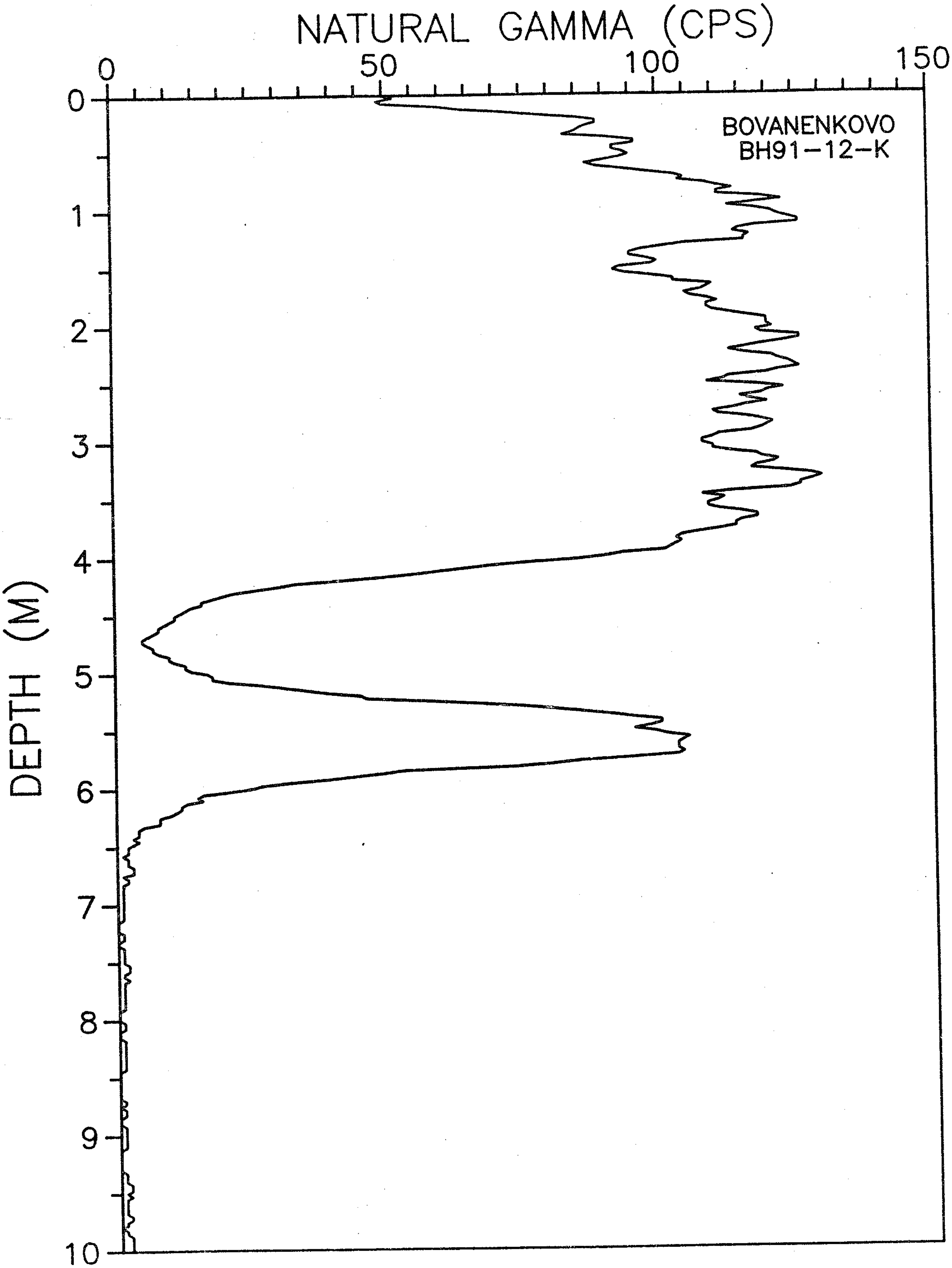

NATURAL GAMMA (CPS)
0
50
100
150
0
1
2
3
4
5
6
7
8
9
10
DEPTH (M)
BOVANENKOVO
BH91-12-K

Figure 45

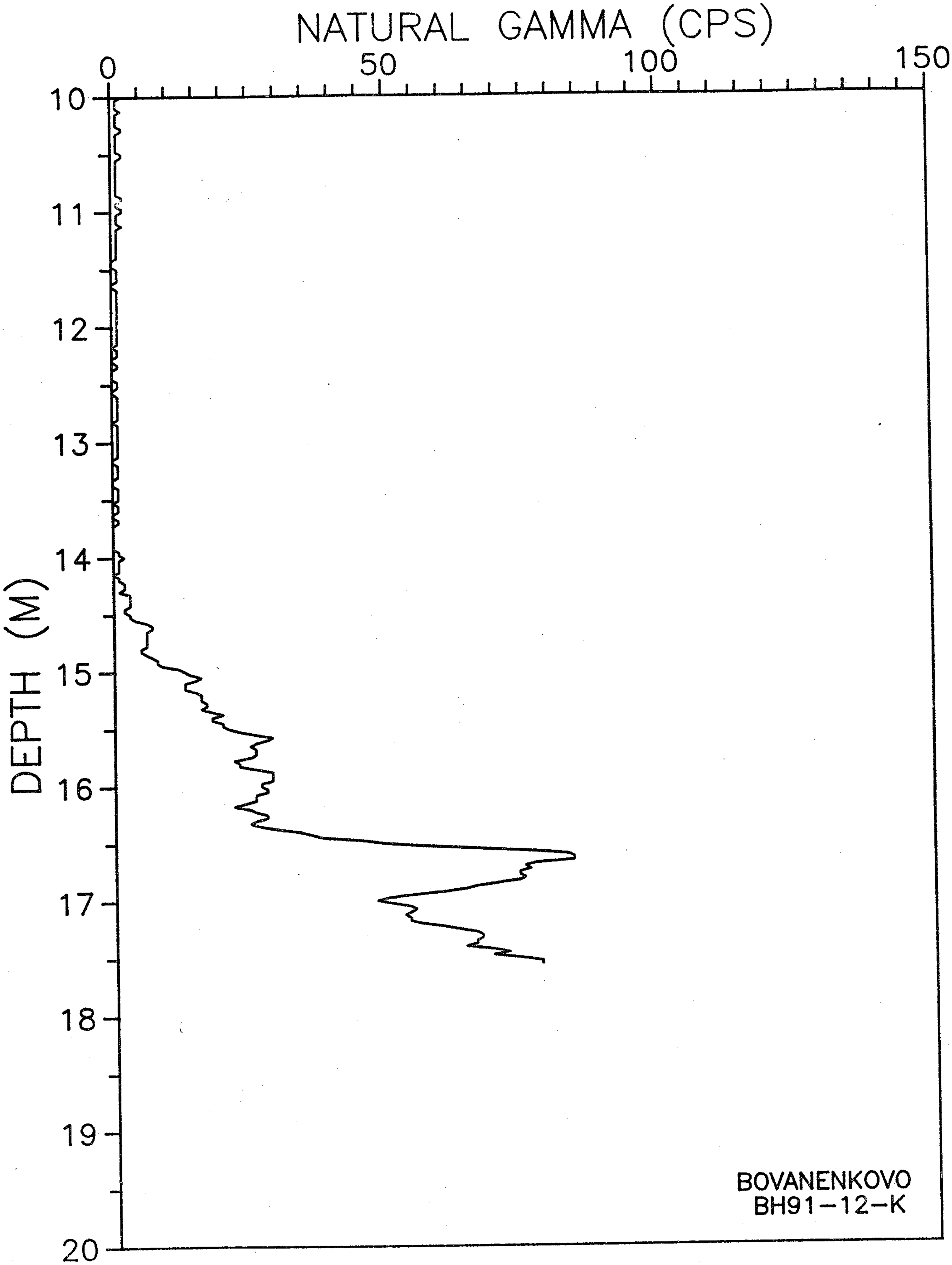


Figure 45 cont.

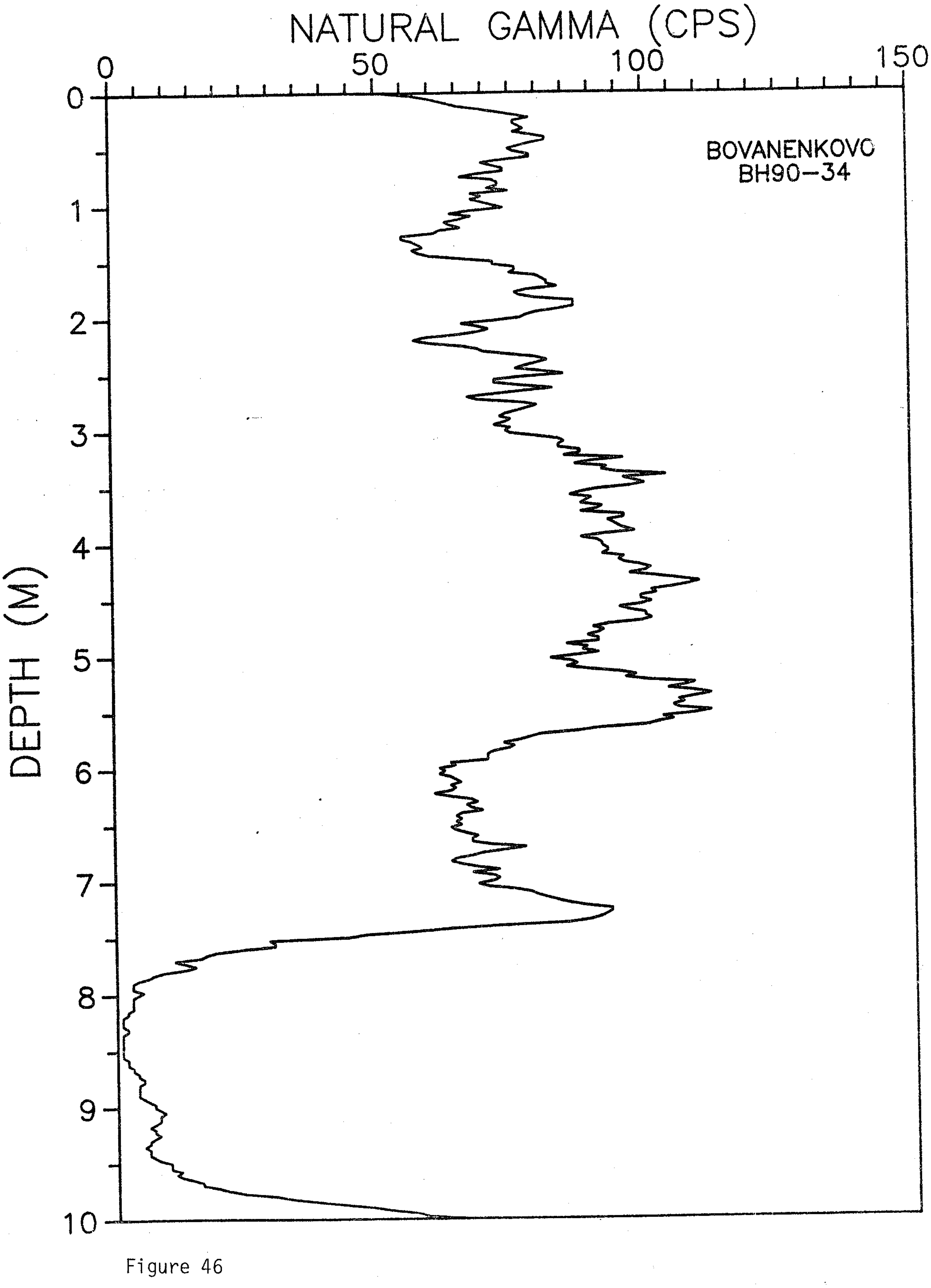

NATURAL GAMMA (CPS)
0
50
100
150
BOVANENKOVO
BH90-34
DEPTH (M)
0
1
2
3
4
5
6
7
8
9
10

Figure 46

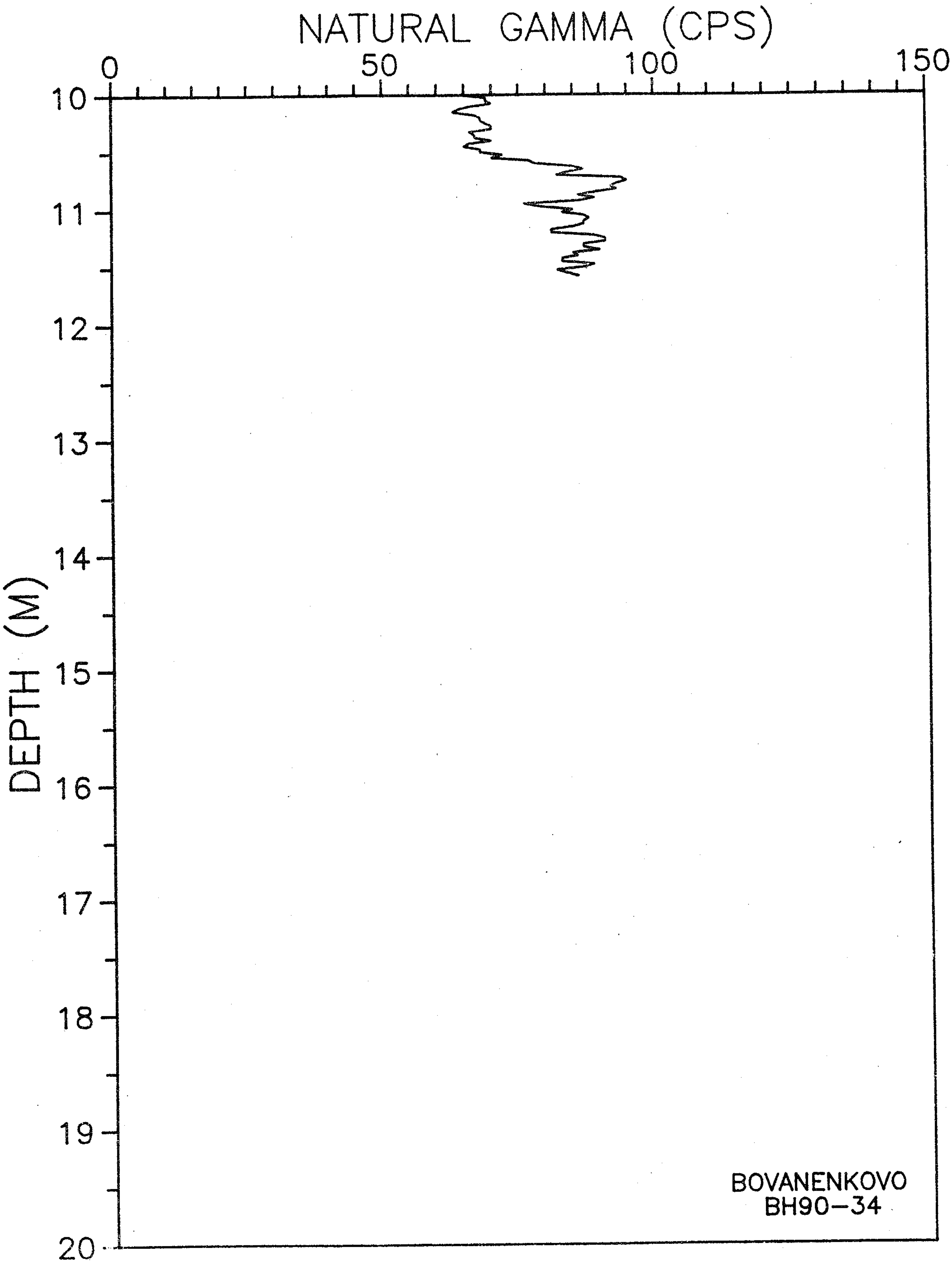


Figure 46 cont.

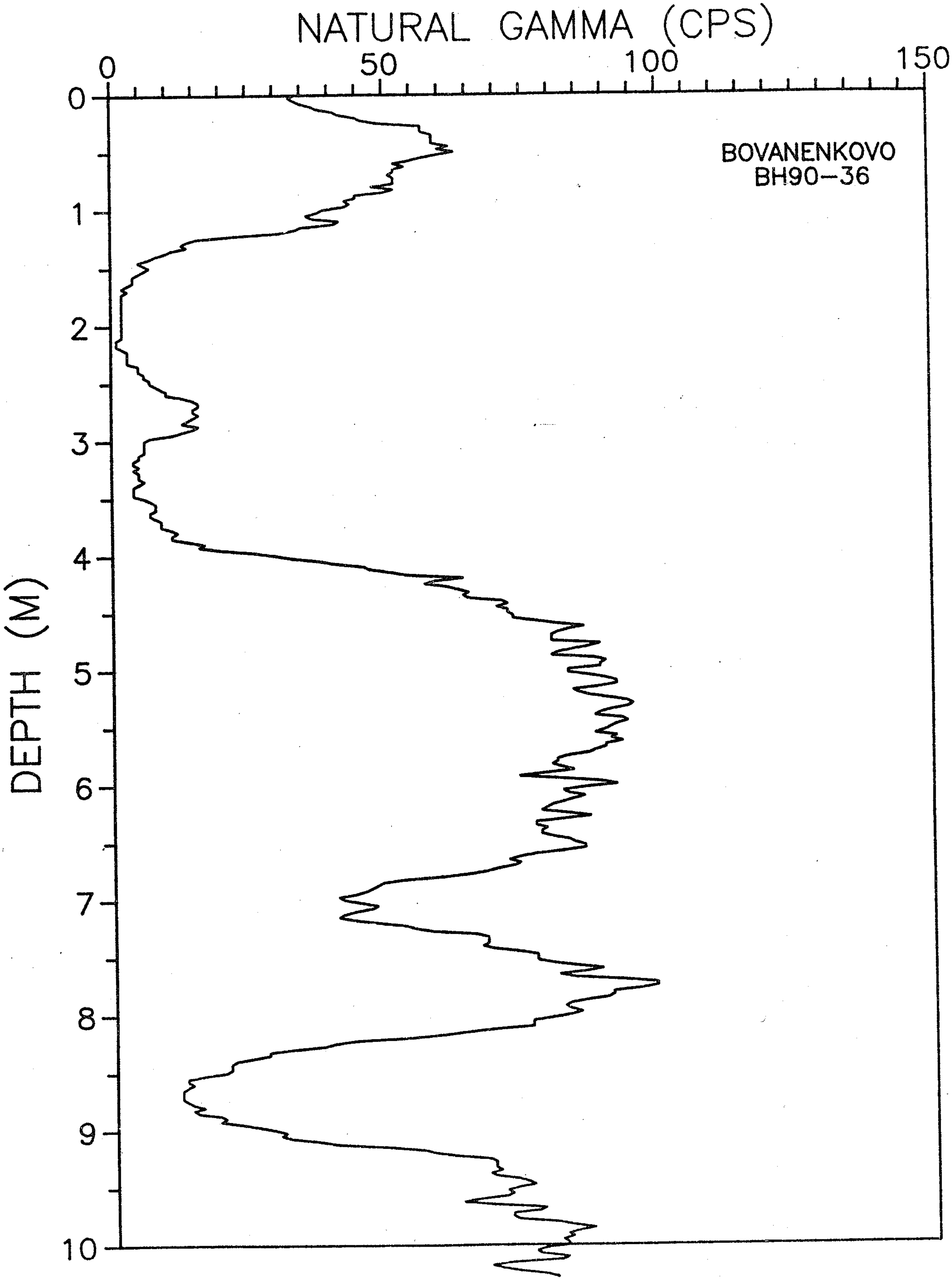

NATURAL GAMMA (CPS)
0
50
100
150
0
1
2
3
4
5
6
7
8
9
10
DEPTH (M)
BOVANENKOVO
BH90-36

Figure 47

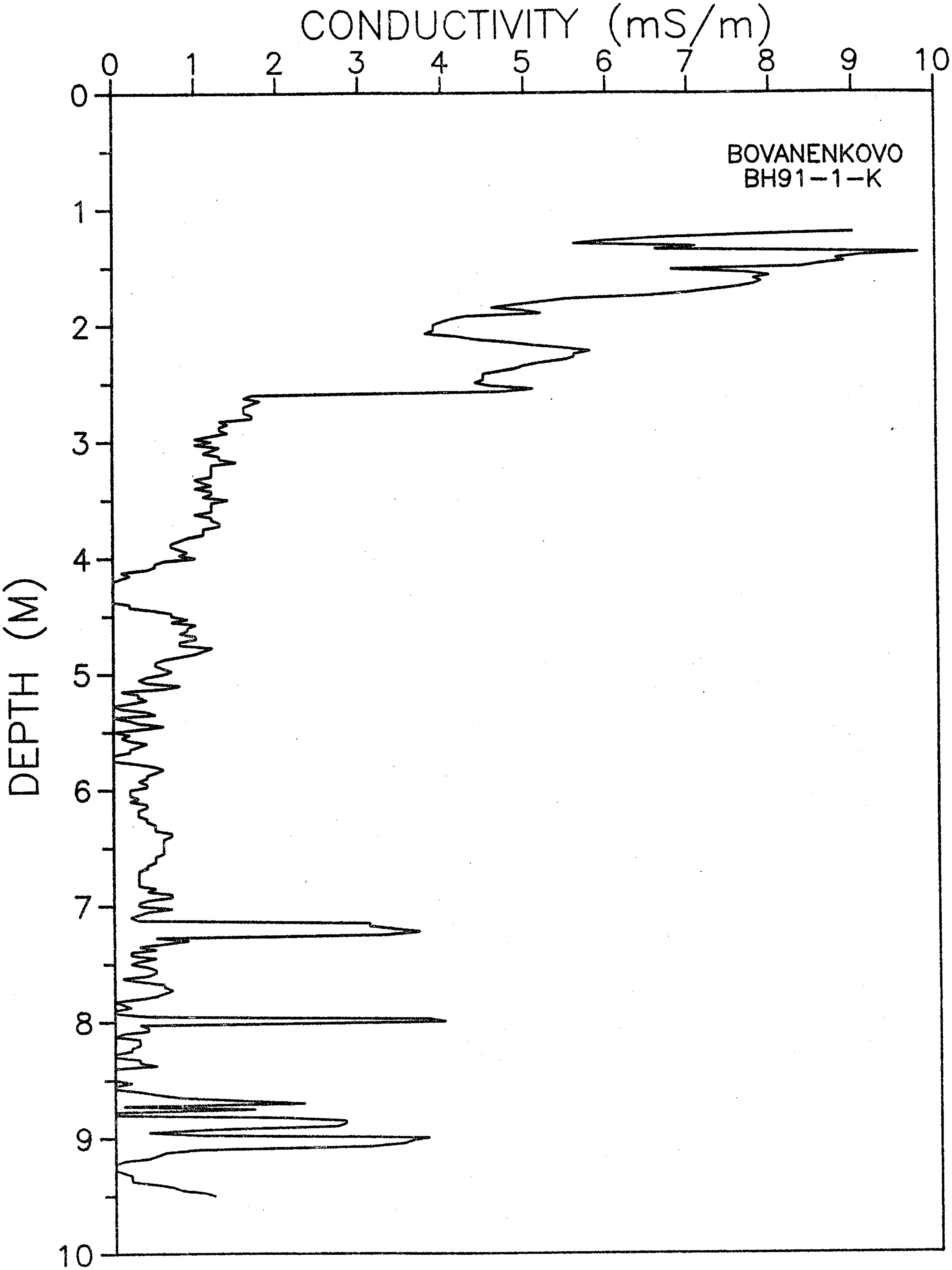

CONDUCTIVITY (mS/m)
0 1 2 3 4 5 6 7 8 9 10
BOVANENKOVO
BH91-1-K
DEPTH (M)
0 1 2 3 4 5 6 7 8 9 10

Figure 48

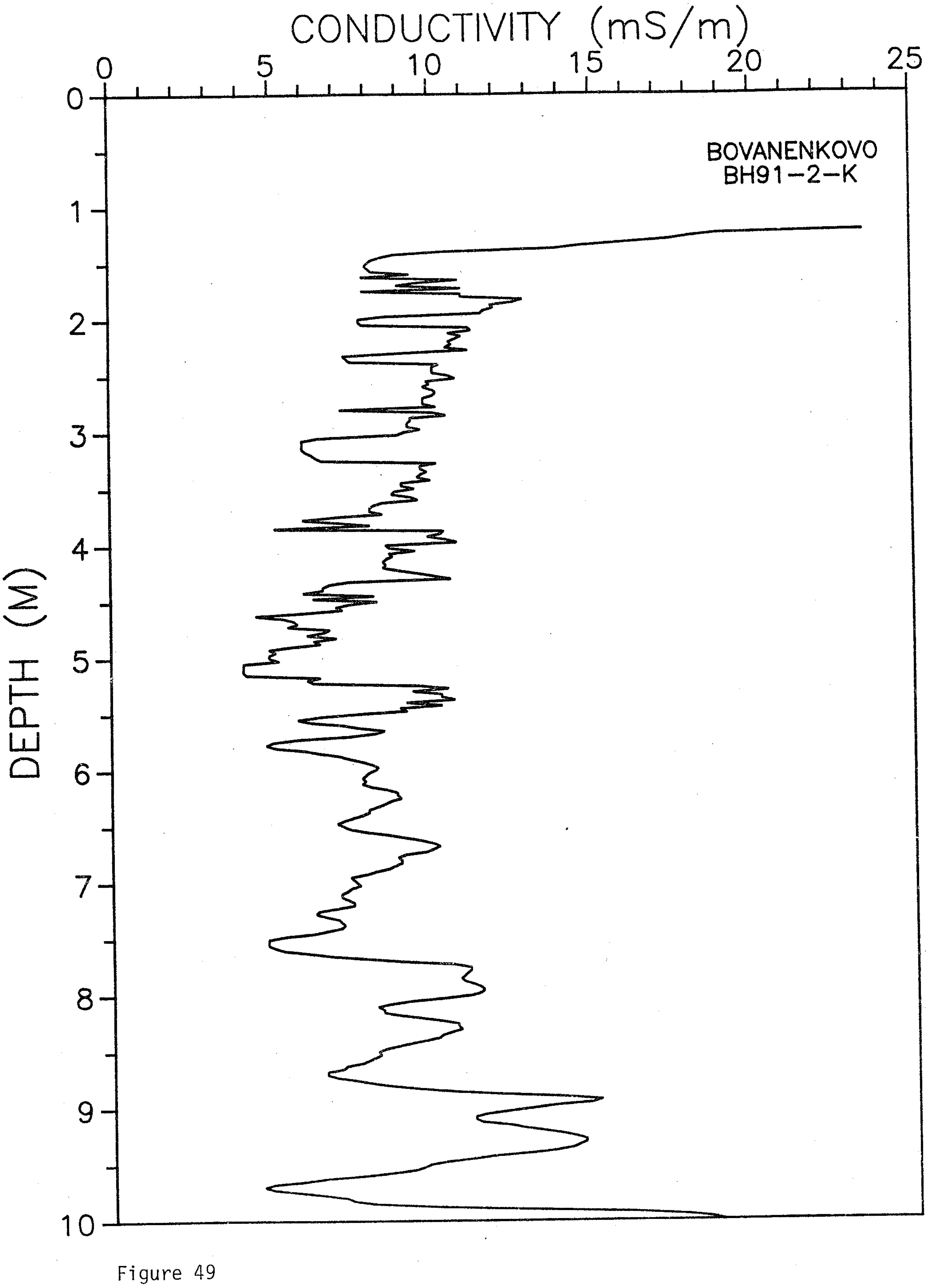

CONDUCTIVITY (mS/m)
0
5
10
15
20
25
BOVANENKOVO
BH91-2-K
DEPTH (M)
0
1
2
3
4
5
6
7
8
9
10

Figure 49

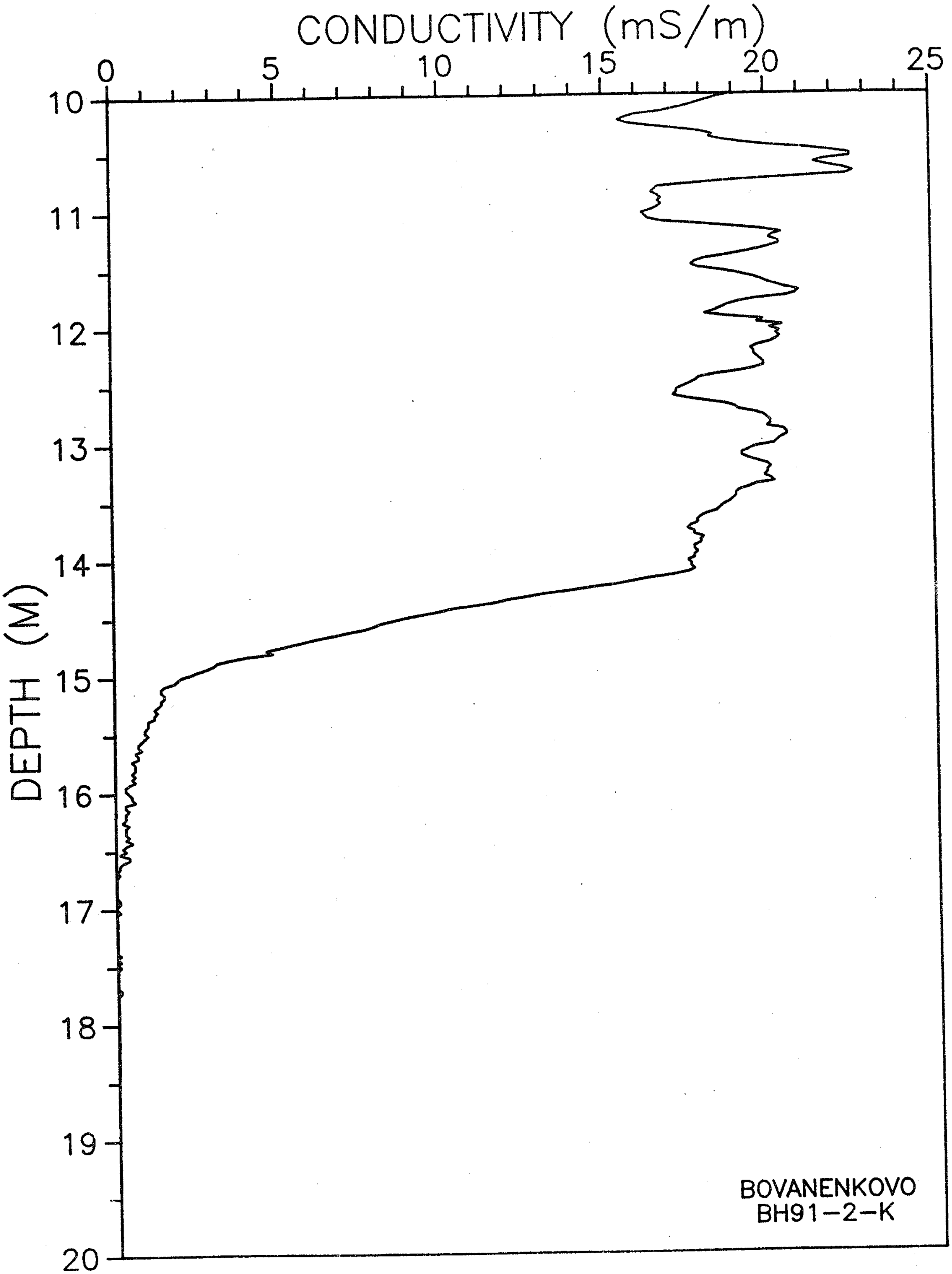


Figure 49 cont.

EM-39 LOGGING SYSTEM

CONDUCTIVITY LOGS

Fig. 48-61

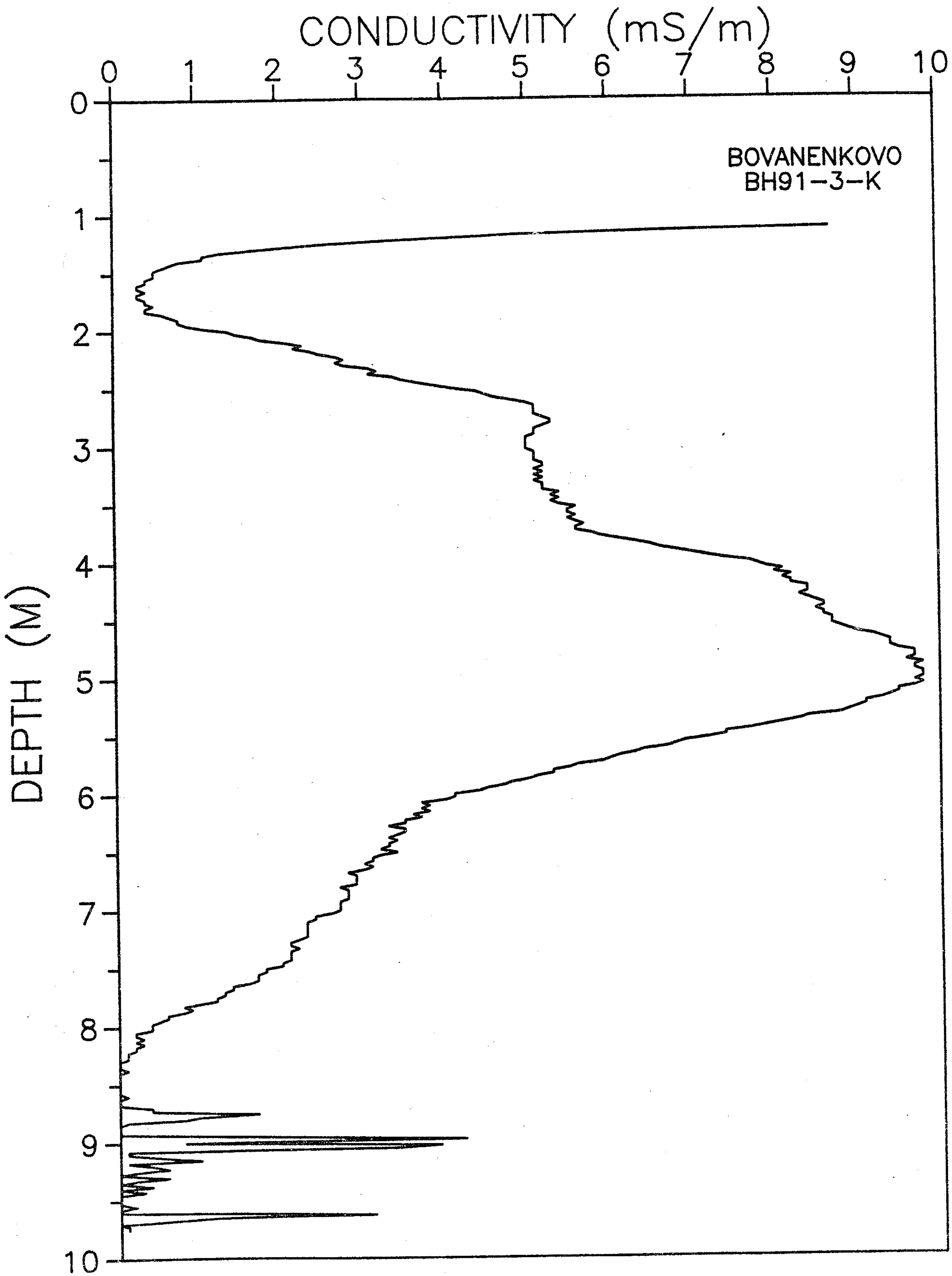

CONDUCTIVITY (mS/m)
0
1
2
3
4
5
6
7
8
9
10
DEPTH (M)
BOVANENKOVO
BH91-3-K

Figure 50

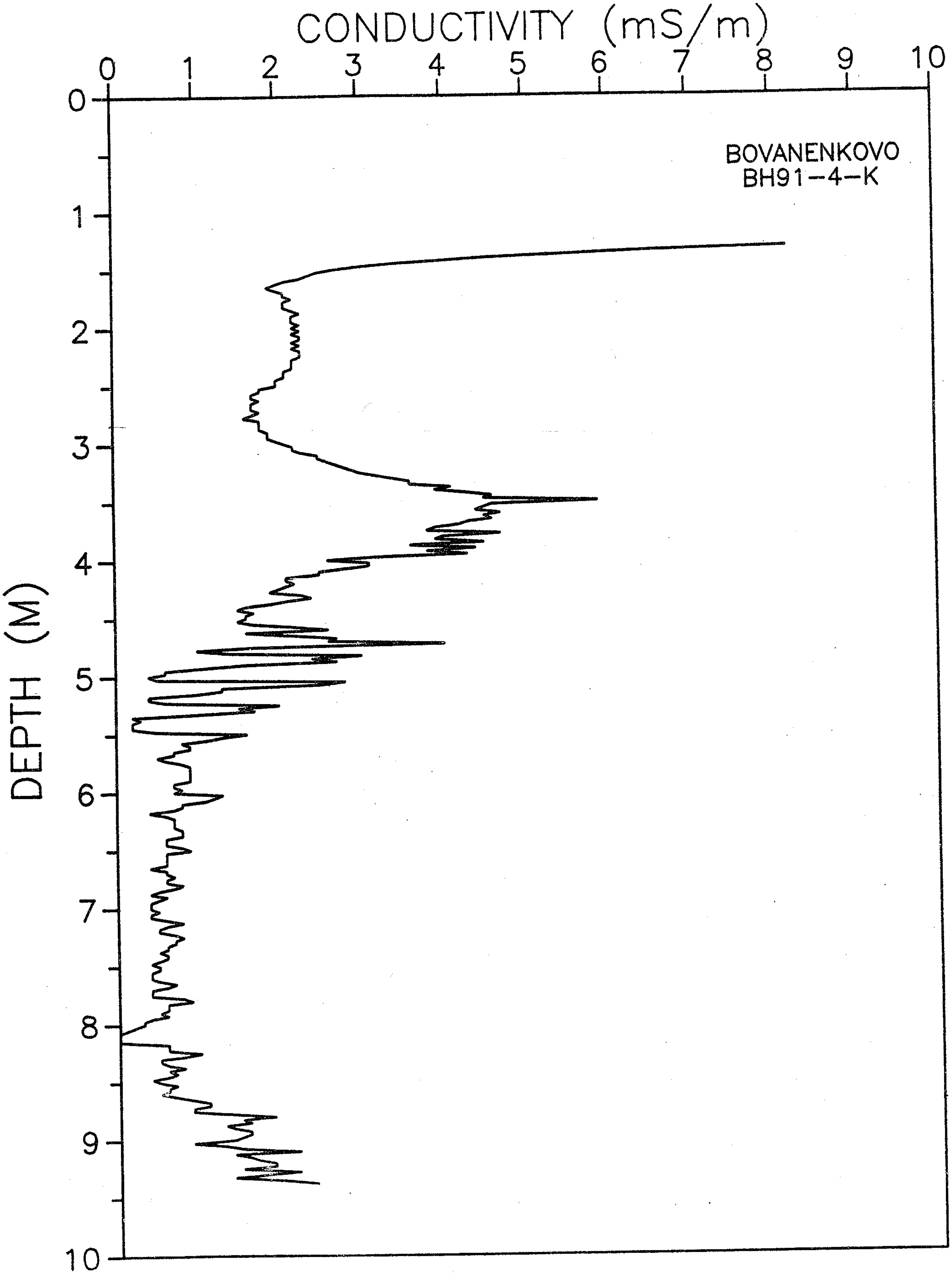

CONDUCTIVITY (mS/m)
0
1
2
3
4
5
6
7
8
9
10
BOVANENKOVO
BH91-4-K
DEPTH (M)
0
1
2
3
4
5
6
7
8
9
10

Figure 51

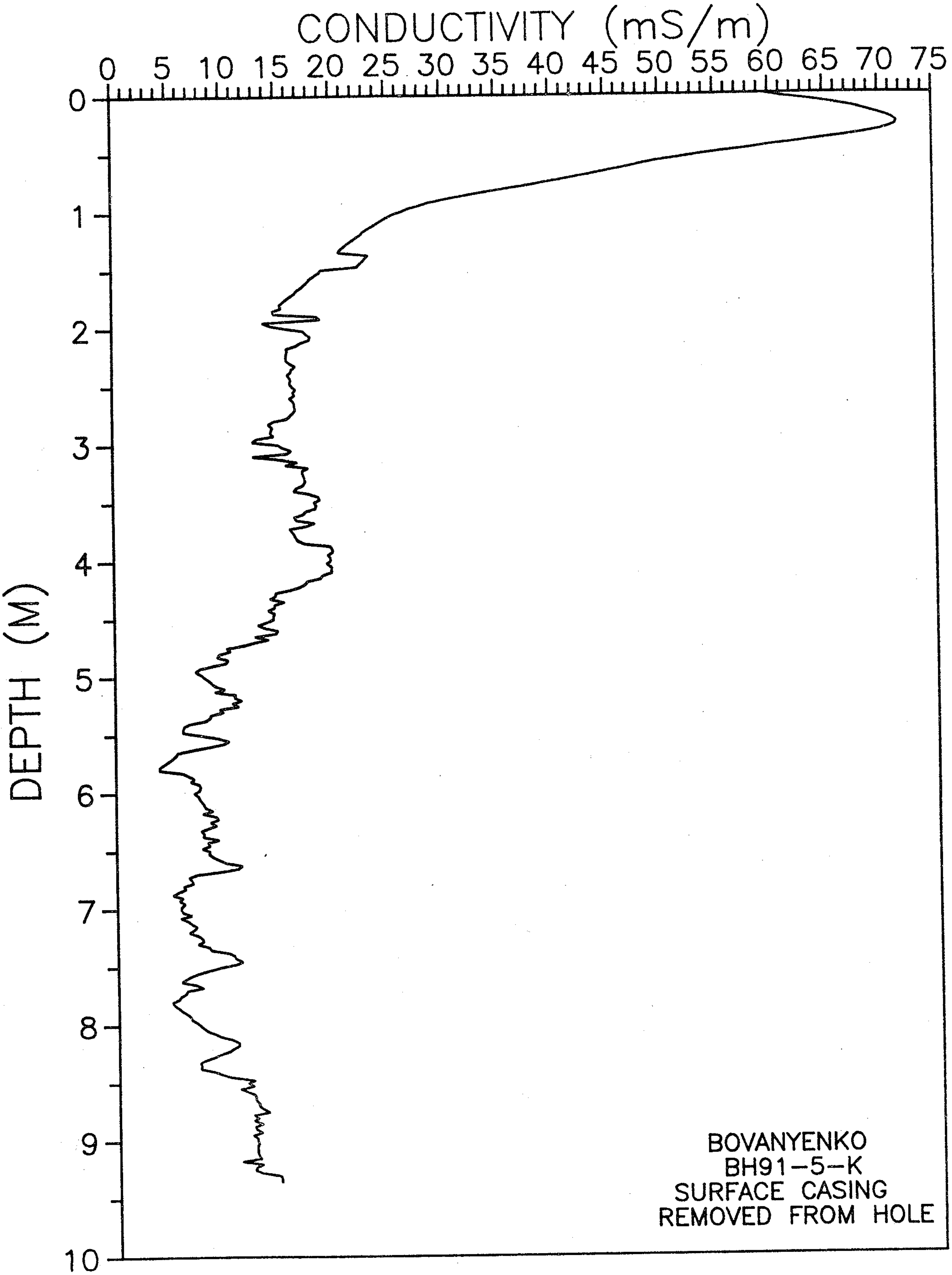

CONDUCTIVITY (mS/m)
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
0 1 2 3 4 5 6 7 8 9 10
DEPTH (M)
BOVANYENKO
BH91-5-K
SURFACE CASING
REMOVED FROM HOLE

Figure 52

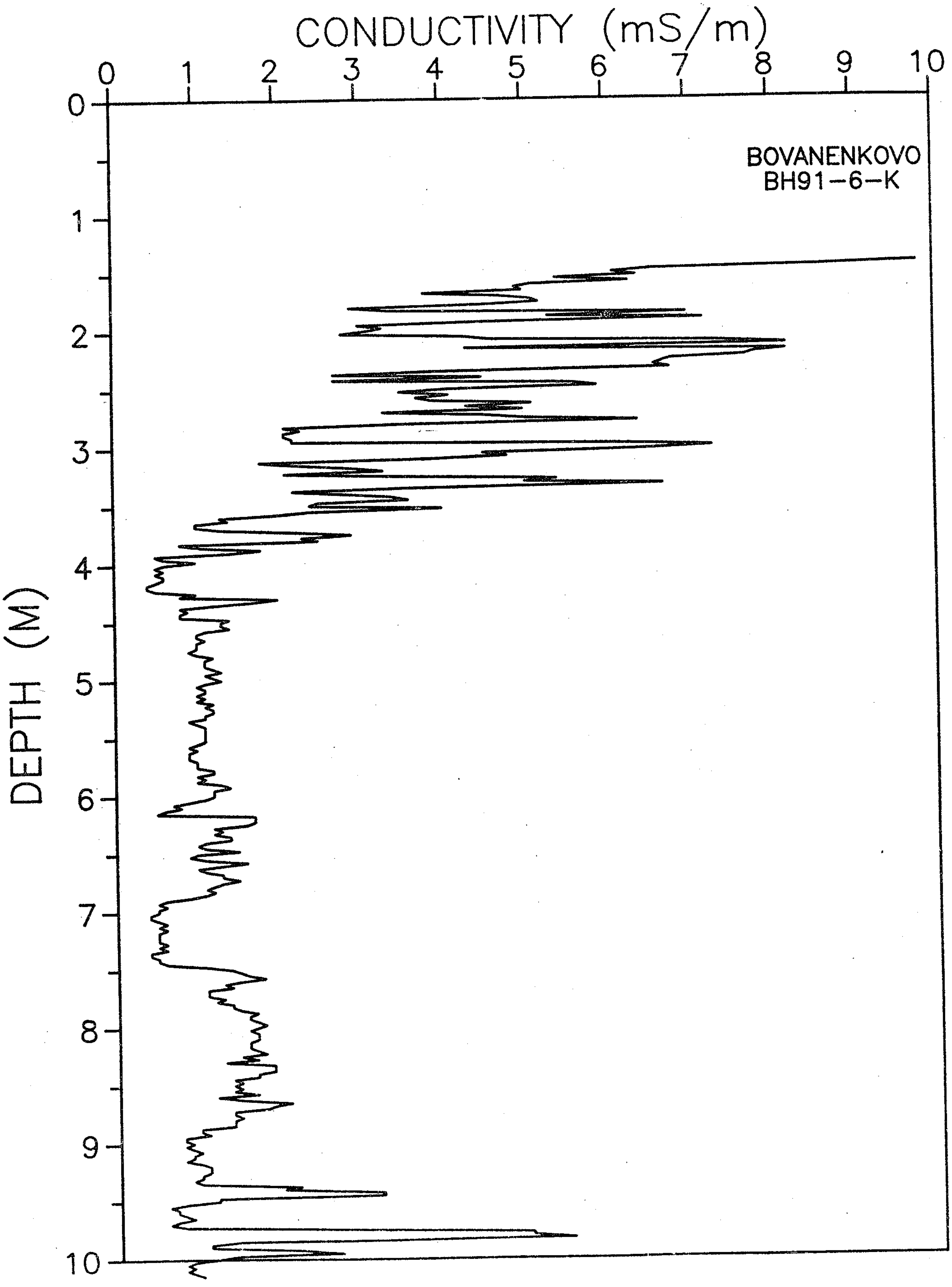

CONDUCTIVITY (mS/m)
0
1
2
3
4
5
6
7
8
9
10
DEPTH (M)
BOVANENKOVO
BH91-6-K

Figure 53

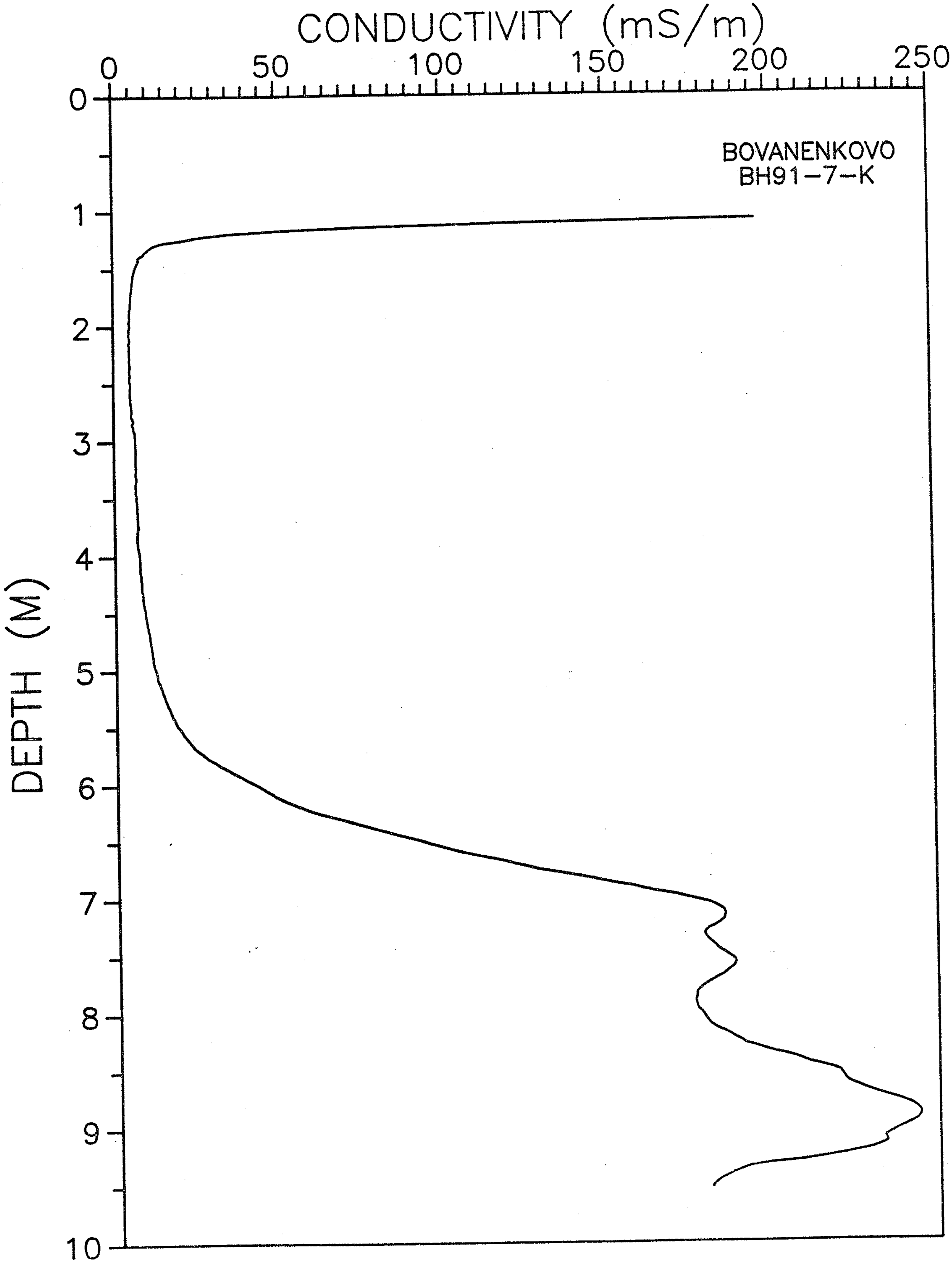

CONDUCTIVITY (mS/m)
0
50
100
150
200
250
0
1
2
3
4
5
6
7
8
9
10
DEPTH (M)
BOVANENKOVO
BH91-7-K

Figure 54

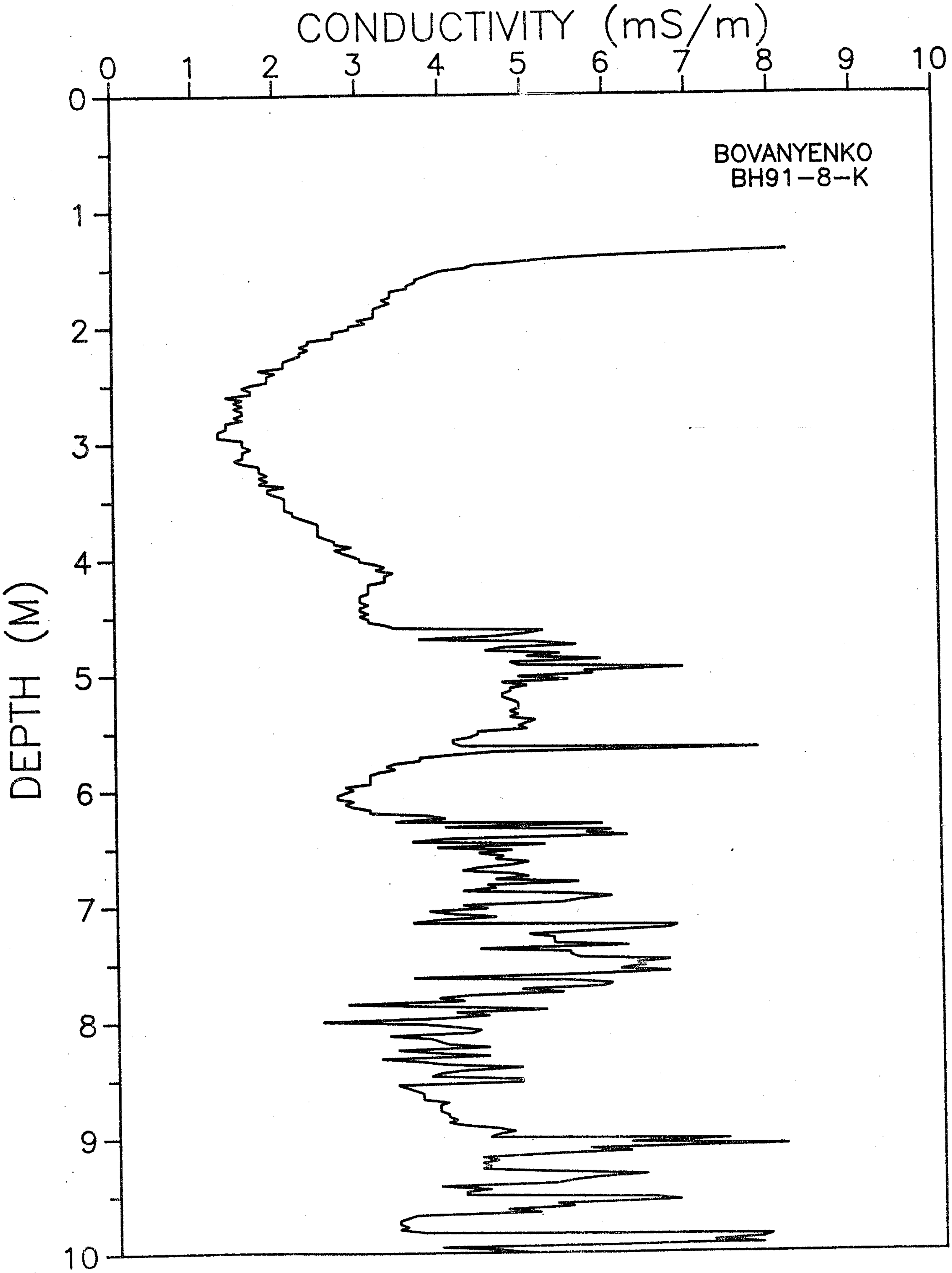


Figure 55

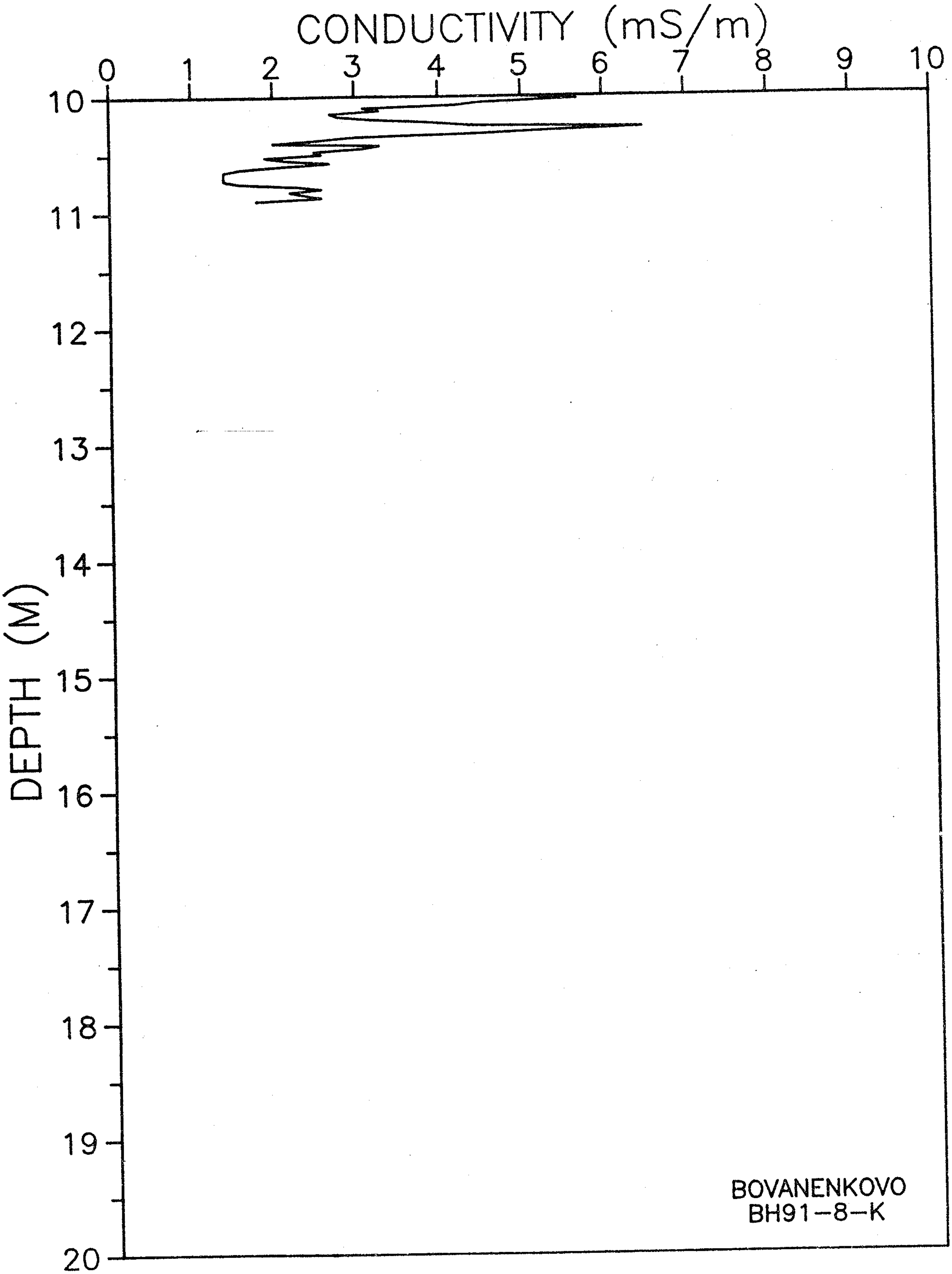


Figure 55 cont.

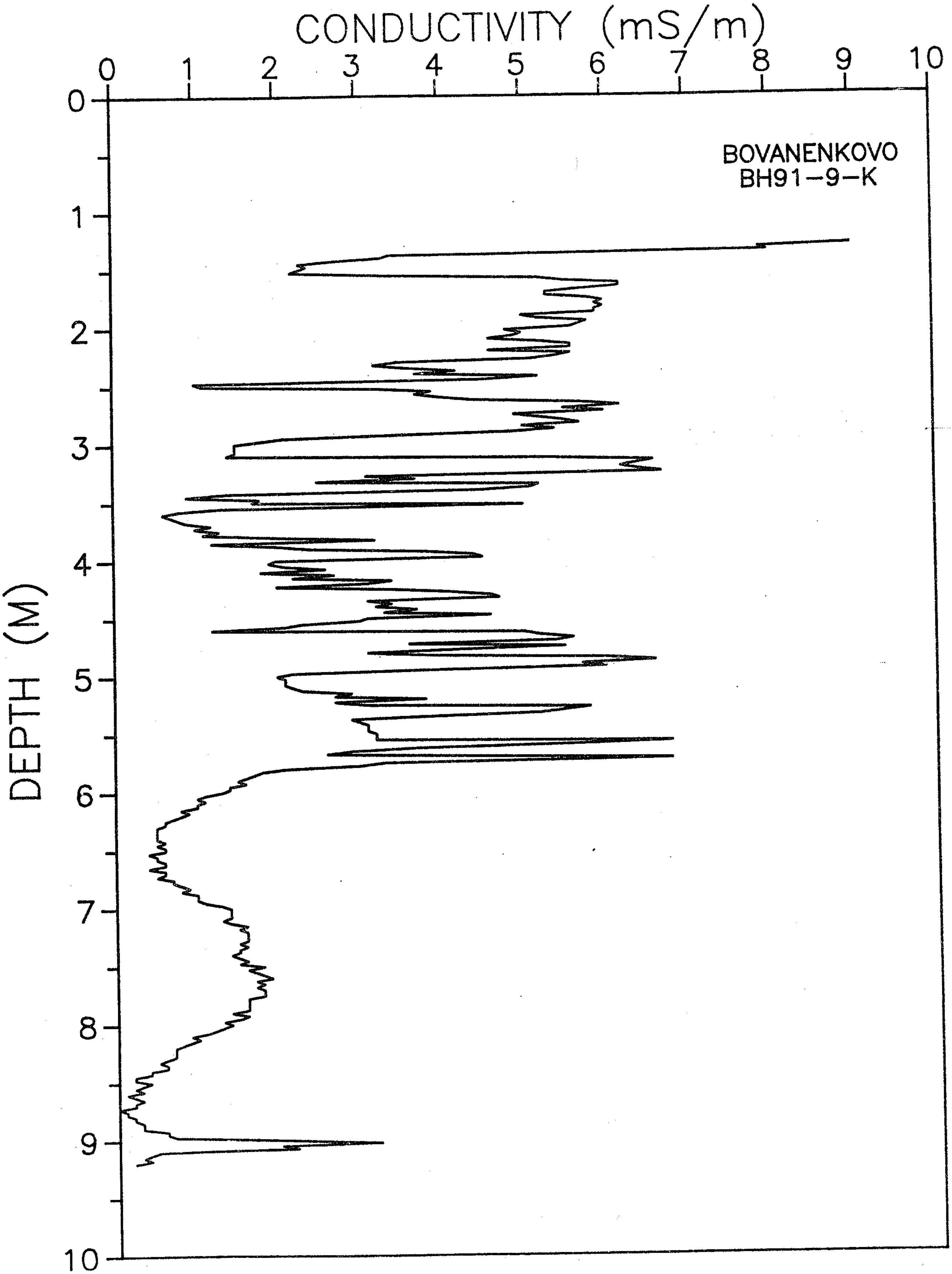

CONDUCTIVITY (mS/m)
0
1
2
3
4
5
6
7
8
9
10
DEPTH (M)
0
1
2
3
4
5
6
7
8
9
10
BOVANENKOVO
BH91-9-K

Figure 56

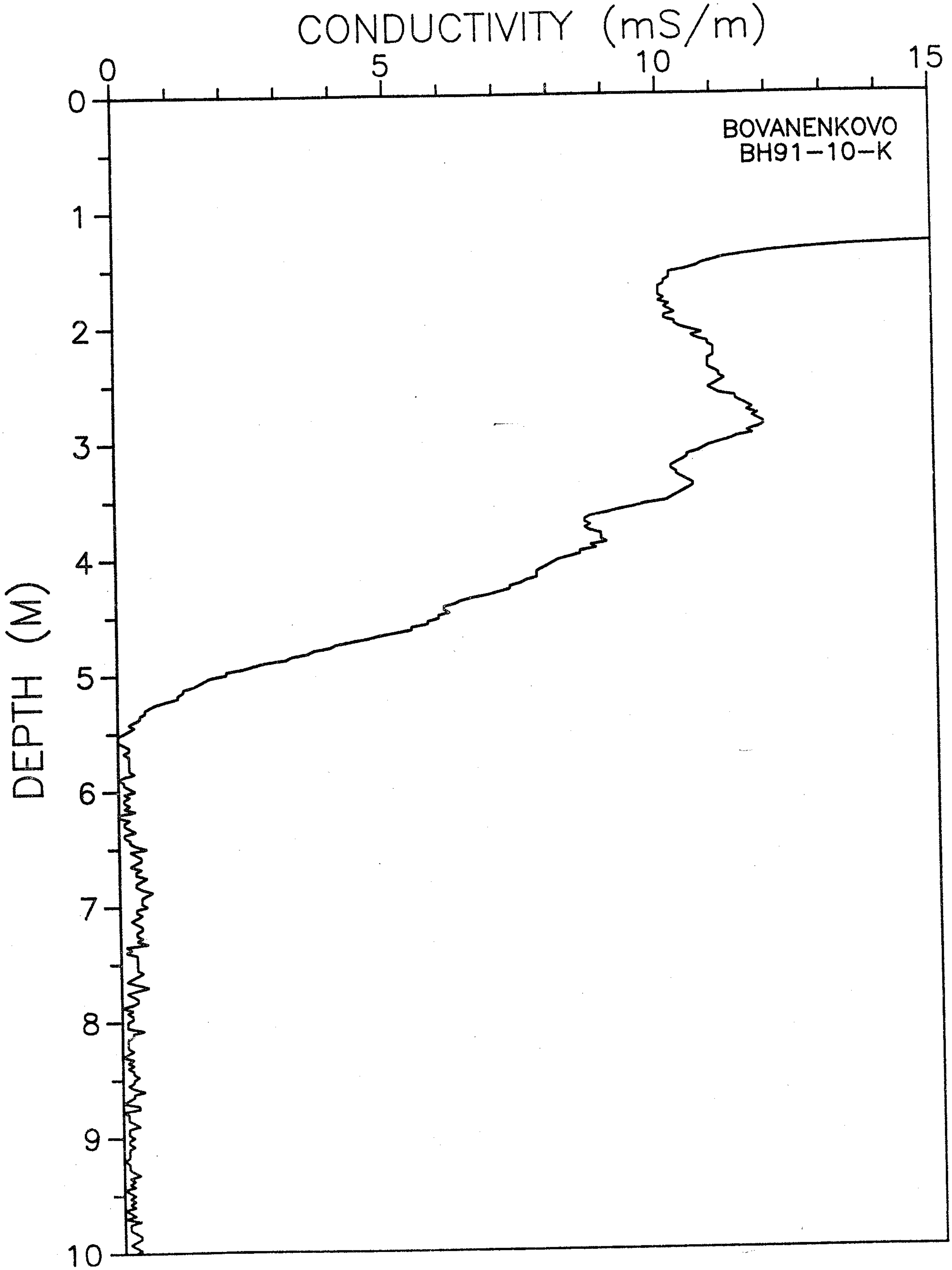

CONDUCTIVITY (mS/m)
0
5
10
15
0
1
2
3
4
5
6
7
8
9
10
DEPTH (M)
BOVANENKOVO
BH91-10-K

Figure 57

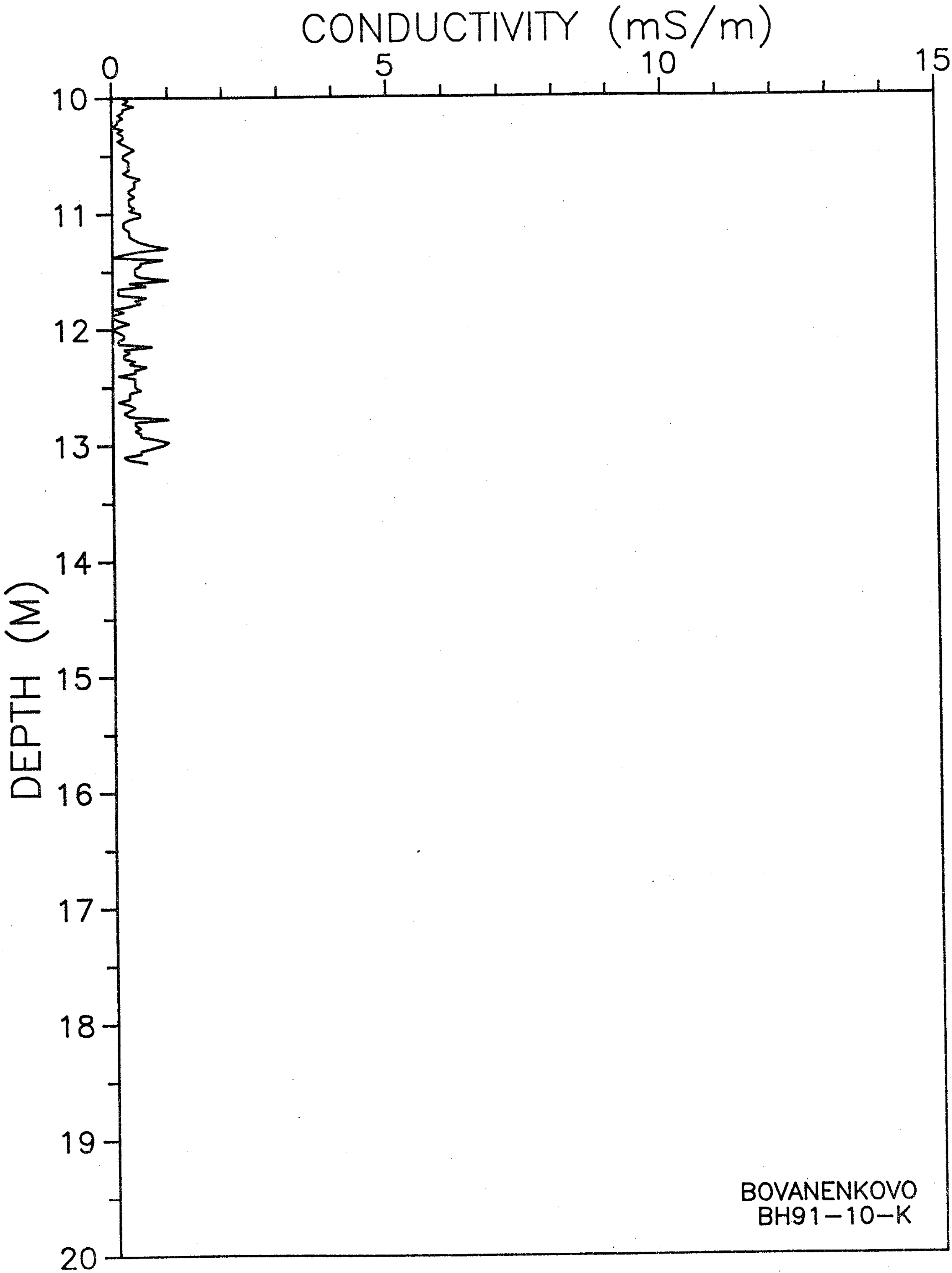


Figure 57 cont.

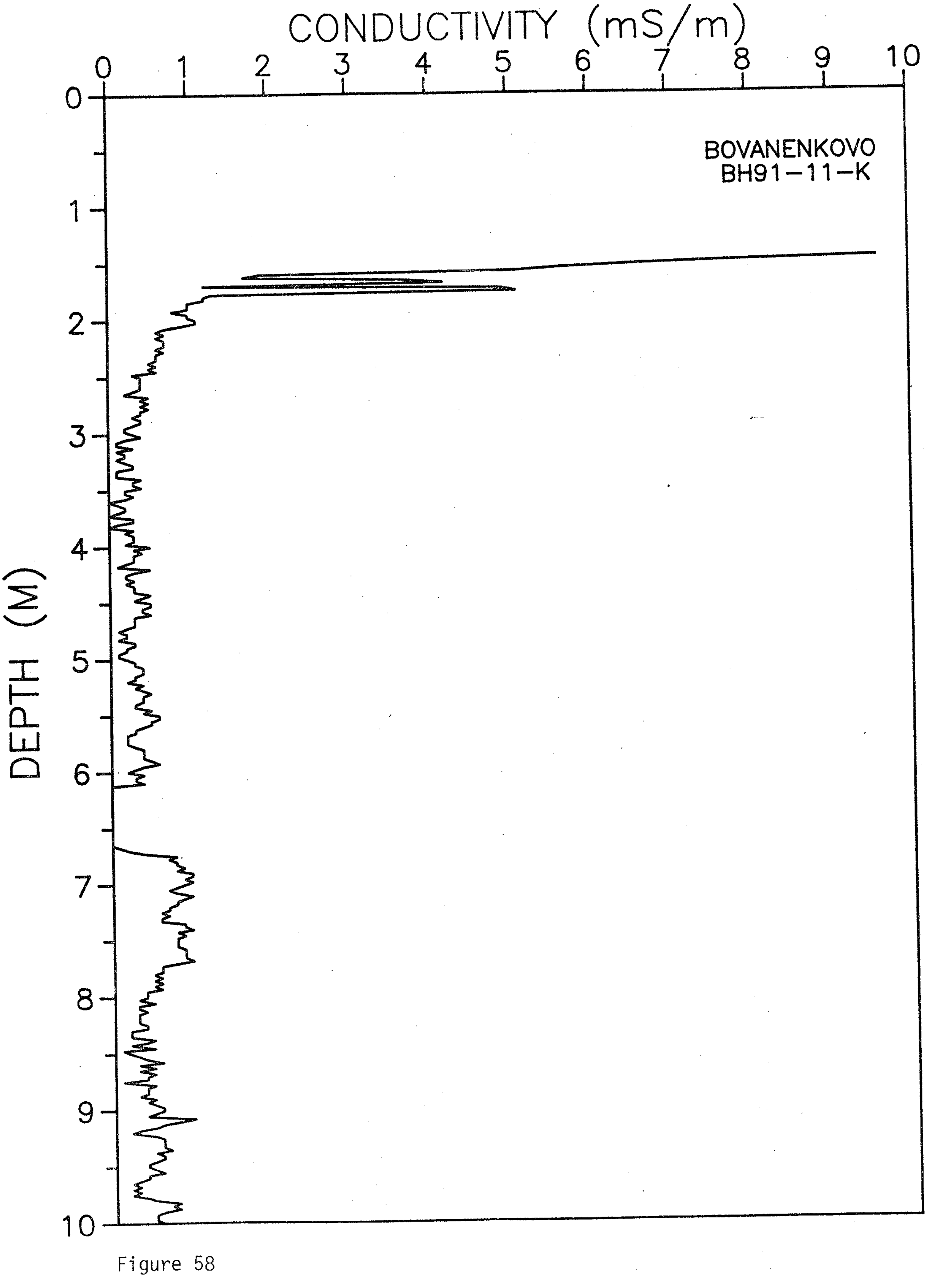

CONDUCTIVITY (mS/m)
0
1
2
3
4
5
6
7
8
9
10
BOVANENKOVO
BH91-11-K
DEPTH (M)
0
1
2
3
4
5
6
7
8
9
10

Figure 58

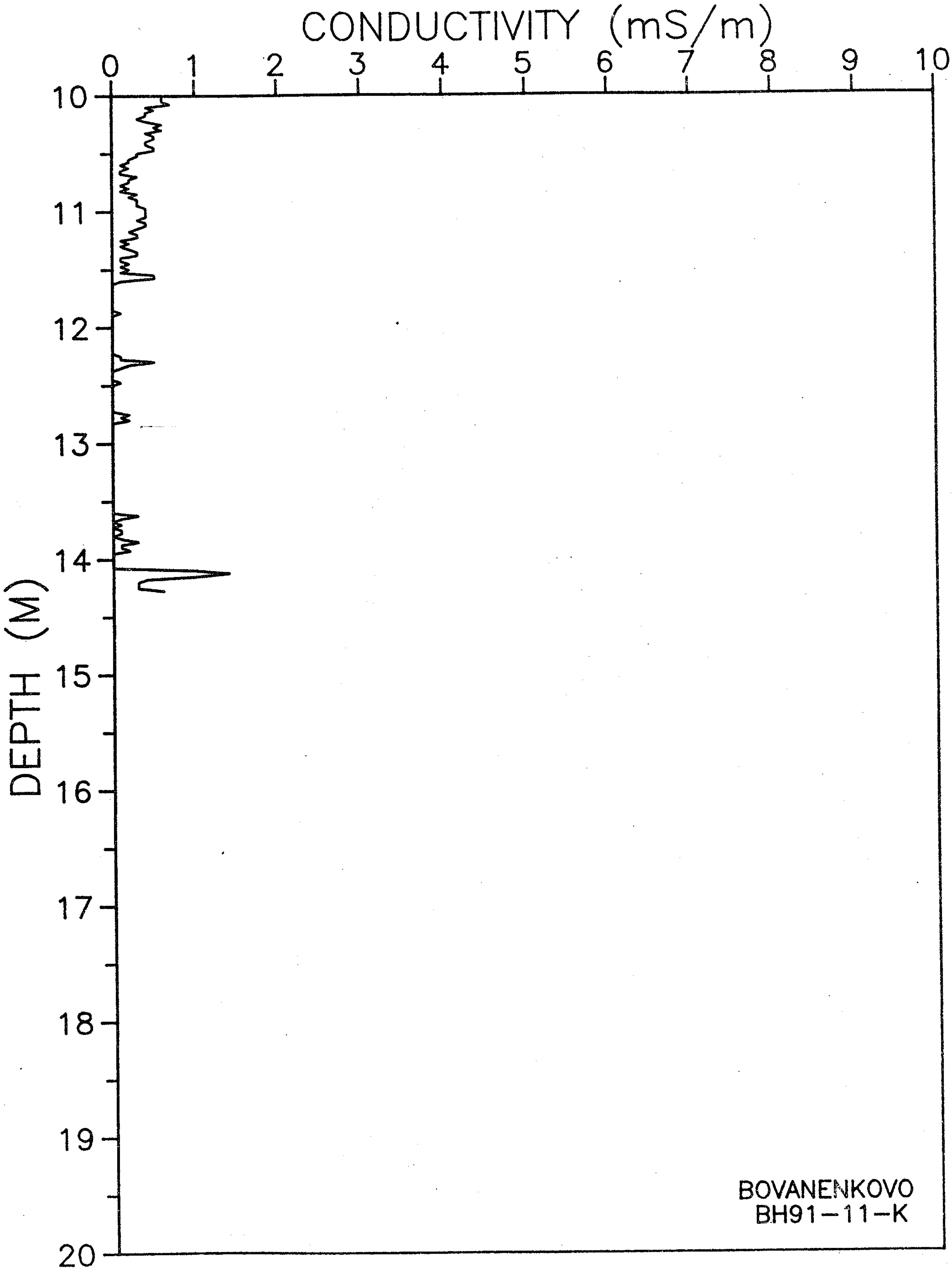


Figure 58 cont.

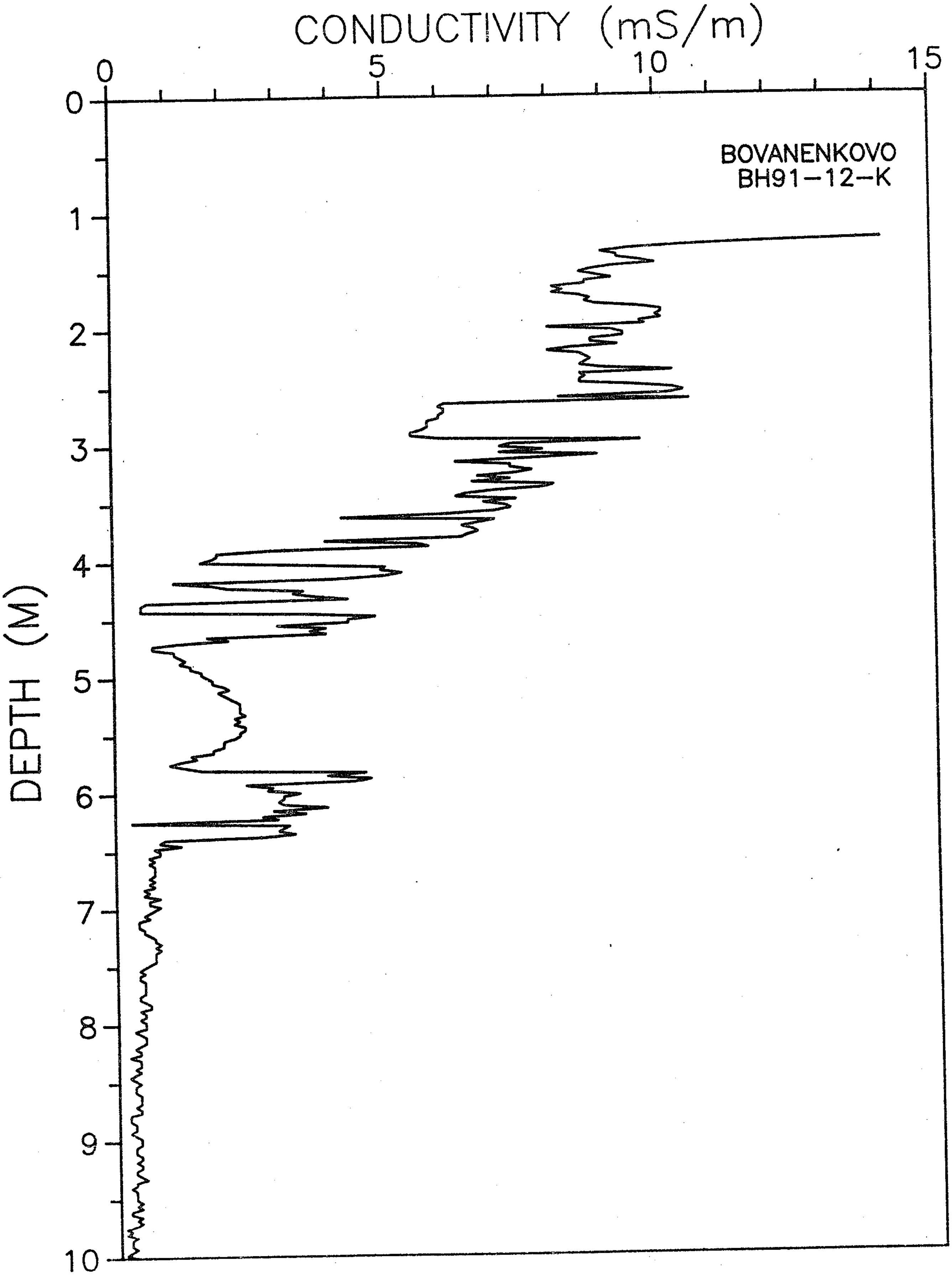

CONDUCTIVITY (mS/m)
0
5
10
15
0
1
2
3
4
5
6
7
8
9
10
DEPTH (M)
BOVANENKOVO
BH91-12-K

Figure 59

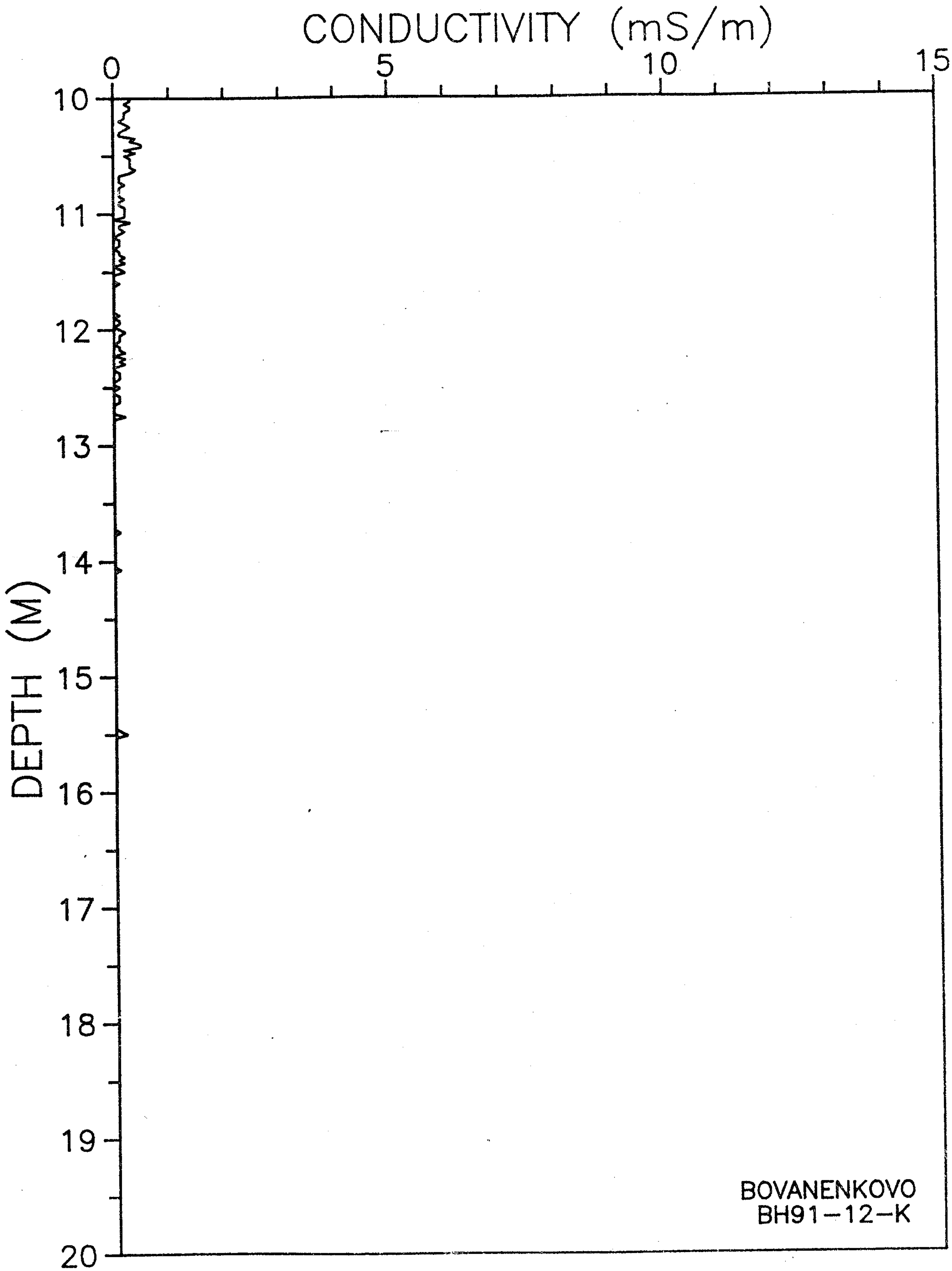


Figure 59 cont.

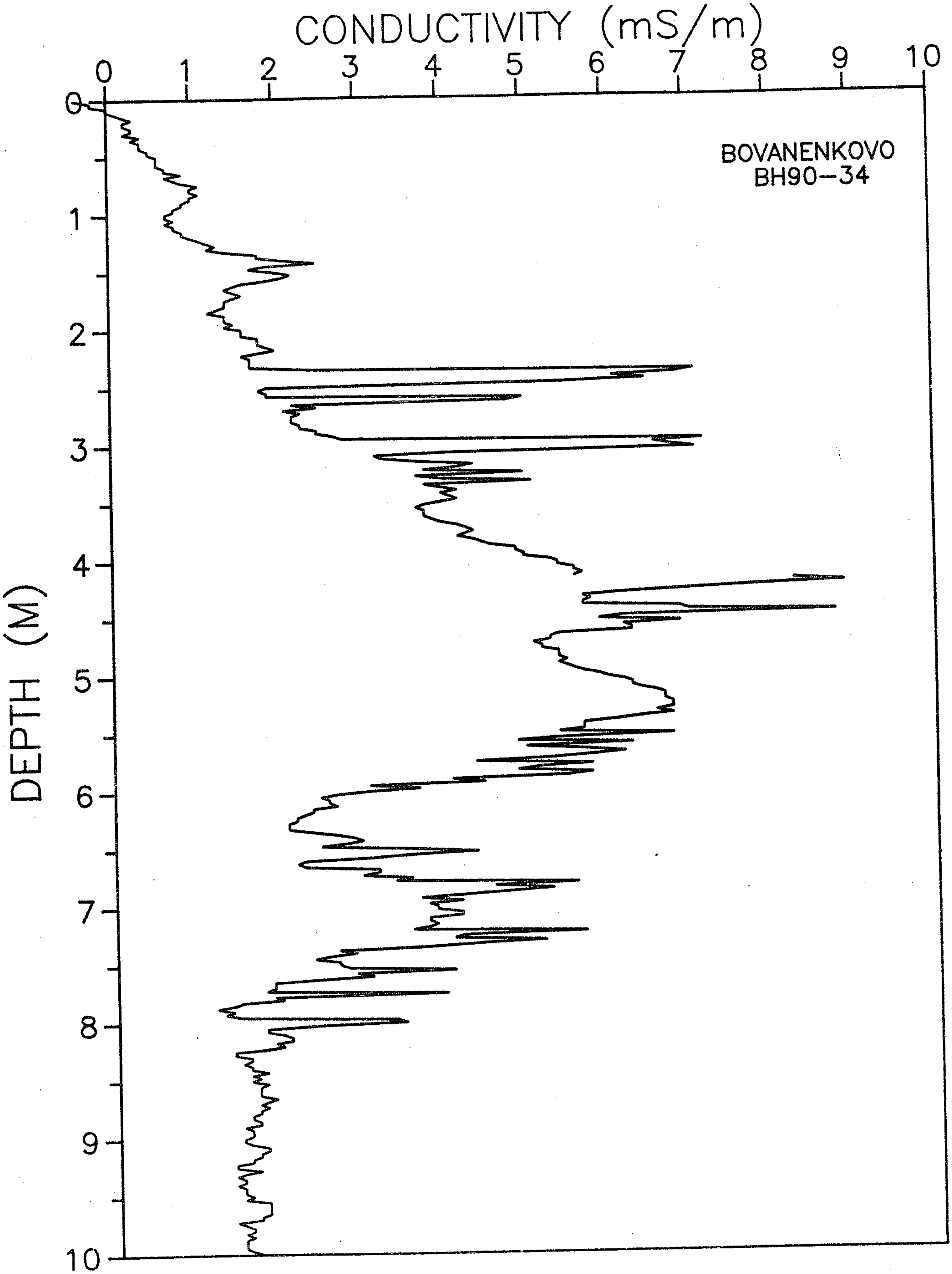

CONDUCTIVITY (mS/m)
0
1
2
3
4
5
6
7
8
9
10
BOVANENKOVO
BH90-34
DEPTH (M)
0
1
2
3
4
5
6
7
8
9
10

Figure 60

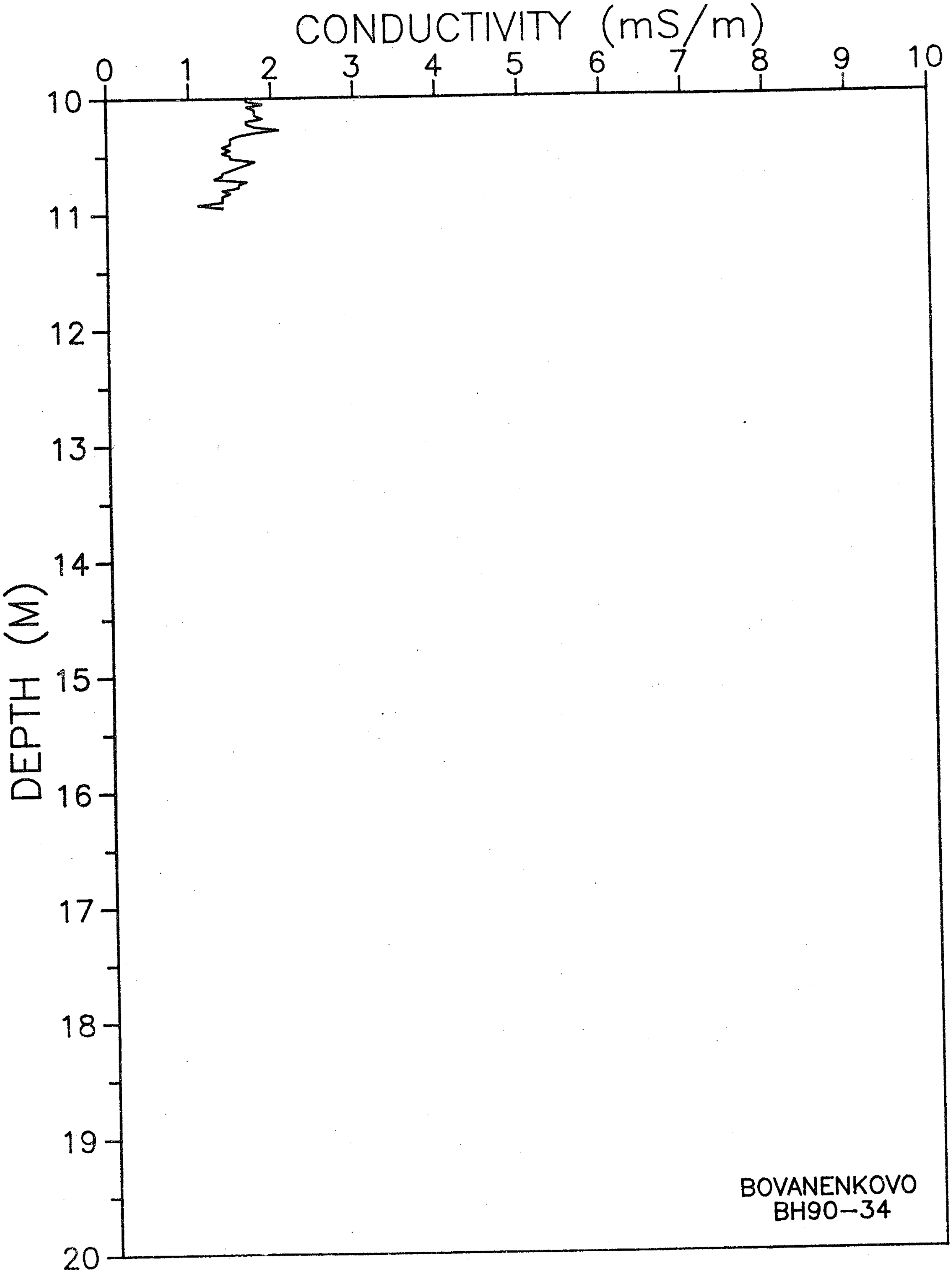


Figure 60 cont.

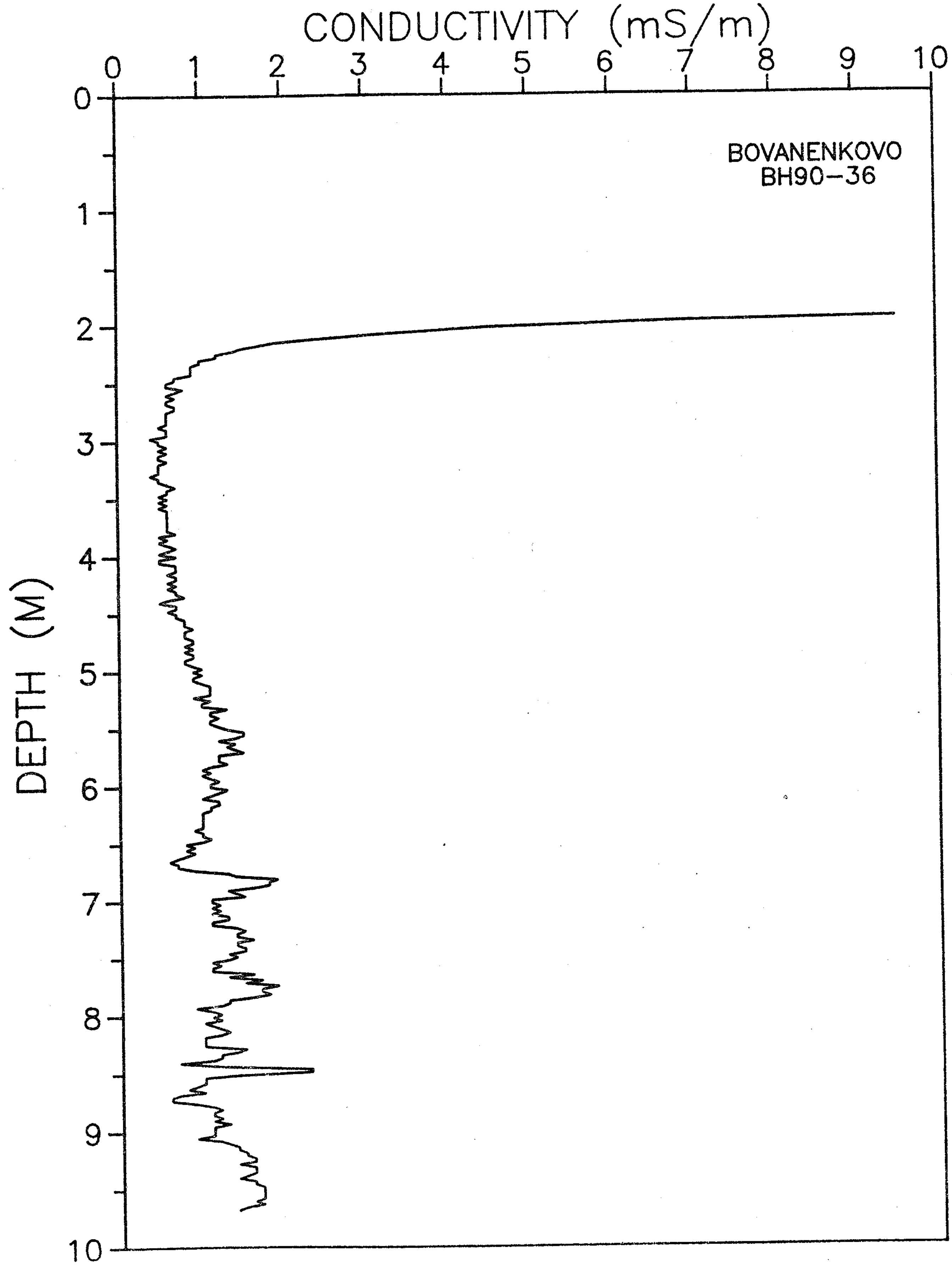

CONDUCTIVITY (mS/m)
0
1
2
3
4
5
6
7
8
9
10
BOVANENKOVO
BH90-36
DEPTH (M)
0
1
2
3
4
5
6
7
8
9
10

Figure 61

VSEGINGEO LOGGING SYSTEM

DENSITY LOGS

Figs. 62-74

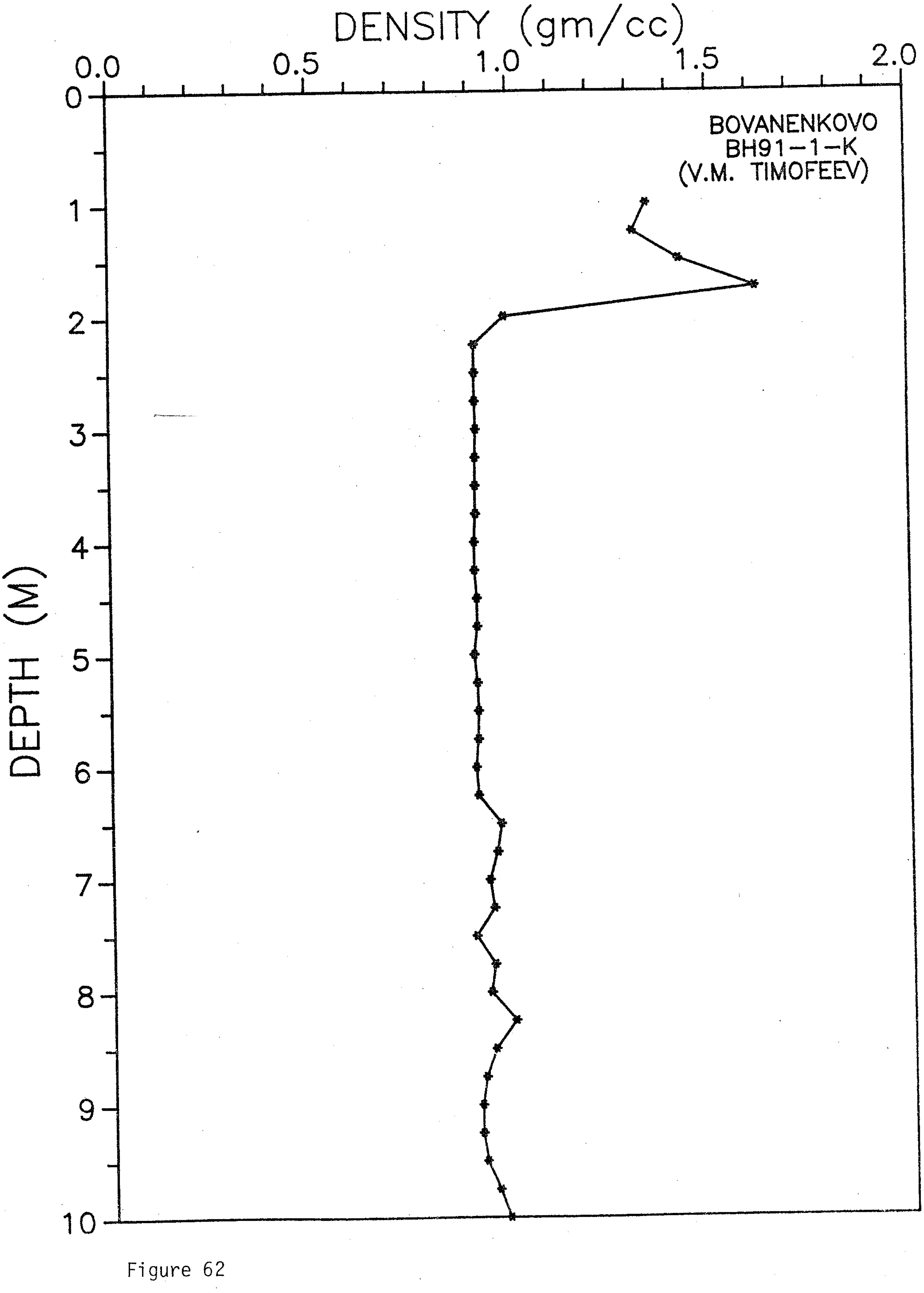

DENSITY (gm/cc)
0.0
0.5
1.0
1.5
2.0
0
1
2
3
4
5
6
7
8
9
10
DEPTH (M)
BOVANENKOVO
BH91-1-K
(V.M. TIMOFEEV)

Figure 62

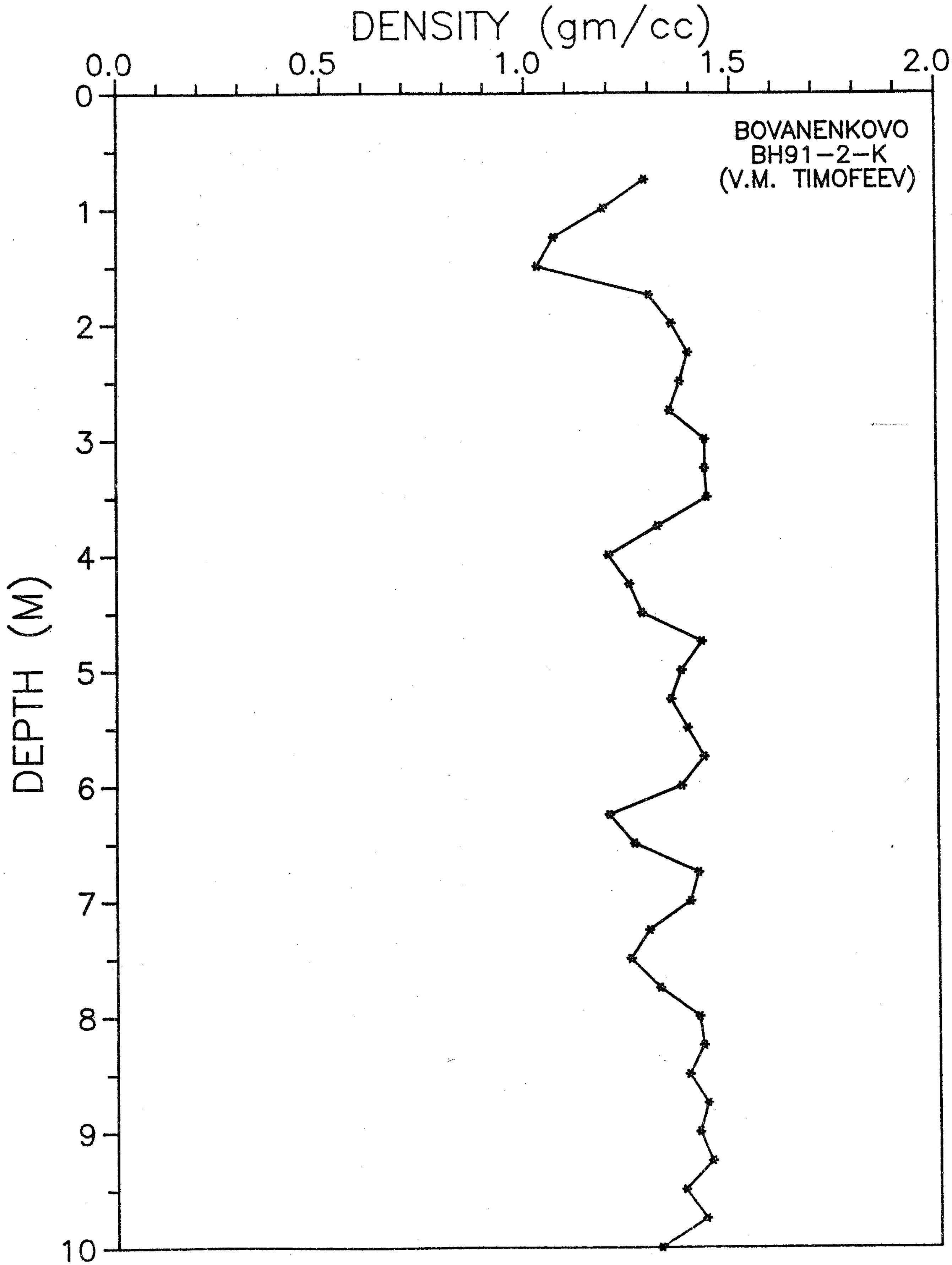

DENSITY (gm/cc)
0.0
0.5
1.0
1.5
2.0
0
1
2
3
4
5
6
7
8
9
10
DEPTH (M)
BOVANENKOVO
BH91-2-K
(V.M. TIMOFEEV)

Figure 63

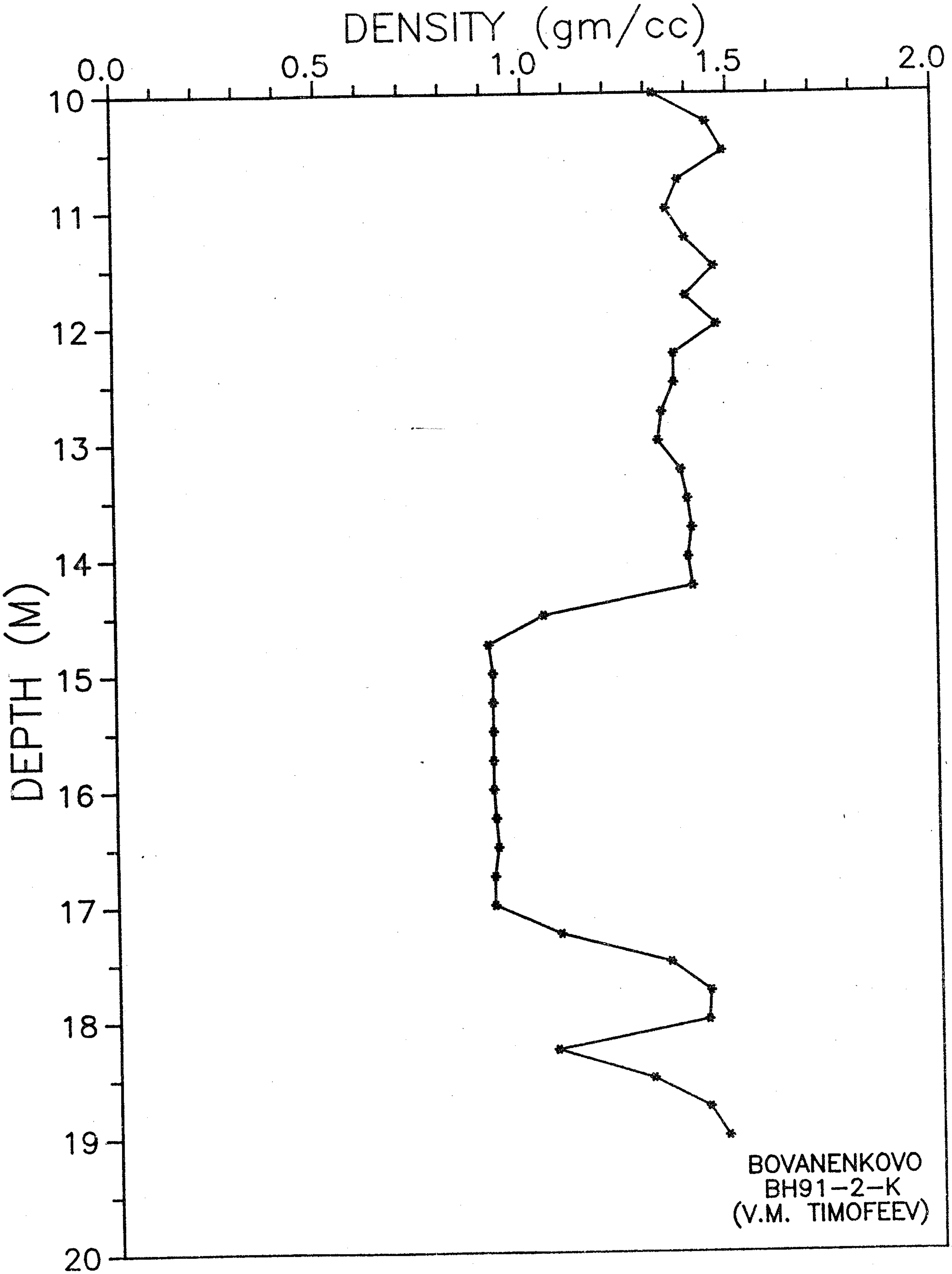


Figure 63 cont.

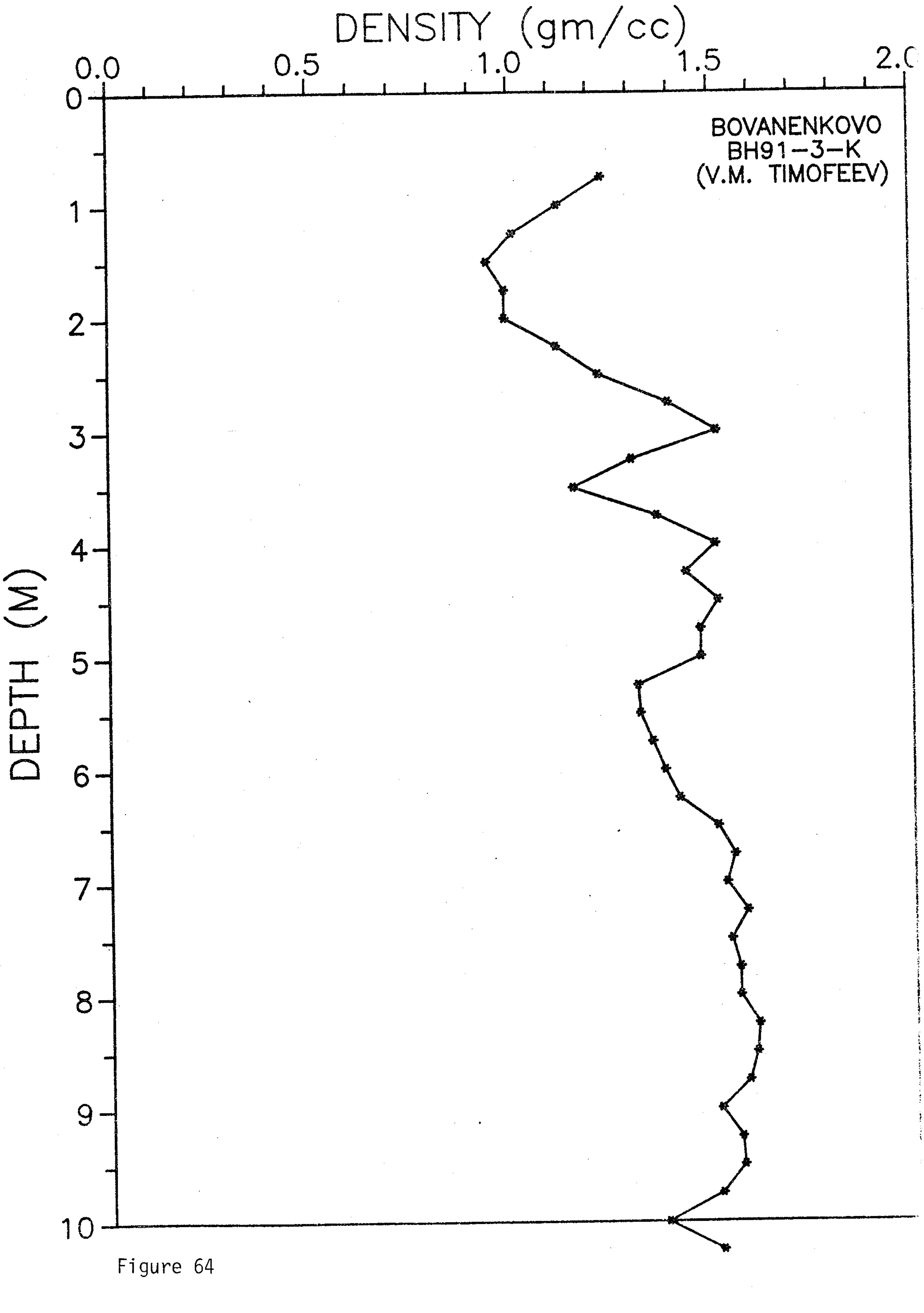

DENSITY (gm/cc)
0.0
0.5
1.0
1.5
2.0
0
1
2
3
4
5
6
7
8
9
10
DEPTH (M)
BOVANENKOVO
BH91-3-K
(V.M. TIMOFEEV)

Figure 64

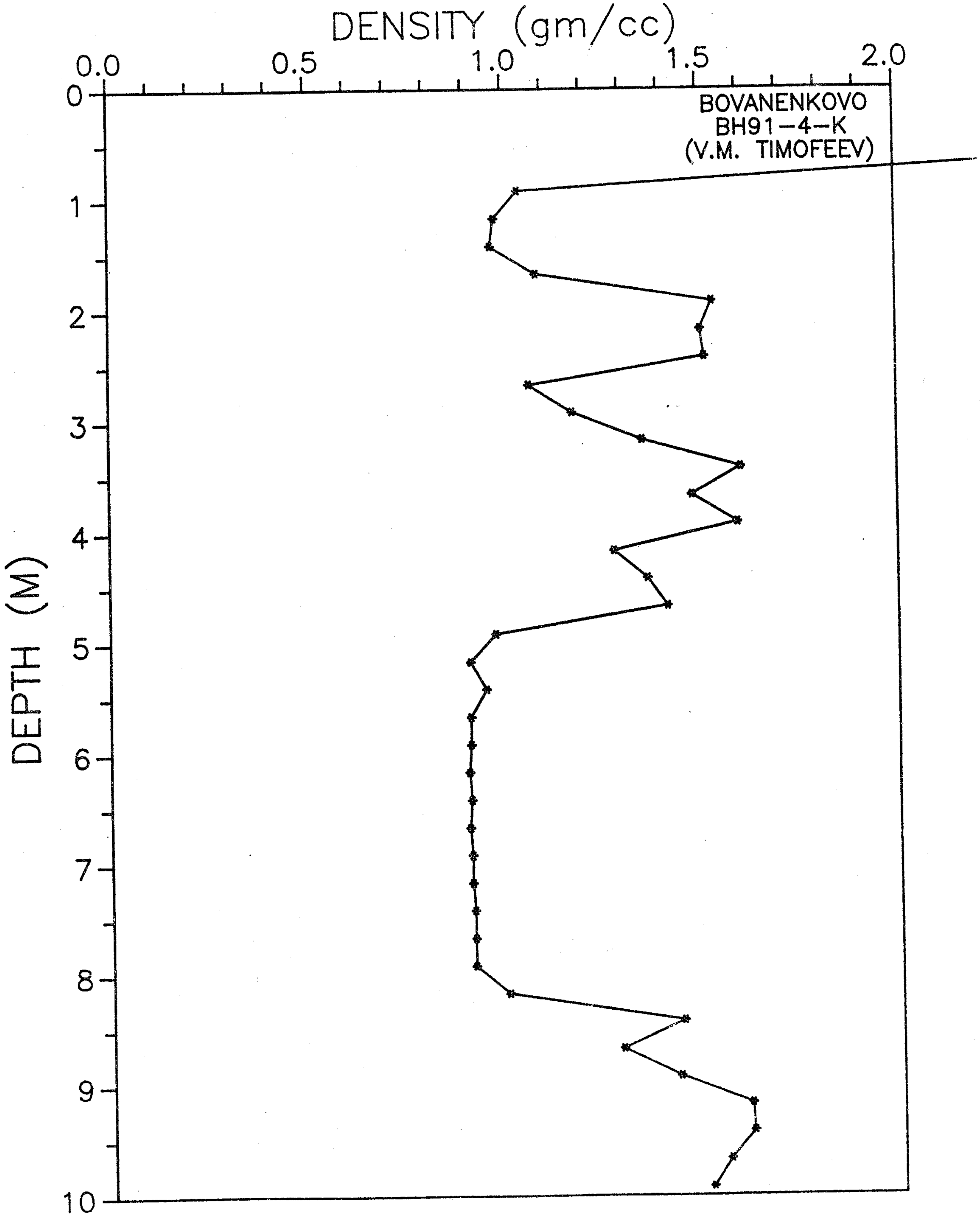

DENSITY (gm/cc)
0.0
0.5
1.0
1.5
2.0
BOVANENKOVO
BH91-4-K
(V.M. TIMOFEEV)
DEPTH (M)
0
1
2
3
4
5
6
7
8
9
10

Figure 65

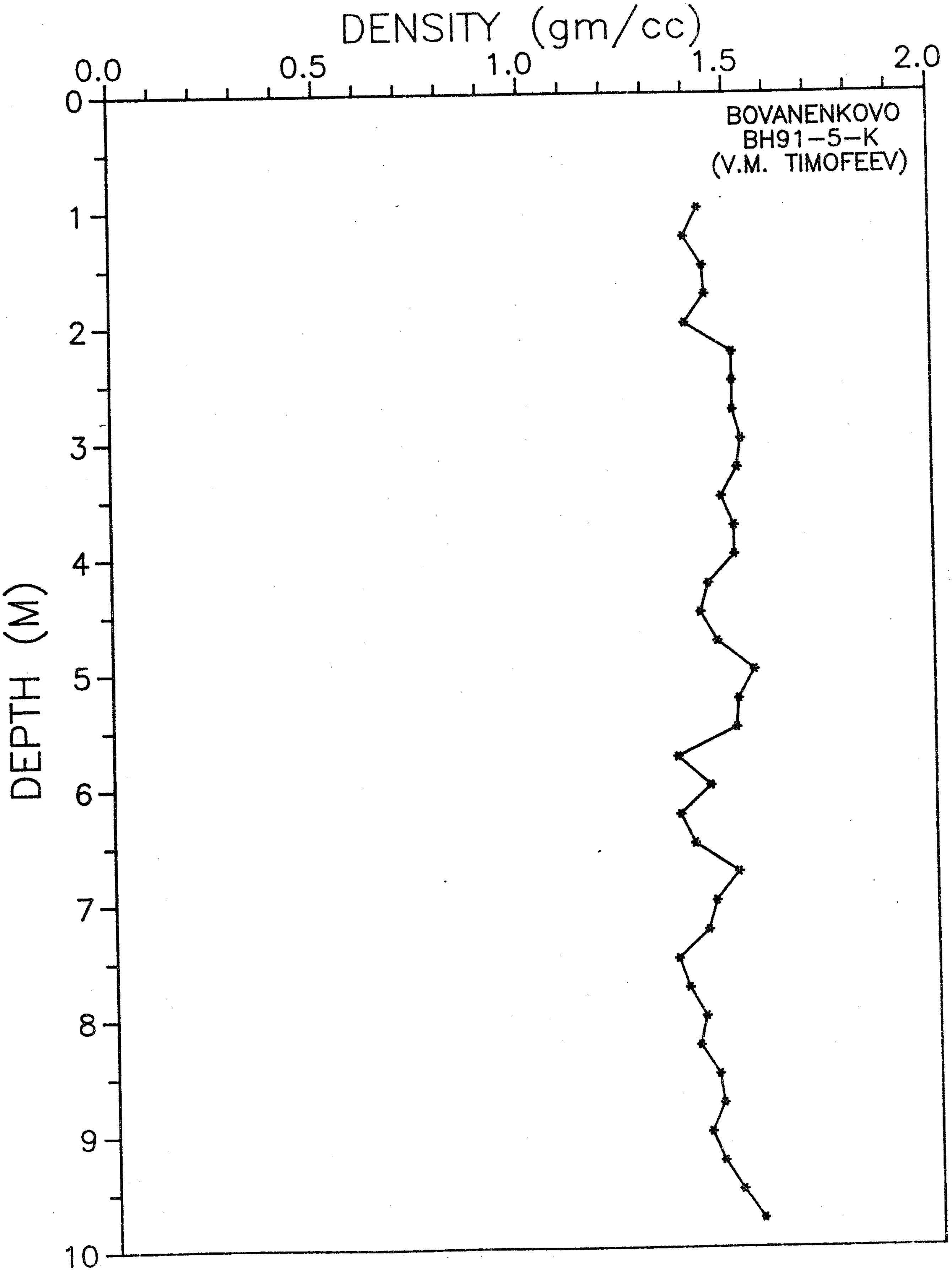

DENSITY (gm/cc)
0.0
0.5
1.0
1.5
2.0
0
1
2
3
4
5
6
7
8
9
10
DEPTH (M)
BOVANENKOVO
BH91-5-K
(V.M. TIMOFEEV)

Figure 66

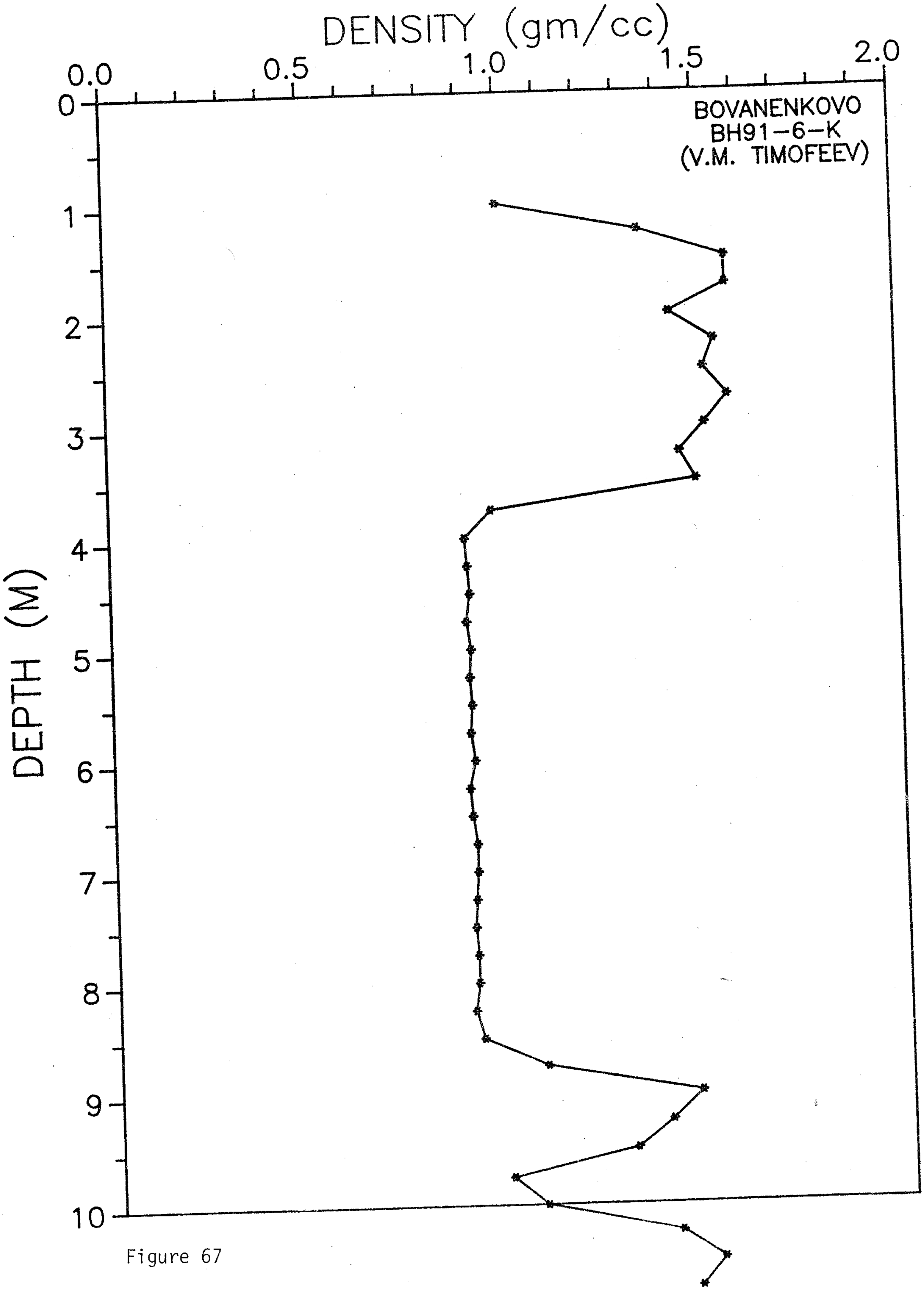

DENSITY (gm/cc)
0.0
0.5
1.0
1.5
2.0
0
1
2
3
4
5
6
7
8
9
10
DEPTH (M)
BOVANENKOVO
BH91-6-K
(V.M. TIMOFEEV)

Figure 67

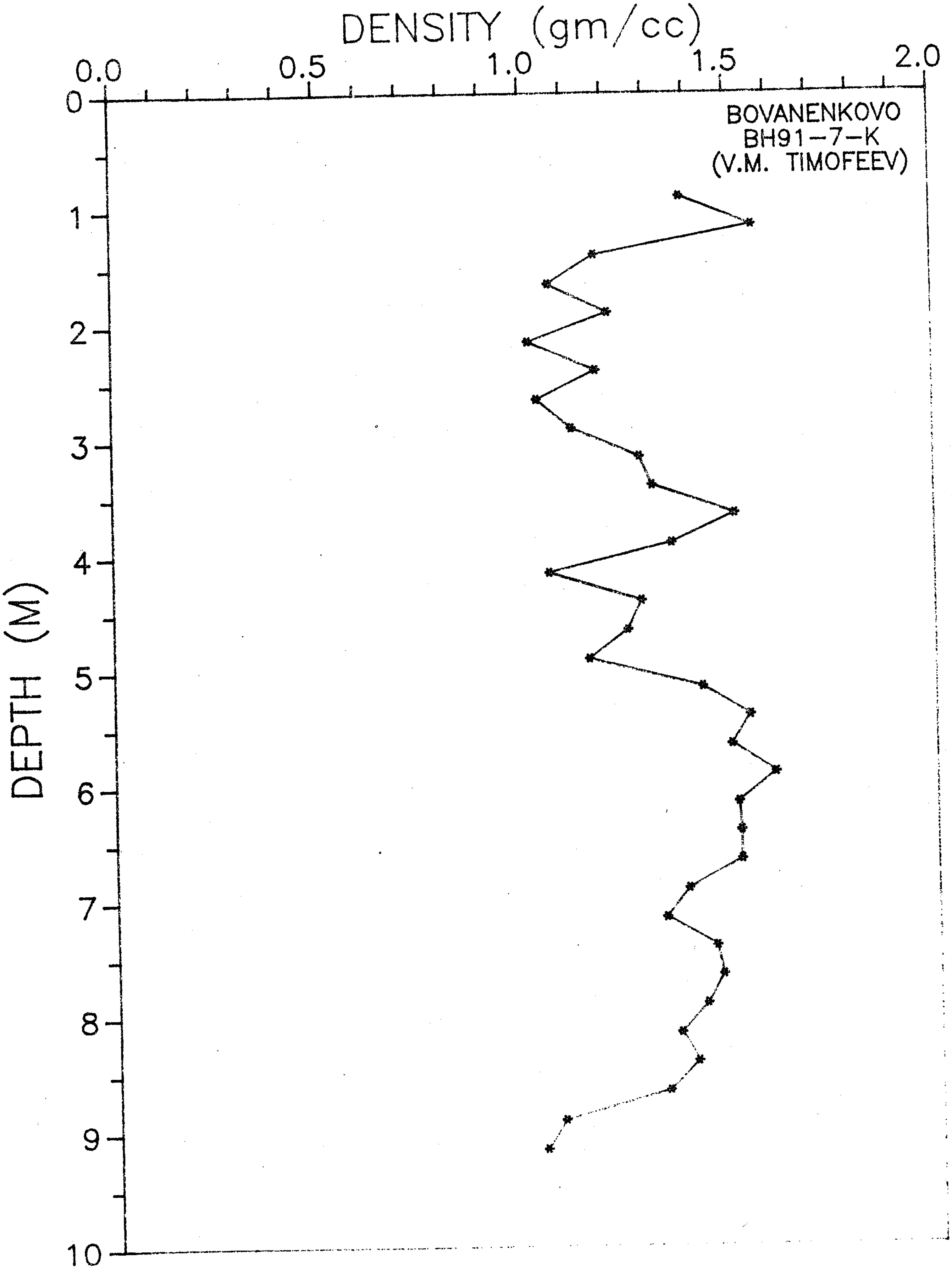

DENSITY (gm/cc)
0.0
0.5
1.0
1.5
2.0
0
1
2
3
4
5
6
7
8
9
10
DEPTH (M)
BOVANENKOVO
BH91-7-K
(V.M. TIMOFEEV)

Figure 68

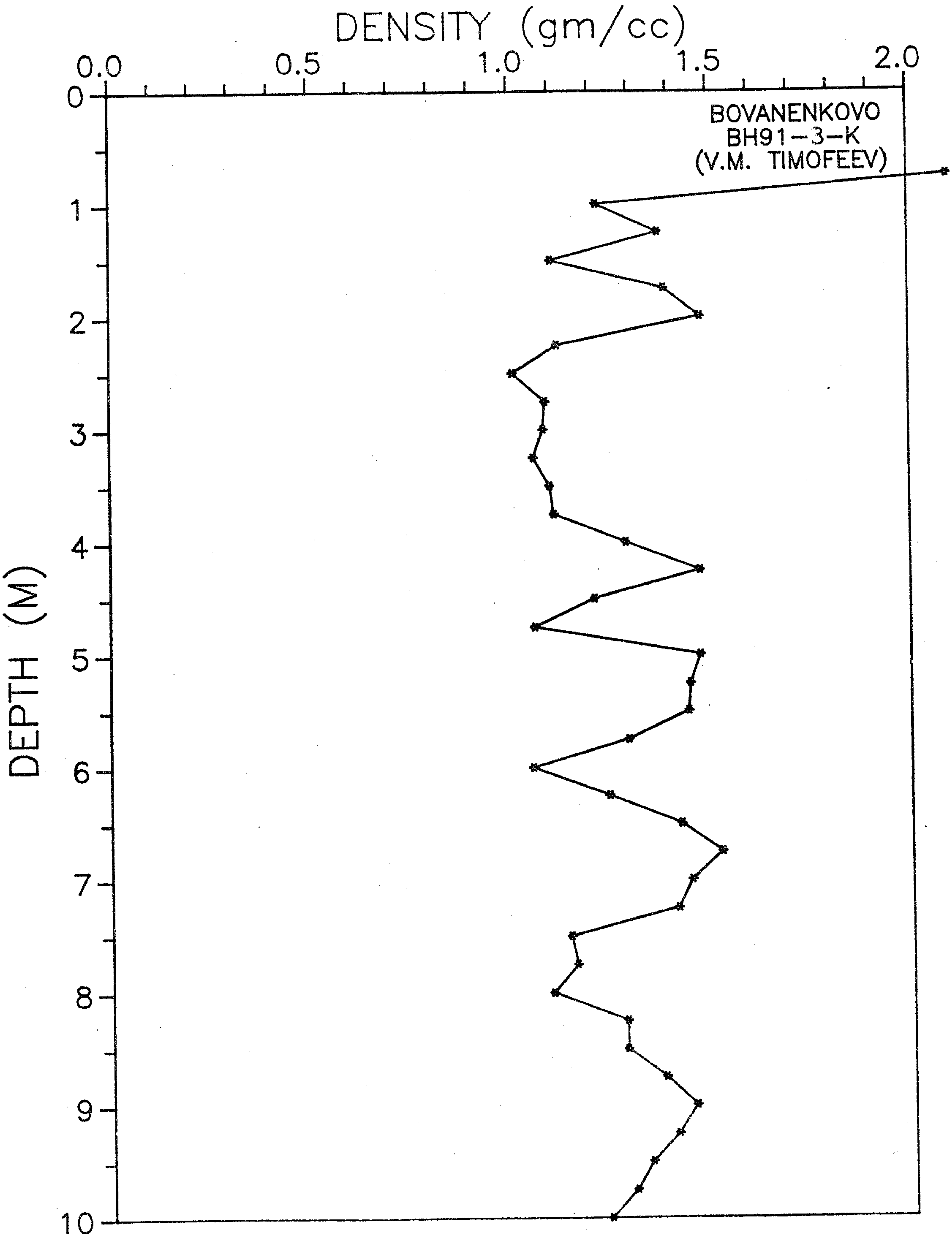

DENSITY (gm/cc)
0.0
0.5
1.0
1.5
2.0
BOVANENKOVO
BH91-3-K
(V.M. TIMOFEEV)
DEPTH (M)
0
1
2
3
4
5
6
7
8
9
10

Figure 69

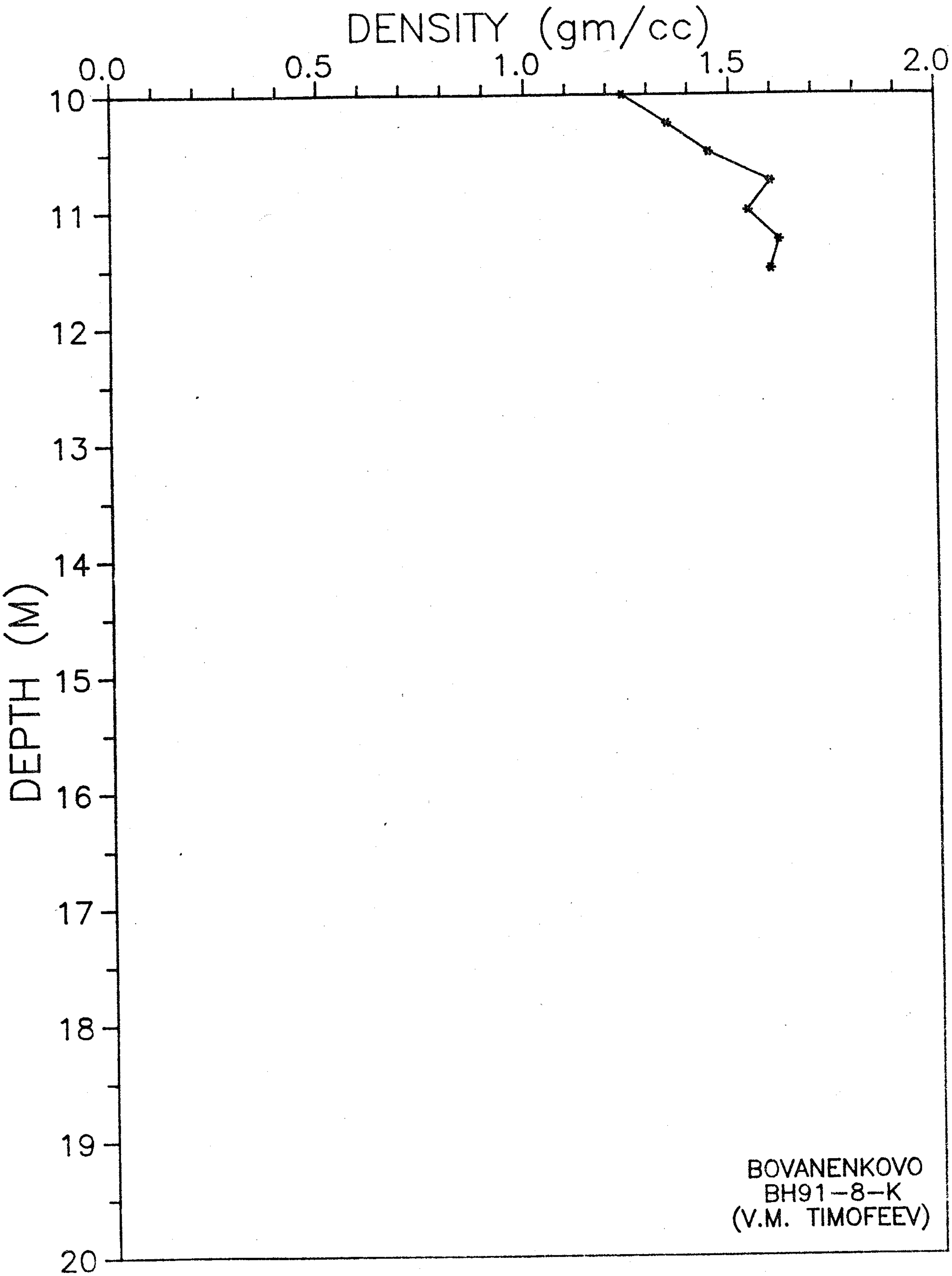


Figure 69 cont.

