**Three-dimensional
magnetotelluric (MT)
modeling of the Northern
Negros Geothermal Project,
Central Philippines**

by

Carlos Emmanuel Fajardo Los Banos

A thesis
submitted to the Victoria University of Wellington
in fulfilment of the
requirements for the degree of
Master of Science
in Physics.

Victoria University of Wellington
2012

Abstract

The latest magnetotelluric (MT) survey was conducted in the Northern Negros Geothermal Project (NNGP), which is one of the geothermal fields being developed in the Philippines, from December, 2010 to April, 2011. 66 new MT soundings were added to the previous MT dataset. The new stations were located mainly in the southeastern and southern regions to define the extent of drilled high-temperature resource in these areas.

Phase tensor analysis show that the MT data in general is only 1-D in the short period range of <1 s and becomes 3-D at longer periods. 1-D, 2-D and 3-D modeling were performed on the MT dataset after stripping it for distortion based on the phase tensor and correcting for static shifts using Transient Electromagnetic (TEM) data. The resistivity structure from all models show three main layers: a >100 ohm-m resistive top layer, a middle <10 ohm-m conductive layer and a >20 ohm-m moderately resistive bottom layer. The highly resistive top layer is associated with the relatively fresh volcanic deposits of the Canlaon Volcanics (CnV). Correlating the 3-D resistivity structure with subsurface data from the drilled wells shows that the thick conductive layer overlaps with the low-temperature alteration minerals such as smectite while the moderately resistive bottom layer coincides with the high-temperature alteration minerals like illite and epidote. These observations are also consistent with the measured well temperatures wherein the elevated temperatures drilled beneath the Pataan sector coincide with the shallow occurrence or doming portion of the bottom resistive layer.

Tracing the shallow occurrence of the bottom resistive layer revealed

a northeast extension to the drilled resource beneath Pataan. The delineated resource area in Pataan is about 3 to 7 km².

Other possible high-temperature areas are located within the Upper Hagdan and Hardin Sang Balo sectors. However, resolution of the resistivity structure is not well pronounced in these areas due to limited data coverage.

Acknowledgments

This thesis would not have been possible without the guidance and support of the following individuals who in one way or the other contributed to its completion. It is to them I sincerely express my gratitude:

First and foremost, to my supervisor, Dr. Malcolm Ingham, for unselfishly sharing his knowledge about MT particularly 3-D inversion modeling,

Mssrs. Richard Tantoco and Manuel Ogena, on behalf of the management of Energy Development Corporation, for giving me the opportunity to pursue an MSc. degree to enhance my technical capability,

To my family, especially to my wonderful wife Glenda, who took care of our two lovely daughters while I was studying,

To my colleagues in EDC, namely, Mr. Domie Layugan, Mr. Boyie Rigor, Mr. Rhoel Olivar, Mr. Randy Tugawin, Mr. Mike Pastor, Ms. Menchie Melo, Mr. Andy Caliwag, Mr. Manny Teoxon, Ms. Sylvia Ramos and Mr. Jericho Omagbon for providing additional data that I needed,

And of course, to God, who made all these possible.

Contents

List of Figures	ix
List of Tables	xiii
1 Introduction	1
2 The basics of Magnetotelluric (MT) method	5
2.1 Signal sources	6
2.2 Maxwell's equations	6
2.3 Skin depth	8
2.4 A 1-D solution to the induction problem	9
2.5 Solution to a 2-dimensional Earth	13
2.6 Solution to a 3-dimensional Earth	15
2.7 MT sounding: concept of impedance and tipper	15
2.8 Distortion	19
2.9 Phase tensor analysis	20
2.10 Static shift	22
2.11 Modeling	24
2.11.1 1-dimensional modeling	25
2.11.2 Bostick inversion	25
2.11.3 Simple layered model	26
2.11.4 Occam inversion	27
2.11.5 2-dimensional modeling schemes	29
2.11.6 3-dimensional modeling	30

2.12	Instrumentation and data acquisition	31
2.13	Data processing	33
3	Northern Negros Geothermal Project	35
3.1	Geology	38
3.2	Gravity survey	39
3.3	1995 and 2000 MT surveys	43
3.4	Hydrothermal system	45
4	2011 MT survey	47
4.1	Data quality and description	48
4.2	Phase tensor analysis	50
4.3	Induction arrows	57
4.4	Static shift correction	57
5	Modeling	63
5.1	1-D inversion modeling	63
5.1.1	Isoresistivity maps	63
5.2	2-D inversion modeling	64
5.2.1	Isoresistivity maps	66
5.3	3-D inversion modeling	69
5.3.1	Comparison of initial models	70
5.4	3-D inversion results	83
5.4.1	MT data curves	83
5.4.2	Isoresistivity maps	83
5.4.3	Resistivity profiles	84
5.4.4	YZ slices	90
5.4.5	XZ slices	95
5.5	Comparison of 1-D, 2-D and 3-D models	100
5.5.1	Isoresistivity maps	100
5.5.2	Profile lines	101

<i>CONTENTS</i>	vii
6 Discussion and interpretation	111
6.1 Resistivity structure of NNGP	111
6.1.1 Correlation with alteration, temperature and lithol- ogy	112
6.2 Geothermal resource area	118
7 Summary and Conclusions	123
References	127
Appendix I: Data curves and phase tensor analysis	133
Appendix II: MT data description	169
Appendix III: Static shift correction applied	187
Appendix IV: 3-D inversion data file	193
Appendix V: 3-D inversion curve fit	221

List of Figures

2.1	A simple 2-D model	14
2.2	The phase tensor ellipse	22
2.3	Simple 1-D layered model	26
2.4	2-D modeling	29
2.5	Typical MT station layout	32
2.6	MT data processing flowchart	34
3.1	Location map of the Northern Negros Geothermal Project (NNGP)	36
3.2	Location map of wells and thermal areas in NNGP	37
3.3	Simplified geologic map of NNGP	40
3.4	Structural map of NNGP	41
3.5	Residual Bouguer anomaly map	42
3.6	Apparent isoresistivity map at 0.33s	44
3.7	1-D layered model along profile S-01	44
3.8	2-D resistivity model	45
3.9	Delineated resource area at NNGP	46
4.1	MT and TEM stations location map	49
4.2	Samples of extremely noisy MT data	51
4.3	Strike directions of MT stations based on phase tensor . .	53
4.4	Dominant strike directions of the MT data	54
4.5	Phase tensor ellipse at different periods	56
4.6	Induction arrows at 300 Hz	58

4.7	Induction arrows at 10 Hz	58
4.8	Induction arrows at 1 Hz	59
4.9	Induction arrows at 0.1 Hz	59
4.10	Induction arrows at 0.01 Hz	60
4.11	Induction arrows at 0.001 Hz	60
5.1	1-D isoresistivity map at 300 m depth	64
5.2	1-D isoresistivity map at 1000 m depth	65
5.3	1-D isoresistivity map at 2000 m depth	65
5.4	2-D isoresistivity map at 300 m depth	67
5.5	2-D isoresistivity map at 1000 m depth	68
5.6	2-D isoresistivity map at 2000 m depth	68
5.7	Model A isoresistivity map at 300 m depth	72
5.8	Model B isoresistivity map at 300 m depth	72
5.9	Model C isoresistivity map at 300 m depth	73
5.10	Model A isoresistivity map at 2000 m depth	74
5.11	Model B isoresistivity map at 2000 m depth	74
5.12	Model C isoresistivity map at 2000 m depth	75
5.13	Model B isoresistivity map at 1000 m depth	75
5.14	Model A profile line $X=-0.25$ km	76
5.15	Model B profile line $X=-0.25$ km	77
5.16	Model C profile line $X=-0.25$ km	77
5.17	Model A profile line $Y=0.75$ km	79
5.18	Model B profile line $Y=0.75$ km	79
5.19	Model C profile line $Y=0.75$ km	80
5.20	Curve fit of model vs data of MT station 4	81
5.21	Curve fit of model vs data of MT station 14	82
5.22	Isoresistivity map at 10 m depth	85
5.23	Isoresistivity map at 100 m depth	85
5.24	Isoresistivity map at 300 m depth	86
5.25	Isoresistivity map at 500 m depth	86
5.26	Isoresistivity map at 1 km depth	87

5.27 Isoresistivity map at 2 km depth	87
5.28 Isoresistivity map at 3 km depth	88
5.29 Isoresistivity map at 4 km depth	88
5.30 Isoresistivity map at 5 km depth	89
5.31 Isoresistivity map at 8 km depth	89
5.32 Resistivity profile along X=-4.25 km	91
5.33 Resistivity profile along X=-3.75 km	91
5.34 Resistivity profile along X=-2.75 km	92
5.35 Resistivity profile along X=-2.25 km	92
5.36 Resistivity profile along X=-0.25 km	93
5.37 Resistivity profile along X=0.25 km	94
5.38 Resistivity profile along X=2.75 km	94
5.39 Resistivity profile along X=3.25 km	95
5.40 Resistivity profile along Y=-2.75 km	96
5.41 Resistivity profile along Y=-1.75 km	96
5.42 Resistivity profile along Y=-0.75 km	97
5.43 Resistivity profile along Y=0.75 km	98
5.44 Resistivity profile along Y=1.25 km	98
5.45 Resistivity profile along Y=3.75 km	99
5.46 Resistivity profile along Y=4.25 km	99
5.47 Profile lines location map	102
5.48 Profile line NW-SE1	104
5.49 Profile line NW-SE2	106
5.50 Profile line NW-SE3	108
5.51 Profile line SW-NE1	110
6.1 Resistivity model vs. alteration minerals along NW-SE2 .	113
6.2 Resistivity model vs. measured temperatures along NW-SE2	114
6.3 Resistivity model vs. lithology along NW-SE2	115
6.4 Resistivity model vs. alteration minerals along SW-NE1 .	116

6.5	Resistivity model vs. measured temperatures along SW-NE1	117
6.6	Resistivity model vs. lithology along SW-NE1	117
6.7	Profile line SW-NE2 location map	119
6.8	Resistivity model along SW-NE2	120
6.9	Delineated resource area in NNGP based on 3-D inversion	121
7.1	Delineated resource area at NNGP	126

List of Tables

4.1	Summary of data types based on quality	50
6.1	Common mineral geothermometers in Philippine geothermal areas	112

Chapter 1

Introduction

In the past 15 years, the magnetotelluric (MT) method has been one of the effective tools used for understanding and exploring geothermal resources and related environments (Heise et al., 2008; Uchida, 2005; Cumming et al., 2000; Ingham et al., 2005). Significant advancement in the processing and modeling techniques of MT data has been made in recent years (Ogawa, 2002; Siripunvaraporn, 2011). This included the improvement of 3-dimensional inversion softwares for MT data, such as the WSINV3DMT, which enables the processing of data on a personal PC in a shorter time than before (Siripunvaraporn et al., 2005).

The Northern Negros Geothermal Project (NNGP) is one of the geothermal fields currently being developed in the Philippines. It is located in the northern portion of the central Island of Negros and lies about eight kilometers northwest of the active Canlaon Volcano. MT studies have been conducted in NNGP as early as 1995. However, data processing and analysis have been limited to 1-dimensional and 2-dimensional inversion modeling.

MT data in a highly-fractured environment such as NNGP, are in reality highly 3-dimensional and the use of 1-D or 2-D techniques can often lead to misrepresentation of resistivity features which in turn can lead to misinterpretation of the data. In line with this, 3-dimensional

modeling was applied to the MT data of NNGP to be able to accurately define a resistivity structure, which can be related to the hydrothermal system of the study area. Other objectives include the refinement of the delineated boundaries of the high temperature field drilled in Pataa sector particularly to the south-southeastern regions, and to pinpoint areas with similar resistivity characteristics that may be potential resource targets in NNGP.

Additional MT data were collected specifically for this 3-D modeling project with emphasis on getting better quality suited for 3-D inversion. Other new techniques that were applied during processing include the correction for static shifts using the Transient Electromagnetic (TEM) data that were acquired from the TEM survey that was conducted together with the latest MT survey, and the phase tensor analysis technique by Caldwell et al. (2004) to identify data dimensionality, determine the dominant strike direction, and remove distortions in the dataset. Detailed explanation for these applications are found in chapter 2 and 4.

Chapter 2 reviews the main theories behind MT. It also gives brief discussion of the different processing techniques applied to the MT data such as the phase tensor distortion, static shifts, etc. The concept behind the different MT modeling methods that were applied during this project are also discussed in this chapter. An overview of the equipment used and the general steps in data processing is also given.

Chapter 3 gives an overview of NNGP with emphasis on the previous geoscientific studies conducted in the area, such as the geological mapping, gravity, earlier MT surveys and the subsurface data based on the drilled wells. The postulated hydrothermal model is also presented.

Chapter 4 described the MT dataset that was used during modeling. This included data from the latest MT survey that was conducted primarily to get better quality data than the previous surveys that would be suitable for 3-D inversion. This chapter also deals with the treatment of

the MT data which involves the mapping of induction arrows, correcting for static shift using TEM data, removal of distortion, and determining dimensionality, among others.

Chapter 5 summarizes the results of the 1-D, 2-D and 3-D modeling methods used for the NNGP MT dataset, with more detail given to the 3-D inversion results. The results are presented through iso-resistivity maps and resistivity structures along selected profile lines. A discussion on the different initial models used for 3-D inversion and the subsequent selection of the 30 ohm-m half space as the initial model used for the final 3-D models is also given in this chapter. Comparison of the results between the 1-D, 2-D, and 3-D models, as well as, the results from the different 3-D initial models, show both the consistent and the distinct features of the various models. This enables the determination of the "true" resistivity features from the ones that may be artefacts of the processing algorithms.

Chapter 6 discusses the interpretation of resistivity structure particularly from the 3-D models, in terms its significance in the geothermal resource at NNGP. This is done by correlating the models with the subsurface data, which consists of alteration mineralogy, lithology and measure well temperatures. The delineation of the high temperature resource based on the resistivity structure at NNGP is also presented in this chapter.

Lastly, Chapter 7 gives a summary of the processing techniques applied to the MT data in preparation for 3-D modeling. This chapter also highlights the new findings from 3-D modeling and its significance to the geothermal resource in NNGP. These include the delineation of a shallow moderately resistive body "doming" beneath Pataan sector, which can be associated with the extent of the high temperature resource that was drilled in the area. The 3-D model also suggests the presence of possible high temperature regions beneath Upper Hagdan and Hardin Sang Balo at the southern portion of NNGP.

Chapter 2

The basics of Magnetotelluric (MT) method

The concept of the magnetotelluric method (MT) was first introduced by Tikhonov (1950) and Cagniard (1953) . It is a passive electromagnetic (EM) technique that involves measuring fluctuations in the natural electric (E) and magnetic (B) fields in orthogonal directions at the surface of the Earth as a means of determining the conductivity structure of the Earth. Compared to other electrical methods, MT has the advantage to penetrate very deep levels reaching to hundreds of kilometers. In geothermal exploration, this method is effectively used to map low resistivity anomalies, which can be interpreted as hydrothermally altered zones indicating passage of hot fluids. MT is also useful in mapping out resistivity contrasts, which could reveal geologic structures such as faults that could act as pathways for the geothermal fluids. This chapter presents the basic theories behind the MT method, its properties and applications. This section also includes the parameters considered during processing and modeling of the data. Unless otherwise stated, the main basis for this chapter are the notes from lectures and discussions with Dr. M. R. Ingham.

2.1 Signal sources

MT signals have a very wide spectrum ranging from milliseconds to several years. However, signals with periods less than 1 msec do not penetrate very far into the earth while oscillations with periods longer than one day are usually not recorded for MT. Natural sources for these signals above 1 Hz, also known as “sferics”, are the lightning activity during thunderstorms, whereas signals below 1 Hz, are caused by micropulsations in the magnetic field of the earth. Between 0.5 to 5 Hz lies the so called “dead band” wherein the signals have low amplitude. This is usually reflected in the poor data quality at this range in the MT sounding data. The major source for the MT signals is the magnetosphere, which is the region composed of highly charged particles such as the solar wind (Gold, 1959). This zone includes the atmosphere and the ionosphere, which is the high conductivity zone formed essentially through ionization of gases (i. e. oxygen and nitrogen) by ultraviolet rays from the sun (Vozoff, 1991).

2.2 Maxwell's equations

The basic theory of electromagnetic induction of the earth is based on Maxwells equations and may be written in terms of magnetic induction $\underline{B}$ as:

$$\nabla \times \underline{B} = \mu_0 \underline{J} + \mu_0 \varepsilon_0 \frac{\partial \underline{E}}{\partial t} \quad (Ampere's Law) \quad (2.1)$$

$$\nabla \times \underline{E} = -\frac{\partial \underline{B}}{\partial t} \quad (Faraday's Law) \quad (2.2)$$

$$\nabla \cdot \underline{B} = 0 \quad (Gauss's Law for Magnetism) \quad (2.3)$$

$$\nabla \cdot \underline{E} = \frac{q}{\varepsilon_0} \quad (Gauss's Law) \quad (2.4)$$

where $\underline{J}$ is the electric current density, $\underline{E}$ is the electric field, q is the volume density of charge, μ_0 is the permeability, and ε_0 is the permittivity of free space.

CHAPTER 2. THE BASICS OF MAGNETOTELLURIC (MT) METHOD

These four equations can be simplified by relating $\underline{J}$ to $\underline{E}$ through the electrical conductivity of the medium, and by noting that in the context of electromagnetic induction in the Earth, the displacement current factor in the first Maxwell equation is negligible. This can be shown by replacing $\underline{J} = \sigma \underline{E}$ (according to Ohm's Law), and assuming that the time variation of the electric field of the form $\exp(-i\omega t)$, which gives the ratio of the magnitudes of the two terms on the right hand side of the 1st equation as $\mu_0\sigma/\mu_0\varepsilon_0\omega$.

Comparing the typical values for σ and $\varepsilon_0\omega$ wherein σ within the crust and mantle range from 10^{-4} to 1 Sm^{-1} and frequencies which are measured in induction studies range from 1 kHz to 10^{-4} Hz, gives $\varepsilon_0\omega$ values ranging from 10^{-6} to 10^{-13} which is very small compared to the values of σ . Thus the displacement term on the right side of equation 2.1 can be ignored. Neglecting the displacement current and taking the curl of equation 2.1 gives

$$\nabla x(\nabla x \underline{B}) = \mu_0 \nabla x \underline{J} \quad (2.5)$$

Again, using the fact that $\underline{J} = \sigma \underline{E}$ and assuming the conductivity is uniform, we get

$$\nabla x(\nabla x \underline{B}) = \mu_0 \sigma \nabla x \underline{E}. \quad (2.6)$$

Using equation 2.2 for the curl of $\underline{E}$ now yields

$$\nabla x(\nabla x \underline{B}) = -\mu_0 \sigma \frac{\partial \underline{B}}{\partial t}. \quad (2.7)$$

The vector identity

$$\nabla x(\nabla x \underline{B}) = \nabla(\nabla \cdot \underline{B}) - \nabla^2 \underline{B} \quad (2.8)$$

and equation 2.3 yields a second expression for $\nabla x(\nabla x \underline{B}) = -\nabla^2 \underline{B}$ shown as

$$\nabla^2 \underline{B} = \mu_0 \sigma \frac{\partial \underline{B}}{\partial t}. \quad (2.9)$$

This shows that in a uniform conductor, $\underline{B}$ satisfies the diffusion equation.

2.3. SKIN DEPTH

It is also possible to eliminate $\underline{B}$ rather than $\underline{E}$ from Maxwells equations to deduce that a time varying electric field obeys

$$\nabla^2 \underline{E} = \mu_0 \sigma \frac{\partial \underline{E}}{\partial t} + \nabla \frac{q}{\varepsilon_0}. \quad (2.10)$$

The second term on the right hand side of the equation arises because the diffusion of an electric field into a conducting medium is modified by the accumulation of charge on the boundaries of the medium. In any situation a measured $\underline{B}$ or $\underline{E}$ field is a complicated function of time, that it may be represented as a Fourier Series (i.e. a summation of signals of different frequencies). As equations 2.9 and 2.10 are linear, the B or E field at any single frequency may be treated separately as obeying the diffusion equation.

2.3 Skin depth

Consider a horizontally oscillating B field and a plane with a semi-infinite conductor. If the time variations of the field are the same everywhere in the xy plane, then the field can be represented as a wave of infinite wavelength that strikes the surface of the conductor. Within the conductor the field is a wave with the general form

$$\underline{B} = \underline{B}_0 e^{\alpha z} e^{-i\omega t}. \quad (2.11)$$

Substituting into the diffusion equation

$$\frac{\partial^2 \underline{B}}{\partial z^2} = \mu_0 \sigma \frac{\partial \underline{B}}{\partial t} \quad (2.12)$$

$$\alpha^2 \underline{B}_0 e^{\alpha z} e^{-i\omega t} = \mu_0 \sigma (-i\omega) \underline{B}_0 e^{\alpha z} e^{-i\omega t} \quad (2.13)$$

$$\alpha^2 = \mu_0 \sigma (-i\omega) \quad (2.14)$$

$$\alpha = \pm(1 - i)(\mu_0 \omega \sigma / 2)^{1/2} \quad (2.15)$$

For a physically realistic solution $\underline{B}$ must decrease with depth z into the Earth and thus the positive (+) solution can be ignored leaving:

$$\underline{B} = \underline{B}_0 e^{-z/\delta} e^{-i(\omega t - z/\delta)} \quad (2.16)$$

where

$$\delta = \sqrt{\frac{2}{\mu_0 \sigma \omega}} = \sqrt{\frac{(10^7)(2)\rho T}{(4\pi)(10^{-7})(2\pi)}} = 503\sqrt{\rho T}. \quad (2.17)$$

Thus, the inverse of the real part of α is known as the skin depth δ which is defined as the distance over which the initial amplitude decays by a factor of $1/e$. As can be seen, the skin depth δ increases with decreasing frequency (i.e. longer period signals penetrate more deeply) and with decreasing conductivity (i.e. for a given frequency, penetration is greater into a more resistive medium).

2.4 A 1-D solution to the induction problem: Concept of apparent resistivity and phase

Electromagnetic induction in the Earth can be analytically solved for a 1-dimensional case, i.e. the electrical conductivity structure varies only with depth. In this case, expressions for the ratio of the internally and externally originating variations in the magnetic field and also for the electric and magnetic fields measured at the surface can be derived. Assuming that the Earth is a plane of uniform half-space with conductivity σ , the region between the surface of the earth and ionosphere has no currents and sources of magnetic field. Thus, the Earth's external magnetic field ($z < 0$) can be represented by the gradient of a scalar potential

$$\underline{B} = -\nabla U. \quad (2.18)$$

On the other hand, currents exist within the earth and therefore the internal magnetic field ($z > 0$) can be represented by the curl of a vector

2.4. A 1-D SOLUTION TO THE INDUCTION PROBLEM

potential

$$\underline{B} = \nabla x \underline{A}. \quad (2.19)$$

Based on equations 2.3 and 2.18, U must obey Laplace's equation and should satisfy $\nabla^2 U = 0$ where U can be defined as the sum of elliptically polarized waves travelling in the y direction with amplitudes varying with z and is expressed as

$$U(y, z) = -\frac{1}{\nu} e^{i\nu y} (B_e e^{-\nu z} + B_i e^{+\nu z}) e^{-i\omega t} \quad (2.20)$$

where

ν characterizes the spatial dimension of the wave (i. e. how uniform it is), B_e and B_i represent the amplitudes associated with the fields that originate externally or internally from the Earth, respectively.

For consistency, the vector potential $\underline{A}$ for the conductor (Earth) is defined as

$$\underline{A} = A_x = F(y) (C e^{-\alpha z} + D e^{+\alpha z}) e^{-i\omega t} \quad (2.21)$$

where $F(y)$ is expressed such that $\underline{A}$ also satisfies the diffusion equation

$$\nabla^2 \underline{A} = \frac{\partial^2 \underline{A}}{\partial x^2} + \frac{\partial^2 \underline{A}}{\partial y^2} + \frac{\partial^2 \underline{A}}{\partial z^2} = \mu_0 \sigma \frac{\partial \underline{A}}{\partial t}. \quad (2.22)$$

Expanding and calculating for $F(y)$ as shown

$$\frac{\partial^2 F}{\partial y^2} (C e^{-\alpha z} + D e^{+\alpha z}) e^{-i\omega t} + \alpha^2 F (C e^{-\alpha z} + D e^{+\alpha z}) e^{-i\omega t} = -\mu_0 \sigma i \omega F (C e^{-\alpha z} + D e^{+\alpha z}) e^{-i\omega t} \quad (2.23)$$

and relating

$$\frac{\partial^2 F}{\partial y^2} + (\alpha^2 - k^2) F = 0 \quad (2.24)$$

gives

$$F(y) = e^{i(\alpha^2 - k^2)^{1/2} y} \quad (2.25)$$

where $k^2 = -i\omega\mu_0\sigma$, and

$$\underline{A} = A_x = e^{i(\alpha^2 - k^2)^{1/2} y} (C e^{-\alpha z} + D e^{+\alpha z}) e^{-i\omega t}. \quad (2.26)$$

CHAPTER 2. THE BASICS OF MAGNETOTELLURIC (MT) METHOD

At the surface of the earth ($z = 0$), the magnetic field must be continuous, thus equating the internal and external magnetic fields at the surface gives:

$$-\nabla U = \nabla x \underline{A} \quad (2.27)$$

Expanding these

$$-\frac{\partial U}{\partial x} \underline{i} - \frac{\partial U}{\partial y} \underline{j} - \frac{\partial U}{\partial z} \underline{k} = \left(\frac{\partial A_z}{\partial y} - \frac{\partial A_y}{\partial z} \right) \underline{i} + \left(\frac{\partial A_x}{\partial z} - \frac{\partial A_z}{\partial x} \right) \underline{j} + \left(\frac{\partial A_y}{\partial x} - \frac{\partial A_x}{\partial y} \right) \underline{k} \quad (2.28)$$

Therefore, at the surface of the earth ($z = 0$)

$$B_y = -\frac{\partial U}{\partial y} = \frac{\partial A_x}{\partial z} \quad (2.29)$$

and

$$B_z = -\frac{\partial U}{\partial z} = \frac{\partial A_x}{\partial y}. \quad (2.30)$$

Applying the boundary condition of continuity of the tangential component of $\underline{B}$, gives

$$ie^{i\nu y}(B_e + B_i) = F(y)(-\alpha C + \alpha D) \quad (2.31)$$

which means that

$$F(y) = e^{i\nu y}. \quad (2.32)$$

Equating

$$ie^{i\nu y} = e^{i(\alpha^2 - k^2)(12)y} \quad (2.33)$$

gives

$$\alpha^2 = \nu^2 + k^2. \quad (2.34)$$

Equation 2.31 becomes

$$B_e + B_i = -\alpha C + \alpha D \quad (2.35)$$

Applying the continuity to the z component of $\underline{B}$ yields

$$B_e - B_i = i\nu(C + D). \quad (2.36)$$

2.4. A 1-D SOLUTION TO THE INDUCTION PROBLEM

As A_x must go to zero as z goes to infinity it follows that $D = 0$ and this yields

$$B_e + B_i = -\alpha C \quad (2.37)$$

and

$$B_e - B_i = i\nu C, \quad (2.38)$$

which then yields the ratio of the coefficients of the internal and external magnetic fields to be

$$\frac{B_i}{B_e} = \frac{\alpha - \nu}{\alpha + \nu}. \quad (2.39)$$

In EM studies, however, the actual ratios of interest are B_z/B_y and E_x/B_y . Using equation 2.31 to find the B_y and B_z components at $z = 0$, its ratio at the surface of the Earth is given by

$$\frac{B_z}{B_y} = \frac{i\nu}{\alpha} = \frac{i\nu}{(\nu^2 + k^2)^{1/2}}. \quad (2.40)$$

To obtain E_x/B_y , substitute equation 2.19 into equation 2.2, yields

$$E = -\frac{\partial A}{\partial t} \quad (2.41)$$

and since E_x is parallel to the surface of the Earth there is no charge accumulation, which leads to

$$\frac{E_x}{B_y} = -\frac{i\omega}{\alpha} = -\frac{i\omega}{(\nu^2 + k^2)^{1/2}}. \quad (2.42)$$

Assuming that the inducing field is spatially uniform ($\nu = 0$) yields $\frac{B_z}{B_y} = 0$, implying that over a uniform conducting half space there is no vertical magnetic field and

$$\frac{E_x}{B_y} = -\frac{i\omega}{k} = \frac{-i\omega}{(-i\omega\mu_0\sigma)^{1/2}}, \quad (2.43)$$

which means that the ratio of the electric and magnetic field at the surface at any frequency is related to the conductivity of the medium. The latter is usually expressed as the apparent resistivity in the form

$$\rho_a = \frac{\mu_0 |E_x|^2}{\omega |B_y|} = \frac{\mu_0 \omega^2}{\omega \mu_0 \sigma} = \frac{1}{\sigma}. \quad (2.44)$$

This indicates that in a homogenous half-space, the apparent resistivity is equal to the true resistivity. The phase relationship ϕ between E_x and B_y is related to the ratio of the real and imaginary parts of E_x/B_y as shown by

$$\frac{E_x}{B_y} = \frac{i\omega}{(-i\omega\mu_0\sigma)^{1/2}} = (1-i)\left(\frac{\omega}{2\mu_0\sigma}\right)^{1/2} \quad (2.45)$$

and

$$\phi = \tan^{-1} \frac{Im}{Re} = \tan^{-1} 1, \quad (2.46)$$

which gives the phase difference between the electric and magnetic fields for a homogeneous half-space equal to 45° .

2.5 Solution to a 2-dimensional Earth

Figure 2.1 shows a simple 2-dimensional model with two regions divided by a vertical resistivity boundary extending to infinite depth (z) and striking in the x direction. In this case, the electric current now crosses a boundary but the electric current density must be conserved on both sides. This means that (based on Ohms Law: $\underline{J} = \sigma \underline{E}$) $\underline{E}$ changes as it crosses the boundary. Furthermore, for a conductive region that depends only on the y and z directions (Figure 2.1), Maxwells equations (assuming a time variation of $e^{-i\omega t}$ and neglecting displacement currents) can be written as $\nabla x \underline{E} = i\omega \underline{B}$ and $\nabla x \underline{B} = \mu_0 \sigma(y, z) \underline{E}$. Expressed in component form following the procedure, $\nabla x A = (\frac{\partial A_z}{\partial y} - \frac{\partial A_y}{\partial z}, \frac{\partial A_x}{\partial z} - \frac{\partial A_z}{\partial x}, \frac{\partial A_y}{\partial x} - \frac{\partial A_x}{\partial y})$ yields

$$\frac{\partial B_z}{\partial y} - \frac{\partial B_y}{\partial z} = \mu_0 \sigma \underline{E}_x \quad (2.47)$$

$$\frac{\partial E_z}{\partial y} - \frac{\partial E_y}{\partial z} = i\omega \underline{B}_x \quad (2.48)$$

$$\frac{\partial B_x}{\partial z} = \mu_0 \sigma \underline{E}_y \quad (2.49)$$

$$\frac{\partial E_z}{\partial z} = i\omega \underline{B}_y \quad (2.50)$$

2.5. SOLUTION TO A 2-DIMENSIONAL EARTH

Figure 2.1: A simple 2-D model

$$-\frac{\partial B_x}{\partial y} = \mu_0 \sigma E_z \quad (2.51)$$

$$-\frac{\partial E_x}{\partial y} = i\omega B_z. \quad (2.52)$$

It can be noticed that Equations 2.47, 2.50 and 2.51 contain only $\underline{E}_x, \underline{B}_y$ and $\underline{B}_z$ components. Eliminating $\underline{B}_y$ and $\underline{B}_z$, these equations give

$$\frac{\partial^2 \underline{E}_x}{\partial y^2} - \frac{\partial^2 \underline{E}_x}{\partial z^2} = -i\omega \mu_0 \sigma \underline{E}_x \quad (2.53)$$

which describe the electric current flowing parallel to the strike direction (x). This is known as the E-polarization or the transverse electric or TE mode of induction. On the other hand, equations 2.48, 2.49 and 2.51 include only $\underline{E}_y, \underline{E}_z$ and $\underline{B}_x$ components. Eliminating $\underline{E}_y$ and $\underline{E}_z$, these equations lead to

$$\frac{\partial^2 \underline{B}_x}{\partial y^2} - \frac{\partial^2 \underline{B}_x}{\partial z^2} - \frac{1}{\sigma} \left(\frac{\partial \sigma}{\partial x} \frac{\partial B_x}{\partial y} + \frac{\partial \sigma}{\partial z} \frac{\partial B_x}{\partial z} \right) = -i\omega \mu_0 \sigma \underline{B}_x \quad (2.54)$$

which describes the magnetic field flowing parallel to the strike direction (x). This is referred to as the B-polarization or TM mode of induction.

As was just shown, induction in a 2-dimensional Earth can be divided into two independent modes represented by two separate equations, which can be resolved using numerical techniques involving matrix calculations.

In general, the TM mode has an advantage in resolving the lateral resistivity boundary while the TE mode is more stable in estimating the variation of resistivity with depth.

2.6 Solution to a 3-dimensional Earth

For a 3-dimensional Earth, all the properties of the magnetic and electric fields in all directions are considered. These properties are linked through the concept of the impedance tensor Z , which will be discussed in detail in the next section. The solution also needs numerical programs to solve for the matrix calculations involving the impedance. In principle, this can be done the same way like the 2-D case but would consist of much larger matrices and the needed computational requirements would also increase.

2.7 MT sounding: concept of impedance and tipper

MT only needs the orthogonal components of $\underline{E}$ and $\underline{H}(B)$, which are the horizontal components along the north (x) and east (y) directions, to estimate the conductivity structure beneath and around the recording site. However, the magnetic field's vertical component ($\underline{H}_z$) is also usually measured.

2.7. MT SOUNDING: CONCEPT OF IMPEDANCE AND TIPPER

Since the conductivity within the Earth is much greater than that outside the Earth, it can be assumed that for a horizontally layered Earth, all currents and fields are horizontal. Even in situations where conductivity varies laterally, it can be assumed that only the horizontal components of $\underline{H}$ cause induction and the response are the horizontal components of $\underline{E}$.

This can be mathematically represented as the convolution of $\underline{H}$ with a response function of the earth $\underline{Z}$ to give $\underline{E}$ as a function of time, stated as

$$\underline{E}(\tau) = \int \underline{Z}(t - \tau) \underline{H}(t) dt. \quad (2.55)$$

Through Fourier Transformation this can be further described as a function of frequency and give

$$\underline{E}(\omega) = \underline{Z}(\omega) \underline{H}(\omega) \quad (2.56)$$

where $\underline{Z}$ is known as the “impedance tensor”. Written in terms of x and y components, this becomes

$$\underline{E}_x = Z_{xx} \underline{H}_x + Z_{xy} \underline{H}_y \quad (2.57)$$

$$\underline{E}_y = Z_{yx} \underline{H}_x + Z_{yy} \underline{H}_y \quad (2.58)$$

respectively. In practice, the impedance tensor Z_{ij} is complex and is usually expressed in terms of an apparent resistivity (ρ_a) where

$$\rho_a = \frac{1}{\mu_0 \omega} |Z_{ij}|^2 \quad (2.59)$$

and phase (ϕ_a) where

$$\phi_a = \tan^{-1} \frac{Z_i}{Z_r} \quad (2.60)$$

where Z_i and Z_r are the imaginary and real parts of Z_{ij} .

In a uniform conductor, equation 2.59 would also reflect the true resistivity of the conductor. In a 1-dimensional situation the electric field

components are related only to the orthogonal magnetic field components. This means that $Z_{xx} = Z_{yy} = 0$ and $Z_{xy} = -Z_{yx}$. The minus sign of the off-diagonal components indicates the phase lag.

In a 2-dimensional setting, all the components of the impedance tensor will be non-zero, and will depend on the orientation of the measurements with respect to the strike direction of the conductivity structure. However, when one of the measurement axes is aligned to the strike direction of the conductivity structure, the impedance tensor simplifies to $Z_{\parallel}$ and $Z_{\perp}$ corresponding to the TE and TM modes, respectively. In this case, $\underline{E}_x$ is now only associated with $\underline{H}_y$ and $\underline{E}_y$ to $\underline{H}_x$. Assuming that the measurement axes are oriented at an angle γ clockwise from the strike direction, the impedances from the measurement axes can be expressed in terms of the strike oriented axis as

$$Z_{xx} = \left(\frac{Z_{\parallel} + Z_{\perp}}{2}\right) \sin 2\gamma \quad (2.61)$$

$$Z_{xy} = \left(\frac{Z_{\parallel} - Z_{\perp}}{2}\right) + \left(\frac{Z_{\parallel} + Z_{\perp}}{2}\right) \cos 2\gamma \quad (2.62)$$

$$Z_{yx} = -\left(\frac{Z_{\parallel} - Z_{\perp}}{2}\right) + \left(\frac{Z_{\parallel} + Z_{\perp}}{2}\right) \cos 2\gamma \quad (2.63)$$

$$Z_{yy} = -\left(\frac{Z_{\parallel} + Z_{\perp}}{2}\right) \sin 2\gamma. \quad (2.64)$$

Evaluating these equations show $Z_{xx} = Z_{yy} = 0$, $Z_{xy} = Z_{\parallel}$ and $Z_{yx} = Z_{\perp}$. Thus, the impedance has only two non-zero components which relates to the TE and TM modes.

In practice, however, the strike direction is unknown and has to be recovered from the measured impedances. Although this was originally done by applying a mathematical rotation to the measured impedances that would result in maximum and minimum values for $Z'_{xy}(\theta)$ and $Z'_{yx}(\theta)$, which corresponds to the rotated impedances of $Z_{\parallel}$ and $Z_{\perp}$ at an angle θ (Swift, 1967), more sophisticated techniques for identifying the strike are now widely used often as part of the distortion analysis (Bahr, 1991; Groom and Bailey, 1989; Caldwell et al., 2004). It should be

2.7. MT SOUNDING: CONCEPT OF IMPEDANCE AND TIPPER

noted that the determined strike angle has a 90° ambiguity since rotating it to 90° also gives a minimum and maximum value for $Z'_{xy}(\theta + 90^\circ)$ and $Z'_{yx}(\theta + 90^\circ)$, but swapping the $Z_{\parallel}$ and $Z_{\perp}$ impedances

In 3-dimensional cases, the impedance elements will be non zero at any orientation. Nevertheless, a certain section over a frequency range may exhibit a 2-dimensional characteristic that enables the calculation of a sensible strike direction. How this is achieved is discussed further in distortion analysis section.

So far, only the horizontal components of the magnetic field (H_x, H_y) have been considered. The measured vertical component of the magnetic field (H_z), defines the geomagnetic deep sounding complex transfer functions, which reflect the relationship between the magnitude and phase of the horizontal inducing field and the vertical anomalous field for a given frequency ω . This relationship can be expressed as

$$H_z = AH_x + BH_y. \quad (2.65)$$

where A and B are the transfer functions, also known as the Tipper vectors. This relationship is usually represented by the real $|R|$ and imaginary $|I|$ components of the induction arrows whose magnitudes are defined by

$$|R| = (A_r^2 + B_r^2)^{1/2} \quad (2.66)$$

$$|I| = (A_i^2 + B_i^2)^{1/2}. \quad (2.67)$$

The *real* and *imaginary* directions of the arrows are given by

$$\theta_R = \tan^{-1}\left(\frac{B_r}{A_r}\right) + \pi \quad (2.68)$$

$$\theta_I = \tan^{-1}\left(\frac{B_i}{A_i}\right), \quad (2.69)$$

respectively. The *real* induction arrow points to regions of high conductance (Parkinson, 1962).

