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Abstract

Seismic refraction survey was conducted in the south-east Niger Delta at 27 stations using surface-detectors, and estimated near-surface compressional-wave velocities. At each station, a borehole was drilled with casing down to 60-m depth, and determined downhole compressional-wave velocities. Compressional-wave velocities estimated by surface-detectors were then compared with those estimated by downhole survey. The acquisition system includes 0.2kg dynamite, 12-channel-geophone and 11-channel-hydrophone receiver cables for surface-detectors and downhole surveys respectively. The soil layers in the Niger Delta has 2 distinct layers specified as follows, namely, top weathered layer of loose sand sediments with compressional wave velocity ranging from 213 to 763 ms^{-1} with an average of 503ms^{-1}. Weathered-layer thickness ranges from 2.7 to 16.50m, with an average of 8.1m. Consolidated-layer compressional wave velocity ranges from 1580 to 1906ms^{-1}, with an average of 737ms^{-1}. A vertical velocity gradient of 30.5s^{-1} was calculated for the area. There exists a 7-18% difference between the velocities determined by the surface-wave and downhole methods. The surface-wave method gives spatially-averaged velocities along the line of traverse coincident with the geophone spread. In the case of downhole seismic method, velocities are specifically applicable only to the borehole location. The implication is that downhole measurements can be adversely affected by the local borehole factors and conditions resulting from casings and excessive collapse around the flushed-zone of the borehole. The spatially-averaged velocities and depths estimated by surface-detector method are more reliable for the site-specific characterization for reflection seismology, geotechnical engineering and groundwater.

Key words: Near surface, surface and downhole seismic, lithology, velocity-depth, Niger Delta Nigeria.

Introduction

The near-surface is considered to be the low-velocity shallow part of the earth's subsurface. Often it is that part of the subsurface in which seismic coherent noise propagates. The velocity-depth information of the near surface can be applied in static corrections and for shallow drilling programme for reflection work (Uko *et al*, 1992, Eze *et al*., 2003). The base of the low-velocity-layer (LVL) is thought to be the water table (Okwueze, 1991), and so the results of this project are useful in water exploration, geotechnical, environmental investigations, and for foundation laying for bridges, dams, and high-rise buildings (Karastathis and Papamarino, 1997).

Miller *et al* (1998) used refraction and reflection data to investigate radioactive waste site. Lanz *et al* (1998) also used refraction tomography method to discover or image a buried waste disposal site in Switzerland. The LVL can also be used to obtain overburden velocities, which are used to determine the quality of the different lithologies. Refraction seismic data can be used to map lateral velocity variation as published by Palmer (1981).

Geophysicists use these weathered layer parameters in the design of receiver-source arrays for field filtering purposes. The unconsolidated layer slows down and absorbs seismic energy, and therefore increases the travel time of the waves through it (Dobrin and Savit, 1988). If this delay is not corrected for, it can lead to errors in depth determinations.

Since the characteristics of the near surface are of high relevance, it becomes necessary for accurate determination of its characteristics. The aim of this research is to compare the results obtained from surface and downhole detector arrays commonly used to determine LVL characteristics.

The Geology of the Niger Delta, Nigeria

This research was carried out in southeast Niger Delta, Nigeria. The Niger Delta is situated at the West African margin of the Gulf of Guinea, which occupies an area located between longitudes $4^{o} – 9^{o}$ E, and latitudes $4^{o} – 6^{o}$ N (Fig. 1). The lithostratigraphic section of the near-surface in the area of survey is demonstrated in Fig. 2. The topsoil is made up predominantly of sand, clay, and clayey sand, while the subsoil is geologically older and physically denser and consolidated with depth. The sand sequence varied in sizes from fine through medium to coarse. The sand is an admixture of the various sizes but demarcation is based on the size as defined by Wentworth scale of classification. The sequences conformed to the typical deltaic depositional environment.

Methodology and Data Acquisition

In this research, both surface and downhole detectors were investigated at twenty seven (27) sites randomly selected. In the downhole detector array method, hydrophone spread consisting of 11 hydrophones at specified interval was lowered into a hole drilled to 66m deep (Fig. 3). Plastic casings were installed in the hole to prevent the hole from collapsing and caving in. Before lowering the hydrophones string, a heavy metal was attached to the end of the hydrophone spread to stabilize it from floating in the borehole water. The hydrophones were spaced from the surface at 1m, 3m, 5m, 10m, 15m, 20m, 25m, 30m, 40m, 50m, and 60m (Fig. 3).