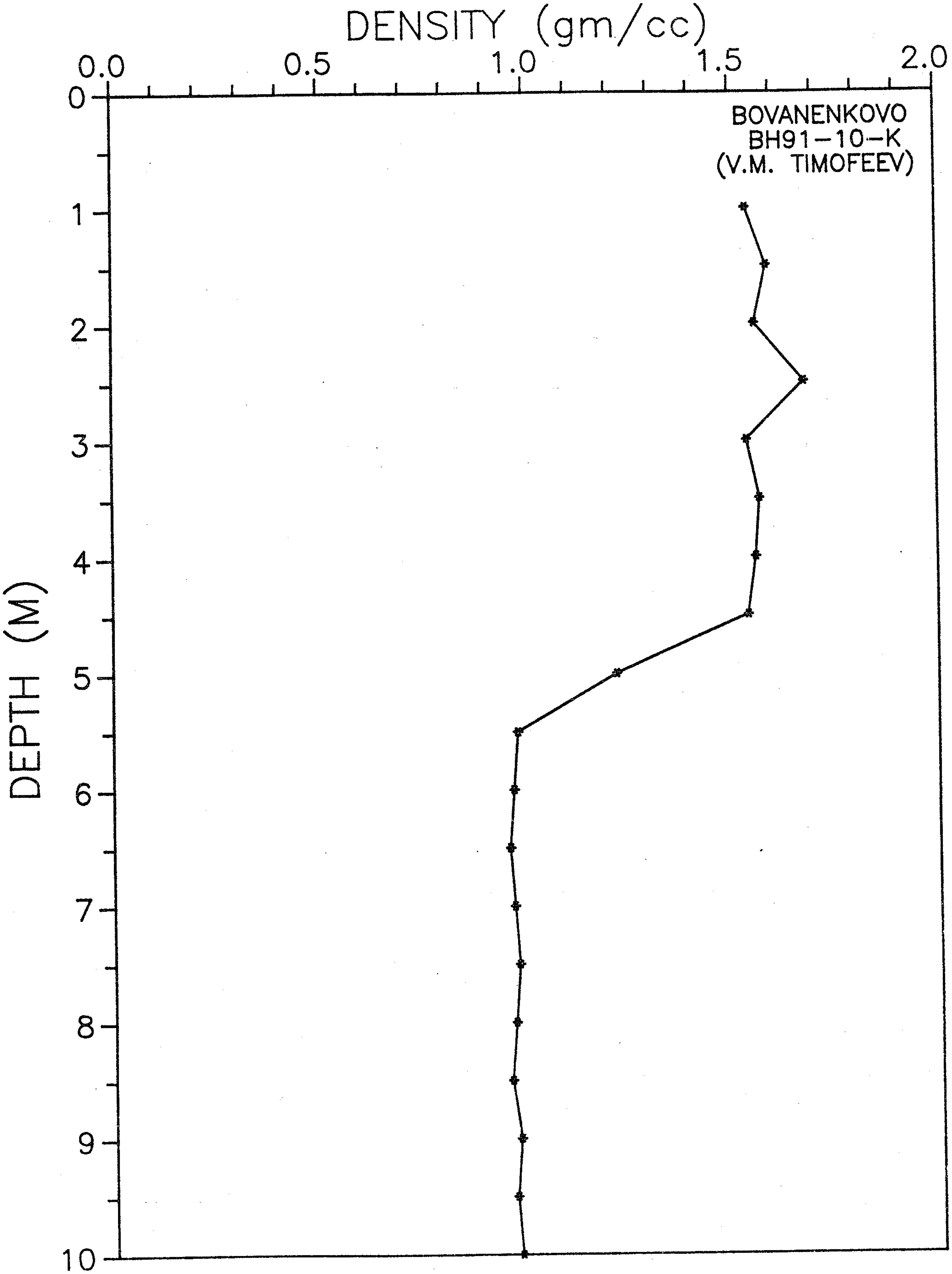

DENSITY (gm/cc)
0.0
0.5
1.0
1.5
2.0
BOVANENKOVO
BH91-10-K
(V.M. TIMOFEEV)
DEPTH (M)
0
1
2
3
4
5
6
7
8
9
10

Figure 70

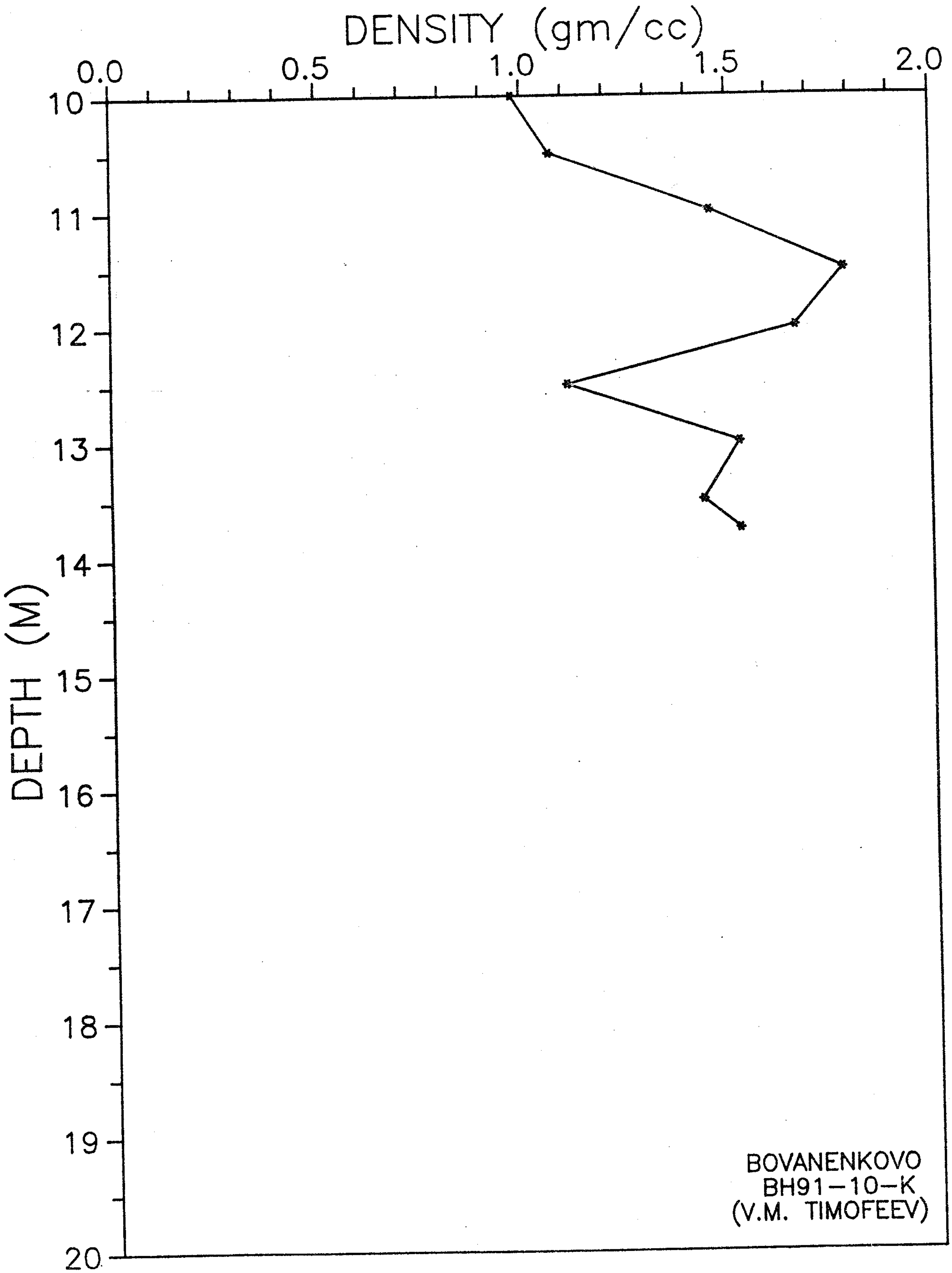


Figure 70 cont.

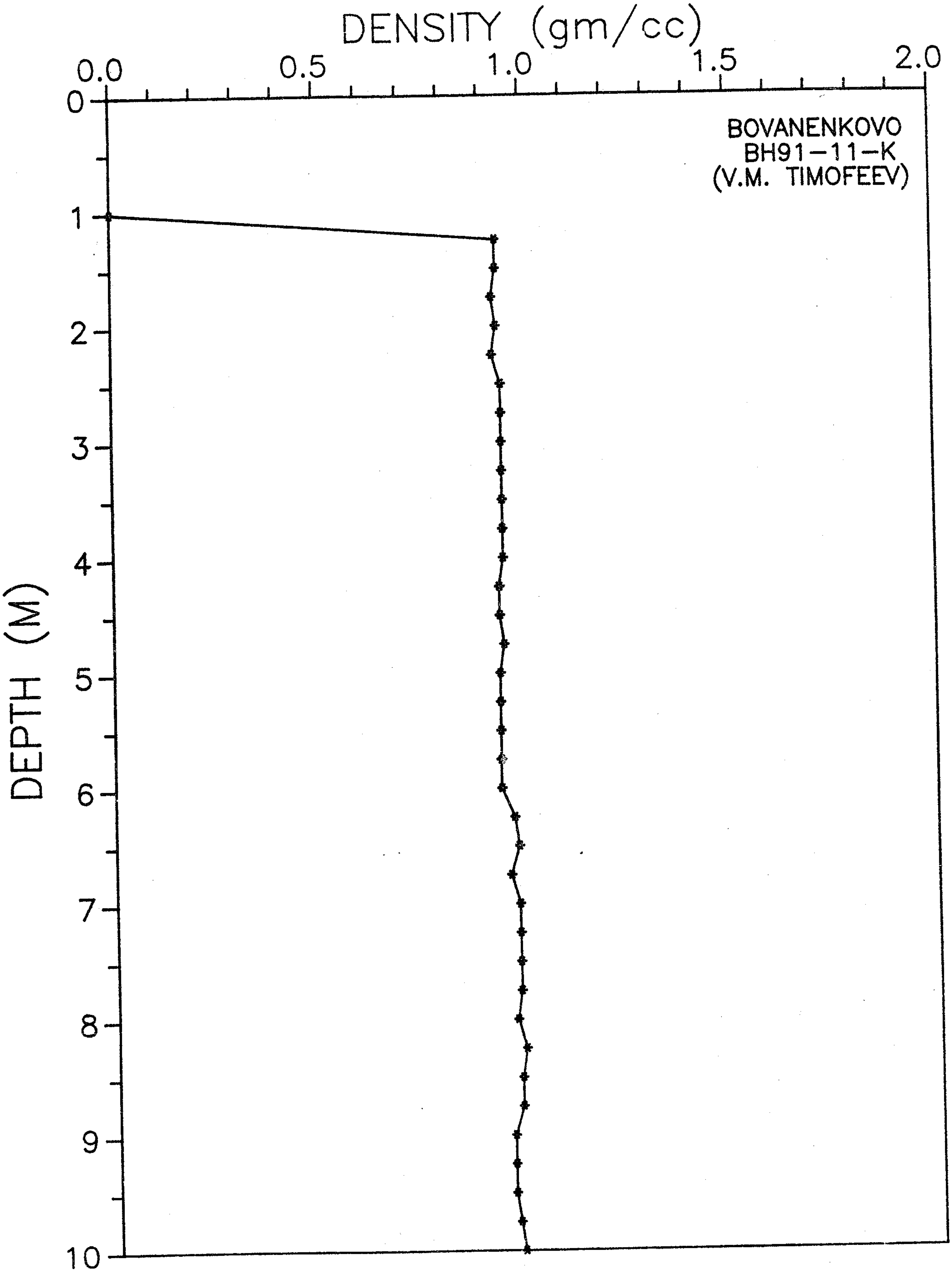

DENSITY (gm/cc)
0.0
0.5
1.0
1.5
2.0
0
1
2
3
4
5
6
7
8
9
10
DEPTH (M)
BOVANENKOVO
BH91-11-K
(V.M. TIMOFEEV)

Figure 71

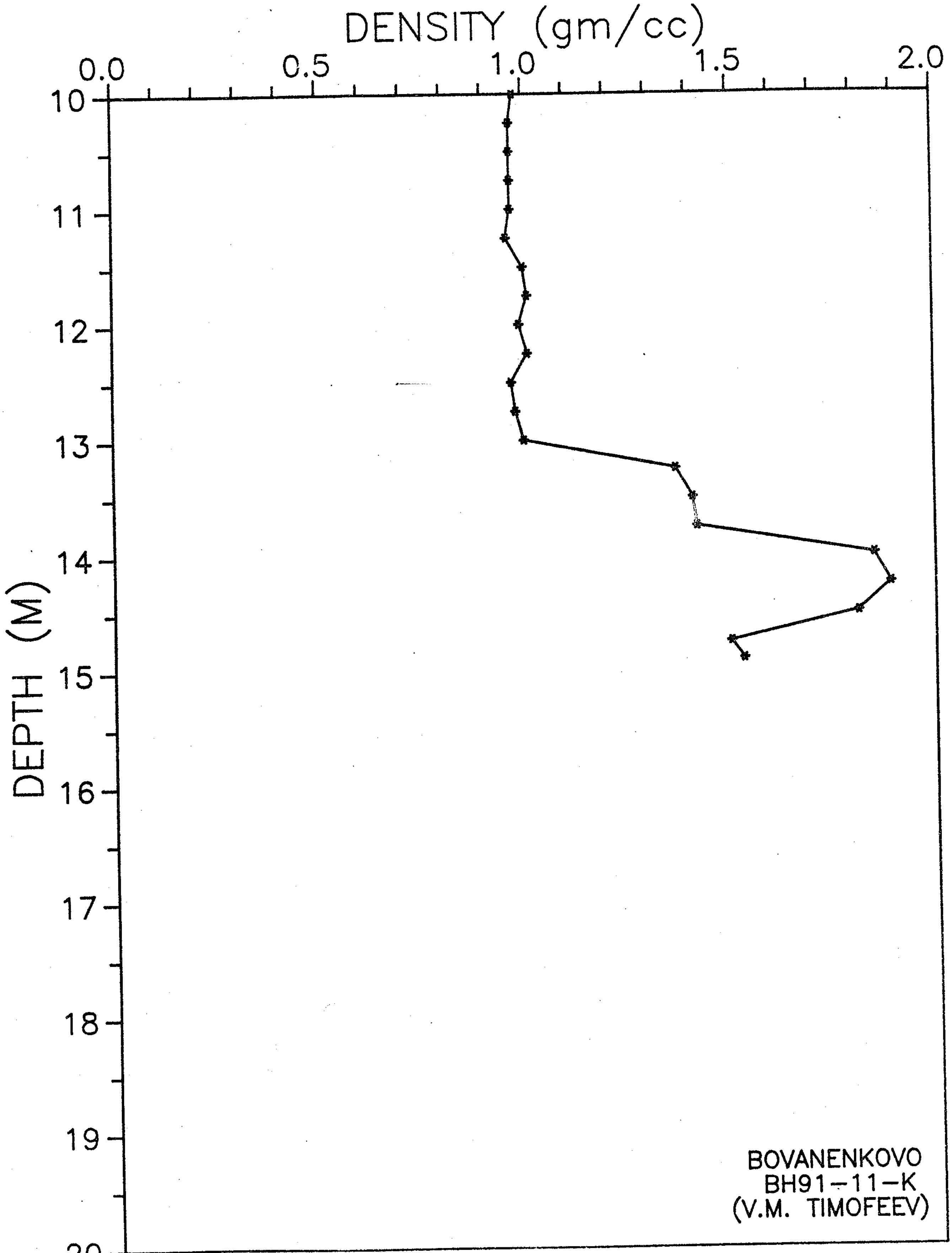


Figure 71 cont.

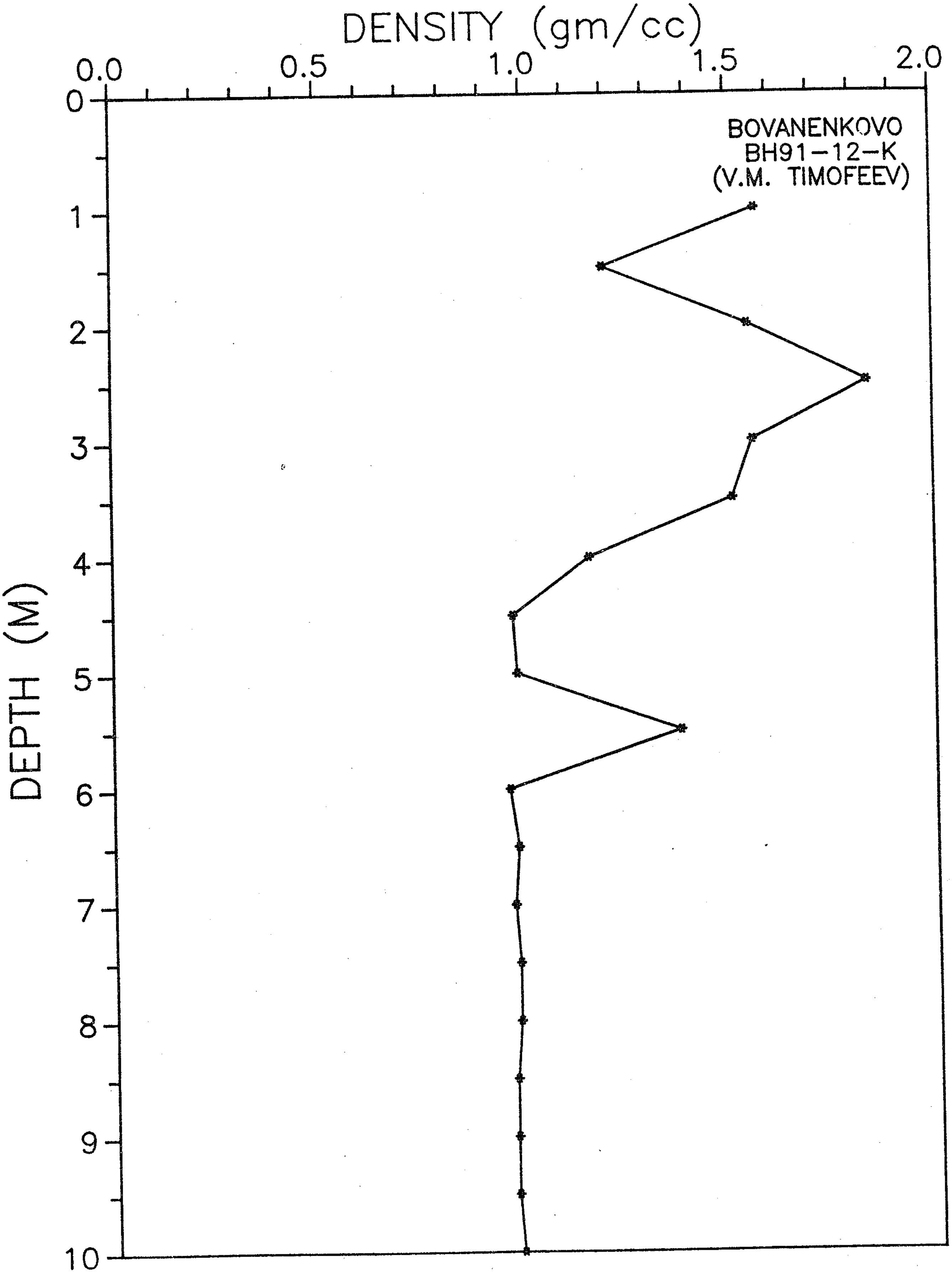

DENSITY (gm/cc)
0.0
0.5
1.0
1.5
2.0
BOVANENKOVO
BH91-12-K
(V.M. TIMOFEEV)
DEPTH (M)
0
1
2
3
4
5
6
7
8
9
10

Figure 72

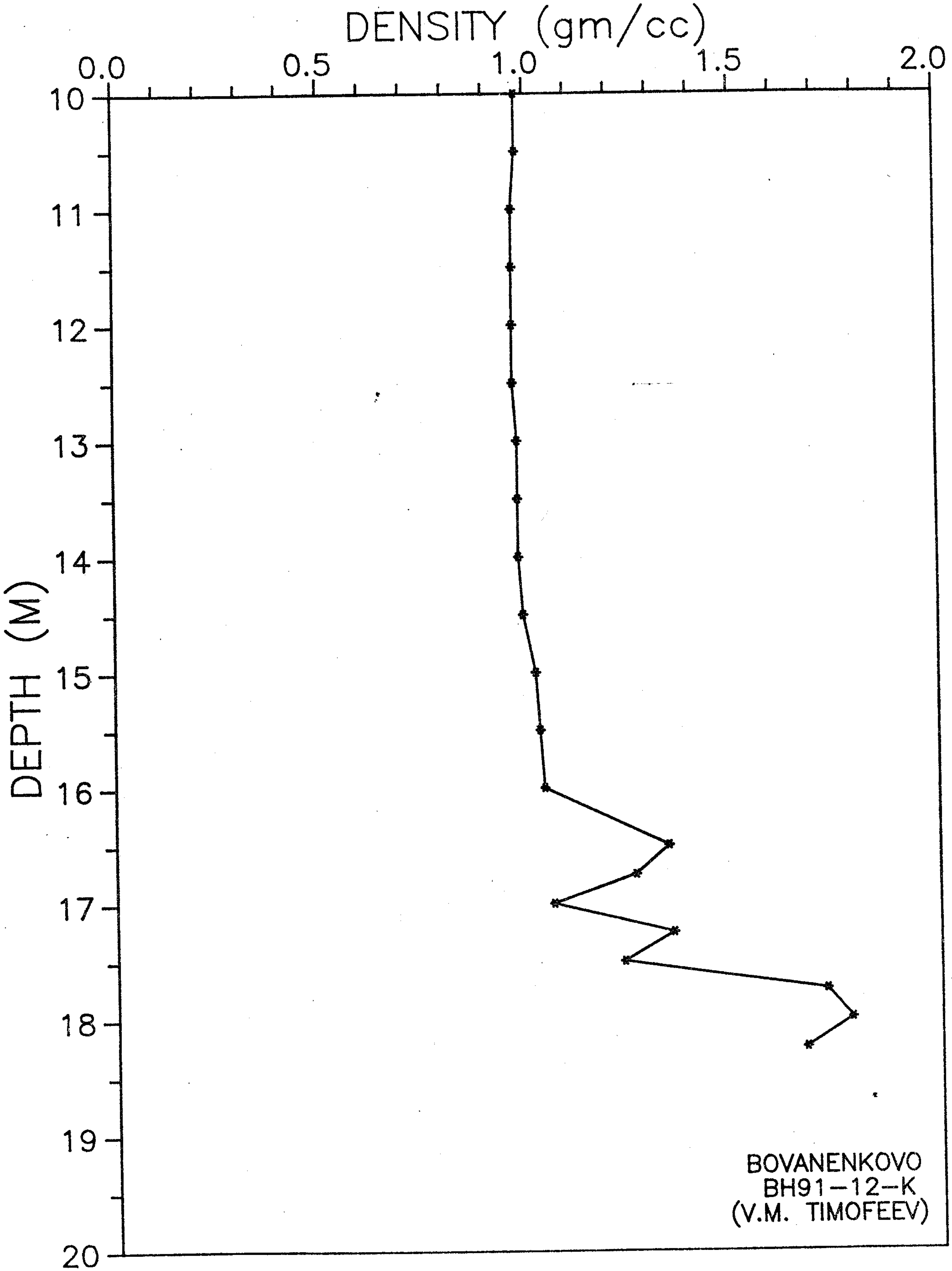


Figure 72 cont.

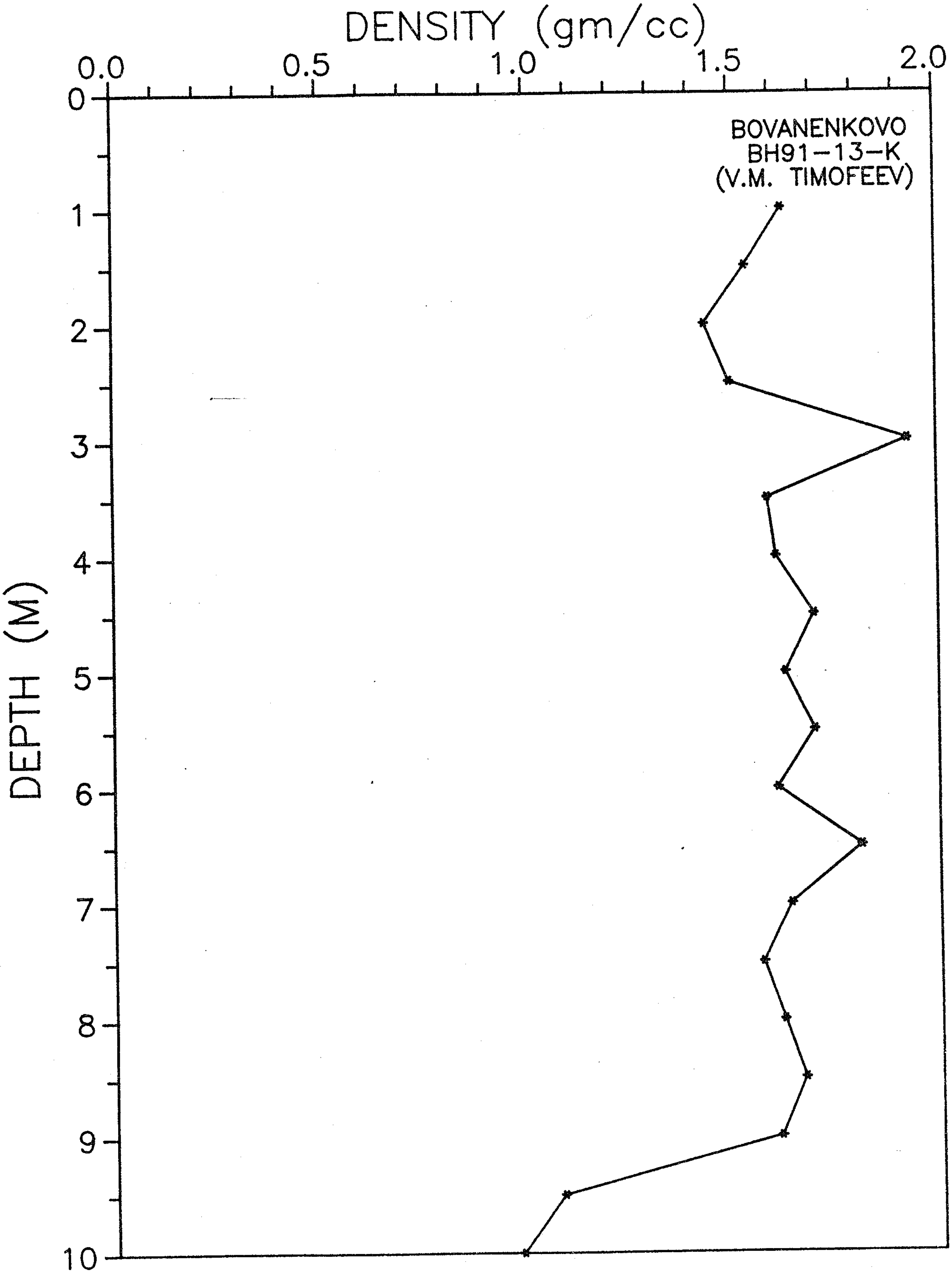

DENSITY (gm/cc)
0.0
0.5
1.0
1.5
2.0
0
1
2
3
4
5
6
7
8
9
10
DEPTH (M)
BOVANENKOVO
BH91-13-K
(V.M. TIMOFEEV)

Figure 73

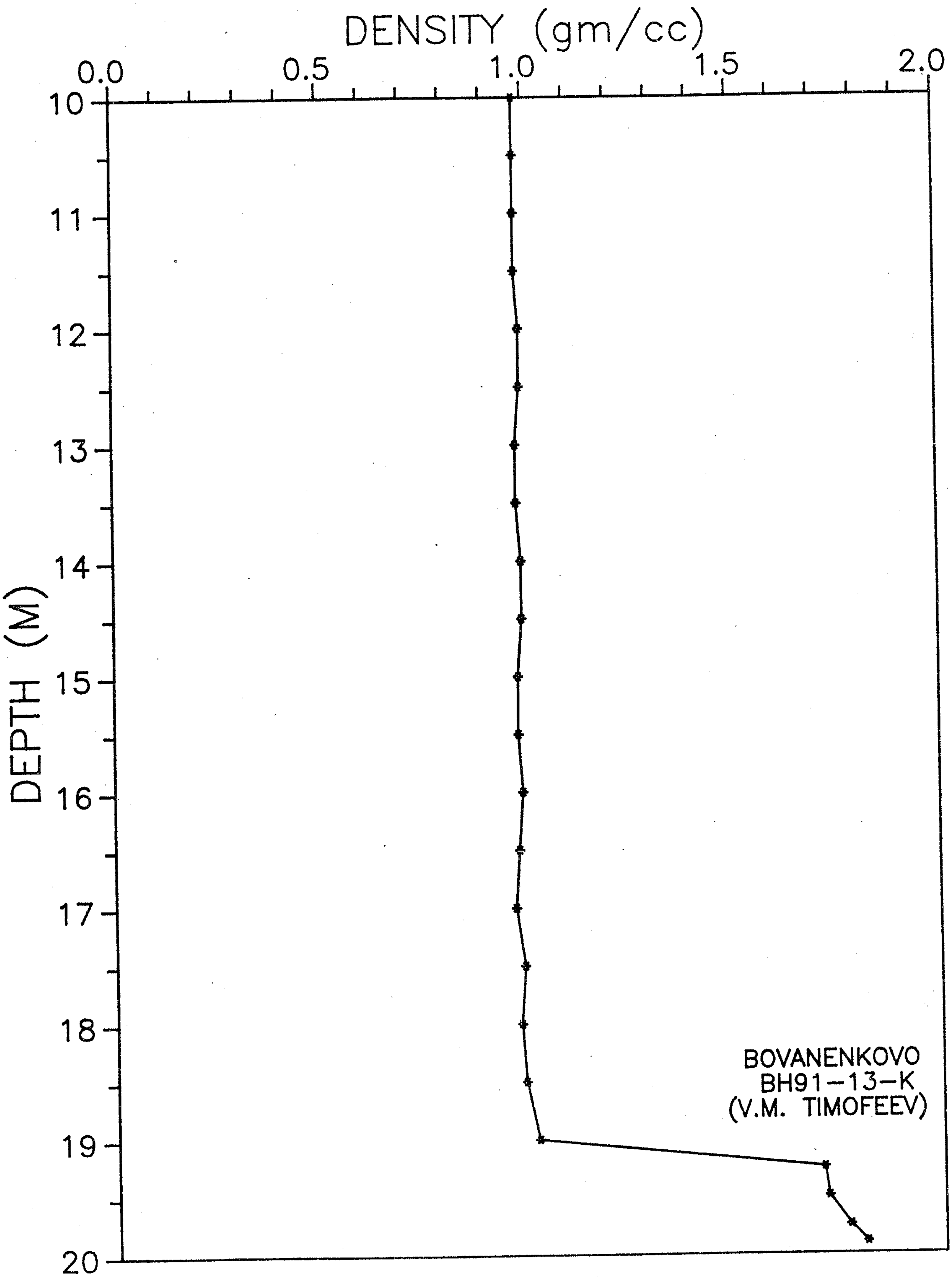


Figure 73 cont.

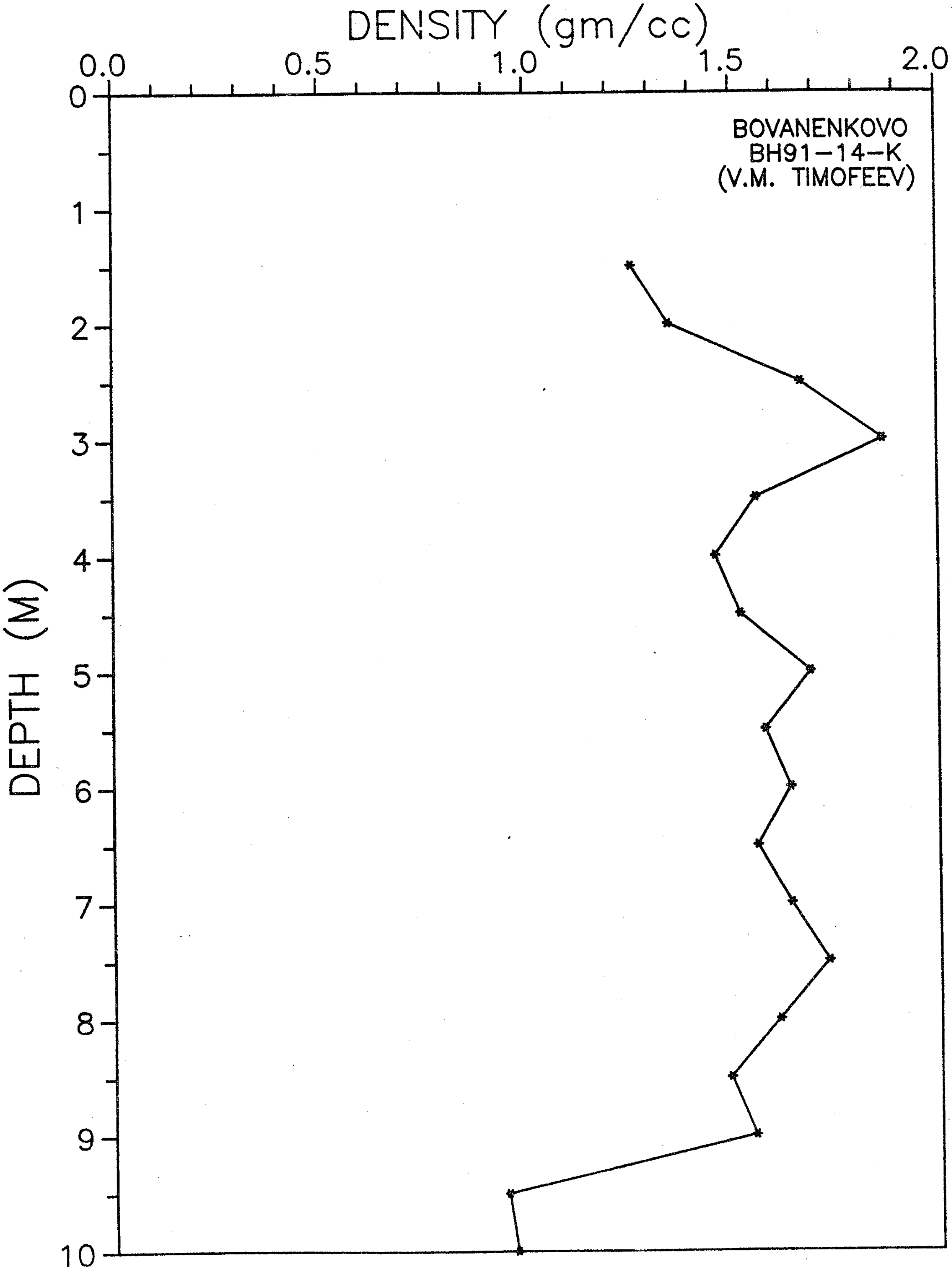

DENSITY (gm/cc)
0.0
0.5
1.0
1.5
2.0
0
1
2
3
4
5
6
7
8
9
10
DEPTH (M)
BOVANENKOVO
BH91-14-K
(V.M. TIMOFEEV)

Figure 74

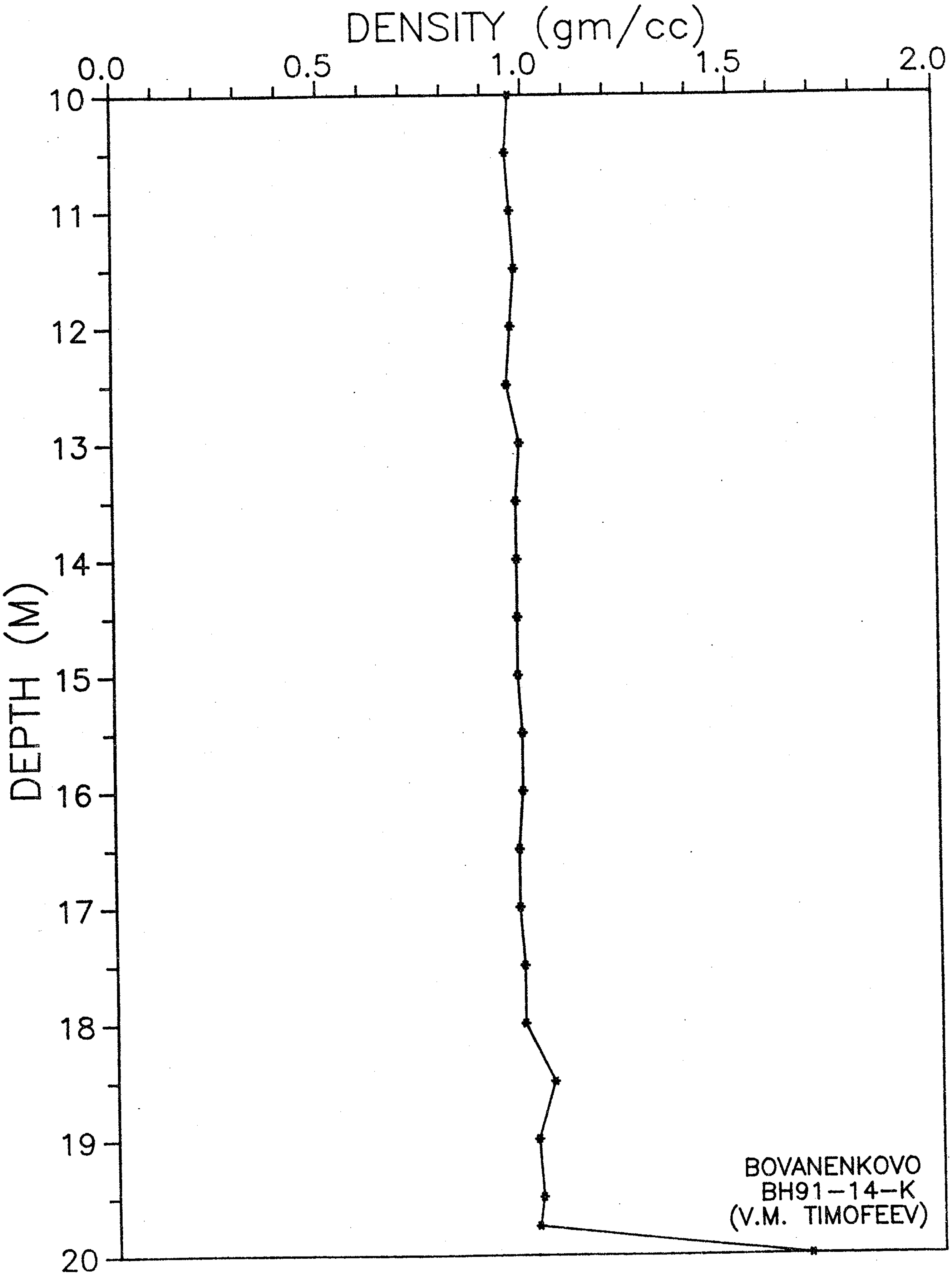


Figure 74 cont.

VSEGINGEO LOGGING SYSTEM

WATER CONTENT LOGS

Figs. 75-87

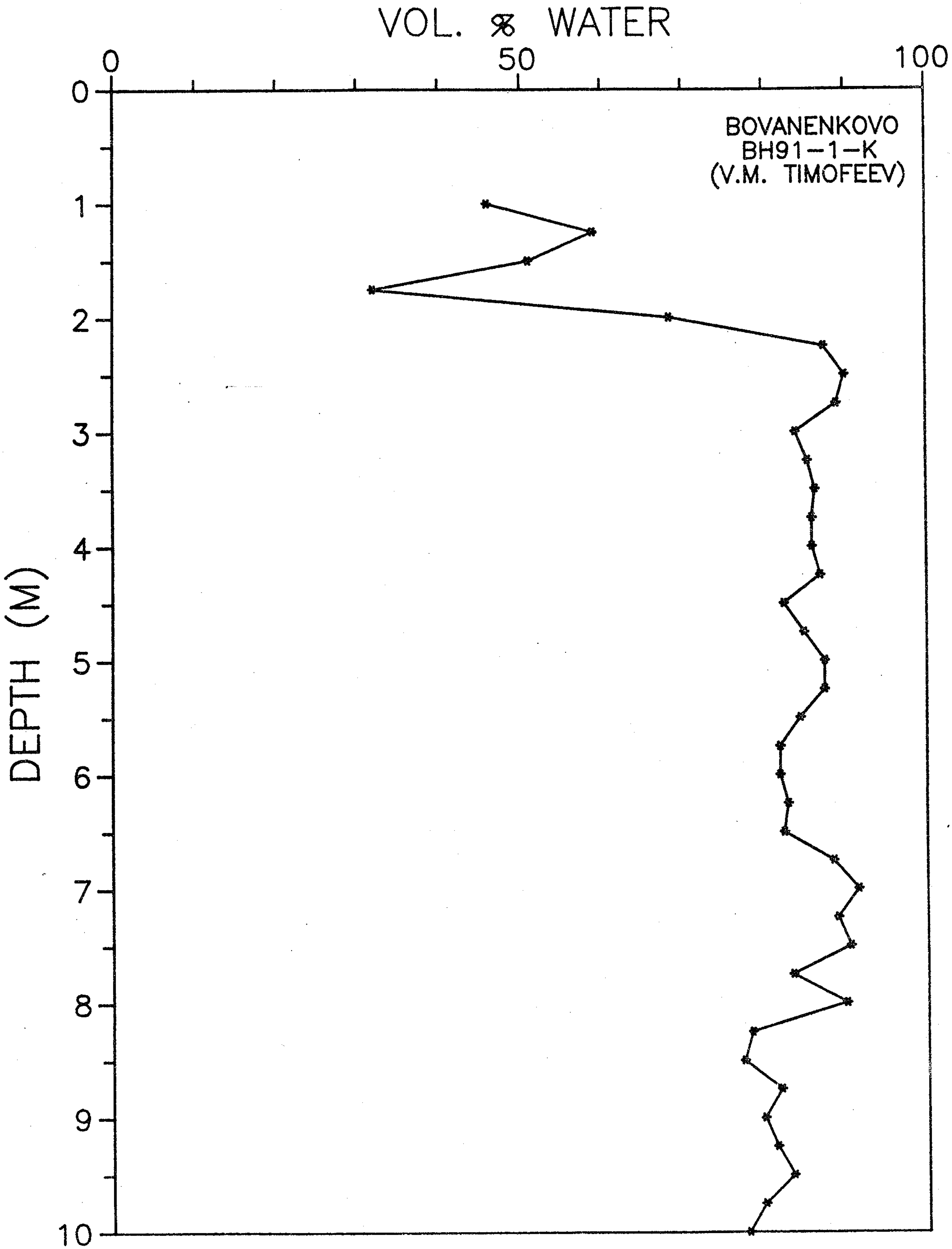

VOL. % WATER
0
50
100
0
1
2
3
4
5
6
7
8
9
10
DEPTH (M)
BOVANENKOVO
BH91-1-K
(V.M. TIMOFEEV)

Figure 75

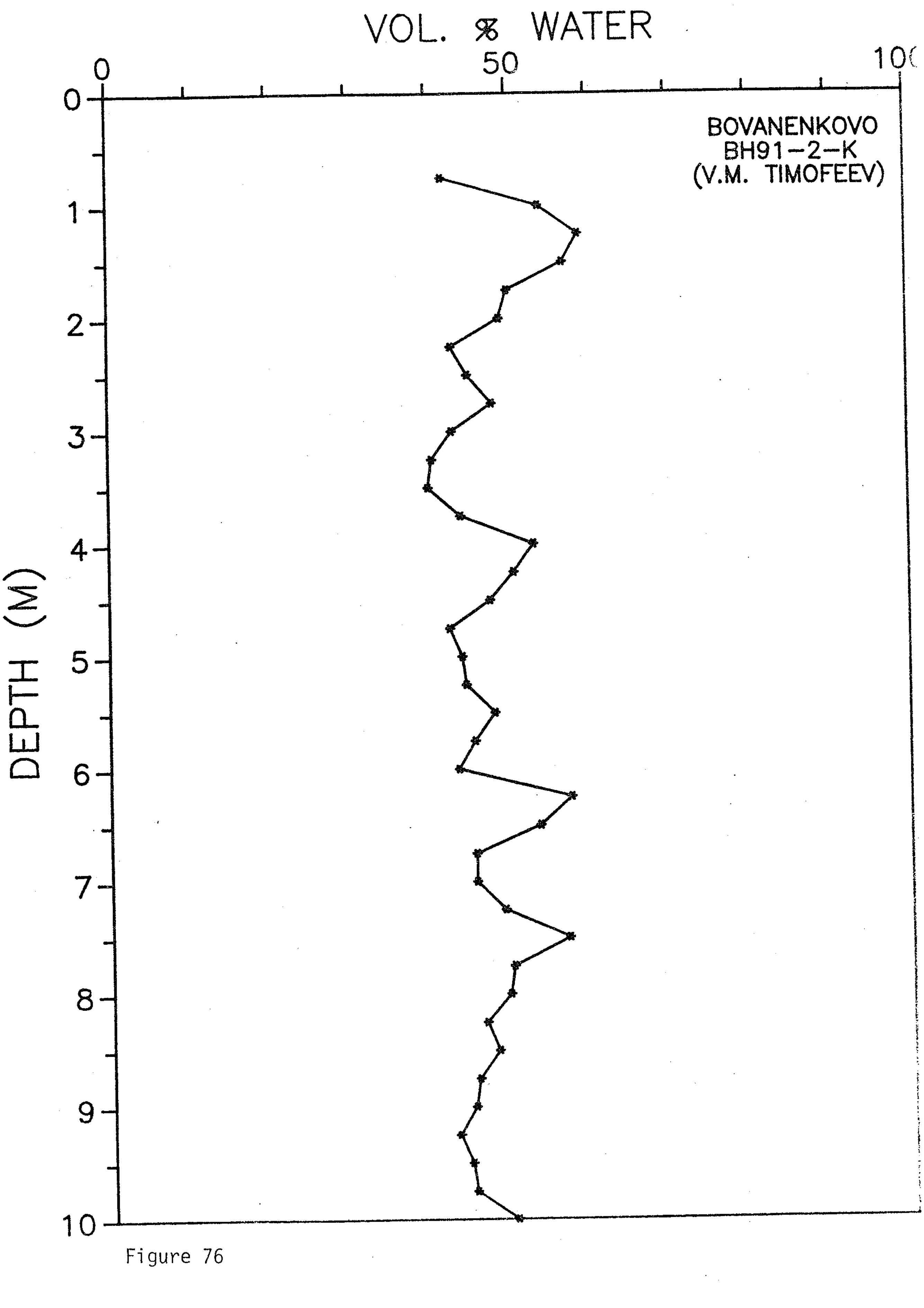

VOL. % WATER
0
50
100
BOVANENKOVO
BH91-2-K
(V.M. TIMOFEEV)
DEPTH (M)
0
1
2
3
4
5
6
7
8
9
10

Figure 76

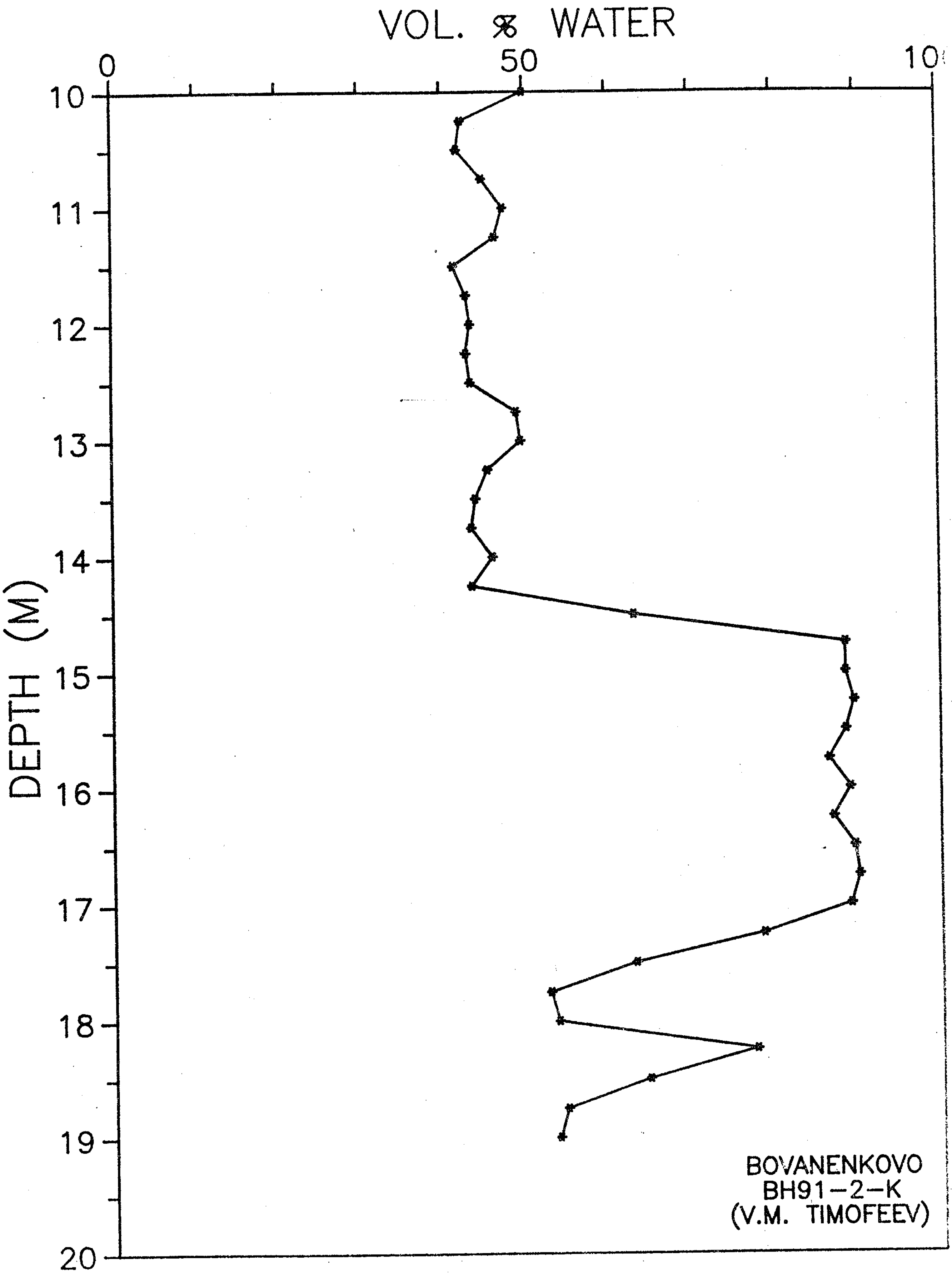


Figure 76 cont.

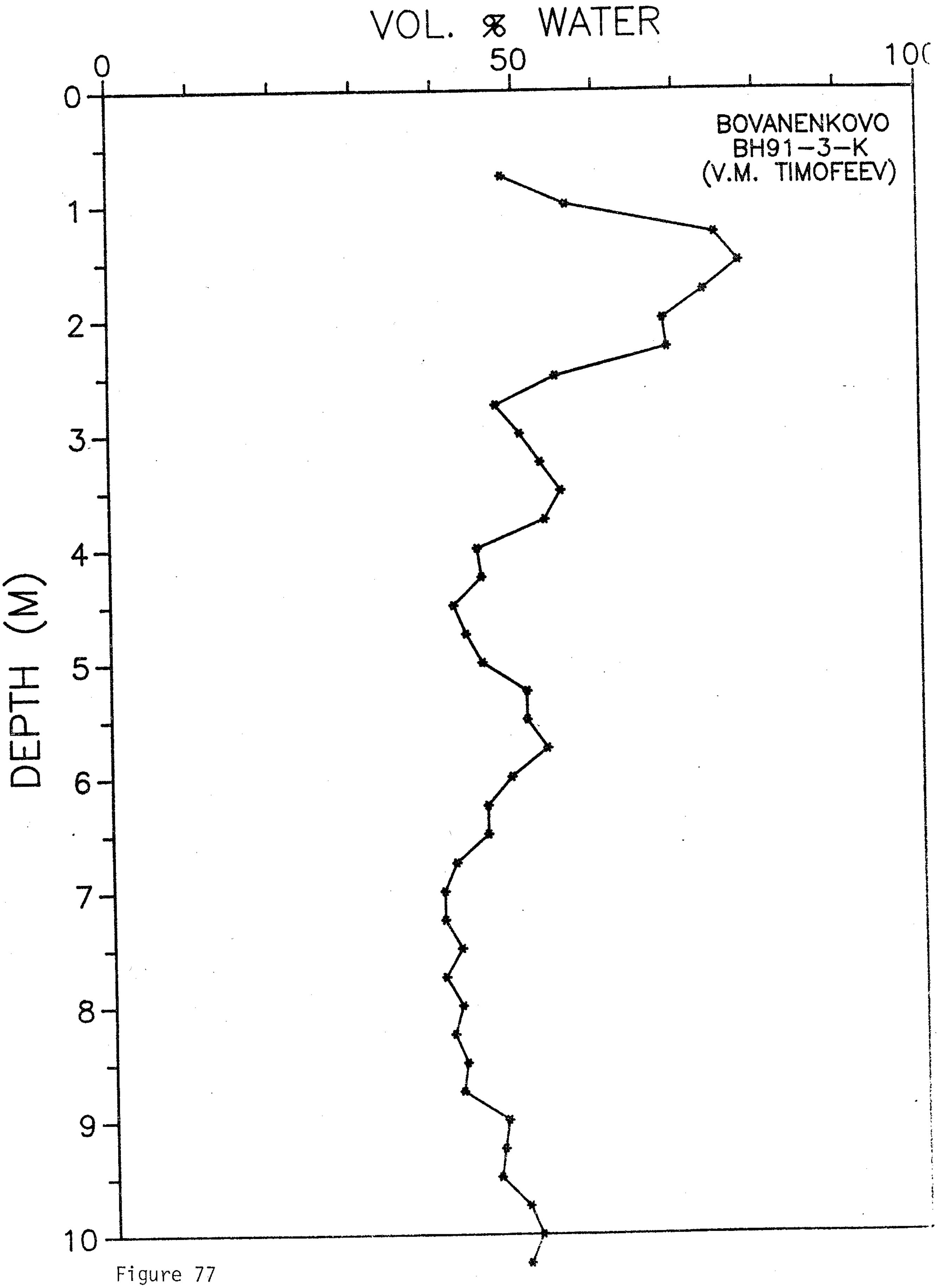

VOL. % WATER
0
50
100
0
1
2
3
4
5
6
7
8
9
10
DEPTH (M)
BOVANENKOVO
BH91-3-K
(V.M. TIMOFEEV)

Figure 77

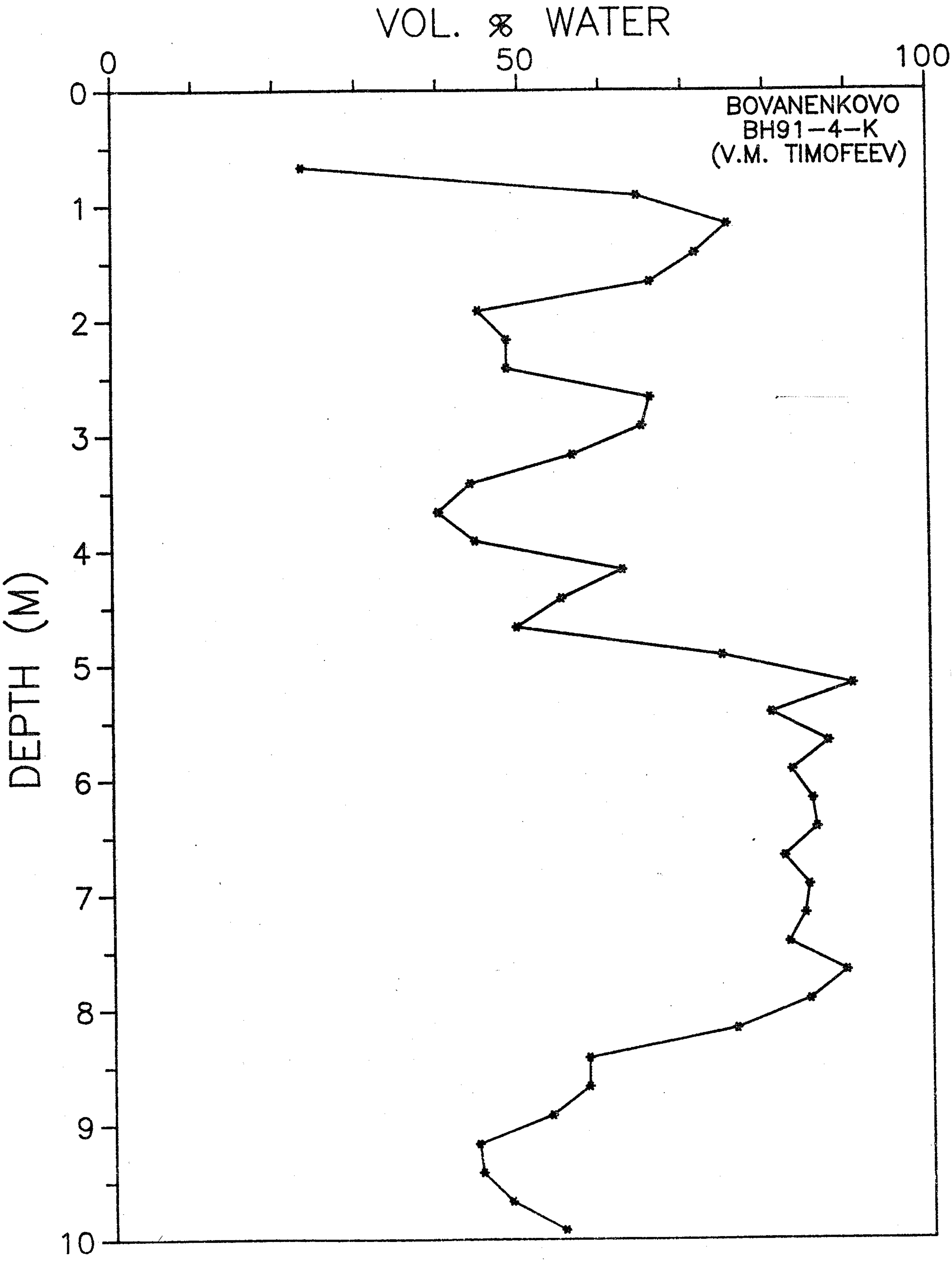

VOL. % WATER
0
50
100
BOVANENKOVO
BH91-4-K
(V.M. TIMOFEEV)
DEPTH (M)
0
1
2
3
4
5
6
7
8
9
10

Figure 78

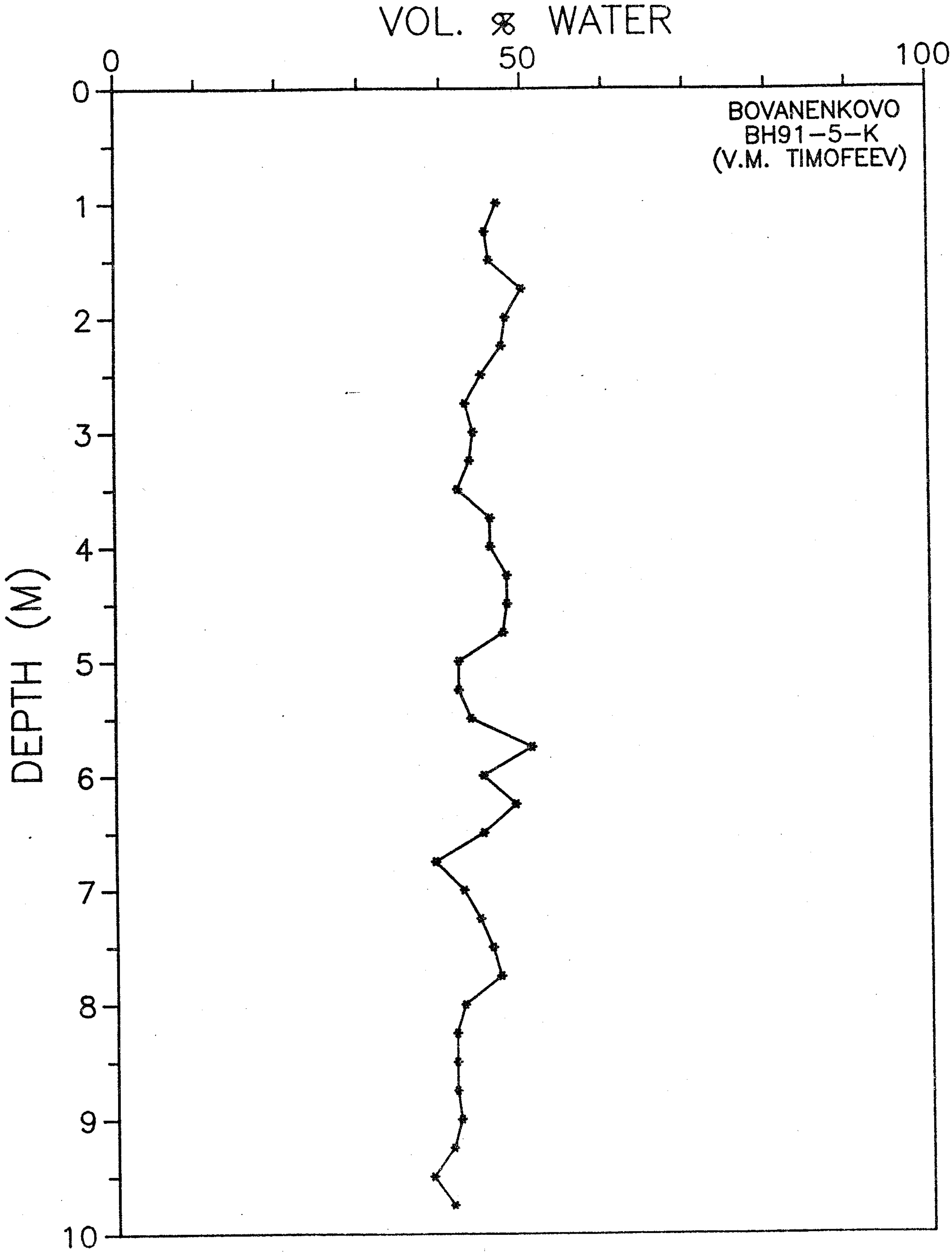

VOL. % WATER
0
50
100
0
1
2
3
4
5
6
7
8
9
10
DEPTH (M)
BOVANENKOVO
BH91-5-K
(V.M. TIMOFEEV)

Figure 79

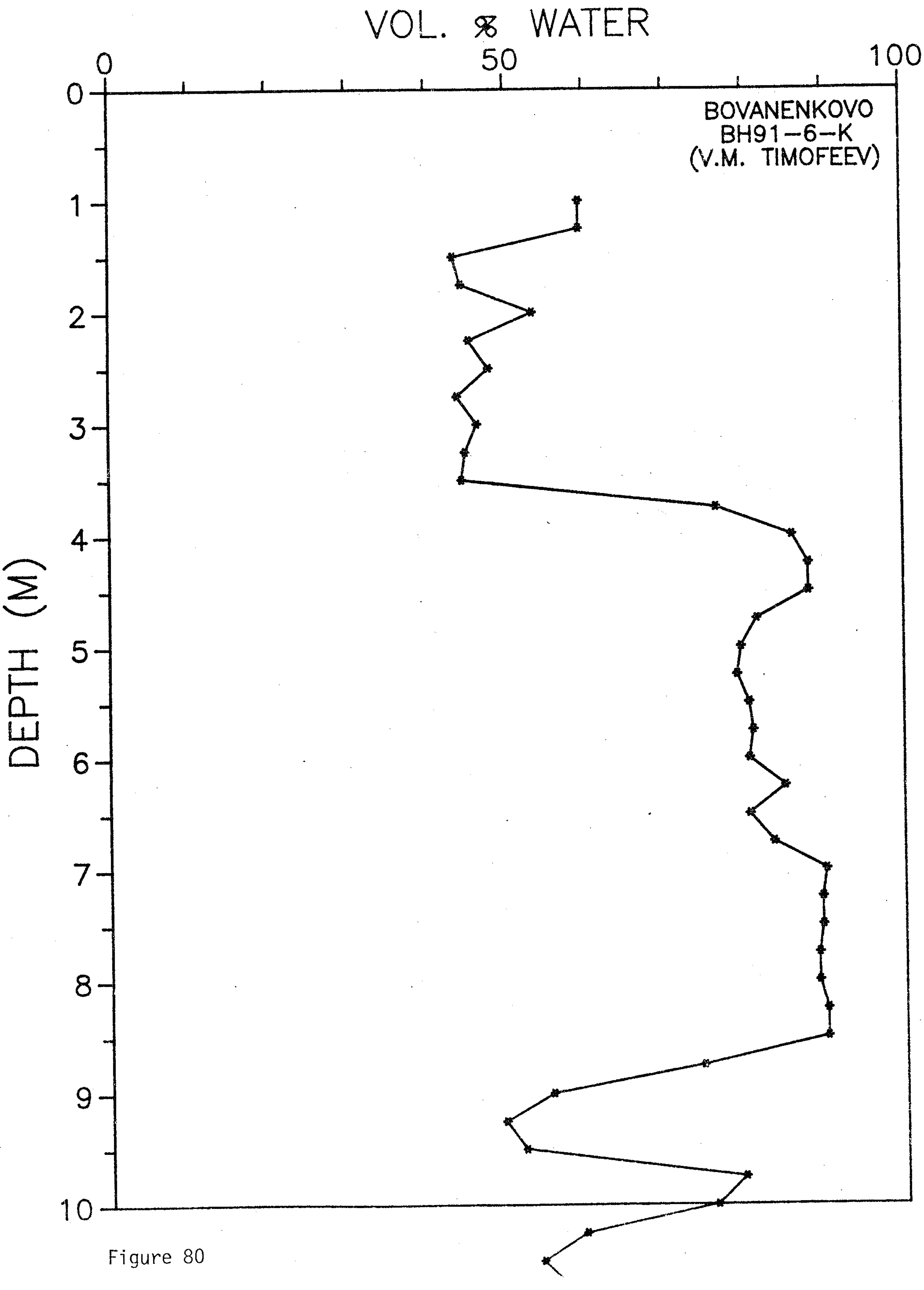

VOL. % WATER
0
50
100
0
1
2
3
4
5
6
7
8
9
10
DEPTH (M)
BOVANENKOVO
BH91-6-K
(V.M. TIMOFEEV)

Figure 80

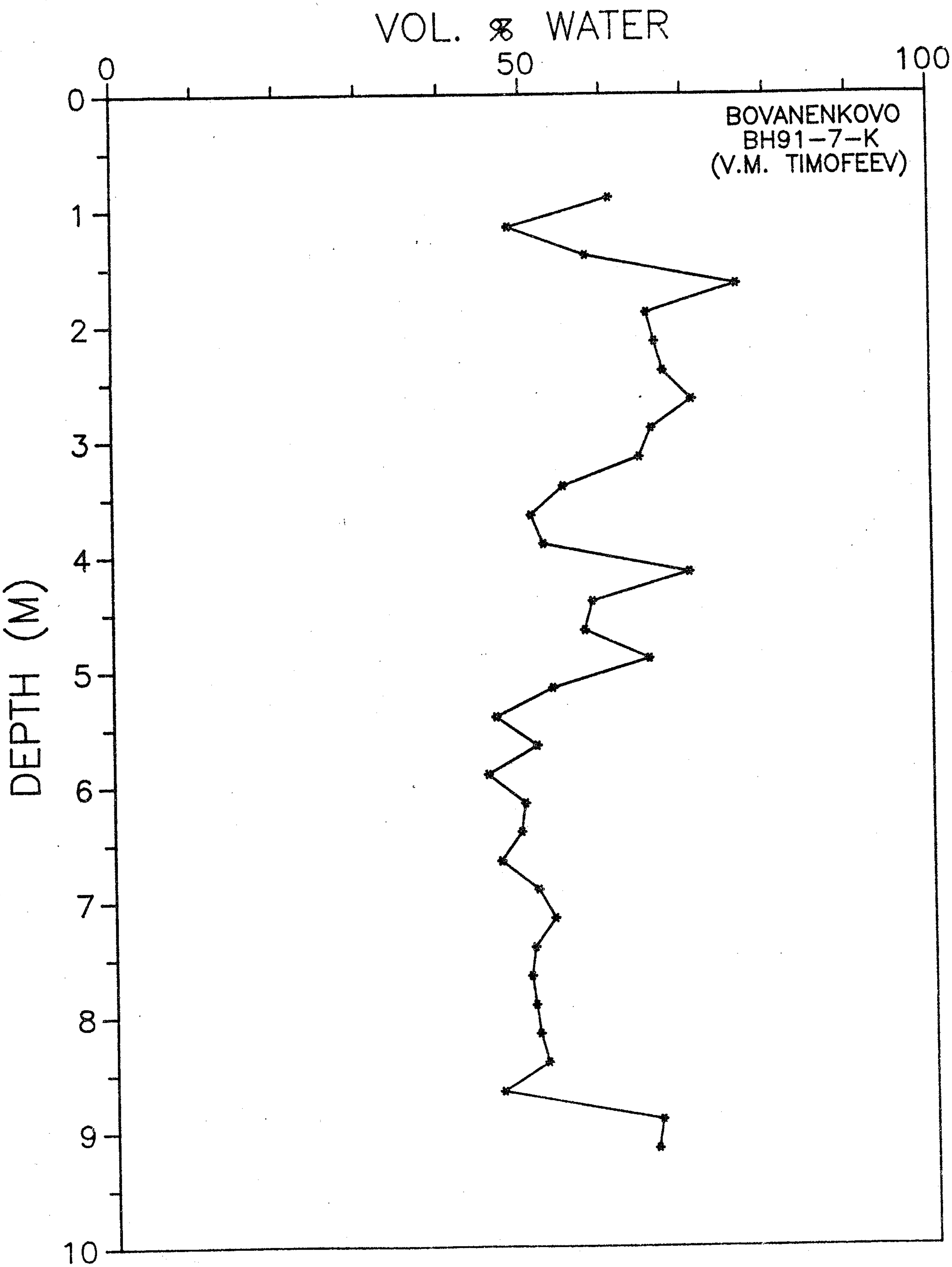

VOL. % WATER
0
50
100
0
1
2
3
4
5
6
7
8
9
10
DEPTH (M)
BOVANENKOVO
BH91-7-K
(V.M. TIMOFEEV)

Figure 81

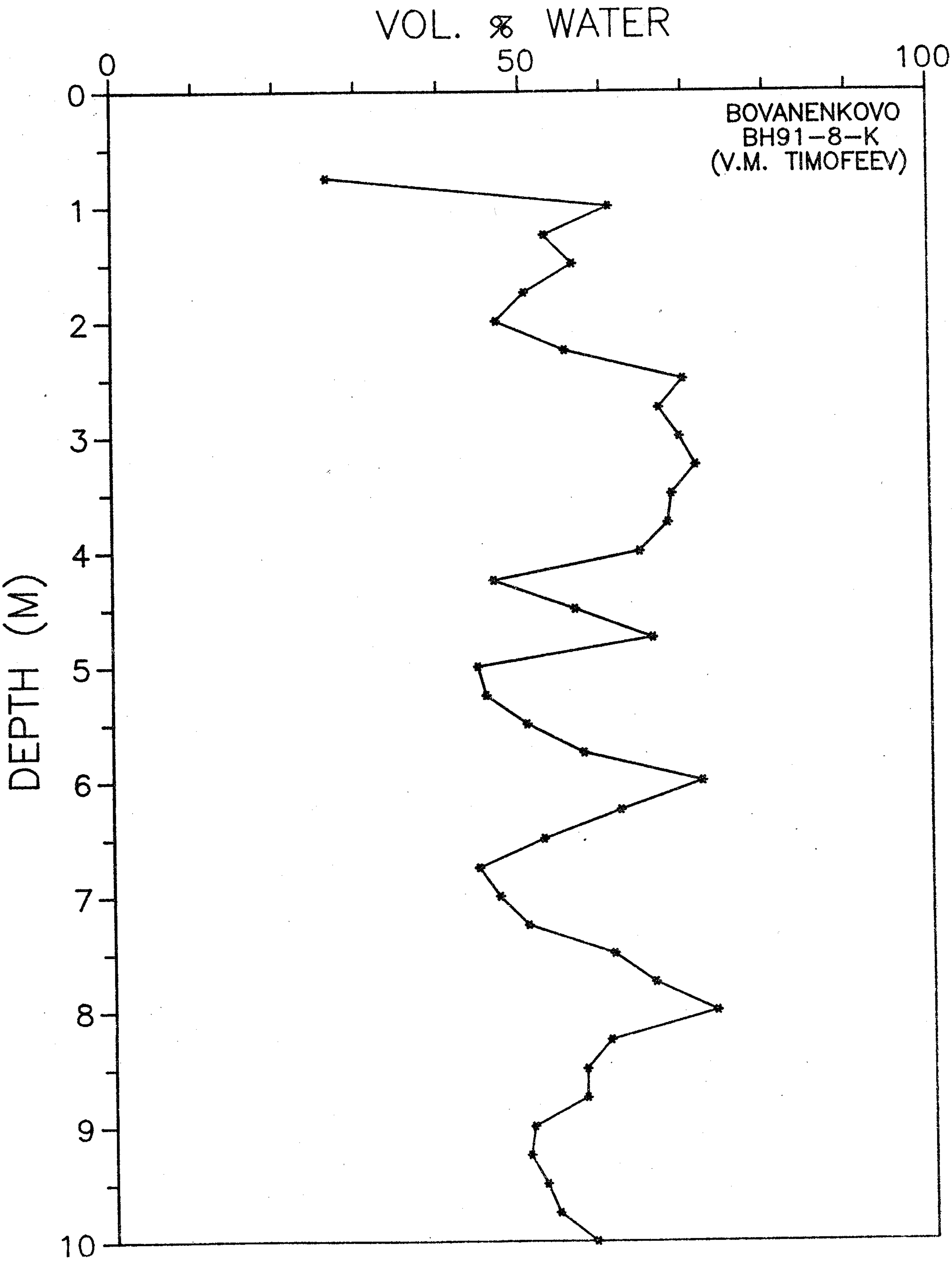

VOL. % WATER
0
50
100
BOVANENKOVO
BH91-8-K
(V.M. TIMOFEEV)
DEPTH (M)
0
1
2
3
4
5
6
7
8
9
10

Figure 82

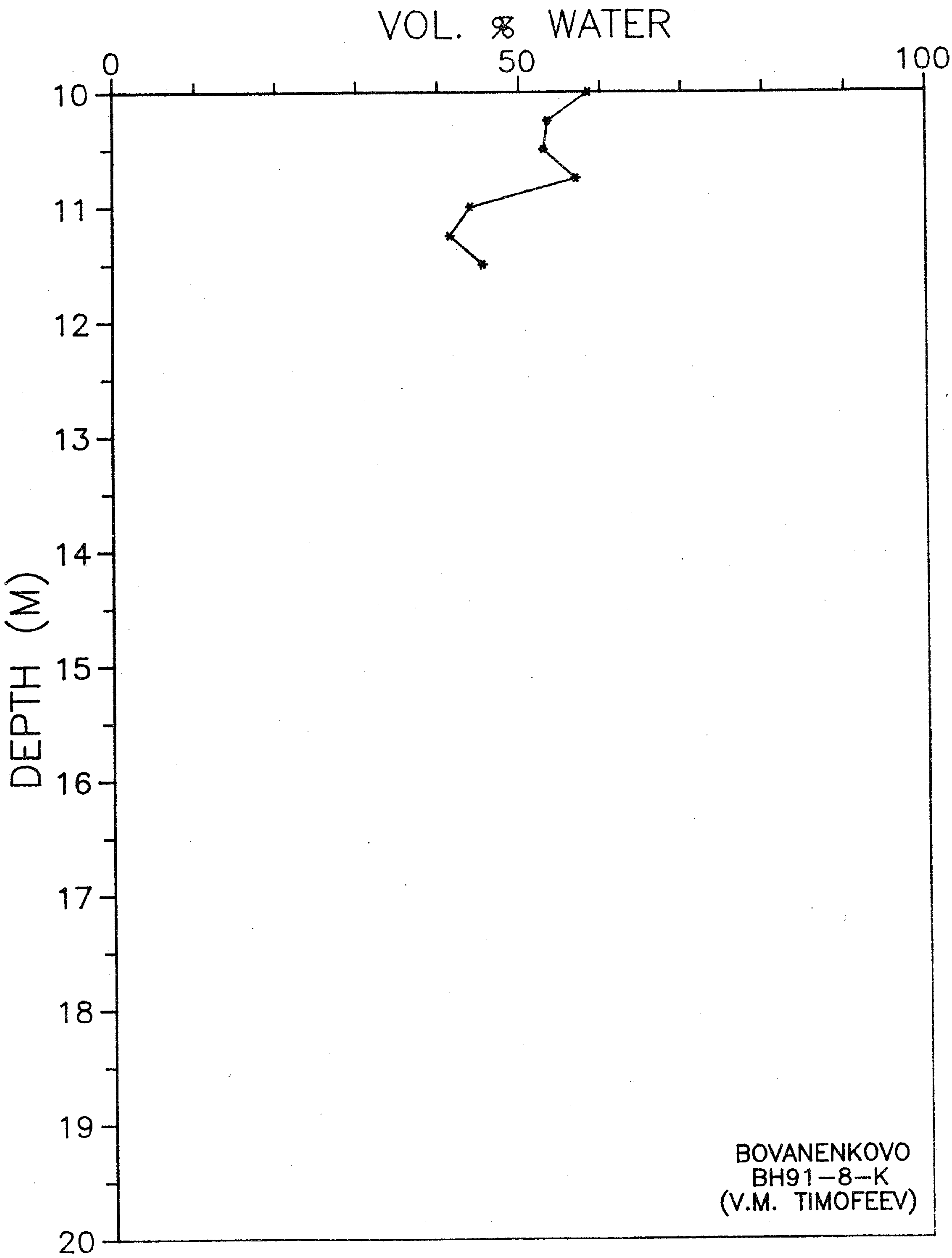


Figure 82 cont.

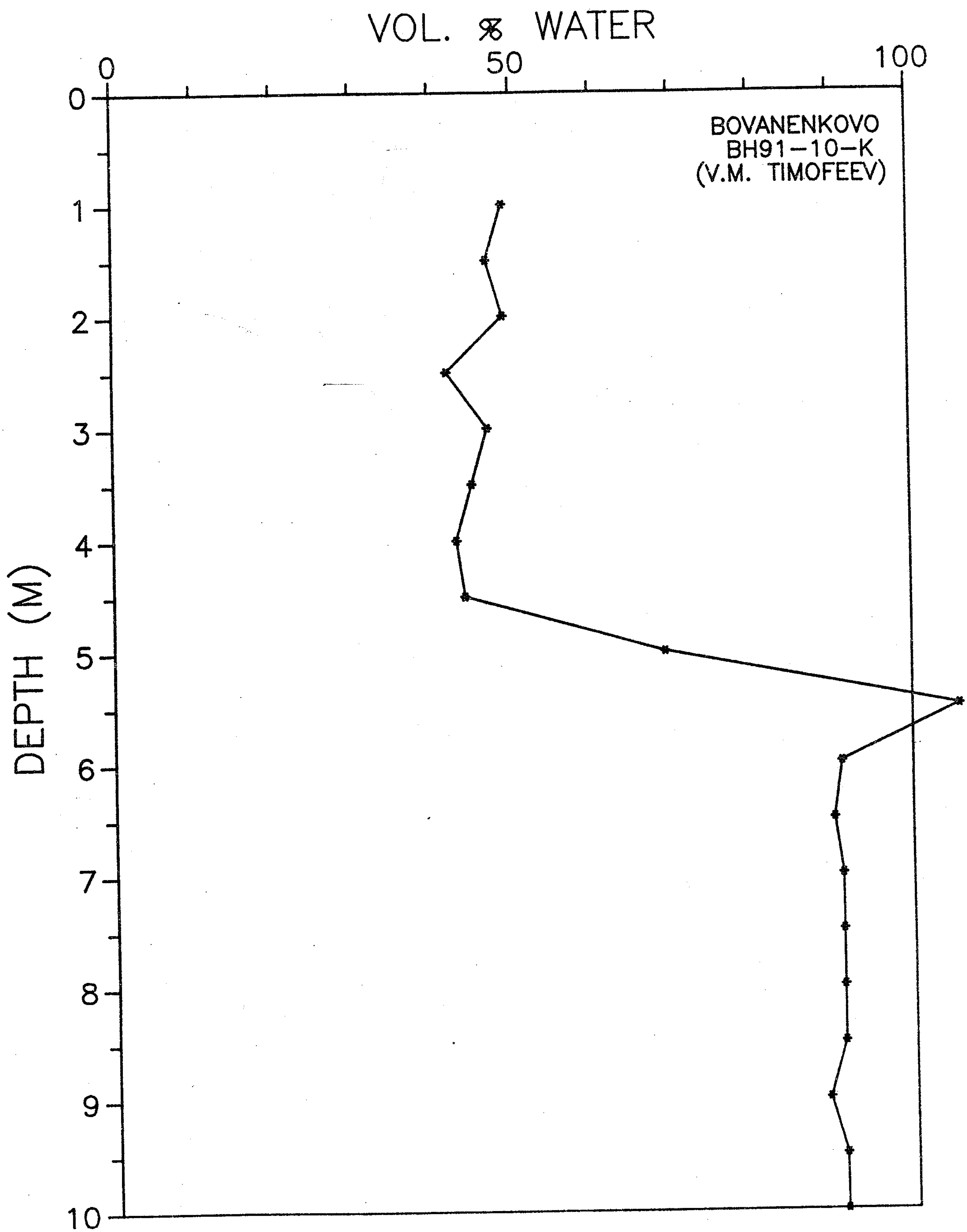

VOL. % WATER
0
50
100
BOVANENKOVO
BH91-10-K
(V.M. TIMOFEEV)
DEPTH (M)
0
1
2
3
4
5
6
7
8
9
10

Figure 83

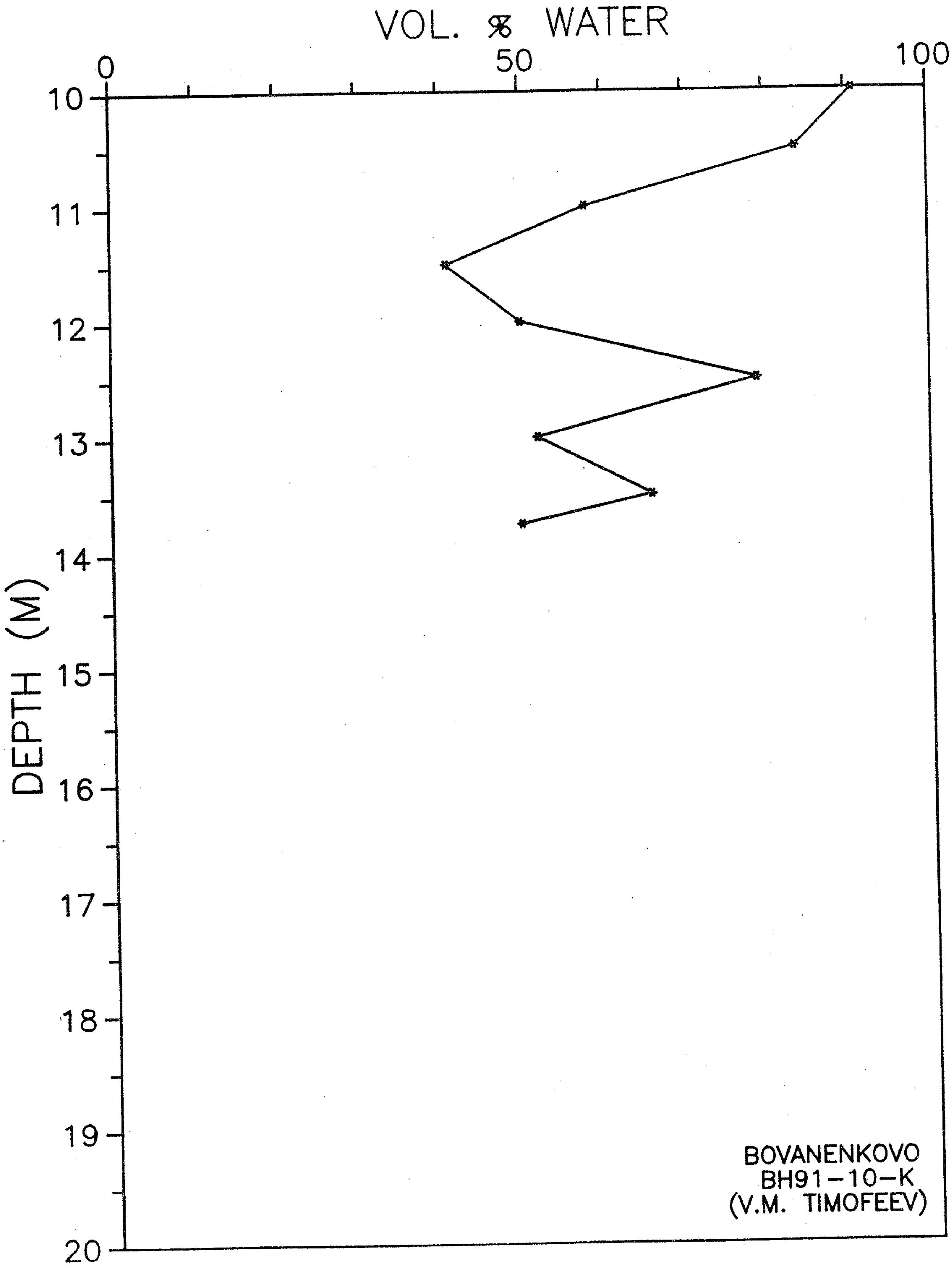


Figure 83 cont.

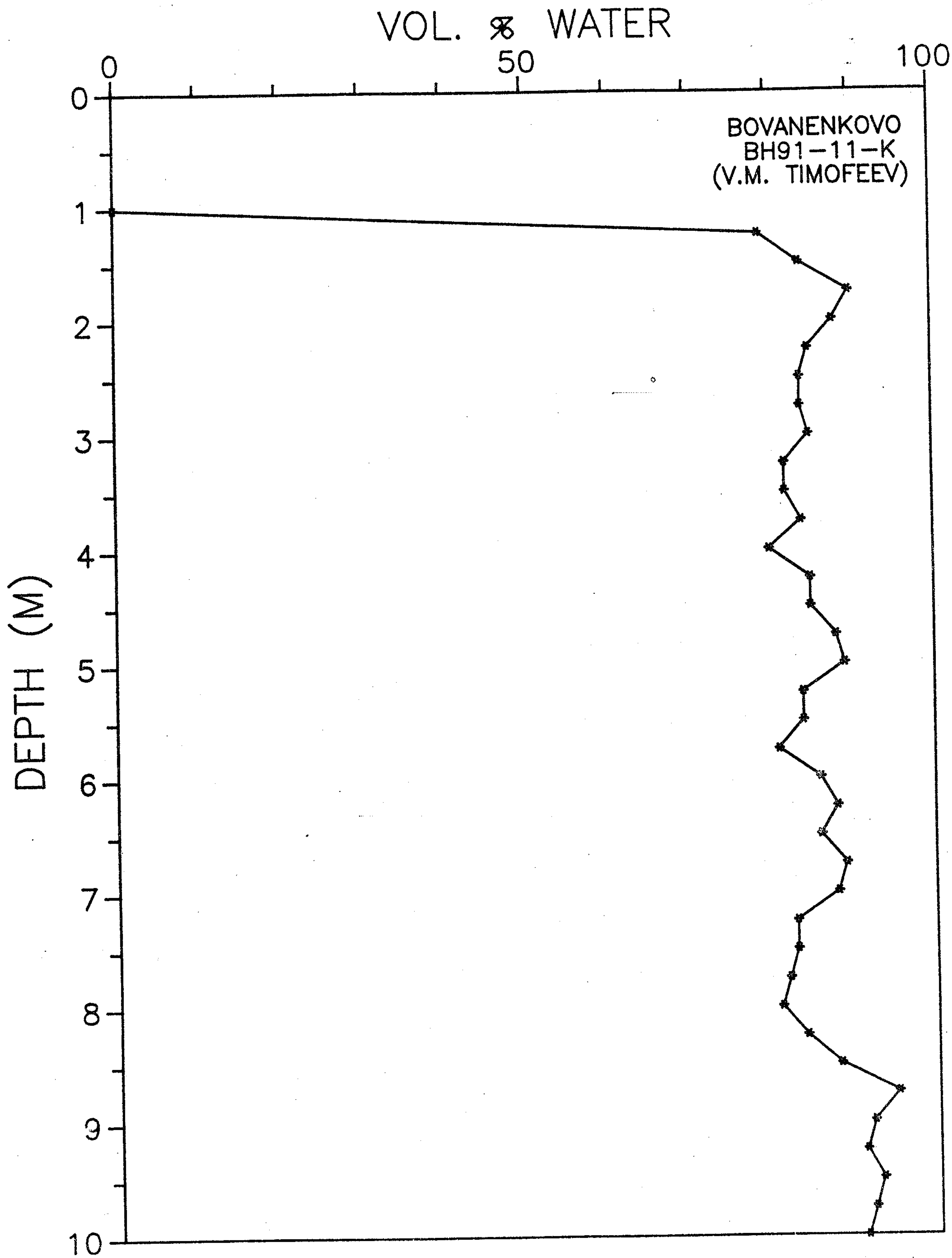

VOL. % WATER
0
50
100
0
1
2
3
4
5
6
7
8
9
10
DEPTH (M)
BOVANENKOVO
BH91-11-K
(V.M. TIMOFEEV)

Figure 84

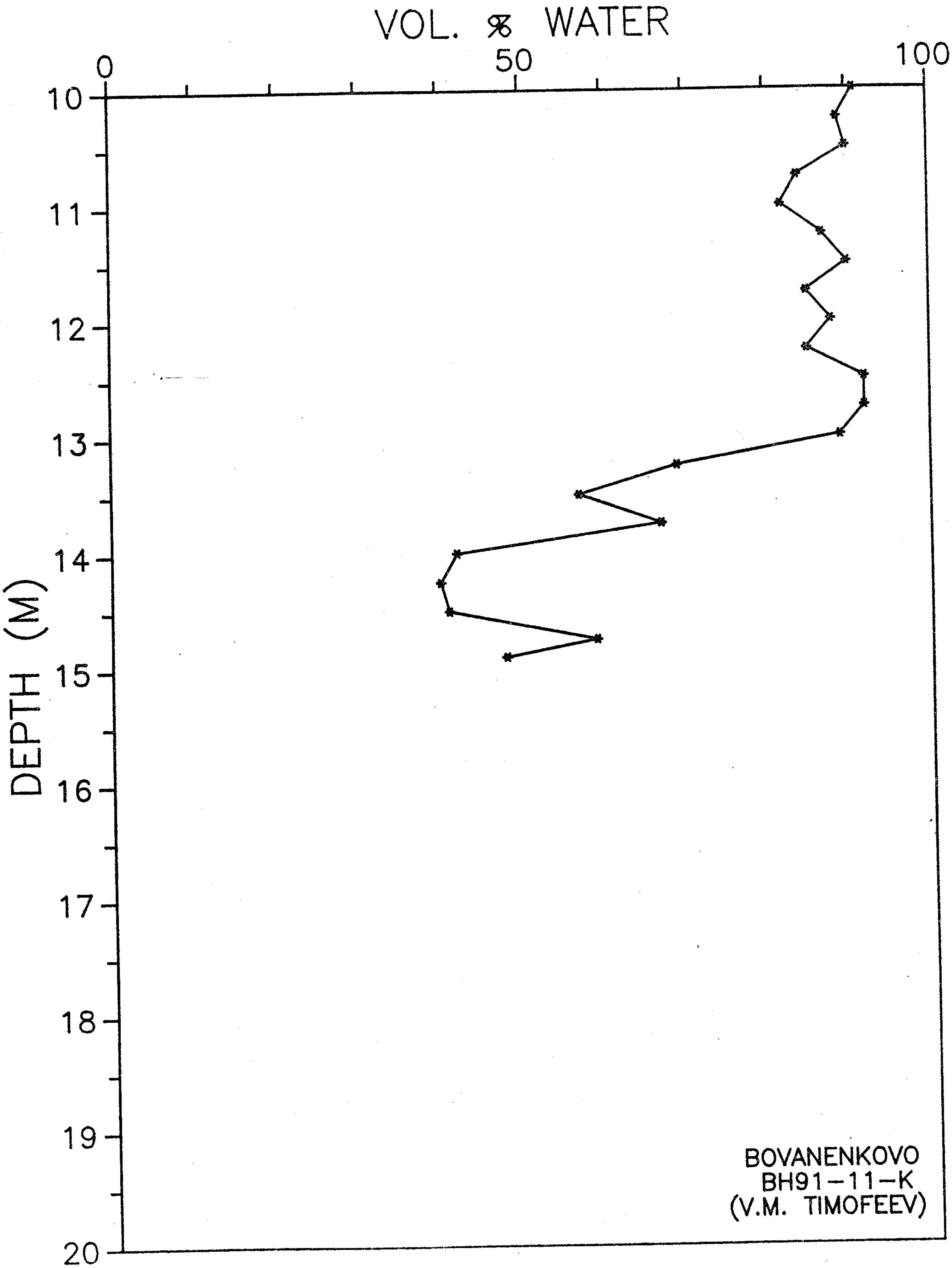
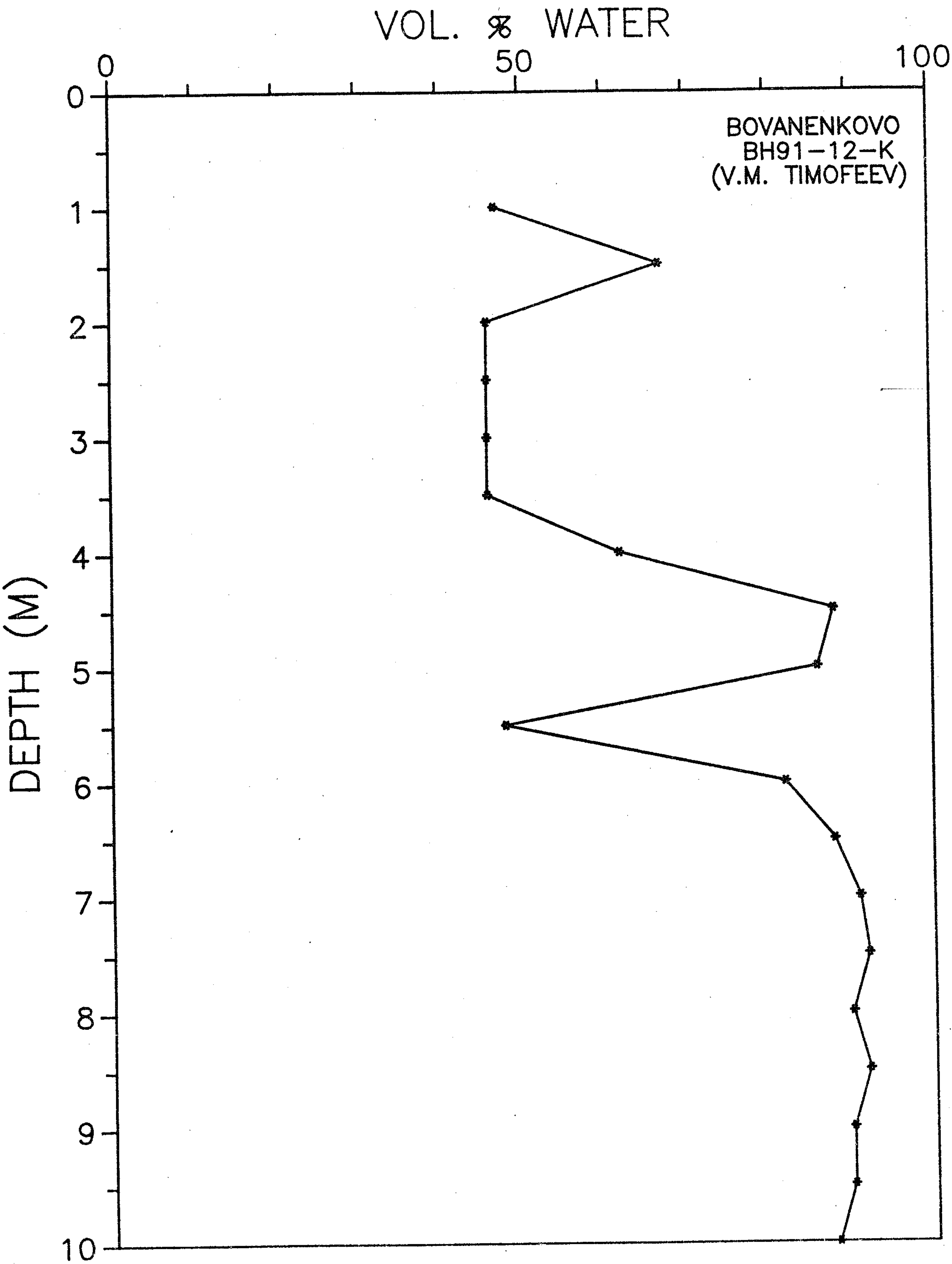


Figure 84 cont.



VOL. % WATER
0
50
100
0
1
2
3
4
5
6
7
8
9
10
DEPTH (M)
BOVANENKOVO
BH91-12-K
(V.M. TIMOFEEV)

Figure 85

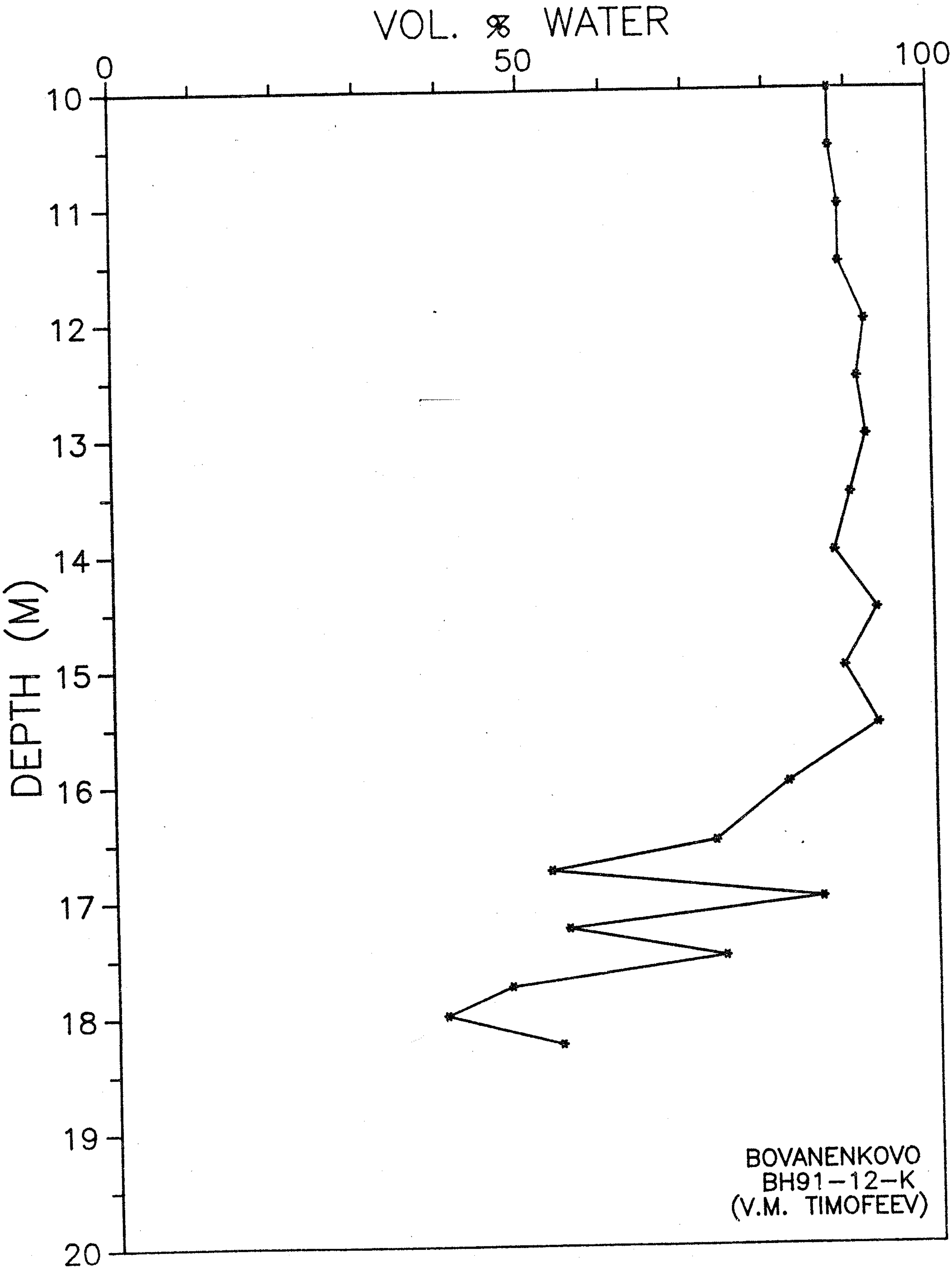


Figure 85 cont.

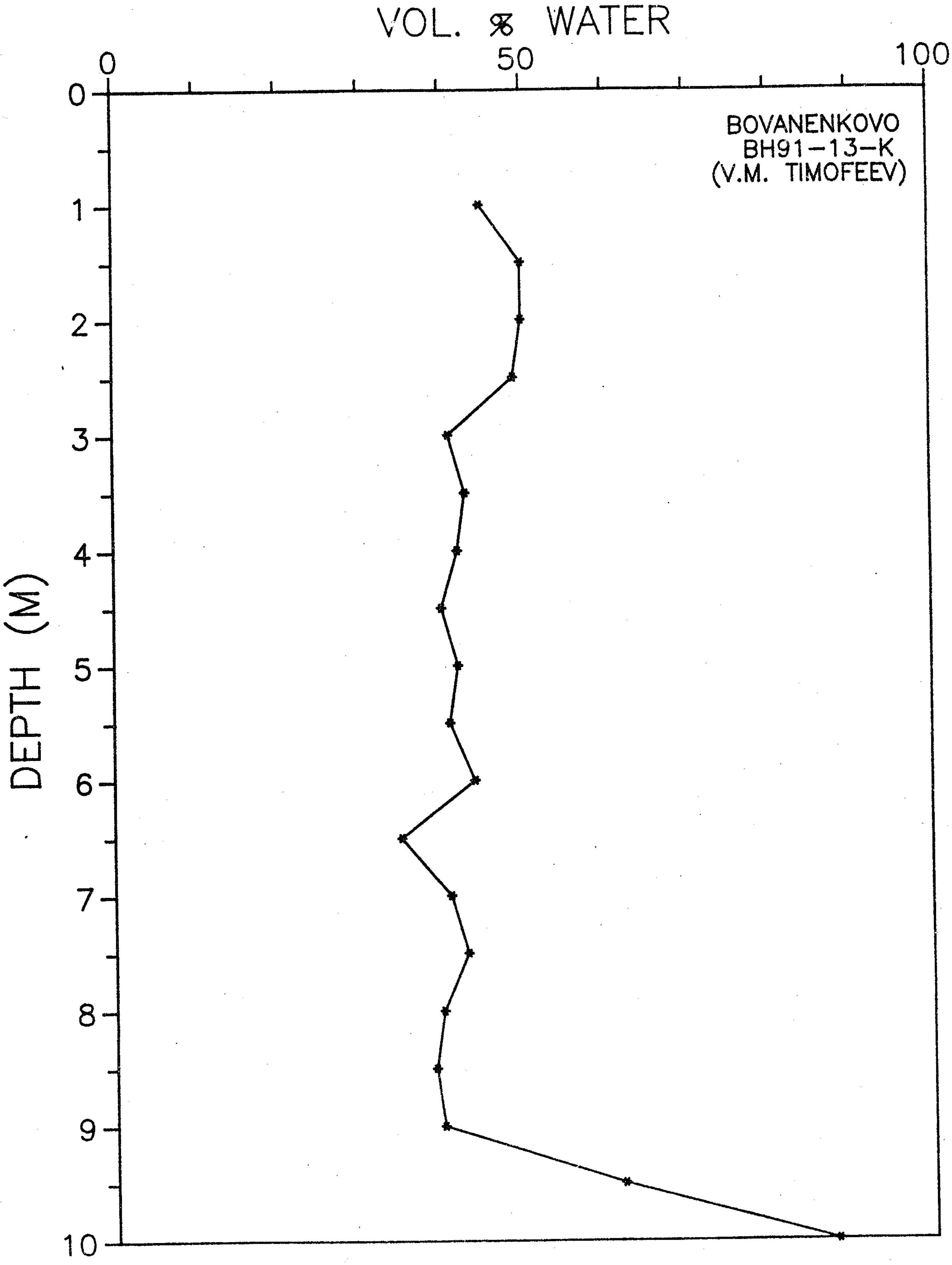

VOL. % WATER
0
50
100
0
1
2
3
4
5
6
7
8
9
10
DEPTH (M)
BOVANENKOVO
BH91-13-K
(V.M. TIMOFEEV)

Figure 86

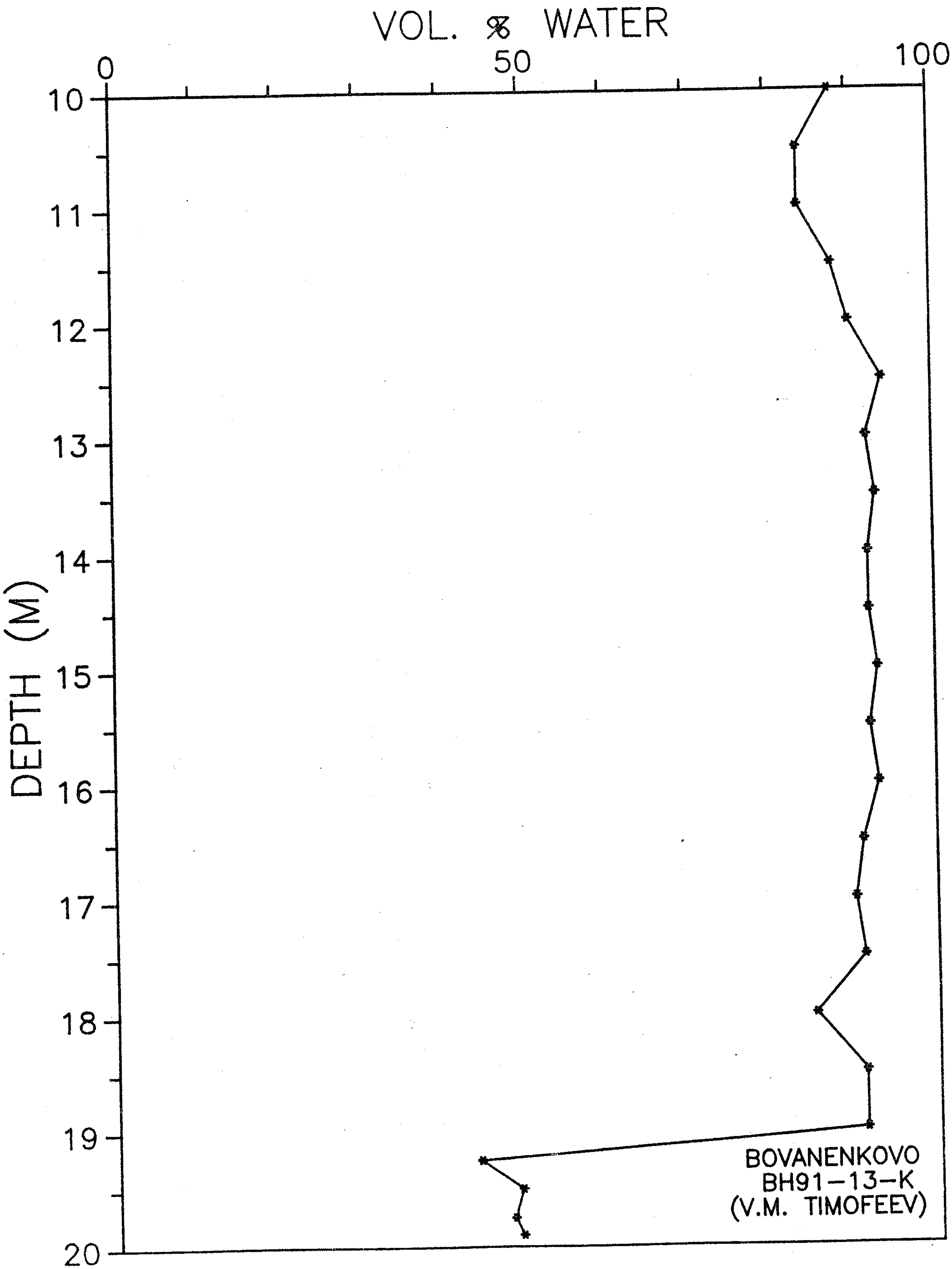


Figure 86 cont.

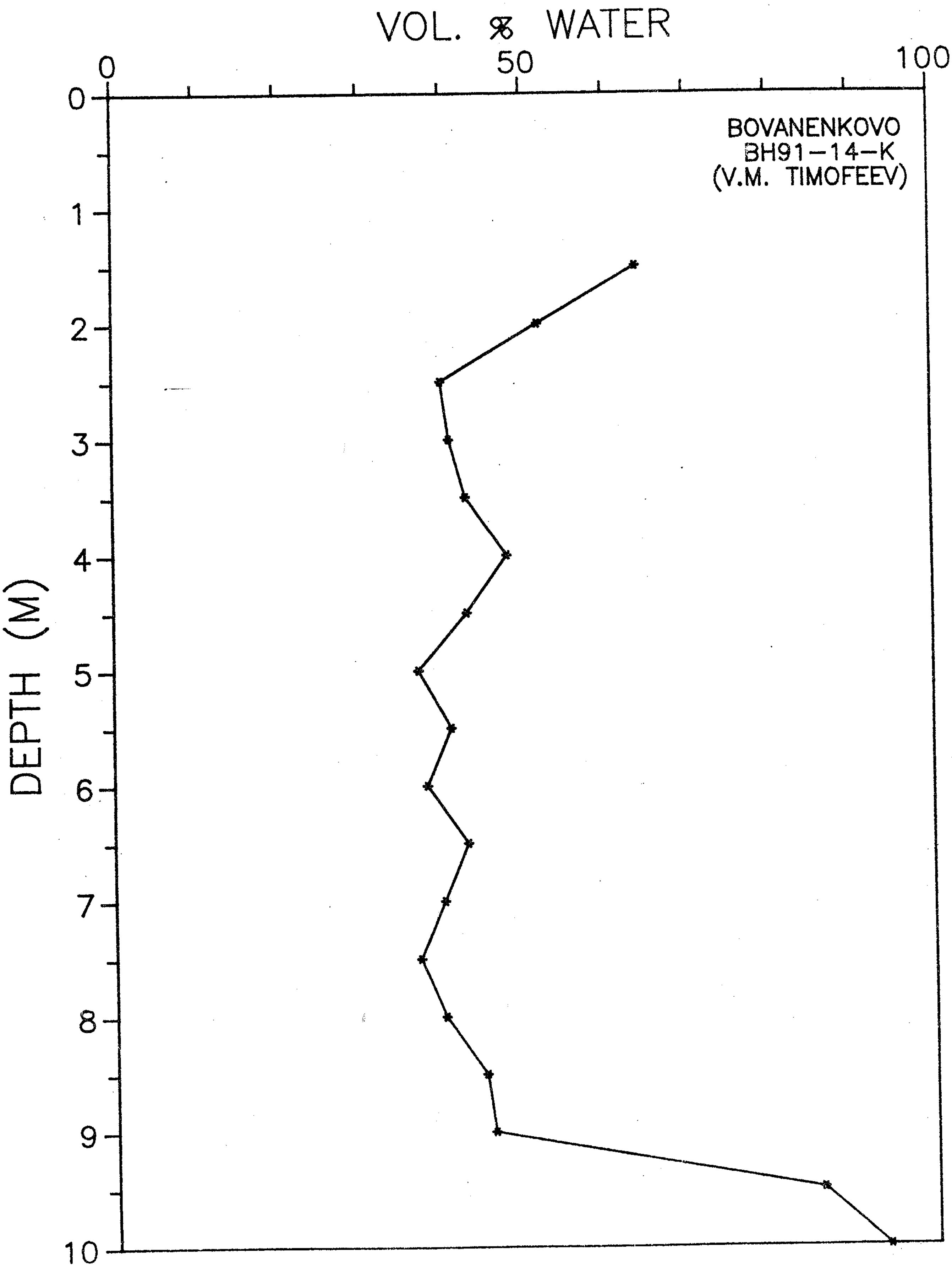

VOL. % WATER
0
50
100
0
1
2
3
4
5
6
7
8
9
10
DEPTH (M)
BOVANENKOVO
BH91-14-K
(V.M. TIMOFEEV)

Figure 87

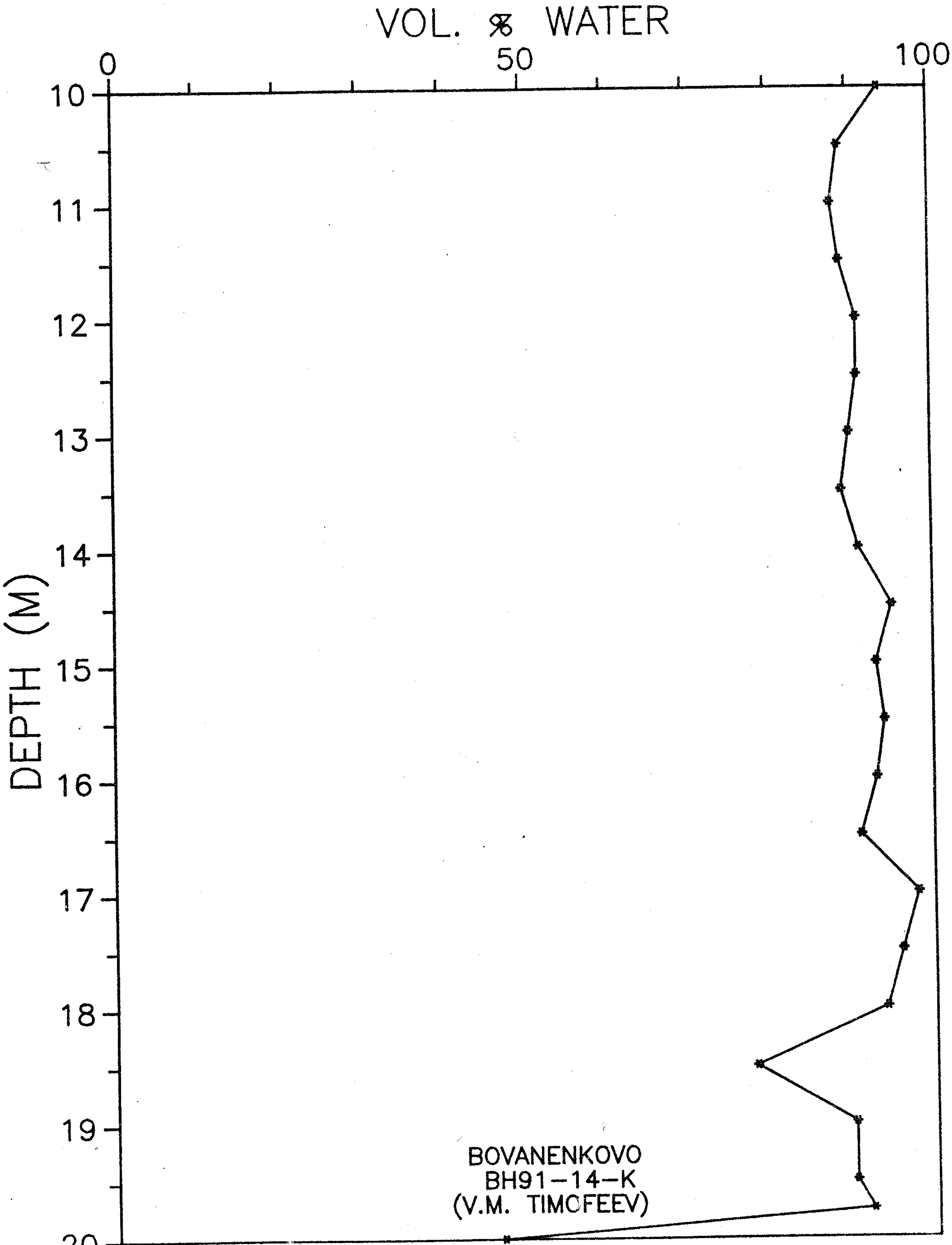


Figure 87 cont.

SEISMIC DOWNHOLE LOGS

Figs. 88-92

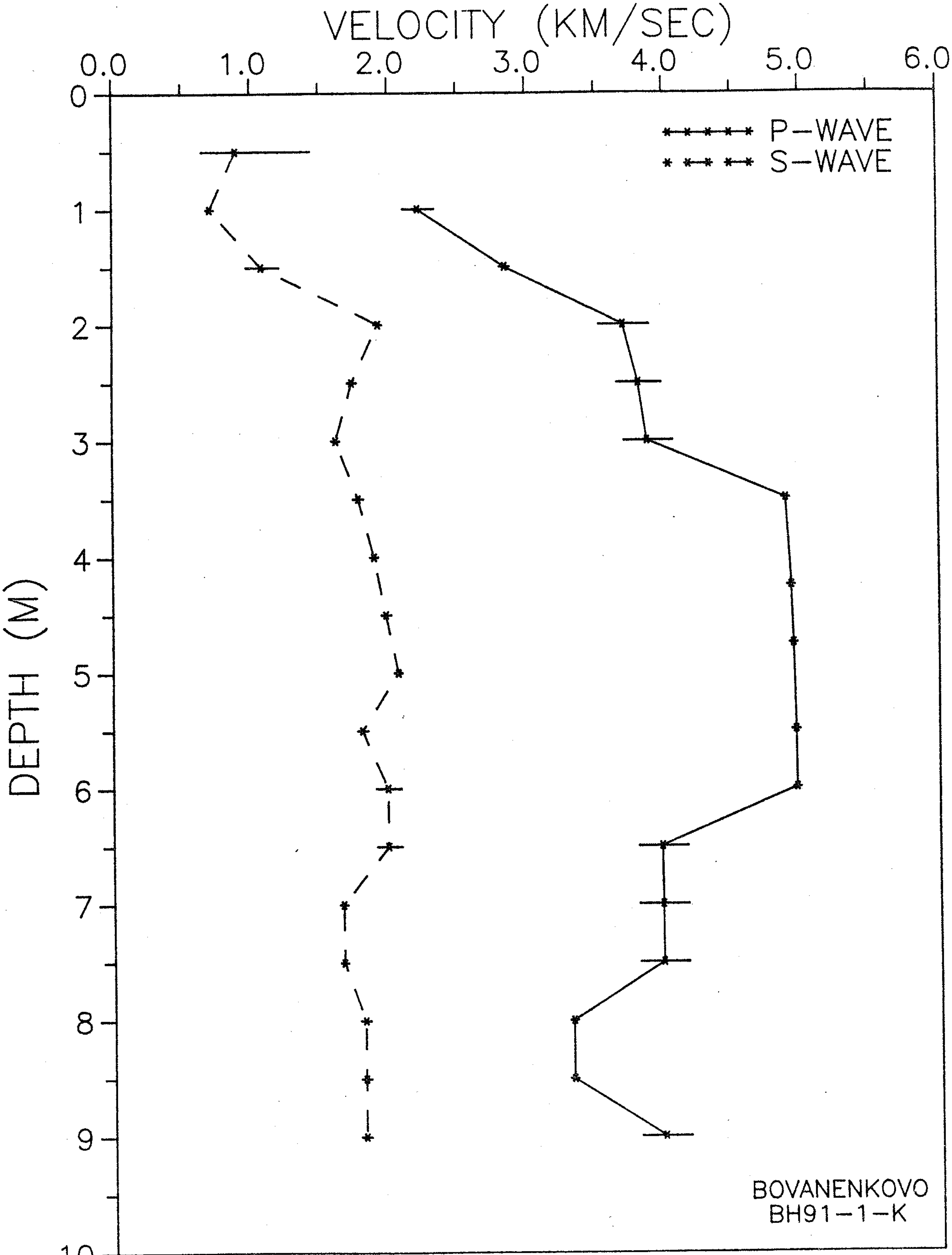

VELOCITY (KM/SEC)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
0
1
2
3
4
5
6
7
8
9
10
DEPTH (M)
P-WAVE
S-WAVE
BOVANENKOVO
BH91-1-K

Figure 88

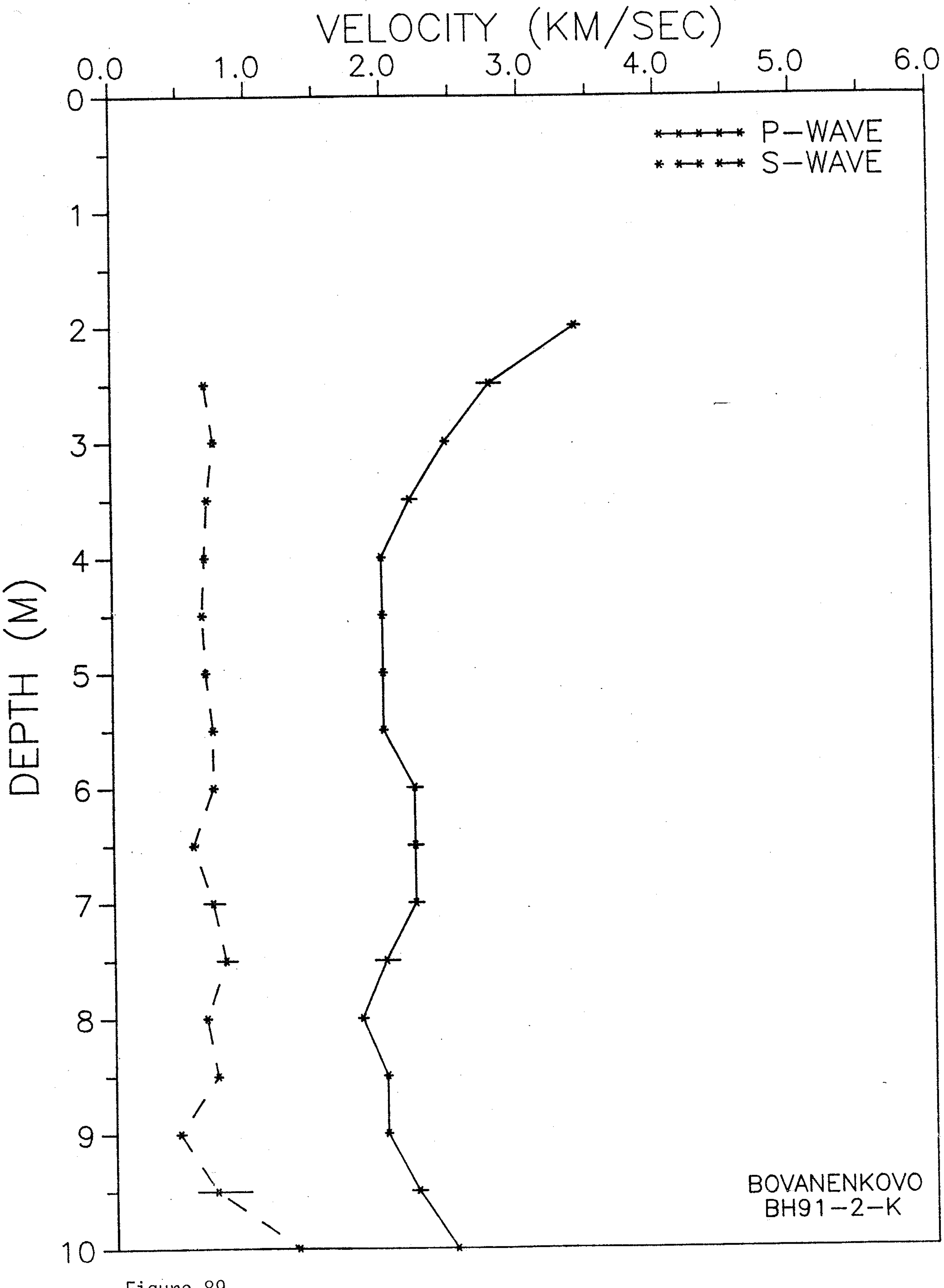

VELOCITY (KM/SEC)
0.0 1.0 2.0 3.0 4.0 5.0 6.0
0 1 2 3 4 5 6 7 8 9 10
DEPTH (M)
P-WAVE
S-WAVE
BOVANENKOVO
BH91-2-K

Figure 89

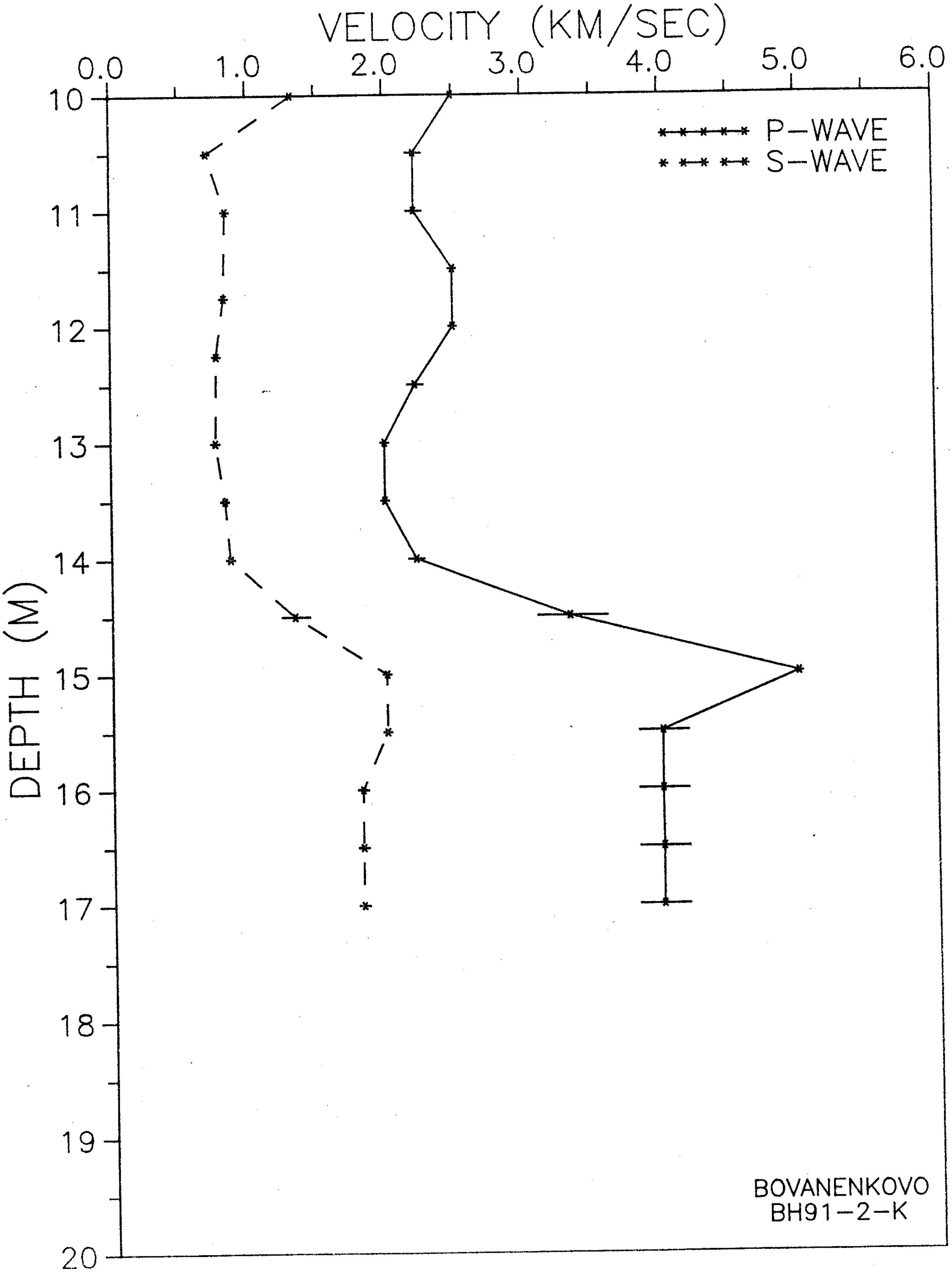


Figure 89 cont.

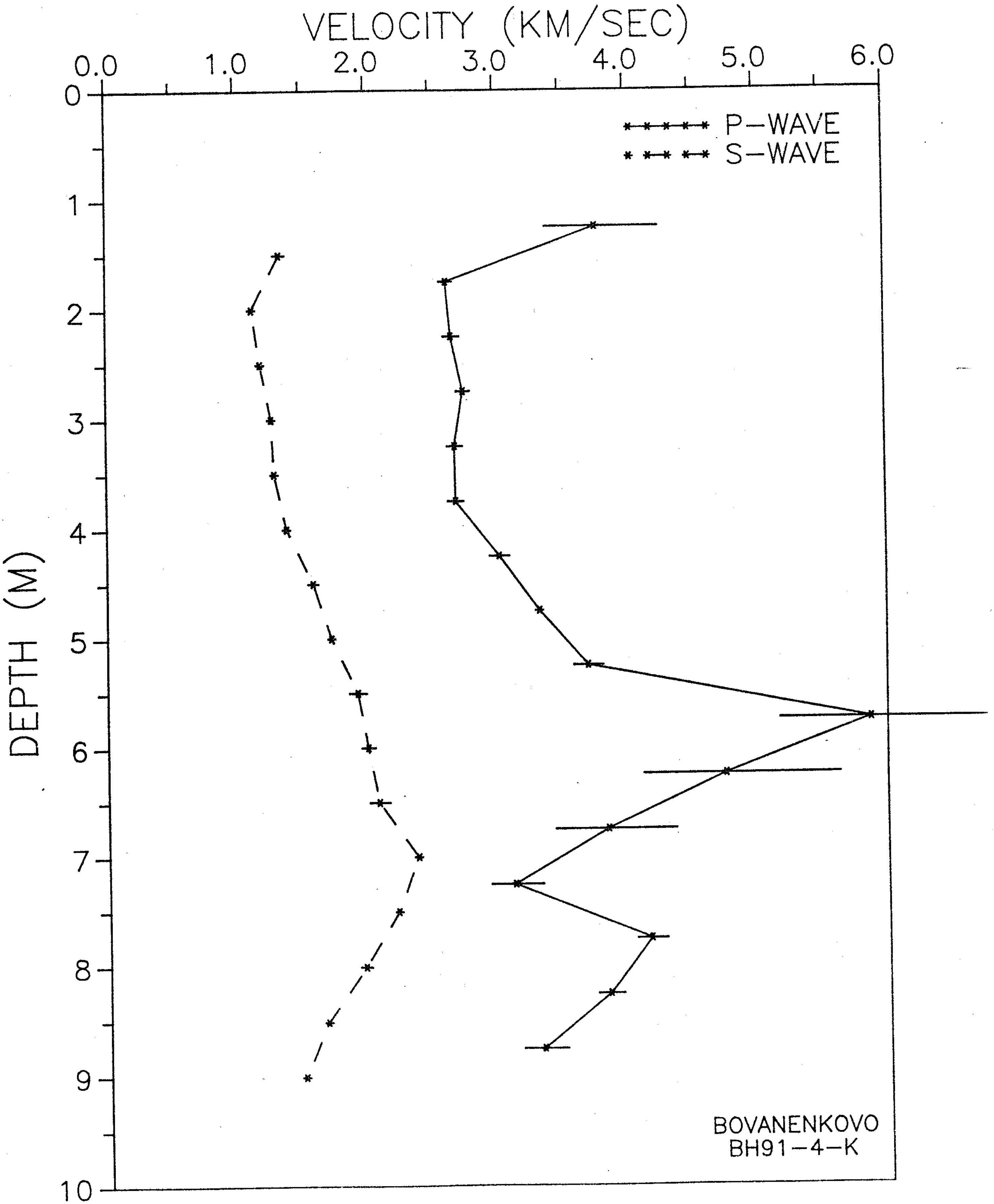

VELOCITY (KM/SEC)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
DEPTH (M)
0
1
2
3
4
5
6
7
8
9
10
P-WAVE
S-WAVE
BOVANENKOVO
BH91-4-K

Figure 90

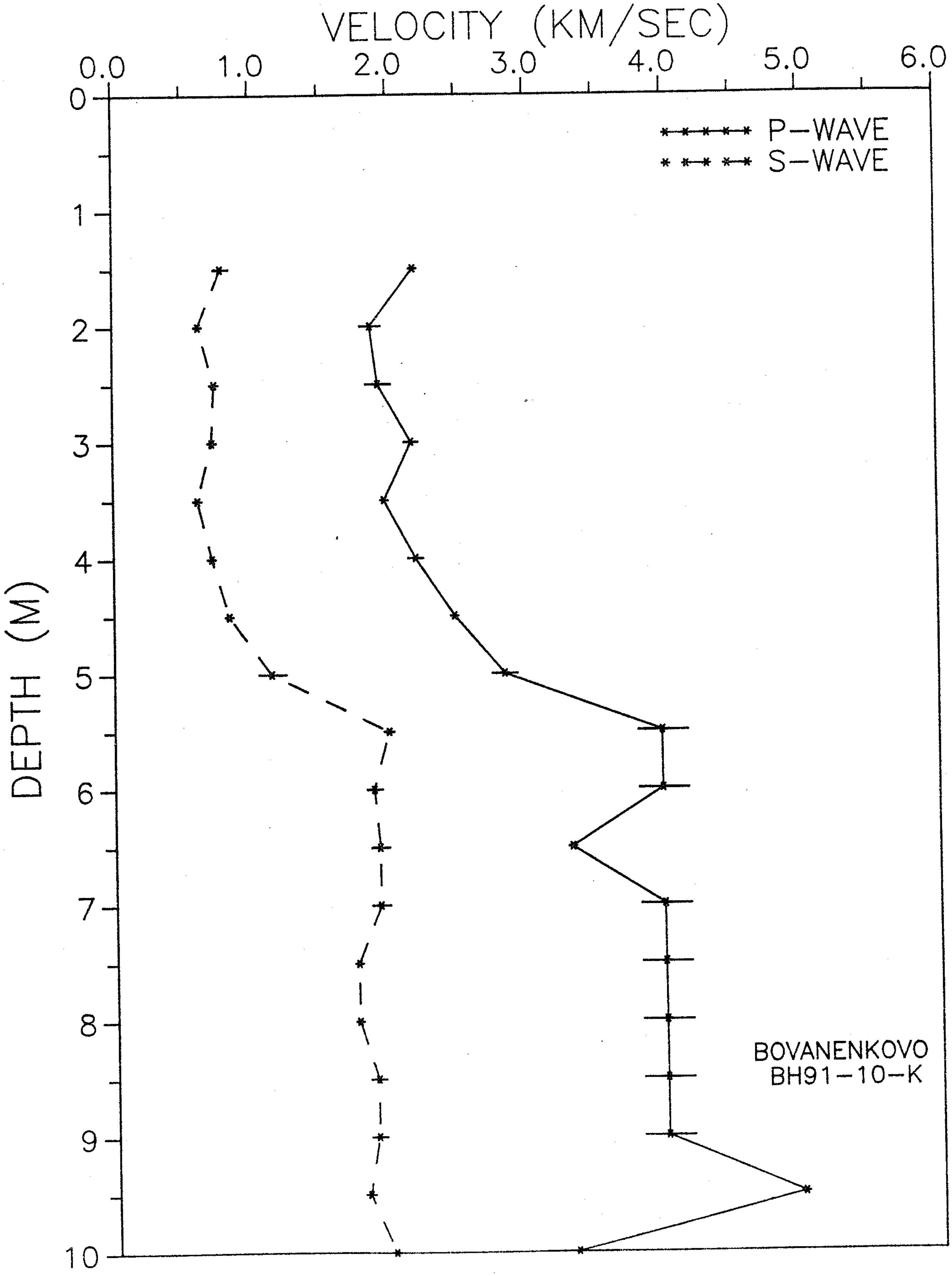

VELOCITY (KM/SEC)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
P—WAVE
S—WAVE
DEPTH (M)
0
1
2
3
4
5
6
7
8
9
10
BOVANENKOVO
BH91—10—K

Figure 91

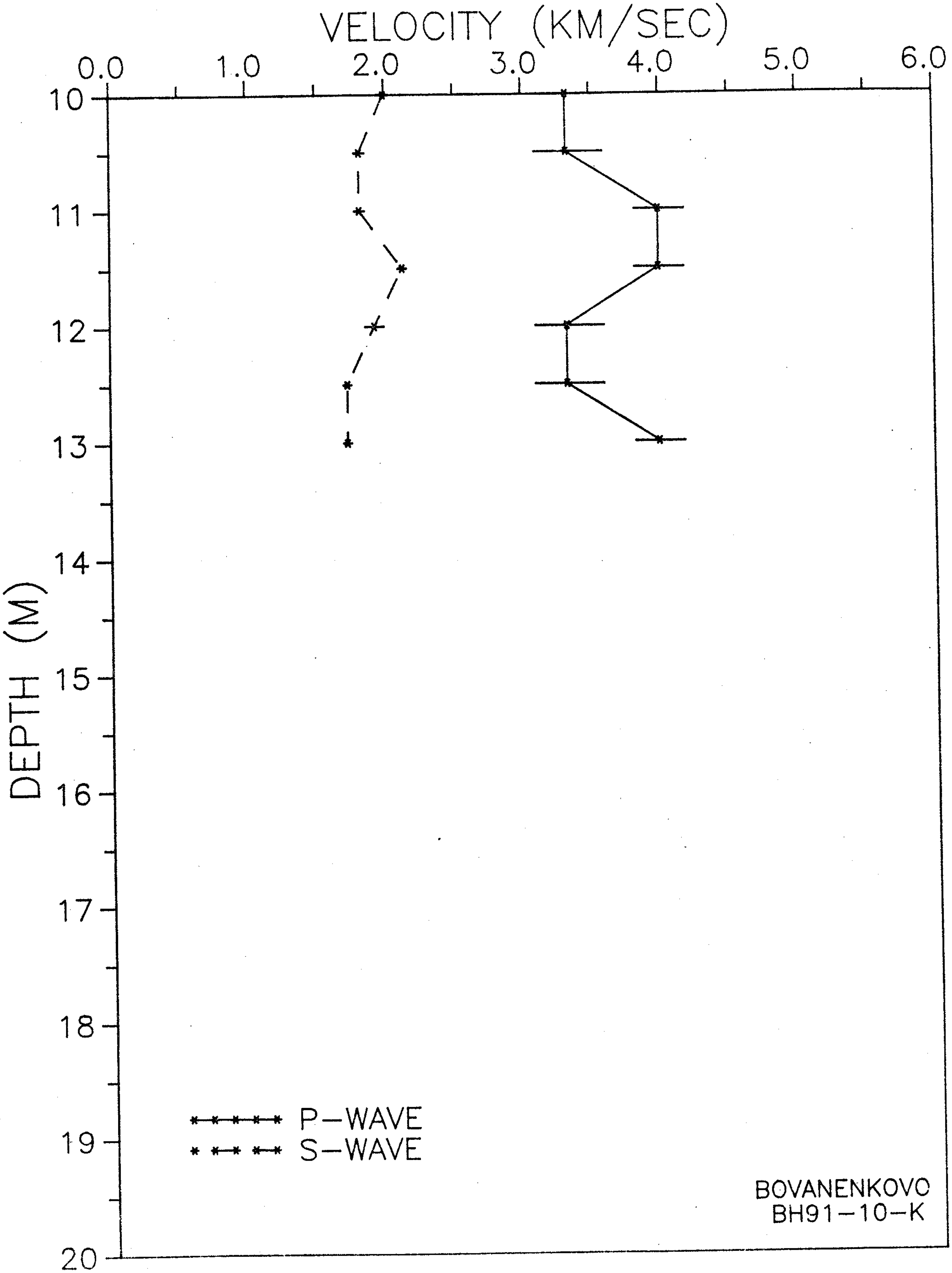


Figure 91 cont.

