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RESISTIVITY SOUNDINGS IN VICTORIA AND BEACON VALLEYS, ANTARCTICA

INITIAL REPORT FROM K047, 2004

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Contents

Summary

Ground resistivity soundings measured in the McMurdo Dry Valleys indicate that ice, regolith and bedrock can be identified, and that the technique could be useful for studying buried bodies of ice, but only with larger and more intensive surveys. Profile surveys would be needed to constrain the shape of the buried ice bodies, and a spread of several hundred metres might be necessary to measure the total depth to bedrock. Better quality data are obtained from measurements at higher elevation (colder) locations.

N.B.: This report is an initial analysis, with relatively short preparation time and only simple inverse modelling.

1. Introduction

Buried ice exists in several regions within the McMurdo Dry Valleys, and interpretation of its age and origin provides strong constraints on reconstructions of the paleoenvironment. Event K047 in 2004 studied buried ice in two locations: Victoria Valley, and Beacon Valley.

In Victoria Valley, the buried ice may be either lacustrine, from an expanded Lake Vida, or glacial, left after an advance of the Victoria Lower Glacier. K047 aimed to address this question with a number of methods, including gas bubble composition, radiocarbon and OSL dating techniques, and possibly fabric analysis. Resistivity profiles were measured at several sites where ice was sampled, to investigate the electrical properties of the ground where the depth to ice is known.

In Beacon Valley, it has been suggested that the buried ice may be as much as 8 million years old (Sugden et al., 1995; Schäfer et al., 2000, but also see Ng et al., 2005). This has profound implications for Antarctic and global climate reconstructions, and recent studies have concentrated on determining the deposition time of the ice by dating the development of the till layer at the surface. The thickness and distribution of the ice within the valley floor is not known. If it can be determined, it could indicate whether the ice was deposited by a glacier flowing southwards into the valley, of whether it may be related to the rock glaciers flowing from tributary valleys into Beacon Valley. The aim of the resistivity surveys was to measure the electrical properties of the till, ice and bedrock, and if possibly measure the thickness of ice in the middle of the valley.

2. Method

The resistivity measurements were made using a Megger DET 5/4R Earth Tester belonging to Canterbury University. Soundings were measured with a Wenner Array configuration, with four equally spaced electrodes in a line. The maximum spacing between the electrodes was 70 m, resulting in an array spanning 210 m, but this was not always possible due to the terrain. The minimum spacing was usually 0.2 m.

Two sets of electrodes were used: a small (30 cm) set of sharpened steel rods, and a larger (~1 m) set of stakes with foot-rests for pushing them into the ground, and reels of cable attached. In Victoria Valley, the small electrodes were used with short cables allowing measurement out to approx a=7 m. At wider spacings the large electrodes were used, and a duplicate measurement was made at the changeover. Because the ground was often bouldery, and the gear had to be carried some distance to most sites, the large electrodes were not very suitable: they are large and heavy, and were damaged by being hammered into stony ground. In Beacon Valley the cable reels were removed from the large electrodes and used with the small electrodes for the entire sounding.

The Megger unit has a built-in battery, which has to be charged from a 240 V power supply. Although the battery was thought to be in poor condition before the trip, it performed well, usually with two days endurance. It was not necessary to keep the unit warm to improve battery performance.

Locations

The sites and the measurements are described more precisely in Appendix 1. This brief list explains why each site was chosen:

Victoria Valley: These sites are all adjacent to sites sampled by K047 for ice and/or sediment. They sample several types of buried ice, and may help discriminate between them and help us understand how they were deposited.

- VR1 Buried ice in middle of Victoria Valley
- VR2 Buried ice in Hummocky till
- VR3 Buried ice by Victoria Lower Glacier snout
- VR4 Buried ice furthest down valley
- VR5 Delta deposit – no buried massive ice

Beacon Valley: The main aim was to determine the depth to bedrock in the middle of Beacon Valley. To do this, it was necessary to determine the resistivity of bedrock.

- BR1 Site believed to be on thin till over bedrock
- BR1a Repeat measurement of BR1
- BR2 On top of polygon surface in middle of valley
- BR3 In large trough in middle of valley, approx. 5 m below polygon surface
- BR4 High on valley wall, definitely thin regolith over bedrock.

Measurements

At first glance, the measurements seem to be meaningful: they are generally reproducible and form patterns which can be interpreted as changes in the ground's resistivity with depth. The remainder of this Draft Report consists mainly of such interpretations. Some aspects of the sounding measurements remain unexplained. They will be addressed in more detail in a subsequent report.

The character of the readings differed strongly between the two locations (Victoria Valley and Beacon Valley). In Victoria Valley, which is at lower altitude and approximately 10 degrees warmer, the measurements show more scatter. The individual measurements were also more variable, drifting over several minutes before stabilising. Electrode contact errors were also more common. In Beacon Valley all of these problems were much rarer.

3. Interpretation

The resistivity soundings have been interpreted in terms of a 1-dimensional layered model using a demonstration version of the inverse modelling program "IX1D" from Interpex Limited (Golden, Colorado, USA), which runs on computers with the Windows operating system. These interpretations are preliminary, and the results are attached in Appendix 2.

At many of the locations studied, the assumption of horizontal layering is probably reasonably justified. The sites were level, so any sediment layers could be expected to be horizontal and locally continuous. In areas of buried ice, patchy distribution and/or ablation results in a hummocky landscape which we could recognise and avoid in most cases. Notable exceptions included site BR2, where we could not avoid the sounding line crossing cracks between frost polygons, and site BR3, which is in the bottom of a deep trough, probably the result of uneven ablation of buried ice.

Although buried ice may be locally extensive, we should remember that it is not a uniform medium; the folds and contortions observed at outcrop scale probably also occur on a larger scale throughout the buried ice body. The interpreted values of resistivity are therefore 'apparent' values, crudely representative of the ice/sediment mixture.

Victoria Valley

VR1 The resistive bottom layer is consistent with buried ice.

VR2 The very high resistivity basal layer, probably represents buried ice, extending from 2 – 2.5 m depth to beyond the limit of the sounding.

