LICENCE TO McMASTER UNIVERSITY

This Thesis has been written
[Thesis, Project Report, etc.]

by Danielle Heather Parker for
[Full Name(s)]
Undergraduate course number 4K06 at McMaster University under the supervision/direction of Dr. R. G. Walker.

In the interest of furthering teaching and research, I/we hereby grant to McMaster University:

1. The ownership of 5 copy(ies) of this work;
2. A non-exclusive licence to make copies of this work, (or any part thereof) the copyright of which is vested in me/us, for the full term of the copyright, or for so long as may be legally permitted. Such copies shall only be made in response to a written request from the Library or any University or similar institution.

I/we further acknowledge that this work (or a surrogate copy thereof) may be consulted without restriction by any interested person.

R. G. Walker
Signature of Witness, Supervisor

Danielle Parker
Signature of Student

June 5/96
date

(This Licence to be bound with the work)

The Search for Episodic Remobilization of Basement Faults as a Controlling Mechanism on the Location and Trend of the Joffre and Fenn Linear Cretaceous Sand Bodies.

By

Danielle Parker

B.A.

The Search for Episodic Remobilization of Basement Faults as a Controlling Mechanism on the Location and Trend of the Joffre and Fenn Linear Cretaceous Sand Bodies.

By

Danielle Parker

Bachelor of Arts Thesis

McMaster University

May 1996

Table of Contents

Acknowledgements

I would like to thank my advisor, Dr. R. G. Walker, for the opportunity to work with him and for all the time he put it into advising me. I would like to acknowledge Lithoprobe who funded the collection of research for this project. I would also like to acknowledge Amoco Canada Petroleum Company Ltd. for the use of their facilities while I collected the research for this project at their offices in Calgary. I would especially like to thank the staff in the Production department for their cooperation and friendliness.

Thank-you to my family for their unconditional support and for sacrificing the car on so many weekends. Thank-you to my brother Dave, without whose printer, this project would have been dull and colourless. Thanks to everyone in the sedimentary lab for their encouragement and for putting up with a bachelor student monopolizing the computer. Thanks especially to Vicky whose constant encouragement and co-suffering kept me sane. And finally, thank-you Salman, for your support and for understanding when this project took over my life.

Abstract

The Alberta foreland basin is marked by long (up to 160 km), linear sandbodies that trend in NW-SE and NNW-SSE directions. This long linear nature has brought attention to this area and has initiated a search for a mechanism controlling the position and geometry of the sandbodies. The purpose of this thesis is to test Hart and Plint's theory that the sandbody trends were controlled by episodic remobilization of basement faults. The larger part of the Cretaceous stratigraphy (of the Alberta Group) is looked at in the area of the Joffre and Fenn fields for consistent thickness variations that would indicate episodic remobilization of basement faults. Underlying basement trends in this area run NE-SW, perpendicular to the trend of the sandbodies.

No consistent trends were found in this area during the Cretaceous period. There was a complete lack of NE-SW trends which one would expect to find if NE-SW basement trends were being remobilized. It follows that remobilization of basement faults, as described by Hart and Plint (1993), were not occurring in this area during the deposition of the Viking sandbodies. Therefore, the Joffre and Fenn linear sandbodies are attributed to sedimentological controls, subsidence and eustatic sea level changes and not to episodic basement movements.

I. Introduction

I. 1 Problem

The Cretaceous Alberta basin is marked by long linear sandbodies that trend in NW-SE and NNW-SSE directions. These sandbody trends extend for long distances, up to 160 km, and are traceable across southern Alberta (Fig. 1). These linear hydrocarbon trends of common strike, have produced oil and gas from the Lower Cretaceous Viking and the Upper Cretaceous Cardium sands. The long linear nature of the sandbodies has brought attention to this area because nothing in nature is found to be this long and linear without a controlling mechanism. This has initiated a search for a mechanism controlling the position and geometry of the sandbodies. There are at least three possible controls that have been postulated. One possibility is that they are purely fault controlled. A second possibility is that they are purely sedimentologically controlled. A third possibility is that structure and sedimentology are both affecting the geometry and position of the sand bodies.

The theory that the sandbodies are purely fault controlled was first suggested by Jones (1980, p. 211) who noted that "numerous widespread vertical faults within the Alberta-British Columbia portion of the Western Canadian Basin have effectively controlled the position of a large number of stratigraphic (clastic and carbonate), structural, and diagenetic hydrocarbon traps. These faults are characterized by comparatively long strike lengths, appear to penetrate to the asthenosphere, and show vertical movement that acted to maintain or restore the isostatic equilibrium of the lithosphere during one or more widely separated geological time periods." Jones' theory of vertical faulting might explain why the sandbodies are so long and linear; however, his theory is dependent on faults that penetrate through the entire asthenosphere, which is unlikely.

An alternative possibility for the long, straight geometry is the idea that the sandbodies are purely sedimentologically controlled. The long linear sandbodies

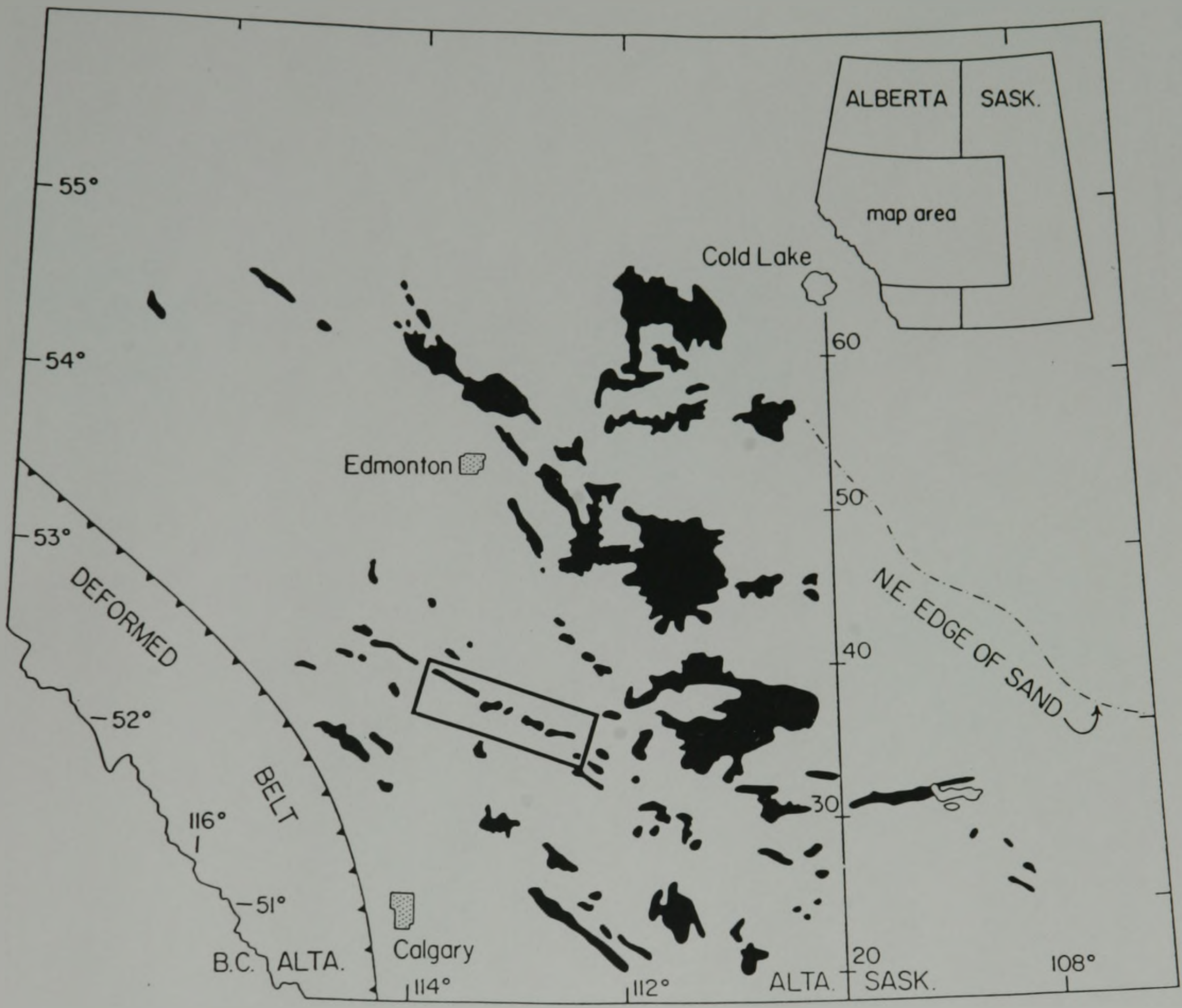


Figure 1. - Location and trend of linear Cretaceous sandbodies which trend NW-SE across the Alberta Basin. The area outlined by a black rectangle is the study area. This map has been adapted from Downing and Walker, 1988.

were originally interpreted to be off shore bars, deposited on the shelf and then stranded during subsequent sea level rise. However, "there are several problems with this interpretation, namely how the sediment was transported across the shelf and molded into ridges with internal coarsening-upward sequences". (Downing and Walker, 1988, p.1)

A second, more accepted interpretation has been put forth by Downing and Walker, who have interpreted the Joffre field to be "an incised shoreface cut during sea level lowstand. During the lowstand, sand and granules were supplied to the shoreface by incised or wave-generated currents. An ensuing rise of sea level covered the sands with marine muds and planed off any evidence of subaerial exposure southwest of the field, leaving only a transgressive lag." (1988, p. 1) Downing and Walker propose that the different linear trends in the sandbodies represent incised shorelines formed during different lowstands at different times in the history of the basin in an overall transgression of sea level. However, the problem remains that we do not see long linear shorefacies in the modern world. This would suggest that there is a second mechanism controlling the linearity of the sandbody trends.

It is also possible that faulting influenced the position of shoreline incision during a transgression. In other words, both faulting and sedimentology acted to control the geometry and position of the sandbodies. Hart and Plint have suggested that "basement structures were being remobilized during Cardium deposition, possibly in response to thrusting in the orogenic belt, and this is why trends of isopachs, facies transitions, erosional bevels on transgressive erosion surfaces, synsedimentary faults and modern production trends closely correspond to basement structural trends ... Our results suggest that patterns of deposition and erosion have been strongly influenced by episodic reactivation of pre-existing basement structural elements." (1993, p.2)

It is Hart and Plint's idea that the episodic remobilization of basement activity controlled the position and geometry of the linear sandbody trends that is tested in this thesis. This paper applies Hart and Plint's explanation of the trend of the linear sandbodies to two Viking sandbodies, namely the Joffre and the Fenn formations. Hart and Plint have concluded that basement activity has controlled the deposition and erosion of the Cardium in an area in the NW portion of the Alberta basin which is influenced by the Peace River Arch and the deformation front. Their study area is underlain by NW-SE basement trends which are parallel to the trend of the sandbodies. Since it is assumed that the same factors have controlled the trend of all the linear Cretaceous sandbodies, and since the two sandbodies that are being considered in this paper were formed during the Viking, the search for evidence of episodic basement control is expanded to include most of the Cretaceous of the Alberta Group.

The Cardium and Viking have been extensively studied both from core and well log. However, most of these works have concentrated on either the Viking or the Cardium but not the larger portion of the Cretaceous stratigraphy (Alberta Group) that contains both formations and all the mud and sand deposited between, beneath and above.

I. 2 Purpose

The purpose of this thesis is to test the hypothesis that the Joffre and Fenn sandbodies are controlled by remobilization of movements in the basement. This theory will be tested by subdividing the Cretaceous section into thin stratigraphic layers and examining them for consistent thickness changes from layer to layer. The Cretaceous is underlain by 3500 m of rock. Any movements in the basement that penetrate through this interval to influence the Cardium would be large and would affect the underlying layers. Episodic remobolization of basement faults would have a greater affect on the depositional pattern of the stratigraphy by repeatedly affecting the unit being formed and the layers stratigraphically below. For example, if five episodes of remobilization occur between the time the Viking was deposited and the time the Cardium was deposited, the Joli Fou (the unit beneath the Viking) will have been affected five times. The direction of movement would be the same each time and the result would be trends that persist through the stratigraphy and stack vertically. It is important to note that unlike Hart and Plint's area, the basement trends underlying the Joffre and Fenn fields run NE-SW, perpendicular to the trend of the sandbodies. To detect evidence of these reoccurring trends through the stratigraphy, the trends in local thickness variations and direction of thinning will be examined. More specifically, NE-SW trends that reoccur through the stratigraphy, will be sought.

II. Study Area

The Western Canada foreland basin lies between the Cordilleran Belt to the west and the Precambrian shield to the east (fig. 2). "The basin is elongated parallel to the orogenic belt." (Cant p. 252) It is a foreland fold, thrust belt which was created from arcs thrust on the crust with subsequent lithospheric loading of the craton. The basin is underlain by granitic crust.

The area of study (figs. 1 and 3) is divided into two blocks. Block 1 is an 838 km^2 area that contains the Joffre Viking oil field and covers Townships 37-39, Ranges 25-27 West of 4. Block 2 is an 745 km^2 area that contains the Fenn and Fenn Big Valley Viking gas fields and covers Townships 35-36, Ranges 18-21 West of 4. Both of these linear Cretaceous sandbodies are aligned along the same strike, trending NW-SE.

Stratigraphic Interval

The stratigraphic interval studied contains the larger part of the Cretaceous of the Alberta Group. It examines the interval from the base of the Joli Fou Formation to the top of Lea Park. It includes the Joli Fou, Viking, Westgate, Fish Scales, Second White Specks, Cardium, First White Specks and Lea Park Formations.

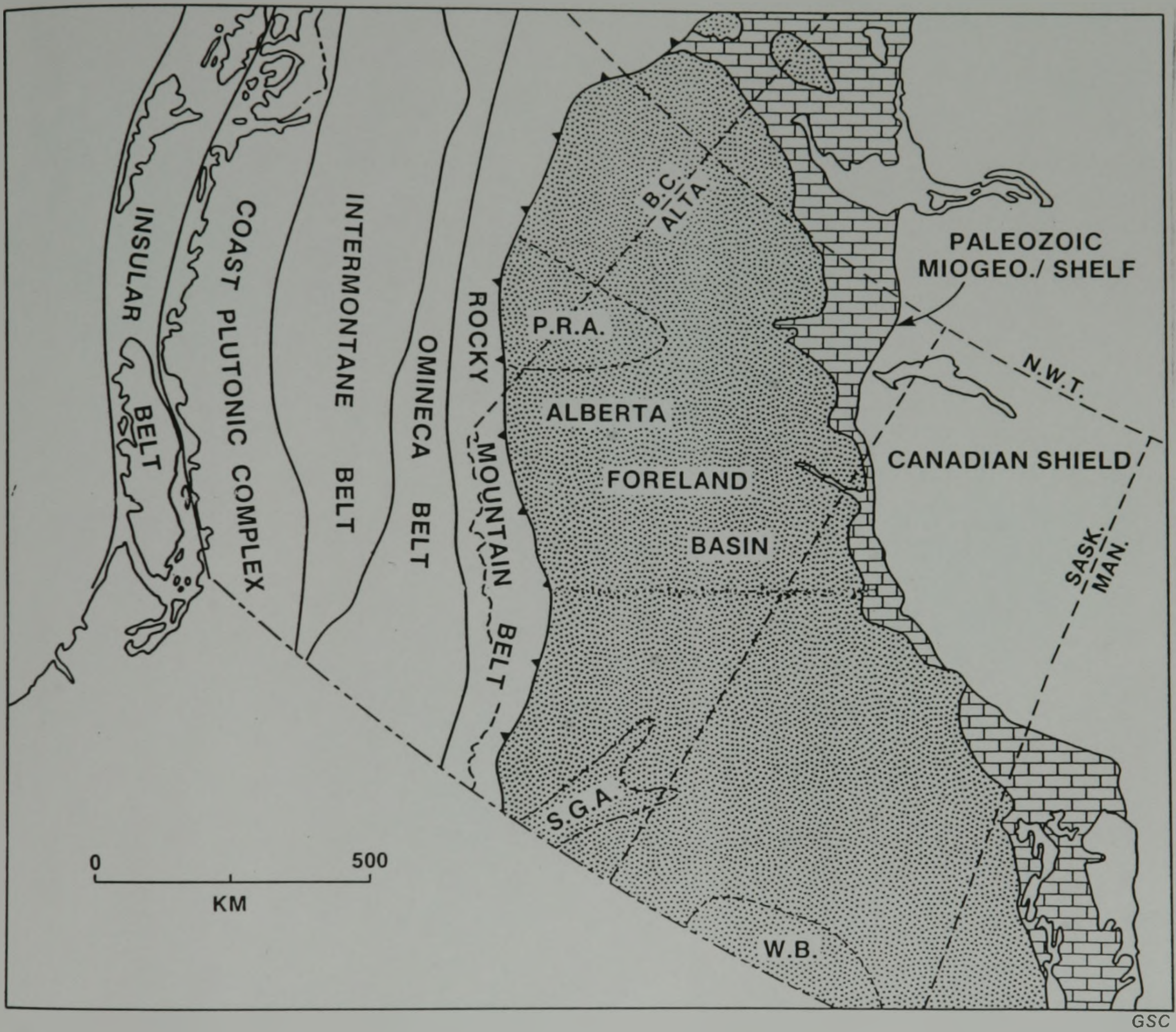


Figure 2 - A map showing the position of the Alberta Foreland Basin. The basin is bounded by the Rocky Mountain belt to the west and Canadian Shield to the east. This map was taken from the Geological Survey's Special Paper, 1993.

Study Area

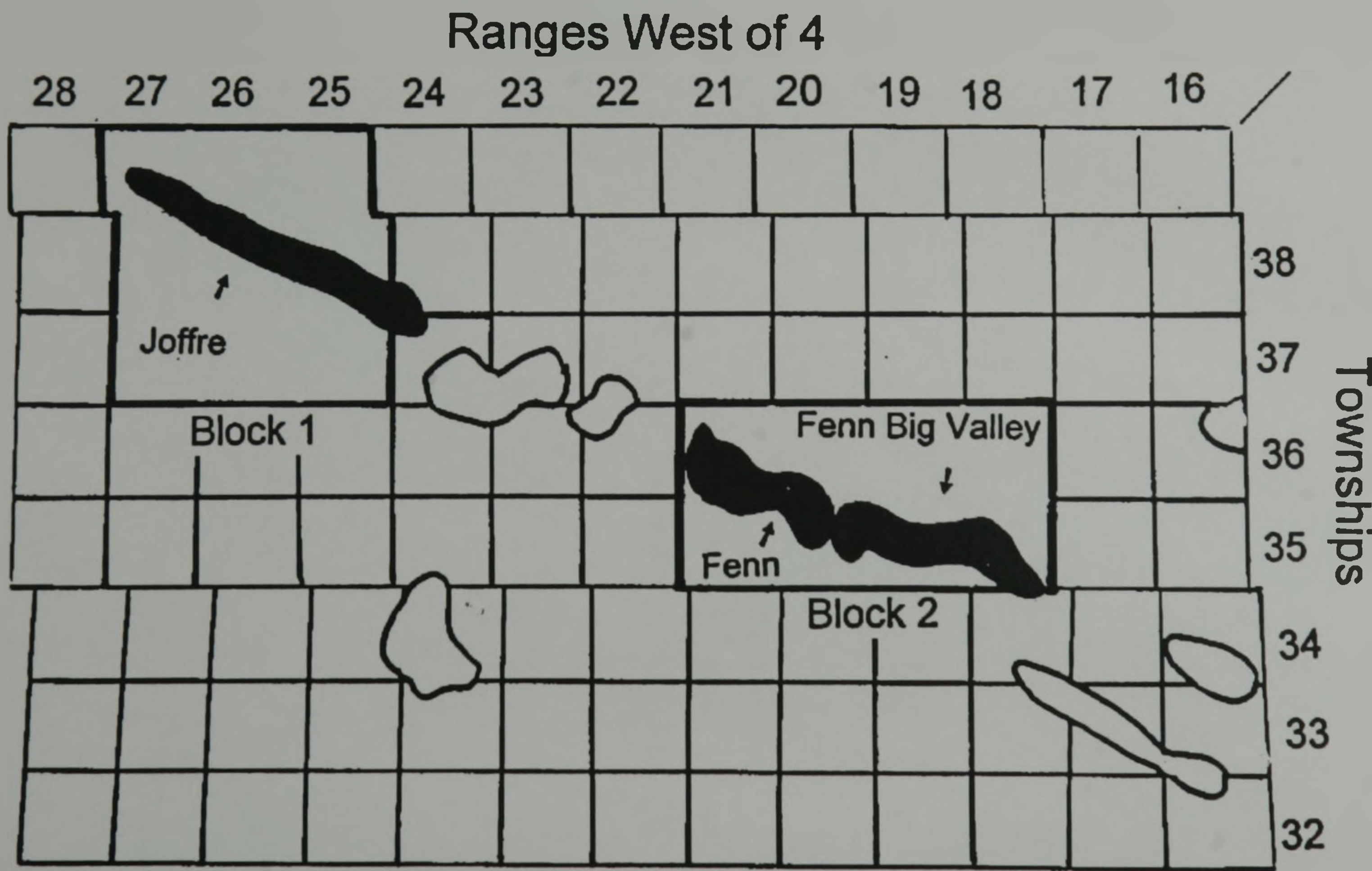


Figure 3. Map showing the location of Block 1 and Block 2 of the study area.

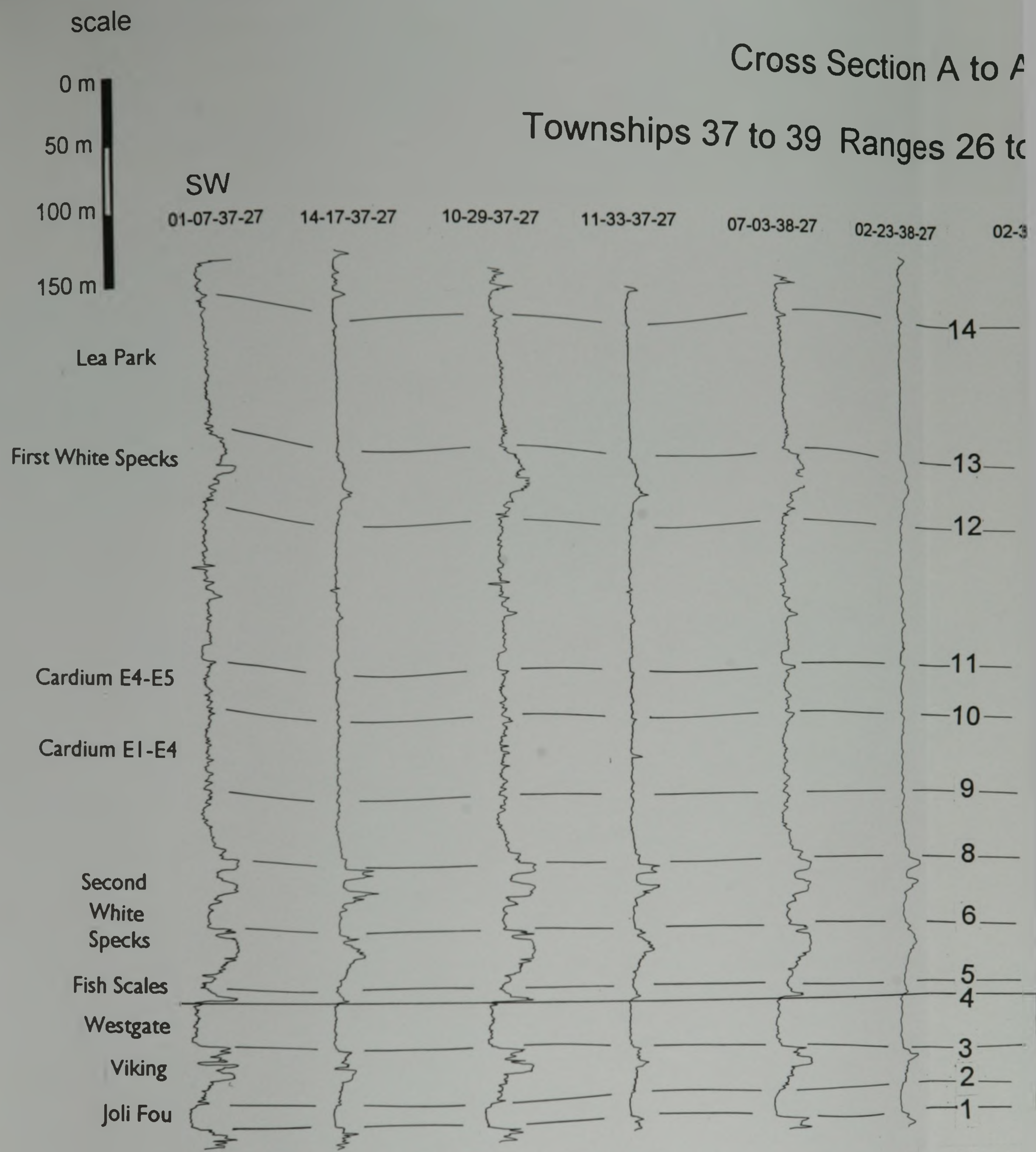
III. Method

III. 1 Data Collection

A library of well log data was collected from well log microfiche at Amoco Canada Petroleum Company Ltd. Both gamma and resistivity well logs were collected. For each well, Kelly Bushing, CPA number, latitude and longitude were recorded using one well per section. 1708 wells were printed from a larger study area, and 186 used in Block 1 and 193 used in
Block 2.

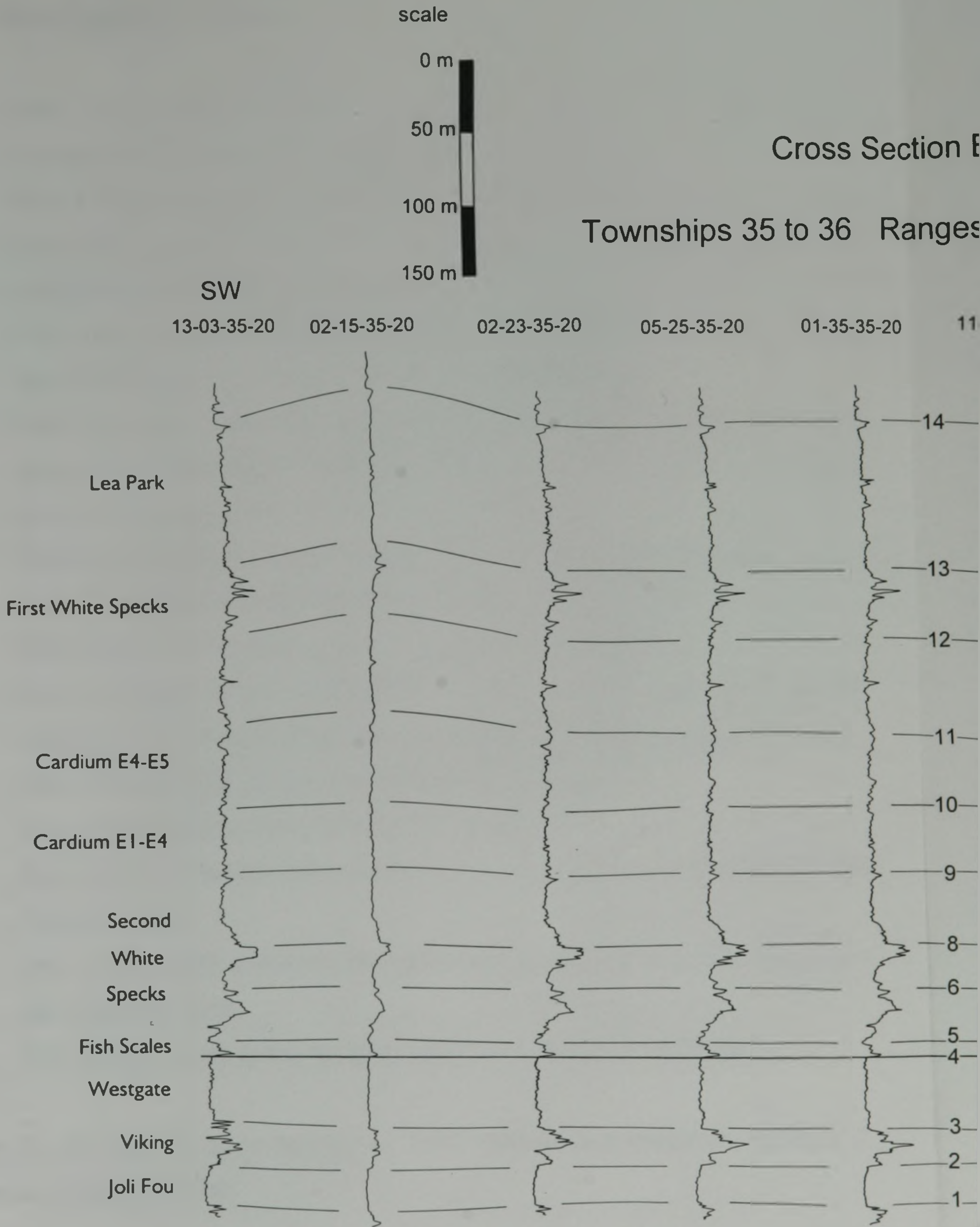
III. 2 Cross Sections

Cross sections, based on resistivity well logs, were made perpendicular to the trend of the linear sandbodies. Cross Section A-A' shown in fig. 4, intersects the Joffre field (see acetate in the back for location of cross sections). Cross Section B-B', shown in fig. 5, intersects the Fenn fields. The well logs were closed into a grid by cross sections trending parallel to the strike of the sandbodies. Thirteen consistent picks were chosen from the cross sections and correlated across the area. Note that pick markers are numbered from 1 to 14 because pick 7 was found not to correlative across both areas and was discarded. The Base of Fish Scales (BFS), found at the boundary between the Lower and Upper Cretaceous, was used as a datum because it was easy and consistent to pick and because it is the best marker representative of a flat sea floor during the Cretaceous time. "BFS's distinctive condensed horizon is a result of the deposition of abundant fish-scales and vertebrae deposited on the sea floor in finely laminated unbioturbated sandstone and siltstone during maximum relative sea level when sedimentation rates in the basin were at a minimum" (Leckie, p. 274). The same picks were made consistently in both areas.



scale
0 m
50 m
100 m
150 m
Cross Section A to A
Townships 37 to 39 Ranges 26 to
SW
01-07-37-27
14-17-37-27
10-29-37-27
11-33-37-27
07-03-38-27
02-23-38-27
Lea Park
First White Specks
Cardium E4-E5
Cardium E1-E4
Second White Specks
Fish Scales
Westgate
Viking
Joli Fou
14
13
12
11
10
9
8
6
5
4
3
2
1

Figure 4



scale
0 m
50 m
100 m
150 m
Cross Section E
Townships 35 to 36 Ranges
SW
13-03-35-20
02-15-35-20
02-23-35-20
05-25-35-20
01-35-35-20
Lea Park
First White Specks
Cardium E4-E5
Cardium E1-E4
Second
White
Specks
Fish Scales
Westgate
Viking
Joli Fou
14
13
12
11
10
9
8
6
5
4
3
2
1

Figur

III. 3 Description of Picks

1. Pick 1 was made at the inflection point between the underlying Manville Formation and the Joli Fou mudstones.
2. Pick 2 was made at the inflection point between the shales of the Joli Fou Formation and the first kick of sand (taken as a sudden increase in resistivity) of the Viking Formation.
3. Pick 3 was made at the inflection point of the flooding surface of the Viking and the introduction of mud in the Westgate formation.
4. Pick 4, the datum, was made at the inflection point of the top of the Westgate muds and the first kick of Fish Scales sand. This marker is commonly known as Base of Fish Scales.
5. Pick 5 is the flooding surface above the Fish Scales Sand Formation.
6. Pick 6 is the first flooding surface in Second White Specks.
8. Pick 8 is the third flooding surface in Second White Specks.
9. Pick 9, known as the Cardium E1 erosion surface, was made at the inflection point at the base of the two distinctive Cardium resistivity kicks.
10. Pick 10 is the E4 erosion surface in the Cardium.
11. Pick 11 is the E5 erosion surface in the Cardium.
12. Pick 12 is the inflection point made by the first major kick of resistivity in the Cardium sand.
13. Pick 13 was made at the inflection point between the First White Specks and the Lea Park muds.
14. Pick 14 was made at the flooding surface at the top of Lea Park.

Note E1, E4 and E5 were defined by Plint, Walker and Bergman, Bulletin of Petroleum Geology 1986,

III. 4 Data Entry

The depths below Kelly Bushing for each marker were entered into a computer database using Quattro Pro, a spreadsheet program. Note that the representation of well logs depended on the available database. Some areas have been extensively logged and others have been ignored by the oil industry. As a result, oil and gas producing fields are perforated with wells, while nonproducing areas have very little well log control. In an attempt to keep the density of well logs roughly equivalent over the area, one well log per section was mapped.

III. 5 Building a Subtraction File

A subtraction file was built which listed in grid format, the thicknesses of each layer between markers, e.g. Layers 9-10 (read as depth of 9 minus the depth of 10). The subtraction file was scanned for obvious errors which were checked and corrected.

III. 6 Building Grid Files

A grid file of the subtracted data was then made using linear Kriging in Surfer Version 6.0, a graphing program. Kriging, a mathematical technique used to produce a grid of regularly spaced data (where there is no data) from irregularly spaced data by interpolating i.e. linear averaging, the surrounding points. All data was used as the search type as this is the most appropriate search type to use for data bases of less that 250 samples. It uses all data points in the calculation of every grid node but uses distance weighting factors to weight data points close to the grid node higher than data points further away.

III. 7 Producing Isopach Maps

Isopach maps of the thickness of each layer were made by contouring the Kriged data files. The contour maps were processed by Surfer smoothing algorithms which round out jagged and sharp angled contour lines and filters out most noise. As a result the contours show up as smooth curves.

III. 8 Bullseyes and Error

The isopach maps were visually checked for bullseyes, which are single points that create concentric patterns of unrealistically high or low values. Bullseyes were checked against the well log for input errors and for an incorrectly made pick. If an error was discovered, the data was corrected, re-Kriged, and re-contoured. The maps were again checked for bullseyes before the final isopach maps were created.

To check that the trends created by the Kriged grid files were not biased, one grid file with strong trends was Kriged using directional selection of data points. Maps were produced using selection of the nearest eight data points in a NS, EW and NW-SE oriented search area (figs. 6a-d). These biased data selection maps were compared to the unbiased Kriged maps and no biasing of the trends were observed. Therefore the Kriged results represent actual trends in the data and are not the product of the mapping program.

III. 9 Trend Surface Analysis

Trend surface analysis was used to visualize the regional trends. Grid files were created using second order quadratic surface polynomial regression. The quadratic surface was then contoured to produce trend surface maps. Trend surface maps fit a surface (second order surface in this case) through a set of points in three dimensional space.

III. 10 Residual Maps

Residual maps were also created. Residuals are the vertical difference between the Z value in the data file and the interpolated Z value on the trend surface. They were made from subtracting the grid file of the quadratic surface from the actual data points. Trends in the residual maps were checked with the contoured thickness maps and the polynomial surface maps. Trends found in the residual map that were not present in the contour map were noted as possible secondary trends superimposed on the fitted surface.

IV. Results

IV. 1 Trends

The Joli Fou Formation

Isopach trends in the Joli Fou Formation (Layer 1-2) of Block 1 run NW-SE and swing around to a NNE-SSW direction in the east (fig. 7a). The unit thins landward to the SW. The Quadratic trend surface emphasizes a thinning direction towards the SW. Thinning direction is also landward in Block 2, which thins to the west and shows NS isopach trends (fig. 7e). The trend surface confirms the general NS trend which thins to the West (fig. 7e). There is 7.0 m of variation in thickness of the muds in Block 1 and less than 9.0 m of variation in thickness of Block 2. The Residuals of the Joli Fou unit mirror the thickness trends noted in the isopach and trend surface map, but emphasizes the NNE-SSW trend in Block 1. Positive residuals correspond to areas which are thicker in the isopach map than in the trend surface and negative residuals correspond to areas which are thinner in the isopach map than in the trend surface. The residual map of Block 2 does not differ significantly from the isopach map. In other words, it does not give any information not already given by the isopach map.

The Viking Formation

There is an strong NW-SE thickness trend in the isopach maps of the Viking Formation (Layer 2-3) in both blocks. The sands thin basinward, to the NE and then thicken again in the NE corner (fig. 8a and d). Thickness variations across the area are significant, 22.0 m in Block 2 and 24.0 m in Block 1. The trend surface highlights the strong NW-SE trend which thins to the NE (fig. 8b and e). The variation in the residual map of Block 1 is very small, less than plus 2.0 m and minus 1.0 m of variation from the trend surface, indicating that the quadratic surface is a good representation of the thickness trends in this area (fig. 8c). There is more variation in Block 2, up to 4.0 m of variation from the fitted surface and therefore the quadratic surface is more generalized (fig. 8f). The residuals generally reflect the NW-SE isopach trends; however, there are a few N-S residuals in Block 1 and NE-SW residuals in Block 2 that may indicate a second trend superimposed on the main trend. The thinnest area in Block 1 corresponds to the location just north of the Joffre Viking oil field and the thinnest area in Block 2 corresponds to a location just north of the Fenn and Fenn Big Valley Viking gas fields. Acetate overlays are provided in an envelope on the back page for the reader to superimpose the position of the Viking and Fenn fields over the isopach maps, trend surface maps and residual maps.

The Westgate Formation

There are good NW-SE thickness trends in the isopach map of the Westgate Formation (Layer 3-4). The muds are thickest in the region of the Viking fields and thins landward, to the SW and NE in both areas (figs. 9a and d). Thickness variations are significant, 13.0 m in Block 1 and 17.0 m in Block 2. The trend surfaces support this NW-SE trend which is thickest in the middle of the area and thins to the SW and NE (figs. 9b and e). The residuals of Block 1 have an interesting N-S grain that is not apparent in the contoured thickness maps; however, there is less than 1.0 m of variation from the fitted surface which indicates that the quadratic surface is a good representation of the unit (fig. 9c). The residual map of Block 2 shows interesting NNE-SSW trends that are perpendicular to the NW-SE trends in the isopach map. The residuals are up to 3.0 m (fig. 9f).

Fish Scales Formation

No strong trends emerge in the Fish Scales Sandstone (Layer 4-5). There is very little thickness variation in the unit, generally less than 4.0 m (figs. 10a and d). The trend surface of Block 1 suggests a NE-SW trend which thins basinward, to the SE. The trend surface of Block 2 suggests a NW-SE trend that thins basinward, to the east. However, due to the limited thickness of this unit, very little confidence is associated with these trends (figs. 10b and e). The residuals do not show any significant trends (figs. 10c and f).

Second White Specks

The thickness trends in the Second White Specks (Layer 5-6) are roughly N-S in Block 1 (fig. 11a). The unit thins basinward, to the east and southeast. The polynomial surface emphasizes this strong NE-SW trend which thins to the SE (fig. 11b). The residual map emphasizes a strong NE-SW trend in thickness that is less obvious in the contour and polynomial maps (fig. 11c). There is 7.0-8.0 m of variation in Blocks 1. There are no strong trends apparent in Block 2. The polynomial regression map does show direction of thinning is towards the east. However, little confidence in associated with this trend. The residual map shows a NW-SE trend superimposed on the fitted surface which is up to 4.0 m thicker than the trend surface. The fitted surface also misses a local low in the northeast corner as well as other local trends.

Like the thickness trends of Layer 5-6, the trends of Layers 6-8, also of the Second White Specks Formation, are also N-S and thin basinward, to the East (figs. 12a and d). The trends in Block 2 are consistently N-S whereas the trends in Block 1 swing to the NNE-SSW as you move to the east. There is a significant thickness variation in both areas, 14.0 m in Block 1 and 18.0 m in Block 2. The polynomial regression fits a simple surface which confirms this general N-S trend which is concentric in Block 1 and flared to the South in Block 2 (figs.12b and e). The residuals in Block 1 emphasize the NNE-SSW grain but otherwise do not indicated any different trends in either study areas (figs. 12c and f).

The thickness trends in the shales of Layer 8-9 are NNW-SSE in Block 1 (fig. 13a). The shales thin to the north. There is 10.0 m of thickness variation. This trend shows up well on the polynomial surface (fig. 13b). Strong NS trends are evident in the contour map but are emphasized in the residual map (fig. 13c). There are interesting thickness trends in Block 2 (fig. 13d). The unit is thickest in the centre and thins both basinwards, to the NE and landward, to the NW. There is significant thickness variation, (5.0 m) between the thickest area and the lows to either side. Like Block 1, strong N-S trends show up in the residual map (fig. 7f). There is significant variation in thickness in both areas, 10.0 m of variation in thickness in Block 1 and 17.0 m of variation in Block 2 .

The Cardium Formation

The Cardium unit from E1 to E4 (Layer 0-10) trends NNW-SSE in Block 1 and strongly N-S in Block 2 (figs. 14a and d). The unit thins basinward, to the NE and SE in Block 1 and to the east in Block 2. The trend surface maps emphasize the trends found in the isopach maps. A local thinning in the NW corner of area 2 stands out in the residual map of Block 2 (figure 14f). Otherwise, the residuals of both areas emphasize a N-S trend
(figs. 14c and f).

The Cardium unit from E4 to E5 (Layer 10-11) is completely opposite that of the Early Cardium (figs. 15a and b). The unit trends roughly NW-SE in both areas, but is thickest in the NE of Block 1 and thins basinward, to the SW and west. The unit is thickest in the SE in Block 2 and thins to the north. There is very little variation in thickness in Block 1, generally less than 3.0 m. The trend surface of Block 1 shows a circular area of greatest deposition in the NE corner with concentric thinning out to the west and south (fig. 15b). The trend surface of Block 2 supports the NW-SE trend that thickens to the SW and thins to the NE, observed in the isopach map (fig. 15e). The residuals of both areas mirror the same thickness patterns and do not show any trends not expressed in the contour maps (figs.15c and f). The thickest area in Block 2, trending NW-SE overlays the position of the Fenn Viking fields (fig. 9d).

There are strong NW-SE trends in the shale unit before First White Specks (Layer 11-12) in both areas (figs. 16 a and d). The unit is thickest in the SW of both areas and thins basinward, to the NE. There is significant thickness variation in both areas, between 32.0 and 34.0 m. The strong NW-SE trends in thickness variations in Block 1 show up well in the polynomial regression as concentric thinning to the NE (fig. 16b). The NW-SE trend of Block 2 shows up well in the trend surface map as concentric thinning to the NE. The trend surface also shows the NW-SE trend rotating to a more N-S direction as you move to the east. This N-S trend is picked up in the residual map (fig. 16f). There are also some N-S residuals that show up in Block 1 (fig. 16c).

The First White Specks Formation

There are weak NW-SE trends in Block 1 of the First White Specks Sand (Layer 12-13) which is thickest in the SW in Block 1 and thins to the North (fig. 17a). NE-SW to E-W trends show up in Block 2 and the unit thins to the SE (fig. 17d). The fitted surface emphasizes a thinning direction to the NW in Block 1 and SE in Block 2 (figs. 17 b and e). There are N-S trends in the residual maps of both areas (figures 17 c and f). There is a significant amount of variation of thickness in both areas, 8.0 m in Block 1 and 13.0 m in Block 2.

Lea Park Formation

The Lea Park interval (Layer 13-14) shows strong E-W trends in Block 1 that thins to the south and NW-SE trends in Block 2 that thickens rapidly to the NE corner and thins to the south (figs. 18a and d). The trend surface emphasizes a thinning direction to the south in both areas (figs. 18 b and e). There is otherwise very little variation in thickness in most of Block 2, only 4.0 m. There are some N-S residuals superimposed on the trend surface on Block 1 (fig. 18 c). No unexpected trends are found in the residuals of Block 2 (fig. 18f).