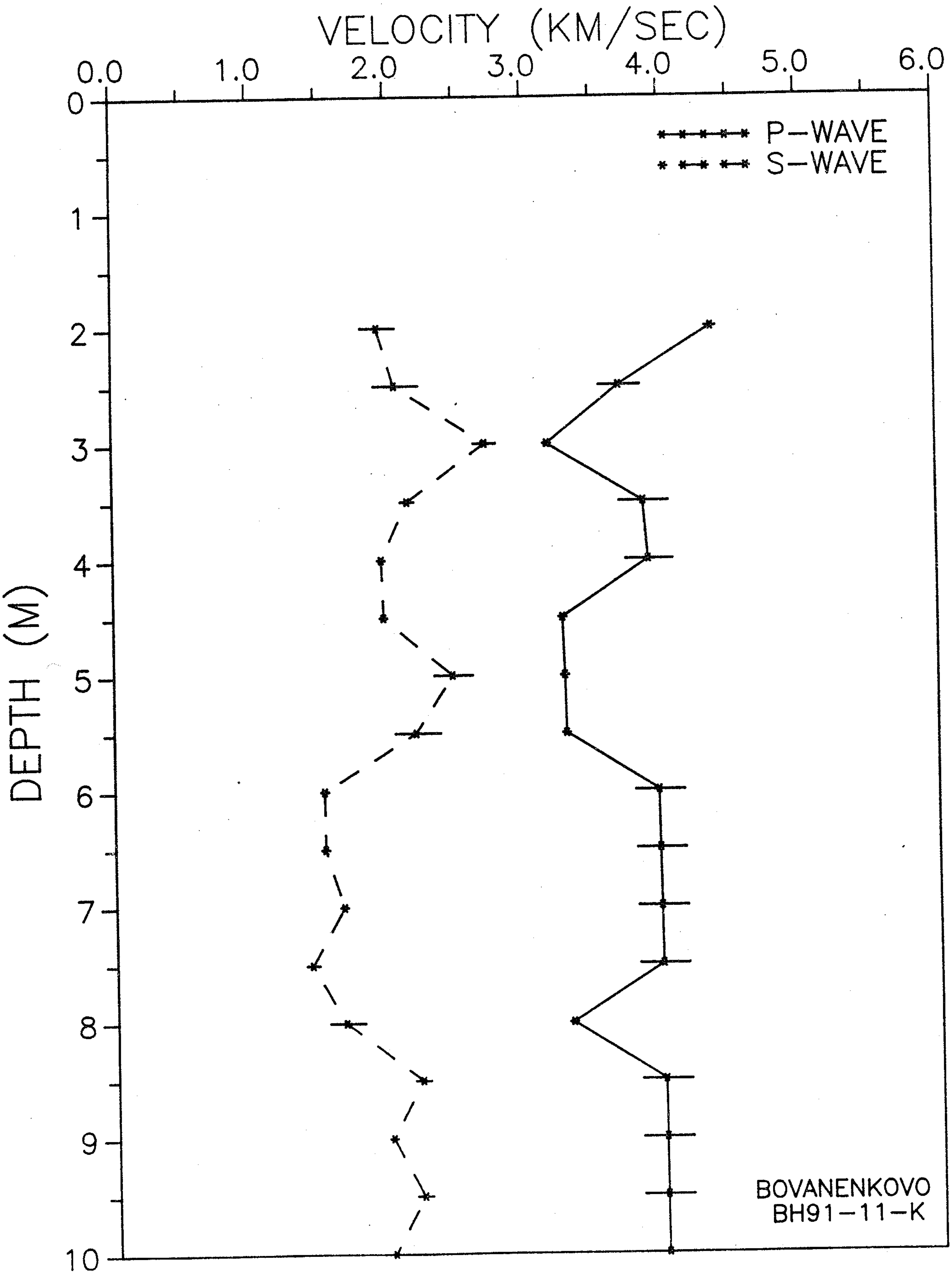

VELOCITY (KM/SEC)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
0
1
2
3
4
5
6
7
8
9
10
DEPTH (M)
P-WAVE
S-WAVE
BOVANENKOVO
BH91-11-K

Figure 92

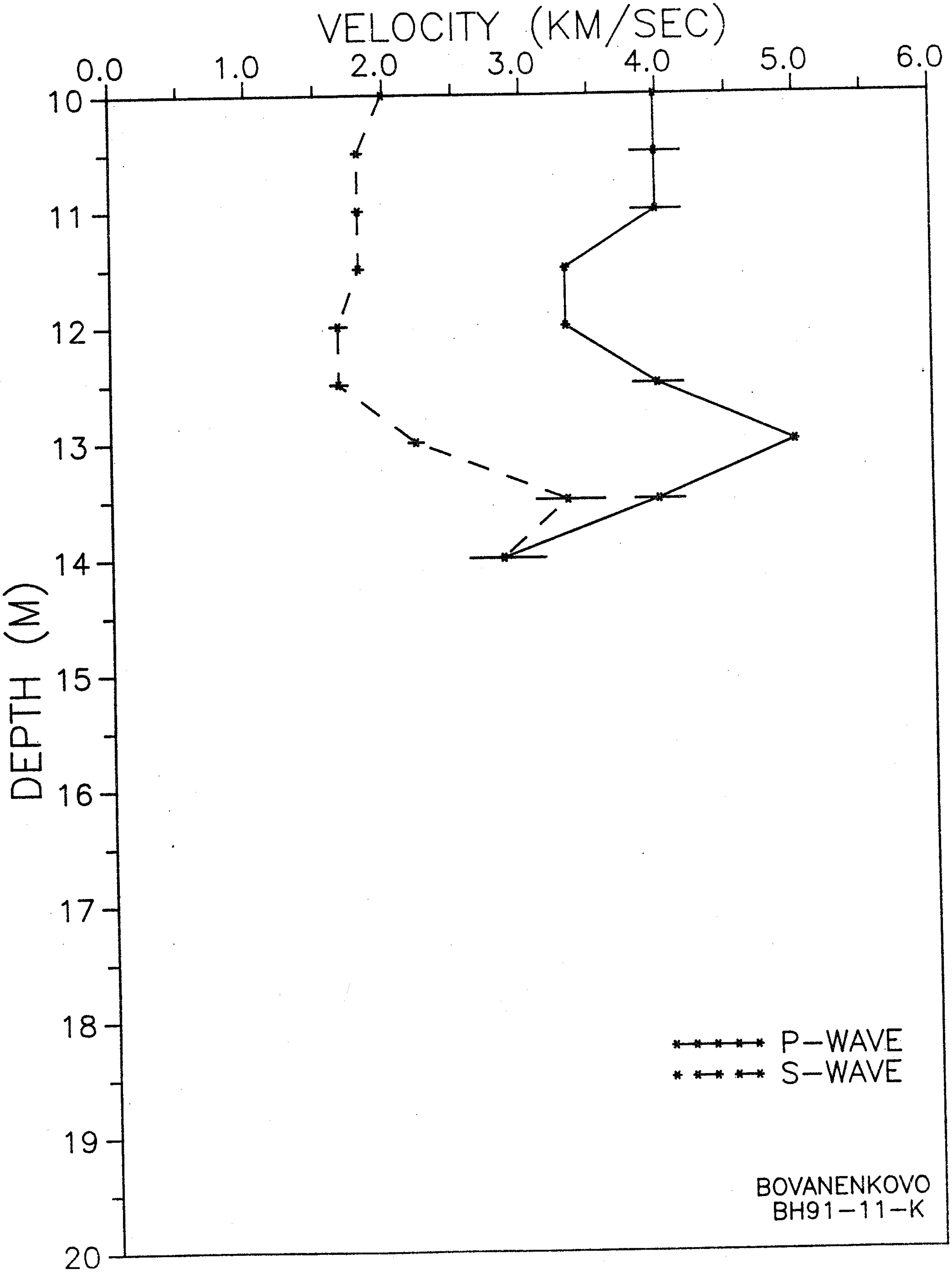


Figure 92 cont.

POISSON'S RATIO

Figs. 93-100

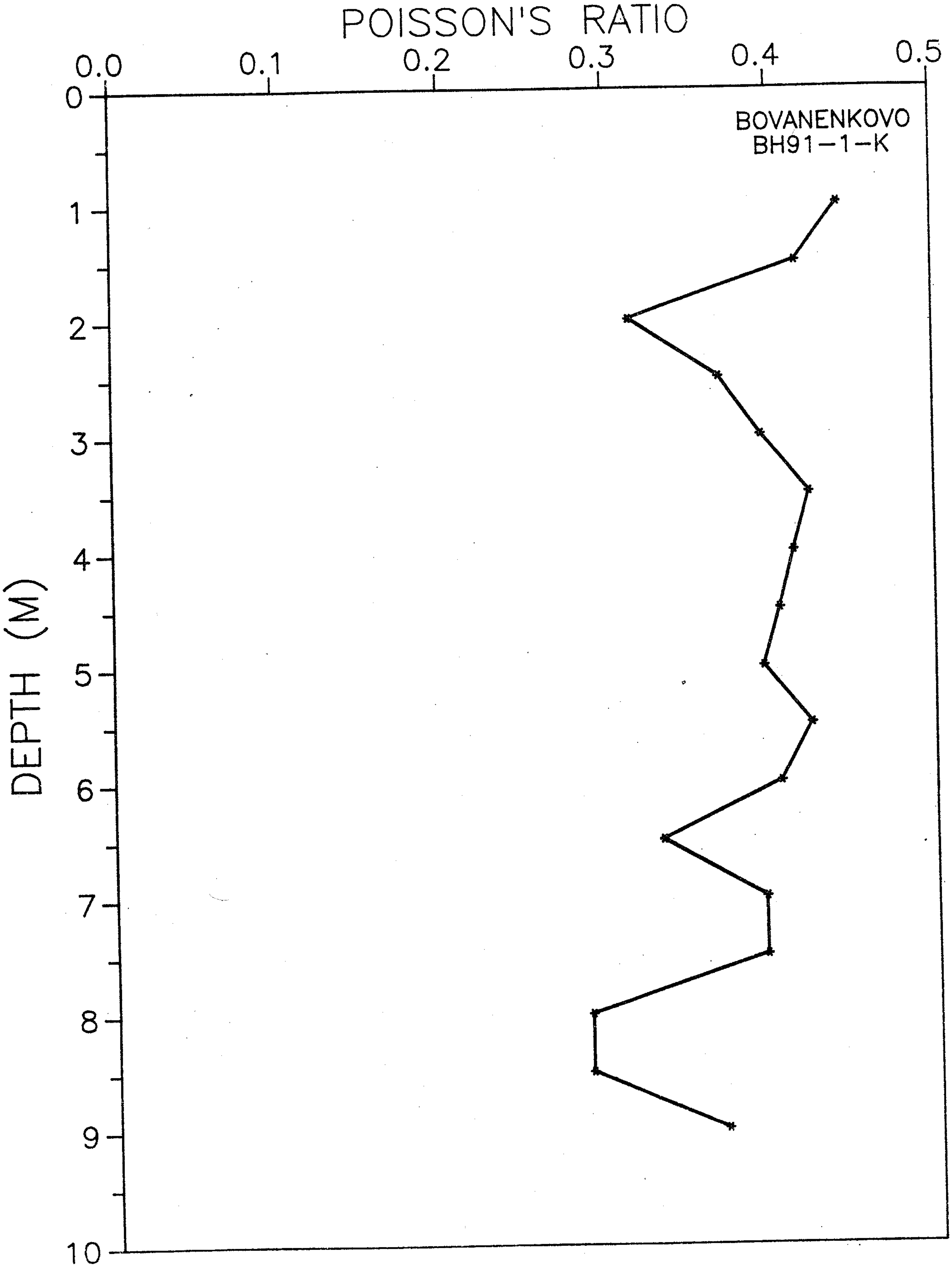

POISSON'S RATIO
0.0
0.1
0.2
0.3
0.4
0.5
BOVANENKOVO
BH91-1-K
DEPTH (M)
0
1
2
3
4
5
6
7
8
9
10

Figure 93

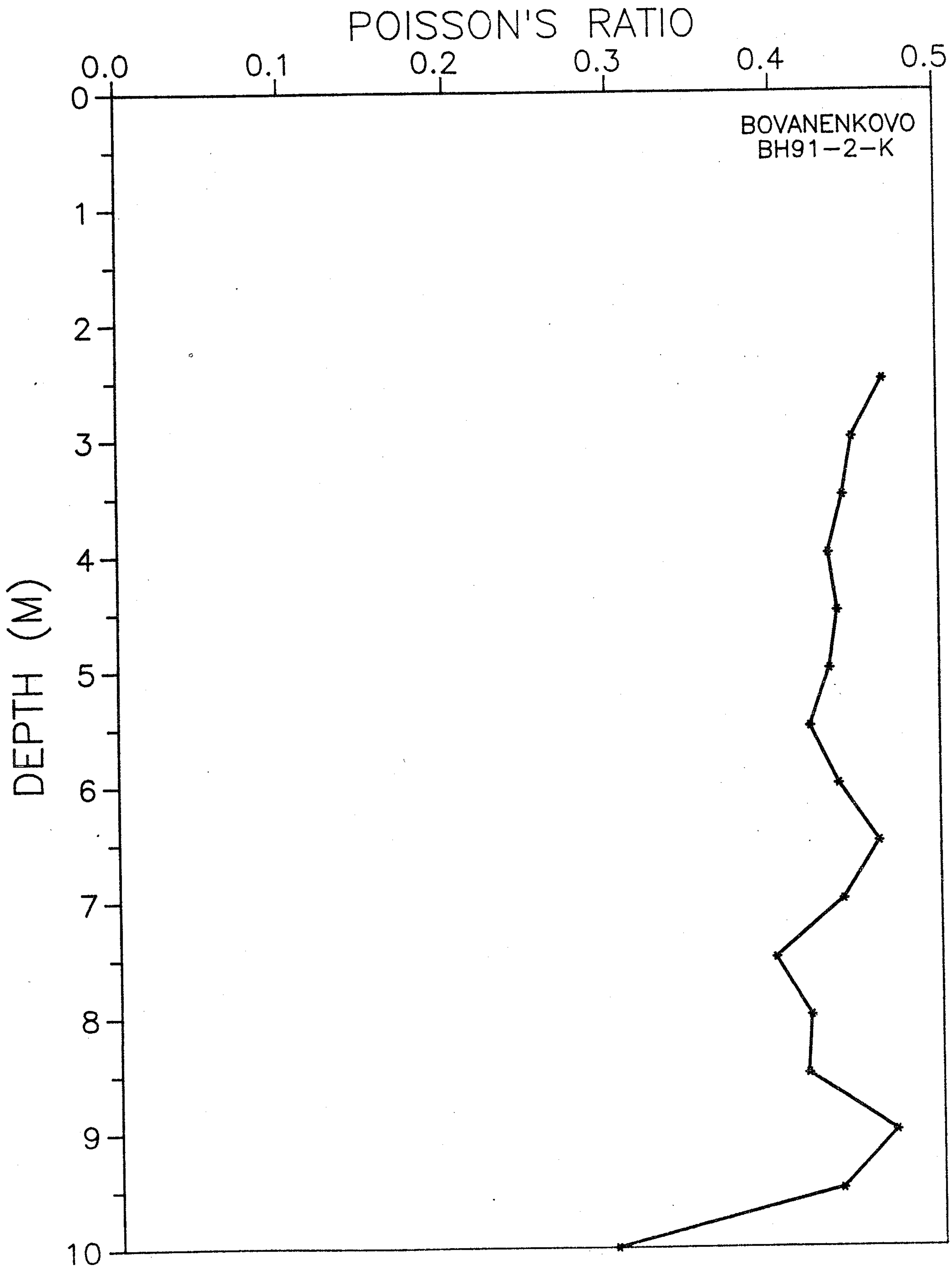

POISSON'S RATIO
0.0
0.1
0.2
0.3
0.4
0.5
BOVANENKOVO
BH91-2-K
DEPTH (M)
0
1
2
3
4
5
6
7
8
9
10

Figure 94

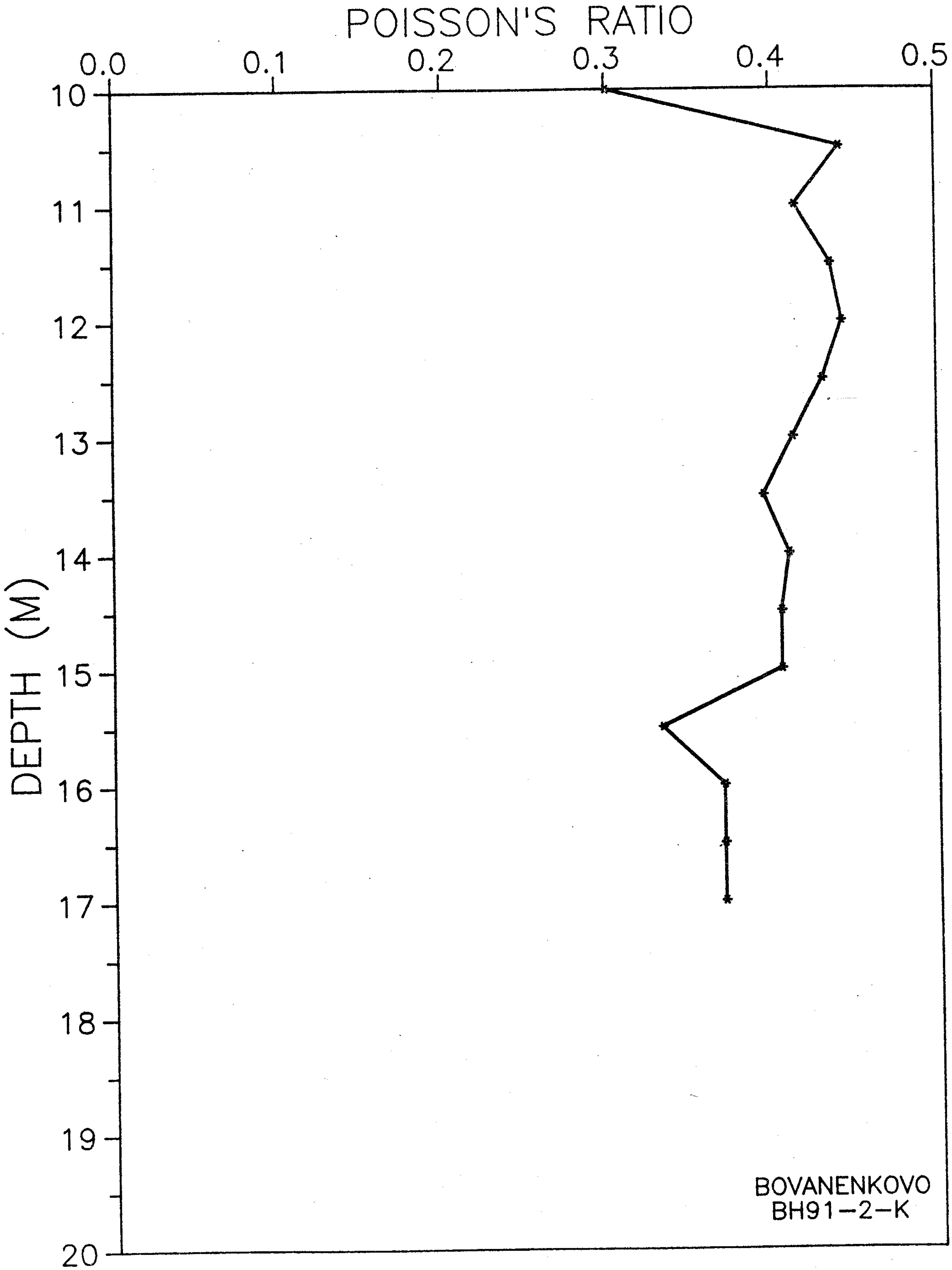


Figure 94 cont.

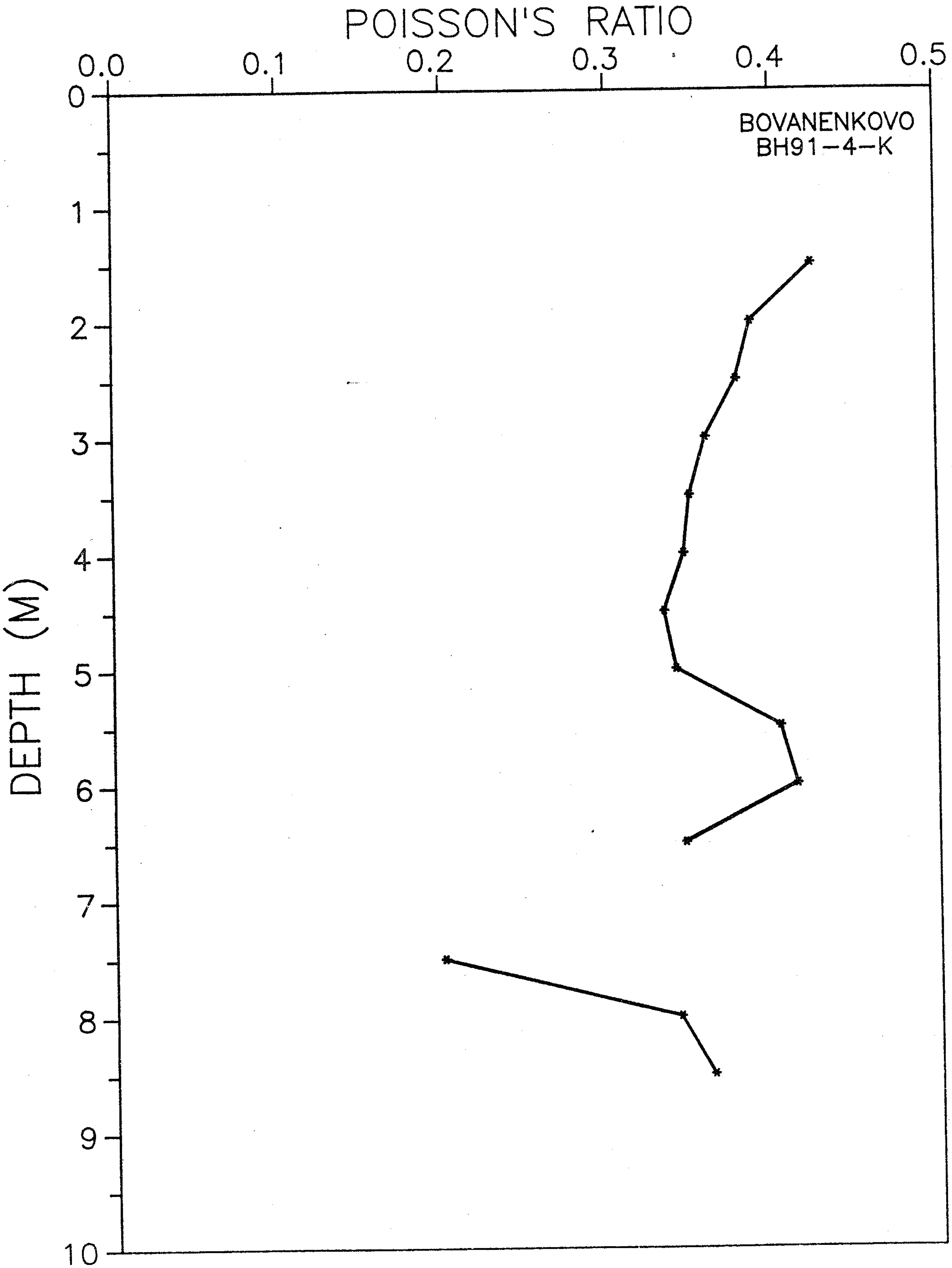

POISSON'S RATIO
0.0
0.1
0.2
0.3
0.4
0.5
BOVANENKOVO
BH91-4-K
DEPTH (M)
0
1
2
3
4
5
6
7
8
9
10

Figure 95

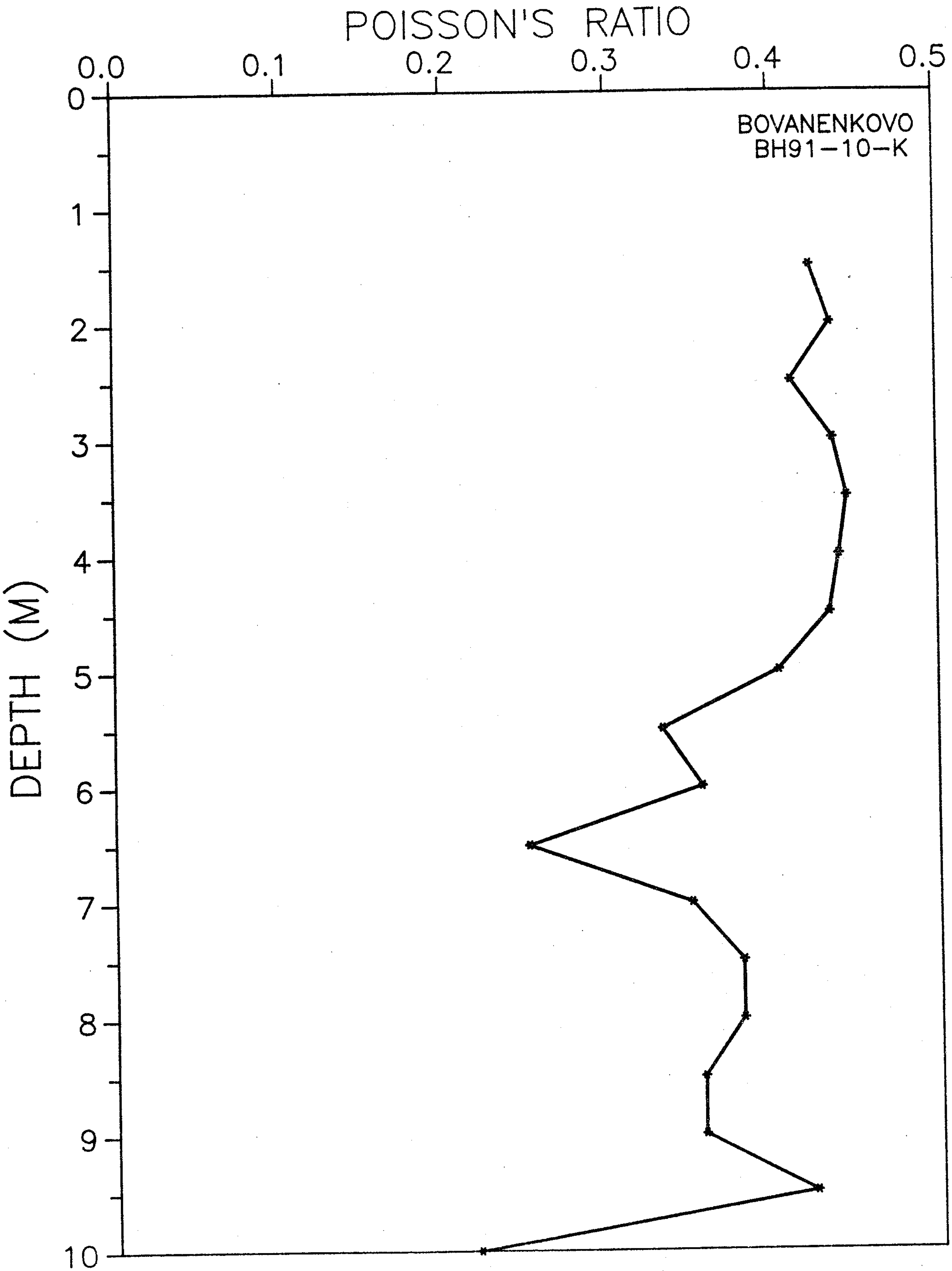

POISSON'S RATIO
0.0
0.1
0.2
0.3
0.4
0.5
DEPTH (M)
0
1
2
3
4
5
6
7
8
9
10
BOVANENKOVO
BH91-10-K

Figure 96

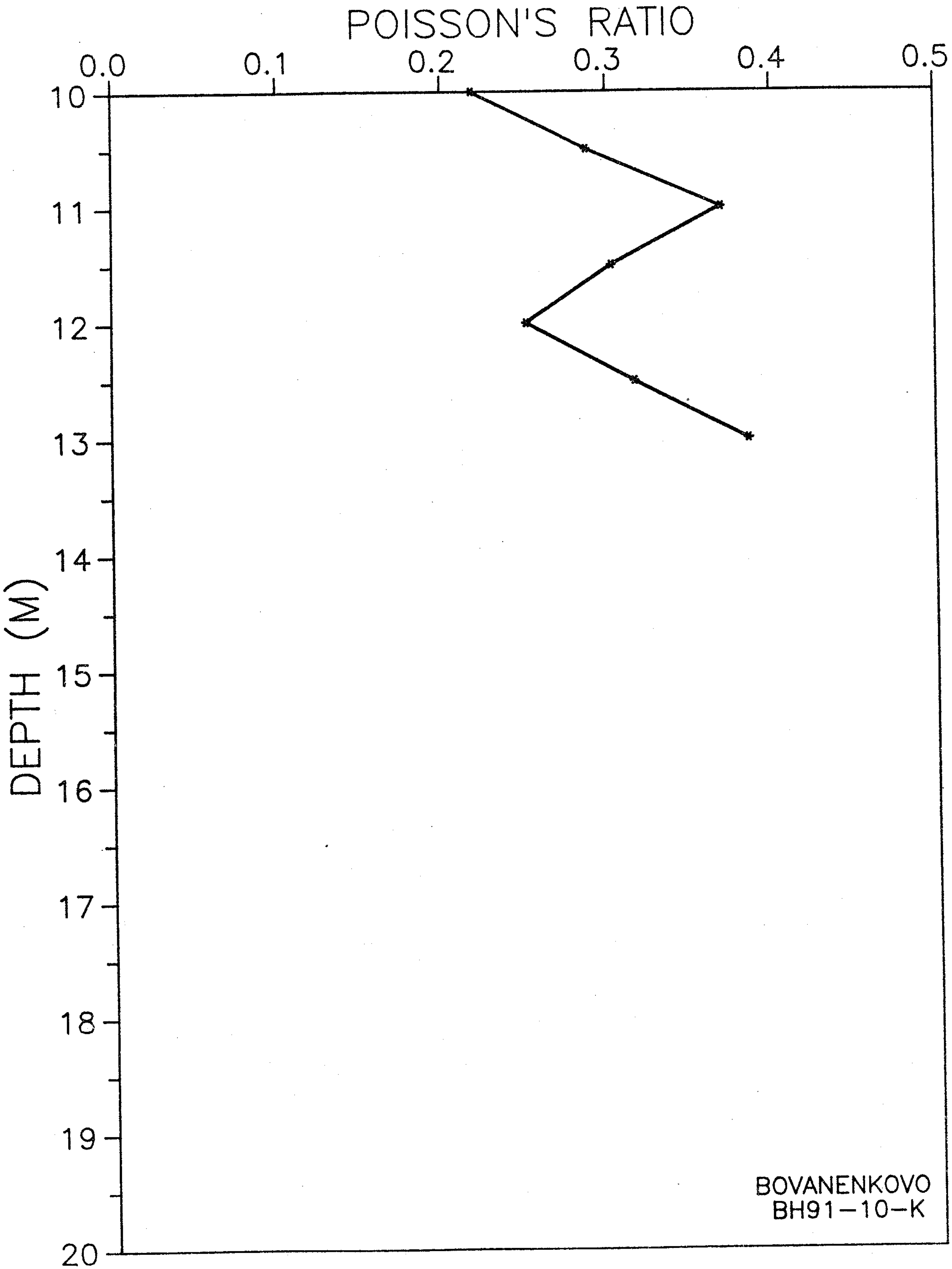


Figure 96 cont.

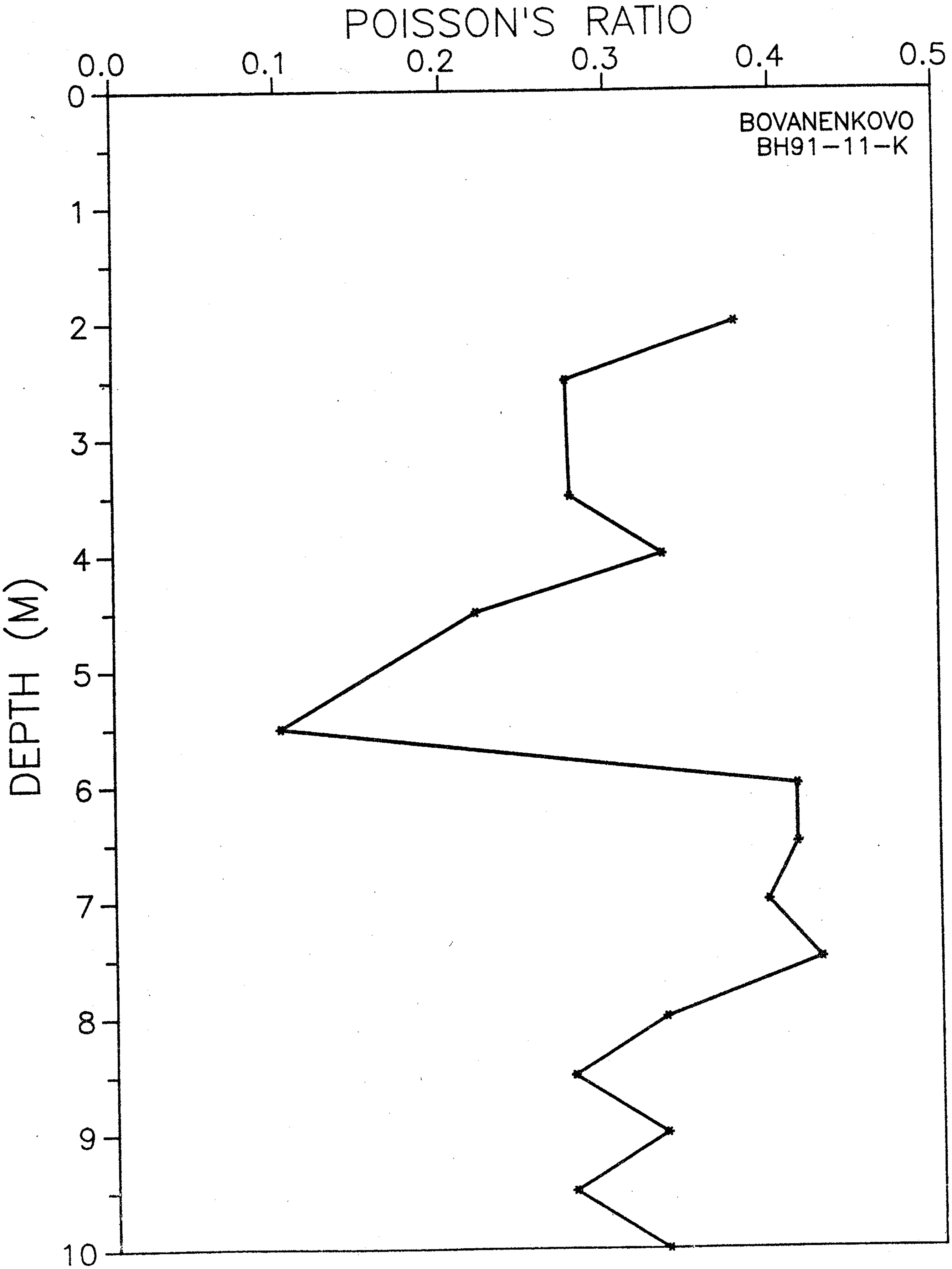

POISSON'S RATIO
0.0
0.1
0.2
0.3
0.4
0.5
BOVANENKOVO
BH91-11-K
DEPTH (M)
0
1
2
3
4
5
6
7
8
9
10

Figure 97

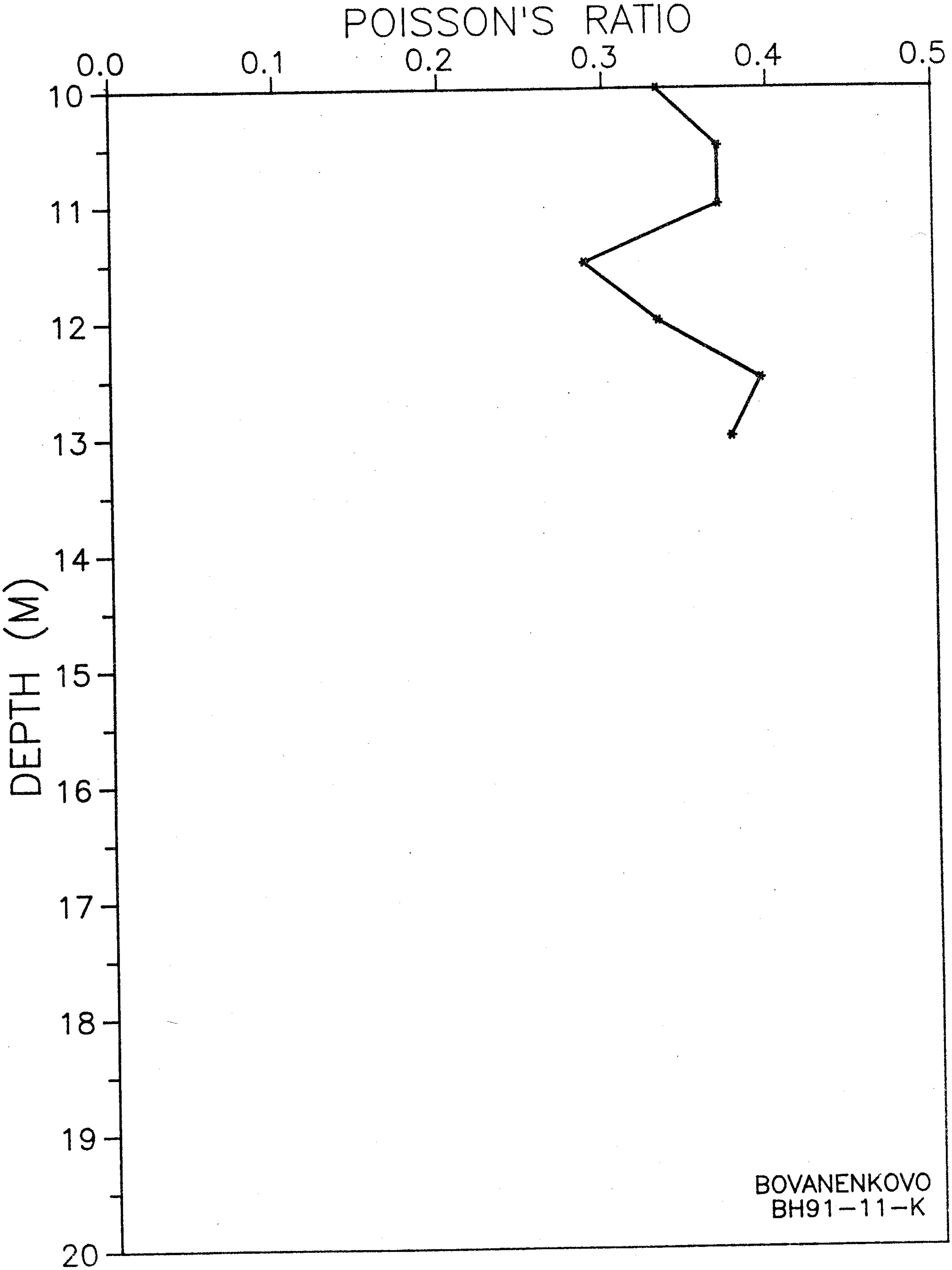


Figure 97 cont.

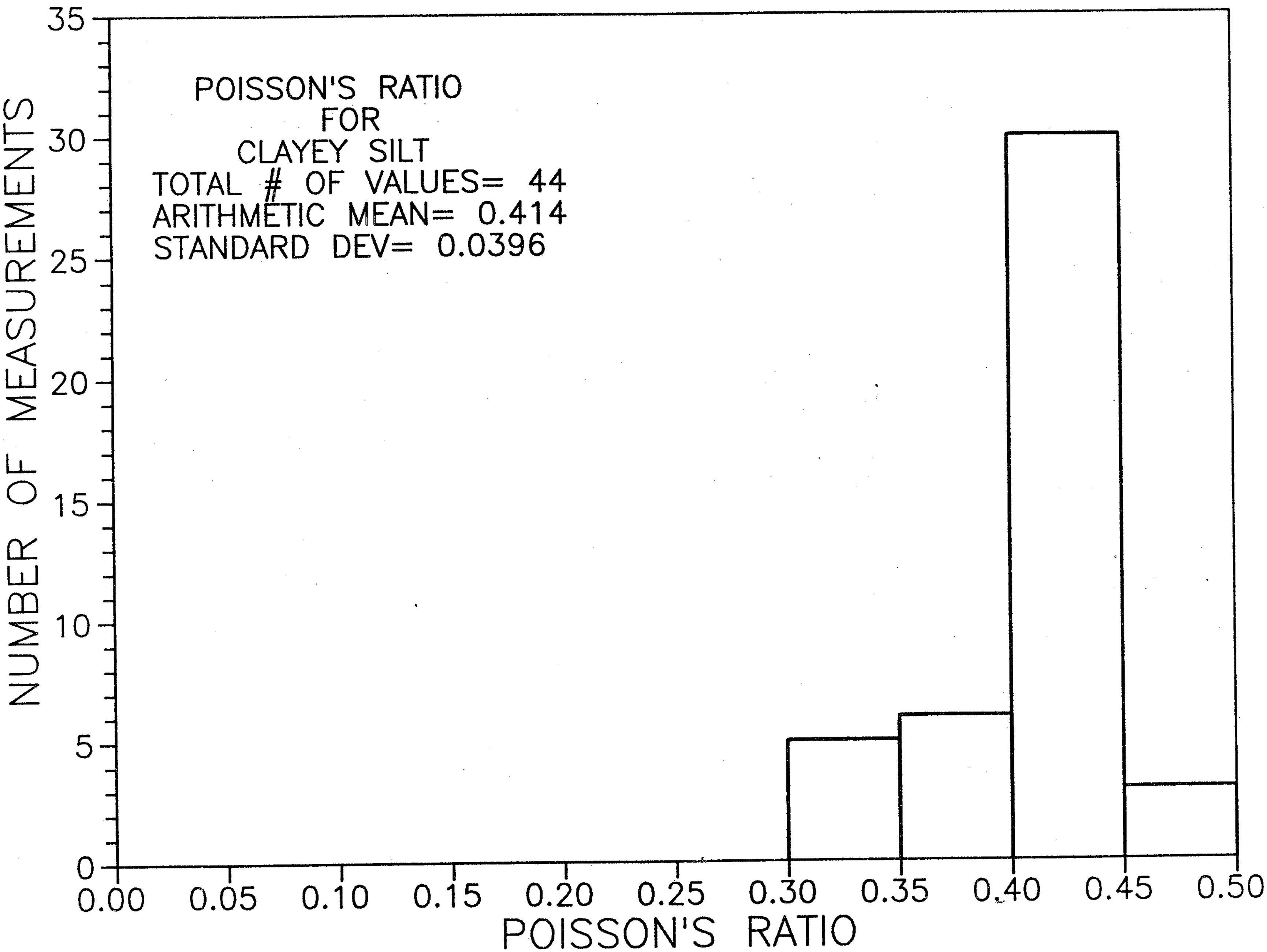

POISSON'S RATIO
FOR
CLAYEY SILT
TOTAL # OF VALUES= 44
ARITHMETIC MEAN= 0.414
STANDARD DEV= 0.0396
NUMBER OF MEASUREMENTS
0
5
10
15
20
25
30
35
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
POISSON'S RATIO

Figure 98

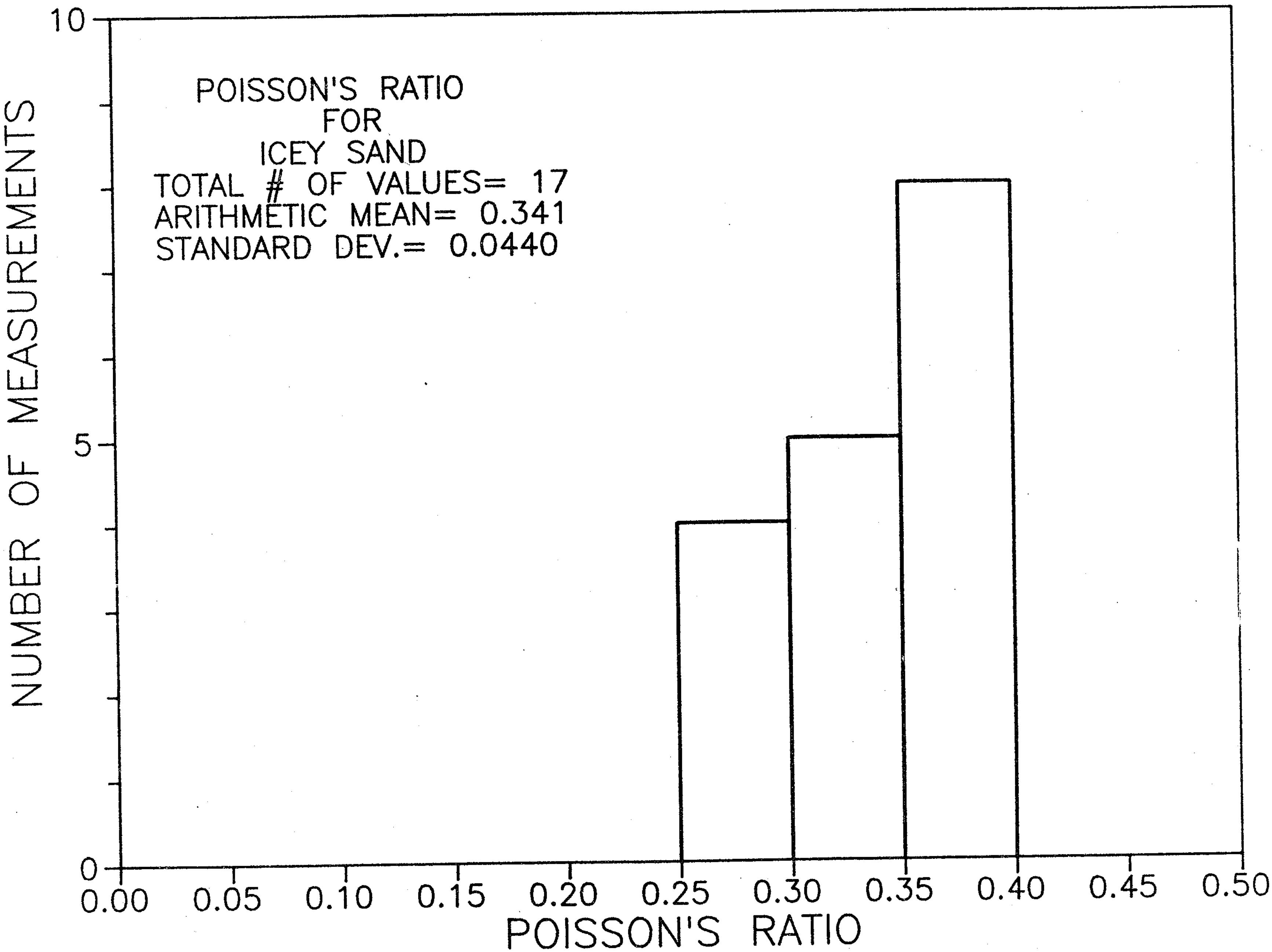

POISSON'S RATIO
FOR
ICEY SAND
TOTAL # OF VALUES= 17
ARITHMETIC MEAN= 0.341
STANDARD DEV.= 0.0440
NUMBER OF MEASUREMENTS
10
5
0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
POISSON'S RATIO

Figure 99

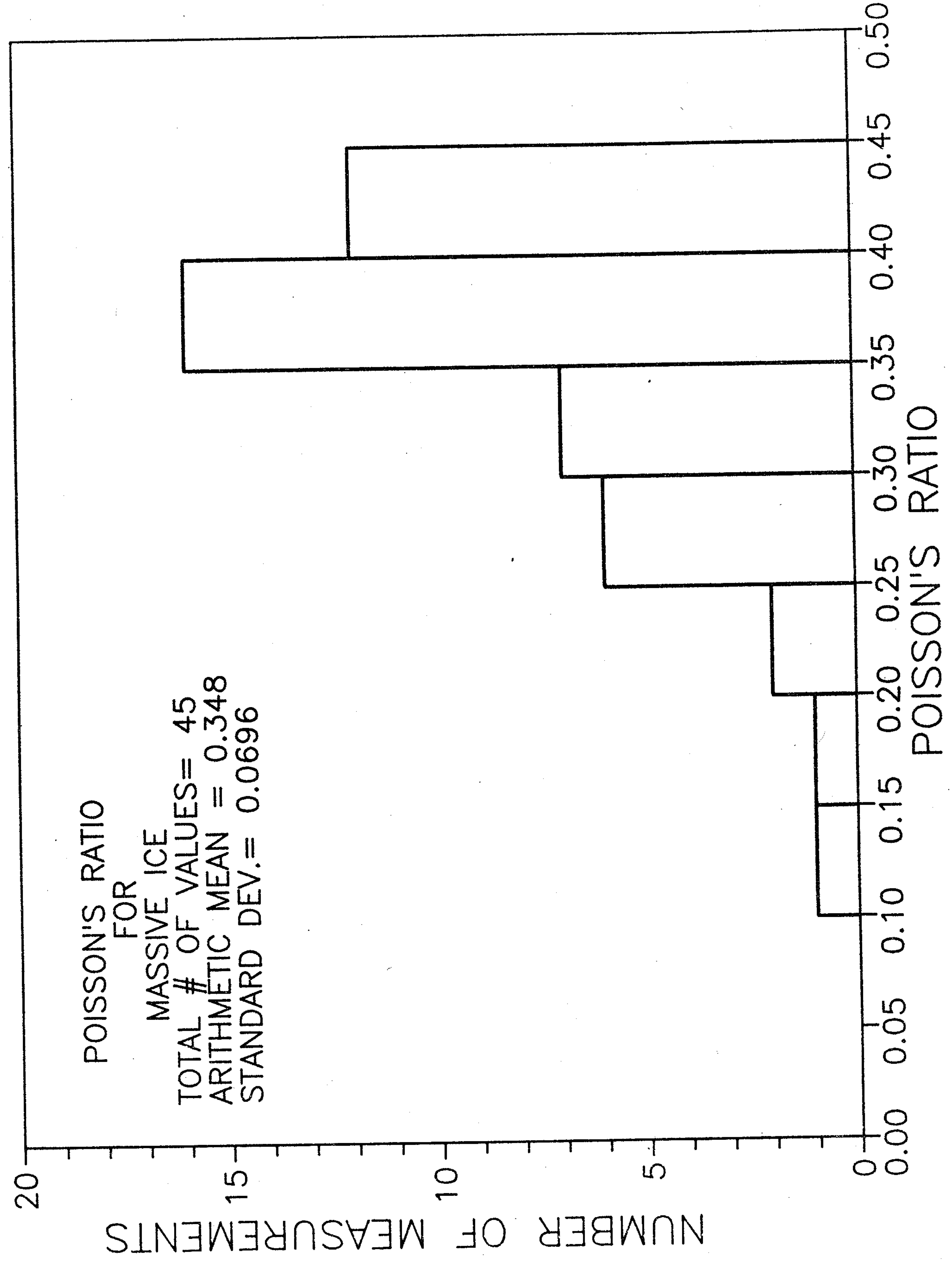

POISSON'S RATIO
FOR
MASSIVE ICE
TOTAL # OF VALUES= 45
ARITHMETIC MEAN = 0.348
STANDARD DEV.= 0.0696
NUMBER OF MEASUREMENTS
20
15
10
5
0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
POISSON'S RATIO

Figure 100

COMPRESSIONAL WAVE LOGS

Figs. 101-103

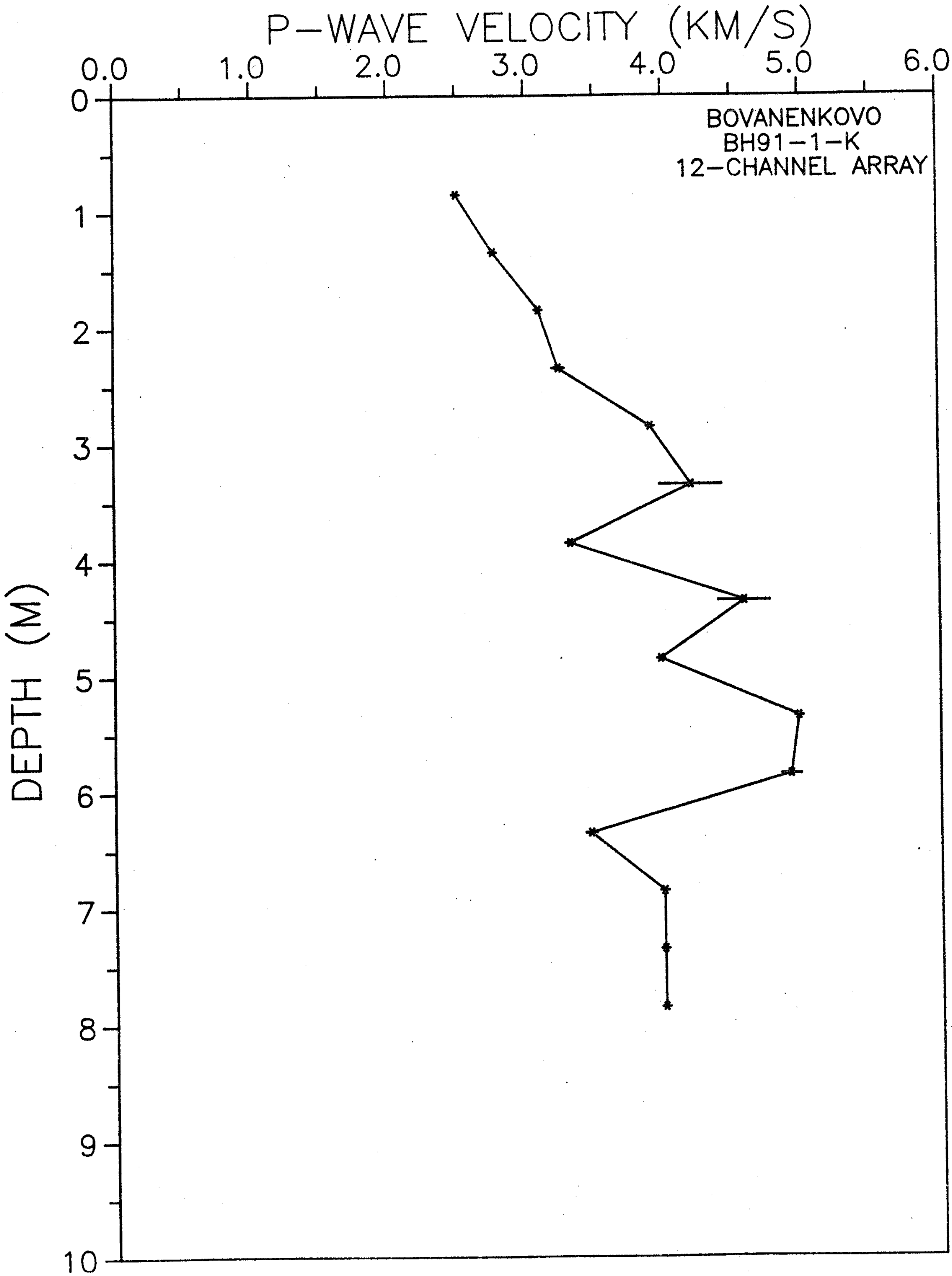

P-WAVE VELOCITY (KM/S)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
0
1
2
3
4
5
6
7
8
9
10
DEPTH (M)
BOVANENKOVO
BH91-1-K
12-CHANNEL ARRAY

Figure 101

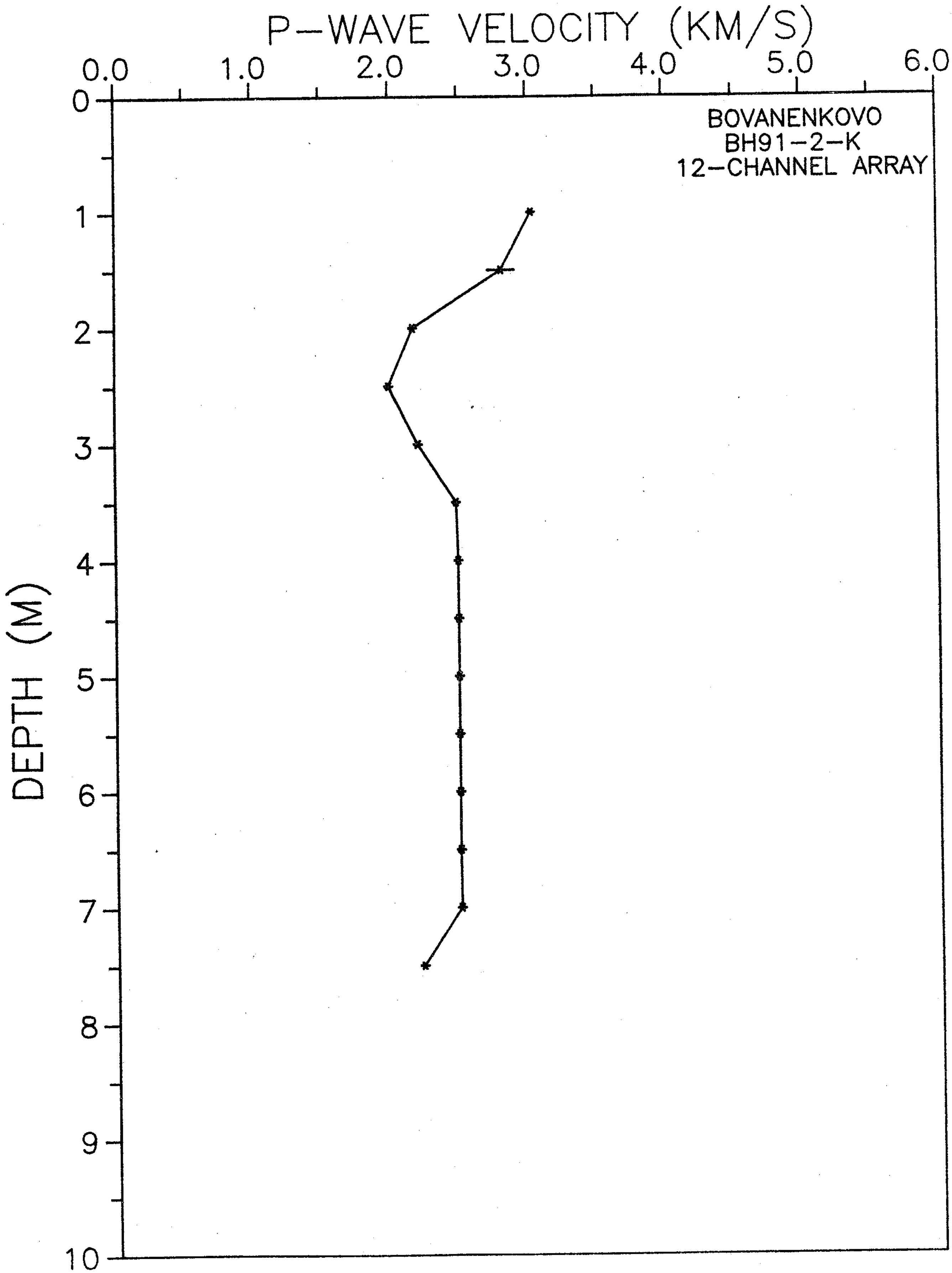

P-WAVE VELOCITY (KM/S)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
0
1
2
3
4
5
6
7
8
9
10
DEPTH (M)
BOVANENKOVO
BH91-2-K
12-CHANNEL ARRAY

Figure 102

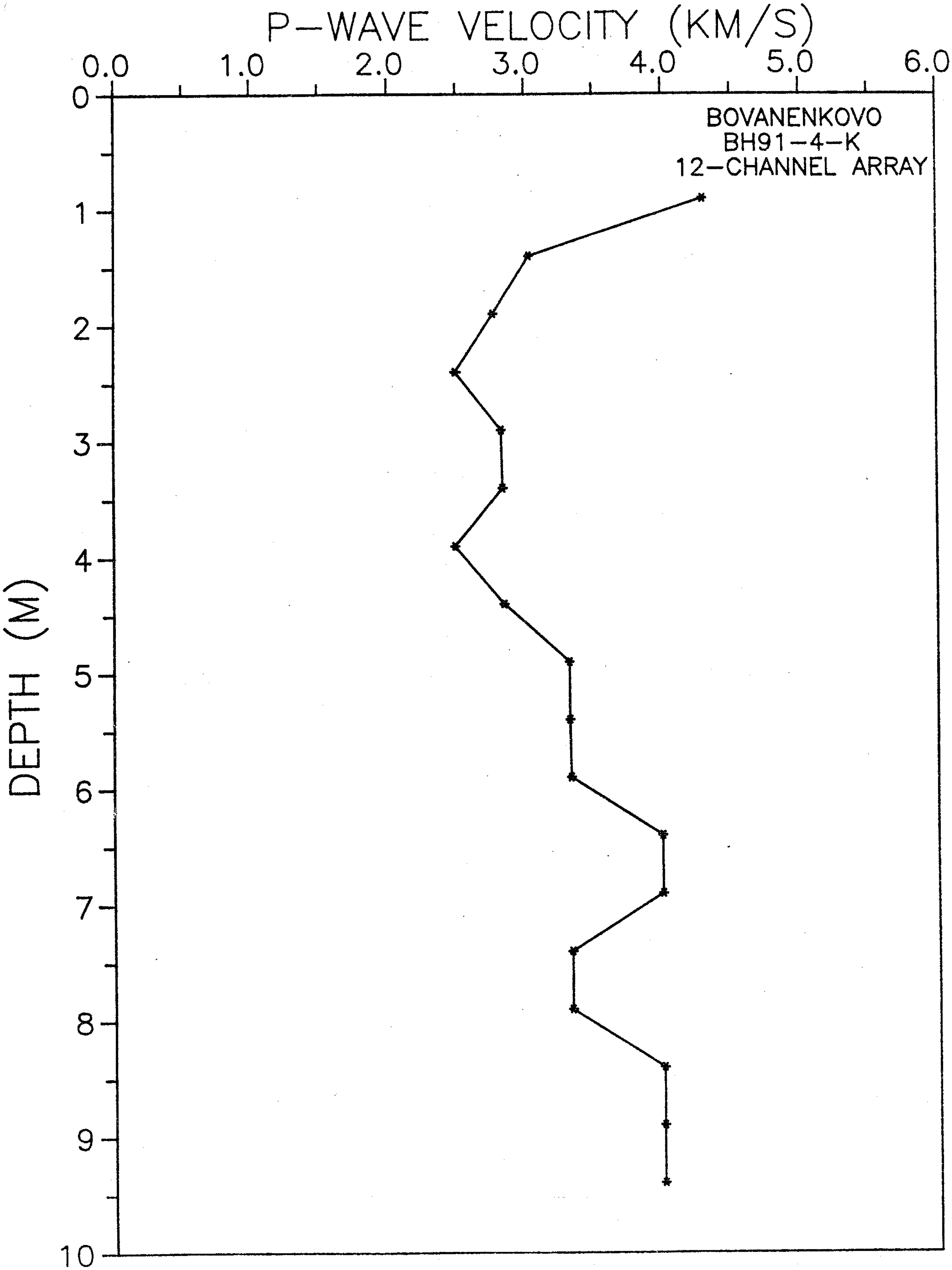

P-WAVE VELOCITY (KM/S)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
0
1
2
3
4
5
6
7
8
9
10
DEPTH (M)
BOVANENKOVO
BH91-4-K
12-CHANNEL ARRAY

Figure 103

DOWNHOLE SHEAR WAVE VSP

BOREHOLE 2

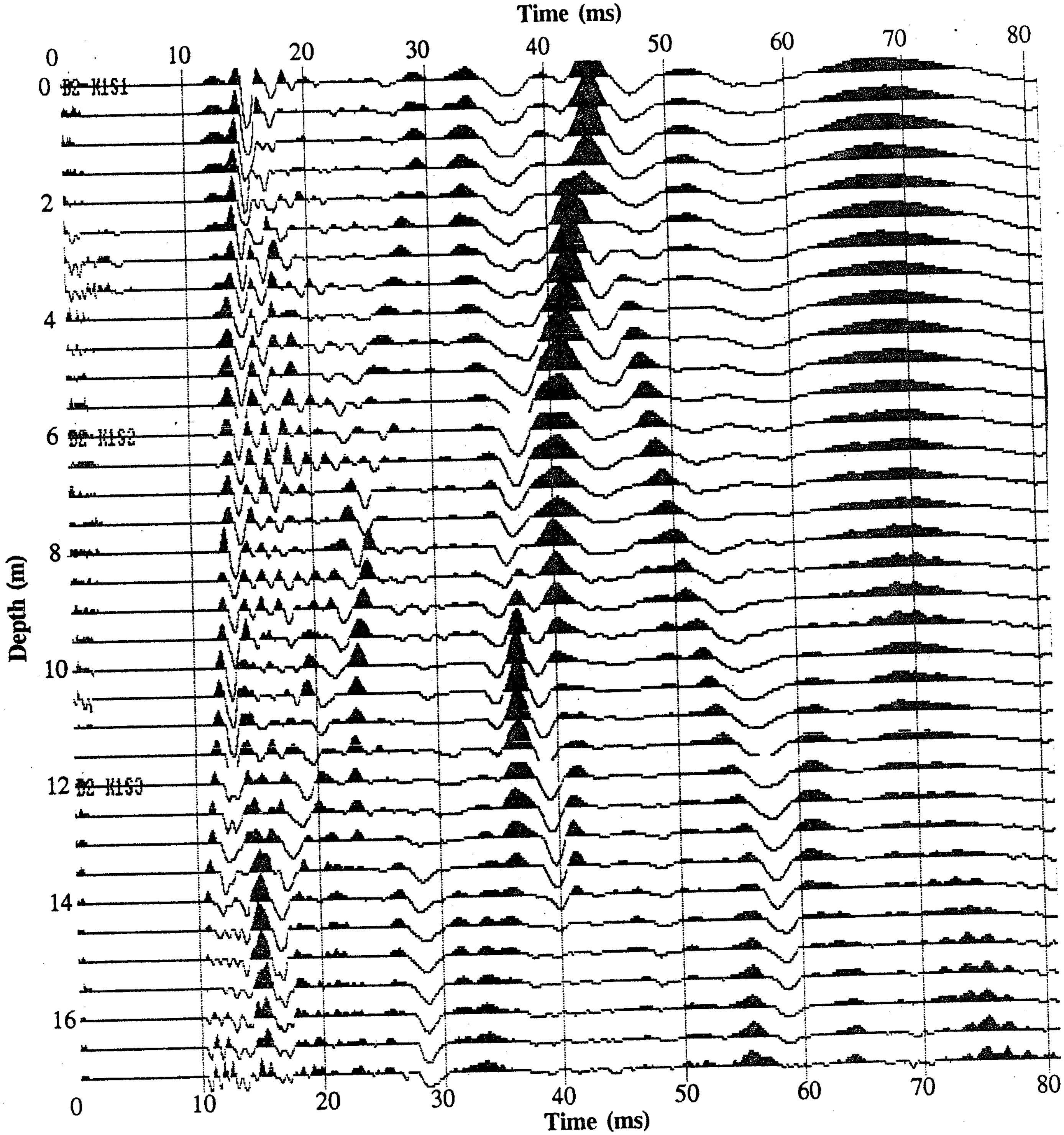
Vertical, Horizontal 1, and Horizontal 2 Components

plotted in raw format and after application of a digital filter.

Source locations and orientations

1.	24 m north of BH	- vertical
2.	24 m north of BH	- 45° N
3.	24 m north of BH	- 45° W
4.	11 m north of BH	- 45° N (no Horizontal 1 component)
5.	11.5 m north of BH	- 45° W
6.	5 m north of BH	- 45° N
7.	5 m north of BH	- 45° W
8.	0.3 m north of BH	- 45° N
9.	12 m south of BH	- 45° S
10.	26 m south of BH	- 45° S

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP

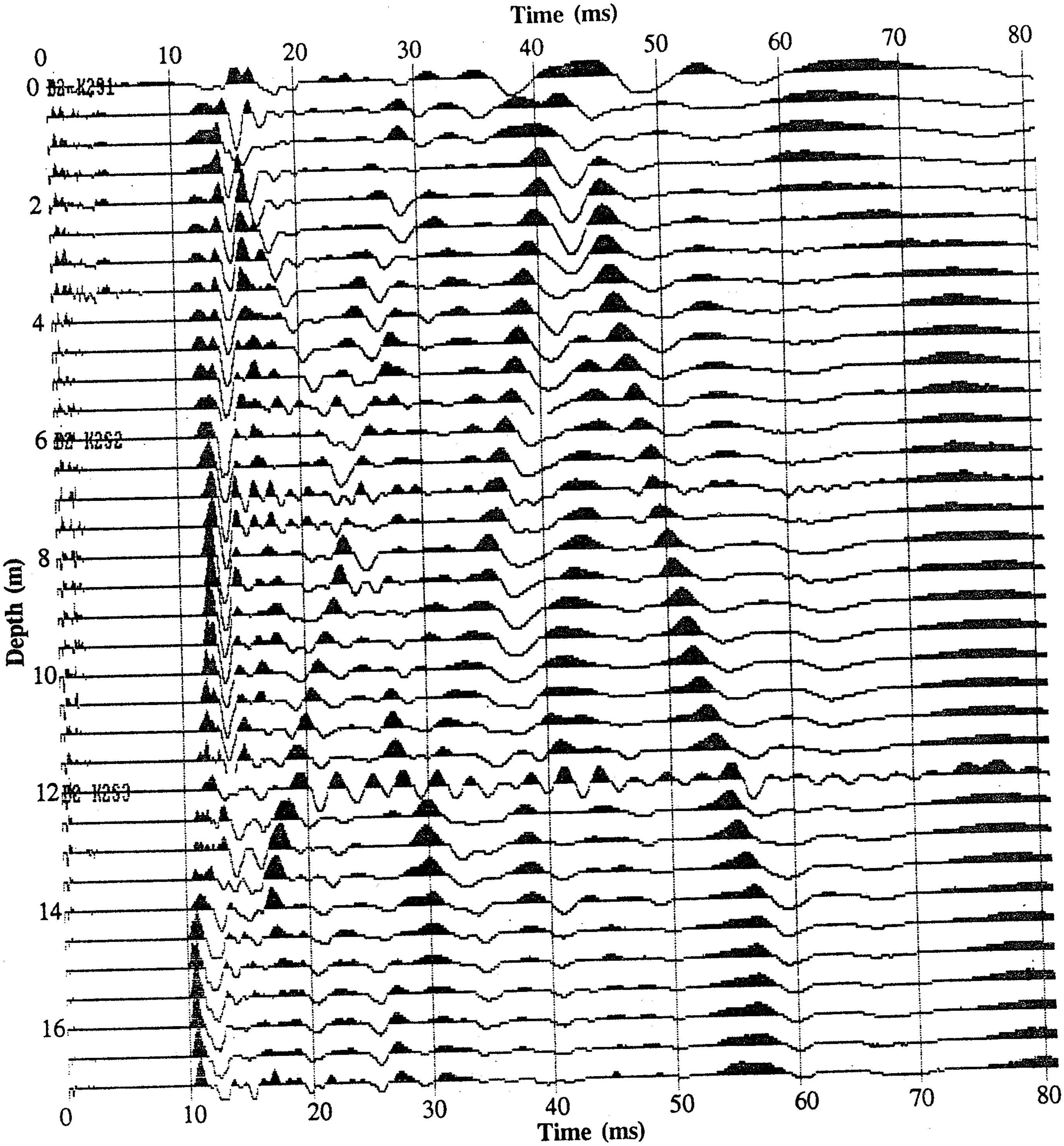


Recording Parameters:
Source: Steel tube - vertical
Source Offset: 24 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Vertical
AGC Parameters: 400 sample window (centred) AGC factor = 400
Bandpass Filter: N/A

Figure 104

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP

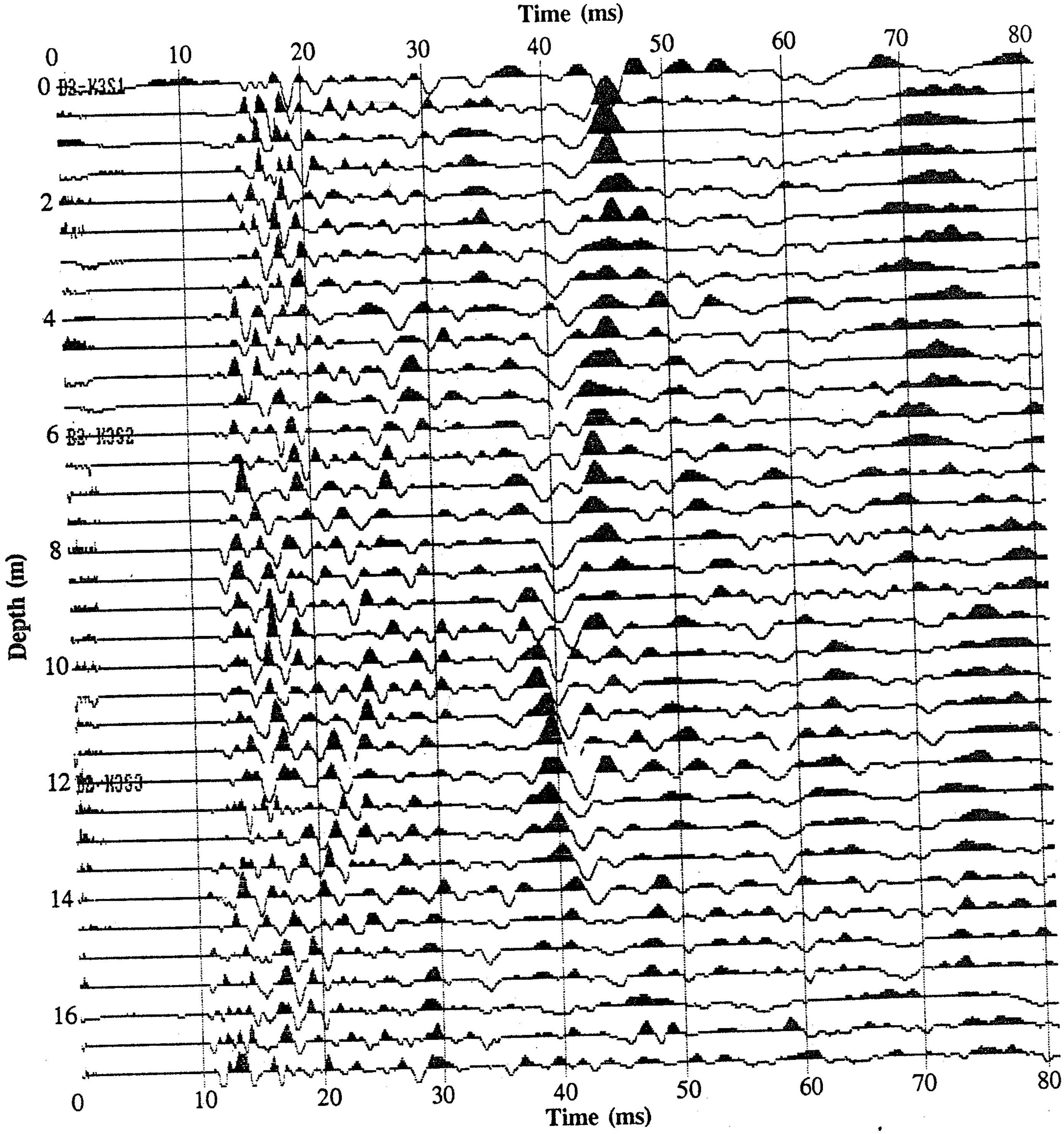


Recording Parameters:
Source: Steel tube - vertical
Source Offset: 24 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 1
AGC Parameters: 400 sample window (centred)
AGC factor = 400
Bandpass Filter: N/A

Figure 105

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:

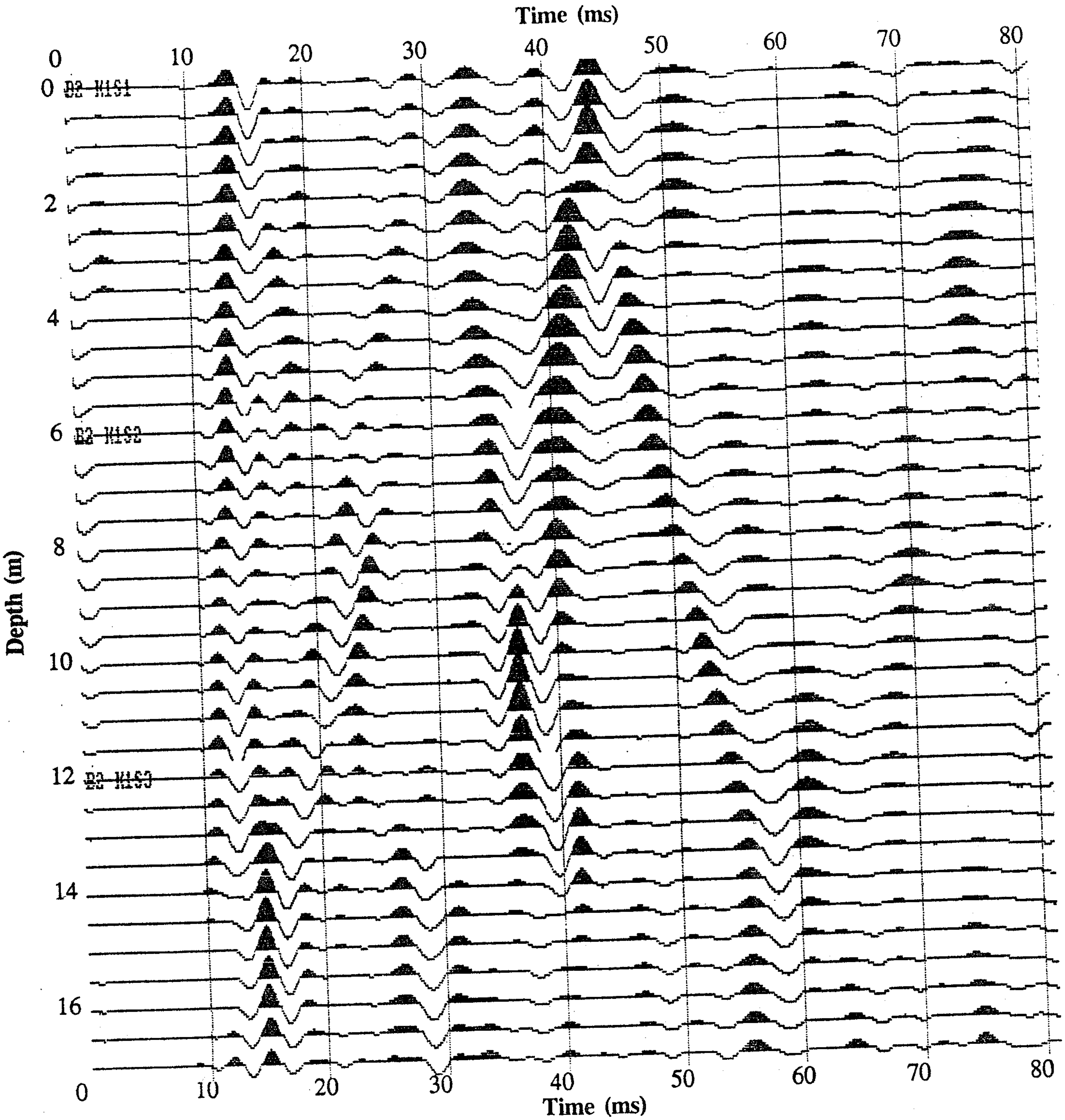
Source: Steel tube - vertical
Source Offset: 24 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:

Component Plotted: Horizontal 2
AGC Parameters: 400 sample window (centred) AGC factor = 400
Bandpass Filter: N/A

Figure 106

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP

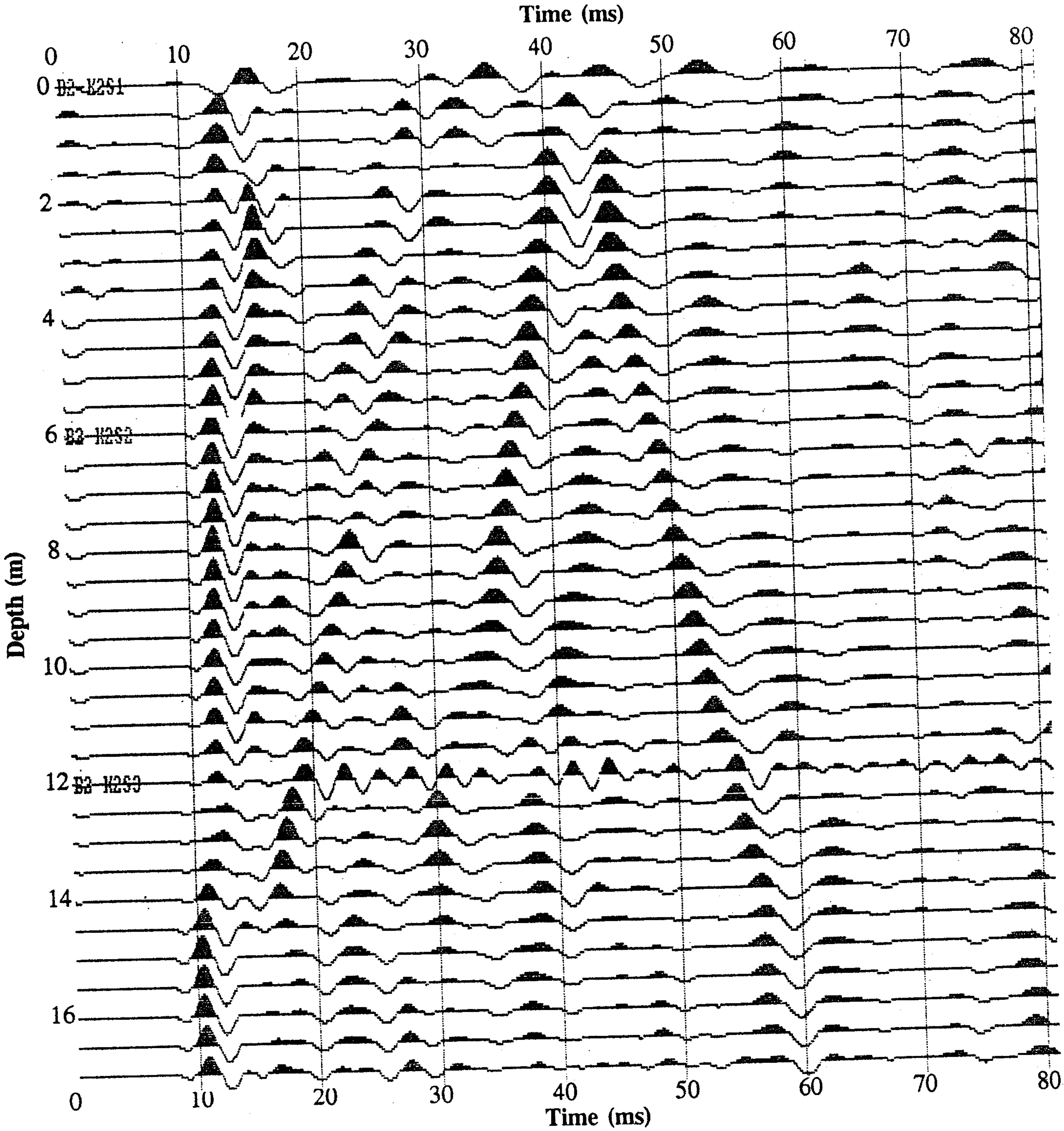


Recording Parameters:
Source: Steel tube - vertical
Source Offset: 24 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Vertical
AGC Parameters: 400 sample window (centred)
AGC factor = 400
Bandpass Filter: 125-375 Hz (12 db rolloffs)

Figure 107

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP

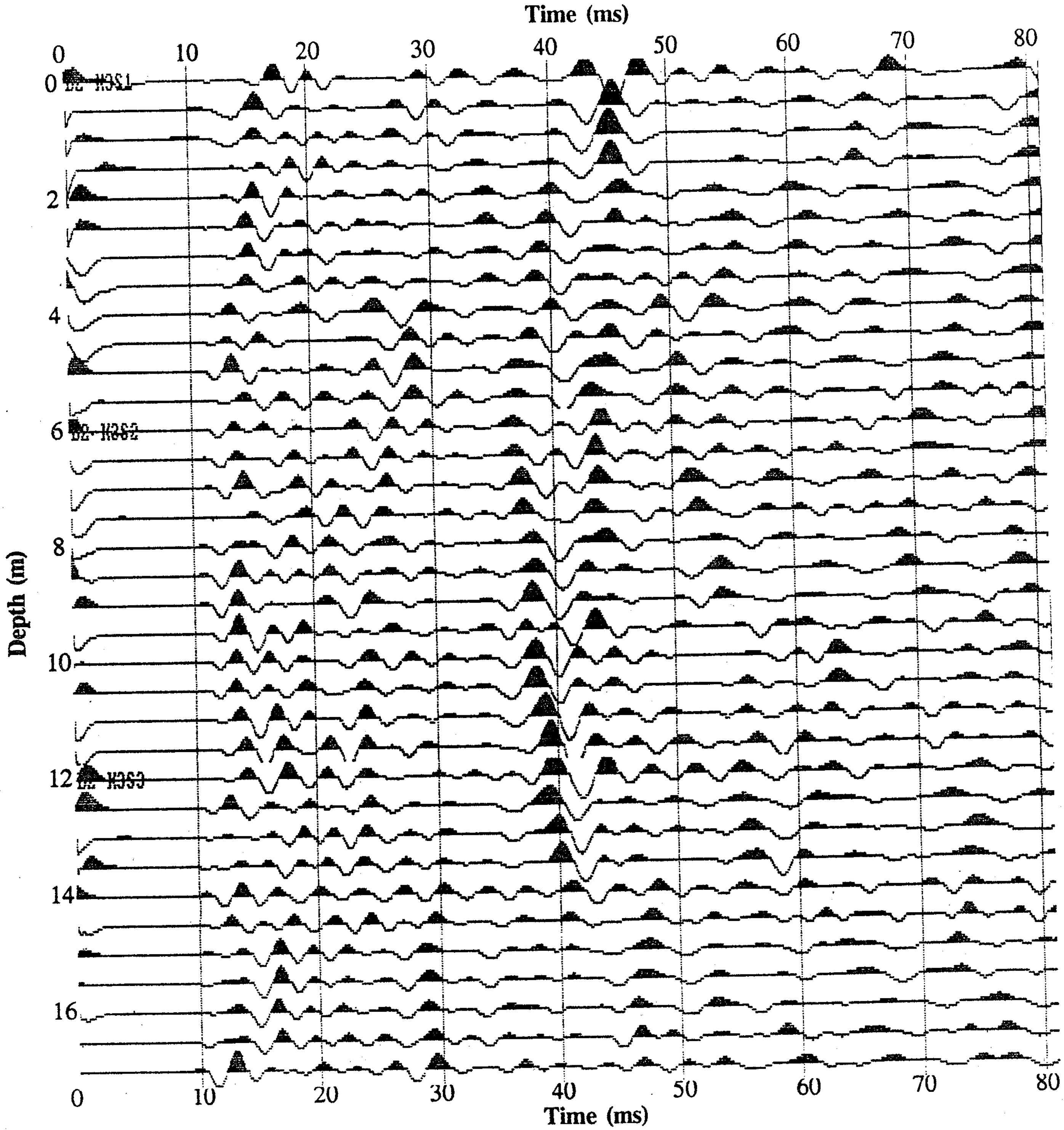


Recording Parameters:
Source: Steel tube - vertical
Source Offset: 24 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 1
AGC Parameters: 400 sample window (centred) AGC factor = 400
Bandpass Filter: 125-375 Hz (12 db rolloffs)

Figure 108

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP

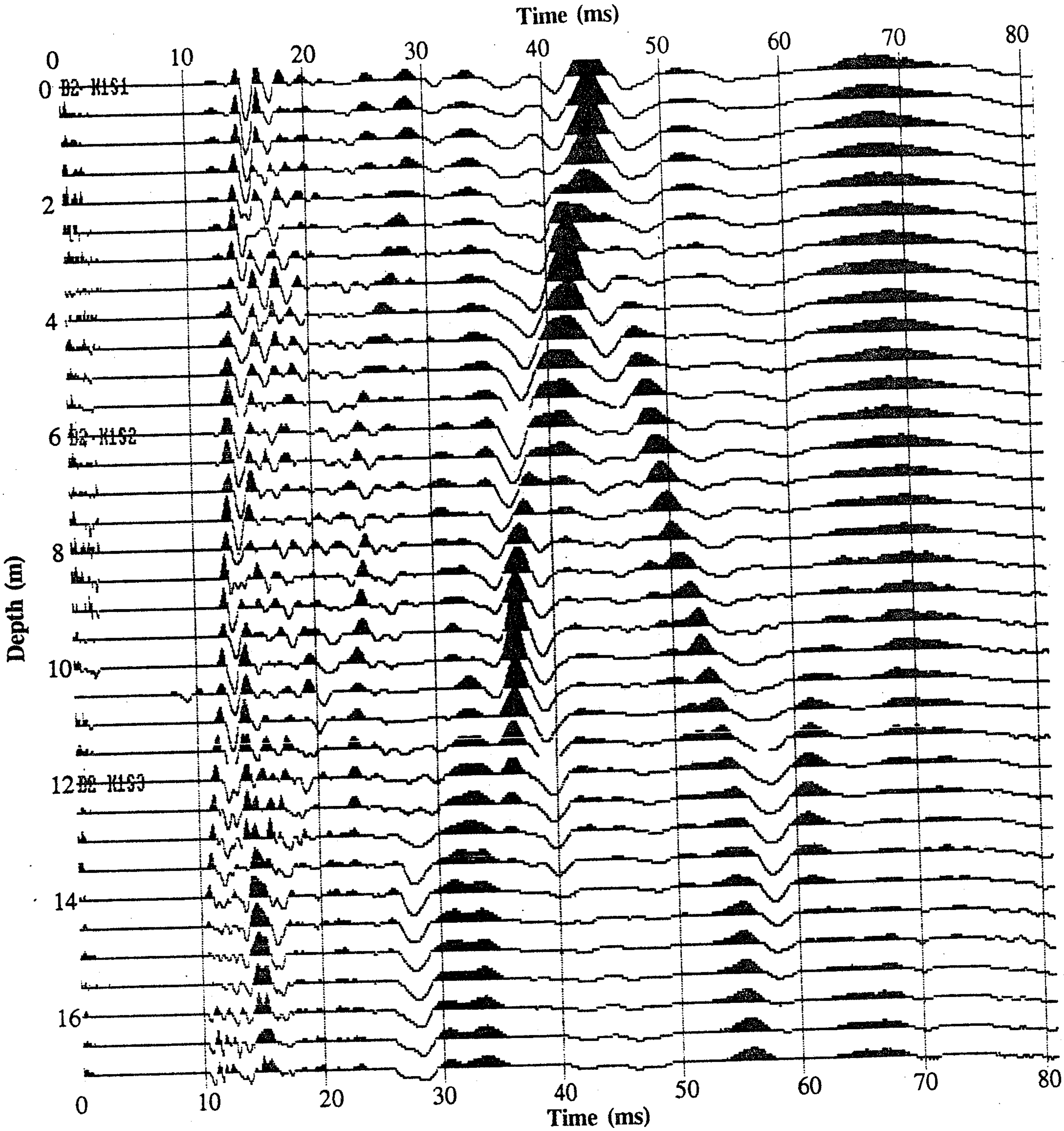


Recording Parameters:
Source: Steel tube - vertical
Source Offset: 24 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 2
AGC Parameters: 400 sample window (centred) AGC factor = 400
Bandpass Filter: 125-375 Hz (12 db rolloffs)

Figure 109

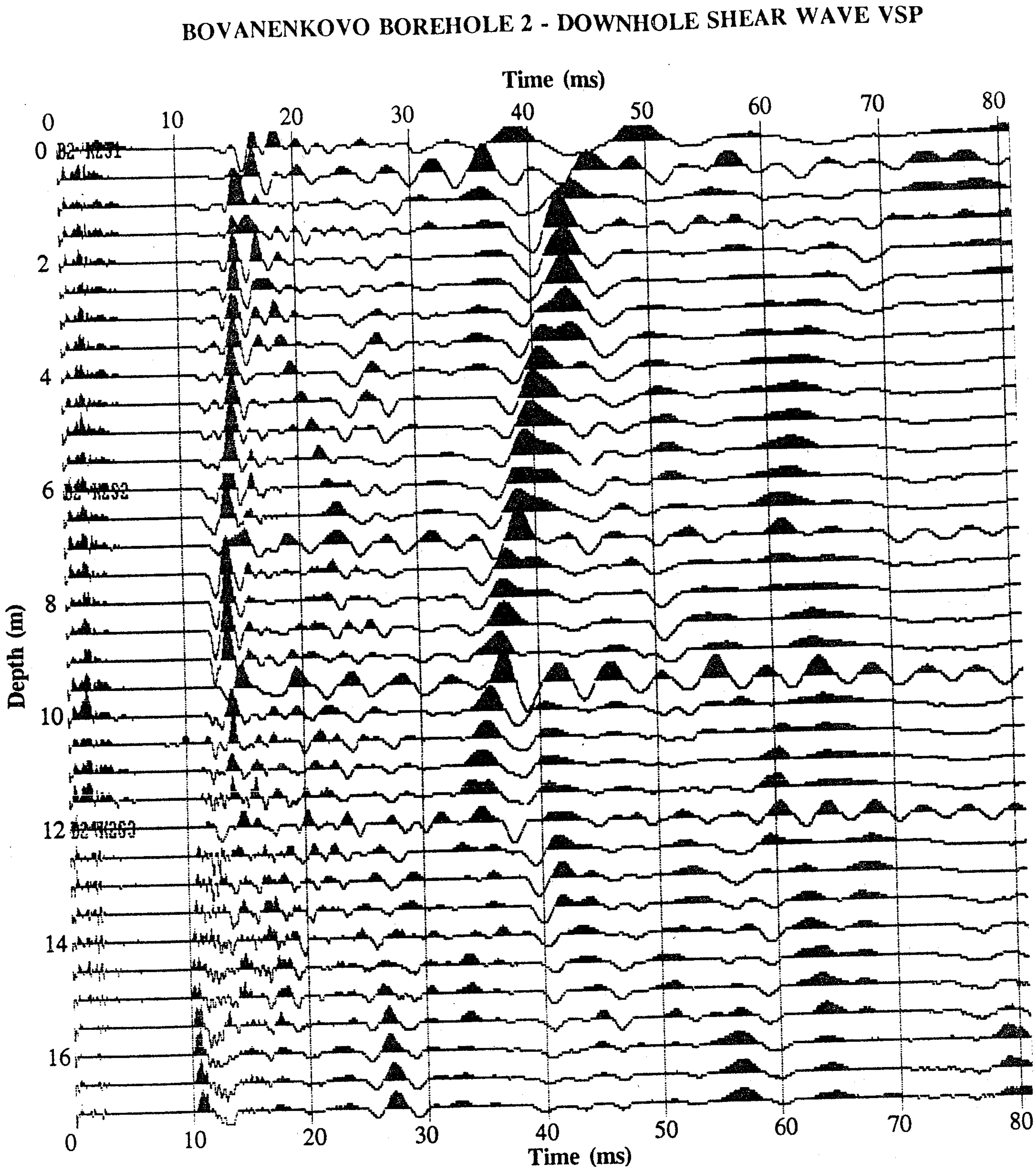
BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:
Source: Steel tube oriented 45° N
Source Offset: 24 m north of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Vertical
AGC Parameters: 400 sample window (centred) AGC factor = 400
Bandpass Filter: N/A

Figure 110

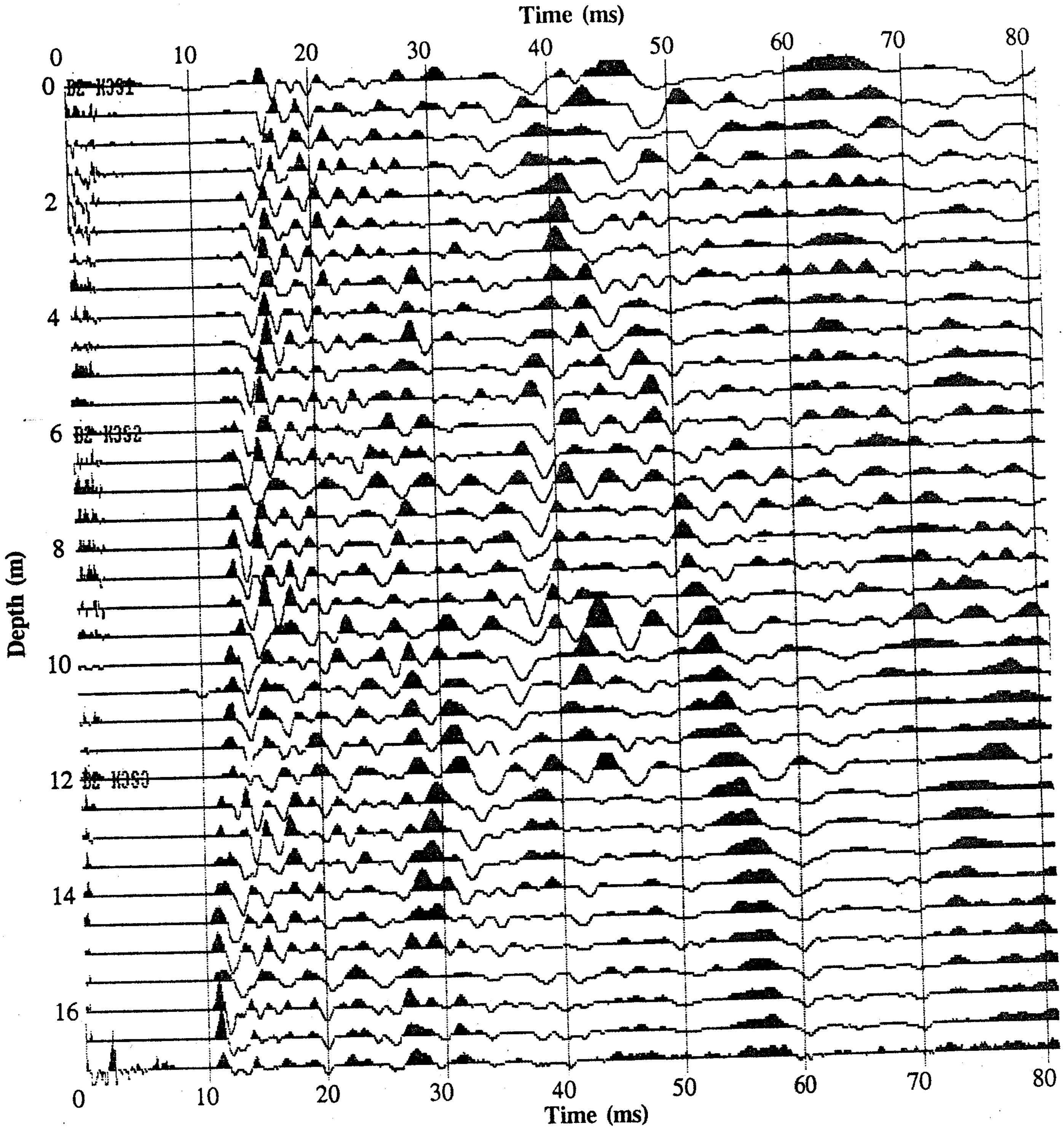


Recording Parameters:
Source: Steel tube oriented 45° N
Source Offset: 24 m north of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 1
AGC Parameters: 400 sample window (centred)
AGC factor = 400
Bandpass Filter: N/A

Figure 111

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP

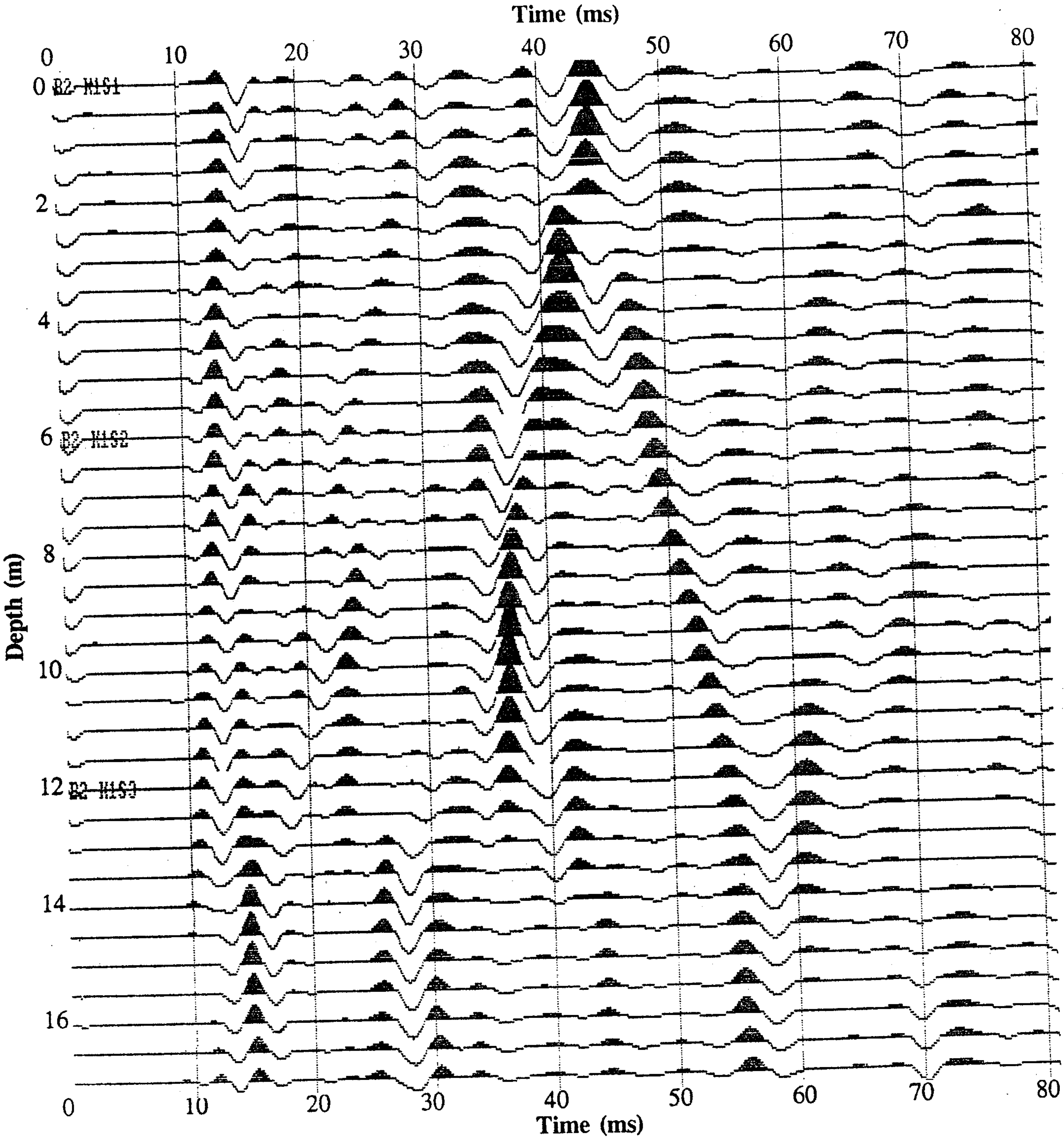


Recording Parameters:
Source: Steel tube oriented 45° N
Source Offset: 24 m north of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 2
AGC Parameters: 400 sample window (centred)
AGC factor = 400
Bandpass Filter: N/A

Figure 112

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:

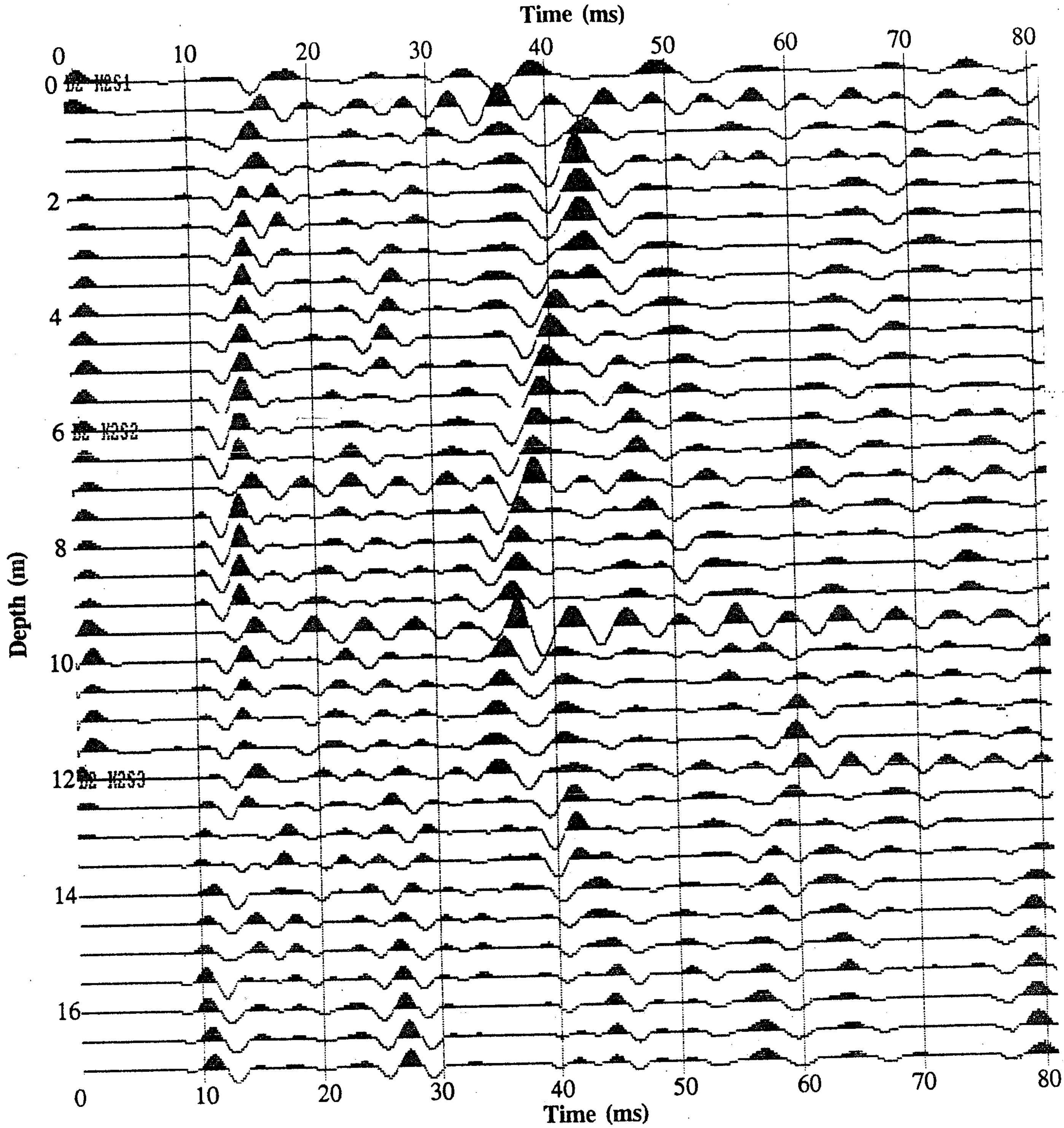
Source: Steel tube oriented 45° N
Source Offset: 24 m north of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:

Component Plotted: Vertical
AGC Parameters: 400 sample window (centred)
AGC factor = 400
Bandpass Filter: 125-375 Hz (12 db rolloffs)

Figure 113

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:

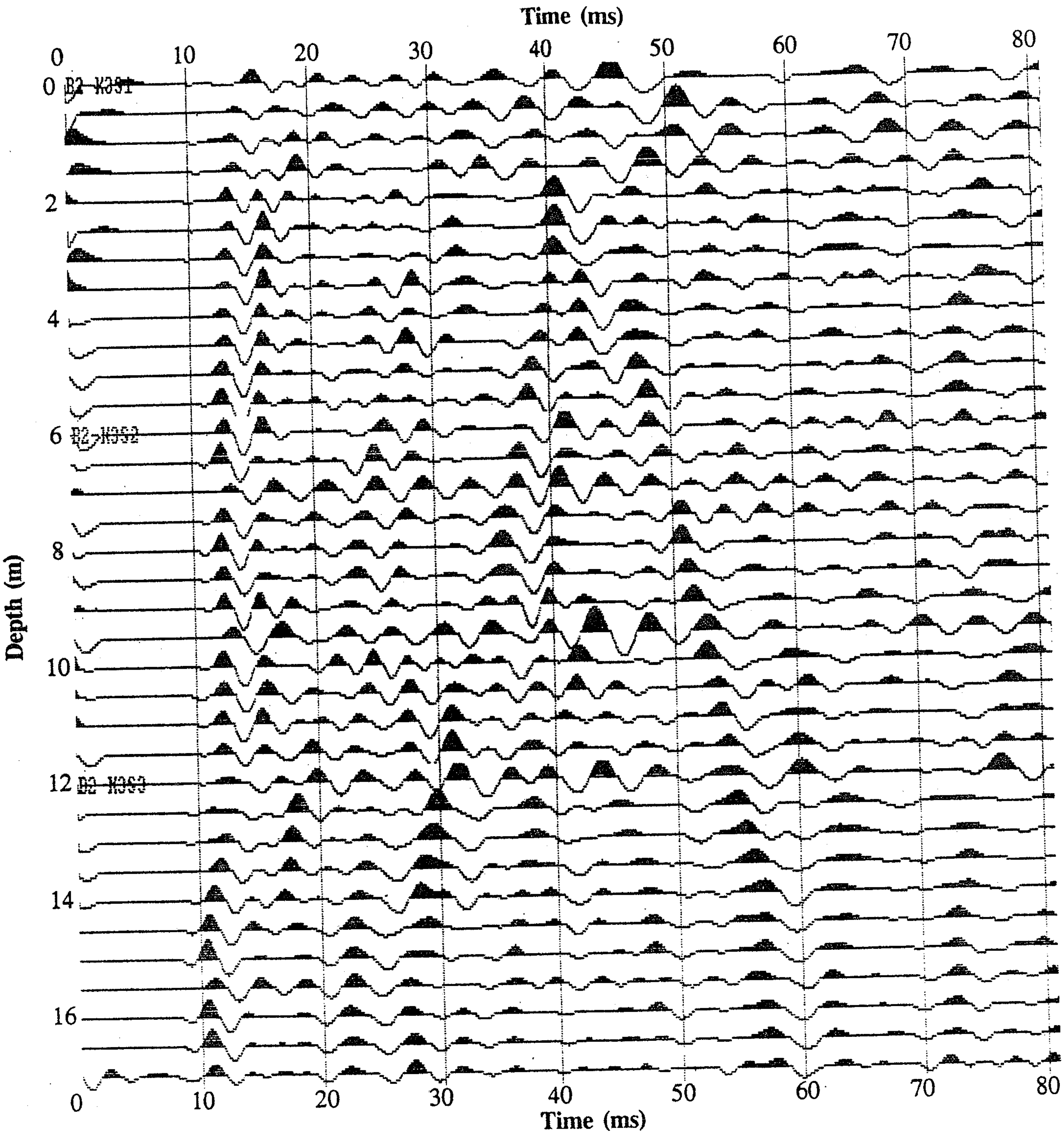
Source: Steel tube oriented 45° N
Source Offset: 24 m north of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:

Component Plotted: Horizontal 1
AGC Parameters: 400 sample window (centred)
AGC factor = 400
Bandpass Filter: 125-375 Hz (12 db rolloffs)

Figure 114

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:

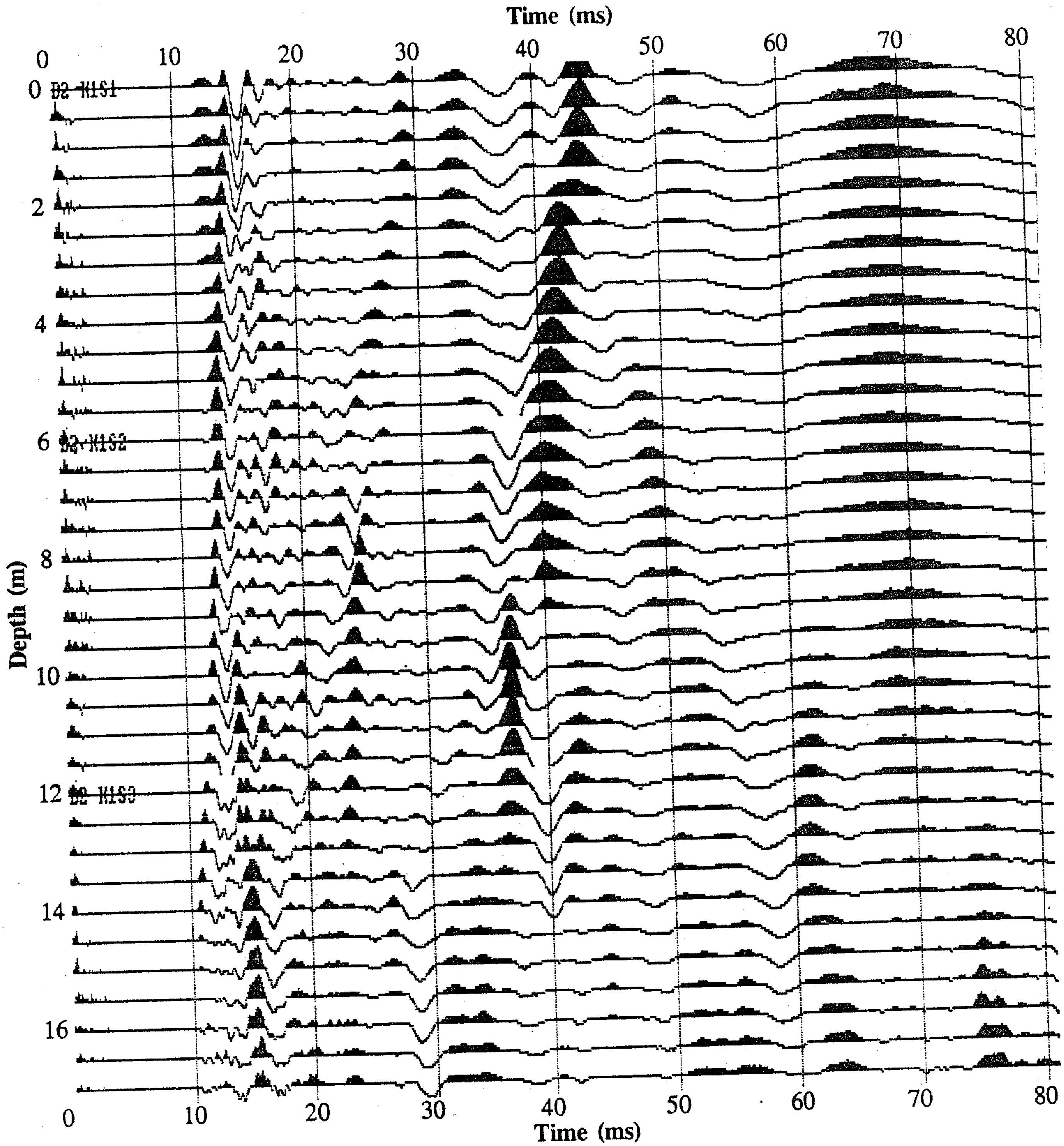
Source: Steel tube oriented 45° N
Source Offset: 24 m north of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:

Component Plotted: Horizontal 2
AGC Parameters: 400 sample window (centred) AGC factor = 400
Bandpass Filter: 125-375 Hz (12 db rolloffs)

Figure 115

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP

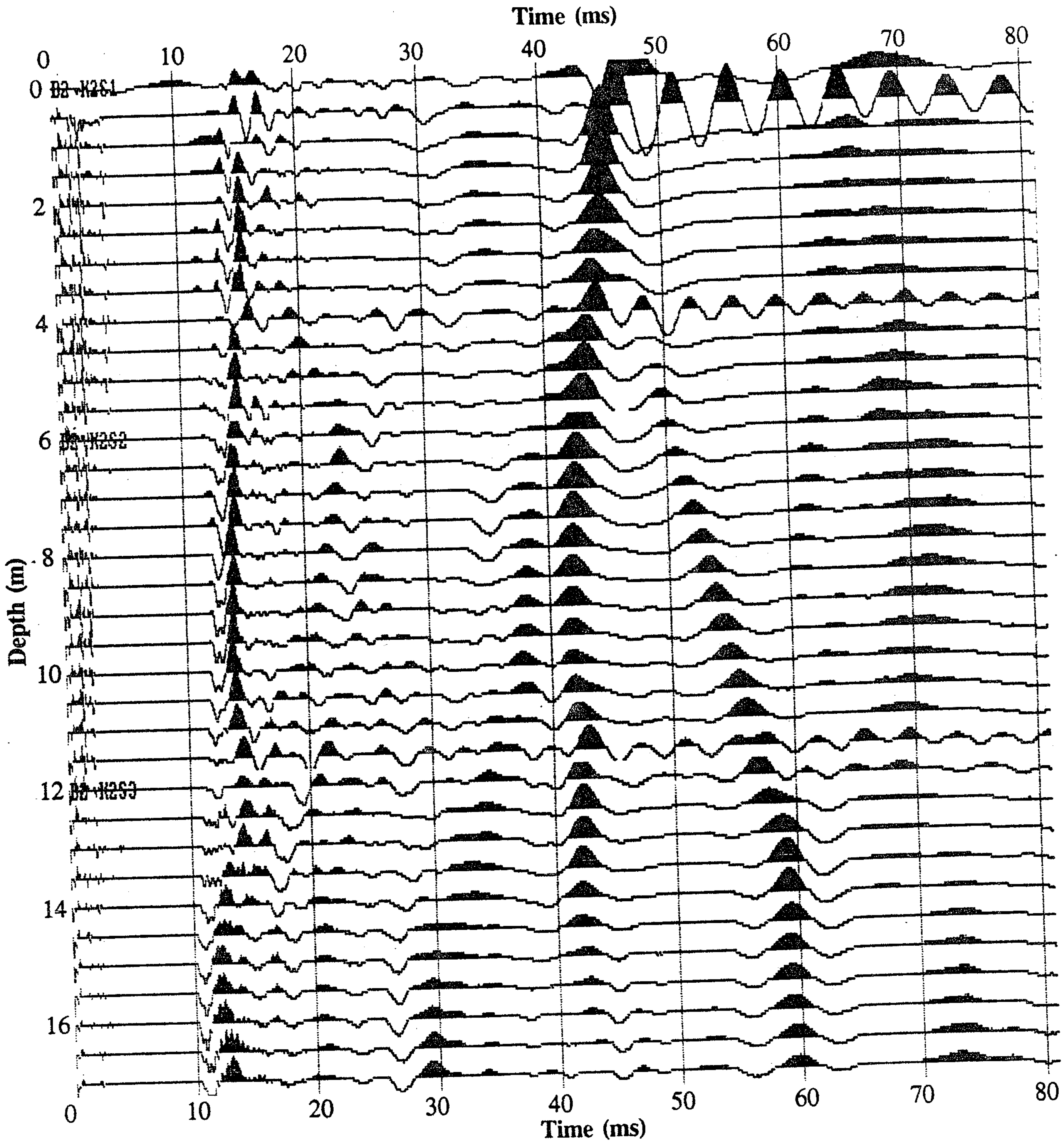


Recording Parameters:
Source: Steel tube oriented 45° W
Source Offset: 24 m north of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Vertical
AGC Parameters: 400 sample window (centred) AGC factor = 400
Bandpass Filter: N/A

Figure 116

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:

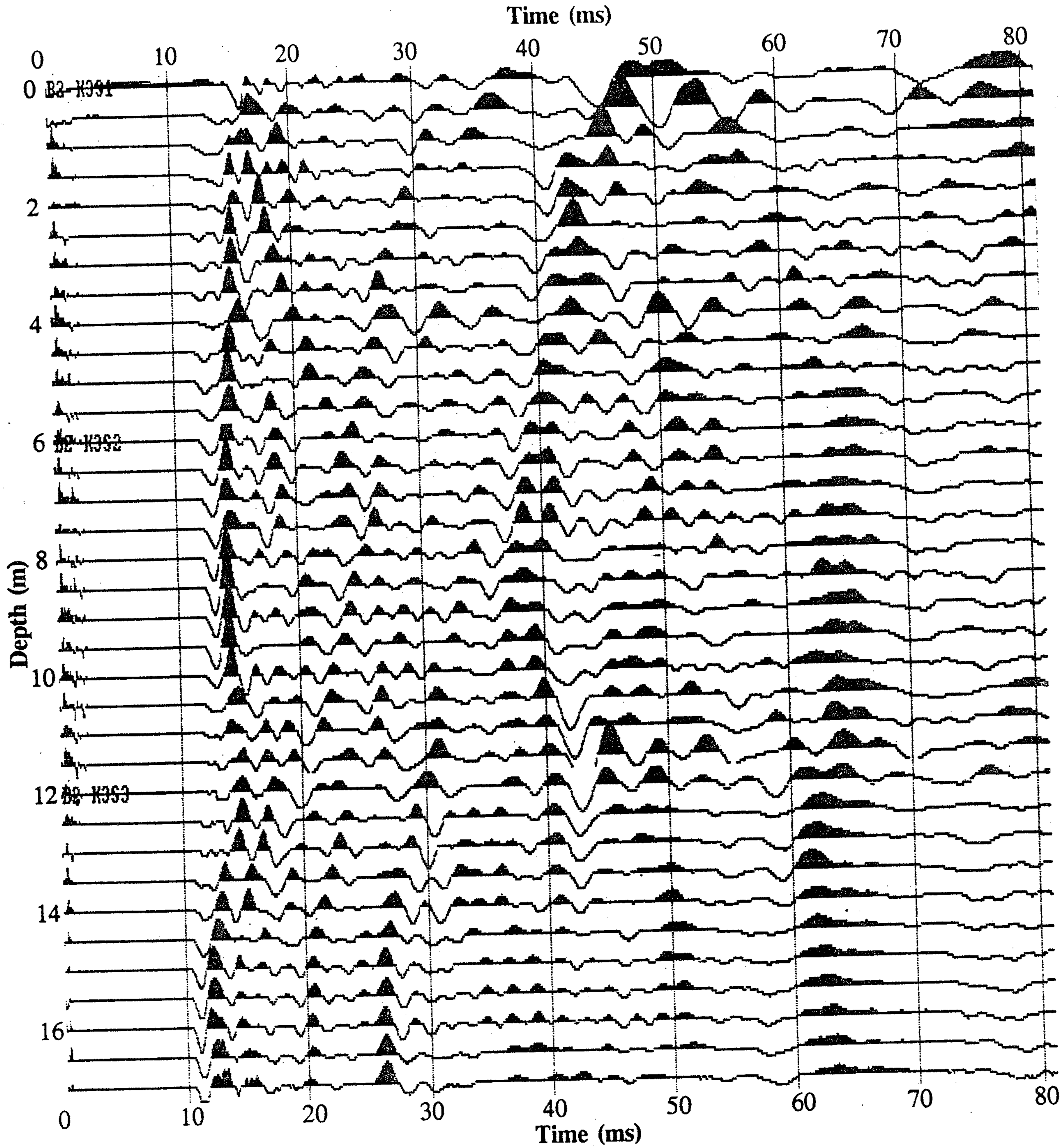
Source: Steel tube oriented 45° W
Source Offset: 24 m north of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:

Component Plotted: Horizontal 1
AGC Parameters: 400 sample window (centred) AGC factor = 400
Bandpass Filter: N/A

Figure 117

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:

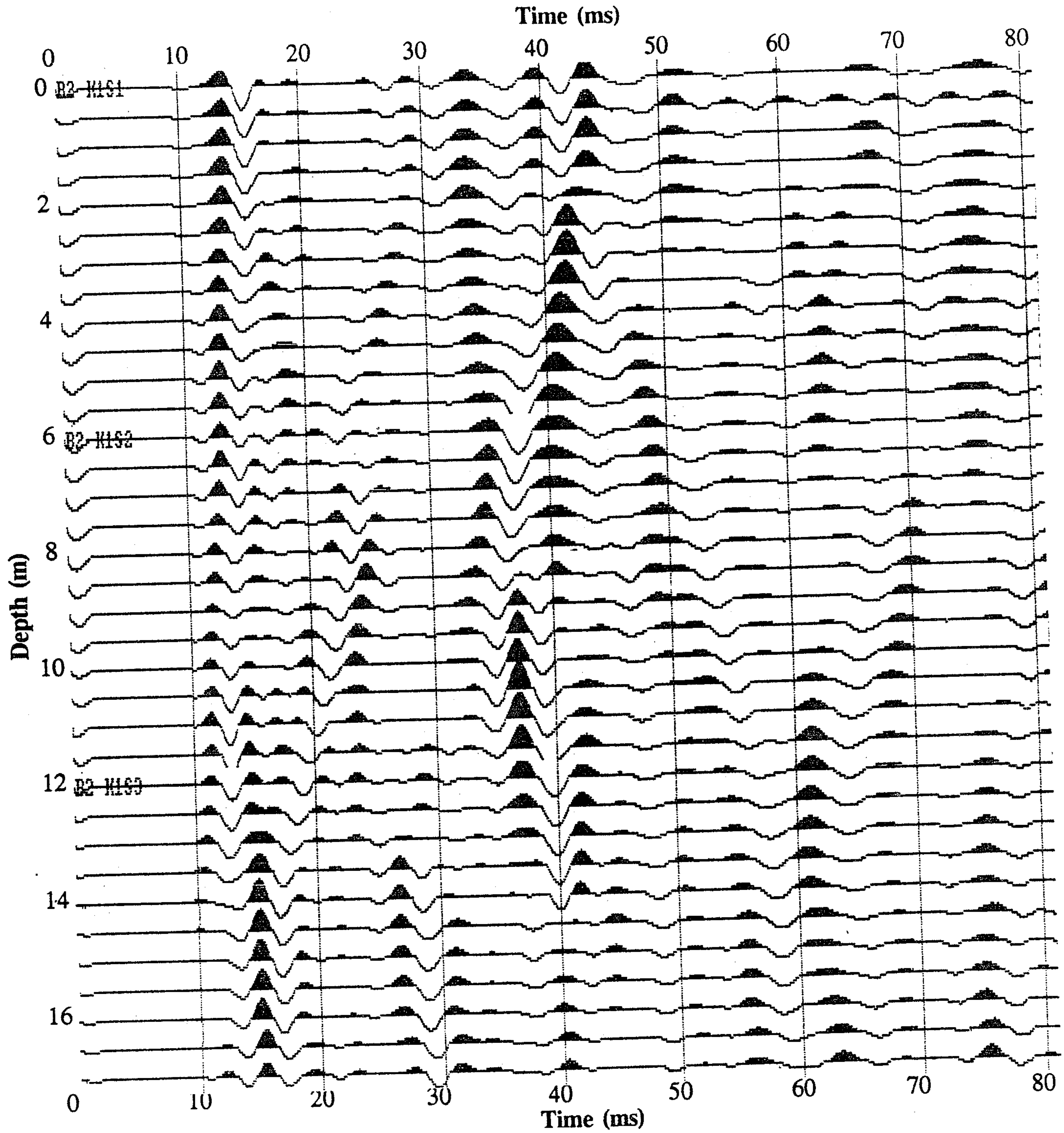
Source: Steel tube oriented 45° W
Source Offset: 24 m north of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:

Component Plotted: Horizontal 2
AGC Parameters: 400 sample window (centred)
AGC factor = 400
Bandpass Filter: N/A

Figure 118

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP

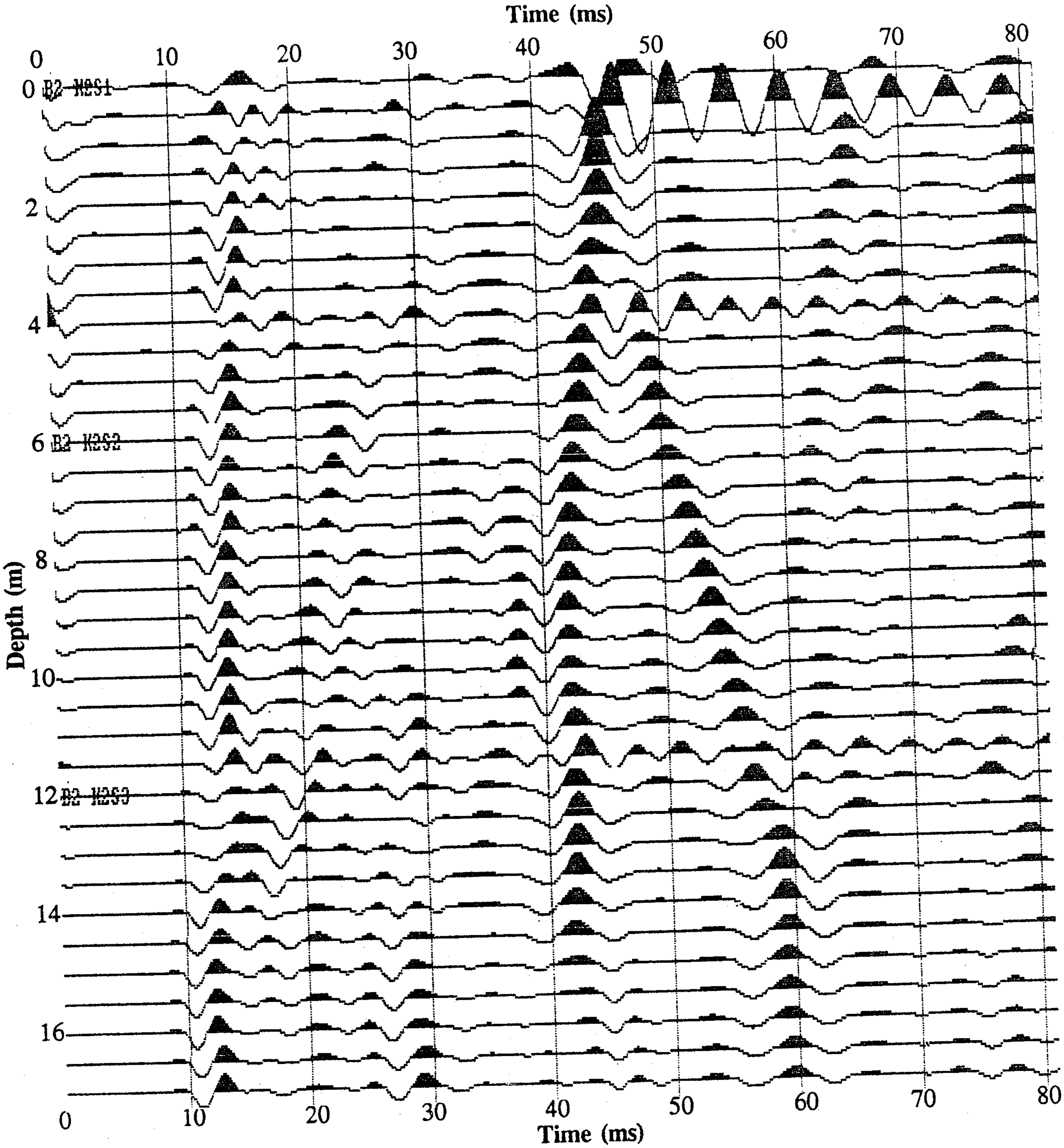


Recording Parameters:
Source: Steel tube oriented 45° W
Source Offset: 24 m north of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Vertical
AGC Parameters: 400 sample window (centred) AGC factor = 400
Bandpass Filter: 125-375 Hz (12 db rolloffs)

Figure 119

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP

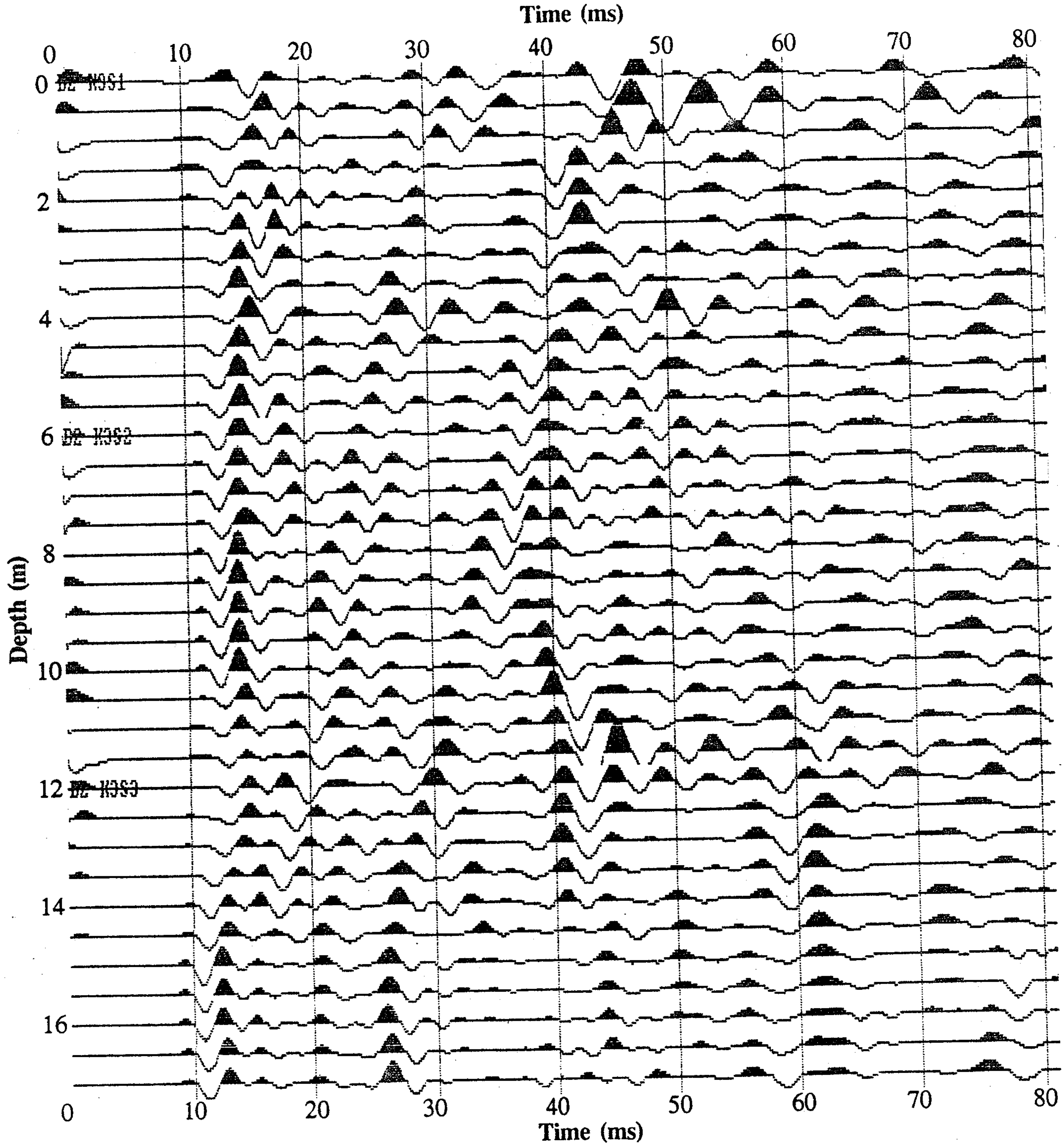


Recording Parameters:
Source: Steel tube oriented 45° W
Source Offset: 24 m north of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 1
AGC Parameters: 400 sample window (centred)
AGC factor = 400
Bandpass Filter: 125-375 Hz (12 db rolloffs)