The hydrophones were linked with an electrical cable to the recording instrument. Energy source was 0.2kg dynamite charge buried 1m deep beneath the earth surface from an offset distance of 2m from the downhole position. The charge was electrically controlled and recorded by the McSeis-160MX recording instrument. The observed traveltimes resulted in first breaks as shown in a sample of the monitor record (Fig. 4a). The picked traveltimes were corrected to account for the 2m offset distance from the seismic source to the borehole head. This correction approximates as though the data were recorded with the seismic source placed exactly at the borehole head. The velocities were determined from the corrected traveltimes.

The field set-up of the survey for surface detectors is as shown in Fig. 5. A spread of 12 geophones was planted on the earth's surface. The geophone distances were 5m, 5m, 5m, 5m, 5m, 10m, 10m, 10m, 5m, 5m, 5m, 5m, 5m. Three separate shots, from offsets of 5m, 70m and 135m, made up of 0.2kg dynamite charge were fired. These 3 shots at the same receiver location served as checks for accuracy. The average results for both direct and reverse shots represent the velocity structure of the location. Fig. 4b shows a typical surface detector refraction monitor record. The monitor records were first edited for dead and noisy traces. The arrival times were picked from the traces of the monitor records and used to compute the velocities.

Results and Discussion

The summary of the results are presented in Tables 1 and 2, and Figs. 6-9. For downhole detectors method, the velocity $(V_o)_{dd}$ for the weathered layer varies between 213 ms^{-1} and 696 ms^{-1} with an average of 505 ms^{-1}. For the second layer, the consolidated layer velocity $(V_1)_{dd}$ varies between 1580 ms^{-1} and 1906 ms^{-1} with an average of 1738 ms^{-1}.

For surface-detectors method, the velocity for the weathered layer velocity $(V_o)_{sd}$ varies between 242 ms^{-1} and 763 ms^{-1} with an average of 500 ms^{-1}. The consolidated layer velocity $(V_1)_{sd}$ varies between 1580 ms^{-1} and 1906 ms^{-1} with an average of 1736 ms^{-1}. Figs. 6 – 9 illustrate the relationship between surface seismic and borehole seismic velocities. The statistical correlation coefficient is 0.98 for surface seismic weathered layer velocity V_o and 0.84 for borehole seismic consolidated layer velocity V_1. The mean absolute difference between surface and borehole seismic weathered velocity is 4.6, and that of consolidated velocity is 1.6. Also the ratio of average weathered velocity from surface seismic to that from downhole seismic, while the ratio of average consolidated velocity from surface seismic to that from downhole seismic have the same value of 0.99. These results clearly demonstrate that there is very close linear correlation between the two methods as demonstrated in Fig. 6.

The downhole seismic velocities compare closely with that of surface-detectors, Fig.6. From the results, the difference between the downhole seismic and surface seismic velocities does not show systematic behaviour. Velocities from one method may be more or less than those obtained from the other method. Xia *et al*. (2000) and Yilmaz *et al*. (2008) also made the same conclusion.

The near-surface oil in the area of study has 2 distinct layers specified as follows: (a) Top weathered layer of loose sand sediments with compressional wave velocity ranging from 213 to 763 ms^{-1}, and (b) Subsoil coherent layer with geologically older and physically consolidated layer with compressional wave velocity in the range 1580 – 1906ms^{-1}. Velocity was observed to generally increase with depth, from surface to the refractor and into the consolidated layer continuum, at each location. Assuming a homogeneous, isotropic horizontal layer model, a vertical velocity gradient of 30.5s^{-1} was calculated for the area.Weathered thickness varies substantially in the area of study, ranges between 2.7 and 16.50m with an average of 8.1m. This indicates the necessity to correct for this layer when conducting reflection seismic survey in the area. There was a good agreement when these depths were compared against the 2 surface and downhole seismic methods. In some locations, the difference was between ±4m, which is considered not disastrous to resolution.

An isopach contour map, Fig. 7, was compared with the elevation contour map for possible trending between the two. The area of study is on the flood plain where elevation and weathered thickness are fairly uniform, averaging 4.6m and 8.1m respectively. The weathered velocity and consolidated velocity contour maps (Figs. 8 and 9) do not show any trending with elevation for the same reason of uniform elevation of the study area.

There exists a 7-18% difference between the velocities determined by the surface-wave and downhole methods. The surface-wave method gives spatially-averaged velocities along the line of traverse coincident with the geophone spread. In the case of downhole seismic method, velocities are specifically applicable only to the borehole location. The implication is that downhole measurements can be adversely affected by the local borehole factors and conditions resulting from PVC casings and excessive collapse around the flushed-zone of the borehole. The spatially-averaged velocities and depths estimated by surface-detector method are more reliable for the site-specific characterization for reflection seismology, geotechnical engineering and groundwater.

Conclusion

Based on the results, the following conclusions are made for the south-east Niger Delta:
Two (2) distinct layers make the near-surface made up of mainly loose sand sediments. Weathered thickness varies substantially in the area of study, ranges between 2.7 and 16.50m with an average of 8.1m.

