CHAPTER 7 PROPOSAL FOR PRELIMINARY GEOTHERMAL RESERVOIR MODEL AND TARGET FOR GEOTHERMAL TEST WELLS

7.1 Purpose

Based on the geological, geochemical and geophysical survey conducted, preliminary reservoir model will be proposed in this chapter. Targets of test wells will also proposed on the basis of the proposed reservoir models

7.2 Tendaho-2 (Ayrobera) Geothermal Site

7.2.1 Interpretation of Survey Results

Table 7.2.1 shows the summary and interpretation of survey results and features as topographic features, result of geological and geochemical surveys and MT/TEM survey that is necessary for preparing preliminary geothermal structural model in Tendaho-2 (Ayrobera) site.

Table 0.1 Summary and Interpretation of survey results and features for Geothermal Structural Modelling

<table>
<tr><th colspan="2">Items</th><th>Features</th></tr>
<tr><td rowspan="2">Geology</td><td>Papers
Satellite Imagery
Field Survey</td><td>・ Located at Manda-Harraro Graben.
・ Mainly composed of basaltic lavas and pyroclastics, and sediments of Afar Stratoid (Pliocene-Pleistocene). Recent basalt lava (Pleistocene) by fissure eruption is observed at the southwest of the survey area.
・ Those volcanic rocks are covered by alluvial deposit in Ayrobera.</td></tr>
<tr><td>Test Well</td><td>・ Six test wells were drilled at Tendaho-1 (Dubti) located at 9-12km south of the site.
・ Altered clay minerals (GL-50 to 350m), chlorite – epidote (below GL-350m) are observed at some test wells, interpreted as cap rock and geothermal reservoir.<table><tr><th>Test well</th><th>Flow rate</th><th>Temp.</th><th>Depth (GL-)</th></tr><tr><td>TD-2</td><td>13kg/s, 46.8t/h</td><td>220℃</td><td>890m</td></tr><tr><td>TD-4</td><td>70kg/s, 252t/h</td><td>216℃</td><td>250m</td></tr><tr><td>TD-1</td><td>Very low</td><td>270℃</td><td>880-900m
1,190-1,265m</td></tr></table>・ Thick sedimentary rock intercalated with basaltic rock was observed at the depth of approx. 2,000m at TD-4 test well (located at 9km southwest of the site)
・ Basaltic rocks are observed below 2,000m at TD-4.</td></tr>
<tr><td rowspan="2">Fault/ Fracture System</td><td>Papers
Satellite Imagery
Field Survey</td><td>・ The Graben is under tensil stress and NW-SE normal fault and fracture system is developed.
・ Spreading axis is located at the southwest of the site, and steep normal faults, dipping to the southwest, are well developed.</td></tr>
<tr><td>Geophysical Survey</td><td>・ NW-SE low resistivity zone are found at the depth of GL-700m to GL-2,500m in the center of the survey area by MT/TEM survey.
・ According to the result of gravity survey, the above-mentioned zone is the boundary between high-gravity area (northeast) and low-gravity area (southwest).
・ According to the result of magnetic survey, the above-mentioned zone is the boundary between high-magnetic intensity area (northeast) and low-magnetic intensity area (southwest). (Yohannes L.,2007)
・ TD-4 is located at southwest area, therefore the combination of low-gravity and low-magnetic intensity was resulted by thick sedimentary rock.
・ NW-SE low resistivity zone obtained by MT/TEM Survey is consistent with the boundary of other geophysical survey results, interpreted as fault zone.</td></tr>
</table>

Items		Features
Heat Source	Geophysical Survey	・ Resistivity value is lower at the depth below 4,000m, may indicates heated zone caused by intrusion of basaltic magma.
Geothermal Fluid	Topography Satellite Imagery	・ Discharge is expected by Awash River and marsh zone, located at the north of the site.
	Geochemical Analysis	・ Fumaroles of 99.3ºC were observed at the southwestern part. ・ Result of geochemical analysis indicates 240-290ºC of geothermal fluid temperature (by silica thermometer)
	Test Well	・ Self flow of 1.8t/h (13kg/s), 220 ºC was confirmed at TD-2 Test well in Tendaho-1 (Dubti). (DAmore et al., 1997)
Cap Rock Structure	Geophysical Survey	・ A low resistivity zone (less than 5ohm-m) were found at the depth of GL-100m to GL-500m), may compose cap rock structure.
	Test Well	・ Altered clay minerals and zeolites are found at the depth of GL-50m to 350m in existing test wells in Tendaho-1 (Dubti). ・ The depth for occurrence of those minerals may be corresponded with the low resistivity zone (less than 5ohm-m).