VR3 The model suggests a layer of pure ice approx 14 m thick. The value of resistivity for this layer is quite similar to that obtained from pure ice on Lake Vanda by Clark (1971)

VR4 The sounding is not useful for interpreting the depth of buried ice. The conductive layer may be due to liquid brine in the sediment on top of the ice.

VR5 The model suggests a resistive layer at 0.8 – 2 m, similar to the buried ice in VR3. This is unexpected here – the delta deposits should contain no massive ice, and none is seen in the eroded sections.

Beacon Valley

BR1 Resistivities are generally low, indicating no ice at this site.

BR1a The pattern of BR1a reproduces BR1 quite well, though the resistivities are consistently lower 6 days after the first measurement. Due possibly to the warm weather in that time Clark (1971) showed that the resistivity of the rock types found as bedrock in this area varies strongly with temperature, making it difficult to draw a strong conclusion from this sounding.

BR2 A complicated sounding was not unexpected here, with the known relationships of ice and till in the polygons, and some differentiation of the sediment on the polygons (e.g. ash layers, infilled fossil cracks). The resistive basal layer may be buried ice.

BR3 Surprisingly, no indication of high resistivity associated with buried ice.

BR4 Probably a reliable measurement of the resistivity of the Beacon sandstone.

4. Discussion

Comparison with earlier work

There has not yet been a detailed comparison between these results and those of Clark (1971). With time, estimating the ground temperatures at our measurement sites (from annual fluctuations and conduction) may allow a better correlation between his laboratory-measured valued and our field measurements.

Repeatability

Several attempts were made to determine whether the measurements were repeatable. Usually this was done at a natural pause in the work (e.g. lunch break or assisting the other K047 members). The time delay between measurements was therefore on the order of 1 hour, and the electrodes were not removed and replaced. Only at one site was a sounding remeasured after a lapse of several days: sounding BR1, at the camp location in Beacon Valley. This was first measured (BR1) on December 3, and partially repeated on December 9 (BR1a). The results of the two soundings are shown in Figure 1.

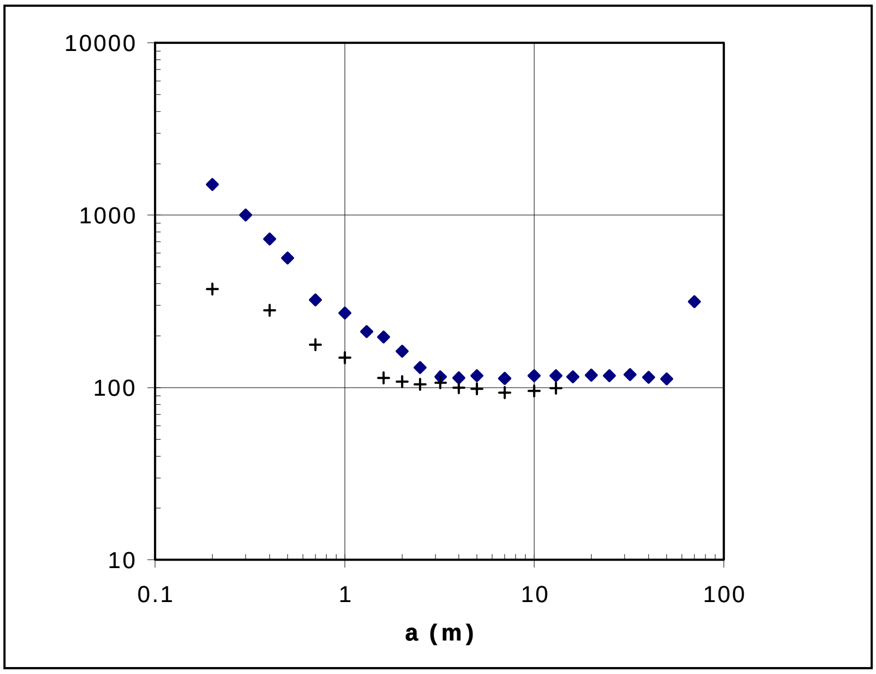

Figure 1: Resistivity soundings BR1 and BR1a, measured 6 days apart at the same site.

5. Acknowledgements

Warren Dickinson, Andrew Mackintosh and Leigh Hyland were excellent company in the field. The Megger resistivity meter and electrodes were generously lent by David Nobes (Canterbury University). Antarctica New Zealand provided logistic support for the field work.

6. References

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Appendix 1: Resistivity sounding measurements

The following tables give the measurement of apparent resistivity (R_E) at each electrode spacing *a* in the Wenner array. All readings were repeated after 2 minutes to check for stability. As mentioned above in section 2, in many cases (especially in Victoria Valley) the measurements were not stable, and the value of R_E given here is the final value of a series which converged over several minutes.

VR1

Location: UTM zone 58 C 0435245 1410353
Date: 20 November 2004
Description: In the middle of Victoria Valley, in front of the Packard Glacier valley. Surface mostly loose dry sand. Close to this site (< 50 m away) clear ice lies approx. 25 cm below the surface, and this was sampled by K047.

a (m)	R_E (ohms)
0.8	7590
1	9000
1.3	4440
1.3	5110
1.8	4130
2.5	3340
3.2	1439
4	9820
5	1835
8	4100
8	2540
5	715
10	1895
13	3020
25	19970
32	3970
40	4980
50	9330
70	15320

VR2

Location: UTM zone 58 C 0435205 1410307
Date: 23, 24 November 2004
Description: Above right bank of 'gorge' in Victoria Lower Valley stream, close to 'chaotica' outcrop (extensively sampled by K047). Visible section is apparently 6 m of sand and till over 10 m of deformed ice and bedded sediment.

a	R_E
0.2	11730
0.3	off scale
0.4	8470
0.5	5580
0.8	2640
1	2210
1.3	1767
1.6	1665
2	1453
2.5	934
3.2	880
4	498
5	287
8	748
6.5	311
10	914
10	1300
13	1980
16	2140
20	3630
25	3950
32	9290
40	6690