Weathered-layer compressional wave velocity ranges from 213 to 763 ms^{-1}, with an average of 503ms^{-1}. Consolidated-layer compressional wave velocity ranges from 1580 to 1906ms^{-1},

with an average of 737ms^{-1}. A vertical velocity gradient of 30.5s^{-1} was calculated for the area.
Though both surface and downhole seismic methods are linearly correlated, but the surface-wave method gives spatially-averaged velocities along the line of traverse coincident with the geophone spread. Whereas in the case of downhole seismic method, velocities are specifically applicable only to the borehole, which can be adversely affected by borehole casings and excessive collapse around the flushed-zone of the borehole. The spatially-averaged velocities and depths estimated by surface-detector method are more reliable for the site-specific characterization for reflection seismology, geotechnical engineering and groundwater.

Acknowledgement

We thank Shell Petroleum Development Company Nigeria Limited for providing us with the data.

Table 1: Comparison between downhole and surface-detectors on weathered velocity (V_o)

S/n	Station No.	Downhole detector velocity (ms^{-1}) $(V_o)_{dd}$	Surface-detector velocity (ms^{-1}) $(V_o)_{sd}$	% velocity difference	Average weathered layer thickness (m)	Elevation (m)
1.	1220-5823	576	560	3	9.2	3.67
2.	1280-5847	446	423	5	11.2	2.25
3.	1370-5839	417	486	-17	5.5	3.37
4.	1420-5839	428	438	-2	9.8	3.31
5.	1530-5863	696	682	2	9.8	4.46
6.	1600-5847	410	430	-5	5.0	4.7
7.	1600-5743	309	300	3	4.7	4.7
8.	1530-5783	500	442	12	10.7	4.76
9.	1460-5791	405	369	9	2.7	3.93
10.	1370-5767	492	478	3	10.6	3.04
11.	1280-5743	745	687	8	9.5	2.84
12.	1220-5751	573	581	-1	13.9	3.15
13.	1190-5655	377	360	5	2.9	3.26
14.	1280-5671	282	266	6	5.3	3.58
15.	1370-5679	651	670	-3	9.6	3.23
16.	1450-5695	539	523	3	10.4	3.82
17.	1540-5679	359	351	2	2.8	4.84
18.	1190-5567	672	663	1	3.2	3.09
19.	1300-5599	589	609	-3	16.5	4.91
20.	1410-5599	419	449	-7	4.8	4.08
21.	1500-5599	213	242	-14	3.3	5.63
22.	1510-5527	304	298	2	5.5	5.89
23.	1360-5527	608	588	3	8.7	3.63
24.	1180-5495	556	552	1	4.8	4.67
25.	1280-5471	661	670	-1	10.3	3.9
26.	1410-5447	622	614	1	13.1	5.44
27.	1500-5439	781	763	2	13.8	6.12
AVERAGE		505	500	18%	8.1	4.6

Table 2: Comparison between downhole and surface-detectors on consolidated layer velocity (V_1)

S/N	STATION NO.	Downhole detector velocity (ms^{-1}) $(V_1)_{dd}$	Surface- detector velocity (ms^{-1}) $(V_1)_{sd}$	% velocity difference
1.	1220-5823	1748	1741	0.4
2.	1280-5847	1670	1695	-1
3.	1370-5839	1726	1718	0.4
4.	1420-5839	1906	1700	11
5.	1530-5863	1757	1785	-2
6.	1600-5847	1799	1774	1
7.	1600-5743	1699	1787	-5
8.	1530-5783	1651	1717	-0.3
9.	1460-5791	1703	1729	-2
10.	1370-5767	1810	1813	-0.2
11.	1280-5743	1811	1801	1
12.	1220-5751	1712	1712	0
13.	1190-5655	1729	1718	0.6
14.	1280-5671	1719	1718	0.1
15.	1370-5679	1747	1720	2
16.	1450-5695	1580	1592	-1
17.	1540-5679	1719	1691	2
18.	1190-5567	1830	1818	1
19.	1300-5599	1725	1755	-2
20.	1410-5599	1717	1718	-0.1
21.	1500-5599	1750	1741	1
22.	1510-5527	1770	1786	-1
23.	1360-5527	1740	1776	-2
24.	1180-5495	1741	1717	1
25.	1280-5471	1677	1696	-1
26.	1410-5447	1772	1723	3
27.	1500-5439	1712	1724	-1
AVERAGE		1738	1736	7%