Source: JICA Project Team

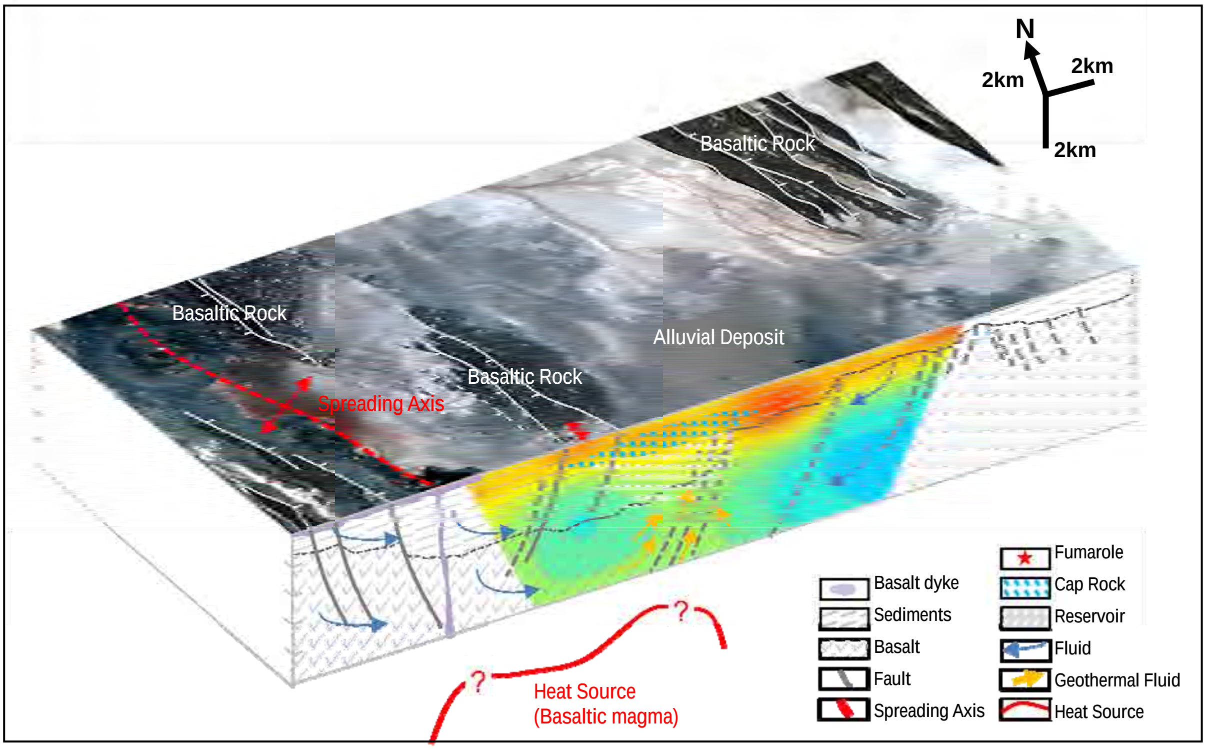
7.2.2 Preliminary Geothermal Reservoir Model

The Conceptual Geothermal Reservoir Model in Tendaho-2 (Ayrobera), which is indicated by the above features, is prepared. The characteristics of the model is shown in Table 7.2.2, diagram and section are shown in Figure 7.2.1 and Figure 7.2.2.