2.8 Distortion

Localized near-surface conductive heterogeneities can cause changes in the magnitude and direction of the electric field because of the accumulation of charges on the conductive boundaries. This results in a distorted electric field measured at a site, independent of frequency. The effect of this distortion can be described by

$$\underline{E}(\omega) = \underline{E}_R(\omega) + \underline{E}_S(\omega) \quad (2.70)$$

where $\underline{E}$ is the observed electric field, $\underline{E}_R$ is the regional electric field and $\underline{E}_S$ is the secondary or scattered electric field resulting from the interaction of the regional field and the conductive heterogeneities. However, if the inductive effects are assumed to be negligible and $\underline{E}_R$ is spatially uniform over the dimensions of the heterogeneities, $\underline{E}_S$ becomes linearly proportional to $\underline{E}_R$. The measured electric field can then be written as

$$\underline{E}(\omega) = D\underline{E}_R(\omega) \quad (2.71)$$

where D is a real, frequency-independent 2×2 distortion matrix. Similarly, assuming that there is no magnetic distortion,

$$\underline{H}(\omega) = \underline{H}_R(\omega) \quad (2.72)$$

where $\underline{H}$ is the measured magnetic field and $\underline{H}_R$ is the regional magnetic field. The regional impedance tensor $\underline{Z}_R$ as related to the regional electric and magnetic fields is given by

$$\underline{E}_R(\omega) = \underline{Z}_R \underline{H}_R(\omega). \quad (2.73)$$

Based on the previous equations, it follows that

$$\underline{E}(\omega) = D\underline{E}_R(\omega) = D\underline{Z}_R \underline{H}_R. \quad (2.74)$$

Thus

$$\underline{Z} = D\underline{Z}_R. \quad (2.75)$$

2.9. PHASE TENSOR ANALYSIS

The main aim of distortion analysis is to eliminate distortion effects and enables the recovery of the regional impedance from the measured data. One such method is the phase tensor analysis by Caldwell et al. (2004) discussed in the next section.

2.9 Phase tensor analysis

As previously stated in equation 2.75, $Z = D\underline{Z}_R$. Expressing Z into the real and imaginary parts yields

$$Z = X + iY \quad (2.76)$$

$$Z_R = X_R + iY_R \quad (2.77)$$

$$X = DX_R \quad (2.78)$$

$$Y = DY_R. \quad (2.79)$$

The phase tensor Φ is defined from the ratio of the real and imaginary parts

$$\Phi = X^{-1}Y = X_R^{-1}D^{-1}DY_R = X_R^{-1}Y_R = \Phi_R. \quad (2.80)$$

This shows that the observed and regional phase tensors are equal and are thus not affected by the distortion tensor. The phase tensor can be expressed as a matrix in terms of its real and imaginary components:

$$\begin{bmatrix} \Phi_{11} & \Phi_{12} \\ \Phi_{21} & \Phi_{22} \end{bmatrix} = \frac{1}{\det(X)} \begin{bmatrix} X_{22}Y_{11} - X_{12}Y_{21} & X_{22}Y_{12} - X_{12}Y_{22} \\ X_{11}Y_{21} - X_{21}Y_{11} & X_{11}Y_{22} - X_{21}Y_{12} \end{bmatrix} \quad (2.81)$$

where $\det(X) = X_{11}Y_{22} - X_{21}Y_{12}$. Three coordinate invariants are used to define the phase tensor: a maximum tensor value (Φ_{max}), a minimum tensor value (Φ_{min}) and the skew angle (β). Mathematically,

$$\Phi_{max} = \frac{1}{2}[(\Phi_{11} + \Phi_{22})^2 + (\Phi_{12} - \Phi_{21})^2]^{1/2} + \frac{1}{2}[(\Phi_{11} - \Phi_{22})^2 + (\Phi_{12} + \Phi_{21})^2]^{1/2} \quad (2.82)$$

$$\Phi_{min} = \frac{1}{2}[(\Phi_{11} + \Phi_{22})^2 + (\Phi_{12} - \Phi_{21})^2]^{1/2} - \frac{1}{2}[(\Phi_{11} - \Phi_{22})^2 + (\Phi_{12} + \Phi_{21})^2]^{1/2} \quad (2.83)$$

$$\beta = \frac{1}{2} \tan^{-1} \left(\frac{\Phi_{12} - \Phi_{21}}{\Phi_{11} - \Phi_{22}} \right). \quad (2.84)$$

Another element of the phase tensor that denotes the dependence of the phase tensor to the coordinate system is

$$\alpha = \frac{1}{2} \tan^{-1} \left(\frac{\Phi_{12} + \Phi_{21}}{\Phi_{11} + \Phi_{22}} \right). \quad (2.85)$$

The predominant strike direction is determined by $\alpha - \beta$.

Using these parameters, the phase tensor can be expressed as

$$\Phi = R^T(\alpha - \beta) \begin{bmatrix} \Phi_{max} & 0 \\ 0 & \Phi_{min} \end{bmatrix} R(\alpha + \beta) \quad (2.86)$$

where $R(\theta) = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix}$ and $R^T(\theta) = R^{-1}(\theta) = R(-\theta)$.

The phase tensor can be represented graphically by an ellipse as shown in Figure 2.2. The phase tensor ellipticity is given by

$$\lambda = \frac{\Phi_{max} - \Phi_{min}}{\Phi_{max} + \Phi_{min}}. \quad (2.87)$$

In 1-D case, the ellipse will reduce to a circle at all periods since $\Phi_{min} = \Phi_{max}$. Furthermore, $\beta = \alpha = 0$ and $\lambda = 0$.

On the other hand, for the 2-D case, when the coordinate axes are rotated parallel or perpendicular to the strike direction, Φ_{min} and Φ_{max} are equal to the axes' lengths and one of these is aligned to the strike, so $\lambda \neq 0$. Also, $\beta = 0$ while $\alpha \neq 0$, making $\alpha - \beta$ constant.

Lastly, for the 3-D case, all of the components of the phase tensor are non-zero ($\beta \neq 0$, $\lambda \neq 0$). β can then be used as a measure of departure from the 2-D case, the bigger the value of β , the greater the departure from the 2-D case (i.e. when $|\beta| > \beta_C$, where β_C is some threshold value that indicates 3-dimensionality). Instances with small values of β can be approximated similar to 2-D cases without significant errors (Bibby et al., 2005).

Figure 2.2: The phase tensor ellipse (Caldwell et al., 2004)

2.10 Static shift

One of the types of galvanic distortion is the so-called static shift, which creates a shift in the apparent resistivity curves (i.e. TE, TM) relative to each other. This is mainly caused by the build up of electrical charges along a discontinuity separating a conductor from a resistor. This can be illustrated mathematically by treating the distortion tensor as a matrix of four real numbers

$$D = \begin{pmatrix} d_{11} & d_{12} \\ d_{21} & d_{22} \end{pmatrix} \quad (2.88)$$

making the impedances as

$$\begin{pmatrix} Z_1 & Z_2 \\ Z_3 & Z_4 \end{pmatrix} = \begin{pmatrix} d_{11} & d_{12} \\ d_{21} & d_{22} \end{pmatrix} \begin{pmatrix} Z_{xx} & Z_{xy} \\ Z_{yx} & Z_{yy} \end{pmatrix}. \quad (2.89)$$

From which

$$Z_1 = d_{11}Z_{xx} + d_{12}Z_{yx} \quad (2.90)$$

CHAPTER 2. THE BASICS OF MAGNETOTELLURIC (MT) METHOD

$$Z_2 = d_{11}Z_{xy} + d_{12}Z_{yy} \quad (2.91)$$

$$Z_3 = d_{21}Z_{xx} + d_{22}Z_{yx} \quad (2.92)$$

$$Z_4 = d_{21}Z_{xy} + d_{22}Z_{yy}. \quad (2.93)$$

If the regional structure is 1-dimensional ($Z_{xx} = Z_{yy} = 0$ and $Z_{xy} = -Z_{yx}$), equations 2.90 to 2.93 simplifies to

$$Z_1 = -d_{12}Z_{xy} \quad (2.94)$$

$$Z_2 = d_{11}Z_{xy} \quad (2.95)$$

$$Z_3 = -d_{22}Z_{xy} \quad (2.96)$$

$$Z_4 = d_{21}Z_{xy}. \quad (2.97)$$

The apparent resistivity can then be expressed as multiples of apparent resistivities calculated from Z_{xy} , such that

$$\rho_{a2} = \frac{1}{\mu_0\omega} |Z_2|^2 = \frac{1}{\mu_0\omega} d_{11}^2 |Z_{xy}|^2 = d_{11}\rho_{axy}. \quad (2.98)$$

This leads to

$$\log \rho_{a2} = \log d_{11}^2 + \log \rho_{axy} = 2\log d_{11} + \log \rho_{axy}. \quad (2.99)$$

Which when shown on a log-log plot of the apparent resistivity against period, the shift is independent of frequency and the entire resistivity curve is shifted by a constant value equivalent to $2\log d_{11}$. This shift can either be going up or going down depending on d_{11} either being > 1 or < 1 , respectively.

Furthermore, as d_{11} is real, $Z_2 = d_{11}Z_{xy}$, the phase is

$$\phi_2 = \tan^{-1} \frac{\text{Im}(Z_2)}{\text{Re}(Z_2)} = \tan^{-1} \frac{\text{Im}(d_{11}Z_{xy})}{\text{Re}(d_{11}Z_{xy})} = \tan^{-1} \frac{\text{Im}(Z_{xy})}{\text{Re}(Z_{xy})} = \phi_{xy}. \quad (2.100)$$

This demonstrates that static shift does not affect the phase.

In a 2-dimensional case, the impedance elements are computed based on the angle of rotation from the strike direction (θ). However, when the

data are rotated parallel or perpendicular to the strike direction the rotated impedance elements (Z') simplify to

$$Z'_1(\theta) = D_{12}Z'_{yx}(\theta) = D_{12}Z_{\perp} \quad (2.101)$$

$$Z'_2(\theta) = D_{11}Z'_{xy}(\theta) = D_{11}Z_{\parallel} \quad (2.102)$$

$$Z'_3(\theta) = D_{22}Z'_{yx}(\theta) = D_{22}Z_{\perp} \quad (2.103)$$

$$Z'_4(\theta) = D_{21}Z'_{xy}(\theta) = D_{21}Z_{\parallel}. \quad (2.104)$$

Similarly by computing the apparent resistivity as simple multiples of the principal impedances shows that the apparent resistivity ρ_a is shifted while the phase θ is not affected.

Static shifts can be corrected using transient electromagnetic (TEM) data since the magnetic field is relatively unaffected by surface inhomogeneities (Sternberg et al., 1988).

2.11 Modeling

Modeling schemes can be classified into two types: forward and inverse. A forward modeling scheme is basically computing for the response (apparent resistivity and phase at the surface) of a given model with known dimensions and properties (i.e. conductivity, thickness). In contrast, an inversion modeling scheme involves the calculation of a model from a given data set until a reasonable fit of the computed response with the measured data is achieved. The main aim of the inversion scheme is to create a real distribution of conductivity (σ) in space (x, y, z) from a series of apparent resistivity and phase data based on the impedance tensors. Most of these schemes are based on finding the smoothest model that fits the data but lies within an accepted threshold value. It should be noted however that a certain data set can produce several models that can equally fit it. Extra care should be given to verify if the resulting model is realistic and sensible. One way to do this is

usually done by comparing the results of the different models produced by 1-D, 2-D and 3-D schemes and check for consistency in the models. The forward model is generally used as the initial model before inversion modeling is performed.

This section gives an overview of the modeling schemes, from 1-D to 3-D, which were used and considered during processing of the data.

2.11.1 1-dimensional modeling

The commonly used 1D inversion schemes are the (Bostick, 1977), the 1-D simple layered model and the Occam Inversion (Constable et al., 1987). An overview of these schemes is presented here.

2.11.2 Bostick inversion

This is one of the simpler inversion schemes which provide a reasonable first approximation to the true conductivity-depth distribution beneath the recording station (Jones, 1983). This is given in terms of $\rho(h)$, where h is the penetration depth in a half-space medium of resistivity which is equal to the apparent resistivity at a particular period. h is related to the apparent resistivity at period T by

$$h = \sqrt{\frac{\rho_a(T)T}{2\pi\mu_0}} \quad (2.105)$$

and the corresponding resistivity at this depth is given by

$$\rho = \rho_a(T) \frac{1 + m(T)}{1 - m(T)} \quad (2.106)$$

where m is the gradient of the $\log \rho_a$ - $\log T$ curve at period T .

One of the strengths of this inversion scheme is its effective determination of the depth to a conductor.

Figure 2.3: Simple 1-D layered model

2.11.3 Simple layered model

In the section 2.4, it was shown how the resistivity of a homogeneous half-space can be calculated from the horizontal components of the $\underline{E}$ and $\underline{B}$ fields. This can be extended to a layered half-space where the conductivity only varies with depth along the z -axis (Figure 2.3).

As previously stated, the magnetic field above the surface can be represented by a scalar potential $\underline{B} = -\nabla U$ with $U_{y,z} = -\frac{1}{\nu}e^{i\nu y}(B_e e^{-\nu z} + B_i e^{+\nu z})e^{i\omega t}$. Within each layer, the vector potential A_j is used giving the magnetic field along the y -direction $\underline{B}_j = \nabla x \underline{A}_j$.

From equation 2.21, it can defined that

$$\underline{A}_{xj} = F(y)(C e^{-\alpha z} + D e^{+\alpha z})e^{-i\omega t} \quad (2.107)$$

where $\alpha_j^2 = \nu^2 + k_j^2$, with ν again being the spatial wave number of the source field. At the boundary between the j and $(j + 1)$ layers (at z_j) both B_z and B_y must be continuous giving

$$-\alpha_j C_j e^{-\alpha_j Z_j} + \alpha_j D_j e^{+\alpha_j Z_j} = -\alpha_{j+1} C_{j+1} e^{-\alpha_{j+1} Z_j} + \alpha_{j+1} D_{j+1} e^{+\alpha_{j+1} Z_j} \quad (2.108)$$

and

$$C_j e^{-\alpha_j Z_j} + D_j e^{\alpha_j Z_j} = C_{j+1} e^{-\alpha_{j+1} Z_j} + D_{j+1} e^{\alpha_{j+1} Z_j}. \quad (2.109)$$

Introducing $R_j = \frac{C_j}{D_j}$ and combining these equations yields

$$R_j = e^{2\alpha_j Z_j} \frac{R_{j+1}(\alpha_j + \alpha_{j+1}) + (\alpha_j + \alpha_{j+1})e^{2\alpha_{j+1} Z_j}}{R_{j+1}(\alpha_j - \alpha_{j+1}) + (\alpha_j + \alpha_{j+1})e^{2\alpha_{j+1} Z_j}}. \quad (2.110)$$

At the lowermost layer (n) the field has to go to zero as $z \rightarrow \infty$, which means that $D_n = 0$. Therefore at the lowermost boundary $z = z_{n-1}$ and

$$R_{n-1} = e^{2\alpha_{n-1} Z_{n-1}} \frac{\alpha_{n-1} + \alpha_n}{\alpha_{n-1} - \alpha_n}. \quad (2.111)$$

Given that at the surface, $\nabla x \underline{A} = \nabla \underline{U}$, values for both B_i/B_e and E_x/B_y can be calculated using

$$\frac{E_x}{B_y} = \frac{-i\omega}{\alpha_1} \frac{R_1 + 1}{R_1 - 1}. \quad (2.112)$$

These set of equations 2.110 to 2.112 form a recursive scheme, which enables the computation of E_x/B_y at the surface if all the z_j and σ_j of all layers are given. Starting from the bottommost layer, equation 2.112 allows R_{n-1} to be computed from Z_{n-1} , σ_{n-1} and σ_n . Equation 2.110 can then be used repeatedly moving up through all the layers until values of R_1 is obtained, which can then be used to get the surface ratio of E_x/B_y from which the apparent resistivities and phase can be calculated.

2.11.4 Occam inversion

The Occam inversion finds the smoothest possible model that fits the data within the expected tolerance level, rather than fitting the data as much as possible which then increases the roughness of the model. This method allows the model to be as flexible as possible and yet suppress complexity explicitly. This is done by introducing two main parameters:

2.11. MODELING

the roughness parameter which is defined as the integrated square of the first or second derivative with respect to depth:

$$R_1 = \int (dm/dz)^2 dz \quad (2.113)$$

$$R_2 = \int (d^2m/dz^2)^2 dz \quad (2.114)$$

where $m(z)$ refers to resistivity or log resistivity, and the weighted least-squares parameter, which is an estimation of the misfit:

$$X^2 = \sum_{j=1}^M (d_j - F_j|m|)^2 / \sigma_j^2 \quad (2.115)$$

where σ_j is the uncertainty in the j th datum. Rewriting both parameters in terms of simple matrix operations and applying the Lagrange multiplier μ^{-1} gives

$$U = \|\tilde{\partial}m_{k+1}\|^2 + \mu^{-1} \{ \|\tilde{W}(d - F[m_1] + \tilde{J}_1 m_1) - \tilde{W}\tilde{J}_1 m_{k+1}\|^2 - X_*^2 \} \quad (2.116)$$

where the first term on the right is the roughness and the second term is the misfit weighted by the Lagrange multiplier with m_1 as the initial model, m_{k+1} is the successive model after the k th iteration that minimizes U , $\tilde{W}$ is the diagonal $M \times M$ matrix, and X_*^2 as the desired misfit value of X^2 . Using this scheme, the final model is independent of the initial model and has the least 'roughness' while at the same time matches a specified 'misfit'. The vector m_{k+1} and its misfit value X_*^2 were defined further as

$$m_{k+1}(\mu) = [\mu\tilde{\partial}^T + (\tilde{W}\tilde{J}_k)^T \tilde{W}\tilde{J}_k]^{-1} (\tilde{W}\tilde{J}_k)^T \tilde{W}\hat{d}_k \quad (2.117)$$

$$X_{k+1}(\mu) = \|\tilde{W}\hat{d}_k - \tilde{W}F[m_{k+1}(\mu)]\|. \quad (2.118)$$

These 1-D modeling schemes enable the computations of the resistivity and phases from a given data set. However, MT data is rarely truly 1-D in a sense that it usually has two sets of curves having different features. Instead of choosing which particular curve to model, it is

Figure 2.4: 2-D modeling (*Brewitt-Taylor and Weaver, 1976*)

customary to use ρ_a and ϕ_a derived from impedances that are invariant with respect to the coordinated axes regardless of the dimensionality of the data. The commonly used invariant impedances are the average (Z_{av}) and the determinant (Z_{det}) which are described as:

$$Z_{av} = \frac{1}{2}(Z_{xy} - Z_{yx}) \quad (2.119)$$

and

$$Z_{det} = \sqrt{(Z_{xx}Z_{yy} - Z_{xy}Z_{yx})}. \quad (2.120)$$

2.11.5 2-dimensional modeling schemes

An inclusive review of several 2-dimensional modeling techniques was made by Ogawa (2002). The classic 2-D modeling scheme by the finite difference method of Brewitt-Taylor and Weaver (1976) is discussed briefly here.

The structure is defined by a mesh with rectangular elements of varying dimensions and conductivity values (Figure 2.4). Two solutions can be derived, either for the TE or E-polarization mode or for the TM or

B-polarization mode. The scheme consists of formulating equations to compute for $\underline{E}$ at all sides of the structure (i.e. left, right, top and bottom) taking into account that these should conform to the boundary conditions and diffusion equation. These series of equations can then be expressed as a matrix that allows the computation of $\underline{E}$ (for TE mode solution) at any point when $\underline{E}$ along the nodes have been estimated. Once the value for $\underline{E}$ is found the corresponding $\underline{B}$ can then be calculated using finite difference approximations of the Maxwells equation.

If the TM mode is used, a similar finite difference scheme is applied for $\underline{B}$ along the y axis then $\underline{E}$ can then be derived from Maxwells equations.

2.11.6 3-dimensional modeling

Several 3-D inversion algorithms have been developed over the years (i.e. Madden and Mackie (1989); Siripunvaraporn et al. (2005); Sasaki (2001)). A comprehensive review of these methods was made by Siripunvaraporn (2011).

The 3-D code that was used for this project is the WSINV3DMT (Siripunvaraporn et al., 2005). The algorithm is based on the Occam's method (Constable et al., 1987; deGroot Hedlin and Constable, 1990) but considers a data-space scheme (Siripunvaraporn et al., 2005), wherein computation is conducted in a N dimensional *data* space. This is in contrast with the usual model-space format wherein the computation is conducted in the M dimensional *model* parameter space. One of the main advantages of using the data-space scheme is that the computational time and hardware requirement is greatly reduced since the number of independent data N is generally less than M (Siripunvaraporn et al., 2005). This makes the software applicable to invert a modest 3-D dataset on a PC.

2.12 Instrumentation and data acquisition

A typical layout for an MT sounding is shown in Figure 2.5. The MT equipment consists of:

1. a receiver,
2. magnetic sensors, which are usually induction coils,
3. electric wires,
4. potential electrodes, which are made up of a porous ceramic base and non-polarising materials such as $Pb/PbCl_2$ or $Cu/CuSO_4$.

The wires, which are about 60 to 100 m in length depending on the flatness of the site, are arranged orthogonal to each other, oriented north-south and east-west, relative to the magnetic north. These “E-lines” with the potential electrodes attached at the end, measure the voltage drop along the telluric dipole line. These electrodes are buried for better contact with the ground. On the hand, three sets of magnetic coils, oriented north-south, east-west, and vertically, measure the $\underline{H}_x$, $\underline{H}_y$, and $\underline{H}_z$, respectively. These coils are extremely sensitive to any movement that may be caused by wind, walking, vehicles, that they are buried also under the ground.

The wires and the magnetic sensors are connected to the receiver which is usually placed at the center of the layout. The receiver filters and records the data as time series files. Duration time for data recording is usually a minimum of 10 hours. Usually, by extending the recording time, which means more data are stacked up, improves the data quality.

An ideal site should be located in a relatively flat area about 100 m x 100 m, and away from possible “noise” sources such as power lines, electrical fences, power plants, etc.

2.12. INSTRUMENTATION AND DATA ACQUISITION

Figure 2.5: Typical MT station layout

2.13 Data processing

A rundown of the general steps during MT data processing is shown in Figure 2.6. The “raw” time series data are converted to Discrete Fourier Transforms (DFT) to become functions of frequency using the software TStoFT (Phoenix Geophysics Ltd., 2005). The DFT’s are then converted to “crosspowers” through “Robust” routines which filter out noise and outliers in the data. These softwares are included in the SSMT2000 data processing software (Phoenix Geophysics Ltd., 2005). The crosspower data which contain the impedances are then edited and converted to “EDI” files (Soc. of Expl. Geophysics., 1991) using the “MT editor” software (Phoenix Geophysics Ltd., 2005). The MT data are then analyzed using the phase tensors and “stripped” of distortions. The “stripped” EDI files are the ones used for modeling. The WinGLink software (Geosystem SRL, 2008) was used for 1-D and 2-D modeling, also for further editing of the data, which consist of masking of unwanted data points, curve smoothing (D+), static shift correction, TE and TM mode determination, and rotation of the impedances.

2.13. DATA PROCESSING

Figure 2.6: MT data processing flowchart

Chapter 3

Northern Negros Geothermal Project

The Northern Negros Geothermal Project (NNGP) is located on the northern portion of the Philippine central island of Negros (Figure 3.1). It lies on the northwestern flank of the active Mt. Canlaon volcano, which is part of the northeasterly aligned cluster of volcanoes that include Mts. Mandalagan and Silay in the north. These volcanoes are associated with the subduction of the Sulu Sea Basin along the Negros Trench reaching depths of about 150 km (Acharya and Aggarwal, 1980).

Geoscientific studies in the area started in the 1970's when the then Commission on Volcano conducted a reconnaissance survey in Mambucal (Figure 3.2) and found thermal springs in the area (Comm. on Volcanology, 1981). Subsequent studies made by the National Power Corporation and Philippine National Oil Company-Energy Development Corporation (PNOC-EDC) led to the drilling of two exploratory wells MC-1 and MC-2 in 1978-79, which confirmed the existence of near-neutral fluids of almost 200°C (Reyes, 1979).

A new round of surveys during the 1980's to early 1990's which include the southern areas of Pataan and Hagdan, led to the drilling of deep exploration wells CT-1D, HG-1D, PT-1D and PT-2D in 1994-

Figure 3.1: Location map of the Northern Negros Geothermal Project (NNGP)

CHAPTER 3. NORTHERN NEGROS GEOTHERMAL PROJECT

Figure 3.2: Location map of wells and thermal areas in NNGP

3.1. GEOLOGY

95. High temperatures $>230^{\circ}\text{C}$ were encountered at HG-1D and PT-2D but output wellhead pressures were non-commercial. Since then, more studies like magnetotelluric (MT) and Bouguer gravity surveys have been conducted in the area. Nine additional wells (PT3D to PT-11D) have also been drilled prior to the commissioning of the 50 MWe power plant in 1997. The latest of these is well MY-1D drilled towards the southeastern portion of Pataan in 2009 (Figure 3.2).

This chapter presents a summary of the main results of the previous studies conducted in NNGP.

3.1 Geology

The geologic map within the vicinity of Canlaon volcano is shown in Figure 3.3. Five major stratigraphic units have been identified (Pamatian et al., 1992). The oldest rock is the Cretaceous-Paleocene Basak Formation (Bf) which is made up of very thick interbedded sequences of two-pyroxene basalt lavas and clastic sedimentary rocks composed of mudstones, claystones and granule conglomerates. This is overlain by the Budlasan Volcanics (Blv) which is primarily made up of thick lava flows exposed on the southeast of Mt. Canlaon. This in turn is overlain by the Miocene Talave Formation (Tf) which is composed of interbedded sequence of recrystallized fossiliferous coralline limestone, sandstone, siltstone, claystone, conglomerate and volcanoclastic breccias (Pamatian et al., 1992). On top of this is a sequence of fossiliferous calcisiltites, calcarenites and calcirudites deposited during the Pliocene and collectively termed as the Caliling Formation (Cf). These are exposed with Karstic features in the eastern coast (Pamatian et al., 1992). The youngest unit is the Canlaon Volcanics (CnV) which is composed of Quaternary volcanic deposits erupted from Mt. Canlaon and its different vents during different episodes of eruptions. This unit includes pyroxene andesite lava flows, tuff breccias, and occasional dacites and basaltic flows. Only the

younger two of these units, namely the Tf and CnV were intersected by the drilled wells in NNGP. Furthermore the Tf appears to occur deeper towards the SE and was not encountered by well MY-1D.

The dominant fault structures mapped in NNGP are the northwest/north-northwest trending ones with minor east-west, north-east and north-south/ north-northeast strike (Figure 3.4). Panem and Leynes (1996) inferred that the northwest and north-northwest trending structures transect the east-west and north-south faults. The east-west faults are found mainly in the southern portion traversing along ridges and stream channels.

The location of the thermal springs in NNGP is shown in Figure 3.2. These are found mainly in and northwest of Mambucal. Two are sited in Hagdan while only one, the Kinabkaban warm spring can be found within Pataan. A warm spring and gas seepage have also been reported at Saray. The most impressive of these is the hot spring in Hagdan reaching temperatures of $>50^{\circ}\text{C}$. All except the Maragandang acid sulphate hot spring have neutral chloride fluids.

3.2 Gravity survey

A Bouguer gravity survey undertaken in 1995-96 detected a prominent gravity high (>12 mgals) enclosing the area of Mt. Canlaon and its northwestern flank towards Hagdan and Pataan (Figure 3.5). A similar gravity high is also exposed within the vicinity of Saray. These were interpreted to be intrusive bodies associated with the Canlaon Volcanic Complex (Rigor and Los Banos, 1997). The decreasing gravity values surrounding the gravity high are attributed to the thickening of pyroclastic materials and sedimentary deposits such as the Basak Formation in the east.

3.2. GRAVITY SURVEY

Figure 3.3: Simplified geologic map of NNGP (enclosed in red box)

3.2. GRAVITY SURVEY

Figure 3.5: Residual Bouguer anomaly map (from Rigor and Los Banos, 1997; NNGP is enclosed by the red box)

3.3 1995 and 2000 MT surveys

Previous MT data at NNGP were collected during two survey seasons. The initial one was in 1995 wherein 30 stations were measured by WestJec-Phoenix Geophysics, Ltd. and PNOC-EDC personnel using the Phoenix V-5 MT-16 equipment. Five channels were recorded which included the vertical magnetic field component H_z . The raw time series data were reprocessed using the remote-reference technique (Gamble et al., 1979). The next MT survey was conducted by EDC staff in 2000 where an additional 63 soundings were measured still using the Phoenix V-5 MT system. However, H_z in some of the stations was not measured.

The MT data was rotated to N53°W and no static shift corrections were applied during processing (Maneja et al., 2001). 1-D layered modeling was then applied using an invariant impedance. The results of the survey shows a northwest-southeast trending conductive zone of <10 ohm-m from Sumaguan to Mambucal (Figure 3.6). This conductive zone was correlated with the clay alteration minerals as shown by a simple layered 1-D model running parallel to the conductive zone (Figure 3.7). It was postulated that the more conductive bottom layers beneath Pataan and Sumaguan sectors were caused by hydrothermal fluids flowing towards Mambucal sector.

A 2-D MT model wherein the data was rotated to the principal axis and both the TE and TM modes, as well as static shifts were included in the inversion is shown in Figure 3.8. The 2-D model shows that the increasing resistivity layers with depth correlates well with the transition of alteration minerals with temperature (smectite-illite-epidote-actinolite/biotite) as encountered in the drilled wells including MY-1D (Technical Services Sector, 2010)

3.3. 1995 AND 2000 MT SURVEYS

Figure 3.6: Apparent iso-resistivity map at 0.33s (from Maneja et al., 2001)

Figure 3.7: 1-D layered model along profile S-01 (from Maneja et al., 2001)

Figure 3.8: 2-D resistivity model (after Technical Services Sector, 2010)

3.4 Hydrothermal system

The hottest portion of NNGP is located near PT-5D and PT-7D, in Pataan sector, where 290°C fluids have been encountered (Dulce, 2001, 2003). The reservoir is hosted by the Talave Formation (Tf) and capped by the thick sequence of the Canlaon Volcanics (CnV). Permeability is primarily fault-controlled. Two of the more permeable of the faults are the Mambucal-A and Kinabkaban-A Faults (PNOC-EDC, 1998). Minor permeability was also attributed to inter-formation contacts. The main out-flow direction is assumed to be towards Mambucal sector in the north-west. On the other hand, the heat source of the system is related to young intrusives associated with the Hardin Sang Balo crater found on the southeast. This is supported by the increasing temperature trend of the alteration minerals towards this direction.

The mineral assemblage intersected by well MY-1D such as secondary

3.4. HYDROTHERMAL SYSTEM

Figure 3.9: Delineated resource area at NNCP (from Maneja et al., 2001)

biotite, actinolite and secondary pyroxene indicate temperatures $>300^{\circ}\text{C}$. This suggests that the area drilled by MY-1D was once hotter than Pataan sector before incursion of peripheral waters cooled it down.

The resource area as delineated by the MT survey and drilled wells is bounded by PT-3D and Asia Splay Fault, Asia Splay Extension Fault to the west, PT-6D in the northwest, well CT-1D on the northeast and MY-1D and Sumaguan-B Extension Fault to the east. The boundary to the south is obscured since no well has yet been drilled and the MT data are scarce in this sector but the contemplated boundary is the Maao East Fault (Figure 3.9).

Chapter 4

2011 MT survey

A recent MT survey was conducted at NNGP from December 2010 to April 2011. Its main objective was to produce a geophysical model using more advanced techniques such as the phase tensor analysis and 3-D modeling to define the resistivity structure with a higher resolution in terms of depth and size. This will also refine the resource boundary in the area particularly in the southern portion where previous data were scarce or noisy. A total of 66 new soundings were measured making the total MT stations occupied at NNGP to 158. The later model MTU-5A system by Phoenix Geophysics, Ltd., was used during the survey. This has a higher data (more than double) frequency sampling rate than the previous V-5 MT-16 units. All five channels were recorded over frequencies ranging from 320-0.0014 Hz . Improving data quality in the latest survey was a challenge since aside from the noise brought about by the bad weather conditions (i.e. strong rain and wind), a lot of cultural noise sources such as a cell-site tower, power plant, drilled wells and electric lines that did not exist during the earlier surveys are now present. One of the steps taken to improve the data quality recording period was to extend the recording time for each MT station between 40-60 hours.

Processing of the MT data was done using the SSMT2000 software (Phoenix Geophysics Ltd., 2005). This included the transformation of

4.1. DATA QUALITY AND DESCRIPTION

the time series files to DFT's, which in turn is translated to cross-power functions through the "Robust" processing scheme. A remote reference site in the town of Hinigaran, about 50 kilometers away from the study area was used during the "Robust" processing. The cross-power data were eventually edited using the "MT editor" software by Phoenix Geophysics, Ltd.

A Transient Electromagnetic (TEM) survey was also conducted at some of the new MT station locations. The distribution of the MT and TEM stations is shown in Figure 4.1.

4.1 Data quality and description

Out of the total 158 stations from the three MT survey seasons, only 138 were used during processing. The rest were too noisy and or had data that were too scattered to give reliable results. Examples of these are data from stations 123 and 124 (Figure 4.2), which were sited near to a cell-site tower near PT-A pad (4.1). All the apparent resistivity and phase curves that were used are shown in Appendix I while a detailed description of each data curve is presented in Appendix II. In general, noisy data are common in the dead band range (about 2 s to 20 s). Most data show static shifts ranging from slight shifts (i.e. 07, 11, 66, 81) to very large ones (i.e. 8, 25, 120, 142). Typical apparent resistivity curves in NNGP show moderately resistive values (>20 ohm-m) at short periods then decrease to <20 ohm-m starting at the mid period range from 0.1 to about 10 s then rise up again to >20 ohm-m on the longer periods (Appendix I). Data from stations in Mambucal sector (i.e. 3, 61, 76, 77) show a conductor with <10 ohm-m as the apparent resistivity curve drops well below the 10 ohm-m line. Similar observations can be said of the stations north (i.e. 51, 85, 86), west (i.e. 25, 37) and south (42, 43, 137) of Pataan sector. However, stations towards Saray in the east (83, 84) as well as stations in the southeast (96, 106, 109) of Pataan, indi-

Figure 4.1: MT and TEM stations location map

4.2. PHASE TENSOR ANALYSIS

Table 4.1: Summary of data types based on quality

Total number of MT stations	Type 1	Type 2	Type 3
138	73	33	32
%	53	24	23

cated a conductor with a slightly higher resistivity since values barely go down to 10 ohm-m. MT data in the vicinity of Hagdan sector also shows a conductor with <10 ohm-m values (67,143, 145) but towards the south, stations indicate a slight increase in the resistivity value (147, 149, 157). The quality of the data is ranked into three types (Appendix II), which are coded as:

1. Type 1: reliable data only up to about 2 s
2. Type 2: good data up to about 100 s but with patches of scattered and noisy data
3. Type 3: smooth data curves extending to >100 s

Based on the concept of skin depth, given the resistivity value of the conductor, which is ~ 10 ohm-m, Type 1 data can only penetrate up to depths of about 1-2 kms, while Types 2 and 3 data can penetrate depths >5 kms. Table 4.1 gives a summary of the data type according to quality rank. This shows that 53% of the data are of the Type 1, while only about 23% can be considered as Type 3.

4.2 Phase tensor analysis

The phase tensor analysis scheme by Caldwell et al. (2004) was used to determine the dimensionality of the data and its associated properties. Analysis of the data indicate 1-D characteristics at periods <1 s while 2-D and 3-D effects are notable in the longer period range. Among the

(a) MT station 123

(b) MT station 124

Figure 4.2: Samples of extremely noisy MT data

4.2. PHASE TENSOR ANALYSIS

data curves that show this observation are stations # 3, 10, 23, 67, 84, 96, 106, 108, 111, 134, 137, 145, 154 (Appendix I). The dominant and consistent semi-major axis angle ($\alpha - \beta$) at periods where 2-D and 3-D character are observed, usually at periods of >1 s, was chosen for each station to determine the prominent strike direction in the area. Plotting these angle orientations show that majority of the MT stations within Mambucal (29, 60, 85, 62, 63), Pataan (94, 99, 04, 86, 99, 107, 43, 104, 106, 107) and Saray (63, 81, 18, 104, 106) sectors show a dominant strike orientation in a northwest-southeast or almost east-west direction (Figure 4.3). The other stations have either northeast-southwest (83, 84, 12, 138, 100) or almost north-south (98, 88, 97, 15) orientation. On the other hand, the stations in Hagdan and Upper Hagdan sectors in the south, show mixed strike angle directions which include northeast-southwest (149, 147, 111, 141, 67, 27), north-south (48, 32) and northwest-southeast directions (142, 120, 143, 49).

A summary of the frequency of the semi-major angles ($\alpha - \beta$) is shown through a rose diagram in Figure 4.4. This indicates that the dominant strike in the MT stations as determined by the phase tensor analysis is a slightly northwest-southeast/almost east-west direction. However, it should be noted that there is a 90° ambiguity as mentioned in Section 2.7, so another possible principal strike direction is the slightly north-east-southwest/almost north-south. Secondary strike directions indicated by the phase tensors are the northwest-southeast and southwest-northeast. This variation in strike directions is reflective of the numerous faults that cut across the project area (Figure 3.4)

The phase tensor was also used to remove the galvanic effects in all the MT site data. This was done using the “strip and rewrite” matlab script by Dr. H. Bibby, wherein a 1-D section of the of the MT data was identified to estimate the real and frequency independent galvanic distortion and used to remove the distortion from all the periods in the data set (Bibby et al., 2005). Strictly speaking, a 1-D characteristic should

Figure 4.3: Strike directions of MT stations based on phase tensor (red lines are oriented according to the strike direction)

4.2. PHASE TENSOR ANALYSIS

Figure 4.4: Dominant strike directions of the MT data based on the phase tensor

have $\phi_{min} = \phi_{max}$, $\beta = 0$ and α cannot be determined (Section 2.9). However, for this study, the parameters considered for determining the 1-D segment include: λ or $(max - min)/(max + min)$ should be < 0.2 , β should be $\leq \pm 5$ and there should no $\alpha - \beta$ value. The “1-D” section selected for each station is shown as the area enclosed by the loop in the plots in Appendix I. The “stripped” data curves were then used during modeling.

The phase tensor ellipses for each Type 3 station were plotted at different periods (Figure 4.5). At short periods (0.007 s, 0.01 s), most stations have an almost circular ellipse indicating 1-D characteristic (Figures 4.5(a) and 4.5(b)). But at longer periods (> 0.056 s), the ellipses show elongation in a certain direction, either in a northwest-southeast (0.222 s, 2.667 s) or southwest-northeast directions (1.778 s, 3.555 s) or both (7.112 s) (Figures 4.5(d) to 4.5(h)). The complexity of the resistivity structure is apparent from these plots and that 3-D effects, as indicated by the

higher degree of ellipticity of the phase tensors, are more pronounced at longer periods which corresponds to deeper levels.

4.2. PHASE TENSOR ANALYSIS

(a) Phase tensor ellipse at 0.007 s (b) Phase tensor ellipse at 0.01 s

(c) Phase tensor ellipse at 0.056 s (d) Phase tensor ellipse at 0.222 s

(e) Phase tensor ellipse at 1.778 s (f) Phase tensor ellipse at 2.667 s

(g) Phase tensor ellipse at 3.555 s (h) Phase tensor ellipse at 7.112 s

Figure 4.5: Phase tensor ellipse at different periods

4.3 Induction arrows

To have a general idea where the possible conductors are located, the induction arrows from the latest MT survey were plotted.