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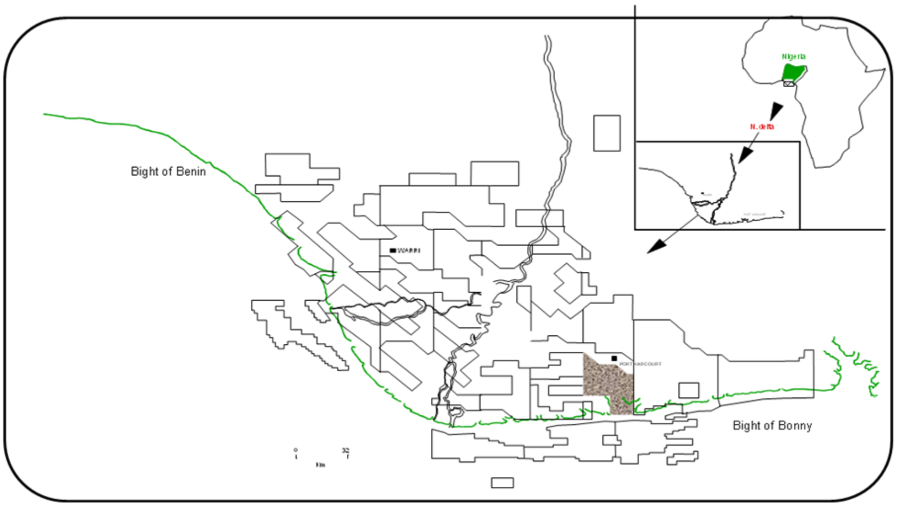