Table 7.2.2 Characteristics of Geothermal Reservoir

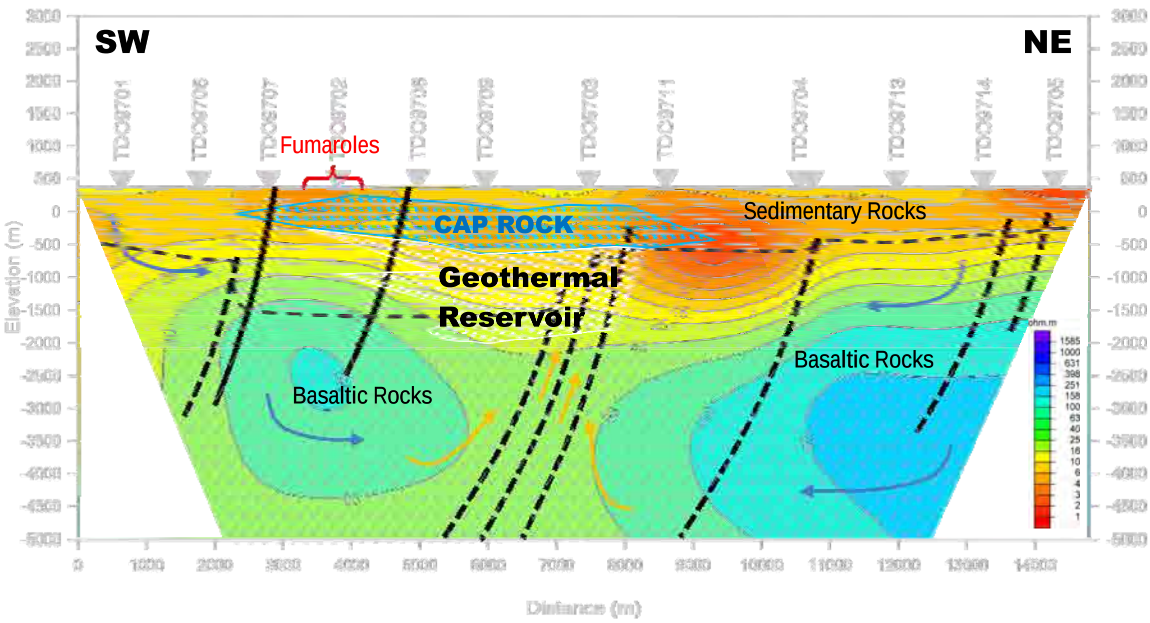
Item	Description
Geothermal Reservoir	Geothermal reservoir may be porous basalts and sandstones. North-eastern margin of the reservoir would be clear with normal faults in basaltic rock, where south-western margin would be along many sand layers in sedimentary rocks. Altered basaltic rocks, fine sandstones and siltstones would be distributed at the top of the reservoir as cap rock.
Geothermal Fluid	Geothermal fluid may be discharged by Awash River and the ground, convecting in the ground restricted by faults and fault zones. Up-flow zone would be formed along the fault zone in the center of the survey area.
Heat Source	Basaltic magma is expected as a heat source in the area, which would be located at the depth of 5-6 km.

Source: JICA Project Team



Source: JICA Project Team

Figure 7.2.1 Preliminary Geothermal Reservoir Model in Tendaho-2 (Ayrobera) Site



Source: JICA Project Team

Figure 7.2.2 Preliminary Geothermal Reservoir Model (Section) in Tendaho-2 (Ayrobera) Site

7.2.3 Preliminary Target for Test Well Drilling

According to the geothermal model, a wide channel of NW-SE high temperature convective zone (low resistivity zone) in the centre of the study area. It is expected that the drilling depth needs to be about 2,000 m to drill up to the assumed faults and high temperature convective zone. Tentative target and specification of the test well drilling is summarized in Table 7.2.3 and Table 7.2.4. Selected drilling locations are shown in Figure 7.3.4 and Figure 7.3.5.