Unbiased Data Selection

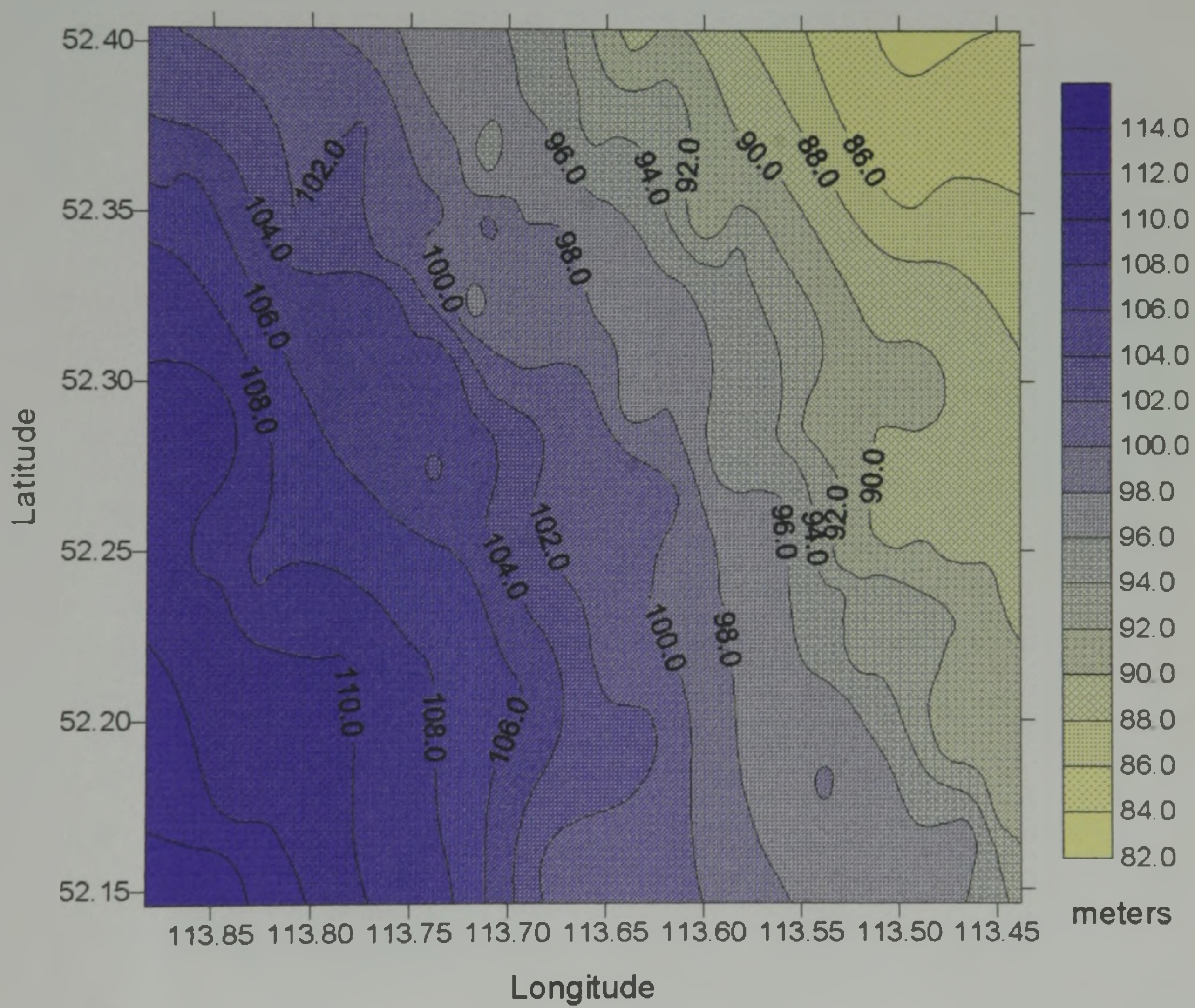


Figure 6a

Data Selection Biased in an E-W Direction

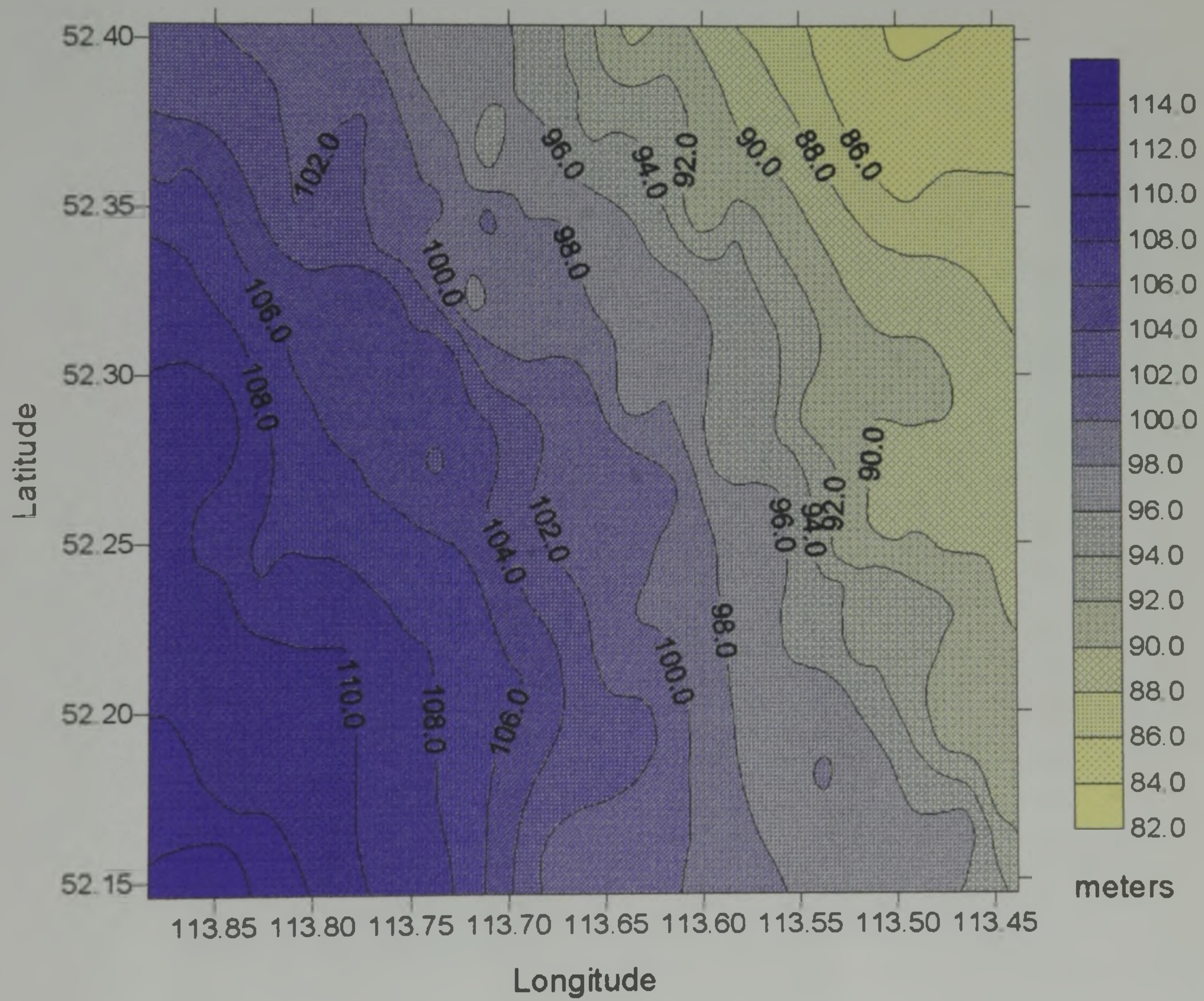


Figure 6b

Data Search Biased in a N-S Direction

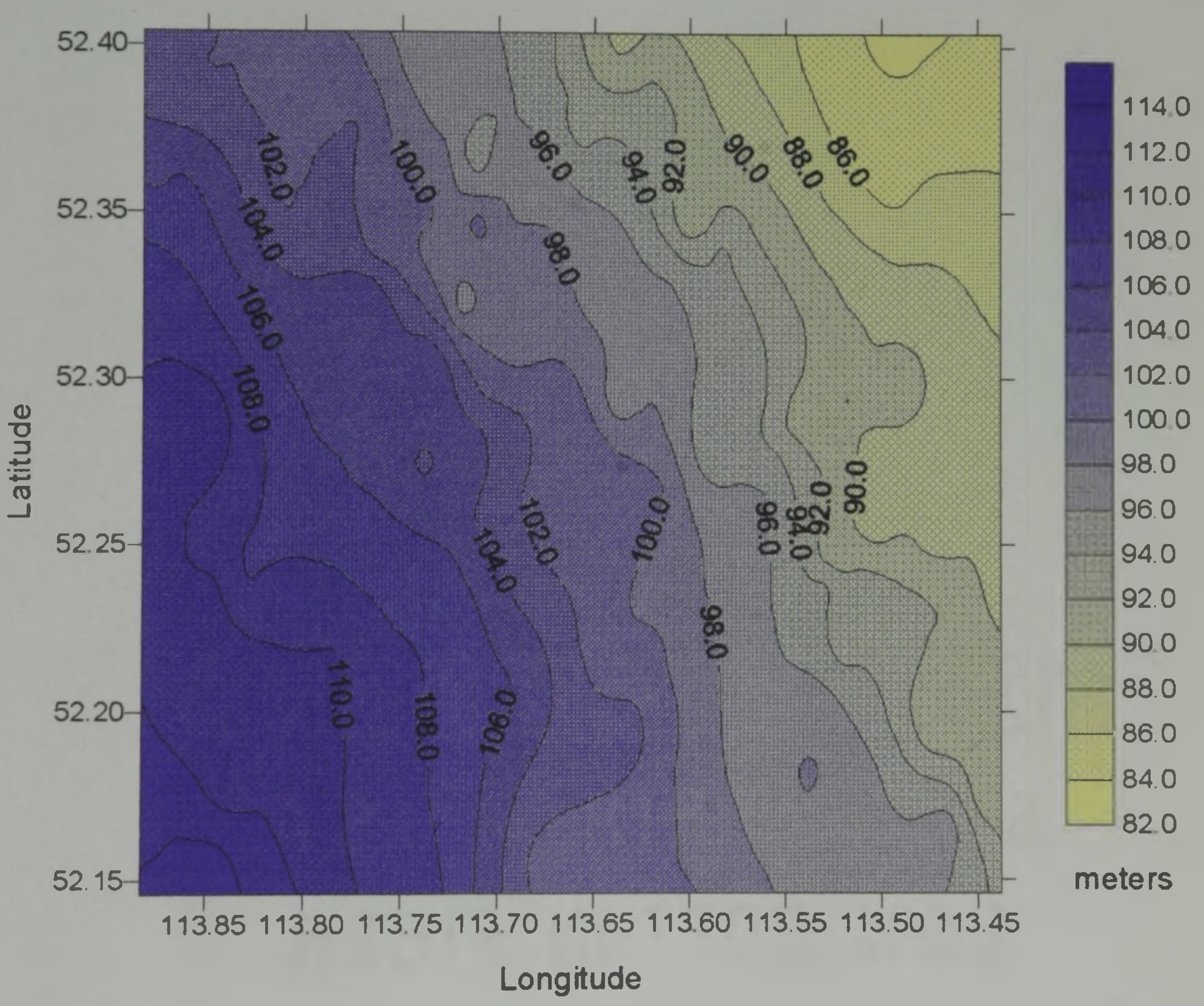


Figure 6c

Data Selection Biased in a NW-SE Direction

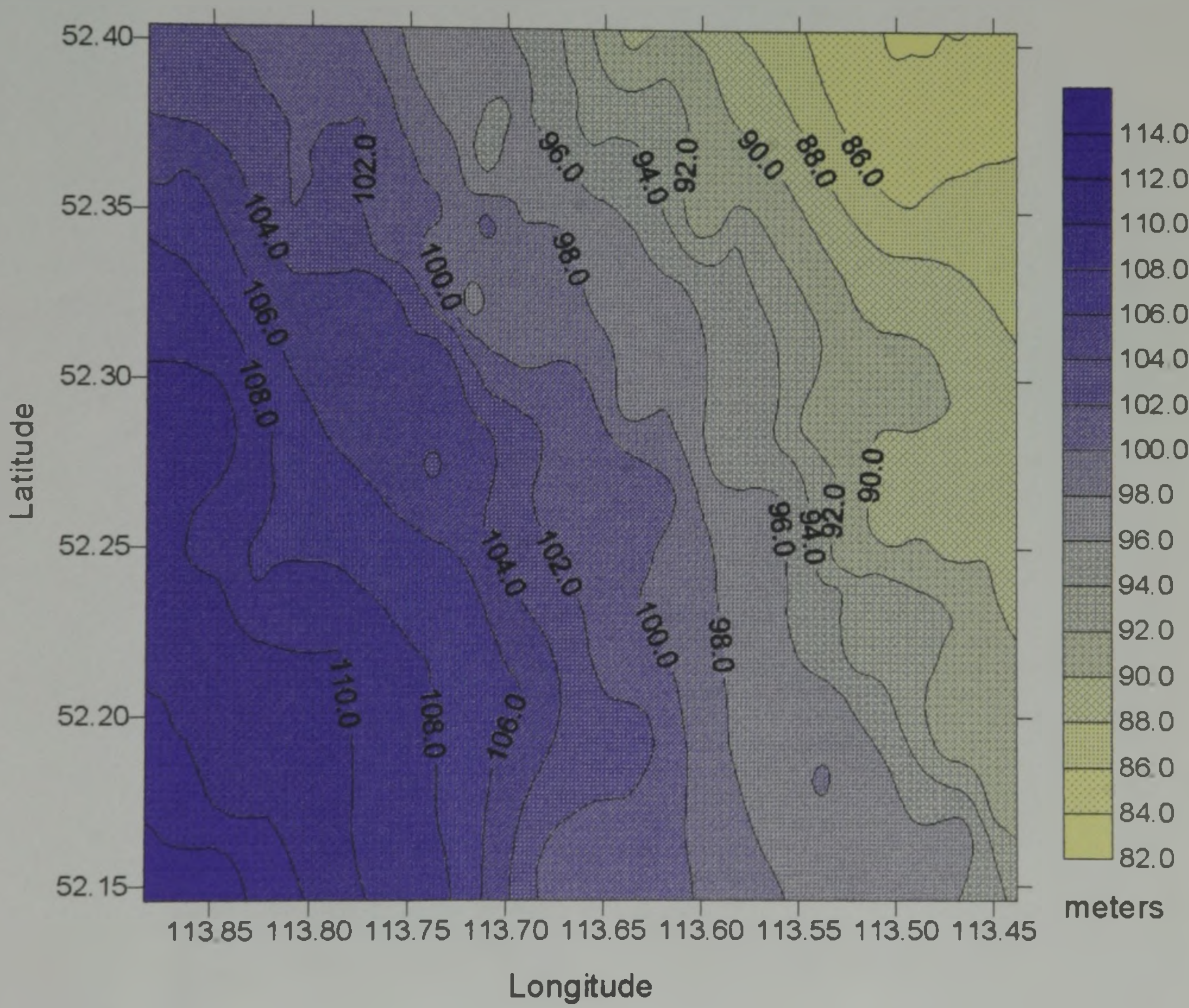


Figure 6d

Block 1 - Joli Fou Formation (Layer 1-2)
Isopach Map - Thickness in Meters

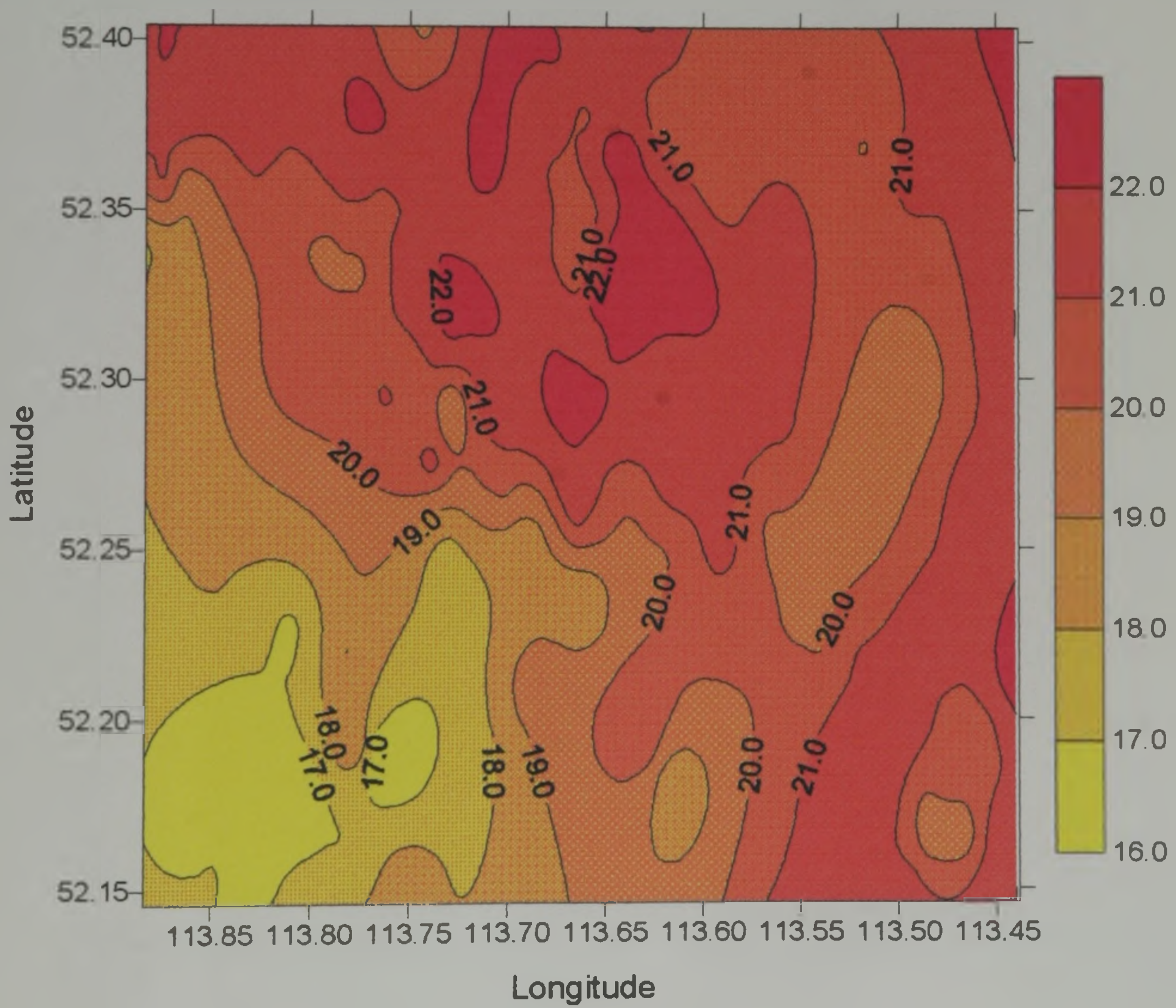


Figure 7a

Block 1 - Joli Fou Formation (Layer 1-2)
Trend Surface - Thickness in Meters

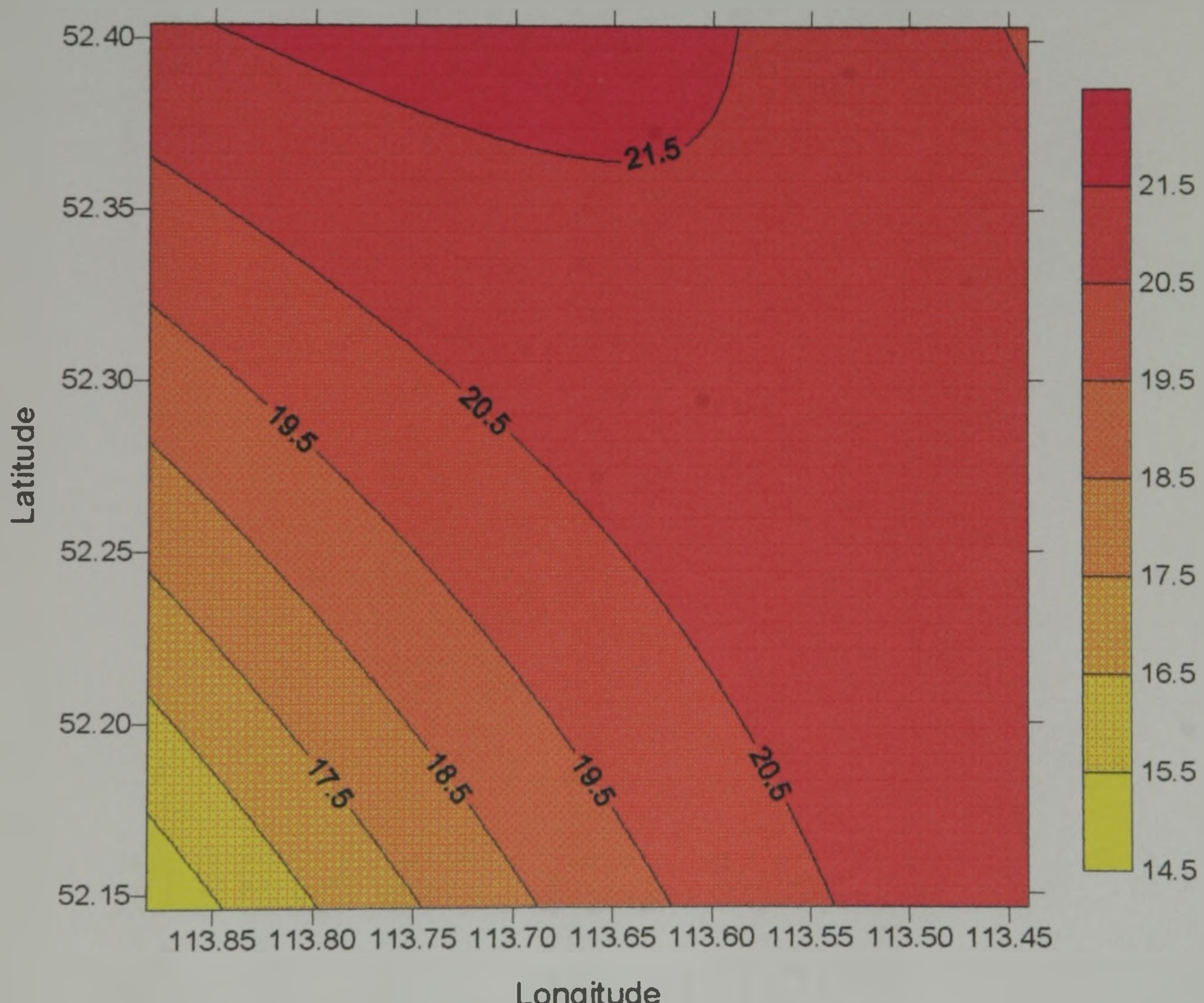


Figure 7b

Block 1 - Joli Fou Formation (Layer 1-2)
Residuals in meters : Data - Trend Surface

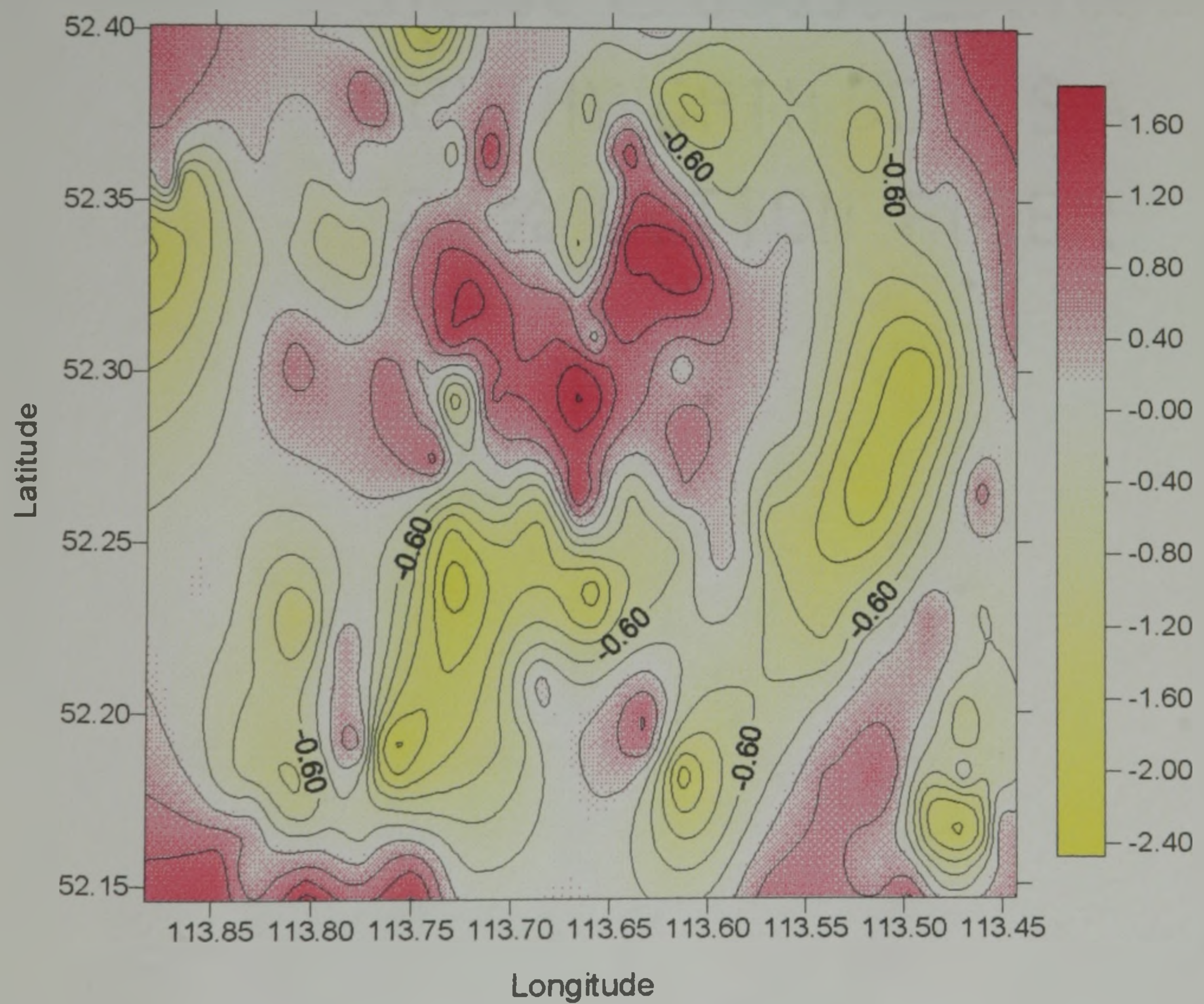


Figure 7c

Block 2 - Joli Fou Formation (Layer 1-2)
Isopach Map - Thickness in Meters

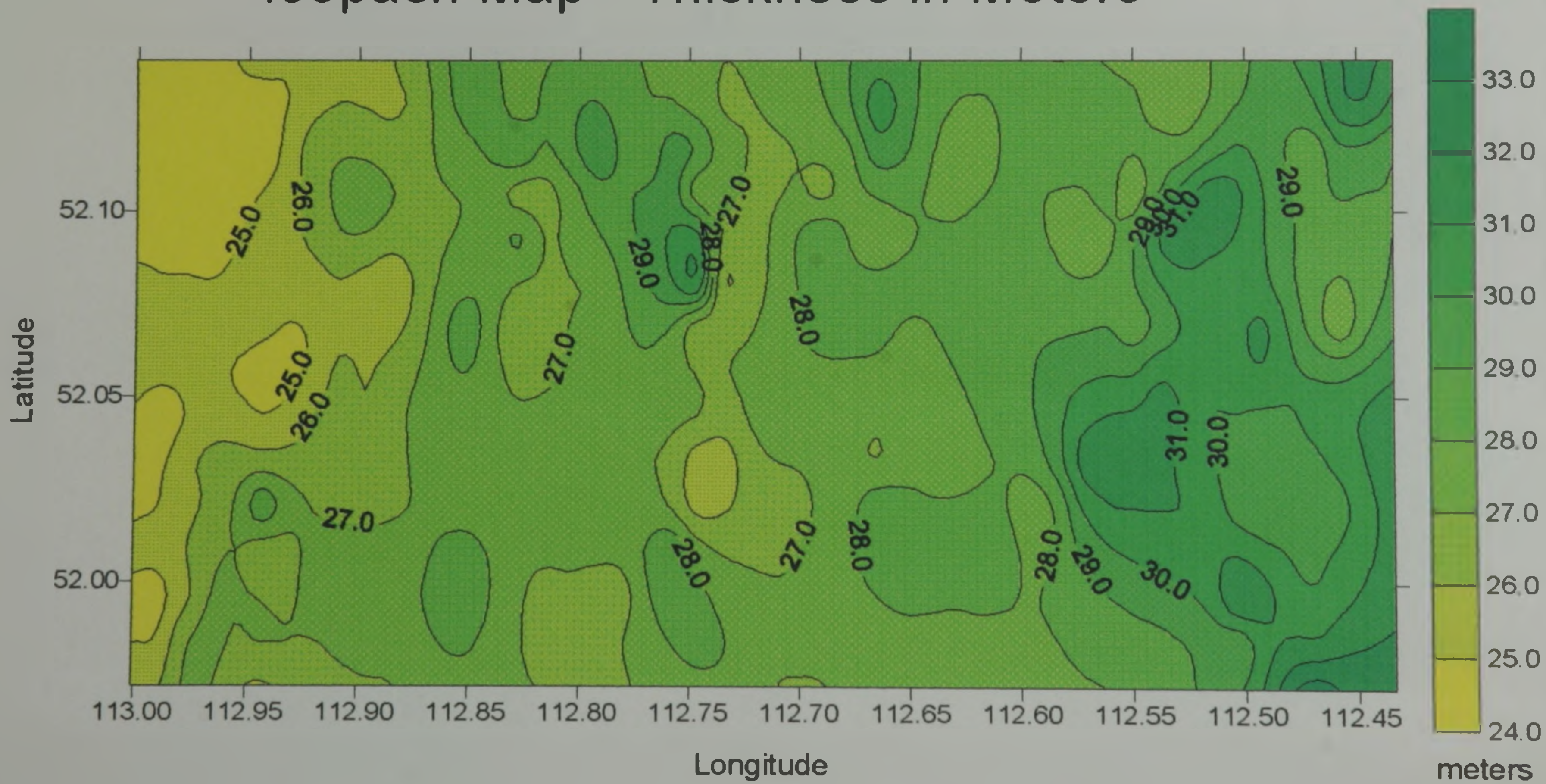


Figure 7d

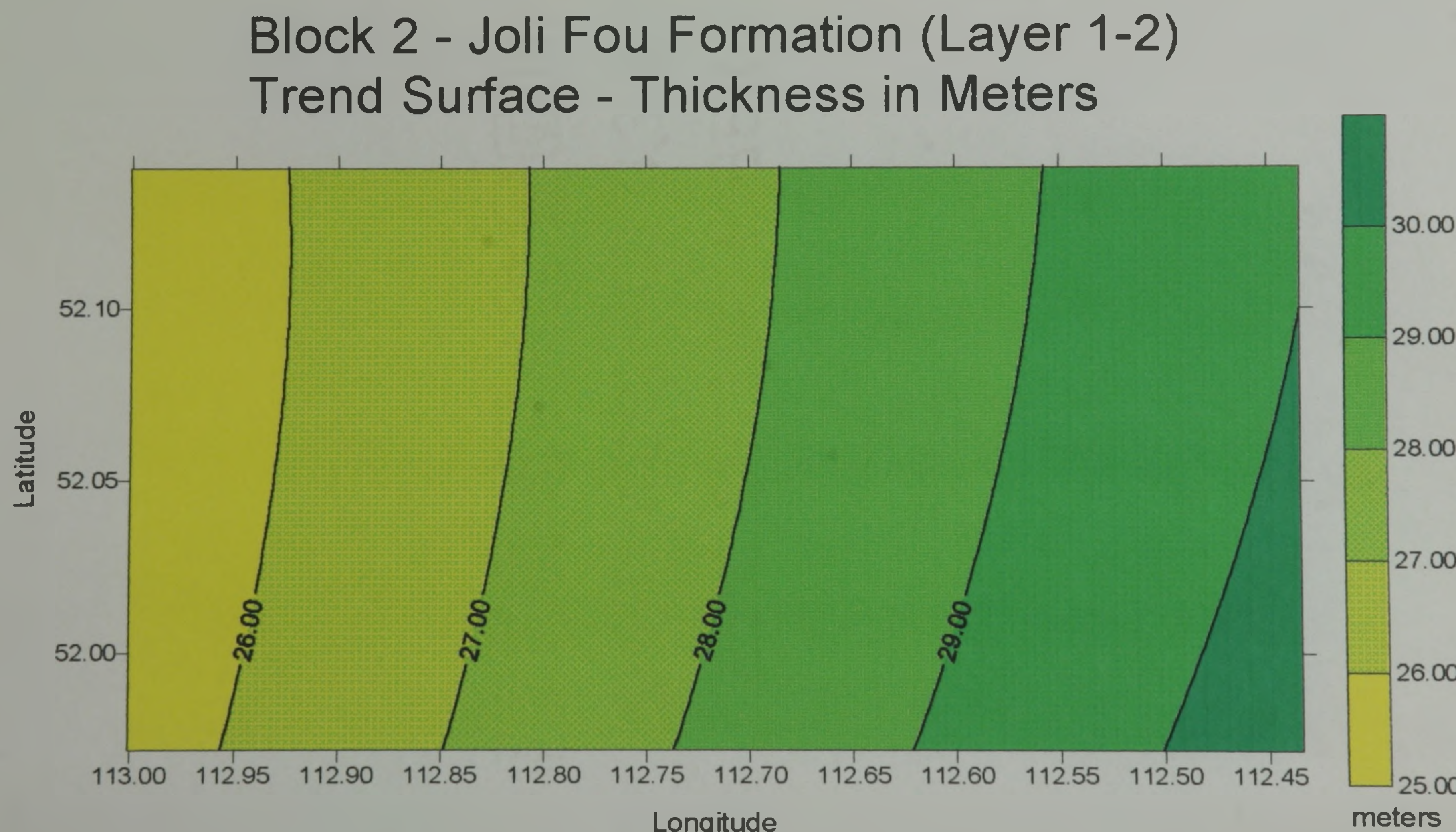

Block 2 - Joli Fou Formation (Layer 1-2)
Trend Surface - Thickness in Meters
Latitude
52.10
52.05
52.00
113.00
112.95
112.90
112.85
112.80
112.75
112.70
112.65
112.60
112.55
112.50
112.45
Longitude
26.00
27.00
28.00
29.00
30.00
29.00
28.00
27.00
26.00
25.00
meters

Figure 7e

Block 2 - Joli Fou Formation (Layer 1-2)
Residuals in meters : Data - Trend Surface

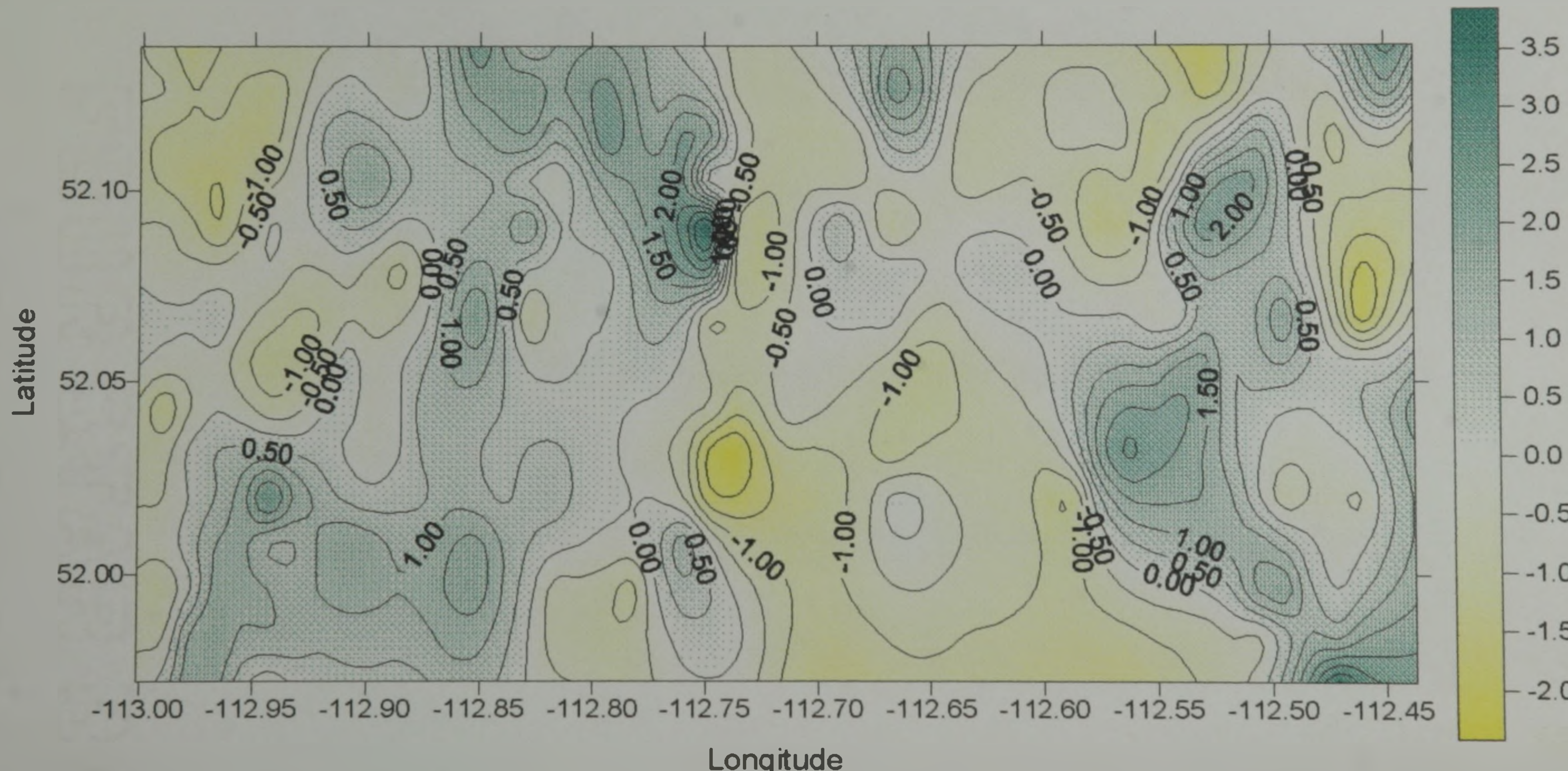


Figure 7f

Block 1 - Viking Formation (Layer 2-3) Isopach Map - Thickness in Meters

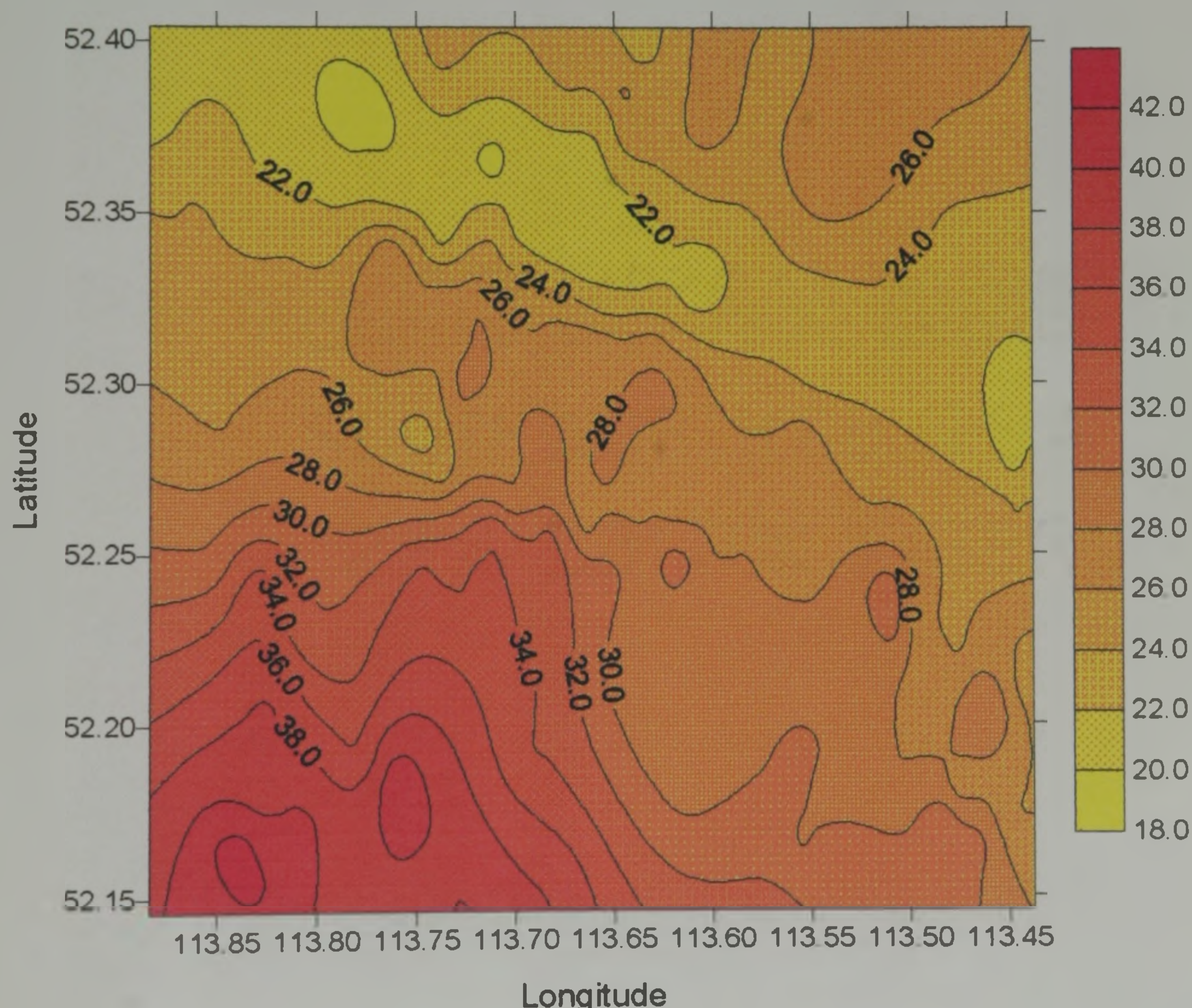


Figure 8a

Block 1 - Viking Formation (Layer 2-3)
Trend Surface - Thickness in Meters

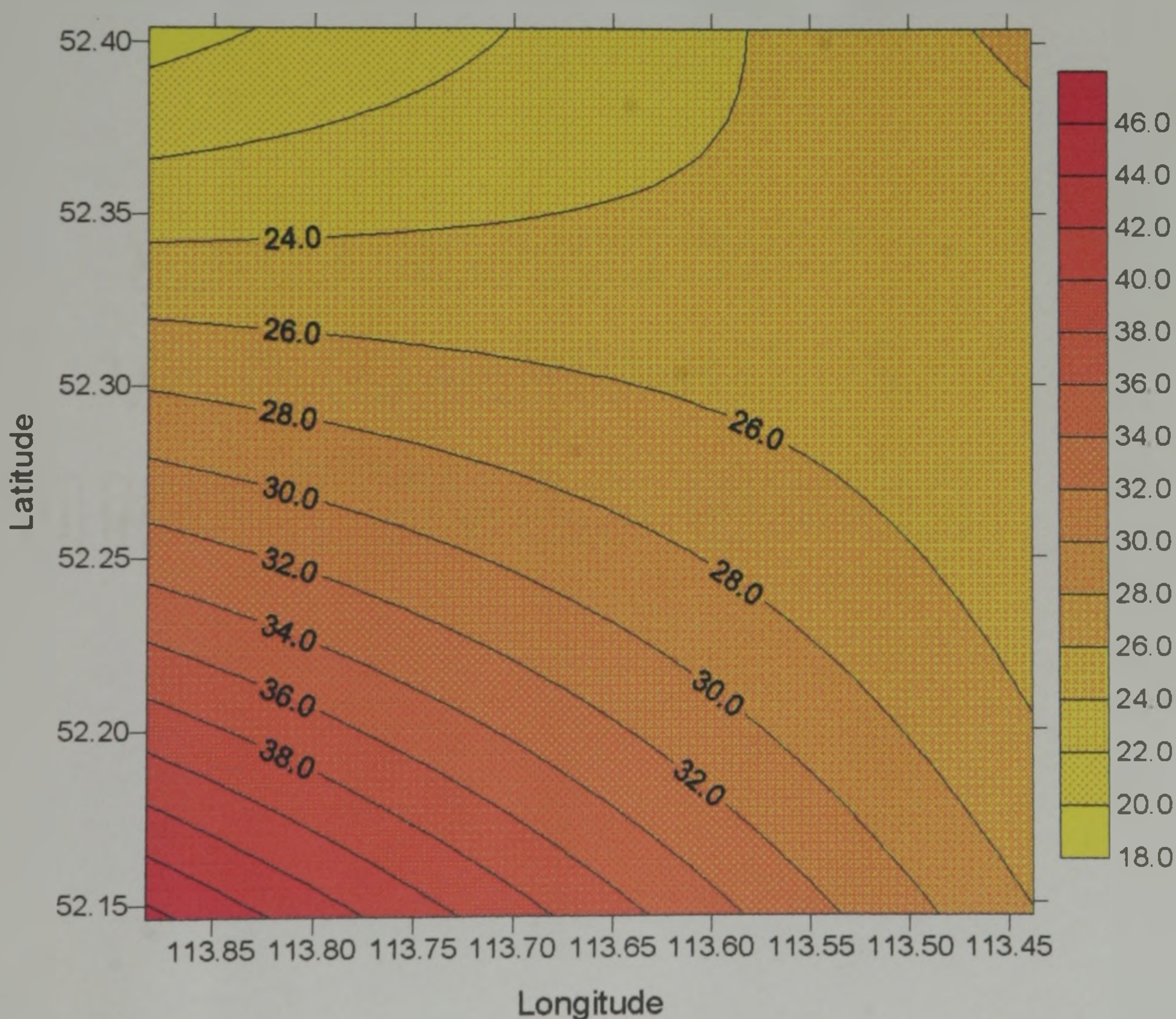


Figure 8b

Block 1 - Viking Formation (Layer 2-3)
Residuals in meters : Data - Trend Surface