Figure 1: Map of the Niger Delta showing the area of study

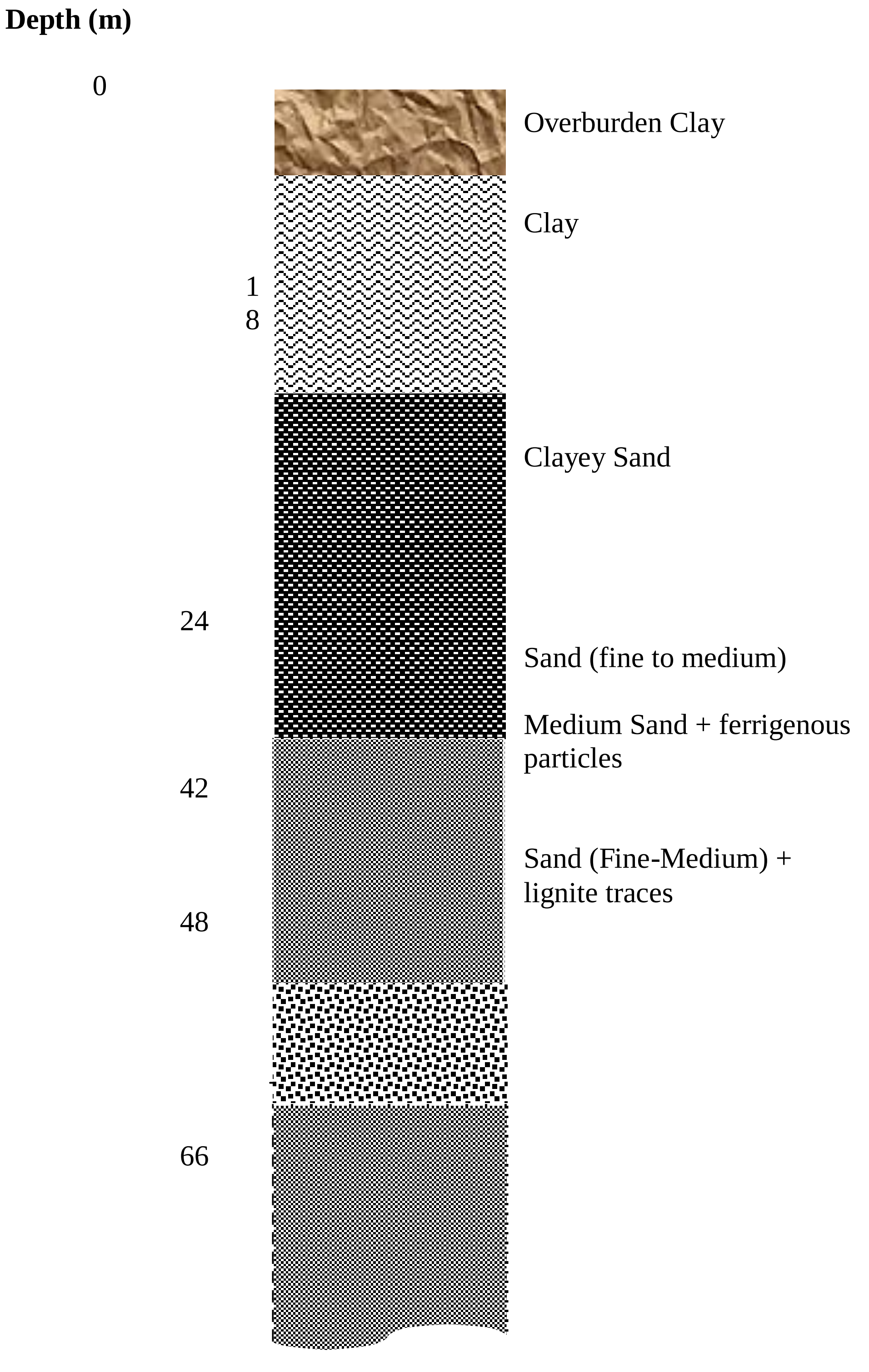

Figure 2: Near-surface showing lithology, example

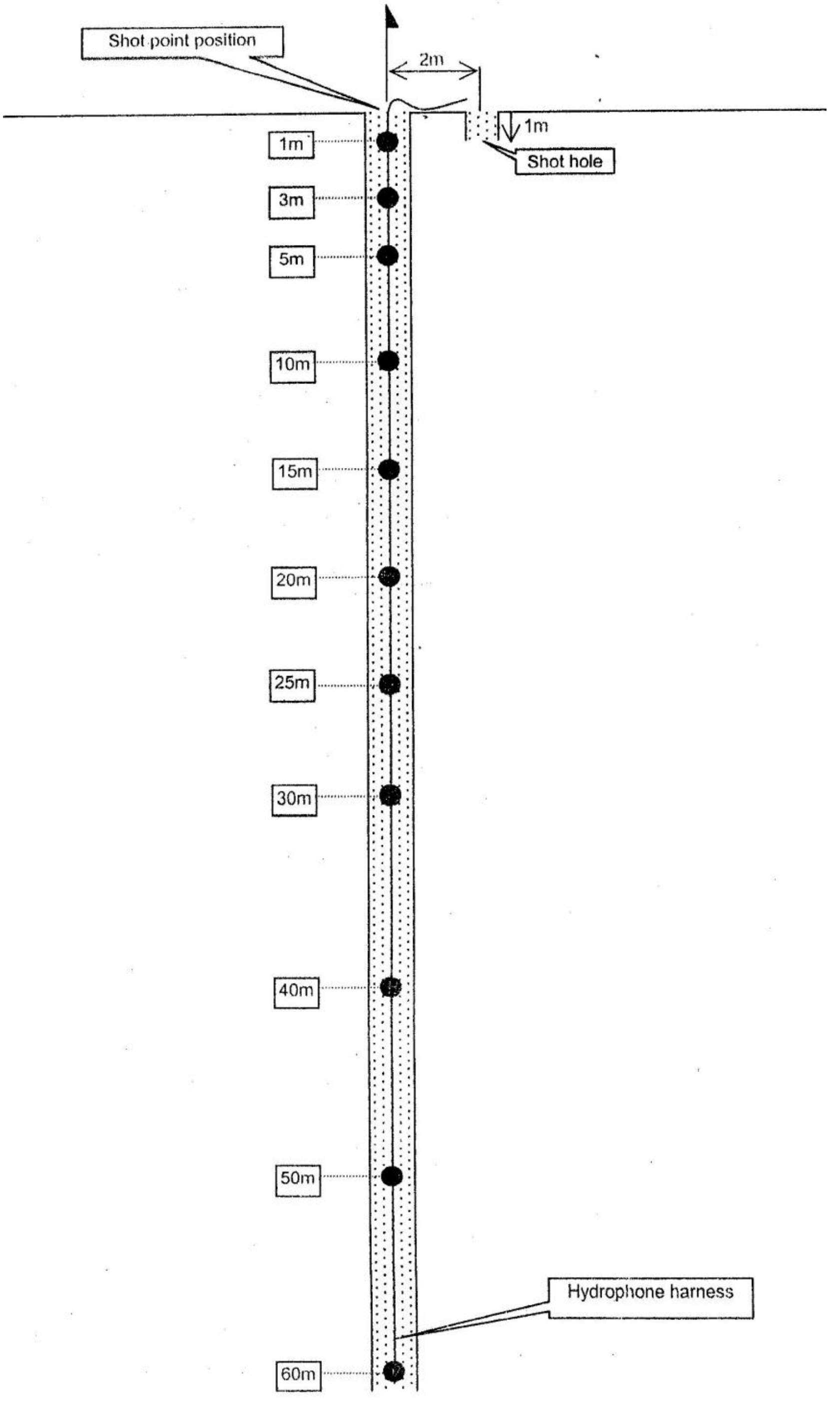