Table 7.2.3 Tentative Target for Test Well Drilling in Tendaho-2 (Ayrobera)

Area	Target	Well Type
AY-1 Area	NW-SE subsurface normal fault zone (dipping to SW)	Directional well
AY-2 Area	NW-SE subsurface normal fault zone (dipping to SW)	Vertical Well
AY-3 Area	NW-SE Normal faults at Fumaroles Point (dipping to SW)	Vertical Well

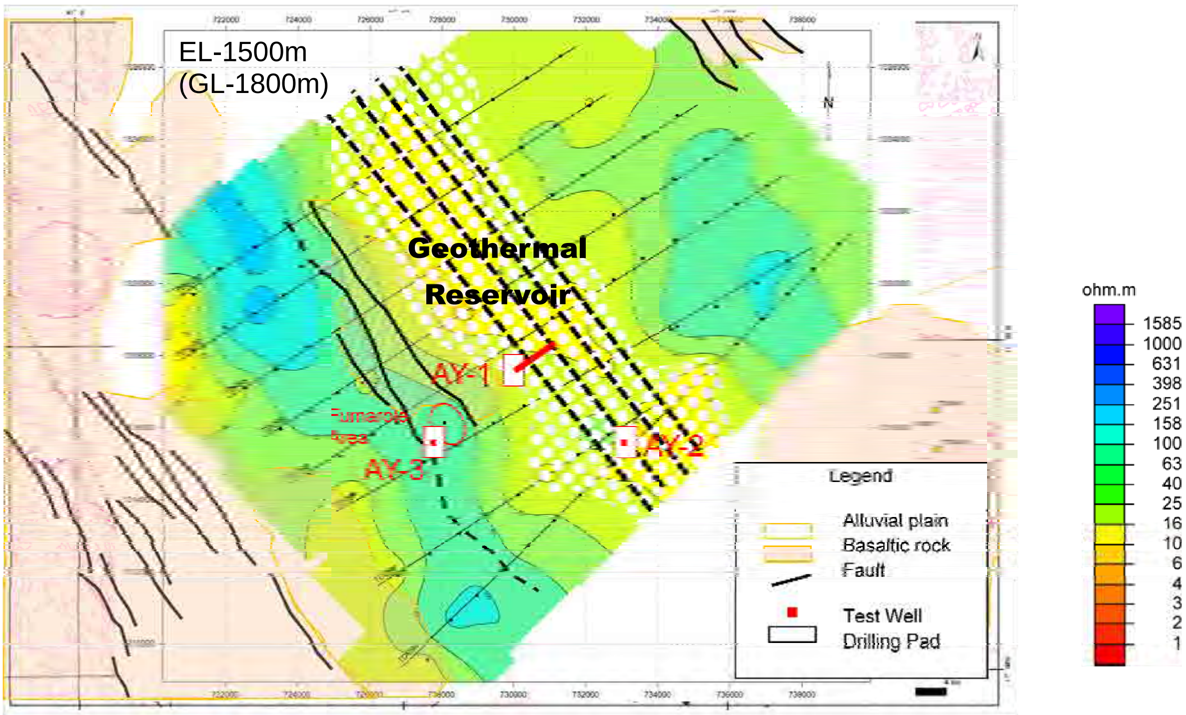
Source: JICA Project Team

Table 7.2.4 Tentative Specification of Test Well Drilling in Tendaho-2 (Ayrobera)

Item	AY 1	AY 2	AY 3
Outline of the target	Aiming at NW-SE low resistivity zone (Fault zone) at the centre.	Aiming at NW-SE low resistivity zone (Fault zone) at northern part.	Aiming at NW-SE Fault zone at Fumaroles point.
Location of the target from well head	Direction from True North standard : N 57° E, Vertical depth: 1,840 m Horizontal distance: 600 m	Vertical depth: 2,000 m	Vertical depth: 2,000 m
Approximate depth of the target (GL-m)	1,000–1,840	1,500-2,000	1,500–2,000
Estimated temperature at the target	Approx. 250–300 °C	Approx. 250–300 °C	Approx. 250–300 °C
KOP	800 m	-	-
Drilling depth to bottom	1,840 m	2,000 m	2,000 m