Figure 120

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP

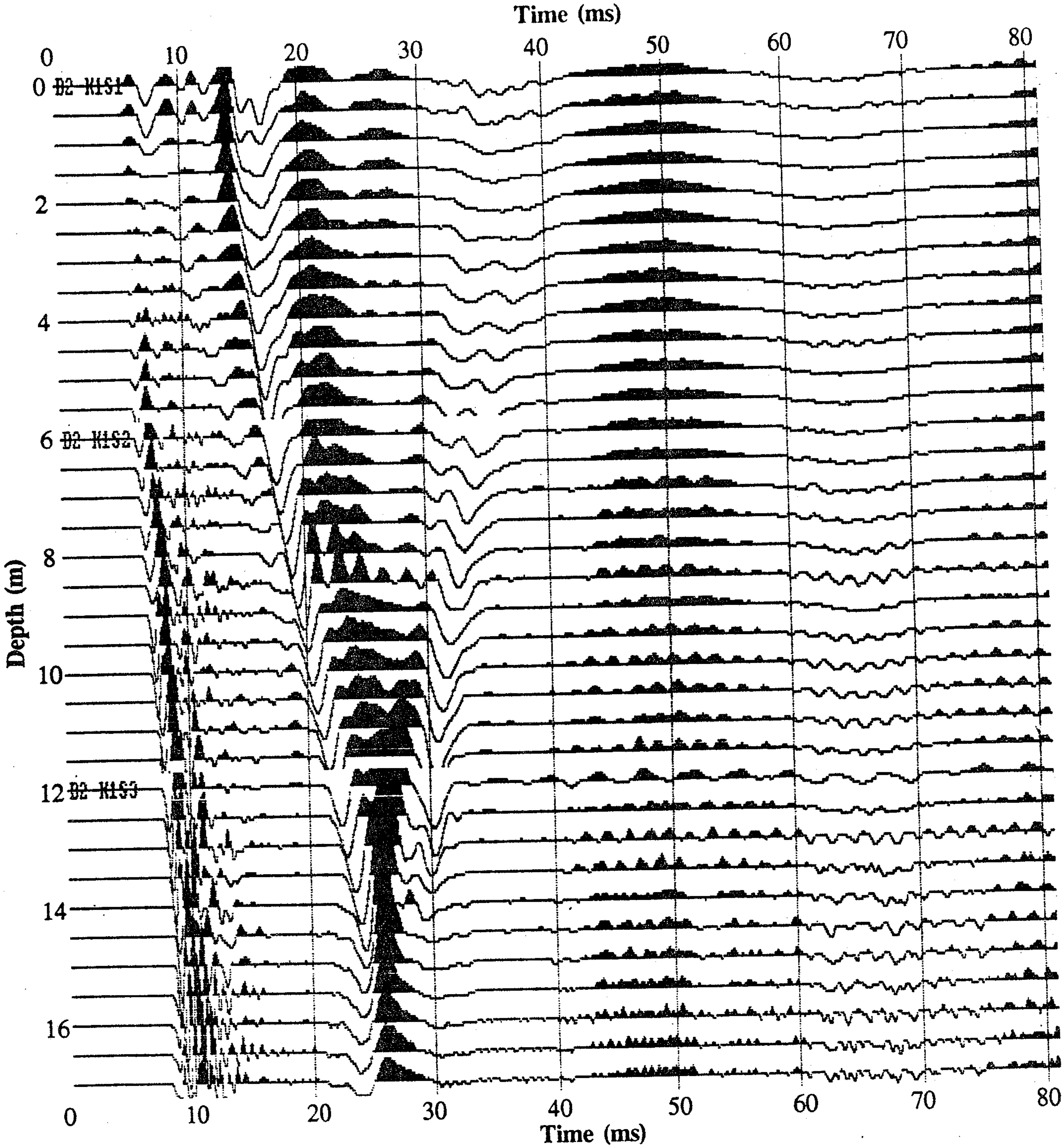


Recording Parameters:
Source: Steel tube oriented 45° W
Source Offset: 24 m north of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 2
AGC Parameters: 400 sample window (centred)
AGC factor = 400
Bandpass Filter: 125-375 Hz (12 db rolloffs)

Figure 121

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP

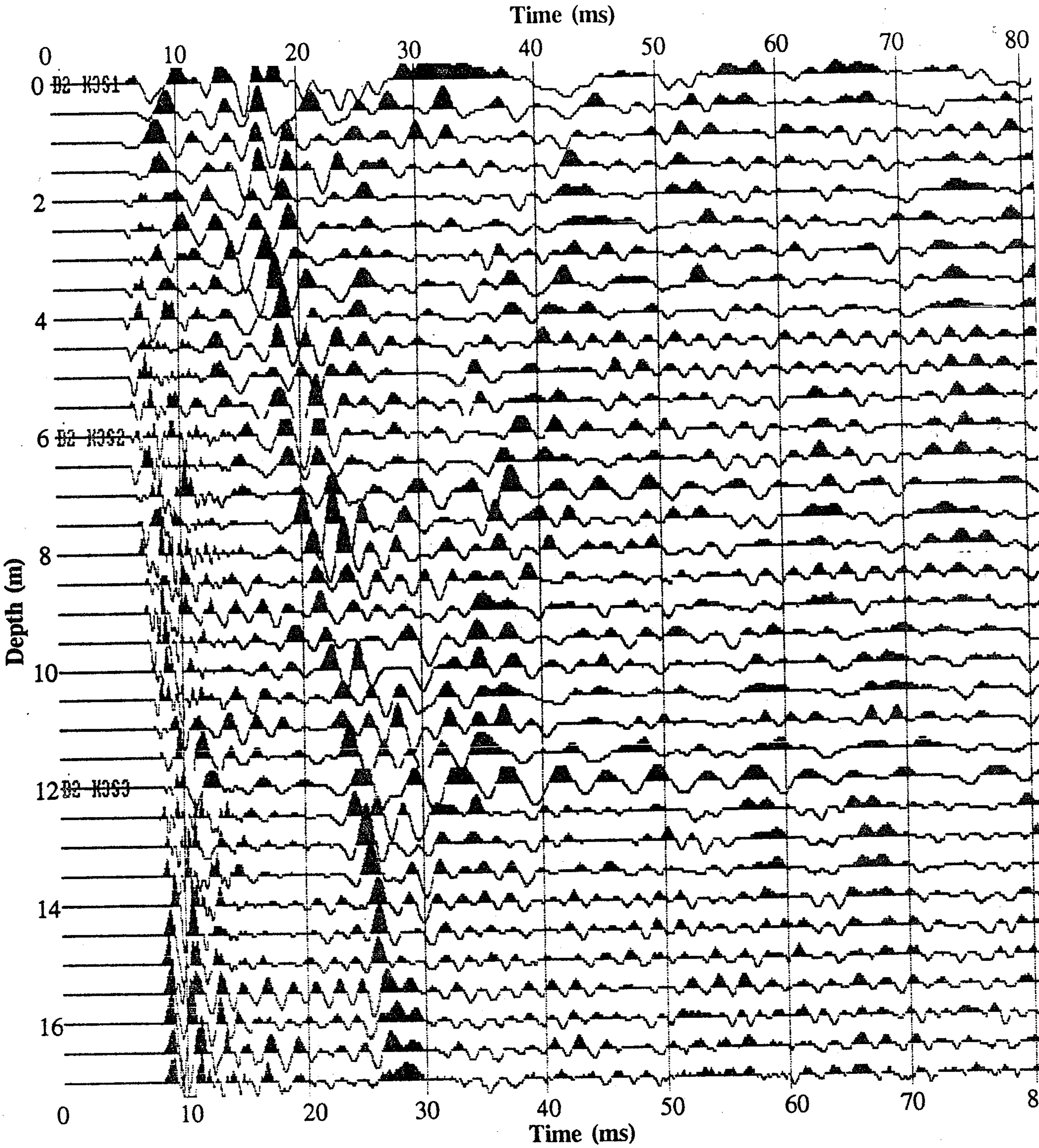


Recording Parameters:
Source: Steel tube oriented 45° N
Source Offset: 11 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Vertical
AGC Parameters: 400 sample window (centred)
AGC factor = 400
Bandpass Filter: N/A

Figure 122

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP

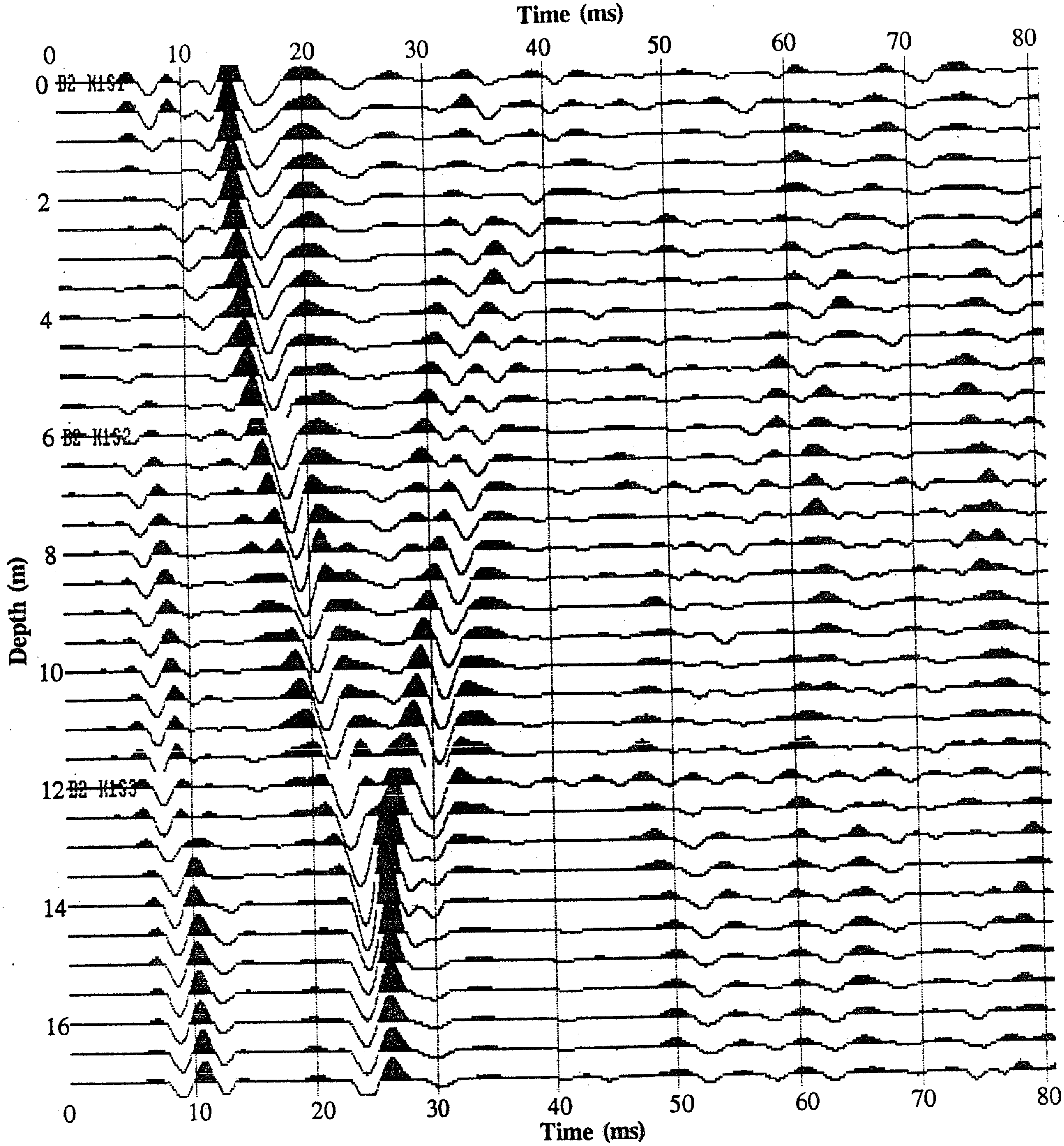


Recording Parameters:
Source: Steel tube oriented 45° N
Source Offset: 11 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 2
AGC Parameters: 400 sample window (centred)
AGC factor = 400
Bandpass Filter: N/A

Figure 123

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP

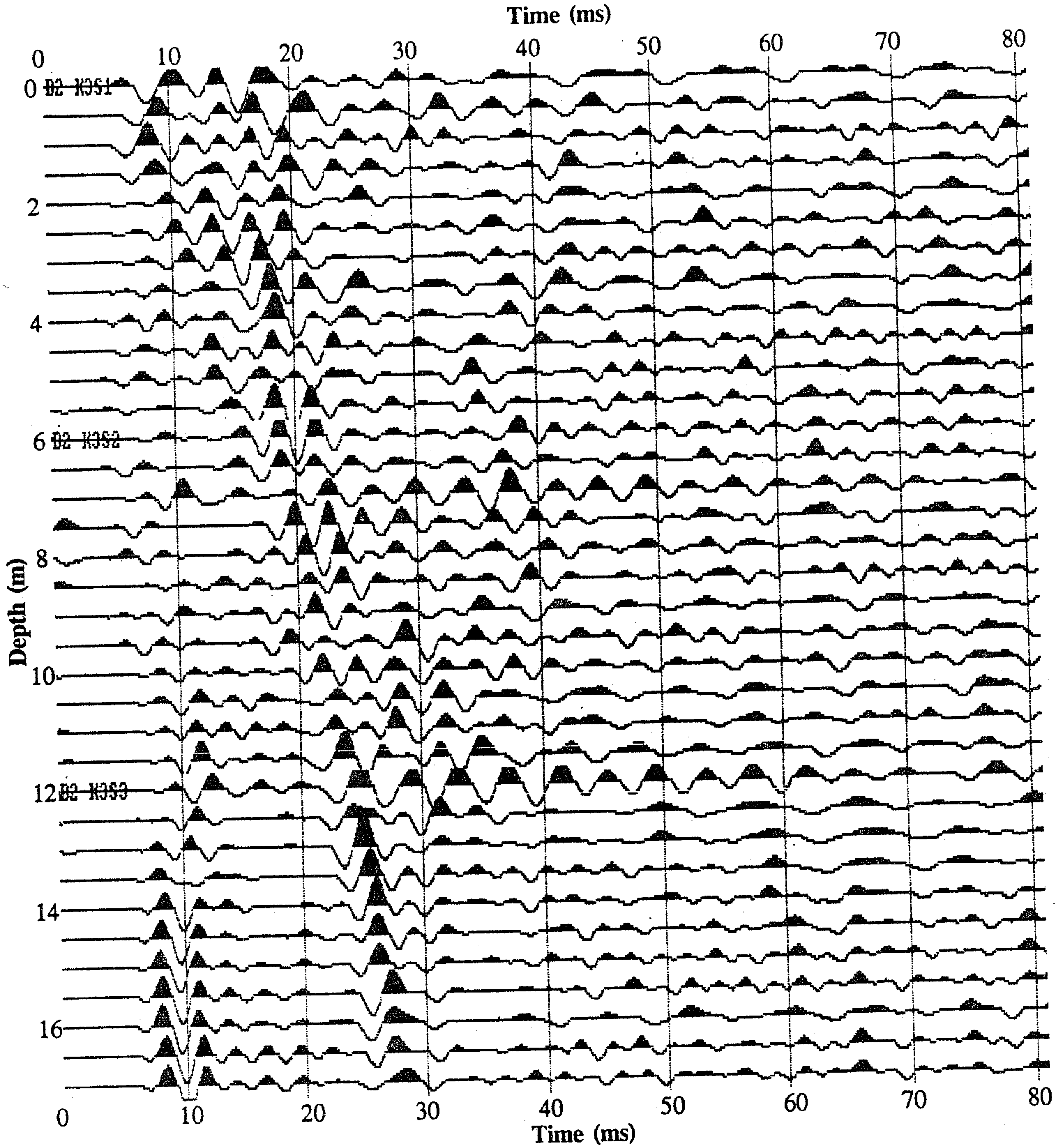


Recording Parameters:
Source: Steel tube oriented 45° N
Source Offset: 11 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Vertical
AGC Parameters: 400 sample window (centred) AGC factor = 400
Bandpass Filter: 125-375 Hz (12 db rolloffs)

Figure 124

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:

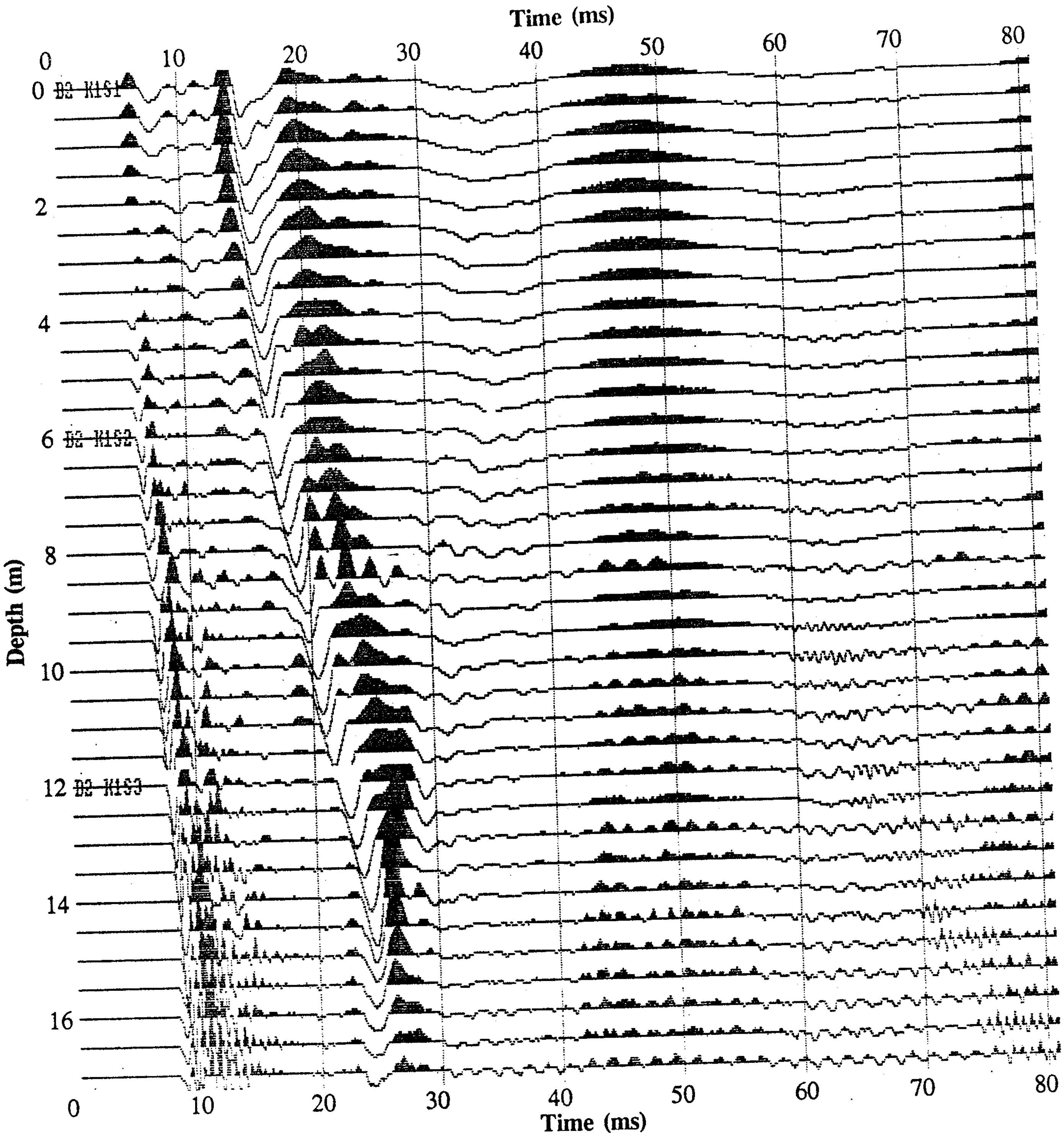
Source: Steel tube oriented 45° N
Source Offset: 11 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:

Component Plotted: Horizontal 2
AGC Parameters: 400 sample window (centred)
AGC factor = 400
Bandpass Filter: 125-375 Hz (12 db rolloffs)

Figure 125

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:

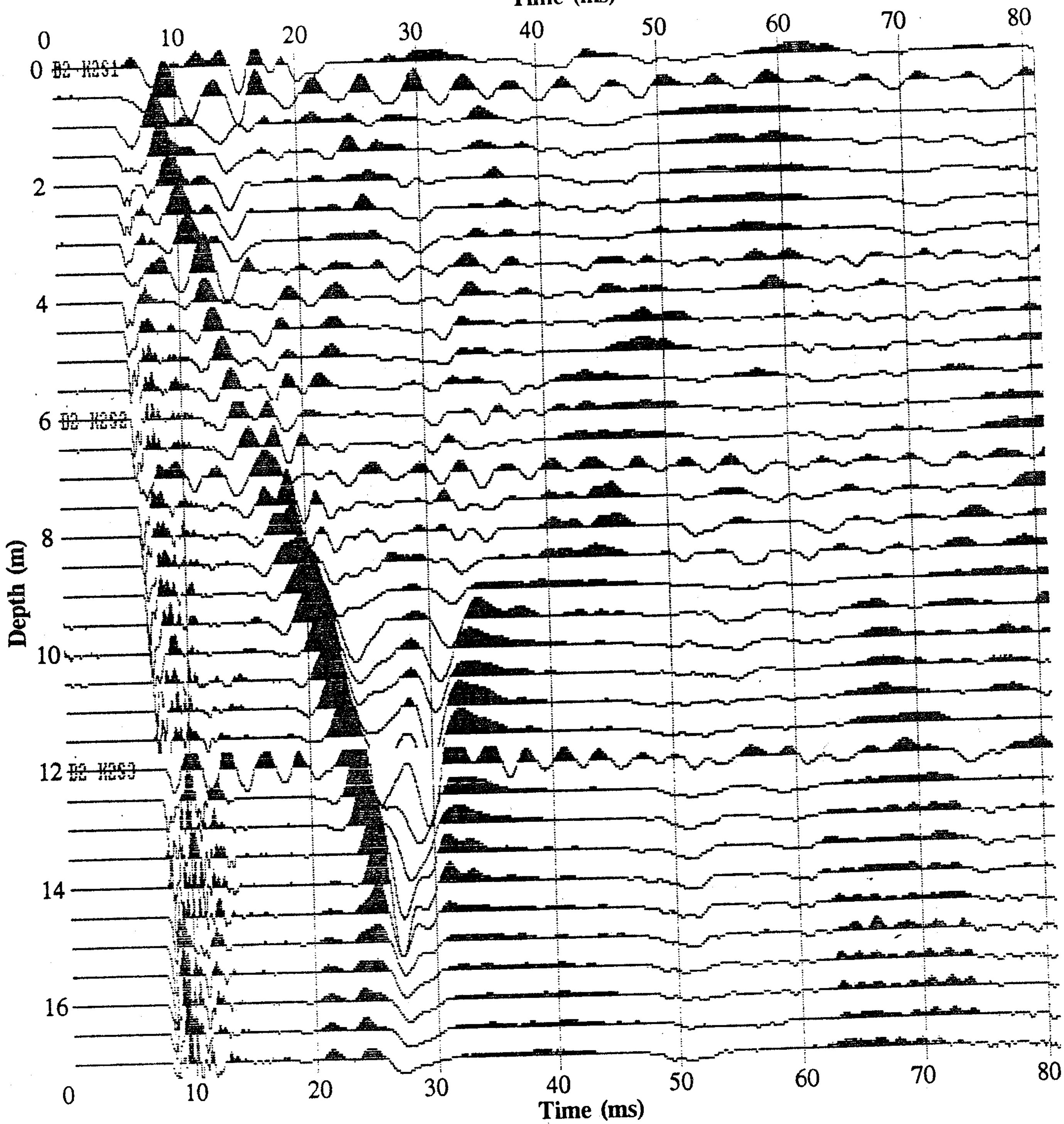
Source: Steel tube oriented 45° W
Source Offset: 11.5 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole
3-component
Sampling Interval: 0.05 ms

Display Parameters:

Component Plotted: Vertical
AGC Parameters: 400 sample window (centred)
AGC factor = 400
Bandpass Filter: N/A

Figure 126

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:

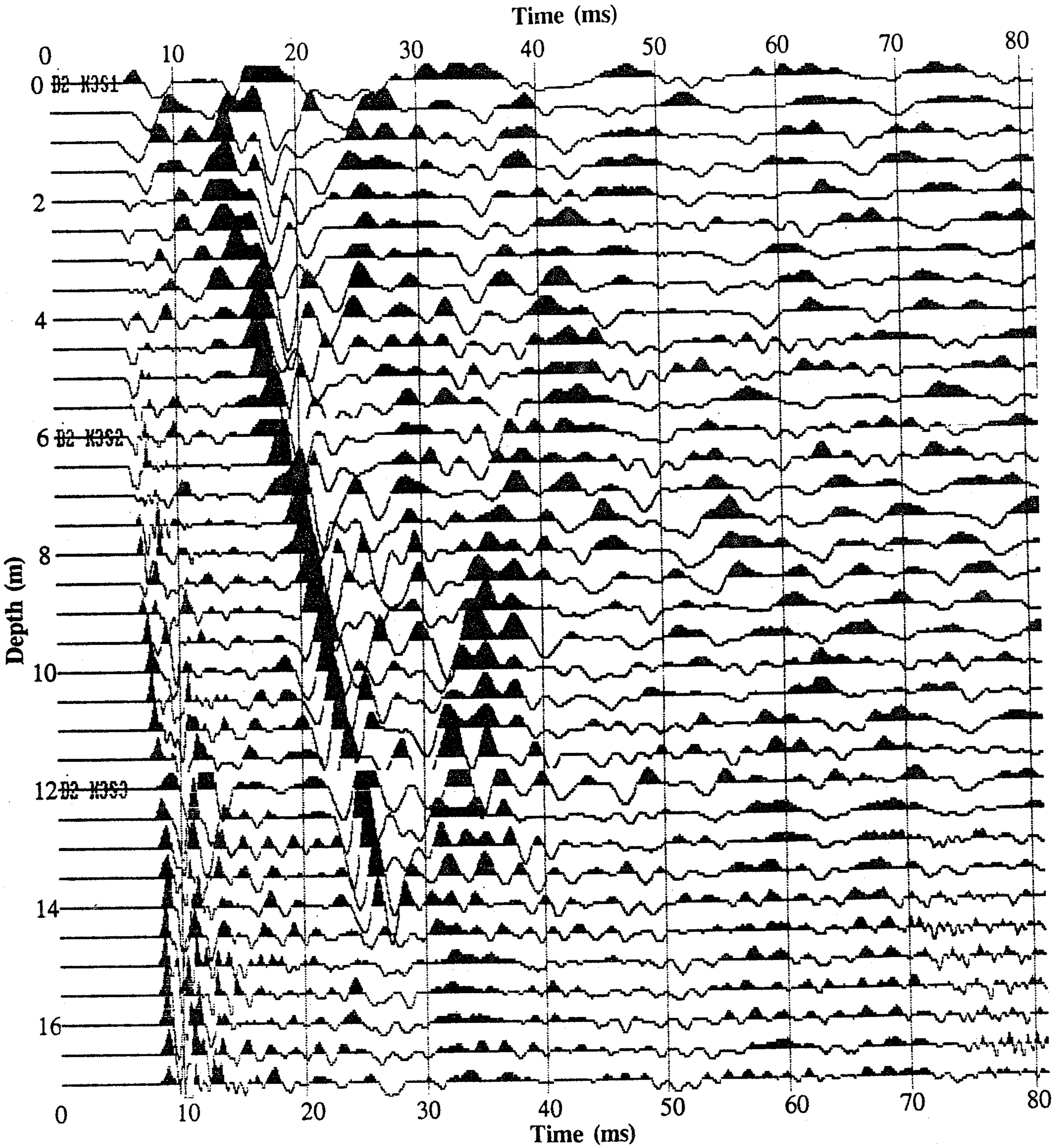
Source: Steel tube oriented 45° W
Source Offset: 11.5 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:

Component Plotted: Horizontal 1
AGC Parameters: 400 sample window (centred) AGC factor = 400
Bandpass Filter: NA

Figure 127

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:

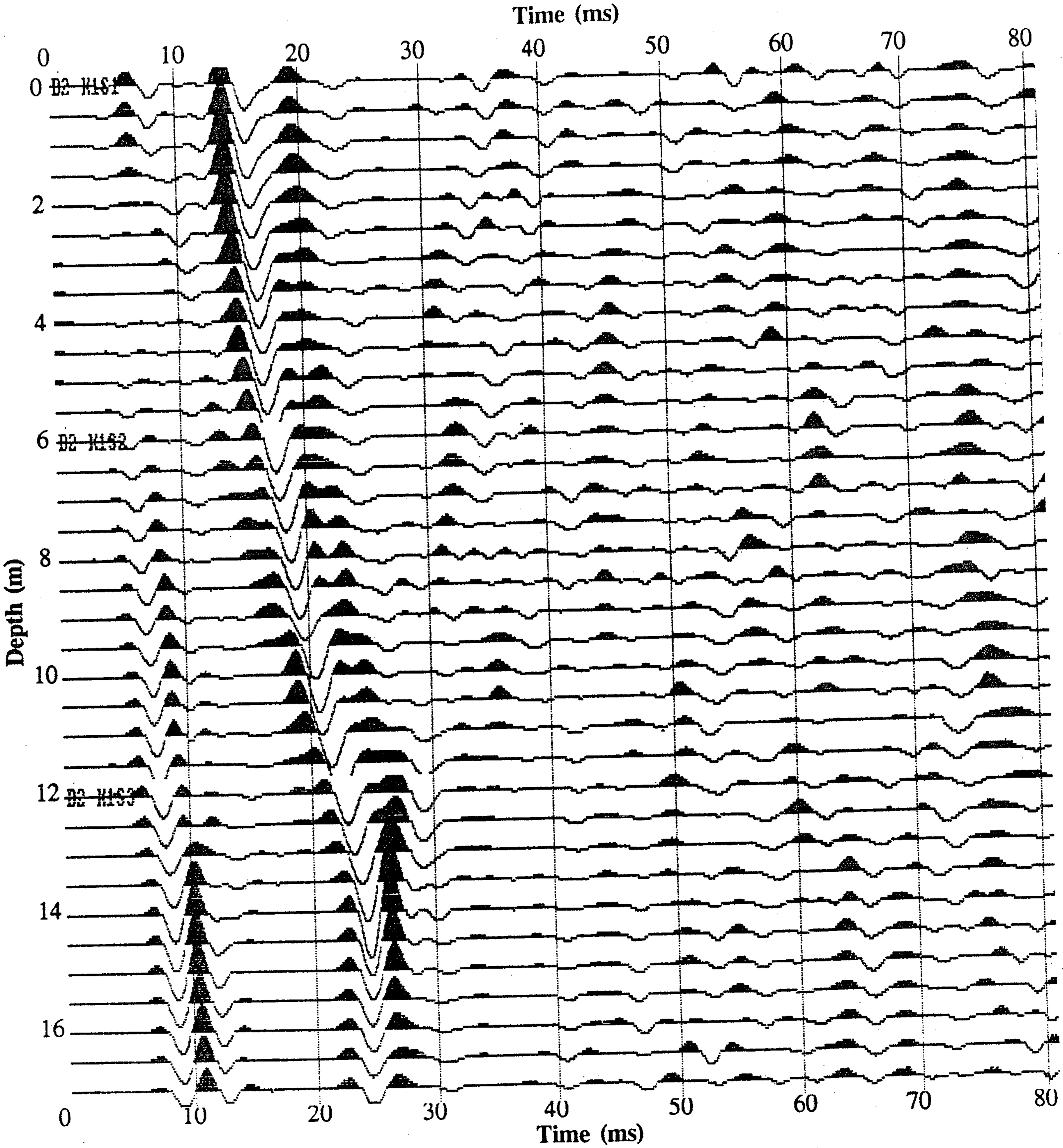
Source: Steel tube oriented 45° W
Source Offset: 11.5 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:

Component Plotted: Horizontal 2
AGC Parameters: 400 sample window (centred)
AGC factor = 400
Bandpass Filter: N/A

Figure 128

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP

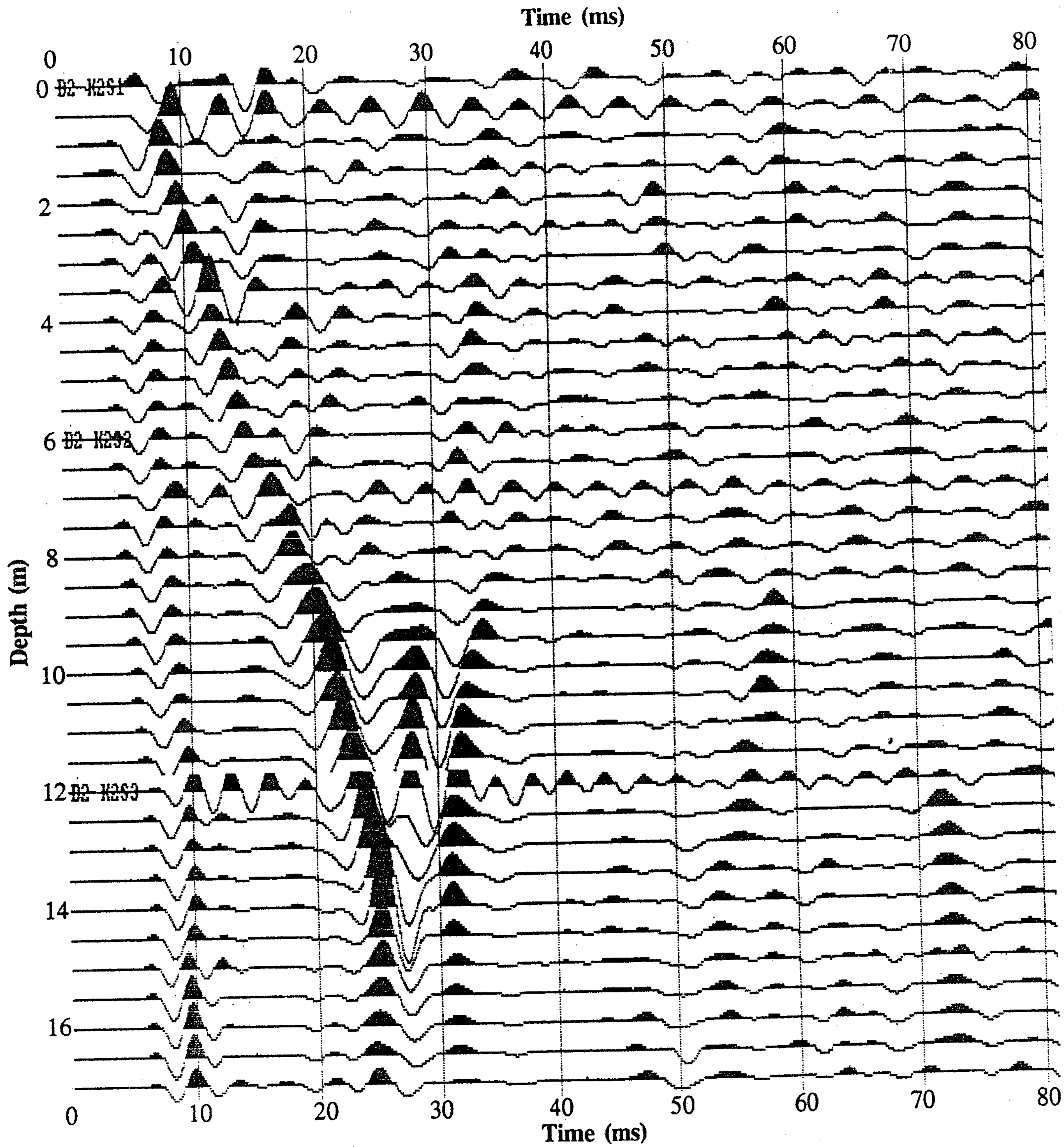


Recording Parameters:
Source: Steel tube oriented 45° W
Source Offset: 11.5 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Vertical
AGC Parameters: 400 sample window (centred) AGC factor = 400
Bandpass Filter: 125-375 Hz (12 db rolloffs)

Figure 129

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP

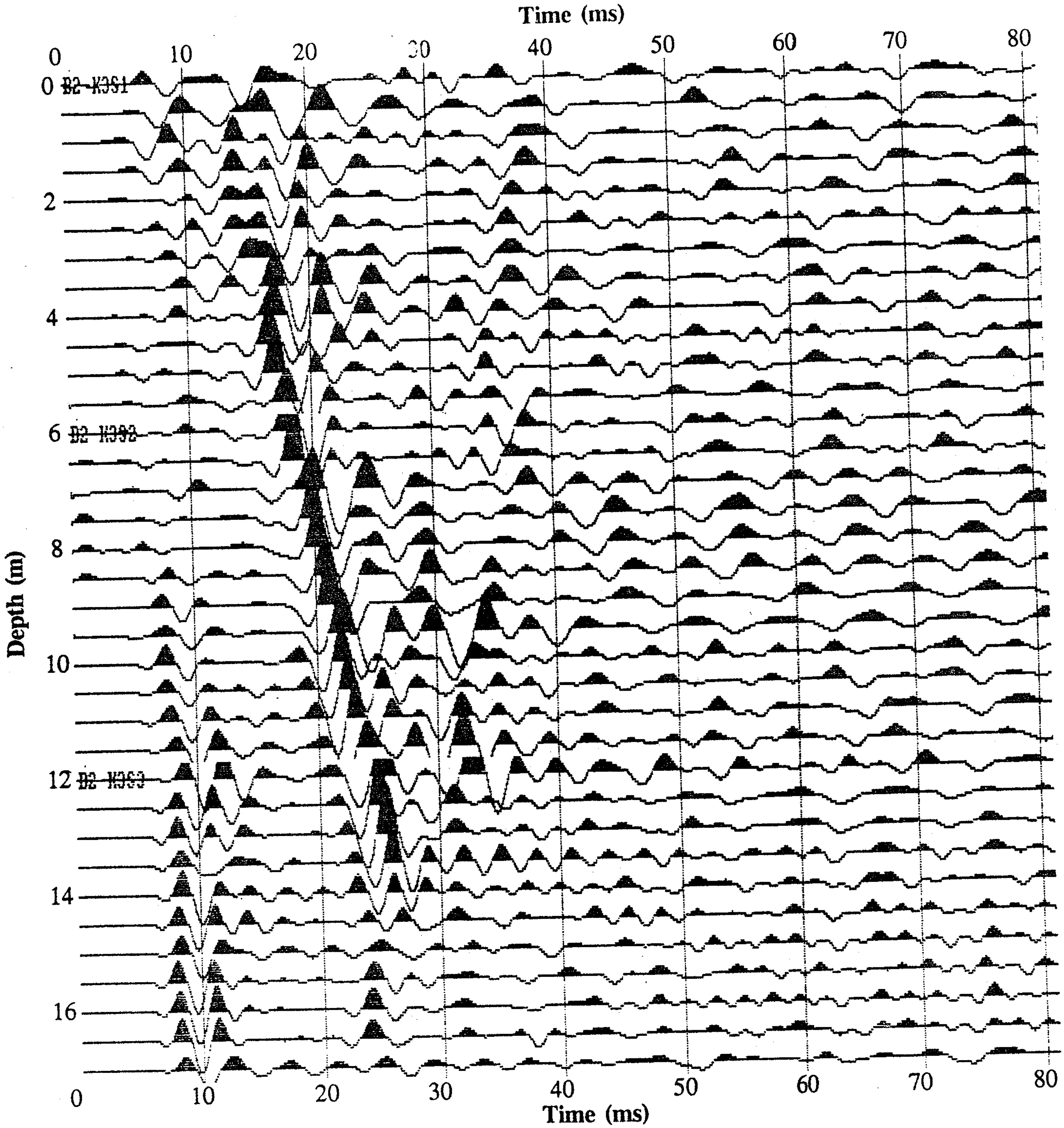


Recording Parameters:
Source: Steel tube oriented 45° W
Source Offset: 11.5 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 1
AGC Parameters: 400 sample window (centred)
AGC factor = 400
Bandpass Filter: 125-375 Hz (12 db rolloffs)

Figure 130

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:

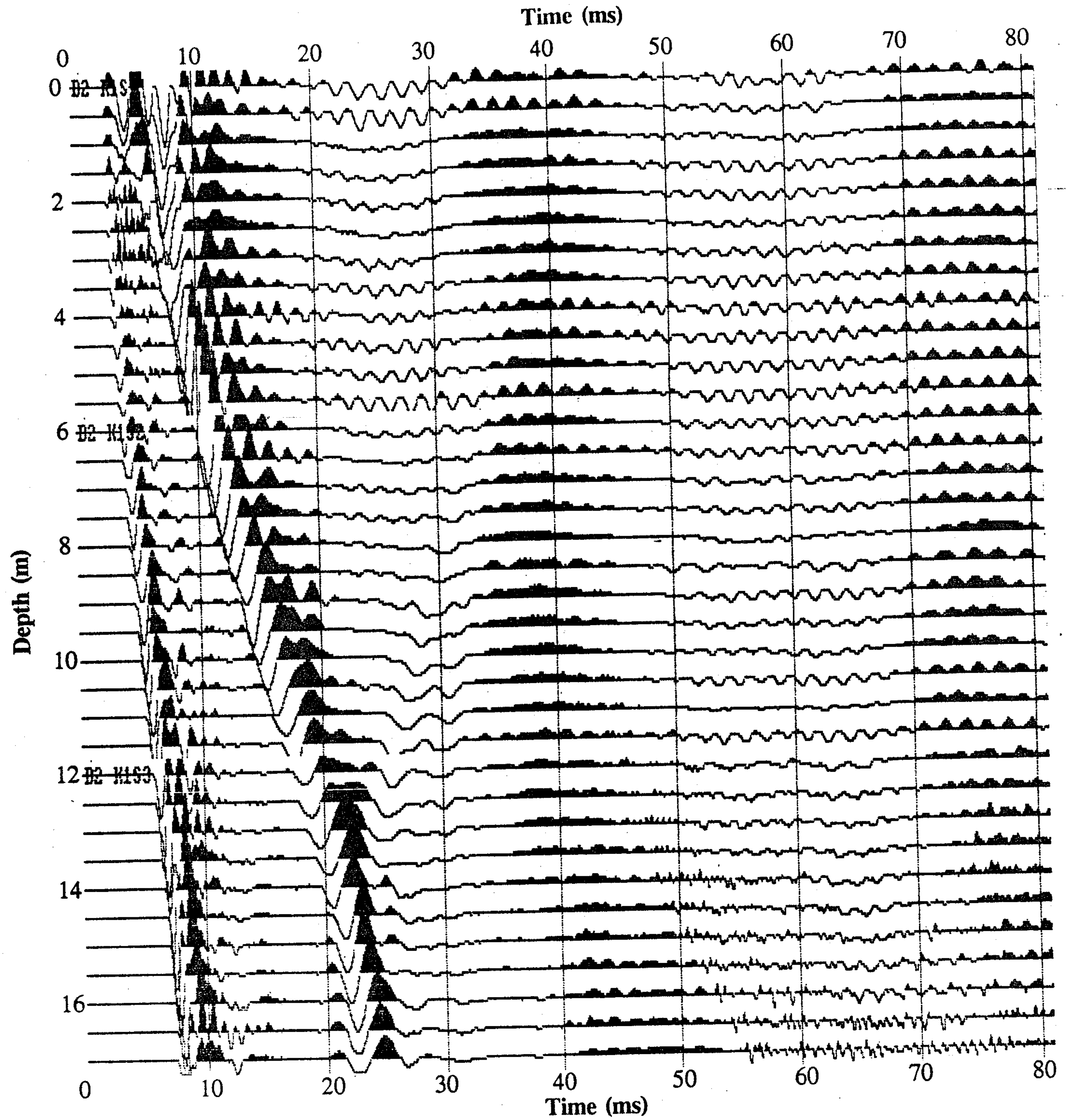
Source: Steel tube oriented 45° W
Source Offset: 11.5 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:

Component Plotted: Horizontal 2
AGC Parameters: 400 sample window (centred) AGC factor = 400
Bandpass Filter: 125-375 Hz (12 db rolloffs)

Figure 131

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:

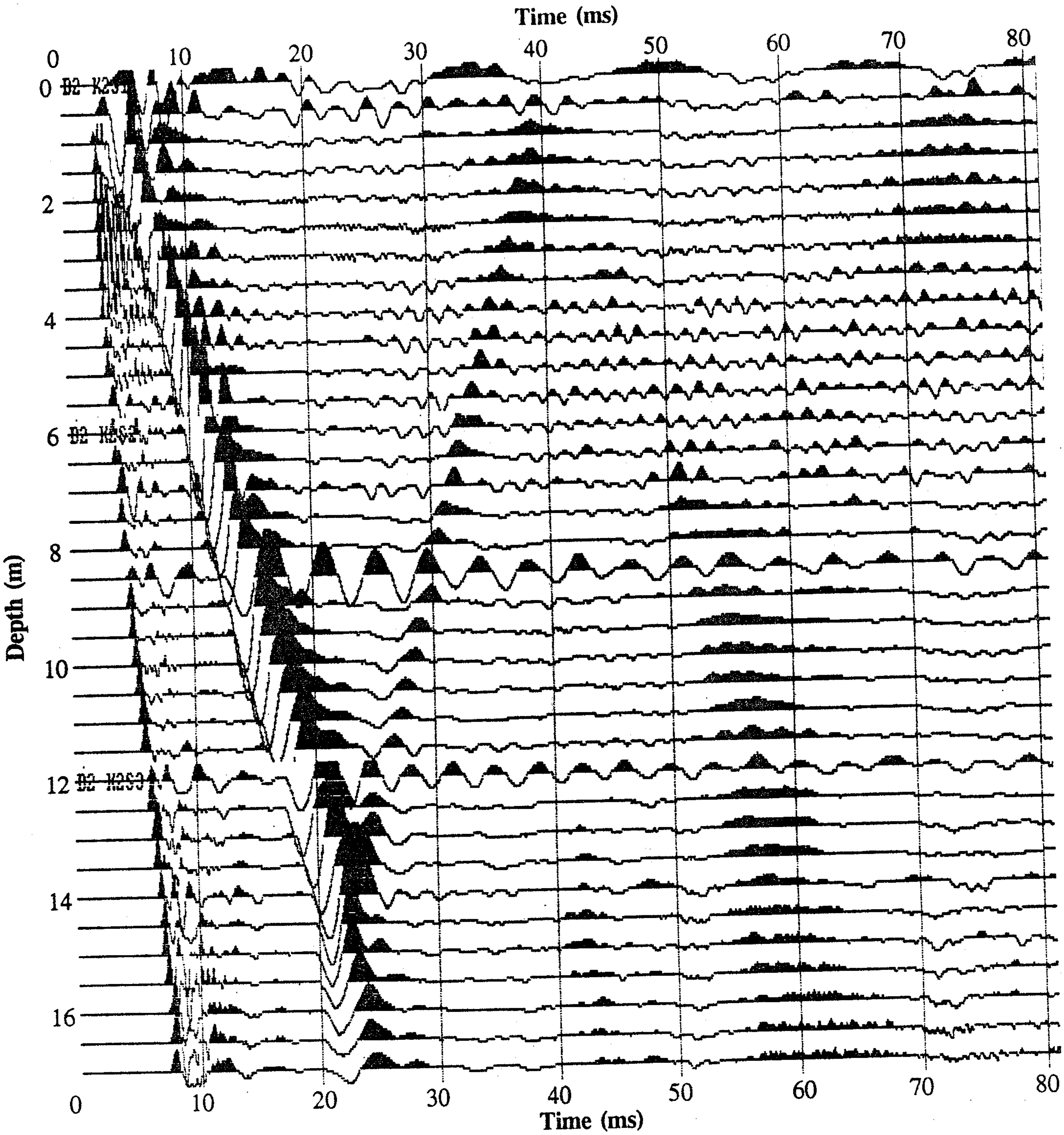
Source: Steel tube oriented 45° N
Source Offset: 5 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:

Component Plotted: Vertical
AGC Parameters: 400 sample window (centred) AGC factor = 400
Bandpass Filter: N/A

Figure 132

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP

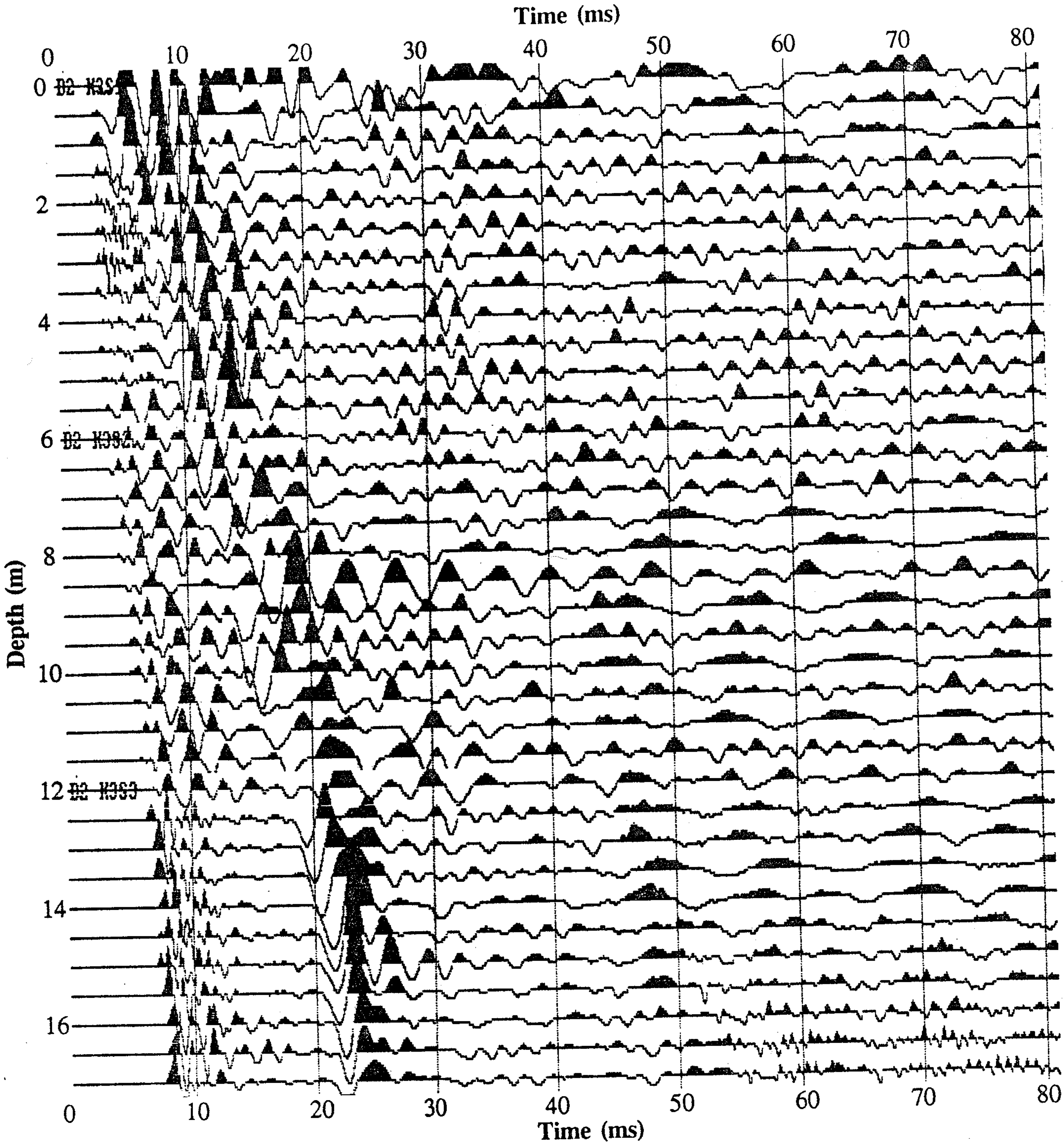


Recording Parameters:
Source: Steel tube oriented 45° N
Source Offset: 5 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 1
AGC Parameters: 400 sample window (centred) AGC factor = 400
Bandpass Filter: N/A

Figure 133

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP

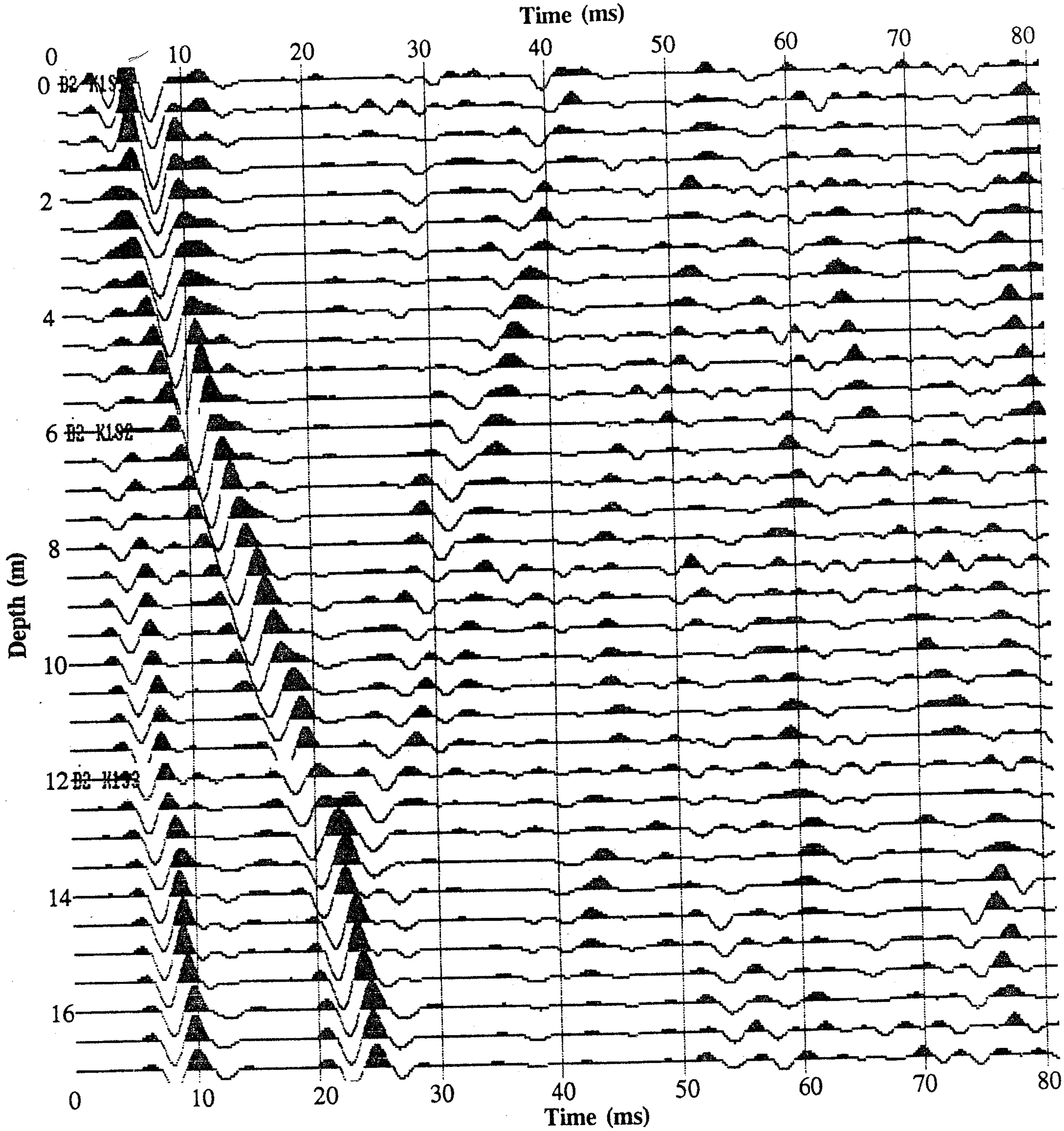


Recording Parameters:
Source: Steel tube oriented 45° N
Source Offset: 5 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 2
AGC Parameters: 400 sample window (centred)
AGC factor = 400
Bandpass Filter: N/A

Figure 134

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP

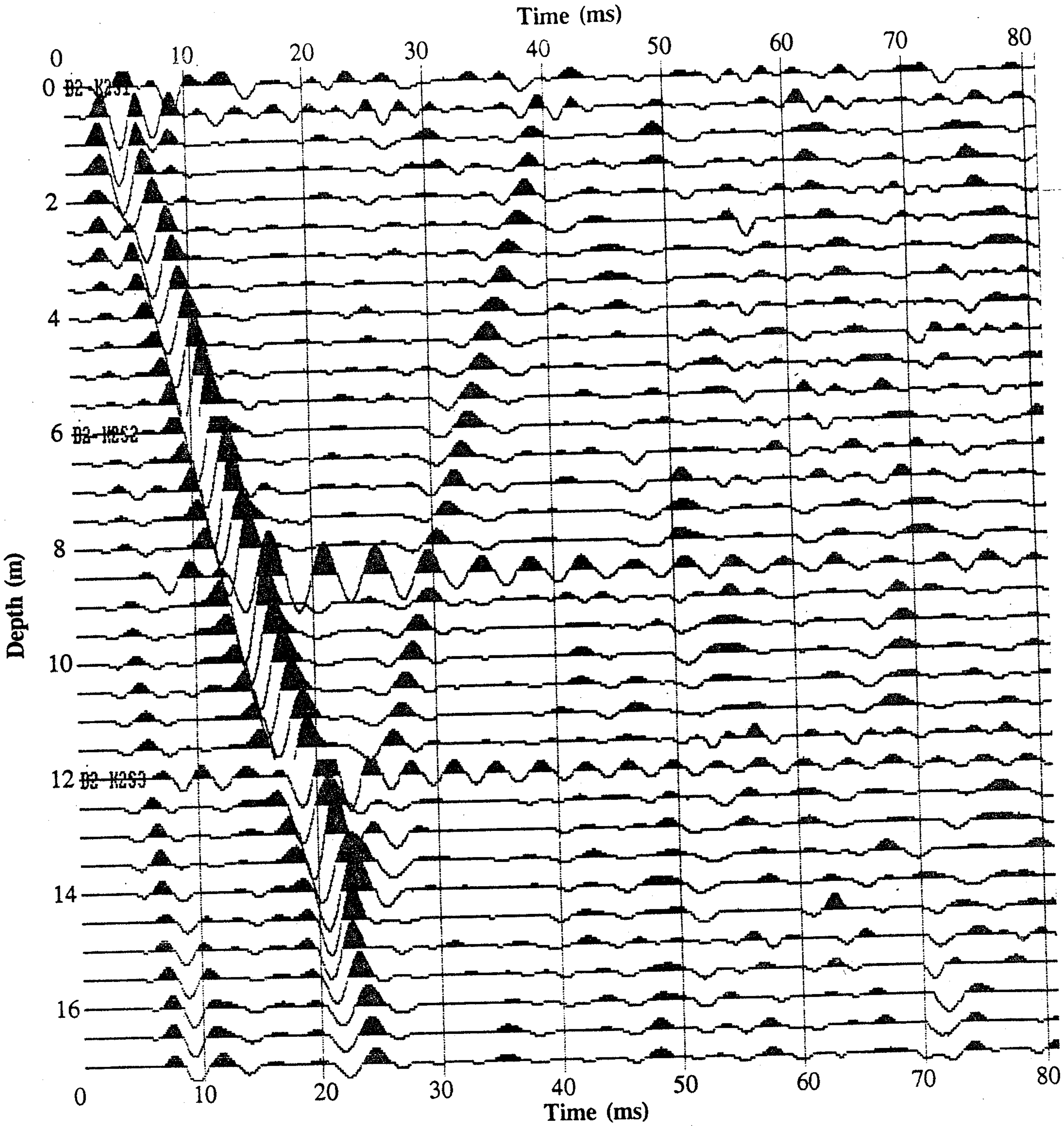


Recording Parameters:
Source: Steel tube oriented 45° N
Source Offset: 5 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Vertical
AGC Parameters: 400 sample window (centred)
AGC factor = 400
Bandpass Filter: 125-375 Hz (12 db rolloffs)

Figure 135

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP

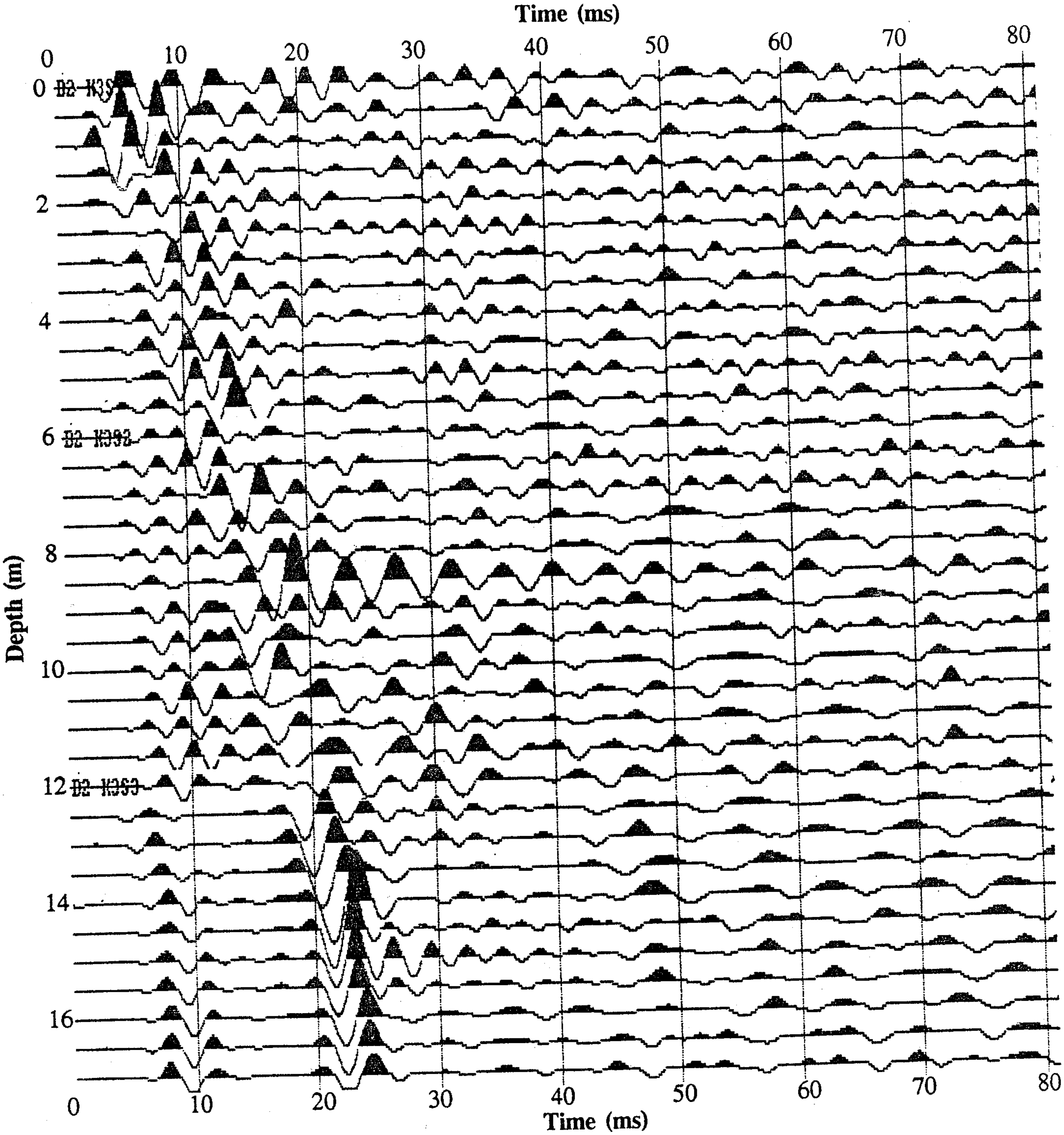


Recording Parameters:
Source: Steel tube oriented 45° N
Source Offset: 5 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 1
AGC Parameters: 400 sample window (centred)
AGC factor = 400
Bandpass Filter: 125-375 Hz (12 db rolloffs)

Figure 136

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP

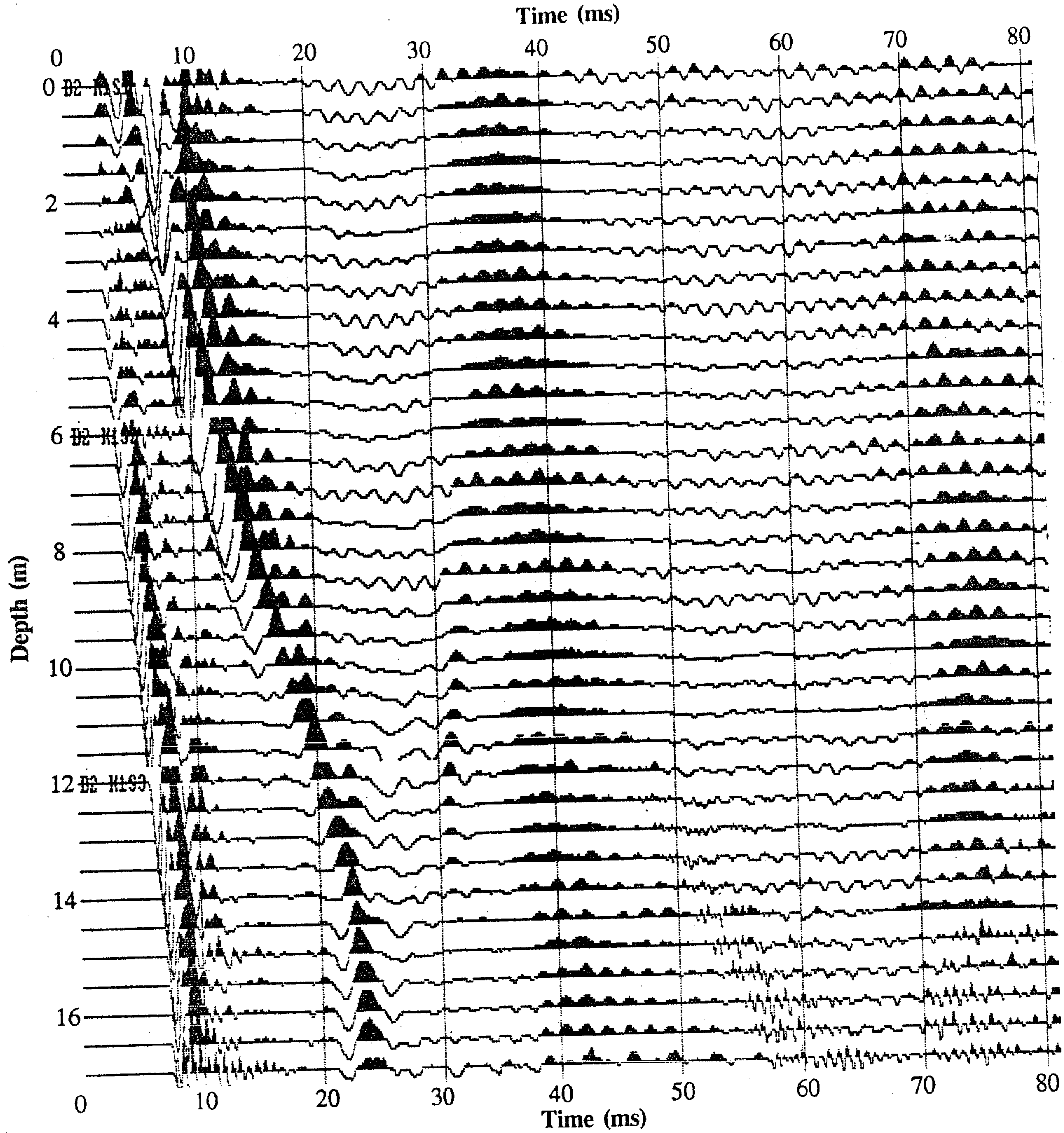


Recording Parameters:
Source: Steel tube oriented 45° N
Source Offset: 5 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 2
AGC Parameters: 400 sample window (centred)
AGC factor = 400
Bandpass Filter: 125-375 Hz (12 db rolloffs)

Figure 137

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP

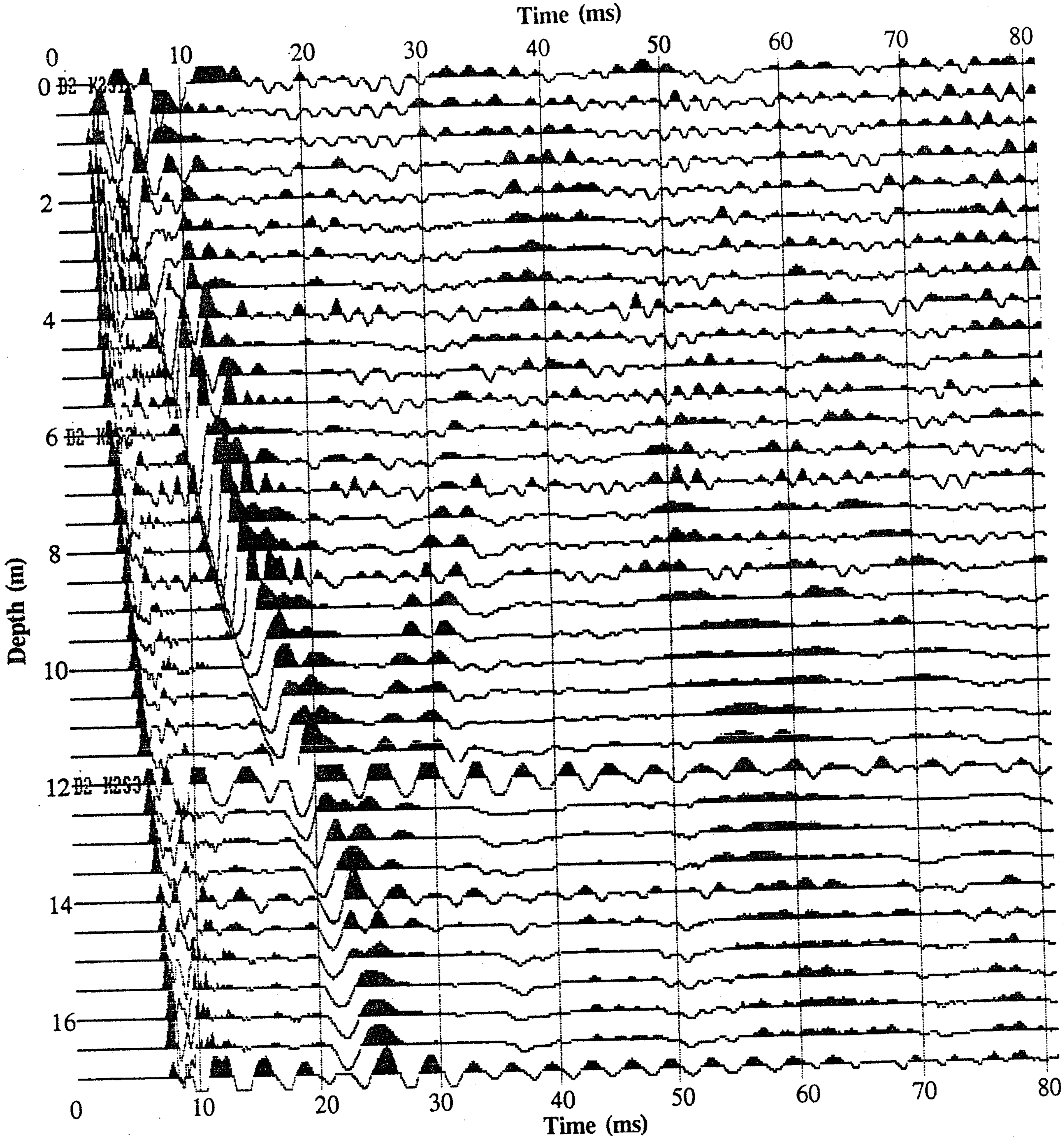


Recording Parameters:
Source: Steel tube oriented 45° W
Source Offset: 5 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Vertical
AGC Parameters: 400 sample window (centred)
AGC factor = 400
Bandpass Filter: N/A

Figure 138

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP

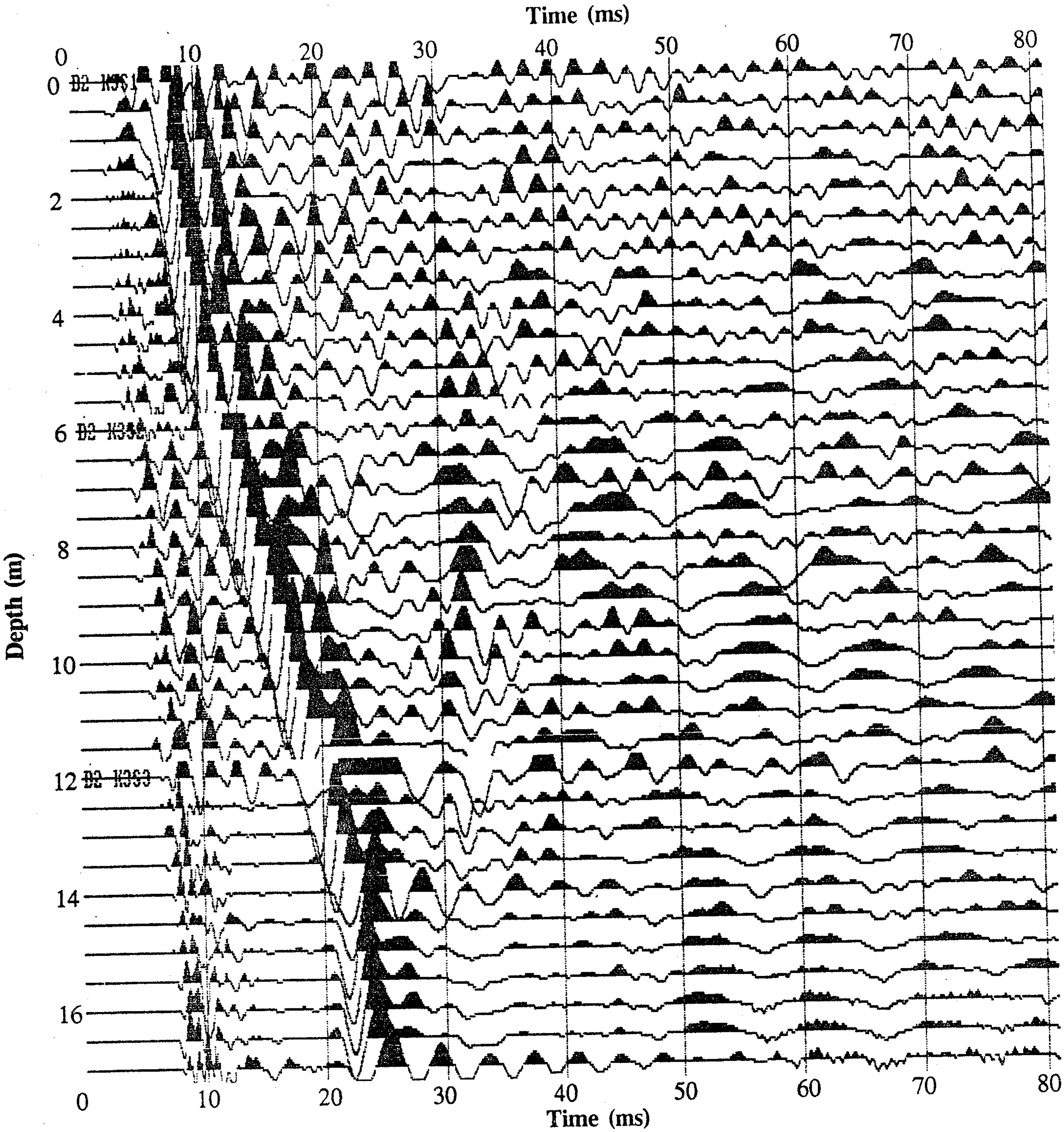


Recording Parameters:
Source: Steel tube oriented 45° W
Source Offset: 5 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 1
AGC Parameters: 400 sample window (centred)
AGC factor = 400
Bandpass Filter: N/A

Figure 139

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:

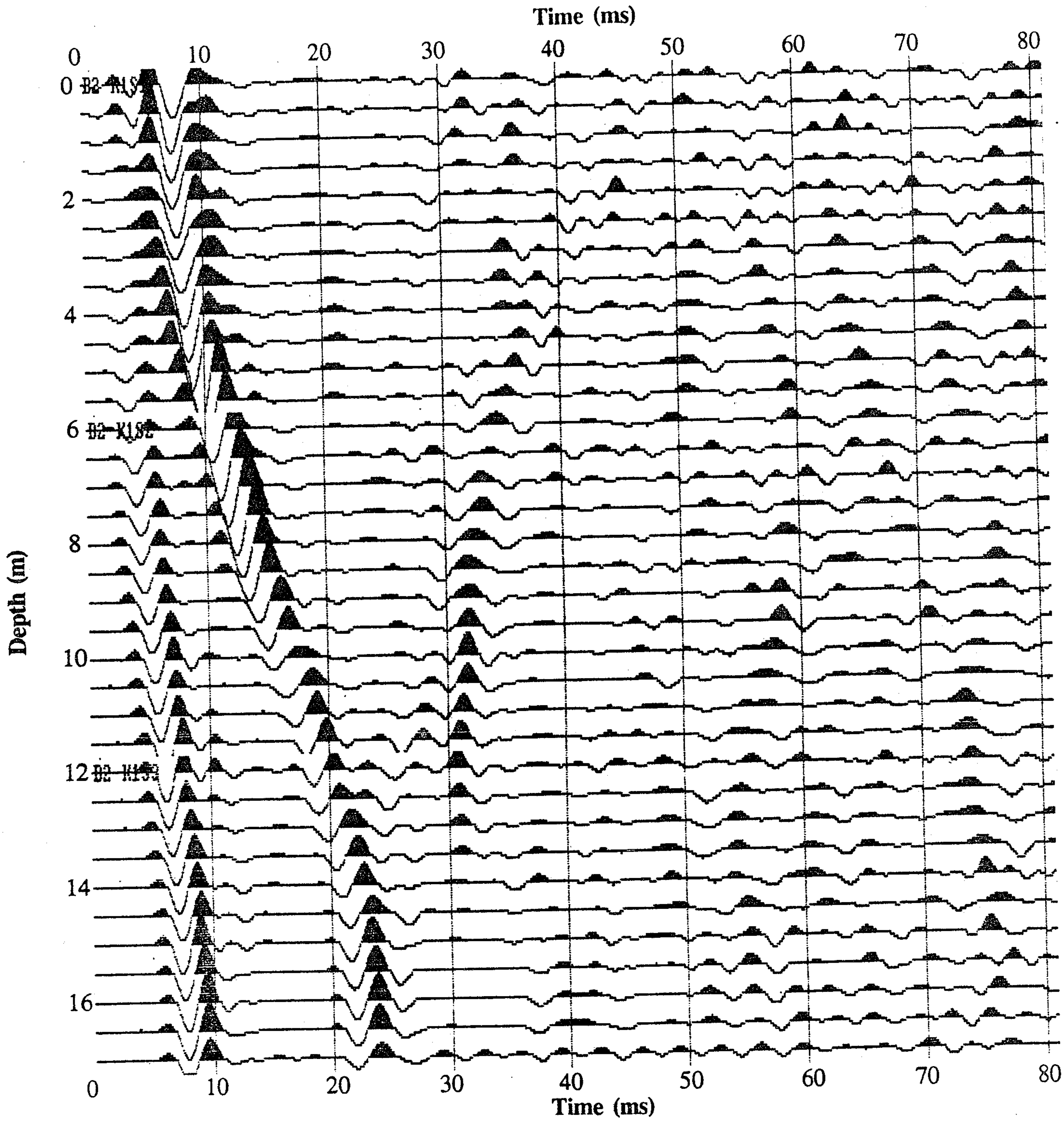
Source: Steel tube oriented 45° W
Source Offset: 5 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:

Component Plotted: Horizontal 2
AGC Parameters: 400 sample window (centred) AGC factor = 400
Bandpass Filter: N/A

Figure 140

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP

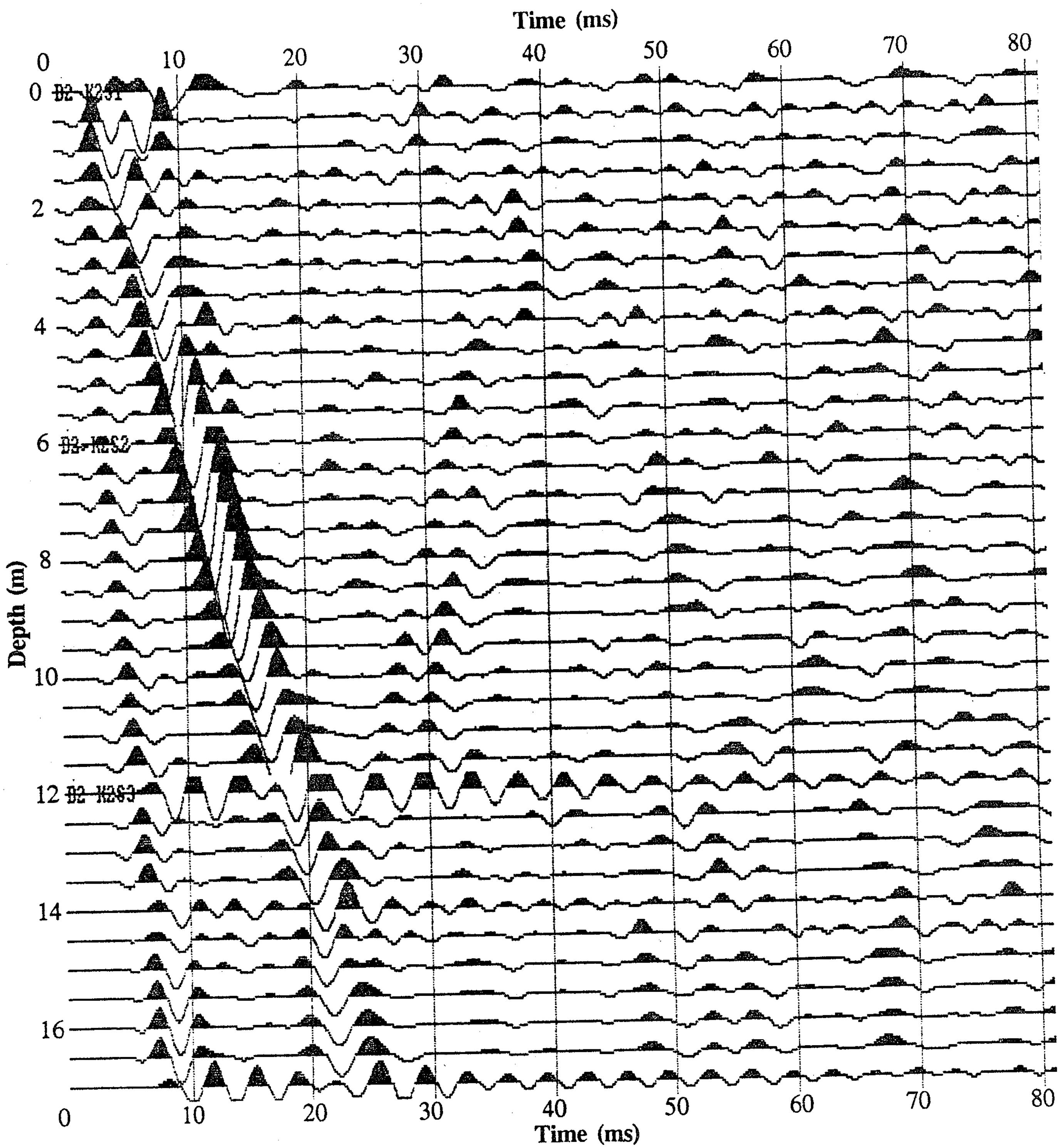


Recording Parameters:
Source: Steel tube oriented 45° W
Source Offset: 5 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Vertical
AGC Parameters: 400 sample window (centred) AGC factor = 400
Bandpass Filter: 125-375 Hz (12 db rolloffs)

Figure 141

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP

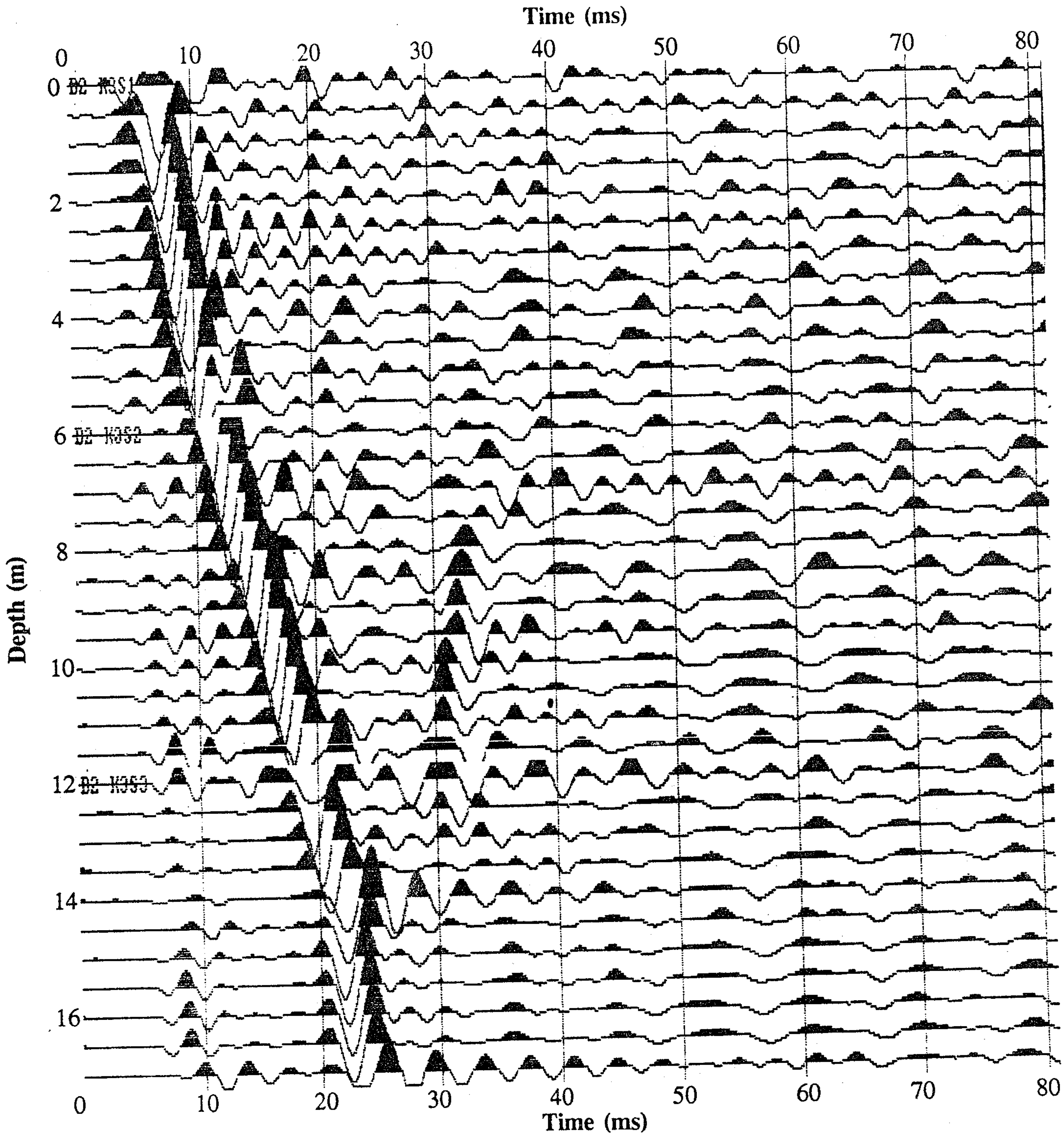


Recording Parameters:
Source: Steel tube oriented 45° W
Source Offset: 5 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 1
AGC Parameters: 400 sample window (centred)
AGC factor = 400
Bandpass Filter: 125-375 Hz (12 db rolloffs)

Figure 142

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:

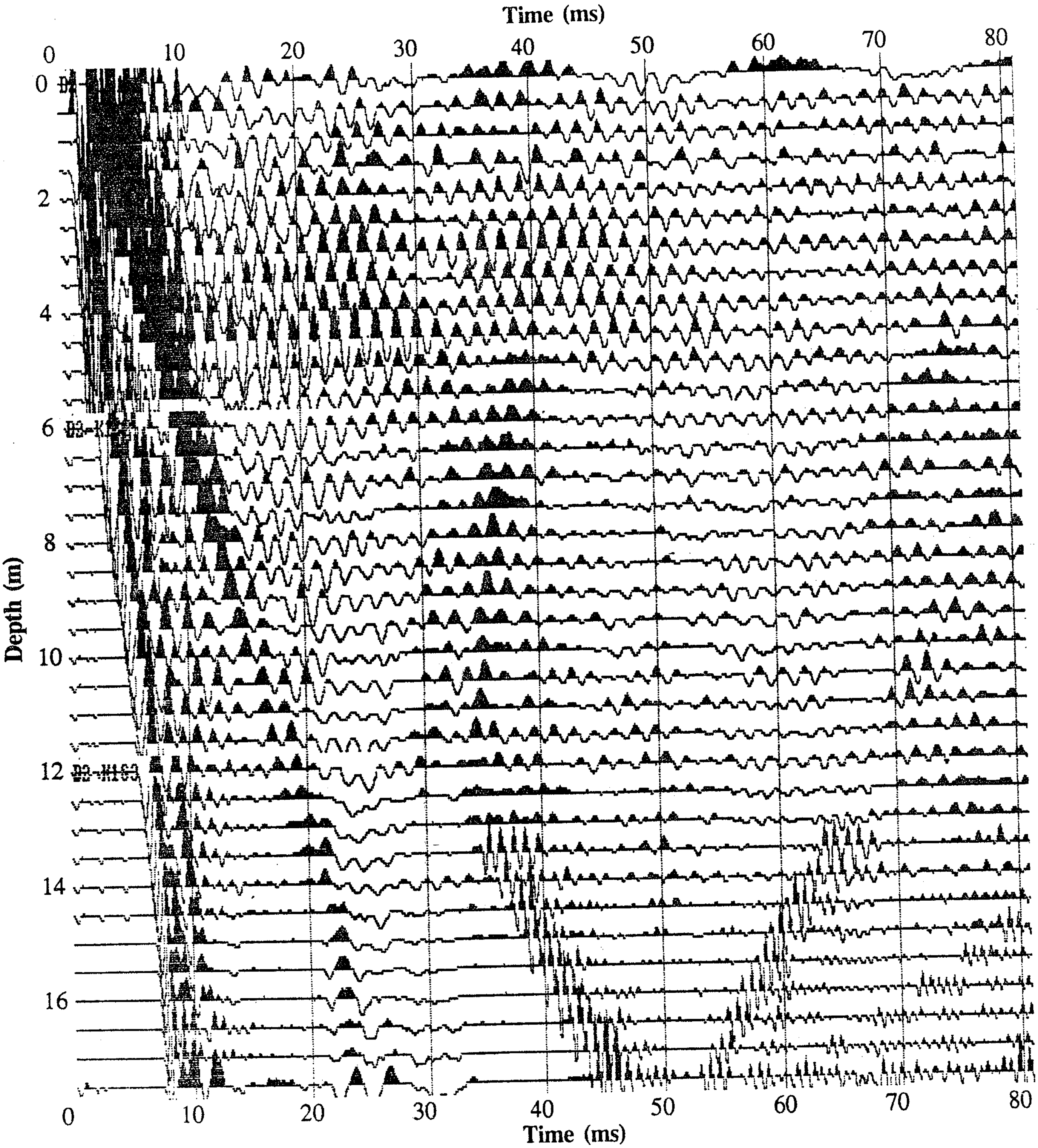
Source: Steel tube oriented 45° W
Source Offset: 5 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:

Component Plotted: Horizontal 2
AGC Parameters: 400 sample window (centred) AGC factor = 400
Bandpass Filter: 125-375 Hz (12 db rolloffs)

Figure 143

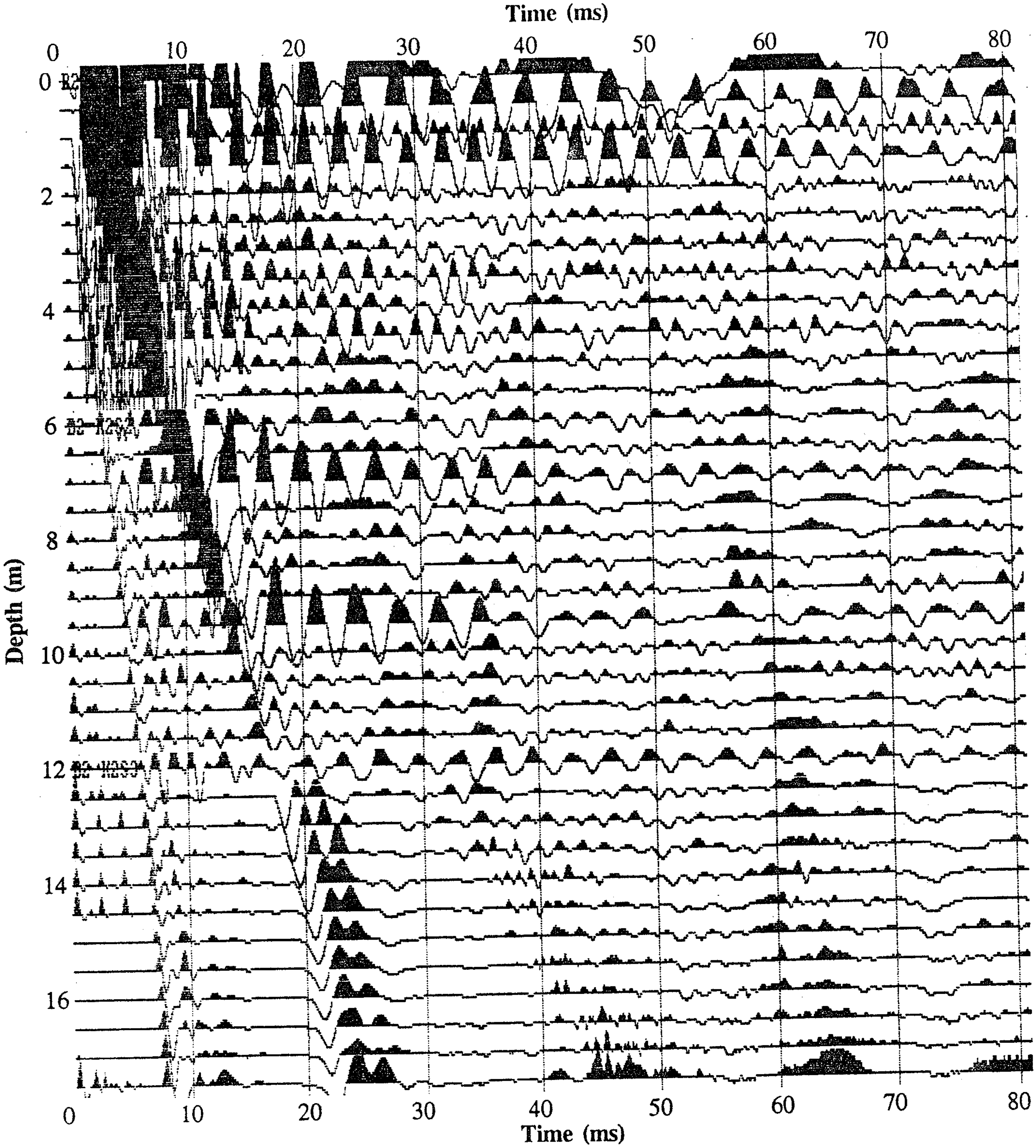
BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:
Source: Steel tube oriented 45° N
Source Offset: 0.3 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Vertical
AGC Parameters: 400 sample window (centred) AGC factor = 400
Bandpass Filter: N/A

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP

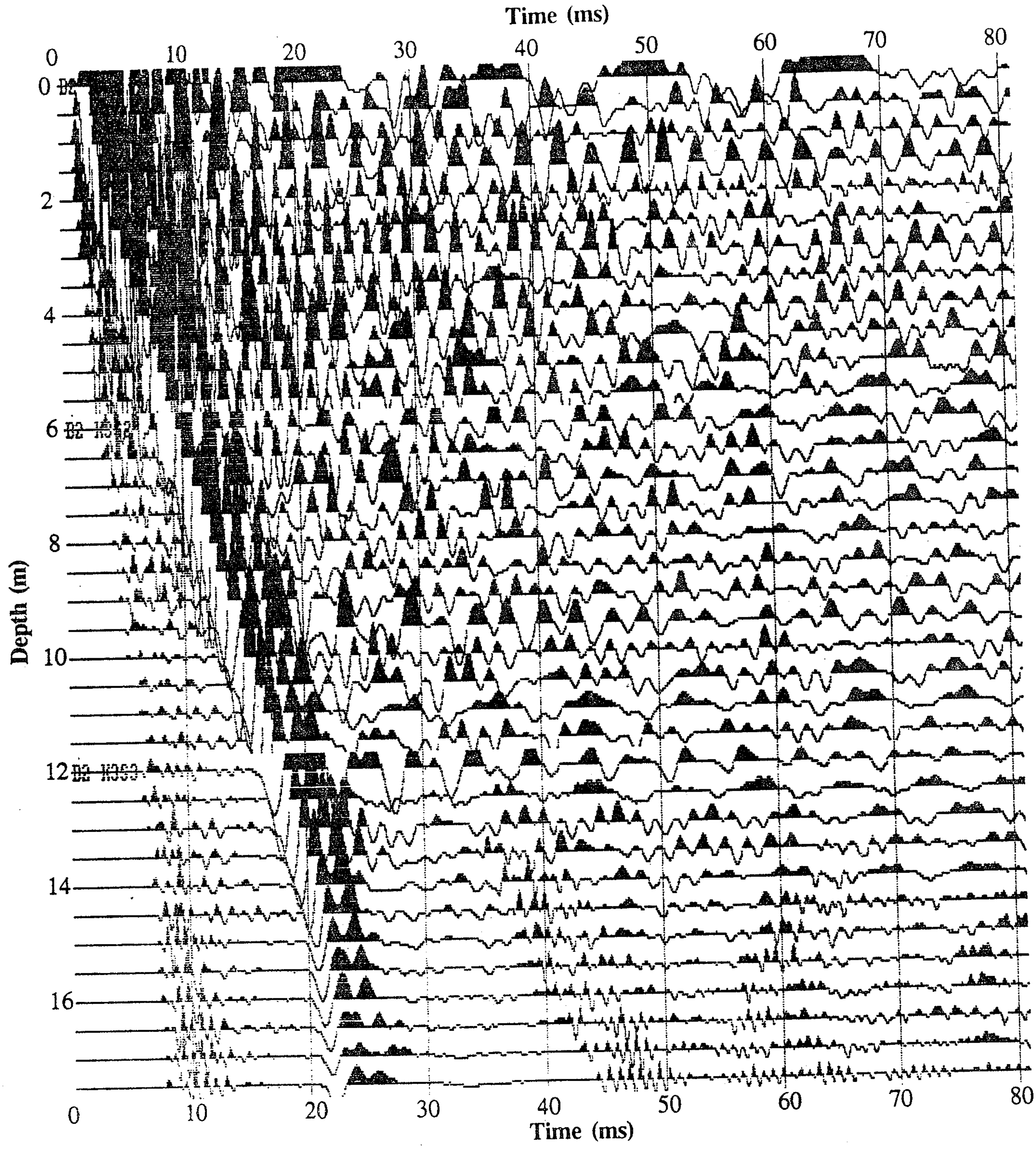


Recording Parameters:
Source: Steel tube oriented 45° N
Source Offset: 0.3 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 1
AGC Parameters: 400 sample window (centred) AGC factor = 400
Bandpass Filter: N/A

Figure 145

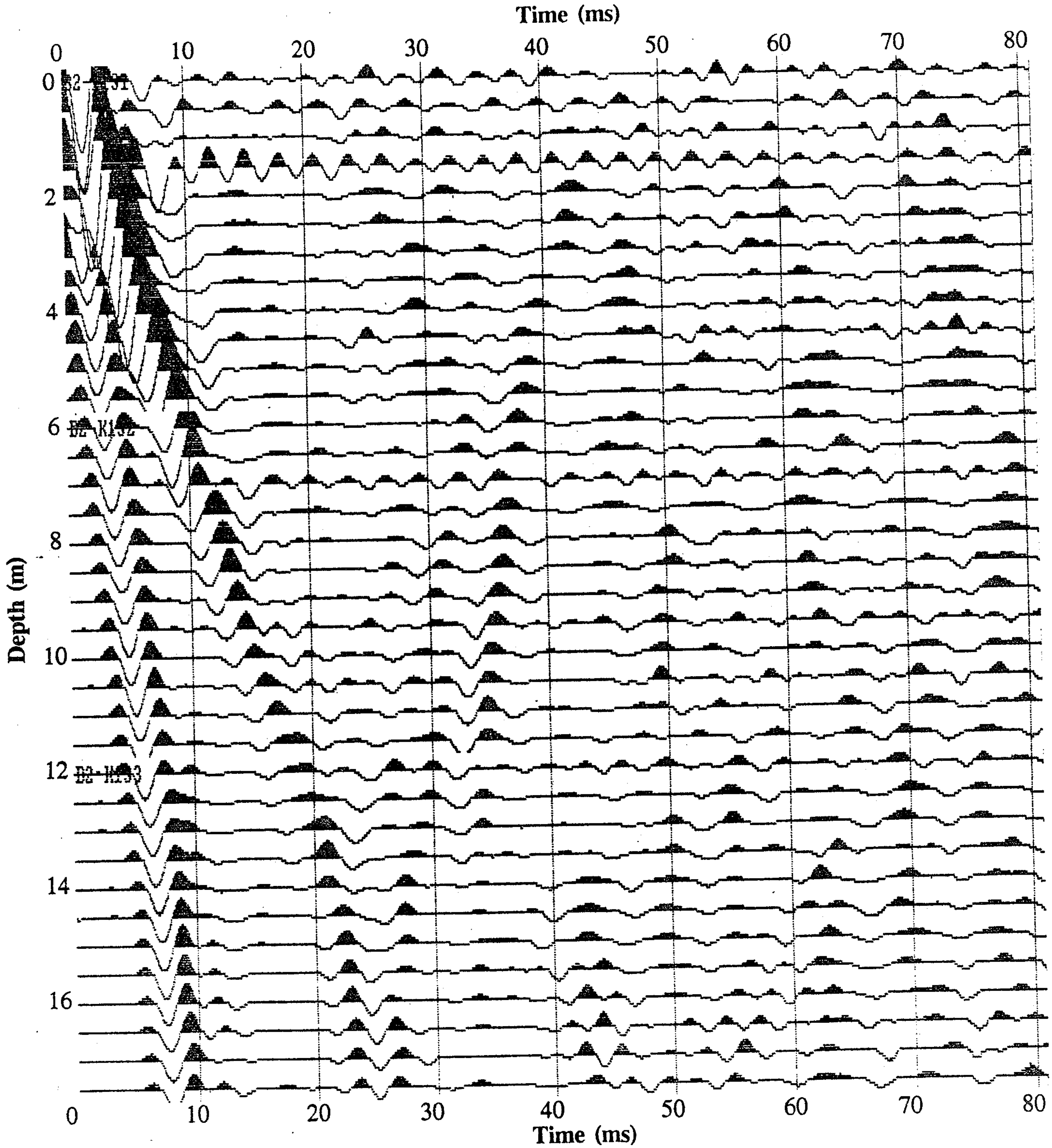
BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:
Source: Steel tube oriented 45° N
Source Offset: 0.3 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 2
AGC Parameters: 400 sample window (centred) AGC factor = 400
Bandpass Filter: N/A

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP

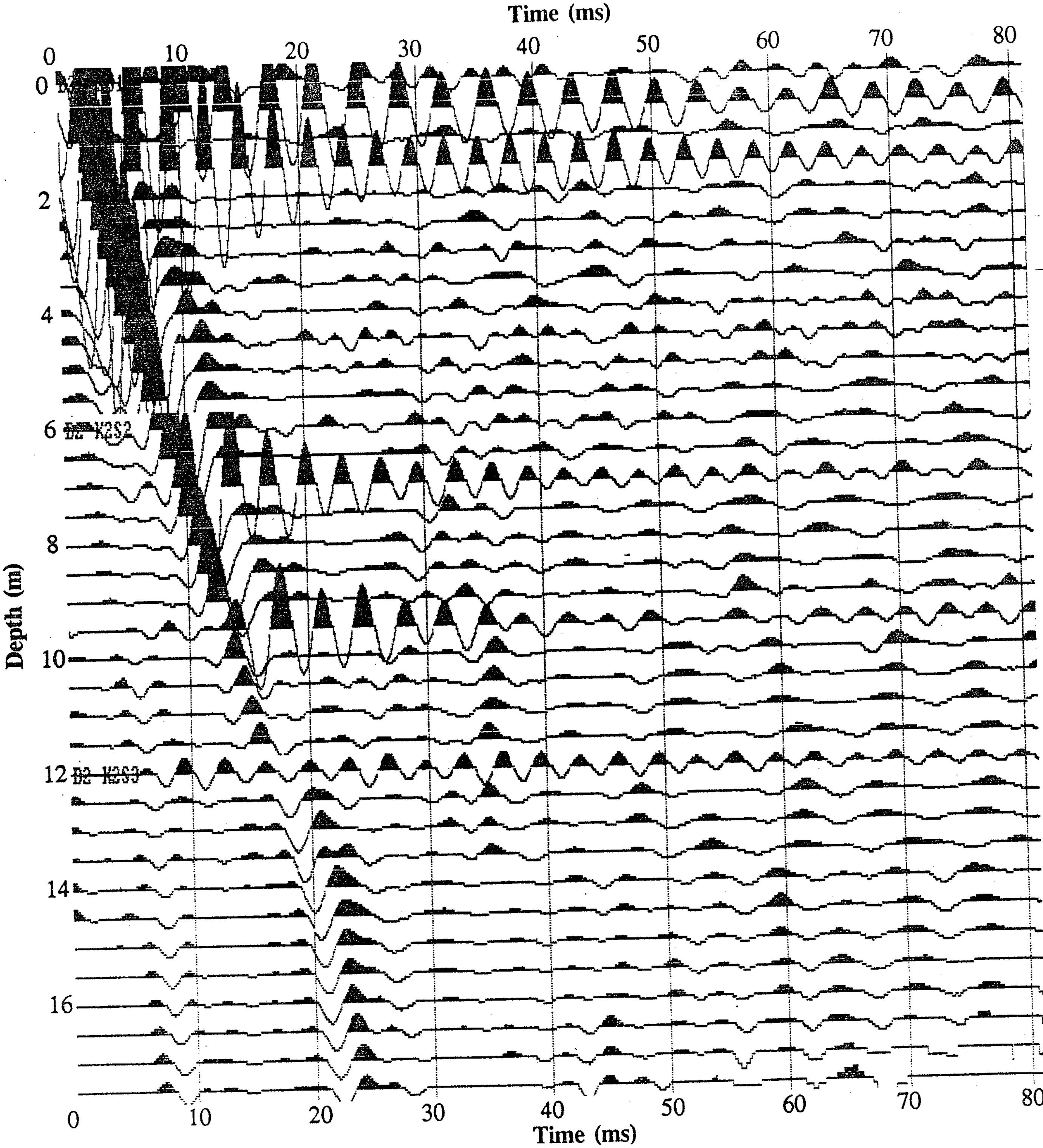


Recording Parameters:
Source: Steel tube oriented 45° N
Source Offset: 0.3 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Vertical
AGC Parameters: 400 sample window (centred) AGC factor = 400
Bandpass Filter: 125-375 Hz (12 db rolloffs)

Figure 147

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP

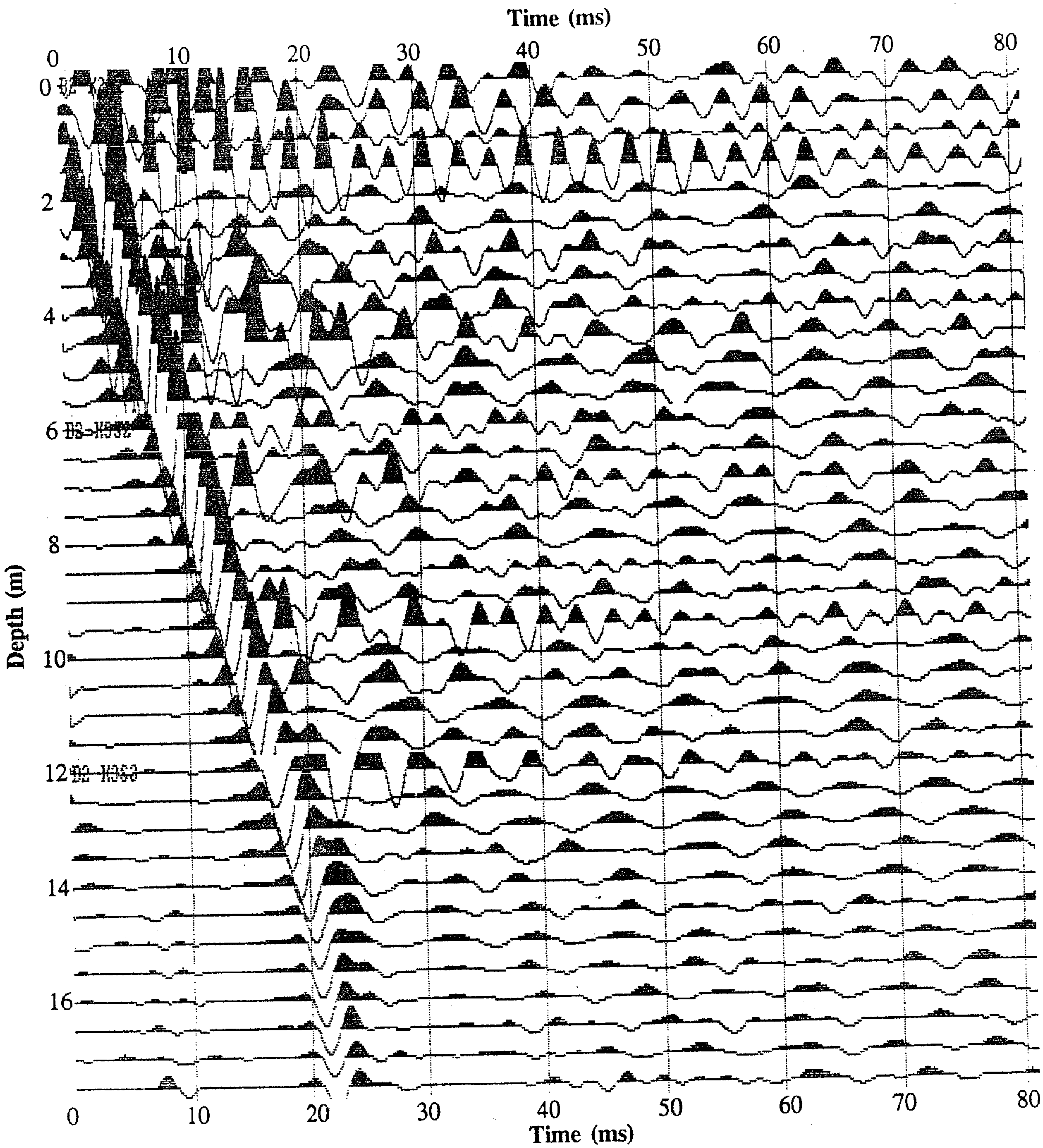


Recording Parameters:
Source: Steel tube oriented 45° N
Source Offset: 0.3 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 1
AGC Parameters: 400 sample window (centred) AGC factor = 400
Bandpass Filter: 125-375 Hz (12 db rolloffs)

Figure 148

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP



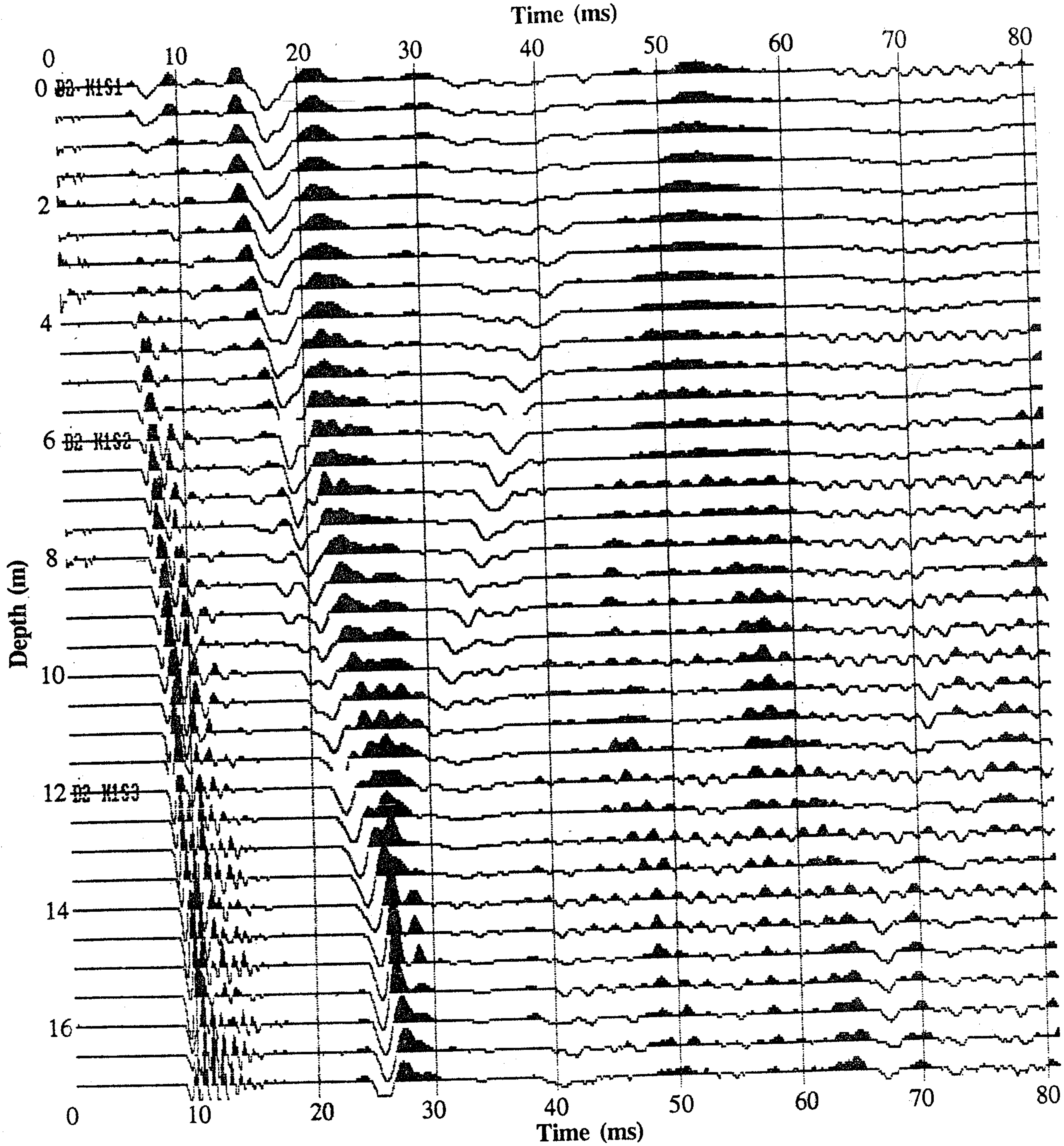
Recording Parameters:

Source: Steel tube oriented 45° N
Source Offset: 0.3 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole
3-component
Sampling Interval: 0.05 ms

Display Parameters:

Component Plotted: Horizontal 2
AGC Parameters: 400 sample window (centred)
AGC factor = 400
Bandpass Filter: 125-375 Hz (12 db rolloffs)

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:

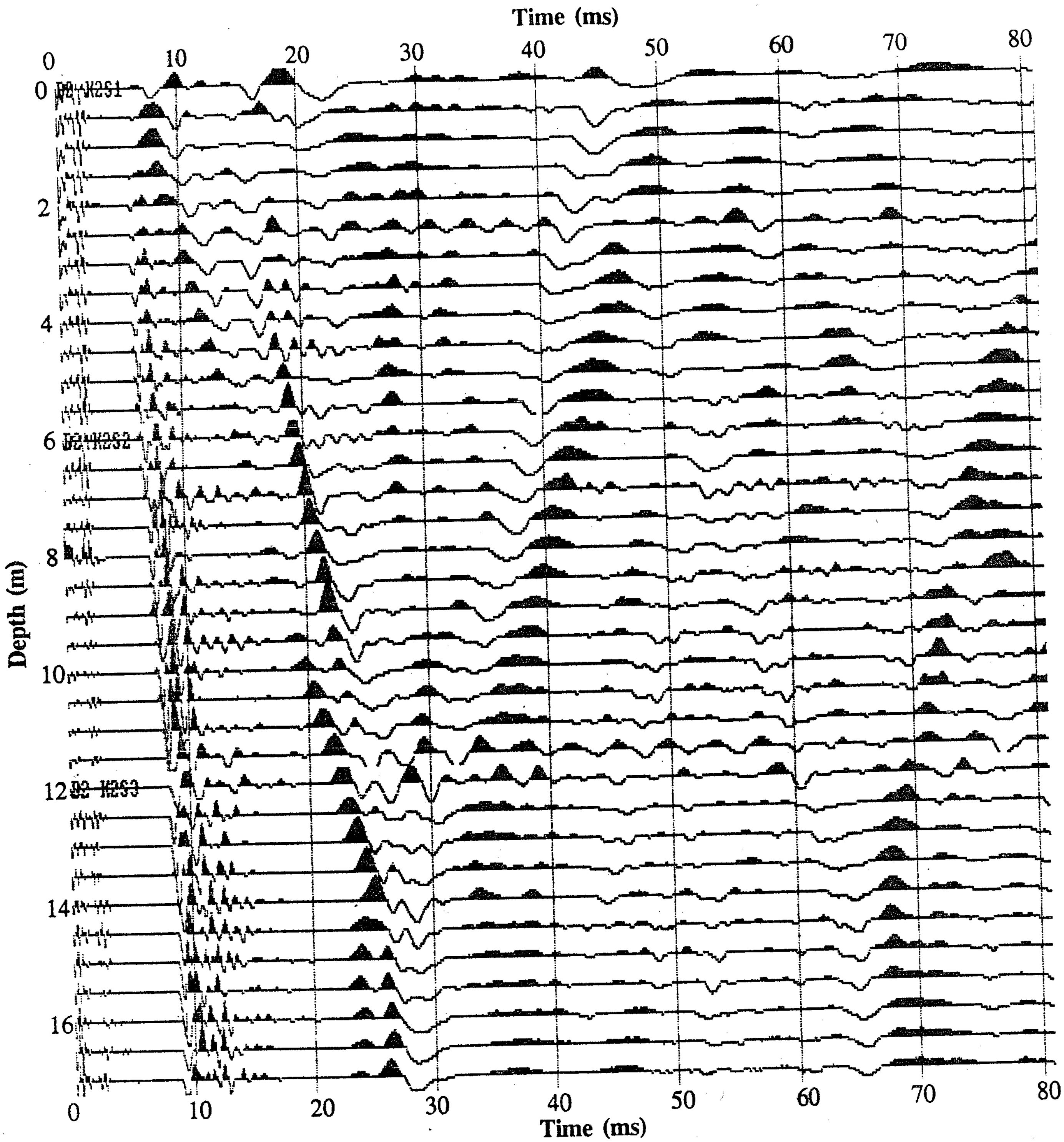
Source: Steel tube oriented 45° S
Source Offset: 12 m south of BH
Source Depth: 0.5 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:

Component Plotted: Vertical
AGC Parameters: 400 sample window (centred) AGC factor = 400
Bandpass Filter: N/A

Figure 150

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:

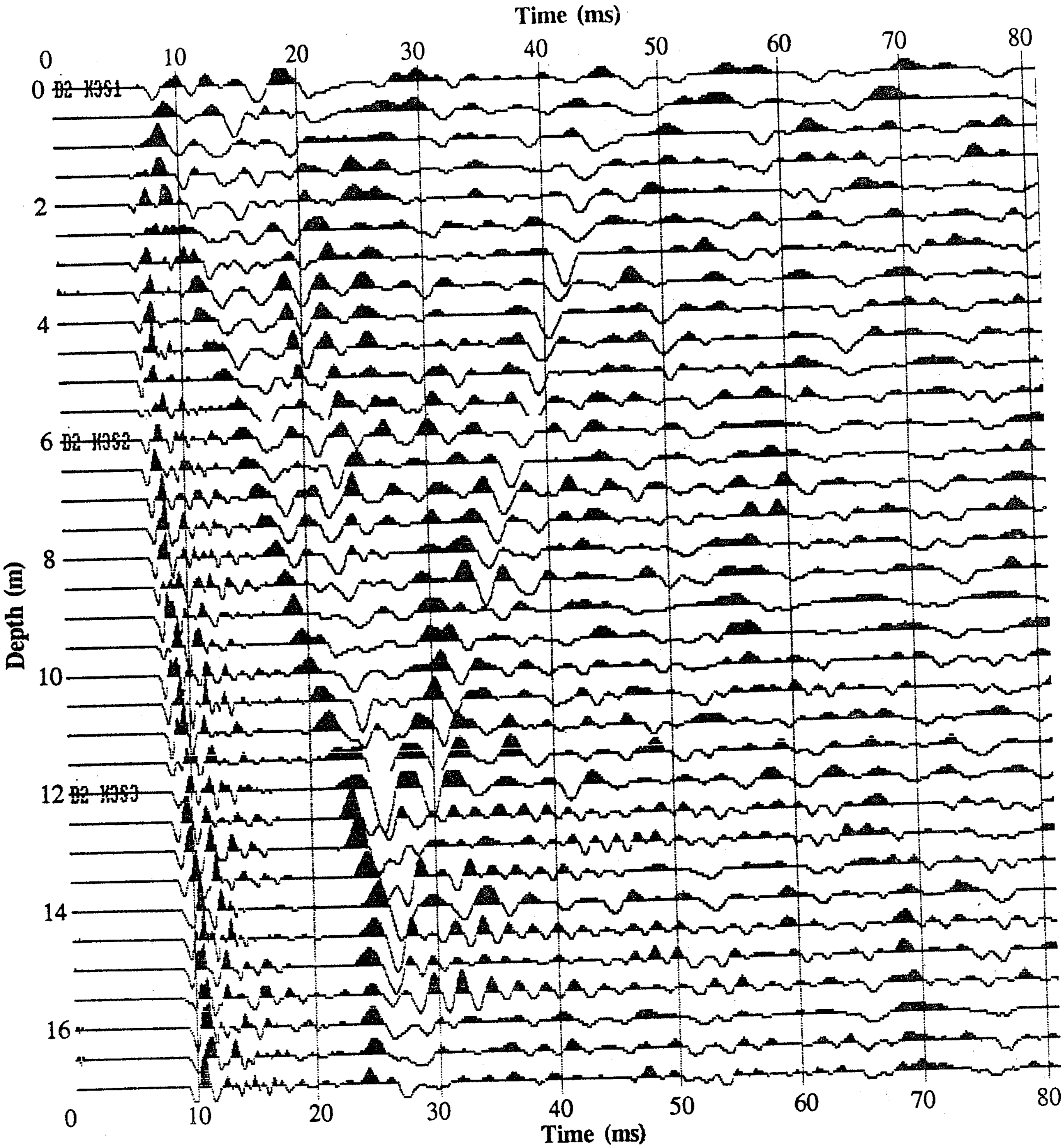
Source: Steel tube oriented 45° S
Source Offset: 12 m south of BH
Source Depth: 0.5 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:

Component Plotted: Horizontal 1
AGC Parameters: 400 sample window (centred) AGC factor = 400
Bandpass Filter: N/A

Figure 151

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP

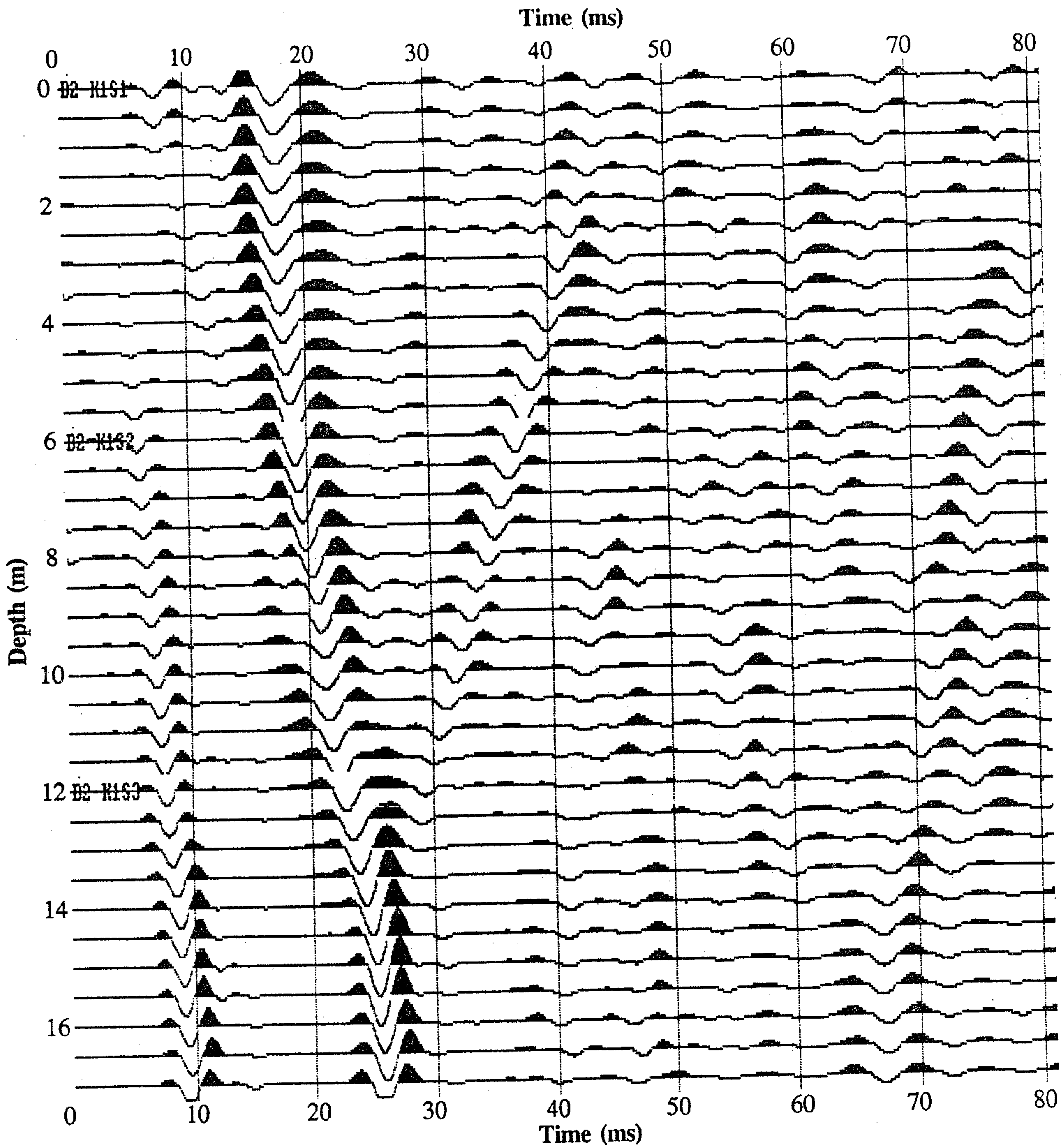


Recording Parameters:
Source: Steel tube oriented 45° S
Source Offset: 12 m south of BH
Source Depth: 0.5 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 2
AGC Parameters: 400 sample window (centred)
AGC factor = 400
Bandpass Filter: N/A

Figure 152

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP

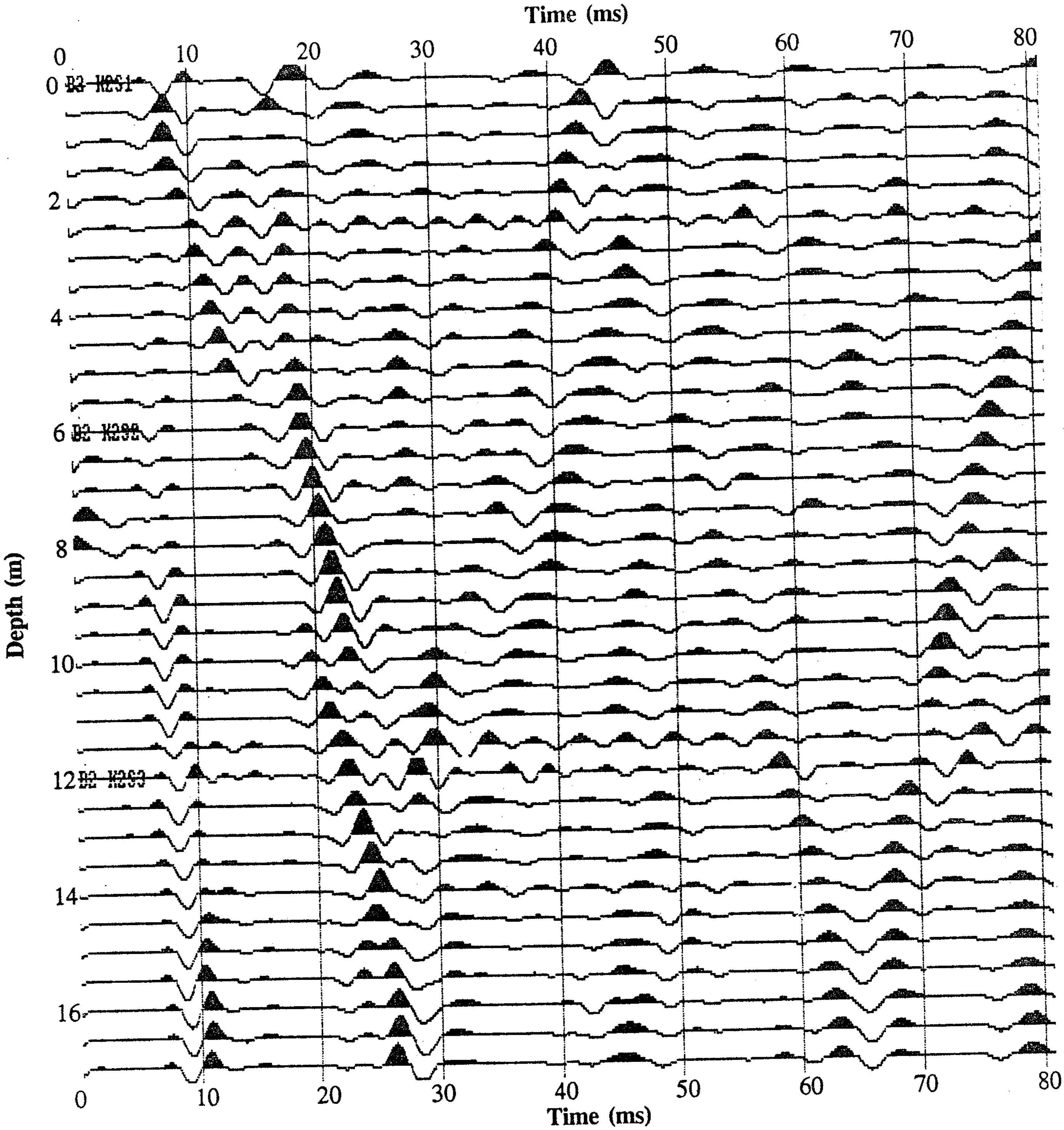


Recording Parameters:
Source: Steel tube oriented 45° S
Source Offset: 12 m south of BH
Source Depth: 0.5 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Vertical
AGC Parameters: 400 sample window (centred) AGC factor = 400
Bandpass Filter: 125-375 Hz (12 db rolloffs)

Figure 153

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:

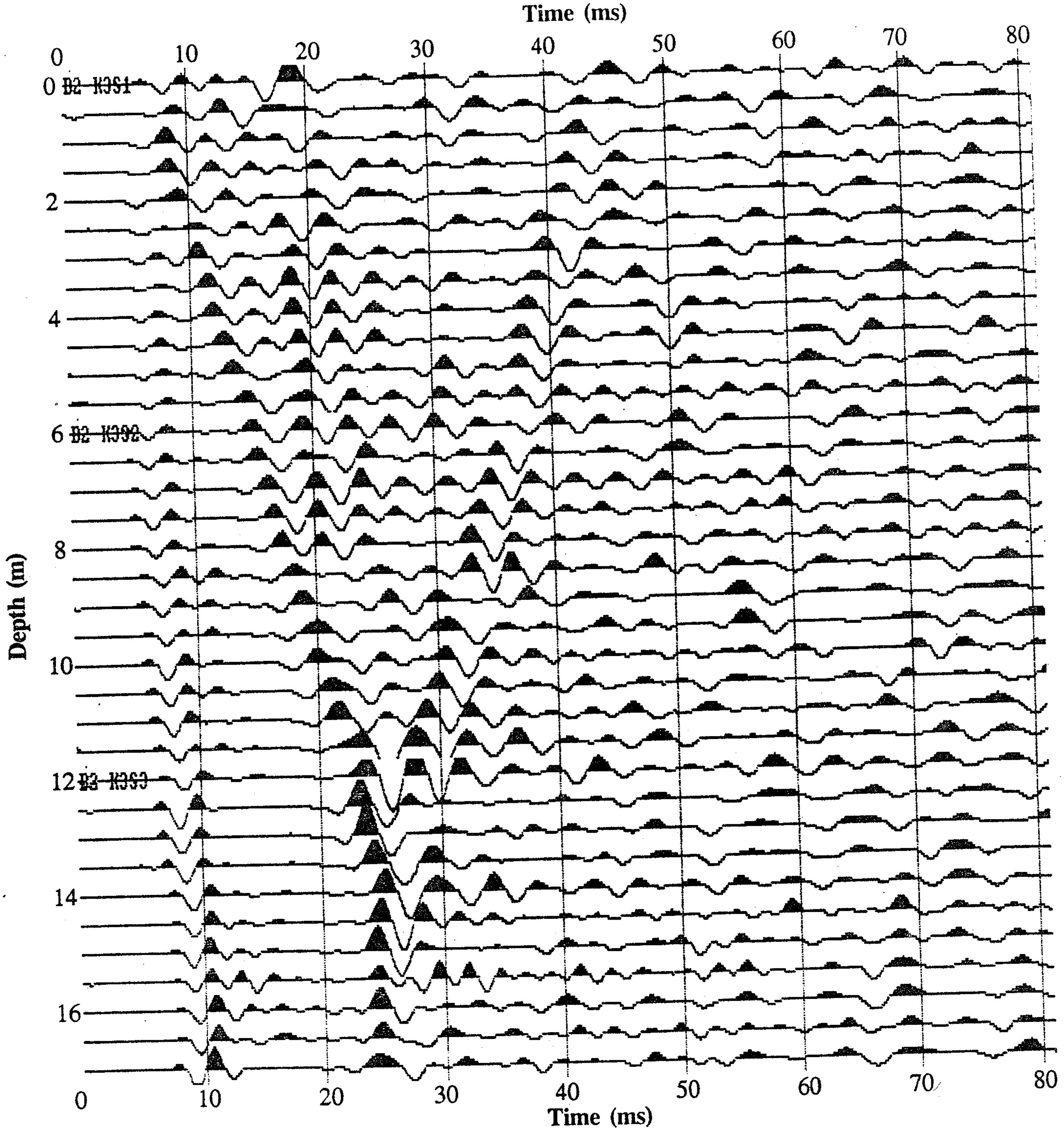
Source: Steel tube oriented 45° S
Source Offset: 12 m south of BH
Source Depth: 0.5 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:

Component Plotted: Horizontal 1
AGC Parameters: 400 sample window (centred) AGC factor = 400
Bandpass Filter: 125-375 Hz (12 db rolloffs)

Figure 154

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP

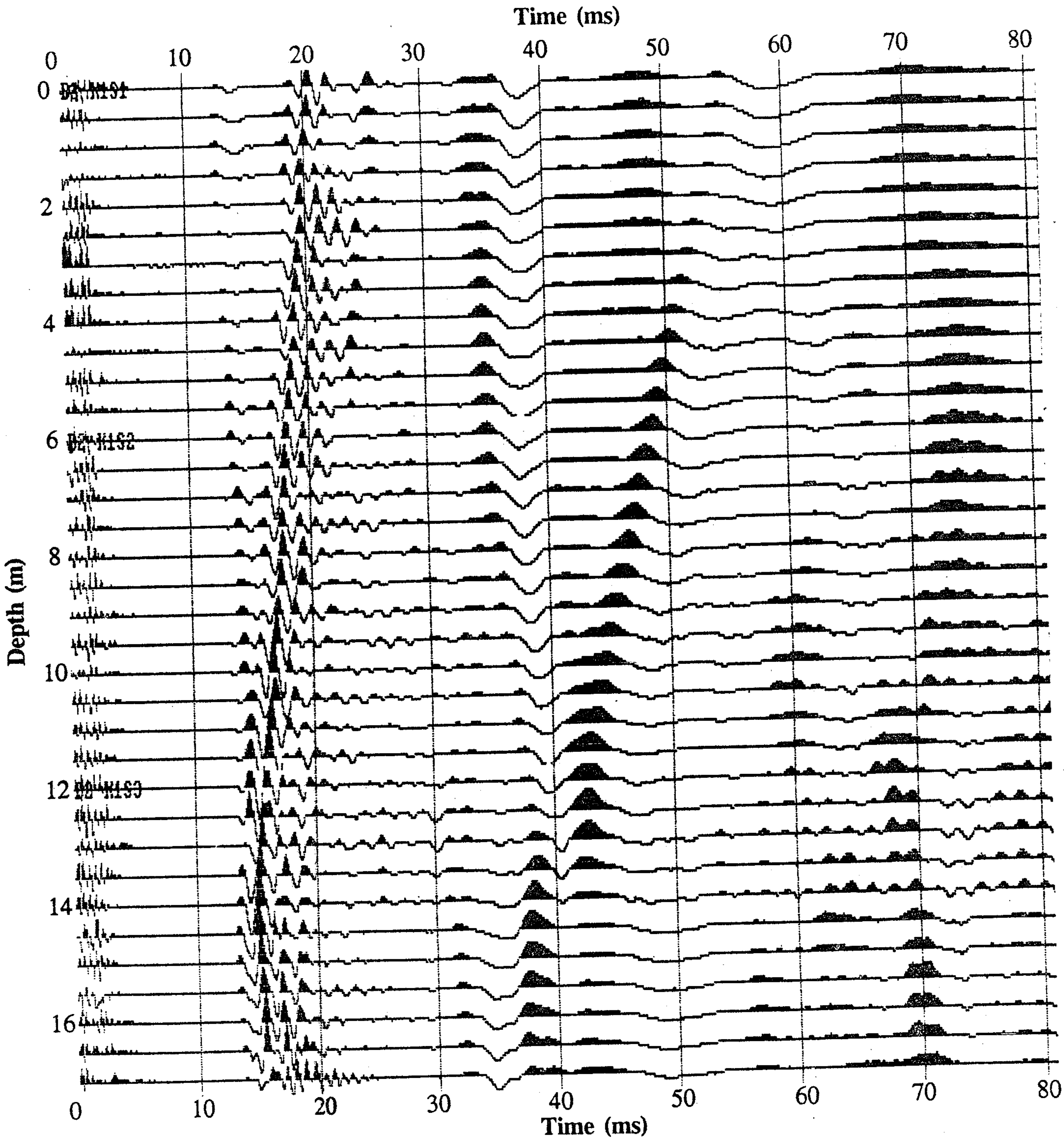


Recording Parameters:
Source: Steel tube oriented 45° S
Source Offset: 12 m south of BH
Source Depth: 0.5 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 2
AGC Parameters: 400 sample window (centred)
AGC factor = 400
Bandpass Filter: 125-375 Hz (12 db rolloffs)