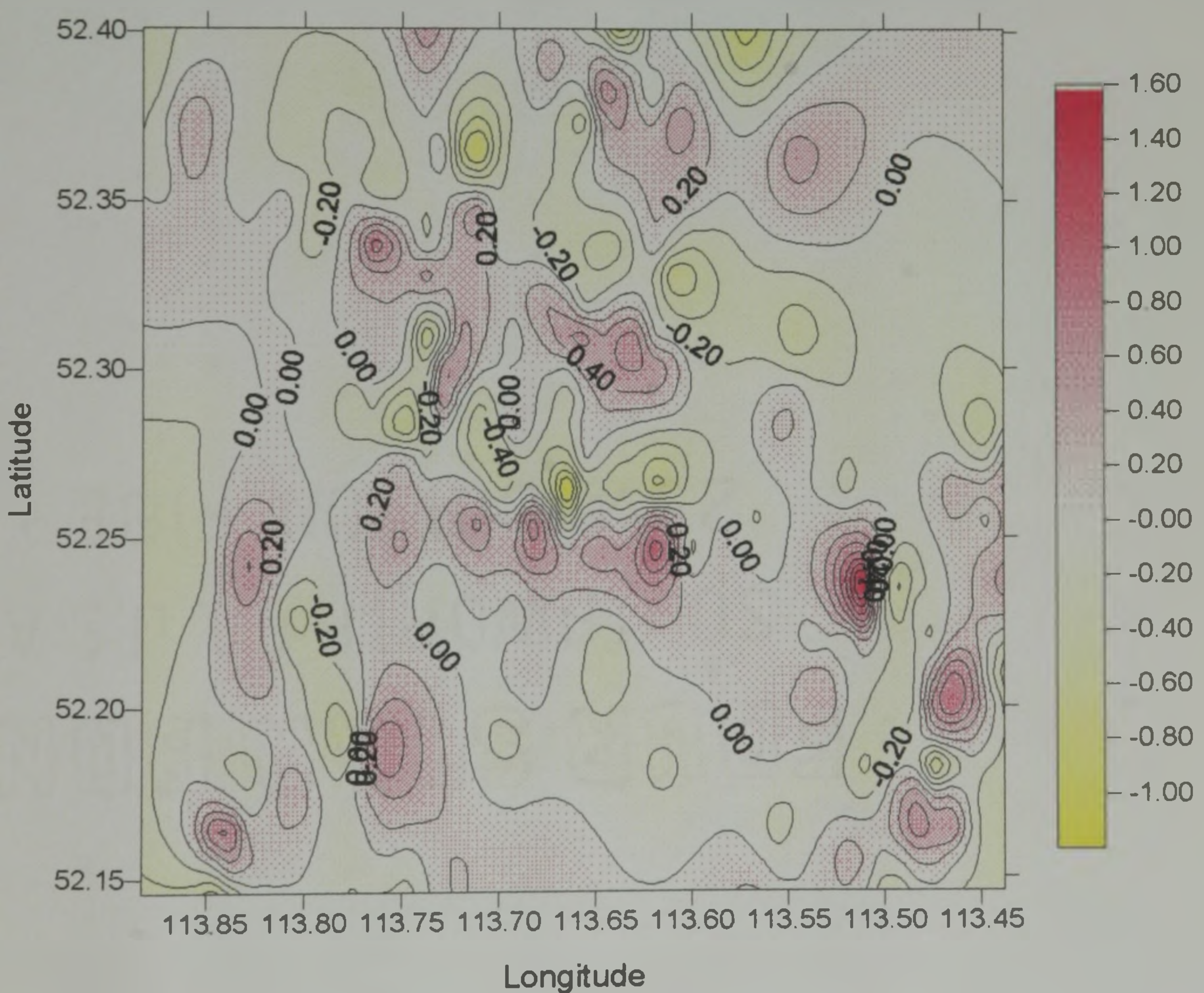


Figure 8c

Block 2 - Viking Formation (Layer 2-3)
Isopach Map - Thickness in Meters

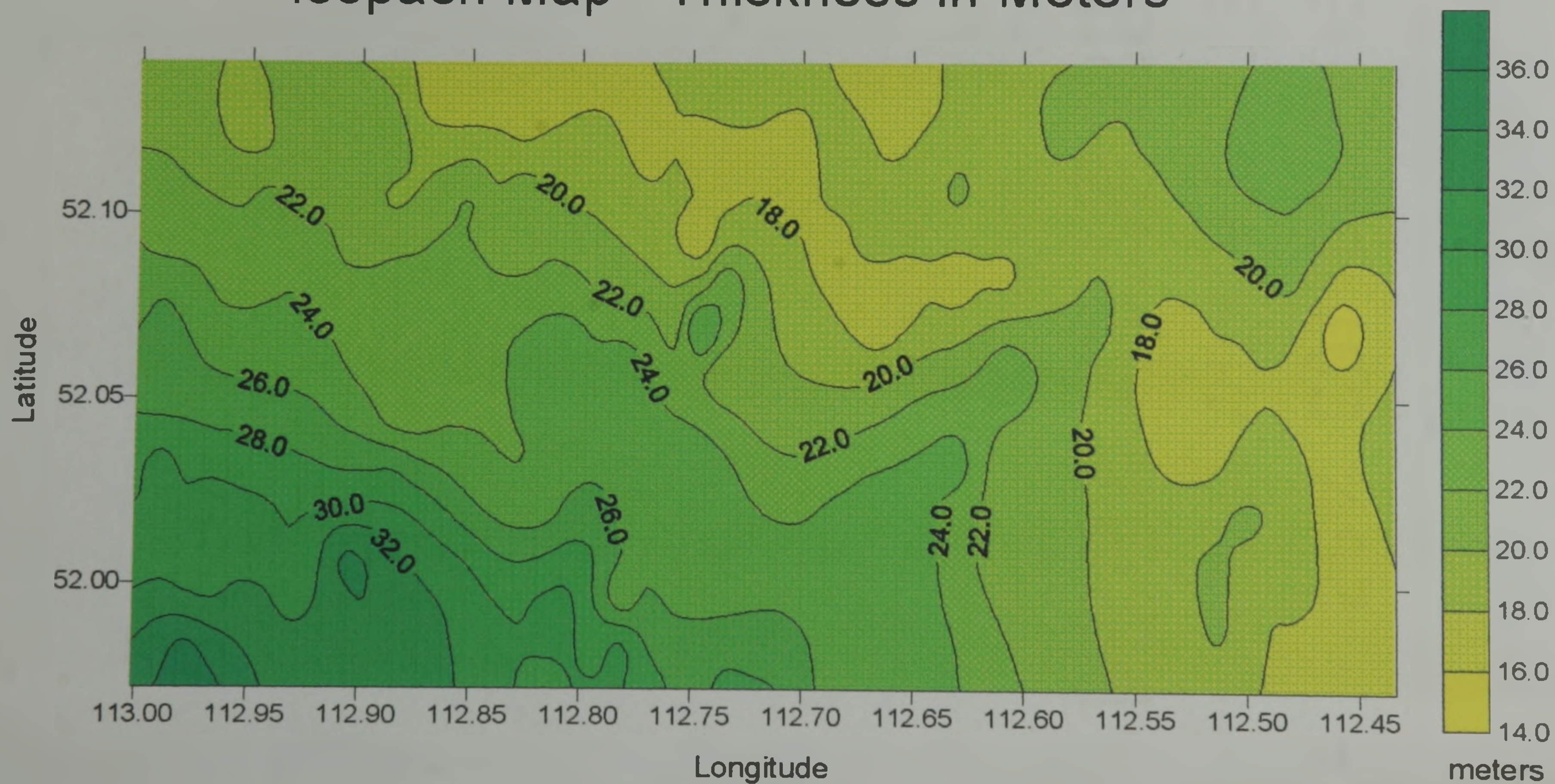


Figure 8d

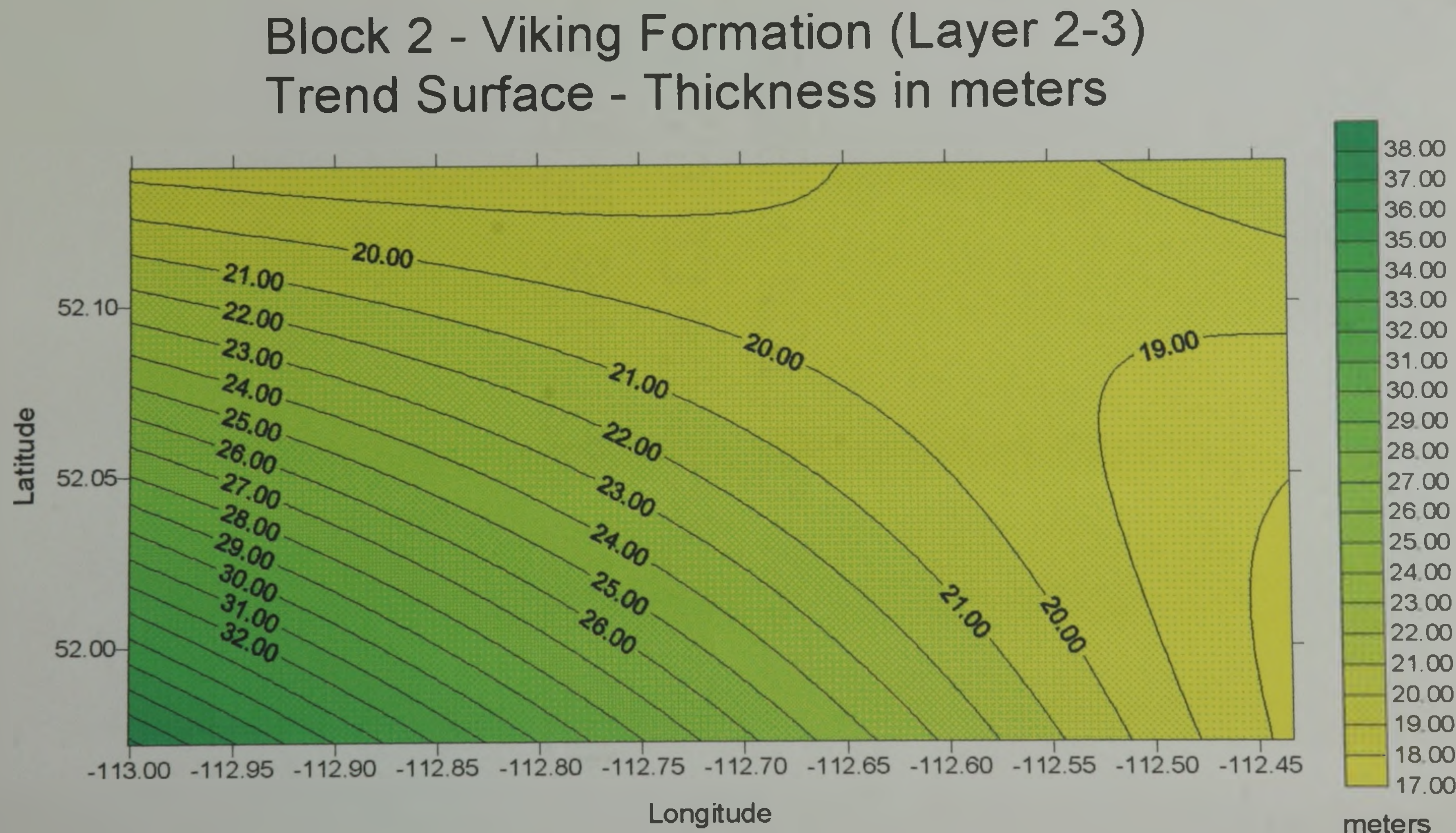

Block 2 - Viking Formation (Layer 2-3)
Trend Surface - Thickness in meters
Latitude
Longitude
meters
52.10
52.05
52.00
-113.00 -112.95 -112.90 -112.85 -112.80 -112.75 -112.70 -112.65 -112.60 -112.55 -112.50 -112.45
38.00 37.00 36.00 35.00 34.00 33.00 32.00 31.00 30.00 29.00 28.00 27.00 26.00 25.00 24.00 23.00 22.00 21.00 20.00 19.00 18.00 17.00

Figure 8e

Block 2 - Viking Formation (Layer 2-3)
Residuals in meters - Data - Trend Surface

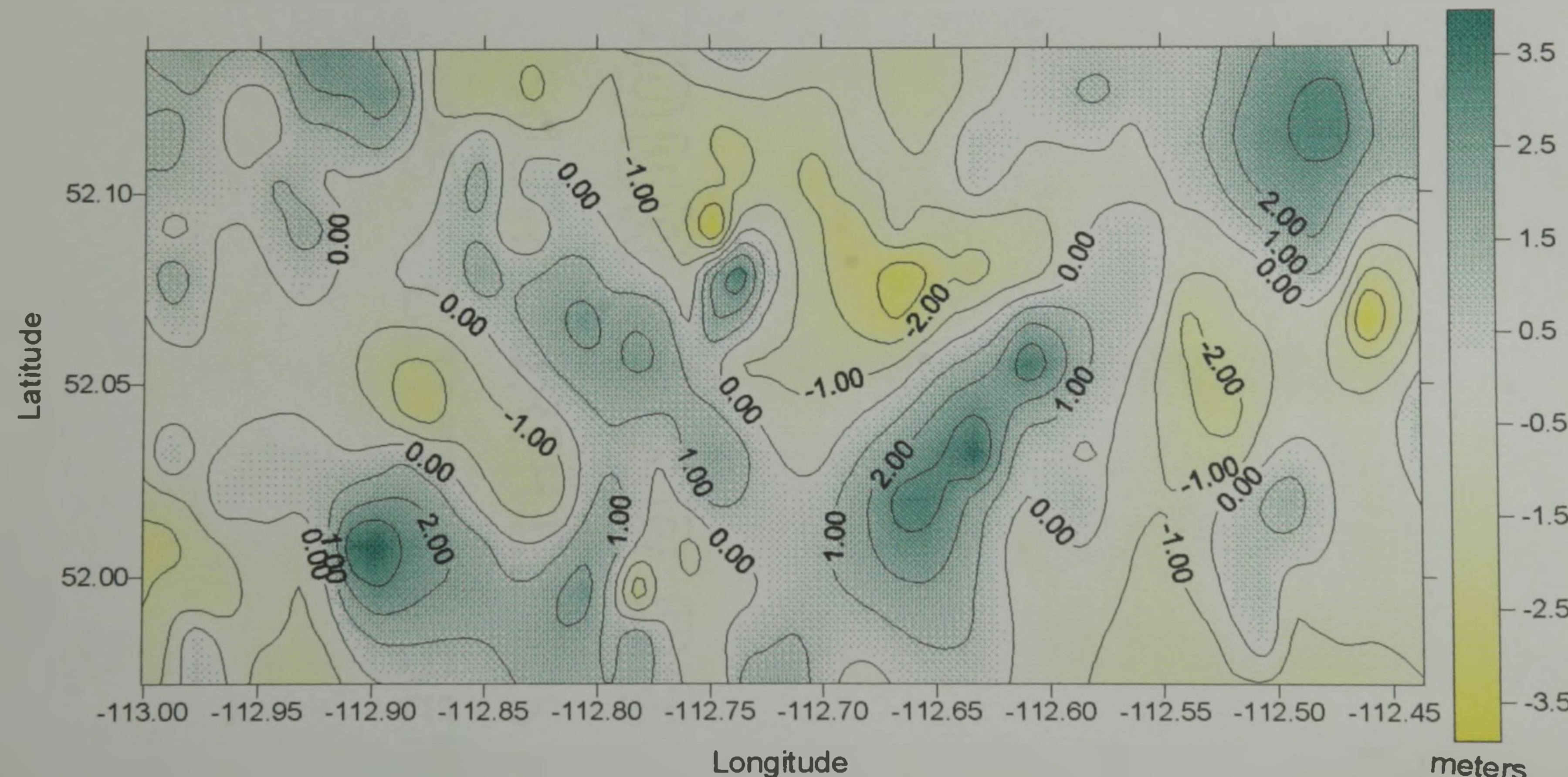


Figure 8f

Block 1 - Westgate Formation (Layer 3-4) Isopach Map - Thickness in Meters

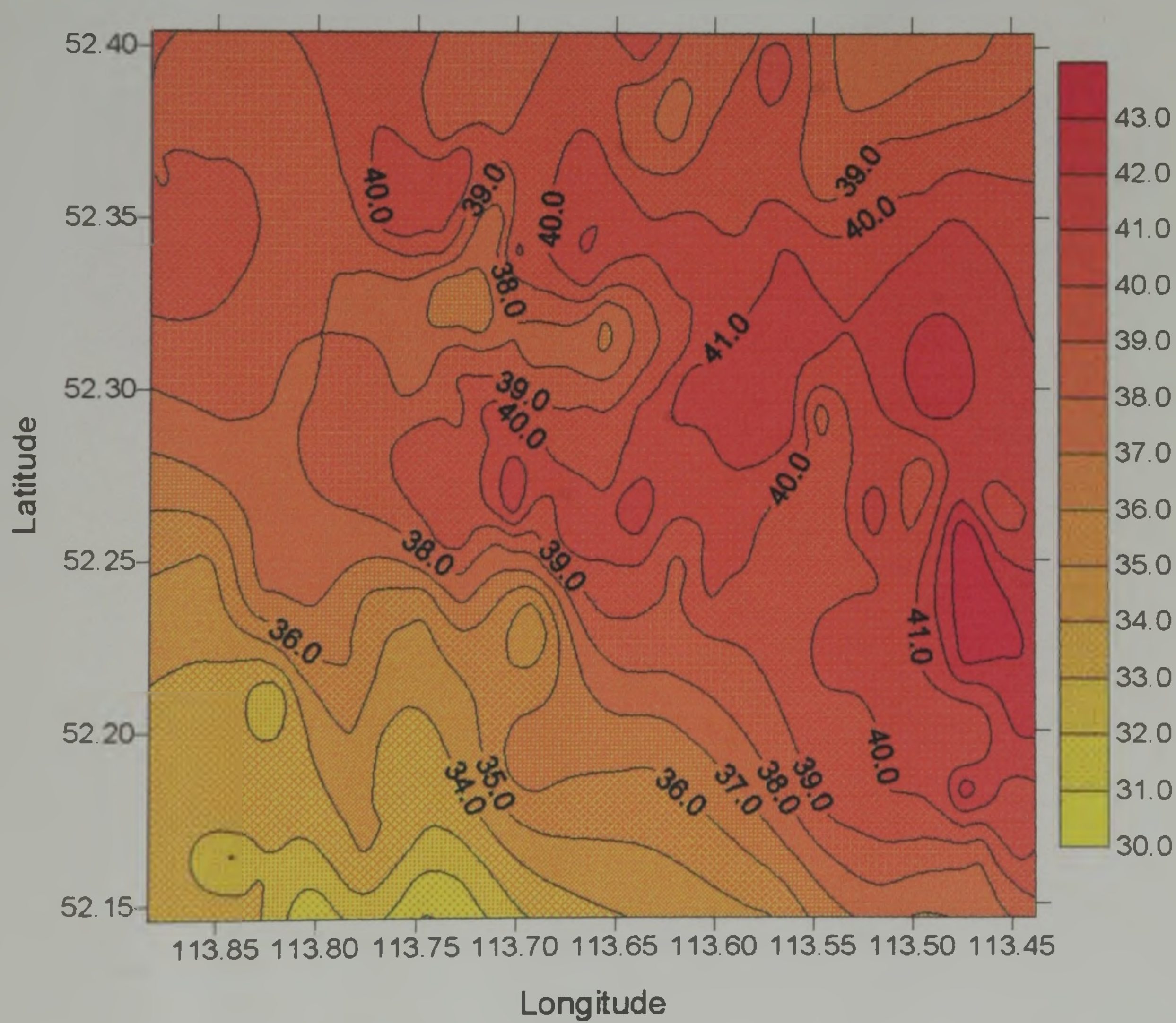


Figure 9a

Block 1 - Westgate Formation (Layer 3-4)
Trend Surface - Thickness in Meters

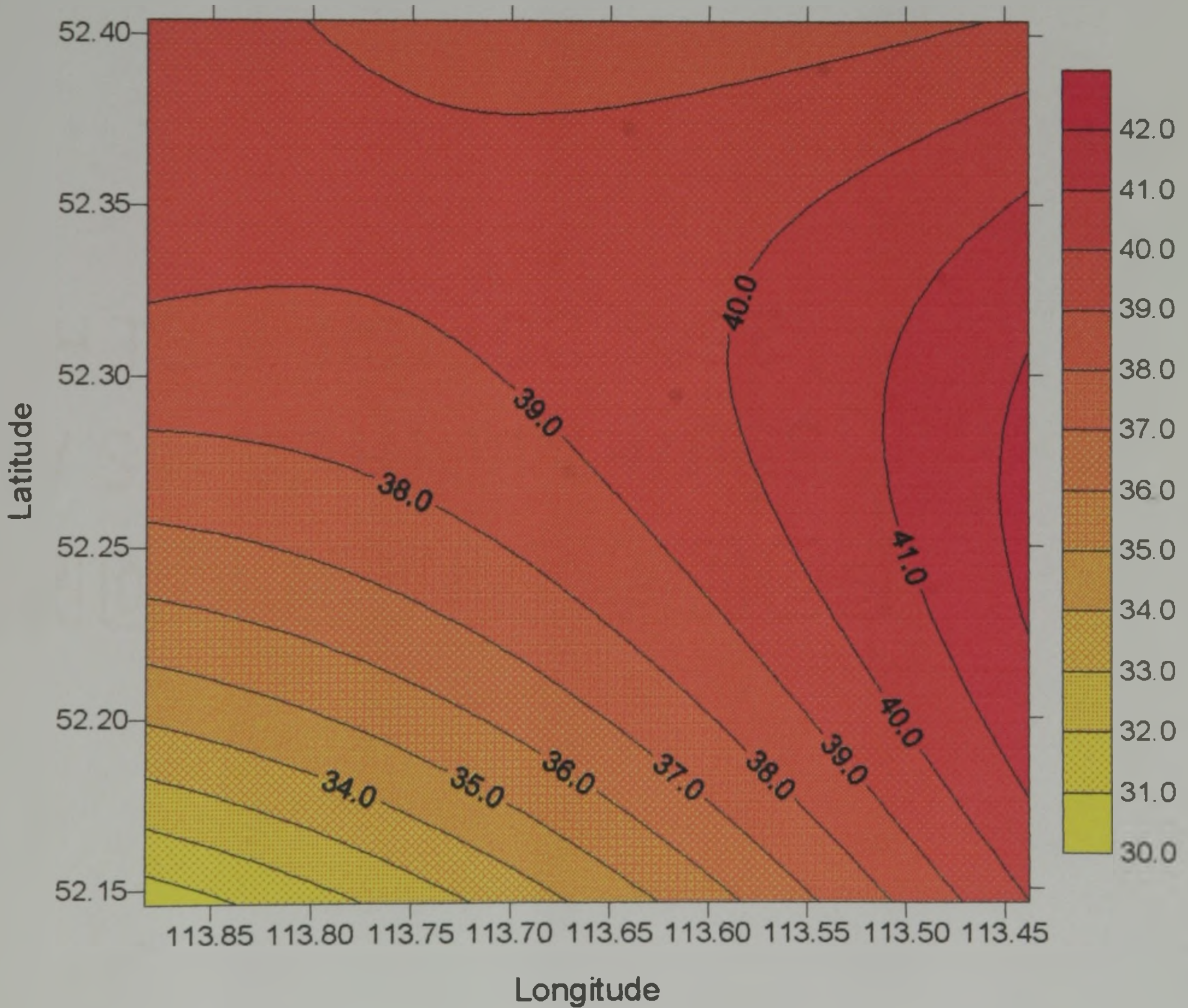
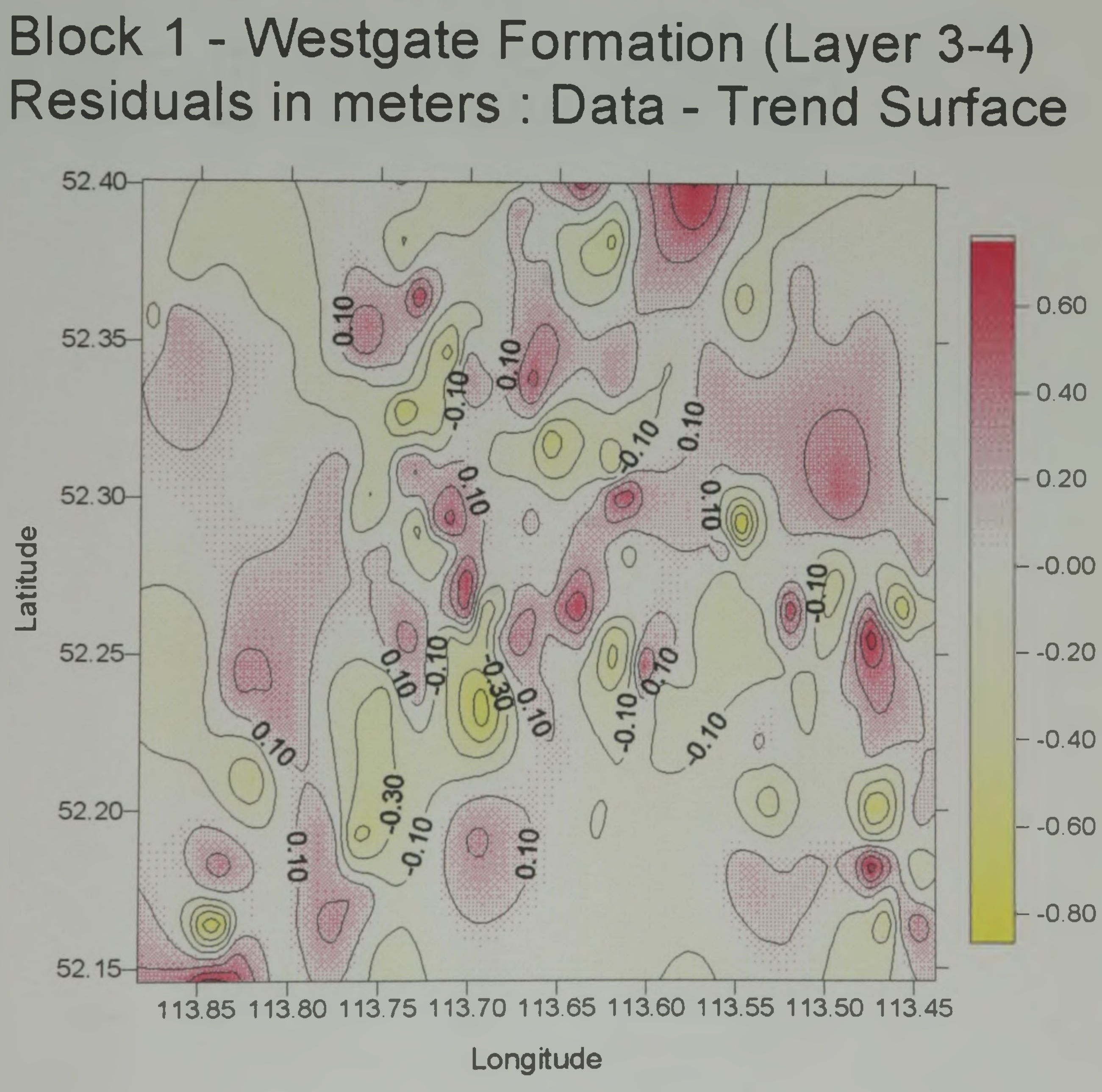


Figure 9b



Block 1 - Westgate Formation (Layer 3-4)
Residuals in meters : Data - Trend Surface
Latitude
Longitude
52.40
52.35
52.30
52.25
52.20
52.15
113.85 113.80 113.75 113.70 113.65 113.60 113.55 113.50 113.45
0.60
0.40
0.20
-0.00
-0.20
-0.40
-0.60
-0.80

Figure 9c

Block 2 - Westgate Formation (Layer 3-4)
Isopach Map - Thickness in Meters

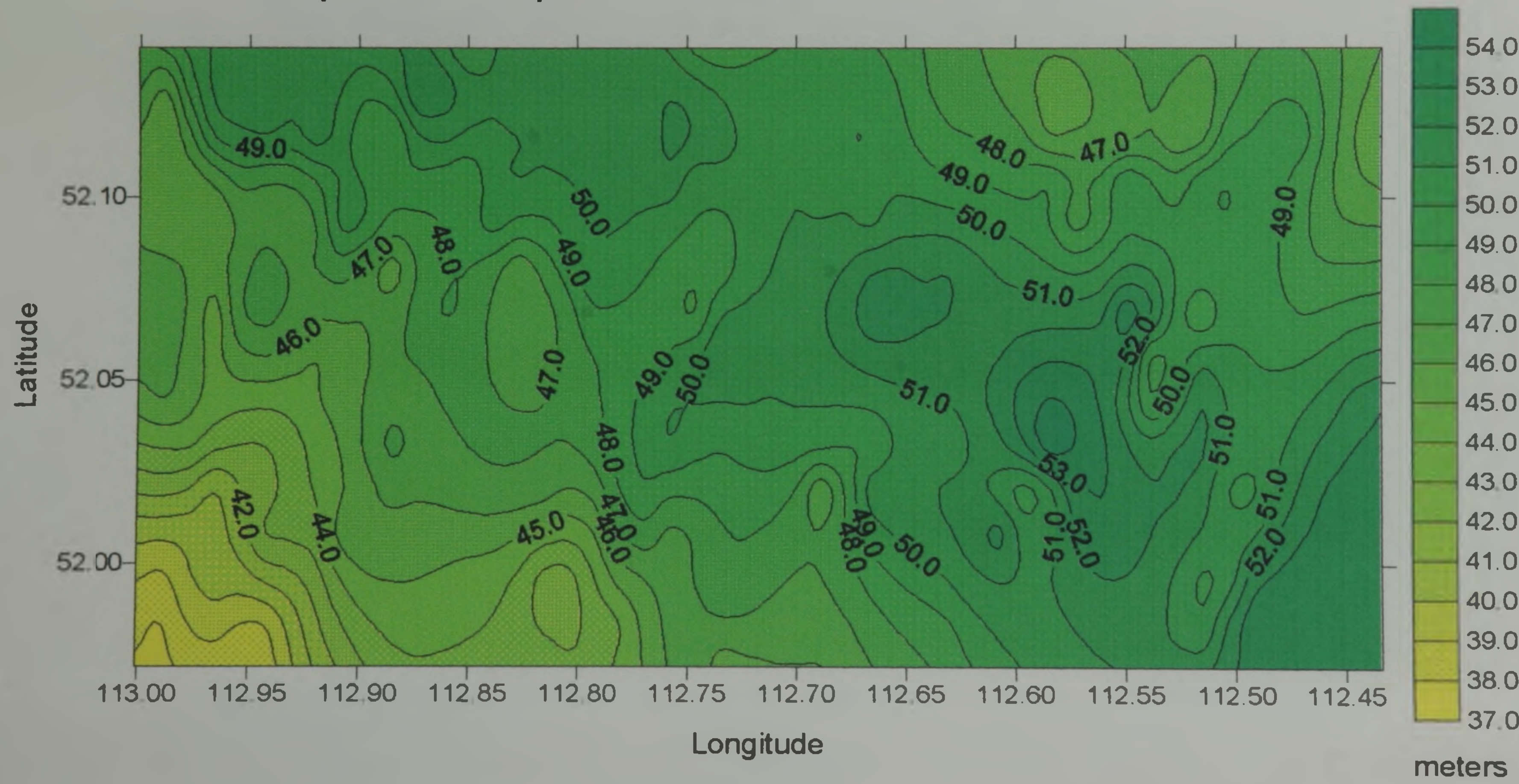


Figure 9d

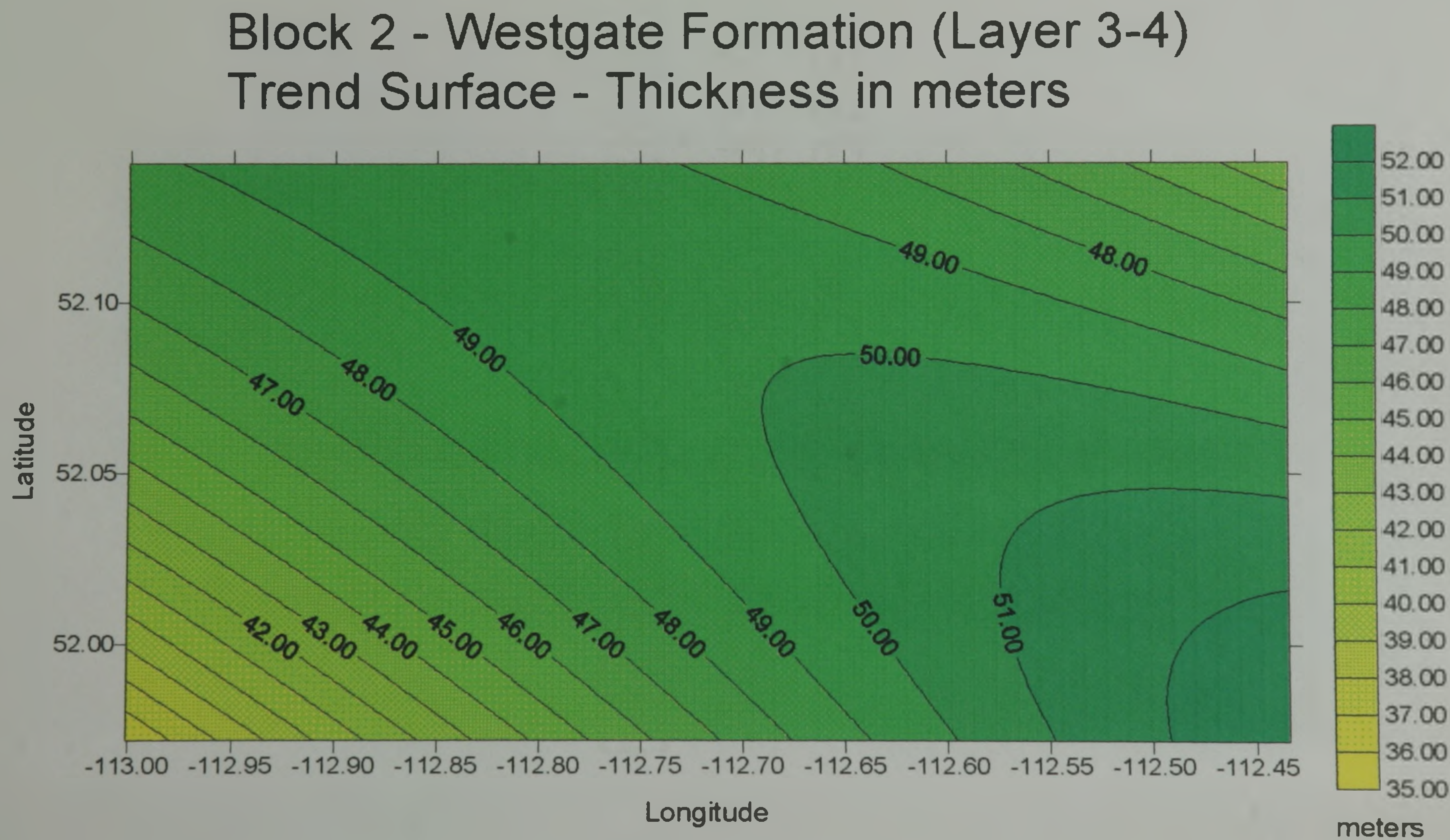

Block 2 - Westgate Formation (Layer 3-4)
Trend Surface - Thickness in meters
Latitude
Longitude
meters
52.10
52.05
52.00
-113.00
-112.95
-112.90
-112.85
-112.80
-112.75
-112.70
-112.65
-112.60
-112.55
-112.50
-112.45
42.00
43.00
44.00
45.00
46.00
47.00
48.00
49.00
50.00
51.00
52.00
35.00
36.00
37.00
38.00
39.00
40.00
41.00

Figure 9e

Block 2 - Westgate Formation (Layer 3-4) Residuals in meters : Data - Trend Surface

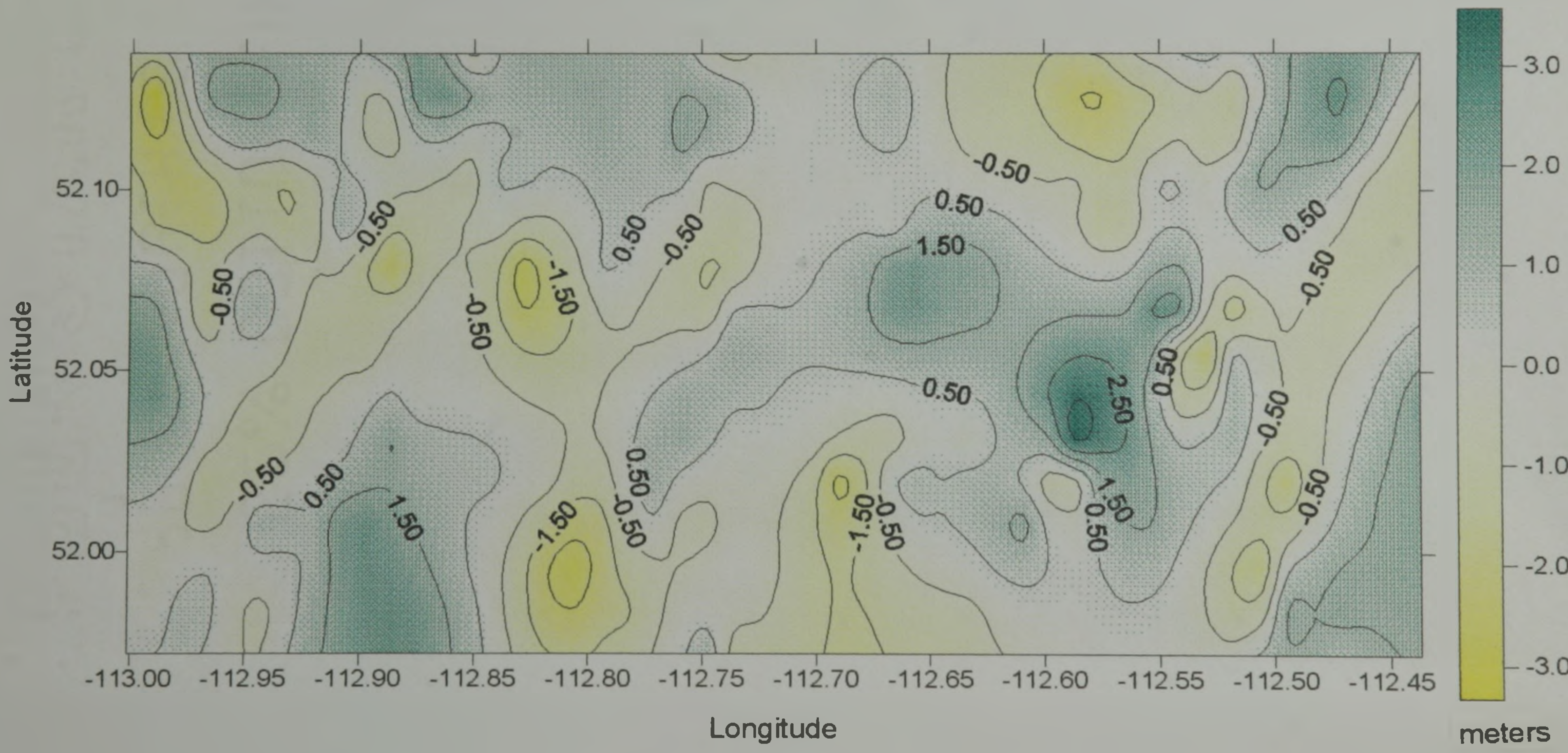


Figure 9f

Block 1 - Fish Scales Formation (Layer 4-5)
Isopach Map - Thickness in Meters

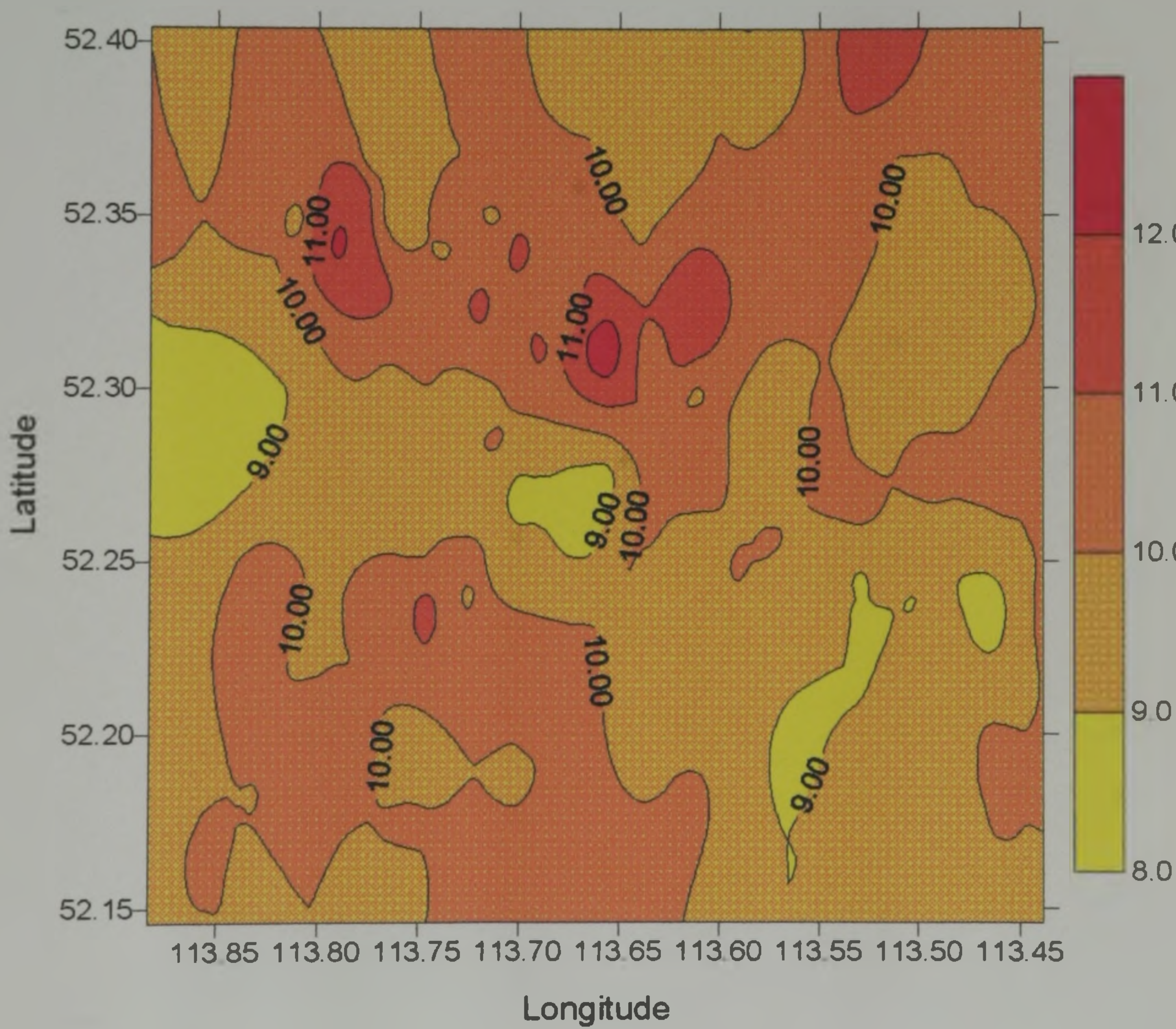


Figure 10a

Block 1 - Fish Scales Formation (Layer 4-5)
Trend Surface - Thickness in Meters

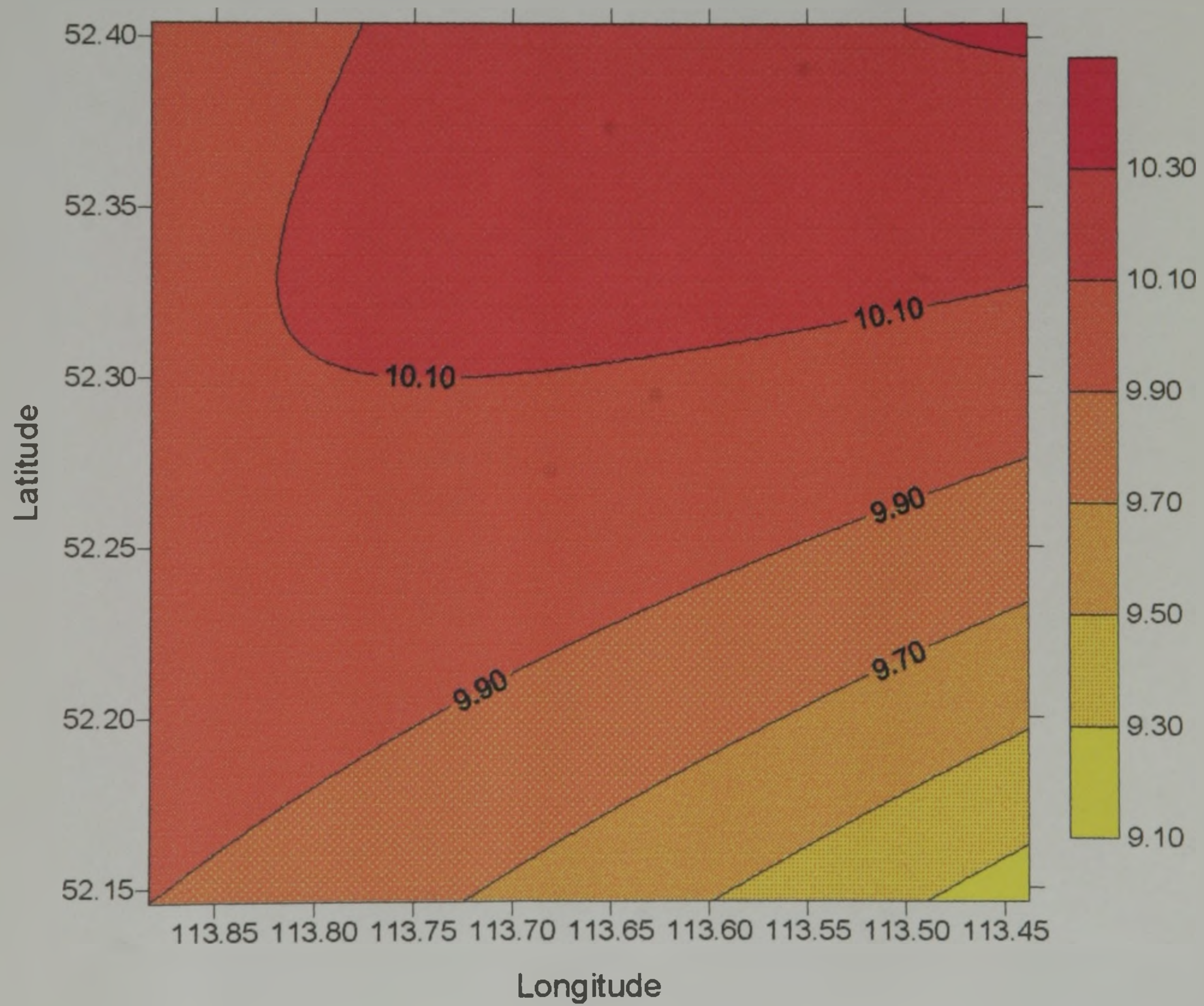


Figure 10b

Block 1 - Fish Scales Formation (Layer 4-5)
Residuals in meters : Data - Trend Surface