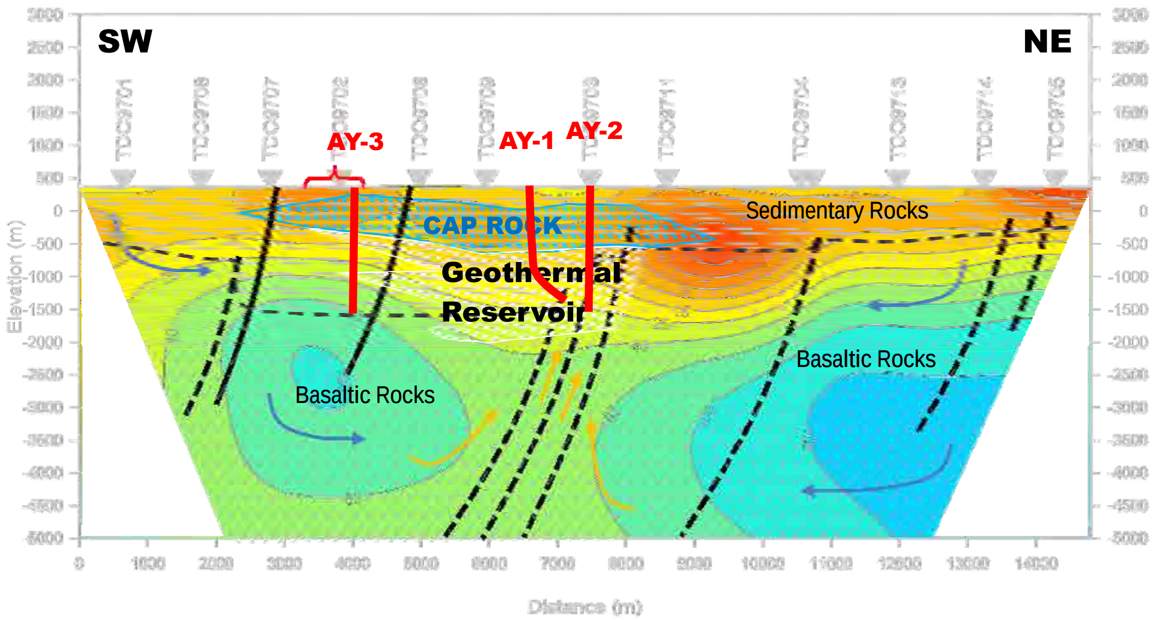
KOP :Kick-Off Point

Source: JICA Project Team



Source: JICA Project Team

Figure 7.2.3 Test Well Drilling Plan in Tendaho-2 (Ayrobera)



Source: JICA Project Team

Figure 7.2.4 Schematic Section of Test Well Drilling in Tendaho-2 (Ayrobera)

7.3 Boseti Geothermal Site

7.3.1 Interpretation of Survey Results

Table 7.3.1 shows the summary and interpretation of survey results and features as topographic features, result of geological and geochemical surveys and MT/TEM survey that is necessary for preparing preliminary geothermal structural model in Boseti site.

Table 7.3.1 Summary and Interpretation of survey results and features for Geothermal Structural Modelling

Item		Features
Geology	Geology	・ Composed of basaltic-rhyolitic lava and pyroclastic rocks, and sedimentary rocks (conglomerate-sandstone) of Nazreth Group (Pliocene-Pleistocene). ・ Boseti volcano and erupted lavas (obsidians), basalt lava at the surface in the northern part are classified as Wonji Group (Pleistocene), underlain by Nazreth group with unconformity.
Fault/Fracture System	Satellite Imagery Geology	・ Many normal faults are developed at the direction of NNE-SSW, which is concordant with the direction of Rift Valley.
	Geophysical Survey	・ Low resistivity zone is observed at the depth of GL-800m to GL-2,300m in the center of survey area and its direction is concordant with normal faults on the ground.
Heat Source	Geology	・ According to the result of topographic analysis, lavas were intruded and erupted along the NNE-SSW fault (Fb-2) in the center of survey area (Korme et.al., 1997).
	Gravity Survey	・ High-density rock is assumed at the depth of GL-2,000m below Boseti Volcano (D.G. Cornwell et al., 2006).
Geothermal Fluid	Geochemical Analysis	・ Fumaroles are observed along NNE-SSW fault (Fb-1) in the survey area. ・ Temperature of geothermal fluid would be 170-220°C, classified as Class C (by Silica Thermometer)
Cap Rock Structure	Geophysical Survey	・ Low resistivity zone (less than 5ohm-m) which was found at the depth of GL-800m to GL-900m is interpreted as cap rock.