VR3

Location: UTM zone 58 C 0435423 1411304
Date: 26 November 2004
Description: 50 m from front of Victoria Lower Glacier, on flat sand surface beside bulging pond ice. 5 cm dry sand over 20 cm bedded sand and snow, over clean pond ice. Pond ice sampled by K047.

a	R_E
0.2	off scale (>20000)
0.3	off scale
0.4	off scale
0.5	off scale
0.7	18600
1	14600
1.3	16110
1.6	16980
2	16940
2.5	9690
3.2	16460
4	14650
5	13980
7	13890
10	13220
10	13340
13	9350
16	8300
20	8430

VR4

Location: UTM zone 58 C 0430537 1409430
Date: 27 November 2004
Description: On right bank of Victoria Lower Valley stream, adjacent to 'karma' outcrop where deformed ice is exposed in the 2 m scarp of the stream bank. Ice and sediment sampled by K047.

a	R_E
0.2	6.5
0.3	5.11
0.4	3.15
0.5	1.837
0.6	1.391
0.8	1.275
1	0.749
1.3	0.713
1.6	0.298
2	0.104
2.5	0.127
3.2	0.794
4	0.412
5	8.61
4.5	1.038
7	1.871
10	1.575
10	1.081
13	1.387
16	2.14
20	0.286
25	0.451
28	16.09
32	20
40	20

VR5

Location: UTM zone 58 C 0428308 1407527
Date: 29 November 2004
Description: On flat upper surface of delta at east end of Lake Vida. East end of line is adjacent to scarp where algal sediments were sampled for OSL and C-14.

a	R_E
0.2	8460
0.3	5730
0.4	4550
0.5	3700
0.7	2740
1	1138
1.3	807
1.6	654
2	1264
2.5	1395
3.2	819
4	3570
5	1012
7	6870
10	1750
10	2560
13	343
16	917

20	263
25	360
32	173.6
40	126

BR1

Location: 25 m upslope from tents at Beacon Valley camp
Date: 3 December 2004
Description: On dolerite pebble armoured surface over finer sediment. Above the polygons in the valley floor, and at base of till slope at the mouth of Farnell Valley

a	R_E
0.2	1497
0.3	1002
0.4	728
0.5	563
0.7	322
1	270
1.3	211
1.6	197
2	163
2.5	131
3.2	116
4	114.1
5	117
7	113.1
7	112.9
10	117.2
13	117.6
16	115.4
20	118.2
25	117.5
32	119
40	114.4
50	112.1
70	316

BR1a

Location: 1 m upslope from BR1
Date 9 December 2004
Description: repeat measurement of BR1

a	R_E
0.2	373
0.4	280
0.7	177.2
1	149
1.6	114.1
2	108.7
2.5	104.7
3.2	106.9
4	100.1
5	98.7
7	93.9
10	95.9
13	99

BR2 (incomplete)

Location: On polygon surface adjacent to the sites sampled for ice and OSL, near instrumented polygon.
Date: 4, 5 December 2004
Description: Central part of line (until a=30 m) on large flat surface of 3 adjacent polygons with only weak cracks between them. Extension of line (to a=70 m) crosses polygons over cracks approx. 2 m deep.

a	R_E
0.2	500
0.3	370
0.4	353
0.5	376
0.7	275
1	274
1.3	280
1.6	292
2	349
2.5	419
3.2	477
4	523
5	529
7	420
10	329
13	363
16	351
20	422

BR3

Location: Along 5 m deep trough in middle of Beacon Valley, adjacent to BR2
Date: 7 December 2004
Description:

a	R_E
0.2	493
0.3	279
0.4	203
0.5	171
0.7	148.7
1	140.4
1.3	136.8
1.6	132
2	137.1
2.5	141.8
3.2	147.7
4	158.7
5	162.1
7	157.1
10	154.4
13	150
16	166
20	180.8
25	202
32	219
40	238
50	249

60	246

BR4

Location: UTM zone 57 C 0537862 1354814
Date: 8 December 2004
Description: high on wall of Beacon Valley, below Vestal Spur. 50 m from outcropping Beacon sandstone, so almost certainly on this regolith cover.

a	R_E
0.2	2360
0.3	1113
0.4	1027
0.5	678
0.7	659
1	595
1.3	518
1.6	455
2	395
2.5	369
3.2	353
4	329
5	296
7	259
10	235
13	220
16	230
20	222
25	221
32	208
40	199