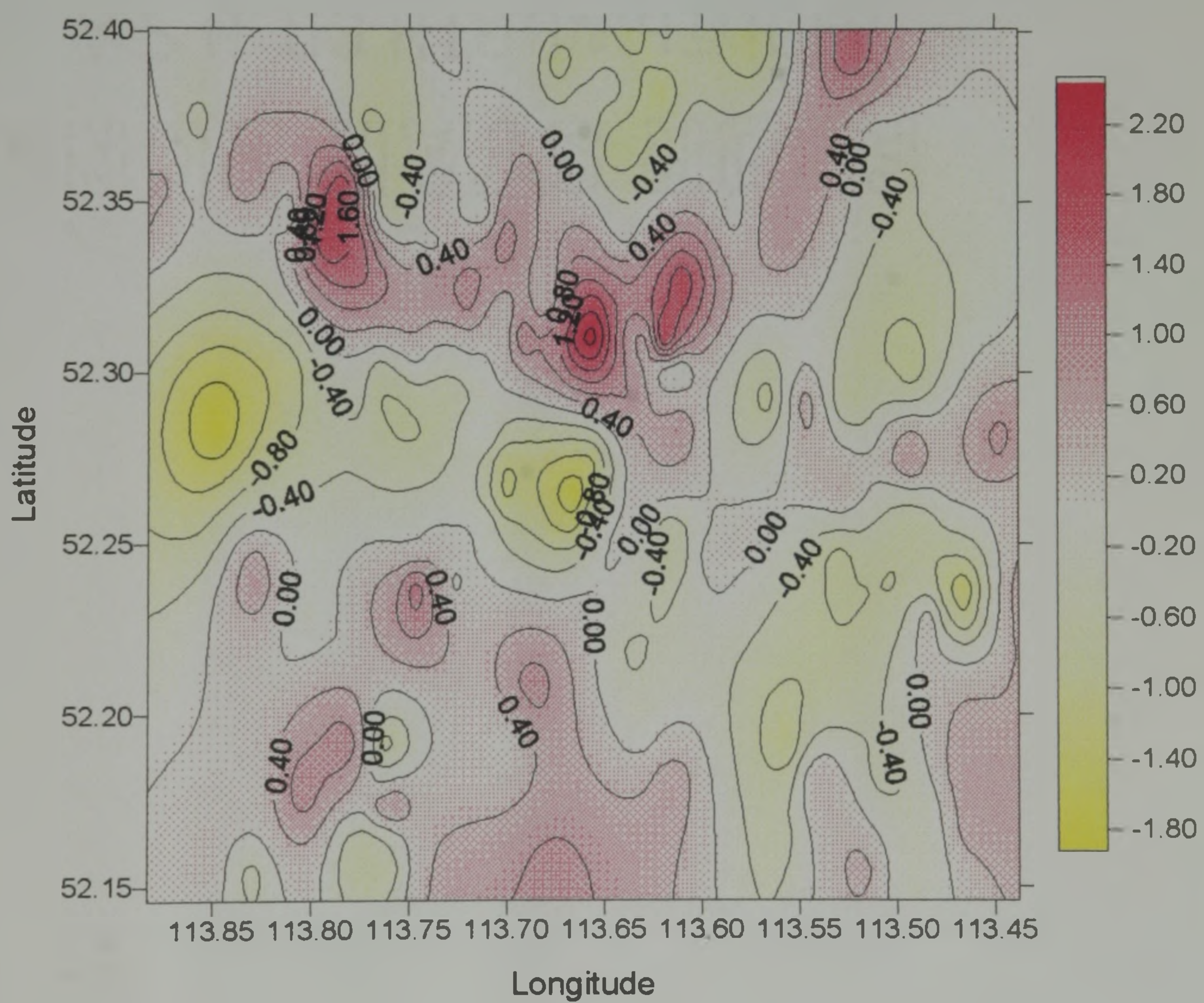
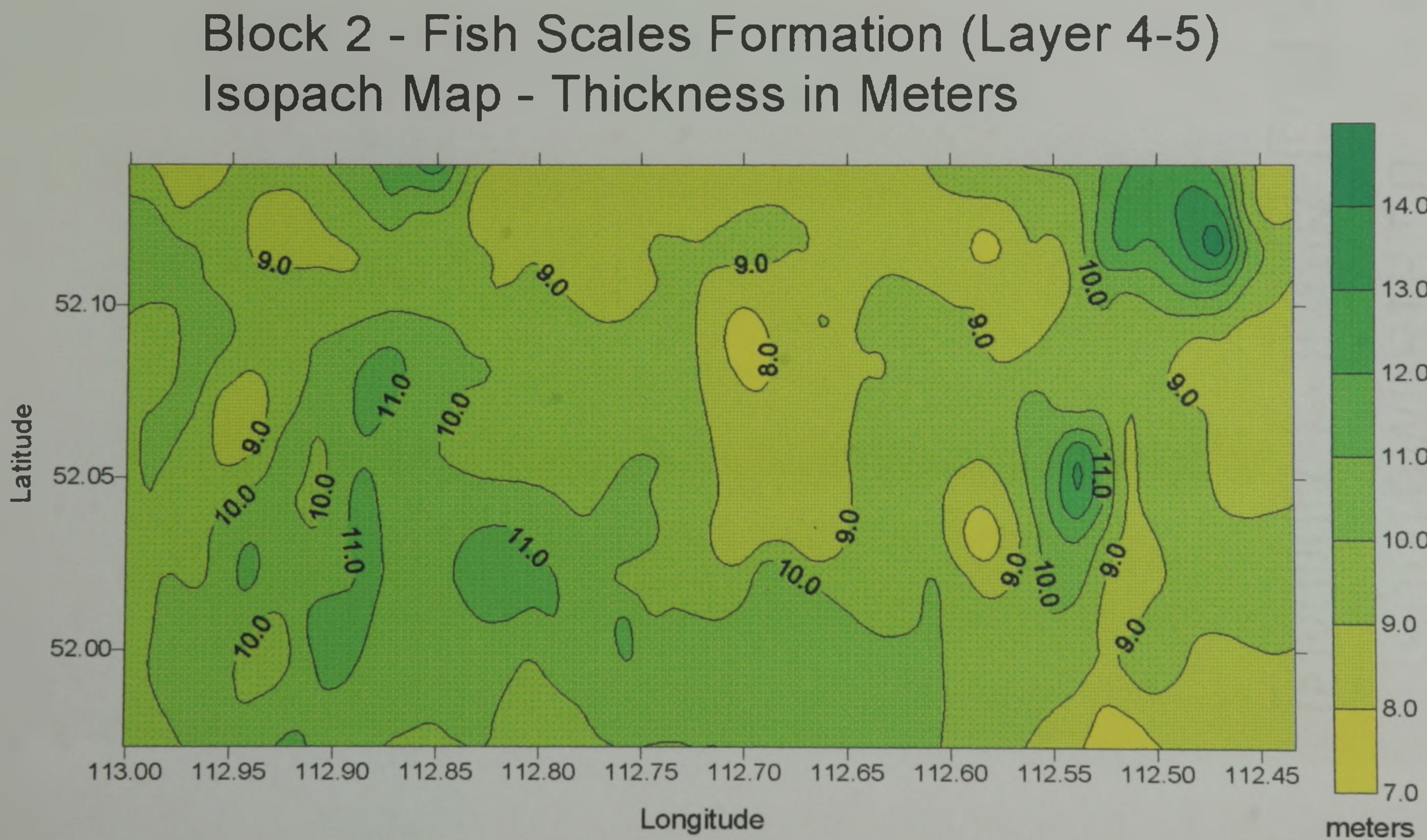


Figure 10c



Block 2 - Fish Scales Formation (Layer 4-5)
Isopach Map - Thickness in Meters
Latitude
52.10
52.05
52.00
113.00
112.95
112.90
112.85
112.80
112.75
112.70
112.65
112.60
112.55
112.50
112.45
Longitude
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
meters

Figure 10d

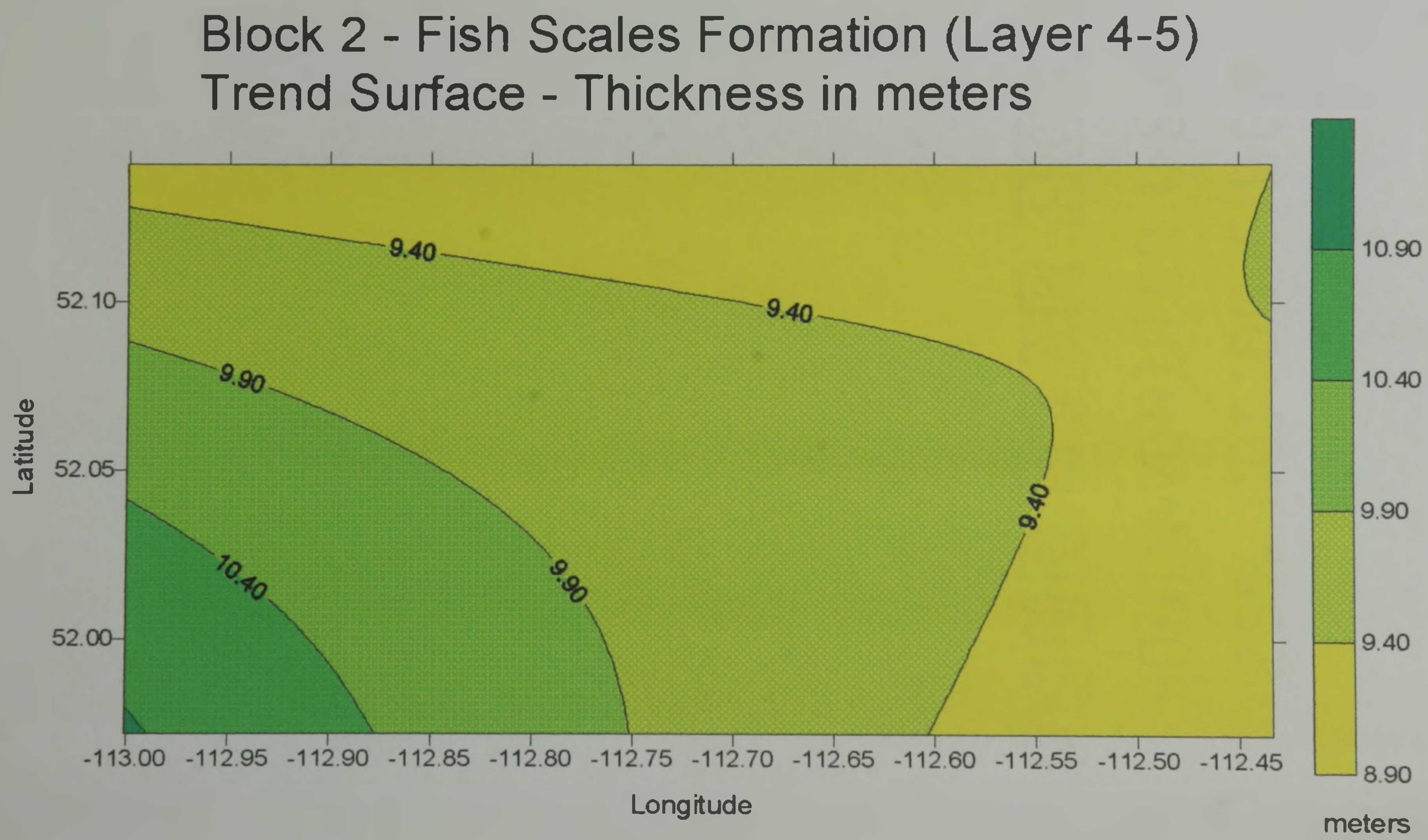

Block 2 - Fish Scales Formation (Layer 4-5)
Trend Surface - Thickness in meters
9.40
9.40
9.90
10.40
9.90
9.40
Latitude
52.10
52.05
52.00
-113.00
-112.95
-112.90
-112.85
-112.80
-112.75
-112.70
-112.65
-112.60
-112.55
-112.50
-112.45
Longitude
10.90
10.40
9.90
9.40
8.90
meters

Figure 10e

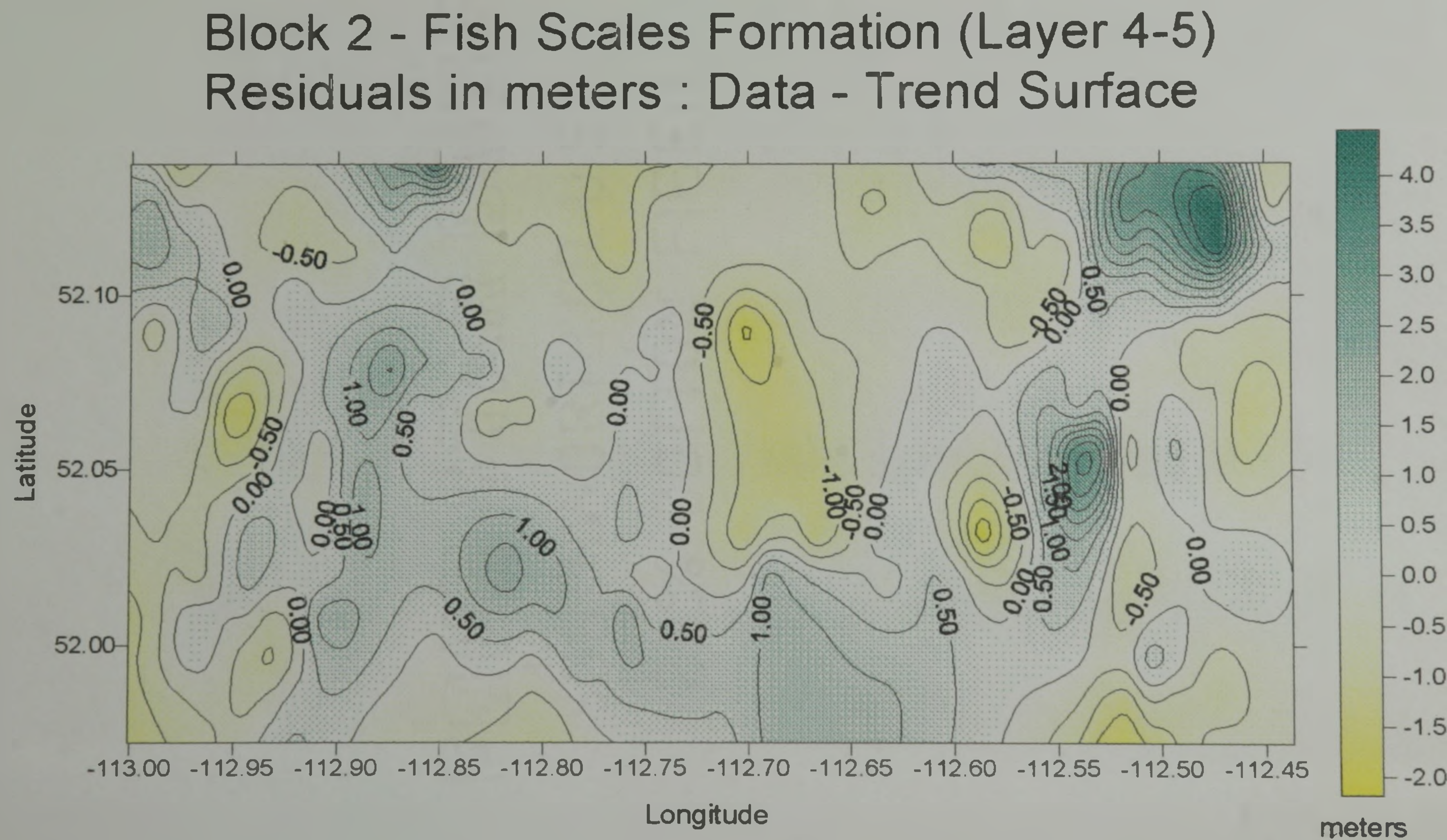

Block 2 - Fish Scales Formation (Layer 4-5)
Residuals in meters : Data - Trend Surface
Latitude
Longitude
meters
52.10
52.05
52.00
-113.00
-112.95
-112.90
-112.85
-112.80
-112.75
-112.70
-112.65
-112.60
-112.55
-112.50
-112.45
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0

Figure 10f

Block 1 - Layer 5-6
Isopach Map - Thickness in Meters

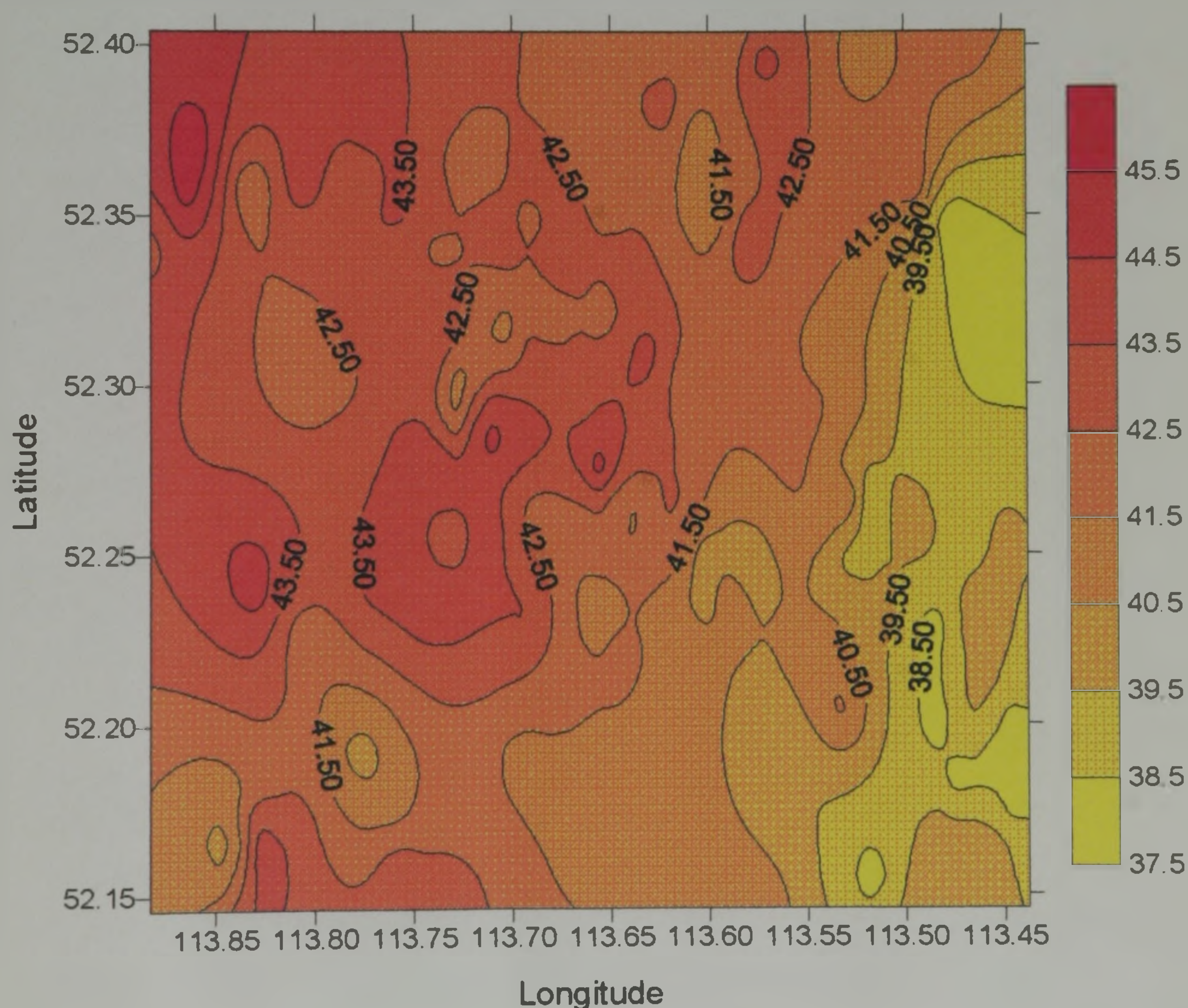


Figure 11a

Block 1 - Layer 5-6
Trend Surface - Thickness in Meters

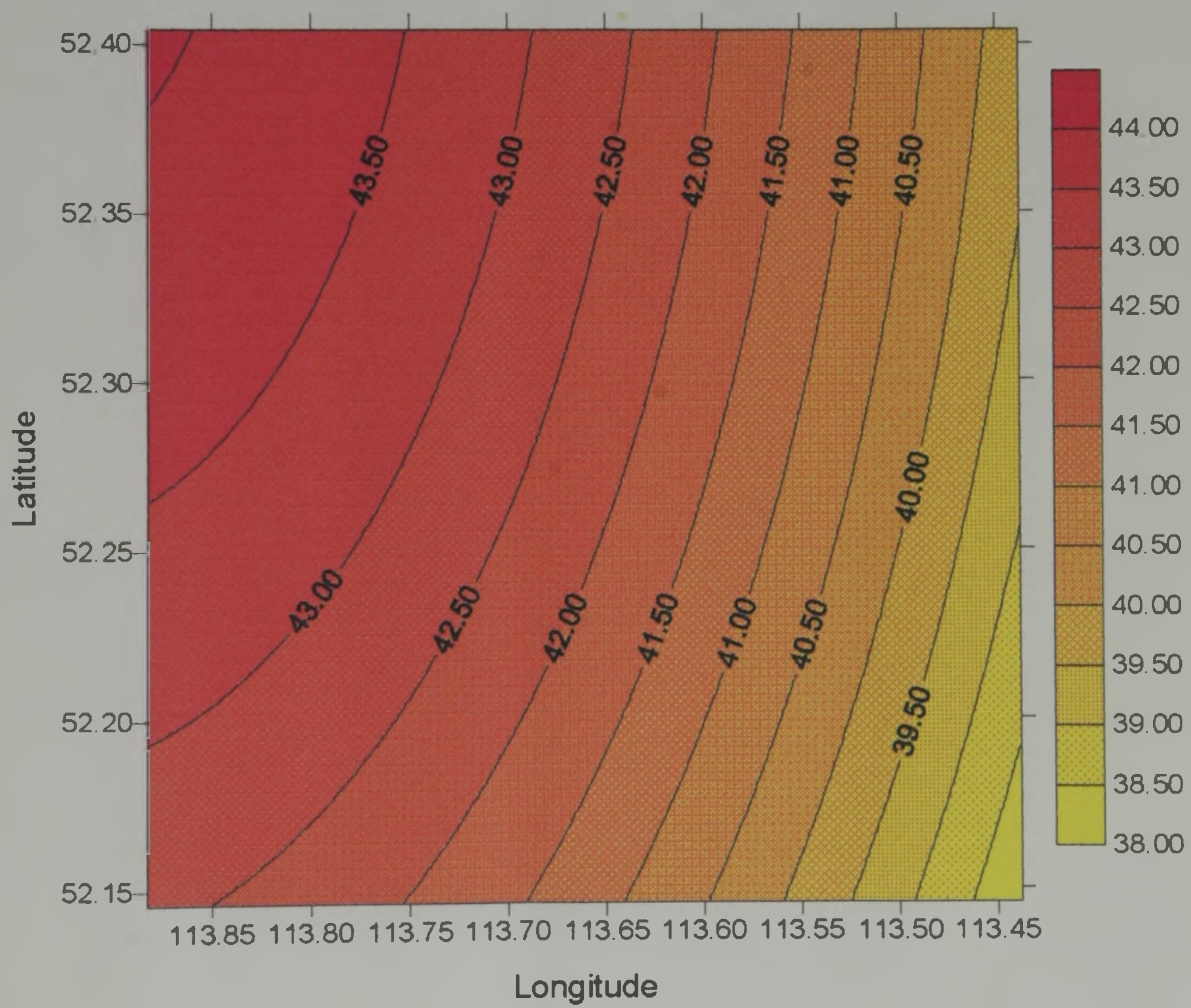


Figure 11b

Block 1 - Layer 5-6
Residuals in meters : Data - Trend Surface

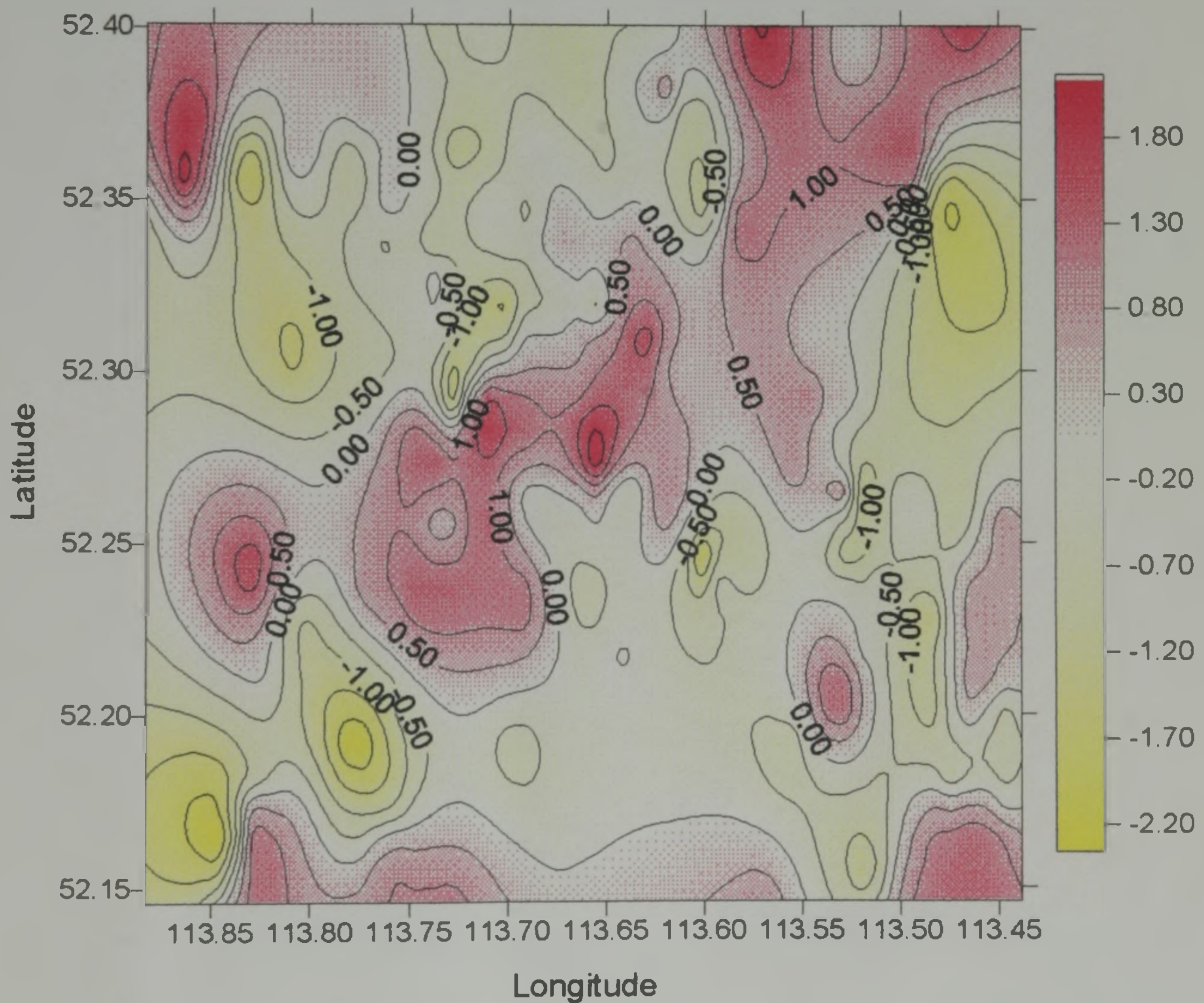


Figure 11c

Block 2 - Layer 5-6
Isopach Map - Thickness in Meters

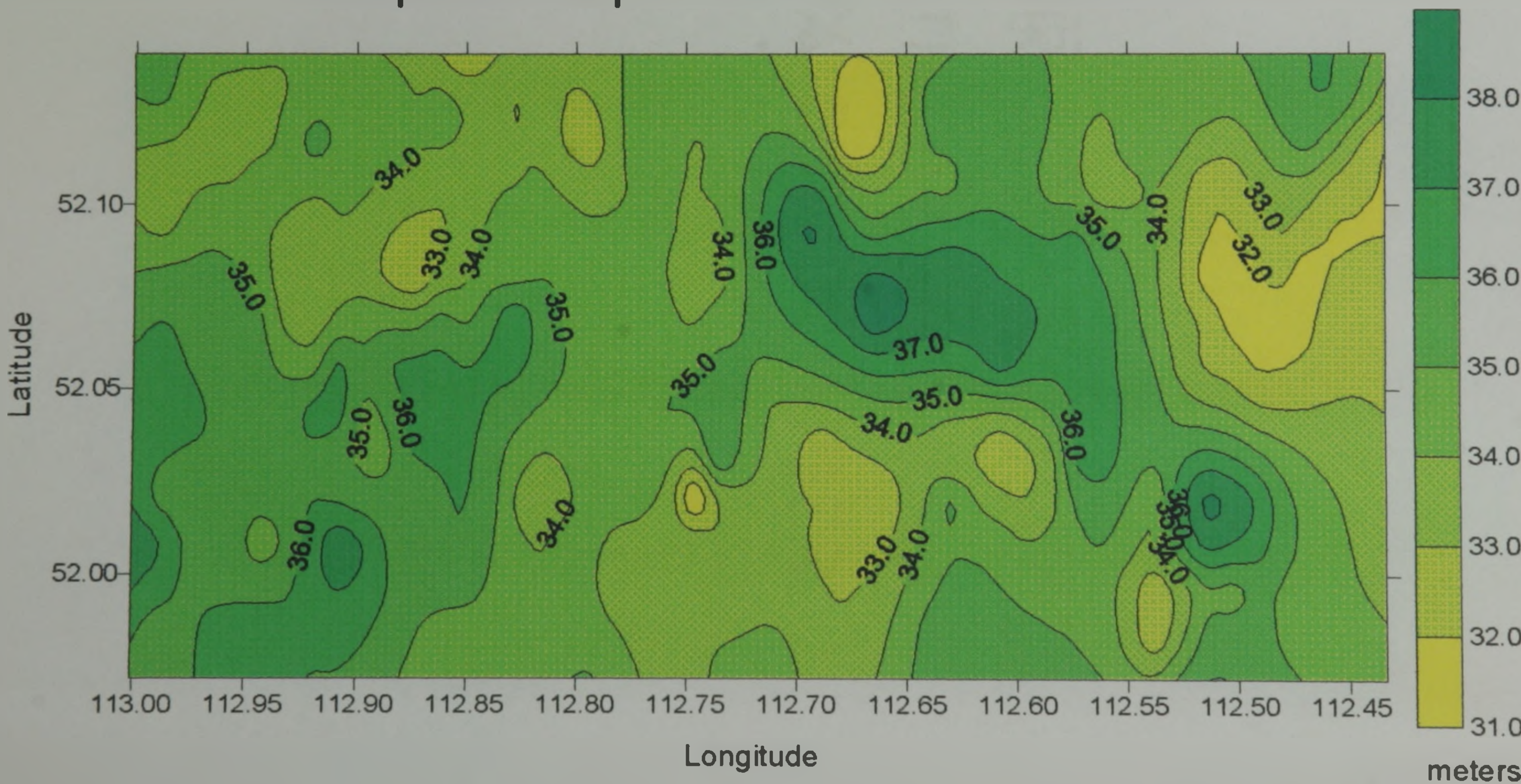


Figure 11d

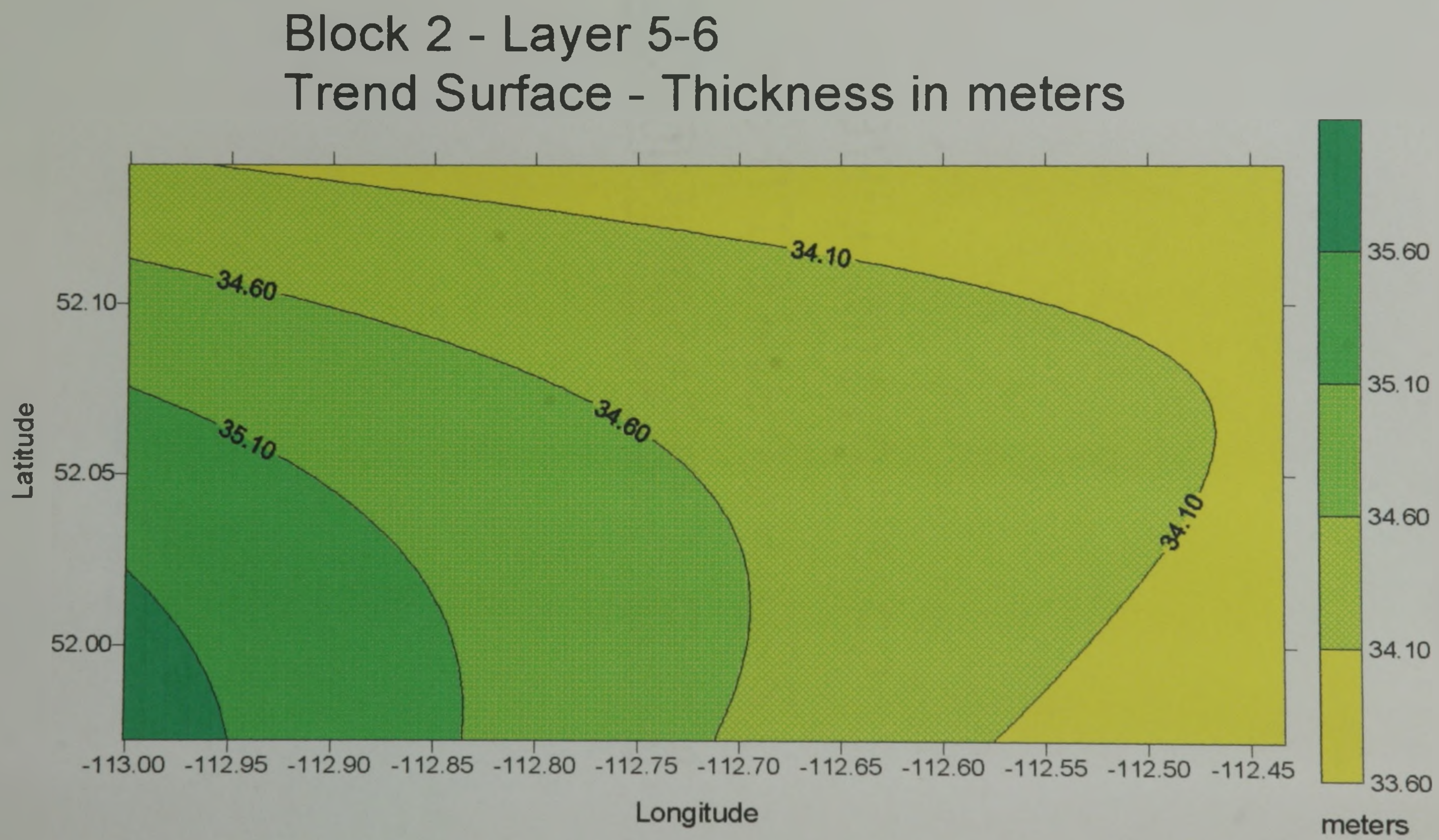

Block 2 - Layer 5-6
Trend Surface - Thickness in meters
34.10
34.60
34.60
35.10
34.10
52.10
52.05
52.00
Latitude
-113.00
-112.95
-112.90
-112.85
-112.80
-112.75
-112.70
-112.65
-112.60
-112.55
-112.50
-112.45
Longitude
35.60
35.10
34.60
34.10
33.60
meters