Figure 3: Schematic diagram of downhole-detector array

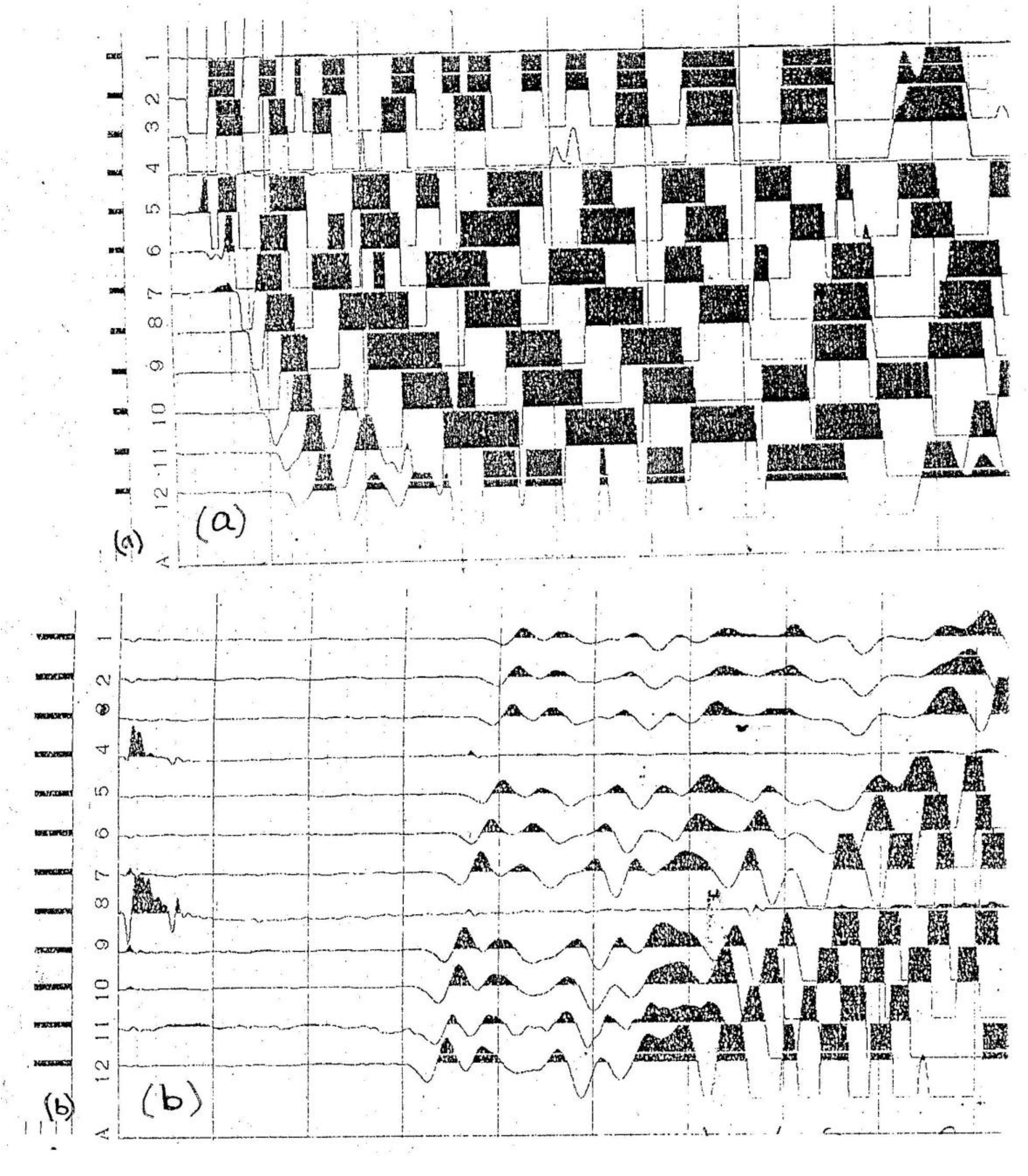

Figure 4: Sample of monitor records from (a) downhole and (b) surface-detector shooting