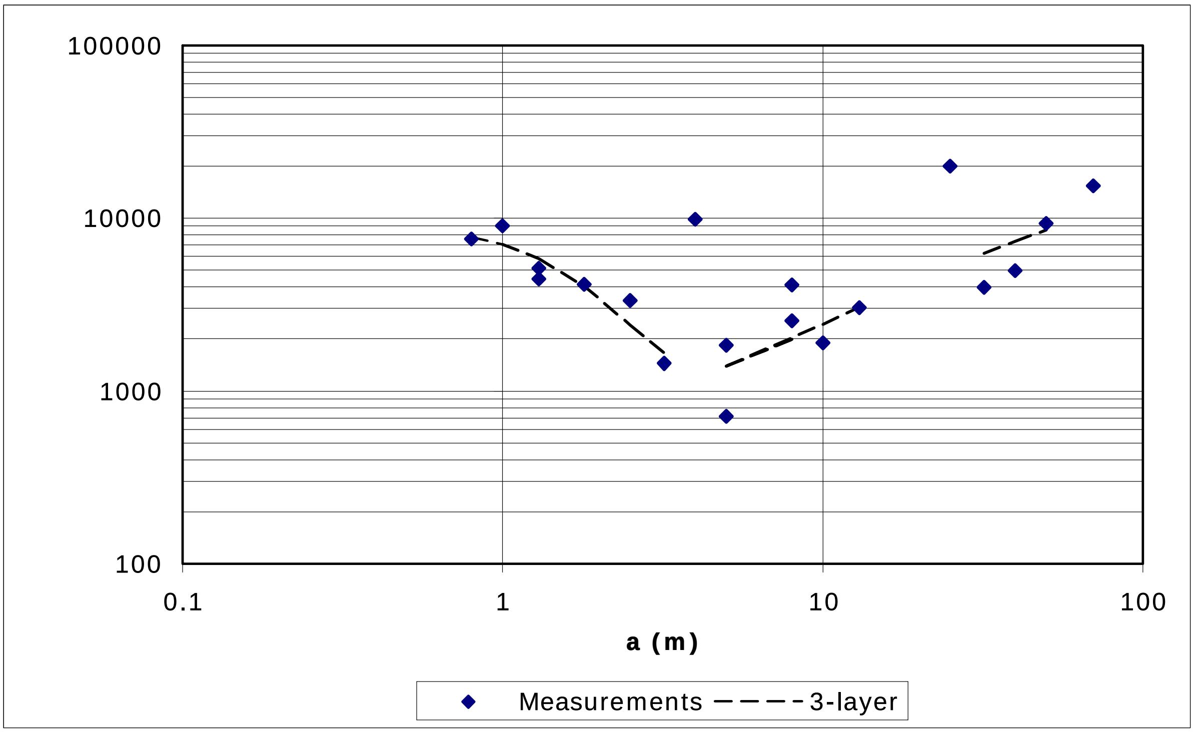
Appendix 2: Ground resistivity models

These are the models obtained using the demo version of the inverse modelling programme IX1D, as described above in section 3. For each model, the synthetic resistivity sounding is plotted for comparison with the actual measurements. Some data are missing: not all RMS fit values were noted, and in some cases outlying data points were excluded from the fit, but that is not noted here. The model output format also resulted in layers thinner than 0.1 m or less than 0.1 ohm-m being presented as of zero thickness/resistivity. These omissions should be rectified in the final version of this report.

VR1

Layers: 3 RMS:

Layer	Resistivity (ohm.m)	Thickness (m)	Depth (m)
1	8943.1	1.2	1.2
2	345.8	1.7	2.9
3	19692.6		



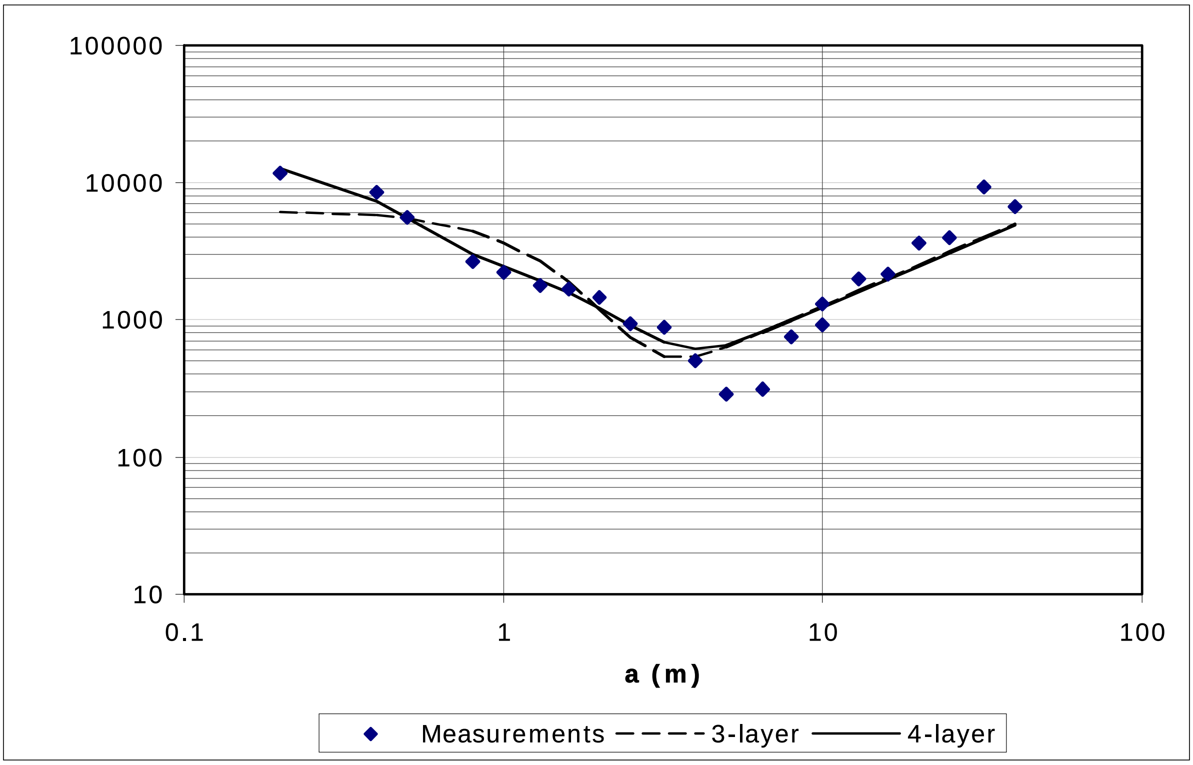
VR2

Layers: 3 RMS: 56.27%

Layer	Resistivity (ohm.m)	Thickness (m)	Depth (m)
1	6160.3	0.9	0.9
2	113.8	1.2	2.1
3	2246277.0		

Layers: 4 RMS:

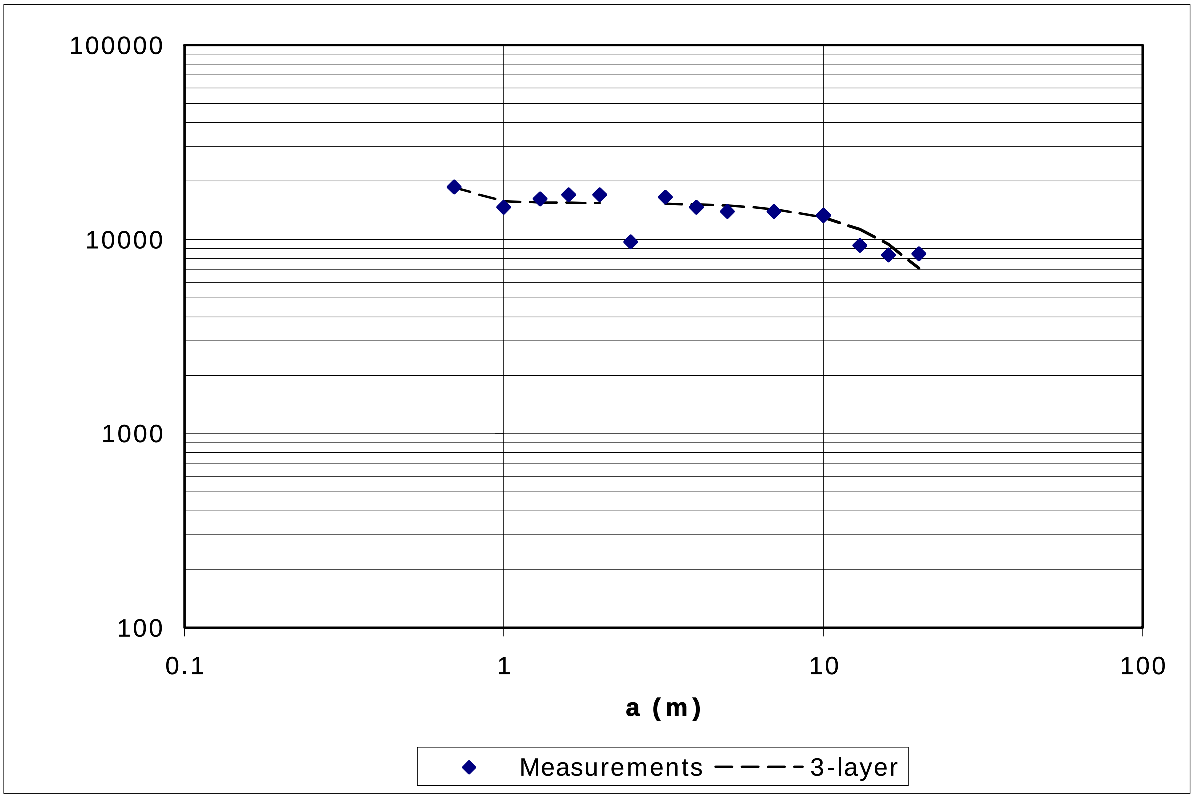
Layer	Resistivity (ohm.m)	Thickness (m)	Depth (m)
1	15273.1	0.2	0.2
2	2391.1	1.2	1.5
3	103.5	1.1	2.6
4	2215270.0		



VR3

Layers: 3 RMS: 9.62%

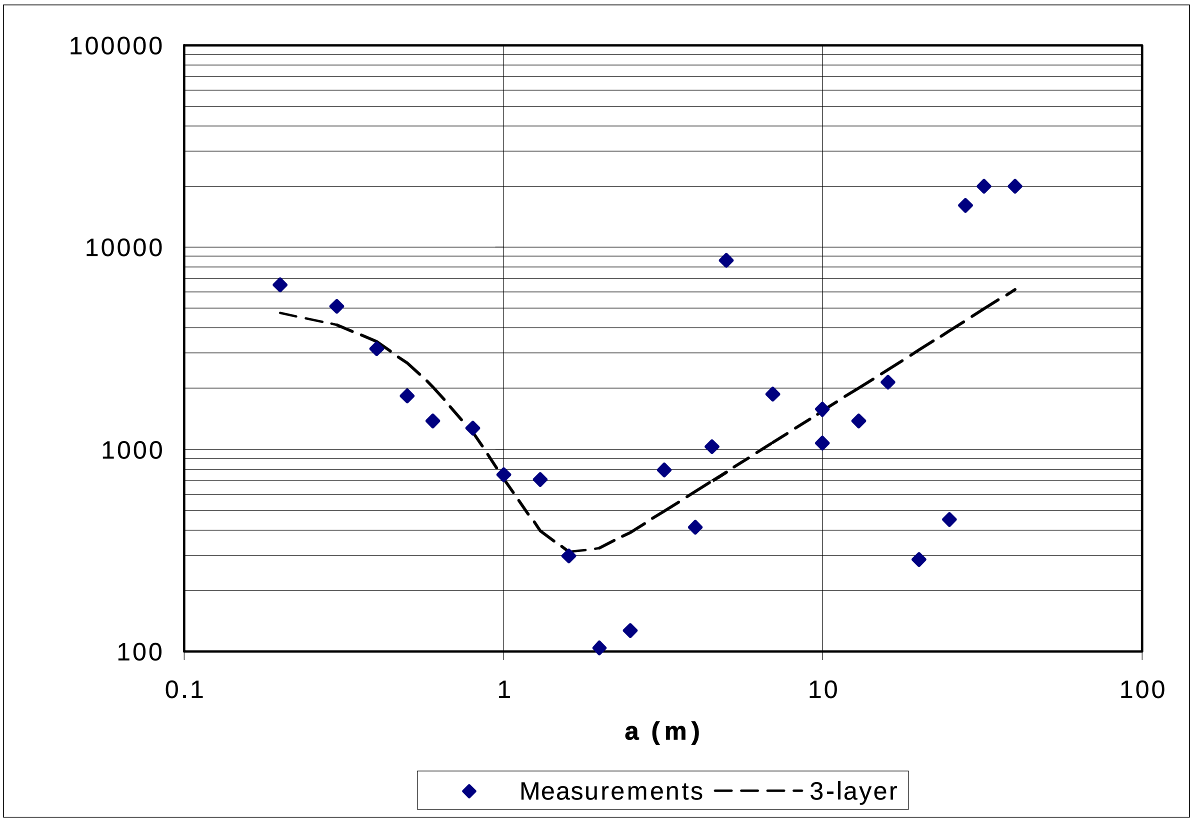
Layer	Resistivity (ohm.m)	Thickness (m)	Depth (m)
1	3035076.2	0.1	0.1
2	15313.2	14.3	14.4
3	17.3		