Source: JICA Project team

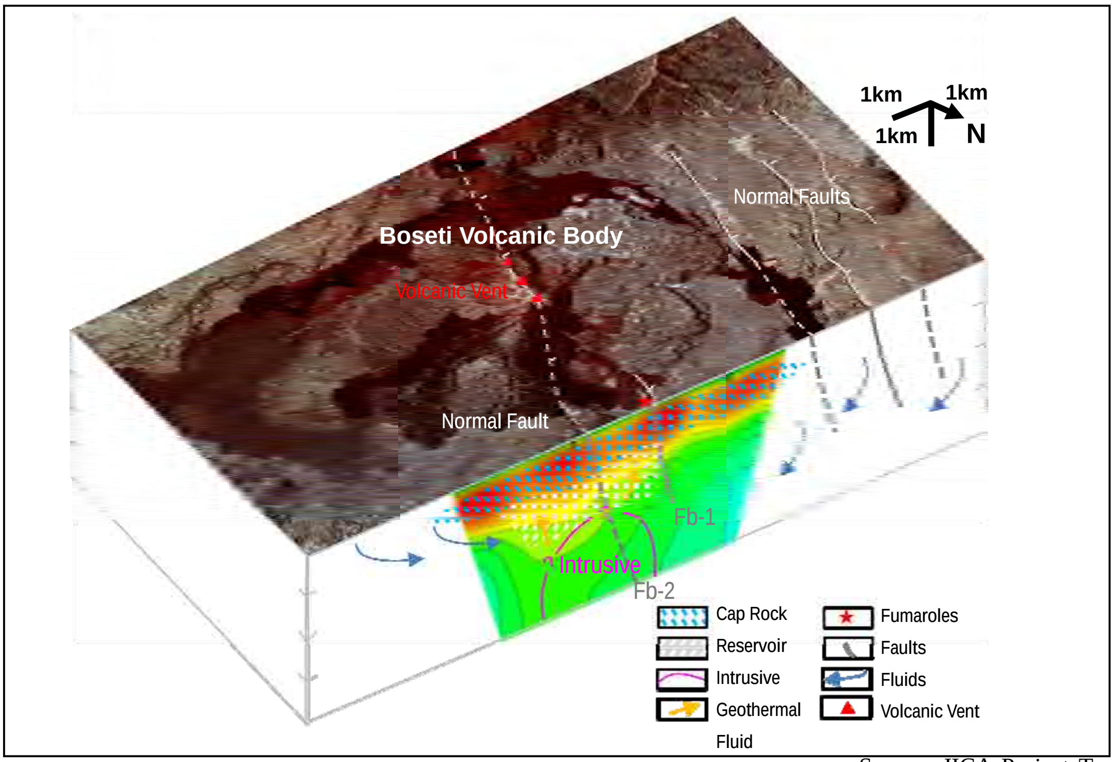
7.3.2 Preliminary Geothermal Reservoir Model

The Conceptual Geothermal Reservoir Model in Boseti, which is indicated by the above features, is prepared. The characteristics of the model is shown in Table 7.3.2, diagram and section are shown in Figure 7.3.1 and Figure 7.3.2.