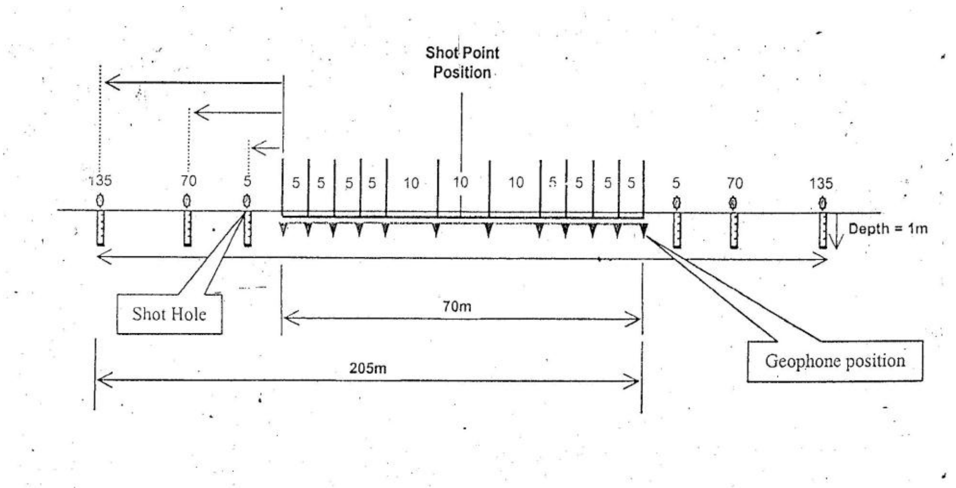

Figure 5: Schematic diagram of surface-detector array

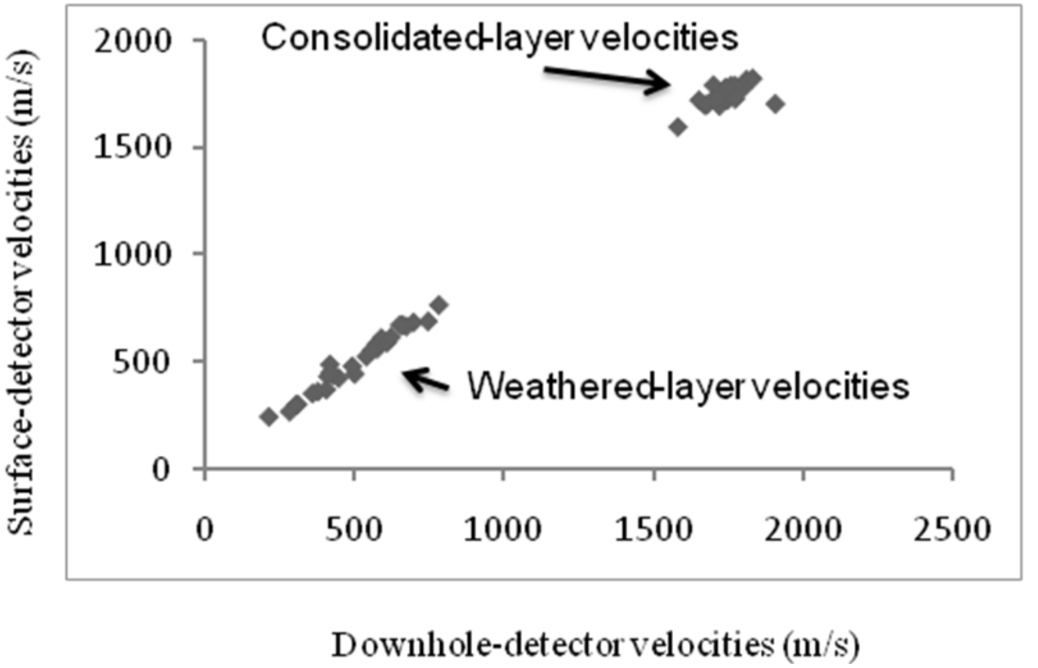

Figure 6: Correlation between surface-detector and downhole-detector velocities.