Figure 11e

Block 2 - Layer 5-6
Residuals in meters : Data - Trend Surface

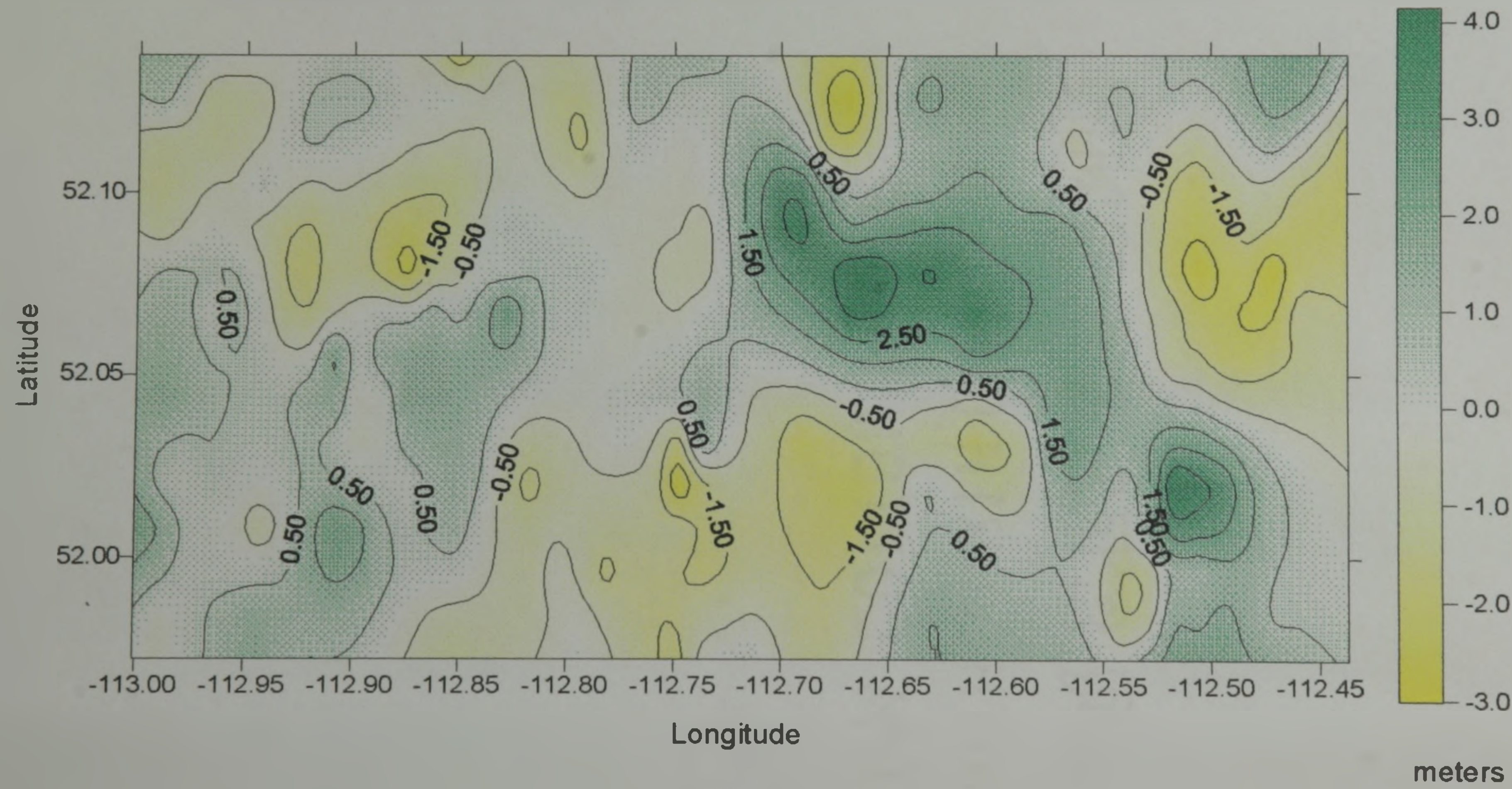


Figure 11f

Block 1 - Layer 6-8
Isopach Map - Thickness in Meters

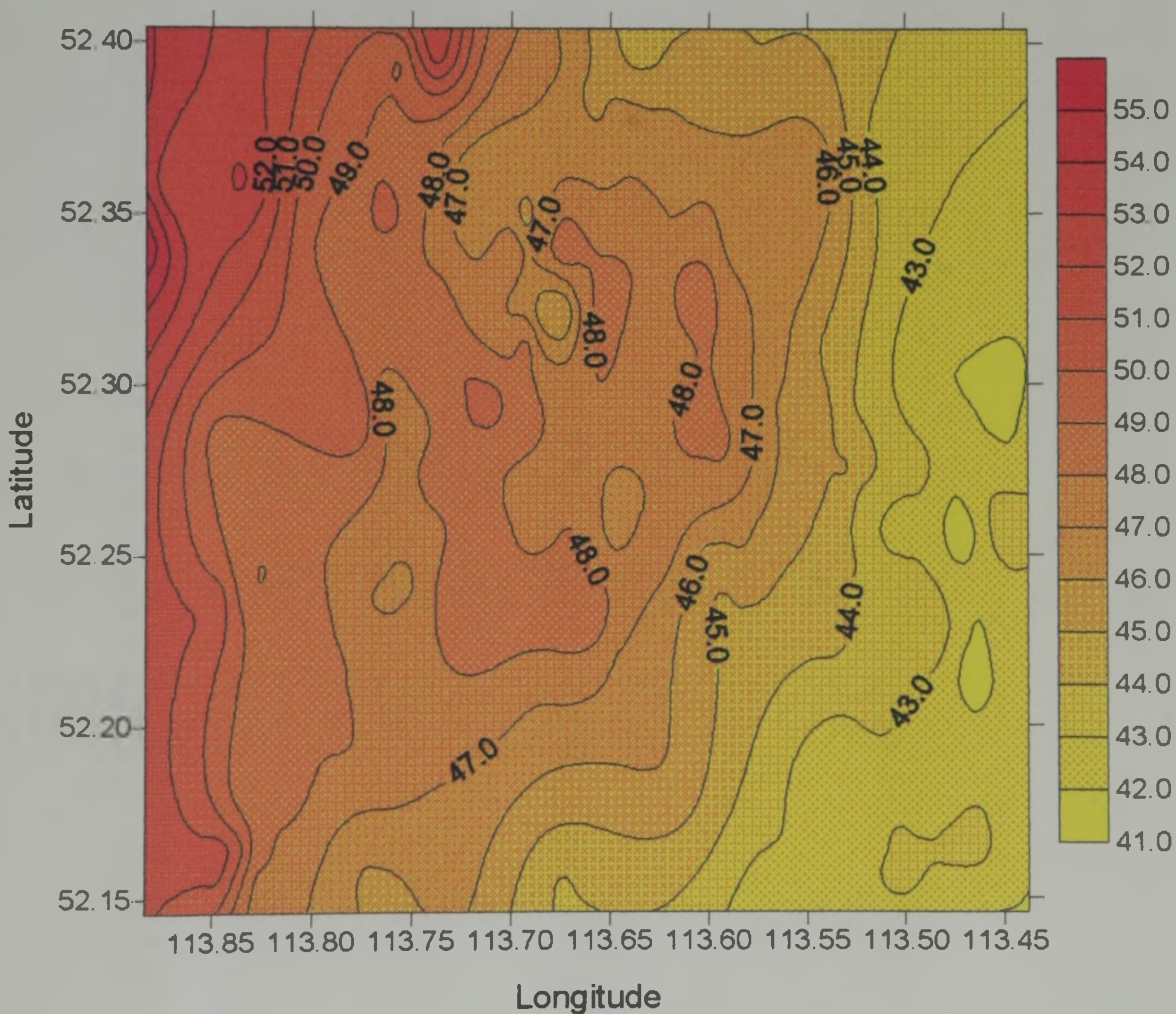


Figure 12a

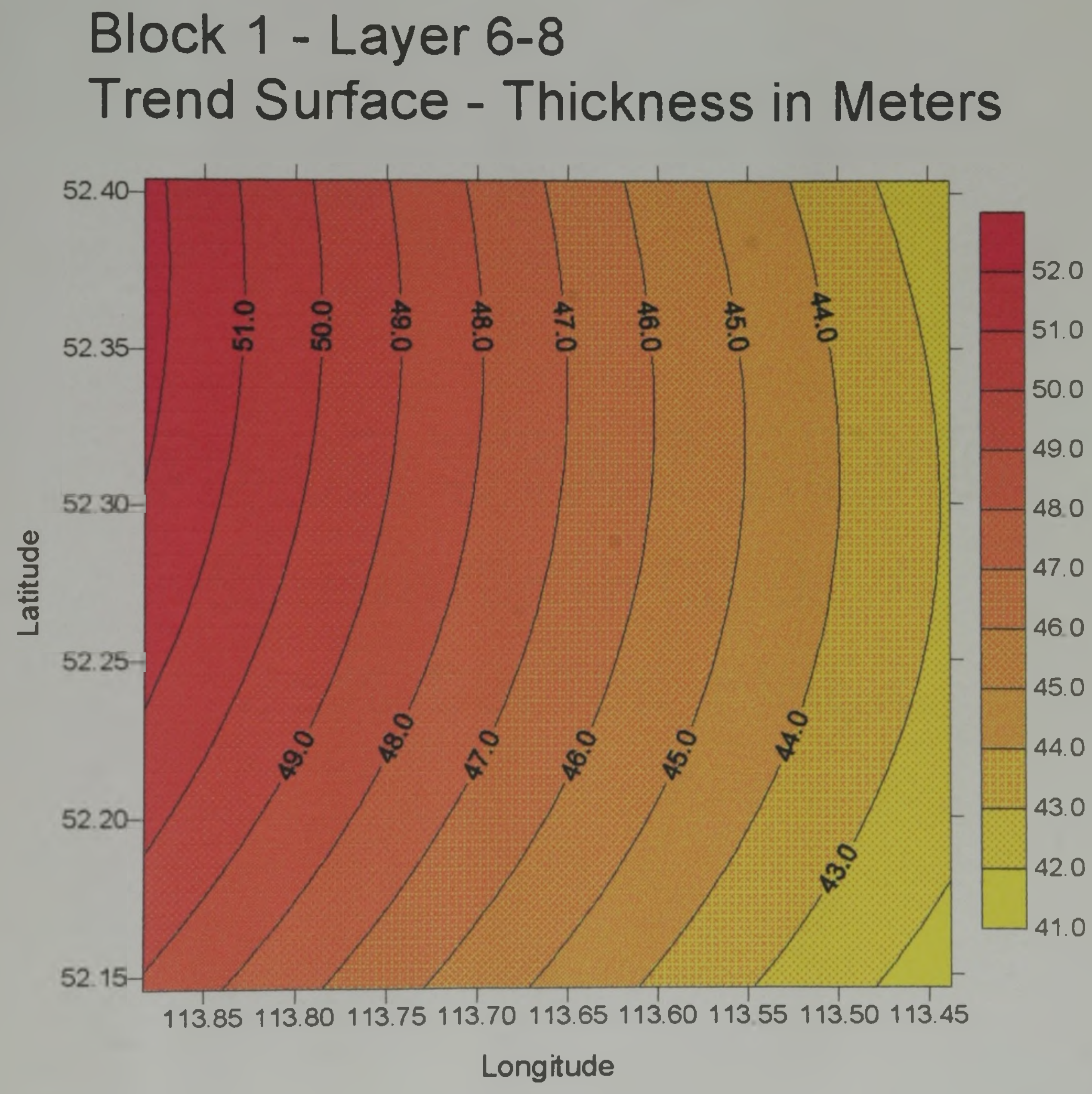

Block 1 - Layer 6-8
Trend Surface - Thickness in Meters
Latitude
52.40
52.35
52.30
52.25
52.20
52.15
Longitude
113.85 113.80 113.75 113.70 113.65 113.60 113.55 113.50 113.45
51.0
50.0
49.0
48.0
47.0
46.0
45.0
44.0
43.0
52.0
51.0
50.0
49.0
48.0
47.0
46.0
45.0
44.0
43.0
42.0
41.0

Figure 12b

Block 1 - Layer 6-8
Residuals in meters : Data - Trend Surface

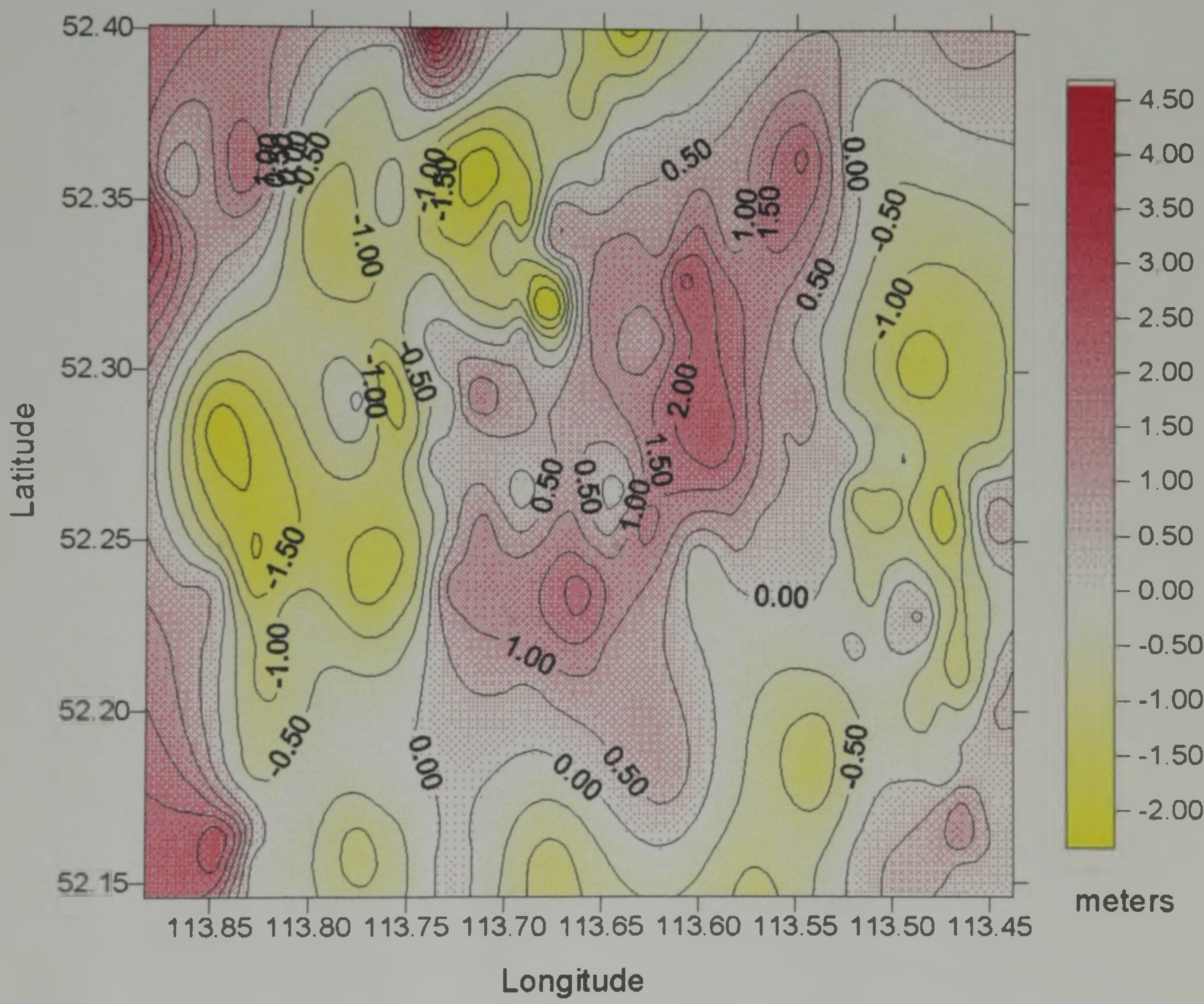


Figure 12c

Block 1 - Layer 8-9
Isopach Map - Thickness in Meters

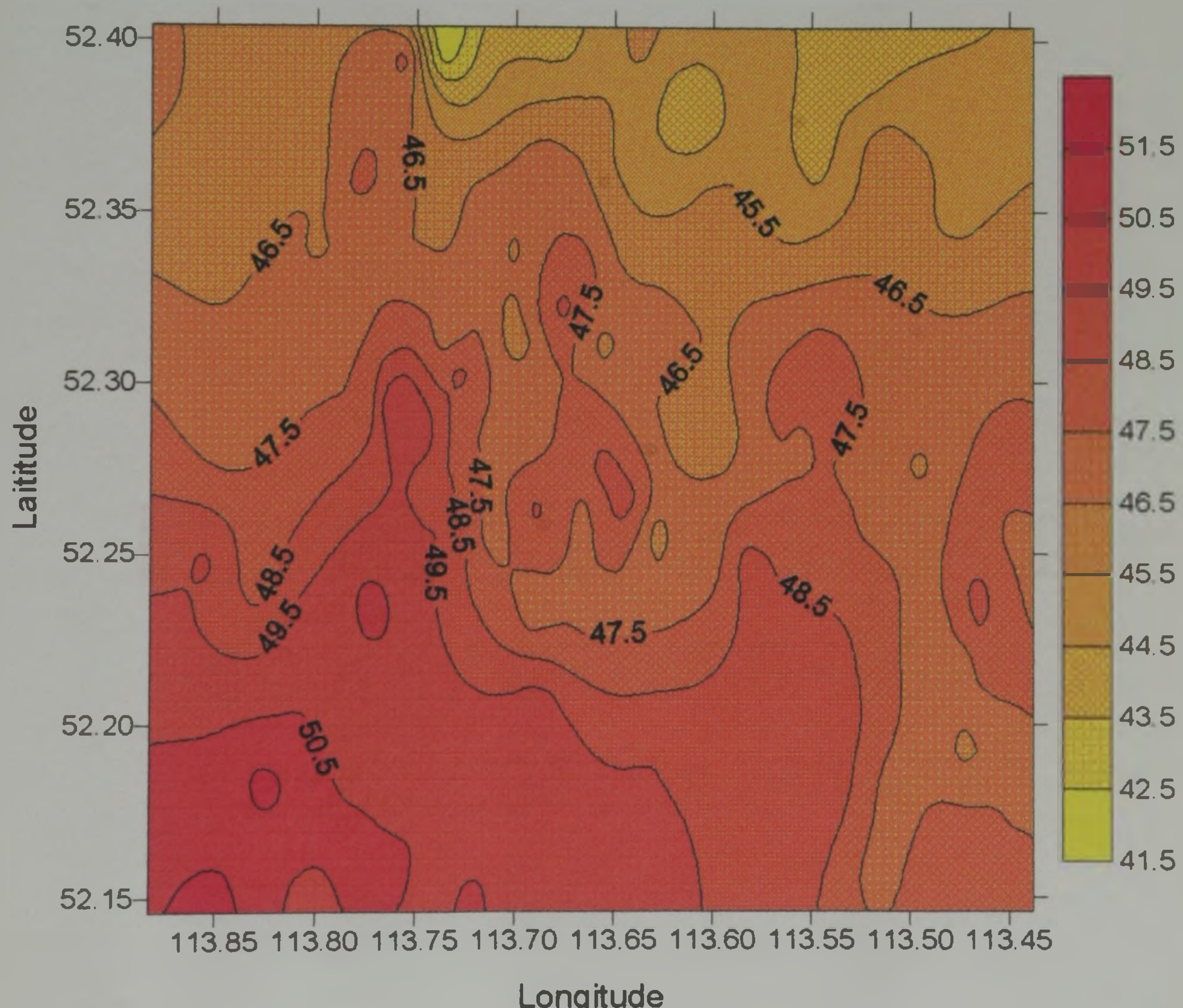


Figure 13a

Block 1 - Layer 8-9
Trend Surface - Thickness in Meters

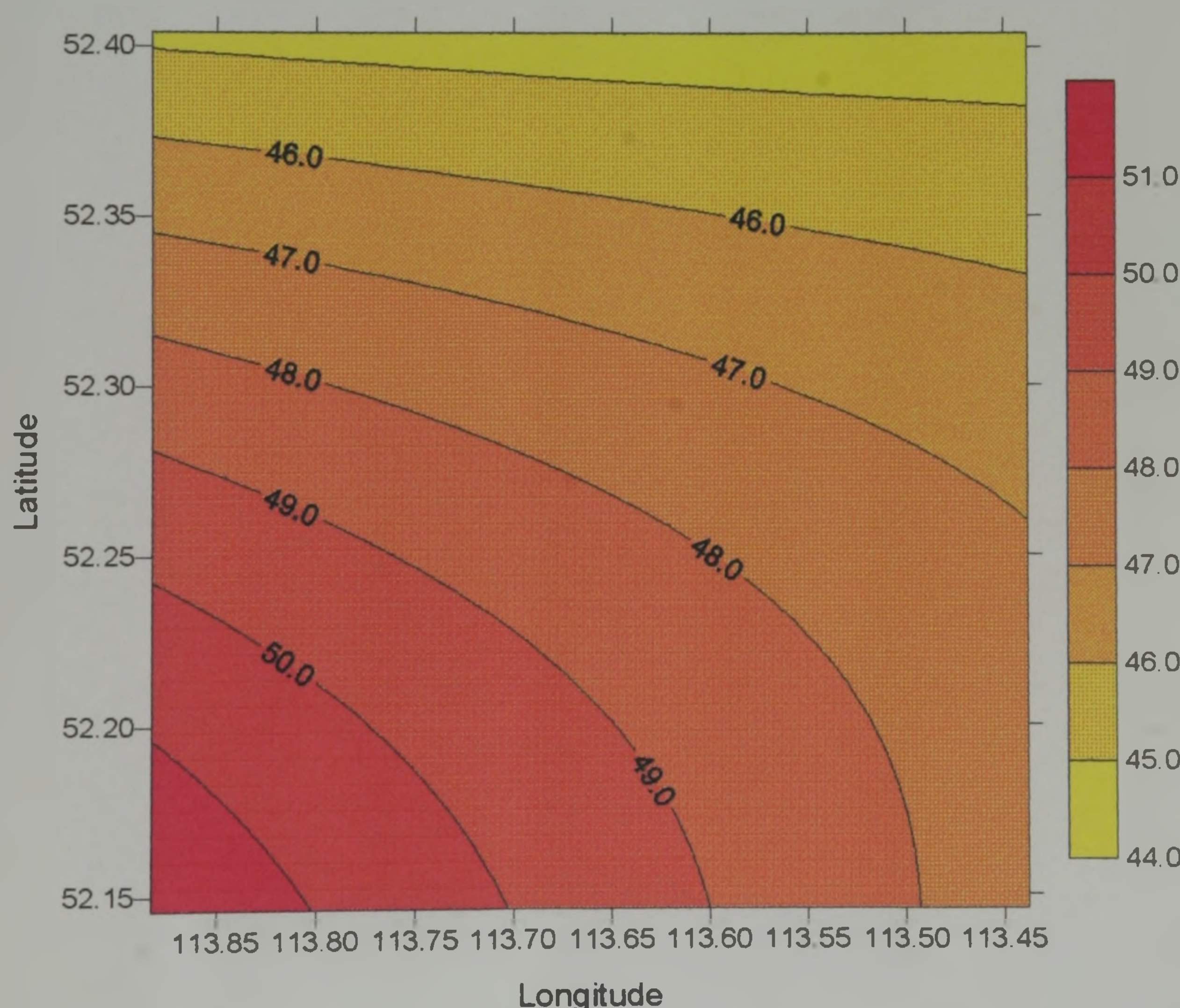


Figure 13b

Block 1 - Layer 8-9
Residuals in meters : Data - Trend Surface

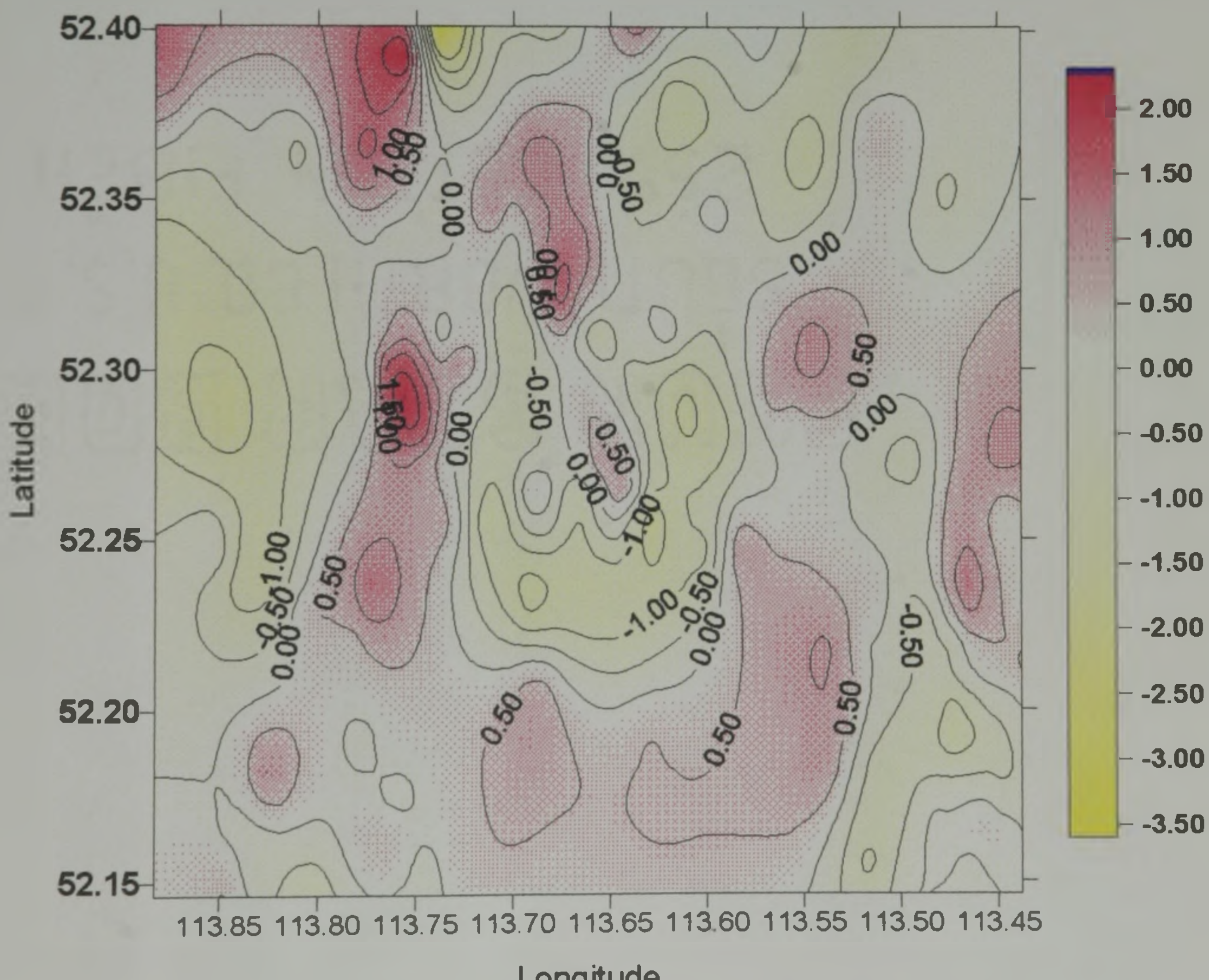


Figure 13c

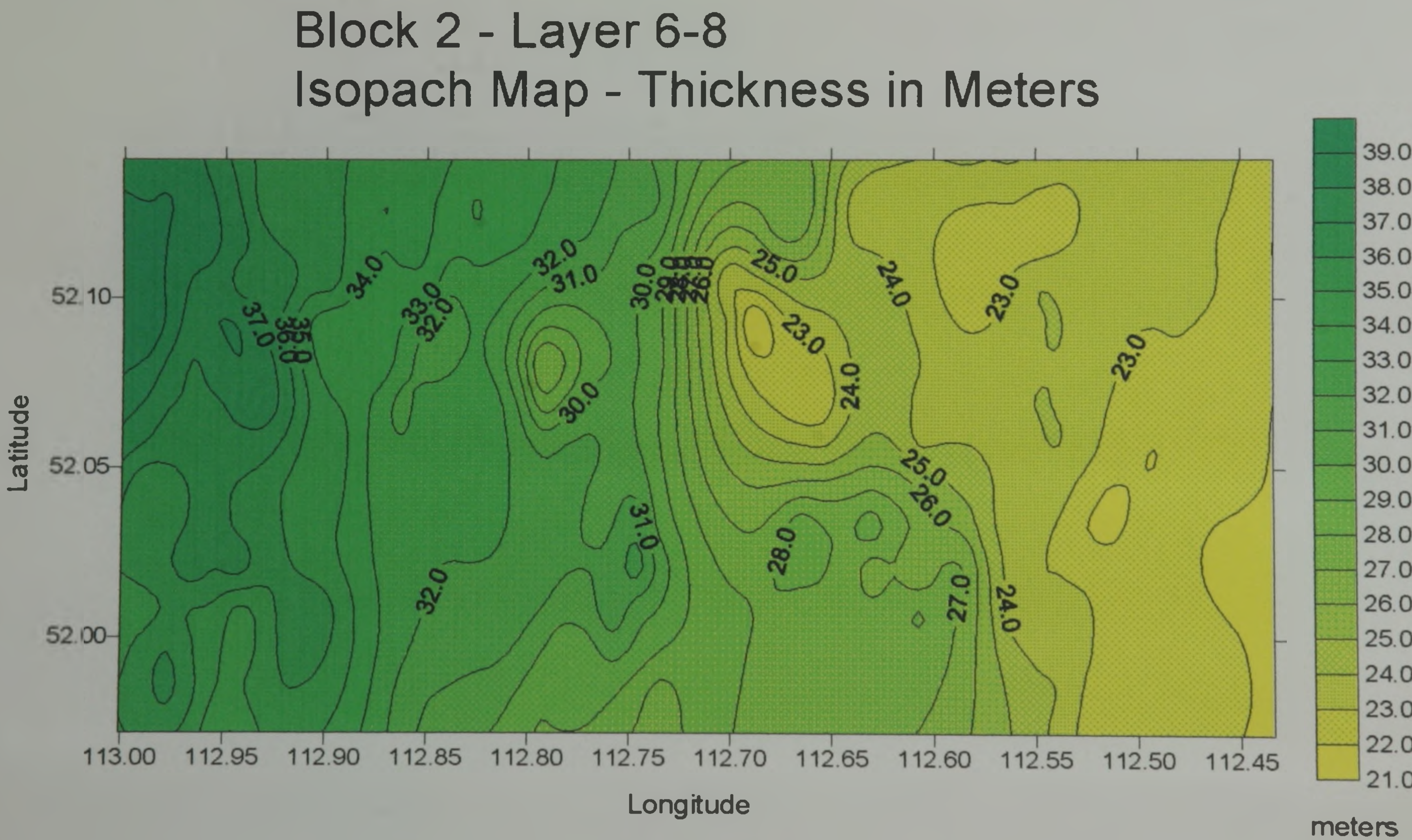

Block 2 - Layer 6-8
Isopach Map - Thickness in Meters
Latitude
Longitude
meters
52.10
52.05
52.00
113.00
112.95
112.90
112.85
112.80
112.75
112.70
112.65
112.60
112.55
112.50
112.45
39.0
38.0
37.0
36.0
35.0
34.0
33.0
32.0
31.0
30.0
29.0
28.0
27.0
26.0
25.0
24.0
23.0
22.0
21.0

Figure 12d

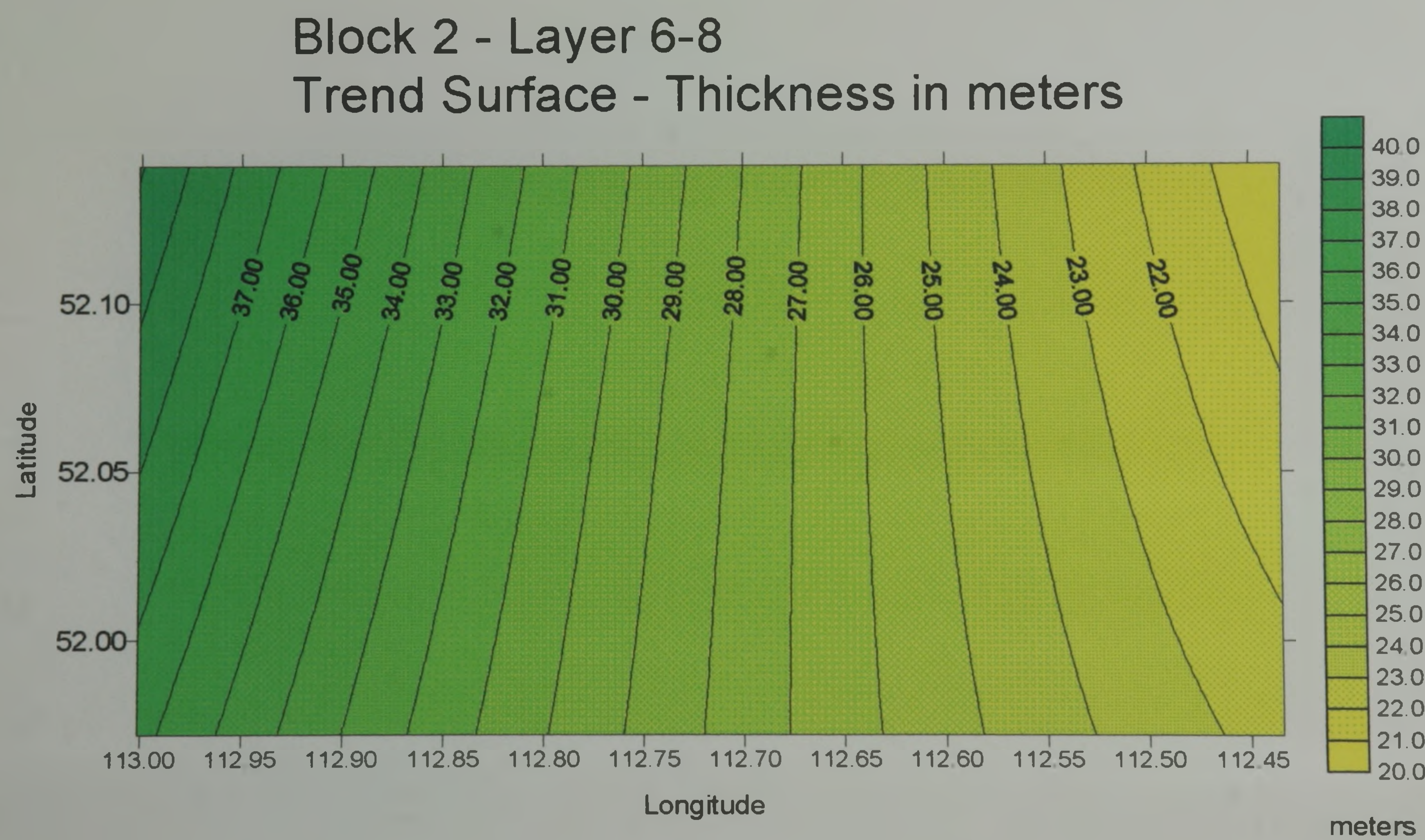

Block 2 - Layer 6-8
Trend Surface - Thickness in meters
Latitude
Longitude
52.10
52.05
52.00
113.00
112.95
112.90
112.85
112.80
112.75
112.70
112.65
112.60
112.55
112.50
112.45
37.00
36.00
35.00
34.00
33.00
32.00
31.00
30.00
29.00
28.00
27.00
26.00
25.00
24.00
23.00
22.00
40.0
39.0
38.0
37.0
36.0
35.0
34.0
33.0
32.0
31.0
30.0
29.0
28.0
27.0
26.0
25.0
24.0
23.0
22.0
21.0
20.0
meters

Figure 12e

Block 2 - Layer 6-8
Residuals in meters : Data - Trend Surface

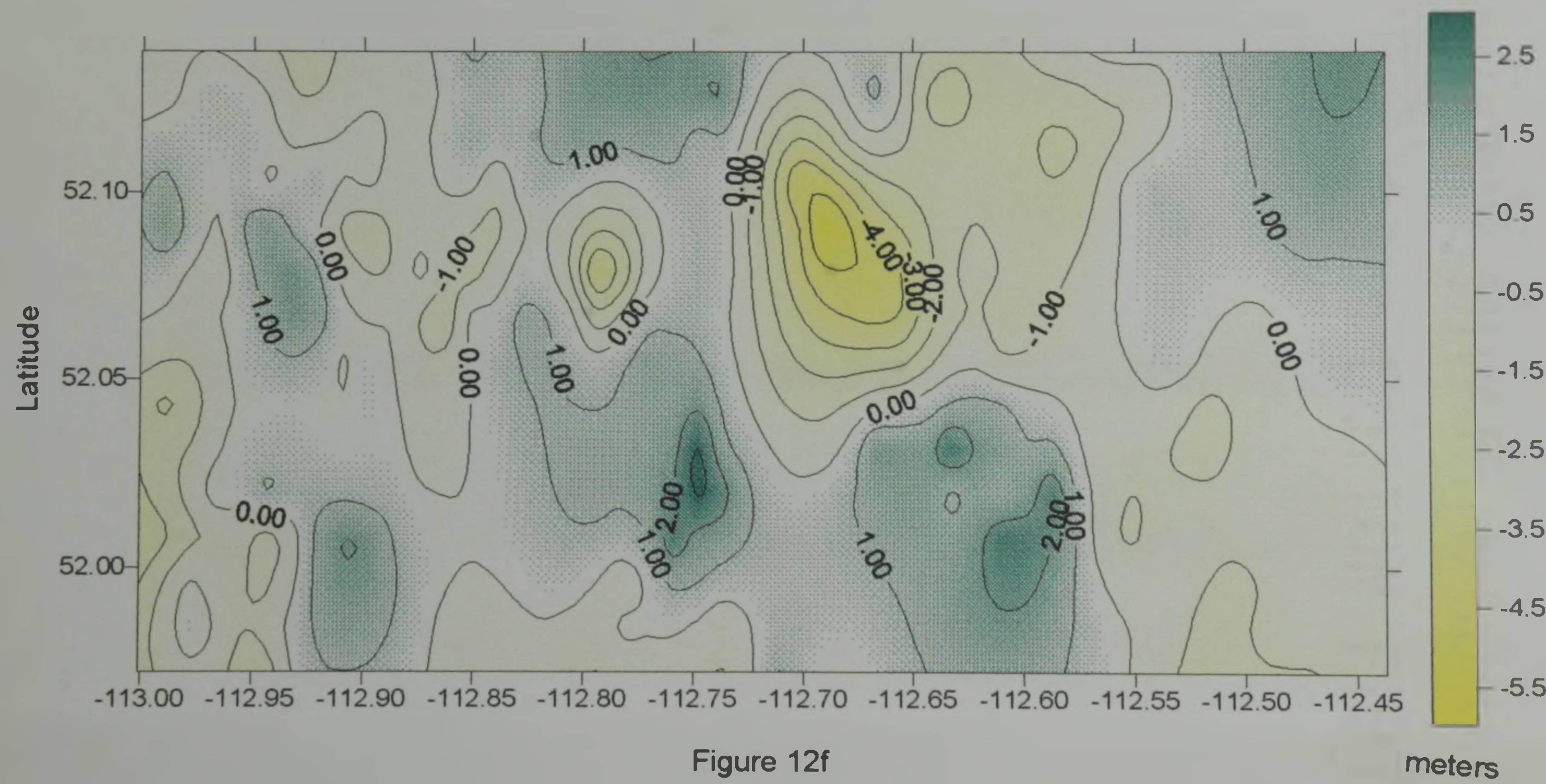


Figure 12f

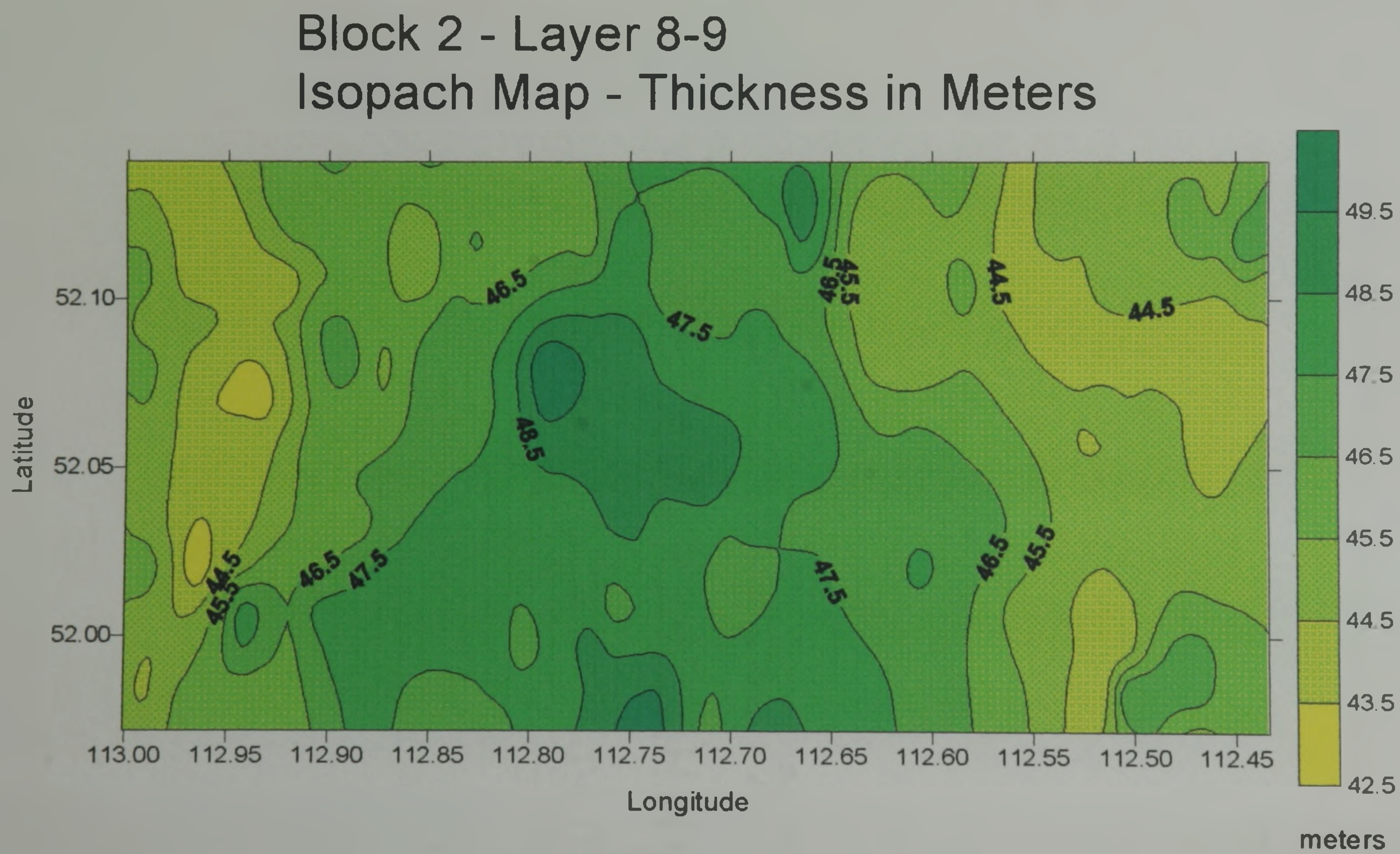
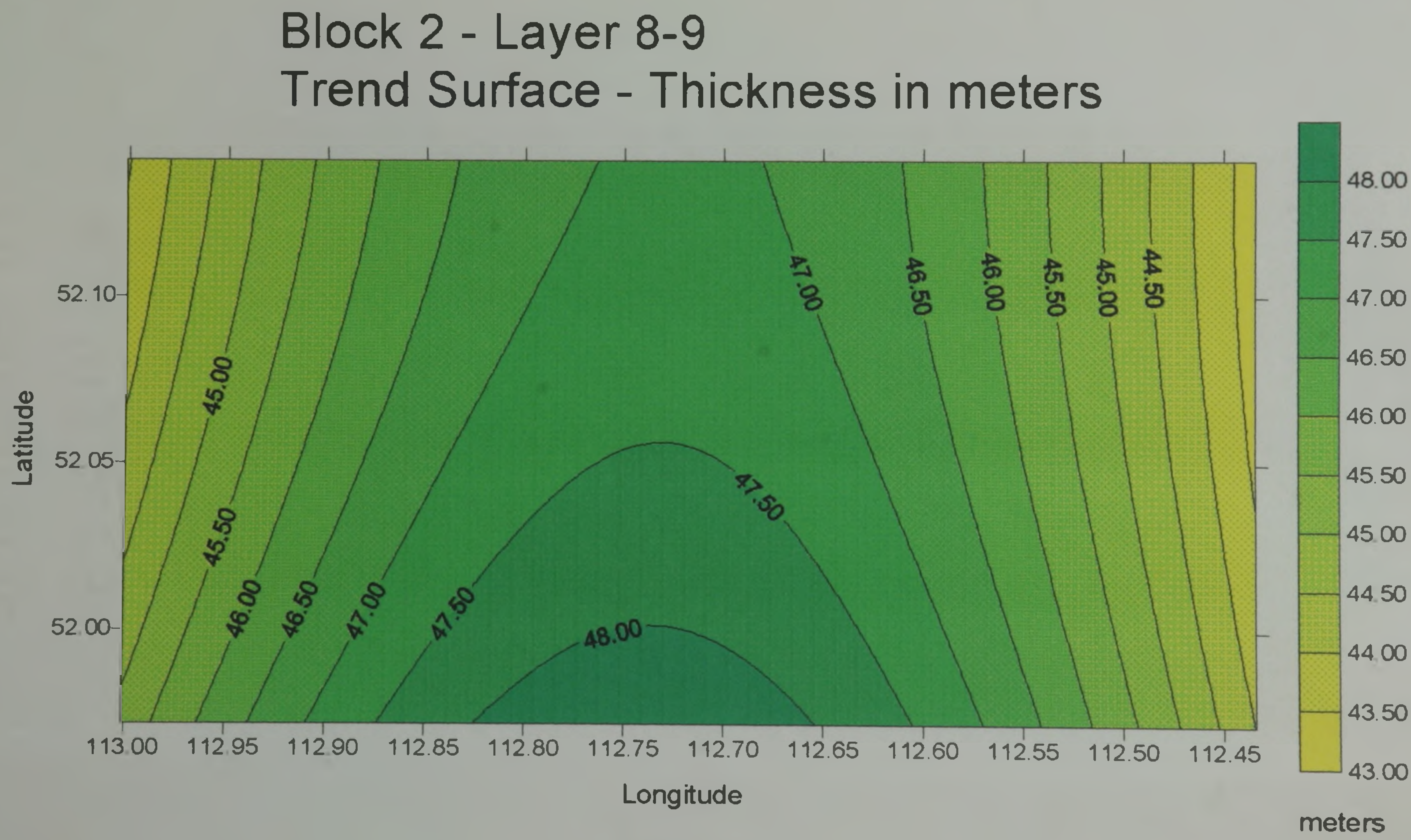

Block 2 - Layer 8-9
Isopach Map - Thickness in Meters
Latitude
Longitude
52.10
52.05
52.00
113.00
112.95
112.90
112.85
112.80
112.75
112.70
112.65
112.60
112.55
112.50
112.45
46.5
47.5
48.5
45.5
44.5
49.5
43.5
42.5
meters

Figure 13d



Block 2 - Layer 8-9
Trend Surface - Thickness in meters
Latitude
52.10
52.05
52.00
Longitude
113.00
112.95
112.90
112.85
112.80
112.75
112.70
112.65
112.60
112.55
112.50
112.45
45.00
45.50
46.00
46.50
47.00
47.50
48.00
47.00
46.50
46.00
45.50
45.00
44.50
47.50
48.00
47.50
47.00
46.50
46.00
45.50
45.00
44.50
44.00
43.50
43.00
meters