VR4

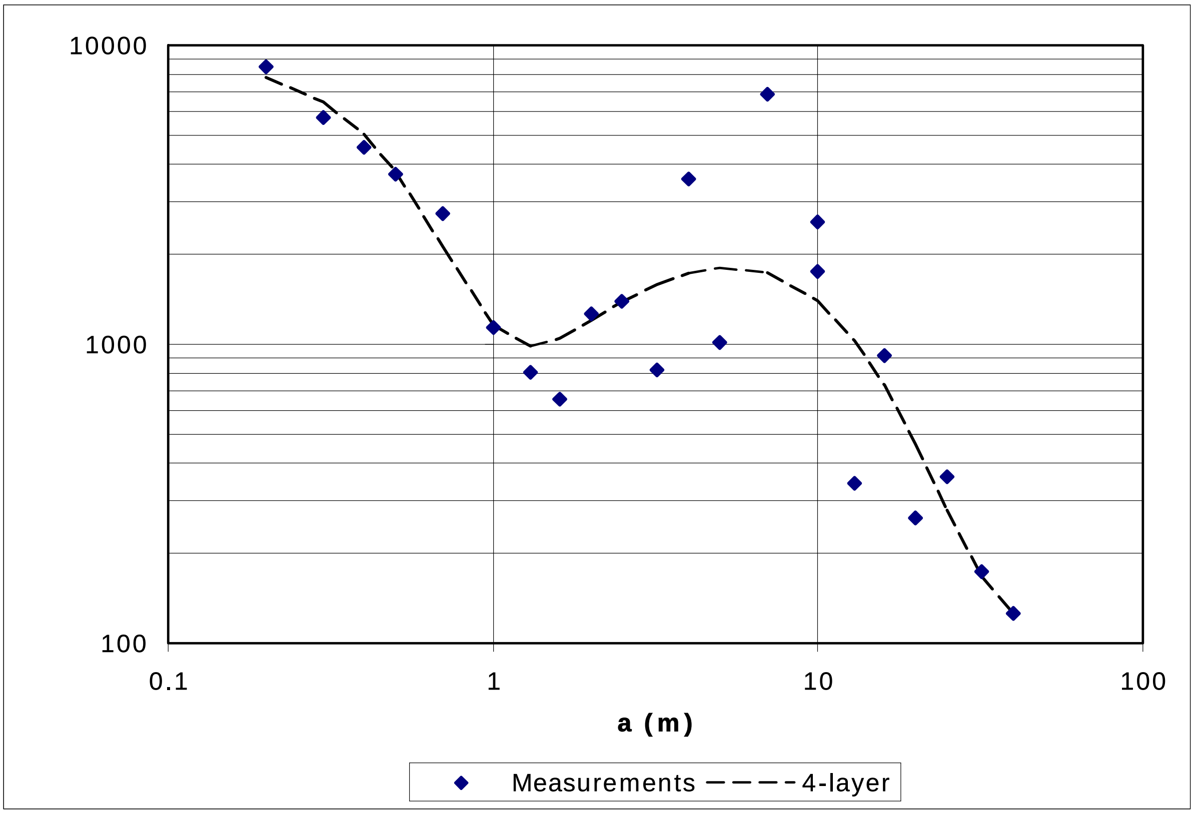
Layers: 3 RMS: 175%

Layer	Resistivity (ohm.m)	Thickness (m)	Depth (m)
1	5.1	0.4	0.4
2	0.0	0.0	0.4
3	2347.8		



VR5

Layers: 4		RMS: 65.75%	
Layer	Resistivity (ohm.m)	Thickness (m)	Depth (m)
1	8721.5	0.3	0.3
2	278.6	0.5	0.8
3	13213.5	1.2	2.0
4	103.4		