At frequency >300 Hz, the real component of the induction arrows generally point towards the west-northwest indicating a major conductive body towards that direction (Figure 4.6). This behavior persists until 10 Hz (Figure 4.7). At 1 Hz, the real induction arrows (shown as red) of the stations on the southwestern section point towards the east while those on the eastern and southeast portion of Pataan point towards the northeast and southeast (Figure 4.8). At deeper levels (0.1 Hz), the real induction arrows now point towards the southeast (Figure 4.9). At 0.01 Hz, the real component of the induction arrows points towards the north and northeast (Figure 4.10). At frequencies <0.001 Hz, the induction arrows point to the northeast and northwest (Figure 4.11). The directions indicated by the induction arrows are generally consistent with the principal strike directions determined from the phase tensors (Figure 4.4)

4.4 Static shift correction

As mentioned in section 2.10, near surface galvanic distortions such as a thin conductor layer at or near the surface can result into the so called "static shift" phenomenon. One of the methods to correct for this is by using TEM data, which are not affected by static shifts. This is achieved by doing a 1-D inversion modeling of the TEM data then using the model fit curve as the true level of the high frequency portion of the MT data curves. This can be done in WinGLink (Geosystem SRL, 2008). For NNGP, only 29 MT stations have TEM data, most of these are the stations located east and southeast of Pataan (Figure 4.1). For the other stations in Pataan, Saray, Hagdan and Upper Hagdan sectors which do not have TEM data, the MT data were adjusted based on the

4.4. STATIC SHIFT CORRECTION

Figure 4.6: Induction arrows at 300 Hz

Figure 4.7: Induction arrows at 10 Hz

Figure 4.8: Induction arrows at 1 Hz

Figure 4.9: Induction arrows at 0.1 Hz

4.4. STATIC SHIFT CORRECTION

nearest TEM station available (i.e. for station 18, TEM data 140 was used). Using the TEM computed models show that even after stripping the data by using the phase tensor decomposition technique (Caldwell et al., 2004), a shift is still evident. It can be observed however that most of the stations have only minimal shifts applied (Appendix III). Only about 15 stations have notable shifts corrected by a factor >2.0 . These stations are located within and south of Pataan suggesting that this block has higher levels of resistivity at the surface compared to the surrounding areas.

For the stations in the Mambucal sector in the north and area east of Pataan, no shifts were applied. Comparing these stations with those nearest them which were shifted show no significant difference in the resistivity levels.

4.4. STATIC SHIFT CORRECTION

Chapter 5

Modeling

This chapter gives the results of the various modeling schemes applied to the MT data. This include 1-D, 2-D and finally 3-D modeling. The results for each model are first presented through iso-resistivity maps then cross-sections along selected profile lines were compared to show the similar and different features of each model.

5.1 1-D inversion modeling

1-D modeling was carried out mainly by using the Occam inversion scheme included in the WinGLink software (Geosystem SRL, 2008)). The determinant mode of the impedance (Equation 2.120) was used during the inversion modeling.

5.1.1 Iso-resistivity maps

Iso-resistivity maps were created to show the variation of resistivity at different depths.

The greater part of the project area including the Pataan, Saray, Haggadan and Hardin Sang Balo sectors, is mainly covered by moderate to high resistivity values (>30 ohm-m), shown by green and blue colours,

5.2. 2-D INVERSION MODELING

Figure 5.1: 1-D isoresistivity map at 300 m depth

at 300 m depth (Figure 5.1). However, a conductive zone enclosed by <10 ohm-m, represented by red and orange colours, can be found within Mambucal area in the northwest. At 1000 m depth, more than half of NNGP is now covered by low resistivity values <10 ohm-m which include Pataa and Hagdan (Figure 5.2). At this depth, the resistive zone is now confined to the eastern and southern portions of Saray, Upper Hagdan and Hardin Sang Balo. At 2000 m depth, a resistive block is delineated southwest of Pataa (Figure 5.3)

5.2 2-D inversion modeling

The 2D inversion was carried out using the non-linear conjugate gradient (NLCCG) based 2D inversion algorithm (Rodi and Mackie, 2001) that is also included in the WinGLink suite. The modeling software inverts

Figure 5.2: 1-D isoresistivity map at 1000 m depth

Figure 5.3: 1-D isoresistivity map at 2000 m depth

5.2. 2-D INVERSION MODELING

using a user-defined finite-difference mesh of resistivity blocks extending laterally and downwards beyond the study area (Geosystem SRL, 2008).

As seen from Figure 4.4 and considering the ambiguous characteristic of the strike, possible strike directions are either N85°W or N5°E. Profiles perpendicular to both of these possible strike orientations were created and 2-D models were run for each profile. As implied by the phase tensor analysis (Appendix I and Figure 4.5) the MT data shows 2-D characteristic only at the lower period <1 s) range. It has been suggested that for situations like this, it is better to use the TM mode during 2-D inversion to give a more accurate resistivity structure because this mode may only be affected by galvanic effects unlike the TE mode wherein it may be influenced by both galvanic and inductive effects (Ledo, 2005). Furthermore, the TE mode does not consider boundary changes that it may give false features in resulting model (Wannamaker et al., 1984). The TM mode was then solely used during inversion.

The starting model used was a mesh with half space of 100 ohm-m. The smoothed curves, wherein a smooth curve was generated from the data curves using D+ smoothing algorithm, was selected during inversion. The other settings during the inversion included the setting of data errors for the “Rho” at 10% while for the phase at 5% . Static shift was not included in the inversion since this was already corrected for using the TEM data in most of the stations. The relaxation parameter τ , which controls the smoothness of the model was set at 10 and the number of iterations made for each model is at least 100. Topography was included in the inversion.

5.2.1 Isoresistivity maps

The 2-D isoresistivity maps were generated by compiling the 2-D resistivity models along profiles lines, that are mainly oriented NW-SE. These profiles were chosen to be able to model the resistivity from the

Figure 5.4: 2-D isoresistivity map at 300 m depth

postulated heat source in the southeast to the outflow zone in the north-west. Some of these profiles will be presented in Section 5.5.

At 300 m depth, moderate to high resistivity values covers most of NNGP particularly east and south of Pataan where > 100 ohm-m can be found (Figure 5.4). A broad conductive zone of < 10 ohm-m was detected at Mambucal sector extending towards the north-northwestern portion of Pataan. At 1000 m depth, the conductive zone now occupies more than half of the project area including Hagdan, Upper Hagdan and west of Pataan (Figure 5.5). The resistive region is confined to east and southeast of Pataan and Saray sectors. At 2000 m depth, a resistive block is still detected east and southeast of Pataan (Figure 5.6). Similar resistive regions are detected in Hardin Sang Balo and Saray. Hagdan and Upper Hagdan are enclosed within the moderately resistive zone. Then again, Mambucal is set apart by high conductivity values < 10 ohm-m. A conductive strip was also detected between Upper Hagdan and Hardin Sang Balo (Figure 5.6).

5.2. 2-D INVERSION MODELING

Figure 5.5: 2-D isoresistivity map at 1000 m depth

Figure 5.6: 2-D isoresistivity map at 2000 m depth

5.3 3-D inversion modeling

The 3D inversion modeling software used is the WSINV3DMT (Siripunvaraporn et al., 2006). The MT data that were classified as “Type 3” (Appendix II) or those that has good quality data extending to periods of 100 s or longer were used in the 3D inversion. However, some of the data that were ranked as “Type 2” were also used to fill up the gaps between the “Type 3” stations for better coverage during inversion. A total of 37 MT stations, which are represented as black squares in the iso-resistivity maps, were included during 3-D inversion. Moreover, 14 periods were used ranging from 0.007 s to 170 s, which is equivalent to skin depths of about 100 m to >5 kms. All eight impedance elements of the MT data which consisted of the real and imaginary components of Z_{xx} , Z_{xy} , Z_{yx} and Z_{yy} were included in the inversion.

The MT stations were located using a grid system wherein “X” denotes the north-south direction while “Y” refers to the east-west axis. The X and Y origin (0,0) is located at the center and the value increase towards the north in the X axis and to the east in the Y direction. Depth is represented by the “Z” axis and it increases from the surface down.

The grid was designed in a manner that it is sufficient to compute the resistivity value at the center of each grid square at the same time as considering the capability of the PC used. A 28 x 28 x 28 grid was used with the X and Y axis having a minimum spacing of 500 m within the first 9 km which encloses the geothermal project site and gradually increases to 20 km further away. The total area coverage in both X and Y directions extended to 55 kilometers, which is much more than the skin depth of the longest period. For the depth (Z), the starting level was the surface (0 meters) then gradually increasing until reaching depths of 45 km. The exact grid values used can be seen in the first sections of the input data file (Appendix IV).

5.3.1 Comparison of initial models

Several 3-D inversions were run using different starting models to determine the features which can be attributed to the MT data from those that could be artefacts of the modeling software. A comparison of three starting models will be presented here, namely:

1. Model A: layered model with 100 ohm-m for the first 100 m, underlain by 10 ohm-m until the bottom
2. Model B: half-space of 10 ohm-m
3. Model C: half-space of 30 ohm-m

The minimum RMS/misfit achieved during iterations for models A, B and C were 36.289, 28.281 and 19.029, respectively. All models were processed with at least 15 iterations. It should be noted that Model A was one of the first inversions run and it had only 35 MT stations incorporated during inversion. The inclusion of the additional two stations within Pataa will be explained in the succeeding sections.

Figures 5.7, 5.8 and 5.9 show the iso-resistivity maps for the three models at 300 m depth. The prominent features that can be observed for all three models include:

1. Mambucal sector is enclosed by a broad conductive region with resistivity values of <10 ohm-m. However, on its eastern portion specifically stations 6 and 85, there are moderately resistive values (>15 ohm-m).
2. A moderately resistive (>30 ohm-m) zone is detected at Saray centered on station 12. For Model A, this resistive zone includes the Pataa sector all the way to the south. On the other hand, Models B and C detected a highly conductive (<10 ohm-m) zone within Pataa. This difference can be attributed to the additional MT stations namely, 46 and 93 that were added in this sector. This conductive zone is connected to the one in Mambucal.

3. Station 24 near Hardin Sang Balo is characterized by resistivity values >15 ohm-m. All the different models show this resistive zone extending towards the south although the resistivity signature towards the southeastern end differs for the models: Models A and B show <10 ohm-m while Model C indicates >20 ohm-m. This could be due to the lack of MT stations in this region that the resistivity values are not well constrained.
4. Hagdan sector, specified by stations 143 and 67 is enclosed by moderately resistivity values (>15 ohm-m) while Upper Hagdan, which is the area between stations 148 and 149 is surrounded by <10 ohm-m.
5. Another moderately resistive zone is delineated in the western portion bounded by stations 58, 19 and 48. This moderately resistive zone is connected to the resistive zone in Hagdan in Models B and C.

Figures 5.10, 5.11 and 5.12 show the iso-resistivity maps at 2 km depth for Models A, B and C, respectively. Among the characteristics noted include:

1. A broad <10 ohm-m conductive region was detected in Pataan and Hagdan. The eastern portion of Pataan are covered by moderately resistive values of >20 ohm-m as shown by Models A and C even when stations 46 and 93 (in Pataan) were not present in Model A. However, this feature cannot be clearly distinguished by Model B at this depth but this moderately resistive layer was indicated at 1 km depth (Figure 5.13).
2. The Mambucal sector (stations 3 and 6) is enclosed by >20 ohm-m resistivity values. This resistive zone extends to stations 77 and 76 in the north in Models B and C.

5.3. 3-D INVERSION MODELING

Figure 5.7: Model A isoresistivity map at 300 m depth

Figure 5.8: Model B isoresistivity map at 300 m depth

Figure 5.9: Model C isoresistivity map at 300 m depth

3. The Saray sector, east of station 12, is moderately resistive (>20 ohm-m) in Models B and C, while it is mainly conductive in Model A.
4. The Upper Hagdan sector in the south is also resistive as shown by station 149.
5. Resistive zones were detected west of Pataa, beneath stations 67, 48 and 54.

The isoresistivity maps of the different models shows similar resistivity patterns where there are sufficient MT data available. The inclusion of two more stations in the Pataa sector proves that shallow moderately resistive body beneath Pataa is not just an artefact of the inversion process. Major differences are observed further from the centre where there were no MT stations. This can be further illustrated through

5.3. 3-D INVERSION MODELING

Figure 5.10: Model A isoresistivity map at 2000 m depth

Figure 5.11: Model B isoresistivity map at 2000 m depth

Figure 5.12: Model C isoresistivity map at 2000 m depth

Figure 5.13: Model B isoresistivity map at 1000 m depth

5.3. 3-D INVERSION MODELING

Figure 5.14: Model A profile line $X=-0.25$ km

the cross sections that cut across the middle of the project area namely lines $X=-0.25$ km and $Y=0.75$ km.

Profile line $X=-0.25$ km traverses the Pataan sector in a west-east direction. It shows similar characteristics in Models A, B and C, such as a resistive cap (>50 ohm-m) layer from 0 to about 300 m depth (Figures 5.14, 5.15 and 5.16). This is followed by a highly conductive layer (<10 ohm-m) which extends to as deep as about 4.5 km in the middle (0 km). This is underlain by a bottom layer with increasing resistivity values (>10 ohm-m) with depth. Slightly lower resistivity values for this layer are found in Model A. The more resistive bottom layer can be found beneath Pataan sector protruding upwards to depth of about 1 km. This feature can be clearly seen in Models A and C while only a portion can be discerned in Model B.

On the other hand, different features among the models can also be observed. These included the resistive layer detected in the eastern end

Figure 5.15: Model B profile line $X=-0.25$ km

Figure 5.16: Model C profile line $X=-0.25$ km

5.3. 3-D INVERSION MODELING

of Model C specifically in the 5 km to 10 km range compared to a conductive layer in Models A and B. Again, differences in the depth extent of this conductive layer can be noted. It reaches depths of about 2 km depth in Model B and only about 1 km depth in Model A. On the western edge (-5 km to -10 km), a conductive layer is detected starting from about 100 m depth in Models A and B while a more resistive layer is detected in Model C. The extent of the conductive layer also varies, it reaches about depths of about 1.5 km and 2.5 km for Models A and B, respectively. These differences correspond to those seen in the isoresistivity maps in the regions where there are few MT sites, outside the central area.

Profile line Y= 0.75 km also traverses the Pataa sector but in a south-north direction. The cross sections are shown in Figures 5.17, 5.18 and 5.19. A similar resistive (>30 ohm-m) layer is detected from surface to about 300 m depth. This is underlain by a <10 ohm-m layer extending at its deepest to about 4.5 km. Below this conductive layer, resistivity values increase with depth. As shown in line X= -0.25 km, the resistivity values of the bottom layer is slightly lower in Model A. Also, just as in the previous cross section, a shallower portion of the resistive bottom layer exists beneath the Pataa sector at depths ranging from of about 1 to 1.5 km. This can be seen in Models A and C while in Model B higher resistivity occurs as an isolated region at about 1 km depth. The resistivity values and extent of the layers on the southern and northern edges also varies for the models. For Model A, the conductive layer persists to the southern and northern edges until about 2 km depth while for Model B this is thinner on the northern tip while going deeper on the southern portion reaching depths of about 4 km. On the other hand for Model C, only the northern edge is conductive from depths of about 300 m to about 1.5 km while the southern portion is resistive. Again, these differences occur in regions of low site density where the grid spacings are increased.

Figure 5.17: Model A profile line Y=0.75 km

Figure 5.18: Model B profile line Y=0.75 km

5.3. 3-D INVERSION MODELING

Figure 5.19: Model C profile line $Y=0.75$ km

A lower RMS is achieved with the model that has a starting model with the higher initial resistivity value at depth of 30 ohm-m (Model C). Compared to Models A and B, the calculated curves have a smoother fit to the apparent resistivity and phase data especially in the long period range. Examples to illustrate this are at stations 4 and 14 (Figures 5.20 and 5.21).

(a) Model A

(b) Model B

(c) Model C

Figure 5.20: Curve fit of model vs data of MT station 4

5.3. 3-D INVERSION MODELING

(a) Model A

(b) Model B

(c) Model C

Figure 5.21: Curve fit of model vs data of MT station 14

5.4 3-D inversion results

The results of the 3-D inversion using Model C as the initial model (with 30 ohm-m half space) will be presented here to describe the resistivity structure of NNGP in more detail.

5.4.1 MT data curves

The MT data curves and fit of the calculated model are shown in Appendix V. The lowest RMS achieved was 19.029 in the 15th iteration.

In general, most of the calculated curves match the station data curves very well, namely the apparent resistivities and phases of both Z_{xy} and Z_{yx} (i.e. stations 3, 4, 10, 12, 19, 27, 42, 46, 48, 58, 67, 77, 82, 85, 93, 96, 106, 129). At some sites, the calculated curves only fit either the Z_{xy} or Z_{yx} curve (i.e. 37, 43, 51, 60, 76, 83, 102, 120). There are also a few data curves that are poorly fitted (i.e. 24, 54, 61, 55, 84) either due to poor data quality or the possible presence of additional static shifts not accounted for. It can also be observed that the Z_{xx} and Z_{yy} components of the station data tend to be poorly matched by the calculated model curves. However, considering that these elements have values at least an order of magnitude less than the Z_{xy} and Z_{yx} , this is not crucial to the overall misfit.

5.4.2 Isoresistivity maps

Several isoresistivity maps were produced to show the variation of resistivity with depth.

The isoresistivity map at 10 m depth shows a massive >50 ohm-m resistivity body extending from Upper Hagdan in the south towards Mambucal in the north (Figure 5.22). This resistive body was subdivided into three smaller blocks within the areas of Pataan, Saray and Hagdan at 100 m depth (Figure 5.23). Hardin Sang Balo, located in the

5.4. 3-D INVERSION RESULTS

southeast is covered by resistivities >20 ohm-m. Meanwhile, the Upper Hagdan and Mambucal sectors are now covered by <10 ohm-m resistivity contours. At 300 m, Hagdan, Saray and Hardin Sang Balo are still enclosed by moderately resistive values >20 ohm-m, while Pataan is now included in the conductive zone that continues to the north of Mambucal (Figure 5.24). Likewise, the conductive zone within Upper Hagdan is now larger. At 500 m depth, most of the region including Mambucal, Pataan, Hagdan and Upper Hagdan, is now highly conductive (Figure 5.25). The sectors of Saray and Hardin Sang Balo are still moderately resistive. At 1 km depth, the conductive zone becomes larger, now extending towards Saray in the east (Figure 5.26). A portion of Pataan is now slightly resistive while Hardin Sang Balo is still resistive. At 2 km depth, Pataan all the way to the northwest in Mambucal, as well Upper Hagdan in the south, is now enclosed by moderate resistivity >20 ohm-m (Figure 5.27). Saray, east of Pataan is slightly resistive. A <10 ohm-m conductive zone which includes Hagdan, extends toward Hardin Sang Balo sector. Deeper down at 3 km depth, the region is mostly resistive (>30 ohm-m) except for the conductive zone comprising Hagdan and Hardin Sang Balo (Figure 5.28). The conductive zone in Hagdan and Hardin Sang Balo are now separated at 4 km depth (Figure 5.29). At 5 km depth, only the Hagdan sector is slightly conductive (Figure 5.30). At 8 km depth, almost the entire region is covered by resistivity >40 ohm-m (Figure 5.31). Upper Hagdan and Hardin Sang Balo in the south have higher resistivities >80 ohm-m.

5.4.3 Resistivity profiles

The lateral variation in the resistivity of NNGP is shown through the resistivity profiles created along the X and Y axes, which extend to 10 kilometers. The MT stations and sector names that were intersected by the cross-section lines are plotted on the profiles for reference.

Figure 5.22: Isoresistivity map at 10 m depth

Figure 5.23: Isoresistivity map at 100 m depth

5.4. 3-D INVERSION RESULTS

Figure 5.24: Isoresistivity map at 300 m depth

Figure 5.25: Isoresistivity map at 500 m depth

Figure 5.26: Isoresistivity map at 1 km depth

Figure 5.27: Isoresistivity map at 2 km depth

5.4. 3-D INVERSION RESULTS

Figure 5.28: Isoresistivity map at 3 km depth

Figure 5.29: Isoresistivity map at 4 km depth

Figure 5.30: Isoresistivity map at 5 km depth

Figure 5.31: Isoresistivity map at 8 km depth

5.4.4 YZ slices

The west-east profiles, which were made by taking the YZ slices from the 3D models, are shown in Figure 5.32 to 5.39 to a depth of 5 km. The resistivity structure at NNGP can be simplified as made up of three main layers:

1. A top layer with resistivity >50 ohm-m
2. A middle layer with <10 ohm-m and
3. A bottom layer with resistivity >20 ohm-m, which increases with depth.

The resistivity structure specifically of the different sectors of NNGP will be described starting from the southernmost to the northernmost portion.

Looking at profile lines $X=-4.25$ km (Figure 5.32) and $X=-3.75$ km (Figure 5.33), respectively, the topmost resistive layer can be found from the surface down to about 50 m in Upper Hagdan but extends to about 2 km beneath Hardin Sang Balo in the east. The highly conductive (<10 ohm-m) middle layer is delineated to about 1.1 km depth near Hagdan but deepens to >3 km depth towards Hardin Sang Balo. It follows that the resistive (>20 ohm-m) third layer likewise deepens beneath Hardin Sang Balo.

Meanwhile, profile lines $X=-2.75$ km (Figure 5.34) and $X=-2.25$ km (Figure 5.35) show that the topmost resistive layer goes from the surface down to about 400 m depth at Hagdan sector. This is underlain by the conductive layer which reaches depths of about 2.5 km in the east but goes beyond 5km depth beneath Hagdan. However, aside from the resistive bottom layer on the east, shallow resistive blocks can be observed on the western portion of Hagdan at depths starting from about 2 km and about 1 km in the eastern side.

Figure 5.32: Resistivity profile along $X = -4.25$ km

Figure 5.33: Resistivity profile along $X = -3.75$ km

5.4. 3-D INVERSION RESULTS

Figure 5.34: Resistivity profile along $X=-2.75$ km

Figure 5.35: Resistivity profile along $X=-2.25$ km

Figure 5.36: Resistivity profile along $X=-0.25$ km

Profile lines $X=-0.25$ km (Figure 5.36) and $X=0.25$ km (Figure 5.37) illustrates the resistivity structure beneath Pataan and Saray. The resistive cap layer can be found from surface until about 400 m depth in Pataan and about 500 m depth in Saray while the conductive middle layer goes to only up to about 1 km depth beneath Pataan but extends deeper beneath Saray at depths >2 km. This goes even deeper on the western portion of Pataan reaching depths >3 km. A prominent feature that can be identified from this profile is the resistive body protruding beneath Pataan.

Going farther north in the vicinity of Mambucal, through profile lines $X=2.75$ km (Figure 5.38) and $X=3.25$ km (Figure 5.39), show that the highly resistive top layer is thinnest beneath Mambucal reaching depths of only about 100 meters but deepens to about 500 m on the western and eastern portions. The conductive middle layer extends to depths of about 1.5 km beneath Mambucal but dips towards the east to >4 km depth.

5.4. 3-D INVERSION RESULTS

Figure 5.37: Resistivity profile along X=0.25 km

Figure 5.38: Resistivity profile along X=2.75 km

Figure 5.39: Resistivity profile along $X=3.25$ km

5.4.5 XZ slices

This section presents the south-north profile lines that were created by taking the XZ slices of the 3D resistivity model. The resistivity structure is described starting from the westernmost towards the easternmost sector. Representative profiles lines west and within Hagdan, namely $Y=-2.75$ km (Figure 5.40) and $Y=-1.75$ km (Figure 5.41), show a resistive cap layer from the surface to about 400 m depth that thins out towards the northern portion. This is underlain by the highly conductive middle layer until depths of about 1.5 km in most areas except beneath Hagdan where it extends beyond 5 km depth. This in turn is underlain by a >20 ohm-m bottom layer which becomes more resistive with depth.

Going towards the midsection of NNGP, as shown by slices $Y=-0.75$ km (Figure 5.42), $Y=0.75$ km (Figure 5.43) and $Y=1.25$ km (Figure 5.44), the resistive cap layer can be found from the surface to about 400 m depth. The <10 ohm-m conductive layer extends to about 1 km depth beneath Upper Hagdan but plunges to >4 km depths on its southern

5.4. 3-D INVERSION RESULTS

Figure 5.40: Resistivity profile along $Y=-2.75$ km

Figure 5.41: Resistivity profile along $Y=-1.75$ km

Figure 5.42: Resistivity profile along $Y=-0.75$ km

portion then shallows up again towards Mambucal in the south. A prominent feature would be the protruding portion of the bottom resistive layer to depths of about 1 km beneath Pataan (Figures 5.43 and 5.44).

Farther east in the vicinity of Hardin Sang Balo and Saray as shown by profile lines $Y=3.75$ (Figure 5.45) and $Y=4.25$ km (Figure 5.46), the three respective resistivity layers namely the resistive cap layer, middle conductive layer and the bottom resistive layer extend to deeper depths on the southern portion beneath Hardin Sang Balo. The resistive cap layer reaches to 1.5 km depth while the <10 ohm-m middle layer goes beyond 3 km depth. On the other hand, the resistive cap layer reaches only about 400 m depth beneath Saray and the resistive bottom is also shallower in this area having been detected at about 2 km depth. Towards the north, the resistivity layers again extends deeper similar to the southern side.

5.4. 3-D INVERSION RESULTS

Figure 5.43: Resistivity profile along Y=0.75 km

Figure 5.44: Resistivity profile along Y=1.25 km

Figure 5.45: Resistivity profile along $Y=3.75$ km

Figure 5.46: Resistivity profile along $Y=4.25$ km

5.5 Comparison of 1-D, 2-D and 3-D models

5.5.1 Isoresistivity maps

The features that were observed among the isoresistivity maps from 1-D, 2-D and 3-D models include:

1. High resistivity blankets the study area at shallow levels. As shallow as 100 m depth, a conductive zone within Mambucal was detected which broadens towards Pataan at 300 m depth (Figures 5.1, 5.4 and 5.24).
2. From 500 m to 1000 m depth, NNGP is mostly covered by low resistivities <10 ohm-m particularly the western portion, which includes Mambucal, Hagdan and Upper Hagdan. In the 1-D isoresistivity map, Pataan is included in the broad conductive zone but in the 2-D and 3-D isoresistivity maps, only the western portion of Pataan is conductive (Figures 5.2, 5.5, 5.25 and 5.26). The eastern portion, which include Saray and Hardin Sang Balo are enclosed by moderate to high resistivities >50 ohm-m.
3. At 2000 m depth, the 2-D and 3-D maps show moderate to highly resistive zones in Upper Hagdan and the east-southeastern portion of Pataan, which are separated by a conductive zone elongated towards the southeast (Figures 5.6 and 5.27). On the other hand, the 1-D model shows the resistive body more to the southeast of Pataan, which extends towards Hardin Sang Balo (Figure 5.3).
4. At 3000 m depth, NNGP is mostly covered by moderate resistivities >30 ohm-m. Conductive zones located south and southeast of Pataan which extends to Hardin Sang Balo were observed (Figure 5.28).

5. At 5000 km depth, NNGP is now covered by mostly by high resistivity values >50 ohm-m (Figure 5.30).

5.5.2 Profile lines

Profiles lines for all models were created to show the resistivity structure with depth. Three lines (NW-SE lines) were oriented almost parallel to the dominant strike direction indicated from the phase tensor analysis which is -85° while one cross-section line (NE-SW) is made almost perpendicular to the other three lines (Figure 5.47). The profile lines cut through the different sectors of NNGP. As mentioned in the previous section, the Occam model was used for the 1-D model while the TM mode was considered for the 2-D models. Moreover, topography was included in the 2-D inversions. The stations that were used for the 3-D models are indicated by the red font colour. The resistivity structure can be generalized into three main layers:

1. A resistive cap layer with resistivity >50 ohm-m
2. A conductive middle layer with <10 ohm-m and
3. A bottom layer with resistivity >20 ohm-m and increases with depth.

Profile NW-SE1 goes from Mambucal in the northwest towards the southeast cutting across the wells MC-1 and MC-2 (Figure 5.47). All three models show consistent features such as a thick conductive middle layer that extends as deep as >3000 m depth in the 2-D model (Figure 5.48). Another prominent feature that can be observed from the models is the shallowing of the resistive bottom layer towards the southeast. It can also be seen that wells MC-1 and MC-2 intersected mainly the thick conductive middle layer. Moreover, the resistivity structure of the 2-D and 3-D models is almost identical which indicates topography has no sig-

5.5. COMPARISON OF 1-D, 2-D AND 3-D MODELS

Figure 5.47: Profile lines location map

nificant effect on the resistivity structure except for an offset of a few hundred meters in terms of vertical displacement (Figure 5.48).

Profile NW-SE2 cuts across the Pataan sector which is the main production zone at NNGP (Figure 5.47). Similar features that can be observed from the three models include the thick conductive middle layer on the western portion that goes beyond 3000 m depth on the 2-D model and the moderate to highly resistive block (>20 ohm-m) beneath Pataan (Figure 5.49). PT-3RD was drilled into the middle conductive layer while wells PT-3D, PT-4D, PT-7D, PT-10D and PT-11D were drilled into the resistive bottom layer. Well MY-1D was also drilled into the resistive zone in the 1-D and 2-D models. However in the 3-D model, MY-1D intersected the conductive layer, which extends towards southeast. Again, the similarity of the resistivity layers of the 2-D and 3-D models particularly on the western portion, suggest a minimum topography effect other than an offset in the vertical displacement (Figure 5.49).

5.5. COMPARISON OF 1-D, 2-D AND 3-D MODELS

(a) 1-D model along line NW-SE2

(b) 2-D model along line NW-SE2; RMS=3.006

(c) 3-D model along line NW-SE2

Figure 5.49: Profile line NW-SE2

Profile NW-SE3 extends across the southern portion of NNGP, passing through the Hagdan sector towards Hardin Sang Balo (Figure 5.47). A thick highly conductive layer (<10 ohm-m) is modeled beneath a resistive cap layer which extends to >4000 m depth in 1-D and 3-D models (Figure 5.50). The 1-D model shows that well HG-1D was drilled into the underlying resistive third layer at about 1000 m depth while in the 2-D and 3-D models, this well was drilled into the thick conductive layer. The 1-D and 2-D models also show that the entire section of Hardin Sang Balo on the southeast is underlain by a resistive layer while the 3-D model exhibited a thick conductive zone beneath a ~ 1500 m thick resistive cap layer. Comparing the resistivity structures of the 2-D and 3-D models particularly the topmost layers, it is apparent that at lower elevations (<1000 m), the topography has no significant effect on the 3-D model. However, as the elevation reaches about 2000 m (i.e. on the southeastern portion), there seem to be an effect in the resistivity structure of the 3-D model as indicated by the resistive body beneath Hardin Sang Balo, which should have occupied the large elevation difference in the southeastern region (Figure 5.50).

5.5. COMPARISON OF 1-D, 2-D AND 3-D MODELS

(a) 1-D model along line NW-SE3

(b) 2-D model along line NW-SE3; RMS=1.627

(c) 3-D model along line NW-SE3

Figure 5.50: Profile line NW-SE3

Profile SW-NE1 goes from Upper Hagdan in the south towards Mambucal in the north (Figure 5.47). A resistive top layer is detected in all models with thickness ranging from 300 m to 500 m (Figure 5.51). This is underlain by the (<10 ohm-m) conductive layer which is thinnest beneath Pataan and thickens towards the southern and northern portions reaching depths >5000 m in the 2-D. A prominent feature is the resistive lump beneath Pataan intersected by wells PT-1D, PT-3D, PT-4D, PT-5D, PT-7D, PT-10D and PT-11D (Figure 5.51). Well CT-1D is situated on the edge of the resistive block. Another resistive block can be observed beneath Upper Hagdan at a similar depth to the resistive body beneath Pataan in the 3-D model. Upon comparison again of the 2-D and 3-D models show no significant consequence when topography was not included in the 3-D inversion except for an offset in terms of the vertical depth (Figure 5.51).

In general, the 1-D, 2-D and 3-D models show good agreement. The main differences occur in the southeast portion of lines NW-SE2 and NW-SE3 where the 2-D models show significantly higher resistivity than, in particular, the 3-D model. The 1-D structures fall between these extremes. These differences may partly reflect the lack of topography in the 3-D model, but may also reflect the limitations of 2-D modeling in an inherently 3-D environment.

5.5. COMPARISON OF 1-D, 2-D AND 3-D MODELS

(a) 1-D model along line SW-NE1

(b) 2-D model along line SW-NE1; RMS=1.657

(c) 3-D model along line SW-NE1

Figure 5.51: Profile line SW-NE1

Chapter 6

Discussion and interpretation

6.1 Resistivity structure of NNGP

The resistivity models show that NNGP is covered by high resistivity values from the surface down to about 400 m depth. This is underlain by a highly conductive layer which extends to as deep as >3000 m depth in some regions such as Hagdan, Upper Hagdan and Hardin Sang Balo. This in turn is underlain by a bottom layer, which has resistivity of >20 ohm-m. A prominent feature of this layer is its “doming” beneath Pataan where it is detected at 1000 m depth (Figures 5.26 and 5.27).

The location of the conductive zones is consistent with the direction of the “real” induction arrows where the arrows of the higher frequency range of 300Hz to 10 Hz (Figures 4.6 and 4.7) point to the northwest and western regions, which coincides with the conductive zones detected with-in Mambucal and Hagdan at 100 m to 500 m depth (Figures 5.23 to 5.25). The induction arrows at 1 Hz (Figure 4.8) points towards the conductive zones of Hagdan in the southwest and Saray in the east as delineated from the iso-resistivity maps of 1000 m and 2000 m depths (Figures 5.26 and 5.27). Furthermore, the induction arrows at frequencies of 0.1 Hz and lower (Figures 4.9 to 4.11) point mainly towards the southeast, where the conductive zones at the southern portion of Pataan

6.1. RESISTIVITY STRUCTURE OF NNGP

Table 6.1: Common mineral geothermometers in Philippine geothermal areas

Minerals	Temperature of stability (°C)
Clays	
Smectite	ambient to 180, may reach 200
Illite-smectite	180-220
Illite	≥ 220
Biotite	≥ 280
Actinolite	≥ 260
Epidote	
Incipient	180
Anhedral	180-200
Subhedral	200-240
Euhedral	≥ 240

and Hardin Sang Balo were detected at >3 km depth (Figure 5.28).

6.1.1 Correlation with alteration, temperature and lithology

In a geothermal system, changes in resistivity are attributed to the interplay of temperature, porosity and fluid chemistry (Heise et al., 2008). This interaction can be reflected through the alteration minerals and temperatures encountered in the wells. A typical progradation hydrothermal alteration mineral suite used to predict temperature regimes in a geothermal field is shown in Table 6.1. To show the relationship between clay alteration minerals, measured temperatures, lithology and the resistivity structure at NNGP, several plots along selected profiles lines were made.

Figure 6.1 shows the plot of the alteration minerals intersected by the wells against the resistivity structure along Line NW-SE2. The resis-

Figure 6.1: Resistivity model vs. alteration minerals along NW-SE2

tivity profile has been shifted to surface level to partly compensate for the offset in depth of the resistivity structure, as a result of not including the topography in the inversion. It is shown that the smectite (Sm) and illite-smectite (Il-Sm) zones, which form at temperatures $<220^{\circ}\text{C}$ (Table 6.1), coincides with the thick highly conductive layer. The onset of the higher temperature alteration minerals particularly illite (Il) and epidote (Ep) overlaps with the doming of the moderately resistive bottom layer beneath Pataan. However, the alteration minerals in MY-1D were intersected at a shallower level. Occurrence of actinolite and biotite (Act/Bt) were also reported (Technical Services Sector, 2010).

Figure 6.2 shows the plot of the temperature measured in the wells against the resistivity structure along Line NW-SE2. Beneath Pataan, the 180°C to 200°C temperature contours lie within the lower portion of the conductive layer while $>220^{\circ}\text{C}$ coincides with the shallower portion of the moderately resistive bottom layer. The measured temperature reaches 290°C in wells PT-5D and PT-7D (Dulce, 2001, 2003) as it goes towards the center of the resistive dome structure. The tempera-

6.1. RESISTIVITY STRUCTURE OF NNGP

Figure 6.2: Resistivity model vs. measured temperatures along NW-SE2

ture contours do not extend to well PT-3RD because it only achieved a maximum measured temperature of 150°C at 1900 mMD (Austria et al., 2009). The steep decline of the temperature contours in wells PT-4D and PT-11D matches the steep resistivity gradient towards the north-west. On the other hand, the temperature contours in MY-1D are again found at an elevated level but the maximum temperature measured by this well is only 269°C at 2600 mMD (Austria et al., 2009).

It could be argued that if the resistivity structure is made to follow the ground level everywhere including the southeastern portion (i. e. by tilting the model), the wells, particularly where the higher temperatures were recorded would penetrate into the higher resistivities. The “doming” moderately resistive layer would also closely follow the pattern of the alteration minerals and elevated temperatures from MY-1D.

Figure 6.3 displays the main rock units intersected by the wells along NW-SE2 line. The contact between the volcanic breccias and hornblende andesite lavas of the Canlaon Volcanic Complex (CnV) and the sedimentary breccias intercalated with calcareous-carbonaceous siltsone, lime-

Figure 6.3: Resistivity model vs. lithology along NW-SE2

stone and lavas of the Talave Formation (TF) lies within the thick conductive layer in PT-3RD but coincides within the moderately resistive body beneath Pataan. In MY-1D, only the CnV was encountered which was composed of completely altered rocks of dacitic composition thought to be caused by thermal metamorphism by intrusion of dikes (Jara, 2010).

Figures 6.4, 6.5 and 6.6 show the plot of the clay alteration minerals, measured temperatures, and intersected lithologies, respectively, as correlated with the resistivity structure along profile line SW-NE1. As previously, the resistivity section has been shifted to make up for the exclusion of topography during the 3-D inversion.

The greater part of the smectite zone overlaps with the highly conductive layer (Figure 6.4). The illite-smectite (Il-Sm), illite (Il) and epidote (Ep) zones delineated from the PT (Pataan) wells coincide with the moderately resistive layer while the illite-smectite (Il-Sm) and illite (Il) zones in well CT-1D plots within the conductive layer. This could be due to the reported cool inflow at depths below 1631 mMD in well CT-1D as manifested by the reappearance of smectite (Pamatian and Camit,

6.1. RESISTIVITY STRUCTURE OF NNGP

Figure 6.4: Resistivity model vs. alteration minerals along SW-NE1

1995).

The high temperatures measured in the Pataan wells particularly PT-5D and PT-8D which reaches $>280^{\circ}\text{C}$ coincide with the doming moderately resistive bottom layer (Figure 6.5). The decreasing temperature gradient in PT-3D and CT-1D matches the steep resistivity gradient towards the southwest and northeast, respectively.

The topmost level of CnV which is composed of relatively fresh volcanic lavas and tuffs coincides with the resistive cap layer (Figure 6.6). The contact of the CnV and TF lies within the conductive zone in PT-3D and CT-1D while it is be found within the resistive “dome” in PT-10D and PT-5D. Only the CnV was intersected by wells PT-1D and PT-8D (Pamatian, 1994; Esperidion et al., 2002)

These correlations agree with the observations in the other studied geothermal fields wherein the <10 ohm-m conductive layers are associated with the low temperature minerals (i.e. smectite) while increasing resistivity with depth can be correlated with the higher temperature anhydrous minerals (i.e. illite, epidote) (Johnston et al., 1992; Anderson et al., 1999). Furthermore, the only relationship that can be established

Figure 6.5: Resistivity model vs. measured temperatures along SW-NE1

Figure 6.6: Resistivity model vs. lithology along SW-NE1

6.2. GEOTHERMAL RESOURCE AREA

between the lithology and resistivity would be the agreement of the relatively unaltered to weakly altered portion of CnV to the resistive cap layer. The deeper portion of CnV which consists of either the highly altered portion of the CnV and/or metamorphosed dacitic rock overlaps both the conductive and high resistivity zones. Likewise, the occurrence of the Talave Formation also encompasses both the conductive and resistive layers.

6.2 Geothermal resource area

The high temperature resource of NNGP is associated with the occurrence of a shallow bottom resistive layer beneath Pataa. The core was intersected by wells PT-5D and 7D where $>290^{\circ}\text{C}$ were measured (Figure 6.5). This is consistent with the model where the upflow zone is the area drilled by PT-5D and PT-7D. The area drilled by well MY-1D lies in the southeastern boundary. It is thought to be the hotter portion of NNGP, reaching temperatures $>300^{\circ}\text{C}$, as indicated by the elevated measured temperatures as well as the shallower onset of the higher temperature alteration minerals (i.e. illite, epidote, actinolite) but has now cooled due to inflow of peripheral waters (Technical Services Sector, 2010). On the other hand, the steep decline of the temperature gradients in wells PT-3D and PT-4D mark the southwestern and western boundaries, respectively, of the resource.