Figure 13e

Block 2 - Layer 8-9
Residuals in meters : Data - Trend Surface

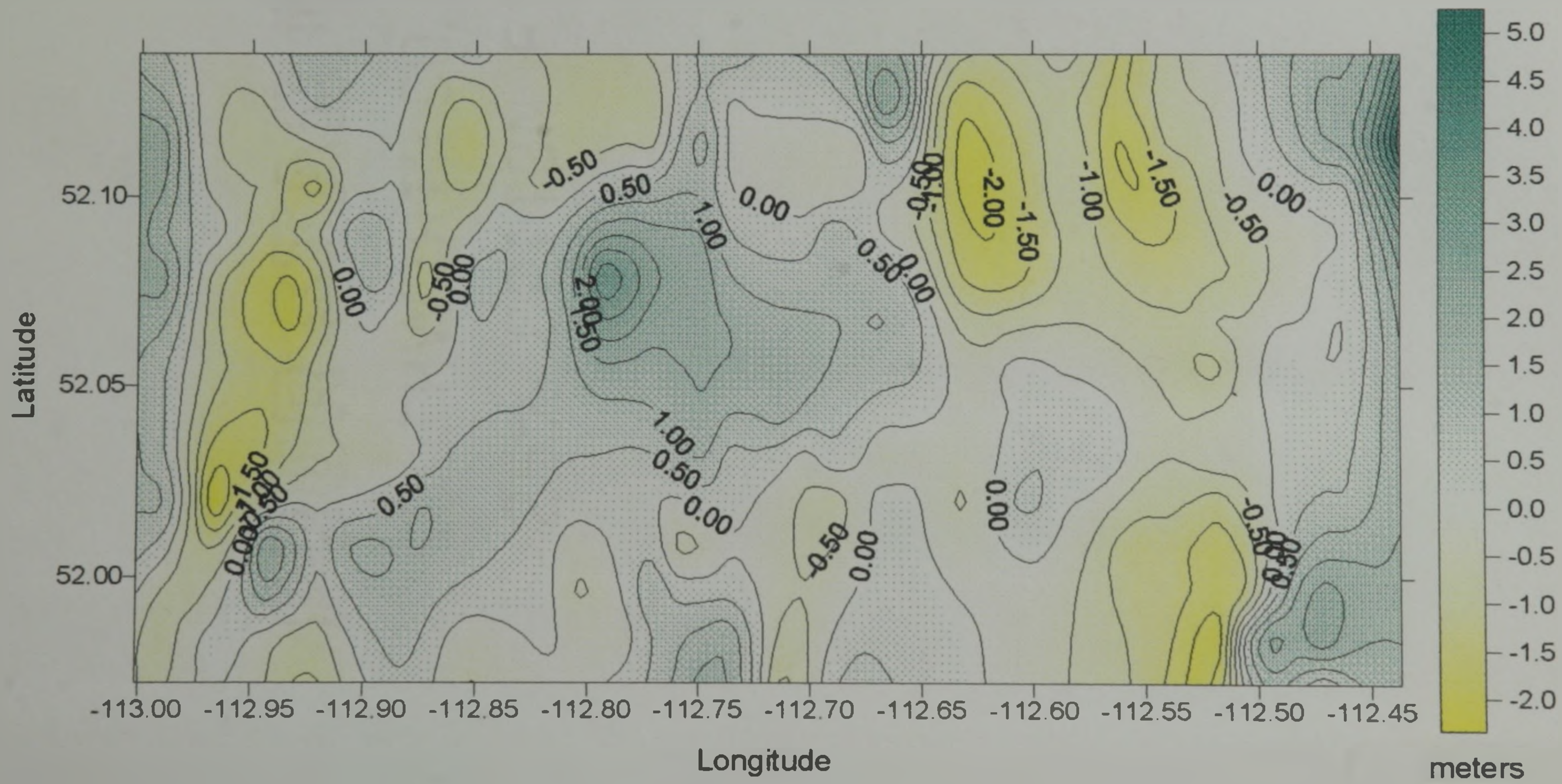


Figure 13f

Block 1 - Cardium E1-E4 (Layer 9-10)
Isopach Map - Thickness in Meters

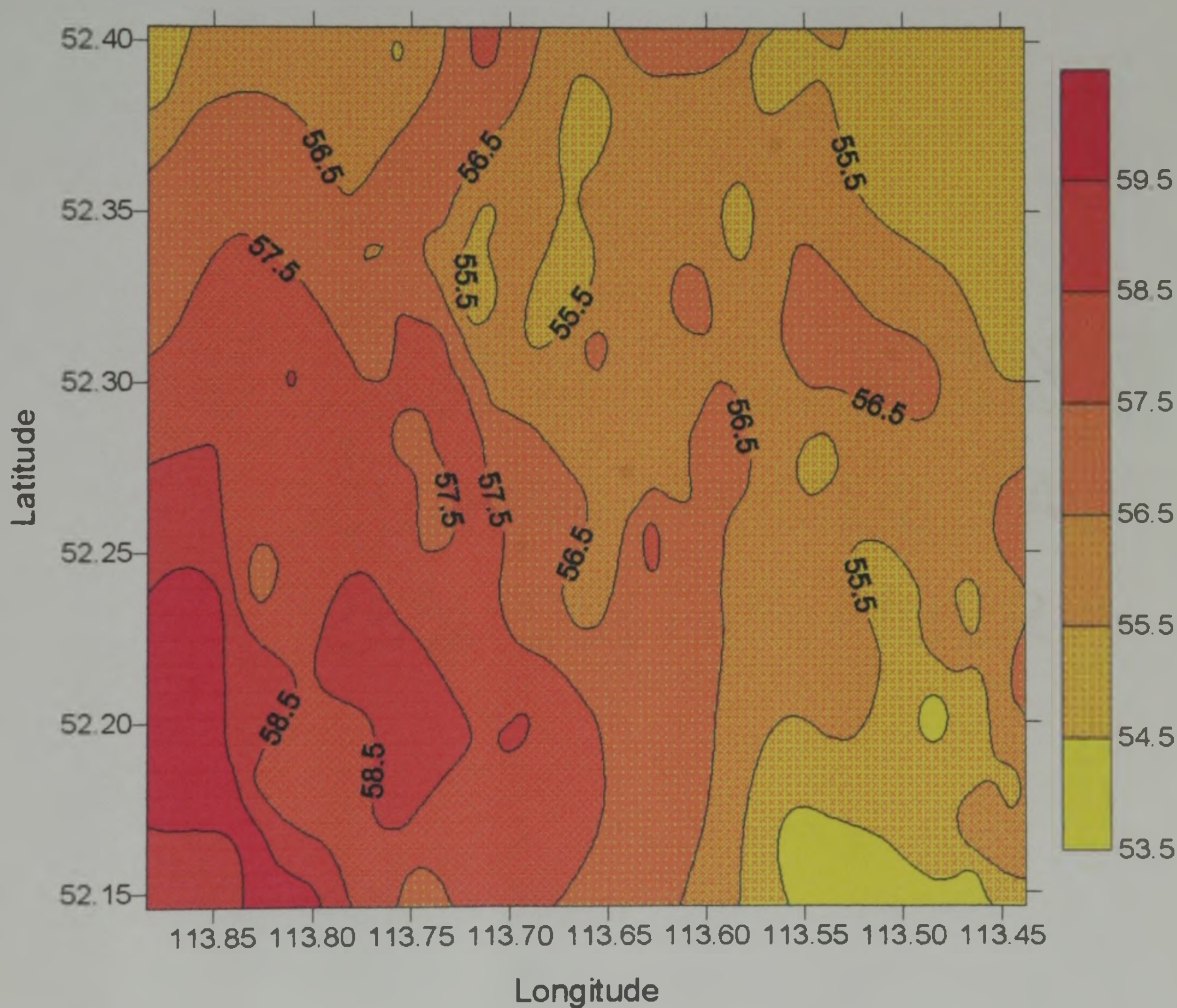


Figure 14a

Block 1 - Cardium E1-E4 (Layer 9-10)
Trend Surface - Thickness in Meters

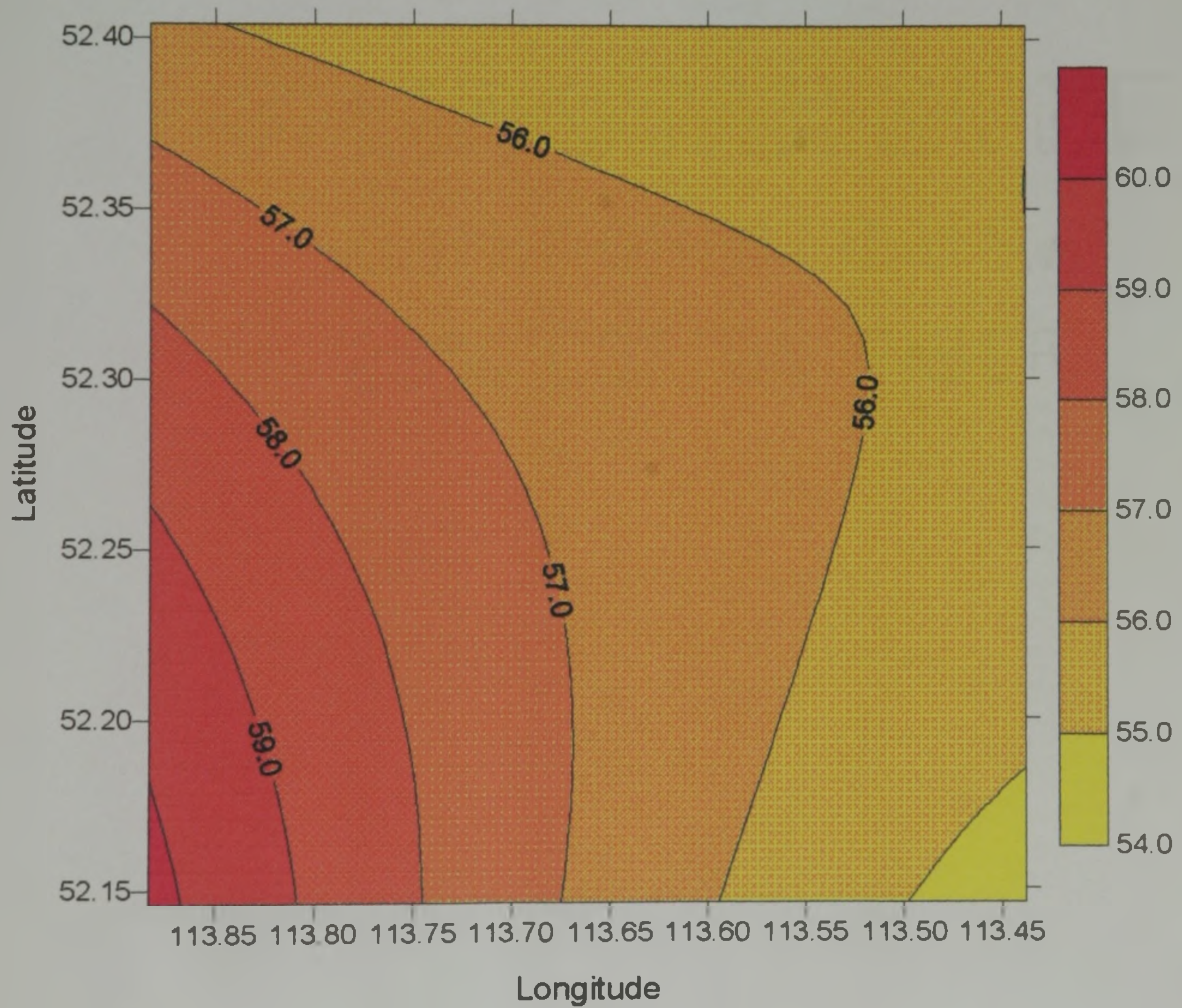


Figure 14b

Block 1 - Cardium E1-E4 (Layer 9-10)
Residuals in meters : Data - Trend Surface

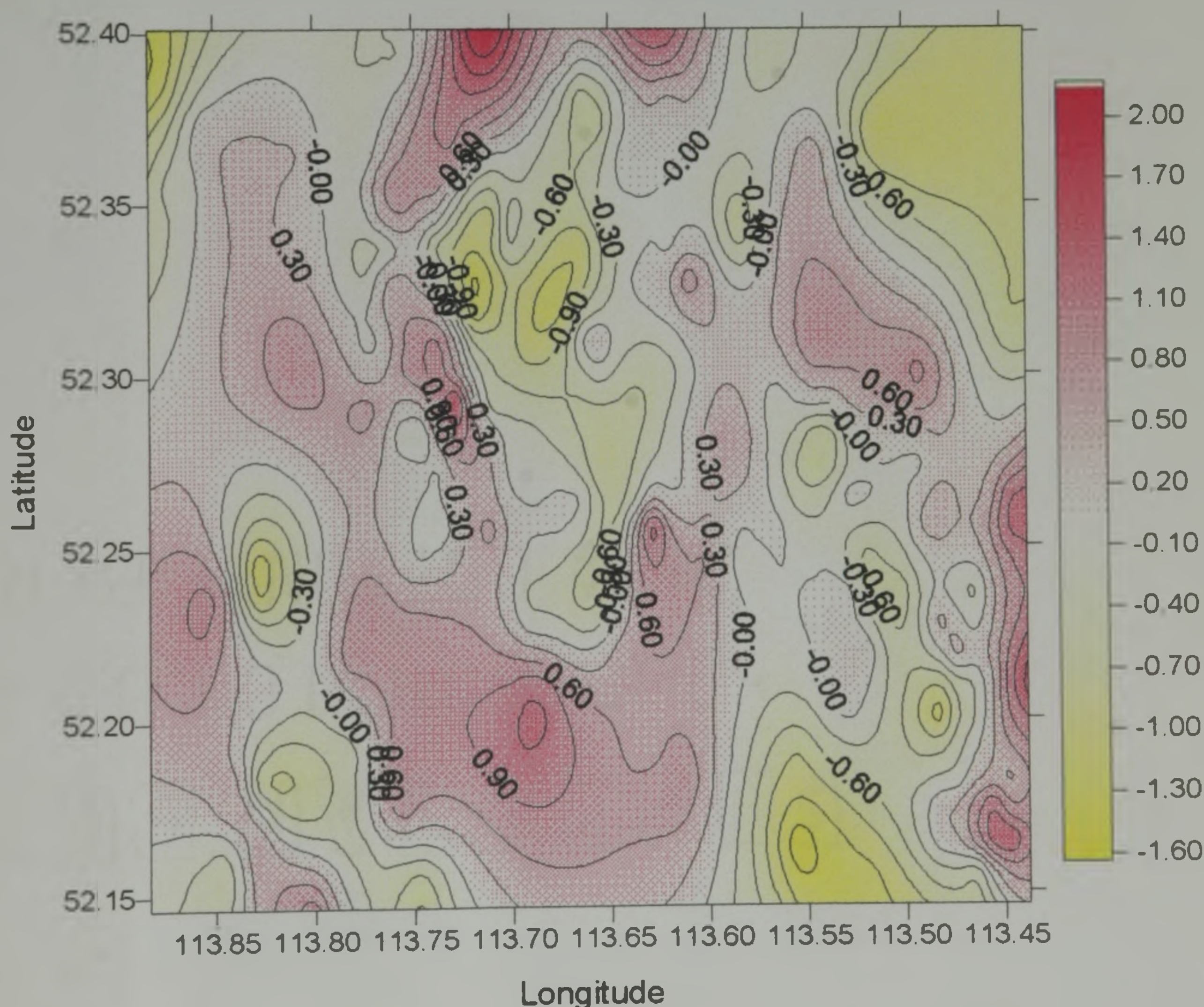


Figure 14c

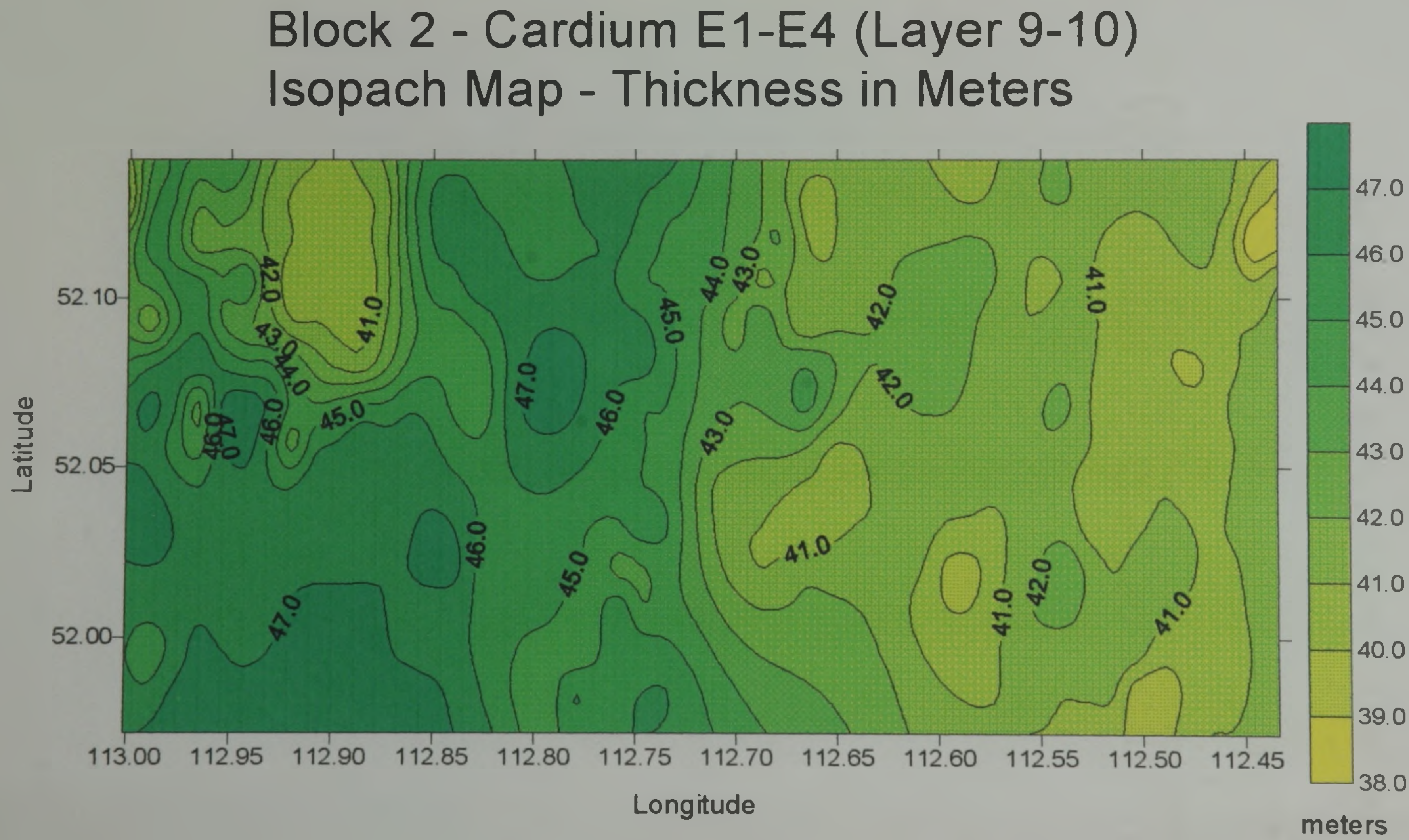

Block 2 - Cardium E1-E4 (Layer 9-10)
Isopach Map - Thickness in Meters
Latitude
52.10
52.05
52.00
113.00
112.95
112.90
112.85
112.80
112.75
112.70
112.65
112.60
112.55
112.50
112.45
Longitude
47.0
46.0
45.0
44.0
43.0
42.0
41.0
40.0
39.0
38.0
meters

Figure 14d

Block 2 - Cardium E1-E4 (Layer 9-10)
Trend Surface - Thickness in meters

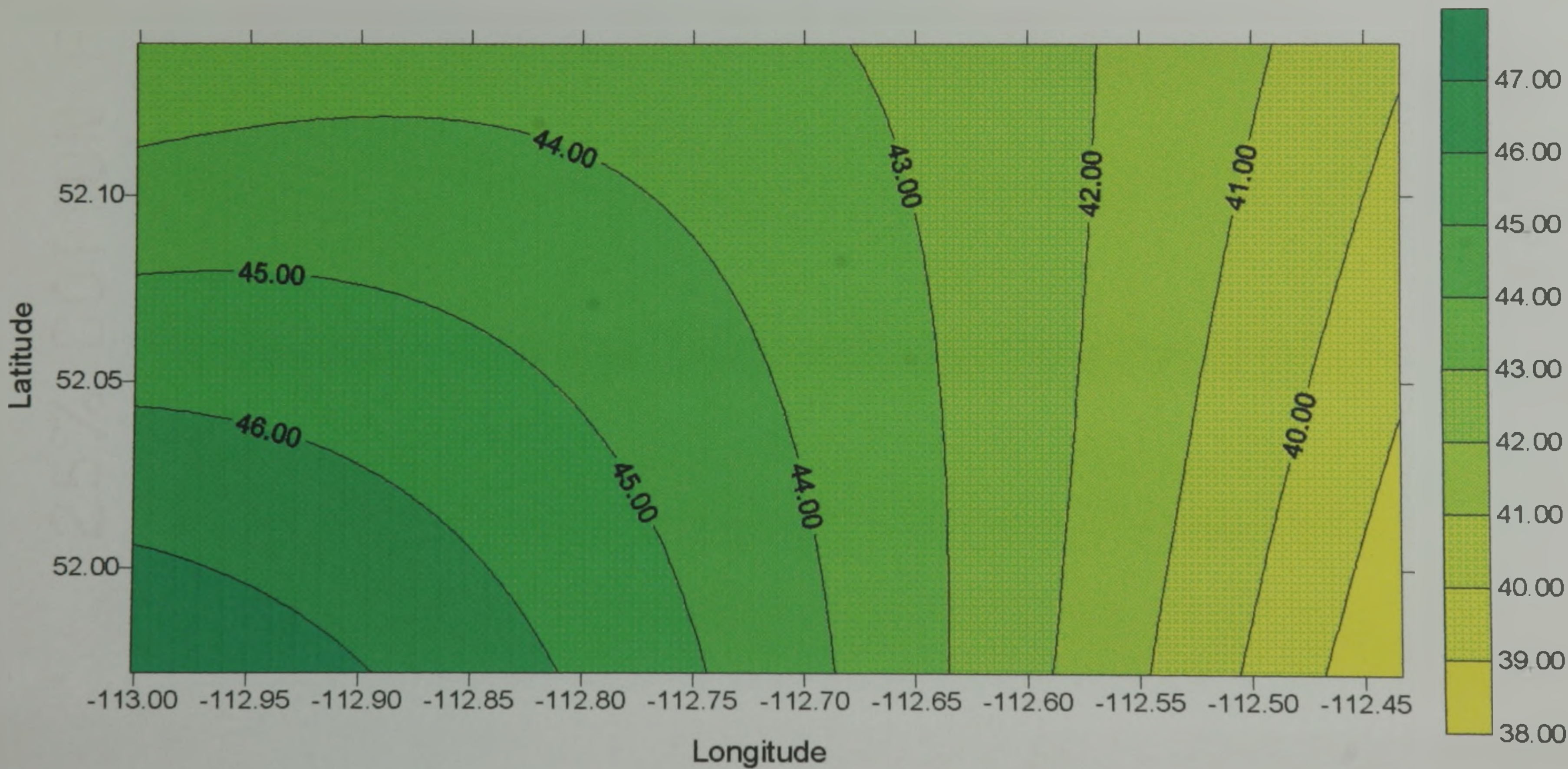


Figure 14e

Block 2 - Cardium E1-E4 (Layer 9-10)
Residuals in meters : Data - Trend Surface

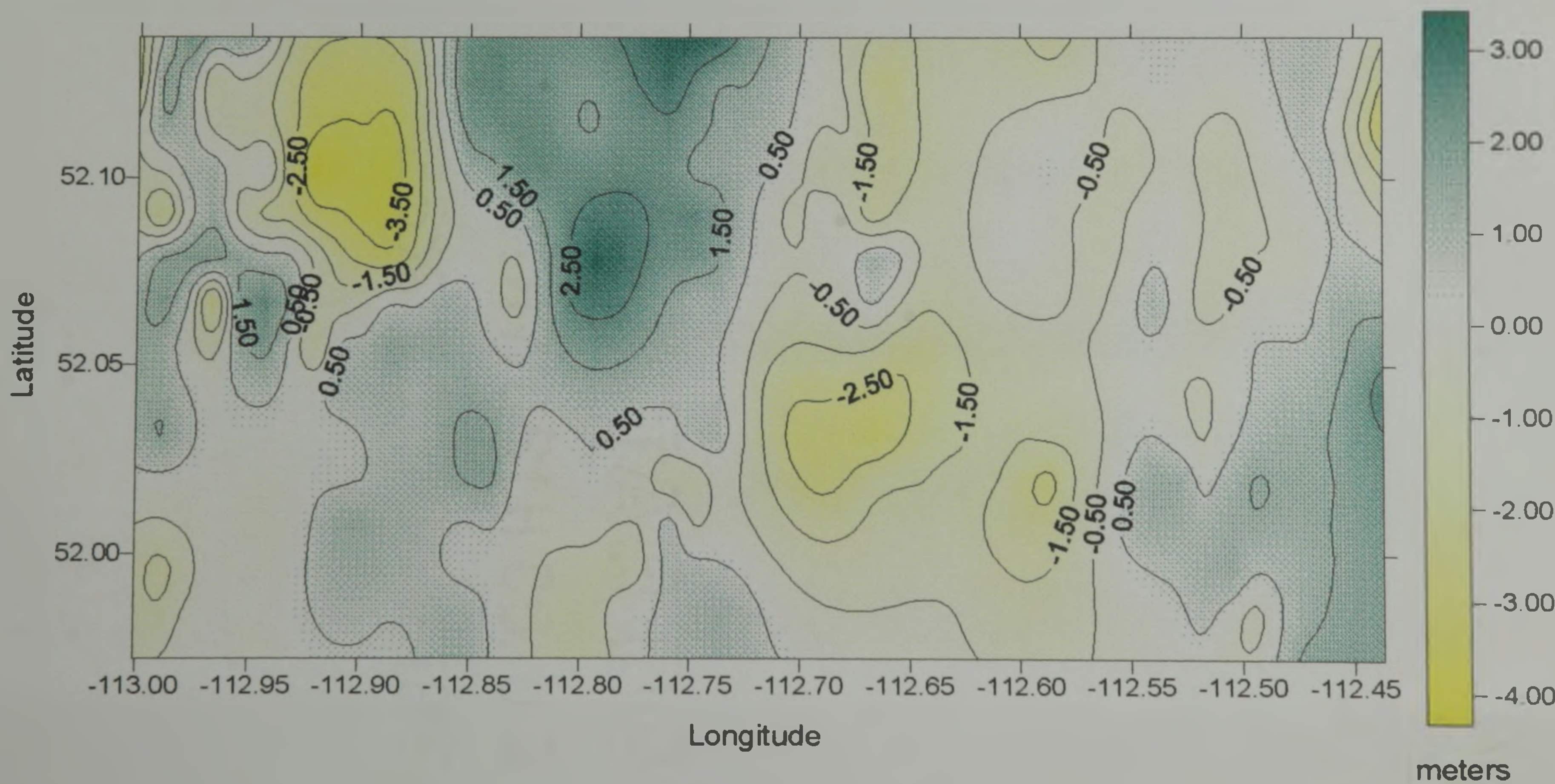


Figure 14f

Block 1 - Cardium E4-E5 (Layer 10-11) Isopach Map - Thickness in Meters

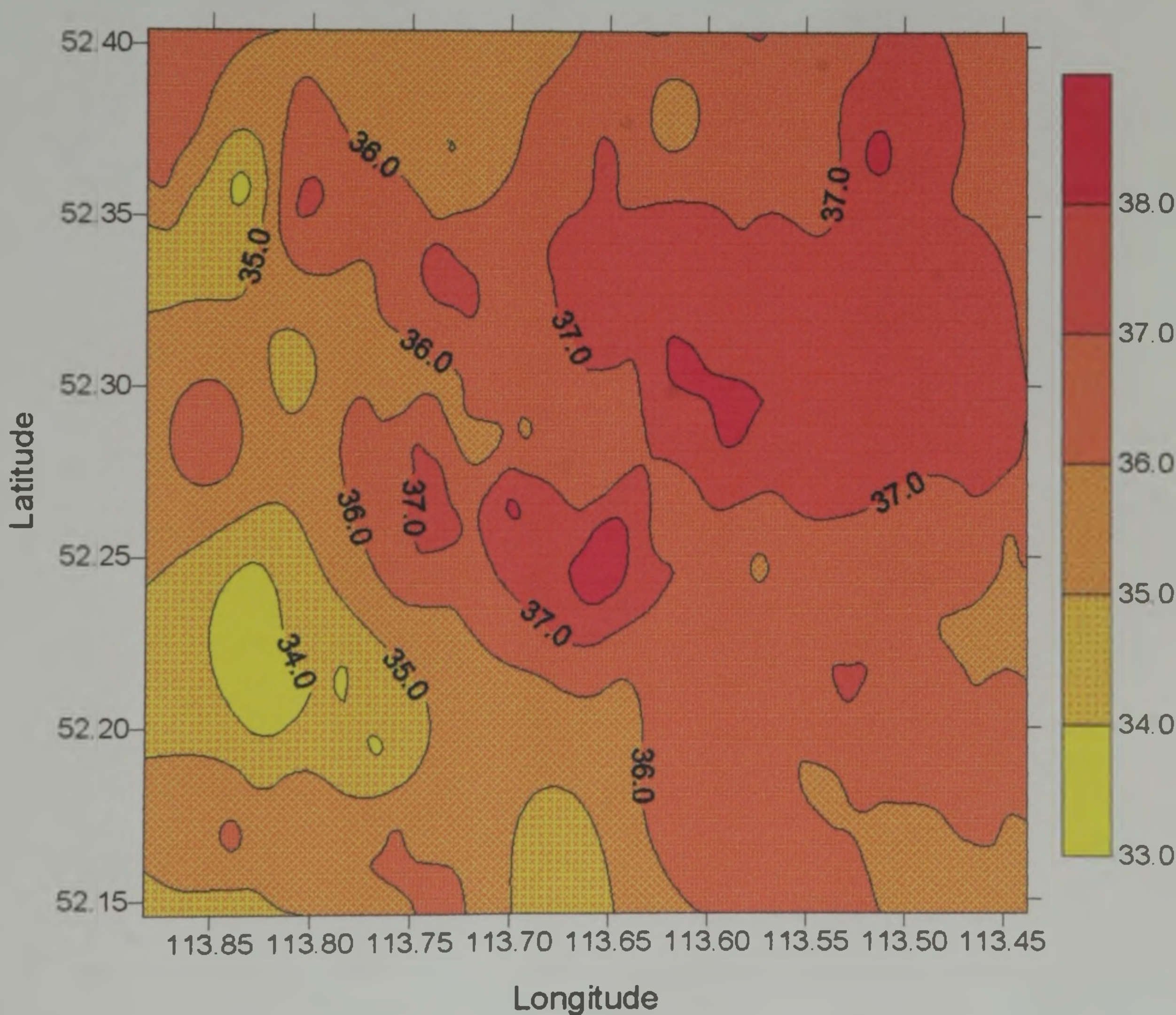


Figure 15a

Block 1 - Cardium E4-E5 (Layer 10-11)
Trend Surface - Thickness in Meters

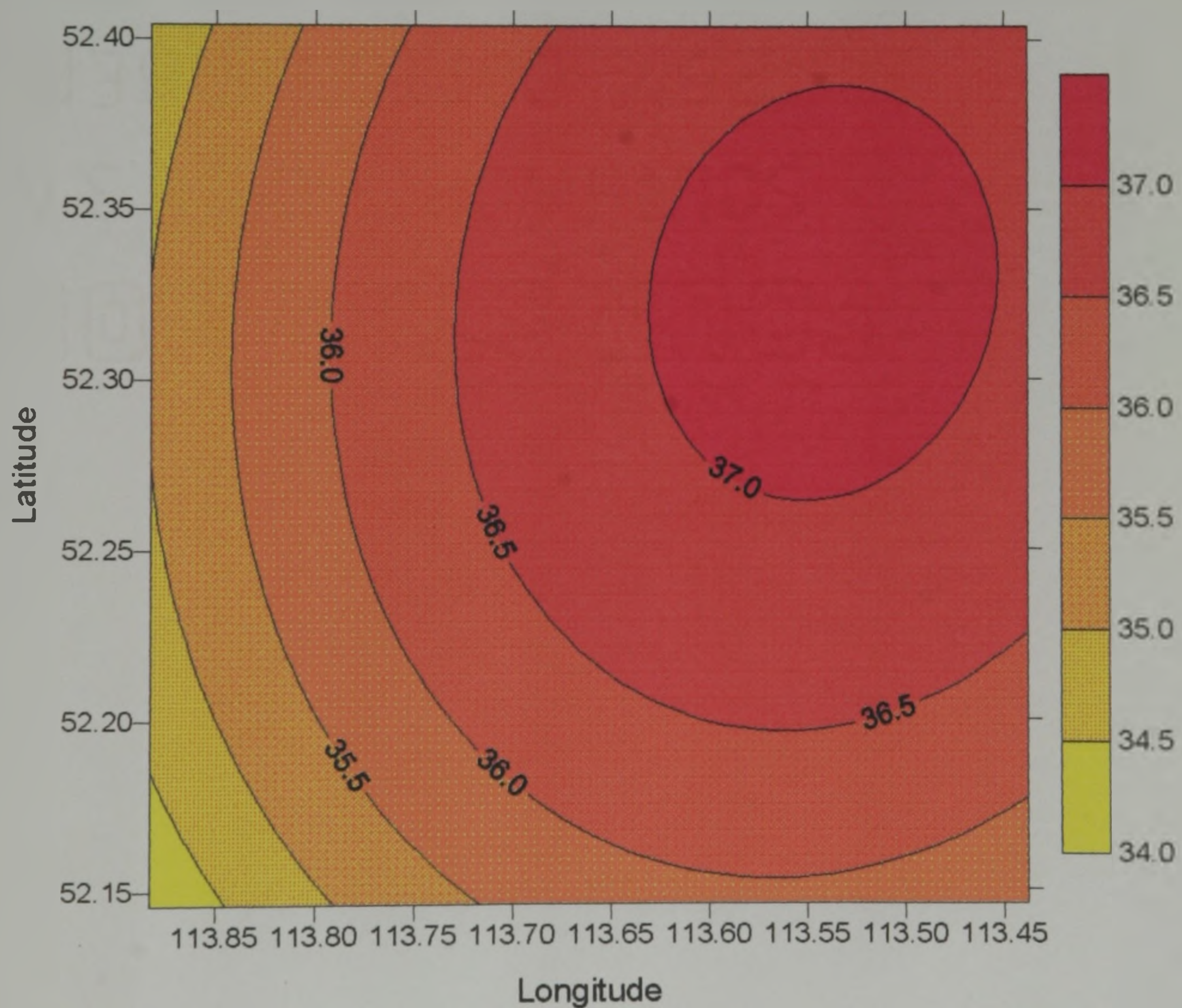


Figure 15b

Block 1 - Cardium E4-E5 (Layer 10-11)
Residuals in meters : Data - Trend Surface

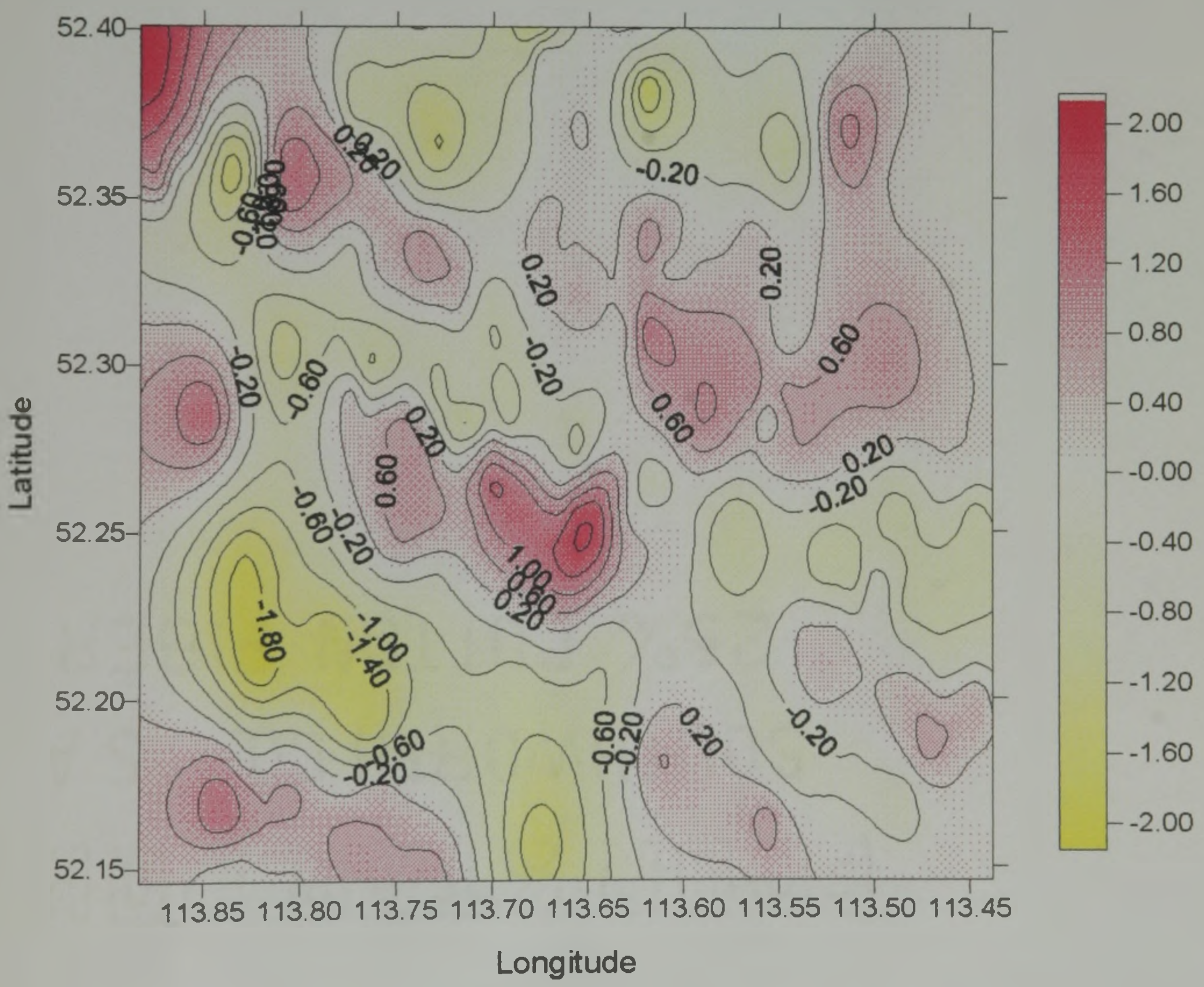


Figure 15c

Block 2 - Cardium E4-E5 (Layer 10-11)
Isopach Map - Thickness in Meters

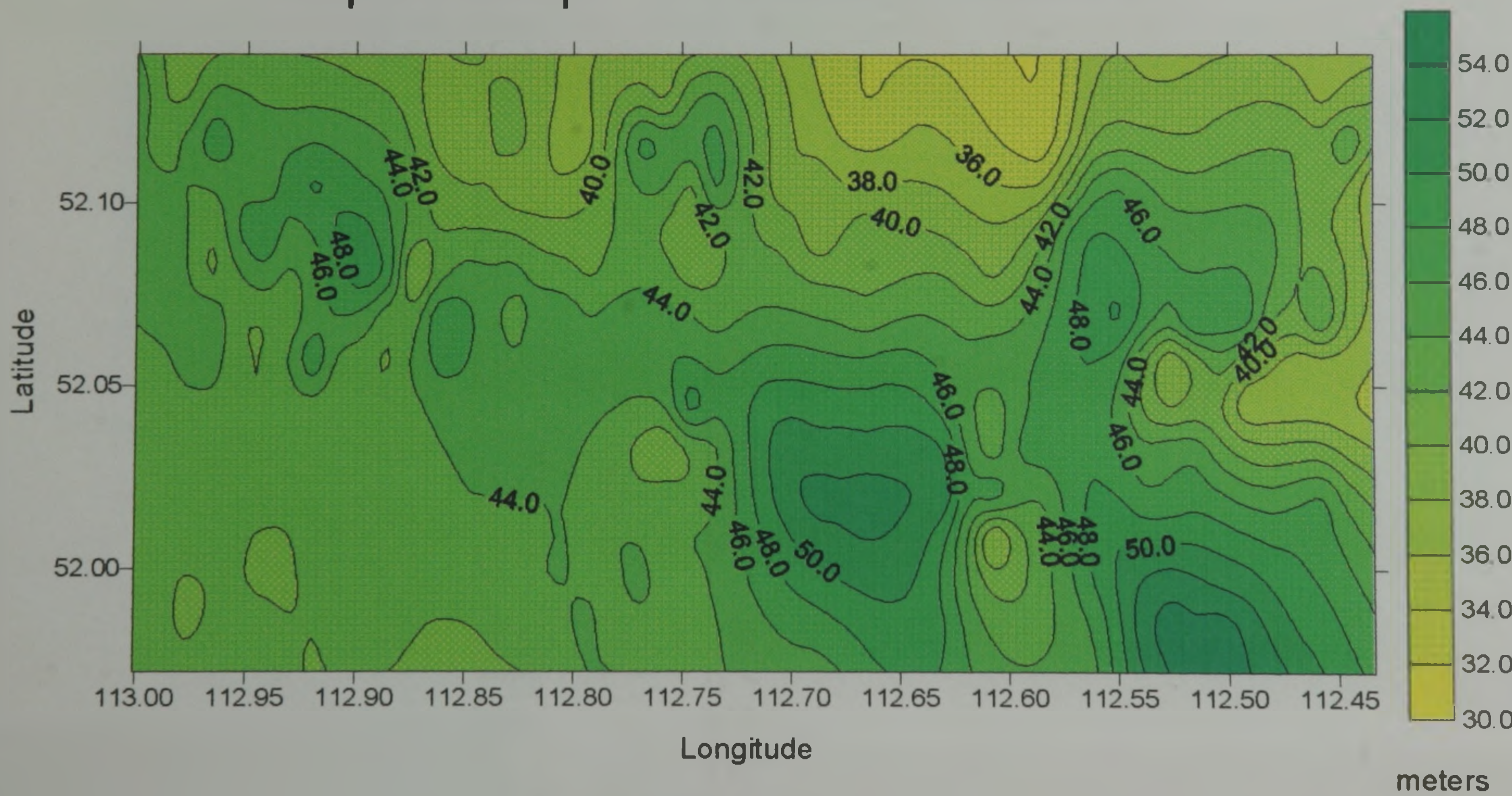


Figure 15d

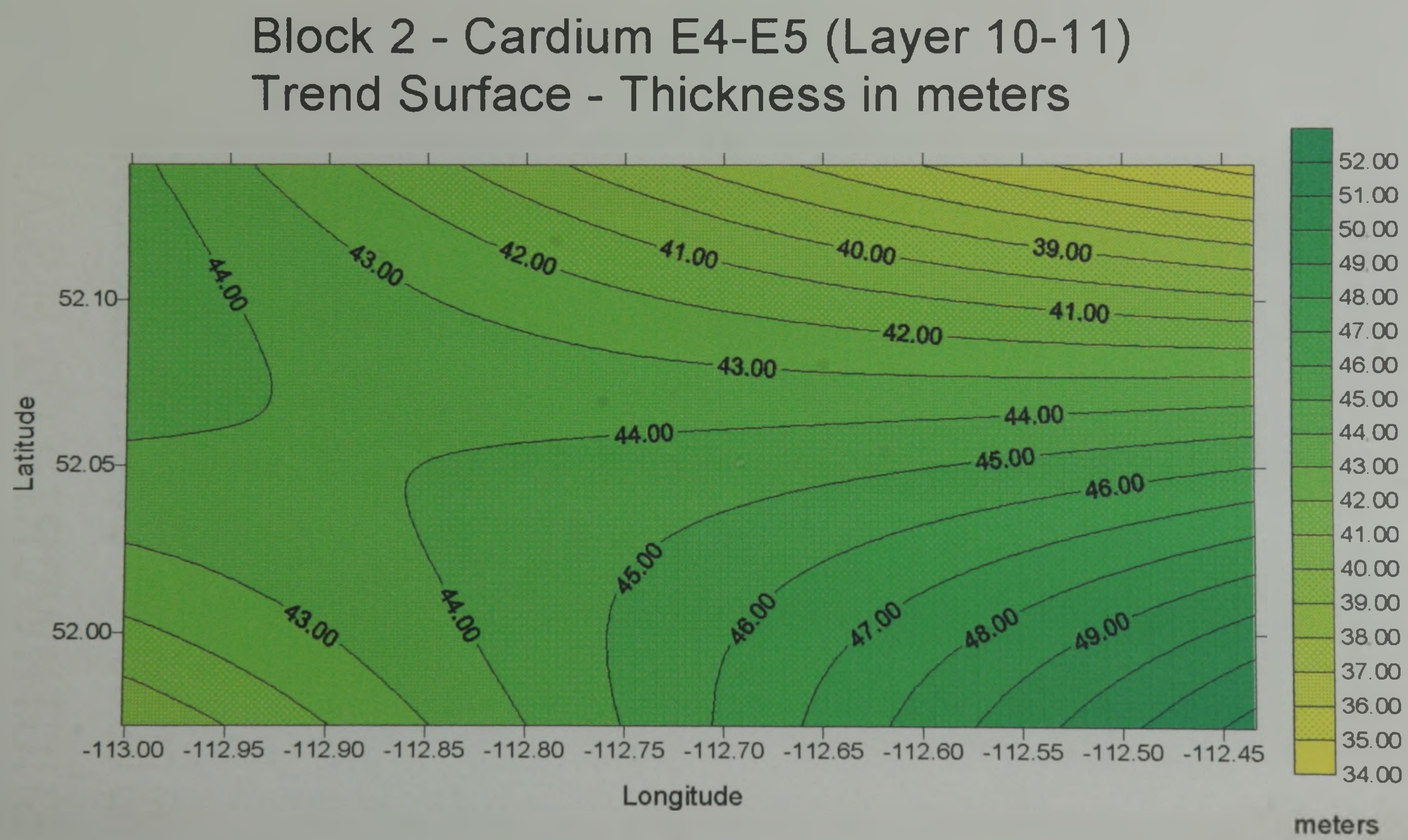
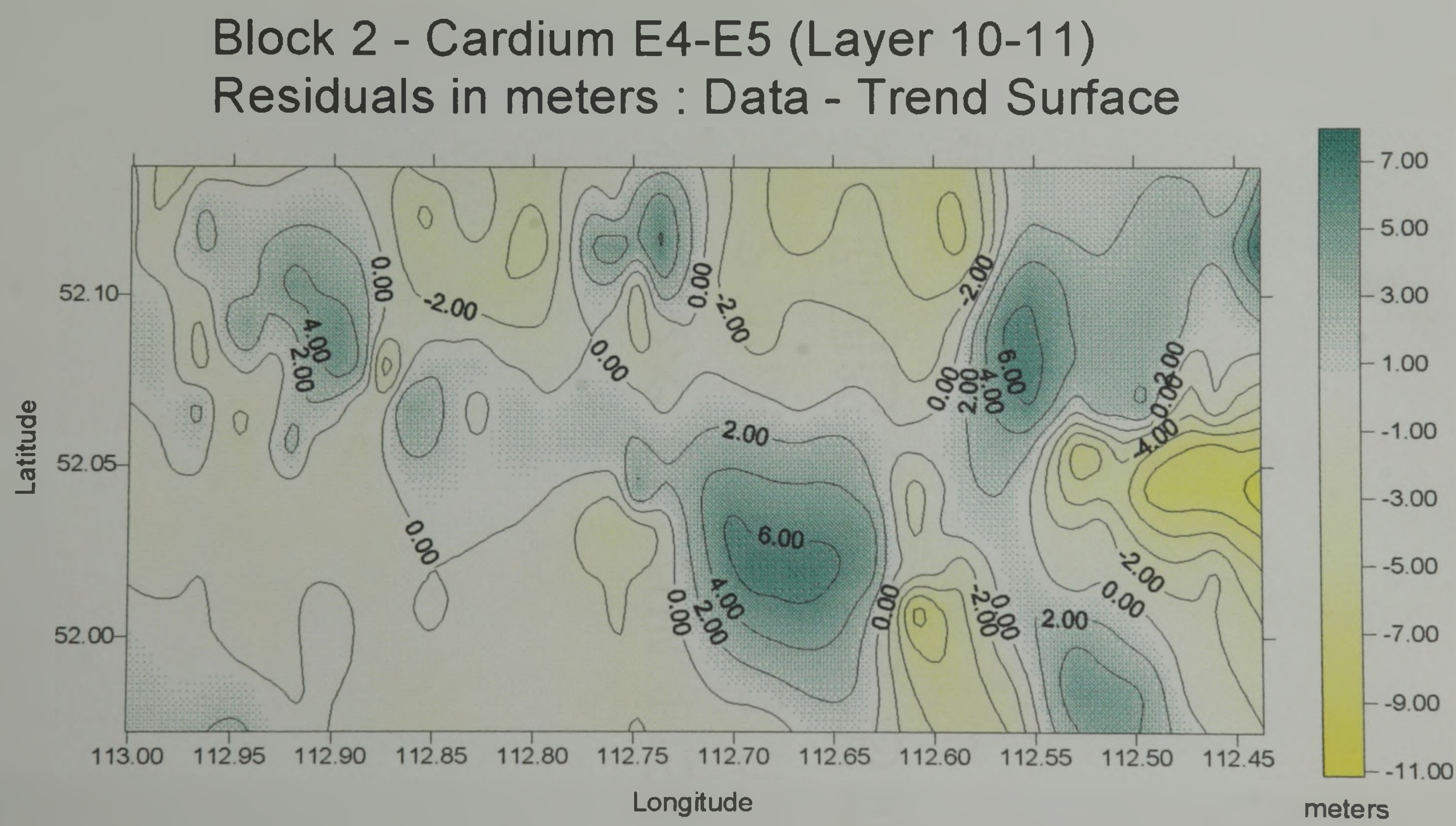