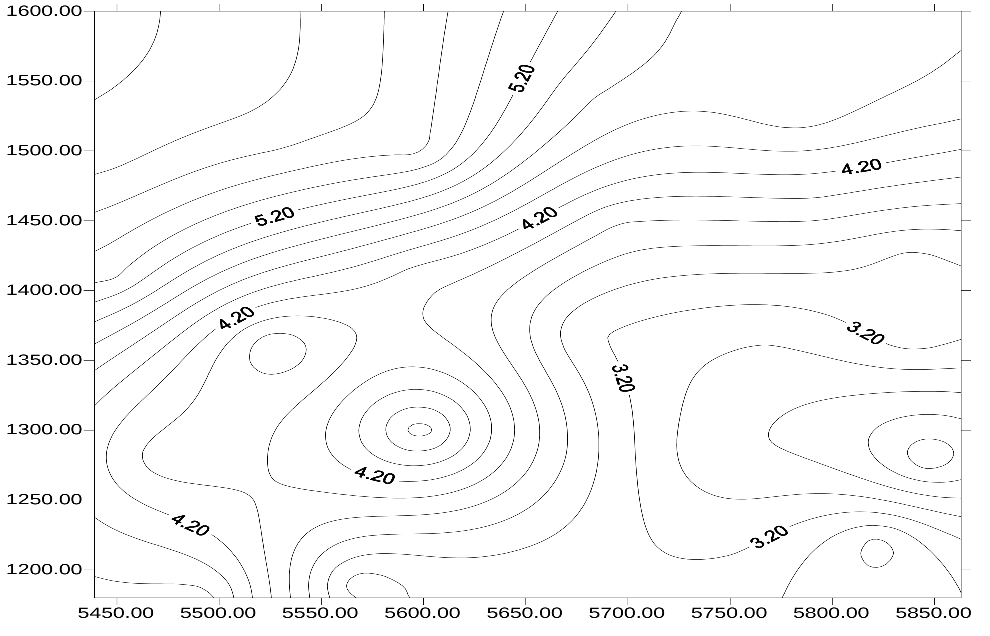

Figure 7: Elevation contour map

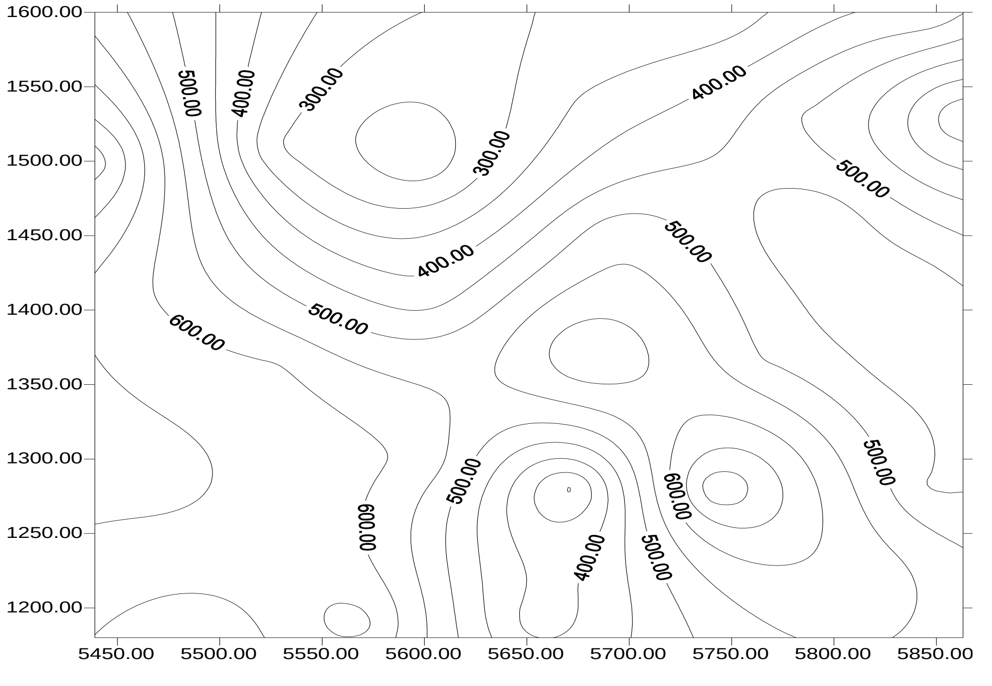

Figure 8: Weathered-layer velocity contour map

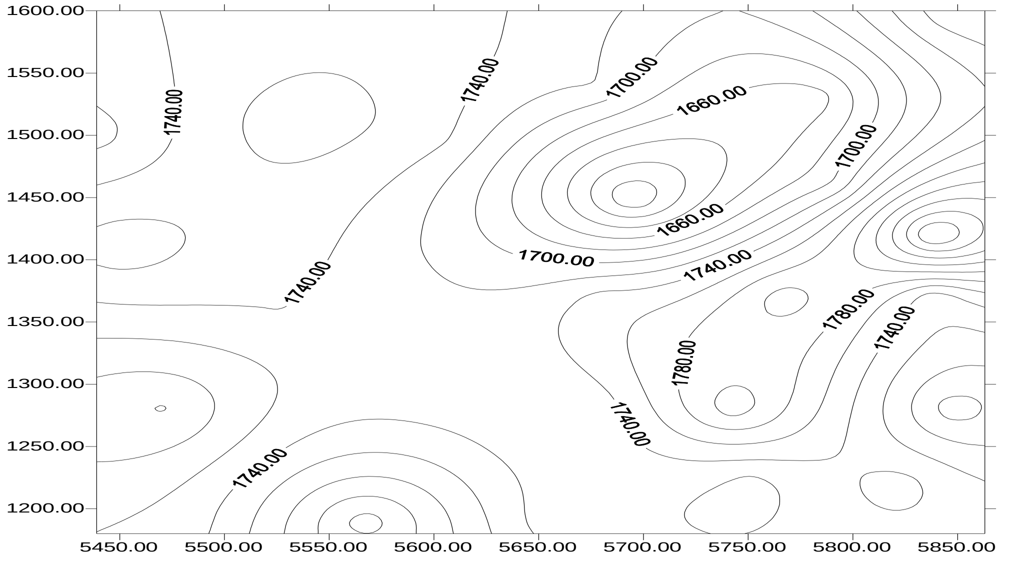

Figure 9: Consolidated-layer velocity contour map