To determine the boundary of the Pataa resource area particularly to the northeast, profile SW-NE2, which follows the delineated moderate resistivity zone at 1 km depth (Figure 5.26), was created (Figure 6.7). It shows that the moderately doming resistive block in Pataa extends towards station 82 (Figure 6.8). Assuming that resistivity reflects the possible temperature in that region, this could indicate the northeastern boundary of the geothermal resource in Pataa. The delineated boundaries of the high temperature resource are marked by the dashed lines,

Figure 6.7: Profile line SW-NE2 location map

red representing the inner boundaries while the purple lines indicating the outer boundaries (Figure 6.8).

The high temperature resource area in Pataa based on the resistivity structure as delineated from the profile lines and iso-resistivity maps is shown in Figure 6.9. The dashed line represents the possible maximum area while the ellipse is the most likely areal extent of the high temperature resource of $>240^{\circ}\text{C}$. The area of the ellipse is about three km^2 while the maximum possible area is about seven km^2 . The boundaries of the delineated resource is marked by well PT-1D on the west, PT-3D on the

6.2. GEOTHERMAL RESOURCE AREA

Figure 6.8: Resistivity model along SW-NE2

southwest, MY-1D on the east, and station 63 on the northeast.

Profile SW-NE2, also shows that well HG-1D where measured temperatures only reach 235°C at about 2100 mVD lies within the thick conductive layer (Figure 6.8). This further suggests that there is no hotter region in the Hagdan sector that can be deduced from the resistivity structure.

Another possible area where high temperatures may be encountered would be Upper Hagdan sector as indicated by the shallow resistive bottom layer in profile NW-SE3 (Figure 5.5.2) and at 1 km and 2 km depth maps (Figures 5.26 and 5.27). It should be noted however, that resolution of resistivity at deeper levels in the southern areas of Hagdan, Upper Hagdan and Hardin Sang Balo may not be well resolved mainly because of the low station density in these areas. Additionally, possible effects of topography may be included in the resistivity structure modelled particularly within the vicinity of Hardin Sang Balo due to its high elevation difference with the majority of the stations.

Figure 6.9: Delineated resource area in NNGP based on 3-D inversion

6.2. GEOTHERMAL RESOURCE AREA

Chapter 7

Summary and Conclusions

To realize a 3-D resistivity model for NNGP, additional stations were occupied during the survey season of December 2010 to April 2011. To overcome the possible noise sources such as the power plant, power lines and other installations, as well as the rainy and windy weather conditions, recording time was extended to 40-60 hours. A remote reference site, which is situated about 50 kms away, was also employed to improve the data quality. 66 new MT stations were added making the total available MT stations in NNGP to 158. Although only about half of the stations have data exceeding periods >100 s, data coverage in the vicinity of Pataan, which is the main producing zone at NNGP is sufficient.

One improvement applied during data processing is the removal of the distortion through the phase tensor analysis method by Caldwell et al. (2004). The dimensionality of the MT data were also determined using this method. It showed that 1-dimensionality of the data is observed only on the short period range (<1 s) but becomes 3-D at the longer periods. Another development is the application of static shift correction using TEM data, which was conducted in some of the MT stations during the latest survey. The MT stations which show the bigger shifts are mainly the ones within Pataan and Saray.

The 1-D, 2-D and 3-D isoresistivity maps consistently delineated conductive zones at Mambucal, Pataan, Saray, Hagdan and Upper Hagdan sectors at shallower depths. The locations of these conductive zones were consistent with the directions of the real component of the induction arrows at high frequencies.

The 1-D, 2-D, and 3-D models also shows a resistivity structure made up of a top >100 ohm-m resistive layer, which extends from surface to depths of about 400 m. This is underlain by a highly conductive <10 ohm-m layer, which reaches >4000 m depth in some sectors. This is underlain in turn by a bottom moderately resistive layer of >20 ohm-m and increases with depth. Moreover, the models consistently detected a "doming" portion of the bottom resistive layer beneath Pataan.

Correlating the 3-D resistivity structure with the subsurface data, which was obtained primarily from the drilled wells showed that the conductive layer overlaps with the low-temperature clay alteration mineral smectite while the moderately resistive layer coincide with the higher temperature ($>200^{\circ}\text{C}$) alteration minerals such as illite and epidote. This agrees with the highest temperatures ($>290^{\circ}\text{C}$) measured in the wells drilled within the moderately resistive layer namely PT-5D and PT-7D. Correlation of the resistivity structure with lithology shows that the top-most highly resistive layer corresponds with relatively fresh volcanic deposits of the Canlaon Volcanics. However, no clear correlation can be seen within the middle and bottom resistivity layers with lithology as these coincide with both the Canlaon Volcanics and the Talave Formation. This could be due to the fact that the deeper portion of the Canlaon Volcanics is highly altered that no major contrast can be made with the sedimentary Talave Formation.

The high-temperature resource drilled in NNGP correlates to the "doming" structure of the bottom moderately resistive layer beneath Pataan (Figure 7.1). It is bounded on the west by well PT-1D, on the southwest by PT-3D and Pataan-C Splay Fault, and on the east by MY-

1D. This delineated resource area is found to be elongated towards the northeast and covers an area of about three to seven km². The highly permeable Mambucal-A and Kinabkaban-A Faults, as well as Asia-B and Sumaguan Faults cut through the resource. These faults could be the channel of the hot fluids from the upflow zone at Pataan towards the outflow zone in Mambucal and PT-A sectors giving rise to the thermal springs of Mambucal, Hda. Paz, Hda. Montinolla and Kinabkaban, in the northwest and west.

Looking further at the 3-D resistivity structure, another possible high-temperature area may be present beneath Upper Hagdan at the southern portion of NNGP, where a similar shallow portion of the moderate resistive layer was detected. The hot springs in Hagdan sector may be associated with this inferred Upper Hagdan resource through Hagdan Fault acting as the conduit. Another area of interest would be Hardin Sang Balo in the southeast. However, model resolution in both of these areas are not well defined due to the limited MT stations in this region. To fully resolve the resistivity structure, more MT stations are needed in this area.

CHAPTER 7. SUMMARY AND CONCLUSIONS

Figure 7.1: Delineated resource area at NNGP

References

- Acharya, H. K. and Aggarwal, Y. P., 1980, Seismicity of the Philippine Island. *J. Geophys. Res.*, 85(B6):3239-3250
- Anderson, E., Crosby, D. and Ussher, G., 1999, As plain as the nose on your face: Geothermal systems revealed by deep resistivity. *Proceedings, 21st New Zealand Geothermal Workshop (1999)*, Univ. of Auckland, Geothermal Institute, 107-112
- Austria, J. J. C., Omagbon, J. B. and O'Sullivan, M. J., 2009, Three-dimensional reservoir simulation of Northern Negros Geothermal Reservoir, Philippines. *Technical Report*, EDC, Philippines
- Bahr, K., 1991, Geological noise in magnetotelluric data: A classification of distortion types. *Phys. Earth Planet. Int.*, 66:2438
- Bibby, H. M., Caldwell, T. G. and Brown, C., 2005, Determinable and non-determinable parameters of galvanic distortion in magnetotellurics. *Geophys. J. Int.*, 163:915-930
- Bostick, F. X., 1977, A simple almost exact method of MT analysis *Workshop on Electrical Methods in Geothermal Exploration*, U.S. Geol. Surv., Contract No. 14080001-8-359
- Brewitt-Taylor, C. R. and Weaver, J. T., 1976, On the finite difference solution of two-dimensional induction problems. *Geophys. J. R. Astr. Soc.*, 47:375-396

REFERENCES

- Cagniard, L, 1953, Basic theory of the magnetotelluric method of geophysical prospecting. *Geophysics*, 18:605–635.
- Caldwell, T. G., Bibby, H. M. and Brown, W., 2004, The magnetotelluric phase tensor. *Geophys. J. Int.*, 158:457–469.
- Commission on Volcanology, 1981, Catalogue of Philippine volcanoes and solfataric areas, *Technical report*, Comvol, Quezon City, Philippines.
- Constable, S. C., Parker, R. L. and Constable, C. G., 1987, Occam's inversion: A practical algorithm for generating smooth models from em sounding data. *Geophysics*, 52:289–300.
- Cumming, W., Nordquist, G. and Astra, D., 2000, Geophysical exploration for geothermal resource: An application for combine MT-TDEM 70th Ann. *International Mtg., Soc. of Expl. Geophys.*, 1071-1074
- deGroot-Hedlin, C. and Constable, S., 1990, Occam's inversion to generate smooth, two-dimensional models from magnetotelluric data. *Geophys.*, 55(12):1613–1624
- Dulce, R. G, 2001 Petrologic summary of well PT-5D. *Technical Report*, PNOC-EDC, Philippines
- Dulce, R. G, 2003 Petrology of well PT-7D. *Technical Report*, PNOC-EDC, Philippines
- Esperidion, J. A., Bien, O. C. and Camit, R. A., 2002, Well geology report PT-8D, Northern Negros Geothermal Project. *Technical Report*, PNOC-EDC, Philippines
- Gamble, T. D., Goubau, W. M. and Clarke, J., 1979, Magnetotellurics with a remote magnetic reference. *Geophysics*, 44:53–68
- Geosystem SRL, 2008, User's guide to WinGLink, Release 2.20.02.01, Milan, Italy

REFERENCES

- Gold, T., 1959, Motions in the magnetosphere of the earth. *J. Geophys. Res.*, 64(9):1219-1224
- Groom, R. W. and Bailey, R.C, 1989, Decomposition of magnetotelluric impedance tensors in the presence of local three-dimensional galvanic distortion. *J. Geophys. Res.*, 94(B2):1913-1925
- Heise, W., Caldwell, T. G., Bibby, H. M. and Bannister, S. C., 2008, Three-dimensional modeling of magnetotelluric data from the Rotokawa Geothermal Field, Taupo Volcanic Zone, New Zealand, *Geophys. J. Int.*, 173:740–750
- Ingham, M. R., Bibby, H. M., Heise, W., Jones, K. A., Cairns, P., Dravitzki, S., Bennie, S. L. , Caldwell, T. G. and Ogawa, Y., 2005, A magnetotelluric study of Mount Ruapehu Volcano, New Zealand. *Geophys. J. Int.*, 179:887–904
- Jara, M. P., 2010, Geology of MY-1D. *Technical Report*, EDC, Philippines
- Johnston, J. M., Pellerin, M. and Hohmann, G. W., 1992, Evaluation of electromagnetic methods for geothermal reservoir detection. *Geothermal Resource Council Transactions*, 16:241–245
- Jones, A.G., 1983, On the equivalence of the Niblett and Bostick transformations in the magnetotelluric method. *J. Geophys*, 53:72–73
- Ledo, J., 2005, 2-D vs. 3-D magnetotelluric data interpretation. *Surveys in Geophys.*, 26:511–543
- Madden, T. R. and Mackie, R. L., 1989, Three-dimensional magnetotelluric modeling and inversion. *IEEE*, 77(2): 318–330
- Maneja, F. C., Los Banos, C. F., Layugan, D. B., Apuada, N. A. and Rigor, D. M., Jr., 2001, Magnetotelluric survey in the Northern Negros Geothermal Field, Central Philippines. *Technical report*, PNOC-EDC, Philippines

REFERENCES

- Ogawa, Y, 2002, On two-dimensional modeling of magnetotelluric field data, *Surveys in Geophysics*, 23(2-3):251-273
- Pamatian, P. I., 1994, Geology of well PT-1D, Northern Negros Geothermal Prospect, Mt. Canlaon, Negros Occidental, *Technical report*, PNOC-EDC, Philippines
- Pamatian, P. I. and Camit, R. A., 1995, Geology of well CT-1D, Northern Negros Geothermal Prospect, Mt. Canlaon, Negros Occidental, *Technical report*, PNOC-EDC, Philippines
- Pamatian, P. I., Salonga, N. D. and Tebar, H. J., 1992, The geology of Northern Negros Geothermal Prospect, Mt. Canlaon, Negros Occidental, *Technical report*, PNOC-EDC, Philippines
- Panem, C. C. and Leynes, R. D. C., 1996, Faults and lineaments in Northern Negros Geothermal Area, *Technical report*, PNOC-EDC, Philippines
- Parkinson, W. D., 1962, The influence of continents and oceans on geomagnetic variations, *Geophys. Journal of the Royal Astronomical Society*, 6:441-449
- Phoenix Geophysics Limited, 2005, Data processing user guide V. 3.0, Toronto, Canada
- PNOC-EDC, 1998, Northern Negros Geothermal Project-resource assessment update, *Technical report*, PNOC-EDC, Philippines
- Reyes, A. G., 1979, Geology of Mambucal-1 exploratory well, Mambucal, Murcia, Negros Occidental. *Technical report*, PNOC-EDC, Philippines
- Rigor, D. M., Jr. and Los Banos, C. F., 1997, Regional gravity survey in the Northern Negros Geothermal Project, Mt. Canlaon, Central Philippines. *Technical report*, PNOC-EDC, Philippines

REFERENCES

- Rodi, W. and Mackie, R. L., 2001, Nonlinear Conjugate Gradients algorithm for 2-D magnetotelluric inversion. *Geophysics*, 66(1):174–187
- Sasaki, Y., 2001, Full 3D inversion of electromagnetic data on PC. *J. Appl. Geophys.*, 46:4554.
- Siripunvaraporn, W., Egbert, G. and Lenbury, Y. and Uyeshima, M., 2005, Three-dimensional magnetotelluric inversion: data-space method, *In: Physics of the Earth and Planetary Interiors*, 150:3-15
- Siripunvaraporn, W., Egbert, G., Uyeshima, M., 2006, WSINV3DMT version 1.0.0 for single processor machine, Bangkok, Thailand
- Siripunvaraporn, W., 2011, Three-dimensional magnetotelluric inversion: An introductory guide for developers and users, *Surv. Geophys.*, 33:5-27
- Society of Exploration Geophysics, 1991, MT/EMAP data interchange standard
- Sternberg, B. K., Washburne, J. C. and Pellerin, L., 1988, Correction for the static shift in magnetotellurics using transient electromagnetic soundings, *Geophysics*, 53:1459–1468
- Swift, C. M. Jr, 1967, A magnetotelluric investigation of an electrical conductivity anomaly in the Southwestern United States, *PhD thesis*, Mass. Inst. of Technology
- Technical Services Sector, 2010, Reassessment of Northern Negros Geothermal Resource. *Technical report*, EDC, Philippines
- Tikhonov, A. N, 1950, The determination of the electrical properties of deep layers of the earth's crust. *Dokl. Acad. Nauk. SSR*, 73:295–297
- Uchida, T., 2005, Three-dimensional magnetotelluric investigation in geothermal fields in Japan and Indonesia. *Proceedings, World Geothermal Congress 2005*, Antalya, Turkey

REFERENCES

- Wannamaker, P. E., Hohmann, G. W. and Ward, S. H., 1984, Magnetotelluric responses of three-dimensional bodies in layered earths, *Geophys.*, 49(9):1517-1533
- Vozoff, K., 1991, The magnetotelluric method, *In: Electromagnetic methods in applied geophysics II (ed.) M. N. Nabighian*, Soc. of Explo. Geophys., V.2

Appendix I: Data curves and phase tensor analysis

NNG-01

NNG-02

NNG-03

NNG-04

NNG-05

NNG-06

NNG-07

NNG-08

NNG-09

NNG-10

NNG-11

NNG-12

NNG-13

NNG-14

NNG-15

NNG-16

NNG-17

NNG-18

NNG-19

NNG-20

NNG-21

NNG-22

NNG-23

NNG-24

NNG-25

NNG-26

NNG-27

NNG-28

NNG-29

NNG-30

NNG-31

NNG-32

NNG-33

NNG-34

NNG-35

NNG-37

NNG-39

NNG-41

NNG-42

NNG-43

NNG-44

NNG-45

NNG-46

NNG-47

NNG-48

NNG-49

NNG-50

NNG-51

NNG-53

NNG-54

NNG-55

NNG-56

NNG-57

NNG-58

NNG-59

NNG-60

NNG-61

NNG-62

NNG-63

NNG-64

NNG-66

NNG-67

NNG-68

NNG-69

NNG-70

NNG-71

NNG-73

NNG-75

NNG-76

NNG-77

NNG-80

NNG-81

NNG-82

NNG-83

NNG-84

NNG-85

NNG-86

NNG-88

NNG-89

NNG-91

NNG-92

NNG-93

NNG-94

NNG-95

NNG-96

NNG-97

NNG-98

NNG-99

NNG-100

NNG-101

NNG-102

NNG-103

NNG-104

NNG-105

NNG-106

NNG-107

NNG-108

NNG-109

NNG-110

NNG-111

NNG-112

NNG-113

NNG-115

NNG-116

NNG-118

NNG-119

NNG-120

NNG-122

NNG-123

NNG-124

NNG-125

NNG-127

NNG-129

NNG-131

NNG-133

NNG-134

NNG-137

NNG-138

NNG-140

NNG-141

NNG-142

NNG-143

NNG-144

NNG-145

NNG-146

NNG-147

NNG-148

NNG-149

NNG-150

NNG-151

NNG-153

NNG-154

NNG-155

NNG-156

NNG-157

NNG-158

Appendix II: MT data description

Station ID	Data description and analysis	Rank	Semi-major angle (deg)
1	Reliable data up to 100 s but missing data points between 7 to 20 s; very small shift between TE and TM curves	2	
2	Data up to 100 s but reliable data is only until 0.8 s; TE and TM curves have minimal shift and show 1-D characteristic at short periods and 2-D at longer period	1	-10
3	Fair data up to 400 s but xy phase data is noisy from 100 s; almost no shift between curves but they split at about 100 s; 3-D at long periods	3	85
4	Data reaches up to about 200 s but contaminated by noise esp the phase between 2 to 20 s; TE and TM curves show minimum shift and show 1-D characteristic at periods less than 1s then 2-D at >10 s	2	-45
5	Reliable data only up to about 4s; TE and TM curves show minimum shift and 1D characteristic	1	

APPENDIX II: MT DATA DESCRIPTION

Station ID	Data description and analysis	Rank	Semi-major angle (deg)
6	Noisy data <0.01 s but reliable data up to 7 s; TE and TM curves have large static shift and show 1-D characteristic	1	
7	Reliable data up to 2 s ; No shift between TE and TM curves; 1-D characteristic	1	
8	Good data up to 200 s but with noise in between 5 s to 20 s; TE and TM curves show large shift; shows 2-D characteristics at short period and 3-D at longer period	3	-45
9	Data up to 200 s but distorted from >9 s; minimal shift between curves; 1-D at short periods <1 s but 3-D at >10 s	2	70
10	Good quality data up to >400 s with some missing and noisy data points between 7 s to 30 s; TE and TM curves show minimum shift and splits at 40 s; 1-D at <1 s and 3-D at >10 s	3	-85
11	Data up to 50 s but reliable data only up to about 4 s since data >4 s is either missing or noisy (phase); TE and TM curves show very minimum shift and 1-D characteristic	1	
12	Fair data up to >400 s with gaps in between 0.05 s to 0.1 s and 3 s to 14 s, and noisy phase data >200 s; TE and TM curves have small static shift and show 1-D characteristic at short period, 2-D at >10 s then 3-D at >100 s	2	60
13	Reliable data only up to 1 s ; Almost no shift between TE and TM curves; 1-D characteristic	1	

APPENDIX II: MT DATA DESCRIPTION

Station ID	Data description and analysis	Rank	Semi-major angle (deg)
14	Fair data up to 100 s but phase curve has some noise at <0.1 s and in between 7 s to 20 s; TE and TM curves show small shift; show 1-D characteristic at <1 s then 3-D at longer periods	2	80
15	Data up to 100 s but data is missing from 4 s to 20 s and phase data has large error bars >40 s; minimal shift between curves; 3-D at >10 s	1	0
16	Fair data up to 1 s; TE and TM curves show small shift and slightly 2-D characteristic	1	
17	Fair data up to 2 s; TE and TM curves show minimum shift and 1-D characteristic	1	
18	Data up to >200 s with gap in between 5 s to 14 s and noisy phase data >5 s. TE and TM curves have small static shift but splits at 0.4 s; 3-D characteristic at >2 s	2	90
19	Data extends to 200 s but with gap or noisy phase data between 6 s to 40 s; Almost no shift between TE and TM curves; 1-D characteristic at short periods but 3-D at longer periods	2	85
20	Reliable data only up to 7 s since phase data is scattered >7 s; TE and TM curves show small shift; shows 2-D characteristic	1	85
21	Data up to 2 s only; small shift between TE and TM mode curves; shows 2-D characteristic	1	10
22	Reliable data only from 0.02 s to about 3 s due to noise which is seen in phase data at <0.02 s and >3 s; small shift between TE and TM curves; 2-D at >1 s	1	-60

APPENDIX II: MT DATA DESCRIPTION

Station ID	Data description and analysis	Rank	Semi-major angle (deg)
23	Good data up to 5 s with some scattering in the phase >5 s to 100 s; small shift between TE and TM curves; 1-D characteristic at <1 s range then 2-D at longer period	3	-70
24	Data up to 200 s but with gap from 5 s to 30 s and noisy data >100 s; has a significant shift between the TE and TM curves; 2-D at >20 s	2	-25
25	Reliable data up to about 200s with some noise at the lower end; significant shift between TE and TM curves; 1-D at short periods then 2-D at longer periods	3	65
26	Data only up to 2 s; large shift between TE and TM mode curves; shows 2-D characteristic	1	80
27	Reliable data up to 400 s with gap from 3 s to 14 s and some noise shown by the phase at the lower end; small static shift between the TE and TM curves; 2-D characteristic esp at longer periods	3	60
28	Data only up to about 2 s with small shift between TE and TM curves; Almost 1-D characteristic	1	
29	Good data up to 400 s with some noise from 2 s to 10 s range; large shift between TE and TM curves that split at 20 s; 3-D feature at >100 s	3	-75
30	Data up to 300 s but with gap from 3 s to 10s and noisy data >100 s; has a significant shift between the TE and TM curves; 2-D at >10 s	2	40

APPENDIX II: MT DATA DESCRIPTION

Station ID	Data description and analysis	Rank	Semi-major angle (deg)
31	Data up to about 80 s with gap in between 3 s to 30 s; significant shift between TE and TM curves; thicker conductive layer compared to other data; 2-D feature	2	40
32	Data up to about 100 s with gap between 3 s to 13 s and noise esp. in the phase data at >13 s; TE and TM mode curves has small shift and splits at about 0.5 s; 2-D characteristic even at short period	1	0
33	Data only up to 3 s; very small static shift between the TE and TM curves; Almost 1-D characteristic all throughout	1	
34	Similar to stn 33; data only up to 3 s; very small static shift between the TE and TM curves; Almost 1-D characteristic	1	
35	Relatively poor data all throughout with gaps at low period and noise in the phase data at >1 s; large shift between TE and TM curves; 2-D characteristic	1	-75
37	Good data up to 200 s but with some scattering in the low period range <0.1 s ; TE and TM curves has very small shift and splits at 3 s; 2-D characteristic	3	-55
39	Data up to 100 s with gap in between 0.01 s to 0.04 s and noise >2 s; TE and TM curves hav a very small shift but splits at about 1 s; 3-D at >8 s	2	80

APPENDIX II: MT DATA DESCRIPTION

Station ID	Data description and analysis	Rank	Semi-major angle (deg)
41	Curve characteristic similar to stn 34; data only up to about 5s with gap between 0.01 s to 0.02 s; TE and TM mode curves has very small shift and shows almost 1-D	1	
42	Reliable data reaching up to >400 s with gap between 0.01 s and 0.04 s; TE and TM mode curves has very small shift but splits at 0.6 s; indicates a thick conductive layer; 1-D at short period but 2-D at >10 s	3	15
43	Good data up to about 200 s with gap between 0.01 s to 0.04 s; very small static shift between the TE and TM curves but split at about 80 s; a thick conductive layer is indicated; 2-D characteristic	3	-80
44	Data is only up to 3 s and contaminated by noise; large shift between TE and TM curves	1	
45	Data is only up to 1 s with noise in the phase at <.01 s; large shift between TE and TM curves	1	
46	Data reaches up to 200 s but with noise in the phase data at >1 s; TE and TM curves have a very small shift	1	
47	Data only up to about 8 s with gap between 0.01 s to 0.04 s; TE and TM mode curves has very small shift and shows almost 1-D characteristic	2	
48	Good data reaching up to >400 s with gap between 0.007 s and 0.05 s; TE and TM mode curves has very small shift but splits at 4 s; 3-D at >100 s	1	90

APPENDIX II: MT DATA DESCRIPTION

Station ID	Data description and analysis	Rank	Semi-major angle (deg)
49	Data up to about 100 s but with gap between 4 s to 10 s and distorted at <1 s and >10 s; large static shift between the TE and TM curves; 3-D at >0.1 s	1	-20
50	Data is only up to 10 s with gap between 0.09 s and 0.3 s; very small shift between TE and TM curves	1	
51	Good data extending up to 300 s with noise in the phase at >100 s; small shift between TE and TM curves; 2-D at >1 s then 3-D at >100 s	3	0
53	Fair data reaching up to 30 s with increasing error bars in the phase at >2 s; large shift between TE and TM curves; shows 3-D characteristic at >1 s	2	-45
54	Fair data only up to about 8s with noisy data between 0.007 s to 0.1 s; TE and TM curves have very small shift	2	
55	Data up to >100 s but contaminated with noise; TE and TM mode curves show no shift	1	
56	Reliable data only up to about 3 s with significant static shift between the TE and TM curves that shows 1-D characteristic	1	
57	Data only up to 1 s with noise on the lower period range <0.1 s; small shift between TE and TM curves; shows 2-D effects on the longer period end	1	-85

APPENDIX II: MT DATA DESCRIPTION

Station ID	Data description and analysis	Rank	Semi-major angle (deg)
58	Data reaching up to 200 s but with scattered phase data starting at >2 s; very small shift between TE and TM curves; 3-D effects shown at >10 s	2	-85
59	Data only up to about 2 s; TE and TM curves have a large shift	1	
60	Very smooth data curve up to 400 s; TE and TM mode curves have small shift but splits at 3 s; shows >2 -D effects at 2 s and 3-D effects at >70 s	3	
61	Very good data reaching up to 700 s but with gap between 0.01 s to 0.04 s; TE and TM mode curves have large shift and splits at 1 s; 3-D characteristic at >10 s	3	90
62	Data up to about 9 s but relatively noisy at periods <0.1 s; almost no static shift between the TE and TM curves; shows 2-D characteristic	1	-90
63	Fair data up to about 100 s but with noise on the 5 s to 20 s period range; small shift between TE and TM curves; show 3-D effects at long periods	2	-85
64	Reliable data only up to about 2 s; TE and TM mode curves have very minimal shift and shows 1-D characteristic	1	
66	Data only up to about 0.7 s with gap between periods 0.01 s to 0.07 s range; TE and TM curves have no shift and show 1-D characteristic	1	
67	Relatively good data up to 500 s with gap between 0.01 s to 0.05 s range; TE and TM mode curves have small shift and splits at 3 s; shows 3-D effects at >100 s	3	15

APPENDIX II: MT DATA DESCRIPTION

Station ID	Data description and analysis	Rank	Semi-major angle (deg)
69	Noisy data up to about 2 s only with gaps on the lower period range <0.1 s; TE and TM mode curves have small shift	1	
70	Data only up to about 4 s with noise and inconsistencies in the phase data; very small static shift between the TE and TM curves; 1-D characteristic	1	
71	Data extend up to about 300 s but is relatively noisy esp. the phase curve making it unreliable at longer periods; large shift between TE and TM curves	1	
73	Data reaches up to about 100 s but has gaps between 0.01 s to 0.1 s and is noisy/scattered (phase) at >10 s; large shift between TE and TM curves	1	
75	Data reaches up to about 50 s but highly distorted and noisy starting at >8 s; very large shift between TE and TM curves	1	
76	Relatively good data up to 40 s with noise present >10 s; TE and TM mode curves have small	2	
77	Data up to about 100 s but with gap between 3 s to 14 s and large phase error bars starting at >10 s; TE and TM mode curves have small shift and is almost 1-D at periods <1 s and 3-D at >10 s	2	-45
80	Data extend to 300 s but with missing data points from 0.9 s to 11 s and scattered phase data at >90 s; large static shift between the TE and TM curves	1	

APPENDIX II: MT DATA DESCRIPTION

Station ID	Data description and analysis	Rank	Semi-major angle (deg)
81	Very smooth data curve extending up to about 400 s; almost no static shift but TE and TM curves split at about 0.1 s; shows 2-D effects at periods >1 s	3	-90
82	Almost similar in configuration to station 81 but noisier with larger error bars at periods >100 s; small shift between TE and TM modes; 2-D effects are indicated even on the short periods	3	
83	Relatively good data that extends to about 700 s; large shift between TE and TM curves; similar configuration with Stn 81 but with the curve modes interchanged; 2-D effects at periods of about >50 s	3	45
84	Similar to station 83 but smoother and has smaller static shift between TE and TM curves; 2-D effects at >20 s; curve level at about 20 ohm-m indicates very thick conductor	3	30
85	Fair data reaching up to about 500 s but with gap between 2 s to 8 s; TE and TM mode curves have very small shift; similar curve configuration to stations 83 and 84 except for the steeper resistivity gradients; 3-D effects at periods >10 s	3	-65
86	Data extends to 100 s but with missing data points from 3 s to 20 s; very large static shift between the TE and TM curves; show 3-D effects at periods >10 s	2	-60
88	Data only up to about 3 s with a considerable static shift between the TE and TM curves; 2-D effects even at short periods	1	0

APPENDIX II: MT DATA DESCRIPTION

Station ID	Data description and analysis	Rank	Semi-major angle (deg)
89	Relatively noisy data up to about 2 s; large shift between TE and TM modes	1	
91	Noisy data up to 1 s with large static shift between TE and TM modes	1	
92	Data up to periods of about 2 s but <0.1 s saturated by noise and with small shift between TE and TM curves	1	
93	Data up to about 100 s but missing data points between 2 s to 20 s and noisy starting at >3 s; very large shift between TE and TM curves; highly distorted (2-D effects) even at high frequency range	1	-85
94	Data up to period of 1000 s but is noisy and scattered at >100 s; TE and TM curves have significant shift and show 3-D characteristic at long periods	2	-85
95	Data extend up to 1000 s but is highly distorted and noisy starting at >1 s; very large static shift between TE and TM curves; 2-D effects at short periods	1	0
96	Relatively good data >500 s with noisy data from 2 s to 100 s range; TE and TM curves have a small shift and exhibit 1-D characteristic at short periods (<1 s) and 3-D effects at long periods	3	85
97	Reliable data up to about 200 s with noise from 5 s to 20 s; TE and TM curves show minimum shift; 2-D effects starting at >0.5 s	3	-15

APPENDIX II: MT DATA DESCRIPTION

Station ID	Data description and analysis	Rank	Semi-major angle (deg)
98	Reliable data only up to about 2 s; TE and TM curves have large static shift and show distortion even at lower periods	1	5
99	Data extend up to periods of about 1000 s but noisy from 2 s to 20 s and >200 s; Large shift between TE and TM curves; Highly distorted even at short periods; 3-D effects at >10 s	2	-60
100	Reliable data only up to about 2s; TE and TM curves show large shift; shows 2-D characteristic at short periods	1	25
101	Data extend up to 1000 s but is highly distorted and noisy starting at >0.2 s; very large static shift between TE and TM curves; 3-D effects at >30 s	1	-30
102	Relatively good data that extends to >500 s but with noisy data from 2 s to 25 s range; TE and TM curves have a large shift; 2-D effects at 0.03 s to 0.2 s and 3-D effects at >7 s	3	-80
103	Relatively good data that extend to periods >100s but with noisy portion from 2 s to 20 s; TE and TM curves have a large shift; shows 3-D characteristic at >100 s	3	60
104	Data is noisy starting at >0.2 s; TE and TM curves have small shift; 3-D effects at >3 s	1	-85
105	Data reaches up to >300 s but is noisy esp. at mid range of 0.2 s to 20 s; TE and TM curves have large shift; highly distorted even at short periods	1	-85

APPENDIX II: MT DATA DESCRIPTION

Station ID	Data description and analysis	Rank	Semi-major angle (deg)
106	Smooth data curves reaching up to >100 s with some noise in the xy curve; TE and TM curves show minimum shift and splits at about 0.2 s; shows 1-D at short periods and 2-D/3-D effects at >1 s	3	-85
107	Fair data up to periods >200 s with noisy data in the range of 0.2 s to 20 s; TE and TM curves show minimum shift; 3-D effects at long periods	2	-85
108	Relatively good data reaching up to >200 s with noise in the 2 s to 20 s range and >70 s esp in the yx curve; TE and TM curves show small shift and show 1D characteristic at short periods then 2-D/3-D effects at periods >0.6 s	1	
109	Data up to >200 s but is noisy esp from 0.2 s to 30 s; small shift between TE and TM curves; 3-D effects at long periods	2	85
110	Data up to about 7 s but is noisy all throughout; TE and TM curves have large shift and highly distorted (2-D effect) at short periods	1	
111	Reliable data only up to about 2 s; TE and TM curves have large shift and show 1-D characteristic at short periods and 2-D at 1 s	1	45
112	Data extends only up to about 0.4 s but noisy; TE and TM curves show large shift	1	
113	Reliable data only up to about 0.7 s; TE and TM curves show large shift	1	
115	Reliable data only up to about 2 s; TE and TM curves show large shift and 1-D characteristic at short periods	1	

APPENDIX II: MT DATA DESCRIPTION

Station ID	Data description and analysis	Rank	Semi-major angle (deg)
116	Reliable data only up to about 2 s; TE and TM curves show small shift and 1-D characteristic at short periods	1	
118	Reliable data only up to about 1 s because of high noise at periods >1s; TE and TM curves have almost no shift and show 1-D characteristic at shorter periods	1	
119	Reliable data only up to about 0.3 s; very small shift between TE and TM curves	1	
120	Relatively good data up to about 200 s but with noise from 1 s to 10 s; TE and TM curves show large shift; 2-D effects at periods >20 s	3	-40
122	Reliable data only up to about 1 s; TE and TM curves show small shift; 2-D effects even at short periods	1	-10
123	Extremely noisy data even at the lower period range; high noise signal is suspected to be caused by its proximity to a cell-site tower		
124	Another station that is located near a cellsite tower; extremely noisy with scattered phase curves		
125	Reliable data is only up to about 1 s; TE and TM curves have a very large shift	1	
127	Reliable data is only up to about 0.5 s since it is highly noisy and scattered at longer periods; a large shift between curves	1	

APPENDIX II: MT DATA DESCRIPTION

Station ID	Data description and analysis	Rank	Semi-major angle (deg)
129	Reliable data can be retrieved up to about 30 s since it is highly noisy and scattered at longer periods; large shift between curves; highly distorted at longer periods	2	-45
131	Reliable data only up to about 1 s; TE and TM curves show small shift and 1-D characteristic at short periods	1	
133	Very good data up to about 200 s when scattering of the xy phase curve starts to occur; noisy data is also present from 2 s to 8 s (indicated by the hump); TE and TM curves have large static shift; shows 3-D effects at periods >80 s	3	65
134	Relatively good data up to about 500 s but noise in 2 s to 20 s range; TE and TM curves have small shift and splits at about 30 s; 3-D effects are indicated at >10 s	3	-85
137	Relatively good data up to about 10 0s with higher noise saturation in the 2 s to 20 s range; TE and TM curves show almost no shift and splits at about 30 s; shows 3-D at >10 s	3	0
138	Data extends up to about 200 s but scattering occurs at higher periods; large shift between TE and TM curves; shows almost 1-D at short periods and 3-D effects starting at > 1s	2	45
140	Reliable data is only up to about 2 s since scattering occurs at higher periods; small shift between TE and TM curves	1	

APPENDIX II: MT DATA DESCRIPTION

Station ID	Data description and analysis	Rank	Semi-major angle (deg)
141	Good data up to about 50 s with noisy section from 1 s to 12 s; TE and TM curves show large shift; 3-D is indicated at long periods	2	10
142	Reliable data is only up to about 1 s since scattering occurs at longer periods; TE and TM curves show very large static shift	1	
143	Good data up to periods >600 s but with noisy section from 1 s to 13 s; TE and TM curves show almost no shift but splits at about 40 s; indicates 2-D at >80 s	3	-85
144	Reliable data is only until 0.8 s as extreme scattering occur at higher periods; TE and TM curves have very large shift; 2-D effects can be seen at short periods	1	-80
145	Fair data up to 100 s with gap 1s to 15 s because of noise; very small shift between curves; shows 3-D characteristic >10 s	2	-85
146	Reliable data only up to 1 s; scattering and large error bar at longer periods; TE and TM curves show very large shift; 2-D is indicated at short periods	1	-90
147	Fair data only up to about 200 s with noisy sections esp in the 2 s to 20 s range; TE and TM curves show minimum shift and 1-D characteristic at short periods but 3-D is indicated at longer periods	2	40

APPENDIX II: MT DATA DESCRIPTION

Station ID	Data description and analysis	Rank	Semi-major angle (deg)
148	Relatively good data until about 200 s with noisy data between 2 s to 20 s; TE and TM curves show large shift; 3-D is indicated at longer periods >100 s	3	0
149	Reliable data can be extracted up to about 200 s but with noisy section from 2 s to about 20 s; almost no shift between TE and TM curves; shows 3-D at long periods	2	70
150	Reliable data is only up to about 2 s; TE and TM curves show large shift	1	
151	Data up to 1 s marked by noise; very large static shift between TE and TM curves	1	
153	Data up to 1 s marked by noise and scattering; large static shift between TE and TM curves	1	
154	Fair data up to about 300 s but with noisy data from 2 s to 20 s; TE and TM curves show very large; 1-D is indicated at short periods and 3-D at periods >70 s	2	45
155	Reliable data only up to about 0.5 s; TE and TM curves have small static shift	1	
156	Reliable data only up to about 0.7 s; very large shift between TE and TM curves	1	
157	Reliable data only up to about 0.2 s; TE and TM curves show small shift	1	
158	Reliable data only up to about 1 s; very large shift between TE and TM curves	1	

Appendix III: Static shift correction applied

Station ID	xy	yx
1	1	1
2	0.512	0.645
3	1	1
4	0.615	0.564
5	1	1
6	1	0.698
7	1	1
8	3.072	1
9	1	1
10	0.82	0.775
11	1.705	1.287
12	1.185	1.754
13	1	1
14	1.881	1.753
15	0.42	0.491
16	1.915	2.082
17	1.107	1
18	4.99	5.411
19	1	1
20	1.888	2.111

APPENDIX III: STATIC SHIFT CORRECTION APPLIED

Station ID	xy	yx
22	0.816	0.864
23	1	1
24	1.047	1.254
25	1	1
26	1.296	1.293
27	0.801	1.546
28	1.159	1.277
29	0.241	0.273
30	1	1
31	1	1
32	1.648	1.296
33	1	1
34	1.04	1.231
35	0.618	0.799
37	1	1.187
39	1	1
41	1	1
42	0.883	0.876
43	0.647	0.583
44	0.87	0.481
45	1.846	1.861
46	2.488	3.805
47	1.467	1.191
48	1	1
49	1.376	1
50	1	1
51	1	1
53	0.846	0.734
54	1	1
55	1	1

APPENDIX III: STATIC SHIFT CORRECTION APPLIED

Station ID	xy	yx
56	0.339	0.332
57	1	1
58	1	1
59	1	1
60	1	1
61	1	1
62	1.224	1.691
63	0.878	0.857
64	1	1
66	1.236	1.383
67	0.768	0.874
68	0.641	1
69	0.824	0.908
70	1	1
71	0.9862	0.68
73	0.663	0.522
75	0.876	0.579
76	1	1
77	1	1
80	1.95	1.734
81	5.001	2.976
82	4.412	6.286
83	1.322	1.309
84	2.702	2.659
85	1	1
86	0.648	1
88	1.965	1
89	1.322	1.545
92	1.289	1.615
93	3.668	4.115