Block 2 - Cardium E4-E5 (Layer 10-11)
Trend Surface - Thickness in meters
Latitude
52.10
52.05
52.00
Longitude
-113.00
-112.95
-112.90
-112.85
-112.80
-112.75
-112.70
-112.65
-112.60
-112.55
-112.50
-112.45
44.00
43.00
42.00
41.00
40.00
39.00
41.00
42.00
43.00
44.00
44.00
45.00
46.00
45.00
43.00
44.00
46.00
47.00
48.00
49.00
52.00
51.00
50.00
49.00
48.00
47.00
46.00
45.00
44.00
43.00
42.00
41.00
40.00
39.00
38.00
37.00
36.00
35.00
34.00
meters

Figure 15e



Block 2 - Cardium E4-E5 (Layer 10-11)
Residuals in meters : Data - Trend Surface
Latitude
52.10
52.05
52.00
113.00
112.95
112.90
112.85
112.80
112.75
112.70
112.65
112.60
112.55
112.50
112.45
Longitude
7.00
5.00
3.00
1.00
-1.00
-3.00
-5.00
-7.00
-9.00
-11.00
meters

Figure 15f

Block 1 - (Layer 11-12)
Isopach Map - Thickness in Meters

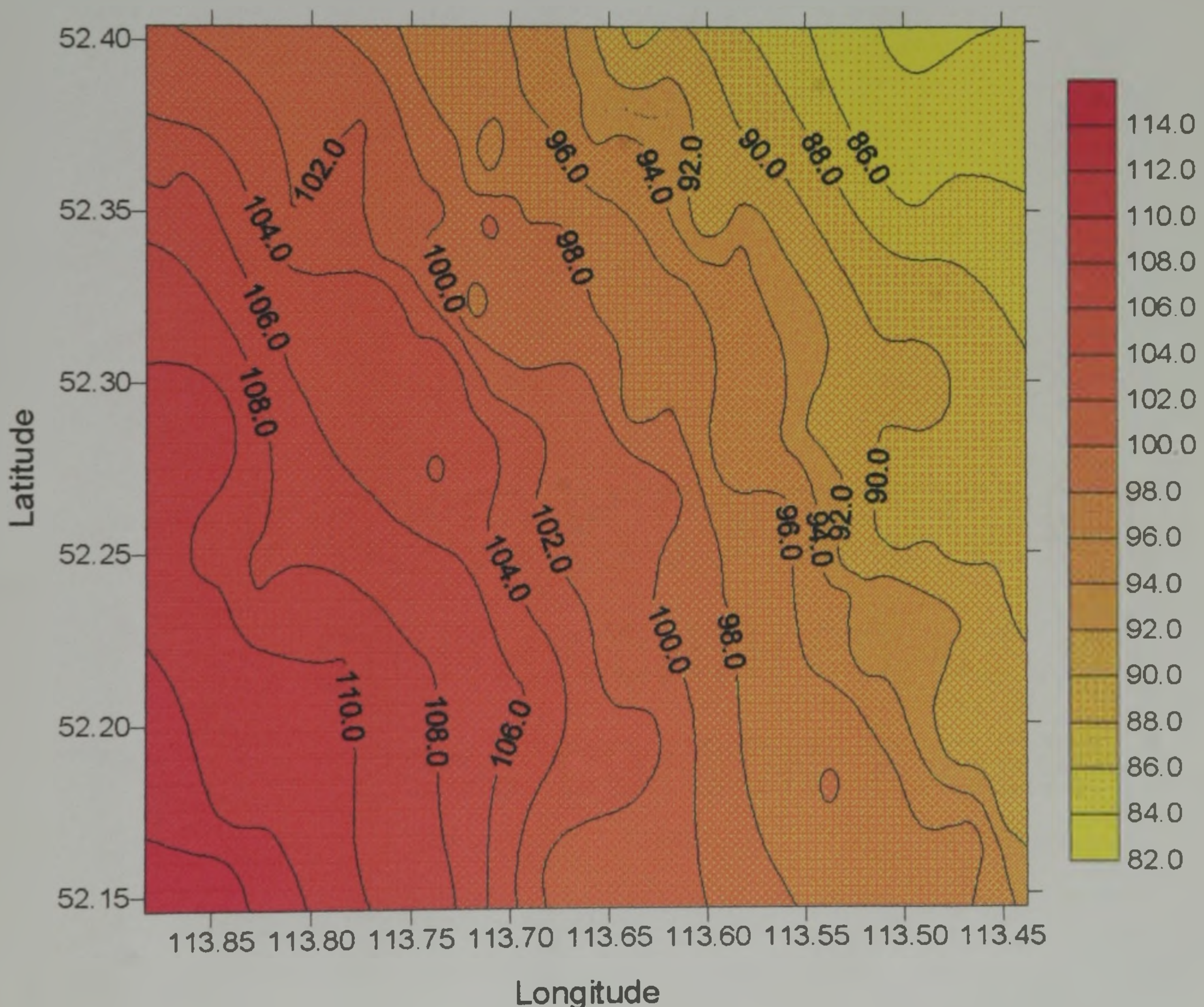


Figure 16a

Block 1 - Layer 11-12
Trend Surface - Thickness in Meters

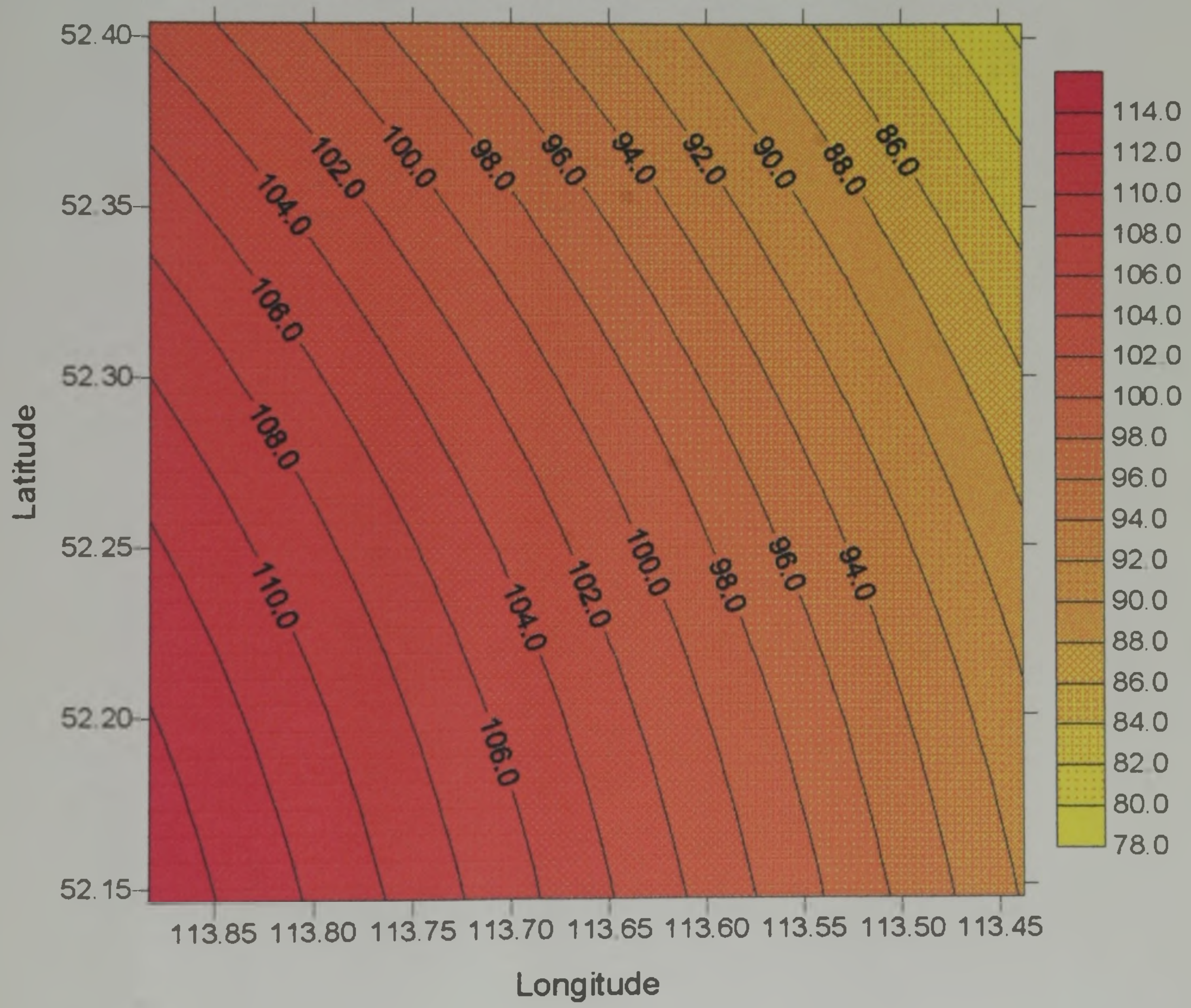


Figure 16b

Block1 - Layer 11-12
Residuals in meters : Data - Trend Surface

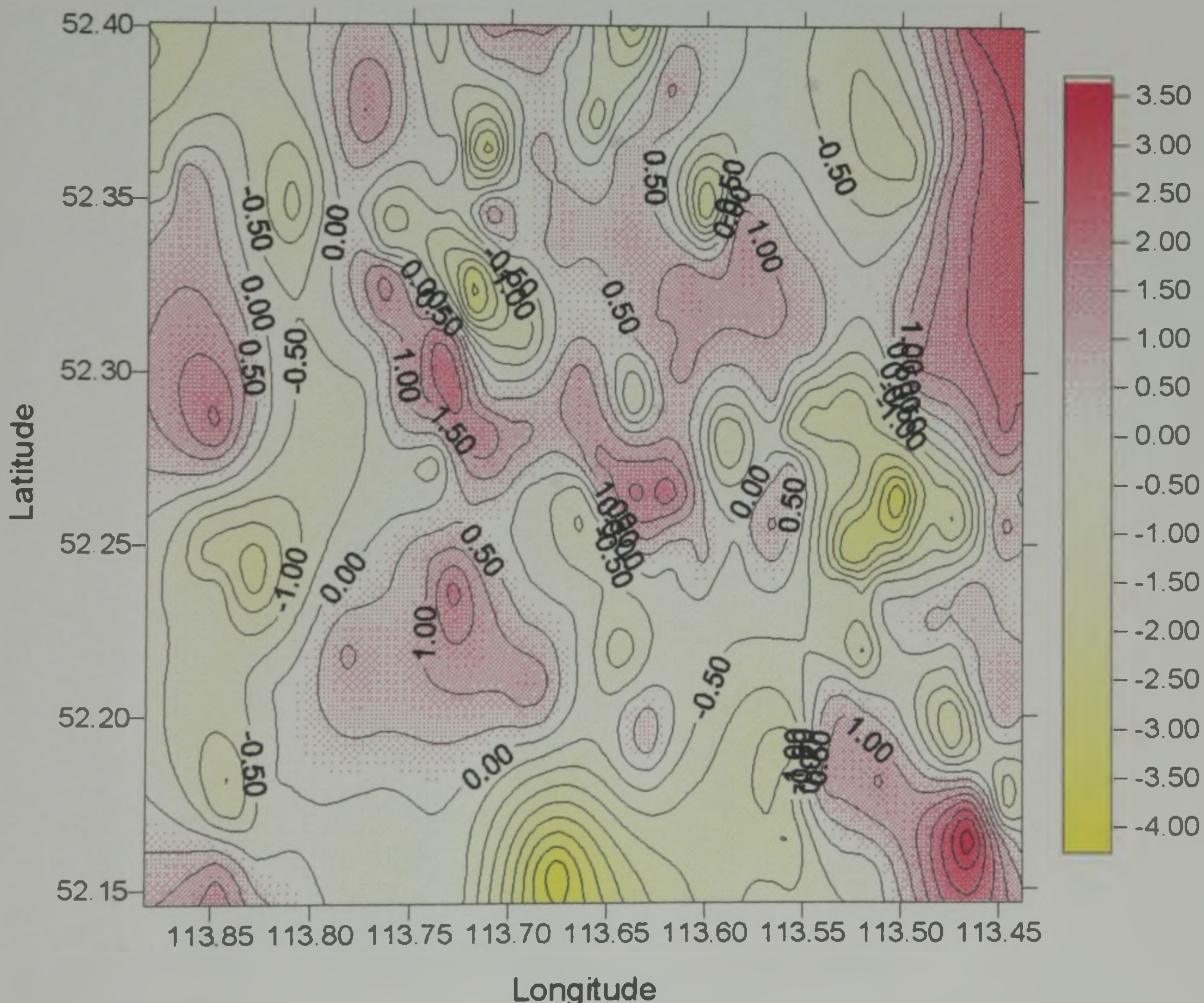


Figure 16c

Block 2 - Layer 11-12
Isopach Map - Thickness in Meters

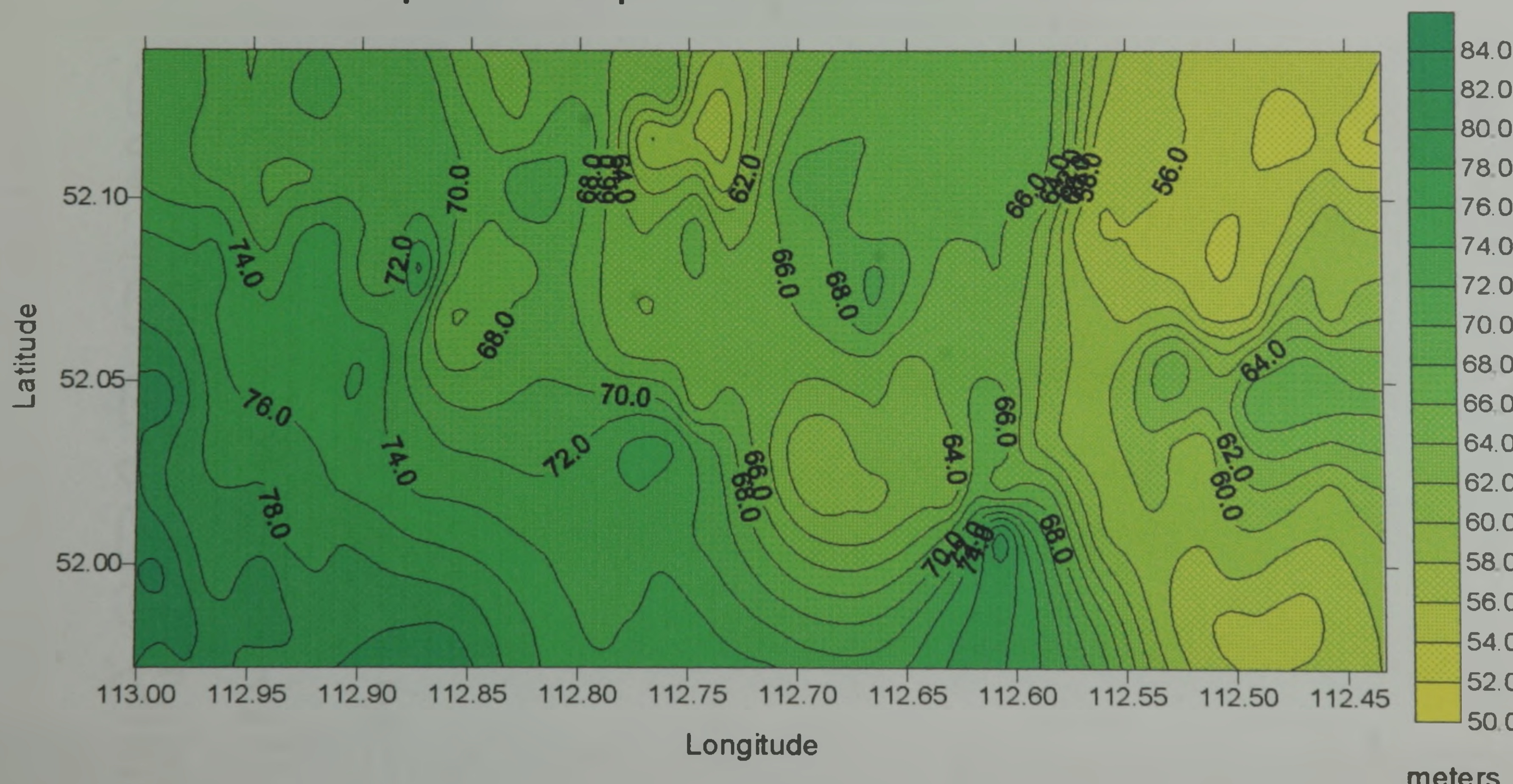


Figure 16d

Block 2 - Layer 11-12
Trend Surface - Thickness in meters

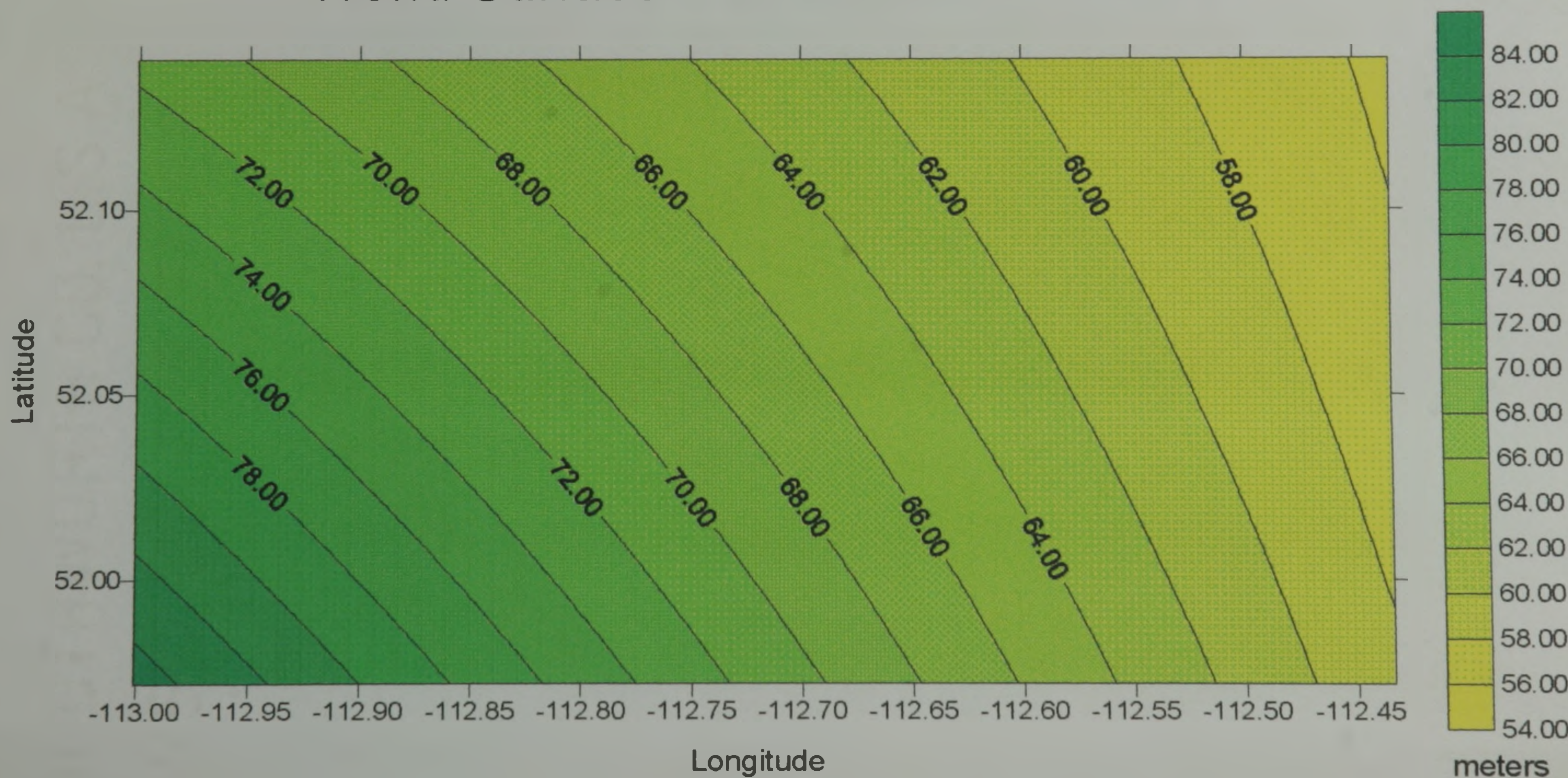


Figure 16e

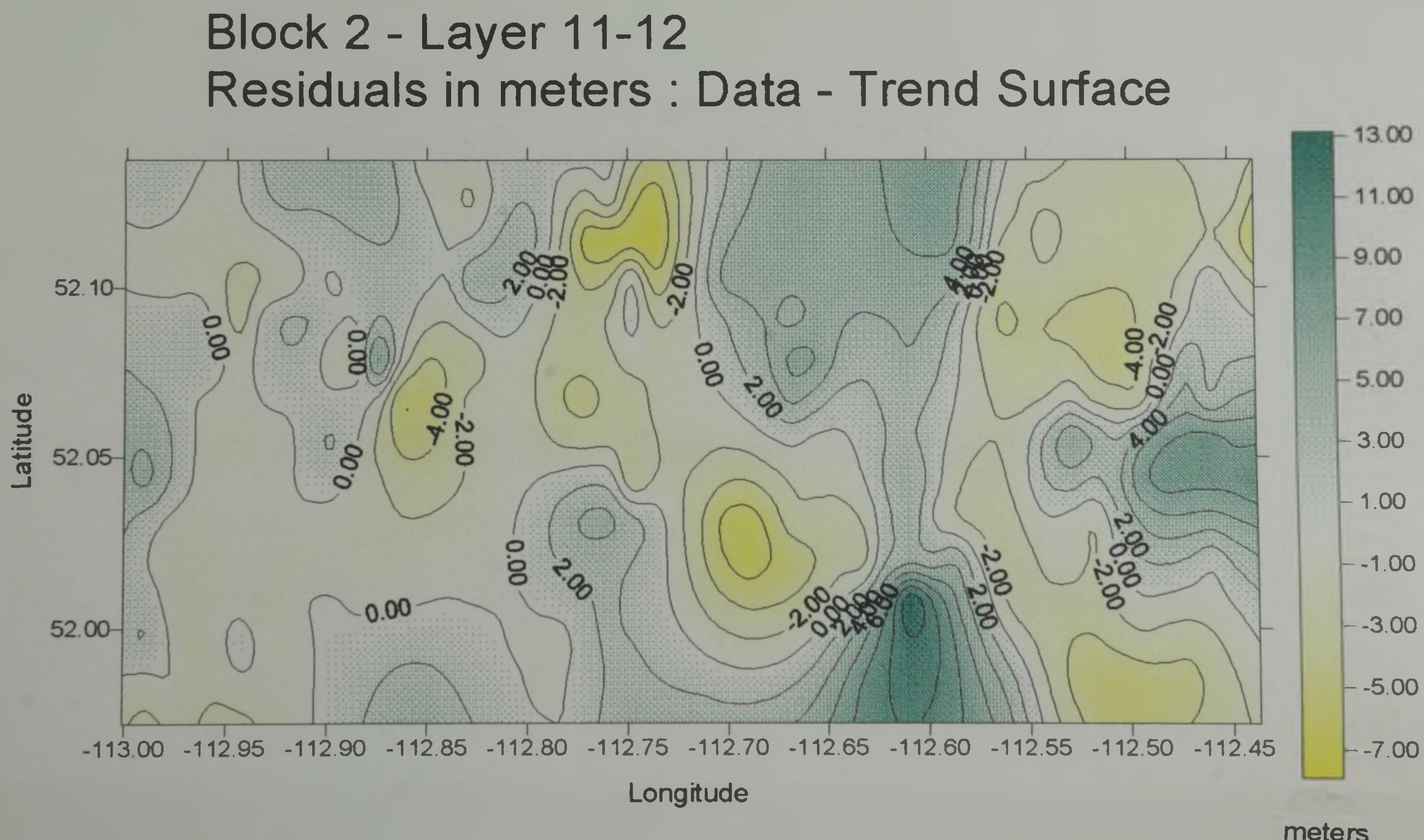

Block 2 - Layer 11-12
Residuals in meters : Data - Trend Surface
Latitude
Longitude
meters
13.00
11.00
9.00
7.00
5.00
3.00
1.00
-1.00
-3.00
-5.00
-7.00
52.10
52.05
52.00
-113.00
-112.95
-112.90
-112.85
-112.80
-112.75
-112.70
-112.65
-112.60
-112.55
-112.50
-112.45

Figure 16f

Block 1 - First White Specks (Layer 12-13)
Isopach Map - Thickness in Meters

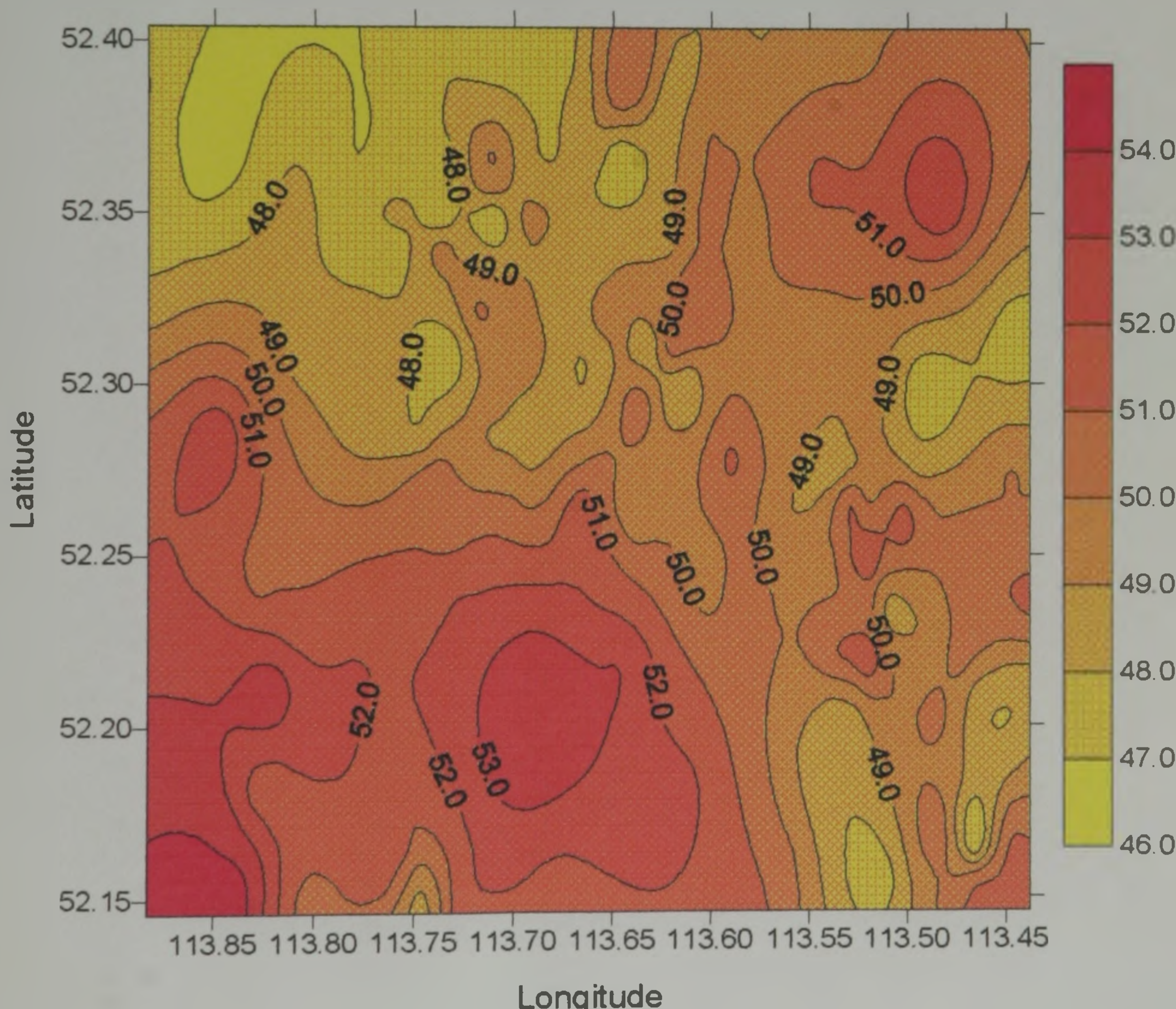


Figure 17a

Block 1 - First White Specks (Layer 12-13)
Trend Surface - Thickness in Meters

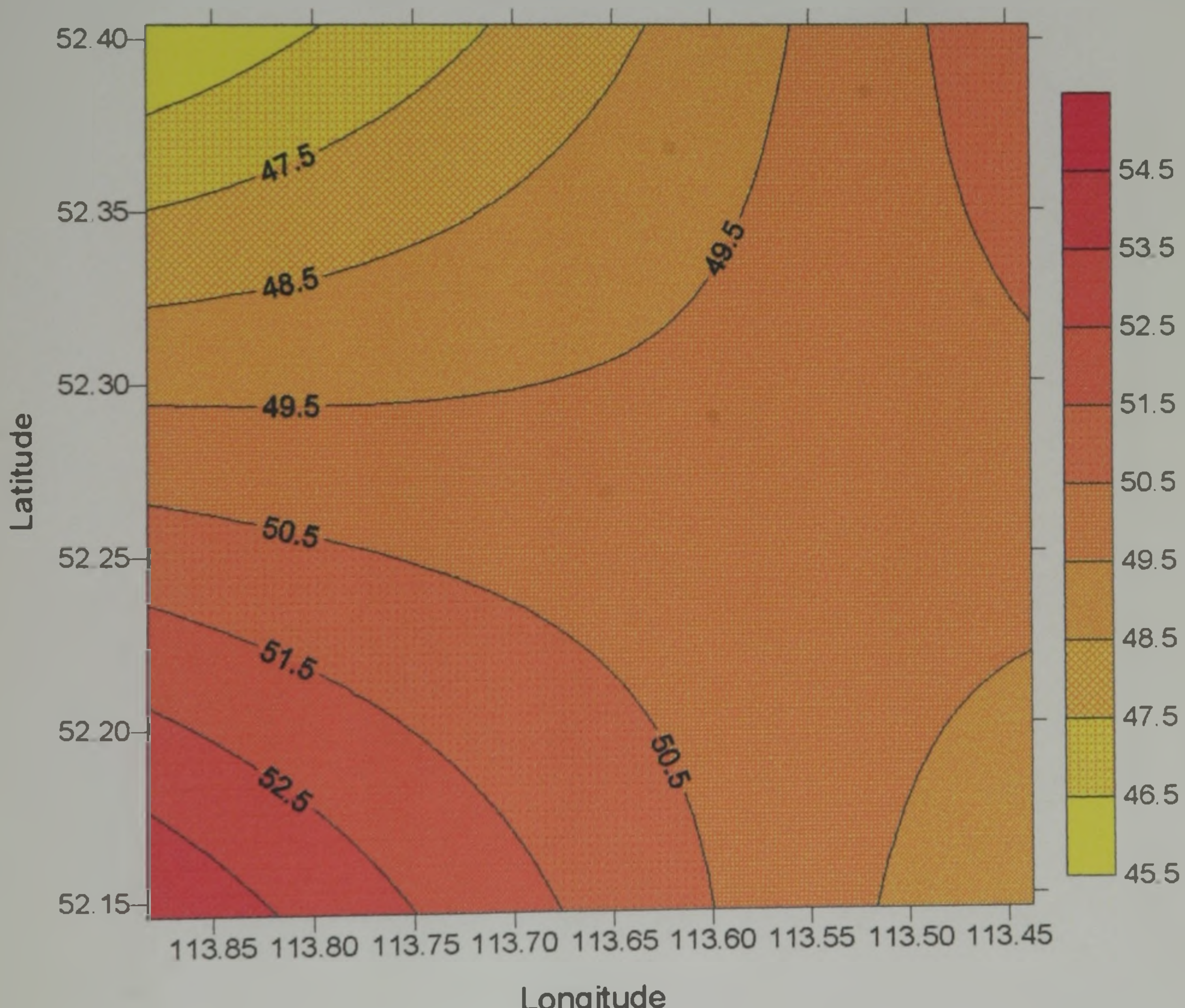


Figure 17b

Block 1 - First White Specks (Layer 12-13) Residuals in meters : Data - Trend Surface

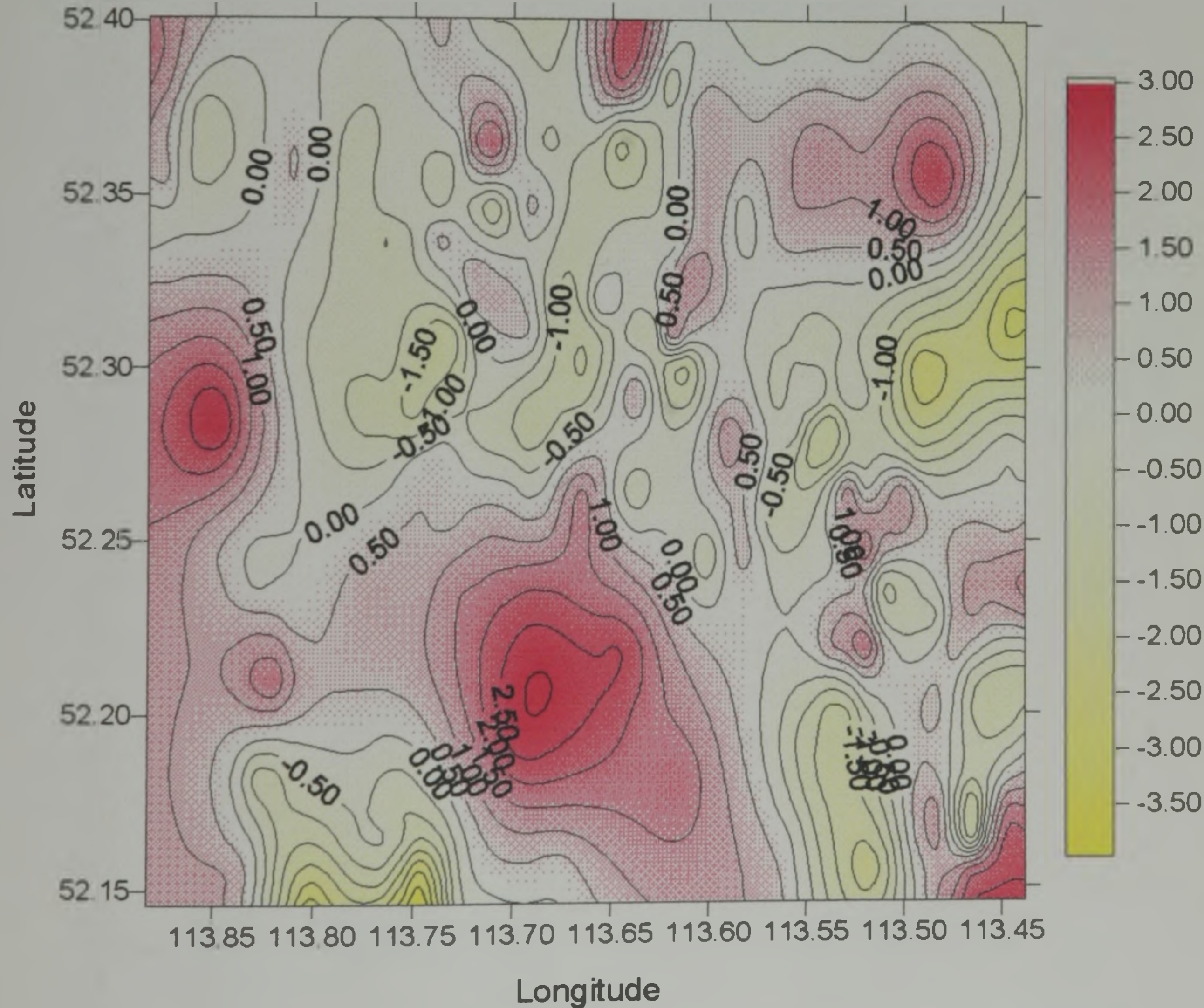


Figure 17c

Block 2 - First White Specks Formation (Layer 12-13)
Isopach Map - Thickness in Meters