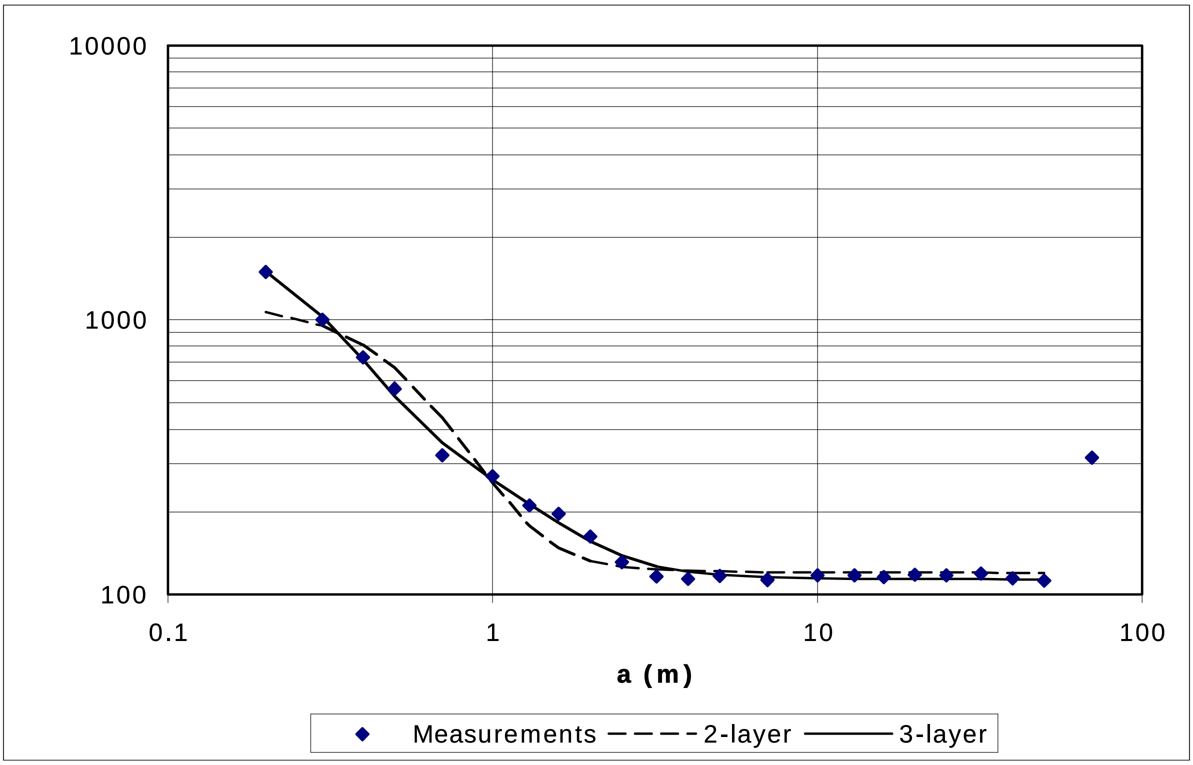
BR1

Layers: 2 — RMS: 14.95%

Layer	Resistivity (ohm.m)	Thickness (m)	Depth (m)
1	1140.3	0.4	0.4
2	120.1		

Layers: 3 — RMS: 4.63%

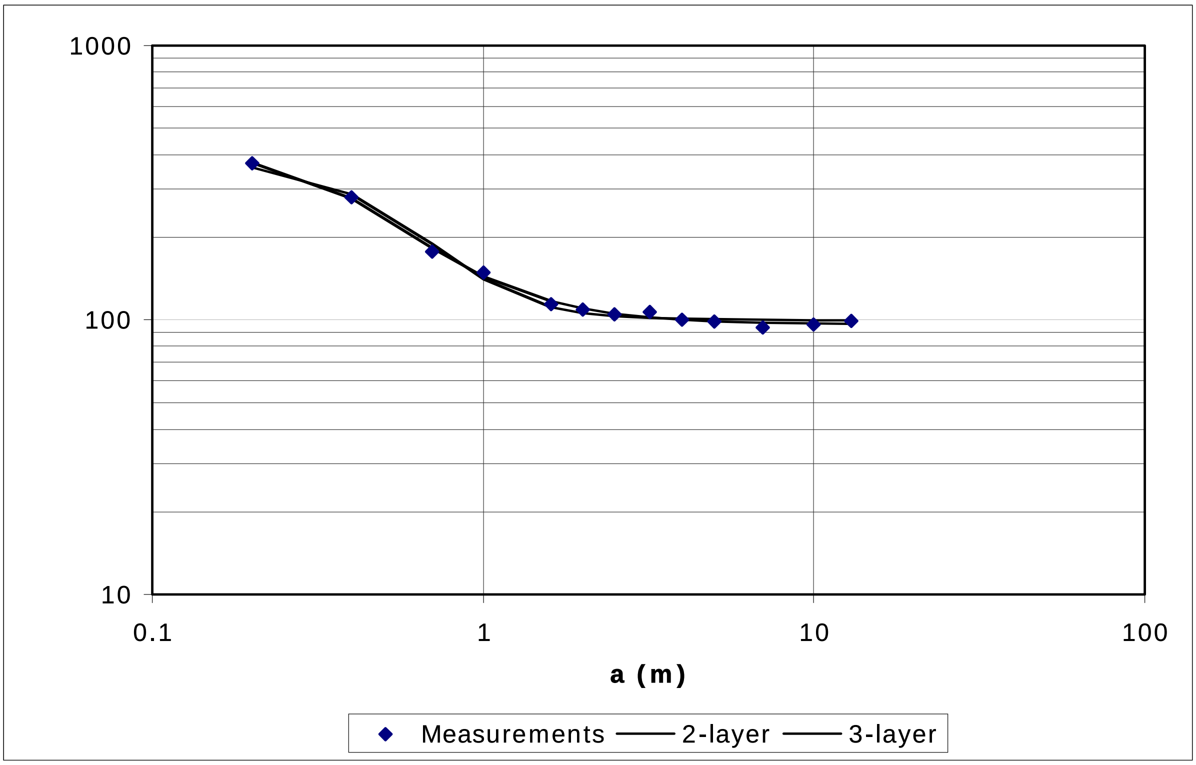
Layer	Resistivity (ohm.m)	Thickness (m)	Depth (m)
1	2124.9	0.2	0.2
2	327.6	0.7	0.9
3	113.6		



BR1a

Layers: 2		RMS: 3.88%	
Layer	Resistivity (ohm.m)	Thickness (m)	Depth (m)
1	382.3	0.3	0.3
2	99.5		

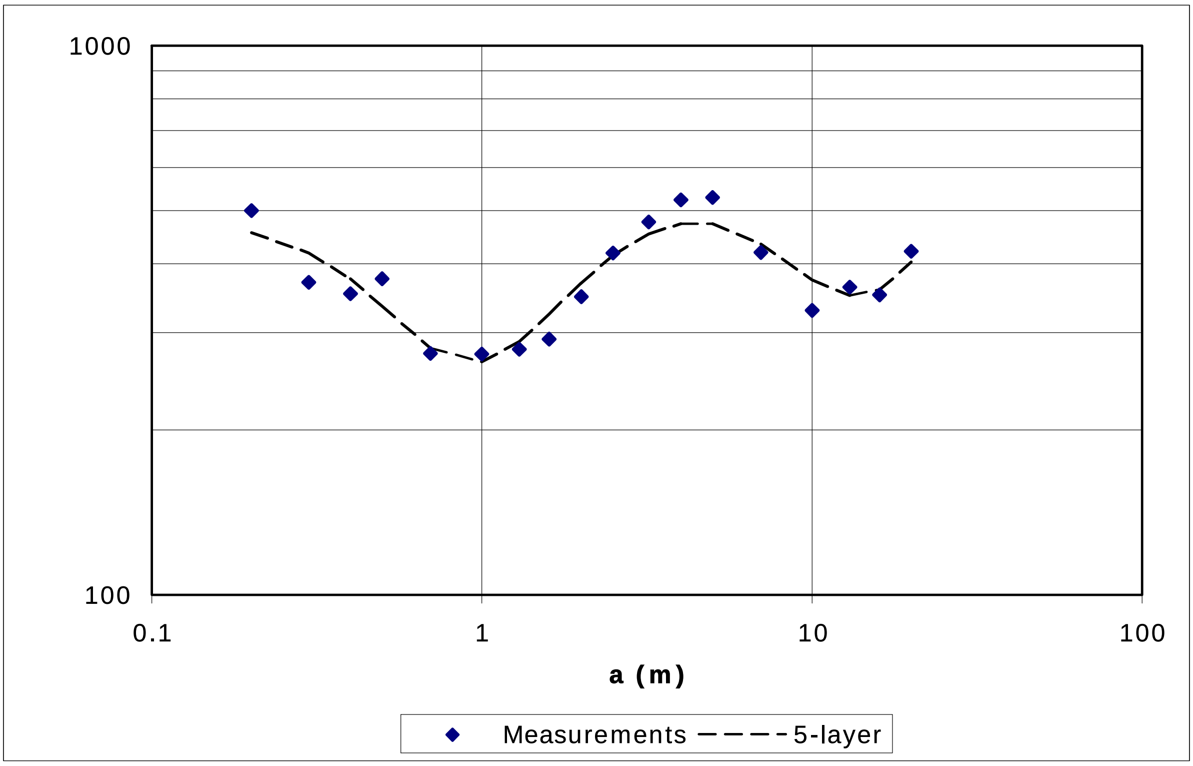
Layers: 3		RMS: 2.46%	
Layer	Resistivity (ohm.m)	Thickness (m)	Depth (m)
1	412.5	0.3	0.3
2	129.5	0.6	0.9
3	96.5		