APPENDIX III: STATIC SHIFT CORRECTION APPLIED

Station ID	xy	yx
94	2.336	1.978
95	1.413	0.65
96	3.382	3.166
97	5.233	5.973
99	3.741	2.636
101	1	1.56
102	1.381	1.411
103	1.397	1.482
104	1.832	1.925
105	2.353	2.341
106	2.353	2.341
107	1.75	1.843
108	0.773	0.874
109	1.136	1.076
111	3.702	3.273
113	2.167	2.54
114	1	1
115	1.55	1.401
116	1.423	1.39
117	1	1
118	1	1
120	1	1
122	1.521	1.494
124	1.113	1.21
125	0.29	0.563
127	1	0.894
129	1.114	1
131	1	1
133	0.78	0.788
134	0.296	0.293

APPENDIX III: STATIC SHIFT CORRECTION APPLIED

Station ID	xy	yx
136	1	1
137	0.644	0.638
138	0.934	0.814
140	2.221	1.852
141	0.529	0.529
143	1	1
144	1.519	1.718
145	0.411	0.421
147	1	1
148	1.699	1.629
149	1.49	1.241
150	0.66	1.285
151	1	0.748
154	0.659	0.767
155	0.627	0.659
156	0.559	0.693
157	2.288	2.179
158	0.878	1.211

Appendix IV: 3-D inversion data file

APPENDIX IV: 3-D INVERSION DATA FILE

3-D inversion data file

37 14 8

Station_Location:N-S

2.75E+03	7.50E+02	7.50E+02	-2.50E+02	-1.25E+03	7.50E+02	-3.25E+03	-2.25E+03
7.50E+02	-7.50E+02	-1.25E+03	-7.50E+02	-2.50E+02	1.75E+03	1.75E+03	1.25E+03
2.25E+03	2.25E+03	2.75E+03	-1.75E+03	4.25E+03	4.25E+03	1.25E+03	7.50E+02
1.25E+03	2.25E+03	-2.50E+02	-7.50E+02	-1.25E+03	-1.75E+03	-2.75E+03	-1.25E+03
-1.75E+03	2.50E+02	-2.75E+03	-3.25E+03	-4.75E+03			

Station_Location:E-W

-2.50E+02	2.50E+02	1.25E+03	2.75E+03	3.75E+03	-2.75E+03	3.75E+03	-3.25E+03
-4.25E+03	-2.50E+02	7.50E+02	7.50E+02	-2.25E+03	2.50E+02	-1.75E+03	-7.50E+02
-2.75E+03	2.50E+02	7.50E+02	-2.25E+03	-2.50E+02	-1.75E+03	2.75E+03	2.75E+03
3.25E+03	1.25E+03	1.25E+03	1.75E+03	2.25E+03	2.25E+03	7.50E+02	-7.50E+02
2.50E+02	1.75E+03	-1.25E+03	7.50E+02	-2.50E+02			

DATA_Period: 6.90E-03

4.27E-03	2.78E-03	4.96E-02	-2.20E-01	-6.18E-02	2.19E-01	2.52E-03	-4.09E-03
-4.90E-03	-2.46E-02	1.32E-01	-4.00E-01	-2.03E-01	4.08E-01	1.06E-02	-2.66E-02
1.25E-02	8.03E-04	1.57E-01	-3.23E-01	-1.59E-01	3.37E-01	-1.41E-02	-1.18E-02
3.96E-03	3.76E-02	1.89E-01	-3.94E-01	-1.75E-01	3.11E-01	-8.78E-03	-2.58E-03
-2.26E-03	-3.96E-02	1.68E-01	-2.83E-01	-1.85E-01	2.97E-01	3.42E-02	-2.70E-03
7.92E-03	1.84E-02	1.25E-01	-3.50E-01	-1.29E-01	3.17E-01	-8.70E-03	-1.06E-02
-4.04E-03	-9.72E-03	1.73E-01	-2.27E-01	-1.75E-01	2.03E-01	4.50E-03	6.25E-03
5.00E-03	3.01E-03	1.17E-01	-2.90E-01	-1.09E-01	1.90E-01	-3.54E-03	1.51E-03
-1.25E-03	-1.67E-03	9.63E-03	-6.18E-02	-2.23E-02	3.97E-02	-7.34E-04	-3.08E-03
1.37E-02	2.44E-02	9.22E-02	-2.97E-01	-1.11E-01	2.80E-01	-2.56E-02	-1.86E-03
1.13E-03	-1.73E-02	1.40E-01	-3.20E-01	-1.67E-01	3.34E-01	1.38E-03	1.20E-02
-1.47E-02	-5.28E-03	8.02E-02	-2.61E-01	-9.51E-02	2.06E-01	-1.88E-03	-5.63E-05
-5.89E-03	5.84E-03	1.17E-01	-2.13E-01	-1.20E-01	2.02E-01	2.98E-03	7.84E-04
9.24E-03	-2.58E-03	9.88E-02	-2.17E-01	-9.79E-02	2.05E-01	-2.90E-03	-2.99E-03
5.54E-02	3.76E-02	1.41E-01	-4.44E-01	-1.25E-01	2.84E-01	-1.96E-02	6.34E-02
6.22E-02	-2.77E-02	1.02E-01	-3.44E-01	-2.14E-01	3.79E-01	2.48E-02	-5.19E-02
2.51E-02	-8.54E-04	1.22E-01	-2.32E-01	-8.74E-02	2.36E-01	9.61E-03	-2.96E-02
4.11E-03	2.88E-04	1.40E-01	-3.15E-01	-9.58E-02	3.75E-01	-7.60E-03	6.14E-03
7.26E-04	2.15E-02	1.50E-01	-3.44E-01	-1.97E-01	3.62E-01	2.54E-03	-3.03E-03
1.70E-03	9.00E-03	1.40E-01	-2.79E-01	-1.33E-01	2.73E-01	-5.05E-03	1.11E-02
-4.83E-03	-5.52E-04	5.06E-02	-2.09E-01	-6.13E-02	1.82E-01	5.34E-03	6.80E-03
-1.20E-03	7.17E-04	6.49E-02	-8.66E-02	-7.37E-02	1.14E-01	-2.69E-04	2.43E-04
-3.03E-03	6.77E-03	7.44E-02	-1.39E-01	-7.99E-02	9.26E-02	-2.02E-03	5.33E-03
9.18E-03	6.14E-03	7.39E-02	-2.50E-01	-9.42E-02	2.46E-01	2.72E-03	-8.11E-03
-6.53E-03	-3.38E-03	1.08E-01	-1.18E-01	-1.10E-01	1.14E-01	3.85E-03	1.11E-03
1.39E-02	5.97E-03	1.17E-01	-2.73E-01	-1.24E-01	2.81E-01	3.29E-03	-9.83E-03

APPENDIX IV: 3-D INVERSION DATA FILE

1.39E-02	1.12E-02	1.04E-01	-2.82E-01	-1.55E-01	2.61E-01	-6.67E-03	-6.63E-03
-3.88E-03	-2.99E-03	1.85E-01	-2.77E-01	-1.79E-01	2.84E-01	-5.69E-03	6.46E-04
8.65E-03	8.13E-03	1.30E-01	-2.27E-01	-1.27E-01	2.15E-01	-9.02E-03	-1.66E-02
1.64E-03	2.05E-03	1.14E-01	-1.24E-01	-1.14E-01	1.25E-01	-6.89E-03	-7.78E-03
-3.60E-03	-4.91E-03	1.31E-01	-3.25E-01	-1.34E-01	3.25E-01	6.58E-03	7.43E-03
2.38E-03	6.80E-03	1.21E-01	-2.18E-01	-1.12E-01	2.39E-01	-9.51E-04	-3.09E-03
1.21E-02	1.07E-02	1.35E-01	-2.66E-01	-1.35E-01	2.66E-01	-6.92E-03	-6.63E-03
-2.65E-03	-2.20E-03	1.63E-01	-3.51E-01	-1.58E-01	3.60E-01	3.35E-03	6.83E-03
-4.39E-03	-3.15E-03	1.41E-01	-2.42E-01	-1.47E-01	2.29E-01	1.39E-03	2.30E-03
-7.43E-04	8.75E-03	8.70E-02	-1.80E-01	-8.05E-02	1.88E-01	1.11E-04	-1.72E-03
-4.89E-04	6.20E-03	1.06E-01	-1.82E-01	-1.08E-01	2.03E-01	6.86E-03	1.50E-02
DATA_Period:	2.08E-02						
3.32E-04	1.55E-04	2.21E-02	-8.81E-02	-1.56E-02	8.56E-02	8.73E-04	-2.93E-03
-1.05E-03	3.79E-03	4.42E-02	-1.24E-01	-4.14E-02	1.34E-01	-2.39E-03	-3.21E-03
-2.18E-03	-1.01E-03	5.34E-02	-1.33E-01	-5.69E-02	1.43E-01	4.59E-04	-3.71E-04
4.18E-03	1.25E-02	5.63E-02	-1.71E-01	-6.16E-02	1.39E-01	-5.64E-03	-4.19E-03
2.20E-03	-6.98E-03	7.04E-02	-1.24E-01	-5.38E-02	1.35E-01	-1.03E-02	-5.72E-03
1.99E-03	-2.23E-03	4.50E-02	-1.54E-01	-3.85E-02	1.45E-01	1.03E-02	-5.01E-03
-2.87E-03	-3.87E-03	7.77E-02	-1.15E-01	-8.03E-02	9.57E-02	3.59E-03	6.22E-03
4.73E-03	8.30E-04	5.40E-02	-1.21E-01	-4.59E-02	9.33E-02	-2.68E-03	-3.56E-04
-1.25E-03	-1.67E-03	9.63E-03	-6.18E-02	-2.23E-02	3.97E-02	-7.34E-04	-3.08E-03
-5.98E-03	2.59E-03	8.02E-02	-2.09E-01	-8.36E-02	2.08E-01	-4.43E-03	6.30E-03
-1.16E-04	-2.35E-02	1.05E-01	-2.36E-01	-1.09E-01	2.56E-01	5.05E-03	-5.03E-04
-7.08E-04	-4.91E-03	3.16E-02	-1.06E-01	-2.83E-02	7.04E-02	2.60E-03	2.53E-04
-2.04E-03	5.86E-04	2.20E-02	-5.36E-02	-2.35E-02	5.26E-02	3.35E-04	-3.29E-04
-3.36E-03	-2.13E-03	3.40E-02	-8.48E-02	-2.87E-02	8.67E-02	5.27E-03	1.12E-03
9.61E-03	-1.06E-02	2.46E-02	-1.31E-01	-2.25E-02	1.43E-01	2.25E-03	-3.22E-03
-6.37E-03	1.47E-02	6.53E-02	-1.95E-01	-7.99E-02	1.32E-01	-8.60E-03	1.15E-02
4.74E-03	-7.05E-03	4.01E-02	-9.23E-02	-2.89E-02	7.40E-02	-1.98E-03	-1.02E-02
2.06E-04	-1.41E-04	3.56E-02	-1.07E-01	-2.82E-02	1.20E-01	-1.84E-03	4.08E-03
7.34E-03	-1.29E-02	8.42E-02	-2.45E-01	-1.06E-01	2.32E-01	1.77E-03	-1.80E-02
5.54E-03	7.00E-03	8.86E-02	-1.85E-01	-7.81E-02	1.65E-01	-1.61E-03	7.73E-03
-2.92E-04	-7.16E-04	1.97E-02	-7.87E-02	-2.13E-02	7.28E-02	1.77E-03	2.46E-03
-7.73E-04	-9.16E-04	2.76E-02	-3.92E-02	-2.52E-02	4.86E-02	1.01E-03	1.13E-03
-2.68E-05	3.09E-03	2.01E-02	-5.57E-02	-2.51E-02	4.62E-02	-4.98E-04	1.55E-03
-4.74E-03	1.95E-03	4.49E-02	-1.15E-01	-4.18E-02	1.14E-01	3.12E-03	5.93E-04
-6.42E-04	-2.00E-03	5.00E-02	-5.00E-02	-4.72E-02	5.73E-02	9.01E-04	2.90E-03
2.08E-03	3.92E-03	9.27E-02	-2.10E-01	-9.79E-02	2.17E-01	-1.22E-03	-5.83E-03
1.46E-03	5.06E-03	2.67E-02	-1.30E-01	-6.18E-02	1.37E-01	-4.19E-03	9.12E-04
6.81E-03	2.71E-03	8.01E-02	-1.51E-01	-7.01E-02	1.48E-01	-5.57E-03	-1.89E-06
4.57E-03	3.65E-03	6.93E-02	-1.20E-01	-4.95E-02	1.15E-01	4.17E-04	-1.37E-02
1.35E-03	4.32E-03	5.89E-02	-7.84E-02	-6.00E-02	7.53E-02	-4.55E-03	-3.40E-03

APPENDIX IV: 3-D INVERSION DATA FILE

-1.79E-03	-2.42E-03	6.20E-02	-1.56E-01	-5.12E-02	1.53E-01	2.00E-03	2.41E-03
2.16E-03	4.13E-03	5.00E-02	-1.09E-01	-4.79E-02	1.15E-01	-1.10E-03	-1.20E-03
1.14E-02	6.27E-03	5.84E-02	-1.34E-01	-6.15E-02	1.33E-01	-4.59E-03	-4.76E-03
-6.87E-04	2.72E-04	5.95E-02	-1.59E-01	-5.51E-02	1.54E-01	9.57E-04	2.08E-03
-2.00E-03	-2.22E-03	6.09E-02	-1.25E-01	-5.89E-02	1.23E-01	-1.68E-05	1.68E-03
2.10E-03	4.09E-03	3.50E-02	-8.52E-02	-3.33E-02	8.60E-02	-1.00E-03	-1.39E-03
1.46E-03	1.77E-03	4.99E-02	-9.23E-02	-4.60E-02	1.00E-01	1.25E-03	3.92E-03
DATA_Period:	4.17E-02						
9.94E-04	-6.71E-04	1.29E-02	-4.69E-02	-1.32E-02	4.79E-02	1.21E-03	-2.62E-03
-3.85E-04	1.75E-03	2.94E-02	-7.53E-02	-2.74E-02	7.58E-02	8.62E-04	-1.93E-03
1.45E-03	4.40E-04	3.09E-02	-7.62E-02	-3.24E-02	7.88E-02	-3.44E-04	-7.26E-04
1.57E-03	5.43E-03	3.35E-02	-9.73E-02	-3.67E-02	8.20E-02	-1.36E-03	-1.78E-03
3.81E-03	-6.00E-04	3.21E-02	-7.74E-02	-3.32E-02	7.94E-02	-2.50E-03	-2.41E-03
1.21E-03	1.86E-03	3.07E-02	-8.70E-02	-2.81E-02	8.37E-02	-1.45E-03	-1.37E-03
-2.60E-04	-1.87E-03	5.65E-02	-7.12E-02	-5.78E-02	6.64E-02	2.92E-03	3.20E-03
3.46E-03	1.76E-03	2.40E-02	-7.41E-02	-2.87E-02	5.67E-02	-1.30E-03	-1.96E-04
-1.25E-03	-1.67E-03	9.63E-03	-6.18E-02	-2.23E-02	3.97E-02	-7.34E-04	-3.08E-03
1.23E-03	3.15E-03	2.41E-02	-7.31E-02	-2.12E-02	7.40E-02	-5.60E-04	3.46E-03
8.50E-04	-4.68E-03	2.91E-02	-8.61E-02	-3.17E-02	9.35E-02	3.13E-03	2.90E-03
4.17E-04	-3.60E-03	1.68E-02	-6.32E-02	-1.50E-02	4.28E-02	1.36E-03	-1.33E-03
-2.04E-03	5.86E-04	2.20E-02	-5.36E-02	-2.35E-02	5.26E-02	3.35E-04	-3.29E-04
-3.07E-04	-3.07E-05	1.96E-02	-5.34E-02	-1.80E-02	5.41E-02	-5.06E-04	5.44E-04
-2.47E-03	-9.37E-03	2.76E-02	-8.79E-02	-7.60E-03	8.96E-02	5.35E-03	1.55E-02
-1.09E-03	1.80E-03	4.02E-02	-1.00E-01	-2.20E-02	8.69E-02	-1.08E-03	4.62E-03
1.18E-03	-1.16E-03	2.88E-02	-6.75E-02	-2.77E-02	7.03E-02	1.72E-03	-1.20E-03
-9.39E-05	-2.34E-04	2.44E-02	-7.99E-02	-2.32E-02	9.35E-02	-1.24E-03	2.76E-03
-7.71E-04	1.60E-03	3.34E-02	-1.06E-01	-3.54E-02	9.77E-02	-2.87E-03	-4.93E-03
-2.12E-03	1.46E-03	2.19E-02	-5.16E-02	-3.01E-02	5.20E-02	8.62E-03	3.23E-03
8.08E-04	-5.67E-04	1.34E-02	-4.59E-02	-1.12E-02	4.10E-02	1.15E-03	1.79E-03
-7.35E-04	-1.19E-03	2.18E-02	-3.01E-02	-1.92E-02	3.69E-02	1.74E-03	1.75E-03
-2.20E-03	-1.28E-04	1.05E-02	-2.89E-02	-1.35E-02	2.66E-02	6.69E-04	1.21E-03
1.46E-03	2.08E-03	3.22E-02	-7.13E-02	-3.45E-02	6.98E-02	-9.87E-04	-2.84E-03
-2.59E-04	-5.27E-04	3.96E-02	-4.20E-02	-3.67E-02	4.84E-02	5.33E-04	2.18E-03
5.97E-04	1.21E-03	2.40E-02	-7.20E-02	-2.40E-02	7.30E-02	-2.53E-03	-2.52E-03
-1.30E-03	-2.56E-04	1.45E-02	-6.93E-02	-3.07E-02	7.87E-02	-1.26E-04	1.44E-03
6.54E-04	1.80E-03	3.48E-02	-8.83E-02	-3.48E-02	8.28E-02	-3.08E-03	3.01E-04
1.63E-03	1.85E-03	3.91E-02	-7.33E-02	-2.25E-02	6.53E-02	1.36E-03	-9.95E-03
2.49E-04	3.49E-03	3.12E-02	-5.15E-02	-3.44E-02	4.91E-02	-2.62E-03	-1.12E-03
3.71E-04	-8.76E-04	3.31E-02	-8.91E-02	-3.21E-02	8.57E-02	1.33E-03	1.09E-03
9.48E-04	2.36E-03	2.46E-02	-6.12E-02	-2.03E-02	6.38E-02	-1.58E-04	-1.23E-04
6.06E-03	3.05E-03	2.90E-02	-7.61E-02	-3.36E-02	7.63E-02	-2.31E-03	-2.99E-03
2.03E-04	5.62E-04	3.22E-02	-8.28E-02	-3.19E-02	7.70E-02	1.08E-03	1.23E-03

APPENDIX IV: 3-D INVERSION DATA FILE

	4.49E-04	-6.37E-04	3.02E-02	-7.26E-02	-3.12E-02	7.10E-02	-1.62E-03	2.78E-04
	1.21E-03	2.13E-03	1.69E-02	-4.62E-02	-1.57E-02	4.71E-02	-4.69E-04	-7.02E-04
	4.32E-04	1.48E-03	2.80E-02	-5.33E-02	-2.50E-02	5.74E-02	1.79E-03	1.44E-03
DATA_Period:	1.11E-01							
	-7.38E-05	-1.23E-04	5.21E-03	-1.50E-02	-5.59E-03	1.54E-02	-1.20E-04	-7.35E-04
	-4.36E-05	8.39E-04	1.19E-02	-3.36E-02	-1.05E-02	3.19E-02	-1.38E-03	-1.27E-03
	1.83E-03	-2.35E-04	1.71E-02	-3.48E-02	-1.73E-02	3.52E-02	-1.20E-03	-1.69E-03
	1.90E-04	7.37E-04	1.23E-02	-3.12E-02	-1.30E-02	2.93E-02	3.63E-05	-7.29E-04
	-5.36E-04	4.00E-04	1.44E-02	-3.65E-02	-1.40E-02	3.44E-02	-5.58E-04	3.96E-04
	2.87E-04	1.55E-03	1.44E-02	-3.96E-02	-1.57E-02	3.63E-02	-1.19E-03	-1.65E-03
	-2.92E-03	-9.68E-04	2.89E-02	-3.73E-02	-3.20E-02	3.85E-02	-1.02E-05	1.91E-03
	-9.32E-04	-7.36E-04	1.32E-02	-3.53E-02	-5.12E-03	3.13E-02	-1.78E-03	7.10E-05
	-1.87E-03	-2.85E-03	1.53E-02	-2.59E-02	-1.21E-02	2.42E-02	1.54E-03	-1.92E-03
	2.49E-04	8.18E-04	1.03E-02	-3.39E-02	-1.08E-02	3.34E-02	-2.99E-04	1.08E-03
	-3.63E-03	-5.38E-03	1.50E-02	-3.81E-02	-1.18E-02	4.19E-02	8.04E-05	-2.15E-03
	1.23E-03	-9.63E-04	1.26E-02	-3.28E-02	-9.31E-03	3.19E-02	-4.75E-04	-1.19E-03
	5.01E-04	1.35E-03	1.86E-02	-4.06E-02	-1.75E-02	4.01E-02	-4.17E-04	-6.36E-04
	-8.70E-05	1.66E-03	9.81E-03	-2.27E-02	-1.04E-02	2.25E-02	-2.86E-03	1.84E-05
	-9.34E-04	-1.93E-03	6.41E-03	-2.81E-02	-6.01E-03	2.80E-02	7.44E-04	1.13E-03
	8.39E-05	2.09E-03	1.39E-02	-3.35E-02	-1.20E-02	2.74E-02	1.66E-04	1.49E-03
	5.20E-04	-1.78E-03	8.80E-03	-2.37E-02	-7.45E-03	2.03E-02	1.34E-04	-1.91E-03
	3.43E-05	-3.17E-04	9.72E-03	-2.63E-02	-7.83E-03	2.94E-02	-1.93E-04	7.74E-04
	2.72E-04	8.54E-04	1.23E-02	-3.25E-02	-1.24E-02	3.20E-02	-8.54E-04	-1.38E-03
	-8.33E-04	-7.54E-04	1.38E-02	-3.45E-02	-1.68E-02	3.95E-02	-1.53E-04	-9.64E-04
	-3.79E-04	-4.54E-04	4.85E-03	-1.53E-02	-4.93E-03	1.34E-02	3.34E-04	2.67E-04
	-2.10E-06	1.93E-04	9.97E-03	-1.59E-02	-8.95E-03	1.81E-02	3.55E-04	7.19E-04
	5.06E-04	1.97E-04	9.71E-03	-1.10E-02	-1.00E-02	1.18E-02	-1.99E-04	-4.31E-04
	6.02E-04	-4.21E-04	1.95E-02	-2.63E-02	-1.34E-02	2.89E-02	1.77E-03	-1.81E-03
	2.78E-04	2.83E-04	2.48E-02	-2.48E-02	-2.10E-02	2.75E-02	5.98E-04	8.32E-04
	1.40E-03	1.54E-03	1.47E-02	-3.19E-02	-1.17E-02	3.47E-02	2.26E-03	9.39E-04
	4.75E-05	-1.74E-03	8.46E-03	-3.28E-02	-1.56E-02	3.92E-02	-6.06E-04	1.10E-04
	6.61E-07	1.18E-03	1.66E-02	-4.47E-02	-1.70E-02	4.19E-02	-1.52E-03	4.68E-04
	3.72E-04	1.13E-03	1.93E-02	-4.14E-02	-9.99E-03	3.24E-02	6.59E-04	-6.05E-03
	-4.87E-04	1.05E-03	1.59E-02	-2.87E-02	-1.80E-02	2.90E-02	6.54E-05	8.42E-04
	-2.43E-04	-2.01E-04	1.54E-02	-4.53E-02	-1.26E-02	4.14E-02	5.32E-04	1.10E-03
	2.31E-04	6.10E-04	1.18E-02	-3.16E-02	-1.10E-02	3.22E-02	1.09E-04	-3.81E-04
	2.65E-03	1.09E-03	1.24E-02	-3.85E-02	-1.61E-02	4.08E-02	-9.72E-04	-1.52E-03
	-6.05E-04	2.82E-04	1.84E-02	-4.11E-02	-1.74E-02	3.75E-02	6.61E-04	1.02E-03
	3.17E-05	-4.04E-04	1.45E-02	-3.81E-02	-1.44E-02	3.73E-02	2.10E-05	3.28E-04
	3.05E-04	9.26E-04	8.05E-03	-2.38E-02	-7.76E-03	2.37E-02	-1.98E-04	-3.67E-04
	1.25E-03	6.60E-04	1.64E-02	-2.89E-02	-1.28E-02	2.92E-02	2.09E-04	-4.22E-04
DATA_Period:	2.22E-01							

APPENDIX IV: 3-D INVERSION DATA FILE

-5.26E-05	-4.13E-05	4.58E-03	-1.16E-02	-4.69E-03	1.19E-02	-2.26E-04	-5.79E-04
6.84E-04	5.95E-04	7.95E-03	-1.88E-02	-6.88E-03	1.86E-02	-2.95E-04	-6.26E-04
4.33E-05	5.04E-05	1.26E-02	-2.07E-02	-1.23E-02	2.14E-02	-1.72E-04	-2.33E-04
1.26E-03	1.61E-03	9.97E-03	-2.47E-02	-1.11E-02	2.36E-02	-6.52E-04	-7.70E-04
2.63E-04	-9.47E-04	9.50E-03	-2.08E-02	-1.07E-02	2.12E-02	1.12E-03	-5.93E-05
4.63E-04	8.89E-04	8.58E-03	-2.44E-02	-1.04E-02	2.48E-02	-1.07E-03	-1.19E-03
4.93E-04	6.16E-04	1.98E-02	-2.56E-02	-2.18E-02	2.85E-02	-8.77E-04	-4.13E-04
5.14E-04	9.53E-05	6.17E-03	-1.95E-02	-7.09E-03	1.71E-02	9.63E-05	2.00E-04
-1.35E-04	-8.48E-04	9.32E-03	-1.73E-02	-8.66E-03	1.62E-02	-7.92E-04	-1.21E-03
-3.60E-05	8.41E-05	5.64E-03	-1.92E-02	-5.91E-03	1.88E-02	1.05E-03	8.19E-04
-3.81E-04	-1.16E-03	9.16E-03	-2.33E-02	-8.77E-03	2.40E-02	3.61E-04	7.12E-04
-4.42E-04	-4.32E-04	4.86E-03	-1.60E-02	-5.44E-03	1.31E-02	-2.05E-04	-3.98E-04
2.25E-04	5.12E-04	8.43E-03	-1.97E-02	-8.60E-03	1.95E-02	-2.85E-04	-4.49E-04
3.55E-07	2.34E-04	6.36E-03	-1.36E-02	-6.29E-03	1.46E-02	-5.10E-04	1.09E-04
-8.82E-04	-1.53E-03	5.21E-03	-2.19E-02	-5.00E-03	2.13E-02	7.63E-04	8.23E-04
-1.78E-03	-4.08E-04	8.42E-03	-2.41E-02	-6.16E-03	2.67E-02	-1.45E-03	-1.57E-04
3.56E-04	-9.81E-04	7.09E-03	-1.88E-02	-6.06E-03	1.74E-02	5.41E-04	-9.01E-04
-5.87E-05	-3.00E-04	8.29E-03	-2.04E-02	-7.04E-03	2.29E-02	-1.76E-04	6.10E-04
-1.85E-05	4.30E-04	1.12E-02	-2.53E-02	-1.04E-02	2.53E-02	-1.27E-04	-9.35E-04
3.68E-04	7.65E-04	6.55E-03	-1.97E-02	-7.42E-03	1.89E-02	1.03E-04	1.14E-03
-4.44E-04	-3.48E-04	3.94E-03	-1.19E-02	-4.32E-03	1.03E-02	2.70E-04	1.22E-04
-2.07E-04	-2.54E-04	7.06E-03	-1.05E-02	-5.60E-03	1.13E-02	3.50E-04	4.86E-04
-2.39E-05	3.25E-04	9.16E-03	-9.45E-03	-8.48E-03	1.01E-02	-4.02E-04	-1.61E-04
-4.12E-04	4.55E-04	1.81E-02	-2.26E-02	-1.08E-02	2.20E-02	-1.06E-03	2.76E-05
-1.71E-04	-2.79E-04	1.81E-02	-1.77E-02	-1.32E-02	1.96E-02	-1.79E-04	1.70E-04
-8.43E-04	-3.97E-04	9.44E-03	-1.96E-02	-7.98E-03	2.11E-02	-2.30E-04	-5.97E-04
3.15E-03	2.89E-03	3.58E-03	-1.95E-02	-9.92E-03	2.60E-02	-2.19E-03	4.08E-04
5.86E-04	2.08E-03	9.18E-03	-2.48E-02	-1.14E-02	2.31E-02	-2.46E-03	-8.24E-04
1.22E-03	8.47E-04	1.05E-02	-2.35E-02	-6.35E-03	1.79E-02	-3.99E-04	-4.07E-03
-9.38E-04	-2.56E-04	1.01E-02	-1.75E-02	-1.18E-02	1.75E-02	7.22E-04	9.91E-04
-4.80E-04	-1.03E-04	8.86E-03	-2.60E-02	-7.86E-03	2.64E-02	3.64E-04	1.37E-03
-9.85E-05	5.94E-04	6.19E-03	-1.87E-02	-5.65E-03	1.92E-02	-2.63E-04	-1.13E-04
1.36E-03	4.43E-04	7.29E-03	-2.26E-02	-9.30E-03	2.40E-02	-5.43E-04	-9.15E-04
-9.36E-04	-3.10E-04	1.36E-02	-2.48E-02	-1.29E-02	2.32E-02	6.02E-04	6.17E-04
-3.08E-04	2.71E-04	9.22E-03	-2.21E-02	-7.46E-03	2.17E-02	-9.11E-04	1.86E-04
1.64E-04	6.50E-04	4.61E-03	-1.39E-02	-5.49E-03	1.36E-02	-9.92E-05	-2.38E-04
9.90E-04	-2.65E-04	1.13E-02	-1.79E-02	-7.55E-03	1.67E-02	-2.81E-04	3.98E-04
DATA_Period:	4.44E-01						
-8.52E-05	7.85E-05	3.37E-03	-6.45E-03	-3.19E-03	6.75E-03	-4.27E-04	-4.38E-04
8.90E-04	4.82E-04	5.49E-03	-1.08E-02	-4.84E-03	1.05E-02	-5.02E-04	-5.73E-04
-1.16E-04	-1.30E-05	9.18E-03	-1.27E-02	-8.71E-03	1.32E-02	1.46E-05	-7.32E-05
-4.17E-05	6.50E-04	8.54E-03	-1.40E-02	-8.72E-03	1.44E-02	-9.26E-05	-2.85E-04

APPENDIX IV: 3-D INVERSION DATA FILE

-8.03E-04	-8.48E-05	8.21E-03	-1.26E-02	-7.61E-03	1.29E-02	1.54E-04	3.14E-04
3.22E-04	7.01E-04	4.39E-03	-1.42E-02	-5.96E-03	1.44E-02	-2.07E-04	-4.01E-04
8.86E-04	9.43E-04	1.52E-02	-1.71E-02	-1.53E-02	1.83E-02	-1.18E-03	-8.83E-04
2.68E-05	6.30E-05	3.81E-03	-1.15E-02	-4.28E-03	1.01E-02	6.82E-05	1.81E-04
-2.47E-04	-2.21E-04	5.22E-03	-1.08E-02	-5.45E-03	9.98E-03	-1.63E-04	-2.96E-04
1.17E-04	-1.02E-04	4.89E-03	-1.14E-02	-4.83E-03	1.10E-02	6.64E-04	4.16E-04
-1.24E-04	-7.80E-04	6.49E-03	-1.35E-02	-6.11E-03	1.38E-02	1.07E-04	3.05E-04
-3.50E-05	-1.85E-04	3.41E-03	-8.65E-03	-4.07E-03	8.03E-03	-1.46E-04	-3.50E-04
3.94E-04	3.50E-04	4.95E-03	-1.16E-02	-4.99E-03	1.18E-02	-1.85E-04	-2.75E-04
1.30E-04	-1.31E-05	4.84E-03	-7.86E-03	-4.13E-03	8.95E-03	-4.49E-04	-7.20E-05
-1.94E-04	-9.83E-04	4.20E-03	-1.20E-02	-3.91E-03	1.20E-02	2.18E-04	3.73E-04
-2.09E-03	-3.18E-03	5.60E-03	-1.95E-02	-1.17E-02	1.40E-02	-2.98E-03	-2.92E-06
-1.33E-04	1.14E-04	4.39E-03	-1.07E-02	-4.33E-03	1.12E-02	-1.89E-04	9.69E-05
-2.10E-04	-3.29E-04	5.37E-03	-1.15E-02	-5.08E-03	1.21E-02	-4.33E-06	3.26E-04
1.63E-04	5.68E-04	6.93E-03	-1.46E-02	-6.46E-03	1.50E-02	-4.49E-04	-5.69E-04
1.56E-04	1.68E-04	4.73E-03	-1.27E-02	-4.53E-03	1.17E-02	6.15E-05	3.00E-04
-2.78E-04	-2.40E-04	2.77E-03	-6.76E-03	-2.85E-03	5.92E-03	1.75E-04	8.22E-05
1.24E-04	-5.90E-05	5.24E-03	-6.87E-03	-3.72E-03	6.73E-03	5.68E-04	5.87E-04
4.99E-05	-1.04E-05	6.62E-03	-6.56E-03	-6.02E-03	7.28E-03	-1.27E-04	-1.70E-04
-1.59E-03	-6.50E-04	1.38E-02	-1.52E-02	-6.31E-03	1.60E-02	-1.80E-03	1.01E-03
5.36E-05	1.22E-04	1.33E-02	-1.29E-02	-8.81E-03	1.24E-02	8.21E-06	2.82E-04
-8.06E-04	-8.46E-04	6.61E-03	-1.19E-02	-5.35E-03	1.31E-02	1.62E-04	4.47E-05
2.07E-03	-2.86E-05	1.43E-04	-9.70E-03	-6.67E-03	1.37E-02	-1.53E-03	-3.69E-04
1.61E-04	7.01E-04	9.27E-03	-1.49E-02	-8.52E-03	1.53E-02	-9.10E-04	2.68E-04
1.14E-03	7.65E-04	7.05E-03	-1.39E-02	-3.91E-03	9.71E-03	-3.08E-04	-2.95E-03
2.63E-04	-8.07E-04	5.90E-03	-1.19E-02	-9.36E-03	1.01E-02	5.24E-04	8.41E-04
4.46E-04	1.73E-04	5.84E-03	-1.50E-02	-7.39E-03	1.38E-02	1.90E-04	6.51E-04
-4.34E-05	3.33E-04	4.12E-03	-1.17E-02	-3.88E-03	1.15E-02	6.34E-05	-1.35E-05
5.72E-04	8.93E-05	4.61E-03	-1.25E-02	-5.78E-03	1.35E-02	-1.36E-04	-5.07E-04
-8.05E-04	-2.64E-04	1.01E-02	-1.56E-02	-9.96E-03	1.49E-02	4.49E-04	4.30E-04
7.88E-04	3.64E-04	4.24E-03	-1.25E-02	-7.85E-03	1.45E-02	4.15E-04	-8.64E-05
-2.58E-05	4.19E-04	3.31E-03	-7.99E-03	-4.09E-03	8.02E-03	-6.84E-05	-1.49E-04
5.31E-04	-4.38E-04	8.49E-03	-1.15E-02	-5.32E-03	1.02E-02	-2.37E-04	6.28E-04
DATA_Period:	8.89E-01						
-1.29E-04	1.10E-04	2.65E-03	-3.72E-03	-2.49E-03	3.95E-03	-1.86E-04	-1.05E-04
6.48E-04	5.00E-04	3.69E-03	-6.47E-03	-3.68E-03	6.40E-03	-5.74E-04	-6.50E-04
-4.61E-04	-2.88E-04	6.64E-03	-8.30E-03	-5.98E-03	8.13E-03	2.26E-04	-6.57E-06
-2.71E-04	4.36E-04	6.10E-03	-8.31E-03	-5.77E-03	9.06E-03	-5.10E-05	-8.43E-05
-9.12E-04	2.14E-05	6.53E-03	-7.86E-03	-5.29E-03	-3.61E-05	5.77E-04	3.51E-04
3.42E-04	2.32E-04	2.74E-03	-7.95E-03	-3.86E-03	8.63E-03	-3.13E-04	-6.08E-04
1.01E-03	1.11E-03	1.14E-02	-1.14E-02	-1.00E-02	1.25E-02	-6.52E-04	-1.19E-03
3.30E-05	-1.58E-05	2.10E-03	-6.38E-03	-2.45E-03	5.91E-03	4.53E-05	7.37E-05

APPENDIX IV: 3-D INVERSION DATA FILE

6.40E-05	-4.55E-05	3.05E-03	-6.60E-03	-3.58E-03	6.05E-03	8.39E-05	-8.36E-05
2.87E-04	-4.59E-04	3.36E-03	-8.64E-03	-4.04E-03	8.04E-03	5.68E-04	1.98E-04
9.28E-05	-3.31E-04	4.77E-03	-8.06E-03	-4.85E-03	8.02E-03	-1.89E-04	1.92E-04
-1.10E-05	-2.58E-04	2.37E-03	-4.91E-03	-3.06E-03	5.07E-03	-6.65E-05	-3.23E-04
1.97E-04	2.03E-04	2.82E-03	-6.86E-03	-3.01E-03	6.83E-03	-5.34E-05	-1.49E-04
3.36E-05	9.56E-05	3.66E-03	-4.68E-03	-2.70E-03	5.16E-03	-3.40E-04	6.81E-05
8.87E-05	-5.95E-04	3.17E-03	-6.81E-03	-3.57E-03	7.21E-03	1.96E-04	5.89E-05
-5.52E-05	1.55E-04	4.60E-03	-8.62E-03	-3.46E-03	7.55E-03	2.78E-05	6.14E-05
-2.07E-04	1.26E-04	2.58E-03	-6.00E-03	-3.05E-03	6.71E-03	-1.39E-04	9.16E-05
-3.05E-04	-2.92E-04	3.75E-03	-6.87E-03	-3.92E-03	6.53E-03	2.42E-04	2.72E-04
-1.57E-04	3.66E-04	5.74E-03	-8.41E-03	-4.47E-03	8.84E-03	-1.30E-04	-2.28E-04
1.87E-04	1.29E-04	2.81E-03	-7.00E-03	-2.57E-03	6.65E-03	-1.27E-04	6.94E-05
-2.38E-05	-1.23E-04	2.09E-03	-3.77E-03	-1.96E-03	3.45E-03	1.09E-04	1.28E-04
2.09E-04	4.28E-05	3.07E-03	-4.08E-03	-2.19E-03	3.92E-03	9.67E-05	3.92E-06
-2.42E-04	-8.41E-05	5.16E-03	-4.47E-03	-4.27E-03	5.00E-03	-3.48E-05	-1.28E-05
-4.46E-04	-3.07E-04	9.93E-03	-1.06E-02	-5.56E-03	8.89E-03	-4.43E-04	2.28E-04
1.72E-04	-3.66E-04	9.16E-03	-9.05E-03	-5.97E-03	7.94E-03	5.69E-04	3.73E-04
-3.56E-04	-2.47E-04	4.63E-03	-6.78E-03	-3.74E-03	6.85E-03	4.41E-04	4.13E-04
-1.18E-04	-3.34E-04	4.72E-03	-6.85E-03	-5.66E-03	9.10E-03	1.19E-05	2.06E-04
-5.76E-04	4.62E-04	5.94E-03	-9.00E-03	-4.95E-03	9.05E-03	-3.40E-04	4.48E-04
5.67E-04	6.42E-04	4.73E-03	-8.85E-03	-4.15E-03	5.87E-03	-2.72E-04	-1.10E-03
-1.46E-04	-3.13E-04	4.22E-03	-7.48E-03	-7.36E-03	6.65E-03	-1.58E-05	2.26E-04
-1.01E-04	-5.35E-04	4.49E-03	-1.10E-02	-5.15E-03	9.87E-03	5.15E-05	-8.95E-04
4.99E-05	4.56E-05	3.11E-03	-6.84E-03	-2.74E-03	6.74E-03	-9.70E-05	-1.62E-04
2.63E-04	2.02E-04	3.25E-03	-6.93E-03	-3.91E-03	7.67E-03	-1.93E-04	-2.67E-04
-1.67E-04	3.35E-04	6.91E-03	-1.08E-02	-8.61E-03	1.06E-02	1.68E-04	-9.01E-05
-2.51E-04	8.41E-05	3.01E-03	-7.10E-03	-2.75E-03	9.10E-03	-4.78E-04	3.73E-04
1.00E-04	3.26E-04	2.29E-03	-4.52E-03	-3.19E-03	4.88E-03	3.46E-05	-1.26E-04
3.06E-04	-3.50E-04	6.04E-03	-7.19E-03	-4.32E-03	6.76E-03	-2.13E-04	6.13E-04
DATA_Period:	1.78E+00						
-1.60E-04	3.71E-05	2.16E-03	-2.36E-03	-2.05E-03	2.35E-03	-7.80E-06	1.01E-04
3.39E-04	1.49E-04	2.93E-03	-3.74E-03	-2.53E-03	3.98E-03	-4.01E-04	-3.11E-04
-5.49E-04	-4.00E-04	4.53E-03	-5.58E-03	-4.60E-03	5.03E-03	1.17E-04	1.91E-04
-6.66E-05	-2.46E-04	5.16E-03	-5.75E-03	-3.78E-03	6.11E-03	5.45E-04	-1.37E-04
-3.00E-04	-8.57E-04	3.84E-03	-5.54E-03	-4.50E-03	5.11E-03	2.85E-04	1.91E-04
-2.91E-05	4.43E-04	1.64E-03	-4.62E-03	-3.30E-03	4.88E-03	-2.54E-04	-4.10E-04
8.44E-04	5.08E-04	8.07E-03	-7.84E-03	-6.01E-03	8.24E-03	-3.45E-04	-9.05E-04
-8.68E-05	-2.41E-05	1.48E-03	-3.66E-03	-1.58E-03	3.45E-03	8.22E-05	8.69E-05
1.08E-04	-5.84E-05	1.94E-03	-3.63E-03	-2.39E-03	3.62E-03	-5.82E-05	-2.24E-04
-9.93E-06	-3.15E-04	2.37E-03	-4.49E-03	-2.66E-03	4.33E-03	1.96E-04	6.65E-05
2.35E-04	-1.31E-04	3.50E-03	-4.98E-03	-3.50E-03	4.96E-03	-3.20E-04	-5.81E-05
6.10E-05	-7.34E-05	2.39E-03	-3.23E-03	-2.20E-03	3.23E-03	-6.13E-05	-1.64E-04