Figure 155

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:

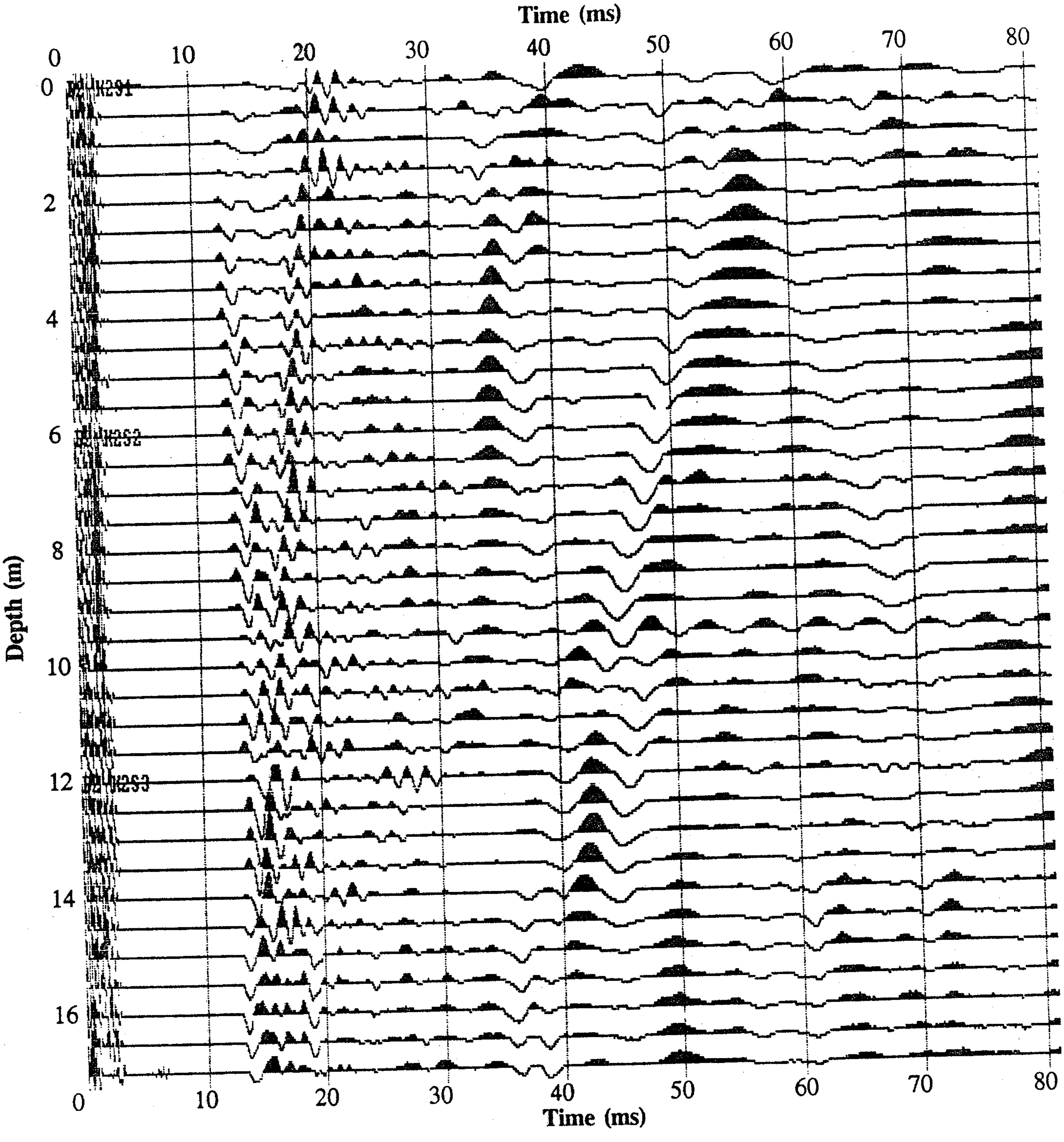
Source: Steel tube oriented 45° S
Source Offset: 26 m south of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:

Component Plotted: Vertical
AGC Parameters: 400 sample window (centred) AGC factor = 400
Bandpass Filter: N/A

Figure 156

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP

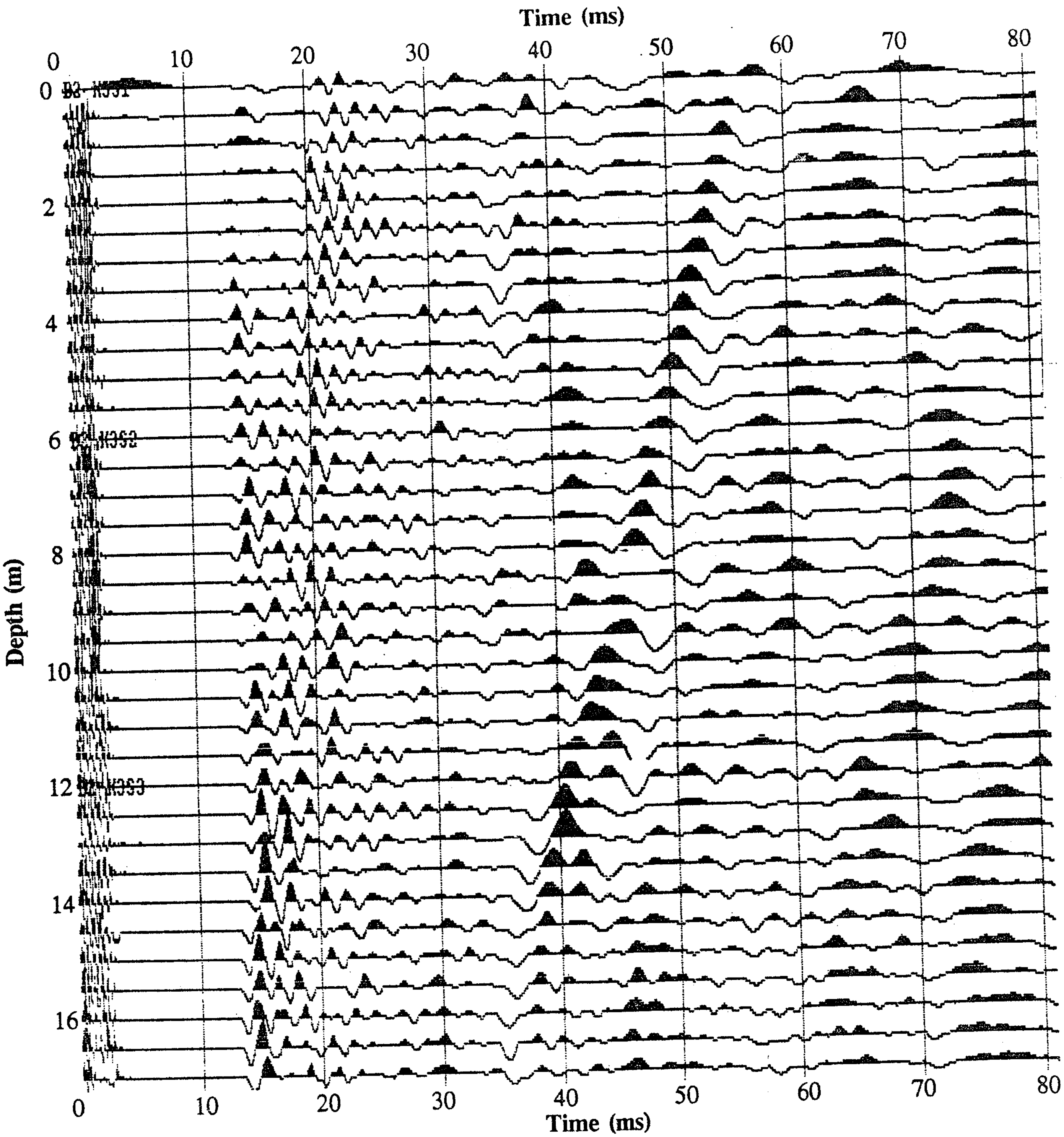


Recording Parameters:
Source: Steel tube oriented 45° S
Source Offset: 26 m south of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 1
AGC Parameters: 400 sample window (centred) AGC factor = 400
Bandpass Filter: N/A

Figure 157

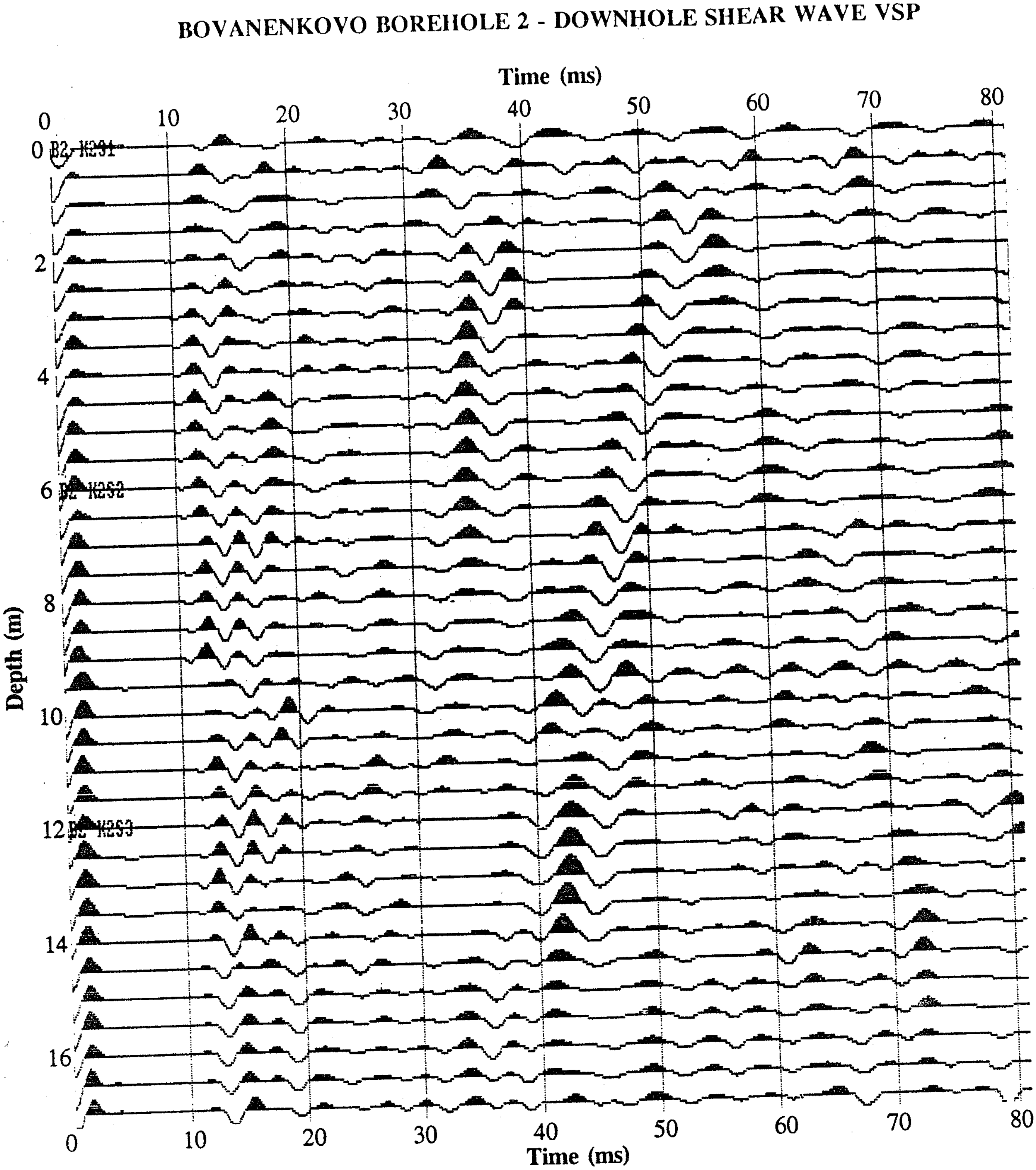
BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:
Source: Steel tube oriented 45° S
Source Offset: 26 m south of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 2
AGC Parameters: 400 sample window (centred)
AGC factor = 400
Bandpass Filter: N/A

Figure 158

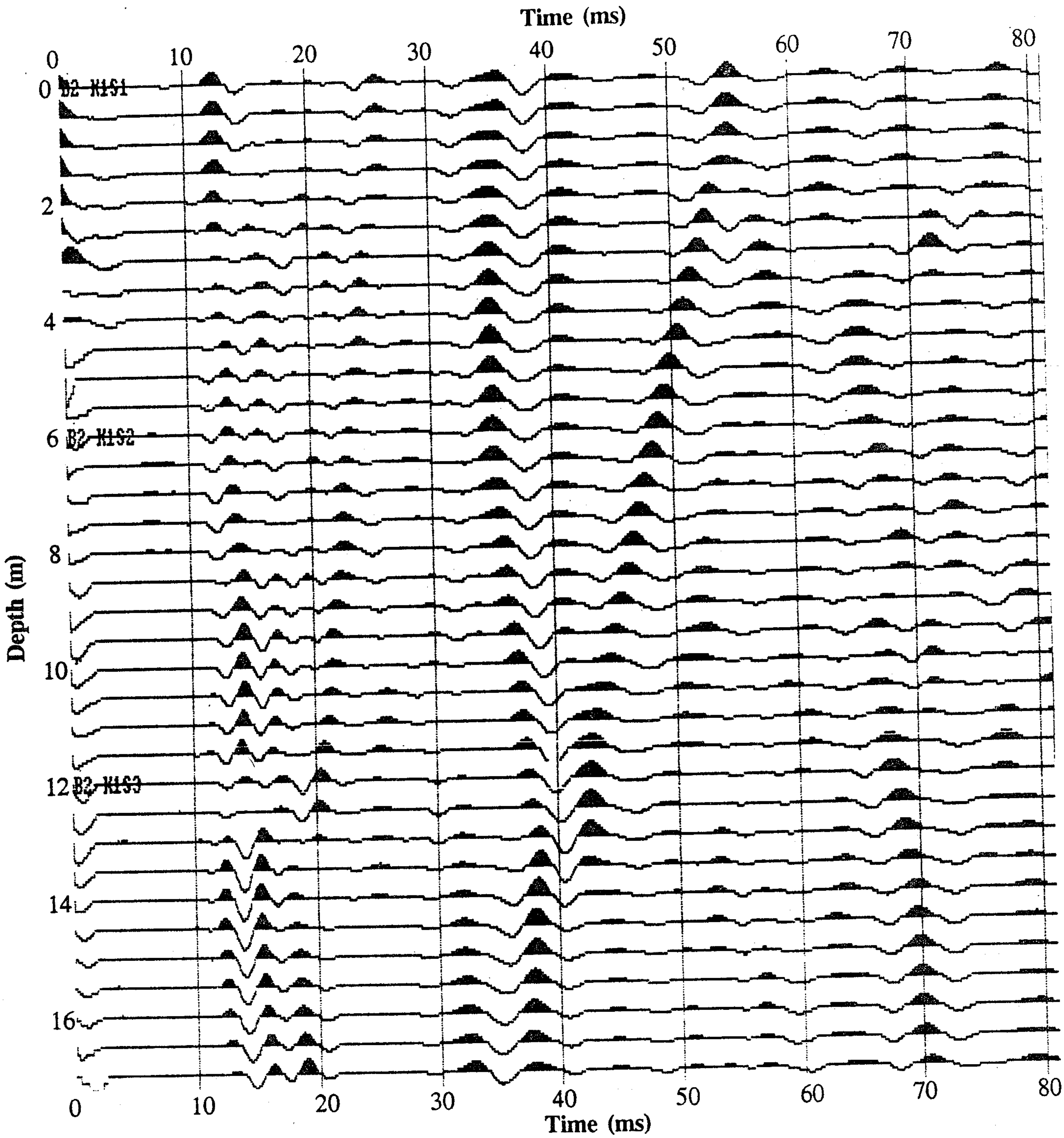


Recording Parameters:
Source: Steel tube oriented 45° S
Source Offset: 26 m south of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Vertical
AGC Parameters: 400 sample window (centred) AGC factor = 400
Bandpass Filter: 125-375 Hz (12 db rolloffs)

Figure 159

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP

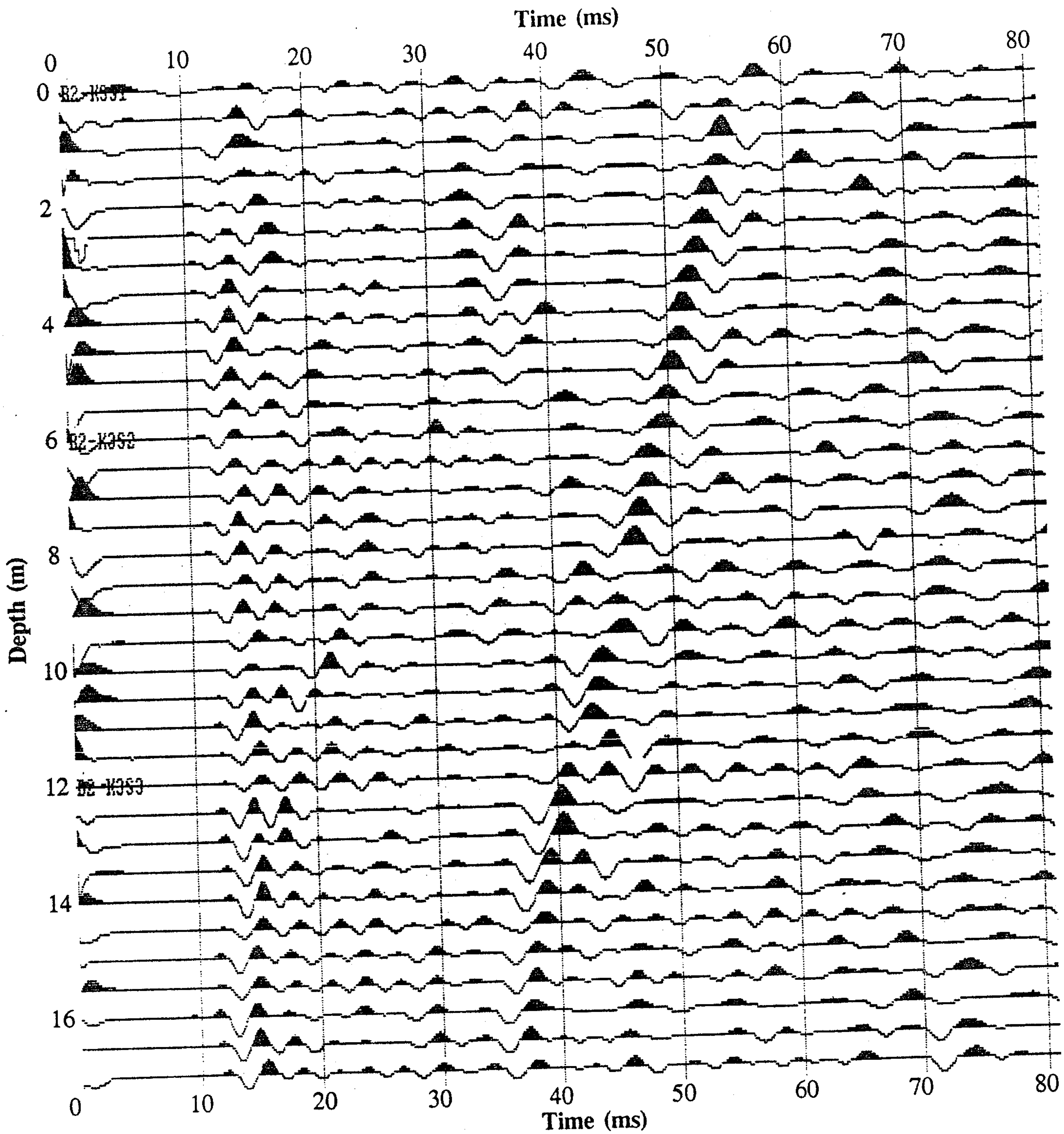


Recording Parameters:
Source: Steel tube oriented 45° S
Source Offset: 26 m south of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 1
AGC Parameters: 400 sample window (centred)
AGC factor = 400
Bandpass Filter: 125-375 Hz (12 db rolloffs)

Figure 160

BOVANENKOVO BOREHOLE 2 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:
Source: Steel tube oriented 45° S
Source Offset: 26 m south of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 2
AGC Parameters: 400 sample window (centred)
AGC factor = 400
Bandpass Filter: 125-375 Hz (12 db rolloffs)

Figure 161

DOWNHOLE SHEAR WAVE VSP

BOREHOLE 4

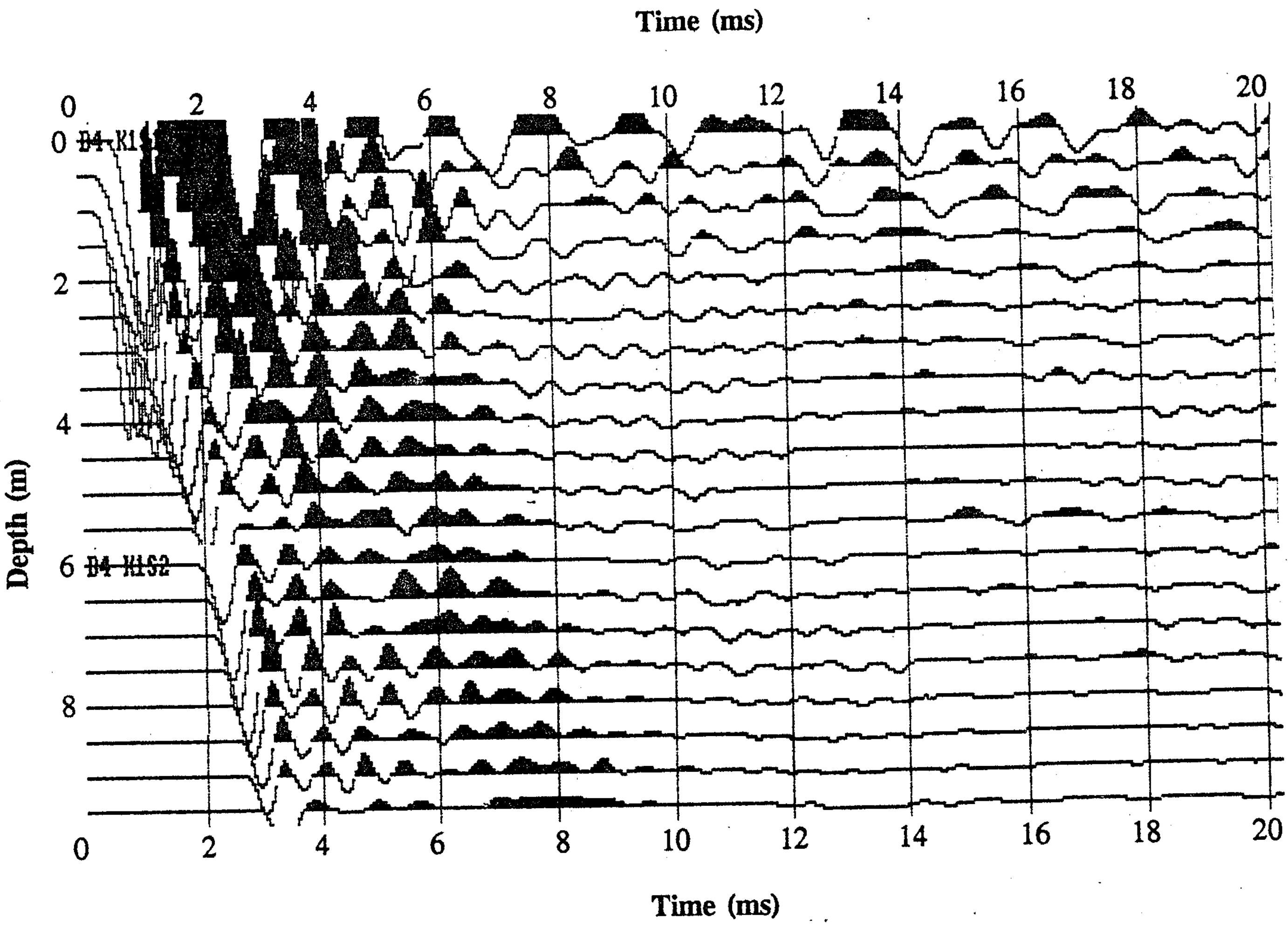
Vertical, Horizontal 1, and Horizontal 2 Components

plotted in raw format and after application of a digital filter.

<u>Source location and orientation</u>

1. 0.2 m east of BH - 45° N

BOVANENKOVO BOREHOLE 4 - DOWNHOLE SHEAR WAVE VSP

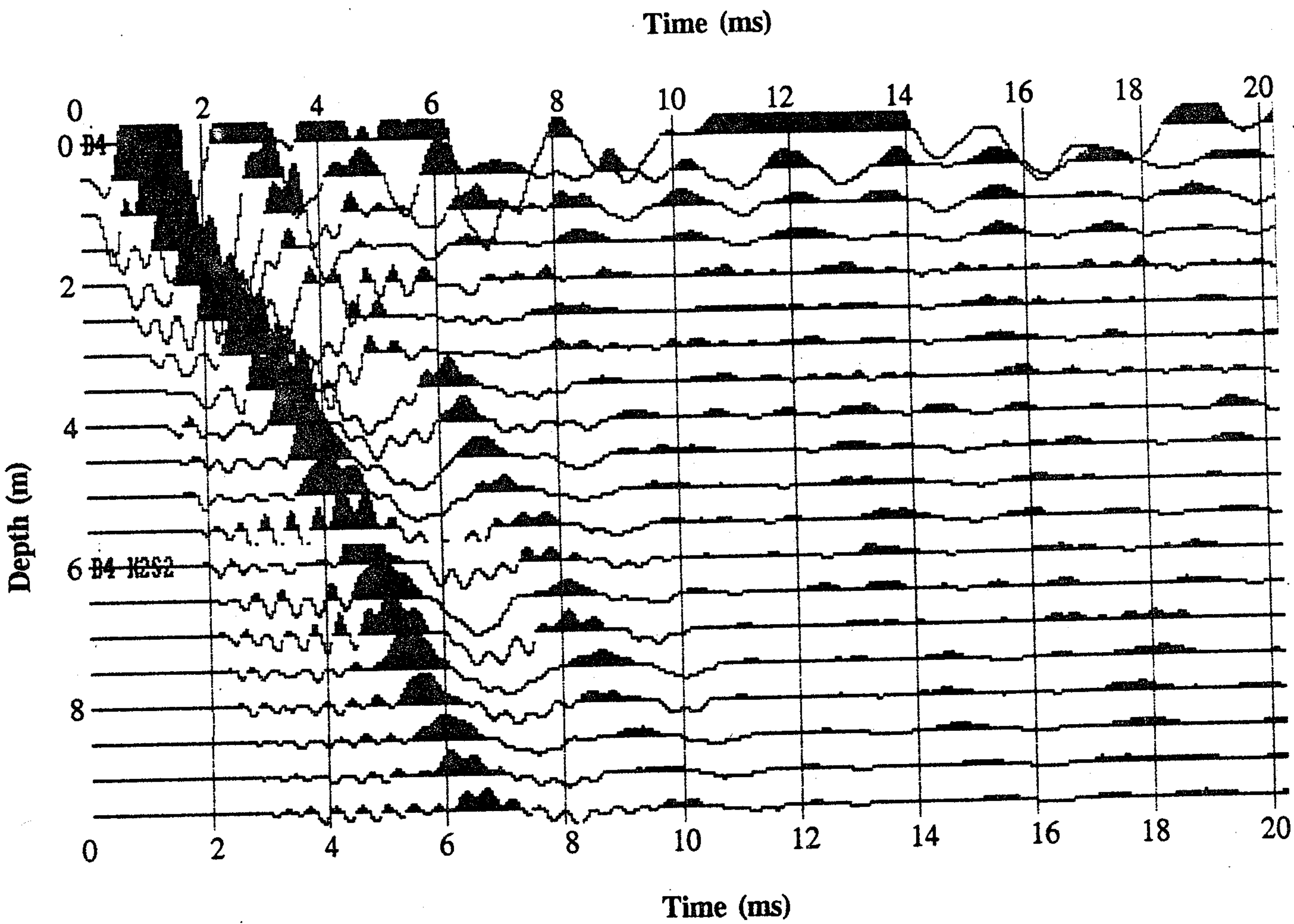


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 0.2 m east of BH
Source Depth: 0.5 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Vertical
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: N/A

Figure 162

BOVANENKOVO BOREHOLE 4 - DOWNHOLE SHEAR WAVE VSP

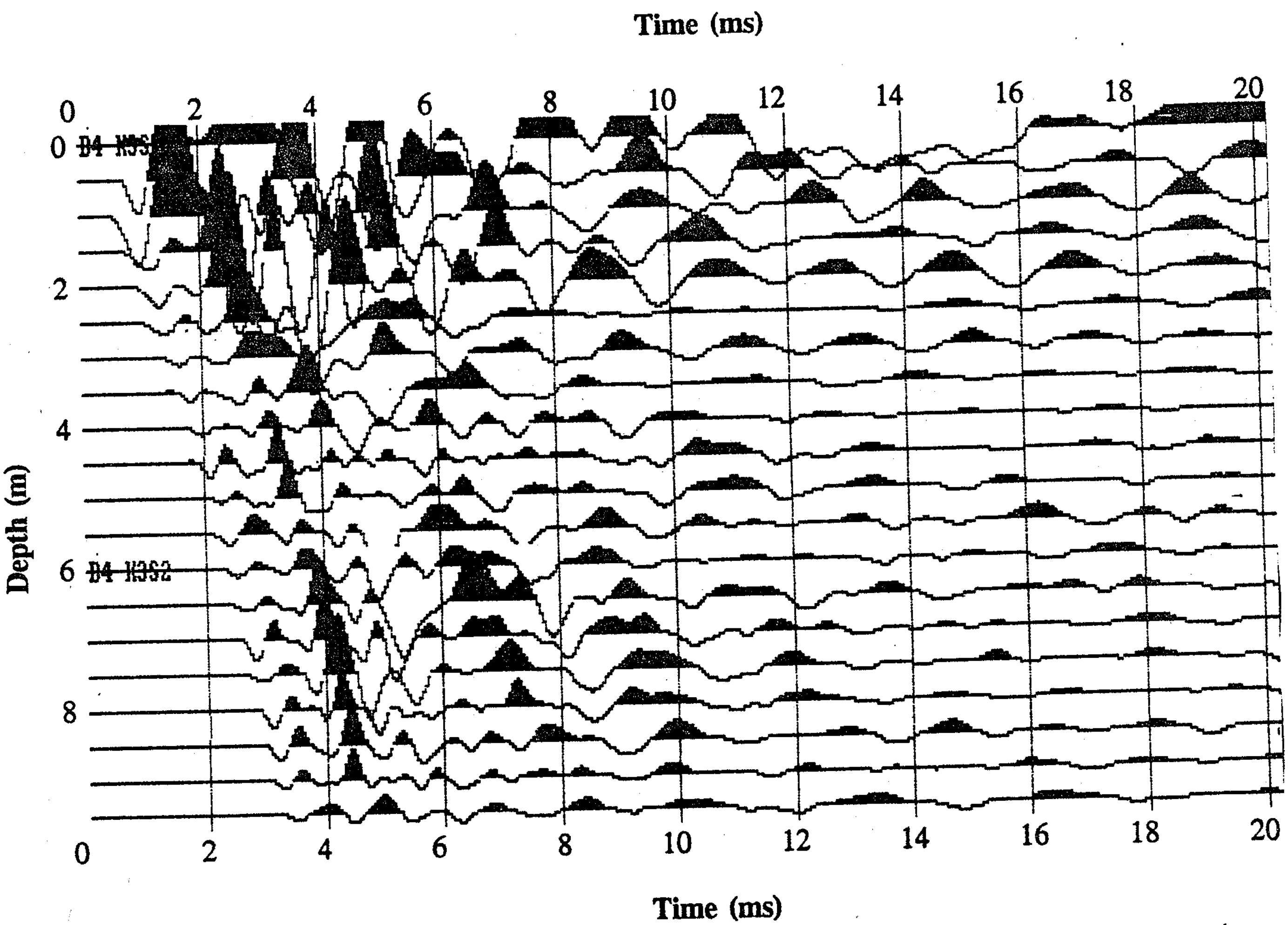


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 0.2 m east of BH
Source Depth: 0.5 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 1
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: N/A

Figure 163

BOVANENKOVO BOREHOLE 4 - DOWNHOLE SHEAR WAVE VSP

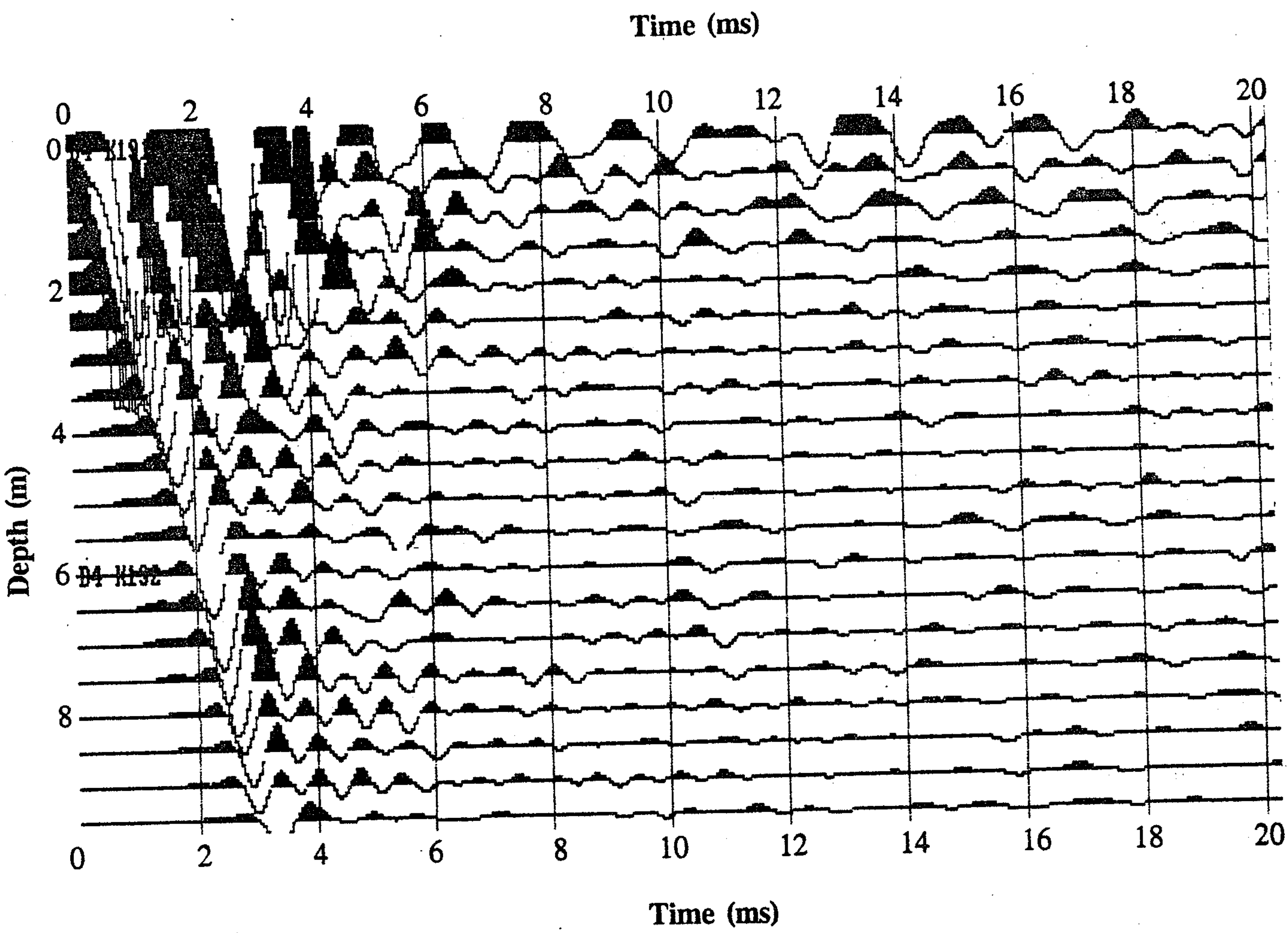


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 0.2 m east of BH
Source Depth: 0.5 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 2
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: N/A

Figure 164

BOVANENKOVO BOREHOLE 4 - DOWNHOLE SHEAR WAVE VSP

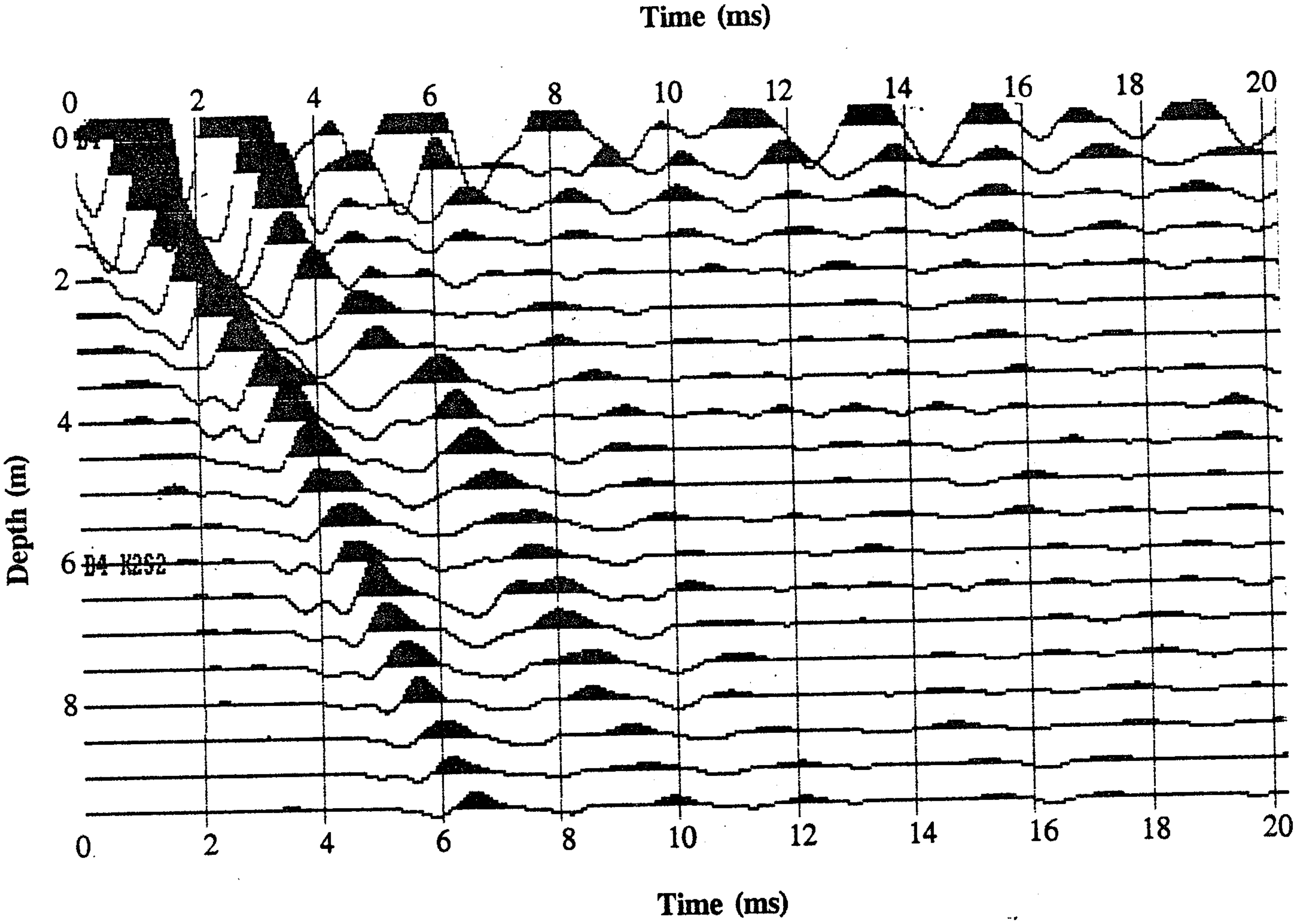


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 0.2 m east of BH
Source Depth: 0.5 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Vertical
AGC Parameters: 160 sample window (centred) AGC factor = 200
Bandpass Filter: 340-1540 Hz (12 db rolloffs)

Figure 165

BOVANENKOVO BOREHOLE 4 - DOWNHOLE SHEAR WAVE VSP

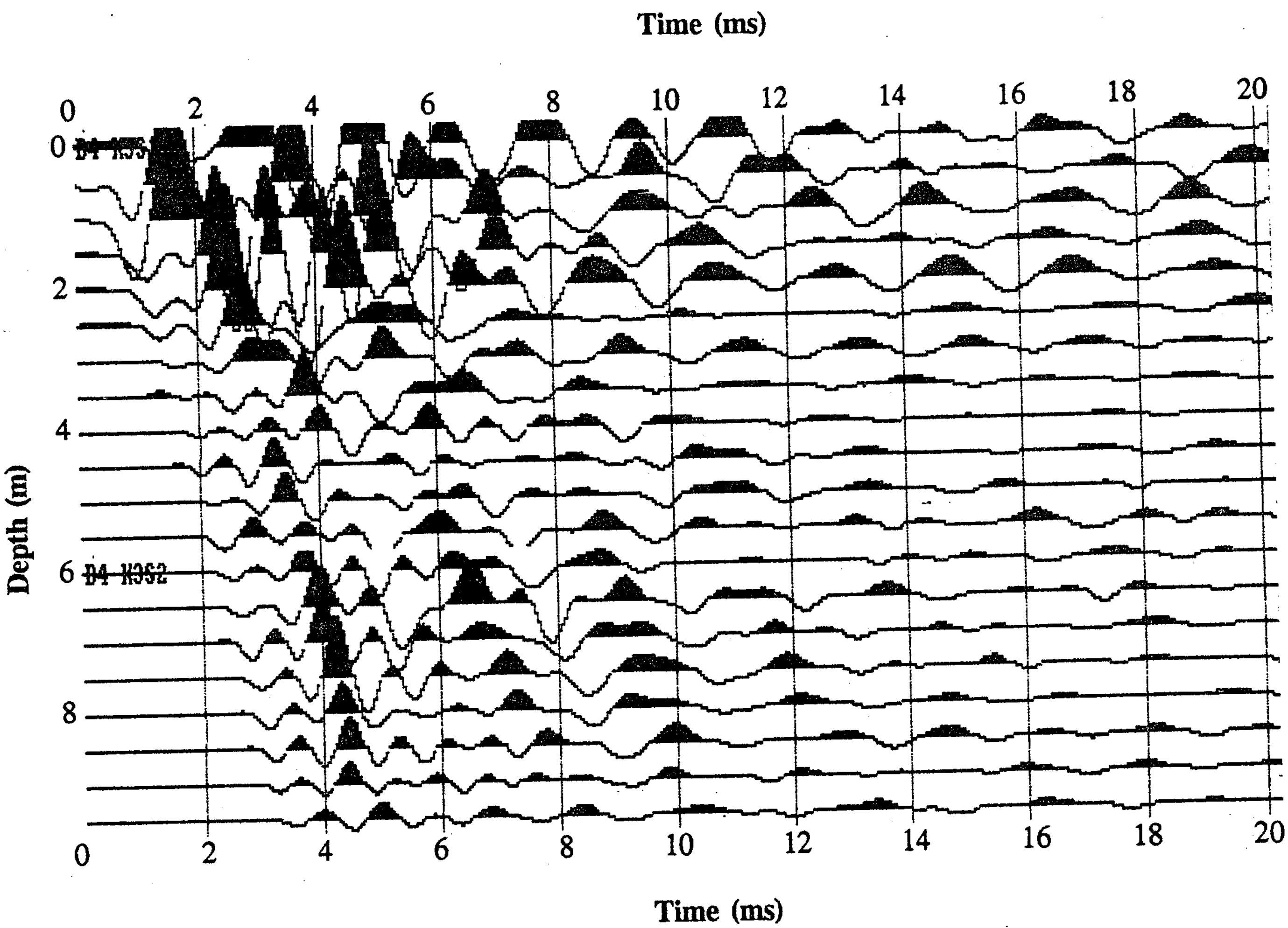


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 0.2 m east of BH
Source Depth: 0.5 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 1
AGC Parameters: 160 sample window (centred) AGC factor = 200
Bandpass Filter: 340-1540 Hz (12 db rolloffs)

Figure 166

BOVANENKOVO BOREHOLE 4 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 0.2 m east of BH
Source Depth: 0.5 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 2
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: 340-1540 Hz (12 db rolloffs)

Figure 167

DOWNHOLE SHEAR WAVE VSP

BOREHOLE 10

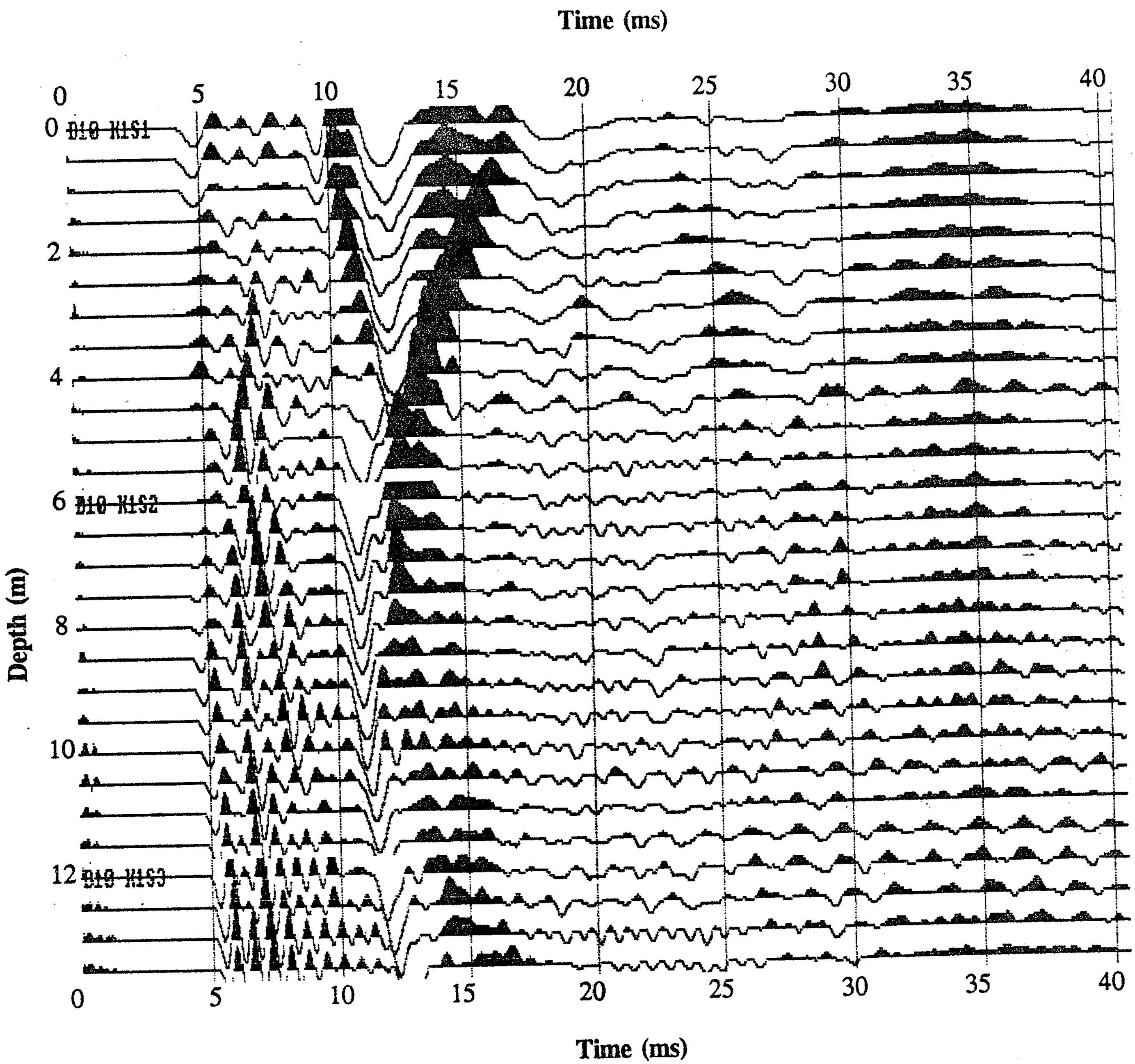
Vertical, Horizontal 1, and Horizontal 2 Components

plotted in raw format and after application of a digital filter.

Source locations and orientations

1. 7.6 m north of BH - 45° N
2. 3.8 m north of BH - 45° N
3. 1.5 m north of BH - 45° N
4. 0.2 m north of BH - 45° N
5. 1.8 m south of BH - 45° S

BOVANENKOVO BOREHOLE 10 - DOWNHOLE SHEAR WAVE VSP

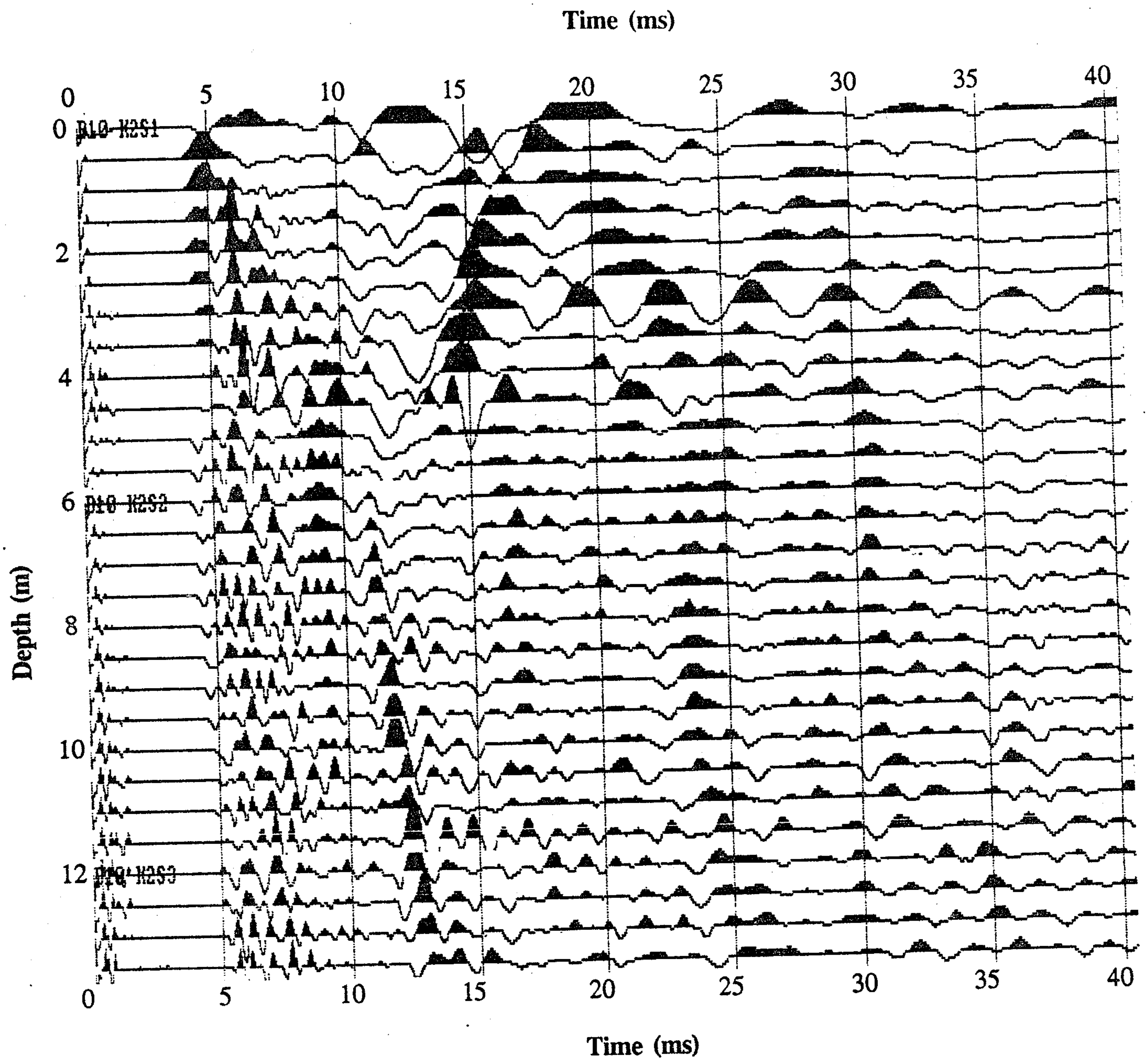


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 7.6 m north of BH
Source Depth: 0.65 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Vertical
AGC Parameters: 160 sample window (centred) AGC factor = 200
Bandpass Filter: N/A

Figure 168

BOVANENKOVO BOREHOLE 10 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:

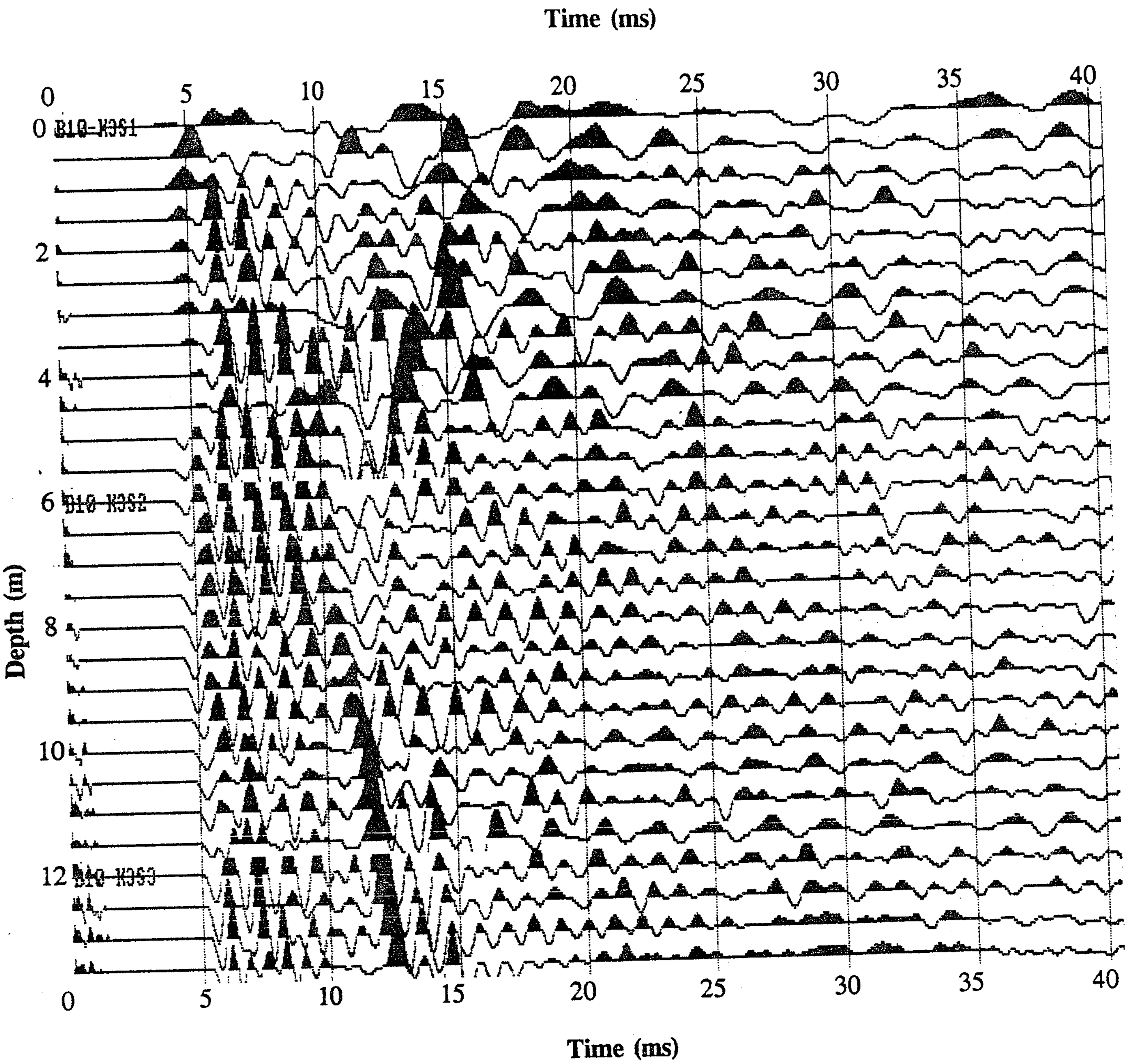
Source: Steel rod oriented 45° N
Source Offset: 7.6 m north of BH
Source Depth: 0.65 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:

Component Plotted: Horizontal 1
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: N/A

Figure 169

BOVANENKOVO BOREHOLE 10 - DOWNHOLE SHEAR WAVE VSP

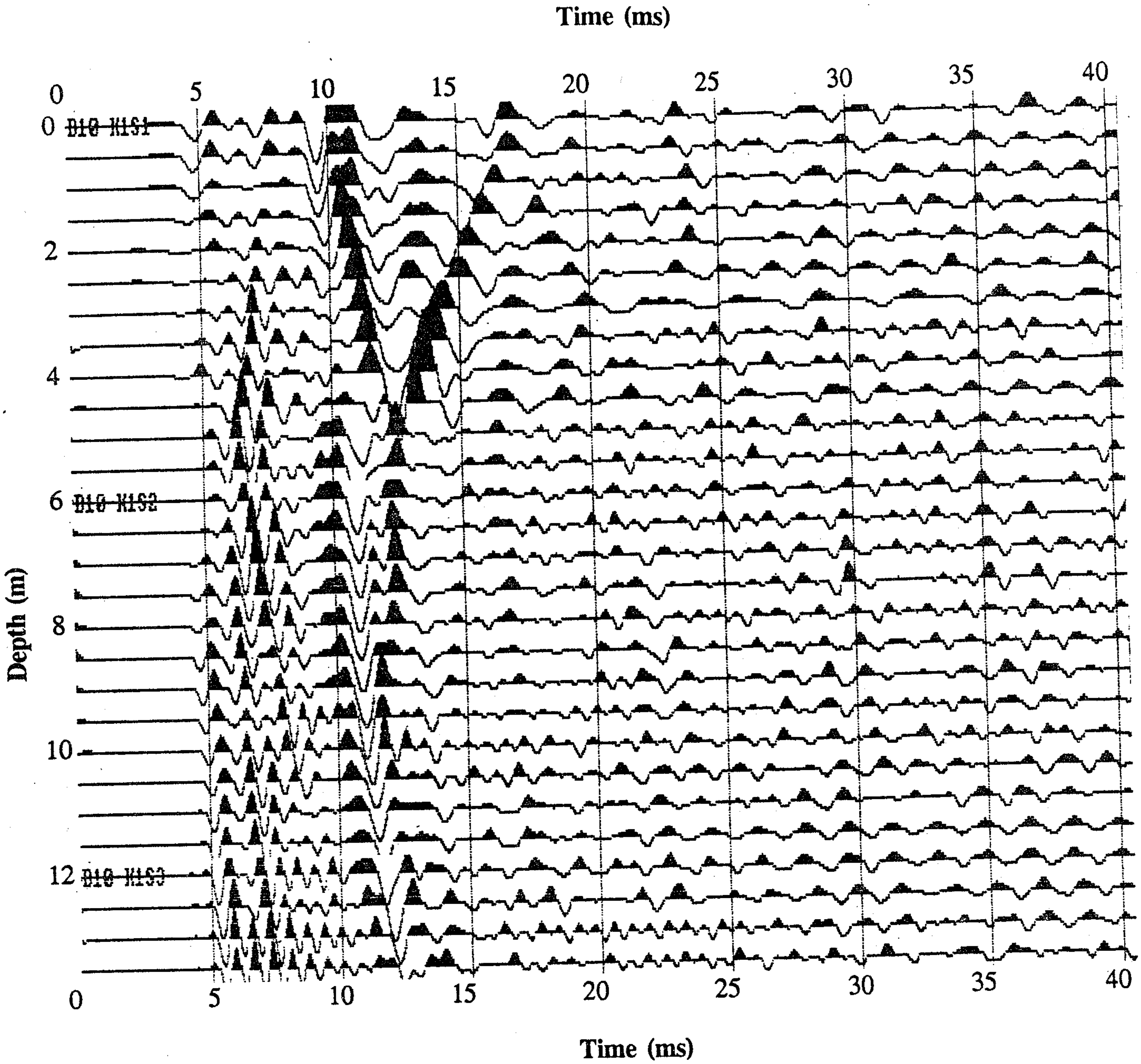


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 7.6 m north of BH
Source Depth: 0.65 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 2
AGC Parameters: 160 sample window (centred) AGC factor = 200
Bandpass Filter: N/A

Figure 170

BOVANENKOVO BOREHOLE 10 - DOWNHOLE SHEAR WAVE VSP

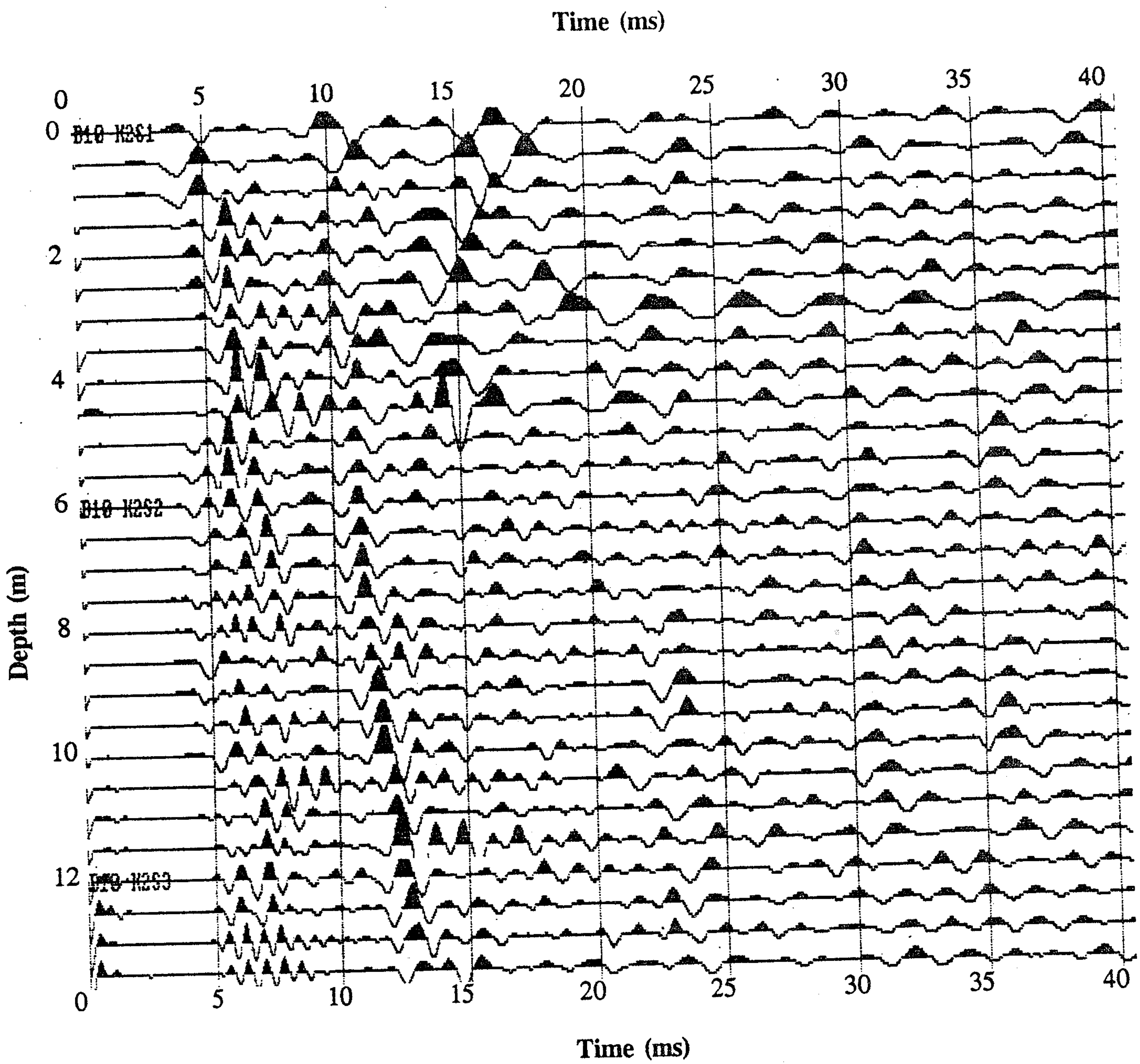


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 7.6 m north of BH
Source Depth: 0.65 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Vertical
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: 340-1540 Hz (12 db rolloffs)

Figure 171

BOVANENKOVO BOREHOLE 10 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:

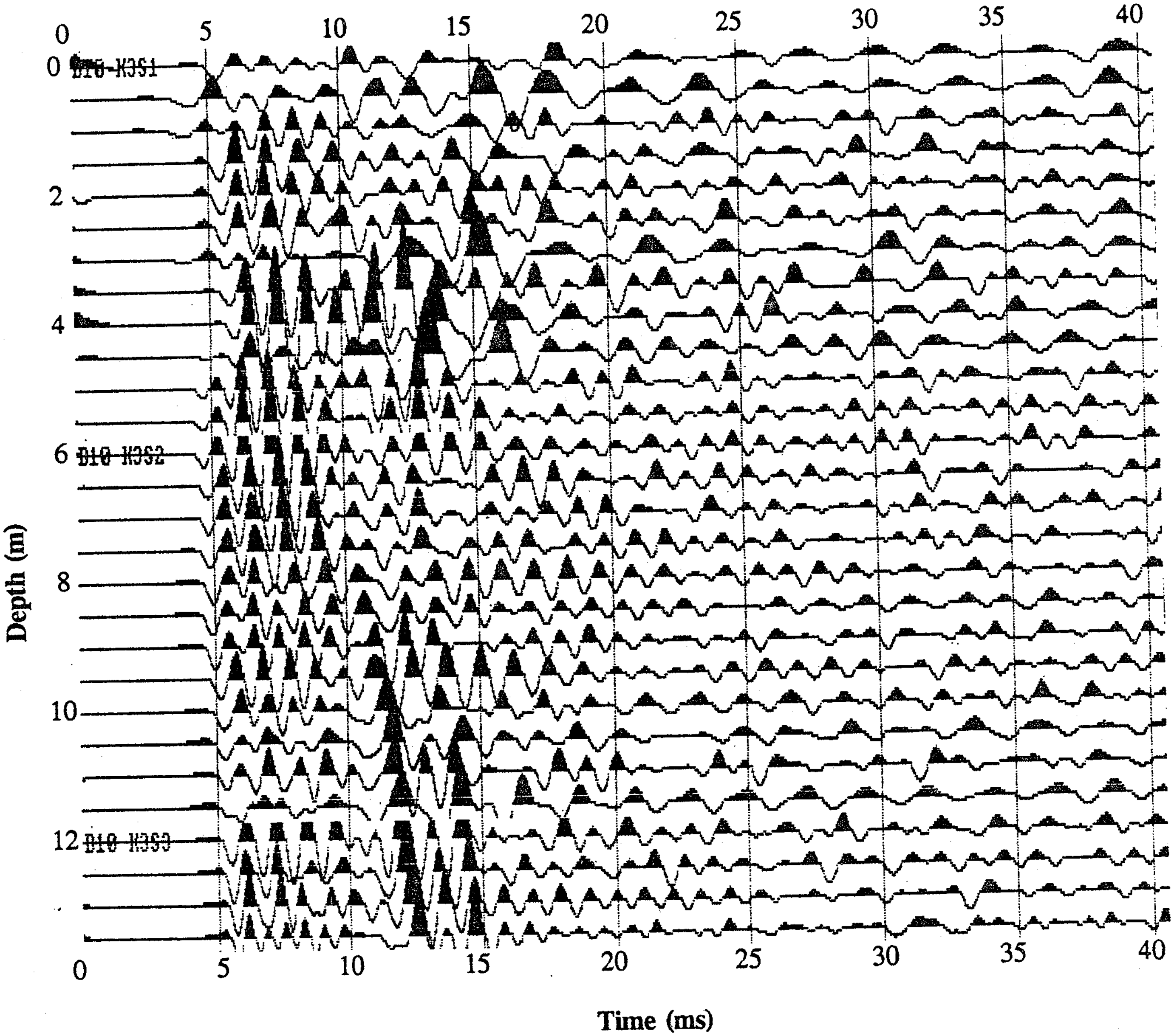
Source: Steel rod oriented 45° N
Source Offset: 7.6 m north of BH
Source Depth: 0.65 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:

Component Plotted: Horizontal 1
AGC Parameters: 160 sample window (centred) AGC factor = 200
Bandpass Filter: 340-1540 Hz (12 db rolloffs)

Figure 172

BOVANENKOVO BOREHOLE 10 - DOWNHOLE SHEAR WAVE VSP

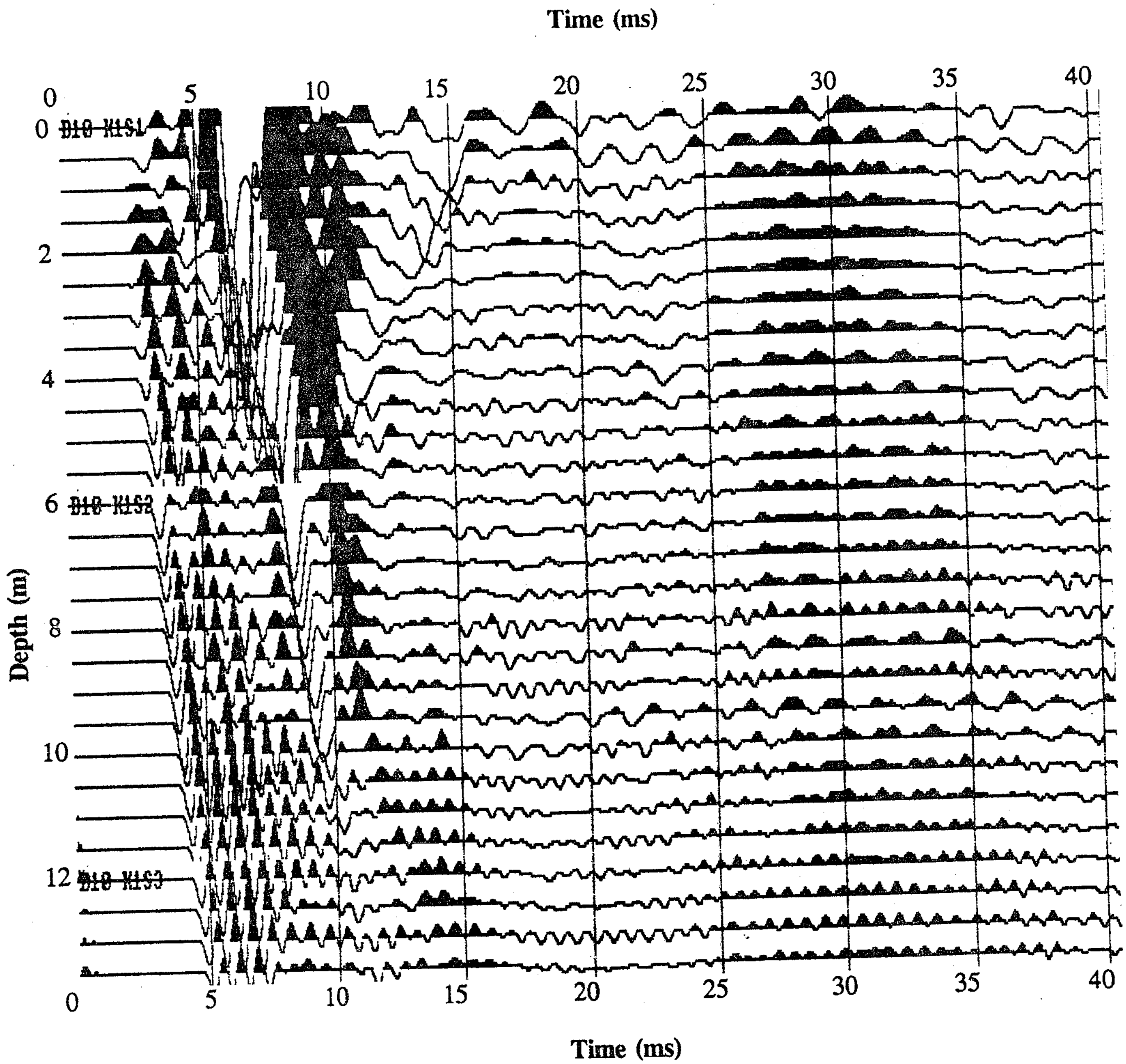


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 7.6 m north of BH
Source Depth: 0.65 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 2
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: 340-1540 Hz (12 db rolloffs)

Figure 173

BOVANENKOVO BOREHOLE 10 - DOWNHOLE SHEAR WAVE VSP

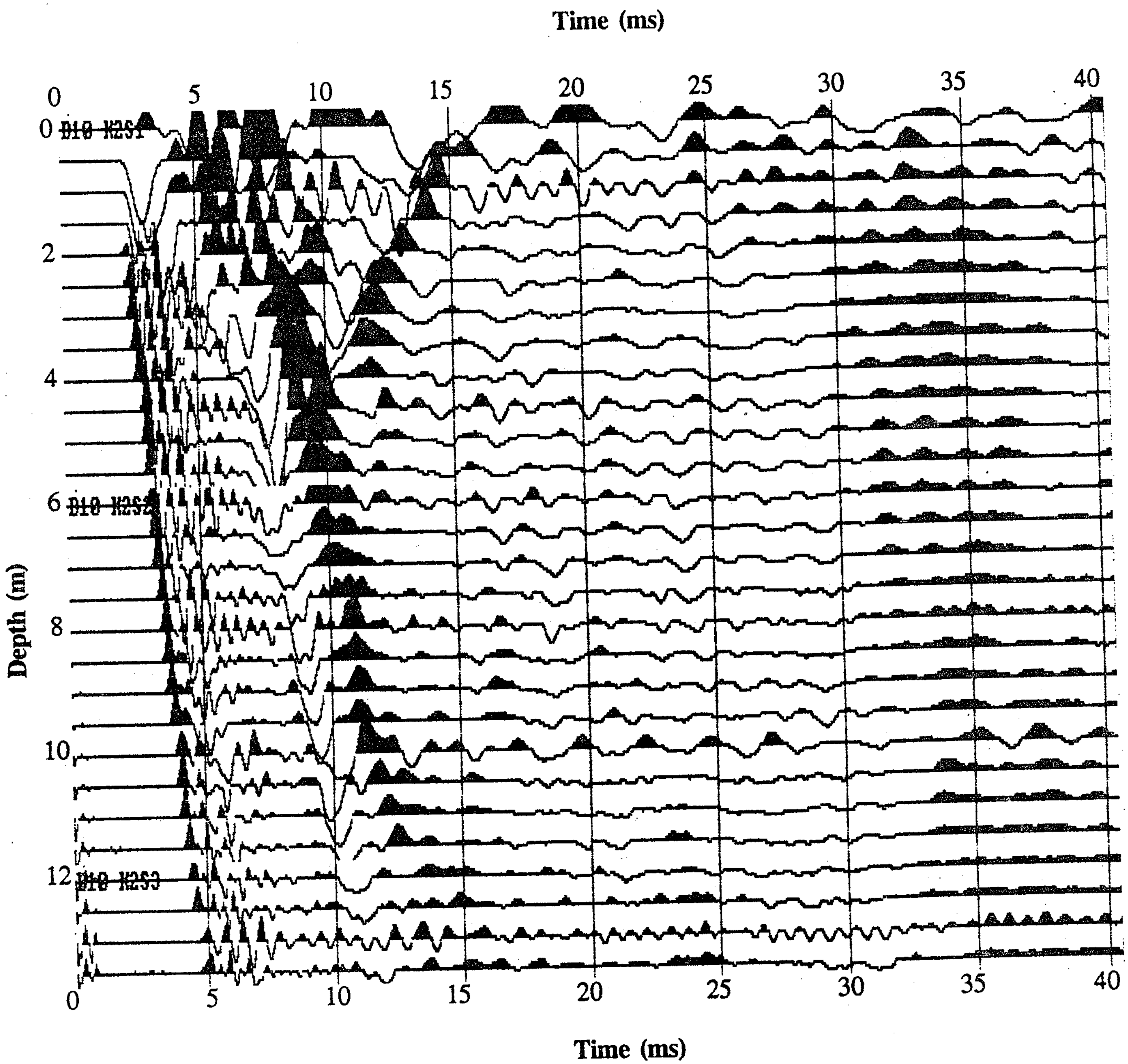


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 3.8 m north of BH
Source Depth: 0.8 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Vertical
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: N/A

Figure 174

BOVANENKOVO BOREHOLE 10 - DOWNHOLE SHEAR WAVE VSP

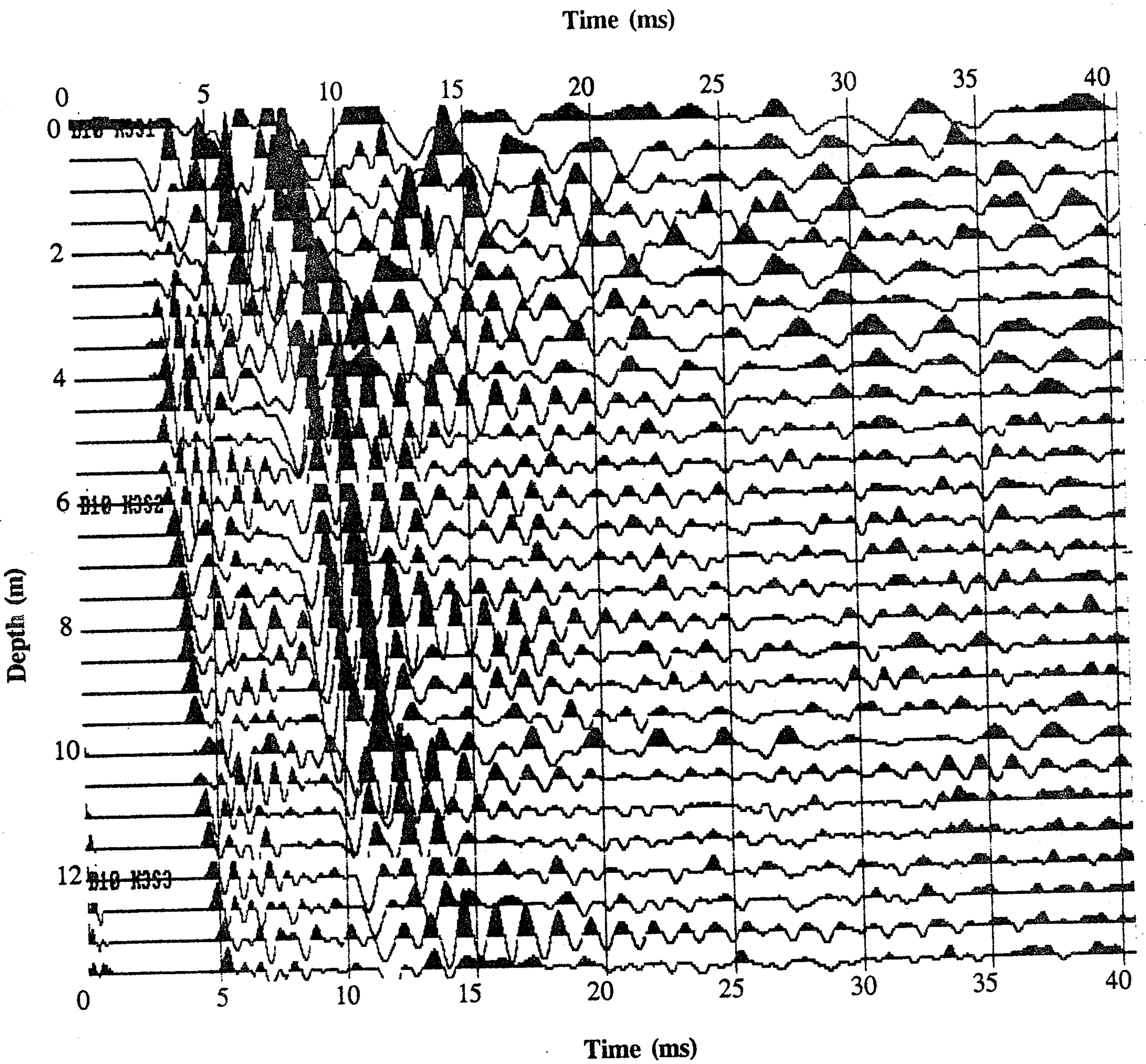


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 3.8 m north of BH
Source Depth: 0.8 m
Geophone: VSEGINGEO Downhole
3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 1
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: N/A

Figure 175

BOVANENKOVO BOREHOLE 10 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:

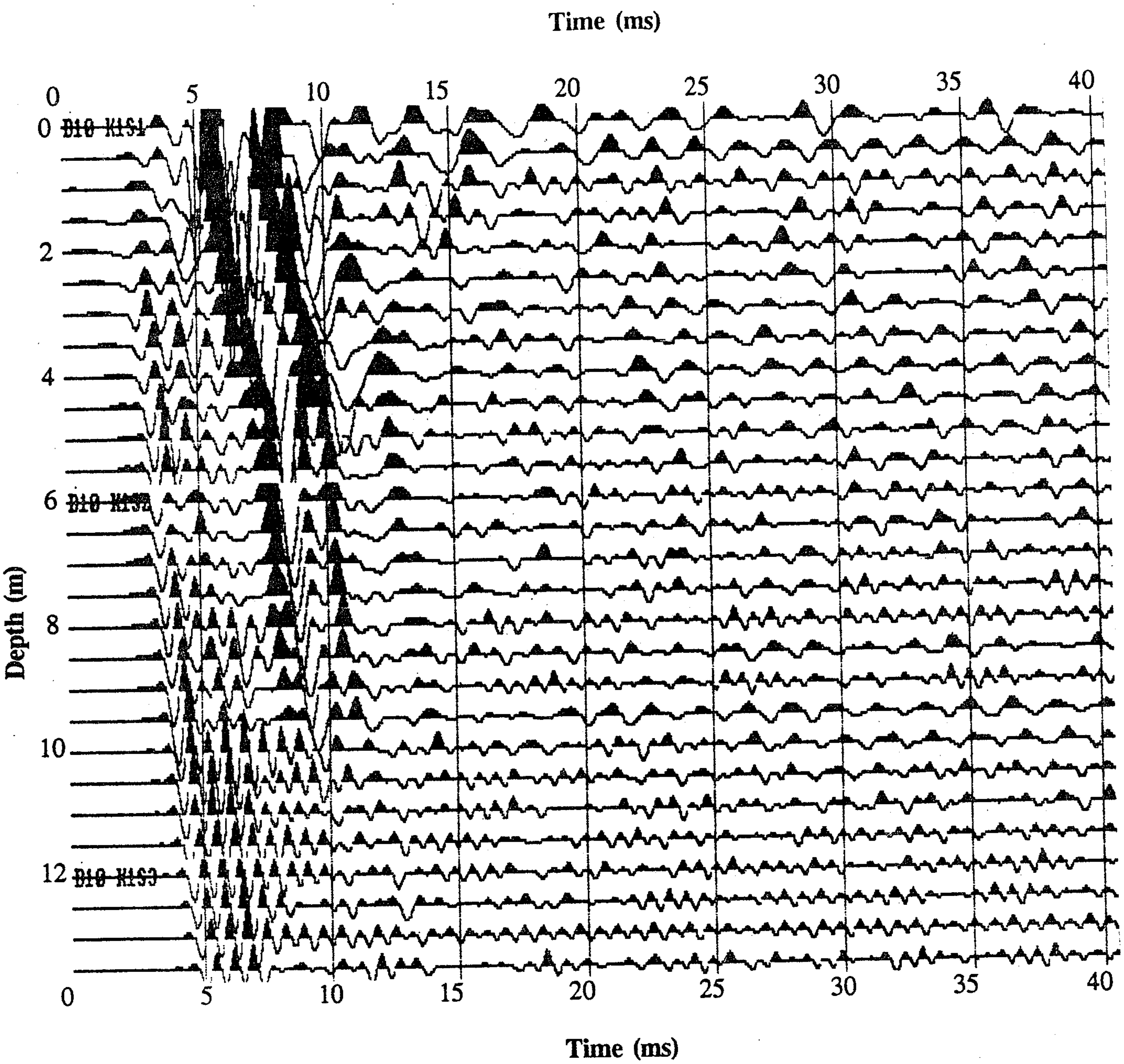
Source: Steel rod oriented 45° N
Source Offset: 3.8 m north of BH
Source Depth: 0.8 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:

Component Plotted: Horizontal 2
AGC Parameters: 160 sample window (centred) AGC factor = 200
Bandpass Filter: N/A

Figure 176

BOVANENKOVO BOREHOLE 10 - DOWNHOLE SHEAR WAVE VSP

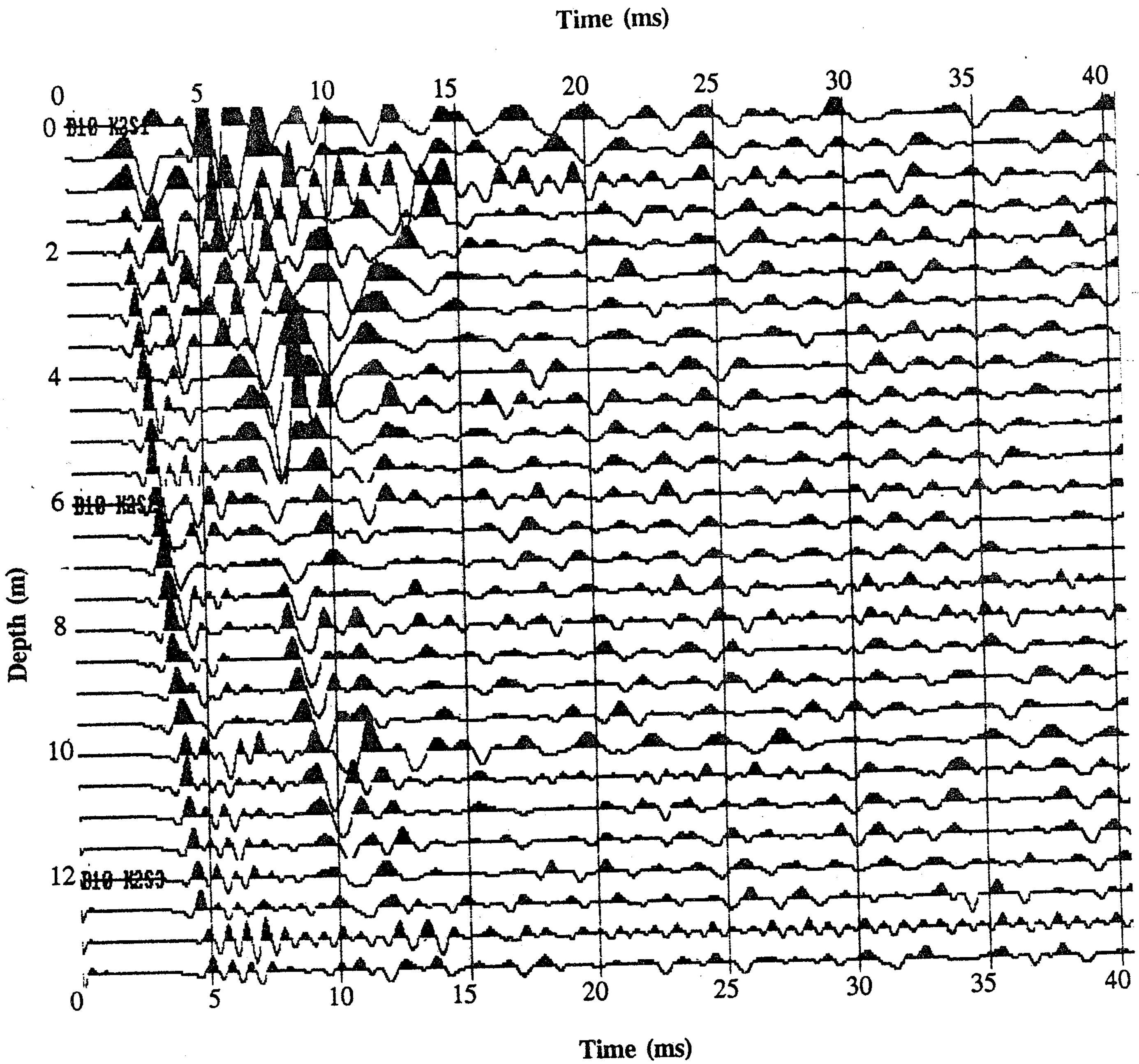


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 3.8 m north of BH
Source Depth: 0.8 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Vertical
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: 340-1540 Hz (12 db rolloffs)

Figure 177

BOVANENKOVO BOREHOLE 10 - DOWNHOLE SHEAR WAVE VSP

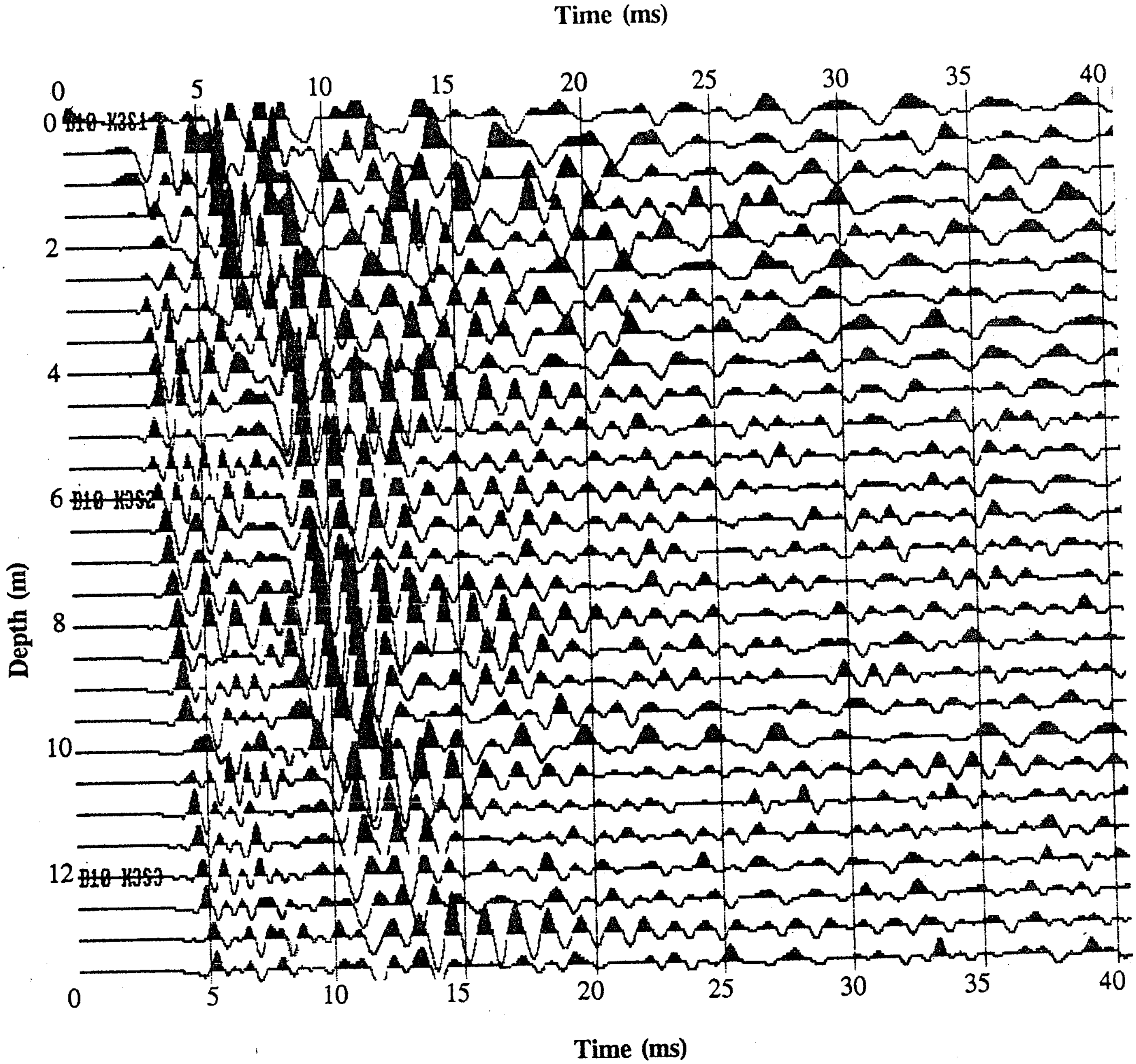


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 3.8 m north of BH
Source Depth: 0.8 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 1
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: 340-1540 Hz (12 db rolloffs)

Figure 178

BOVANENKOVO BOREHOLE 10 - DOWNHOLE SHEAR WAVE VSP

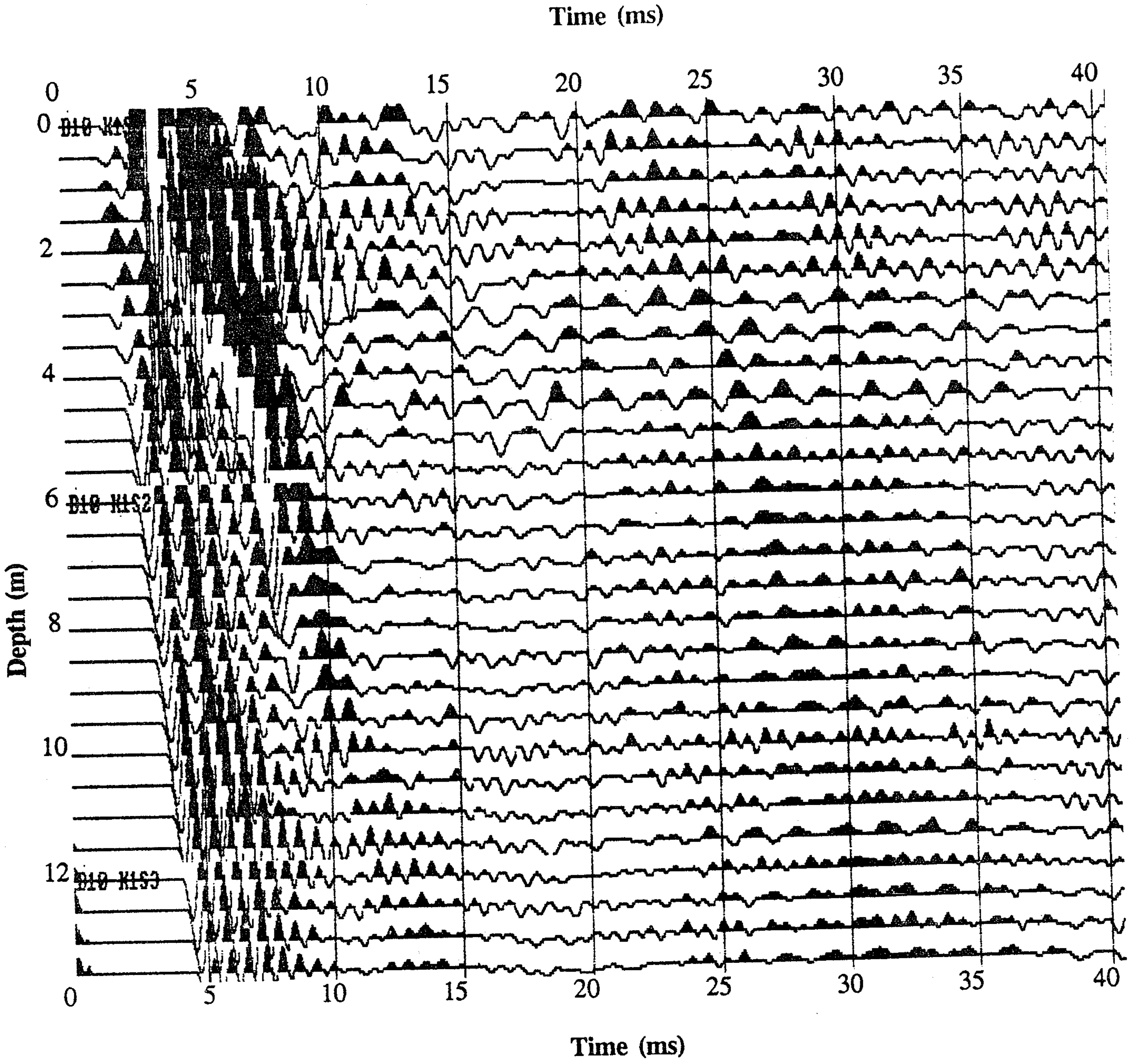


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 3.8 m north of BH
Source Depth: 0.8 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 2
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: 340-1540 Hz (12 db rolloffs)

Figure 179

BOVANENKOVO BOREHOLE 10 - DOWNHOLE SHEAR WAVE VSP

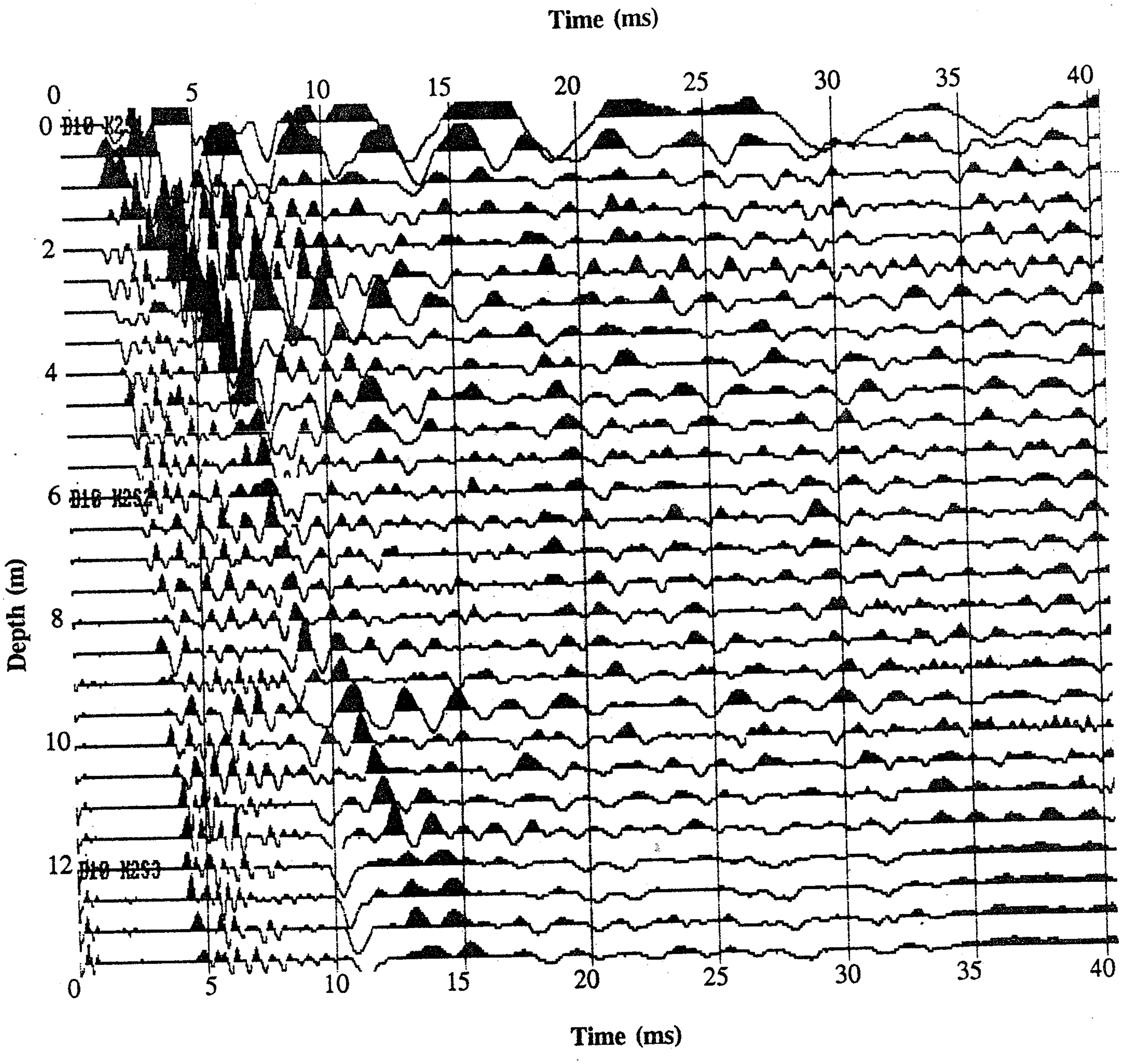


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 1.5 m north of BH
Source Depth: 0.85 m
Geophone: VSEGINGEO Downhole 3-component
Sampling interval: 0.05 ms

Display Parameters:
Component Plotted: Vertical
AGC Parameters: 160 sample window (centred) AGC factor = 200
Bandpass Filter: N/A

Figure 180

BOVANENKOVO BOREHOLE 10 - DOWNHOLE SHEAR WAVE VSP

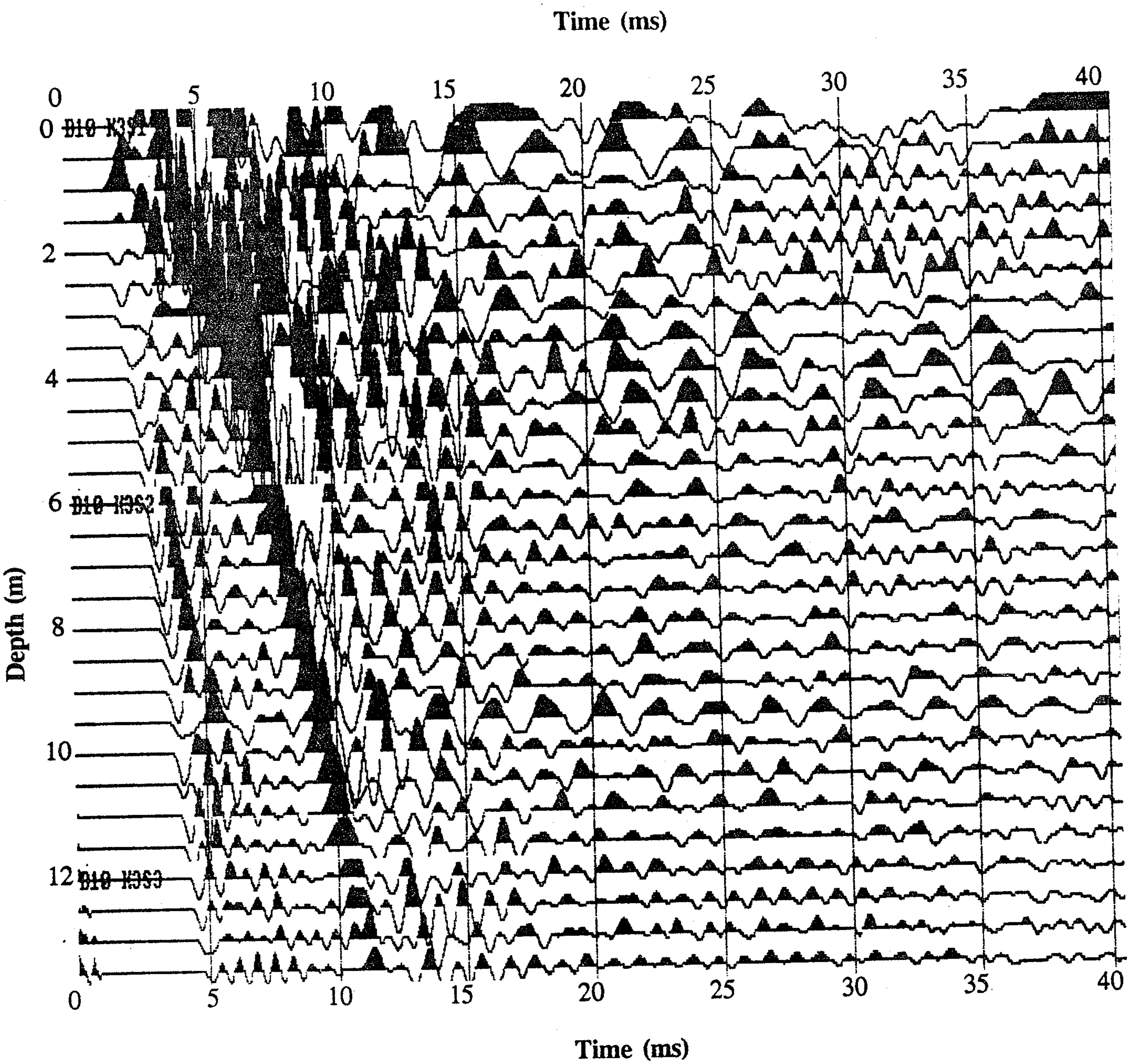


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 1.5 m north of BH
Source Depth: 0.85 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 1
AGC Parameters: 160 sample window (centred) AGC factor = 200
Bandpass Filter: N/A

Figure 181

BOVANENKOVO BOREHOLE 10 - DOWNHOLE SHEAR WAVE VSP

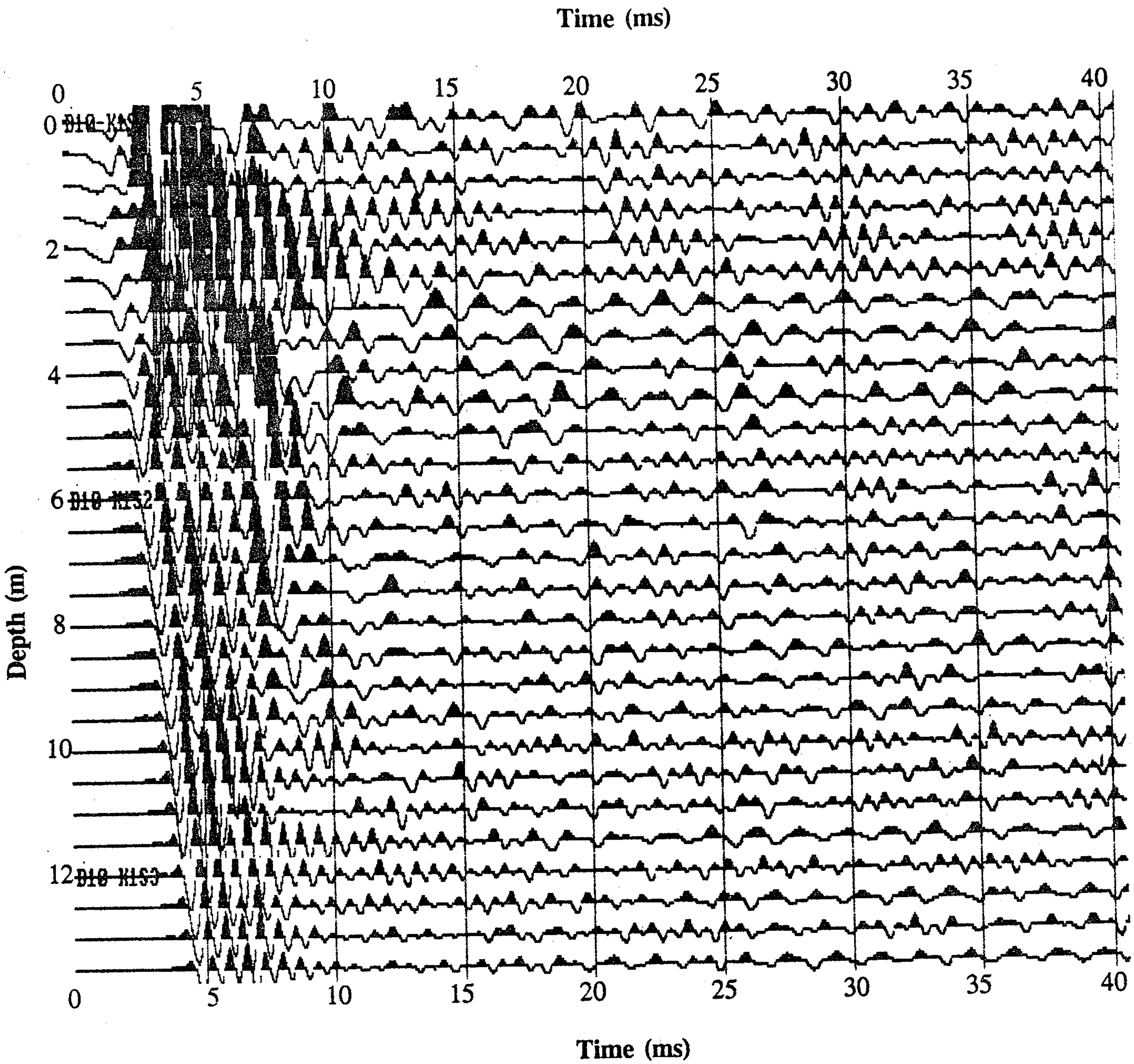


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 1.5 m north of BH
Source Depth: 0.85 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 2
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: N/A

Figure 182

BOVANENKOVO BOREHOLE 10 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:

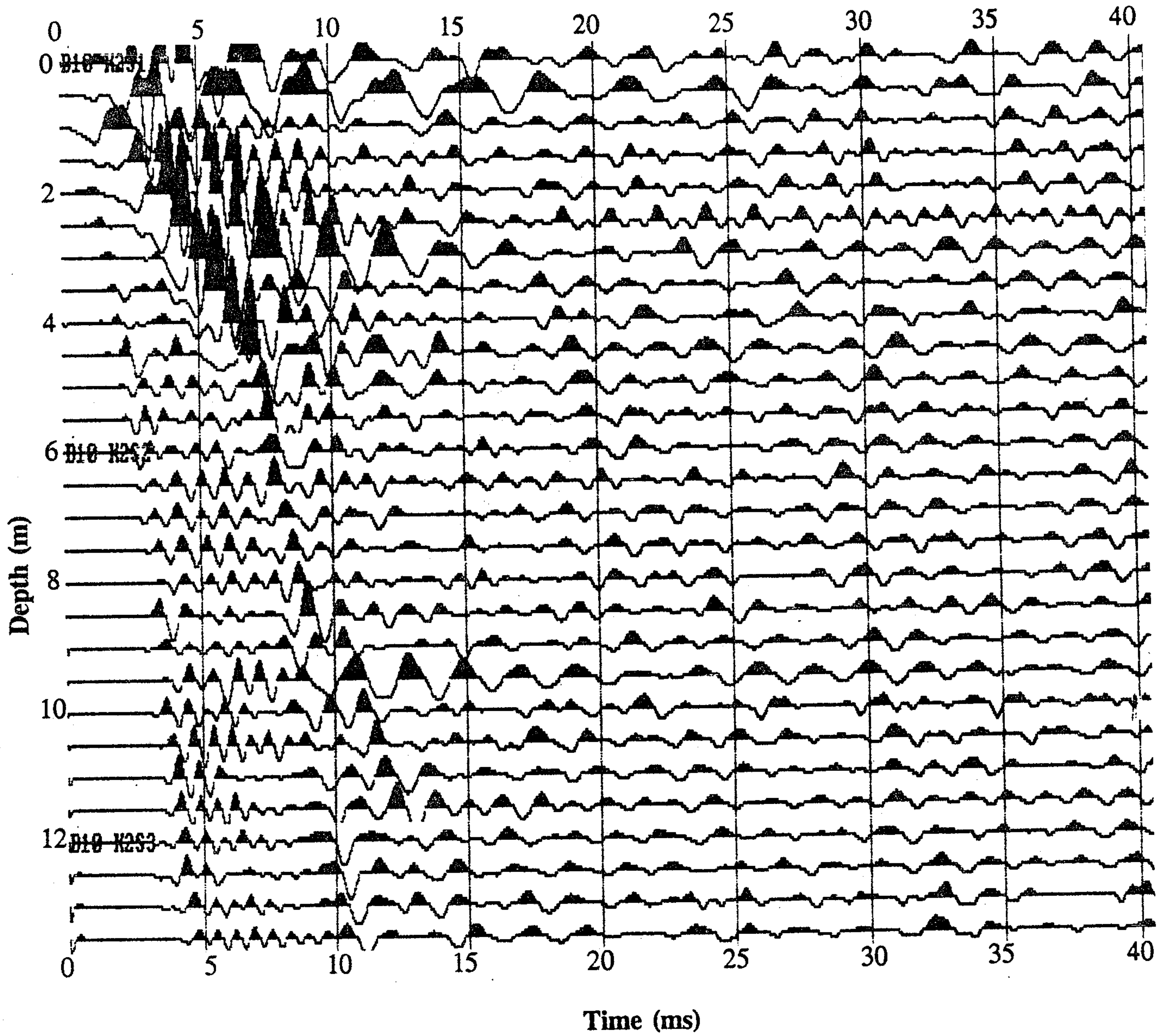
Source: Steel rod oriented 45° N
Source Offset: 1.5 m north of BH
Source Depth: 0.85 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:

Component Plotted: Vertical
AGC Parameters: 160 sample window (centred) AGC factor = 200
Bandpass Filter: 340-1540 Hz (12 db rolloffs)

Figure 183

BOVANENKOVO BOREHOLE 10 - DOWNHOLE SHEAR WAVE VSP

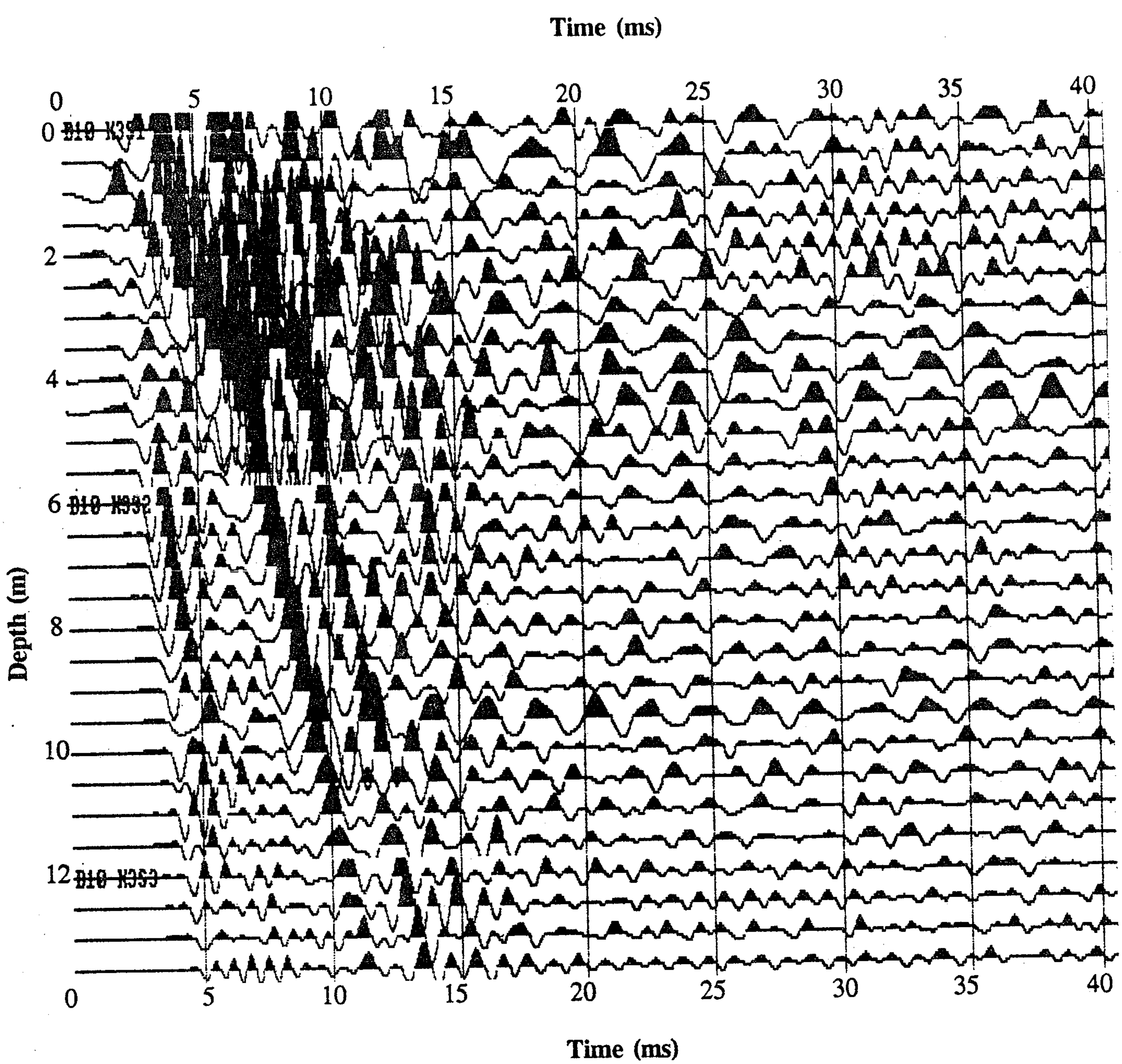


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 1.5 m north of BH
Source Depth: 0.85 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 1
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: 340-1540 Hz (12 db rolloffs)

Figure 184

BOVANENKOVO BOREHOLE 10 - DOWNHOLE SHEAR WAVE VSP

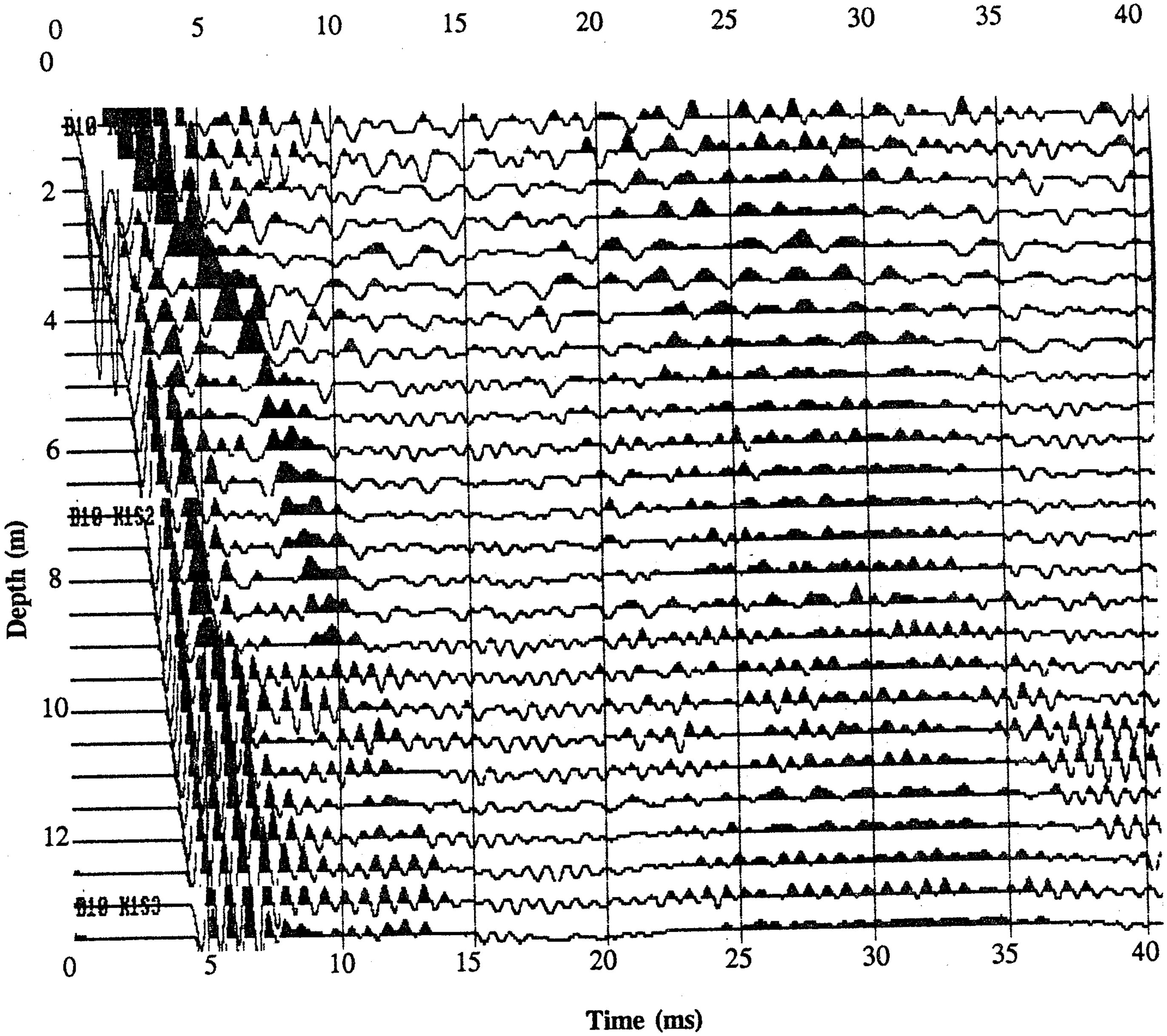


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 1.5 m north of BH
Source Depth: 0.85 m
Geophone: VSEGINGEO Downhole
3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 2
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: 340-1540 Hz (12 db rolloffs)

Figure 185

BOVANENKOVO BOREHOLE 10 - DOWNHOLE SHEAR WAVE VSP

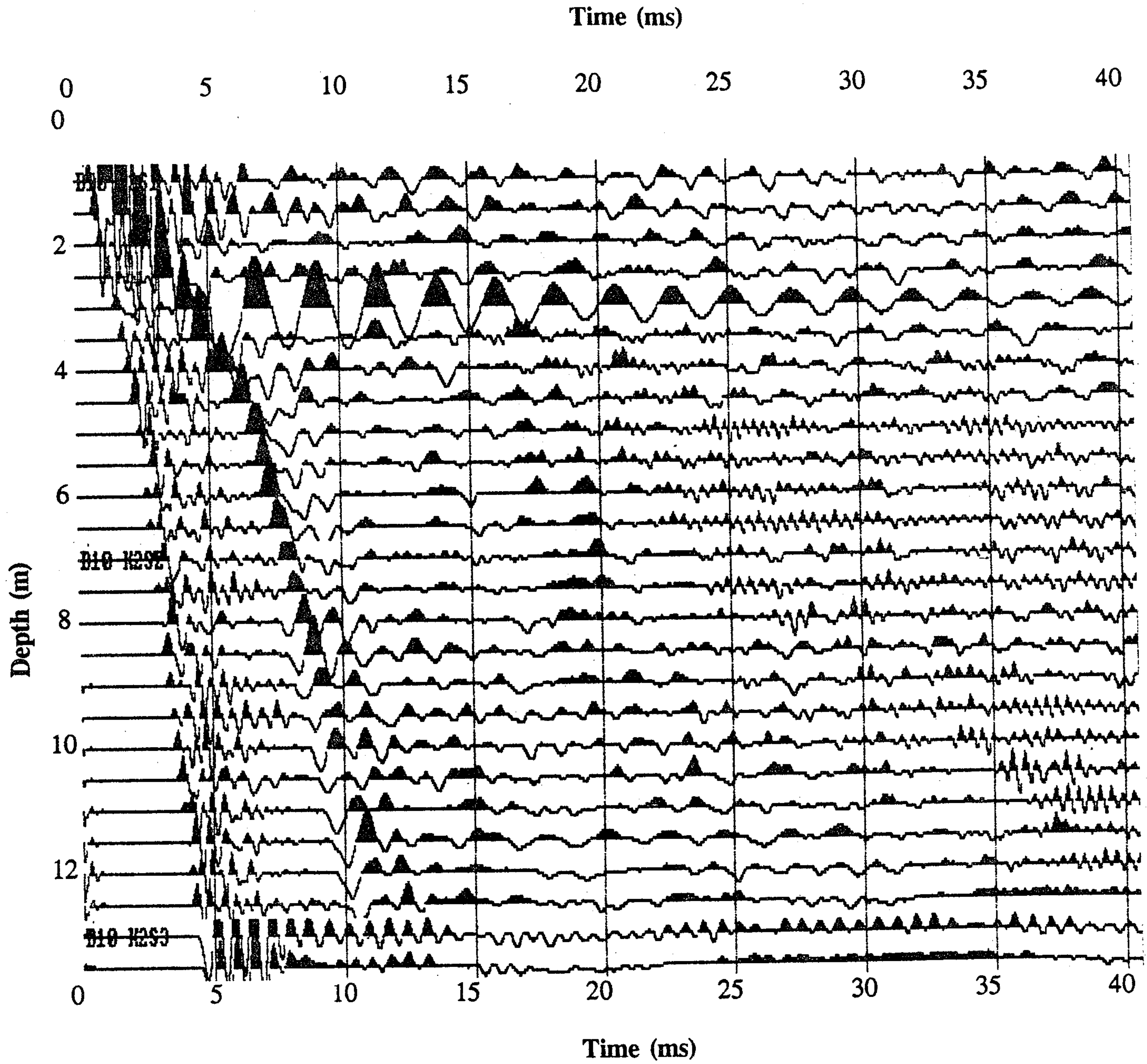


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 0.2 m north of BH
Source Depth: 0.75 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Vertical
AGC Parameters: 160 sample window (centred) AGC factor = 200
Bandpass Filter: N/A

Figure 186

BOVANENKOVO BOREHOLE 10 - DOWNHOLE SHEAR WAVE VSP

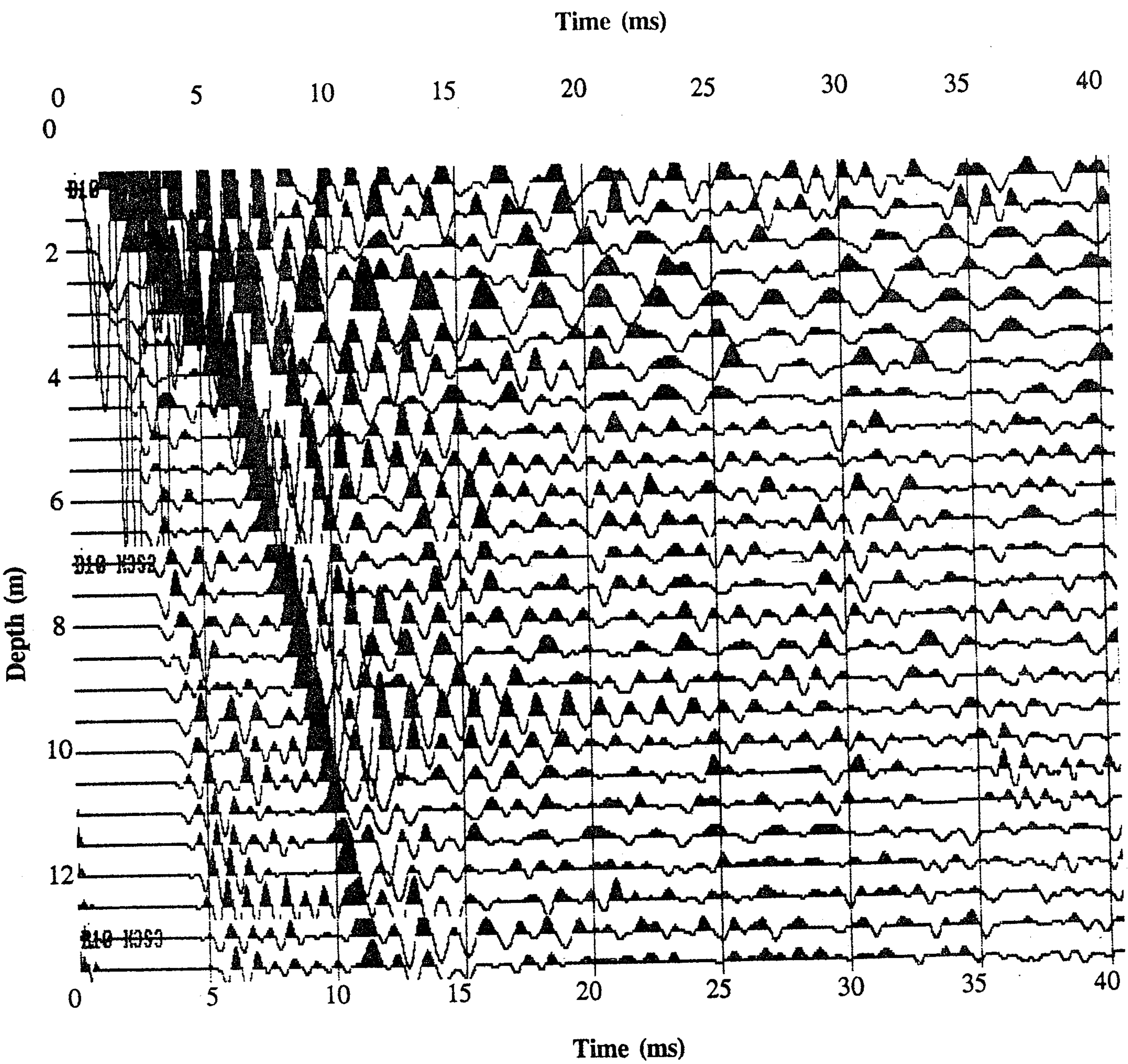


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 0.2 m north of BH
Source Depth: 0.75 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 1
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: N/A

Figure 187

BOVANENKOVO BOREHOLE 10 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:

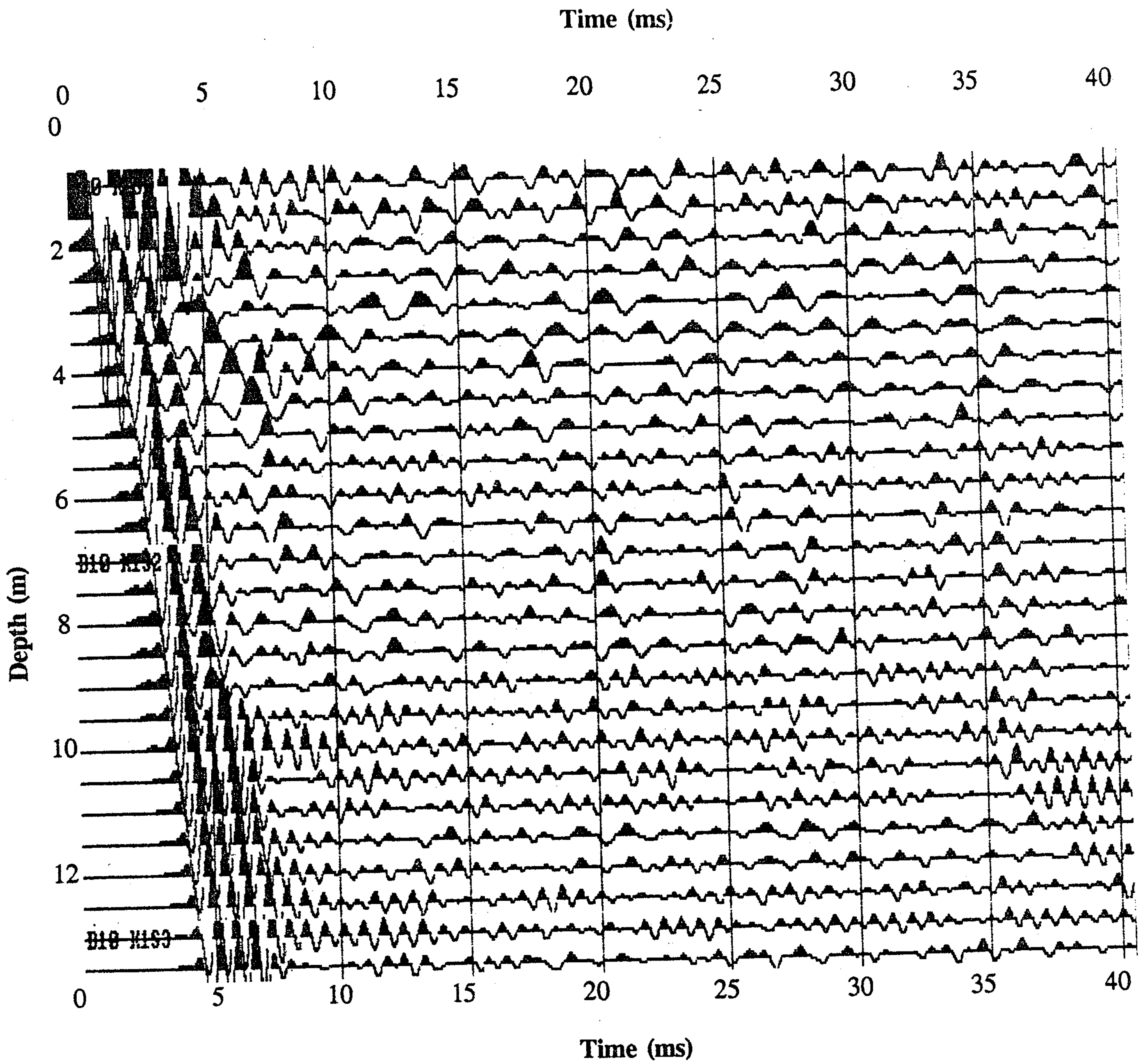
Source: Steel rod oriented 45° N
Source Offset: 0.2 m north of BH
Source Depth: 0.75 m
Geophone: VSEGINGEO Downhole
3-component
Sampling Interval: 0.05 ms

Display Parameters:

Component Plotted: Horizontal 2
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: N/A

Figure 188

BOVANENKOVO BOREHOLE 10 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:

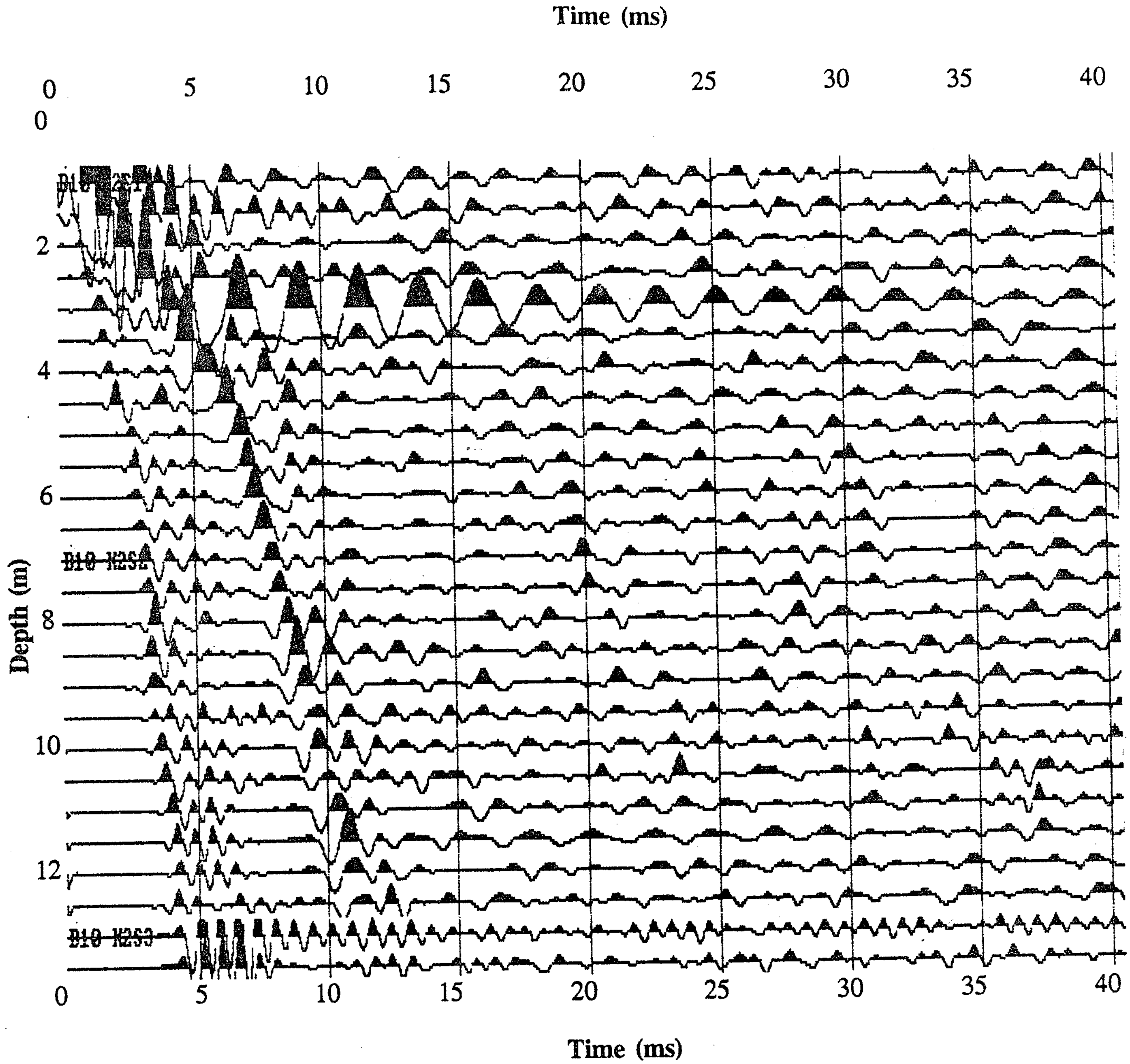
Source: Steel rod oriented 45° N
Source Offset: 0.2 m north of BH
Source Depth: 0.75 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:

Component Plotted: Vertical
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: 340-1540 Hz (12 db rolloffs)

Figure 189

BOVANENKOVO BOREHOLE 10 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:

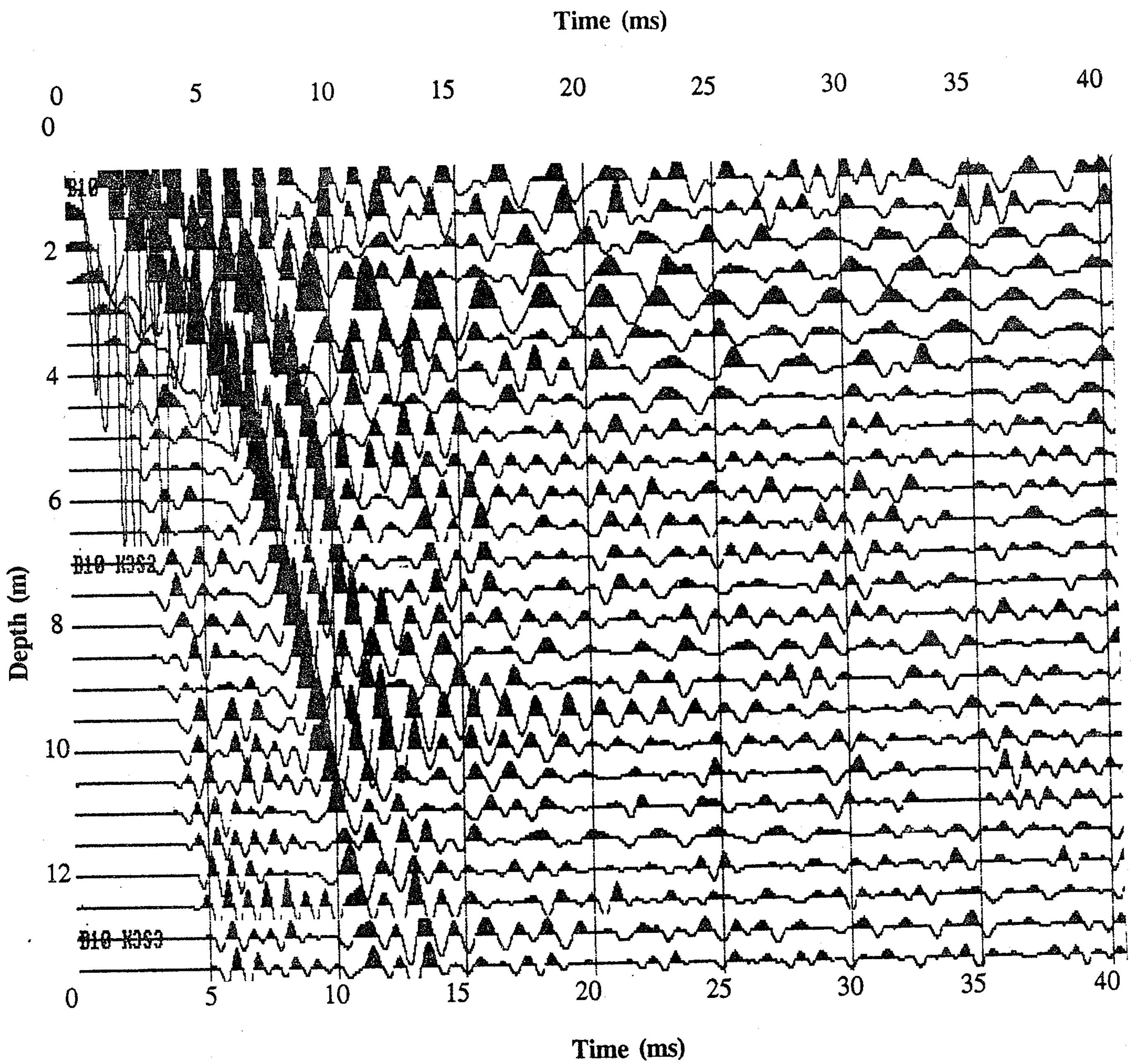
Source: Steel rod oriented 45° N
Source Offset: 0.2 m north of BH
Source Depth: 0.75 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:

Component Plotted: Horizontal 1
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: 340-1540 Hz (12 db rolloffs)

Figure 190

BOVANENKOVO BOREHOLE 10 - DOWNHOLE SHEAR WAVE VSP

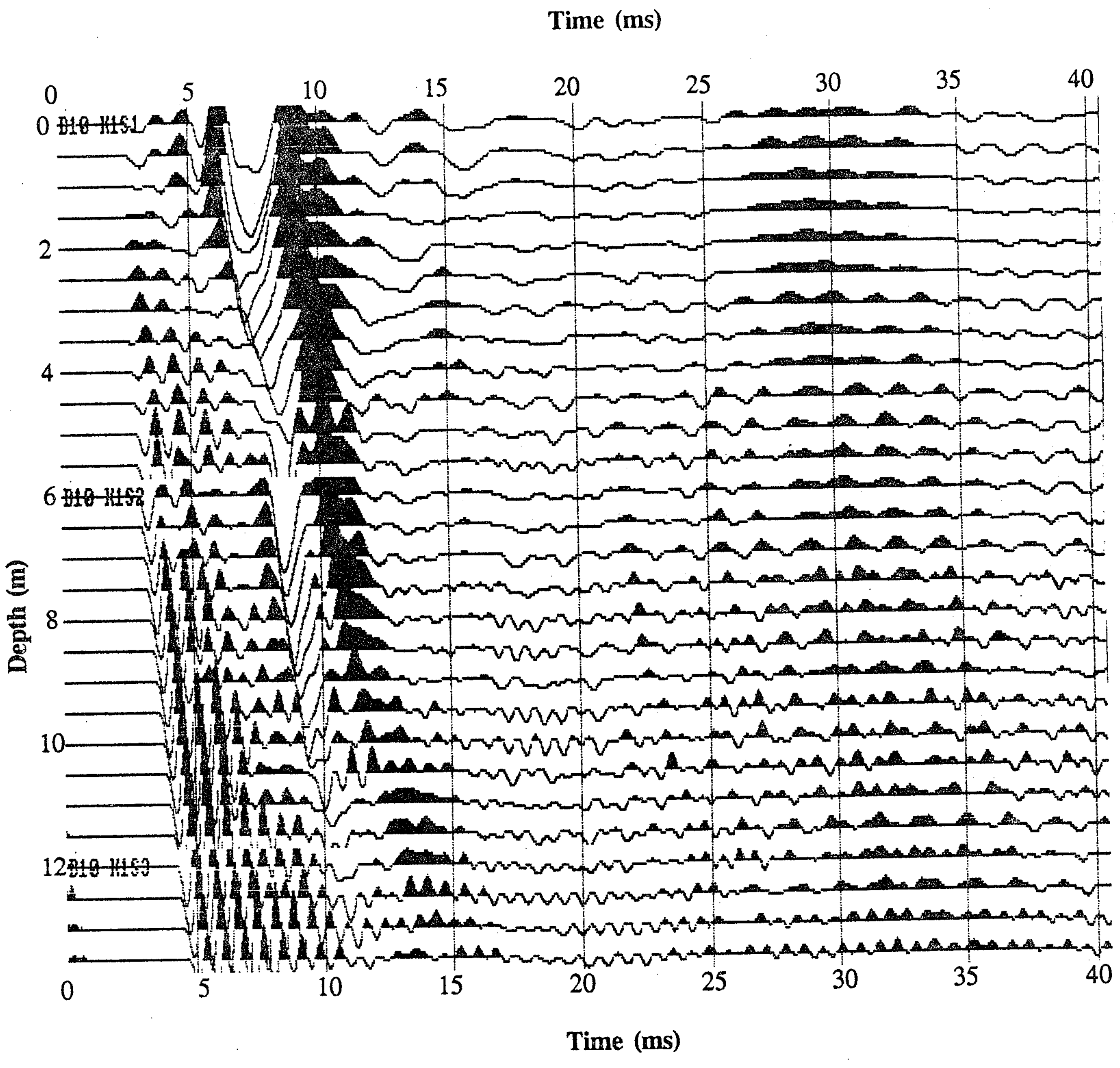


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 0.2 m north of BH
Source Depth: 0.75 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 2
AGC Parameters: 160 sample window (centred) AGC factor = 200
Bandpass Filter: 340-1540 Hz (12 db rolloffs)

Figure 191

BOVANENKOVO BOREHOLE 10 - DOWNHOLE SHEAR WAVE VSP

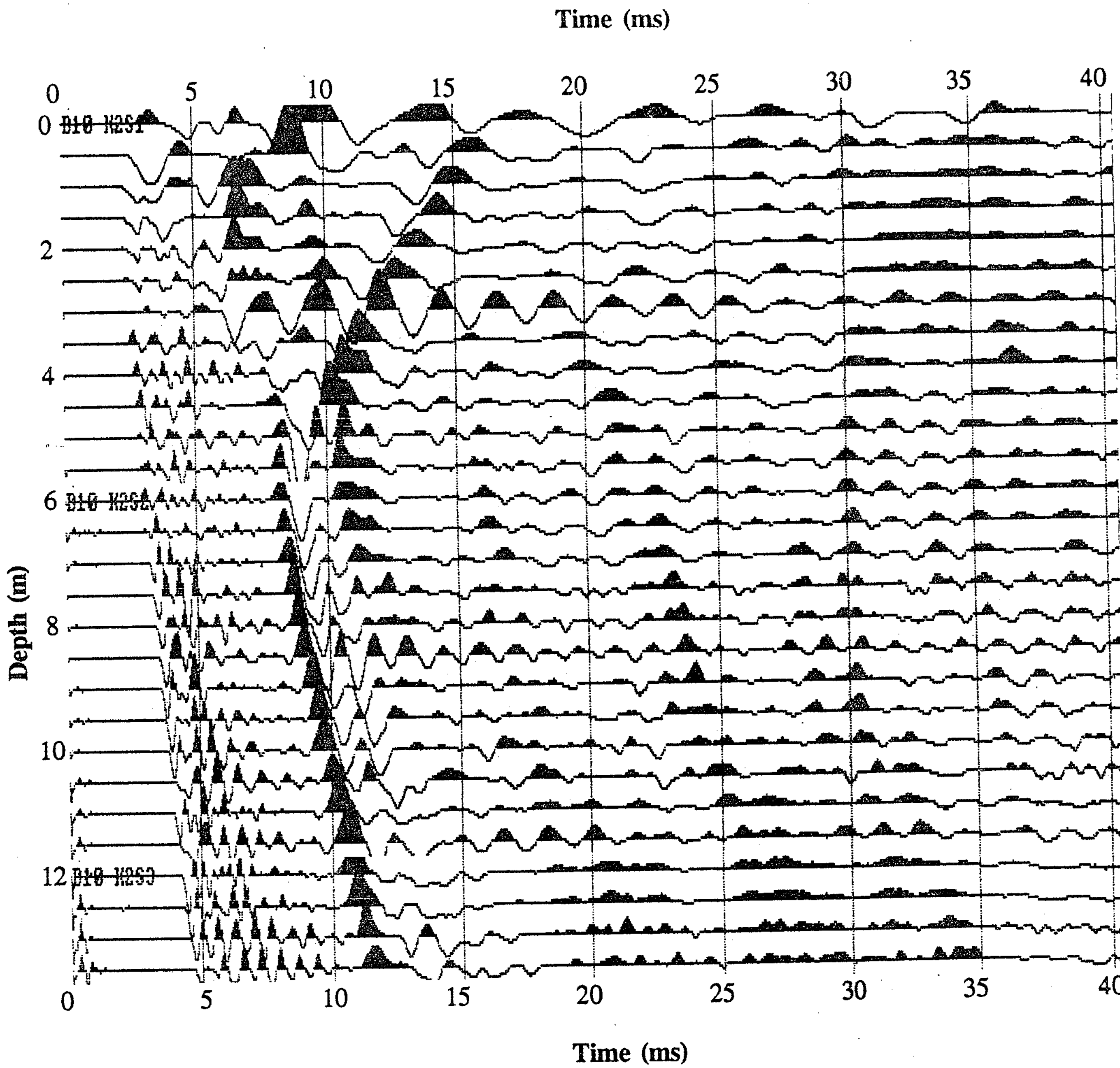


Recording Parameters:
Source: Steel rod oriented 45° S
Source Offset: 1.8 m south of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Vertical
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: N/A

Figure 192

BOVANENKOVO BOREHOLE 10 - DOWNHOLE SHEAR WAVE VSP

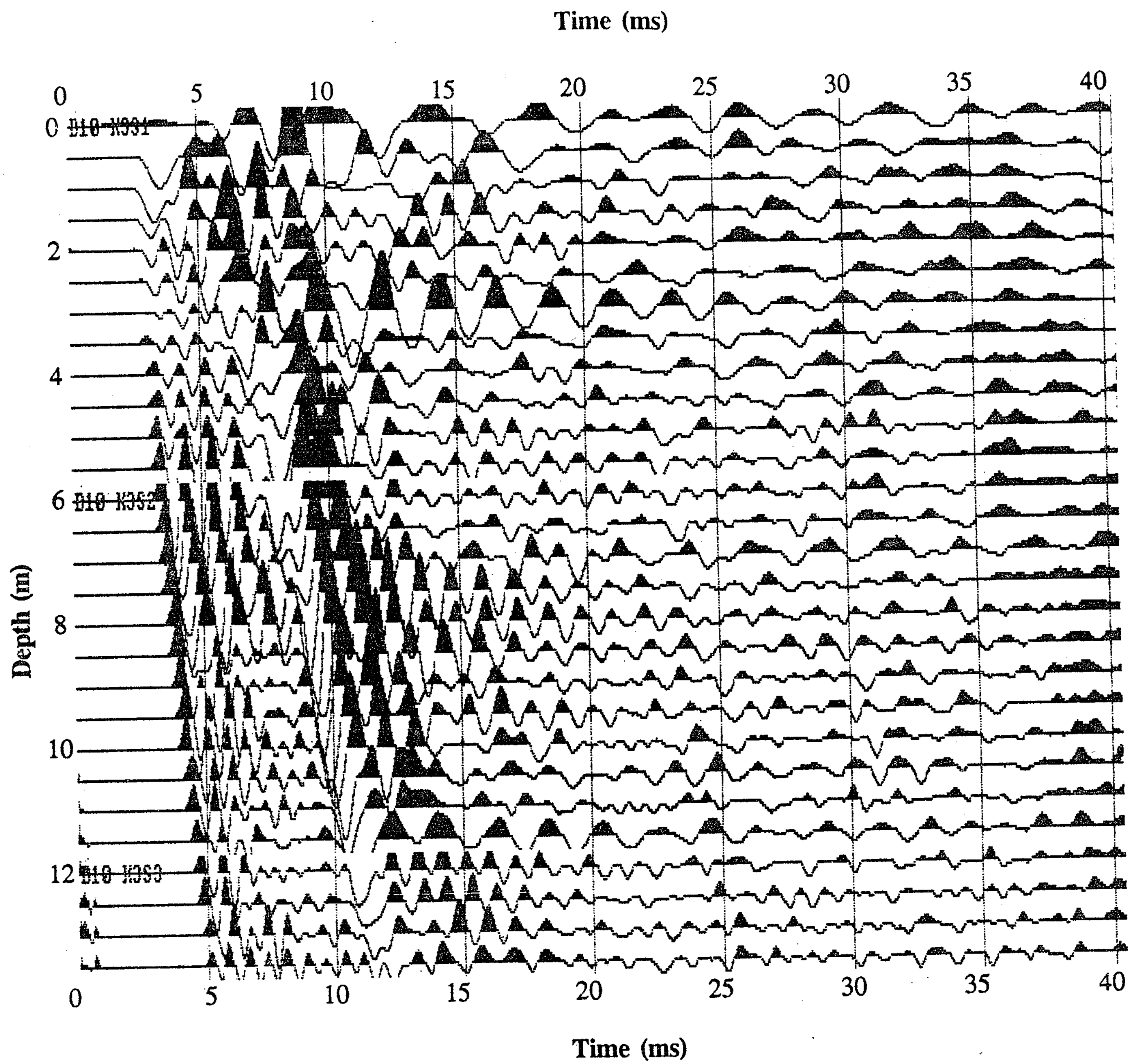


Recording Parameters:
Source: Steel rod oriented 45° S
Source Offset: 1.8 m south of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 1
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: N/A

Figure 193

BOVANENKOVO BOREHOLE 10 - DOWNHOLE SHEAR WAVE VSP

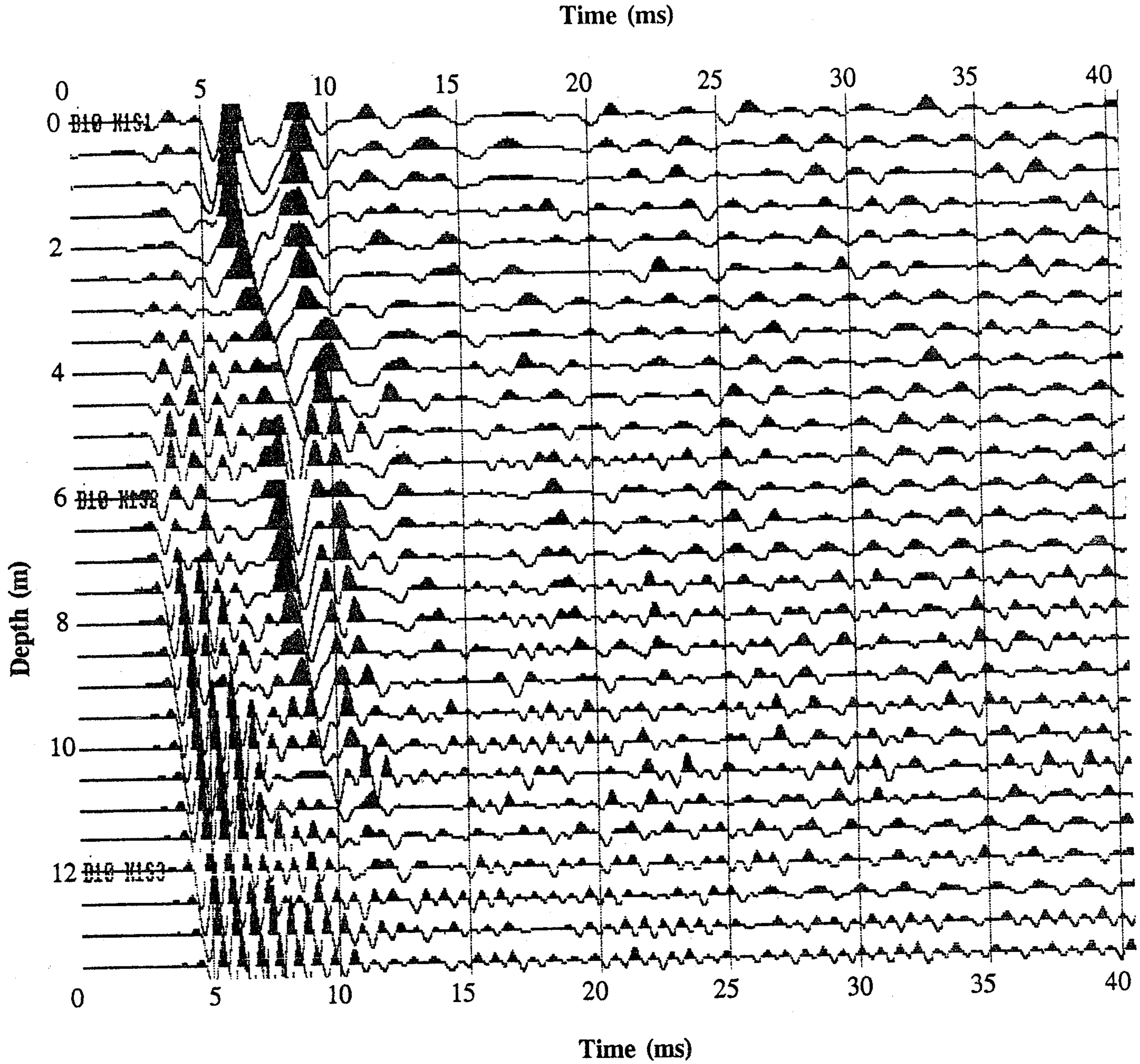


Recording Parameters:
Source: Steel rod oriented 45° S
Source Offset: 1.8 m south of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 2
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: N/A

Figure 194

BOVANENKOVO BOREHOLE 10 - DOWNHOLE SHEAR WAVE VSP

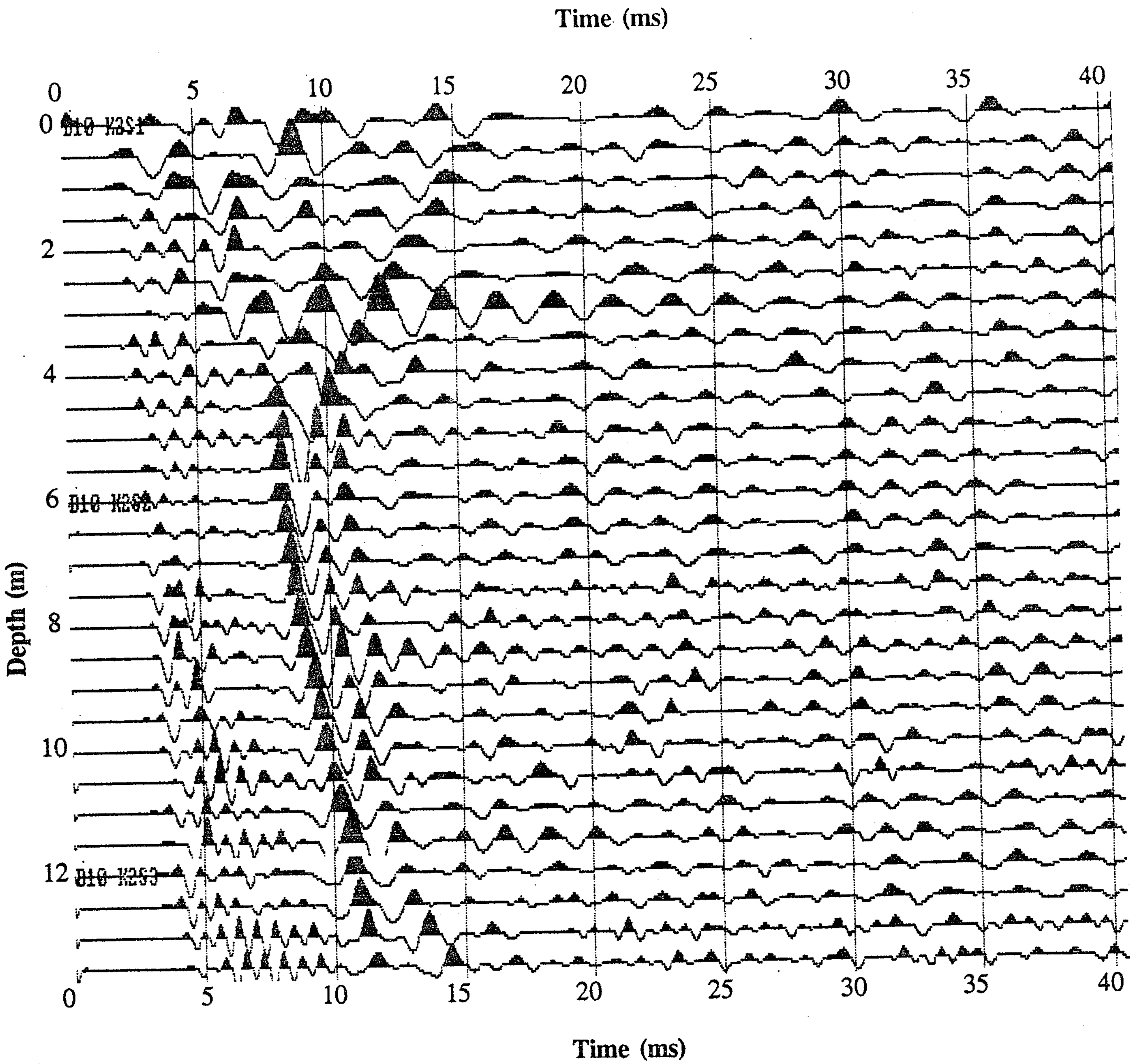


Recording Parameters:
Source: Steel rod oriented 45° S
Source Offset: 1.8 m south of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Vertical
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: 340-1540 Hz (12 db rolloffs)

Figure 195

BOVANENKOVO BOREHOLE 10 - DOWNHOLE SHEAR WAVE VSP

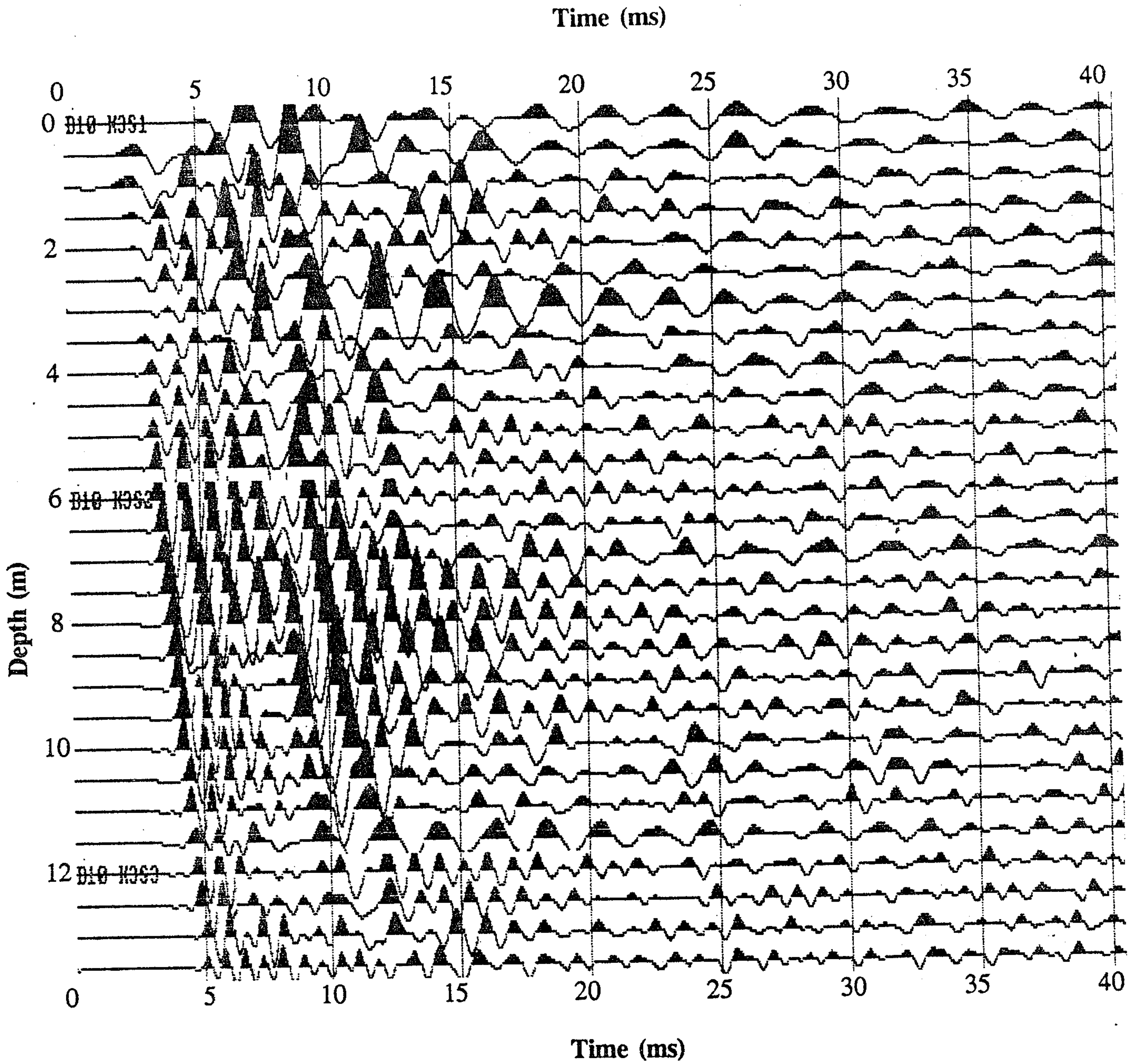


Recording Parameters:
Source: Steel rod oriented 45° S
Source Offset: 1.8 m south of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 1
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: 340-1540 Hz (12 db rolloffs)

Figure 196

BOVANENKOVO BOREHOLE 10 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:
Source: Steel rod oriented 45° S
Source Offset: 1.8 m south of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 2
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: 340-1540 Hz (12 db rolloffs)

Figure 197

DOWNHOLE SHEAR WAVE VSP

BOREHOLE 11

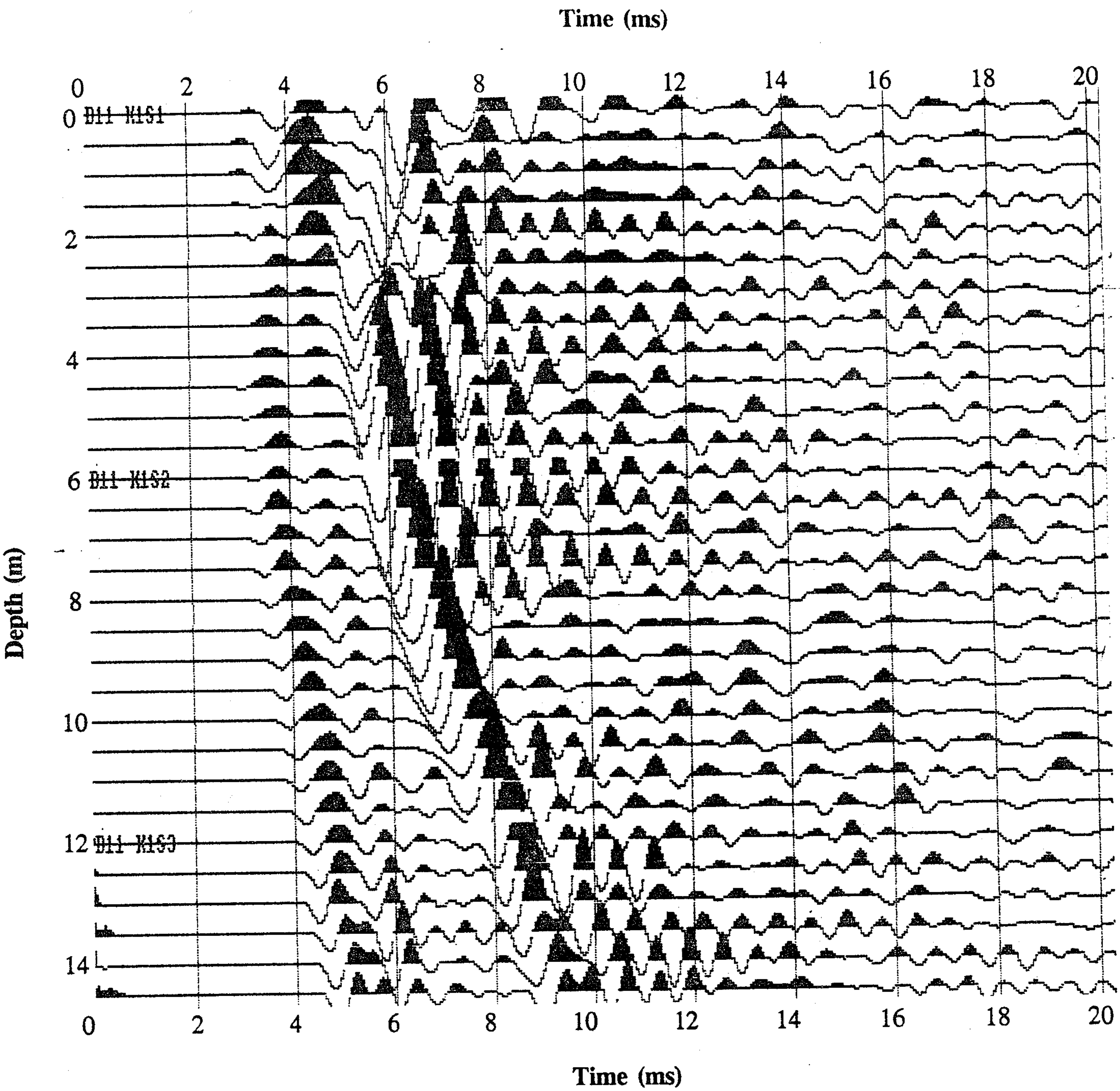
Vertical, Horizontal 1, and Horizontal 2 Components

plotted in raw format and after application of a digital filter.

<u>Source locations and orientations</u>

1. 7.8 m north of BH - 45° N
2. 3.8 m north of BH - 45° N
3. 1.8 m north of BH - 45° N
4. 0.3 m north of BH - 45° N
5. 1.8 m south of BH - 45° S
6. 3.8 m south of BH - 45° S

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP

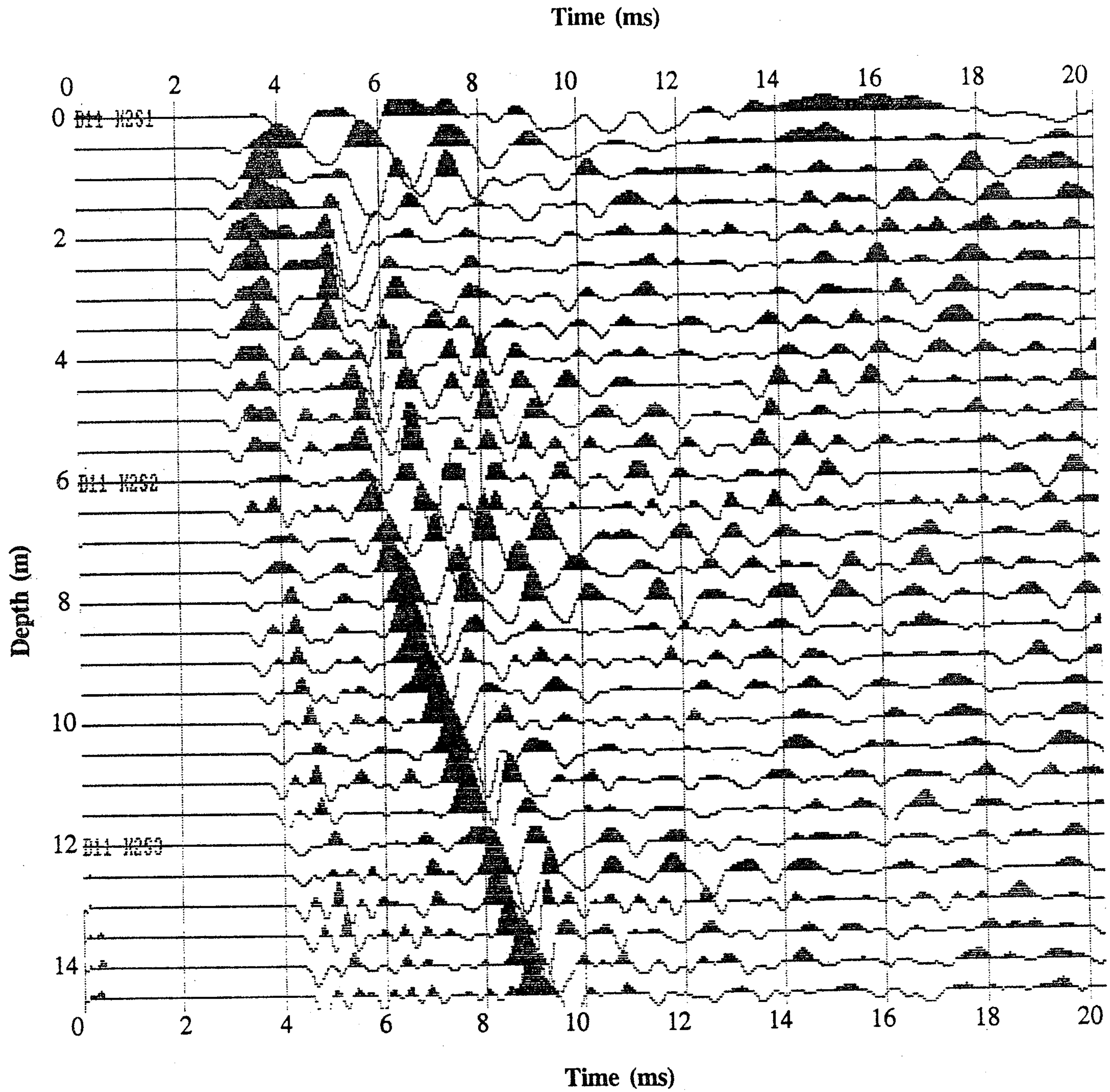


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 7.8 m north of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Vertical
AGC Parameters: 160 sample window (centred) AGC factor = 200
Bandpass Filter: N/A

Figure 198

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP

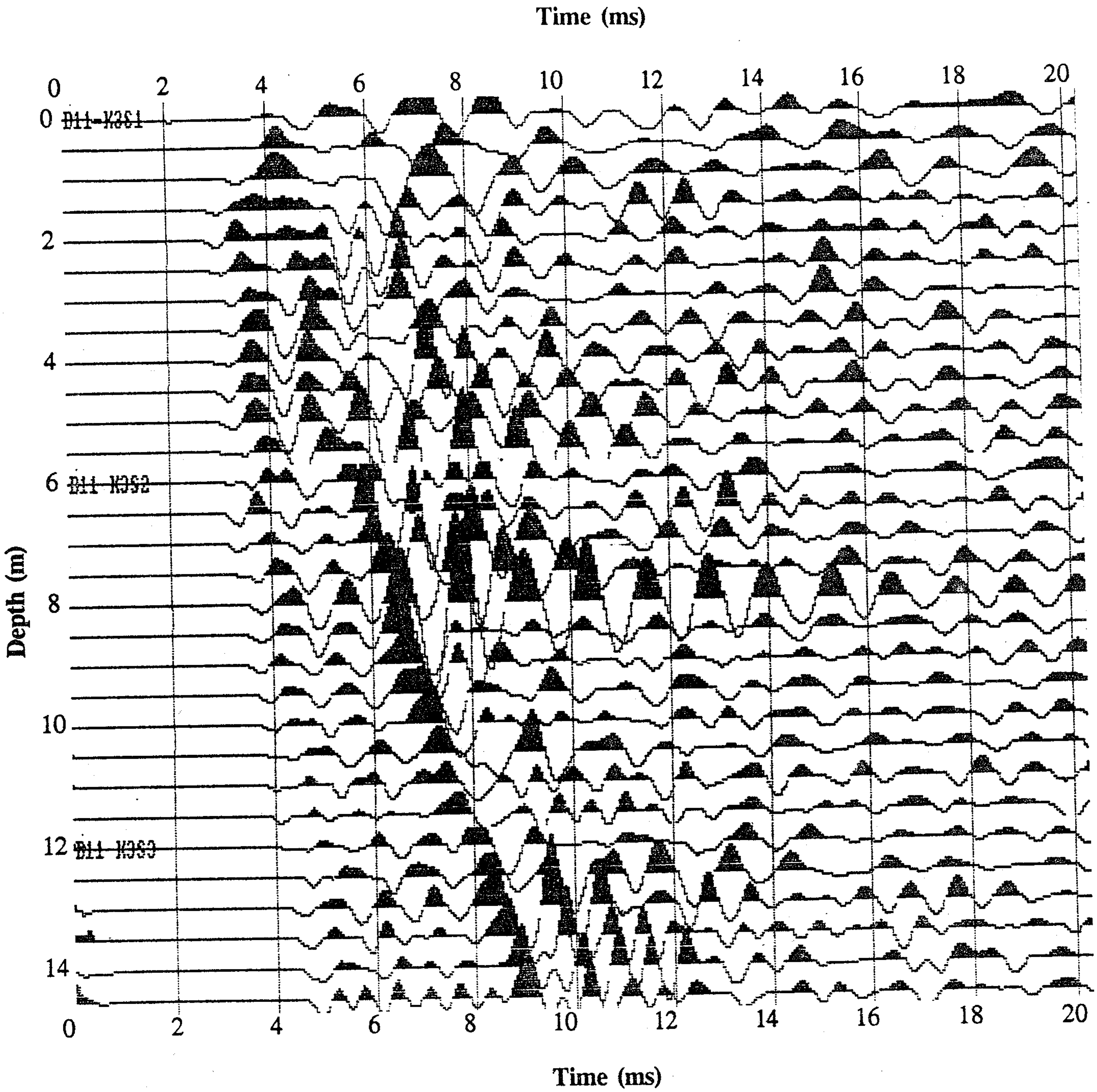


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 7.8 m north of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 1
AGC Parameters: 160 sample window (centred) AGC factor = 200
Bandpass Filter: N/A

Figure 199

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:

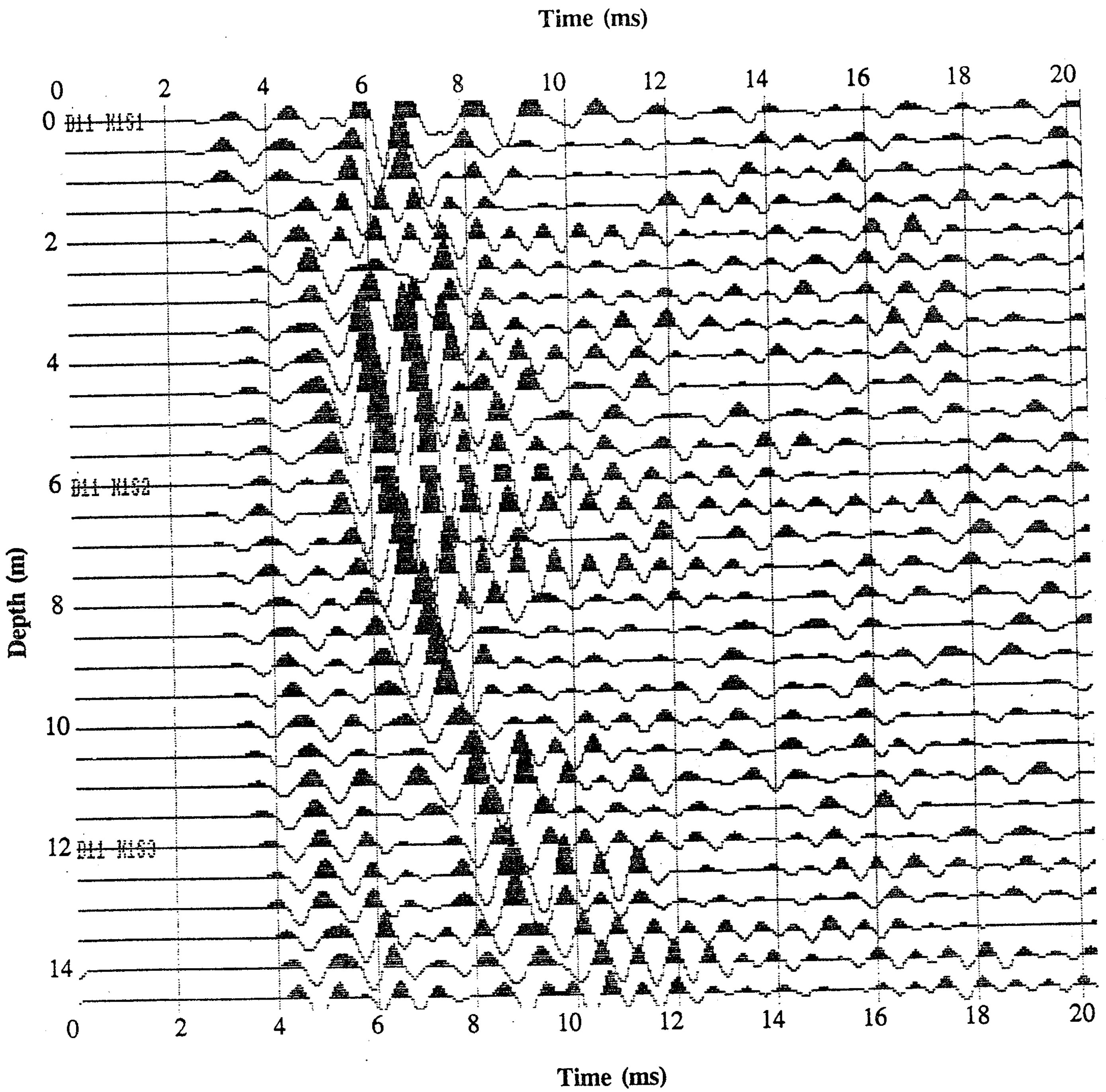
Source: Steel rod oriented 45° N
Source Offset: 7.8 m north of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:

Component Plotted: Horizontal 2
AGC Parameters: 160 sample window (centred) AGC factor = 200
Bandpass Filter: N/A

Figure 200

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP

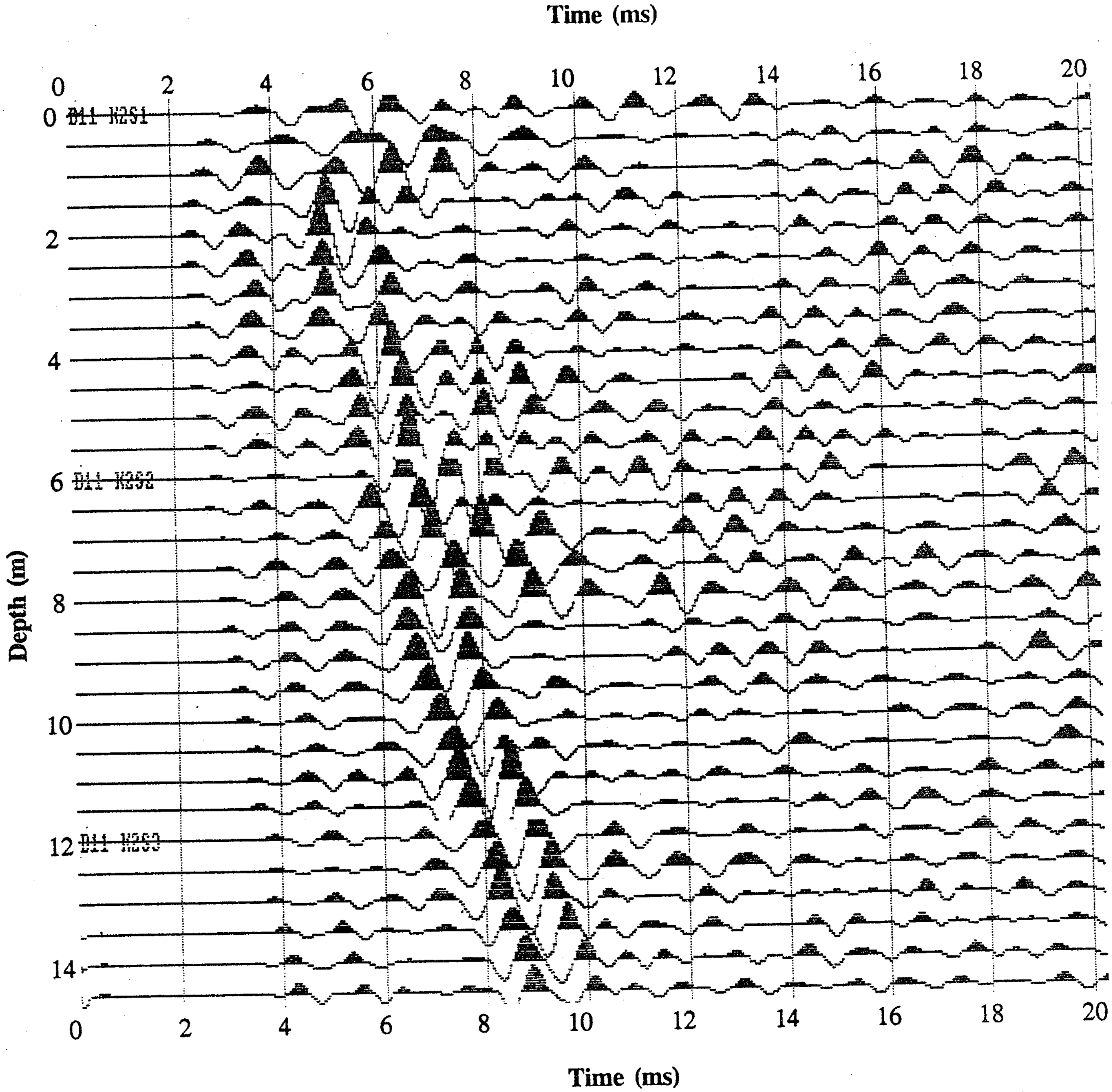


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 7.8 m north of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Vertical
AGC Parameters: 160 sample window (centred) AGC factor = 200
Bandpass Filter: 768-1540 Hz (12 db rolloffs)

Figure 201

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:

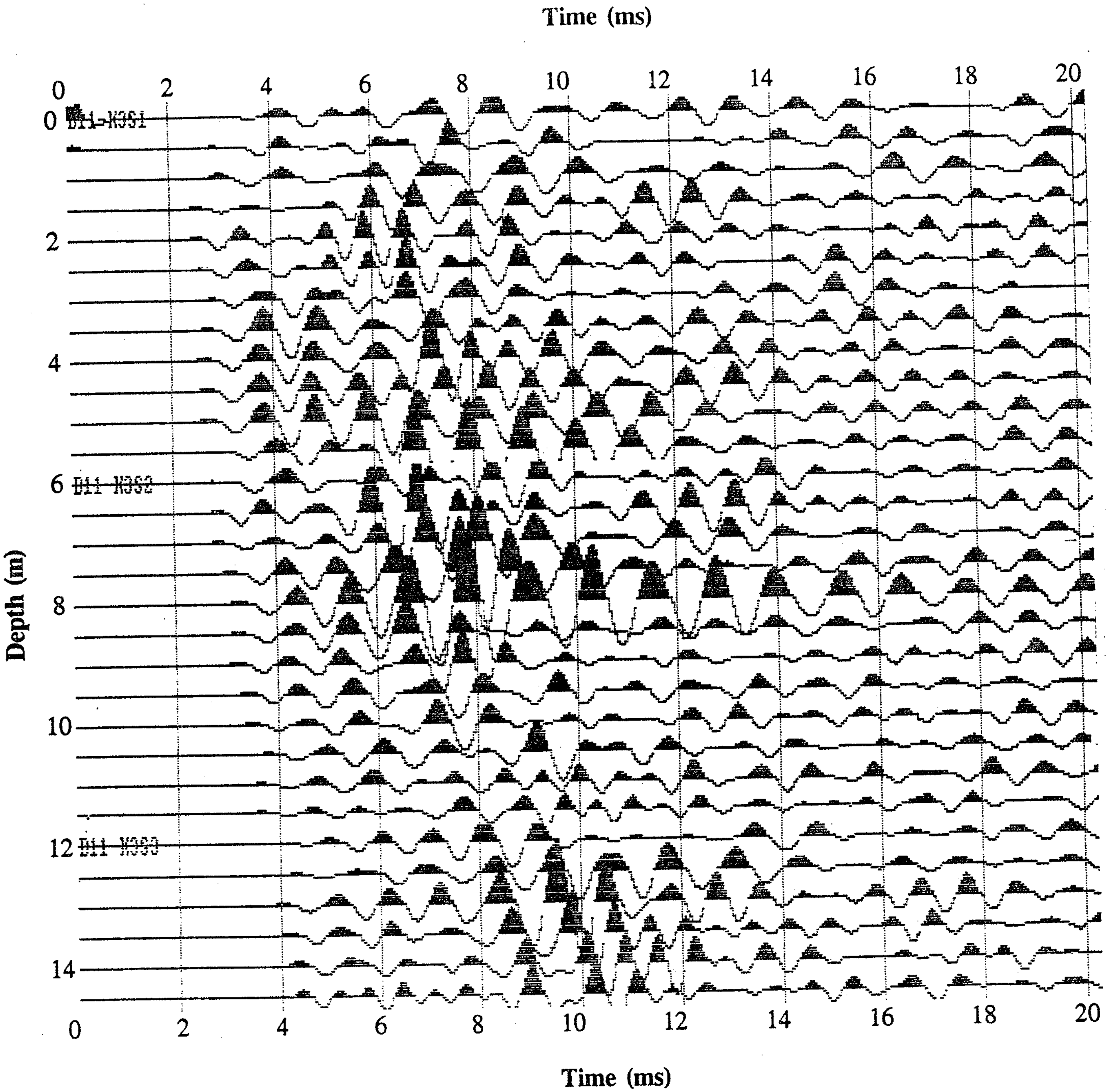
Source: Steel rod oriented 45° N
Source Offset: 7.8 m north of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:

Component Plotted: Horizontal 1
AGC Parameters: 160 sample window (centred) AGC factor = 200
Bandpass Filter: 768-1540 Hz (12 db rolloffs)

Figure 202

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP

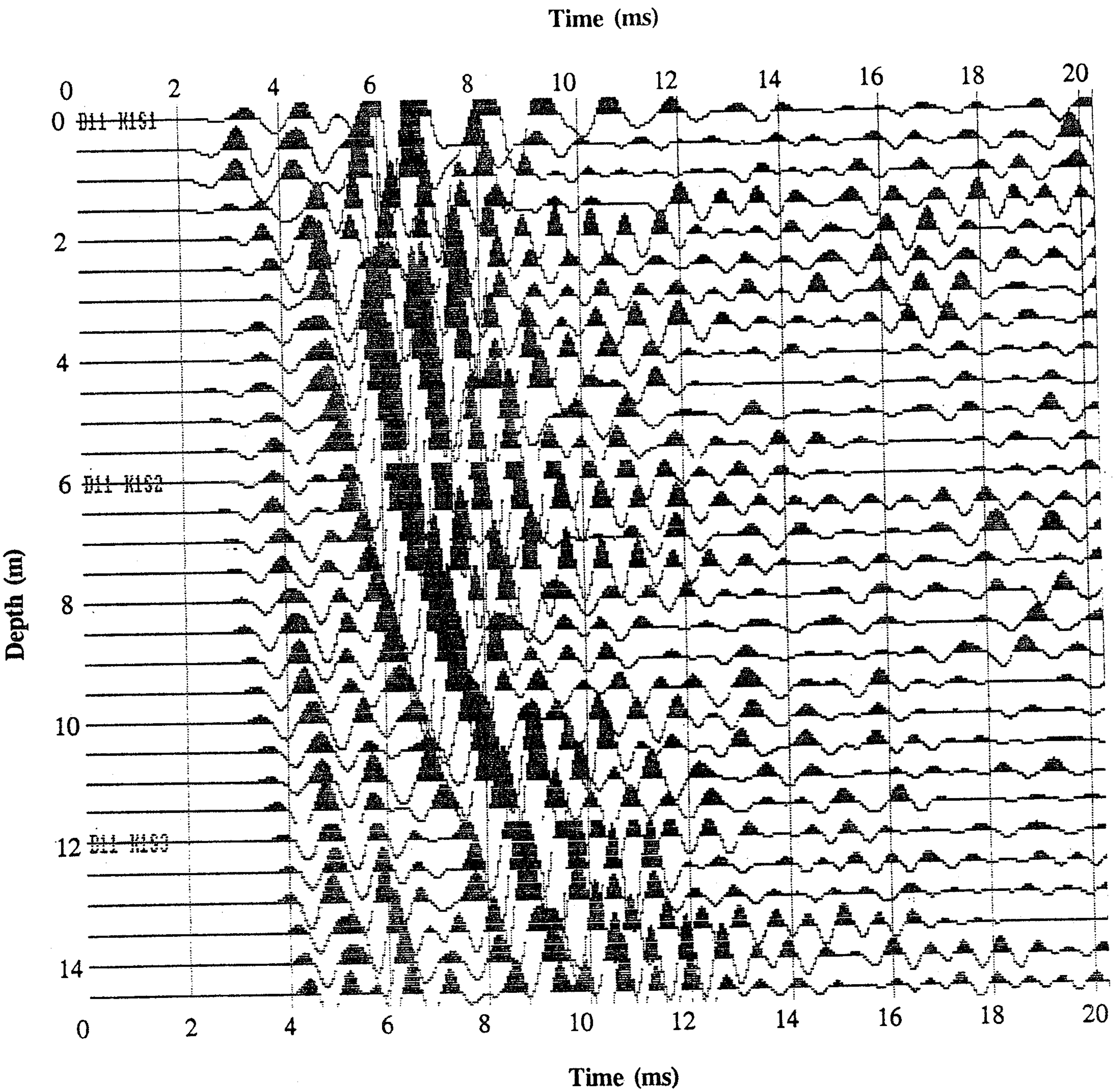


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 7.8 m north of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 2
AGC Parameters: 160 sample window (centred) AGC factor = 200
Bandpass Filter: 768-1540 Hz (12 db rolloffs)

Figure 203

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP

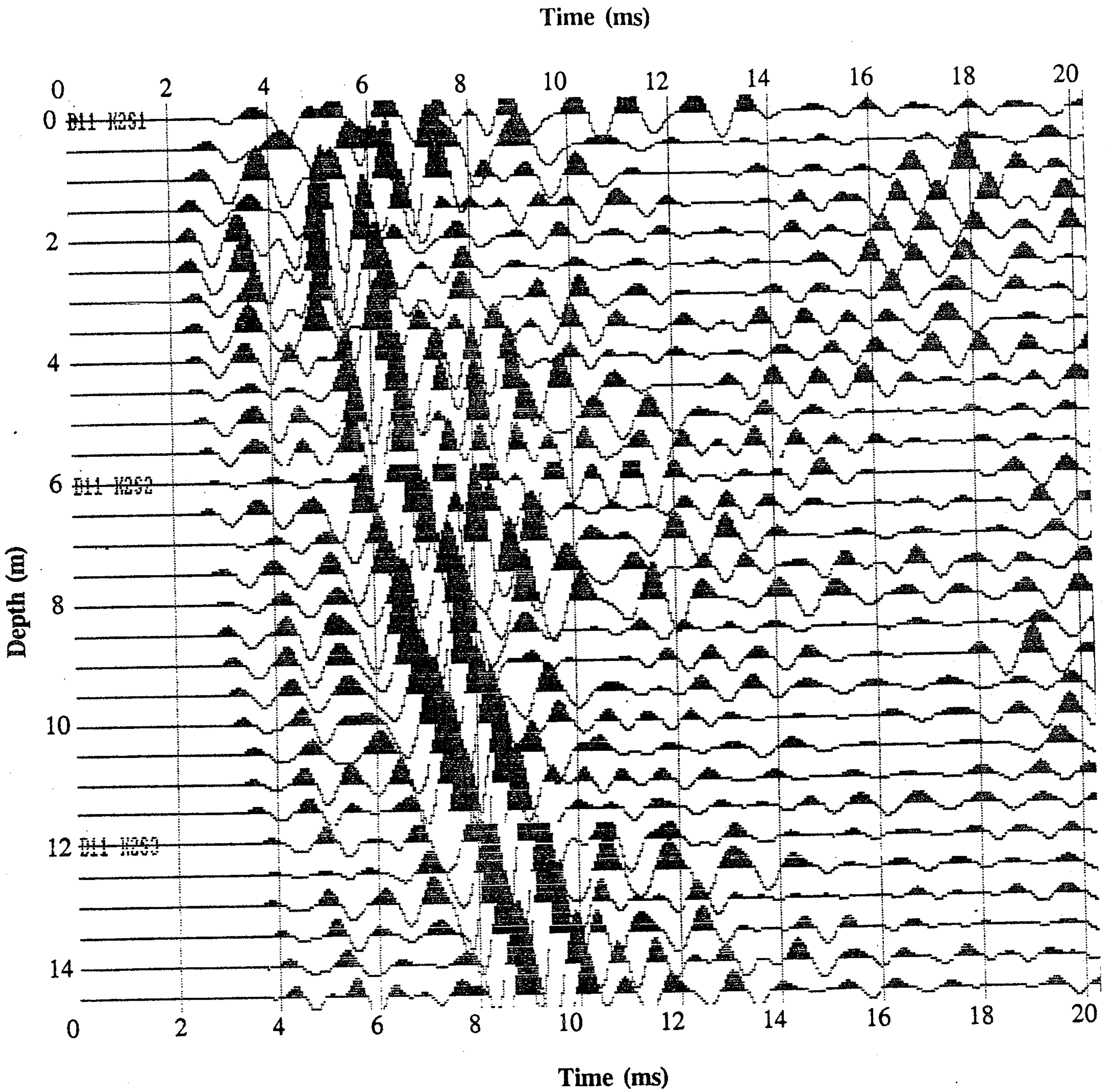


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 7.8 m north of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Vertical
AGC Parameters: 400 sample window (centred)
AGC factor = 400
Bandpass Filter: 768-1540 Hz (12 db rolloffs)

Figure 204

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP

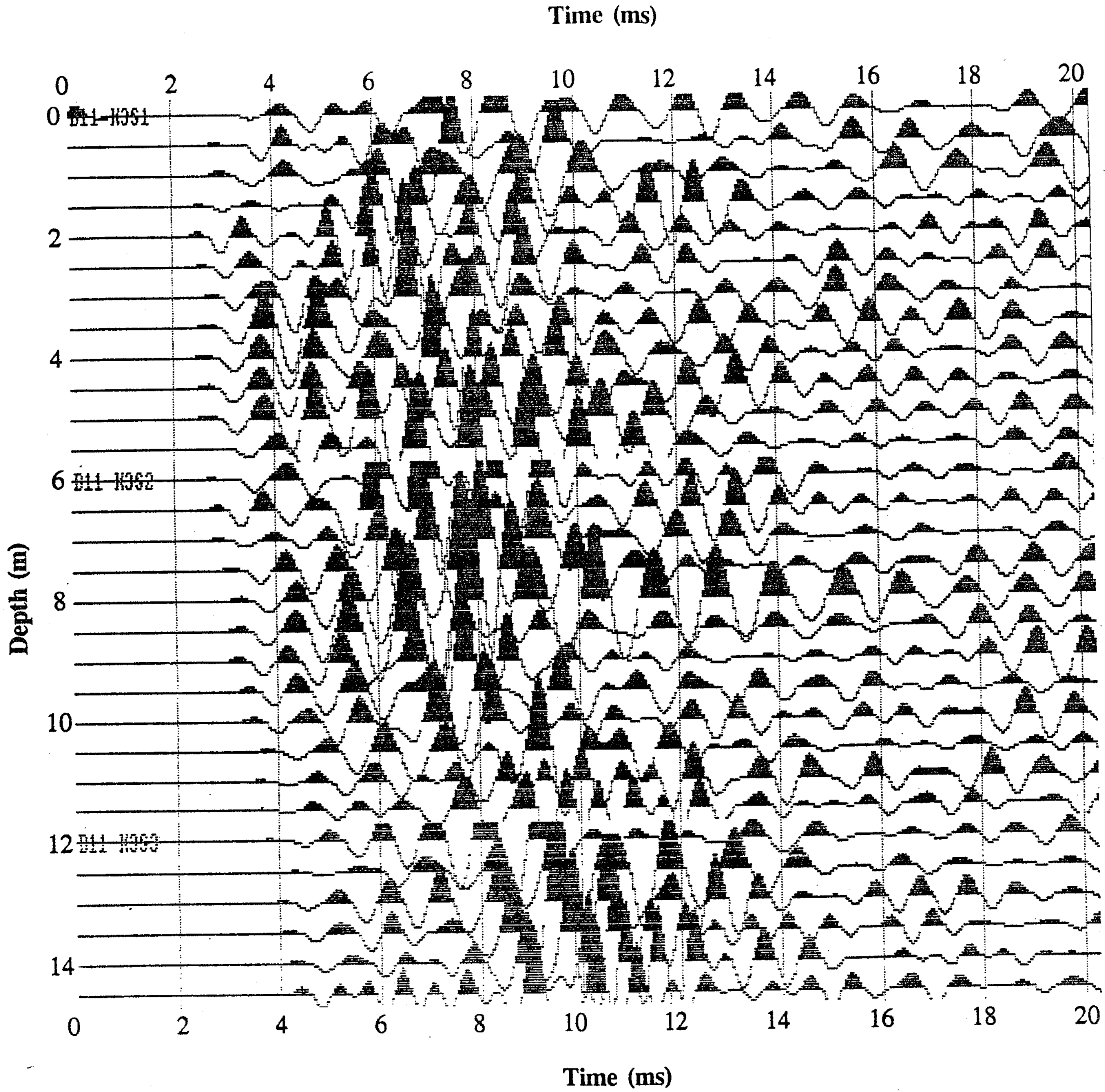


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 7.8 m north of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 1
AGC Parameters: 400 sample window (centred) AGC factor = 400
Bandpass Filter: 768-1540 Hz (12 db rolloffs)

Figure 205

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP

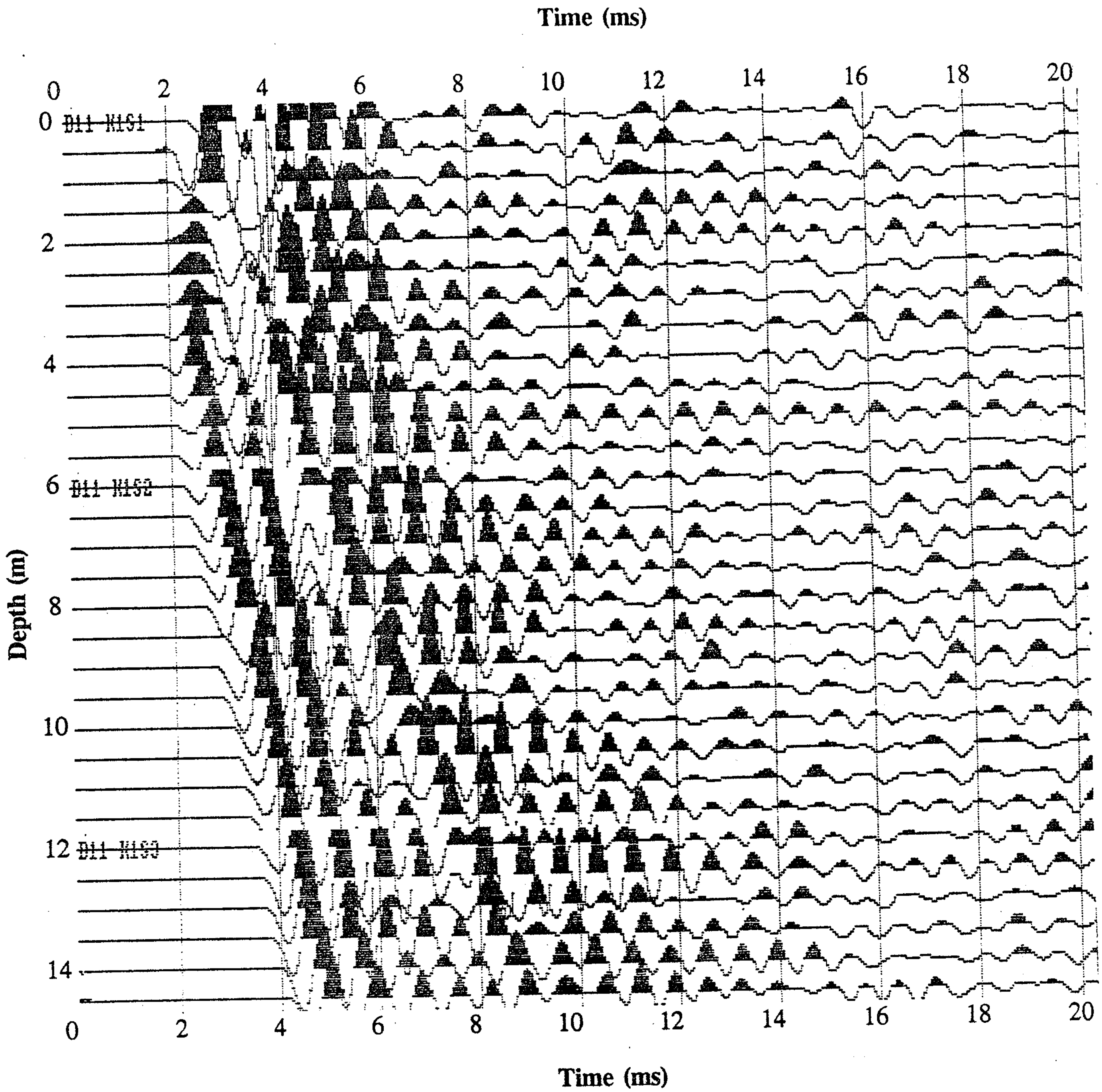


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 7.8 m north of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 2
AGC Parameters: 400 sample window (centred)
AGC factor = 400
Bandpass Filter: 768-1540 Hz (12 db rolloffs)

Figure 206

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP

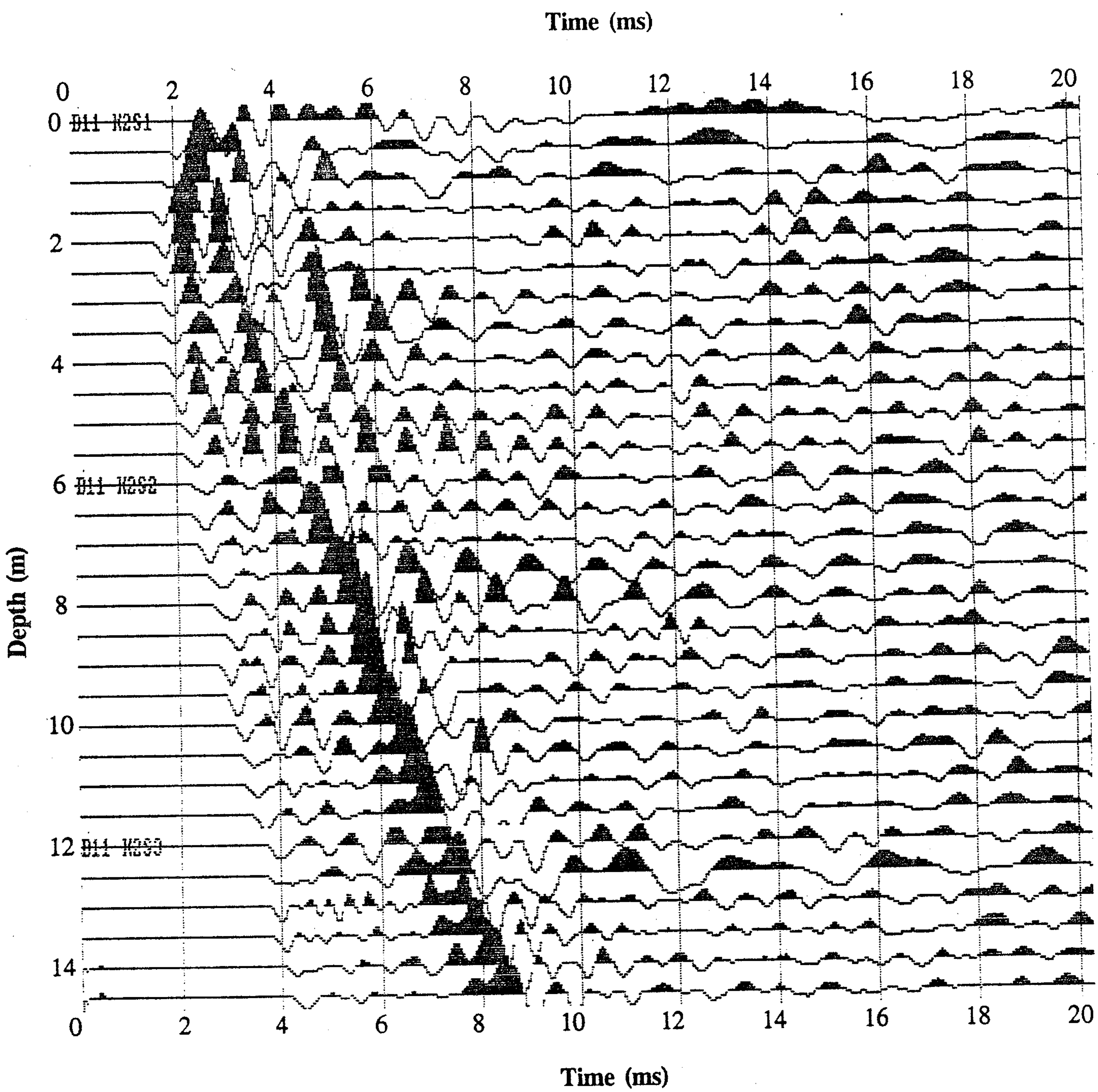


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 3.8 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Vertical
AGC Parameters: 160 sample window (centred) AGC factor = 200
Bandpass Filter: N/A

Figure 207

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP

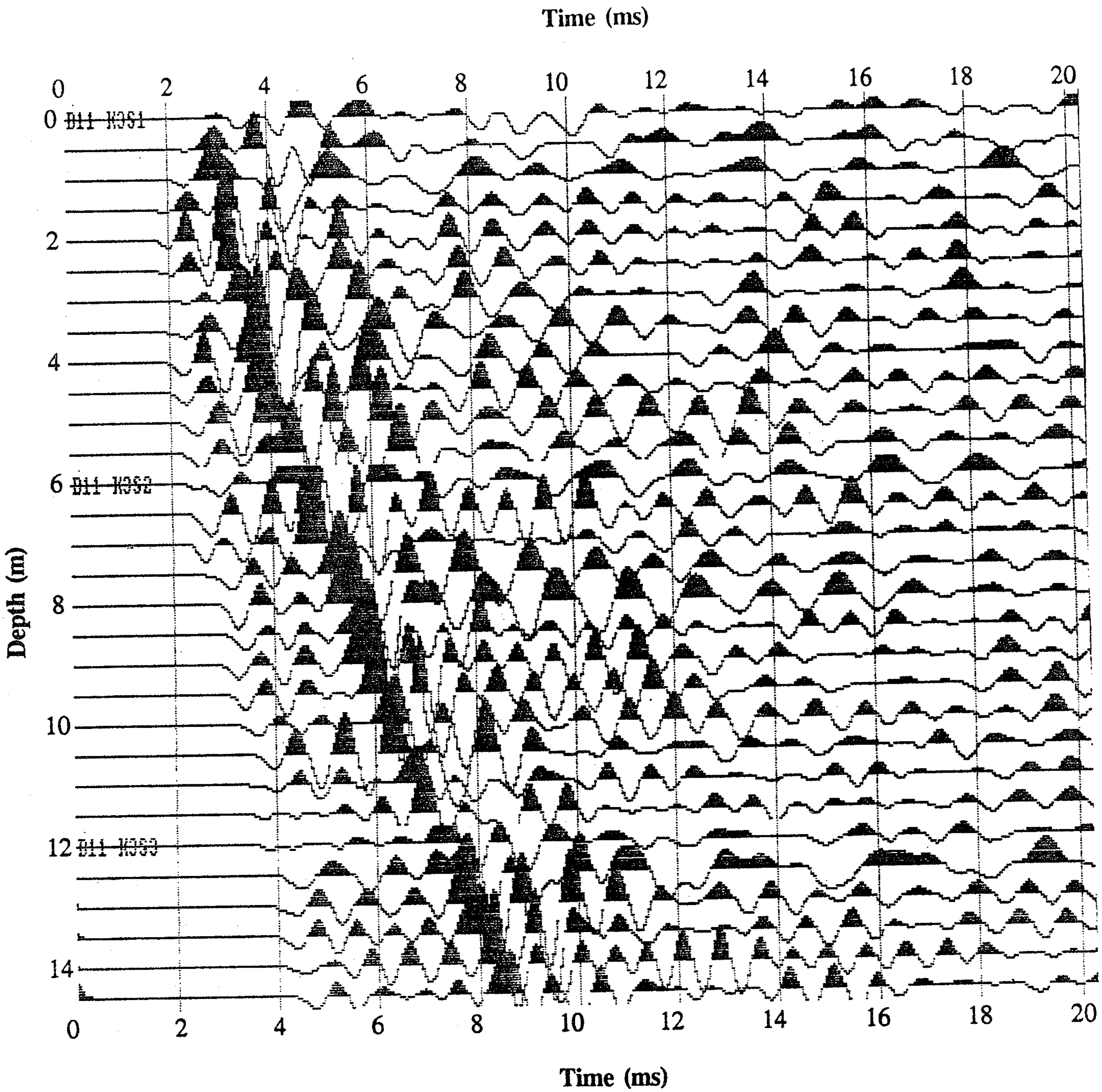


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 3.8 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 1
AGC Parameters: 160 sample window (centred) AGC factor = 200
Bandpass Filter: N/A

Figure 208

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP

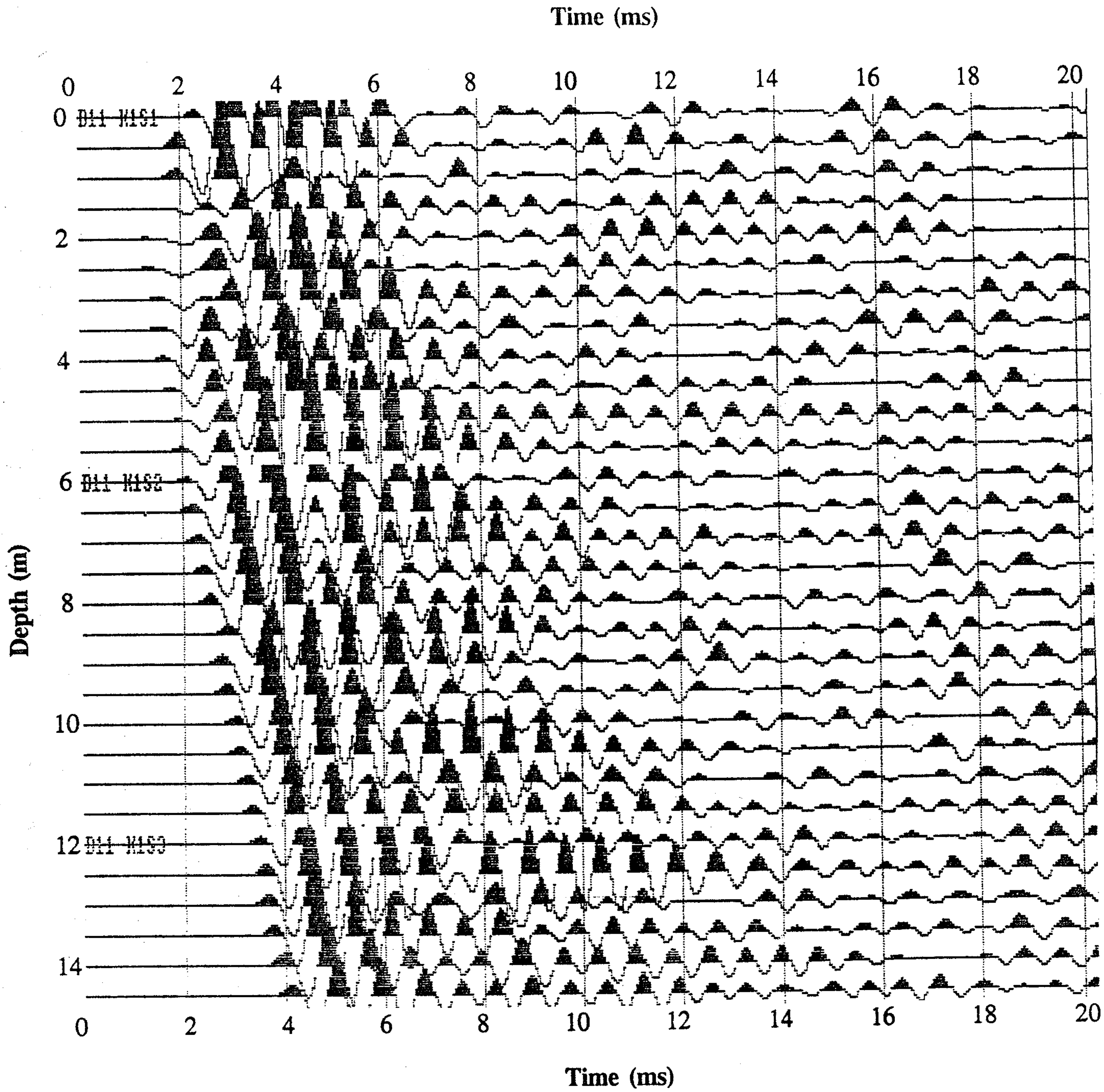


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 3.8 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 2
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: N/A

Figure 209

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:

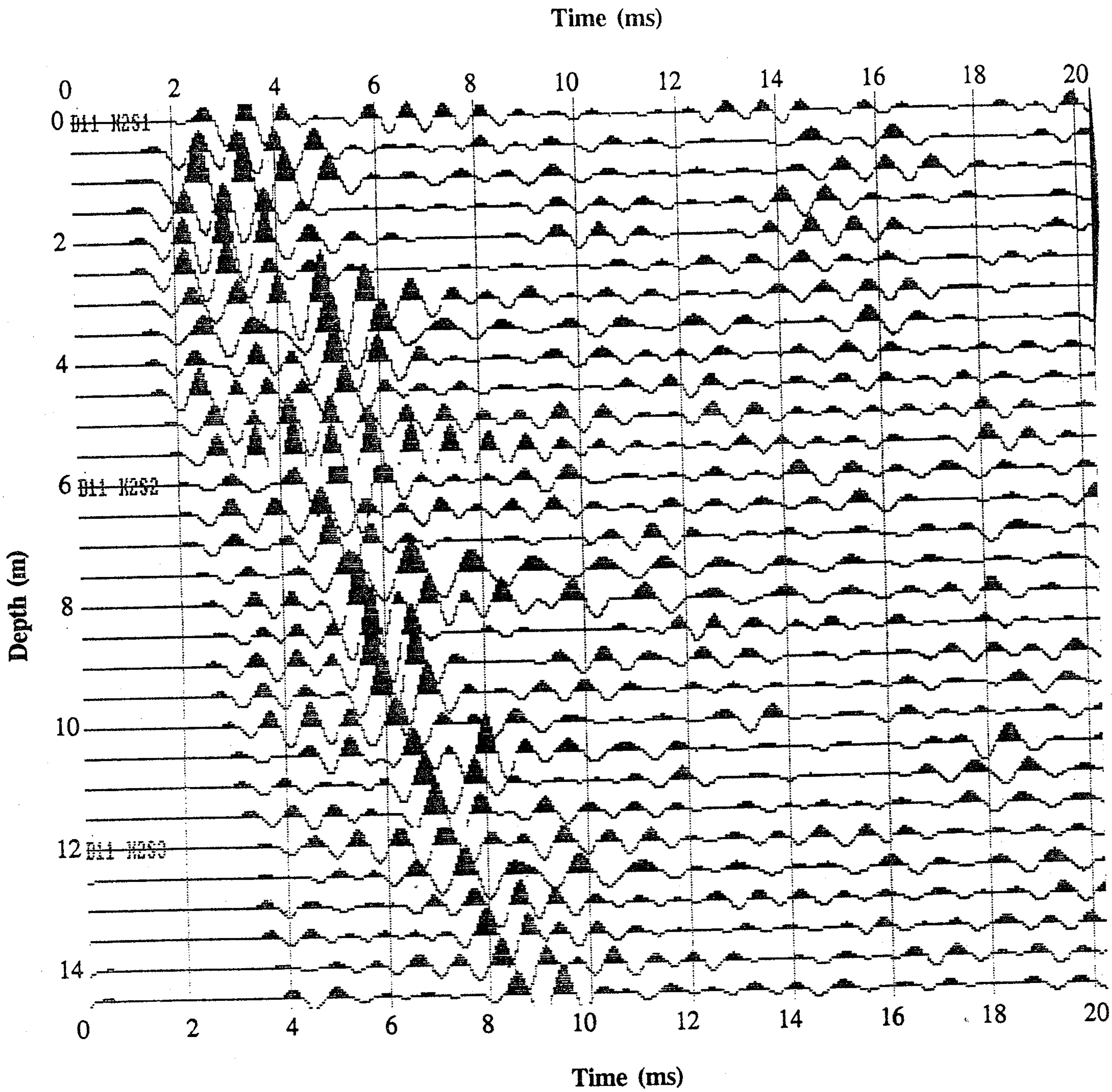
Source: Steel rod oriented 45° N
Source Offset: 3.8 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:

Component Plotted: Vertical
AGC Parameters: 160 sample window (centred) AGC factor = 200
Bandpass Filter: 768-1540 Hz (12 db rolloffs)

Figure 210

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP

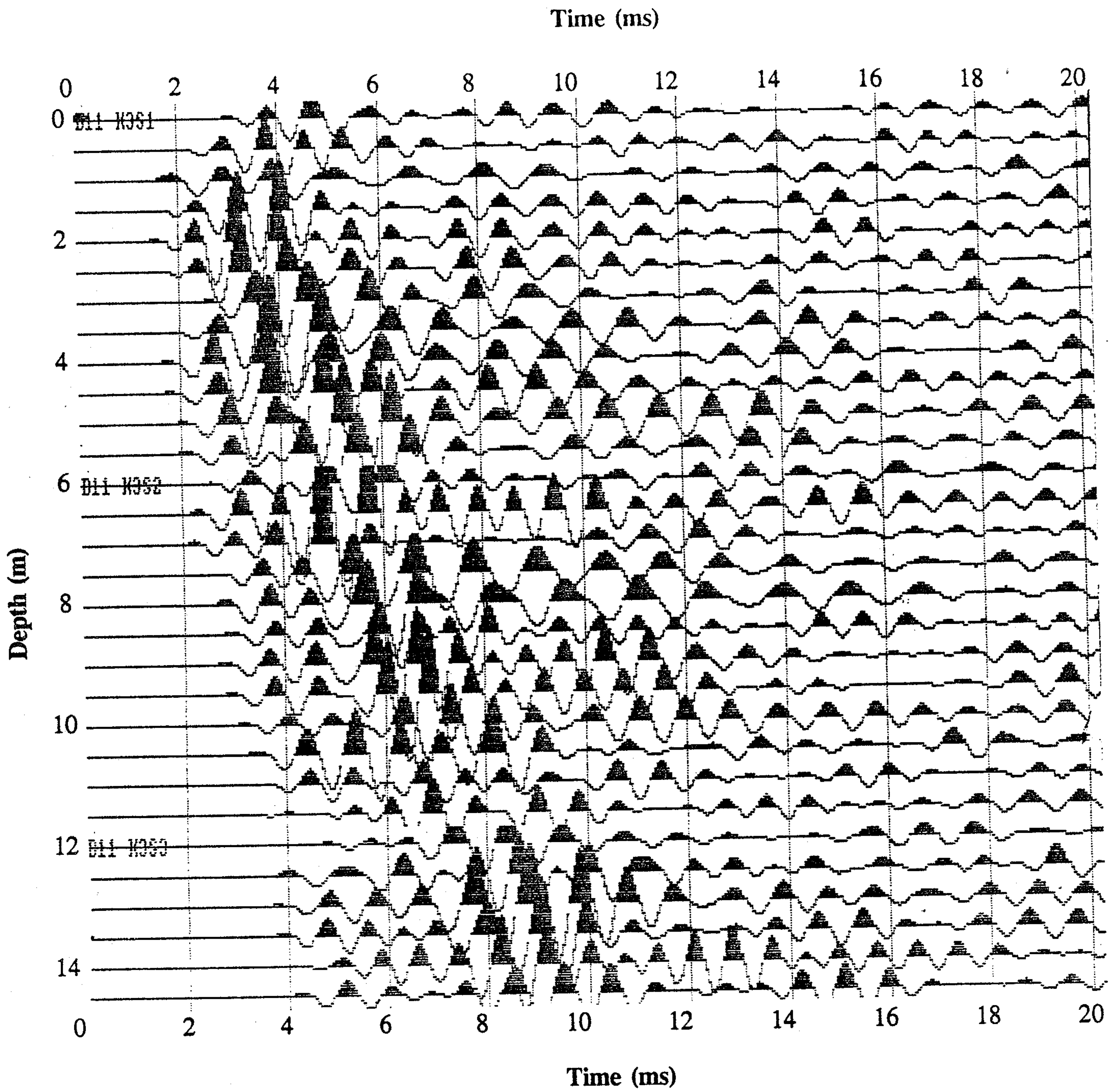


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 3.8 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 1
AGC Parameters: 160 sample window (centred) AGC factor = 200
Bandpass Filter: 768-1540 Hz (12 db rolloffs)

Figure 211

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP

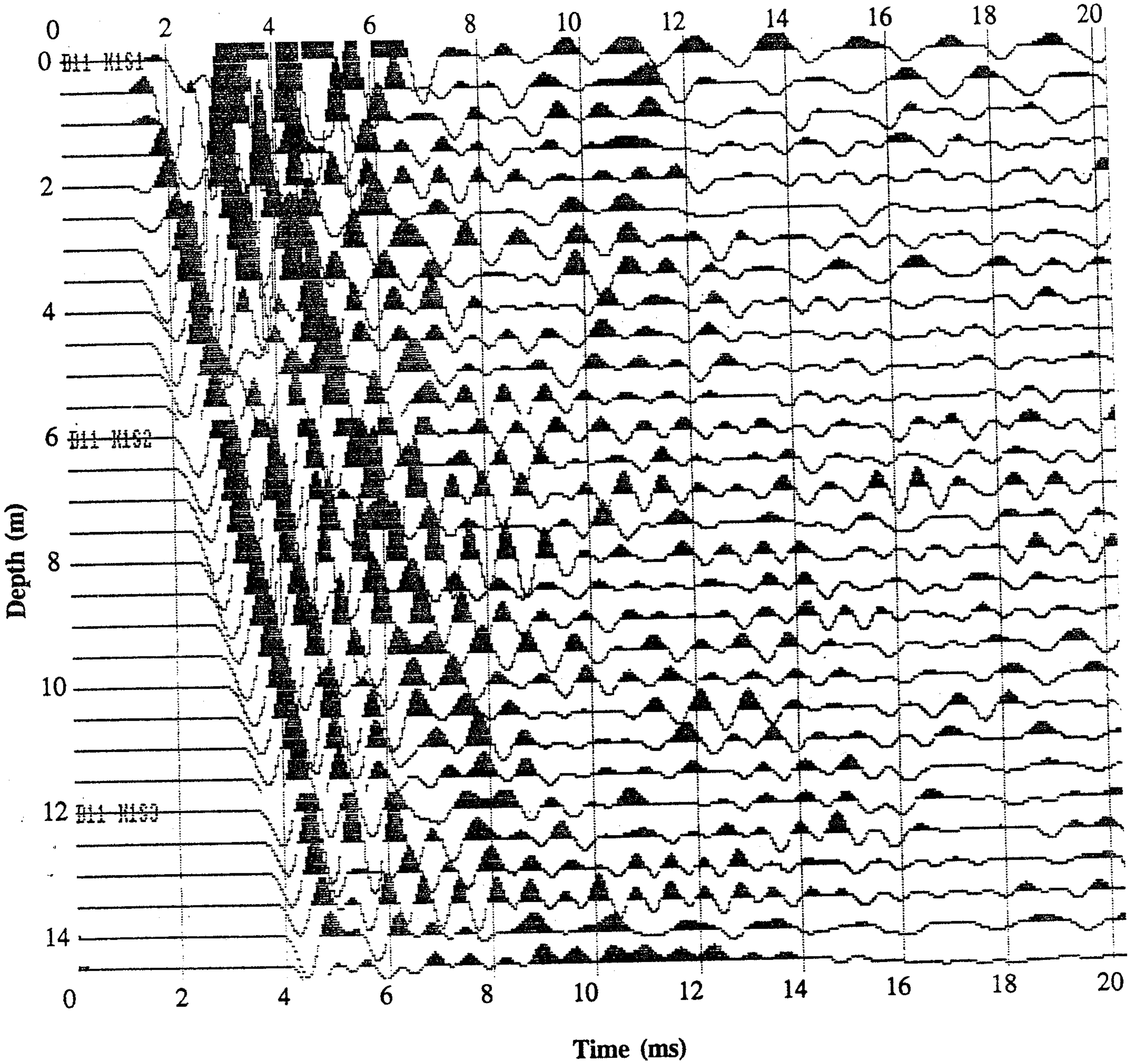


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 3.8 m north of BH
Source Depth: 0.7 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 2
AGC Parameters: 160 sample window (centred) AGC factor = 200
Bandpass Filter: 768-1540 Hz (12 db rolloffs)

Figure 212

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP

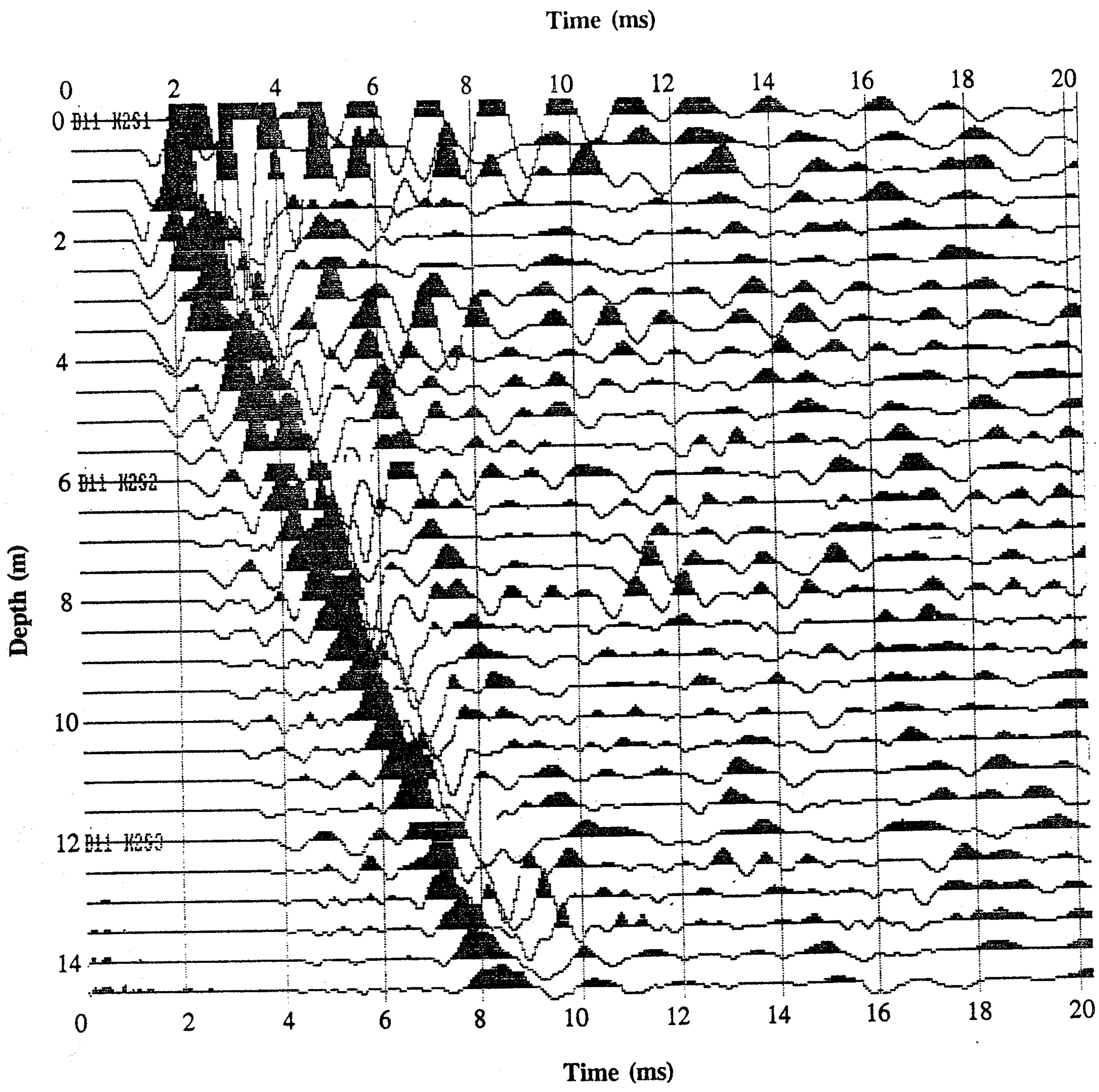


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 1.8 m north of BH
Source Depth: 0.65 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Vertical
AGC Parameters: 160 sample window (centred) AGC factor = 200
Bandpass Filter: N/A

Figure 213

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP

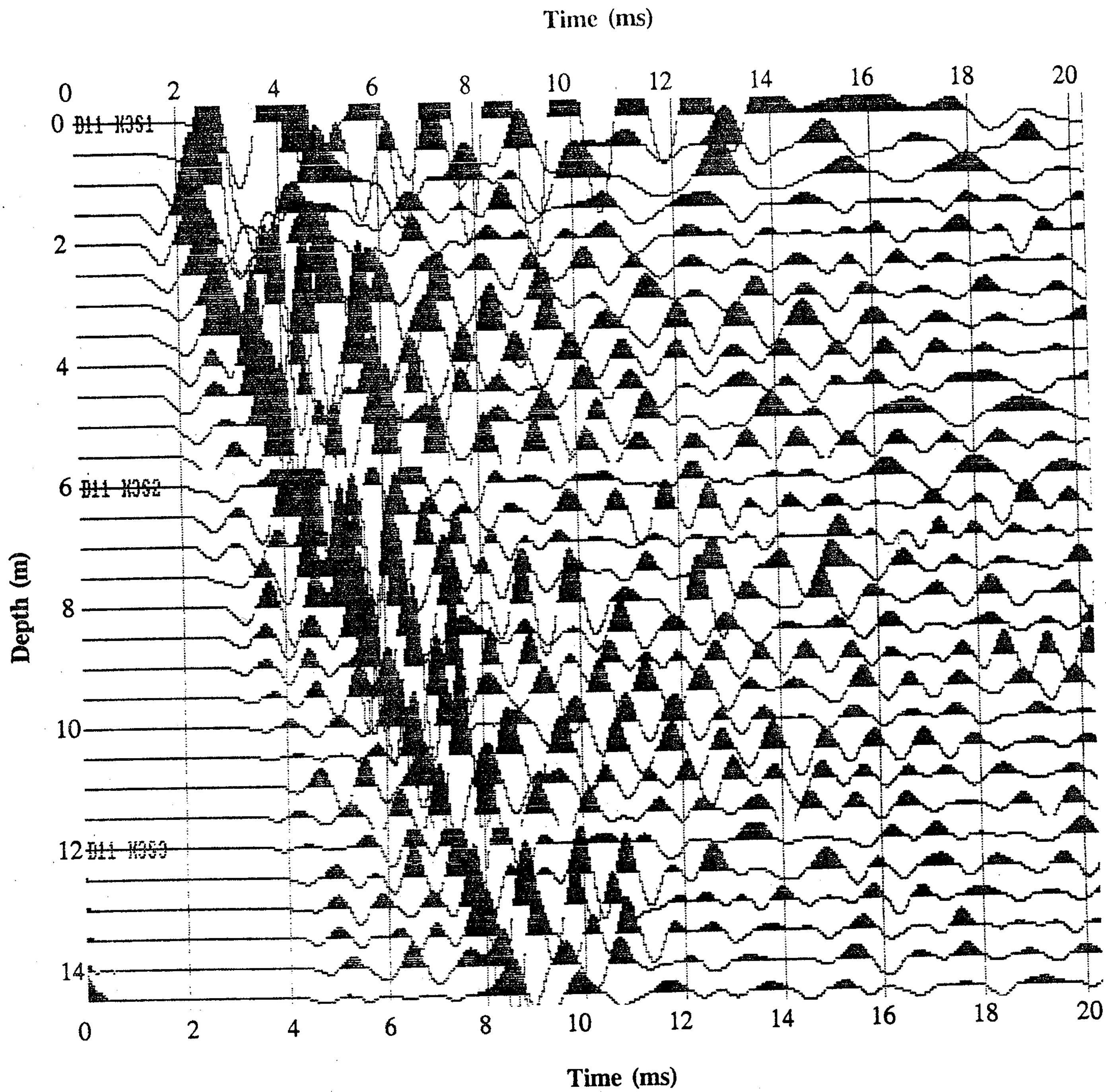


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 1.8 m north of BH
Source Depth: 0.65 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 1
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: N/A

Figure 214

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP

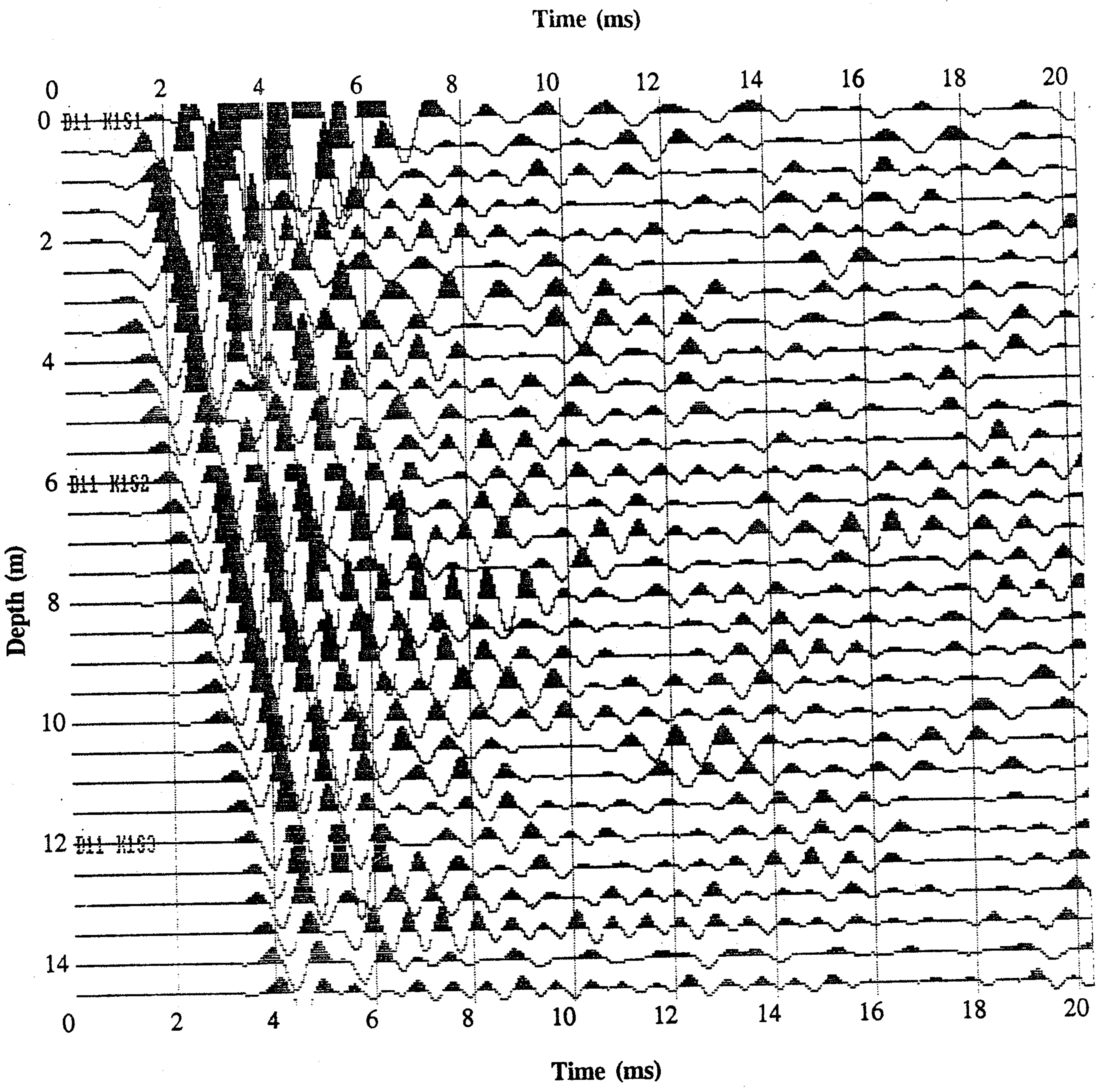


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 1.8 m north of BH
Source Depth: 0.65 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 2
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: N/A

Figure 215

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP

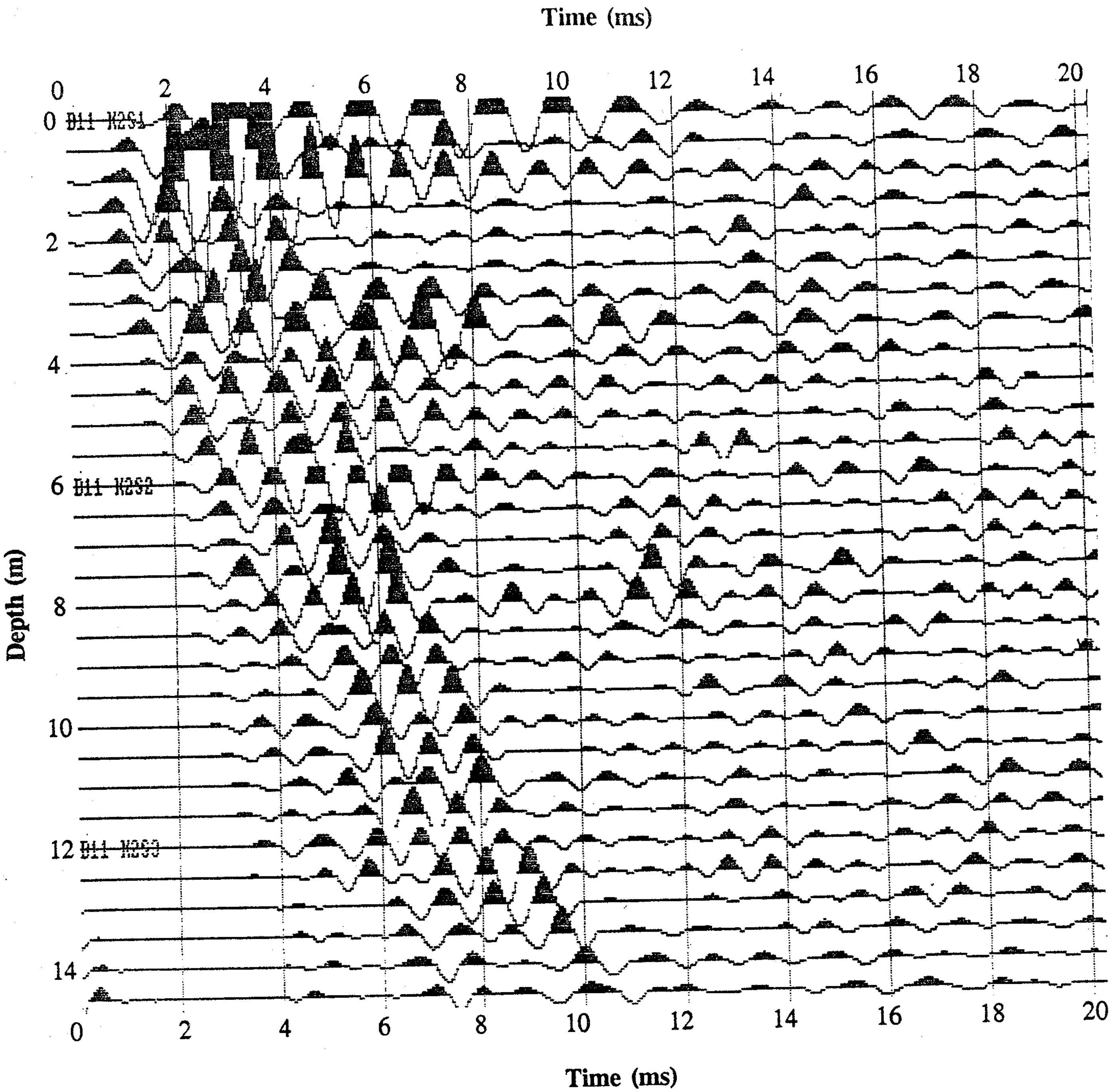


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 1.8 m north of BH
Source Depth: 0.65 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Vertical
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: 768-1540 Hz (12 db rolloffs)

Figure 216

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP

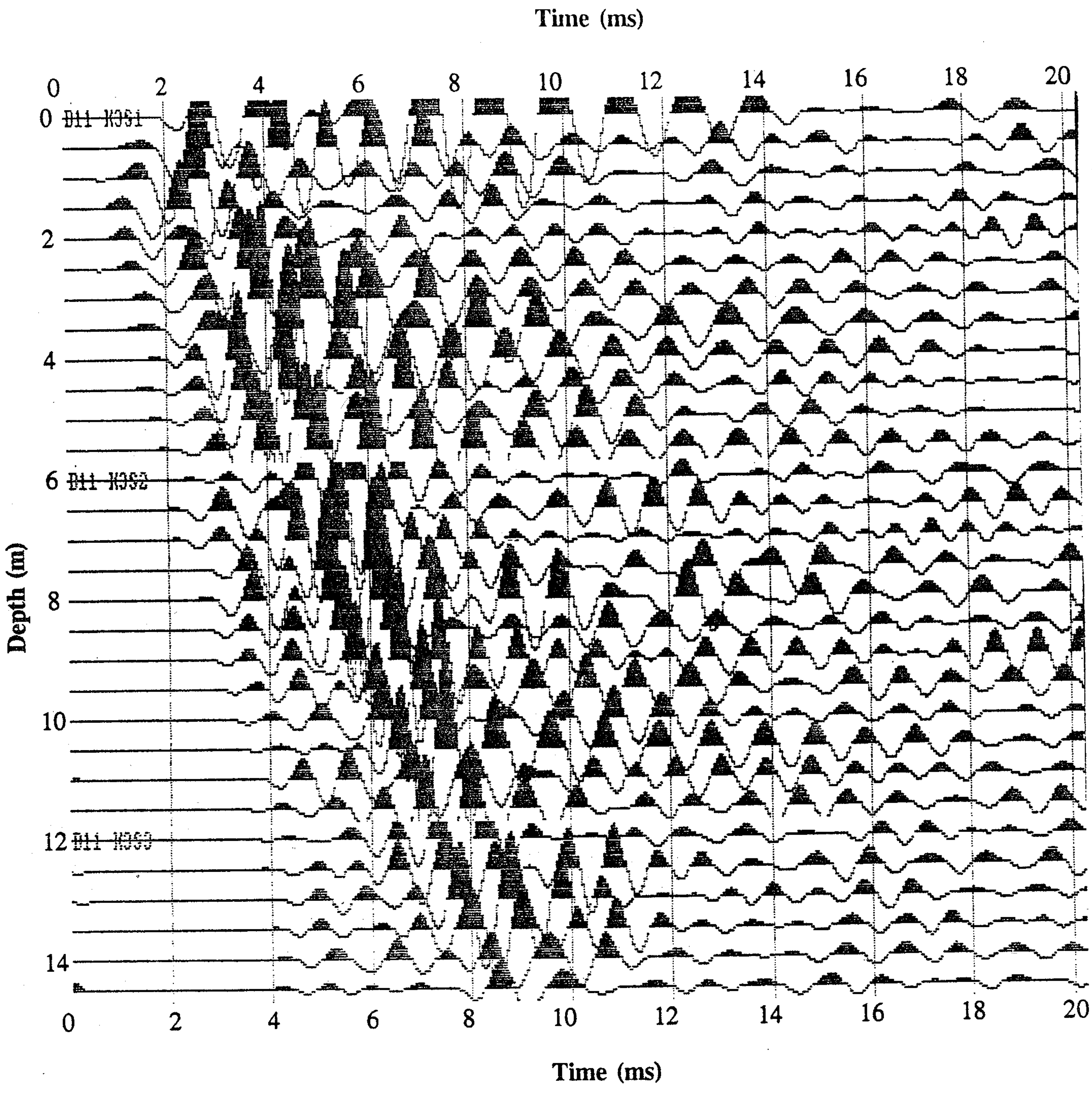


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 1.8 m north of BH
Source Depth: 0.65 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 1
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: 768-1540 Hz (12 db rolloffs)

Figure 217

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:

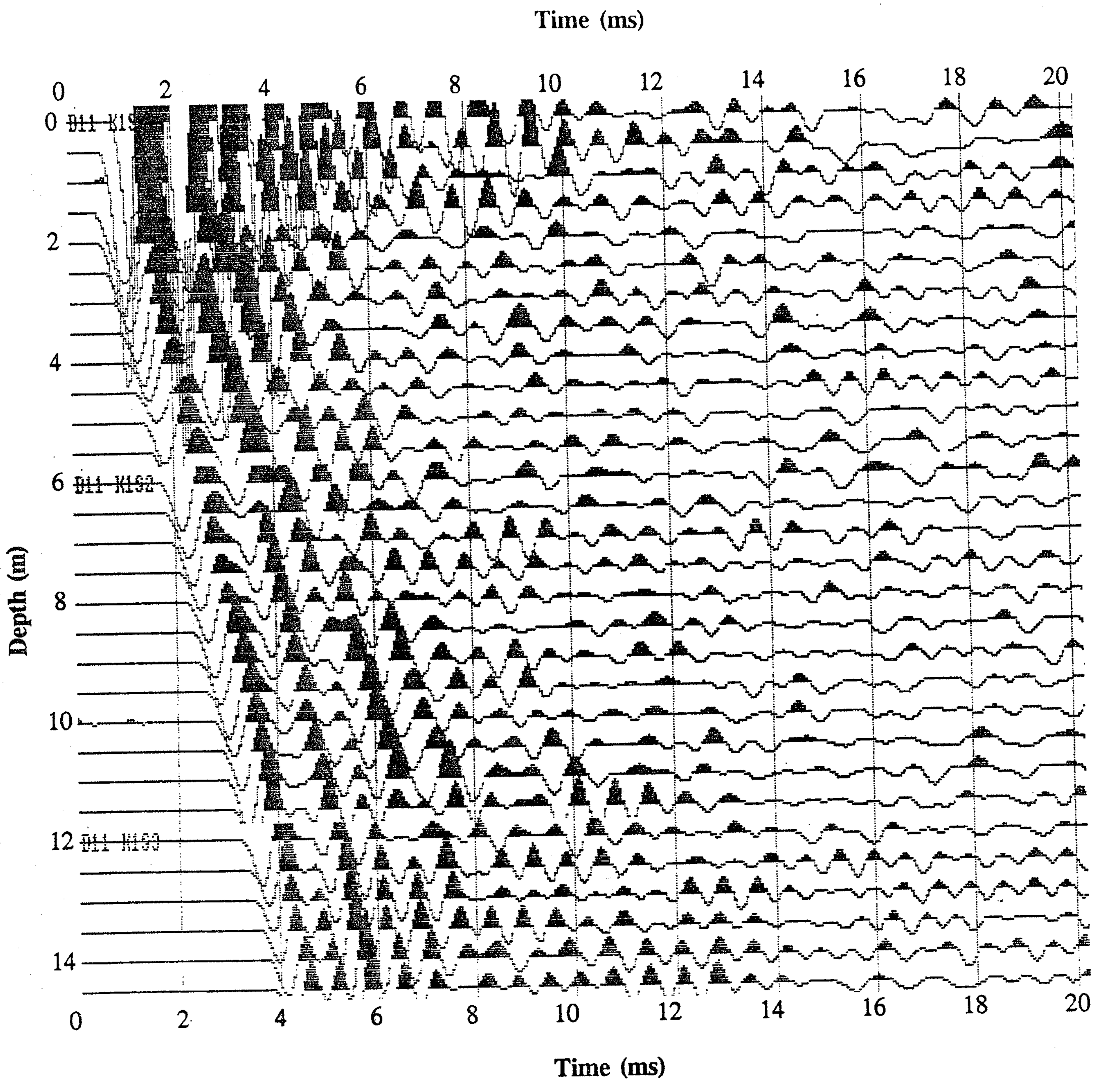
Source: Steel rod oriented 45° N
Source Offset: 1.8 m north of BH
Source Depth: 0.65 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:

Component Plotted: Horizontal 2
AGC Parameters: 160 sample window (centred) AGC factor = 200
Bandpass Filter: 768-1540 Hz (12 db rolloffs)

Figure 218

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP

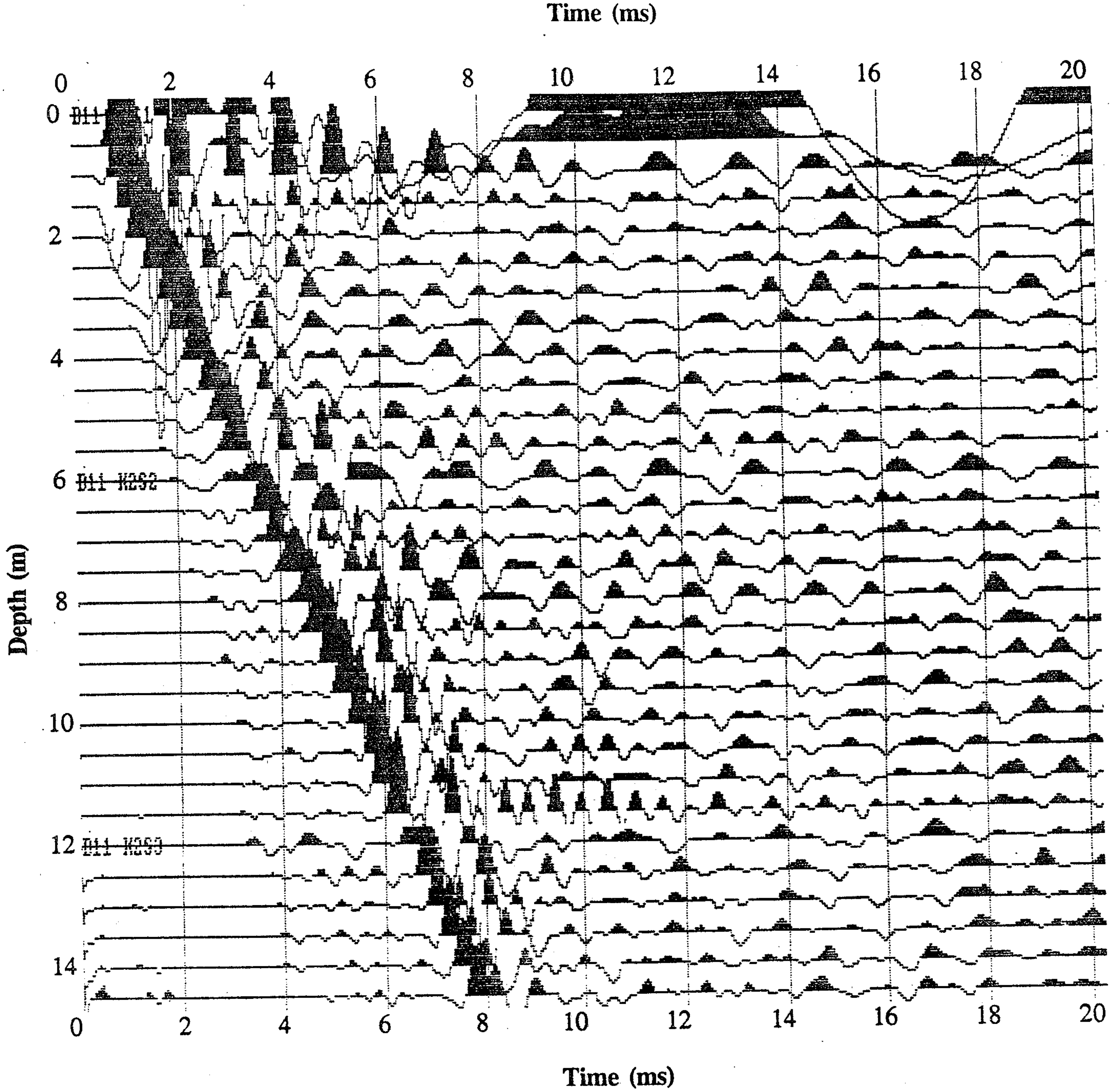


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 0.3 m south of BH
Source Depth: 1.0 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Vertical
AGC Parameters: 160 sample window (centred) AGC factor = 200
Bandpass Filter: N/A

Figure 219

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP

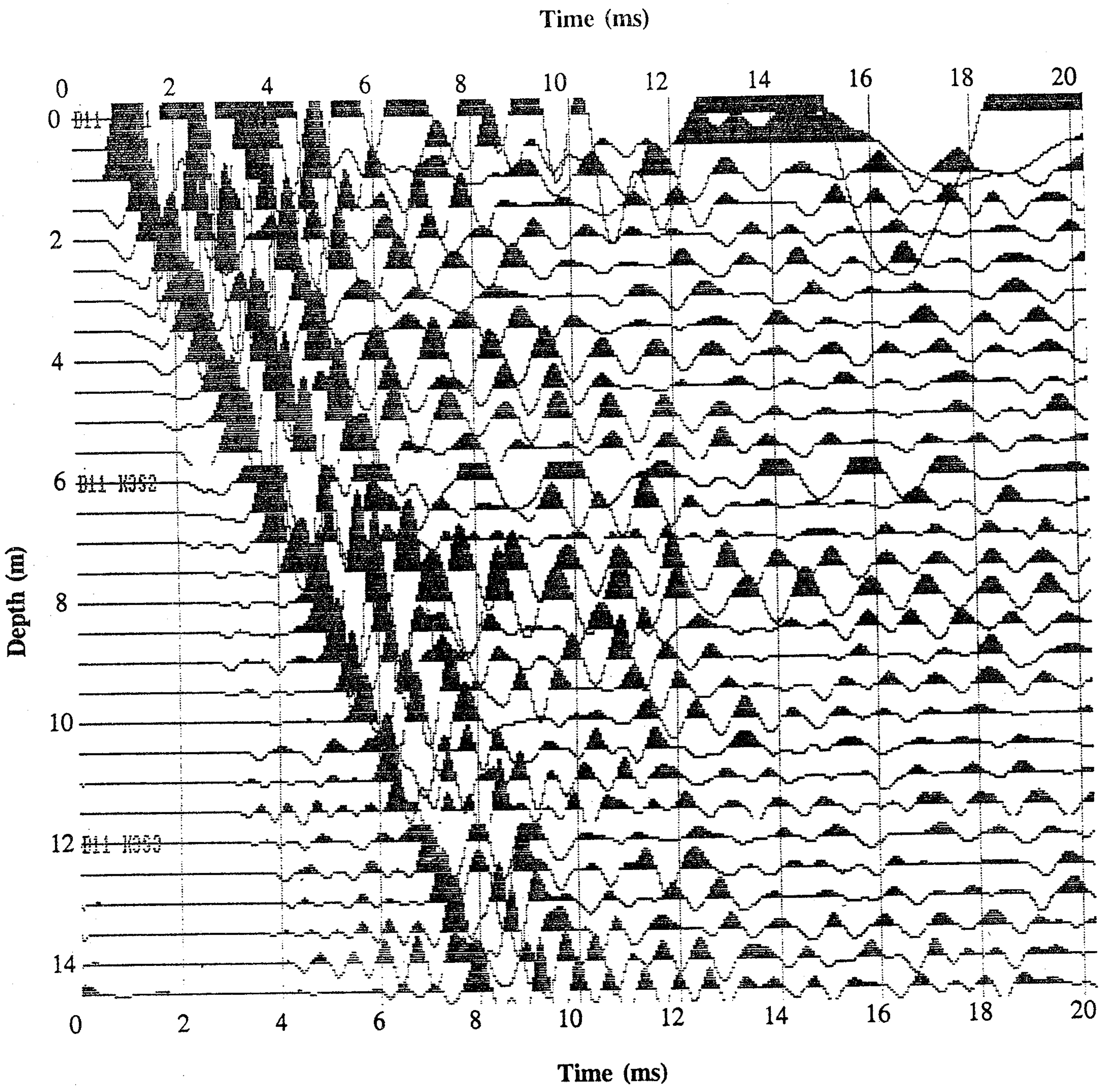


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 0.3 m south of BH
Source Depth: 1.0 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 1
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: N/A

Figure 220

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP

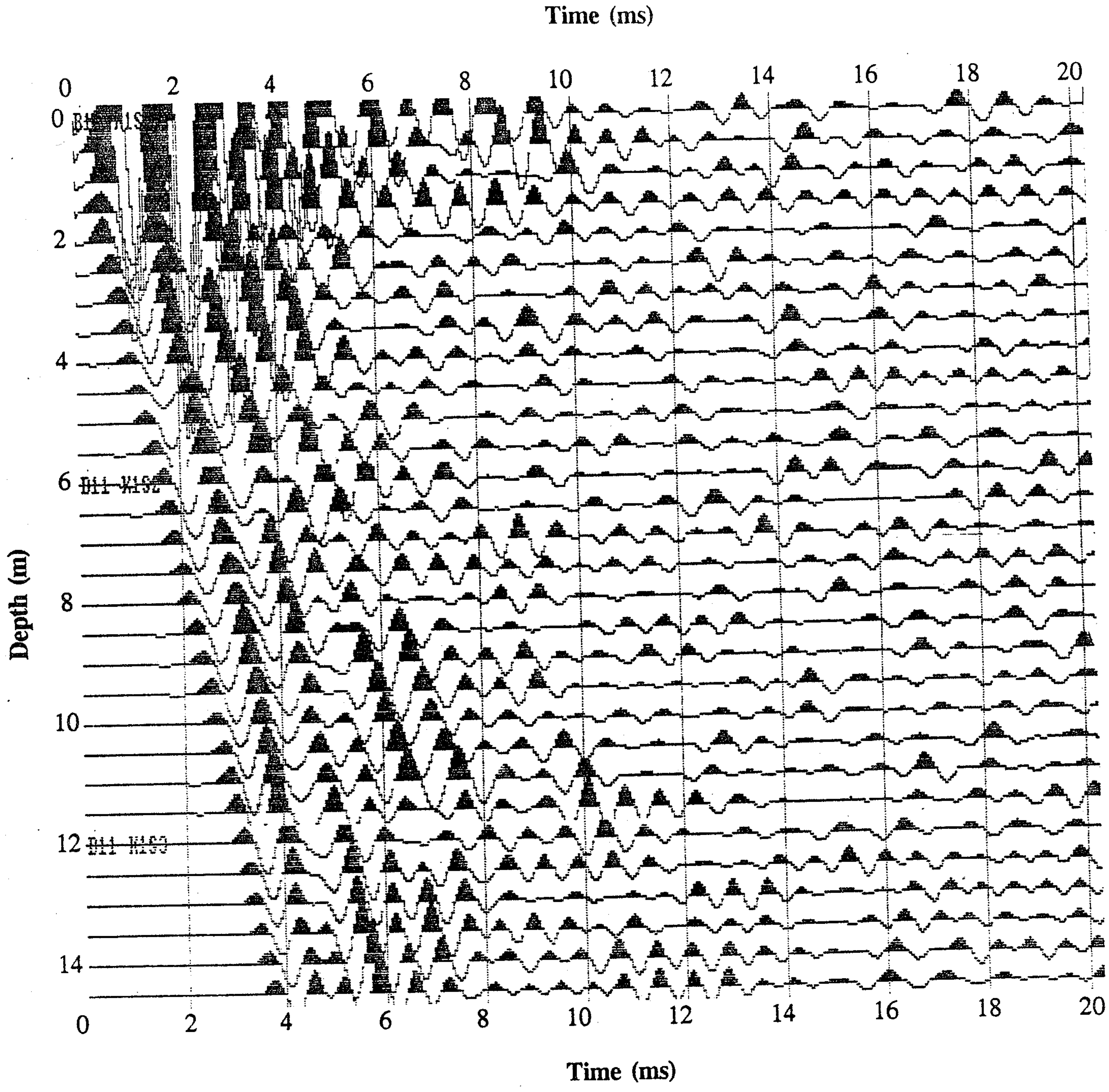


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 0.3 m south of BH
Source Depth: 1.0 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 2
AGC Parameters: 160 sample window (centred) AGC factor = 200
Bandpass Filter: N/A

Figure 221

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP

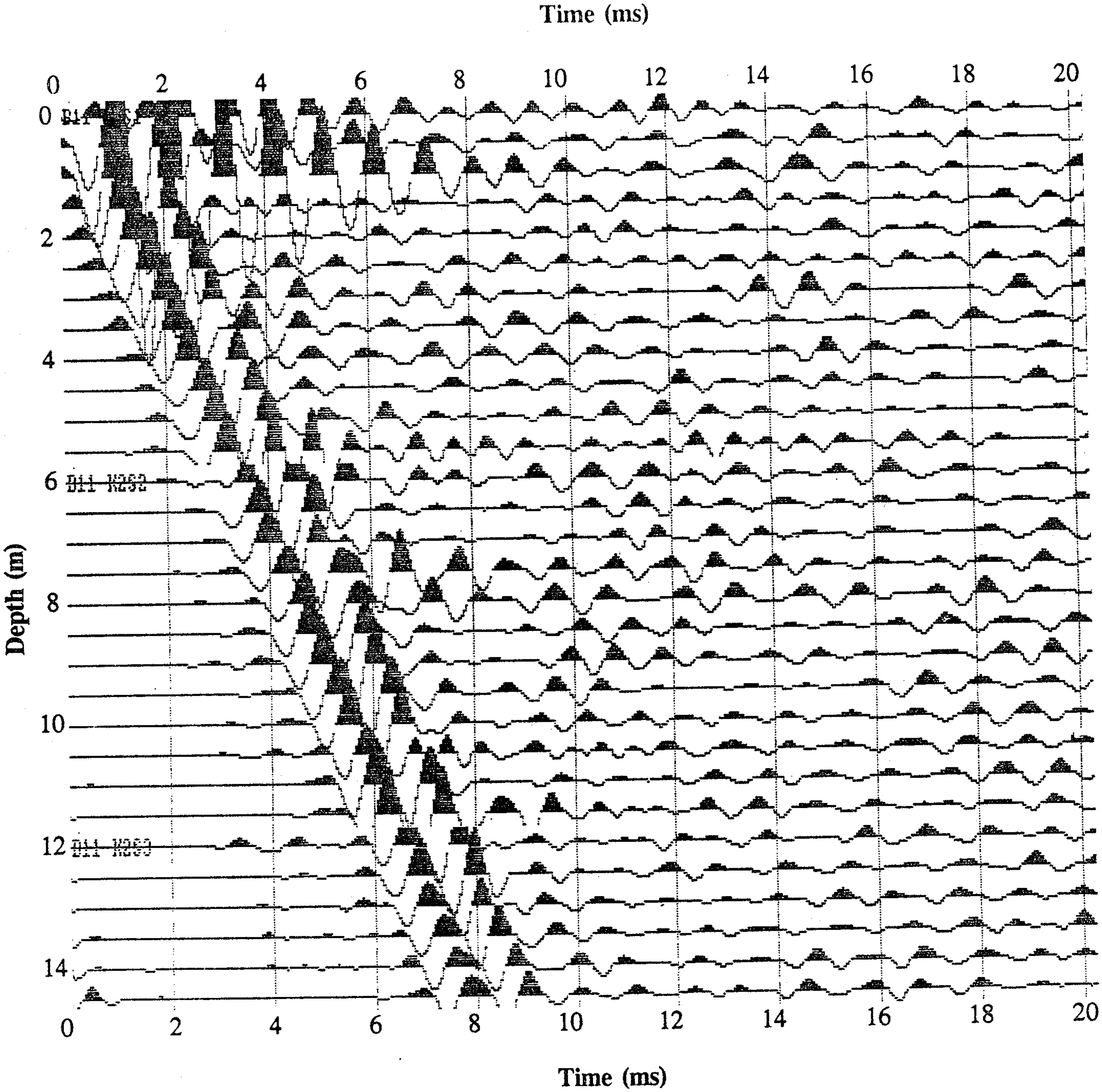


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 0.3 m south of BH
Source Depth: 1.0 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Vertical
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: 768-1540 Hz (12 db rolloffs)

Figure 222

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP

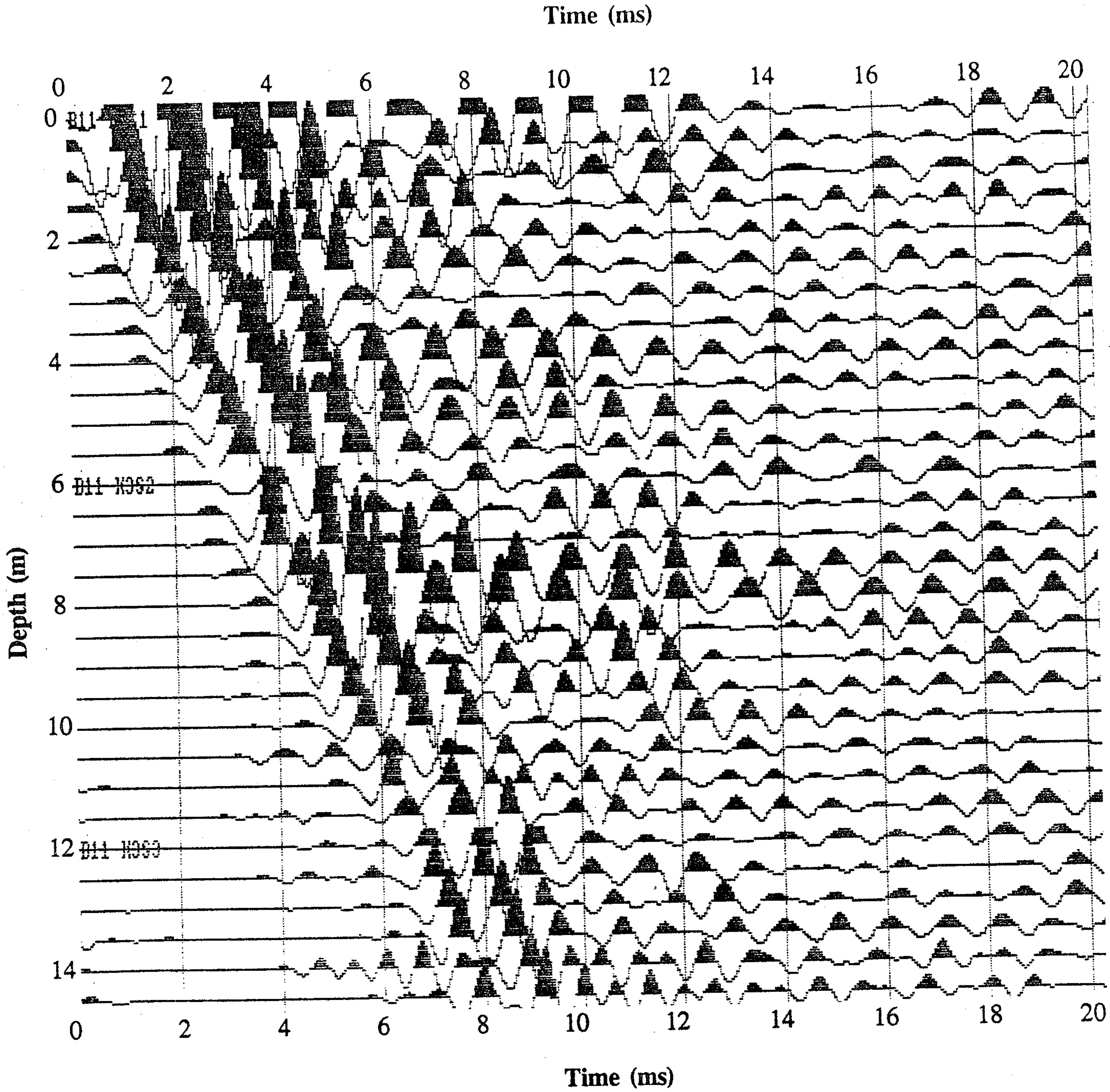


Recording Parameters:
Source: Steel rod oriented 45° N
Source Offset: 0.3 m south of BH
Source Depth: 1.0 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 1
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: 768-1540 Hz (12 db rolloffs)

Figure 223

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:

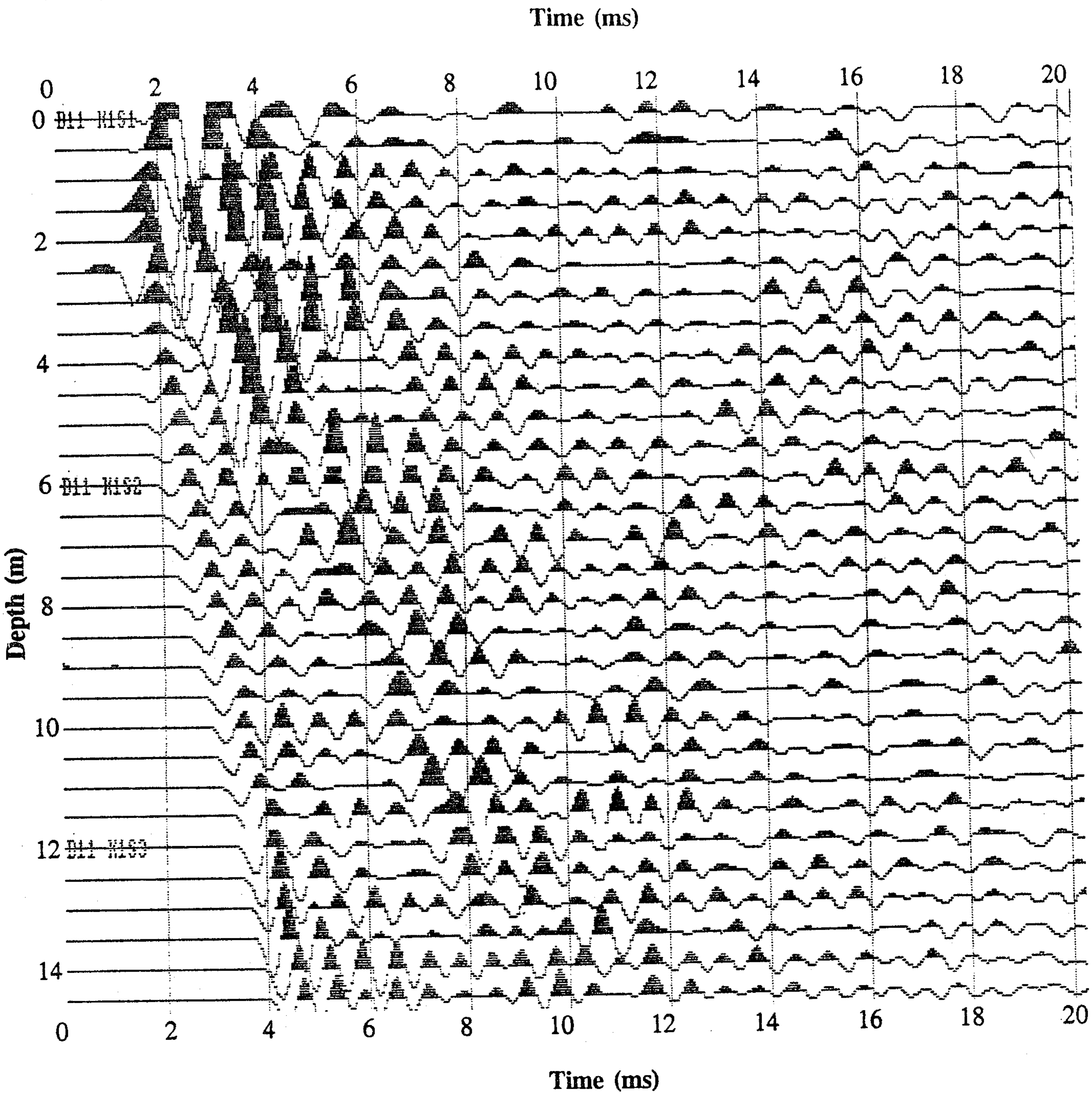
Source: Steel rod oriented 45° N
Source Offset: 0.3 m south of BH
Source Depth: 1.0 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:

Component Plotted: Horizontal 2
AGC Parameters: 160 sample window (centred) AGC factor = 200
Bandpass Filter: 768-1540 Hz (12 db rolloffs)