BR2

Layers: 5 RMS:

Layer	Resistivity (ohm.m)	Thickness (m)	Depth (m)
1	478.7	0.4	0.4
2	0.7	0.0	0.4
3	3048.8	1.0	1.4
4	8.2	0.5	1.9
5	9454.5		



BR3

Layers: 3 RMS: 4.94%

Layer	Resistivity (ohm.m)	Thickness (m)	Depth (m)
1	1119.0	0.1	0.1
2	142.8	13.7	13.8
3	302.6		

Layers: 4 RMS: 4.77%

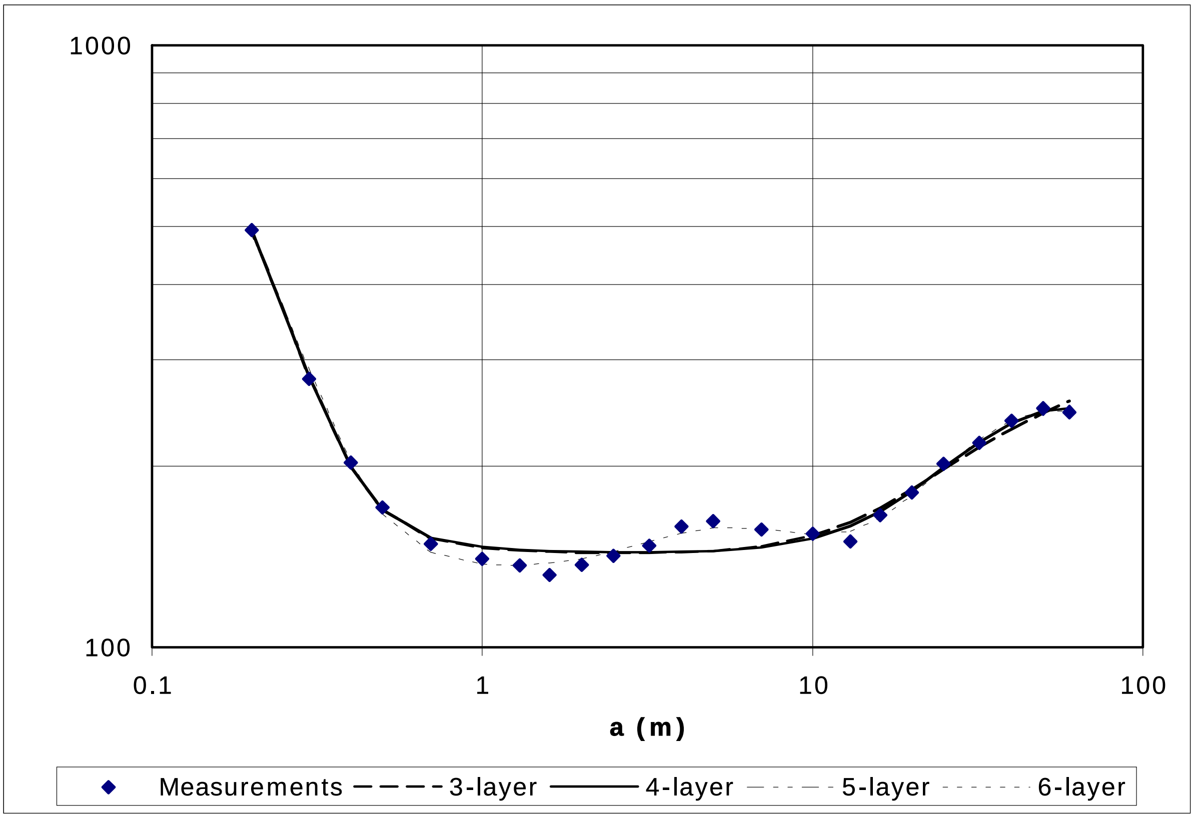
Layer	Resistivity (ohm.m)	Thickness (m)	Depth (m)
1	1127.5	0.1	0.1
2	143.3	18.6	18.7
3	673.9	22.1	40.8
4	107.8		

Layers: 5 RMS: 4.78%

Layer	Resistivity (ohm.m)	Thickness (m)	Depth (m)
1	1127.3	0.1	0.1
2	143.3	14.8	14.9
3	140.6	3.9	18.8
4	758.1	17.6	36.4
5	129.6		

Layers: 6 RMS: 2.20%

Layer	Resistivity (ohm.m)	Thickness (m)	Depth (m)
1	931.6	0.1	0.1
2	131.9	3.0	3.1
3	714.6	0.9	4.0
4	46.9	4.5	8.5
5	747.2	21.7	30.2
6	86.4		



BR4

Layers: 2		RMS: 25.85%	
Layer	Resistivity (ohm.m)	Thickness (m)	Depth (m)
1	1192.3	0.6	0.6
2	249.2		

Layers: 3		RMS: 7.99%	
Layer	Resistivity (ohm.m)	Thickness (m)	Depth (m)
1	4167.5	0.1	0.1
2	554.0	1.7	1.8
3	218.4