APPENDIX IV: 3-D INVERSION DATA FILE

3.77E-05	4.07E-05	1.97E-03	-4.07E-03	-2.03E-03	4.07E-03	-7.90E-05	-1.46E-04
-4.29E-06	2.36E-05	3.03E-03	-2.95E-03	-1.81E-03	2.99E-03	-2.96E-04	1.01E-04
2.39E-04	-1.37E-04	3.01E-03	-4.17E-03	-3.29E-03	5.56E-03	5.41E-05	2.92E-04
-8.86E-05	1.35E-04	2.47E-03	-4.65E-03	-3.20E-03	4.68E-03	-4.33E-04	-3.55E-04
4.48E-05	1.63E-04	2.09E-03	-3.79E-03	-2.14E-03	4.14E-03	-1.35E-04	-5.60E-05
-5.06E-04	-3.59E-04	3.10E-03	-4.17E-03	-3.14E-03	3.65E-03	3.08E-04	3.42E-04
-4.07E-04	2.68E-04	4.95E-03	-4.86E-03	-3.14E-03	5.13E-03	1.09E-04	-2.35E-05
-9.12E-06	2.06E-05	1.64E-03	-3.77E-03	-1.61E-03	3.56E-03	-1.03E-04	2.14E-05
7.97E-05	-3.00E-05	1.76E-03	-2.19E-03	-1.70E-03	2.25E-03	5.28E-05	1.09E-04
1.80E-04	-6.21E-06	2.47E-03	-2.72E-03	-1.77E-03	2.39E-03	1.81E-04	3.73E-05
-6.63E-04	-2.10E-04	5.31E-03	-2.93E-03	-3.65E-03	3.56E-03	-2.68E-04	-8.29E-05
-7.39E-04	-2.53E-04	7.03E-03	-7.27E-03	-4.33E-03	6.38E-03	-1.09E-04	1.03E-03
-1.57E-04	-3.82E-04	6.81E-03	-6.18E-03	-4.31E-03	4.99E-03	2.25E-04	3.64E-04
-3.68E-04	-3.94E-04	3.28E-03	-3.16E-03	-2.49E-03	3.64E-03	-2.00E-04	3.24E-04
5.09E-04	-8.60E-04	2.65E-03	-6.91E-03	-4.42E-03	5.70E-03	5.80E-04	1.72E-04
2.17E-04	-1.19E-03	3.40E-03	-7.60E-03	-5.66E-03	6.35E-03	4.61E-04	5.98E-04
7.05E-04	2.96E-04	2.89E-03	-5.90E-03	-3.54E-03	4.10E-03	-2.59E-04	-8.27E-04
-8.67E-05	-1.49E-04	2.31E-03	-4.63E-03	-5.85E-03	4.85E-03	-6.32E-05	3.52E-05
-6.03E-04	3.49E-05	2.68E-03	-6.61E-03	-3.61E-03	5.71E-03	5.71E-04	8.83E-04
-2.32E-04	5.05E-04	3.07E-03	-5.00E-03	-2.53E-03	5.10E-03	-5.95E-04	7.94E-05
-1.25E-04	1.45E-04	2.42E-03	-4.29E-03	-2.80E-03	4.61E-03	-2.07E-04	-1.25E-04
-4.32E-04	-1.29E-04	5.08E-03	-6.94E-03	-7.19E-03	8.80E-03	-6.87E-04	-3.95E-04
6.56E-04	-6.30E-04	3.92E-03	-6.12E-03	-1.34E-03	7.29E-03	3.81E-04	1.10E-03
-8.92E-05	2.89E-04	1.29E-03	-2.83E-03	-1.76E-03	3.52E-03	2.74E-06	2.22E-05
6.21E-05	2.96E-04	4.76E-03	-5.41E-03	-4.56E-03	6.90E-03	-2.55E-04	3.76E-04
DATA_Period:	3.55E+00						
-2.02E-04	7.85E-05	1.71E-03	-1.57E-03	-2.15E-03	1.30E-03	1.05E-04	2.40E-04
-3.33E-05	-5.30E-04	3.04E-03	-2.94E-03	-1.29E-03	2.42E-03	-1.23E-04	1.56E-04
-2.61E-04	-1.22E-04	3.11E-03	-3.67E-03	-3.81E-03	3.15E-03	-1.07E-04	8.60E-05
-1.13E-03	-3.25E-04	4.02E-03	-3.56E-03	-2.74E-03	3.74E-03	6.68E-04	1.39E-04
1.23E-04	-3.11E-04	1.89E-03	-3.69E-03	-3.78E-03	3.38E-03	2.85E-04	2.86E-04
3.31E-05	4.86E-04	1.91E-03	-2.57E-03	-2.61E-03	2.86E-03	-8.86E-05	3.88E-05
7.39E-04	2.97E-04	6.19E-03	-5.84E-03	-4.67E-03	5.32E-03	-2.65E-04	-5.19E-04
-1.04E-04	1.45E-04	1.85E-03	-2.19E-03	-1.50E-03	2.17E-03	-6.12E-05	7.67E-05
-1.33E-04	2.29E-04	1.76E-03	-2.36E-03	-1.77E-03	1.95E-03	-1.24E-04	4.09E-05
1.88E-04	-3.12E-04	2.04E-03	-2.51E-03	-1.91E-03	2.79E-03	3.59E-04	-6.70E-05
2.29E-05	-5.79E-05	2.59E-03	-2.58E-03	-2.38E-03	3.03E-03	-3.67E-04	4.48E-05
-2.54E-04	-1.39E-04	1.59E-03	-2.55E-03	-1.72E-03	2.35E-03	-1.76E-04	-1.61E-04
1.16E-04	2.31E-05	1.79E-03	-2.34E-03	-1.66E-03	2.35E-03	-1.16E-05	-1.24E-04
8.39E-05	5.51E-05	2.41E-03	-2.02E-03	-1.41E-03	1.69E-03	-1.01E-04	1.39E-04
-4.38E-05	1.20E-04	3.46E-03	-2.85E-03	-3.03E-03	3.61E-03	-2.63E-04	1.10E-04
-7.48E-05	-7.28E-05	2.83E-03	-3.13E-03	-3.72E-03	2.88E-03	-1.63E-04	-3.36E-04

APPENDIX IV: 3-D INVERSION DATA FILE

-3.25E-04	5.46E-04	2.66E-03	-1.29E-03	-1.94E-03	2.63E-03	6.38E-05	2.28E-05
-4.38E-04	-2.34E-04	2.60E-03	-2.60E-03	-2.93E-03	2.25E-03	1.08E-06	2.18E-04
-7.55E-04	-5.54E-05	4.62E-03	-3.35E-03	-2.66E-03	3.24E-03	3.78E-04	-3.80E-05
-6.42E-05	3.22E-06	1.45E-03	-2.22E-03	-1.41E-03	2.16E-03	-3.21E-06	7.99E-05
1.90E-04	2.16E-04	1.53E-03	-1.40E-03	-2.23E-03	1.69E-03	1.49E-04	1.33E-04
2.58E-04	4.35E-04	2.64E-03	-1.92E-03	-2.65E-03	2.10E-03	8.14E-05	1.79E-04
-2.89E-04	-2.95E-04	4.11E-03	-2.44E-03	-3.76E-03	2.27E-03	1.91E-04	5.28E-04
-7.94E-04	4.04E-04	5.02E-03	-4.86E-03	-2.70E-03	3.73E-03	-1.03E-03	1.51E-03
-1.32E-04	-2.16E-04	5.09E-03	-4.13E-03	-3.30E-03	3.24E-03	1.03E-04	2.85E-04
-5.59E-05	7.73E-05	1.93E-03	-1.61E-03	-1.73E-03	1.52E-03	8.22E-05	1.88E-04
-1.29E-03	-1.52E-03	-1.29E-03	1.06E-03	-6.08E-03	6.18E-03	-1.36E-03	6.36E-04
-1.14E-03	7.83E-04	1.23E-03	-4.20E-03	-2.97E-03	4.80E-03	-2.71E-04	1.34E-03
6.07E-04	-7.53E-05	2.13E-03	-3.67E-03	-3.31E-03	3.07E-03	3.70E-05	-7.83E-04
-2.96E-05	1.22E-04	1.66E-03	-3.28E-03	-4.36E-03	3.66E-03	-9.48E-05	-1.32E-07
3.09E-04	3.08E-04	2.40E-03	-3.12E-03	-2.42E-03	2.31E-03	-3.11E-04	1.41E-04
-1.34E-03	9.34E-04	2.08E-03	-2.96E-03	-2.78E-03	4.46E-03	-1.46E-03	6.79E-05
3.48E-04	1.09E-04	3.05E-03	-3.96E-03	-2.21E-03	3.60E-03	-1.71E-03	-1.09E-04
4.38E-04	-1.80E-04	3.91E-03	-5.76E-03	-6.47E-03	9.12E-03	3.27E-04	-3.00E-04
-1.91E-04	3.62E-04	2.97E-03	-5.61E-03	-5.68E-03	4.36E-03	3.54E-04	-5.57E-04
-3.36E-04	-1.50E-04	4.82E-04	-1.14E-03	-5.82E-04	8.04E-04	-2.55E-04	-2.64E-04
2.58E-04	-1.97E-04	3.73E-03	-4.43E-03	-5.31E-03	7.26E-03	1.01E-04	-4.65E-04
DATA_Period:	7.11E+00						
-1.04E-04	-3.31E-05	1.48E-03	-5.78E-04	-1.50E-03	5.60E-04	3.63E-06	1.34E-04
-2.16E-05	4.88E-04	2.53E-03	-2.19E-03	-1.84E-03	1.78E-03	2.32E-05	-1.03E-04
-2.05E-04	5.66E-05	2.52E-03	-2.29E-03	-3.27E-03	2.27E-03	-1.48E-04	5.86E-05
9.99E-05	1.46E-04	3.40E-03	-1.72E-03	-2.21E-03	1.36E-03	1.55E-04	5.50E-05
-3.67E-04	-1.16E-03	1.02E-03	-2.27E-03	-3.54E-03	2.12E-03	3.92E-05	6.64E-04
9.89E-04	1.70E-04	2.73E-03	-3.11E-03	-1.29E-03	1.61E-03	5.94E-04	-1.14E-04
3.93E-04	2.29E-04	5.18E-03	-4.12E-03	-4.20E-03	4.15E-03	-9.24E-05	-1.24E-04
6.23E-04	8.50E-05	8.50E-04	-1.90E-03	-1.24E-03	2.07E-03	2.07E-04	1.90E-05
8.04E-05	1.87E-04	1.21E-03	-1.29E-03	-1.63E-03	1.06E-03	4.03E-05	-2.10E-05
-2.24E-04	4.94E-05	9.37E-04	-3.56E-04	-1.13E-03	6.68E-04	-1.50E-04	5.87E-05
1.50E-04	1.85E-04	1.83E-03	-1.79E-03	-2.12E-03	1.83E-03	-2.19E-04	-1.41E-04
-4.14E-05	2.93E-04	1.37E-03	-1.16E-03	-2.01E-03	1.34E-03	2.20E-05	1.48E-04
2.49E-05	4.55E-05	1.66E-03	-1.11E-03	-1.30E-03	1.26E-03	-5.30E-05	-4.92E-05
-1.07E-04	6.92E-05	2.49E-03	-9.57E-04	-1.32E-03	8.07E-04	-1.22E-04	-4.98E-06
1.58E-04	-2.75E-04	3.14E-03	-4.85E-03	-3.26E-03	6.14E-03	-1.23E-04	2.21E-04
1.15E-03	5.33E-04	3.78E-03	-6.64E-04	-4.26E-03	3.51E-03	5.20E-04	4.33E-04
-3.76E-04	-2.55E-04	2.89E-03	-1.79E-03	-1.84E-03	1.57E-03	-4.37E-04	-1.06E-05
-2.17E-04	-3.91E-04	2.56E-03	-1.25E-03	-2.31E-03	1.90E-03	-4.19E-04	4.61E-04
-4.86E-04	-4.20E-04	3.90E-03	-2.65E-03	-2.81E-03	1.56E-03	1.68E-04	3.16E-04
-9.76E-05	-4.37E-05	1.14E-03	-1.25E-03	-1.39E-03	1.24E-03	2.27E-04	1.05E-04

APPENDIX IV: 3-D INVERSION DATA FILE

9.55E-05	-5.33E-06	2.34E-03	-1.42E-03	-2.03E-03	1.39E-03	4.27E-06	8.68E-05
1.13E-04	-3.23E-05	2.02E-03	-3.47E-04	-1.48E-03	5.44E-04	1.11E-04	7.96E-05
-2.65E-04	-1.98E-04	3.77E-03	-1.22E-03	-3.06E-03	1.91E-03	-2.19E-06	-8.66E-06
-2.09E-04	5.52E-06	4.54E-03	-2.62E-03	-2.58E-03	1.85E-03	-4.43E-04	3.07E-04
-1.38E-04	-1.15E-04	4.56E-03	-2.41E-03	-2.99E-03	2.01E-03	9.92E-06	4.89E-04
-3.29E-04	-1.51E-05	8.82E-04	-7.90E-04	-2.48E-03	9.49E-04	-2.45E-04	-3.65E-04
1.12E-02	4.30E-03	3.92E-03	-7.61E-03	-4.11E-03	8.11E-03	1.01E-03	-7.77E-04
-1.01E-03	-6.70E-04	1.42E-03	-2.84E-03	-4.13E-03	3.22E-03	-4.78E-04	5.68E-04
5.03E-04	-5.69E-05	1.83E-03	-2.26E-03	-3.08E-03	2.36E-03	1.46E-04	-3.36E-04
-1.90E-04	2.60E-04	1.38E-03	-1.85E-03	-3.40E-03	2.12E-03	-1.49E-04	2.78E-04
1.01E-03	-1.23E-03	2.41E-03	-8.34E-04	-1.08E-02	3.87E-03	1.22E-03	-3.10E-03
-3.72E-04	1.45E-04	3.13E-03	-2.08E-03	-1.35E-03	1.90E-03	-1.56E-04	-8.73E-05
-7.24E-04	-5.17E-05	2.53E-03	-2.24E-03	-1.70E-03	2.54E-03	-2.44E-04	-5.61E-05
5.87E-04	4.51E-04	3.70E-03	-2.54E-03	-5.11E-03	4.60E-03	-3.96E-04	-1.39E-04
-1.63E-03	4.67E-04	9.26E-04	-4.09E-03	-1.84E-03	2.36E-03	9.17E-05	-1.97E-04
-2.86E-04	1.38E-04	1.08E-03	-1.37E-03	-9.96E-04	1.28E-03	-2.16E-04	-2.83E-06
-8.43E-05	2.74E-04	4.48E-03	-4.01E-03	-3.66E-03	2.54E-03	-3.51E-05	8.99E-04
DATA_Period:	1.42E+01						
-1.04E-04	-3.31E-05	1.48E-03	-5.78E-04	-1.50E-03	5.60E-04	3.63E-06	1.34E-04
1.06E-04	4.63E-04	3.18E-03	-1.60E-03	-9.06E-04	9.17E-04	1.21E-04	-2.61E-04
-3.17E-04	2.13E-05	2.96E-03	-7.40E-04	-2.59E-03	1.09E-03	-1.90E-04	1.28E-05
9.99E-05	1.46E-04	3.40E-03	-1.72E-03	-2.21E-03	1.36E-03	1.55E-04	5.50E-05
-4.57E-04	-4.30E-04	1.65E-03	-9.54E-04	-3.01E-03	1.74E-03	-7.56E-05	5.13E-05
2.75E-04	-4.59E-04	1.45E-03	-1.16E-03	-8.77E-04	1.47E-03	1.68E-04	-3.80E-04
3.57E-04	-1.98E-04	3.97E-03	-1.52E-03	-2.38E-03	1.63E-03	3.33E-05	-3.28E-04
3.44E-05	-6.07E-05	1.47E-03	-7.84E-04	-9.76E-04	7.57E-04	5.35E-05	3.57E-05
-3.23E-05	1.80E-04	1.38E-03	-6.28E-04	-1.72E-03	6.56E-04	-1.08E-04	-2.16E-04
-1.92E-04	1.34E-04	1.08E-03	-8.45E-04	-1.49E-03	9.37E-04	-2.40E-04	-1.81E-05
-5.59E-05	1.28E-04	1.79E-03	-1.25E-03	-1.86E-03	1.15E-03	-2.16E-04	-3.21E-05
4.10E-04	4.52E-04	1.80E-03	-4.02E-04	-1.50E-03	8.81E-04	8.71E-05	1.29E-04
8.06E-06	4.23E-05	1.53E-03	-6.48E-04	-1.09E-03	8.00E-04	-6.55E-05	-2.32E-05
-6.17E-05	-5.65E-05	2.46E-03	-9.04E-04	-1.21E-03	7.66E-04	-1.50E-04	5.99E-05
-2.75E-04	5.44E-05	3.05E-03	-1.47E-03	-2.16E-03	8.27E-04	-5.63E-04	1.53E-04
4.54E-04	-8.48E-04	2.05E-03	-1.00E-03	-3.46E-03	1.07E-03	3.84E-04	-1.91E-04
-1.66E-04	-4.77E-05	1.65E-03	-8.50E-04	-1.49E-03	8.41E-04	-2.45E-04	-1.58E-04
-1.51E-04	-1.76E-04	2.36E-03	-8.65E-04	-2.38E-03	1.08E-03	-2.32E-04	2.41E-04
-6.47E-04	-4.46E-04	4.06E-03	-1.57E-03	-2.57E-03	8.51E-04	-6.83E-05	-5.85E-05
-2.10E-05	1.56E-04	9.15E-04	-6.31E-04	-1.93E-03	8.55E-04	7.26E-05	-2.69E-04
-2.59E-04	3.58E-04	1.34E-03	2.74E-04	-2.58E-03	8.93E-04	-8.07E-05	4.47E-04
1.13E-04	-3.23E-05	2.02E-03	-3.47E-04	-1.48E-03	5.44E-04	1.11E-04	7.96E-05
-5.39E-04	1.92E-05	3.54E-03	-1.21E-03	-2.76E-03	1.49E-03	-6.58E-05	3.03E-04
-1.07E-04	-4.76E-05	4.45E-03	-1.91E-03	-2.50E-03	1.32E-03	-2.87E-04	2.47E-04

APPENDIX IV: 3-D INVERSION DATA FILE

4.03E-05	5.15E-05	4.31E-03	-1.65E-03	-2.75E-03	-2.93E-05	2.93E-05	2.57E-04
-3.32E-04	3.05E-05	8.78E-04	-6.19E-04	-3.67E-03	1.36E-03	-2.06E-04	-2.77E-04
-6.49E-04	-3.01E-04	4.97E-03	-5.58E-03	-5.02E-03	7.30E-03	2.66E-04	3.25E-04
-1.60E-03	-6.06E-04	4.74E-03	-2.70E-03	-5.76E-03	3.19E-03	4.13E-05	1.74E-03
2.41E-04	1.82E-04	1.67E-03	-9.80E-04	-1.70E-03	1.02E-03	-1.55E-04	-5.61E-04
-2.88E-05	6.51E-05	1.29E-03	-2.42E-03	-3.89E-03	1.71E-03	-6.33E-05	1.85E-05
6.25E-05	-2.61E-06	1.24E-03	-1.21E-03	-8.97E-04	1.02E-03	1.26E-04	-1.87E-05
1.92E-04	4.32E-05	1.63E-03	-1.40E-03	-7.54E-04	6.16E-04	-2.48E-05	-9.54E-05
-3.87E-05	2.34E-05	1.05E-03	-8.40E-04	-1.32E-03	9.96E-04	7.17E-05	8.85E-05
2.56E-04	6.61E-05	2.59E-03	-1.63E-03	-3.59E-03	3.15E-03	9.38E-04	4.65E-04
-2.86E-04	3.36E-04	1.60E-03	-1.56E-03	-1.09E-03	4.86E-04	1.96E-04	6.41E-04
1.91E-04	3.69E-04	5.88E-04	-5.70E-04	-7.86E-04	9.16E-04	-4.21E-05	3.83E-05
6.17E-04	3.06E-04	1.46E-03	-1.09E-03	-3.59E-03	2.65E-03	5.13E-04	-2.68E-04
DATA_Period:	2.13E+01						
1.97E-05	-8.68E-05	1.38E-03	-4.50E-04	-1.31E-03	5.26E-04	9.96E-05	1.08E-04
-3.61E-04	2.23E-04	2.36E-03	-1.41E-03	-8.15E-04	6.16E-04	-2.46E-04	-1.02E-04
-3.17E-04	2.13E-05	2.96E-03	-7.40E-04	-2.59E-03	1.09E-03	-1.90E-04	1.28E-05
-2.69E-04	-2.95E-04	2.88E-03	-1.32E-03	-1.79E-03	1.10E-03	2.34E-04	4.43E-05
2.62E-04	-1.45E-04	1.14E-03	-8.67E-04	-2.18E-03	9.07E-04	2.23E-04	-6.25E-05
-8.53E-05	-1.14E-04	1.33E-03	-1.40E-04	-8.84E-04	3.70E-04	-5.02E-05	-1.14E-04
3.57E-04	-1.98E-04	3.97E-03	-1.52E-03	-2.38E-03	1.63E-03	3.33E-05	-3.28E-04
4.25E-05	-4.07E-05	1.11E-03	-4.96E-04	-8.59E-04	5.26E-04	4.41E-05	3.88E-05
-9.36E-06	1.27E-04	1.47E-03	-6.46E-04	-1.66E-03	5.56E-04	-2.10E-05	-9.45E-05
-1.41E-04	5.99E-05	1.11E-03	-7.04E-04	-1.39E-03	6.61E-04	-1.48E-04	4.88E-06
8.94E-06	1.99E-04	1.57E-03	-1.04E-03	-1.80E-03	7.83E-04	-7.64E-05	4.31E-05
2.82E-04	2.22E-04	1.54E-03	-4.47E-04	-1.39E-03	3.86E-04	1.30E-04	-5.94E-05
2.66E-05	7.58E-05	1.54E-03	-5.68E-04	-1.10E-03	5.86E-04	-8.43E-05	-6.84E-05
-2.85E-05	2.22E-05	2.40E-03	-7.10E-04	-1.06E-03	4.44E-04	-1.07E-04	8.32E-06
-2.75E-04	5.44E-05	3.05E-03	-1.47E-03	-2.16E-03	8.27E-04	-5.63E-04	1.53E-04
-1.63E-04	-2.11E-04	1.63E-03	-6.15E-04	-2.66E-03	5.76E-04	-1.91E-04	-1.70E-04
-1.02E-04	-5.10E-04	1.54E-03	-3.55E-04	-1.42E-03	8.72E-04	-4.47E-05	-7.14E-04
-2.28E-04	-1.56E-04	2.19E-03	-8.42E-04	-2.23E-03	8.82E-04	-2.08E-04	4.08E-04
-5.05E-04	-2.18E-05	4.21E-03	-1.41E-03	-2.12E-03	1.22E-03	2.06E-04	-4.56E-05
2.74E-05	7.39E-05	7.96E-04	-3.74E-04	-1.58E-03	8.51E-04	-9.11E-05	-1.33E-04
-2.47E-04	-2.24E-04	1.44E-03	-7.43E-05	-1.86E-03	9.11E-04	1.82E-04	-8.87E-05
7.09E-06	8.17E-05	1.76E-03	-7.87E-04	-1.12E-03	3.79E-04	-2.71E-04	-2.01E-04
-5.78E-05	-2.04E-04	1.77E-03	-1.26E-03	-1.88E-03	5.67E-04	-4.82E-05	1.72E-04
-1.88E-04	-1.79E-04	4.07E-03	-1.73E-03	-2.39E-03	1.06E-03	-2.73E-04	2.68E-04
-1.74E-06	-2.46E-05	4.01E-03	-1.47E-03	-2.60E-03	1.31E-03	5.02E-06	2.57E-04
-3.36E-04	-4.57E-05	1.13E-03	-2.80E-04	-3.65E-03	1.23E-03	-2.49E-04	-3.43E-04
3.32E-04	3.63E-04	1.42E-03	-1.84E-03	-2.47E-03	1.24E-03	5.16E-05	2.56E-04
-1.87E-04	-9.71E-05	1.60E-03	-1.18E-03	-2.42E-03	1.14E-03	-1.21E-04	2.45E-04

APPENDIX IV: 3-D INVERSION DATA FILE

2.13E-04	1.34E-04	1.29E-03	-8.13E-04	-1.30E-03	9.03E-04	5.00E-05	-3.48E-04
-9.51E-05	7.54E-05	8.42E-04	-5.84E-04	-2.47E-03	1.10E-03	-1.00E-04	6.36E-05
2.31E-05	7.11E-05	1.24E-03	-8.30E-04	-8.85E-04	7.46E-04	-1.16E-04	-8.82E-05
-6.19E-05	-4.93E-05	9.65E-04	-6.53E-04	-7.33E-04	5.19E-04	-1.42E-05	-1.41E-05
-9.95E-05	4.05E-05	1.00E-03	-6.28E-04	-1.25E-03	8.21E-04	1.58E-05	7.89E-05
-5.16E-05	-2.07E-05	2.31E-03	-9.18E-04	-2.40E-03	1.28E-03	-6.55E-05	-2.04E-05
-6.05E-05	1.69E-06	1.13E-03	-6.88E-04	-1.06E-03	5.84E-04	-1.73E-05	-8.24E-05
-4.01E-05	6.67E-05	6.13E-04	-3.76E-04	-6.62E-04	5.18E-04	2.17E-06	1.85E-05
-7.00E-05	-1.44E-04	9.32E-04	-6.27E-04	-1.90E-03	1.27E-03	2.33E-04	1.68E-04
DATA_Period:	4.27E+01						
-1.04E-04	-4.95E-05	1.08E-03	-4.92E-04	-1.29E-03	3.28E-04	1.17E-04	-1.06E-06
-1.89E-04	-7.36E-05	1.97E-03	-8.19E-04	-8.68E-04	3.46E-04	2.25E-05	7.73E-05
-1.77E-04	7.90E-05	2.15E-03	-1.03E-03	-2.44E-03	6.66E-04	-1.17E-04	-9.14E-05
-2.67E-04	-3.58E-04	2.27E-03	-1.17E-03	-1.83E-03	7.87E-04	5.34E-05	2.48E-04
7.96E-05	-1.25E-04	1.25E-03	-9.05E-04	-2.33E-03	5.91E-04	8.90E-05	-1.76E-04
1.08E-04	-1.31E-05	7.53E-04	-7.14E-04	-1.02E-03	4.41E-04	3.70E-05	1.90E-04
4.28E-04	4.75E-04	3.55E-03	-1.38E-03	-1.92E-03	1.29E-03	-2.16E-05	-2.31E-04
1.31E-04	-8.31E-05	1.01E-03	-4.19E-04	-7.70E-04	2.93E-04	7.75E-05	8.43E-05
-2.96E-05	1.45E-04	1.29E-03	-3.24E-04	-1.57E-03	5.32E-04	-9.10E-05	-5.89E-05
-2.57E-04	-8.03E-05	1.00E-03	-4.68E-04	-1.11E-03	6.72E-04	-1.24E-04	5.71E-05
-3.82E-05	2.38E-04	1.48E-03	-9.79E-04	-1.62E-03	4.42E-04	-1.07E-04	1.98E-04
-1.21E-04	3.32E-05	8.63E-04	-3.40E-04	-1.14E-03	3.88E-04	-4.50E-05	1.96E-05
-5.77E-05	-1.84E-05	1.32E-03	-4.75E-04	-9.59E-04	4.07E-04	5.06E-05	4.18E-06
1.91E-05	-2.56E-04	2.13E-03	-7.63E-04	-8.94E-04	5.22E-04	-5.43E-05	1.79E-04
-2.75E-04	5.44E-05	3.05E-03	-1.47E-03	-2.16E-03	8.27E-04	-5.63E-04	1.53E-04
9.09E-05	6.33E-05	1.54E-03	-4.89E-04	-1.83E-03	1.04E-03	-2.17E-04	-1.68E-04
-1.39E-04	-9.54E-05	8.45E-04	-8.37E-04	-1.19E-03	5.06E-04	-1.03E-04	-9.67E-05
-2.29E-04	-1.61E-04	1.91E-03	-8.75E-04	-2.07E-03	5.74E-04	-2.10E-04	4.63E-05
-2.62E-04	-1.35E-04	3.25E-03	-1.84E-03	-2.02E-03	5.35E-04	-4.35E-06	-1.30E-04
2.67E-06	-3.79E-05	7.60E-04	-2.80E-04	-1.53E-03	8.03E-04	6.54E-05	-5.96E-05
-4.77E-05	3.46E-04	1.25E-03	-5.13E-04	-2.33E-03	5.20E-04	-3.95E-05	-2.61E-04
1.11E-04	9.04E-05	1.55E-03	-6.65E-04	-1.26E-03	2.54E-04	5.83E-05	8.16E-05
-5.78E-05	-2.04E-04	1.77E-03	-1.26E-03	-1.88E-03	5.67E-04	-4.82E-05	1.72E-04
-2.57E-04	-3.10E-04	3.46E-03	-1.55E-03	-2.10E-03	8.70E-04	-1.84E-04	3.26E-04
5.16E-05	-3.84E-04	3.53E-03	-1.37E-03	-2.03E-03	1.07E-03	2.07E-04	3.12E-04
-1.83E-04	1.33E-04	9.91E-04	-4.04E-04	-3.44E-03	9.04E-04	-4.72E-05	-1.95E-04
-2.46E-04	-2.15E-04	1.34E-03	-6.56E-04	-1.33E-03	7.55E-04	1.75E-04	2.57E-04
-2.17E-04	2.40E-06	1.26E-03	-9.05E-04	-2.18E-03	7.21E-04	-2.19E-04	2.23E-05
1.71E-04	1.09E-04	1.10E-03	-4.73E-04	-1.09E-03	7.61E-04	1.86E-04	-3.52E-04
-9.43E-05	4.44E-05	6.77E-04	-6.34E-04	-2.35E-03	7.83E-04	-1.25E-04	-1.11E-04
8.20E-05	1.12E-04	1.05E-03	-5.52E-04	-8.39E-04	5.05E-04	-7.05E-06	-1.07E-04
-7.89E-05	-8.48E-06	8.21E-04	-4.06E-04	-7.15E-04	3.35E-04	-3.42E-05	5.28E-06

APPENDIX IV: 3-D INVERSION DATA FILE

-5.32E-05	-8.14E-05	8.63E-04	-5.02E-04	-1.11E-03	5.33E-04	5.42E-05	1.05E-04
-7.79E-05	1.52E-05	2.03E-03	-6.38E-04	-1.73E-03	1.22E-03	-1.63E-04	6.94E-05
8.16E-06	-1.08E-05	9.91E-04	-5.22E-04	-9.12E-04	3.34E-04	7.69E-06	-1.43E-07
4.41E-05	7.35E-05	5.53E-04	-2.47E-04	-5.90E-04	4.91E-04	2.79E-05	4.81E-07
-1.28E-06	-1.23E-04	8.38E-04	-4.16E-04	-1.53E-03	9.56E-04	2.95E-04	1.87E-04
DATA_Period:	8.53E+01						
-1.20E-04	-8.98E-06	7.50E-04	-6.18E-04	-1.25E-03	2.70E-04	1.04E-04	-1.51E-04
-3.26E-04	-4.97E-05	1.33E-03	-1.00E-03	-8.40E-04	2.22E-04	6.76E-05	-1.47E-05
-2.77E-04	-1.98E-05	1.44E-03	-1.18E-03	-2.24E-03	5.65E-04	-2.09E-04	-1.37E-04
-8.40E-05	-1.62E-04	1.75E-03	-9.67E-04	-1.50E-03	7.02E-04	9.88E-05	1.72E-04
-2.36E-05	-2.20E-04	8.28E-04	-5.76E-04	-2.02E-03	4.80E-04	2.65E-05	1.02E-04
-4.10E-05	4.36E-05	1.09E-03	-6.75E-04	-7.99E-04	2.51E-04	3.52E-05	5.50E-05
6.49E-04	2.60E-04	3.24E-03	-1.17E-03	-1.42E-03	1.10E-03	3.43E-04	-2.89E-04
1.88E-04	-1.48E-04	9.41E-04	-3.88E-04	-7.00E-04	2.05E-04	8.17E-05	7.81E-05
-7.16E-05	-3.62E-05	1.11E-03	-2.39E-04	-1.30E-03	6.60E-04	-2.53E-05	-1.06E-06
-2.26E-04	-4.43E-05	9.09E-04	-2.71E-04	-9.51E-04	5.98E-04	-5.44E-05	7.69E-05
-1.14E-04	6.73E-05	1.20E-03	-8.12E-04	-1.42E-03	4.23E-04	-2.97E-05	-1.79E-04
8.62E-05	-9.07E-05	4.68E-04	-2.76E-04	-9.62E-04	3.53E-04	1.35E-04	1.55E-04
-1.29E-04	-1.48E-04	9.72E-04	-6.13E-04	-9.09E-04	2.90E-04	-9.74E-05	1.67E-05
4.69E-06	-1.96E-04	1.74E-03	-5.29E-04	-6.33E-04	2.98E-04	-4.58E-05	2.38E-05
-2.75E-04	5.44E-05	3.05E-03	-1.47E-03	-2.16E-03	8.27E-04	-5.63E-04	1.53E-04
-2.41E-04	-8.35E-05	1.51E-03	-3.40E-04	-1.88E-03	1.14E-03	-3.35E-04	-1.11E-04
-4.28E-05	-1.11E-04	8.58E-04	-4.50E-04	-1.32E-03	5.31E-05	-9.35E-05	-4.42E-05
-3.39E-04	-2.91E-04	1.48E-03	-1.07E-03	-1.94E-03	4.50E-04	-1.41E-04	-2.60E-04
-4.63E-05	-1.60E-04	2.41E-03	-1.46E-03	-1.80E-03	4.25E-04	-6.31E-06	5.42E-05
-5.91E-05	3.70E-06	6.97E-04	-1.86E-04	-1.16E-03	7.57E-04	6.73E-05	1.25E-05
-4.77E-05	3.46E-04	1.25E-03	-5.13E-04	-2.33E-03	5.20E-04	-3.95E-05	-2.61E-04
7.43E-05	-5.07E-05	1.46E-03	-4.46E-04	-1.17E-03	2.72E-04	4.31E-05	-1.51E-04
-1.63E-04	-2.25E-04	1.24E-03	-8.66E-04	-1.70E-03	5.26E-04	-3.25E-05	2.05E-04
-3.81E-04	-5.55E-04	2.82E-03	-1.34E-03	-1.73E-03	8.12E-04	-3.56E-05	3.99E-04
-4.58E-05	-5.74E-04	2.98E-03	-9.56E-04	-1.68E-03	1.18E-03	-1.12E-04	2.91E-04
-3.50E-04	1.58E-04	9.05E-04	-4.33E-04	-2.68E-03	9.55E-04	-4.52E-04	-5.01E-04
2.64E-05	-1.58E-04	1.05E-03	-4.25E-04	-1.22E-03	6.28E-04	1.45E-04	2.16E-04
-2.44E-04	-9.04E-05	9.20E-04	-7.74E-04	-1.94E-03	4.28E-04	-2.50E-04	2.23E-05
1.02E-04	8.68E-05	9.70E-04	-3.00E-04	-8.28E-04	7.00E-04	2.53E-04	-3.61E-04
-9.32E-05	-9.59E-07	5.28E-04	-4.07E-04	-2.14E-03	5.44E-04	-9.28E-05	6.01E-05
1.32E-04	1.27E-04	8.68E-04	-4.16E-04	-6.98E-04	4.78E-04	7.79E-05	-2.49E-04
-2.16E-04	5.91E-05	8.53E-04	-1.56E-04	-5.34E-04	4.73E-04	8.08E-05	9.02E-05
-6.00E-05	-1.77E-04	6.72E-04	-4.52E-04	-1.05E-03	3.99E-04	3.27E-05	1.27E-04
-6.80E-05	3.36E-05	1.85E-03	-5.14E-04	-1.43E-03	1.11E-03	-7.63E-05	2.63E-05
2.18E-05	-2.25E-05	7.13E-04	-5.09E-04	-8.48E-04	2.11E-04	-9.54E-06	-2.50E-05
5.69E-06	1.09E-05	5.66E-04	-1.67E-04	-4.97E-04	3.05E-04	2.50E-05	-3.60E-06