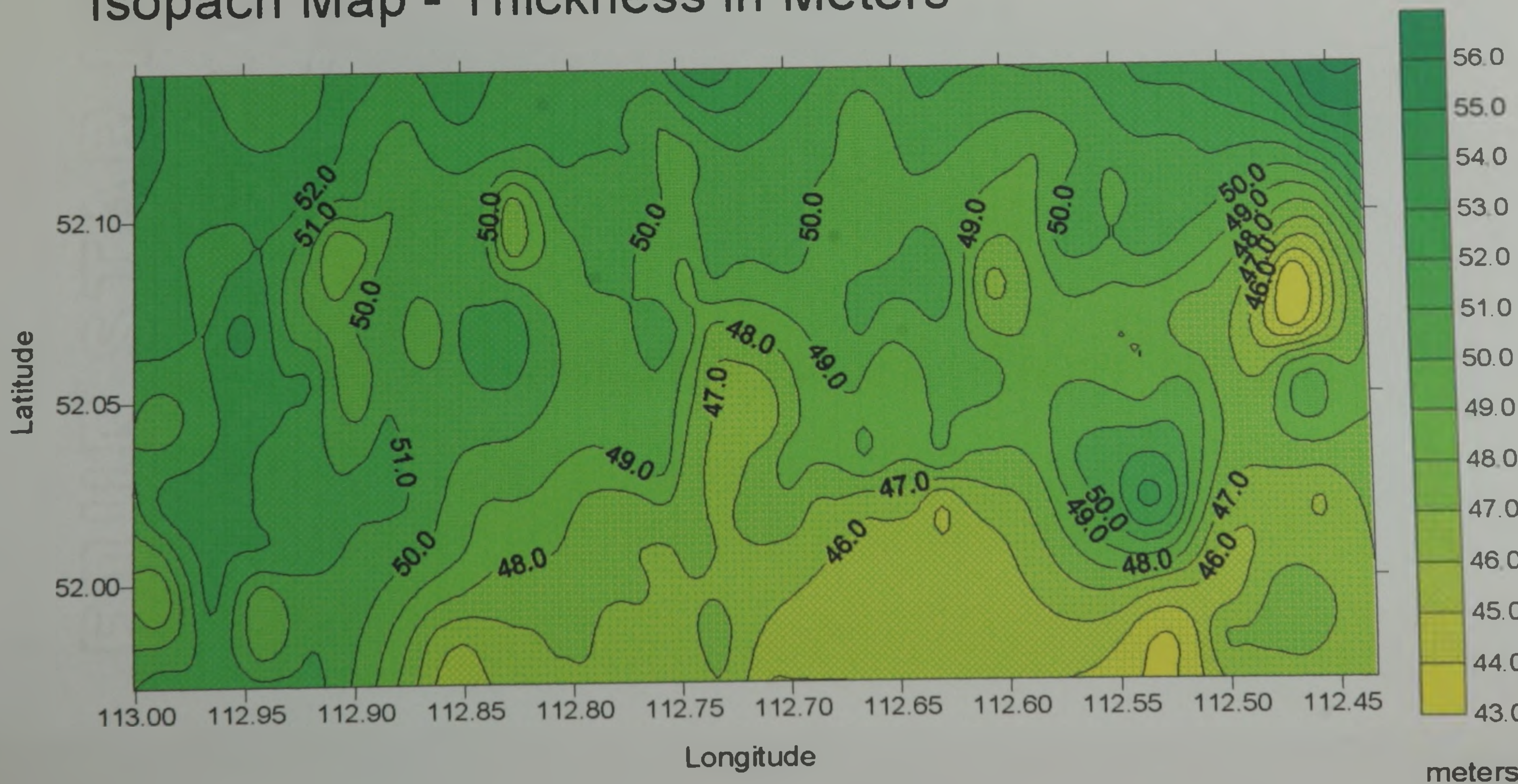


Figure 17d

Block 2 - First White Specks Formation (Layer 12-13)
Trend Surface - Thickenss in meters

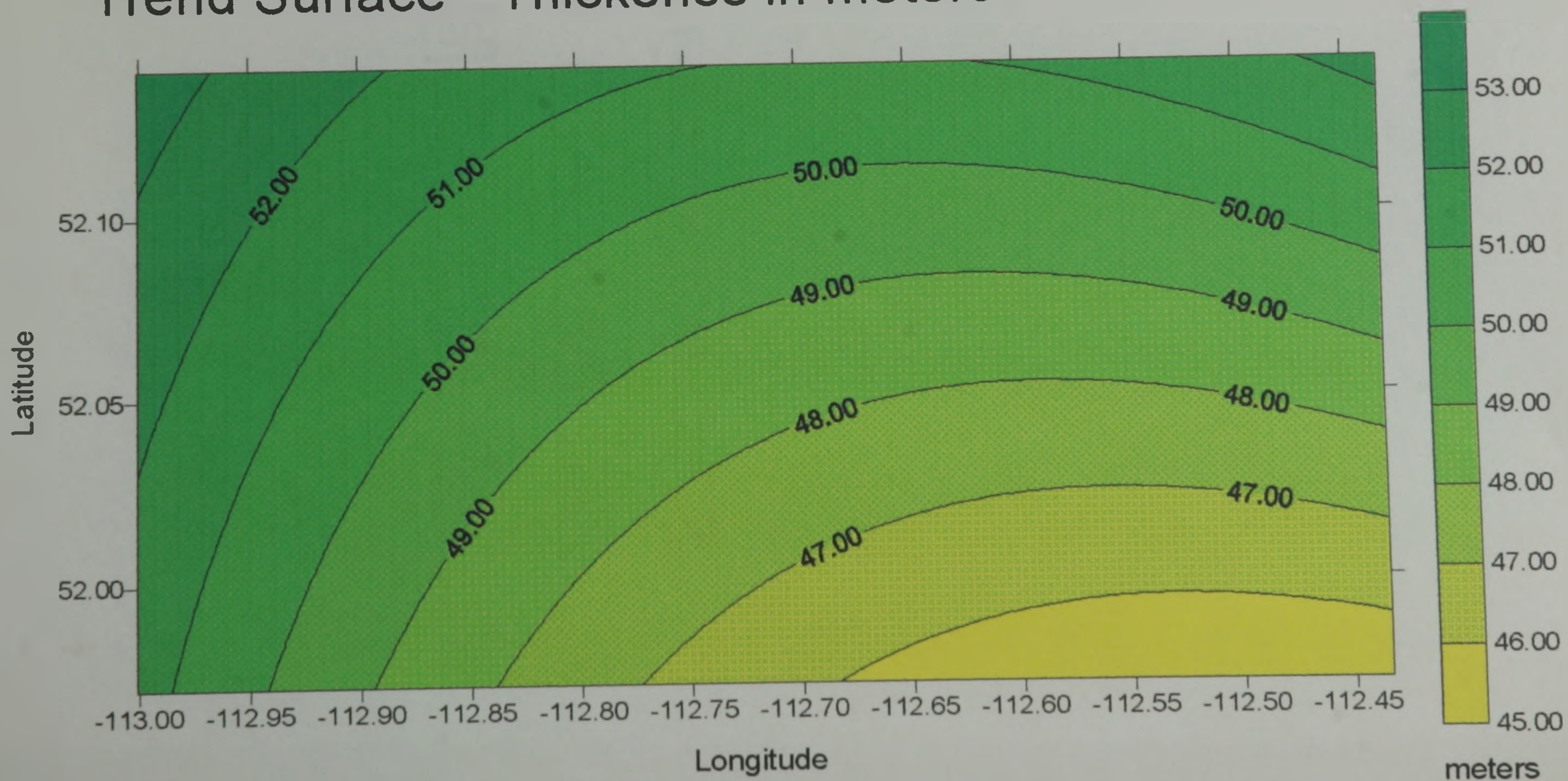


Figure 17e

Block 2 - First White Specks Formation (Layer 12-13)
Residuals in meters : Data - Trend Surface

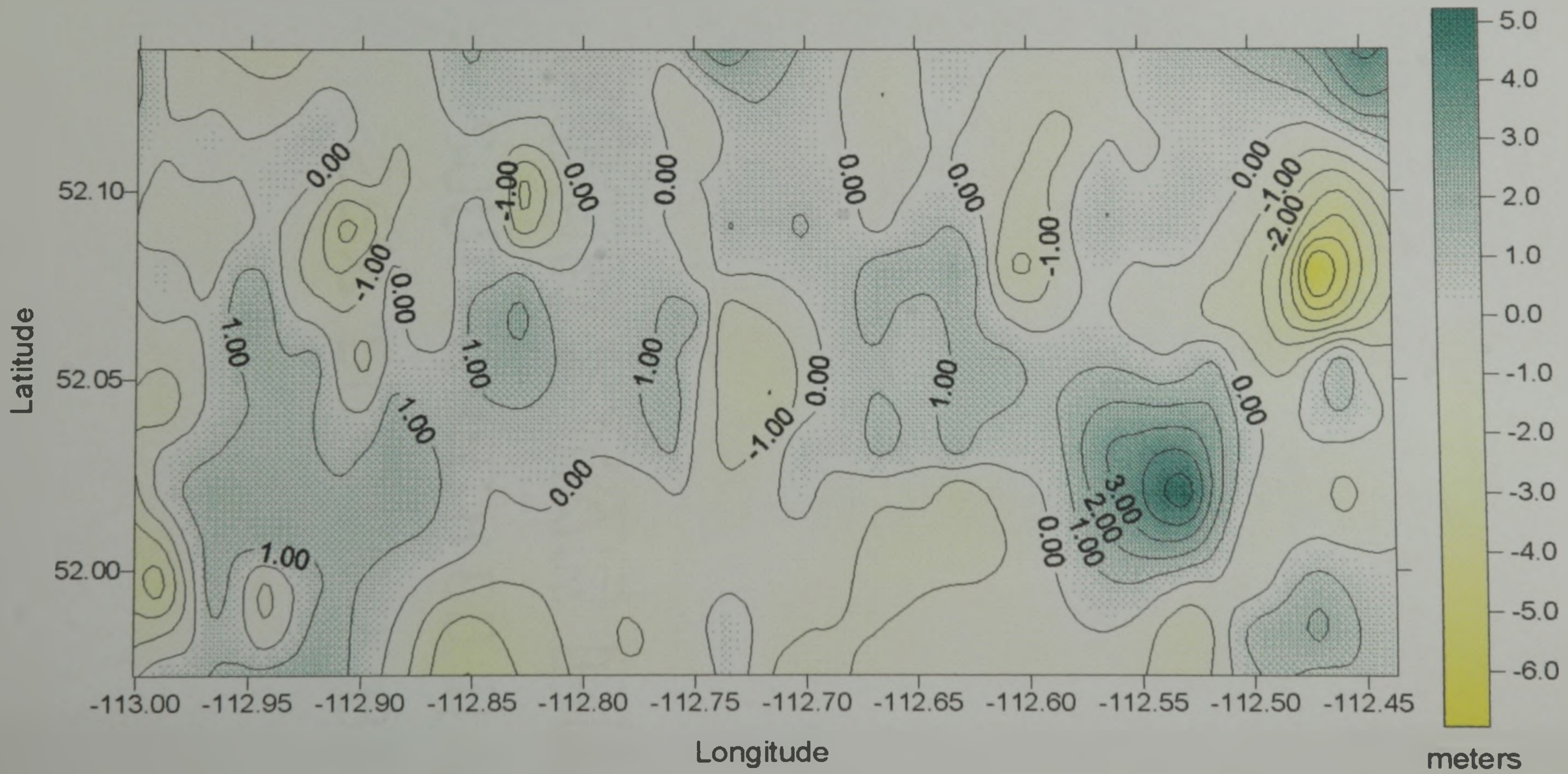


Figure 17f

Block 1 - Lea Park Formation (Layer 13-14) Isopach Map - Thickness in Meters

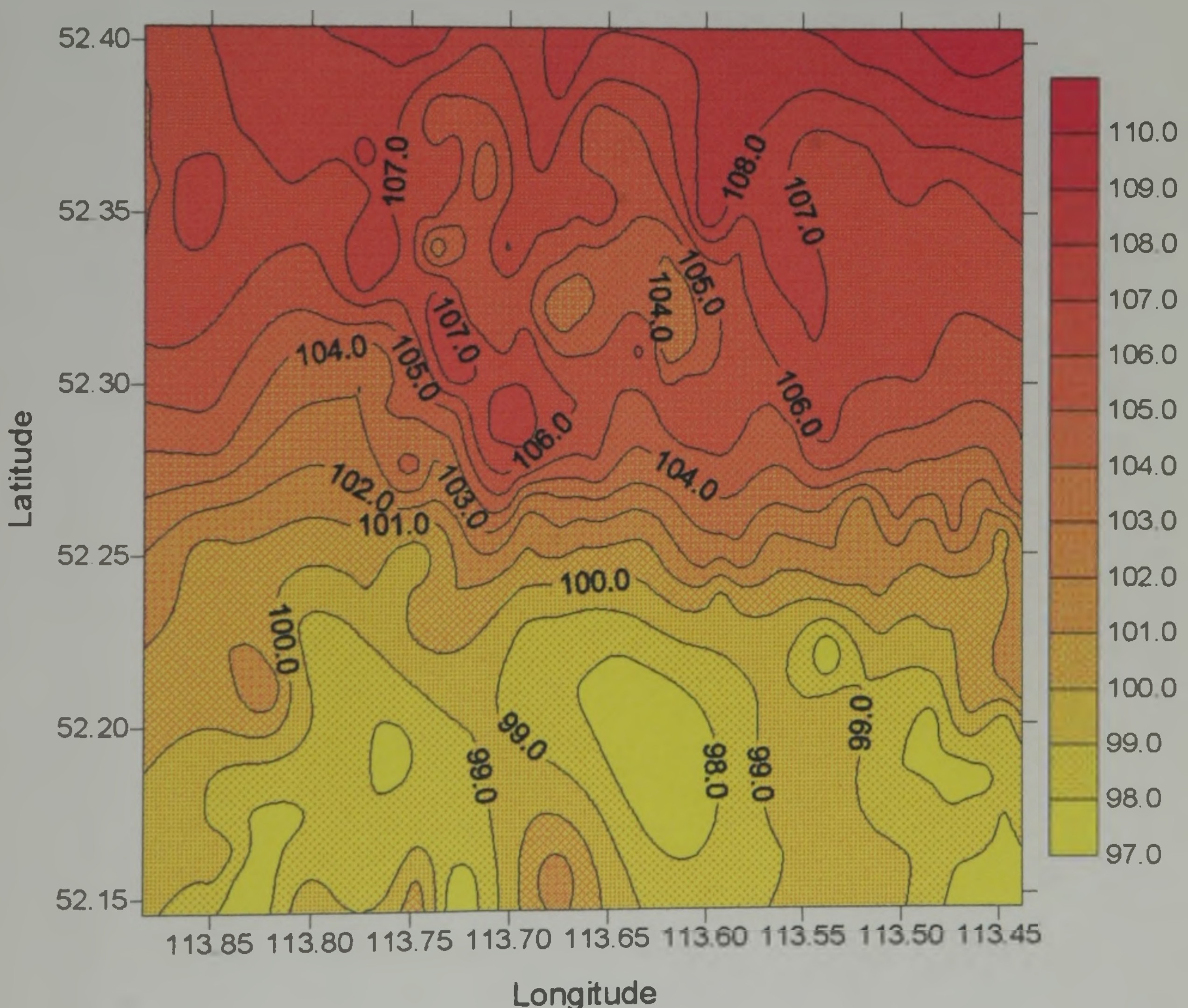


Figure 18a

Block 1 - Lea Park Formation (13-14)
Trend Surface - Thickness in Meters

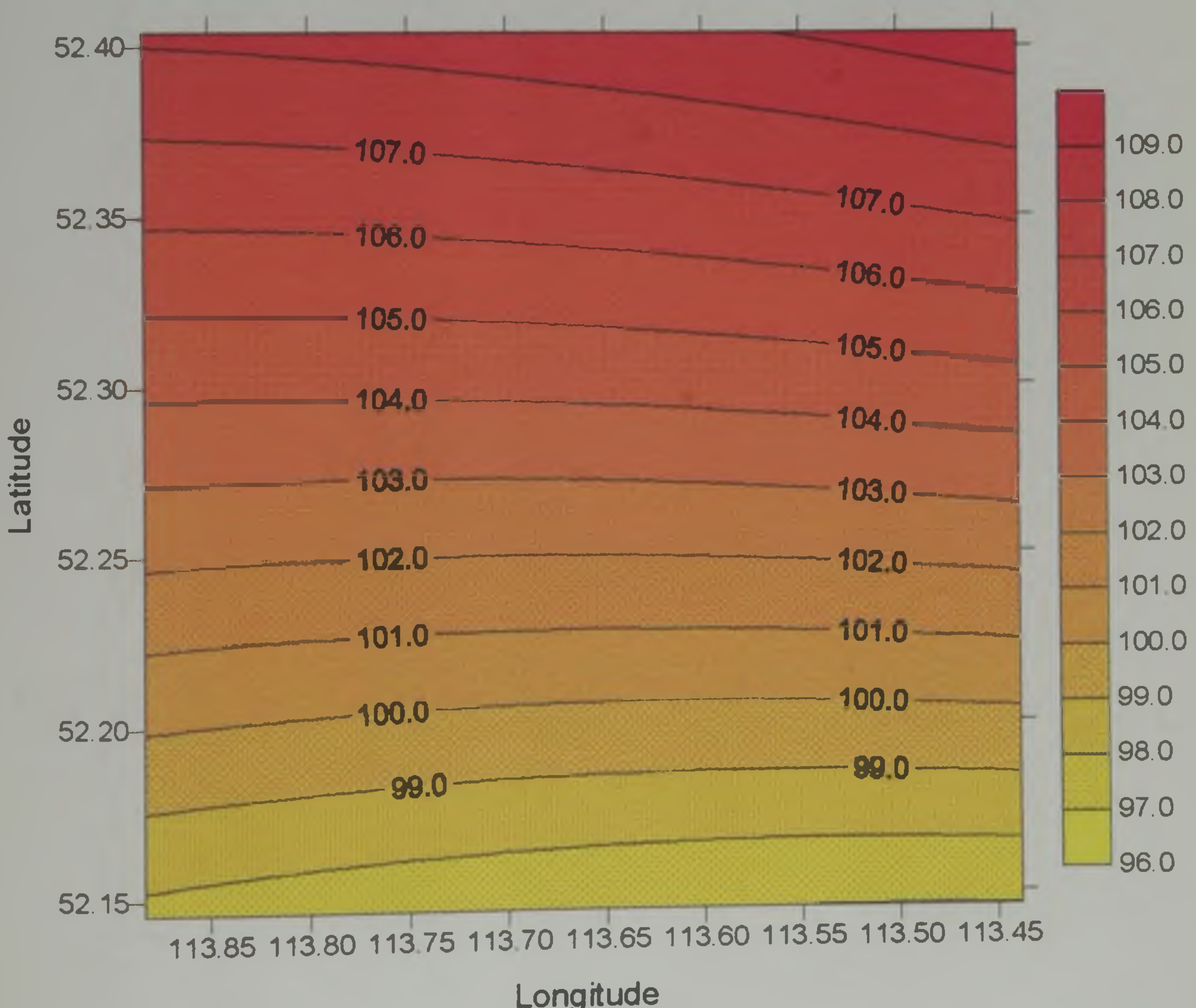


Figure 18b

Block 1 - Lea Park Formation (Layer 13-14)
Residuals in meters : Data - Trend Surface

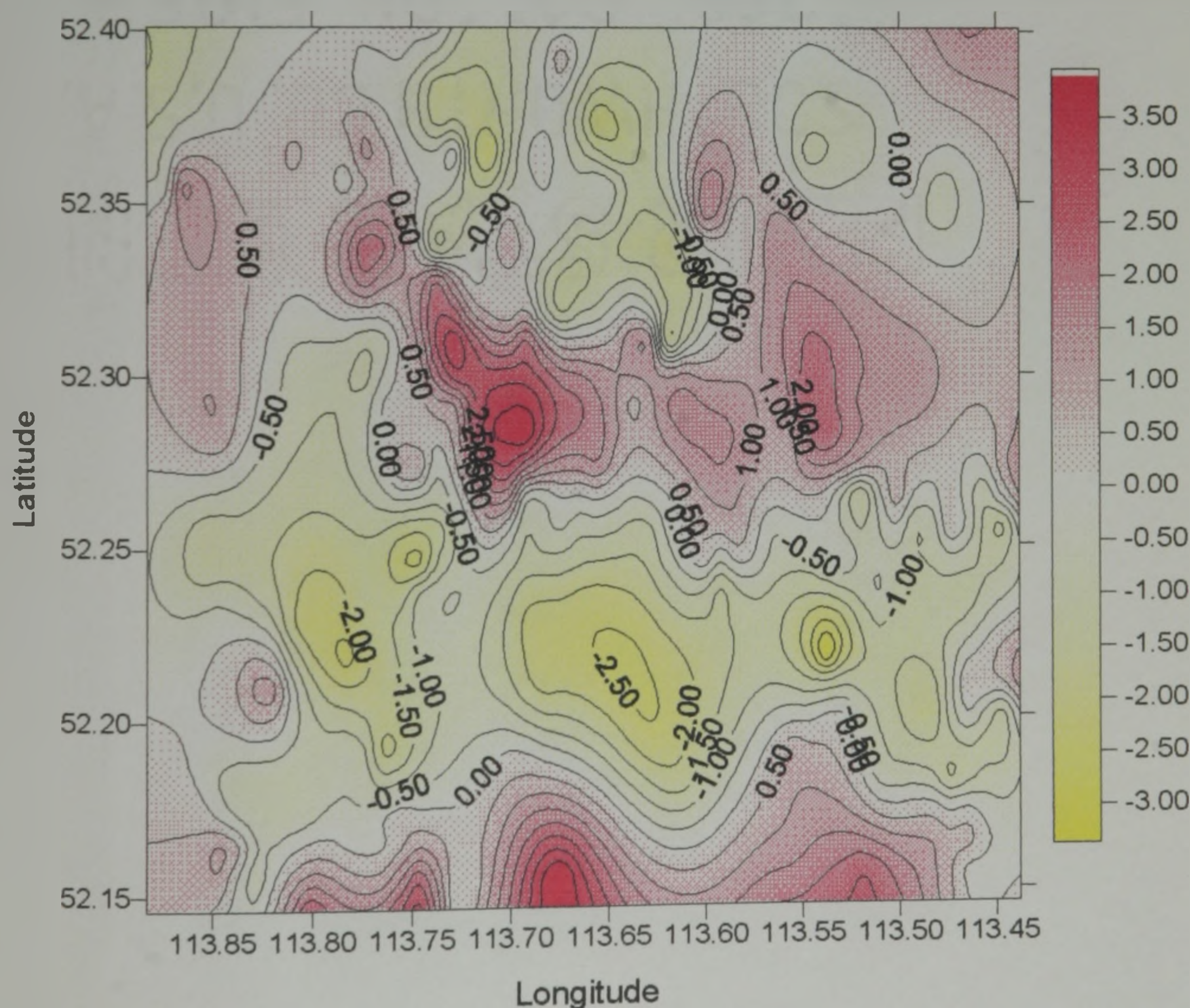


Figure 18c

Block 2 - Lea Park Formation (Layer 13-14)
Isopach Map - Thickness in Meters

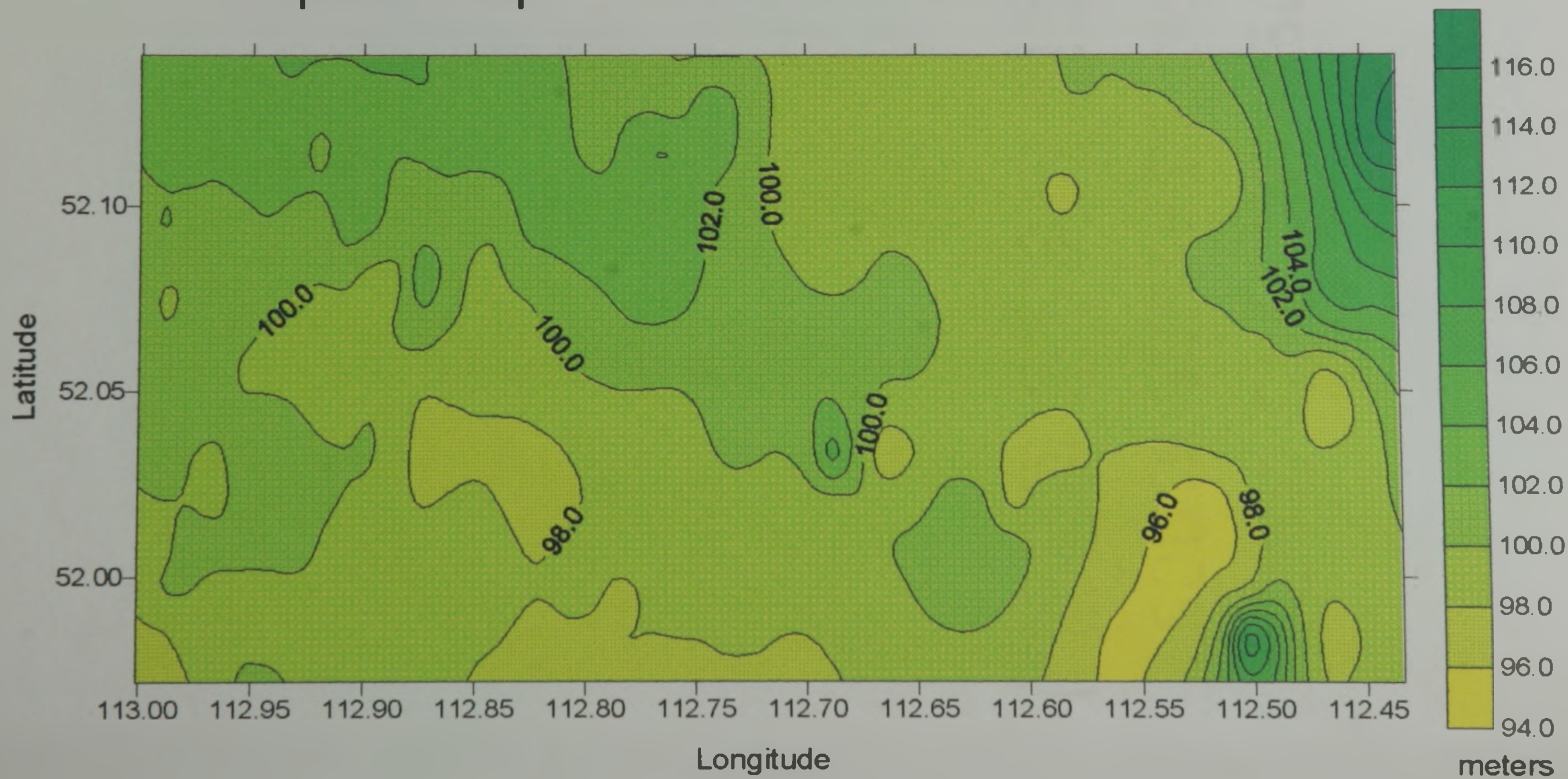


Figure 18d

Block 2 - Lea Park Formation (Layer 13-14)
Trend Surface - Thickness in meters

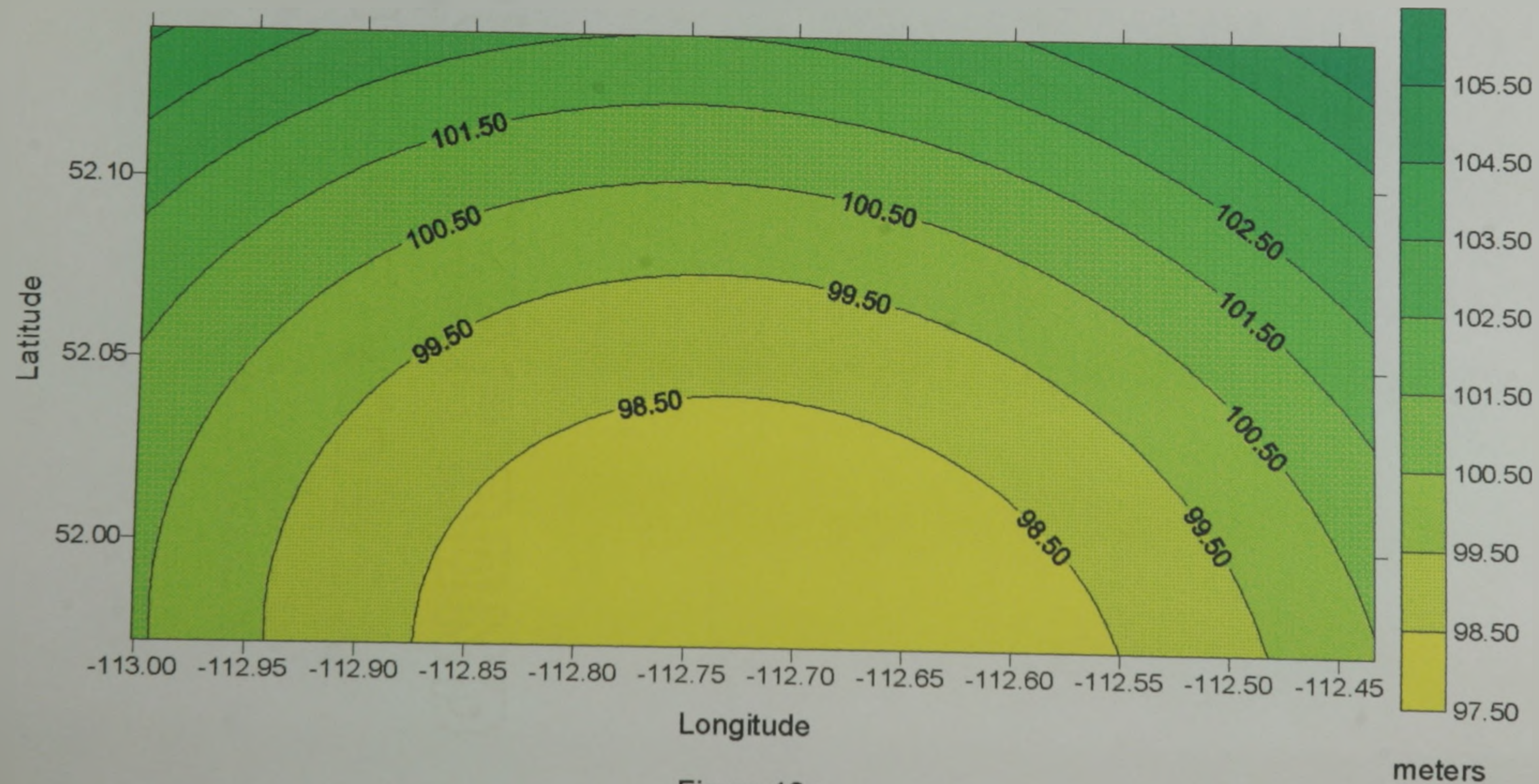
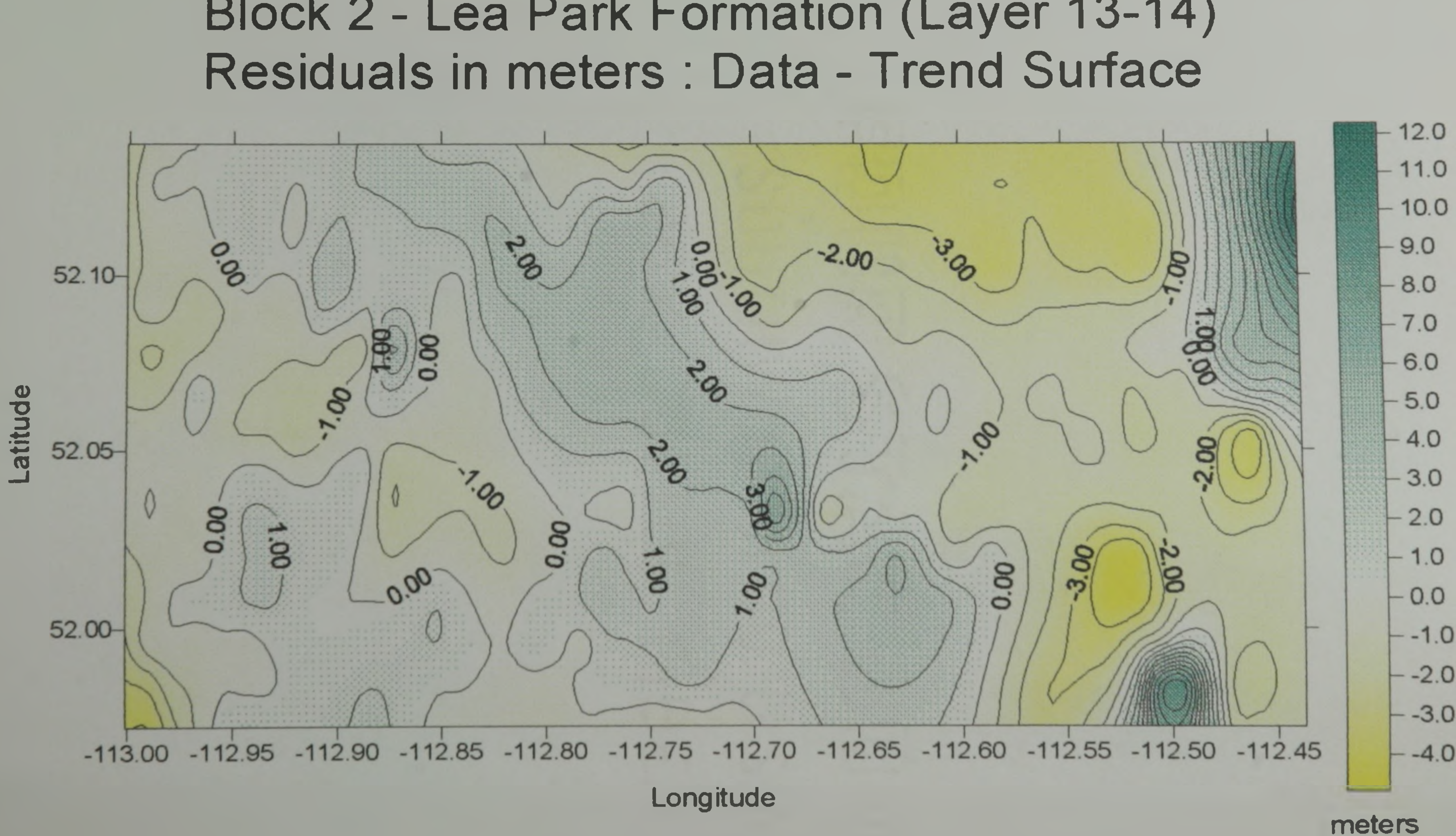


Figure 18e



Block 2 - Lea Park Formation (Layer 13-14)
Residuals in meters : Data - Trend Surface
Latitude
Longitude
meters

Figure 18f

IV. 2 Stacking Patterns

The isopach maps of the Joli Fou Formation (Layer 1-2) trend in a NW-SE direction (Block 1) and roughly N-S direction (Block 2). In both areas the muds thin landward (to the west). Like the Joli Fou, the isopach maps of the Viking Formation (Layer 2-3) also trend NW-SE; but the formation thins basinward (NE). It should be noted that this thinning corresponds to the location of the Joffre and Fenn fields and that the sandstone thickens again northeast of the fields. The isopach maps of the Westgate Formation (Layer 3-4) also trends in a NW-SE direction; but the muds thin landward again, as they did in the Joli Fou. No strong trends emerge in the isopach maps of the Fish Scales Sandstone (Layer 4-5); however a thinning direction towards the basin is indicated in Block 2. The direction of trend of the isopach maps changes in the Second White Specks Formation. The isopachs of the sandstone Layer 5-6 trends roughly N-S and thins basinward. The isopachs of the sandstone Layer 6-8 also trends N-S and thins basinward. The N-S trend swings to a NNE-SSE direction as you move to the east in Block 1. The isopachs of Layer 8-9 again trend roughly NW-SE and thin basinward in Block 1 (to the NE). Block 2 is interesting in that it is thickest in the centre and thins both northeastward (towards the basin) and northwestward (towards land). The isopachs of the Cardium unit from E1-E4 (Layer 9-10) trends in a NNW-SSE direction in Block 1 and strongly N-S in Block 2 and thins basinward (to the east) in both areas. The NW-SE trend of isopachs shows up again in the Cardium E4-E5 (Layer 10-11). However, the formation now thins landward in Block 1. The unit thins both landward to the SW and basinward to the NE in Block 2. The NW-SE trend in isopachs remains strong in the shale unit before First White Specks (Layer 11-12). The direction of thinning returns basinward (to the NE). There is also a possible N-S trend superimposed on the NW-SE trend in Block 2. The isopachs of the First White Specks Formation (layer 12-13) continues to trend weakly in a NW-SE direction in Block 1. The thinning pattern; however, has changed again. The sandstone thins towards the NW and thickens to SW. No clear trends are apparent in Block 2; but, the sands thin towards the south. Surprisingly, strong E-W trends are found Block 1 of the Lea Park Formation (Layer 13-14). The trend is not clear in Block 2 but thinning is towards the south in both areas.

\IV. 3 Control of Trends

Thinning basinward is the expected pattern of deposition in a foreland basin. The units are thickest landward because subsidence is occurring from accreted island arc terrains loading the crust. This creates accommodation space which is then filled in by the sediment being supplied from erosion of the accreted terrains. The combination of greater sediment supply combined with greater accommodation space created by subsidence results in units being thickest to the west and thinning basinward. However, units that thin landward are also found in this stratigraphic interval. They result from onlapping onto an underlying layer which either thinned basinward or was tilted basinward by uplift. There are three examples of landward thinning in this interval: the Joli Fou onlapping the older Manville surface, the Westgate onlapping the Viking interval and the Cardium E4-E5 unit onlapping the Cardium E1-E4 package.

It should also be noted that sandstone formations, e.g., Viking and Cardium are composite bodies. They consist of stacked sandstones separated by erosion surfaces. They are what is left after a series of transgressions and regressions that have influenced deposition and erosion patterns. They cannot be interpreted as one package of deposition.

V. Conclusions

Thinning patterns flip-flop almost continuously through the stratigraphic interval. They start off thinning landward in the Joli Fou Formation, reverse to thin basinward in the Viking Formation, thin landward again in the Westgate, thin basinward during Fish Scales and Second White Specks, thin both basinward and landward in the shales before the Cardium, thin basinward during the Cardium E1-E4 layer, reverse to thin landward during the Cardium E4-E5 layer, thin basinward in the shales before First White Specks, and then change to thin to the south and NW in First White Specks and continues to thin south during Lea Park.

The direction of isopach trends also changes throughout the section. Although there is a predominance of trends parallel to the orientation of the basin and orogeny zone to the west (NW-SE), which is expected, there are also strong N-S and E-W trends that show up in Joli Fou (N-S), Second White Specks (N-S and NNE-SSW), Cardium E1-E4 (N-S) and Lea Park (E-W).

Eight out of the twelve layers show secondary residual trends at oblique angles to the primary isopach trends. In general these trends run roughly N-S. Five out of twelve residual trends run N-S. Three out of twelve residuals trend NNE-SSW. One layer showed NW-SE trending residuals. The predominance of secondary trends indicates that more than one mechanism was acting to control deposition and erosion patterns.

Some NNE-SSW trends are found as secondary trends in the residuals of the Joli Fou, the Viking, Layer 6-8, and also in the isopach map of Layer 5-6. However, no strong re-occurring NE-SW trends are found as would be expected if NE-SW trending basement faults were being episodically remobilized during the Cretaceous.

In conclusion, no evidence of re-occurring trends were found in this area during the Cretaceous period. In fact the direction of thinning changes continuously through the stratigraphy. Isopach trends occur at oblique angles to the NE-SW trend of basement faults and also change through the stratigraphy. Secondary trends are found in the residual maps, generally trending N-S. There is clearly no strong NE-SW movement in the basement that is propagating up through 3500 m of rock and effecting the position of the linear sand bodies. Therefore, the direction of deposition and trend of thickness patterns in the Alberta Group of the Cretaceous in this area were not controlled by repeated movements in the basement. It follows that the linear Cretaceous sand bodies of the Joffre and Fenn were not created by movements in the basement as Hart and Plint have suggested. Sedimentological control is likely the most important factor controlling the thickness patterns of the formations as well as subsidence and relative changes in sea level.

VI. Recommendations

It is still not known why the sandbody trends are so long and linear. Although I have concluded that there is no evidence of episodic remobilization of basement movements in this area, the study area of this project was limited. It included the linear sandbody trends but very little of the surrounding area. Continuing this project by expanding the study area may give greater insight into possible controls. As part of this thesis, many more well logs were collected and are available to be correlated.

VII. References

Cant, D. J., 1993, Chapter 11 Zuni Sequence : The Foreland Basin Lower Zuni Sequence : Middle Jurassic to Middle Cretaceous, Evolution of the Western Interior Basin: Geological Survey of Canada, Special Paper 39, p.251-267.

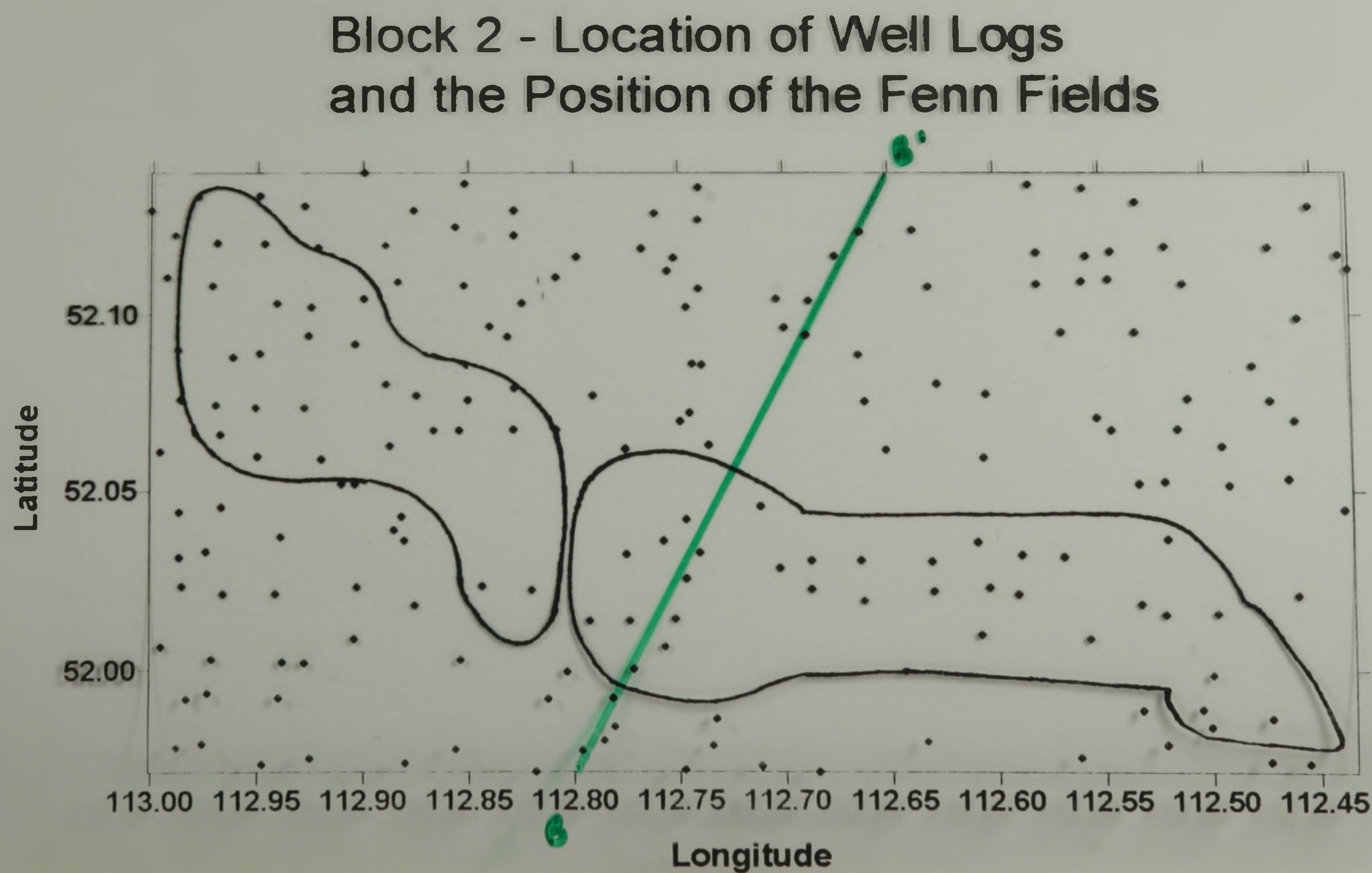
Downing, K. P., and R. G. Walker, 1988, Viking Formation, Joffre Field, Alberta: Shoreface Origin of Long, Narrow Sand Body Encased in Marine Mudstones: American Association of Petroleum Geologists Bulletin, v.72, p. 1212-1226.

Hart, B. S., and A.G. Plint, 1993, Tectonic Influence on Depositional and Erosion in a Ramp Setting : Upper Cretaceous Cardium Formation, Alberta Basin: American Association of Petroleum Geology, v.77, p. 2092-2107.

Jones, R. M. P., 1980, Basinal isostatic adjustment faults and their petroleum significance: Bulletin of Canadian Petroleum Geology, v. 28, p. 211-251.

Leckie, D. A., 1993, Upper Zuni : Upper Cretaceous to Lower Tertiary: Evolution of the Western Interior Basin: Geological Survey of Canada, Special Paper 39, p. 269-281.

ACETATE OVERLAYS


Block 2 - Location of Well Logs
and the Position of the Fenn Fields
B'
B
52.10
52.05
52.00
Latitude
113.00
112.95
112.90
112.85
112.80
112.75
112.70
112.65
112.60
112.55
112.50
112.45
Longitude

Block 1 - Location of Well Logs and the Position of Joffre Field