Figure 224

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP

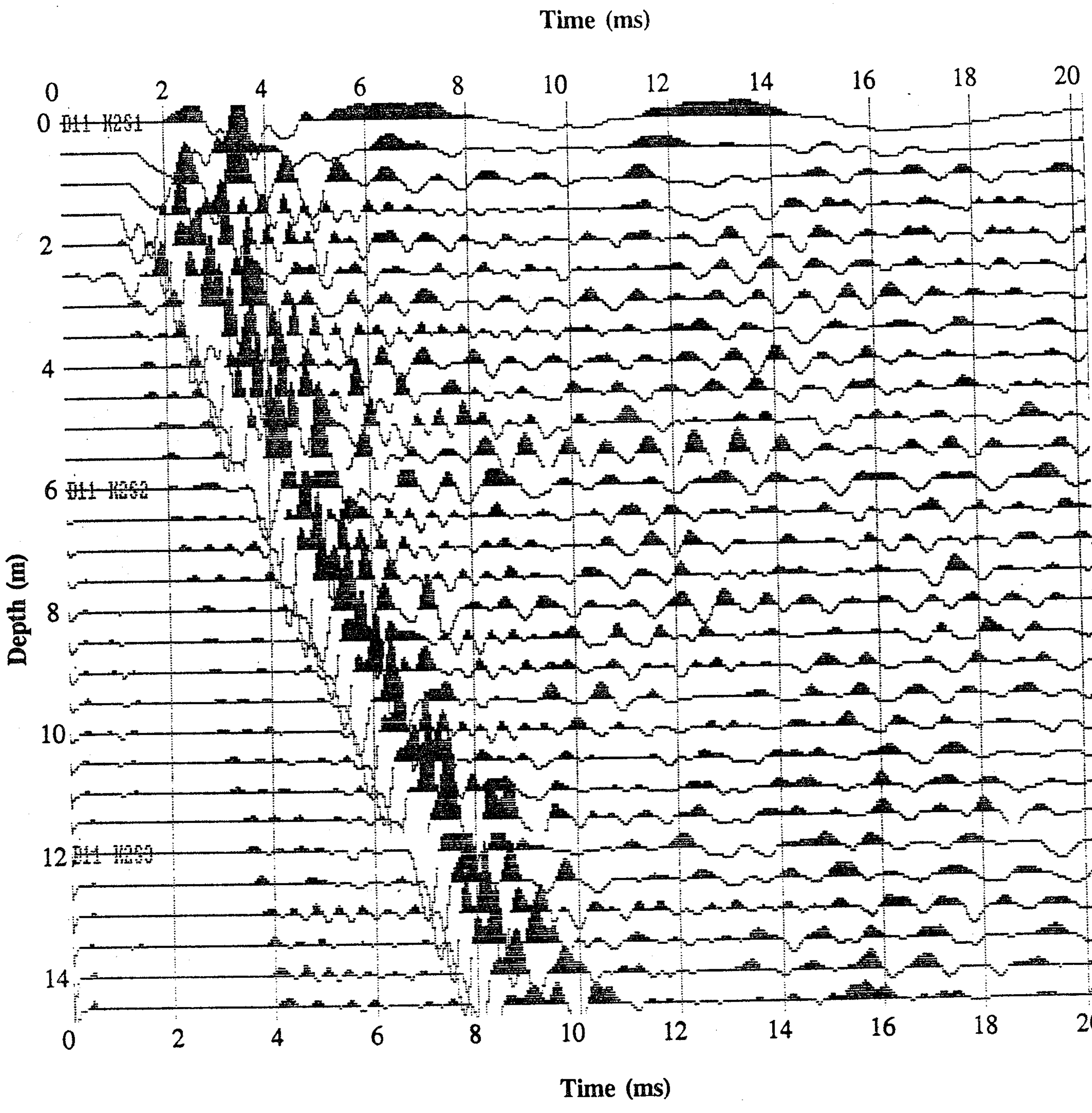


Recording Parameters:
Source: Steel rod oriented 45° S
Source Offset: 1.8 m south of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Vertical
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: N/A

Figure 225

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP

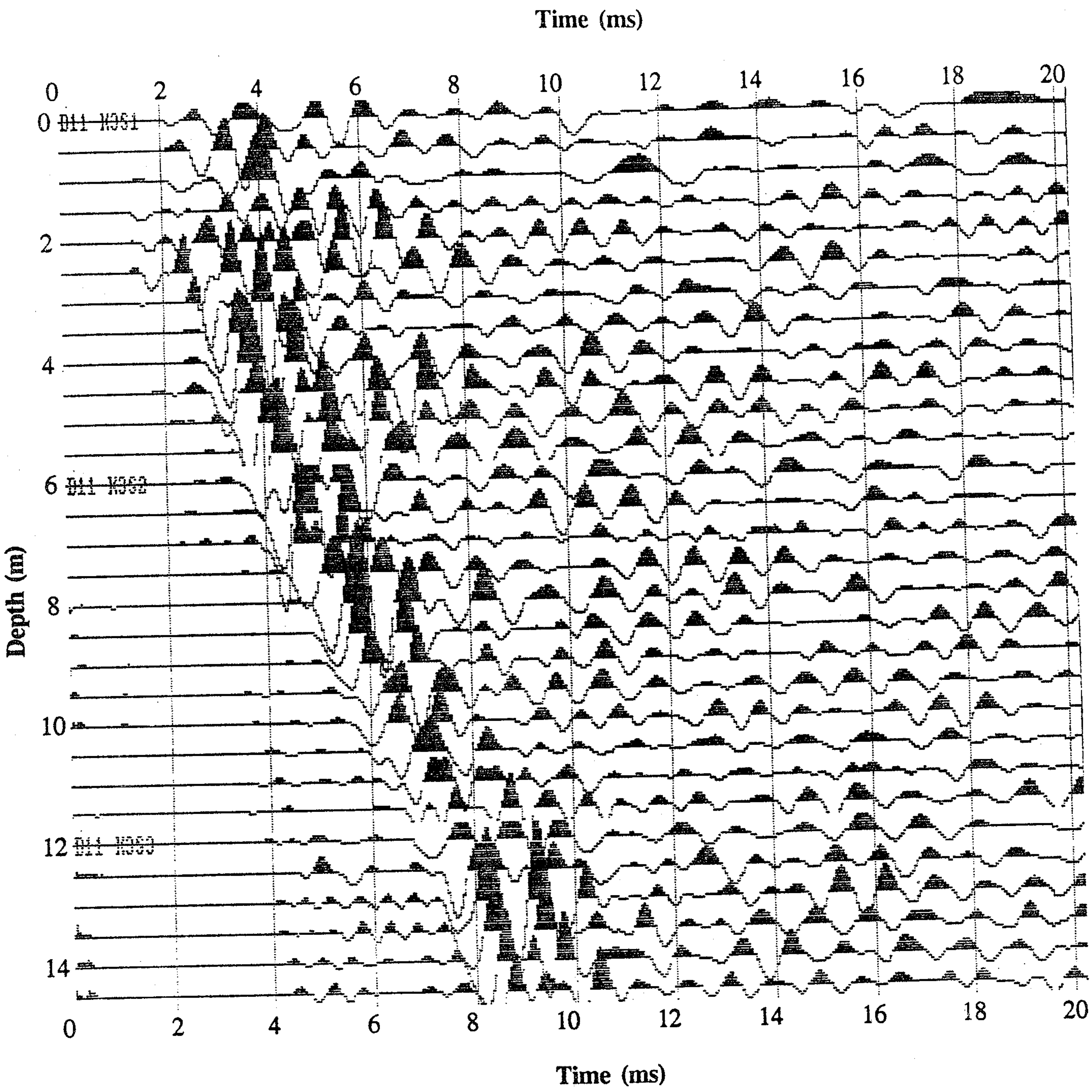


Recording Parameters:
Source: Steel rod oriented 45° S
Source Offset: 1.8 m south of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 1
AGC Parameters: 160 sample window (centred) AGC factor = 200
Bandpass Filter: N/A

Figure 226

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:

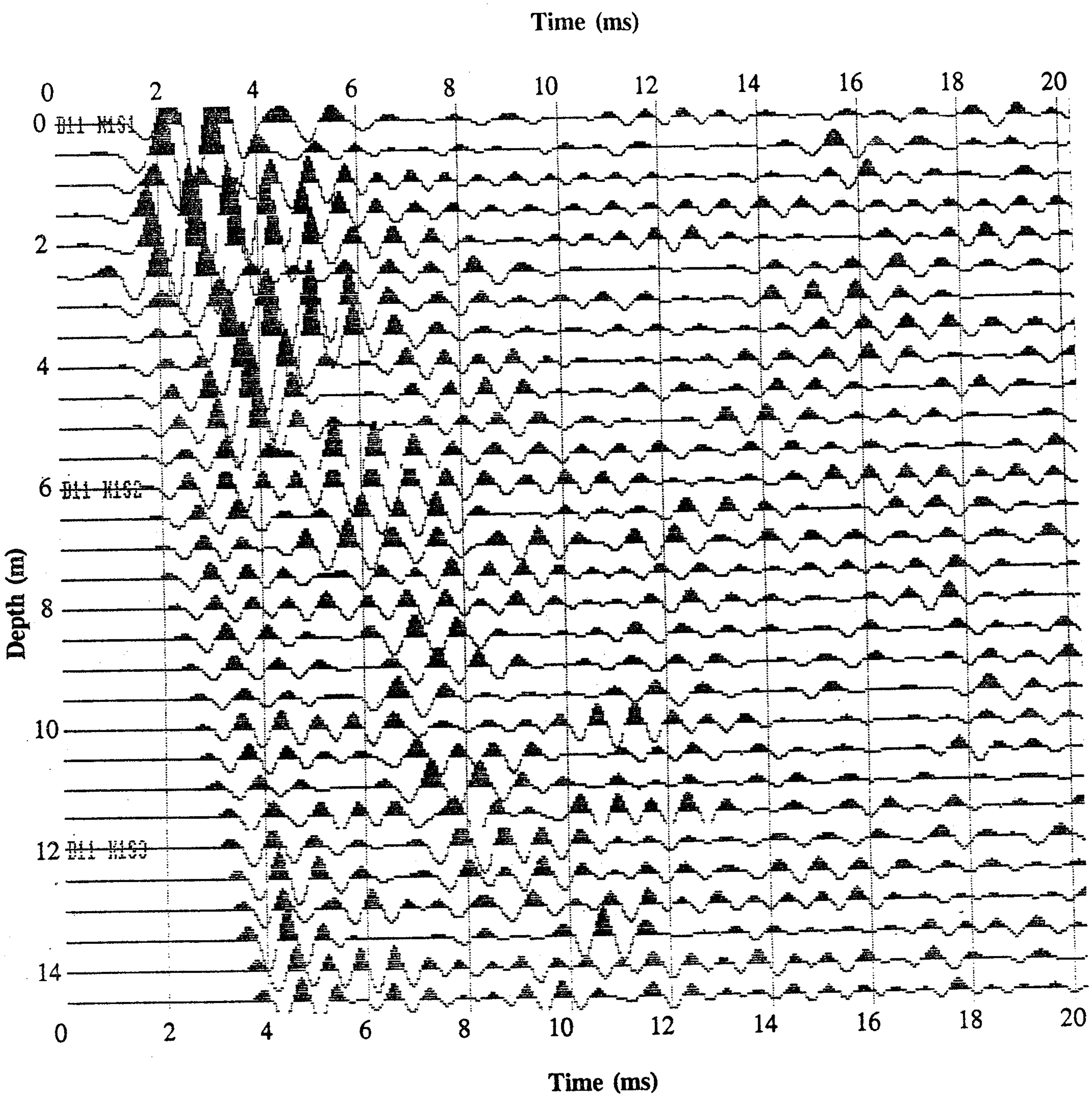
Source: Steel rod oriented 45° S
Source Offset: 1.8 m south of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:

Component Plotted: Horizontal 2
AGC Parameters: 160 sample window (centred) AGC factor = 200
Bandpass Filter: N/A

Figure 227

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP

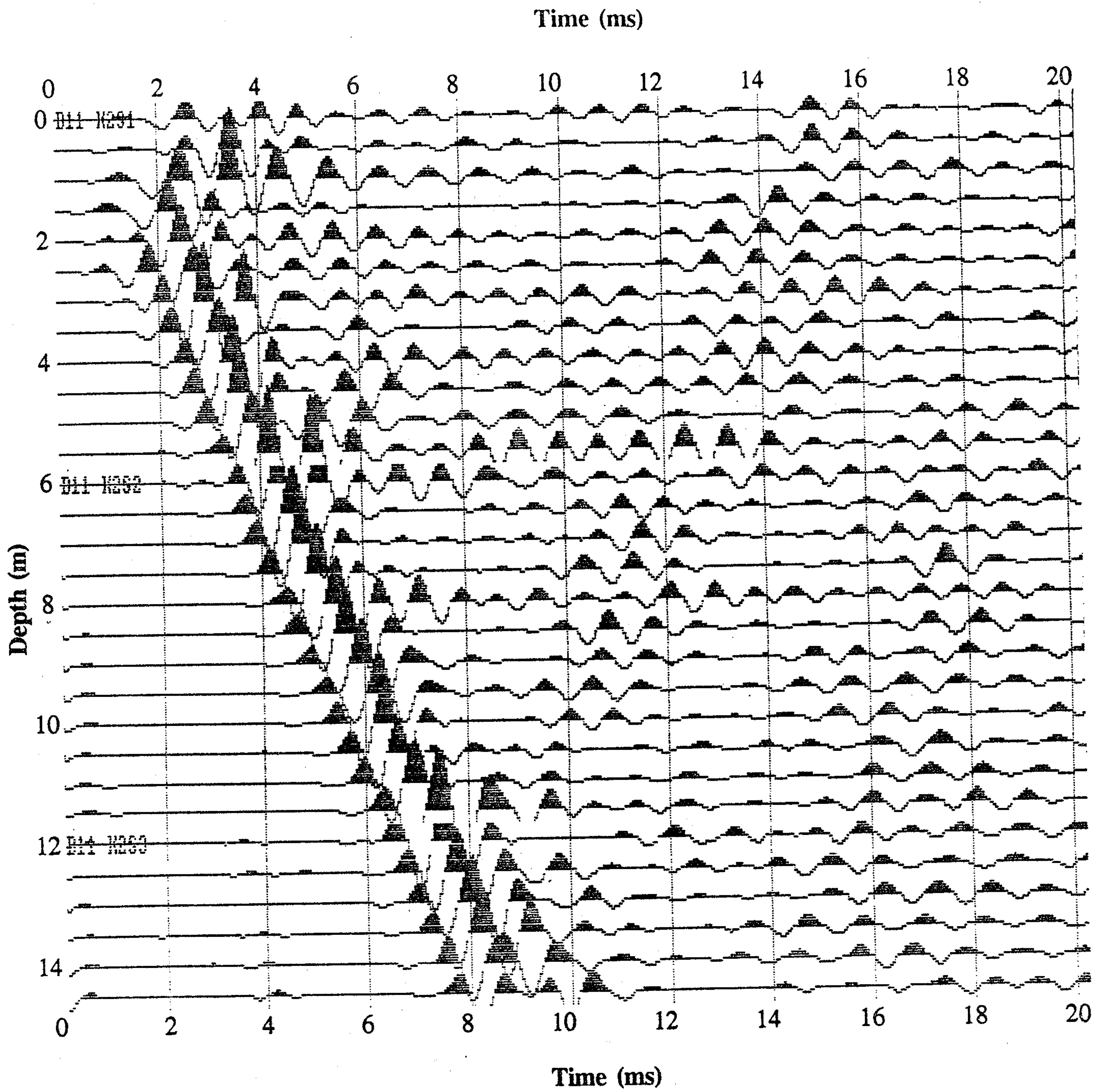


Recording Parameters:
Source: Steel rod oriented 45° S
Source Offset: 1.8 m south of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Vertical
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: 768-1540 Hz (12 db rolloffs)

Figure 228

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP

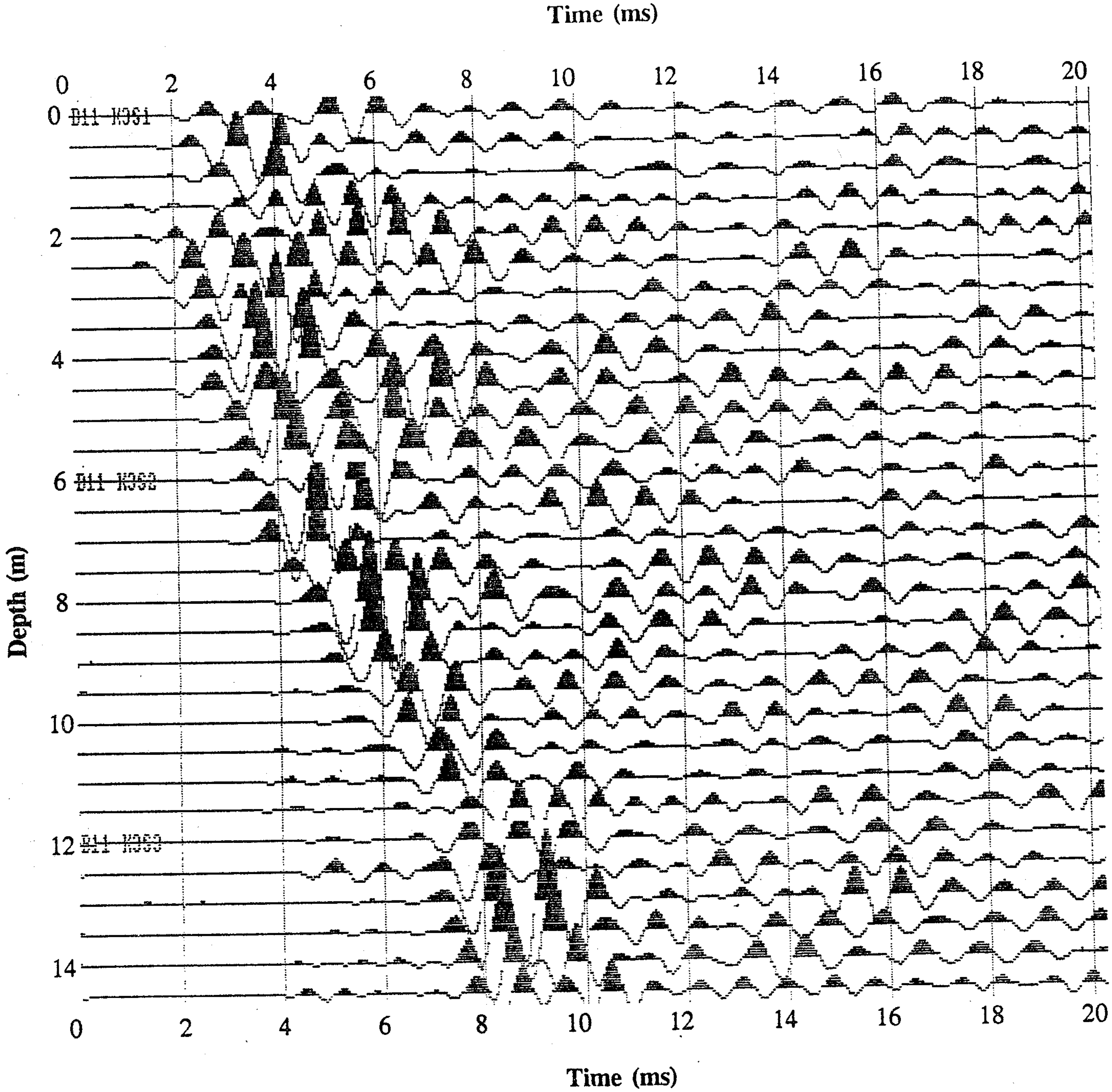


Recording Parameters:
Source: Steel rod oriented 45° S
Source Offset: 1.8 m south of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 1
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: 768-1540 Hz (12 db rolloffs)

Figure 229

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP

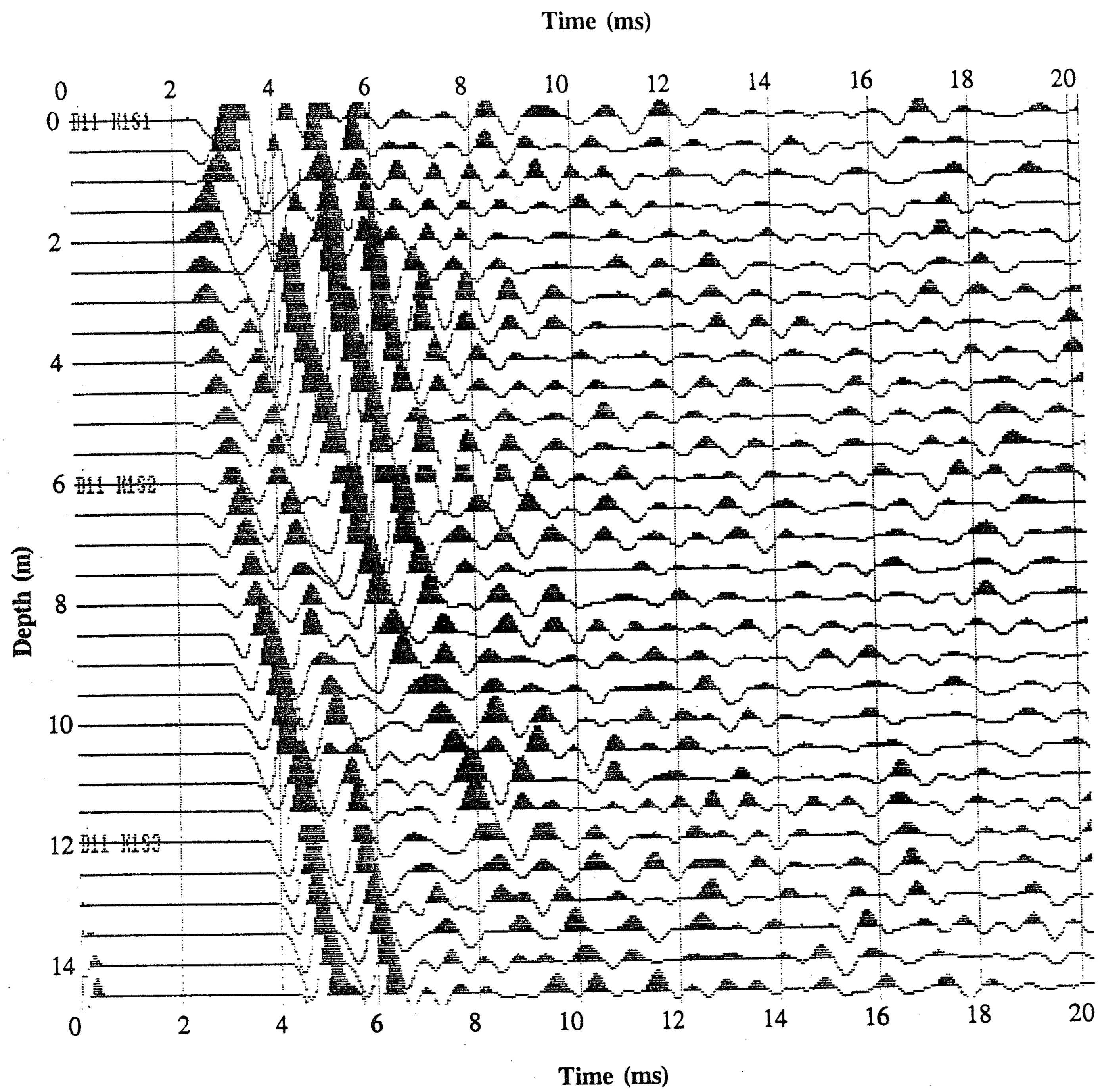


Recording Parameters:
Source: Steel rod oriented 45° S
Source Offset: 1.8 m south of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 2
AGC Parameters: 160 sample window (centred) AGC factor = 200
Bandpass Filter: 768-1540 Hz (12 db rolloffs)

Figure 230

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP

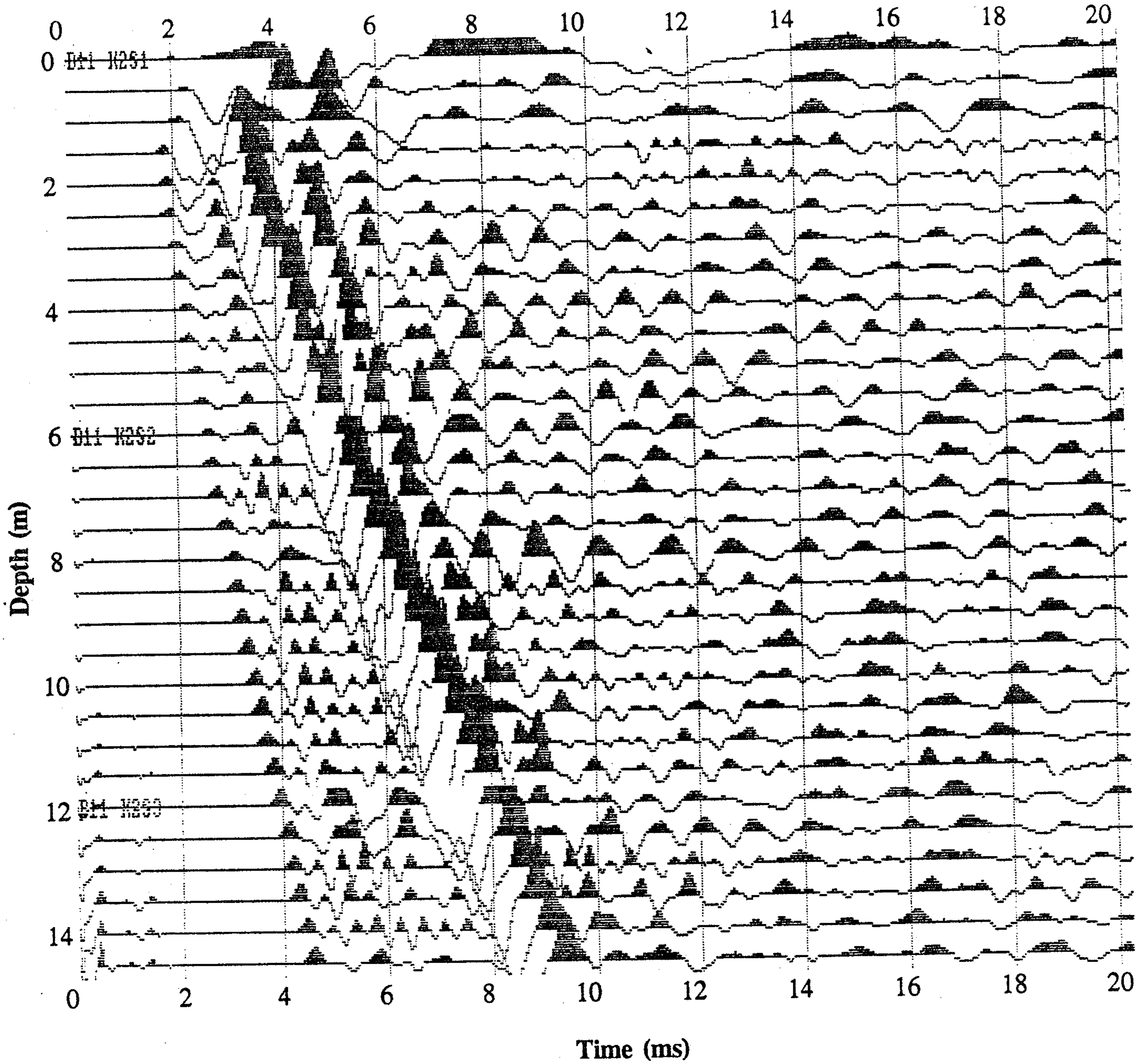


Recording Parameters:
Source: Steel rod oriented 45° S
Source Offset: 3.8 m south of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Vertical
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: N/A

Figure 231

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP

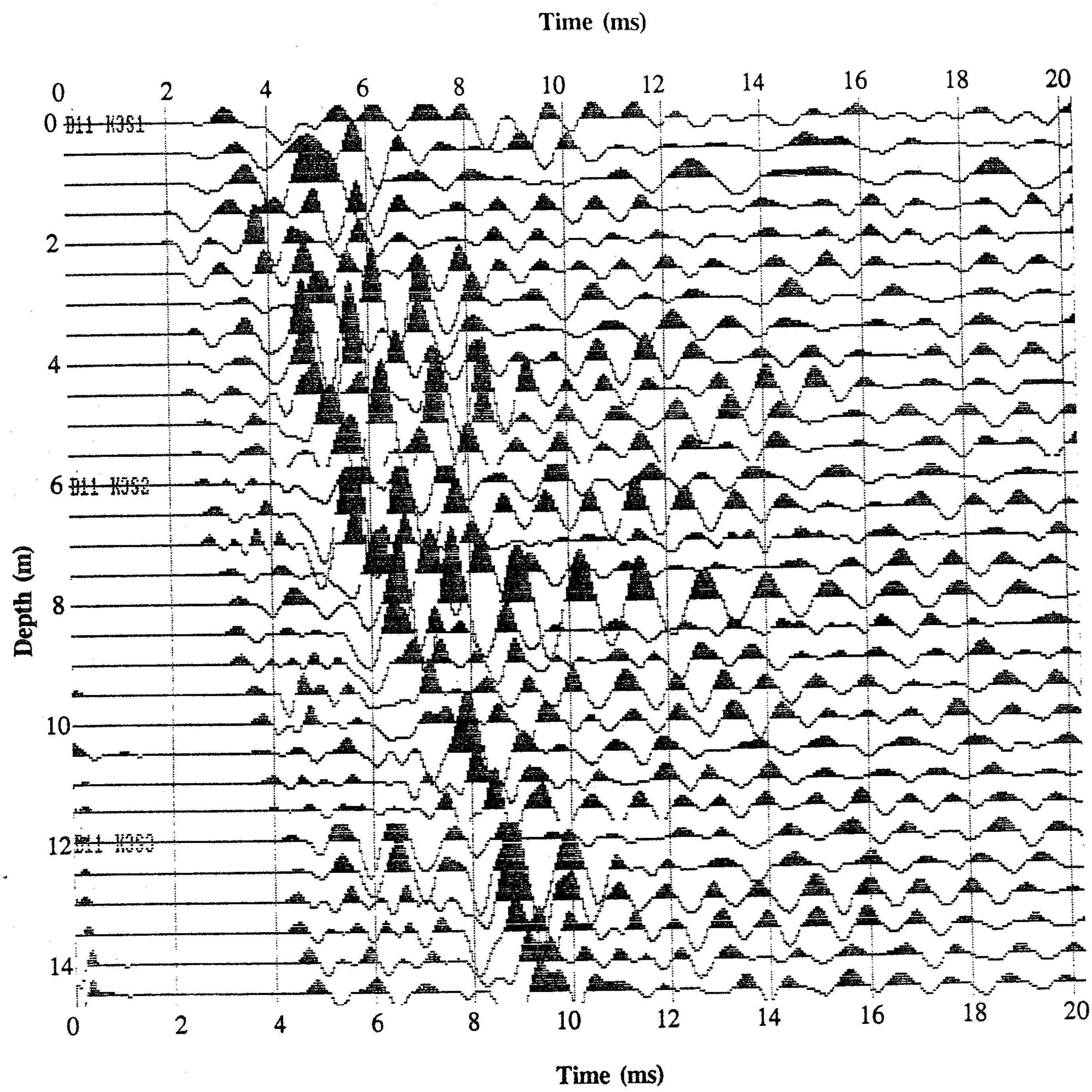


Recording Parameters:
Source: Steel rod oriented 45° S
Source Offset: 3.8 m south of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 1
AGC Parameters: 160 sample window (centred) AGC factor = 200
Bandpass Filter: N/A

Figure 232

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP

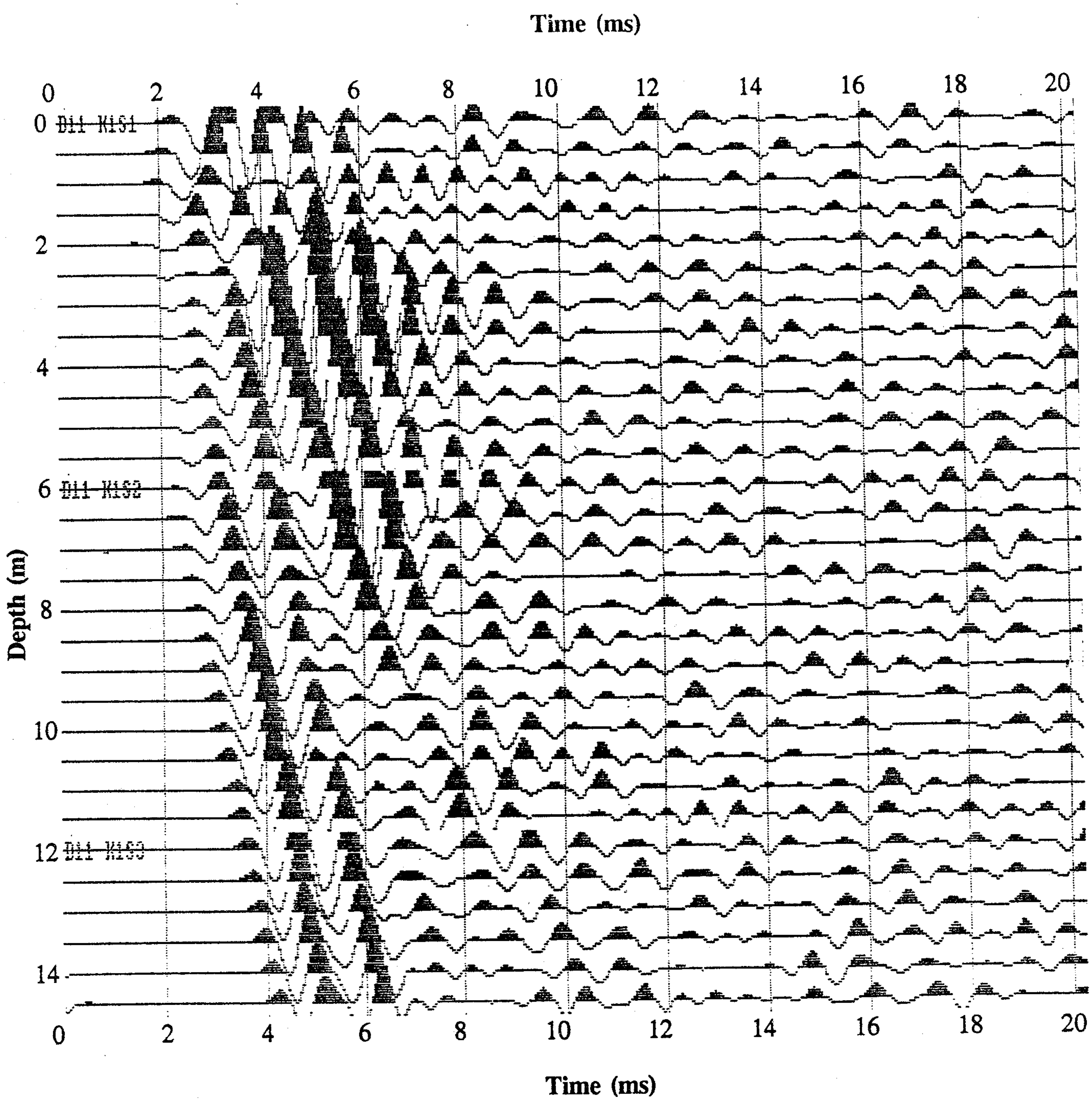


Recording Parameters:
Source: Steel rod oriented 45° S
Source Offset: 3.8 m south of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 2
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: N/A

Figure 233

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:

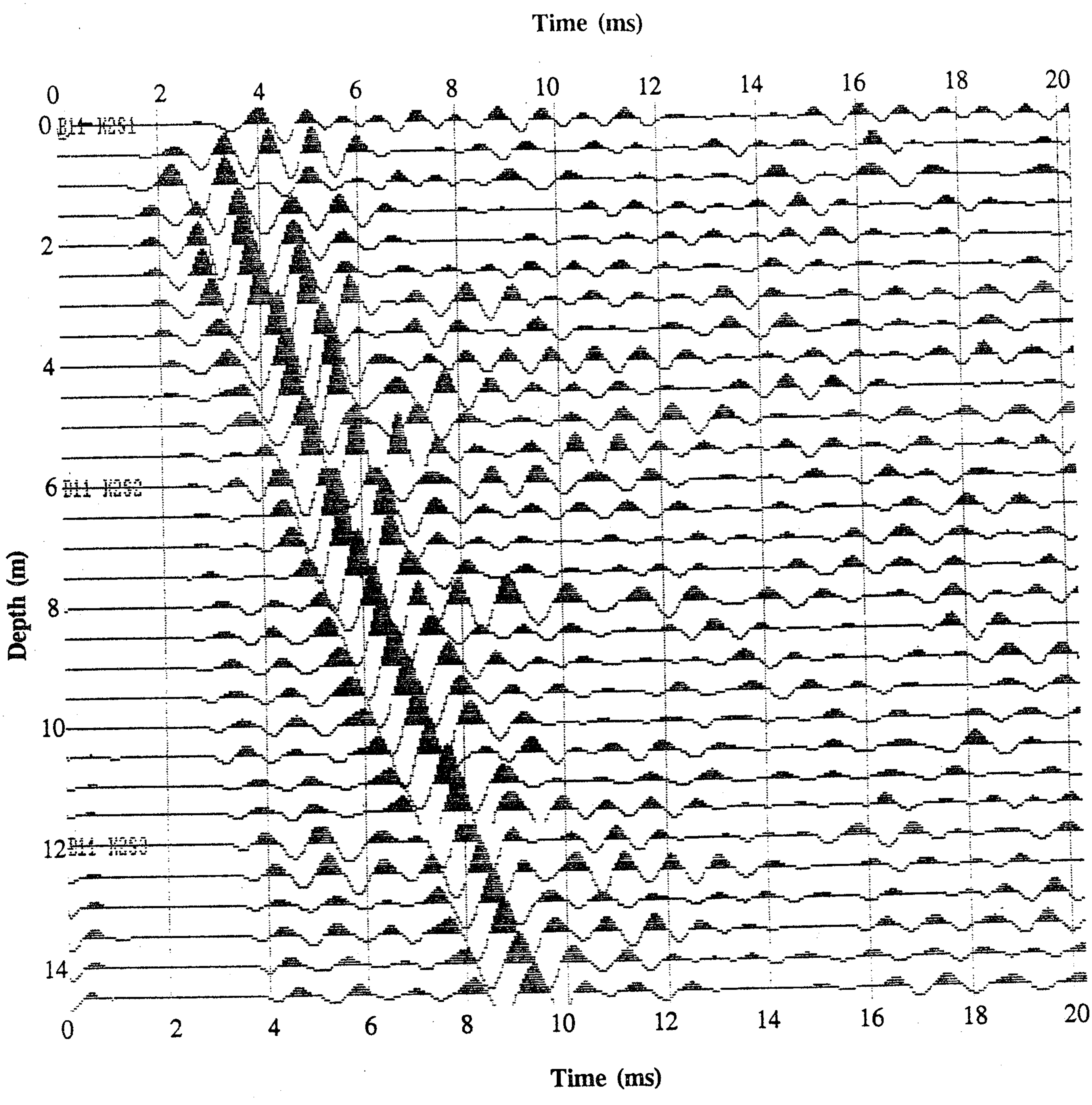
Source: Steel rod oriented 45° S
Source Offset: 3.8 m south of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:

Component Plotted: Vertical
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: 768-1540 Hz (12 db rolloffs)

Figure 234

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP

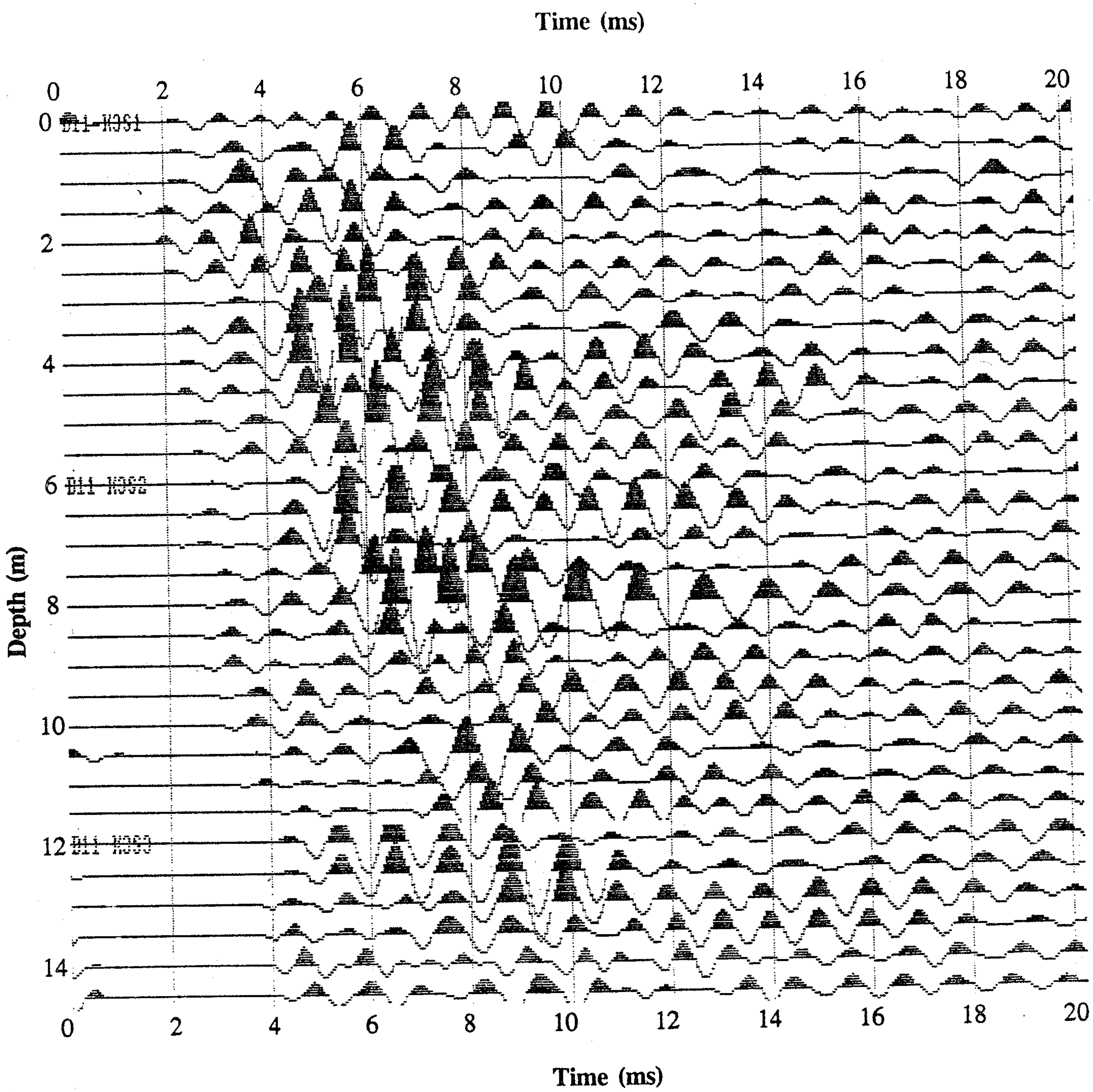


Recording Parameters:
Source: Steel rod oriented 45° S
Source Offset: 3.8 m south of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

Display Parameters:
Component Plotted: Horizontal 1
AGC Parameters: 160 sample window (centred)
AGC factor = 200
Bandpass Filter: 768-1540 Hz (12 db rolloffs)

Figure 235

BOVANENKOVO BOREHOLE 11 - DOWNHOLE SHEAR WAVE VSP



Recording Parameters:
Source: Steel rod oriented 45° S
Source Offset: 3.8 m south of BH
Source Depth: 0.9 m
Geophone: VSEGINGEO Downhole 3-component
Sampling Interval: 0.05 ms

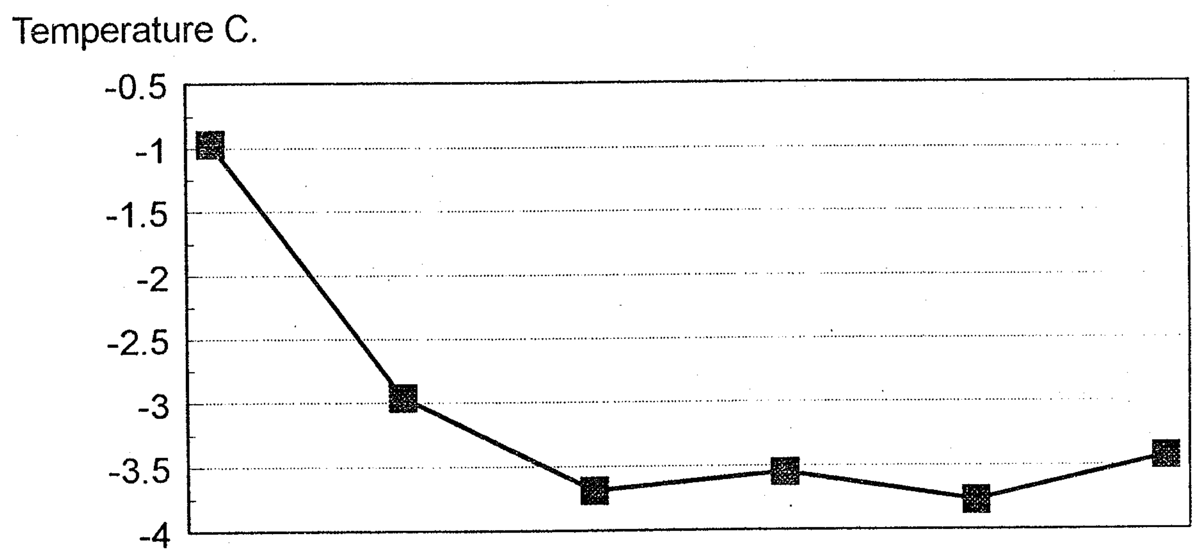
Display Parameters:
Component Plotted: Horizontal 2
AGC Parameters: 160 sample window (centred) AGC factor = 200
Bandpass Filter: 768-1540 Hz (12 db rolloffs)

Figure 236

GROUND TEMPERATURES

Figs. 237-248

Bovanenkovo Borehole # 1K

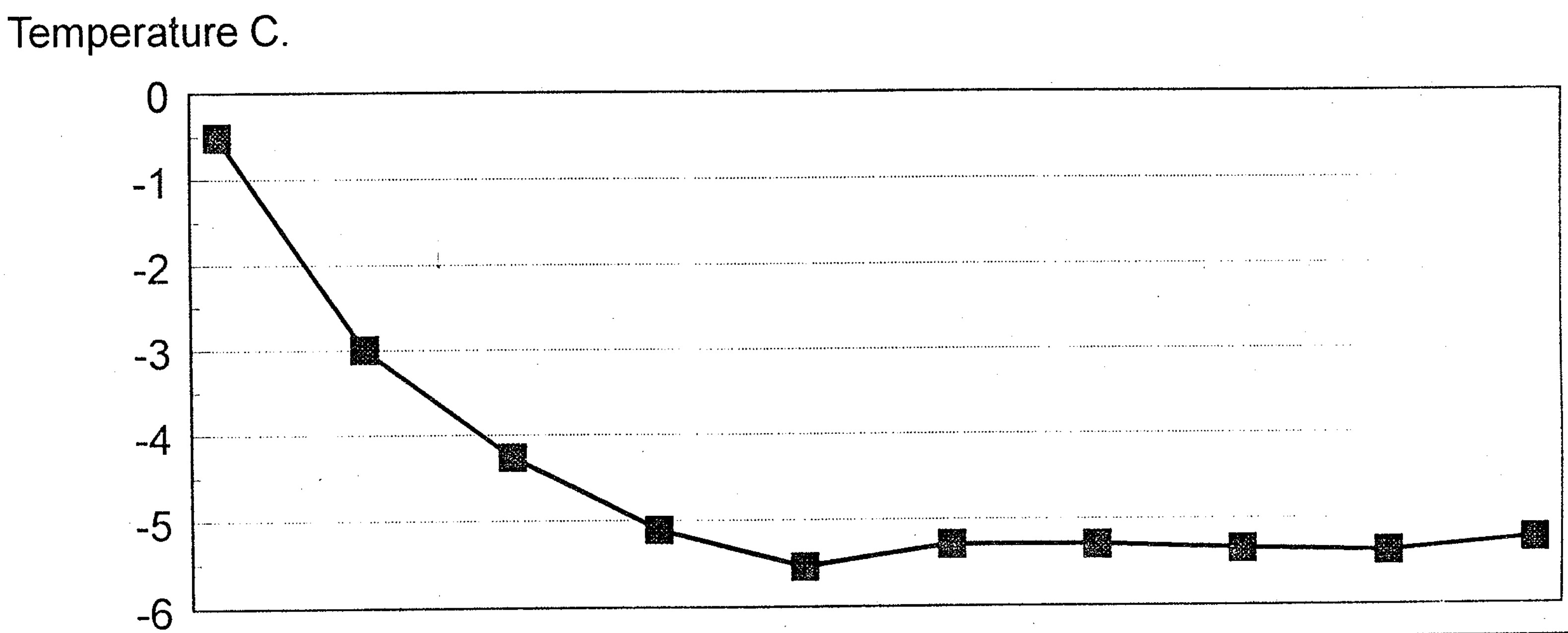


Depth m.	1.0	2.0	4.3	5.5	6.8	8.0
—■—	-0.97	-2.96	-3.69	-3.55	-3.77	-3.43

Measurements of 17 July 1991

Figure 237

Bovanenkovo Borehole # 2K

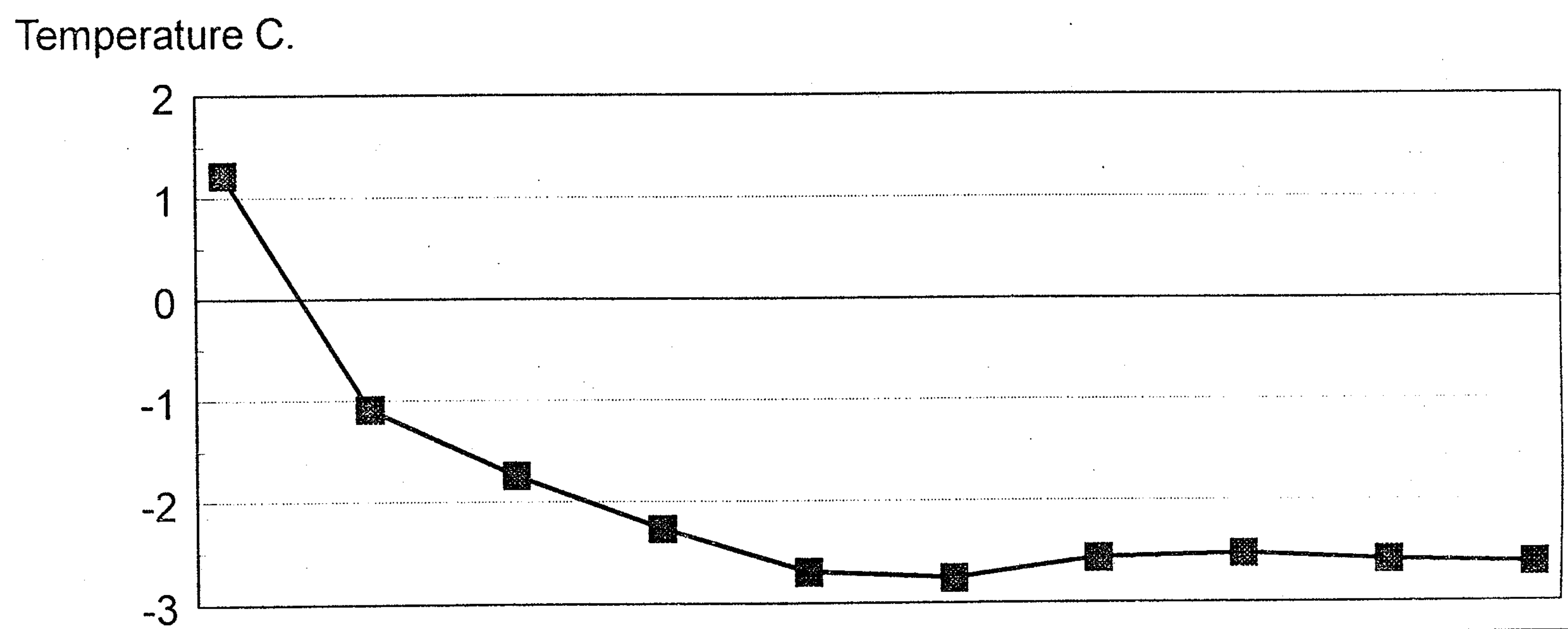


Depth m.	0.5	1.0	1.5	2.0	3.0	5.0	6.3	7.5	8.8	10.0
■	-0.51	-3.00	-4.26	-5.11	-5.54	-5.29	-5.30	-5.35	-5.38	-5.24

Measurements of 17 July 1991

Figure 238

Bovanenkovo Borehole # 3K

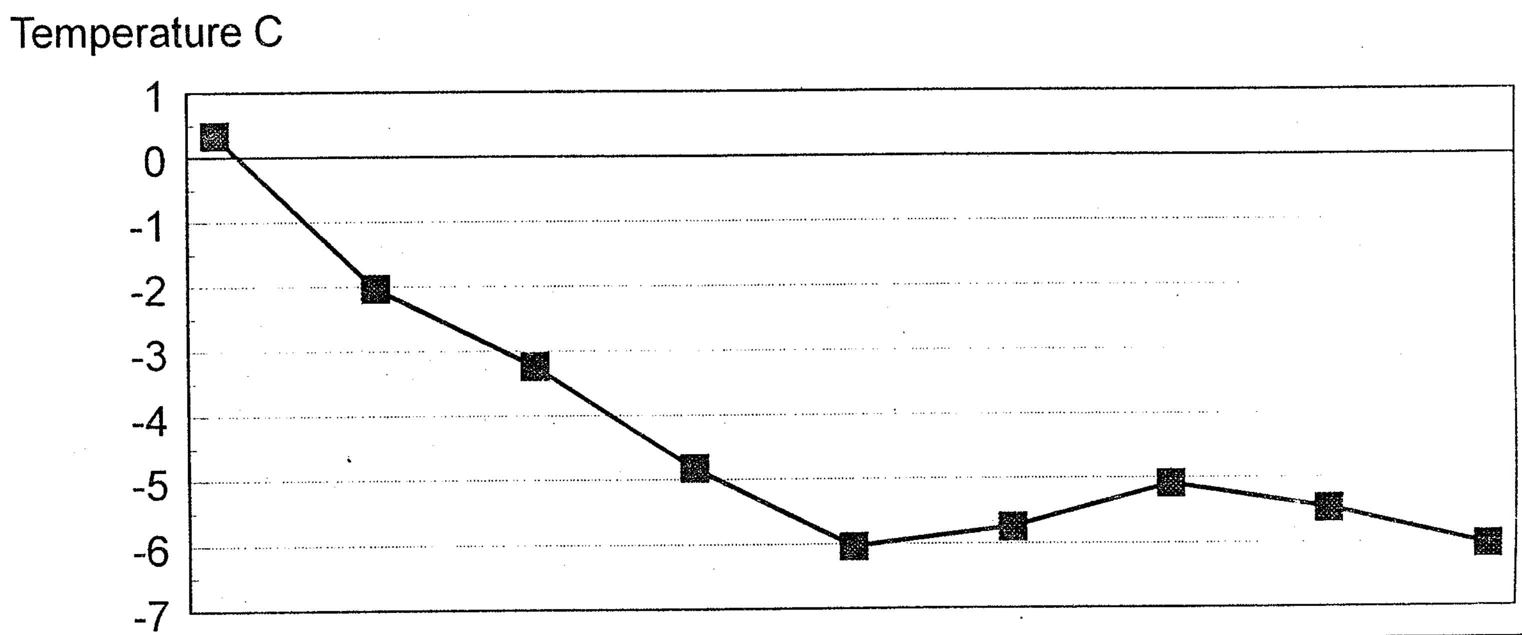


Depth m.	0.5	1.0	1.5	2.0	3.0	5.0	6.3	7.5	8.8	10.0
-■-	1.22	-1.09	-1.74	-2.27	-2.70	-2.76	-2.57	-2.53	-2.59	-2.62

Measurements of 18 July 1991

Figure 239

Bovanenkovo Borehole # 4K

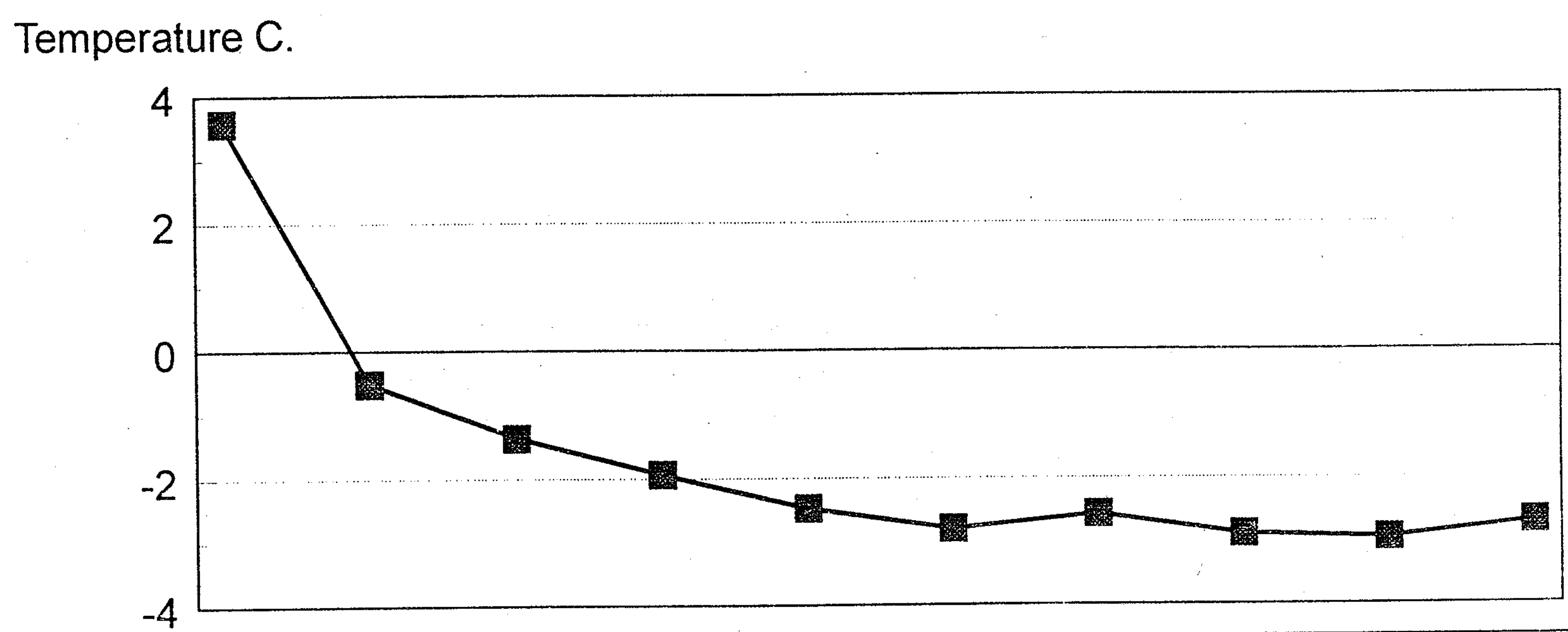


Depth m.	0.5	1.0	1.5	2.5	4.5	5.8	7.0	8.3	9.5
■	0.34	-2.03	-3.24	-4.82	-6.04	-5.75	-5.09	-5.47	-6.03

Measurements of 17 July 1991

Figure 240

Bovanenkovo Borehole # 7K

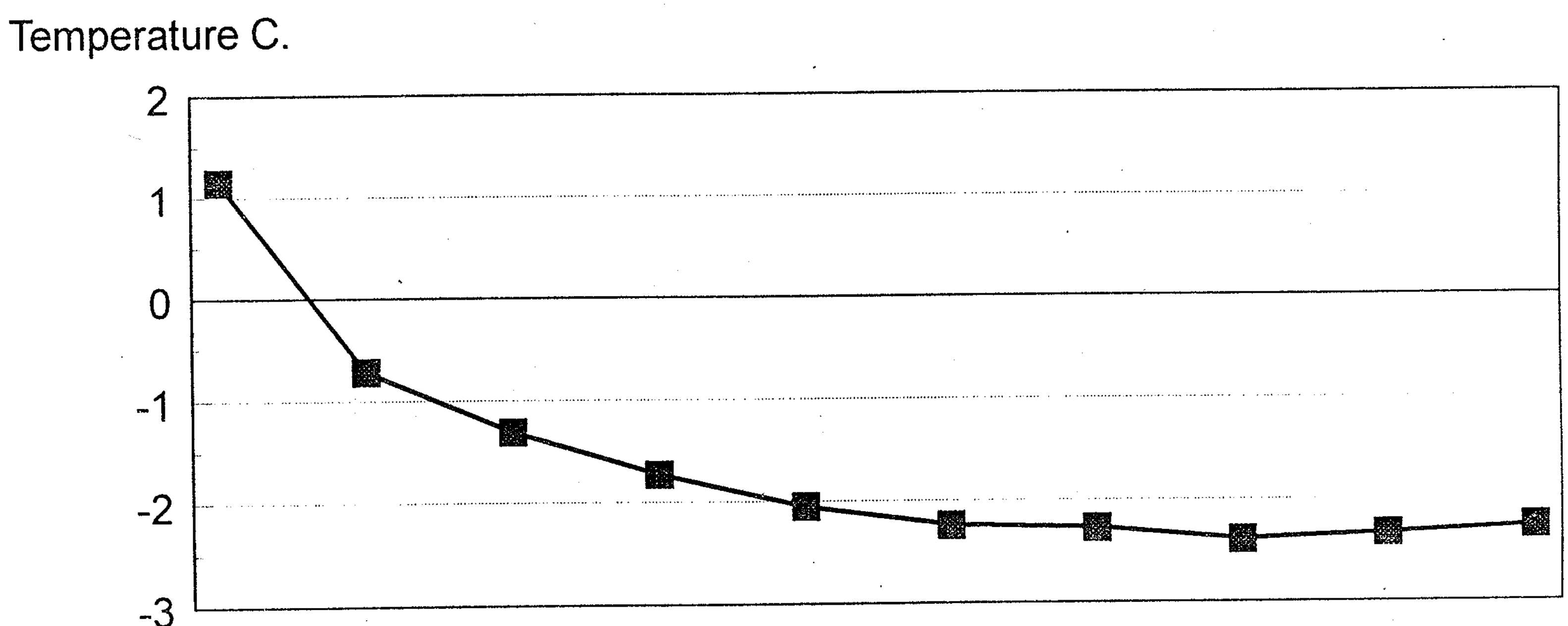


Depth m.	0.5	1.0	1.5	2.0	3.0	5.0	6.3	7.5	8.8	10.0
-■-	3.58	-0.51	-1.36	-1.94	-2.47	-2.80	-2.57	-2.89	-2.95	-2.69

Measurements of 21 July 1991

Figure 241

Bovanenkovo Borehole # 8K

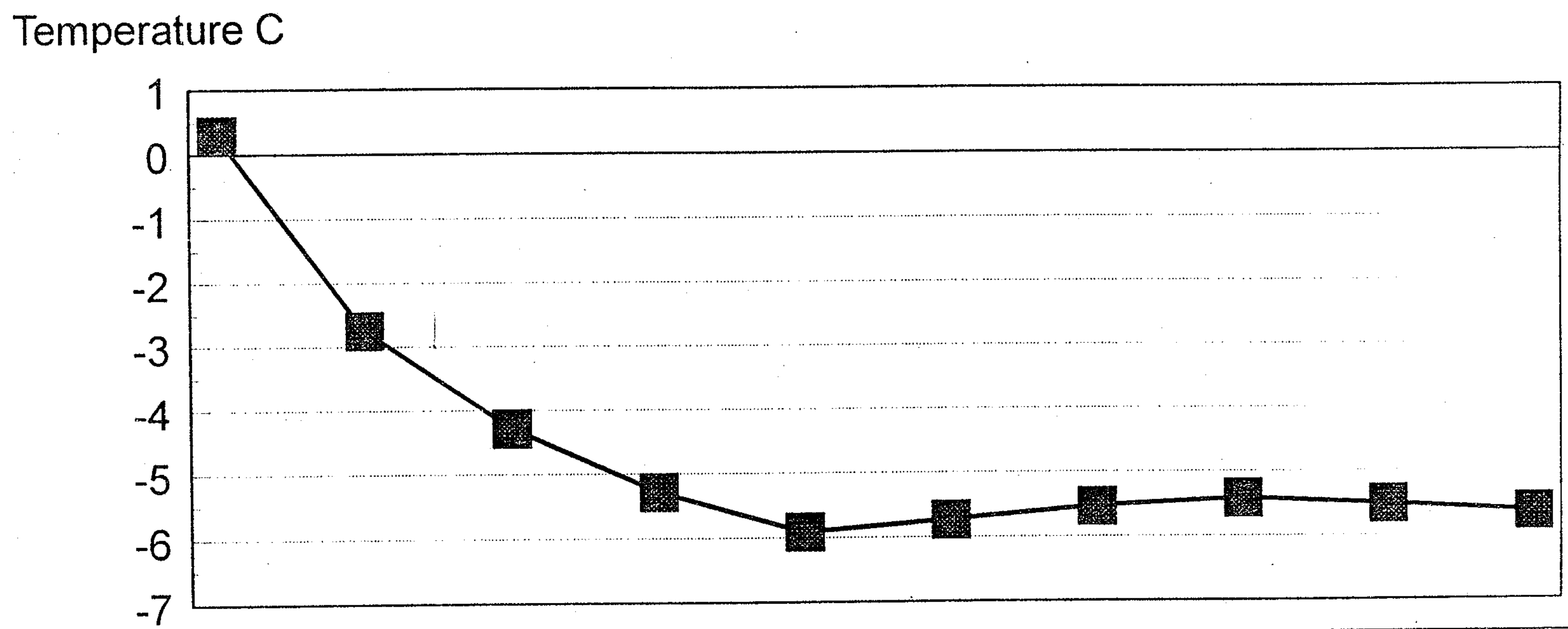


Depth m.	0.5	1.0	1.5	2.0	3.0	5.0	6.3	7.5	8.8	10.0
■	1.15	-0.72	-1.31	-1.73	-2.05	-2.24	-2.27	-2.39	-2.33	-2.26

Measurements of 20 July 1991

Figure 242

Bovanenkovo Borehole # 10K

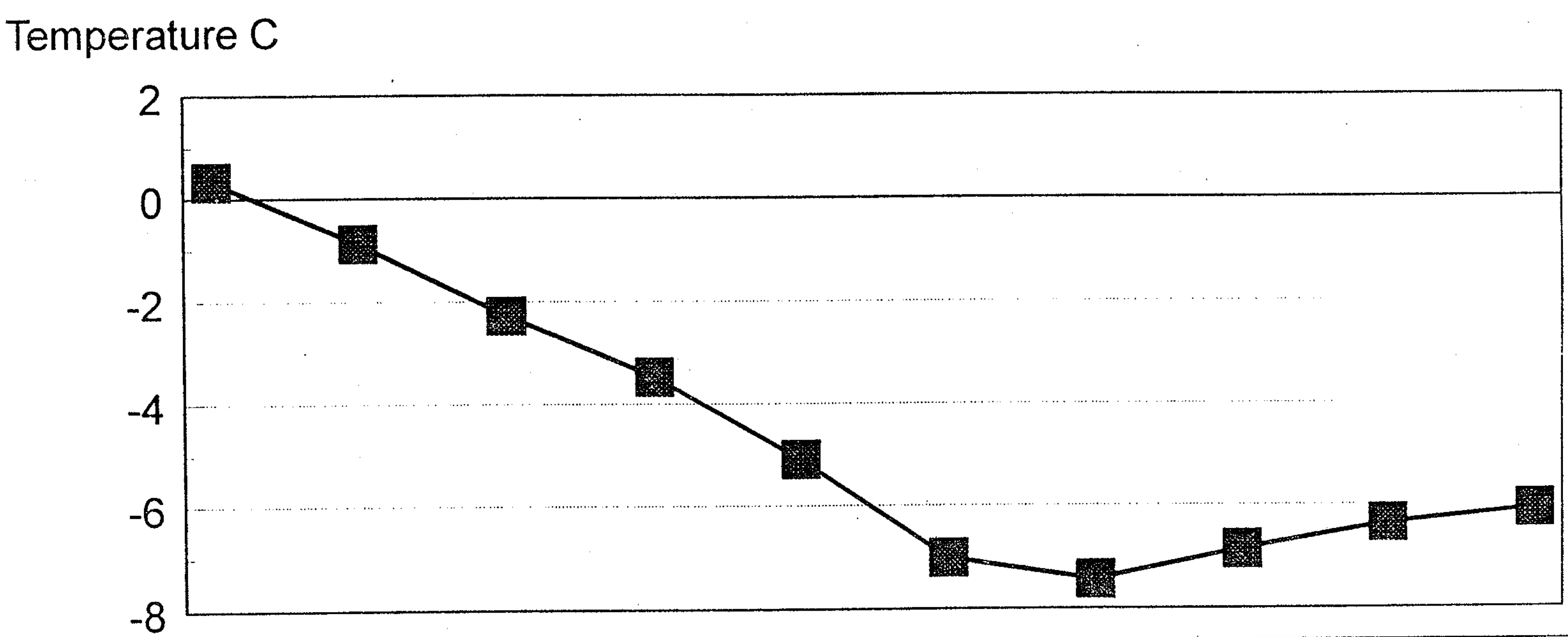


Depth m.	0.5	1.0	1.5	2.0	3.0	5.0	6.3	7.5	8.8	10.0
■	0.30	-2.75	-4.28	-5.29	-5.92	-5.74	-5.54	-5.42	-5.52	-5.64

Measurements of 20 July 1991

Figure 243

Bovanenkovo Borehole # 11K

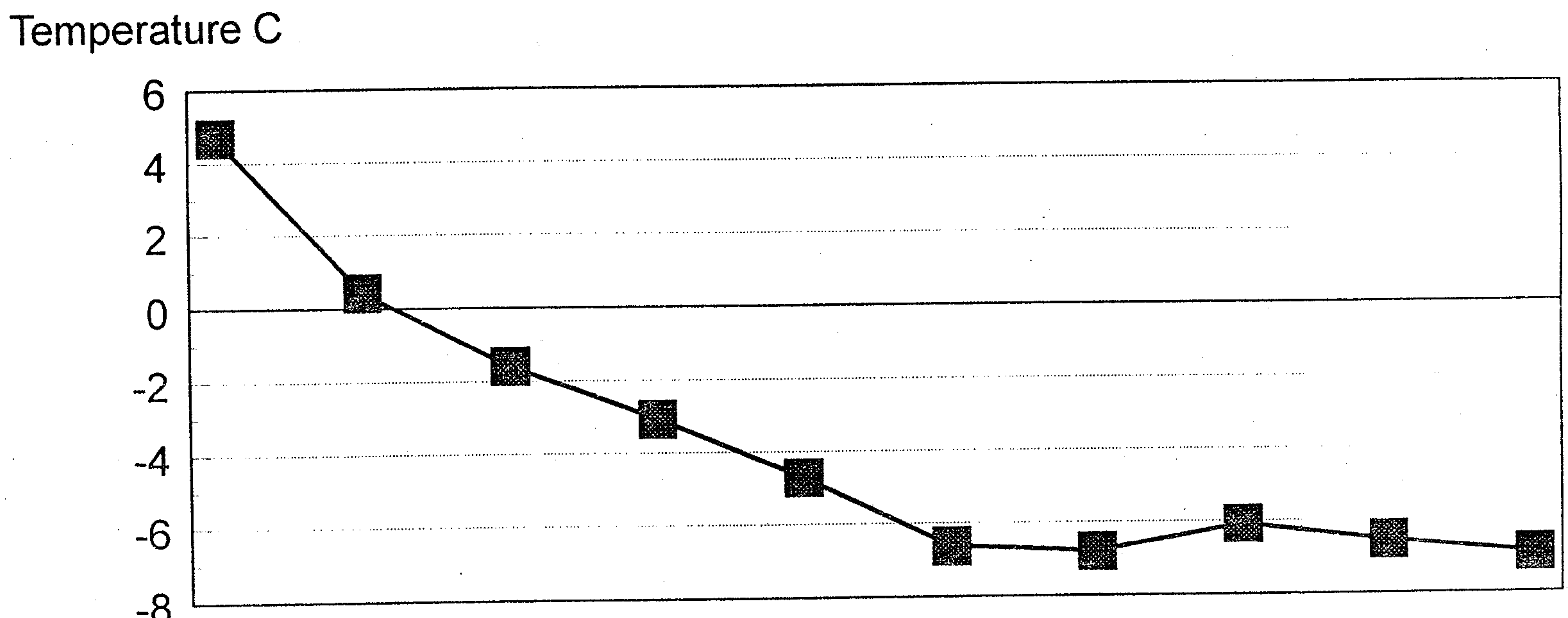


Depth m.	0.5	1.0	1.5	2.0	2.5	5.0	7.5	10.0	12.5	15.0
■	0.34	-0.87	-2.28	-3.48	-5.09	-7.02	-7.44	-6.86	-6.36	-6.08

Measurements of 22 July 1991

Figure 244

Bovanenkovo Borehole # 34

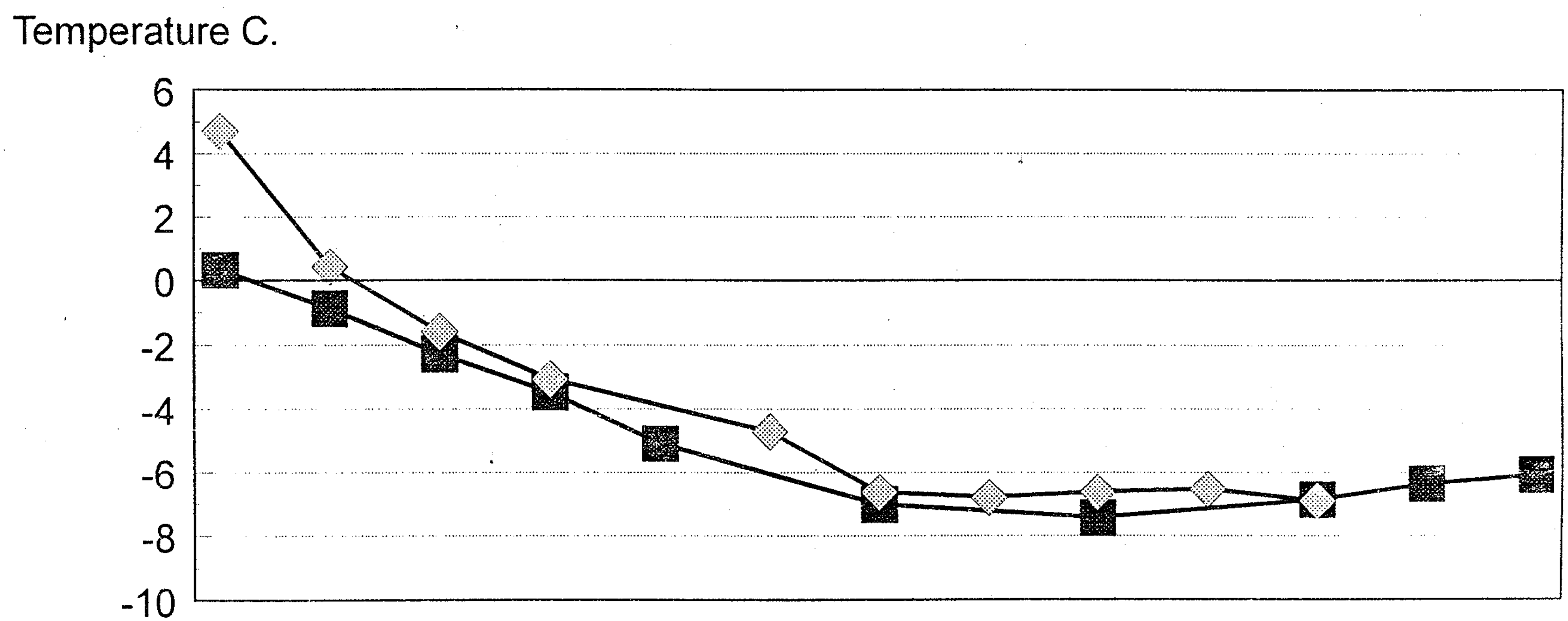


Depth m.	0.5	1.0	1.5	2.0	3.0	5.0	6.3	7.5	8.8	10.0
■	4.70	0.43	-1.59	-3.08	-4.71	-6.63	-6.80	-6.08	-6.54	-6.91

Measurements of 20 July 1991

Figure 245

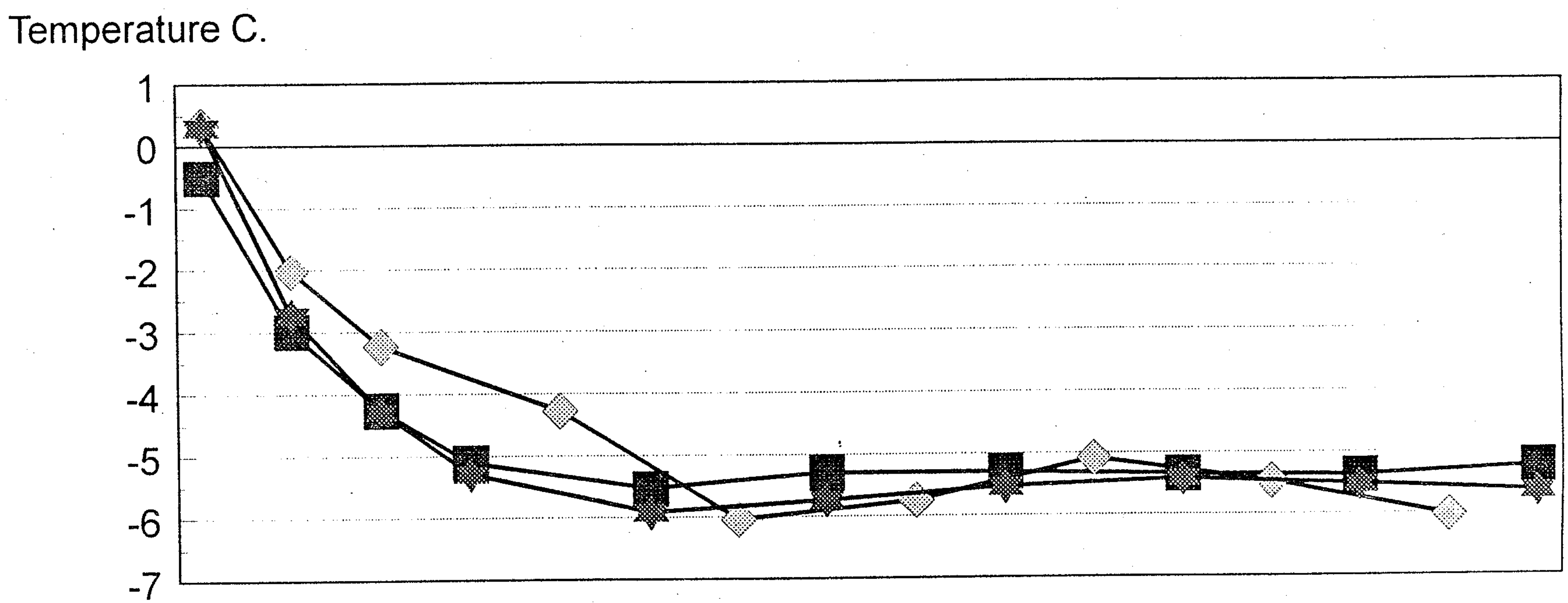
Yamal Interfluve Terrace - sandy soil



Depth m.	0.5	1.0	1.5	2.0	2.5	3.0	5.0	6.3	7.5	8.8	10.0	12.5	15.0
11K ■	0.34	-0.87	-2.28	-3.48	-5.09		-7.02		-7.44		-6.86	-6.36	-6.08
34 ◇	4.70	0.43	-1.59	-3.08		-4.71	-6.63	-6.80	-6.63	-6.54	-6.91		

Figure 246

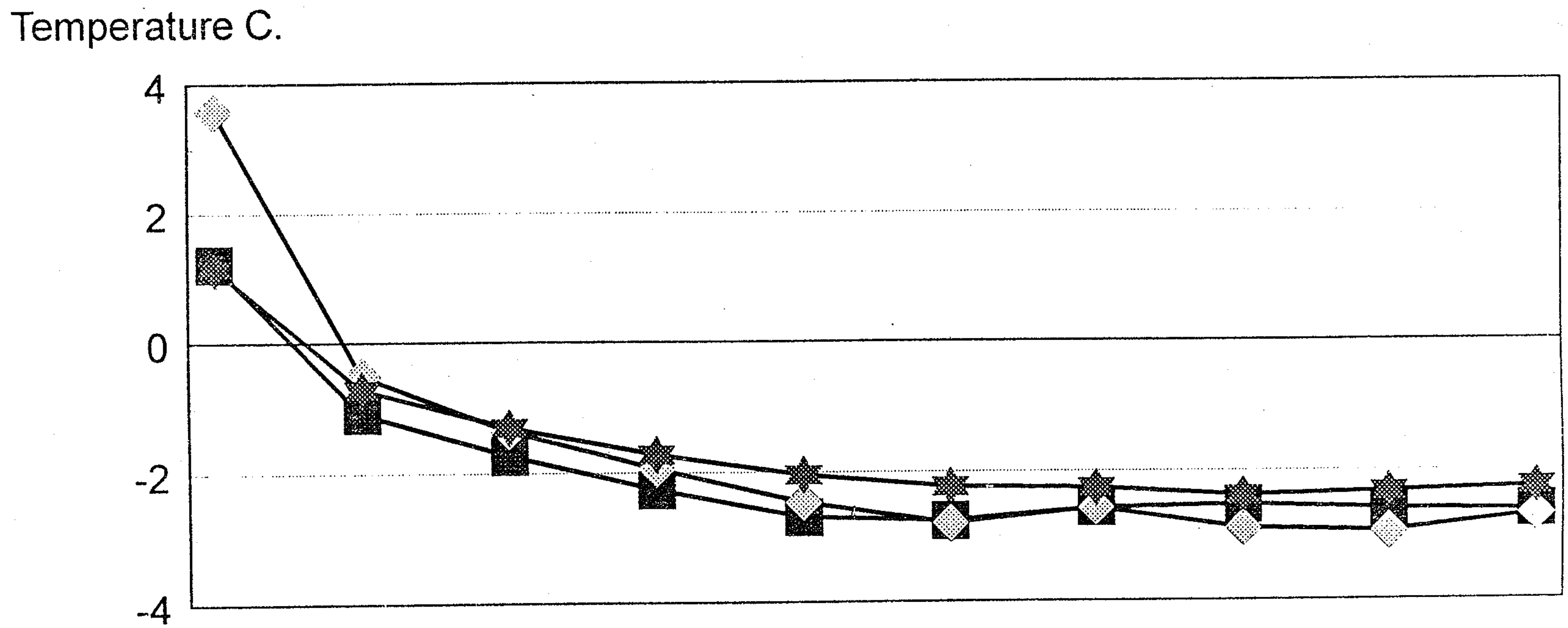
Yamal Interfluve Terrace - clayey soil



Depth m.	0.5	1.0	1.5	2.0	2.5	3.0	4.5	5.0	5.8	6.3	7.0	7.5	8.3	8.8	9.5	10.0
2K ■	-0.51	-3.00	-4.26	-5.11		-5.54		-5.29		-5.30		-5.35		-5.38		-5.24
4K ◇	0.34	-2.03	-3.24		-4.28		-6.04		-5.75		-5.09		-5.47		-6.03	
10K ✸	0.30	-2.75	-4.28	-5.29		-5.92		-5.74		-5.54		-5.42		-5.52		-5.64

Figure 347

Yamal Floodplain



Depth m.	0.5	1.0	1.5	2.0	3.0	5.0	6.3	7.5	8.8	10.0
3K ■	1.22	-1.09	-1.74	-2.27	-2.70	-2.76	-2.57	-2.53	-2.59	-2.62
7K ◆	3.58	-0.51	-1.36	-1.94	-2.47	-2.80	-2.57	-2.89	-2.95	-2.69
8K ✱	1.15	-0.72	-1.31	-1.73	-2.05	-2.24	-2.27	-2.39	-2.33	-2.26

Figure 248

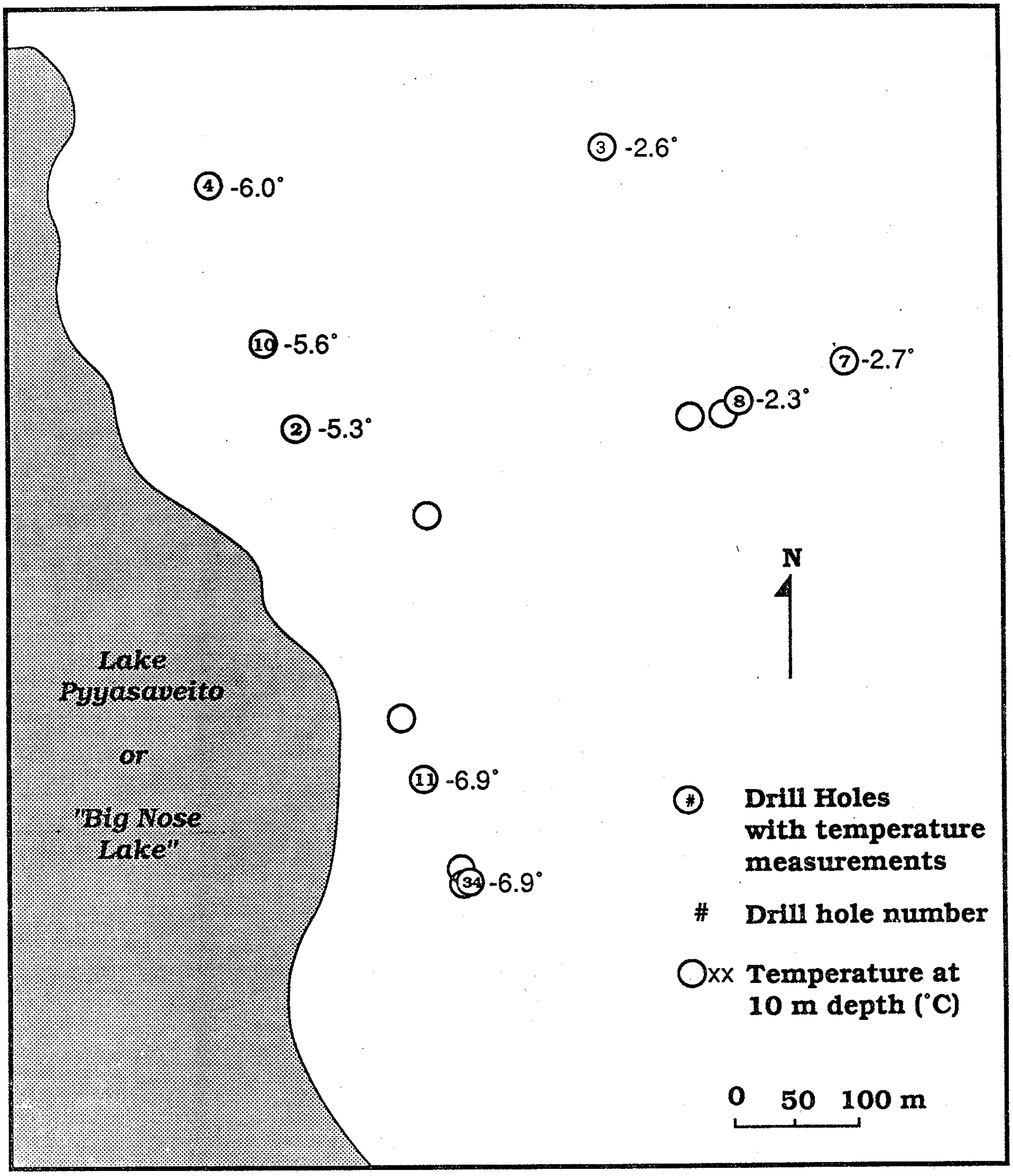
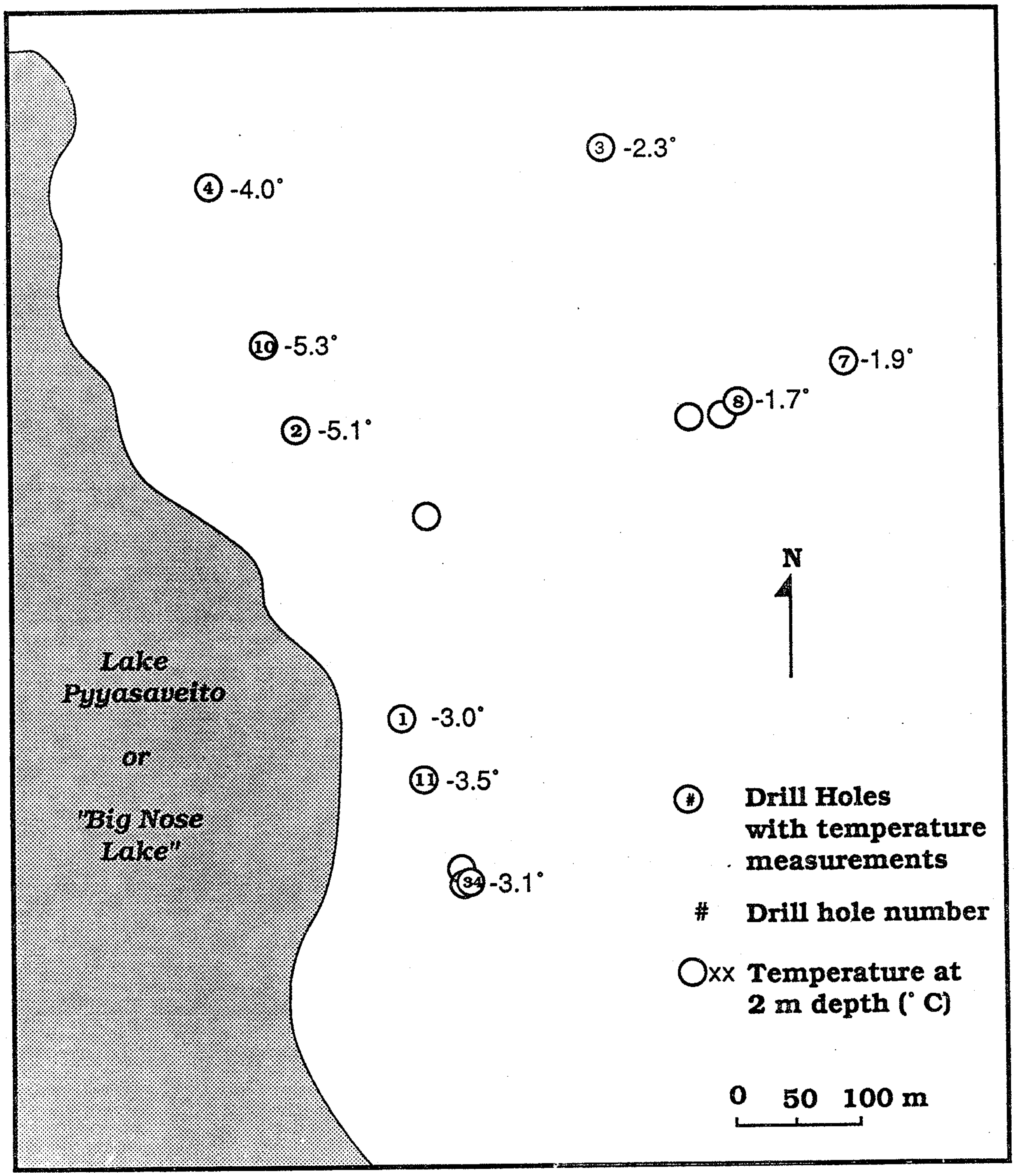
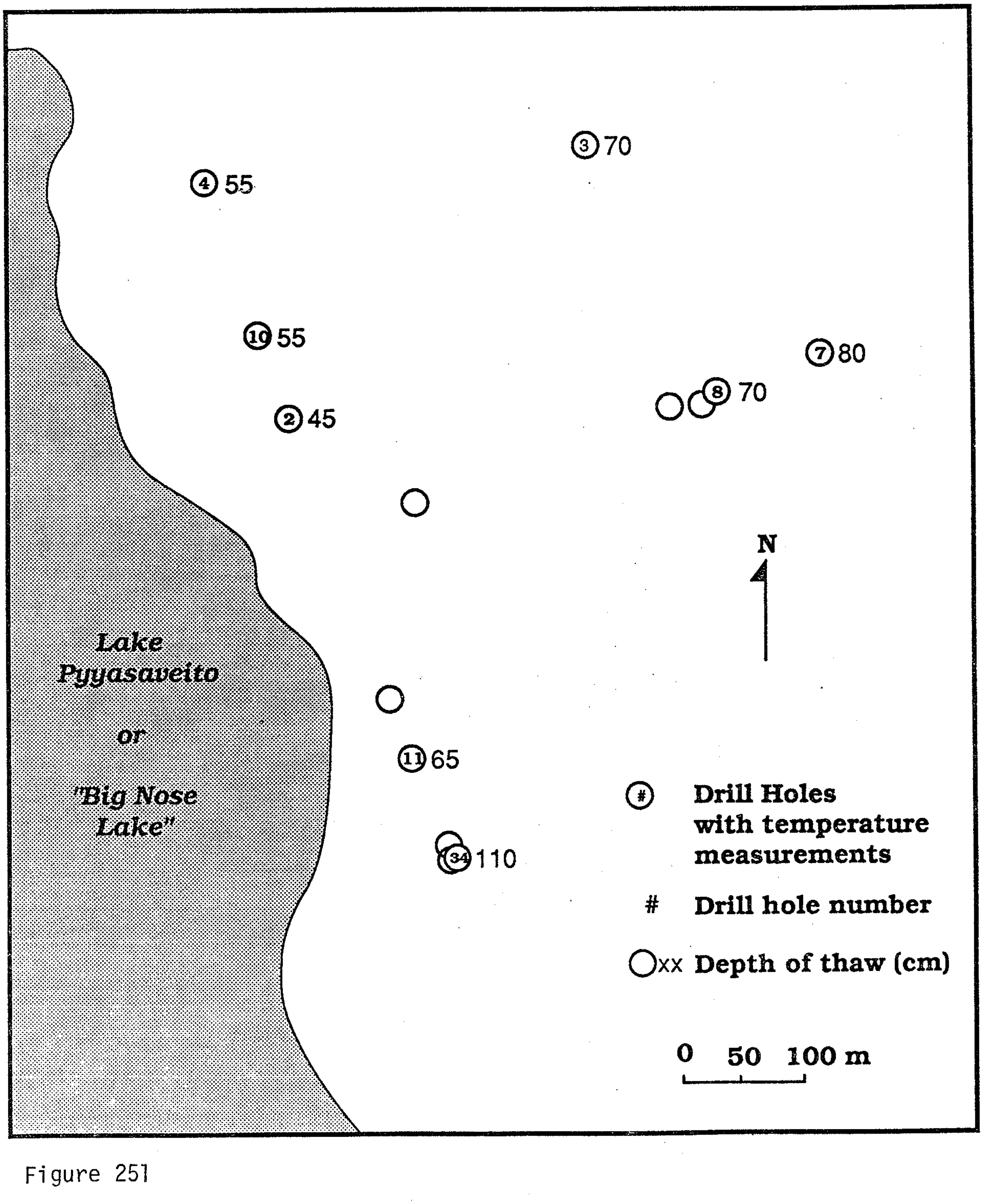

3 -2.6°
4 -6.0°
10 -5.6°
7 -2.7°
8 -2.3°
2 -5.3°
N
Lake Pyyasaveito or "Big Nose Lake"
11 -6.9°
34 -6.9°
Drill Holes with temperature measurements
Drill hole number
xx Temperature at 10 m depth (°C)
0 50 100 m

Figure 249



③ -2.3°
④ -4.0°
⑩ -5.3°
⑦ -1.9°
⑧ -1.7°
② -5.1°
N
Lake
Pyyasaveito
or
"Big Nose
Lake"
① -3.0°
⑪ -3.5°
㉞ -3.1°
Drill Holes
with temperature
measurements
Drill hole number
xx Temperature at
2 m depth (° C)
0 50 100 m

Figure 250



3 70
4 55
10 55
7 80
8 70
2 45
N
Lake Pyyasaveito or "Big Nose Lake"
11 65
34 110
Drill Holes with temperature measurements
Drill hole number
xx Depth of thaw (cm)
0 50 100 m

Figure 251

Active Layer Development at Bovanenkovo Site

	clay terrace cm.	sand terrace cm.	floodplain cm.
Borehole 2K	45		
Borehole 4K	55		
Borehole 10K	55		
Borehole 11K		65	
Borehole 34		110	
Borehole 3K			70
Borehole 7K			80
Borehole 8K			70

Measurements between 17 and 22 July 1991

- Active layer thickness ranged from 45 to 110 cm.
- Thickness least on clay terrace [45 to 55 cm.]
- Similar thickness on sand terrace and on floodplain [65 to 110 cm.]

Figure 252

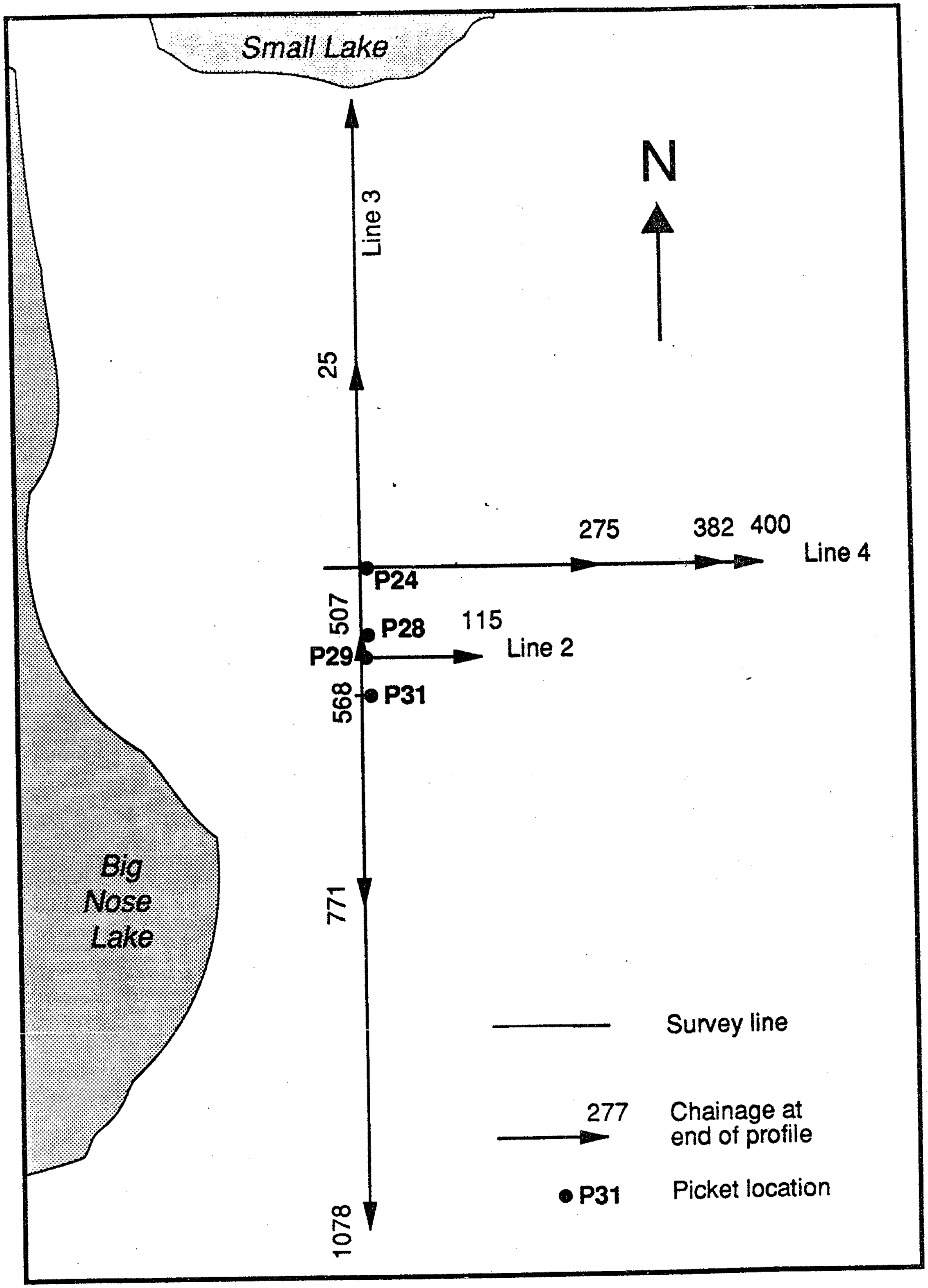

Small Lake
N
Line 3
25
275
382
400
Line 4
P24
507
P28
115
Line 2
P29
568
P31
Big Nose Lake
771
Survey line
277
Chainage at end of profile
P31
Picket location
1078

Figure 253

GROUND PROBING RADAR – LINE 2

Fig. 254

Picket Number 29

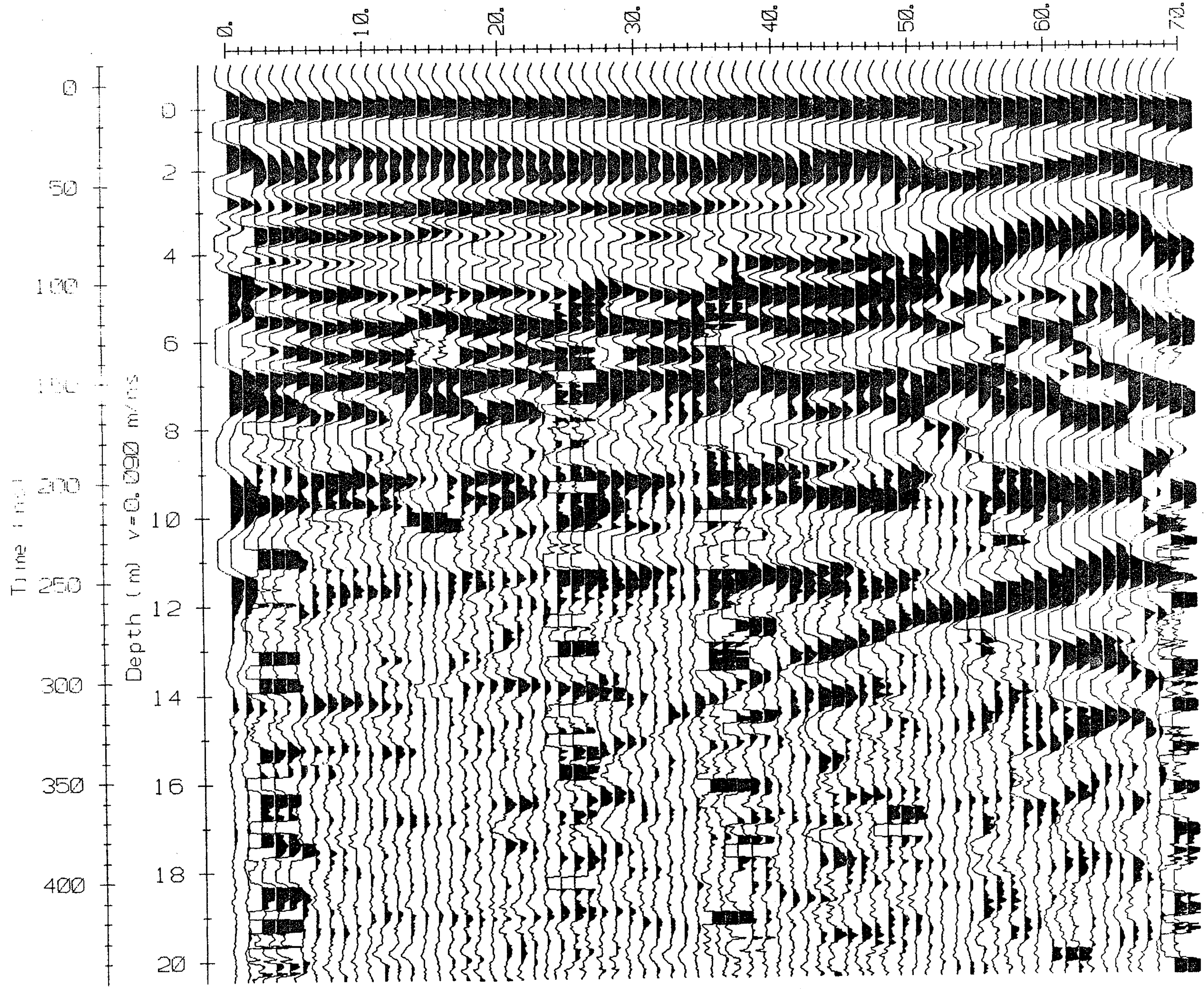


Figure 254

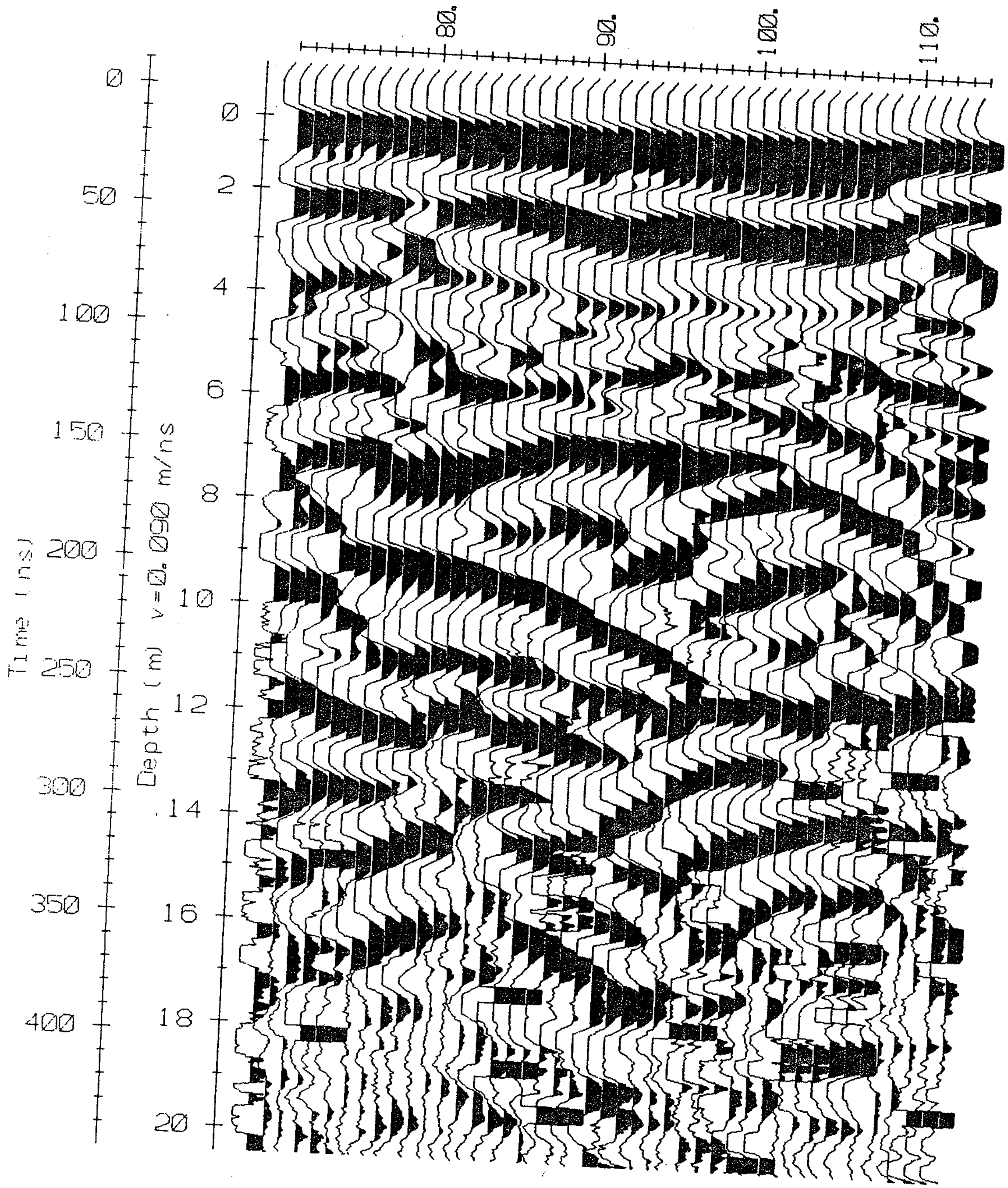


Figure 254 cont.

GROUND PROBING RADAR – LINE 3

Fig. 255

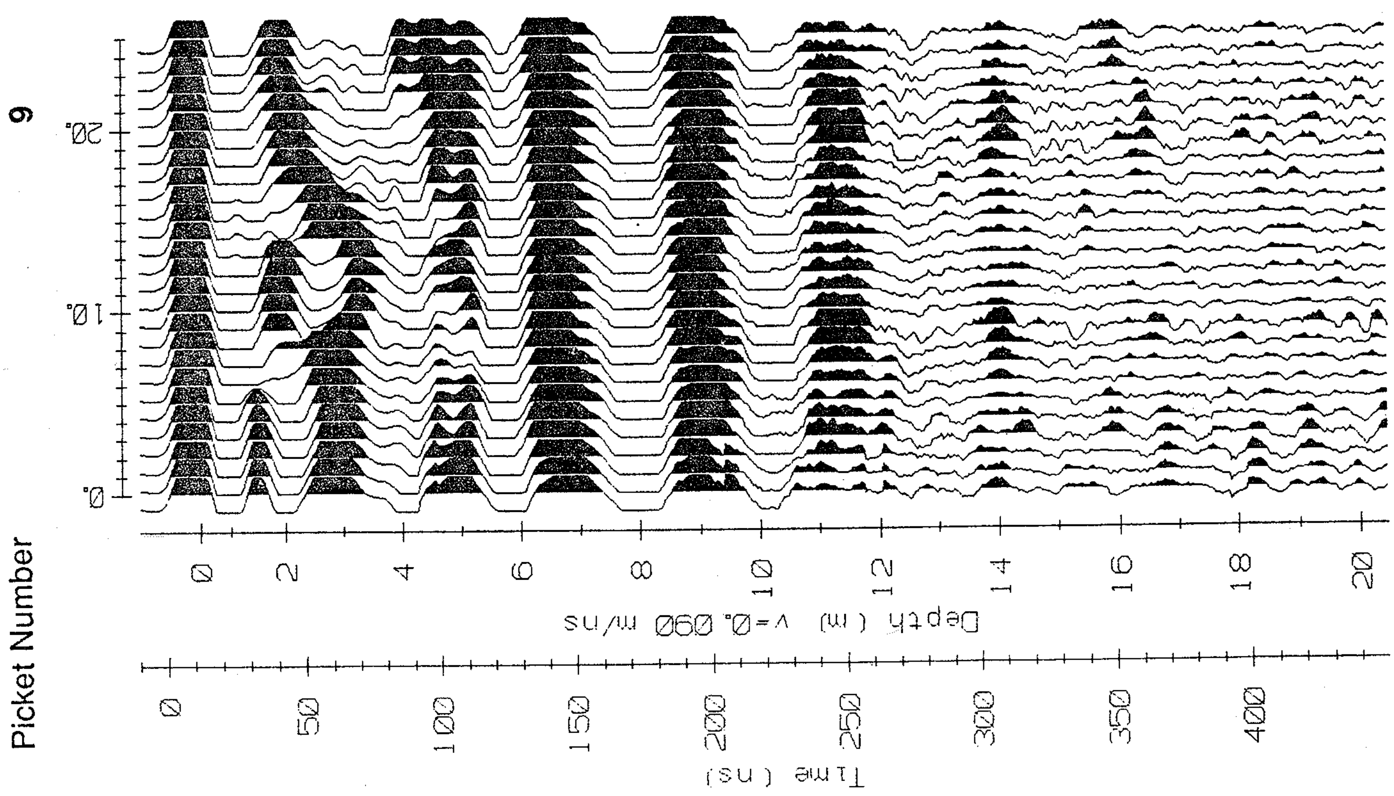

Picket Number
9
0.
10.
20.
Depth (m) v=0.090 m/ns
0
2
4
6
8
10
12
14
16
18
20
Time (ns)
0
50
100
150
200
250
300
350
400

Figure 255

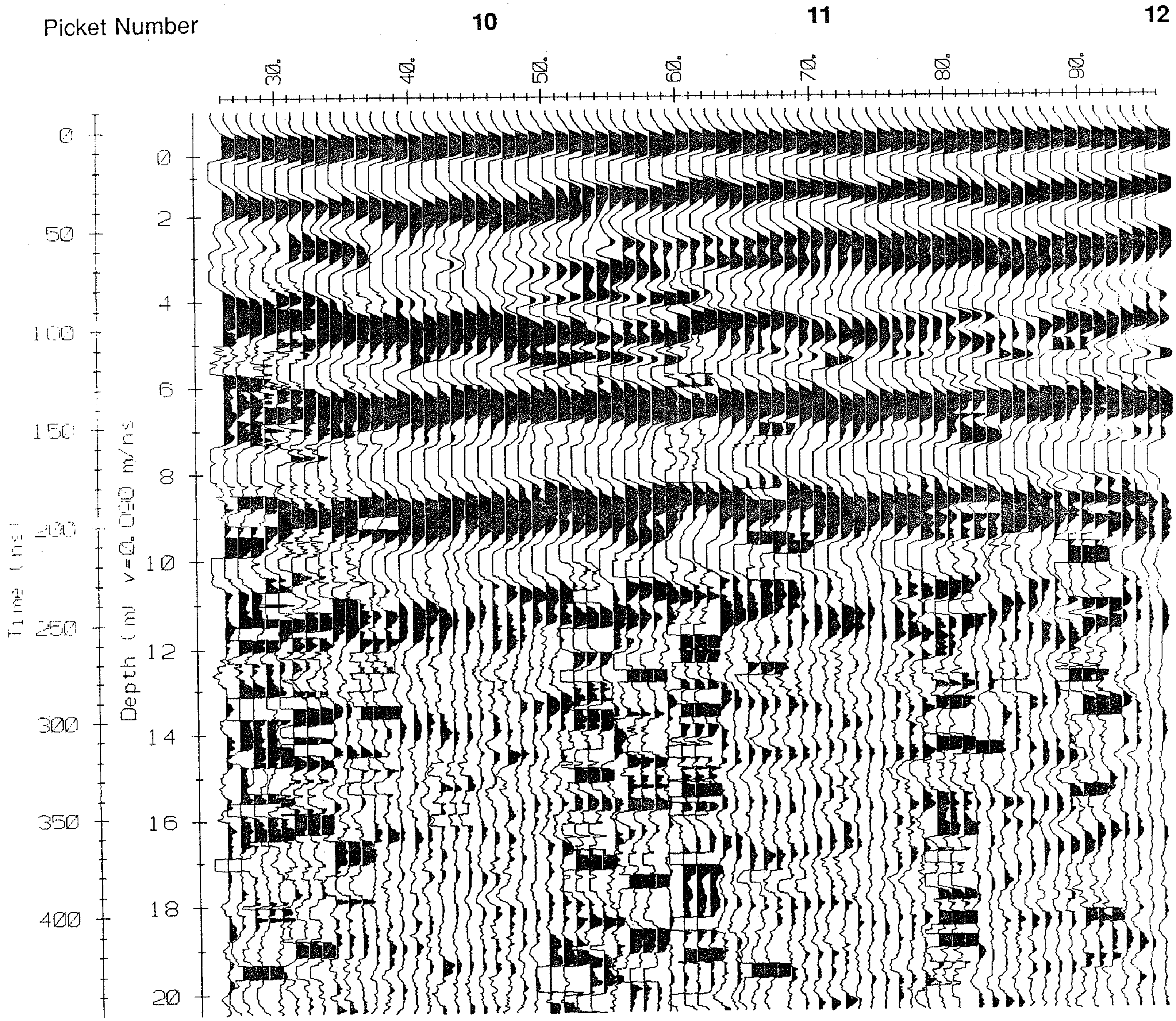


Figure 255 cont.

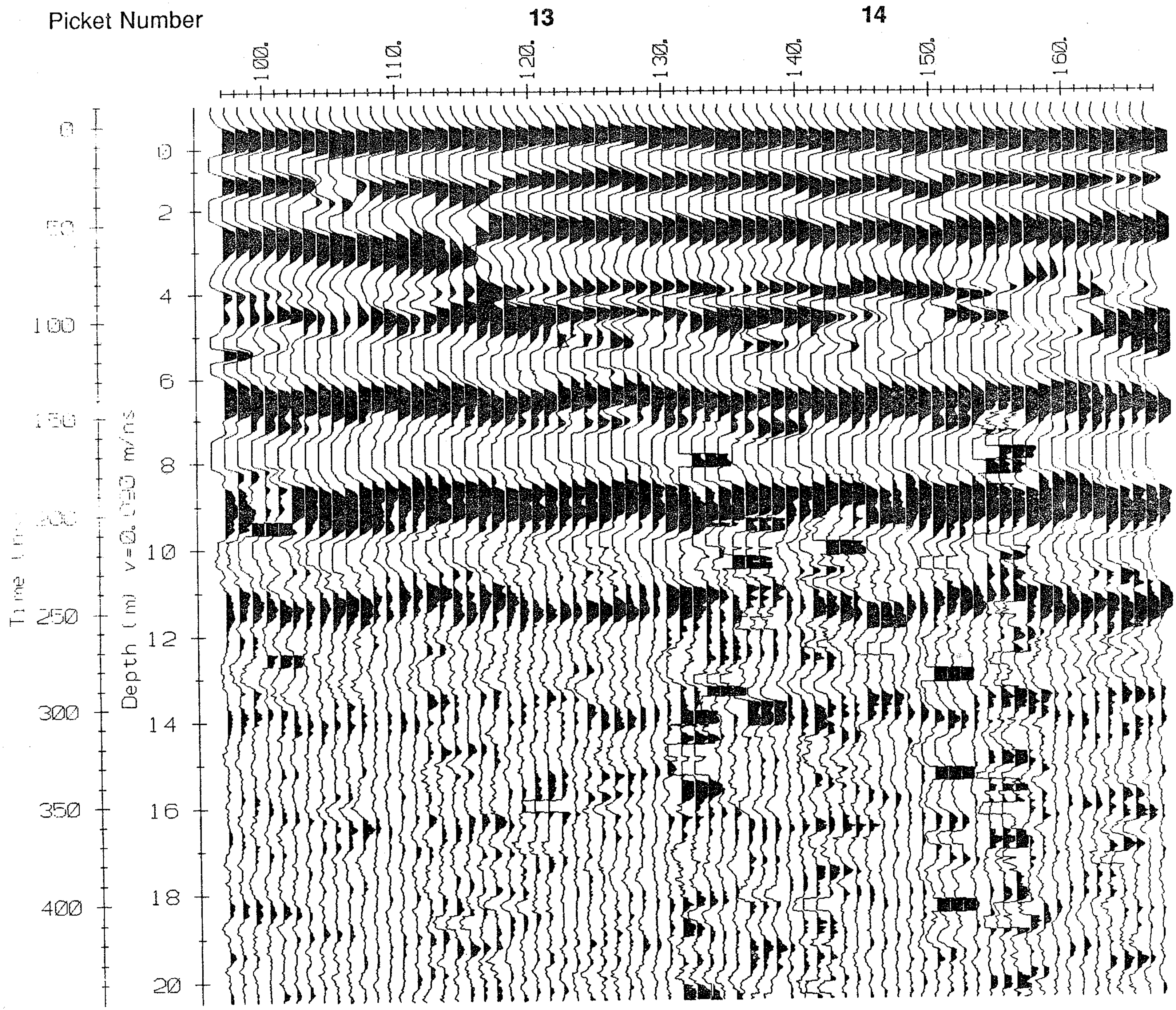


Figure 255 cont.

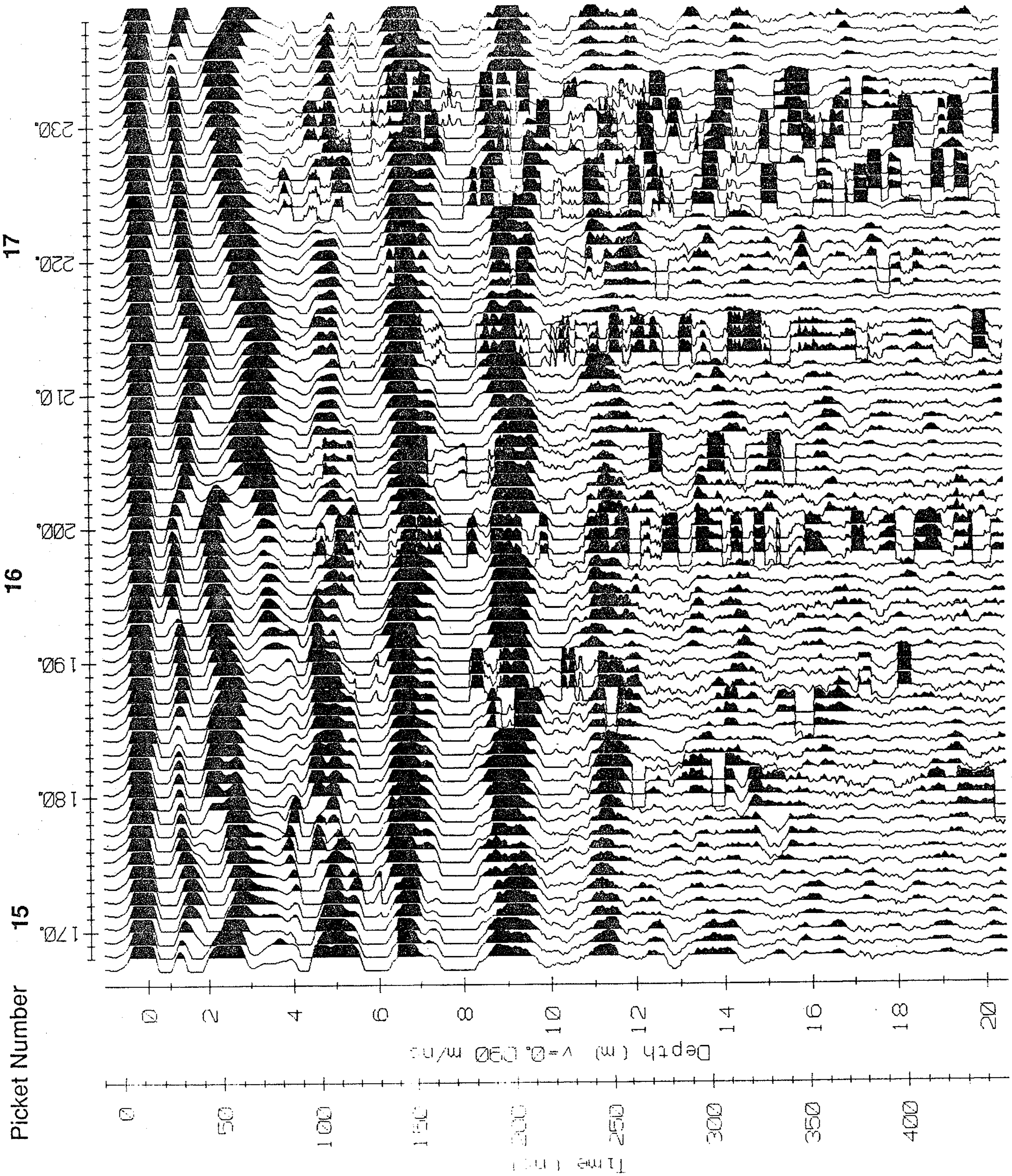


Figure 255 cont.

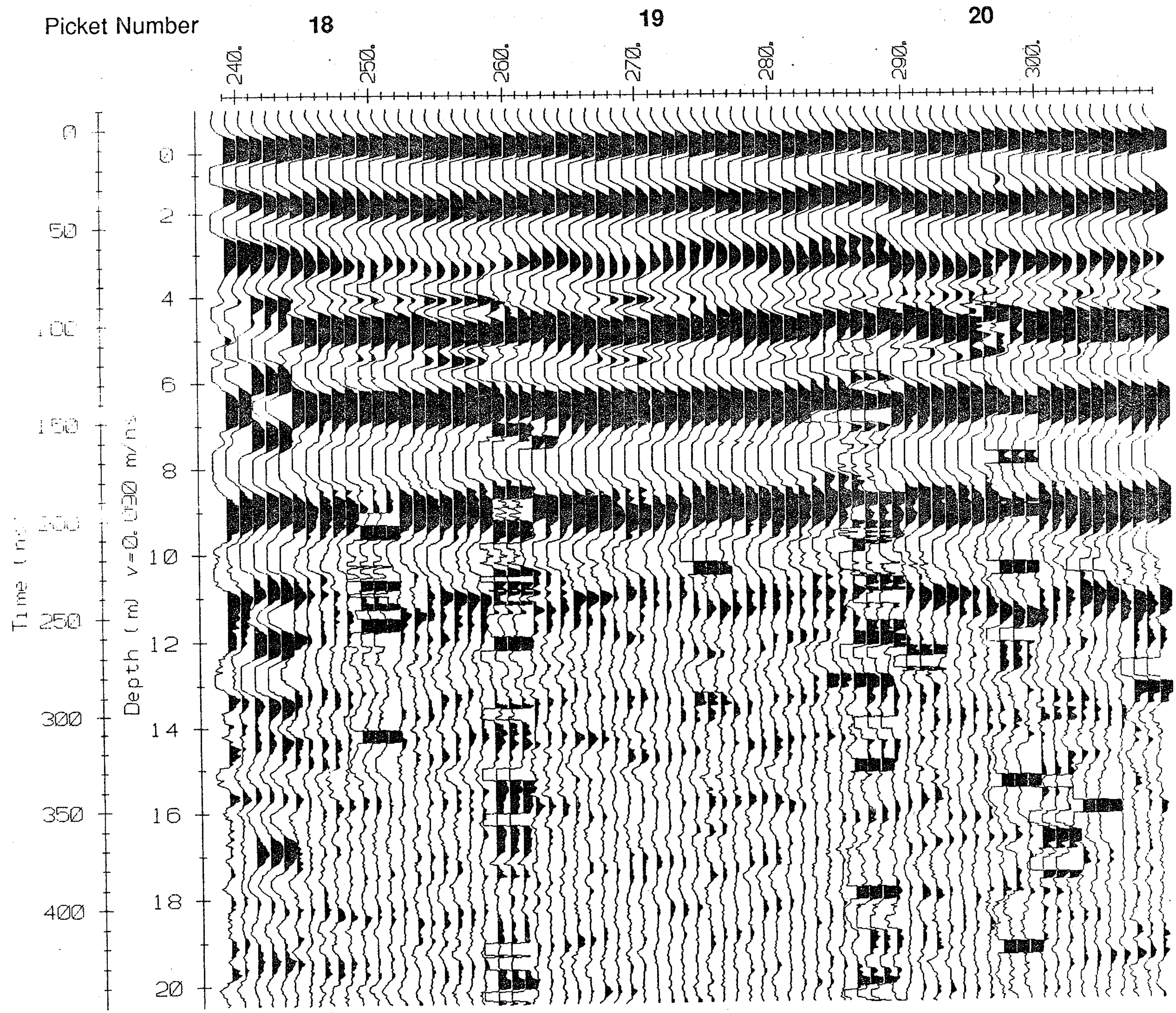


Figure 255 cont.

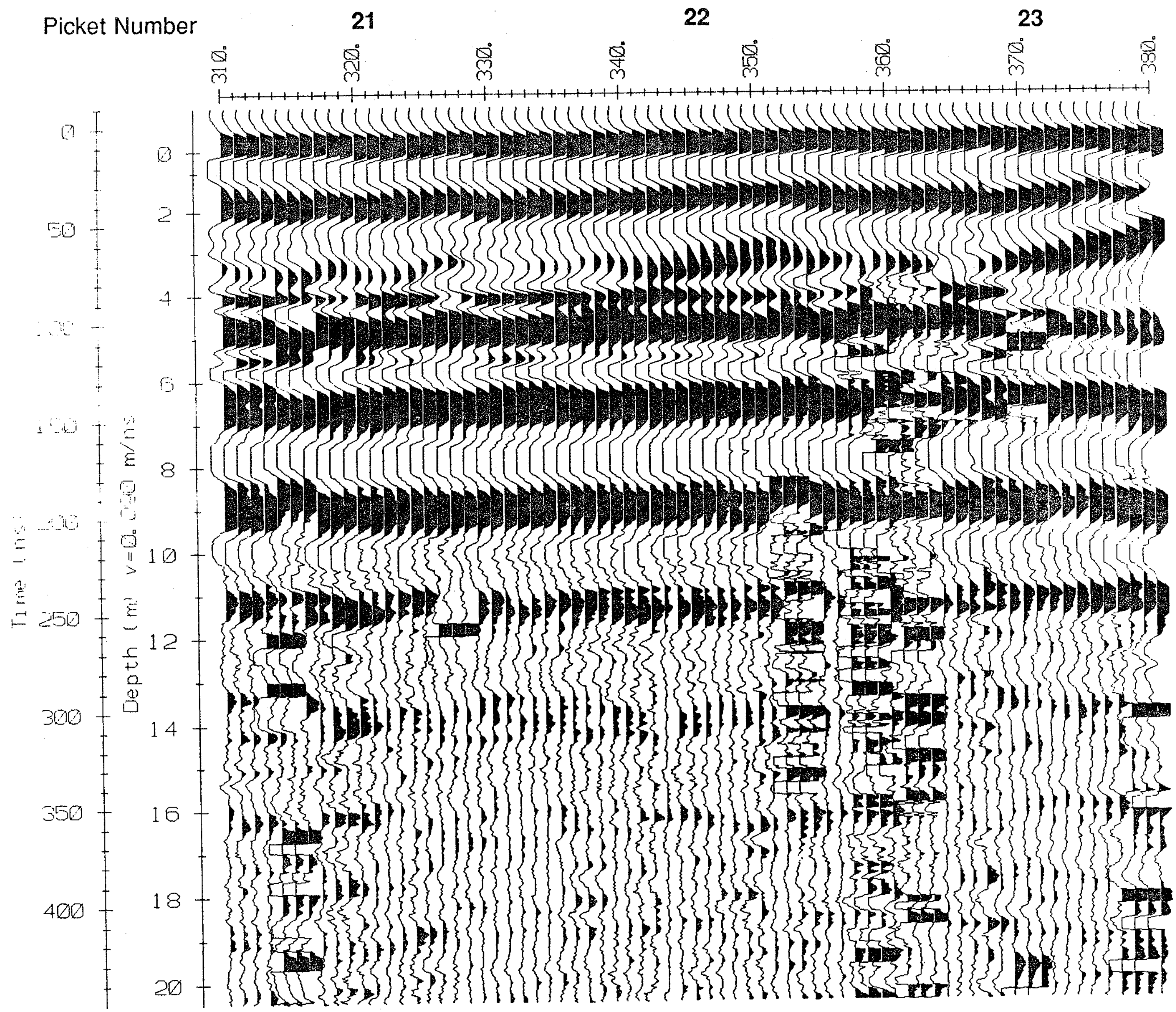


Figure 255 cont.

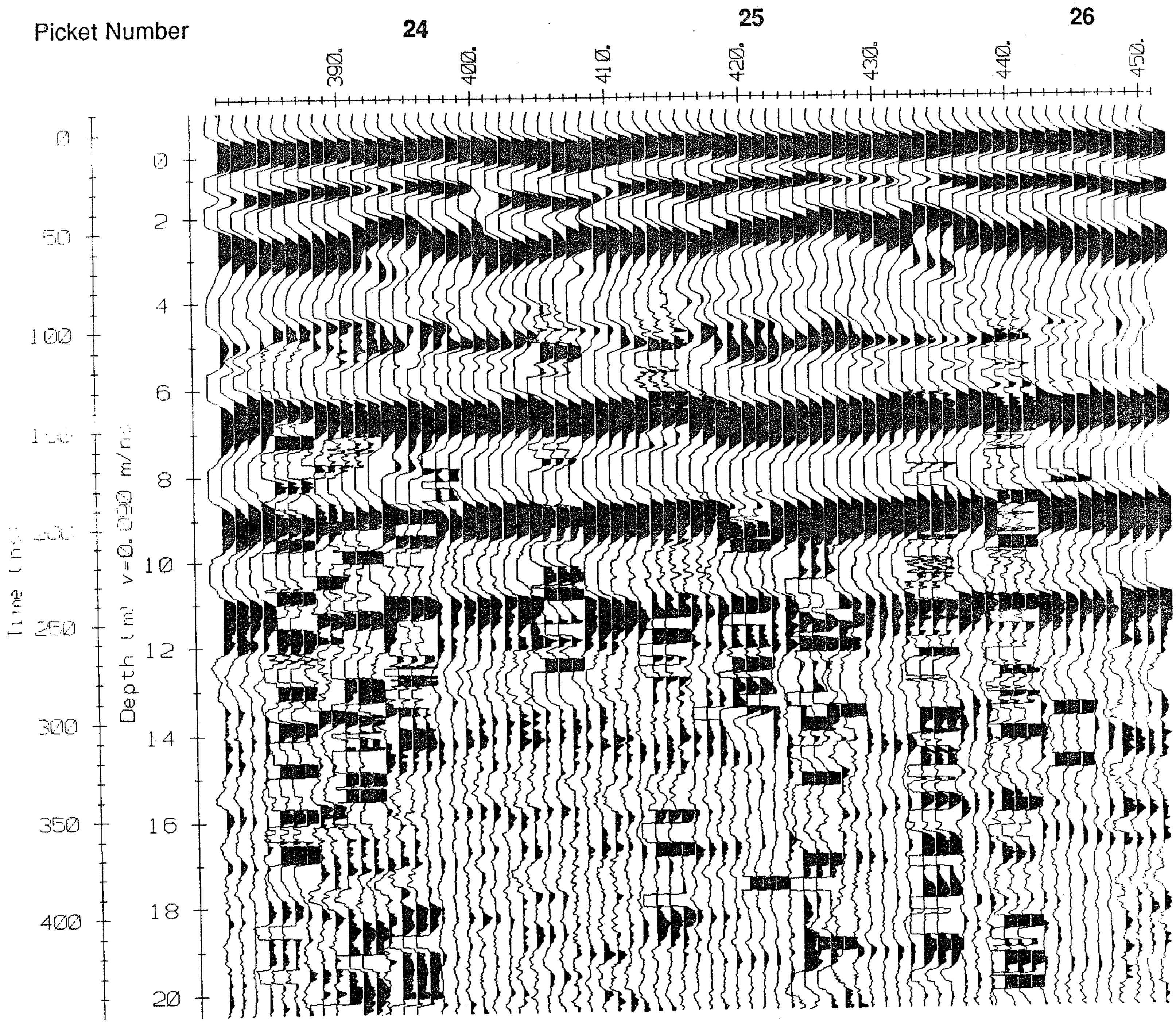


Figure 255 cont.

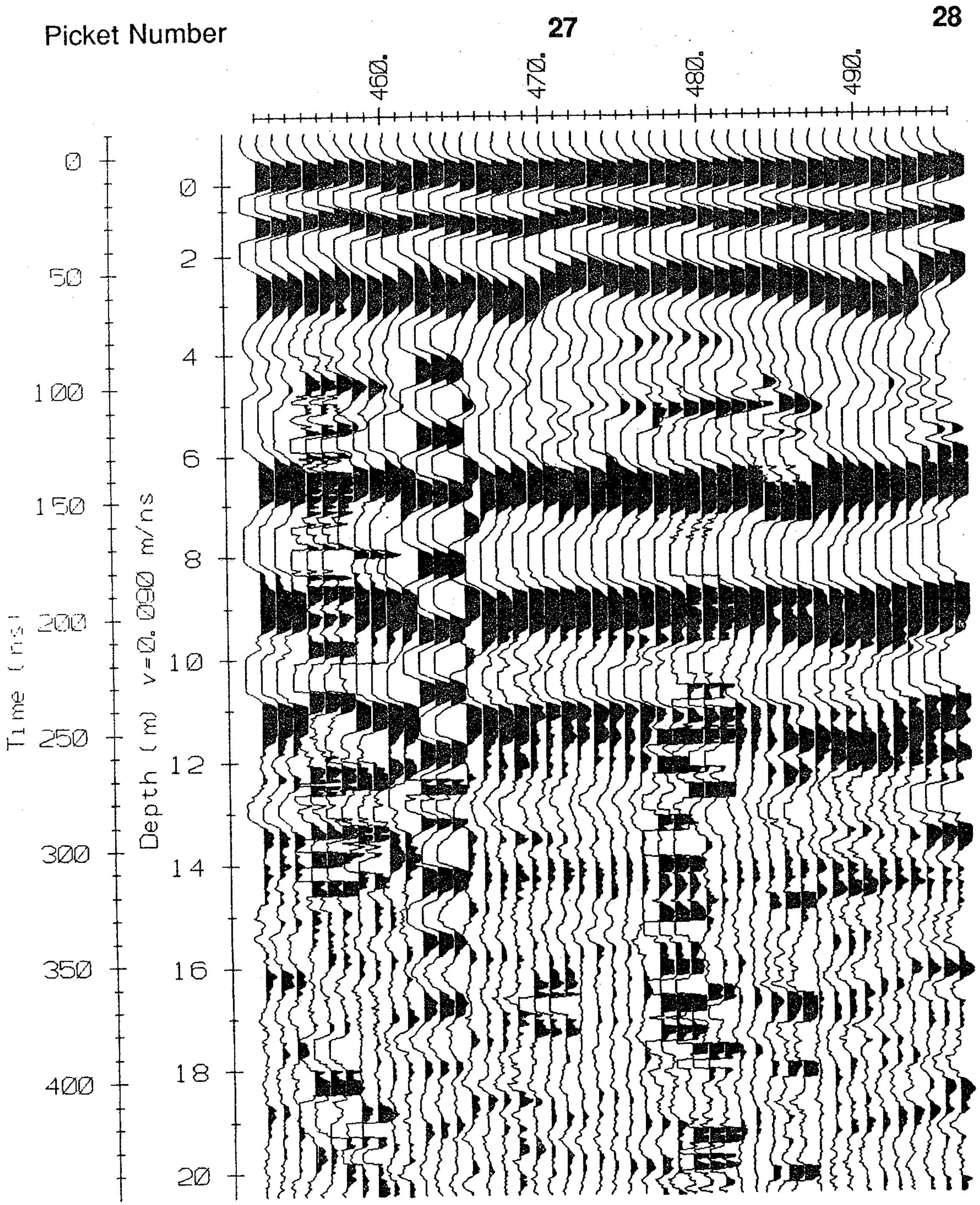


Figure 255 cont.