APPENDIX IV: 3-D INVERSION DATA FILE

	-1.72E-05	-1.60E-04	4.59E-04	-2.61E-04	-1.42E-03	4.29E-04	1.31E-04	1.34E-04
ERROR_Period:	6.90E-03							
	6.09E-02	-6.09E-02	3.96E-02	-3.96E-02	1.77E-01	-1.77E-01	1.23E-01	-1.23E-01
	2.40E+01	-2.40E+01	2.59E+01	-2.59E+01	1.30E+01	-1.30E+01	1.21E+01	-1.21E+01
	2.87E+00	-2.87E+00	2.53E+00	-2.53E+00	1.18E+00	-1.18E+00	1.25E+00	-1.25E+00
	2.45E-01	-2.45E-01	1.21E+00	-1.21E+00	1.63E-01	-1.63E-01	6.00E-02	-6.00E-02
	4.76E-01	-4.76E-01	5.90E+00	-5.90E+00	2.86E+00	-2.86E+00	2.02E-01	-2.02E-01
	4.46E-02	-4.46E-02	8.24E-01	-8.24E-01	3.31E-01	-3.31E-01	7.59E-02	-7.59E-02
	9.60E-02	-9.60E-02	6.32E-01	-6.32E-01	1.79E+00	-1.79E+00	9.96E-02	-9.96E-02
	1.96E-02	-1.96E-02	1.31E+00	-1.31E+00	3.27E-02	-3.27E-02	5.07E-03	-5.07E-03
	2.67E+00	-2.67E+00	2.54E+00	-2.54E+00	1.40E+00	-1.40E+00	1.34E+00	-1.34E+00
	6.67E-02	-6.67E-02	3.32E-01	-3.32E-01	1.32E-01	-1.32E-01	9.40E-02	-9.40E-02
	1.87E-01	-1.87E-01	3.63E-01	-3.63E-01	3.56E-01	-3.56E-01	4.30E-02	-4.30E-02
	3.57E-02	-3.57E-02	7.34E-02	-7.34E-02	1.58E-02	-1.58E-02	2.18E-02	-2.18E-02
	4.04E-02	-4.04E-02	2.50E-02	-2.50E-02	7.80E-03	-7.80E-03	1.53E-02	-1.53E-02
	4.50E-02	-4.50E-02	3.96E-01	-3.96E-01	8.97E-02	-8.97E-02	2.75E-02	-2.75E-02
	2.80E+00	-2.80E+00	3.40E+01	-3.40E+01	1.03E+02	-1.03E+02	4.63E+00	-4.63E+00
	4.33E+00	-4.33E+00	4.29E+01	-4.29E+01	3.22E+01	-3.22E+01	2.98E+00	-2.98E+00
	7.92E-02	-7.92E-02	9.34E-01	-9.34E-01	1.13E+00	-1.13E+00	1.31E-01	-1.31E-01
	3.39E-02	-1.40E-01	3.30E-01	-3.30E-01	1.01E+00	-1.01E+00	9.68E-02	-9.68E-02
	1.96E-01	-1.96E-01	3.17E+00	-3.17E+00	4.25E-01	-4.25E-01	7.17E-02	-7.17E-02
	3.16E-02	-3.16E-02	5.27E-01	-5.27E-01	8.56E-01	-8.56E-01	1.36E-01	-1.36E-01
	2.88E-02	-2.88E-02	1.40E-01	-1.40E-01	9.08E-02	-9.08E-02	1.40E-02	-1.40E-02
	8.69E-03	-8.69E-03	1.14E-01	-1.14E-01	1.14E+00	-1.14E+00	1.87E-02	-1.87E-02
	1.02E-02	-1.02E-02	3.34E-01	-3.34E-01	5.06E-02	-5.06E-02	3.58E-03	-3.58E-03
	4.20E-02	-4.20E-02	1.35E-01	-1.35E-01	1.01E+00	-1.01E+00	5.18E-02	-5.18E-02
	9.42E-03	-9.42E-03	2.12E-01	-2.12E-01	4.65E-01	-4.65E-01	1.09E-02	-1.09E-02
	8.53E-02	-8.53E-02	5.00E-01	-5.00E-01	1.12E+00	-1.12E+00	7.20E-02	-7.20E-02
	6.27E-02	-6.27E-02	1.49E+00	-1.49E+00	1.09E-01	-1.09E-01	1.17E-02	-1.17E-02
	2.10E-02	-2.10E-02	9.80E-01	-9.80E-01	3.03E-01	-3.03E-01	2.30E-02	-2.30E-02
	1.37E-02	-1.37E-02	5.45E-02	-5.45E-02	6.30E-01	-6.30E-01	5.11E-02	-5.11E-02
	7.16E-03	-7.16E-03	1.63E-02	-1.63E-02	7.22E-03	-7.22E-03	3.91E-02	-3.91E-02
	1.23E-02	-1.23E-02	2.33E-02	-2.33E-02	5.44E-01	-5.44E-01	1.63E-02	-1.63E-02
	1.34E-02	-1.34E-02	2.51E-02	-2.51E-02	4.22E-03	-4.22E-03	2.98E-03	-2.98E-03
	1.46E-02	-1.46E-02	9.48E-03	-9.48E-03	1.26E-03	-1.26E-03	5.31E-03	-5.31E-03
	5.77E-03	-5.77E-03	9.62E-02	-9.62E-02	1.04E-01	-1.04E-01	1.56E-02	-1.56E-02
	7.13E-03	-7.13E-03	1.14E-02	-1.14E-02	1.42E-02	-1.42E-02	3.58E-03	-3.58E-03
	1.17E-02	-1.17E-02	1.41E-02	-1.41E-02	1.71E-03	-1.71E-03	2.52E-03	-2.52E-03
	1.21E-02	-1.21E-02	2.93E-02	-2.93E-02	2.78E-02	-2.78E-02	3.60E-02	-3.60E-02
ERROR_Period:	2.08E-02							
	6.32E-04	-6.32E-04	4.56E-03	-4.56E-03	7.64E-03	-7.64E-03	2.65E-03	-2.65E-03

APPENDIX IV: 3-D INVERSION DATA FILE

4.63E-03	-4.63E-03	1.53E-02	-1.53E-02	2.76E-03	-2.76E-03	4.73E-03	-4.73E-03
8.67E-03	-8.67E-03	4.83E-03	-4.83E-03	1.84E-03	-1.84E-03	2.88E-03	-2.88E-03
1.99E-02	-1.99E-02	1.45E-02	-1.45E-02	1.31E-03	-1.31E-03	3.48E-03	-3.48E-03
3.11E-02	-3.11E-02	2.25E-02	-2.25E-02	7.49E-03	-7.49E-03	2.15E-02	-2.15E-02
1.32E-02	-1.32E-02	1.92E-01	-1.92E-01	9.15E-02	-9.15E-02	1.55E-02	-1.55E-02
1.71E-02	-1.71E-02	4.96E-02	-4.96E-02	1.54E-01	-1.54E-01	1.39E-02	-1.39E-02
4.14E-03	-4.14E-03	1.42E-01	-1.42E-01	3.25E-03	-3.25E-03	1.14E-03	-1.14E-03
1.33E+00	-1.33E+00	1.27E+00	-1.27E+00	7.00E-01	-7.00E-01	6.69E-01	-6.69E-01
3.41E+00	-3.41E+00	3.84E+00	-3.84E+00	1.38E+00	-1.38E+00	6.64E+00	-6.64E+00
8.88E+00	-8.88E+00	4.81E+00	-4.81E+00	3.62E+00	-3.62E+00	2.89E+00	-2.89E+00
4.50E-03	-4.50E-03	5.60E-02	-5.60E-02	9.29E-03	-9.29E-03	3.33E-03	-3.33E-03
2.59E-01	-2.59E-01	1.98E-01	-1.98E-01	7.40E-02	-7.40E-02	9.97E-02	-9.97E-02
9.63E-03	-9.63E-03	7.43E-02	-7.43E-02	2.12E-02	-2.12E-02	5.81E-03	-5.81E-03
2.78E-01	-2.78E-01	2.96E+00	-2.96E+00	5.91E+00	-5.91E+00	4.09E-01	-2.66E-01
3.73E-01	-3.73E-01	4.07E+00	-4.07E+00	2.82E+00	-2.82E+00	2.66E-01	-2.66E-01
1.90E-01	-1.90E-01	2.70E-01	-2.70E-01	2.83E-01	-2.83E-01	3.83E-01	-3.83E-01
1.58E-01	-1.58E-01	1.31E-01	-1.31E-01	3.68E-01	-3.68E-01	2.94E-01	-2.94E-01
5.33E+00	-5.33E+00	7.31E+00	-7.31E+00	1.22E+00	-1.22E+00	1.69E+00	-1.69E+00
8.14E-01	-8.14E-01	1.30E+00	-1.30E+00	2.07E+00	-2.07E+00	3.25E+00	-3.25E+00
3.93E-03	-3.93E-03	4.56E-03	-4.56E-03	2.72E-03	-2.72E-03	2.50E-03	-2.50E-03
5.68E-02	-5.68E-02	1.08E-01	-1.08E-01	6.85E-01	-6.85E-01	1.89E-01	-1.89E-01
1.19E-03	-1.19E-03	2.60E-02	-2.60E-02	5.42E-03	-5.42E-03	3.08E-04	-3.08E-04
9.42E-03	-9.42E-03	4.64E-02	-4.64E-02	2.27E-01	-2.27E-01	1.79E-02	-1.79E-02
8.71E-02	-8.71E-02	2.28E-01	-2.28E-01	4.25E-01	-4.25E-01	1.16E-01	-1.16E-01
5.45E+00	-5.45E+00	3.26E+00	-3.26E+00	7.17E+00	-7.17E+00	4.71E+00	-4.71E+00
1.52E-02	-1.52E-02	6.31E-02	-6.31E-02	1.23E-02	-1.23E-02	1.68E-03	-1.68E-03
3.49E-03	-3.49E-03	1.86E-02	-1.86E-02	4.71E-03	-4.71E-03	4.20E-03	-4.20E-03
2.11E-03	-2.11E-03	1.44E-02	-1.44E-02	9.82E-02	-9.82E-02	1.21E-02	-1.21E-02
1.99E-03	-1.99E-03	8.98E-04	-8.98E-04	4.17E-04	-4.17E-04	1.05E-02	-1.05E-02
1.54E-03	-1.54E-03	8.16E-04	-8.16E-04	1.54E-02	-1.54E-02	3.29E-03	-3.29E-03
2.57E-03	-2.57E-03	4.39E-03	-4.39E-03	8.20E-04	-8.20E-04	5.75E-04	-5.75E-04
3.10E-03	-3.10E-03	1.81E-03	-1.81E-03	2.96E-04	-2.96E-04	1.01E-03	-1.01E-03
7.99E-04	-7.99E-04	2.67E-03	-2.67E-03	2.69E-03	-2.69E-03	2.25E-03	-2.25E-03
1.18E-03	-1.18E-03	2.23E-03	-2.23E-03	2.61E-03	-2.61E-03	1.46E-03	-1.46E-03
2.15E-03	-2.15E-03	2.36E-03	-2.36E-03	3.98E-04	-3.98E-04	4.69E-04	-4.69E-04
2.26E-03	-2.26E-03	6.58E-03	-6.58E-03	5.06E-03	-5.06E-03	8.00E-03	-8.00E-03
ERROR_Period:	4.17E-02						
3.15E-04	-3.15E-04	2.84E-04	-2.84E-04	8.70E-04	-8.70E-04	8.60E-04	-8.60E-04
2.24E-03	-2.24E-03	6.99E-03	-6.99E-03	1.32E-03	-1.32E-03	2.19E-03	-2.19E-03
3.01E-03	-3.01E-03	1.79E-03	-1.79E-03	6.74E-04	-6.74E-04	1.04E-03	-1.04E-03
7.29E-03	-7.29E-03	5.36E-03	-5.36E-03	5.28E-04	-5.28E-04	1.30E-03	-1.30E-03
9.51E-03	-9.51E-03	3.69E-03	-3.69E-03	1.72E-03	-1.72E-03	3.99E-03	-3.99E-03

APPENDIX IV: 3-D INVERSION DATA FILE

1.84E-03	-1.84E-03	4.51E-03	-4.51E-03	1.37E-03	-1.37E-03	4.27E-03	-4.27E-03
8.28E-03	-8.28E-03	4.75E-03	-4.75E-03	1.47E-02	-1.47E-02	6.22E-03	-6.22E-03
1.70E-03	-1.70E-03	5.81E-03	-5.81E-03	2.62E-04	-2.62E-04	2.55E-04	-2.55E-04
1.33E-02	-1.33E-02	6.36E-02	-6.36E-02	3.50E-02	-3.50E-02	6.69E-03	-6.69E-03
2.61E-03	-2.61E-03	3.39E-03	-3.39E-03	1.05E-03	-1.05E-03	5.96E-03	-5.96E-03
4.94E-01	-4.94E-01	2.42E-02	-2.42E-02	1.84E-02	-1.84E-02	2.96E-03	-2.96E-03
2.48E-03	-2.48E-03	2.18E-02	-2.18E-02	4.71E-03	-4.71E-03	1.36E-03	-1.36E-03
2.59E-01	-2.59E-01	1.98E-01	-1.98E-01	7.40E-02	-7.40E-02	9.97E-02	-9.97E-02
2.88E-03	-2.88E-03	2.23E-02	-2.23E-02	6.21E-03	-6.21E-03	1.71E-03	-1.71E-03
6.50E-02	-6.50E-02	5.48E-01	-5.48E-01	5.74E-01	-5.74E-01	1.61E-01	-1.61E-01
7.50E-02	-7.50E-02	4.62E-01	-4.62E-01	2.73E-01	-2.73E-01	5.93E-02	-5.93E-02
4.00E-03	-4.00E-03	4.27E-03	-4.27E-03	5.90E-03	-5.90E-03	6.01E-03	-6.01E-03
2.53E-03	-2.53E-03	1.85E-03	-1.85E-03	5.43E-03	-5.43E-03	3.66E-03	-3.66E-03
7.29E-03	-7.29E-03	7.58E-02	-7.58E-02	8.01E-03	-8.01E-03	3.43E-03	-3.43E-03
3.84E-01	-3.84E-01	3.86E-01	-3.86E-01	9.35E-01	-9.35E-01	9.12E-01	-9.12E-01
1.45E-03	-1.45E-03	2.29E-03	-2.29E-03	1.17E-03	-1.17E-03	1.36E-03	-1.36E-03
7.33E-04	-7.33E-04	1.41E-03	-1.41E-03	8.14E-03	-8.14E-03	2.69E-03	-2.69E-03
8.76E-03	-8.76E-03	1.64E-02	-1.64E-02	3.89E-03	-3.89E-03	2.43E-03	-2.43E-03
6.32E-03	-6.32E-03	2.72E-02	-2.72E-02	1.55E-01	-1.55E-01	1.04E-02	-1.04E-02
1.11E-03	-1.11E-03	2.91E-03	-2.91E-03	5.20E-03	-5.20E-03	1.53E-03	-1.53E-03
3.49E-03	-3.49E-03	2.35E-03	-2.35E-03	4.65E-03	-4.65E-03	3.42E-03	-3.42E-03
4.97E-03	-4.97E-03	2.11E-02	-2.11E-02	3.66E-03	-3.66E-03	5.15E-04	-5.15E-04
1.03E-03	-1.03E-03	3.66E-03	-3.66E-03	1.25E-03	-1.25E-03	8.94E-04	-8.94E-04
4.17E-04	-4.17E-04	4.44E-03	-4.44E-03	1.99E-02	-1.99E-02	3.56E-03	-3.56E-03
6.43E-04	-6.43E-04	2.47E-04	-2.47E-04	1.28E-04	-1.28E-04	2.93E-03	-2.93E-03
5.70E-04	-5.70E-04	2.14E-04	-2.14E-04	6.10E-03	-6.10E-03	9.38E-04	-9.38E-04
4.81E-04	-4.81E-04	1.08E-03	-1.08E-03	1.85E-04	-1.85E-04	1.81E-04	-1.81E-04
9.25E-04	-9.25E-04	4.51E-04	-4.51E-04	8.66E-05	-8.66E-05	2.52E-04	-2.52E-04
2.64E-04	-2.64E-04	7.75E-04	-7.75E-04	9.13E-04	-9.13E-04	6.60E-04	-6.60E-04
3.28E-04	-3.28E-04	5.52E-04	-5.52E-04	6.44E-04	-6.44E-04	1.93E-04	-1.93E-04
4.83E-04	-4.83E-04	5.53E-04	-5.53E-04	9.24E-05	-9.24E-05	1.12E-04	-1.12E-04
6.72E-04	-6.72E-04	2.06E-03	-2.06E-03	1.49E-03	-1.49E-03	2.52E-03	-2.52E-03
ERROR_Period:	1.11E-01						
4.26E-03	-4.26E-03	3.43E-03	-3.43E-03	1.32E-02	-1.32E-02	1.20E-02	-1.20E-02
6.15E-04	-6.15E-04	1.43E-03	-1.43E-03	3.44E-04	-3.44E-04	5.09E-04	-5.09E-04
1.11E-03	-1.11E-03	7.88E-04	-7.88E-04	3.10E-04	-3.10E-04	4.30E-04	-4.30E-04
8.21E-02	-8.21E-02	6.26E-02	-6.26E-02	4.29E-03	-4.29E-03	1.50E-02	-1.50E-02
2.49E-03	-2.49E-03	1.51E-03	-1.51E-03	6.96E-04	-6.96E-04	1.19E-03	-1.19E-03
7.40E-04	-7.40E-04	1.22E-03	-1.22E-03	5.44E-04	-5.44E-04	1.10E-03	-1.10E-03
2.73E-03	-2.73E-03	1.32E-03	-1.32E-03	4.91E-03	-4.91E-03	1.81E-03	-1.81E-03
1.42E-03	-1.42E-03	1.52E-02	-1.52E-02	1.15E-03	-1.15E-03	2.85E-04	-2.85E-04
3.68E-02	-3.68E-02	1.89E-01	-1.89E-01	9.83E-02	-9.83E-02	2.01E-02	-2.01E-02

APPENDIX IV: 3-D INVERSION DATA FILE

1.00E-03	-1.00E-03	1.07E-03	-1.07E-03	4.50E-04	-4.50E-04	1.34E-03	-1.34E-03
2.02E-03	-2.02E-03	1.78E-03	-1.78E-03	1.07E-03	-1.07E-03	1.12E-03	-1.12E-03
2.69E-01	-2.69E-01	3.79E-01	-3.79E-01	9.58E-02	-9.58E-02	1.22E-01	-1.22E-01
2.19E-03	-2.19E-03	1.92E-03	-1.92E-03	7.16E-04	-7.16E-04	9.16E-04	-9.16E-04
1.78E-03	-1.78E-03	2.13E-03	-2.13E-03	7.93E-04	-7.93E-04	8.92E-04	-8.92E-04
1.15E-01	-1.15E-01	2.51E-01	-2.51E-01	1.69E+00	-1.69E+00	3.47E-01	-3.47E-01
1.52E+00	-1.52E+00	1.71E+00	-1.71E+00	1.13E+00	-1.13E+00	1.13E+00	-1.13E+00
1.12E-02	-1.12E-02	1.64E-02	-1.64E-02	1.82E-02	-1.82E-02	2.36E-02	-2.36E-02
2.47E-02	-2.47E-02	1.91E-02	-1.91E-02	7.13E-02	-7.13E-02	5.32E-02	-5.32E-02
9.51E-02	-9.51E-02	3.18E-01	-3.18E-01	1.92E-02	-1.92E-02	7.07E-02	-7.07E-02
2.63E-01	-2.63E-01	2.81E-01	-2.81E-01	6.40E-01	-6.40E-01	6.73E-01	-6.73E-01
1.58E-02	-1.58E-02	2.16E-02	-2.16E-02	8.55E-03	-8.55E-03	8.28E-03	-8.28E-03
2.79E-04	-2.79E-04	4.16E-04	-4.16E-04	2.09E-03	-2.09E-03	8.66E-04	-8.66E-04
1.82E-04	-1.82E-04	5.70E-04	-5.70E-04	8.14E-05	-8.14E-05	6.16E-05	-6.16E-05
8.87E-03	-8.87E-03	6.68E-03	-6.68E-03	2.13E-02	-2.13E-02	2.73E-02	-2.73E-02
4.42E-04	-4.42E-04	1.21E-03	-1.21E-03	1.81E-03	-1.81E-03	7.02E-04	-7.02E-04
1.16E-03	-1.16E-03	1.13E-03	-1.13E-03	1.62E-03	-1.62E-03	1.66E-03	-1.66E-03
3.53E-03	-3.53E-03	2.22E-02	-2.22E-02	3.99E-03	-3.99E-03	9.62E-04	-9.62E-04
7.08E-04	-7.08E-04	1.07E-03	-1.07E-03	4.86E-04	-4.86E-04	2.92E-04	-2.92E-04
6.71E-04	-6.71E-04	1.49E-03	-1.49E-03	4.04E-03	-4.04E-03	4.73E-03	-4.73E-03
2.04E-04	-2.04E-04	8.84E-05	-8.84E-05	7.13E-05	-7.13E-05	7.98E-04	-7.98E-04
6.71E-04	-6.71E-04	4.79E-04	-4.79E-04	1.52E-03	-1.52E-03	6.40E-04	-6.40E-04
1.73E-04	-1.73E-04	2.97E-04	-2.97E-04	8.15E-05	-8.15E-05	8.47E-05	-8.47E-05
2.19E-04	-2.19E-04	9.61E-05	-9.61E-05	2.75E-05	-2.75E-05	5.97E-05	-5.97E-05
1.69E-04	-1.69E-04	3.40E-04	-3.40E-04	4.11E-04	-4.11E-04	3.50E-04	-3.50E-04
1.06E-04	-1.06E-04	2.35E-04	-2.35E-04	1.75E-04	-1.75E-04	1.58E-04	-1.58E-04
1.46E-04	-1.46E-04	1.38E-04	-1.38E-04	3.79E-05	-3.79E-05	3.16E-05	-3.16E-05
2.23E-04	-2.23E-04	7.36E-04	-7.36E-04	4.81E-04	-4.81E-04	9.18E-04	-9.18E-04
ERROR_Period:	2.22E-01						
3.00E-05	-3.00E-05	2.66E-05	-2.66E-05	9.30E-05	-9.30E-05	9.31E-05	-9.31E-05
1.09E-04	-1.09E-04	4.70E-04	-4.70E-04	6.62E-05	-6.62E-05	1.39E-04	-1.39E-04
3.44E-04	-3.44E-04	1.98E-04	-1.98E-04	5.68E-05	-5.68E-05	1.26E-04	-1.26E-04
6.12E-04	-6.12E-04	4.14E-04	-4.14E-04	3.36E-05	-3.36E-05	9.90E-05	-9.90E-05
9.01E-04	-9.01E-04	2.67E-04	-2.67E-04	1.30E-04	-1.30E-04	3.13E-04	-3.13E-04
1.97E-04	-1.97E-04	3.28E-04	-3.28E-04	1.49E-04	-1.49E-04	3.16E-04	-3.16E-04
1.14E-03	-1.14E-03	5.29E-04	-5.29E-04	2.01E-03	-2.01E-03	6.49E-04	-6.49E-04
7.93E-05	-7.93E-05	3.62E-04	-3.62E-04	1.29E-05	-1.29E-05	1.36E-05	-1.36E-05
2.02E-04	-2.02E-04	5.24E-04	-5.24E-04	9.83E-05	-9.83E-05	2.41E-04	-2.41E-04
8.55E-05	-8.55E-05	1.11E-04	-1.11E-04	1.95E-05	-1.95E-05	2.92E-04	-2.92E-04
4.95E-04	-4.95E-04	2.70E-04	-2.70E-04	1.82E-04	-1.82E-04	1.56E-04	-1.56E-04
5.38E-05	-5.38E-05	2.00E-04	-2.00E-04	3.00E-05	-3.00E-05	5.60E-05	-5.60E-05
1.47E-04	-1.47E-04	6.92E-05	-6.92E-05	1.39E-05	-1.39E-05	5.29E-05	-5.29E-05

APPENDIX IV: 3-D INVERSION DATA FILE

1.47E-04	-1.47E-04	2.96E-04	-2.96E-04	5.65E-05	-5.65E-05	9.84E-05	-9.84E-05
8.12E-04	-8.12E-04	1.67E-03	-1.67E-03	1.17E-02	-1.17E-02	2.42E-03	-2.42E-03
9.74E-02	-9.74E-02	1.04E-01	-1.04E-01	6.96E-02	-6.96E-02	7.07E-02	-7.07E-02
7.24E-05	-7.24E-05	1.06E-04	-1.06E-04	1.18E-04	-1.18E-04	1.53E-04	-1.53E-04
9.98E-05	-9.98E-05	6.96E-05	-6.96E-05	2.88E-04	-2.88E-04	1.94E-04	-1.94E-04
3.36E-04	-3.36E-04	1.31E-03	-1.31E-03	6.81E-05	-6.81E-05	2.91E-04	-2.91E-04
7.41E-05	-7.41E-05	9.90E-05	-9.90E-05	2.13E-04	-2.13E-04	2.61E-04	-2.61E-04
1.22E-04	-1.22E-04	1.43E-04	-1.43E-04	6.61E-05	-6.61E-05	5.48E-05	-5.48E-05
4.89E-05	-4.89E-05	1.31E-04	-1.31E-04	6.56E-04	-6.56E-04	2.23E-04	-2.23E-04
1.20E-04	-1.20E-04	5.07E-04	-5.07E-04	5.74E-05	-5.74E-05	5.37E-05	-5.37E-05
6.18E-04	-6.18E-04	2.51E-03	-2.51E-03	7.47E-03	-7.47E-03	2.22E-03	-2.22E-03
1.45E-04	-1.45E-04	6.00E-04	-6.00E-04	6.75E-04	-6.75E-04	3.07E-04	-3.07E-04
3.26E-04	-3.26E-04	2.63E-04	-2.63E-04	4.18E-04	-4.18E-04	3.71E-04	-3.71E-04
1.45E-03	-1.45E-03	5.39E-04	-5.39E-04	2.97E-04	-2.97E-04	9.41E-05	-9.41E-05
2.29E-04	-2.29E-04	3.35E-04	-3.35E-04	1.61E-04	-1.61E-04	8.77E-05	-8.77E-05
7.17E-05	-7.17E-05	1.22E-04	-1.22E-04	3.94E-04	-3.94E-04	3.76E-04	-3.76E-04
7.66E-05	-7.66E-05	1.36E-04	-1.36E-04	1.05E-04	-1.05E-04	3.14E-04	-3.14E-04
1.42E-04	-1.42E-04	1.85E-04	-1.85E-04	8.03E-04	-8.03E-04	7.56E-04	-7.56E-04
6.08E-05	-6.08E-05	8.97E-05	-8.97E-05	3.55E-05	-3.55E-05	2.97E-05	-2.97E-05
7.13E-05	-7.13E-05	3.09E-05	-3.09E-05	7.10E-06	-7.10E-06	1.79E-05	-1.79E-05
5.27E-05	-5.27E-05	1.44E-04	-1.44E-04	1.64E-04	-1.64E-04	1.27E-04	-1.27E-04
5.94E-05	-5.94E-05	1.09E-04	-1.09E-04	1.36E-04	-1.36E-04	1.63E-04	-1.63E-04
6.86E-05	-6.86E-05	4.70E-05	-4.70E-05	2.17E-05	-2.17E-05	1.45E-05	-1.45E-05
9.21E-05	-9.21E-05	3.62E-04	-3.62E-04	1.60E-04	-1.60E-04	4.28E-04	-4.28E-04
ERROR_Period:	4.44E-01						
1.42E-05	-1.42E-05	1.50E-05	-1.50E-05	4.36E-05	-4.36E-05	5.19E-05	-5.19E-05
5.88E-05	-5.88E-05	2.25E-04	-2.25E-04	3.43E-05	-3.43E-05	6.68E-05	-6.68E-05
1.74E-04	-1.74E-04	1.06E-04	-1.06E-04	2.93E-05	-2.93E-05	6.76E-05	-6.76E-05
3.73E-04	-3.73E-04	1.51E-03	-1.51E-03	9.96E-05	-9.96E-05	7.26E-05	-7.26E-05
4.67E-04	-4.67E-04	1.93E-04	-1.93E-04	6.90E-05	-6.90E-05	2.36E-04	-2.36E-04
6.61E-05	-6.61E-05	8.58E-05	-8.58E-05	5.01E-05	-5.01E-05	8.26E-05	-8.26E-05
5.55E-04	-5.55E-04	3.05E-04	-3.05E-04	9.74E-04	-9.74E-04	3.69E-04	-3.69E-04
3.13E-05	-3.13E-05	1.42E-04	-1.42E-04	5.31E-06	-5.31E-06	5.84E-06	-5.84E-06
8.28E-05	-8.28E-05	1.68E-04	-1.68E-04	4.04E-05	-4.04E-05	7.72E-05	-7.72E-05
5.83E-05	-5.83E-05	8.26E-05	-8.26E-05	1.31E-05	-1.31E-05	2.19E-04	-2.19E-04
2.43E-04	-2.43E-04	1.38E-04	-1.38E-04	9.04E-05	-9.04E-05	8.05E-05	-8.05E-05
3.13E-05	-3.13E-05	1.00E-04	-1.00E-04	1.71E-05	-1.71E-05	2.81E-05	-2.81E-05
5.36E-05	-5.36E-05	2.74E-05	-2.74E-05	6.06E-06	-6.06E-06	1.97E-05	-1.97E-05
6.70E-05	-6.70E-05	1.73E-04	-1.73E-04	2.60E-05	-2.60E-05	5.79E-05	-5.79E-05
4.48E-04	-4.48E-04	1.06E-03	-1.06E-03	7.07E-03	-7.07E-03	1.35E-03	-1.35E-03
9.40E-01	-9.40E-01	9.22E-01	-9.22E-01	7.23E-01	-7.23E-01	6.53E-01	-6.53E-01
3.57E-05	-3.57E-05	4.04E-05	-4.04E-05	5.88E-05	-5.88E-05	5.82E-05	-5.82E-05

APPENDIX IV: 3-D INVERSION DATA FILE

5.32E-05	-5.32E-05	3.09E-05	-3.09E-05	1.54E-04	-1.54E-04	8.58E-05	-8.58E-05
1.29E-04	-1.29E-04	5.05E-04	-5.05E-04	2.62E-05	-2.62E-05	1.12E-04	-1.12E-04
2.76E-05	-2.76E-05	5.13E-05	-5.13E-05	7.94E-05	-7.94E-05	1.35E-04	-1.35E-04
5.34E-05	-5.34E-05	7.08E-05	-7.08E-05	2.92E-05	-2.92E-05	2.74E-05	-2.74E-05
2.32E-05	-2.32E-05	7.39E-05	-7.39E-05	2.90E-04	-2.90E-04	1.40E-04	-1.40E-04
6.69E-05	-6.69E-05	2.68E-04	-2.68E-04	3.06E-05	-3.06E-05	2.96E-05	-2.96E-05
2.25E-04	-2.25E-04	1.28E-03	-1.28E-03	2.71E-03	-2.71E-03	1.20E-03	-1.20E-03
7.00E-05	-7.00E-05	3.29E-04	-3.29E-04	3.08E-04	-3.08E-04	1.73E-04	-1.73E-04
1.57E-04	-1.57E-04	1.37E-04	-1.37E-04	2.03E-04	-2.03E-04	1.94E-04	-1.94E-04
1.76E-02	-1.76E-02	7.92E-03	-7.92E-03	1.30E-03	-1.30E-03	5.64E-04	-5.64E-04
1.90E-04	-1.90E-04	3.17E-04	-3.17E-04	1.48E-04	-1.48E-04	9.46E-05	-9.46E-05
3.15E-04	-3.15E-04	4.74E-04	-4.74E-04	1.01E-03	-1.01E-03	1.09E-03	-1.09E-03
9.46E-05	-9.46E-05	6.63E-05	-6.63E-05	2.77E-05	-2.77E-05	1.29E-04	-1.29E-04
5.53E-04	-5.53E-04	1.01E-03	-1.01E-03	2.83E-03	-2.83E-03	4.82E-03	-4.82E-03
1.11E-04	-1.11E-04	1.12E-04	-1.12E-04	5.49E-05	-5.49E-05	4.69E-05	-4.69E-05
2.80E-05	-2.80E-05	1.29E-05	-1.29E-05	2.94E-06	-2.94E-06	7.38E-06	-7.38E-06
7.16E-05	-7.16E-05	1.47E-04	-1.47E-04	2.15E-04	-2.15E-04	2.57E-04	-2.57E-04
2.27E-04	-2.27E-04	1.78E-04	-1.78E-04	5.18E-04	-5.18E-04	3.91E-04	-3.91E-04
4.93E-04	-4.93E-04	3.14E-04	-3.14E-04	3.34E-04	-3.34E-04	2.04E-04	-2.04E-04
3.65E-05	-3.65E-05	1.96E-04	-1.96E-04	7.61E-05	-7.61E-05	2.39E-04	-2.39E-04
ERROR_Period:	8.89E-01						
8.89E-06	-8.89E-06	9.34E-06	-9.34E-06	2.69E-05	-2.69E-05	3.20E-05	-3.20E-05
3.41E-05	-3.41E-05	1.02E-04	-1.02E-04	1.99E-05	-1.99E-05	3.07E-05	-3.07E-05
8.33E-05	-8.33E-05	5.61E-05	-5.61E-05	1.46E-05	-1.46E-05	3.58E-05	-3.58E-05
1.66E-04	-1.66E-04	1.57E-04	-1.57E-04	9.52E-06	-9.52E-06	3.76E-05	-3.76E-05
2.30E-04	-2.30E-04	6.36E-04	-6.36E-04	1.81E-03	-1.81E-03	1.50E-04	-1.50E-04
2.96E-05	-2.96E-05	3.55E-05	-3.55E-05	2.25E-05	-2.25E-05	3.38E-05	-3.38E-05
2.39E-04	-2.39E-04	1.76E-04	-1.76E-04	4.18E-04	-4.18E-04	2.16E-04	-2.16E-04
9.97E-06	-9.97E-06	4.28E-05	-4.28E-05	1.69E-06	-1.69E-06	1.74E-06	-1.74E-06
4.07E-05	-4.07E-05	3.15E-04	-3.15E-04	1.01E-04	-1.01E-04	2.94E-05	-2.94E-05
4.55E-03	-4.55E-03	4.59E-03	-4.59E-03	1.15E-03	-1.15E-03	1.07E-02	-1.07E-02
1.55E-04	-1.55E-04	3.88E-04	-3.88E-04	2.92E-04	-2.92E-04	4.54E-05	-4.54E-05
9.53E-05	-9.53E-05	2.51E-04	-2.51E-04	5.07E-05	-5.07E-05	7.12E-05	-7.12E-05
2.18E-05	-2.18E-05	1.15E-05	-1.15E-05	3.16E-06	-3.16E-06	7.48E-06	-7.48E-06
3.08E-05	-3.08E-05	1.01E-04	-1.01E-04	1.21E-05	-1.21E-05	3.38E-05	-3.38E-05
3.64E-04	-3.64E-04	3.02E-03	-3.02E-03	2.93E-02	-2.93E-02	7.80E-04	-7.80E-04
2.10E-04	-2.10E-04	4.25E-04	-4.25E-04	1.94E-04	-1.94E-04	2.24E-04	-2.24E-04
1.86E-05	-1.86E-05	1.53E-05	-1.53E-05	3.04E-05	-3.04E-05	2.20E-05	-2.20E-05
3.34E-05	-3.34E-05	1.83E-05	-1.83E-05	9.60E-05	-9.60E-05	4.99E-05	-4.99E-05
6.58E-05	-6.58E-05	3.48E-04	-3.48E-04	1.34E-05	-1.34E-05	7.74E-05	-7.74E-05
9.86E-06	-9.86E-06	1.90E-05	-1.90E-05	2.77E-05	-2.77E-05	4.96E-05	-4.96E-05
2.53E-05	-2.53E-05	4.07E-05	-4.07E-05	1.40E-05	-1.40E-05	1.60E-05	-1.60E-05

APPENDIX IV: 3-D INVERSION DATA FILE

9.24E-06	-9.24E-06	2.64E-05	-2.64E-05	1.02E-04	-1.02E-04	4.56E-05	-4.56E-05
4.02E-05	-4.02E-05	1.69E-04	-1.69E-04	1.79E-05	-1.79E-05	2.01E-05	-2.01E-05
1.49E-04	-1.49E-04	1.32E-04	-1.32E-04	3.51E-04	-3.51E-04	6.09E-04	-6.09E-04
3.52E-05	-3.52E-05	1.58E-04	-1.58E-04	1.45E-04	-1.45E-04	8.89E-05	-8.89E-05
7.54E-05	-7.54E-05	6.81E-05	-6.81E-05	9.77E-05	-9.77E-05	9.61E-05	-9.61E-05
1.69E-03	-1.69E-03	2.70E-03	-2.70E-03	2.70E-04	-2.70E-04	3.06E-04	-3.06E-04
1.98E-04	-1.98E-04	2.72E-04	-2.72E-04	1.44E-04	-1.44E-04	1.38E-04	-1.38E-04
5.18E-05	-5.18E-05	2.64E-04	-2.64E-04	1.89E-04	-1.89E-04	1.14E-04	-1.14E-04
3.83E-05	-3.83E-05	1.04E-05	-1.04E-05	1.02E-05	-1.02E-05	5.67E-05	-5.67E-05
1.10E-03	-1.10E-03	1.07E-02	-1.07E-02	2.18E-02	-2.18E-02	8.26E-03	-8.26E-03
8.26E-05	-8.26E-05	3.48E-04	-3.48E-04	2.51E-04	-2.51E-04	3.59E-05	-3.59E-05
1.53E-05	-1.53E-05	4.77E-05	-4.77E-05	1.59E-05	-1.59E-05	6.00E-06	-6.00E-06
1.18E-04	-1.18E-04	1.25E-04	-1.25E-04	1.93E-04	-1.93E-04	1.46E-04	-1.46E-04
2.47E-05	-2.47E-05	1.18E-04	-1.18E-04	1.68E-03	-1.68E-03	2.76E-04	-2.76E-04
2.11E-04	-2.11E-04	1.35E-04	-1.35E-04	1.43E-04	-1.43E-04	1.03E-04	-1.03E-04
3.76E-05	-3.76E-05	1.09E-04	-1.09E-04	7.13E-05	-7.13E-05	1.36E-04	-1.36E-04
ERROR_Period:	1.78E+00						
7.45E-06	-7.45E-06	7.53E-06	-7.53E-06	2.07E-05	-2.07E-05	2.34E-05	-2.34E-05
2.31E-05	-2.31E-05	7.20E-05	-7.20E-05	1.32E-05	-1.32E-05	2.32E-05	-2.32E-05
4.96E-05	-4.96E-05	2.66E-05	-2.66E-05	8.97E-06	-8.97E-06	1.69E-05	-1.69E-05
9.32E-05	-9.32E-05	1.32E-04	-1.32E-04	9.75E-06	-9.75E-06	3.18E-05	-3.18E-05
1.78E-04	-1.78E-04	5.93E-05	-5.93E-05	3.16E-05	-3.16E-05	5.98E-05	-5.98E-05
3.27E-05	-3.27E-05	2.57E-05	-2.57E-05	2.39E-05	-2.39E-05	2.12E-05	-2.12E-05
9.88E-05	-9.88E-05	1.02E-03	-1.02E-03	1.79E-03	-1.79E-03	1.39E-04	-1.39E-04
1.11E-05	-1.11E-05	2.80E-05	-2.80E-05	1.81E-06	-1.81E-06	1.95E-06	-1.95E-06
2.16E-05	-2.16E-05	2.91E-05	-2.91E-05	1.08E-05	-1.08E-05	1.38E-05	-1.38E-05
3.64E-05	-3.64E-05	3.85E-05	-3.85E-05	1.43E-05	-1.43E-05	6.14E-05	-6.14E-05
8.41E-05	-8.41E-05	4.50E-05	-4.50E-05	3.24E-05	-3.24E-05	2.64E-05	-2.64E-05
8.01E-05	-8.01E-05	2.71E-04	-2.71E-04	3.68E-05	-3.68E-05	7.77E-05	-7.77E-05
1.23E-05	-1.23E-05	7.91E-06	-7.91E-06	2.44E-06	-2.44E-06	4.57E-06	-4.57E-06
1.54E-05	-1.54E-05	6.93E-05	-6.93E-05	6.20E-06	-6.20E-06	2.34E-05	-2.34E-05
3.25E-04	-3.25E-04	2.78E-03	-2.78E-03	2.49E-02	-2.49E-02	6.96E-04	-6.96E-04
1.24E-04	-1.24E-04	1.65E-04	-1.65E-04	1.28E-04	-1.28E-04	9.63E-05	-9.63E-05
1.32E-05	-1.32E-05	1.39E-05	-1.39E-05	2.04E-05	-2.04E-05	1.96E-05	-1.96E-05
2.22E-05	-2.22E-05	1.34E-05	-1.34E-05	6.17E-05	-6.17E-05	3.33E-05	-3.33E-05
3.87E-05	-3.87E-05	2.62E-04	-2.62E-04	8.09E-06	-8.09E-06	5.83E-05	-5.83E-05
4.52E-06	-4.52E-06	7.27E-06	-7.27E-06	1.23E-05	-1.23E-05	1.87E-05	-1.87E-05
2.03E-05	-2.03E-05	3.00E-05	-3.00E-05	1.19E-05	-1.19E-05	1.27E-05	-1.27E-05
1.05E-05	-1.05E-05	2.16E-05	-2.16E-05	7.92E-05	-7.92E-05	4.37E-05	-4.37E-05
4.99E-05	-4.99E-05	1.99E-04	-1.99E-04	1.96E-05	-1.96E-05	2.65E-05	-2.65E-05
1.33E-04	-1.33E-04	1.09E-04	-1.09E-04	3.39E-04	-3.39E-04	4.34E-04	-4.34E-04
1.99E-05	-1.99E-05	8.90E-05	-8.90E-05	7.84E-05	-7.84E-05	5.01E-05	-5.01E-05

APPENDIX IV: 3-D INVERSION DATA FILE

3.84E-05	-3.84E-05	3.78E-05	-3.78E-05	5.11E-05	-5.11E-05	5.42E-05	-5.42E-05
7.36E-03	-7.36E-03	1.85E-02	-1.85E-02	2.15E-03	-2.15E-03	3.17E-04	-3.17E-04
1.06E-03	-1.06E-03	1.17E-03	-1.17E-03	4.86E-03	-4.86E-03	5.25E-04	-5.25E-04
6.51E-05	-6.51E-05	2.61E-04	-2.61E-04	1.65E-04	-1.65E-04	7.49E-05	-7.49E-05
2.33E-05	-2.33E-05	1.16E-05	-1.16E-05	1.05E-05	-1.05E-05	2.04E-05	-2.04E-05
3.87E-04	-3.87E-04	3.22E-03	-3.22E-03	1.08E-02	-1.08E-02	3.51E-03	-3.51E-03
2.39E-04	-2.39E-04	3.61E-03	-3.61E-03	4.57E-03	-4.57E-03	1.62E-04	-1.62E-04
9.42E-06	-9.42E-06	7.55E-06	-7.55E-06	1.96E-06	-1.96E-06	3.81E-06	-3.81E-06
1.72E-04	-1.72E-04	3.66E-03	-3.66E-03	2.08E-02	-2.08E-02	3.97E-04	-3.97E-04
8.31E-04	-8.31E-04	4.04E-02	-4.04E-02	6.41E-02	-6.41E-02	1.24E-03	-1.24E-03
2.45E-04	-2.45E-04	1.72E-03	-1.72E-03	2.73E-03	-2.73E-03	1.92E-04	-1.92E-04
1.03E-04	-1.03E-04	5.87E-04	-5.87E-04	1.04E-03	-1.04E-03	1.85E-04	-1.85E-04
ERROR_Period:	3.55E+00						
1.36E-05	-1.36E-05	1.09E-05	-1.09E-05	3.18E-05	-3.18E-05	2.50E-05	-2.50E-05
1.71E-04	-1.71E-04	2.35E-03	-2.35E-03	8.91E-04	-8.91E-04	1.07E-04	-1.07E-04
3.89E-05	-3.89E-05	1.77E-05	-1.77E-05	8.30E-06	-8.30E-06	1.03E-05	-1.03E-05
1.43E-04	-1.43E-04	1.69E-04	-1.69E-04	2.97E-05	-2.97E-05	4.23E-05	-4.23E-05
1.65E-04	-1.65E-04	3.10E-04	-3.10E-04	2.15E-04	-2.15E-04	3.86E-05	-3.86E-05
6.29E-05	-6.29E-05	6.65E-05	-6.65E-05	4.47E-05	-4.47E-05	5.08E-05	-5.08E-05
7.98E-05	-7.98E-05	8.04E-05	-8.04E-05	1.53E-04	-1.53E-04	1.27E-04	-1.27E-04
4.10E-05	-4.10E-05	6.97E-05	-6.97E-05	6.57E-06	-6.57E-06	7.11E-06	-7.11E-06
4.06E-05	-4.06E-05	5.07E-05	-5.07E-05	2.13E-05	-2.13E-05	2.57E-05	-2.57E-05
3.26E-05	-3.26E-05	3.78E-05	-3.78E-05	1.48E-05	-1.48E-05	5.07E-05	-5.07E-05
4.00E-05	-4.00E-05	2.52E-05	-2.52E-05	1.57E-05	-1.57E-05	1.47E-05	-1.47E-05
1.69E-04	-1.69E-04	2.50E-04	-2.50E-04	6.40E-05	-6.40E-05	7.91E-05	-7.91E-05
1.28E-05	-1.28E-05	1.03E-05	-1.03E-05	3.48E-06	-3.48E-06	5.36E-06	-5.36E-06
1.69E-05	-1.69E-05	5.09E-05	-5.09E-05	7.23E-06	-7.23E-06	1.81E-05	-1.81E-05
4.56E-04	-4.56E-04	4.49E-03	-4.49E-03	2.24E-02	-2.24E-02	1.14E-03	-1.14E-03
2.32E-04	-2.32E-04	2.85E-04	-2.85E-04	2.17E-04	-2.17E-04	1.73E-04	-1.73E-04
2.86E-05	-2.86E-05	3.54E-05	-3.54E-05	4.06E-05	-4.06E-05	4.88E-05	-4.88E-05
2.12E-05	-2.12E-05	1.32E-05	-1.32E-05	5.58E-05	-5.58E-05	2.78E-05	-2.78E-05
5.06E-05	-5.06E-05	2.45E-04	-2.45E-04	1.12E-05	-1.12E-05	5.49E-05	-5.49E-05
4.86E-06	-4.86E-06	6.99E-06	-6.99E-06	1.25E-05	-1.25E-05	1.75E-05	-1.75E-05
4.43E-05	-4.43E-05	3.32E-05	-3.32E-05	3.11E-05	-3.11E-05	2.17E-05	-2.17E-05
6.39E-05	-6.39E-05	7.13E-05	-7.13E-05	2.89E-04	-2.89E-04	1.77E-04	-1.77E-04
9.76E-05	-9.76E-05	1.74E-04	-1.74E-04	3.37E-05	-3.37E-05	3.31E-05	-3.31E-05
1.05E-04	-1.05E-04	4.96E-04	-4.96E-04	1.46E-03	-1.46E-03	3.60E-04	-3.60E-04
1.65E-05	-1.65E-05	5.47E-05	-5.47E-05	5.27E-05	-5.27E-05	3.47E-05	-3.47E-05
4.22E-03	-4.22E-03	3.79E-03	-3.79E-03	6.12E-03	-6.12E-03	5.71E-03	-5.71E-03
1.38E-01	-1.38E-01	1.25E-01	-1.25E-01	3.73E-02	-3.73E-02	3.41E-02	-3.41E-02
4.14E-03	-4.14E-03	1.13E-02	-1.13E-02	2.13E-02	-2.13E-02	2.31E-03	-2.31E-03
5.87E-05	-5.87E-05	3.16E-04	-3.16E-04	1.91E-04	-1.91E-04	1.30E-04	-1.30E-04

APPENDIX IV: 3-D INVERSION DATA FILE

3.47E-05	-3.47E-05	2.62E-05	-2.62E-05	3.69E-05	-3.69E-05	4.46E-05	-4.46E-05
2.66E-04	-2.66E-04	6.17E-04	-6.17E-04	6.00E-03	-6.00E-03	5.47E-04	-5.47E-04
1.03E-03	-1.03E-03	6.88E-03	-6.88E-03	6.58E-03	-6.58E-03	4.35E-04	-4.35E-04
1.76E-04	-1.76E-04	1.92E-04	-1.92E-04	8.67E-05	-8.67E-05	1.04E-04	-1.04E-04
8.57E-04	-8.57E-04	4.54E-03	-4.54E-03	8.68E-03	-8.68E-03	1.81E-03	-1.81E-03
2.23E-03	-2.23E-03	1.00E-02	-1.00E-02	1.07E-02	-1.07E-02	4.71E-04	-4.71E-04
5.78E-04	-5.78E-04	8.67E-03	-8.67E-03	4.34E-03	-4.34E-03	6.51E-04	-6.51E-04
9.26E-04	-9.26E-04	5.91E-03	-5.91E-03	2.00E-02	-2.00E-02	1.24E-03	-1.24E-03
ERROR_Period:	7.11E+00						
5.25E-04	-5.25E-04	4.98E-04	-4.98E-04	1.32E-03	-1.32E-03	1.35E-03	-1.35E-03
4.32E-05	-4.32E-05	4.04E-03	-4.04E-03	2.01E-03	-2.01E-03	4.11E-04	-4.11E-04
9.88E-05	-9.88E-05	8.25E-05	-8.25E-05	3.94E-05	-3.94E-05	4.04E-05	-4.04E-05
1.08E-02	-1.08E-02	1.31E-02	-1.31E-02	2.31E-03	-2.31E-03	3.30E-03	-3.30E-03
8.14E-04	-8.14E-04	6.90E-04	-6.90E-04	3.80E-04	-3.80E-04	3.55E-04	-3.55E-04
6.69E-04	-6.69E-04	6.97E-03	-6.97E-03	4.66E-03	-4.66E-03	4.93E-04	-4.93E-04
2.44E-02	-2.44E-02	2.39E-02	-2.39E-02	5.23E-02	-5.23E-02	4.95E-02	-4.95E-02
3.82E-02	-3.82E-02	3.77E-02	-3.77E-02	6.02E-03	-6.02E-03	5.91E-03	-5.91E-03
4.66E-05	-4.66E-05	2.42E-04	-2.42E-04	1.23E-04	-1.23E-04	2.10E-05	-2.52E-05
1.69E-05	-1.69E-05	4.34E-05	-4.34E-05	1.80E-05	-1.80E-05	8.48E-06	-8.48E-06
1.97E-04	-1.97E-04	5.49E-05	-5.49E-05	5.24E-05	-5.24E-05	6.32E-06	-6.32E-06
4.35E-04	-4.35E-04	4.80E-04	-4.80E-04	1.58E-04	-1.58E-04	1.61E-04	-1.61E-04
8.00E-06	-8.00E-06	7.27E-06	-7.27E-06	2.22E-06	-2.22E-06	3.94E-06	-3.94E-06
3.10E-05	-3.10E-05	6.89E-05	-6.89E-05	1.38E-05	-1.38E-05	2.60E-05	-2.60E-05
3.13E-02	-3.13E-02	5.96E-02	-5.96E-02	4.88E-01	-4.88E-01	7.35E-02	-7.35E-02
5.63E-04	-5.63E-04	6.67E-04	-6.67E-04	4.72E-04	-4.72E-04	4.24E-04	-4.24E-04
8.51E-05	-8.51E-05	9.54E-05	-9.54E-05	1.16E-04	-1.16E-04	1.29E-04	-1.29E-04
1.59E-05	-1.59E-05	1.30E-05	-1.30E-05	4.29E-05	-4.29E-05	3.32E-05	-3.32E-05
8.49E-05	-8.49E-05	2.04E-04	-2.04E-04	2.29E-05	-2.29E-05	4.88E-05	-4.88E-05
7.50E-06	-7.50E-06	7.96E-06	-7.96E-06	1.83E-05	-1.83E-05	1.89E-05	-1.89E-05
7.94E-05	-7.94E-05	1.03E-04	-1.03E-04	7.52E-05	-7.52E-05	8.03E-05	-8.03E-05
7.90E-03	-7.90E-03	8.90E-03	-8.90E-03	2.53E-02	-2.53E-02	2.34E-02	-2.34E-02
1.02E-04	-1.02E-04	1.71E-03	-1.71E-03	3.36E-04	-3.36E-04	3.48E-05	-3.48E-05
3.08E-05	-3.08E-05	1.28E-04	-1.28E-04	3.56E-04	-3.56E-04	1.23E-04	-1.23E-04
1.22E-05	-1.22E-05	2.14E-04	-2.14E-04	2.07E-04	-4.96E-05	2.61E-05	-2.61E-05
3.97E-05	-3.97E-05	6.43E-04	-6.43E-04	2.67E-04	-2.67E-04	1.97E-05	-1.97E-05
8.41E+00	-8.41E+00	5.47E+00	-5.47E+00	1.48E+00	-1.48E+00	9.66E-01	-9.66E-01
1.00E-02	-1.00E-02	4.71E-02	-4.71E-02	6.77E-02	-6.77E-02	1.28E-02	-1.28E-02
2.03E-04	-2.03E-04	1.39E-04	-1.39E-04	8.58E-04	-8.58E-04	5.52E-04	-5.52E-04
7.11E-05	-7.11E-05	1.10E-04	-1.10E-04	1.36E-05	-1.36E-05	1.31E-04	-1.31E-04
5.57E-04	-5.57E-04	1.81E-03	-1.81E-03	5.98E-01	-5.98E-01	3.80E-03	-3.80E-03
5.20E-04	-5.20E-04	1.23E-01	-1.23E-01	7.32E-03	-7.32E-03	8.55E-04	-8.55E-04
6.24E-04	-6.24E-04	8.35E-04	-8.35E-04	1.70E-04	-1.70E-04	2.35E-04	-2.35E-04

APPENDIX IV: 3-D INVERSION DATA FILE

1.02E-03	-1.02E-03	2.14E-02	-2.14E-02	2.01E-01	-2.01E-01	8.29E-04	-8.29E-04
1.62E-02	-1.62E-02	8.97E-01	-8.97E-01	1.09E-01	-1.09E-01	3.02E-03	-3.02E-03
6.90E-04	-6.90E-04	2.39E-03	-2.39E-03	1.31E-03	-1.31E-03	1.81E-04	-1.81E-04
9.83E-04	-9.83E-04	2.25E-02	-2.25E-02	1.78E-02	-1.78E-02	4.03E-03	-4.03E-03
ERROR_Period:	1.42E+01						
5.25E-06	-5.25E-06	2.49E-05	-2.49E-05	6.60E-05	-6.60E-05	1.35E-05	-1.35E-05
9.03E-04	-9.03E-04	4.89E-03	-4.89E-03	2.34E-03	-2.34E-03	4.90E-04	-4.90E-04
6.61E-03	-6.61E-03	6.39E-03	-6.39E-03	2.66E-03	-2.66E-03	3.19E-03	-3.19E-03
1.08E-04	-1.08E-04	1.31E-04	-1.31E-04	2.31E-05	-2.31E-05	3.30E-05	-3.30E-05
3.61E-04	-3.61E-04	2.88E-03	-2.88E-03	7.98E-04	-7.98E-04	1.55E-04	-1.55E-04
2.67E-02	-2.67E-02	2.80E-02	-2.80E-02	1.93E-02	-1.93E-02	2.04E-02	-2.04E-02
1.87E-02	-1.87E-02	1.95E-02	-1.95E-02	4.08E-02	-4.08E-02	4.11E-02	-4.11E-02
1.11E-05	-1.11E-05	1.50E-04	-1.50E-04	8.90E-06	-8.90E-06	2.30E-06	-2.30E-06
1.57E-05	-1.57E-05	9.70E-05	-9.70E-05	4.00E-05	-4.00E-05	9.50E-06	-9.50E-06
8.56E-06	-8.56E-06	7.20E-06	-7.20E-06	3.45E-06	-3.45E-06	1.20E-05	-1.20E-05
2.23E-05	-2.23E-05	5.31E-05	-5.31E-05	4.12E-05	-4.12E-05	6.12E-06	-6.12E-06
5.67E-05	-5.67E-05	3.85E-04	-3.85E-04	1.01E-04	-1.01E-04	2.48E-05	-2.48E-05
3.75E-06	-3.75E-06	3.59E-06	-3.59E-06	7.97E-07	-7.97E-07	2.28E-06	-2.28E-06
1.92E-05	-1.92E-05	5.70E-05	-5.70E-05	8.44E-06	-8.44E-06	2.06E-05	-2.06E-05
2.92E-04	-2.92E-04	3.51E-03	-3.51E-03	1.19E-02	-1.19E-02	9.83E-04	-9.83E-04
2.79E-04	-2.79E-04	1.47E-03	-1.47E-03	1.22E-03	-1.22E-03	1.91E-04	-1.91E-04
1.81E-05	-1.81E-05	1.98E-05	-1.98E-05	2.57E-05	-2.57E-05	2.74E-05	-2.74E-05
1.38E-05	-1.38E-05	8.65E-06	-8.65E-06	3.90E-05	-3.90E-05	2.32E-05	-2.32E-05
6.62E-05	-6.62E-05	2.32E-04	-2.32E-04	1.70E-05	-1.70E-05	5.54E-05	-5.54E-05
1.05E-05	-1.05E-05	2.76E-06	-2.76E-06	2.34E-05	-2.34E-05	6.43E-06	-6.43E-06
1.42E-02	-1.42E-02	1.15E-02	-1.15E-02	1.37E-02	-1.37E-02	1.19E-02	-1.19E-02
7.90E-05	-7.90E-05	8.90E-05	-8.90E-05	2.53E-04	-2.53E-04	2.34E-04	-2.34E-04
8.70E-03	-8.70E-03	1.49E-02	-1.49E-02	2.86E-03	-2.86E-03	3.00E-03	-3.00E-03
2.69E-05	-2.69E-05	2.34E-05	-2.34E-05	6.13E-05	-6.13E-05	1.13E-04	-1.13E-04
1.06E-05	-1.06E-05	1.91E-04	-1.91E-04	1.75E-04	-1.75E-04	2.32E-05	-2.32E-05
7.42E-05	-7.42E-05	6.49E-04	-6.49E-04	4.85E-04	-4.85E-04	2.00E-05	-2.00E-05
3.98E-02	-3.98E-02	6.77E-02	-6.77E-02	5.29E-03	-5.29E-03	6.99E-03	-6.99E-03
5.08E-03	-5.08E-03	2.90E-02	-2.90E-02	3.12E-02	-3.12E-02	7.08E-03	-7.08E-03
2.98E-04	-2.98E-04	6.00E-04	-6.00E-04	1.26E-03	-1.26E-03	2.40E-03	-2.40E-03
1.04E-04	-1.04E-04	1.25E-02	-1.25E-02	1.32E-03	-1.32E-03	3.31E-04	-3.31E-04
4.31E-06	-4.31E-06	1.50E-04	-1.50E-04	1.18E-04	-1.18E-04	7.21E-05	-7.21E-05
1.14E-05	-1.14E-05	2.38E-02	-2.38E-02	1.59E-04	-1.59E-04	6.92E-04	-6.92E-04
1.52E-03	-1.52E-03	1.43E-03	-1.43E-03	4.06E-03	-4.06E-03	3.80E-03	-3.80E-03
5.95E-06	-5.95E-06	2.21E-04	-2.21E-04	2.34E-04	-2.34E-04	2.20E-06	-2.20E-06
5.83E-05	-5.83E-05	4.07E-03	-4.07E-03	1.04E-03	-1.04E-03	3.60E-04	-3.60E-04
7.39E-04	-7.39E-04	1.65E-04	-1.65E-04	1.72E-03	-1.72E-03	1.52E-05	-1.52E-05
1.73E-03	-1.73E-03	3.70E-04	-3.70E-04	5.66E-03	-5.66E-03	5.14E-05	-5.14E-05

APPENDIX IV: 3-D INVERSION DATA FILE

ERROR_Period:	2.13E+01						
3.15E-06	-3.15E-06	3.21E-06	-3.21E-06	8.62E-06	-8.62E-06	9.79E-06	-9.79E-06
1.50E-04	-1.50E-04	1.88E-04	-1.88E-04	3.87E-04	-3.87E-04	8.85E-05	-8.85E-05
6.61E-05	-6.61E-05	3.20E-04	-3.20E-04	1.33E-04	-1.33E-04	3.19E-05	-3.19E-05
6.95E-05	-6.95E-05	8.70E-05	-8.70E-05	1.48E-05	-1.48E-05	2.19E-05	-2.19E-05
4.95E-04	-4.95E-04	4.83E-03	-4.83E-03	1.21E-03	-1.21E-03	2.52E-04	-2.52E-04
1.93E-03	-1.93E-03	2.61E-03	-2.61E-03	1.35E-03	-1.35E-03	2.02E-03	-2.02E-03
1.87E-02	-1.87E-02	1.95E-02	-1.95E-02	4.08E-02	-4.08E-02	4.11E-02	-4.11E-02
2.47E-06	-2.47E-06	1.30E-05	-1.30E-05	4.04E-07	-4.04E-07	6.50E-07	-6.50E-07
2.20E-05	-2.20E-05	1.38E-04	-1.38E-04	5.71E-05	-5.71E-05	1.38E-05	-1.38E-05
9.78E-06	-9.78E-06	9.31E-06	-9.31E-06	4.13E-06	-4.13E-06	1.37E-05	-1.37E-05
2.21E-05	-2.21E-05	4.70E-05	-4.70E-05	4.26E-05	-4.26E-05	5.60E-06	-5.60E-06
1.28E-02	-1.28E-02	1.41E-02	-1.41E-02	4.45E-03	-4.45E-03	4.72E-03	-4.72E-03
6.95E-06	-6.95E-06	6.78E-06	-6.78E-06	2.09E-06	-2.09E-06	3.58E-06	-3.58E-06
1.81E-05	-1.81E-05	2.75E-04	-2.75E-04	8.02E-06	-8.02E-06	2.00E-05	-2.00E-05
2.92E-02	-2.92E-02	7.02E-02	-7.02E-02	2.39E-01	-2.39E-01	9.83E-02	-9.83E-02
5.54E-03	-5.54E-03	6.44E-03	-6.44E-03	6.65E-03	-6.65E-03	3.62E-03	-3.62E-03
1.99E-05	-1.99E-05	2.16E-05	-2.16E-05	2.83E-05	-2.83E-05	2.98E-05	-2.98E-05
1.33E-05	-1.33E-05	9.68E-06	-9.68E-06	3.80E-05	-3.80E-05	2.67E-05	-2.67E-05
1.06E-04	-1.06E-04	2.73E-04	-2.73E-04	2.47E-05	-2.47E-05	6.19E-05	-6.19E-05
6.53E-06	-6.53E-06	2.29E-05	-2.29E-05	8.32E-05	-8.32E-05	1.07E-05	-1.07E-05
6.06E-05	-6.06E-05	2.84E-04	-2.84E-04	2.79E-04	-2.79E-04	5.07E-05	-5.07E-05
2.63E-05	-2.63E-05	3.28E-05	-3.28E-05	9.34E-05	-9.34E-05	8.05E-05	-8.05E-05
1.22E-05	-1.22E-05	1.27E-04	-1.27E-04	4.73E-06	-4.73E-06	3.97E-06	-3.97E-06
2.45E-03	-2.45E-03	1.91E-03	-1.91E-03	5.53E-03	-5.53E-03	9.33E-03	-9.33E-03
7.44E-06	-7.44E-06	1.56E-04	-1.56E-04	1.44E-04	-1.44E-04	1.76E-05	-1.76E-05
7.25E-05	-7.25E-05	6.66E-04	-6.66E-04	4.73E-03	-4.73E-03	2.02E-05	-2.02E-05
7.84E-03	-7.84E-03	4.12E-03	-4.12E-03	1.07E-03	-1.07E-03	5.51E-04	-5.51E-04
5.13E-06	-5.13E-06	8.64E-06	-8.64E-06	1.02E-05	-1.02E-05	7.00E-06	-7.00E-06
1.06E-05	-1.06E-05	9.98E-06	-9.98E-06	8.58E-05	-8.58E-05	4.18E-05	-4.18E-05
5.82E-06	-5.82E-06	1.52E-04	-1.52E-04	5.20E-05	-5.20E-05	1.51E-05	-1.51E-05
3.03E-04	-3.03E-04	1.37E-05	-1.37E-05	4.74E-05	-4.74E-05	1.07E-05	-1.07E-05
5.00E-06	-5.00E-06	3.97E-05	-3.97E-05	3.51E-05	-3.51E-05	4.97E-06	-4.97E-06
3.33E-06	-3.33E-06	1.94E-06	-1.94E-06	1.25E-06	-1.25E-06	1.08E-06	-1.08E-06
1.46E-05	-1.46E-05	6.04E-05	-6.04E-05	1.30E-04	-1.30E-04	1.62E-05	-1.62E-05
3.91E-07	-3.91E-07	1.14E-05	-1.14E-05	3.94E-06	-3.94E-06	3.67E-06	-3.67E-06
3.75E-05	-3.75E-05	1.40E-06	-1.40E-06	1.67E-05	-1.67E-05	4.38E-07	-4.38E-07
5.44E-05	-5.44E-05	1.29E-04	-1.29E-04	2.08E-04	-2.08E-04	1.82E-05	-1.82E-05
ERROR_Period:	4.27E+01						
2.99E-06	-2.99E-06	2.22E-06	-2.22E-06	8.28E-06	-8.28E-06	6.45E-06	-6.45E-06
6.14E-06	-6.14E-06	3.28E-05	-3.28E-05	3.27E-06	-3.27E-06	1.06E-05	-1.06E-05
2.39E-05	-2.39E-05	1.66E-05	-1.66E-05	7.28E-06	-7.28E-06	8.88E-06	-8.88E-06

APPENDIX IV: 3-D INVERSION DATA FILE

2.50E-05	-2.50E-05	2.95E-05	-2.95E-05	3.11E-06	-3.11E-06	7.26E-06	-7.26E-06
7.28E-05	-7.28E-05	1.74E-04	-1.74E-04	1.11E-04	-1.11E-04	2.16E-05	-2.16E-05
7.48E-06	-7.48E-06	4.05E-05	-4.05E-05	2.71E-05	-2.71E-05	6.37E-06	-6.37E-06
2.00E-05	-2.00E-05	1.43E-04	-1.43E-04	2.01E-04	-2.01E-04	4.65E-05	-4.65E-05
2.53E-06	-2.53E-06	1.10E-05	-1.10E-05	3.88E-07	-3.88E-07	5.92E-07	-5.92E-07
1.27E-05	-1.27E-05	8.08E-05	-8.08E-05	3.24E-05	-3.24E-05	7.91E-06	-7.91E-06
6.80E-06	-6.80E-06	6.87E-06	-6.87E-06	3.46E-06	-3.46E-06	1.08E-05	-1.08E-05
2.15E-05	-2.15E-05	5.98E-05	-5.98E-05	4.70E-05	-4.70E-05	7.46E-06	-7.46E-06
6.90E-03	-6.90E-03	7.31E-03	-7.31E-03	2.43E-03	-2.43E-03	2.48E-03	-2.48E-03
3.95E-06	-3.95E-06	3.72E-06	-3.72E-06	1.06E-06	-1.06E-06	2.15E-06	-2.15E-06
1.47E-05	-1.47E-05	2.19E-04	-2.19E-04	3.29E-05	-3.29E-05	1.60E-05	-1.60E-05
2.92E-02	-2.92E-02	7.02E-02	-7.02E-02	2.39E-01	-2.39E-01	9.83E-02	-9.83E-02
3.69E-05	-3.69E-05	5.41E-05	-5.41E-05	3.93E-05	-3.93E-05	3.01E-05	-3.01E-05
1.99E-05	-1.99E-05	9.79E-05	-9.79E-05	1.40E-04	-1.40E-04	-1.03E-04	-2.70E-05
9.98E-06	-9.98E-06	6.87E-06	-6.87E-06	3.03E-05	-3.03E-05	2.21E-05	-2.21E-05
1.68E-05	-1.68E-05	1.48E-04	-1.48E-04	3.88E-06	-3.88E-06	3.73E-05	-3.73E-05
6.22E-06	-6.22E-06	9.65E-06	-9.65E-06	8.14E-05	-8.14E-05	4.92E-06	-4.92E-06
8.75E-05	-8.75E-05	6.47E-05	-6.47E-05	7.91E-05	-7.91E-05	6.31E-05	-6.31E-05
1.58E-05	-1.58E-05	2.00E-05	-2.00E-05	6.95E-05	-6.95E-05	4.85E-05	-4.85E-05
1.22E-05	-1.22E-05	2.55E-05	-2.55E-05	4.73E-06	-4.73E-06	3.97E-06	-3.97E-06
1.89E-05	-1.89E-05	1.37E-05	-1.37E-05	4.24E-05	-4.24E-05	6.70E-05	-6.70E-05
4.60E-06	-4.60E-06	1.19E-04	-1.19E-04	8.78E-05	-8.78E-05	1.35E-05	-1.35E-05
6.64E-05	-6.64E-05	6.68E-04	-6.68E-04	4.36E-03	-4.36E-03	2.04E-05	-2.04E-05
3.32E-04	-3.32E-04	2.70E-04	-2.70E-04	5.63E-05	-5.63E-05	3.28E-05	-3.28E-05
3.13E-06	-3.13E-06	4.45E-06	-4.45E-06	4.12E-06	-4.12E-06	1.26E-06	-1.26E-06
9.36E-06	-9.36E-06	6.39E-06	-6.39E-06	6.03E-05	-6.03E-05	1.76E-05	-1.76E-05
3.67E-06	-3.67E-06	7.42E-06	-7.42E-06	8.36E-06	-8.36E-06	3.37E-06	-3.37E-06
3.50E-07	-3.50E-07	8.08E-07	-8.08E-07	2.08E-05	-2.08E-05	8.42E-07	-8.42E-07
4.58E-06	-4.58E-06	1.67E-05	-1.67E-05	1.96E-05	-1.96E-05	2.15E-06	-2.15E-06
7.17E-06	-7.17E-06	3.41E-06	-3.41E-06	2.42E-06	-2.42E-06	2.41E-06	-2.41E-06
1.96E-05	-1.96E-05	1.75E-05	-1.75E-05	8.47E-05	-8.47E-05	2.81E-06	-2.81E-06
2.83E-07	-2.83E-07	3.36E-06	-3.36E-06	3.02E-06	-3.02E-06	6.22E-07	-6.22E-07
6.87E-05	-6.87E-05	7.53E-07	-7.53E-07	3.72E-05	-3.72E-05	2.02E-07	-2.02E-07
7.48E-05	-7.48E-05	1.87E-04	-1.87E-04	2.80E-04	-2.80E-04	2.72E-05	-2.72E-05
ERROR_Period:	8.53E+01						
3.39E-06	-3.39E-06	1.03E-05	-1.03E-05	8.79E-06	-8.79E-06	4.82E-06	-4.82E-06
6.21E-06	-6.21E-06	8.58E-05	-8.58E-05	3.16E-06	-3.16E-06	5.94E-06	-5.94E-06
2.18E-05	-2.18E-05	1.36E-05	-1.36E-05	7.03E-06	-7.03E-06	6.98E-06	-6.98E-06
2.74E-05	-2.74E-05	2.89E-05	-2.89E-05	4.83E-06	-4.83E-06	7.25E-06	-7.25E-06
4.80E-05	-4.80E-05	1.83E-05	-1.83E-05	1.29E-05	-1.29E-05	1.09E-05	-1.09E-05
3.55E-06	-3.55E-06	3.77E-05	-3.77E-05	2.54E-06	-2.54E-06	6.63E-06	-6.63E-06
1.88E-05	-1.88E-05	2.96E-05	-2.96E-05	3.88E-05	-3.88E-05	5.10E-05	-5.10E-05

APPENDIX IV: 3-D INVERSION DATA FILE

4.27E-06	-4.27E-06	1.16E-05	-1.16E-05	6.45E-07	-6.45E-07	8.42E-07	-8.42E-07
6.23E-06	-6.23E-06	4.58E-05	-4.58E-05	1.56E-05	-1.56E-05	4.34E-06	-4.34E-06
3.56E-06	-3.56E-06	1.95E-05	-1.95E-05	8.97E-06	-8.97E-06	7.96E-06	-7.96E-06
1.73E-05	-1.73E-05	9.25E-06	-9.25E-06	7.82E-06	-7.82E-06	5.93E-06	-5.93E-06
4.76E-05	-4.76E-05	4.96E-05	-4.96E-05	1.81E-05	-1.81E-05	1.66E-05	-1.66E-05
4.52E-06	-4.52E-06	3.91E-06	-3.91E-06	1.39E-06	-1.39E-06	1.93E-06	-1.93E-06
1.57E-05	-1.57E-05	1.77E-04	-1.77E-04	3.58E-05	-3.58E-05	1.35E-05	-1.35E-05
5.84E-02	-5.84E-02	1.40E-01	-1.40E-01	4.78E-01	-4.78E-01	1.97E-01	-1.97E-01
6.65E-05	-6.65E-05	3.94E-04	-3.94E-04	3.01E-04	-3.01E-04	4.84E-05	-4.84E-05
1.35E-05	-1.35E-05	6.00E-05	-6.00E-05	1.95E-05	-1.95E-05	1.66E-05	-1.66E-05
9.93E-06	-9.93E-06	7.65E-06	-7.65E-06	3.22E-05	-3.22E-05	2.96E-05	-2.96E-05
1.14E-05	-1.14E-05	8.52E-05	-8.52E-05	2.82E-06	-2.82E-06	2.58E-05	-2.58E-05
6.27E-06	-6.27E-06	2.50E-06	-2.50E-06	1.60E-05	-1.60E-05	6.31E-06	-6.31E-06
8.75E-05	-8.75E-05	6.47E-05	-6.47E-05	7.91E-05	-7.91E-05	6.31E-05	-6.31E-05
4.57E-05	-4.57E-05	5.07E-05	-5.07E-05	1.46E-04	-1.46E-04	1.32E-04	-1.32E-04
8.14E-06	-8.14E-06	6.60E-05	-6.60E-05	3.40E-06	-3.40E-06	2.17E-06	-2.17E-06
1.38E-05	-1.38E-05	9.80E-06	-9.80E-06	3.12E-05	-3.12E-05	4.61E-05	-4.61E-05
3.40E-06	-3.40E-06	1.72E-05	-1.72E-05	1.23E-05	-1.23E-05	9.49E-06	-9.49E-06
3.82E-05	-3.82E-05	7.15E-06	-7.15E-06	4.95E-05	-4.95E-05	1.06E-05	-1.06E-05
6.80E-05	-6.80E-05	1.15E-04	-1.15E-04	1.30E-05	-1.30E-05	1.17E-05	-1.17E-05
2.86E-06	-2.86E-06	2.56E-05	-2.56E-05	4.71E-06	-4.71E-06	1.42E-05	-1.42E-05
5.31E-05	-5.31E-05	1.93E-05	-1.93E-05	1.12E-04	-1.12E-04	3.46E-05	-3.46E-05
2.48E-06	-2.48E-06	8.97E-05	-8.97E-05	6.86E-07	-6.86E-07	3.54E-04	-3.54E-04
3.42E-06	-3.42E-06	1.54E-05	-1.54E-05	4.67E-05	-4.67E-05	6.56E-06	-6.56E-06
1.66E-04	-1.66E-04	1.02E-04	-1.02E-04	2.25E-04	-2.25E-04	2.74E-05	-2.74E-05
9.02E-07	-9.02E-07	1.39E-06	-1.39E-06	7.33E-07	-7.33E-07	2.37E-07	-2.37E-07
1.06E-04	-1.06E-04	1.68E-05	-1.68E-05	2.58E-04	-2.58E-04	2.40E-06	-2.40E-06
2.67E-07	-2.67E-07	5.87E-06	-5.87E-06	3.01E-06	-3.01E-06	3.34E-06	-3.34E-06
1.68E-04	-1.68E-04	5.87E-06	-5.87E-06	6.14E-04	-6.14E-04	5.31E-07	-5.31E-07
3.90E-06	-3.90E-06	1.55E-05	-1.55E-05	3.32E-05	-3.32E-05	3.34E-06	-3.34E-06

Appendix V: 3-D inversion curve fit

APPENDIX V: 3-D INVERSION CURVE FIT

APPENDIX V: 3-D INVERSION CURVE FIT

Apparent Resistivity (XY,YX) for site 10 **Apparent Resistivity (XX,YY) for site 10**

Apparent Resistivity (XY,YX) for site 12 **Apparent Resistivity (XX,YY) for site 12**

APPENDIX V: 3-D INVERSION CURVE FIT

Apparent Resistivity (XY,YX) for site 14 **Apparent Resistivity (XX,YY) for site 14**

Phase (XY,YX) for site 14

Phase (XX,YY) for site 14

Apparent Resistivity (XY,YX) for site 19 **Apparent Resistivity (XX,YY) for site 19**

Phase (XY,YX) for site 19

Phase (XX,YY) for site 19

APPENDIX V: 3-D INVERSION CURVE FIT

Apparent Resistivity (XY,YX) for site 24 **Apparent Resistivity (XX,YY) for site 24**

Apparent Resistivity (XY,YX) for site 27 **Apparent Resistivity (XX,YY) for site 27**

APPENDIX V: 3-D INVERSION CURVE FIT

Apparent Resistivity (XY,YX) for site 37 **Apparent Resistivity (XX,YY) for site 37**

Apparent Resistivity (XY,YX) for site 42 **Apparent Resistivity (XX,YY) for site 42**

APPENDIX V: 3-D INVERSION CURVE FIT

Apparent Resistivity (XY,YX) for site 43 **Apparent Resistivity (XX,YY) for site 43**

Apparent Resistivity (XY,YX) for site 46 **Apparent Resistivity (XX,YY) for site 46**

APPENDIX V: 3-D INVERSION CURVE FIT

Apparent Resistivity (XY,YX) for site 48 Apparent Resistivity (XX,YY) for site 48

Apparent Resistivity (XY,YX) for site 51 Apparent Resistivity (XX,YY) for site 51

APPENDIX V: 3-D INVERSION CURVE FIT

Apparent Resistivity (XY,YX) for site 54 **Apparent Resistivity (XX,YY) for site 54**

Apparent Resistivity (XY,YX) for site 55 **Apparent Resistivity (XX,YY) for site 55**

APPENDIX V: 3-D INVERSION CURVE FIT

Apparent Resistivity (XY,YX) for site 58 **Apparent Resistivity (XX,YY) for site 58**

Apparent Resistivity (XY,YX) for site 60 **Apparent Resistivity (XX,YY) for site 60**

APPENDIX V: 3-D INVERSION CURVE FIT

Apparent Resistivity (XY,YX) for site 61 **Apparent Resistivity (XX,YY) for site 61**

Apparent Resistivity (XY,YX) for site 67 **Apparent Resistivity (XX,YY) for site 67**

APPENDIX V: 3-D INVERSION CURVE FIT

Apparent Resistivity (XY,YX) for site 76 **Apparent Resistivity (XX,YY) for site 76**

Apparent Resistivity (XY,YX) for site 77 **Apparent Resistivity (XX,YY) for site 77**

APPENDIX V: 3-D INVERSION CURVE FIT

Apparent Resistivity (XY,YX) for site 82 **Apparent Resistivity (XX,YY) for site 82**

Apparent Resistivity (XY,YX) for site 83 **Apparent Resistivity (XX,YY) for site 83**

APPENDIX V: 3-D INVERSION CURVE FIT

Apparent Resistivity (XY,YX) for site 84 **Apparent Resistivity (XX,YY) for site 84**

Apparent Resistivity (XY,YX) for site 85 **Apparent Resistivity (XX,YY) for site 85**

APPENDIX V: 3-D INVERSION CURVE FIT

Apparent Resistivity (XY,YX) for site 93 **Apparent Resistivity (XX,YY) for site 93**

Apparent Resistivity (XY,YX) for site 96 **Apparent Resistivity (XX,YY) for site 96**

APPENDIX V: 3-D INVERSION CURVE FIT

Apparent Resistivity (XY,YX) for site 102 **Apparent Resistivity (XX,YY) for site 102**

Apparent Resistivity (XY,YX) for site 106 **Apparent Resistivity (XX,YY) for site 106**

APPENDIX V: 3-D INVERSION CURVE FIT

Apparent Resistivity (XY,YX) for site 120 **Apparent Resistivity (XX,YY) for site 120**

Apparent Resistivity (XY,YX) for site 129 **Apparent Resistivity (XX,YY) for site 129**

APPENDIX V: 3-D INVERSION CURVE FIT

Apparent Resistivity (XY,YX) for site 133 **Apparent Resistivity (XX,YY) for site 133**

Apparent Resistivity (XY,YX) for site 137 **Apparent Resistivity (XX,YY) for site 137**

APPENDIX V: 3-D INVERSION CURVE FIT

Apparent Resistivity (XY,YX) for site 143 **Apparent Resistivity (XX,YY) for site 143**

Apparent Resistivity (XY,YX) for site 148 **Apparent Resistivity (XX,YY) for site 148**

APPENDIX V: 3-D INVERSION CURVE FIT

Apparent Resistivity (XY,YX) for site 149 **Apparent Resistivity (XX,YY) for site 149**