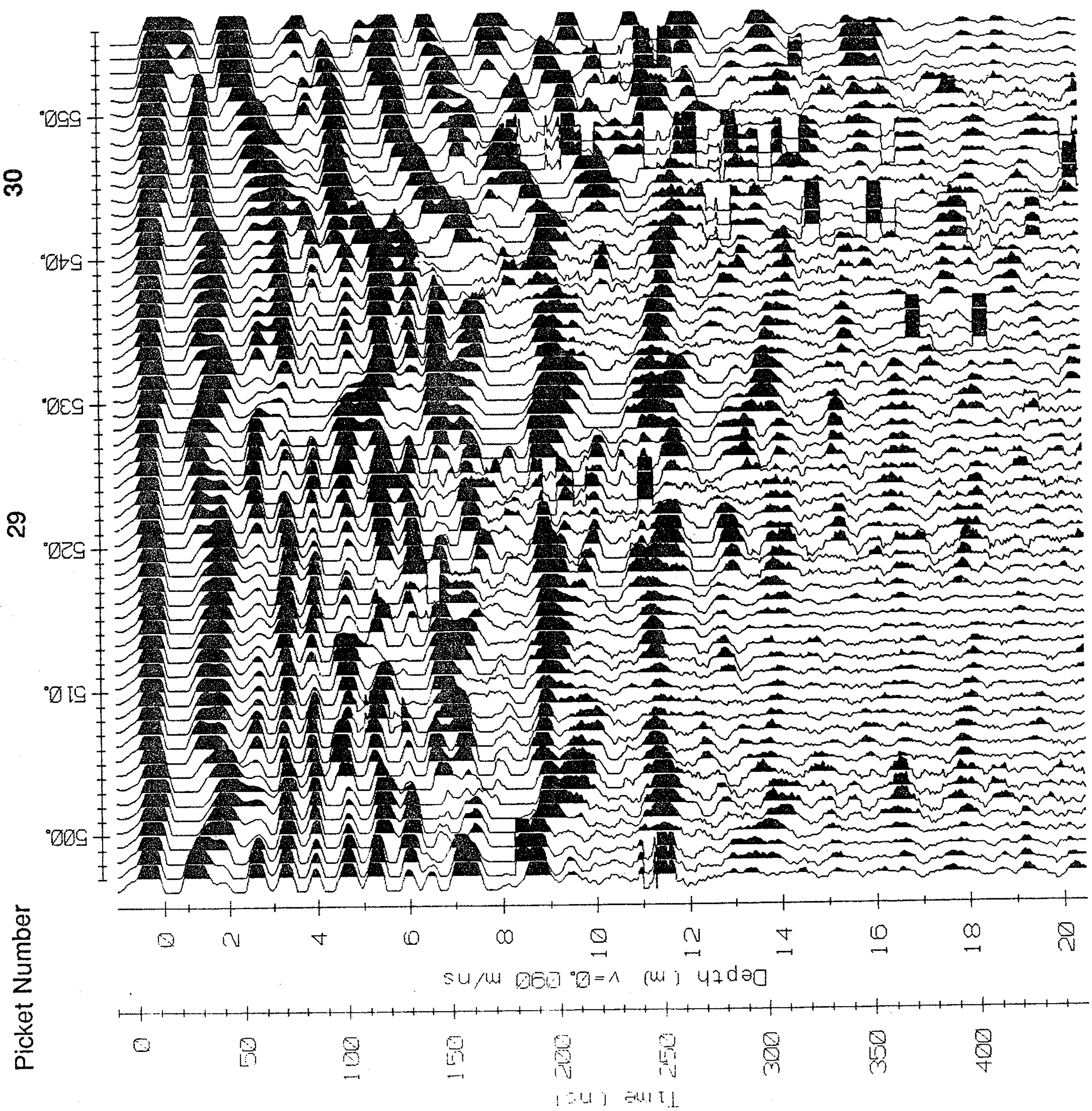


Figure 255 cont.

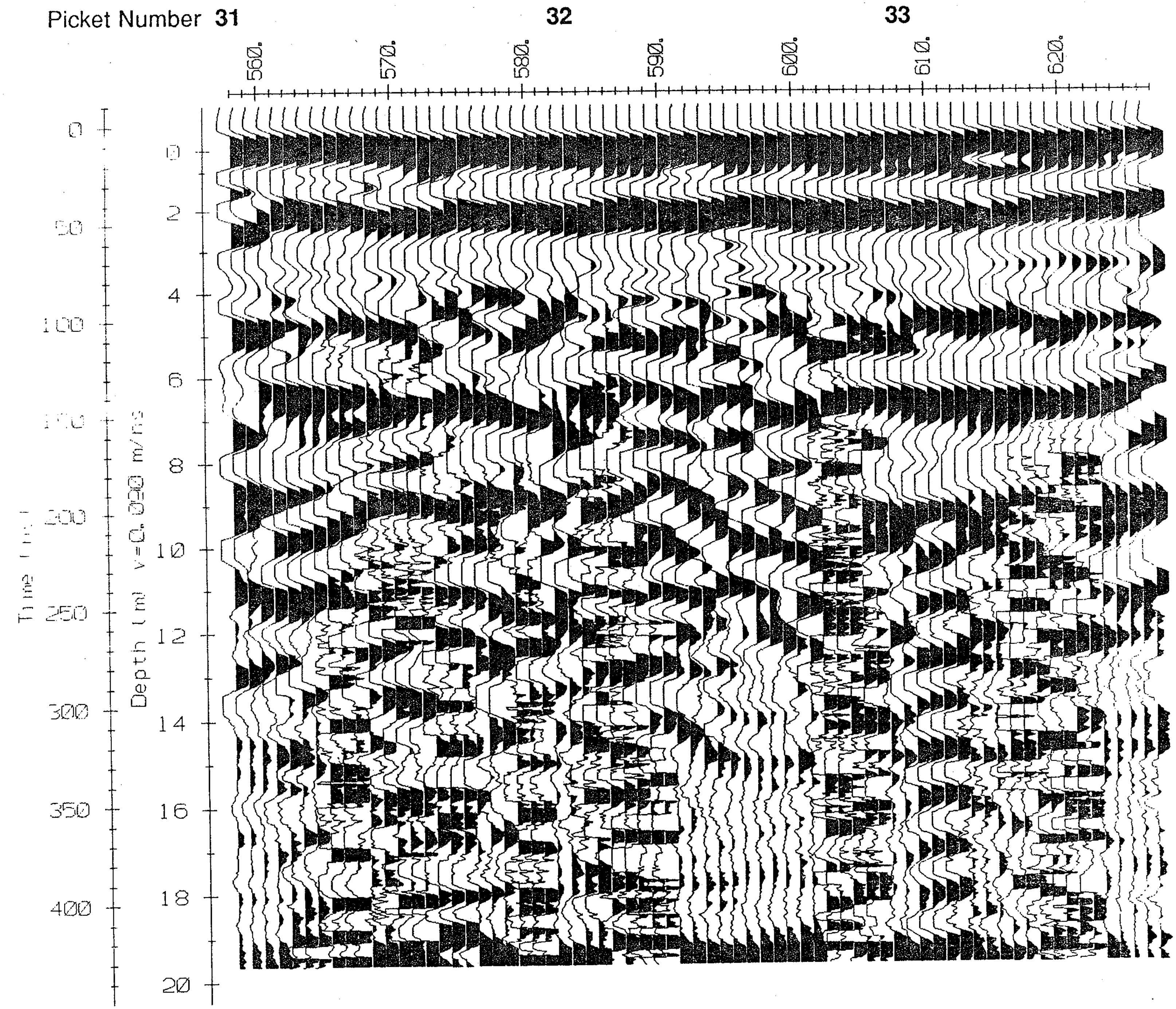


Figure 255 cont.

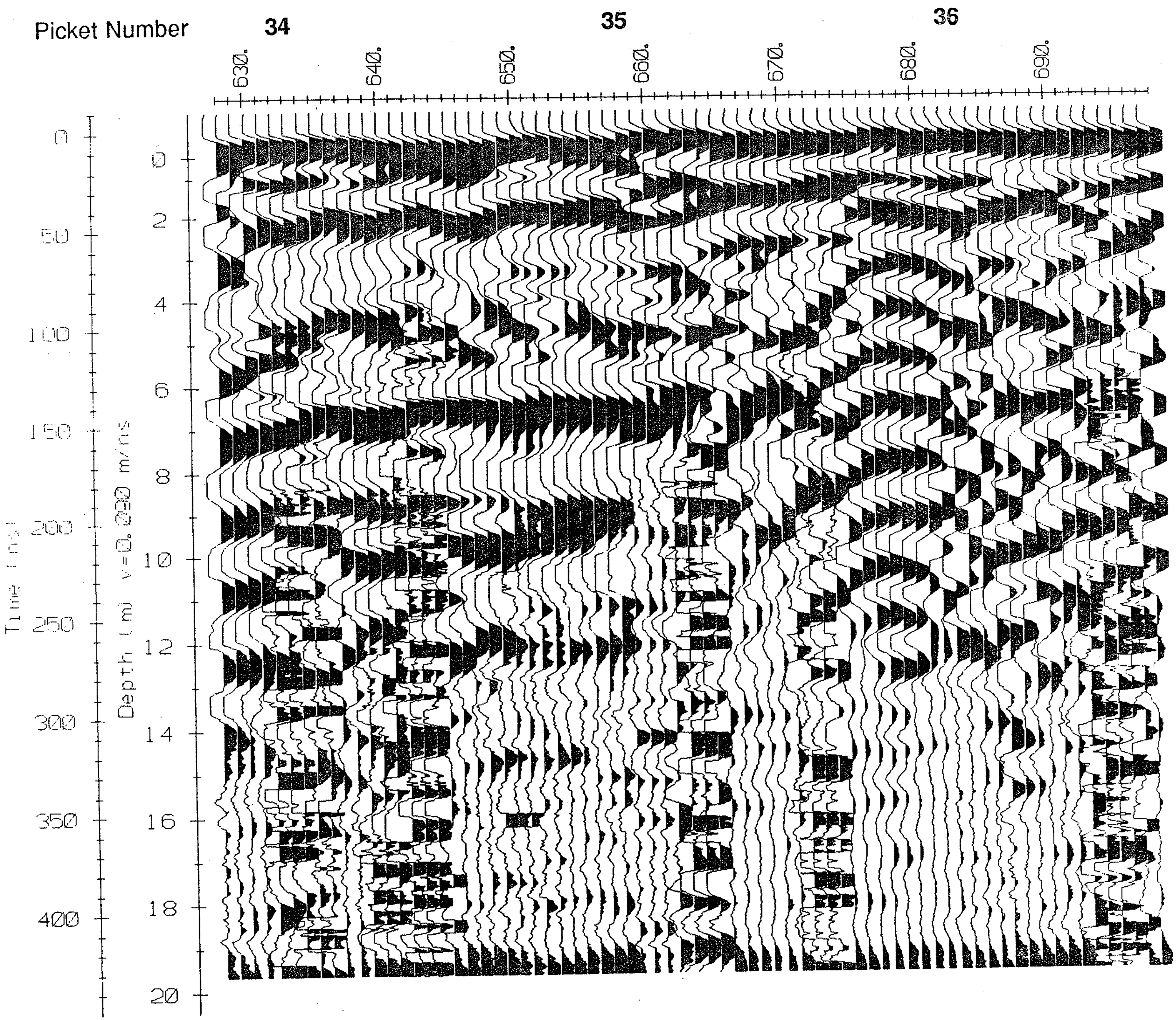


Figure 255 cont.

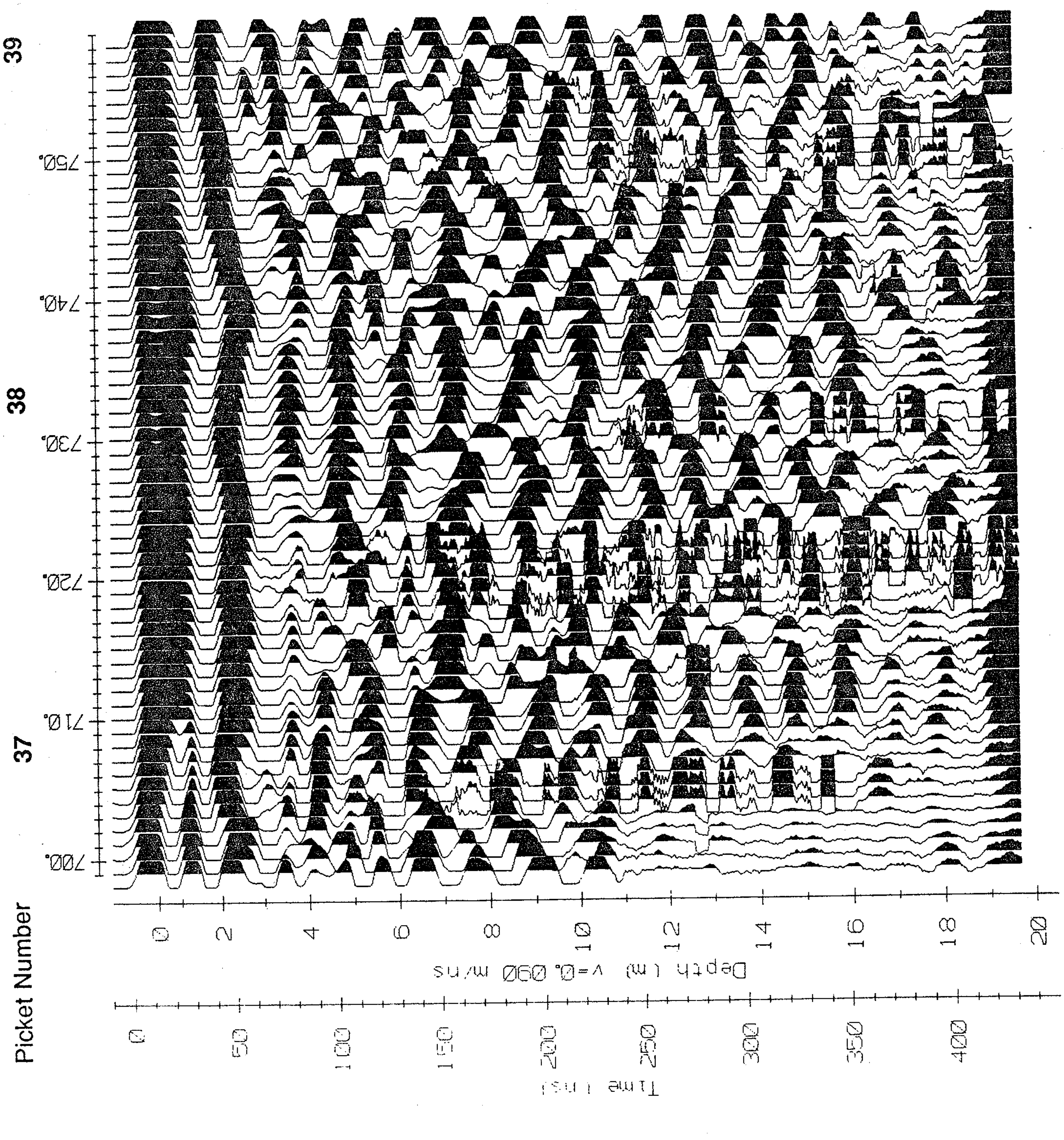


Figure 255 cont.

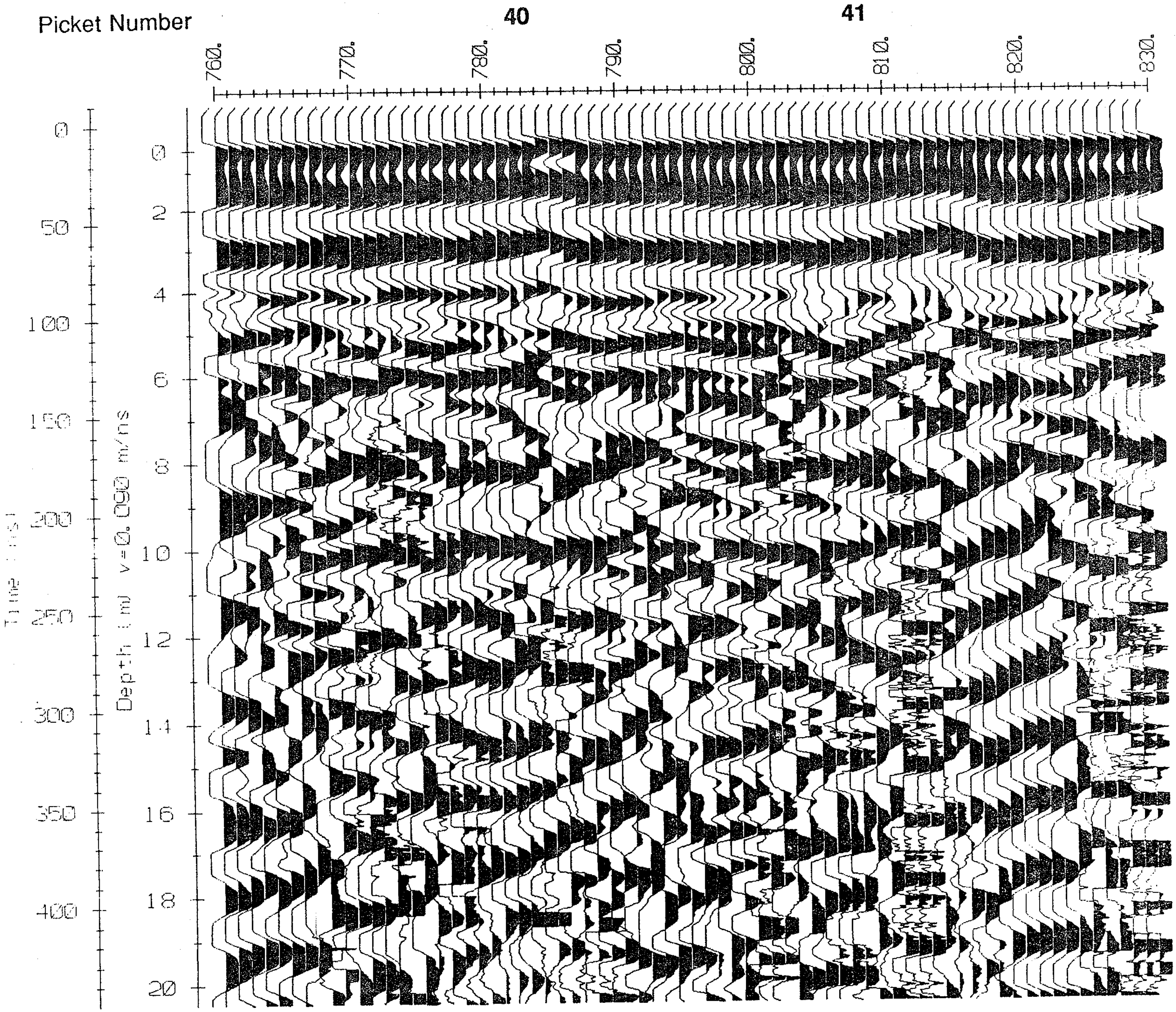


Figure 255 cont.

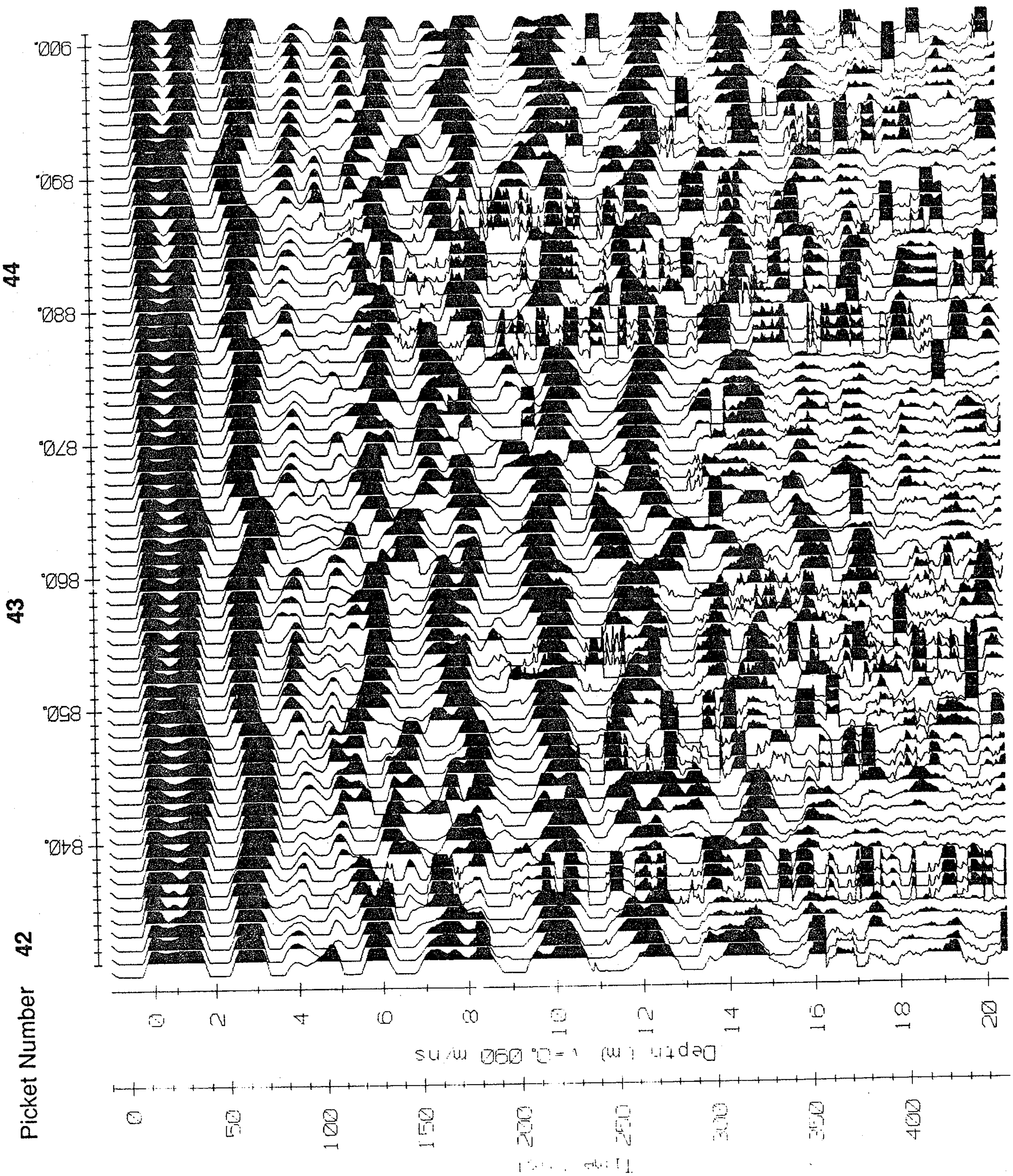


Figure 255 cont.

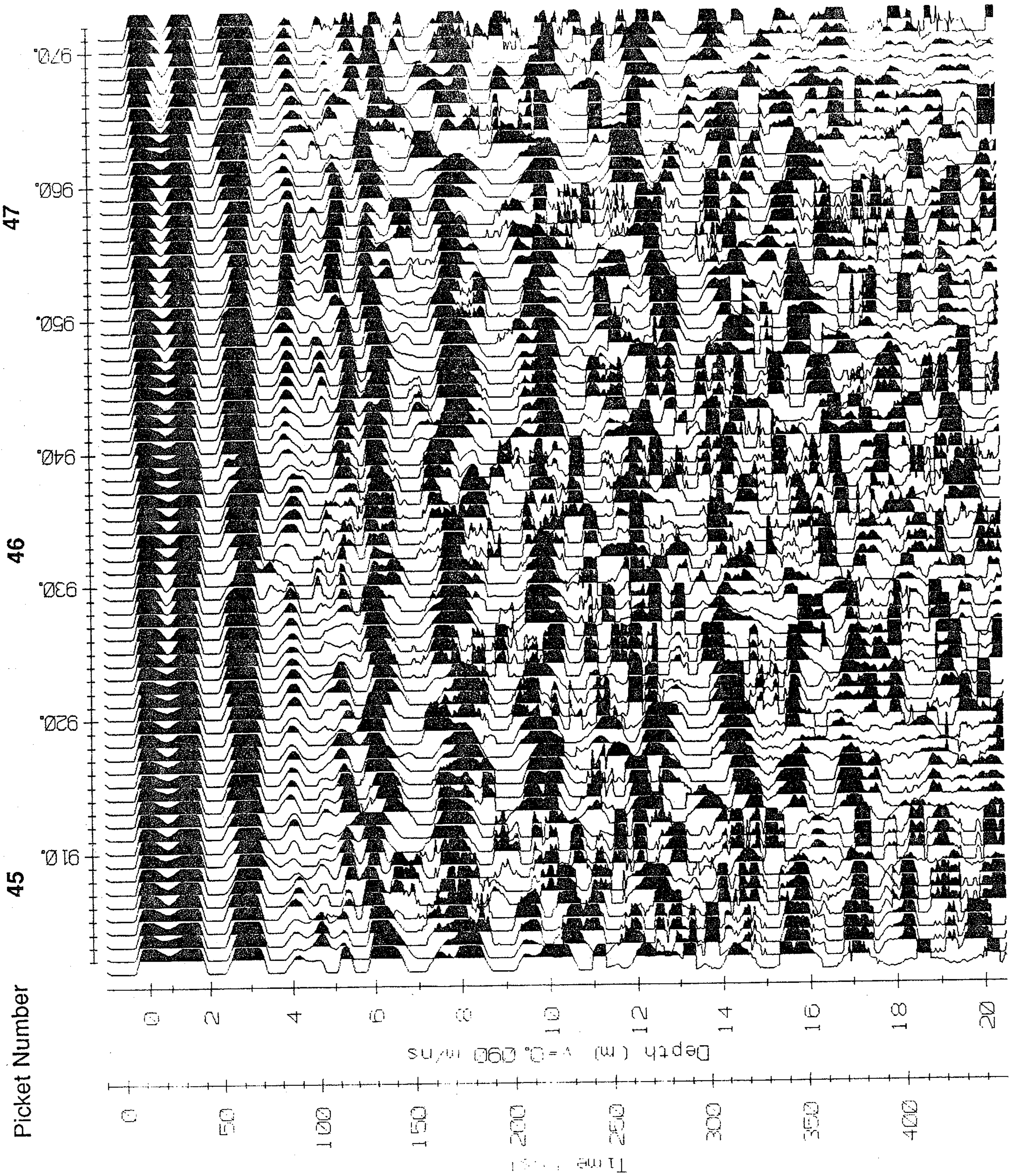


Figure 255 cont.

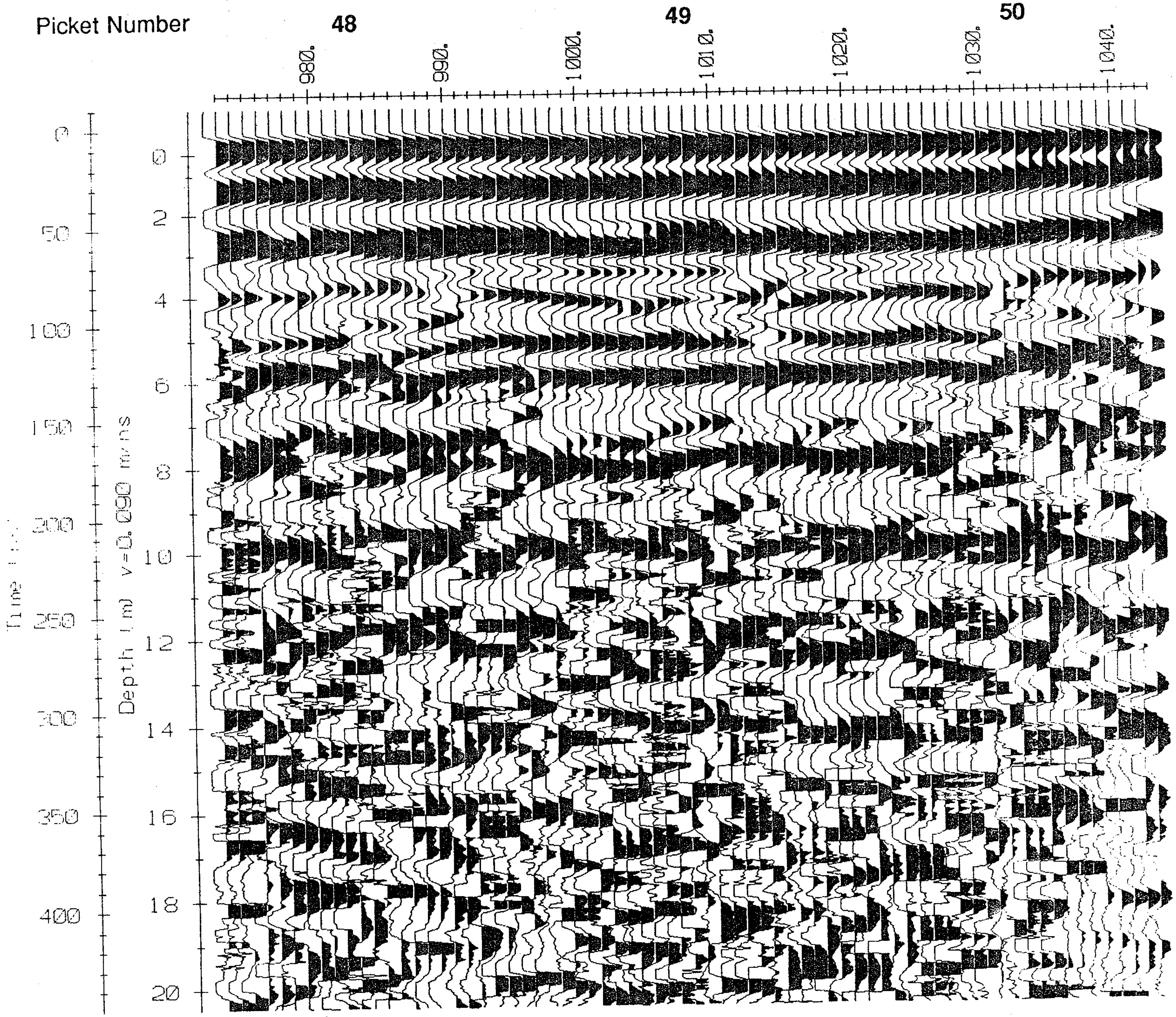


Figure 255 cont.

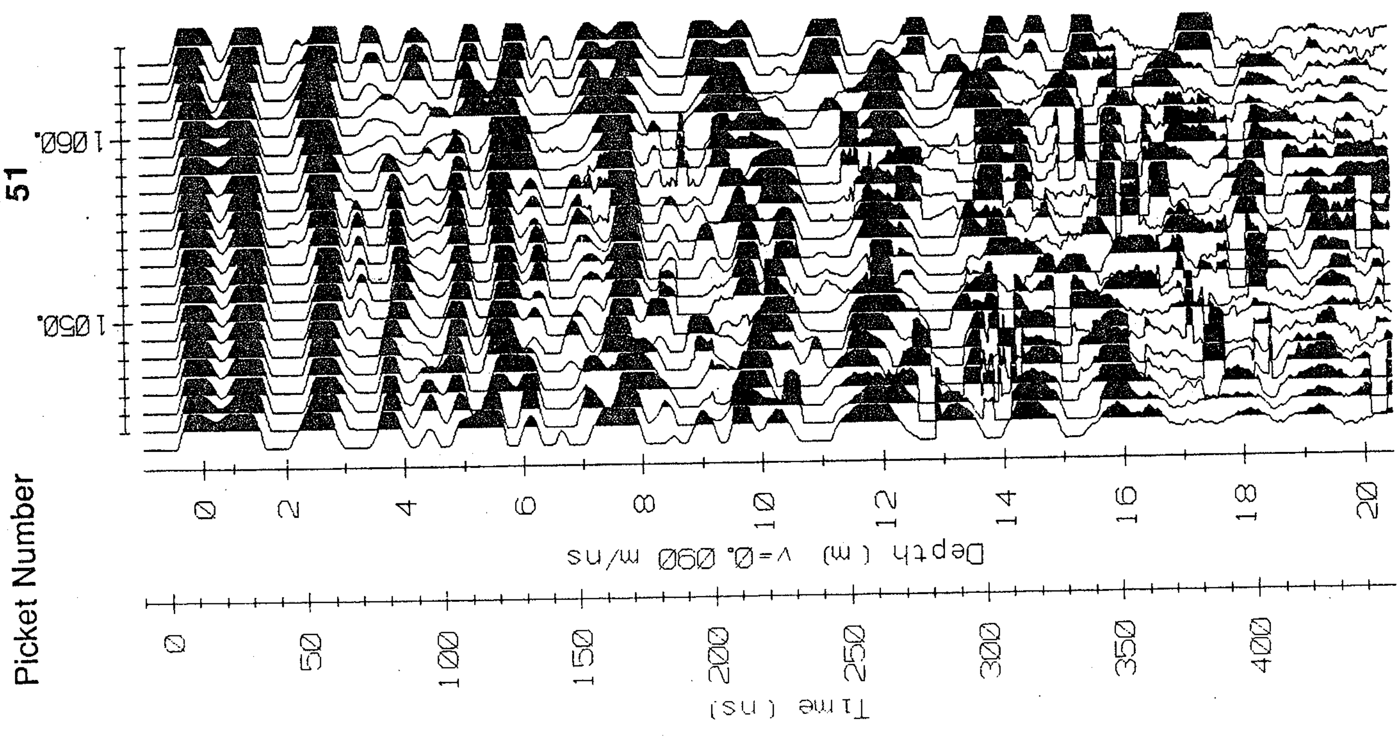


Figure 255 cont.

GROUND PROBING RADAR – LINE 4

Fig. 256

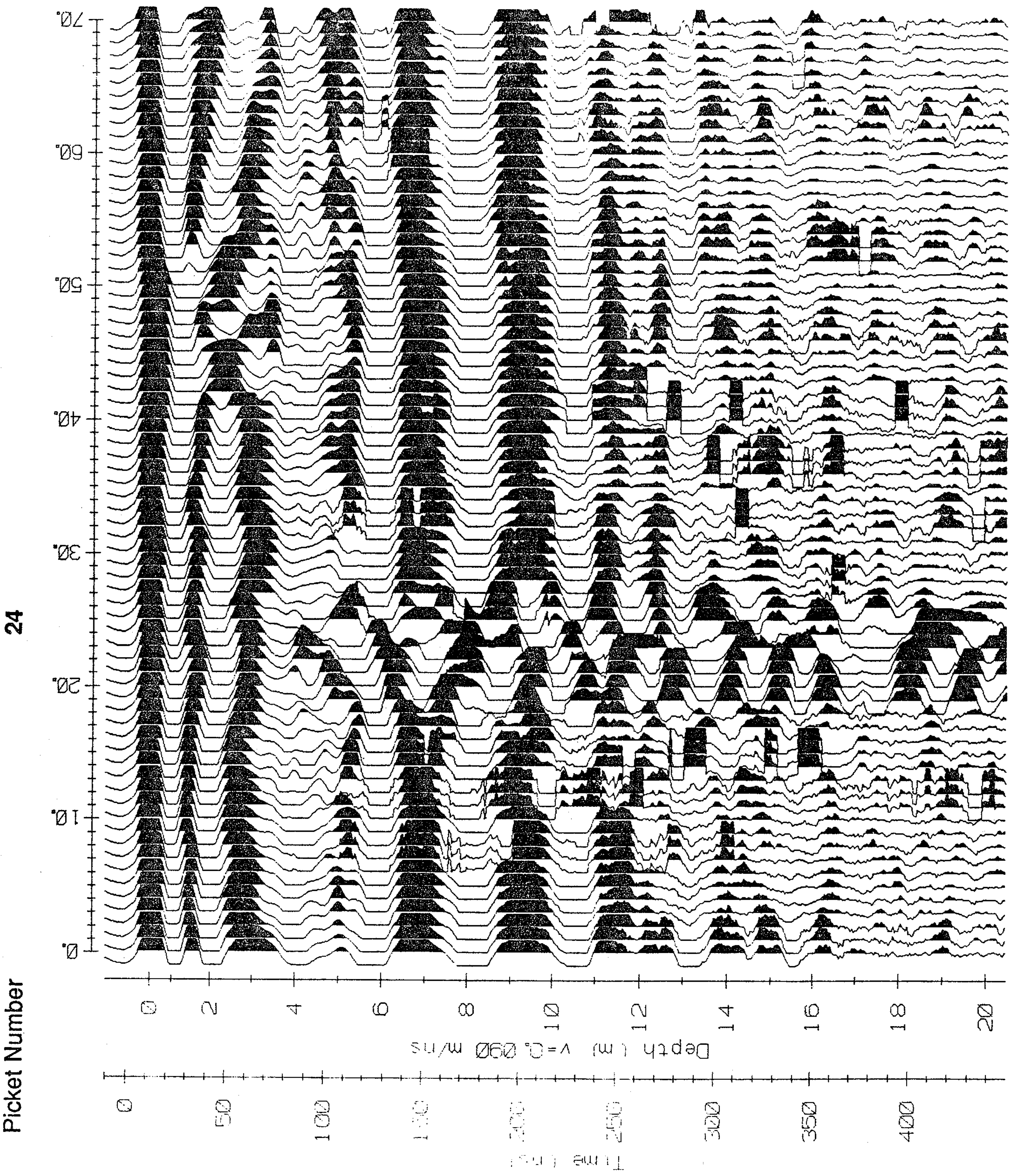

Picket Number
24
0.
10.
20.
30.
40.
50.
60.
70.
0
2
4
6
8
10
12
14
16
18
20
Depth (m) v=0.090 m/ns
0
50
100
150
200
250
300
350
400
Time (ns)

Figure 256

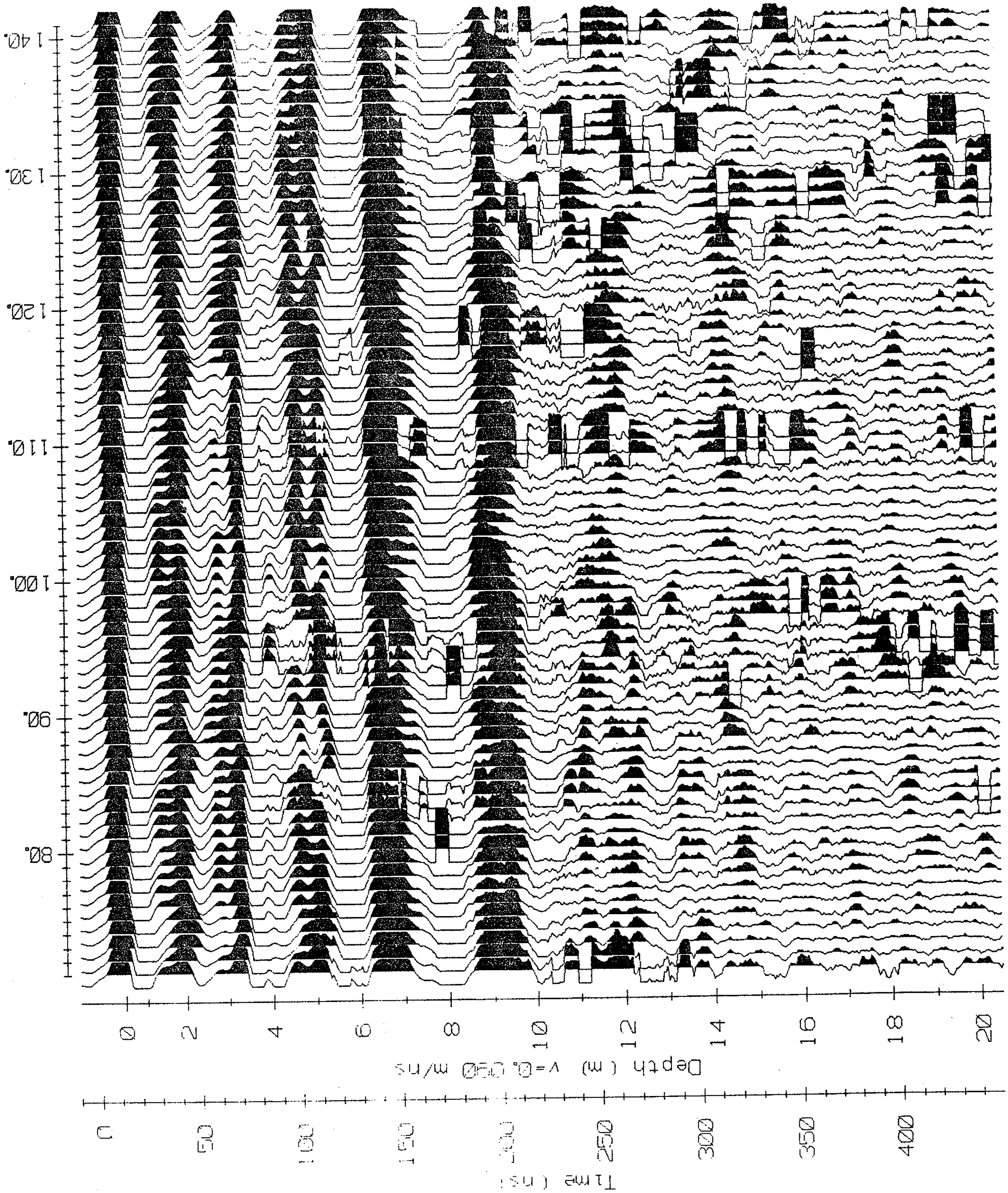


Figure 256 cont.

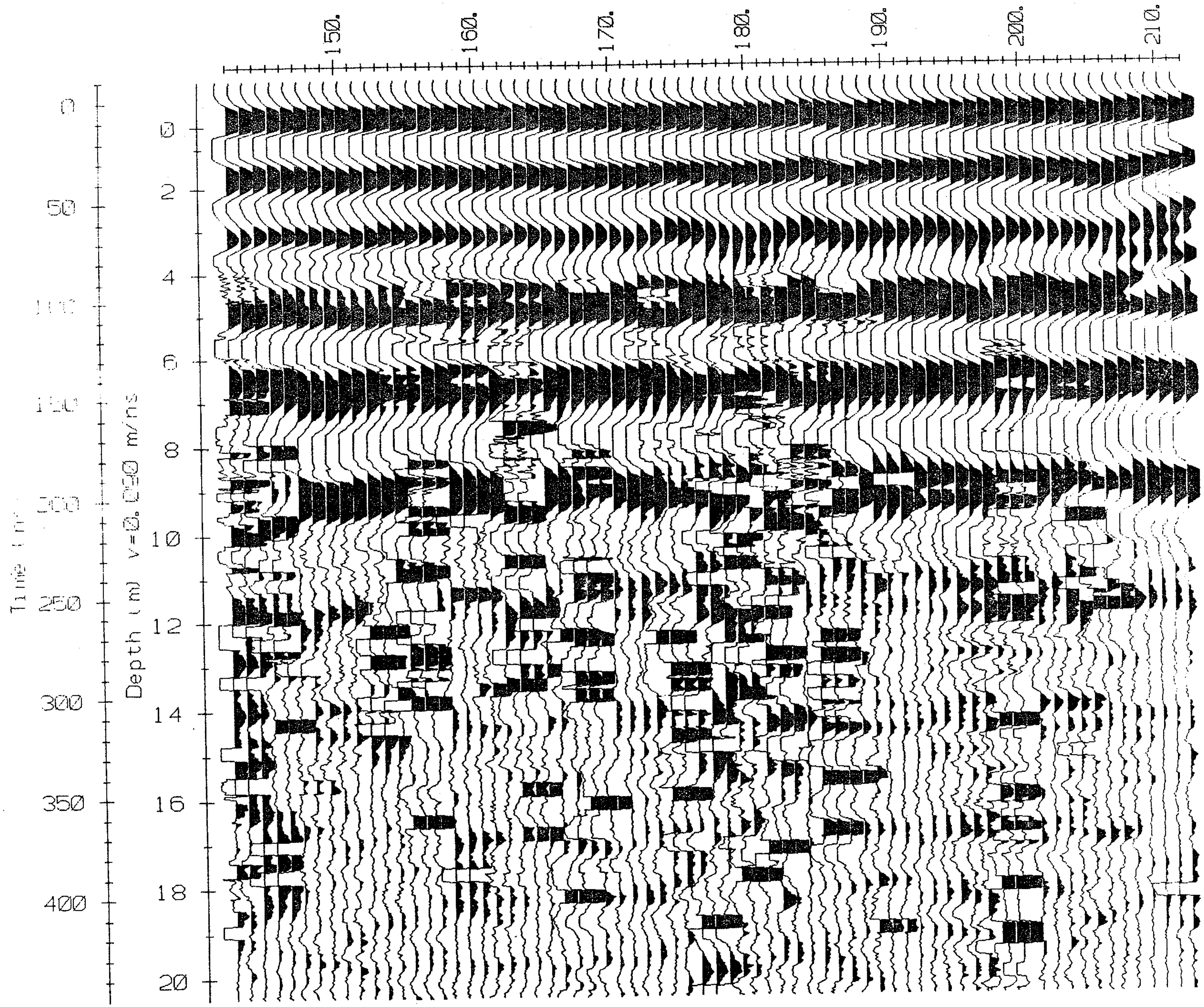


Figure 256 cont.

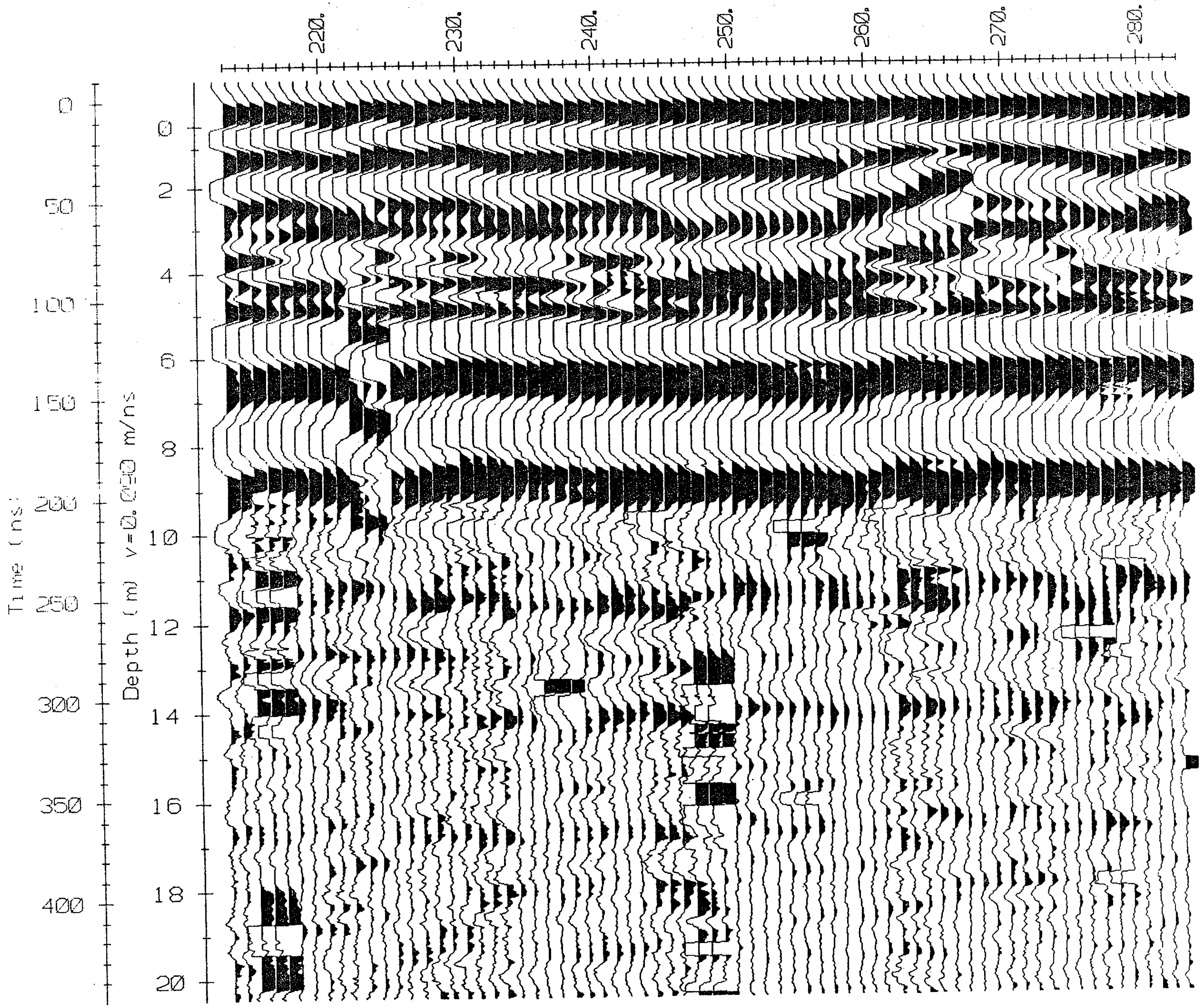


Figure 256 cont.

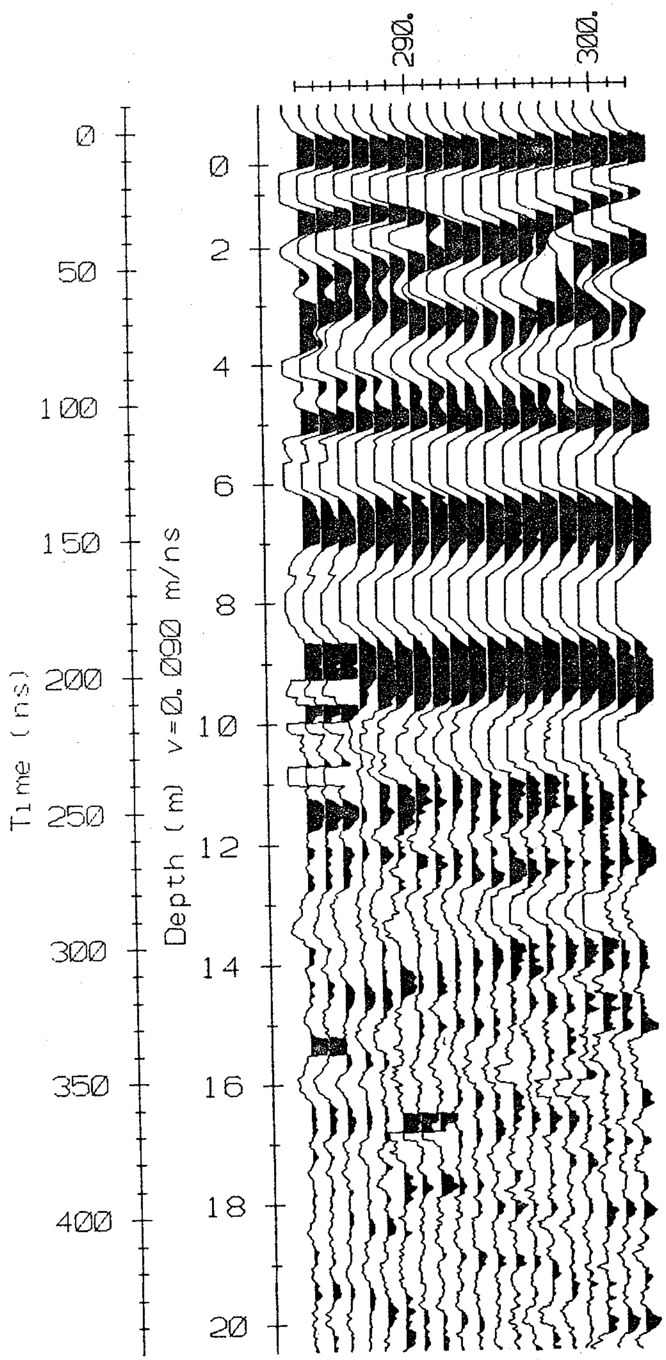


Figure 256 cont.

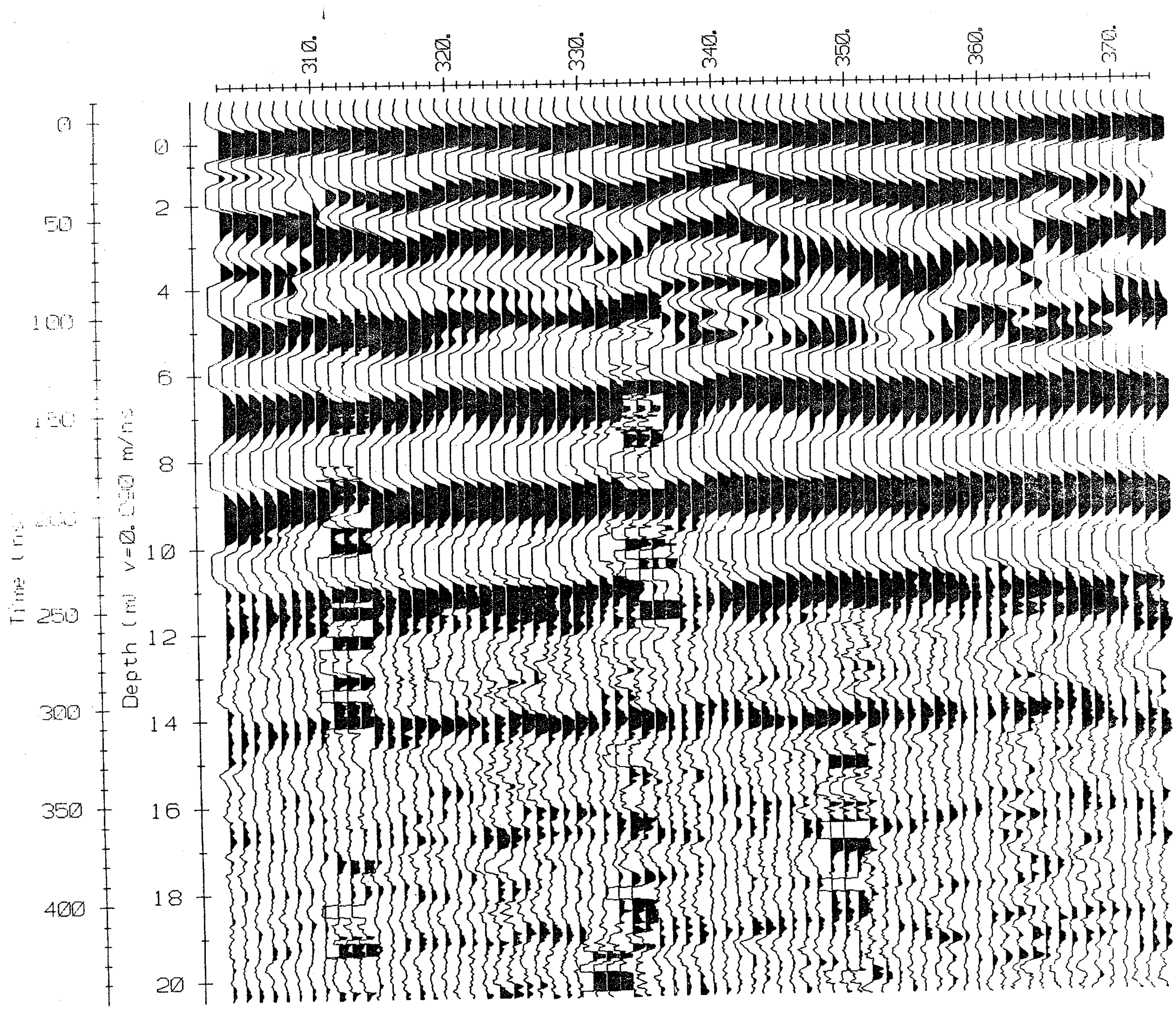


Figure 256 cont.

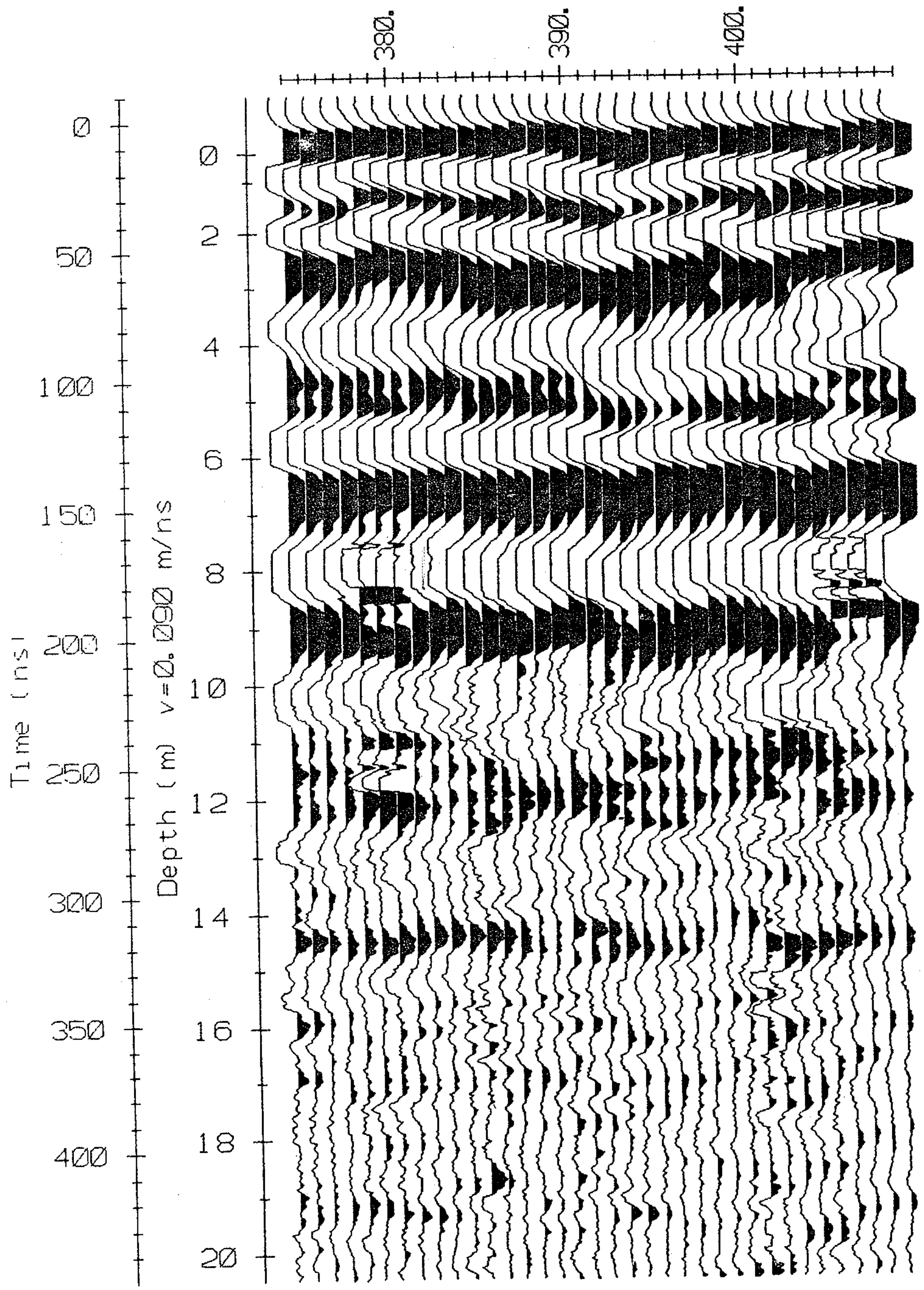


Figure 256 cont.

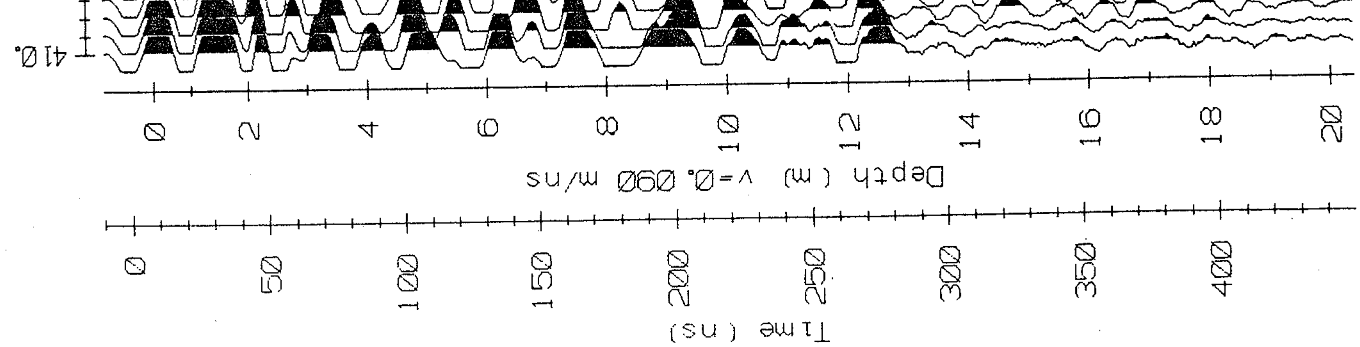
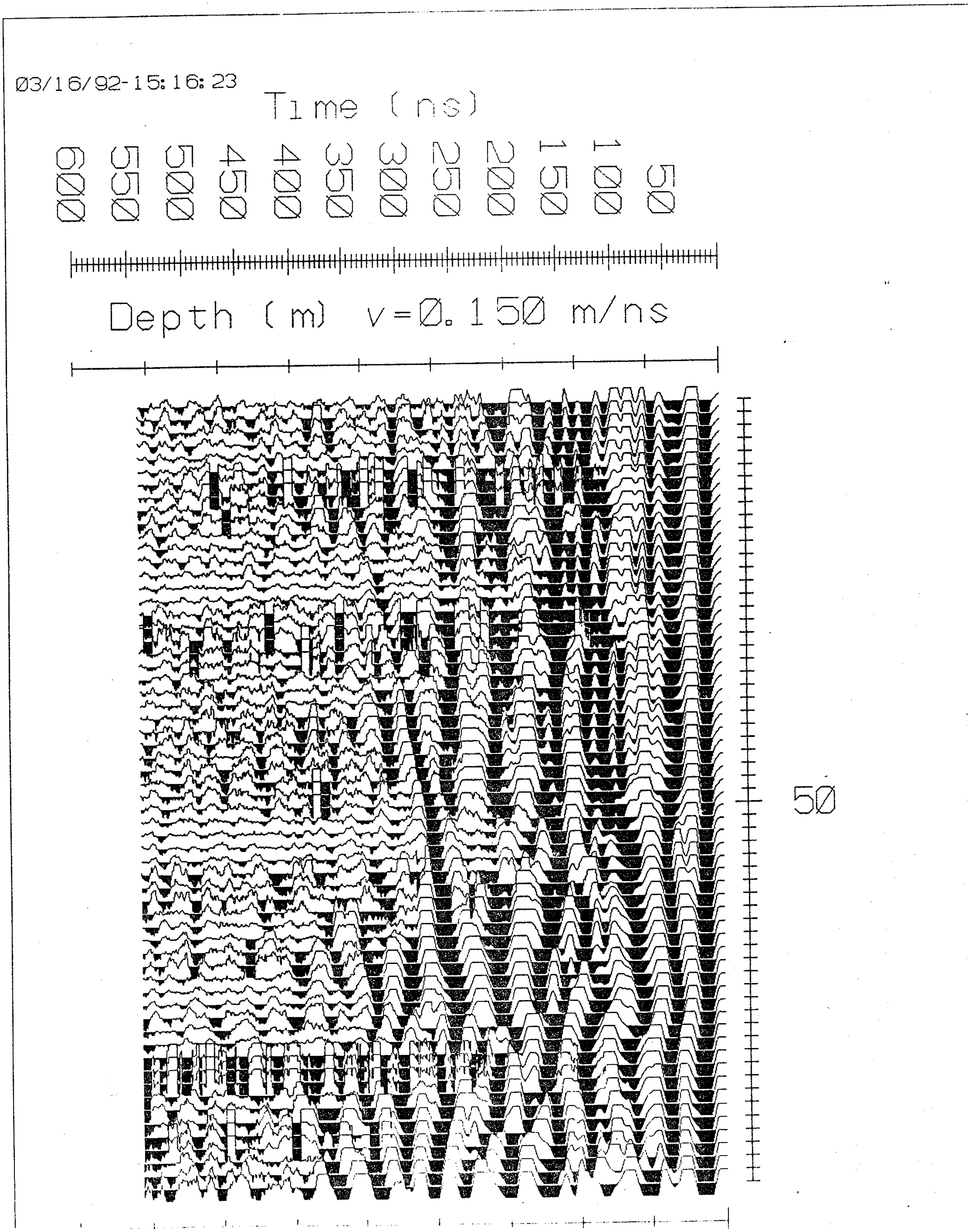


Figure 256 cont.



Ø3/16/92-15:16:23
Time (ns)
600 550 500 450 400 350 300 250 200 150 100 50
Depth (m) v=Ø.15Ø m/ns
5Ø

Figure 257

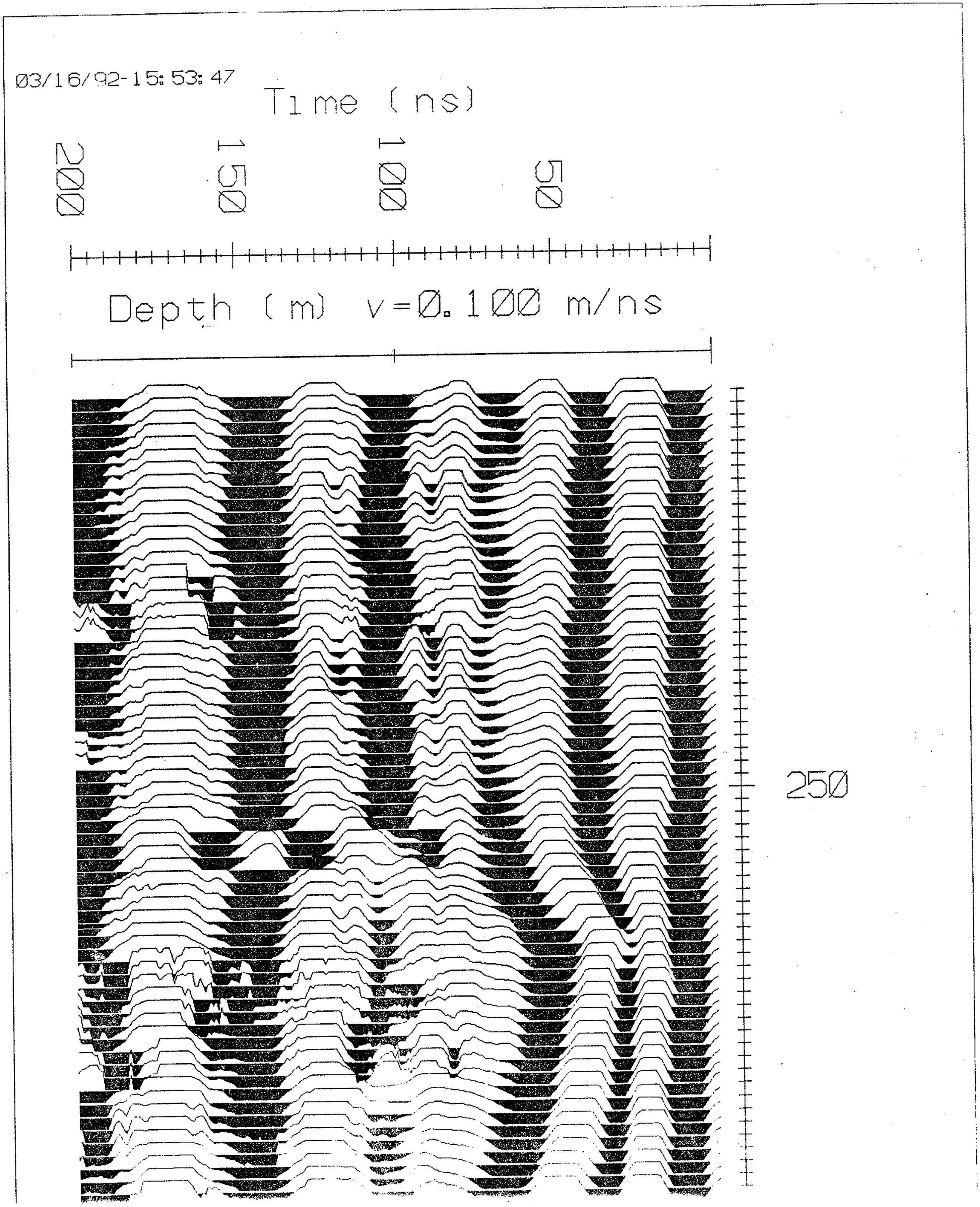


Figure 258

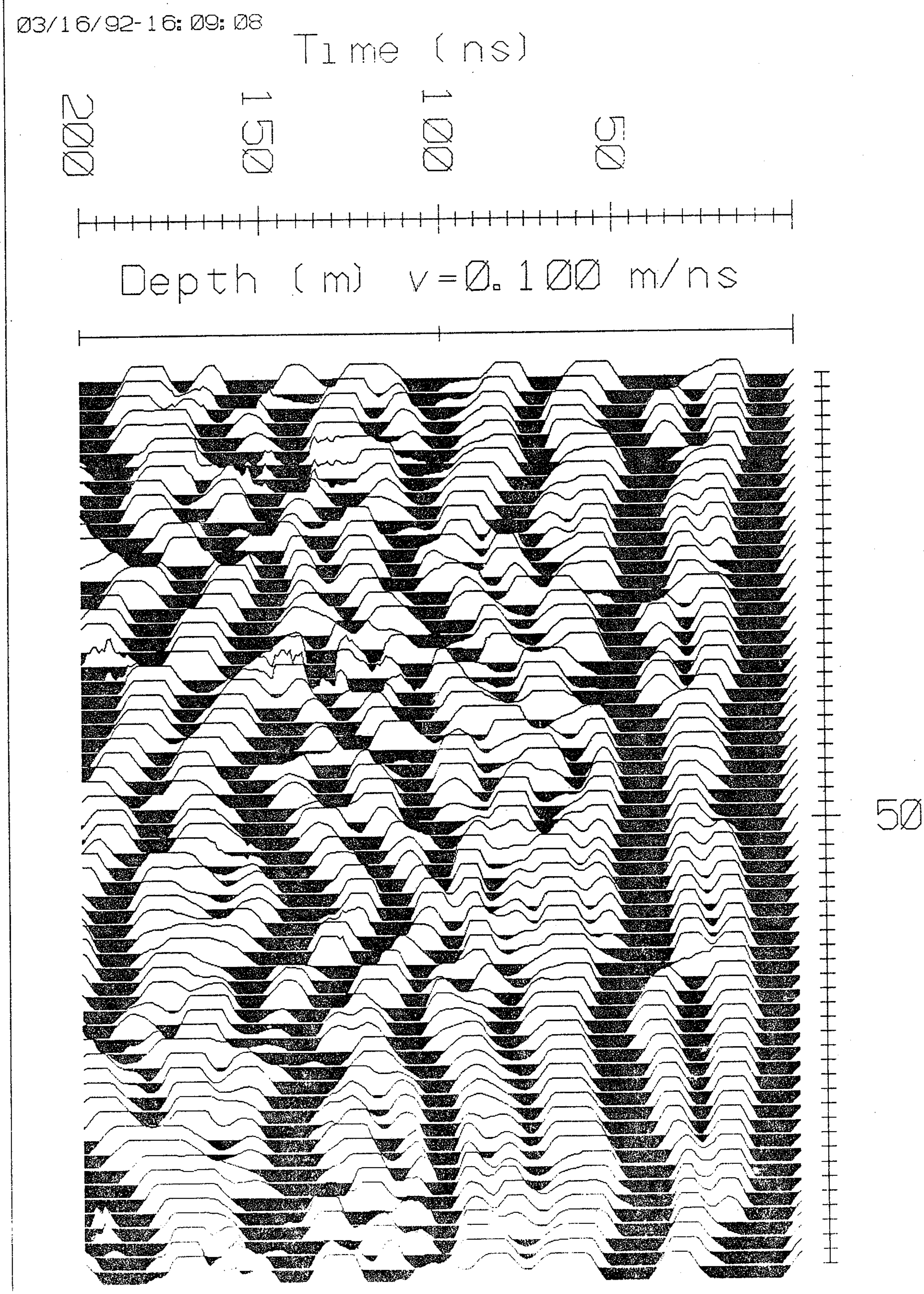


Figure 259

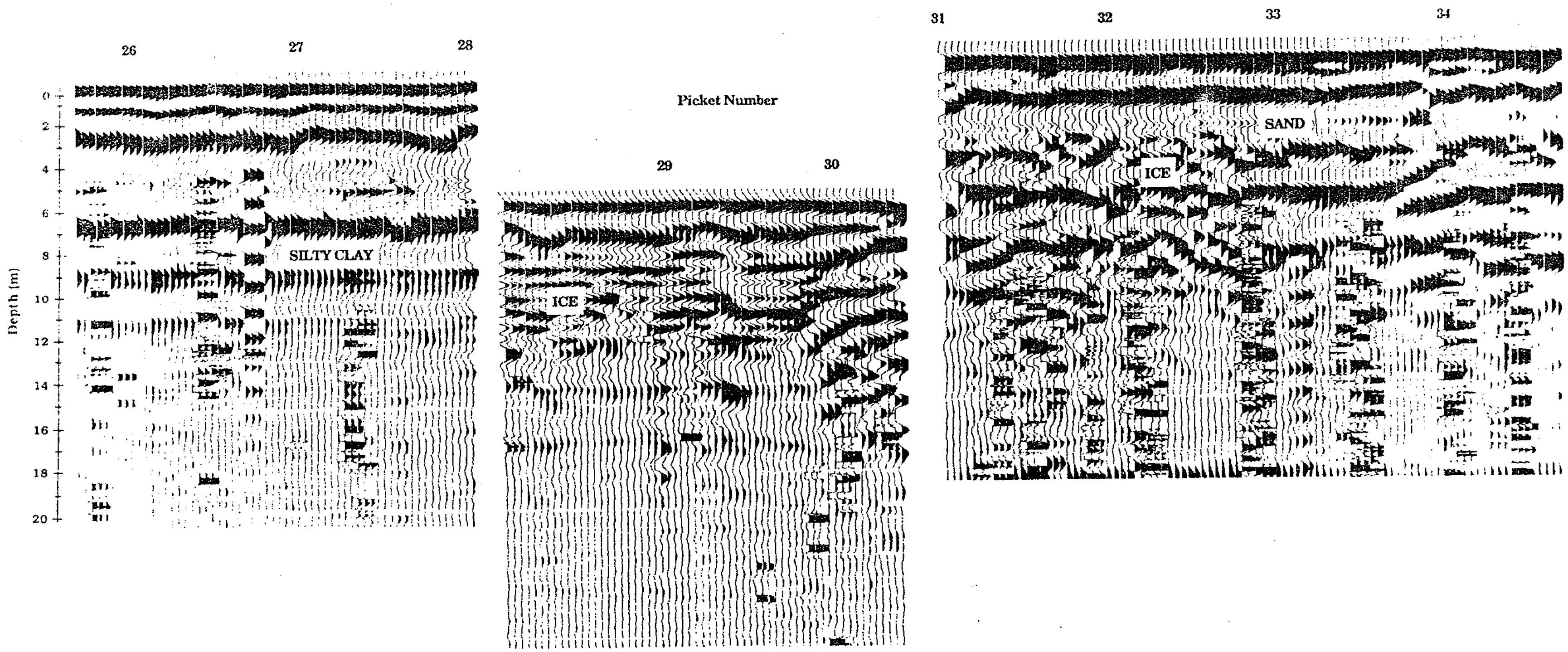

Picket Number
26
27
28
29
30
31
32
33
34
Depth (m)
0
2
4
6
8
10
12
14
16
18
20
SILTY CLAY
ICE
ICE
SAND

Figure 260

GROUND PROBING RADAR – NADYM FACTORY SURVEY

Figs. 261-262

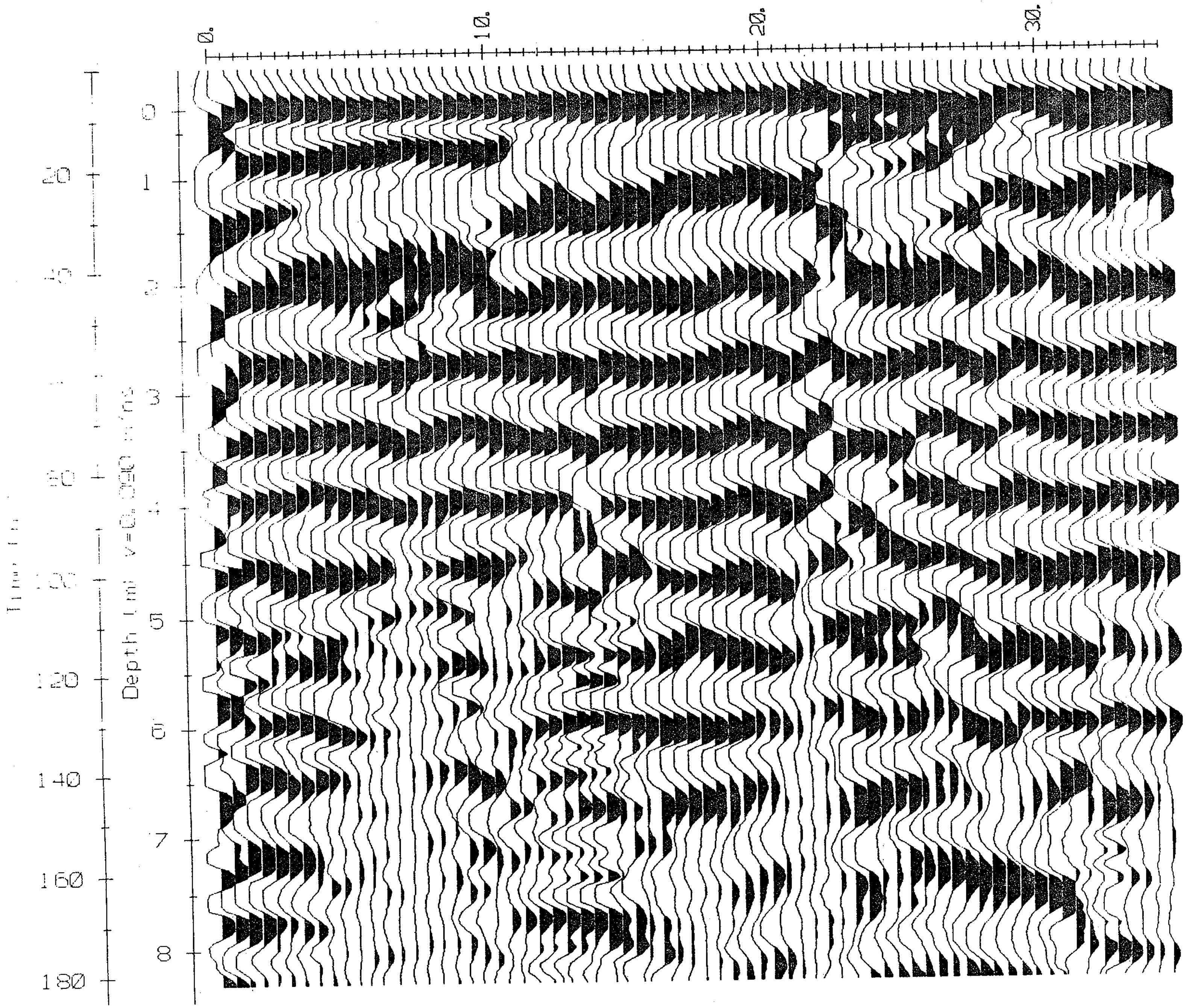


Figure 261

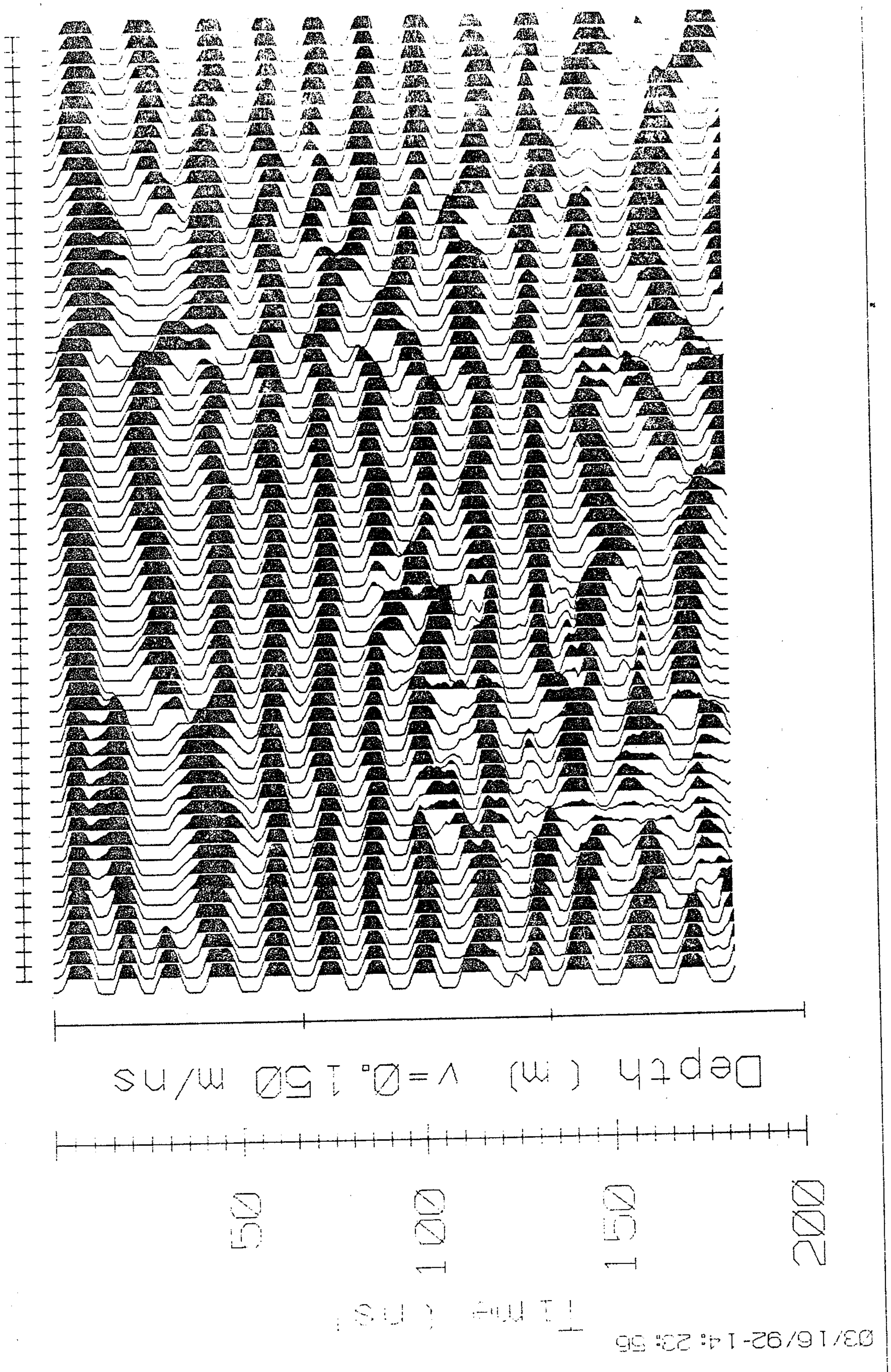


Figure 262

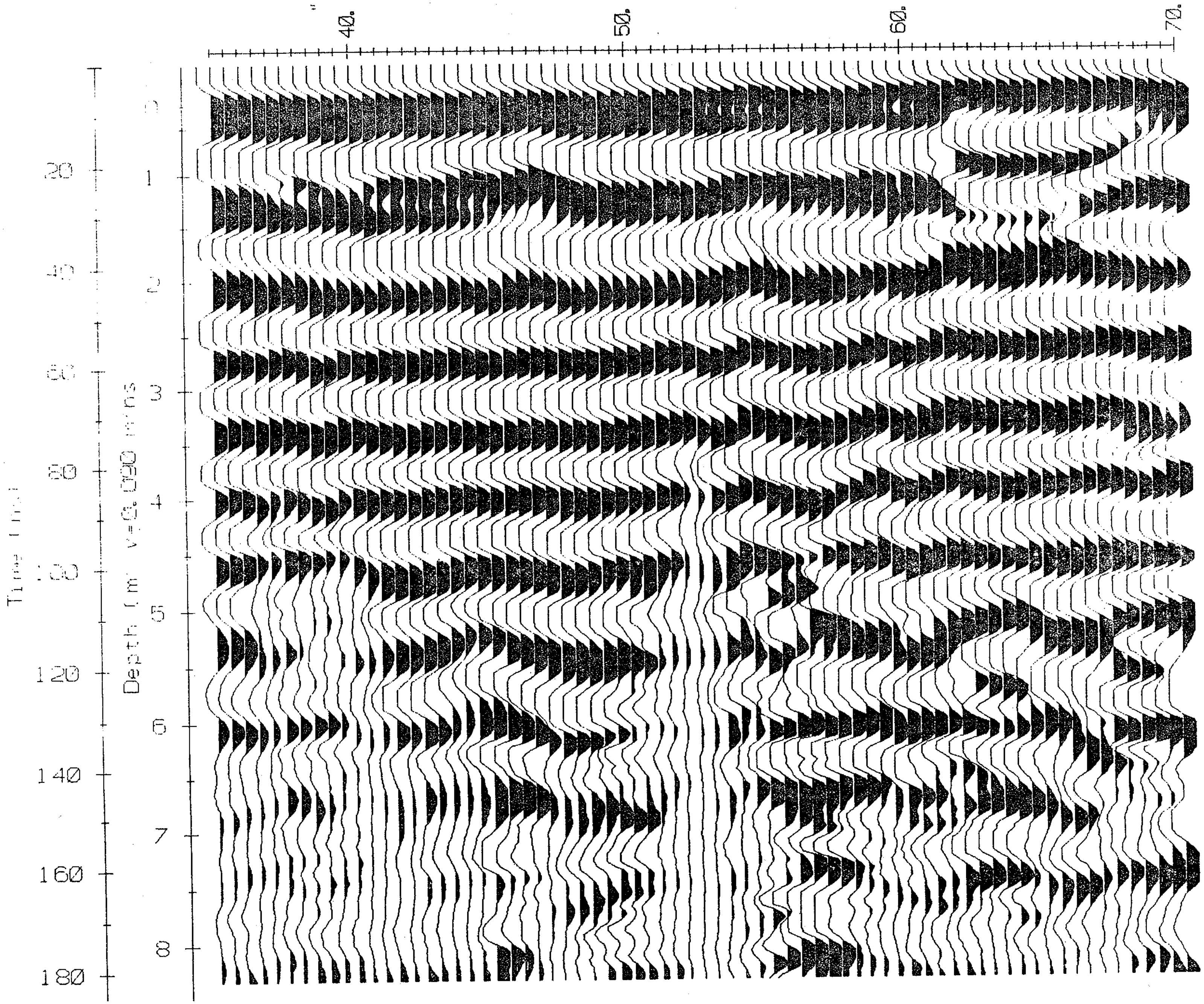


Figure 262 cont.

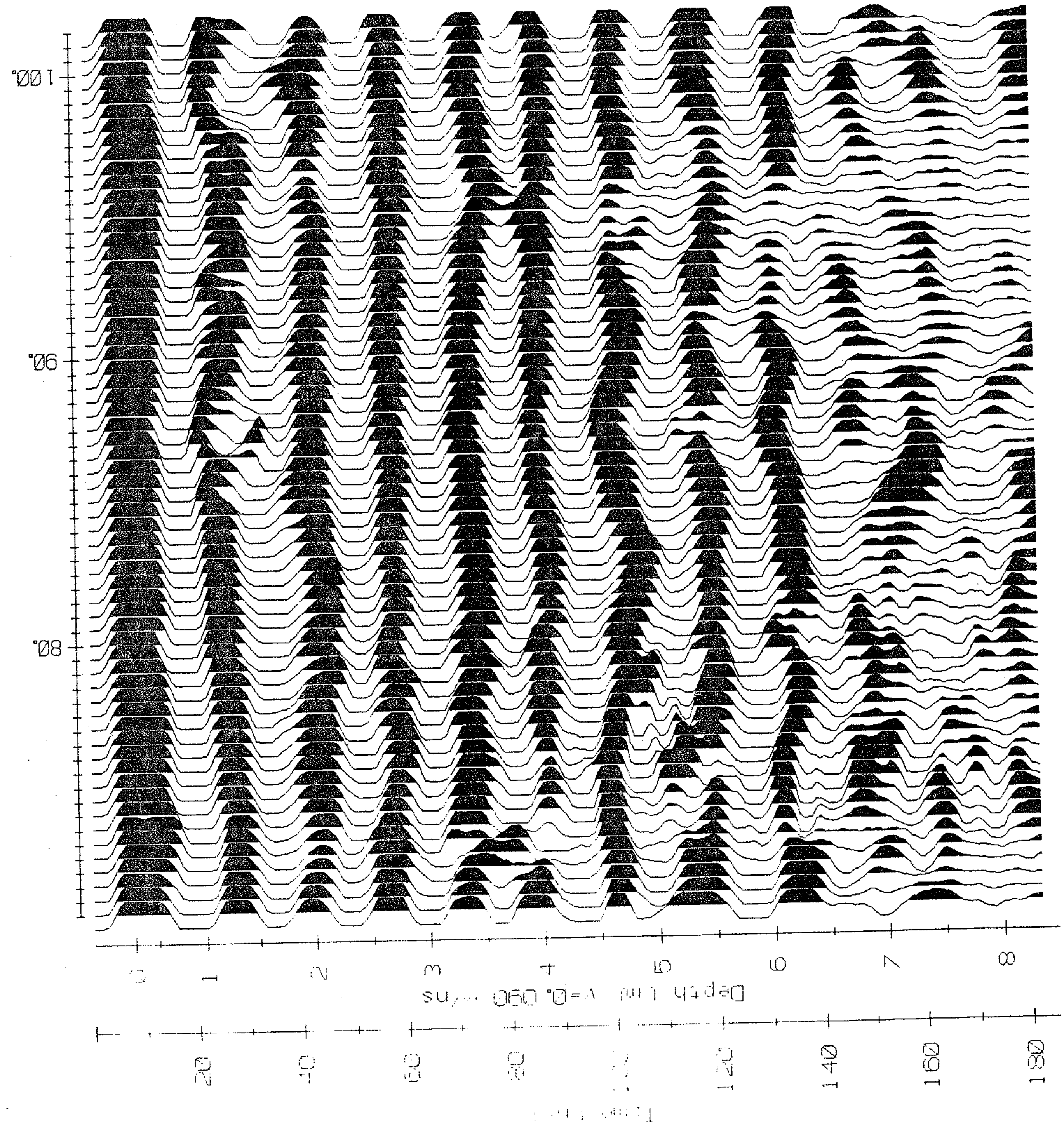


Figure 262 cont.

PHYSICAL PROPERTIES

Figs. 263-276

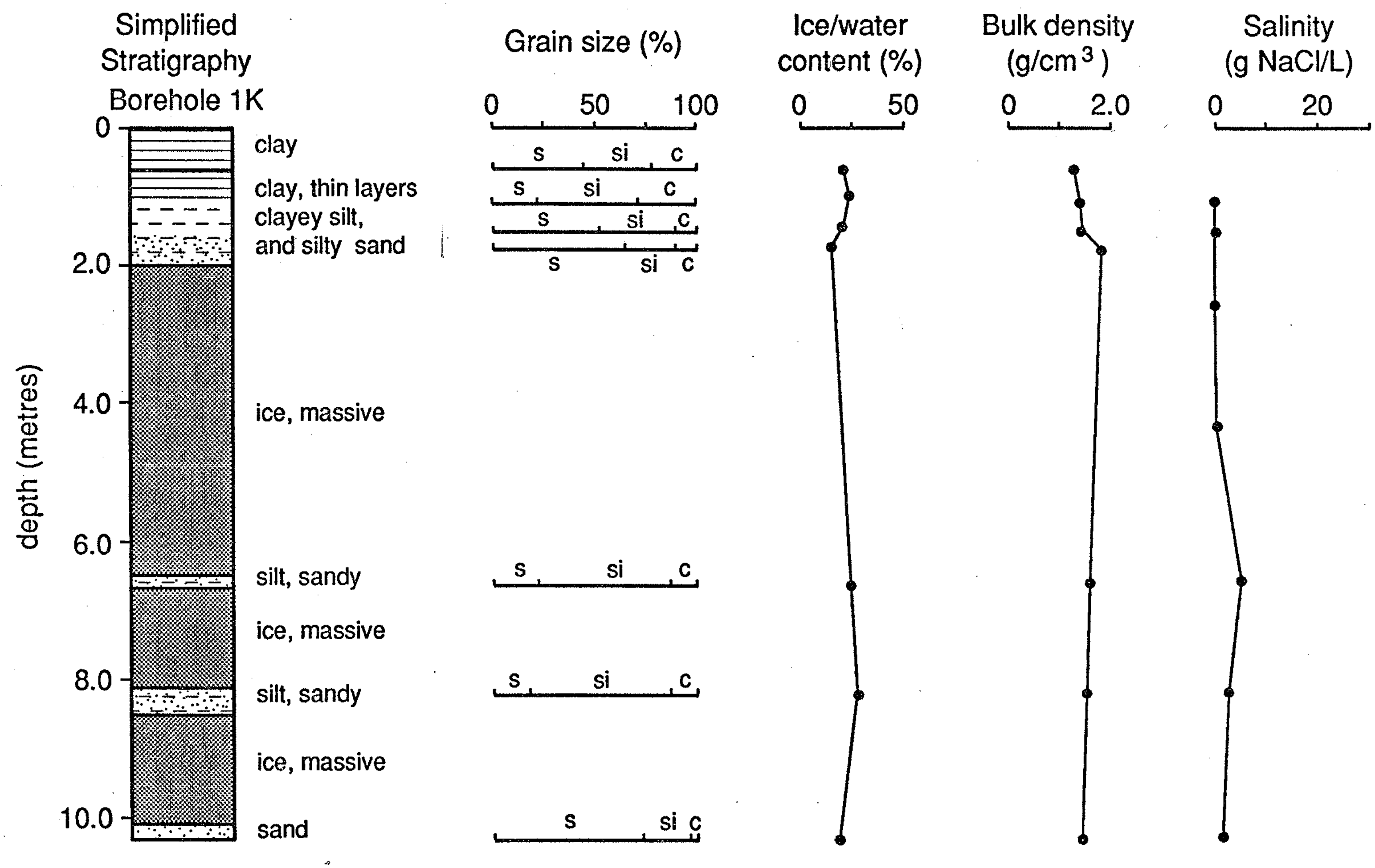

Simplified
Stratigraphy
Borehole 1K
depth (metres)
0
2.0
4.0
6.0
8.0
10.0
clay
clay, thin layers
clayey silt,
and silty sand
ice, massive
silt, sandy
ice, massive
silt, sandy
ice, massive
sand
Grain size (%)
0
50
100
s
si
c
Ice/water
content (%)
0
50
Bulk density
(g/cm3)
0
2.0
Salinity
(g NaCl/L)
0
20

Figure 263

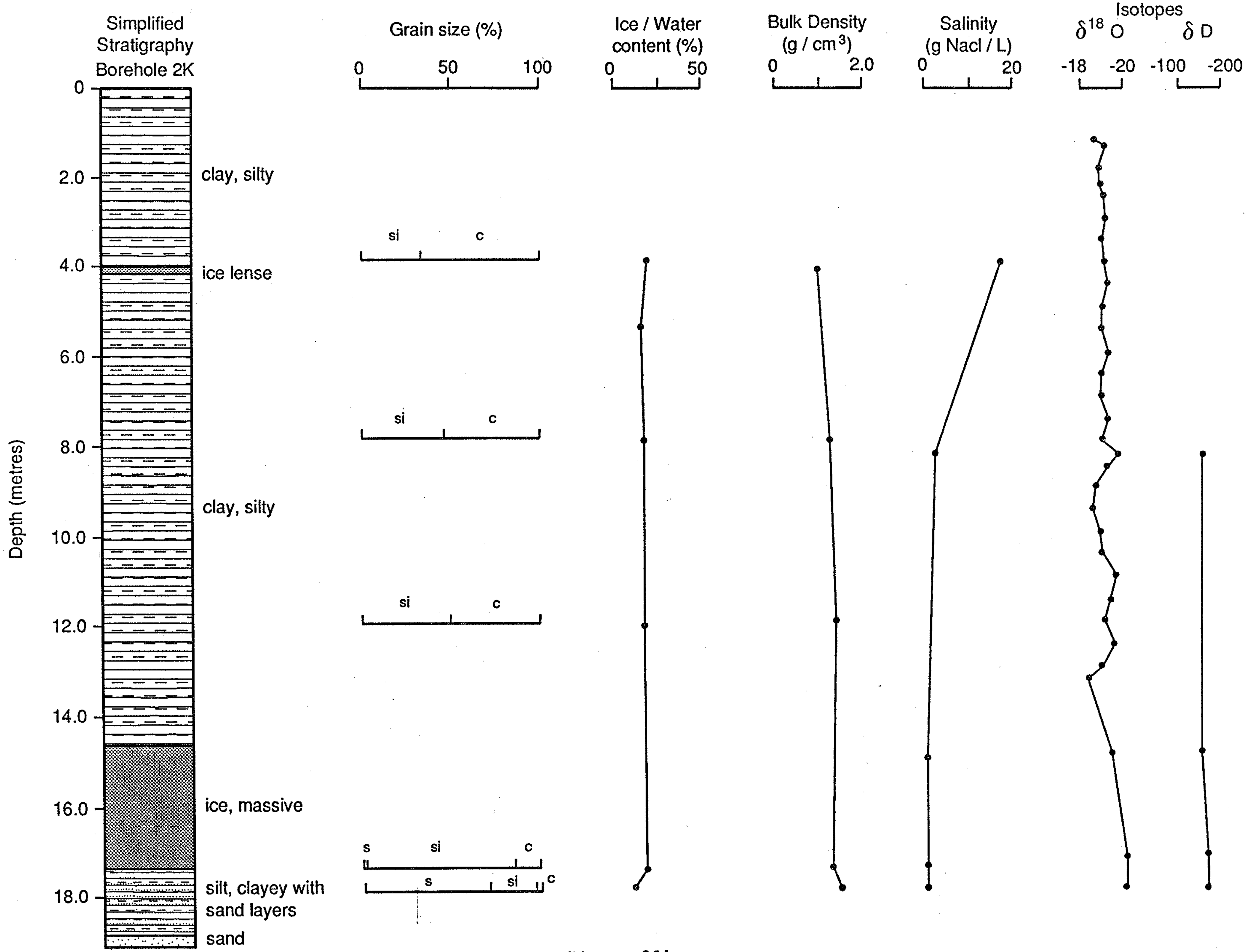

Simplified Stratigraphy Borehole 2K
Depth (metres)
0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
clay, silty
ice lense
clay, silty
ice, massive
silt, clayey with sand layers
sand
Grain size (%)
0
50
100
si
c
s
Ice / Water content (%)
0
50
Bulk Density (g / cm3)
0
2.0
Salinity (g Nacl / L)
0
20
Isotopes
δ18 O
δ D
-18
-20
-100
-200

Figure 264

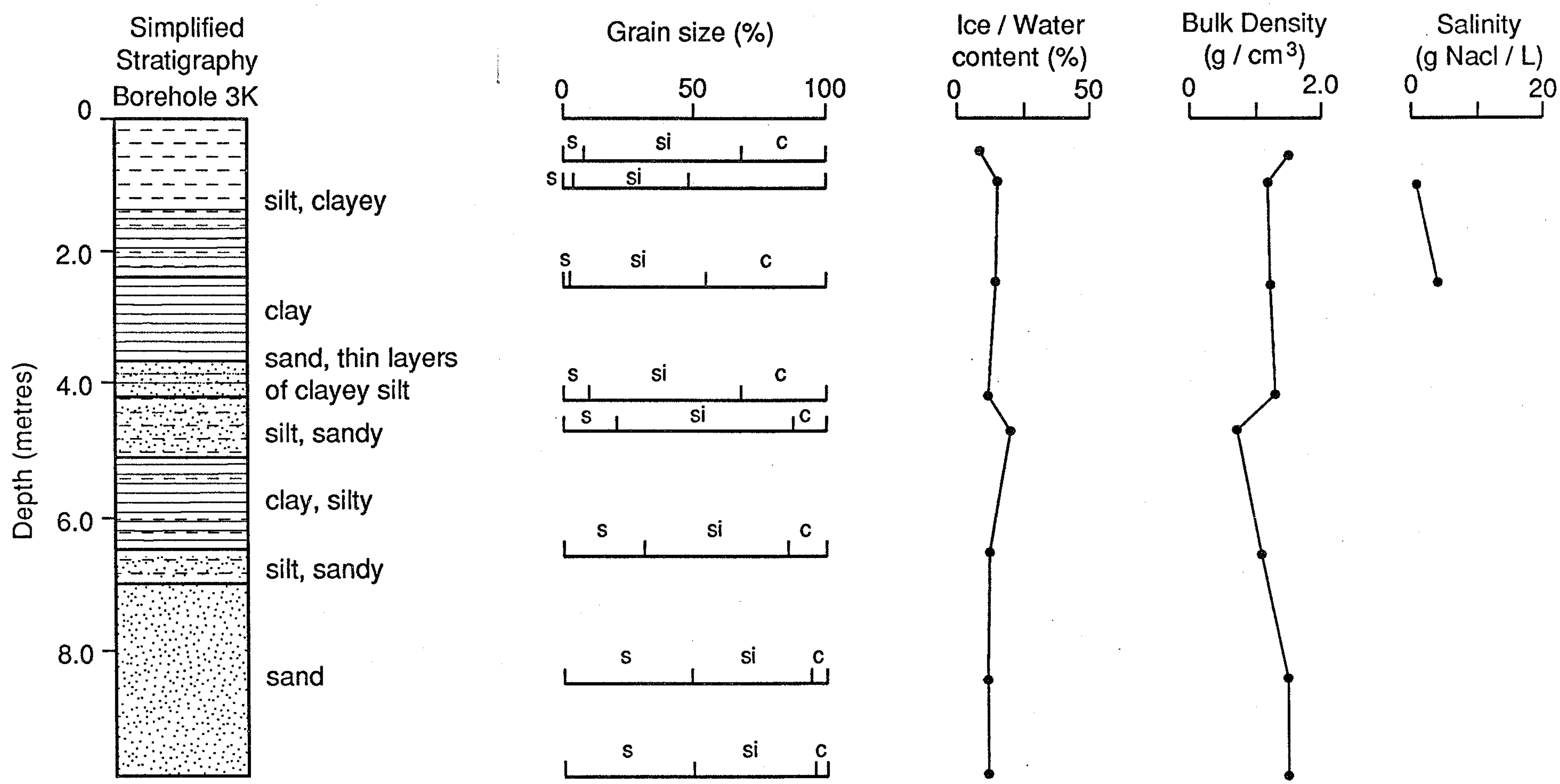

Simplified
Stratigraphy
Borehole 3K
Depth (metres)
0
2.0
4.0
6.0
8.0
silt, clayey
clay
sand, thin layers
of clayey silt
silt, sandy
clay, silty
silt, sandy
sand
Grain size (%)
0
50
100
s
si
c
Ice / Water
content (%)
0
50
Bulk Density
(g / cm3)
0
2.0
Salinity
(g Nacl / L)
0
20

Figure 265

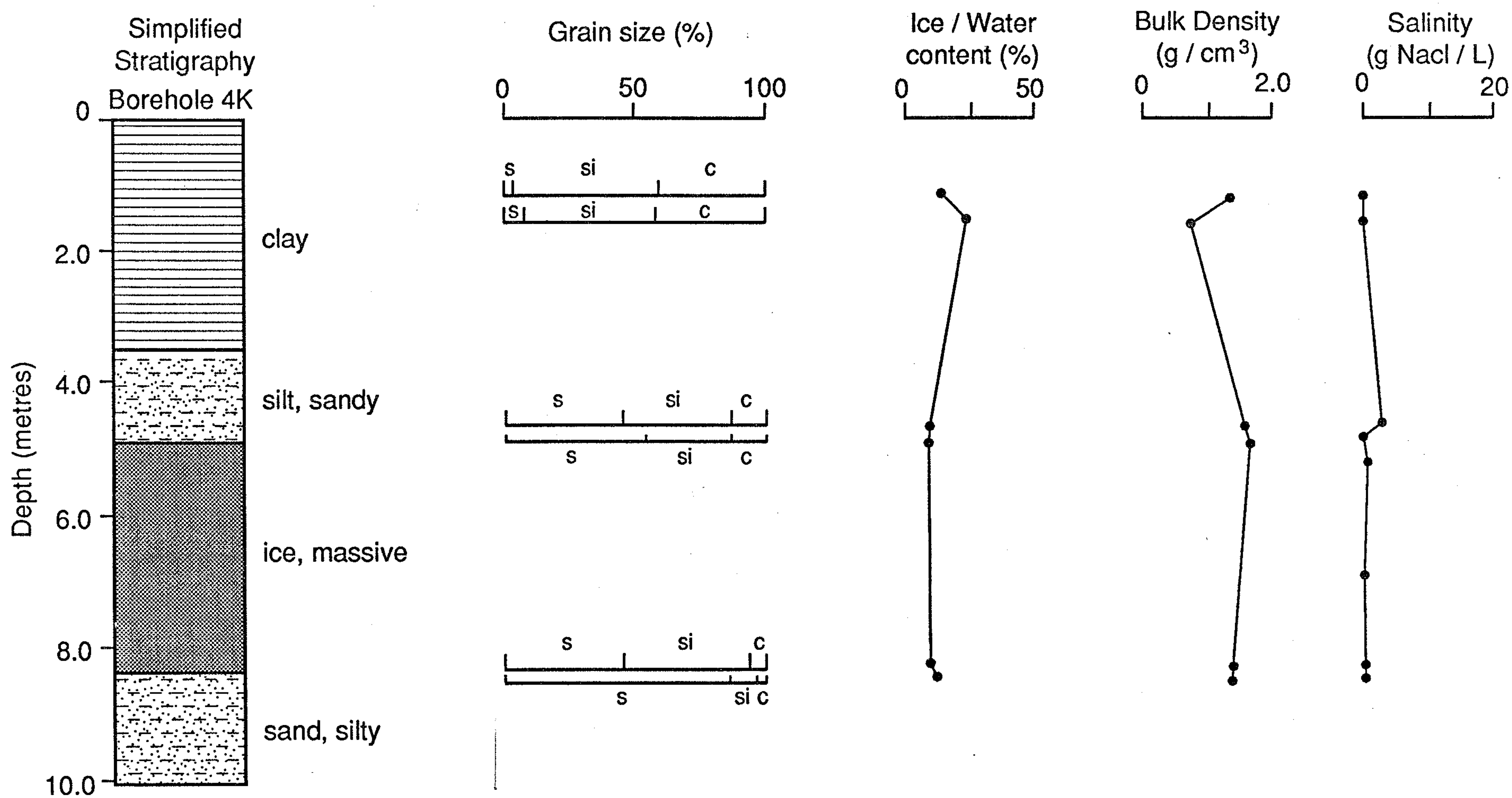
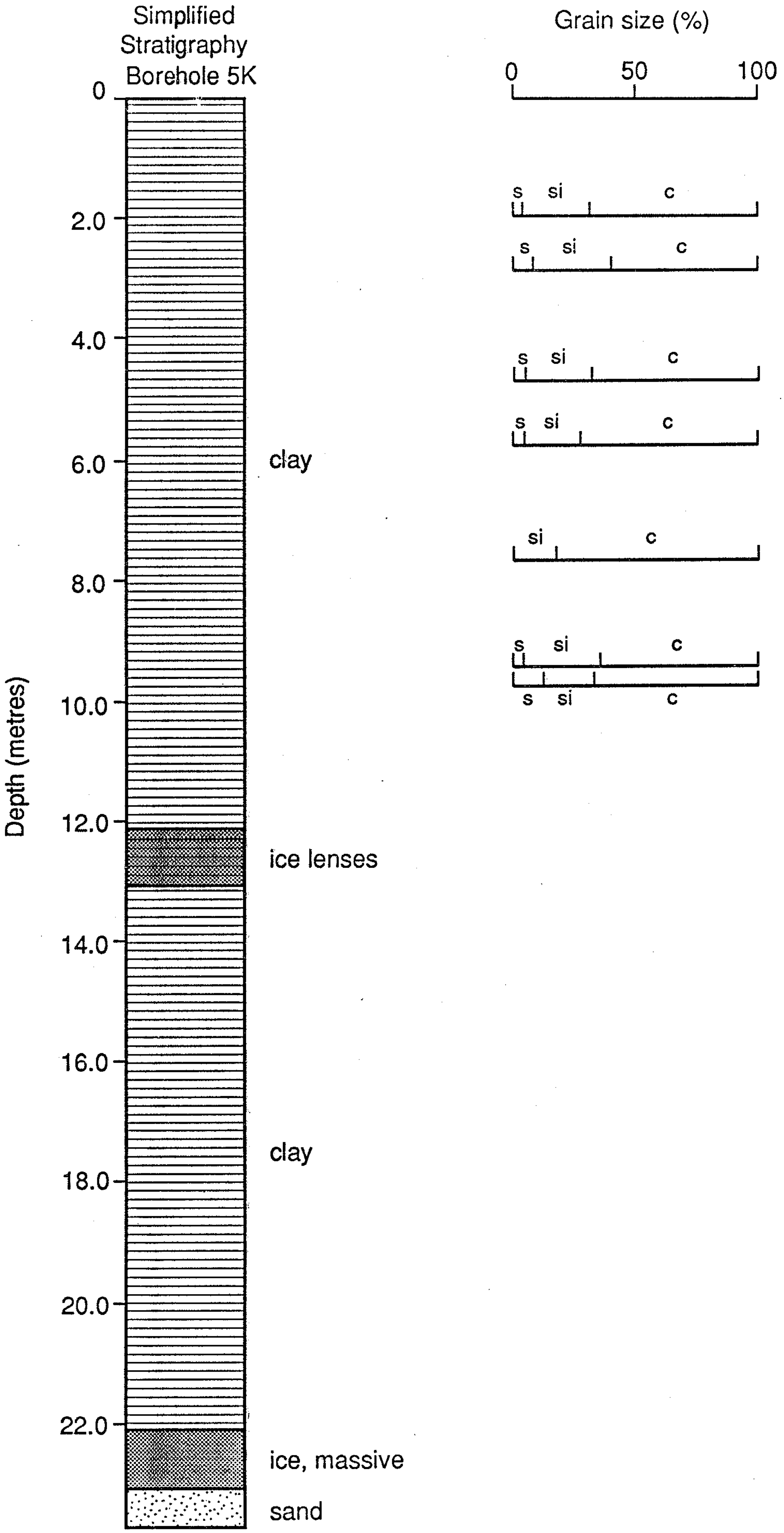

Simplified Stratigraphy Borehole 4K
Depth (metres)
0
2.0
4.0
6.0
8.0
10.0
clay
silt, sandy
ice, massive
sand, silty
Grain size (%)
0
50
100
s
si
c
Ice / Water content (%)
0
50
Bulk Density (g / cm³)
0
2.0
Salinity (g Nacl / L)
0
20

Figure 266



Simplified
Stratigraphy
Borehole 5K
Grain size (%)
0
50
100
Depth (metres)
0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
22.0
clay
ice lenses
clay
ice, massive
sand
s si c
s si c
s si c
s si c
si c
s si c
s si c

Figure 267

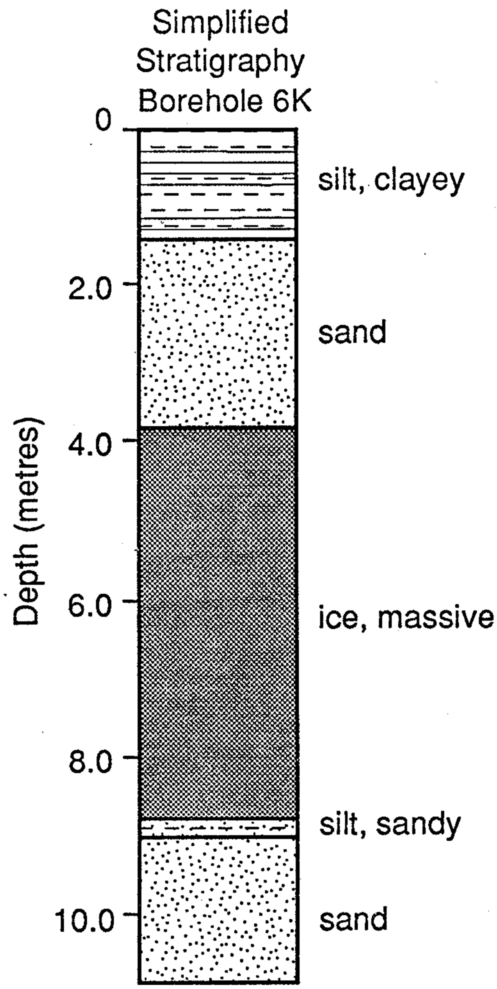
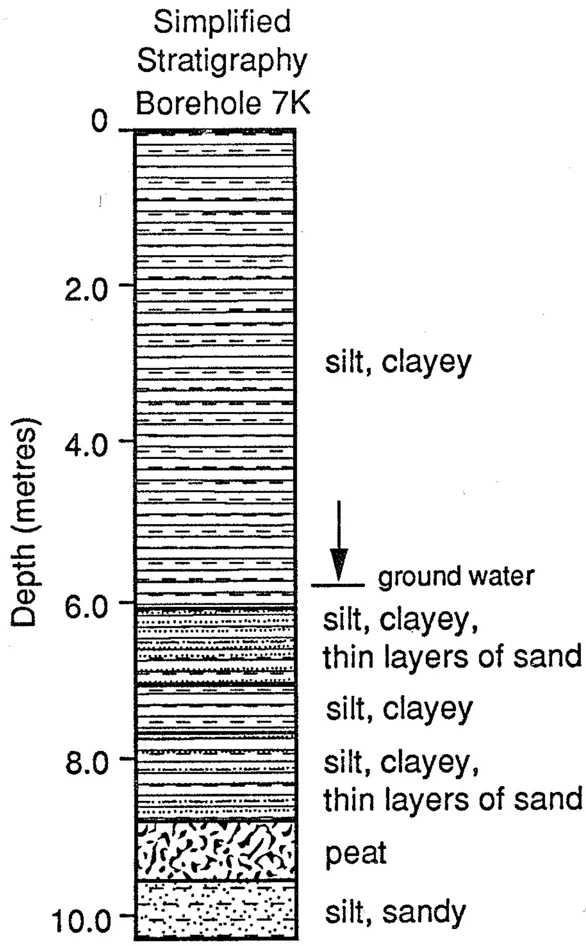

Simplified
Stratigraphy
Borehole 6K
Depth (metres)
0
2.0
4.0
6.0
8.0
10.0
silt, clayey
sand
ice, massive
silt, sandy
sand

Figure 268



Simplified
Stratigraphy
Borehole 7K
0
2.0
4.0
6.0
8.0
10.0
Depth (metres)
silt, clayey
ground water
silt, clayey,
thin layers of sand
silt, clayey
silt, clayey,
thin layers of sand
peat
silt, sandy

Figure 269

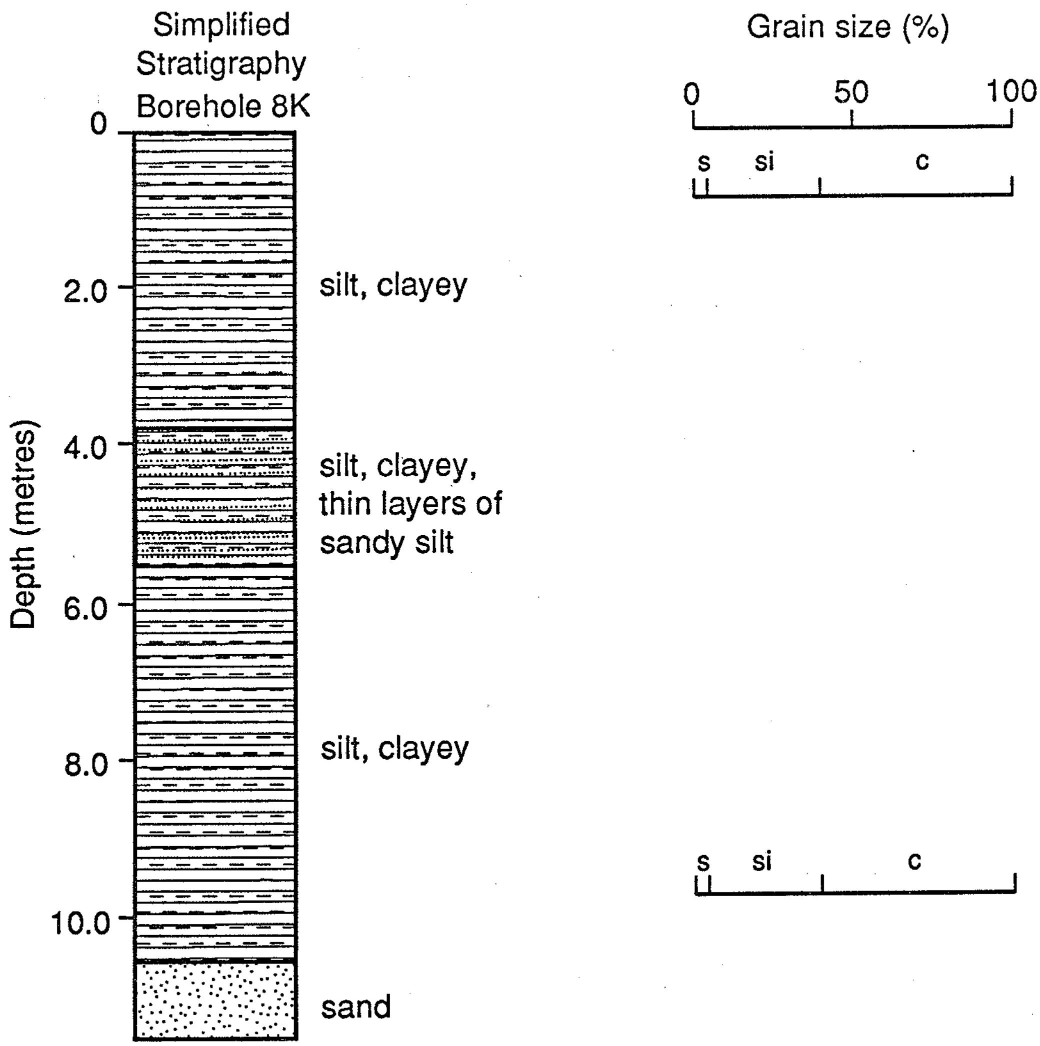
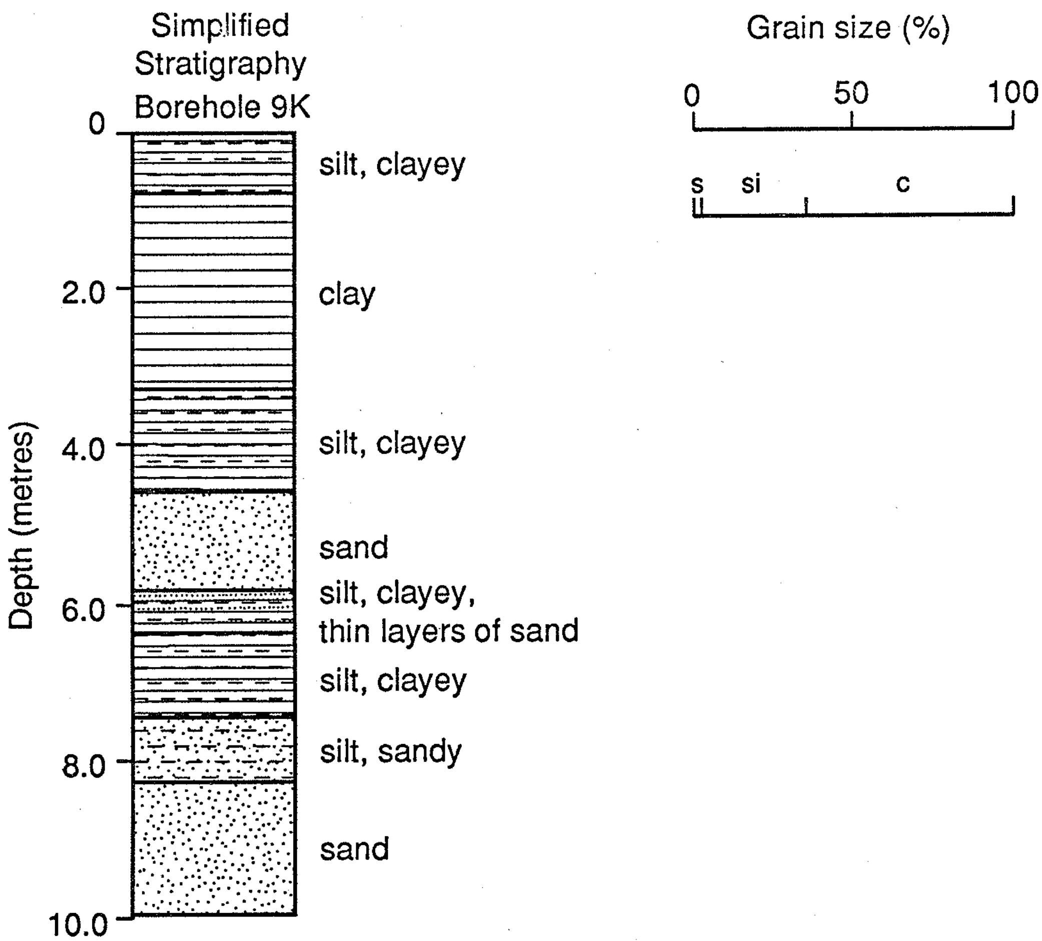

Simplified
Stratigraphy
Borehole 8K
Depth (metres)
0
2.0
4.0
6.0
8.0
10.0
silt, clayey
silt, clayey,
thin layers of
sandy silt
silt, clayey
sand
Grain size (%)
0
50
100
s
si
c
s
si
c

Figure 270



Simplified
Stratigraphy
Borehole 9K
0
2.0
4.0
6.0
8.0
10.0
Depth (metres)
silt, clayey
clay
silt, clayey
sand
silt, clayey,
thin layers of sand
silt, clayey
silt, sandy
sand
Grain size (%)
0
50
100
s
si
c

Figure 271

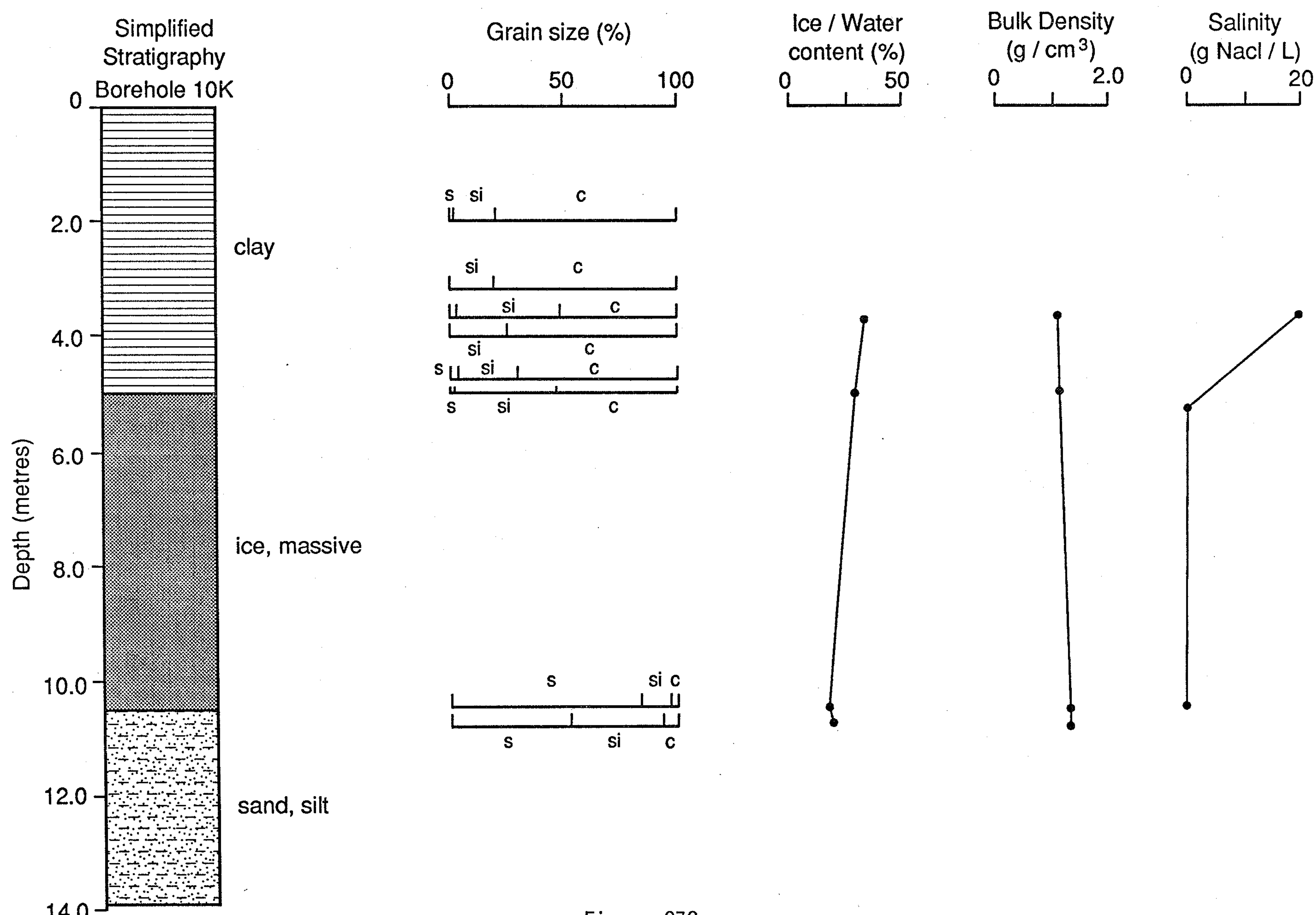

Simplified
Stratigraphy
Borehole 10K
Depth (metres)
0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
clay
ice, massive
sand, silt
Grain size (%)
0
50
100
s
si
c
Ice / Water
content (%)
Bulk Density
(g / cm³)
2.0
Salinity
(g Nacl / L)
20

Figure 272

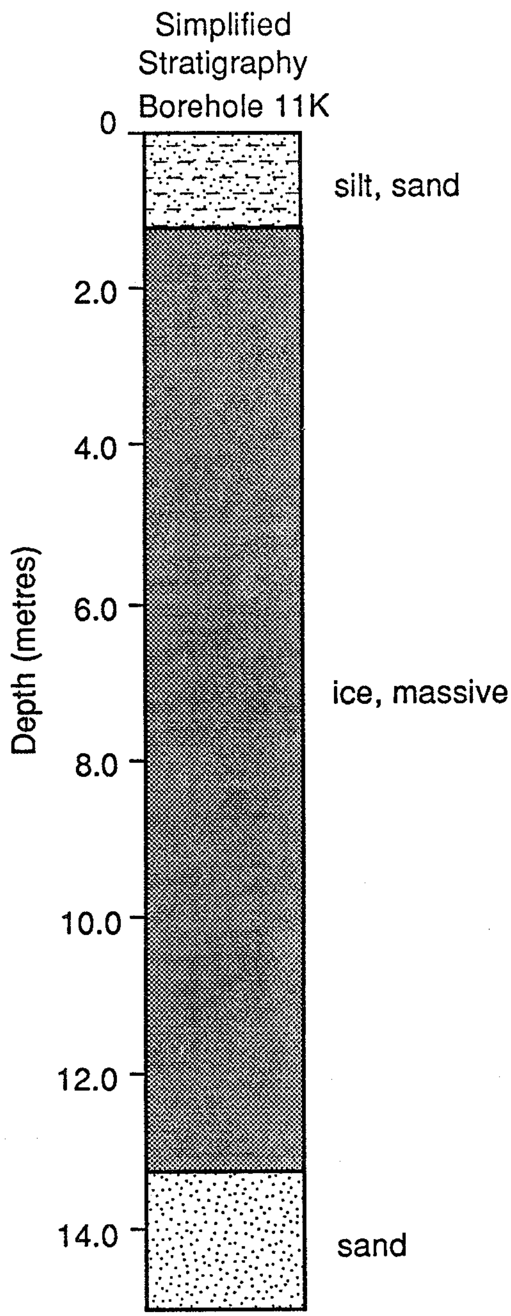

Simplified
Stratigraphy
Borehole 11K
Depth (metres)
0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
silt, sand
ice, massive
sand

Figure 273

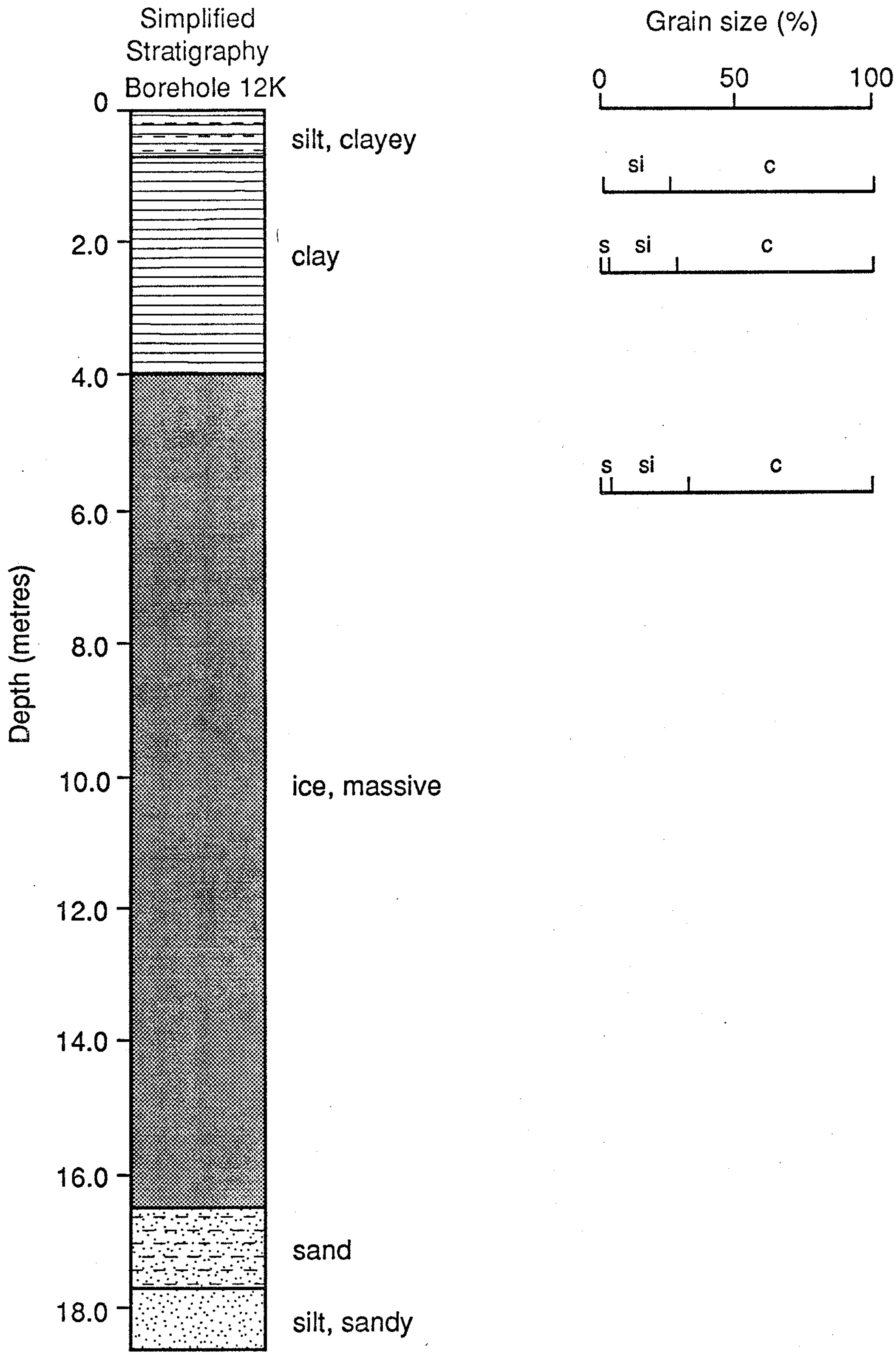

Simplified
Stratigraphy
Borehole 12K
Grain size (%)
0
50
100
silt, clayey
si
c
clay
s
si
c
s
si
c
ice, massive
sand
silt, sandy
Depth (metres)
0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0

Figure 274

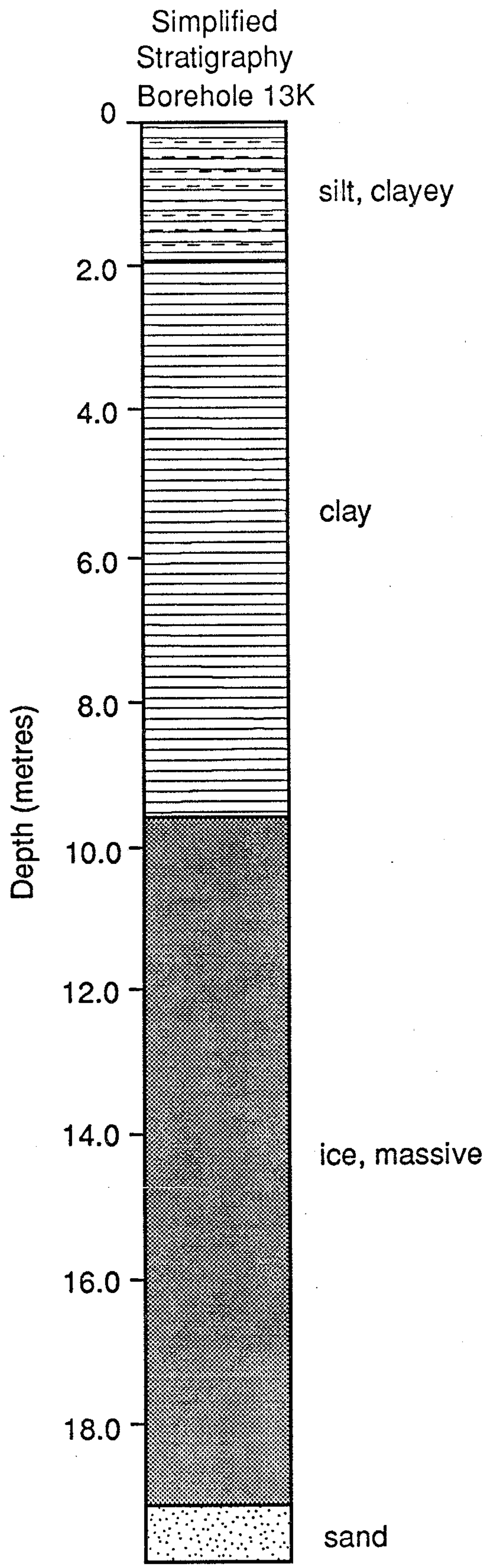

Simplified
Stratigraphy
Borehole 13K
Depth (metres)
0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
silt, clayey
clay
ice, massive
sand

Figure 275

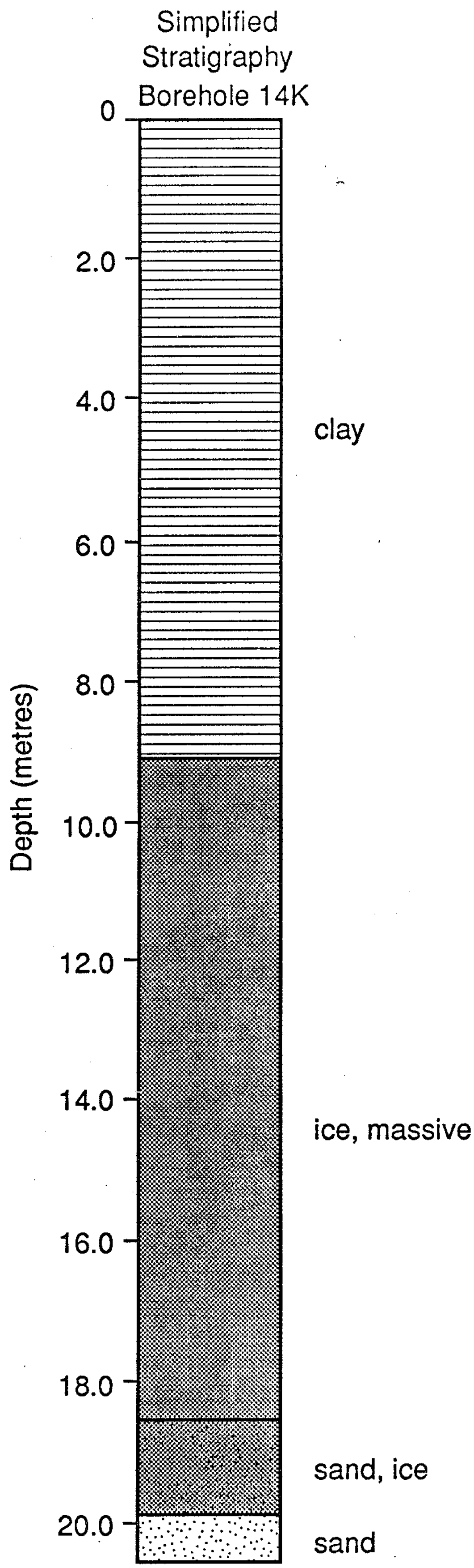

Simplified
Stratigraphy
Borehole 14K
Depth (metres)
0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
clay
ice, massive
sand, ice
sand

Figure 276