Table 7.3.2 Characteristics of Geothermal Reservoir

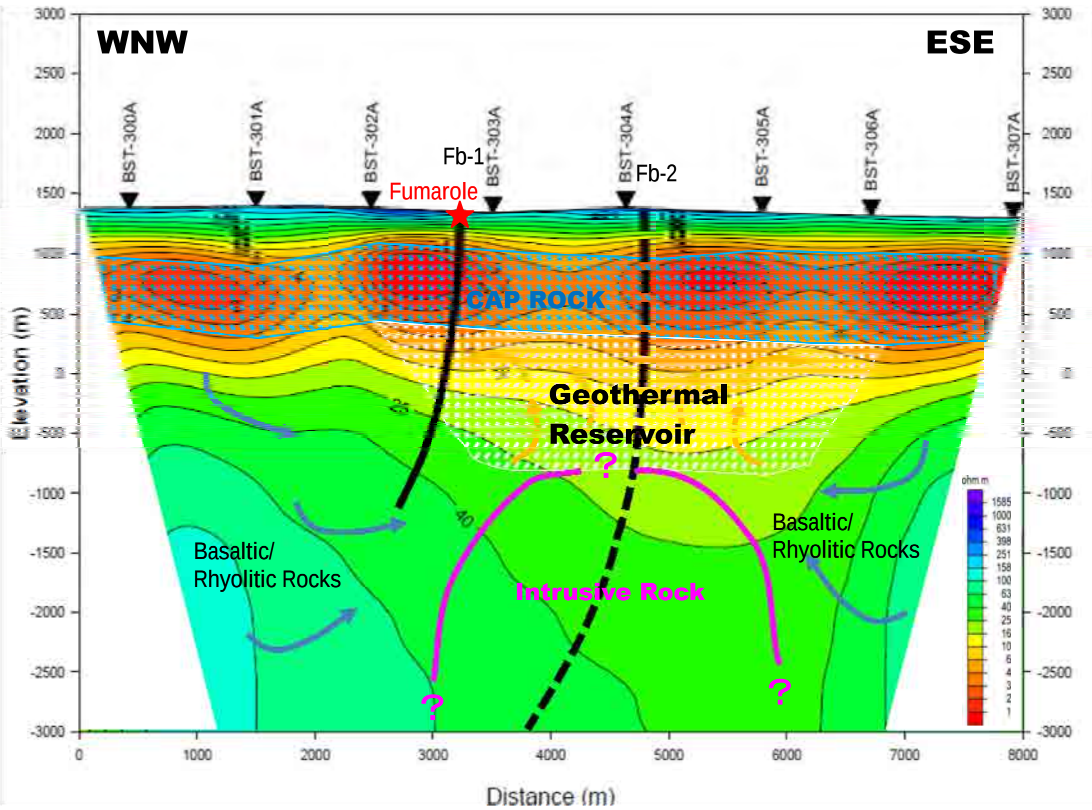
Item	Description
Geothermal Reservoir	Basalt-rhyolite lava and pyroclastic rocks, and sedimentary rocks along the NNE-SSW normal faults are expected as a geothermal reservoir in the area. The margin would be clearly divided by steep faults and/or fractures. Cap rock is assumed at the top of reservoir, which is mainly composed of clay layers altered from basaltic-rhyolitic rocks.
Geothermal Fluid	Fluid may be discharged by the surface and aquifers in Nazreth Group. Geothermal fluid is convecting in the ground restricted by faults and fault zones. Up-flow zone would be formed along the fault zone in the center of the survey area.
Heat Source	Intrusive rock(s) which may be distributed along NNE-SSW at the depth below 2,000m.

Source: JICA Project team



Source: JICA Project Team

Figure 7.3.1 Preliminary Geothermal Reservoir Model in Boseti site



Source: JICA Project Team

Figure 7.3.2 Preliminary Geothermal Reservoir Model (Section) in Boseti site

7.3.3 Preliminary Target for Test Well Drilling

According to the geothermal model, a wide channel of NNE-SSW high temperature convective zone (low resistivity zone) associated with two distinctive faults are observed on the ground, namely Fb-1 and Fb-2. This high-temperature zone may continue toward the south, below Boseti Volcano, and it seems that the reservoir temperature may increase as the zone gets closer to the volcano. It is expected that the drilling depth needs to be about 2,000 m to drill up to the assumed high temperature convective zone with subsurface fault zones. Tentative target and specification of the test well is proposed in Table 7.3.3 and Table 7.3.4. Selected drilling locations are shown in Figure 7.3.3 and Figure 7.3.4.

Table 7.3.3 Tentative Specification of Test Well Drilling in Boseti

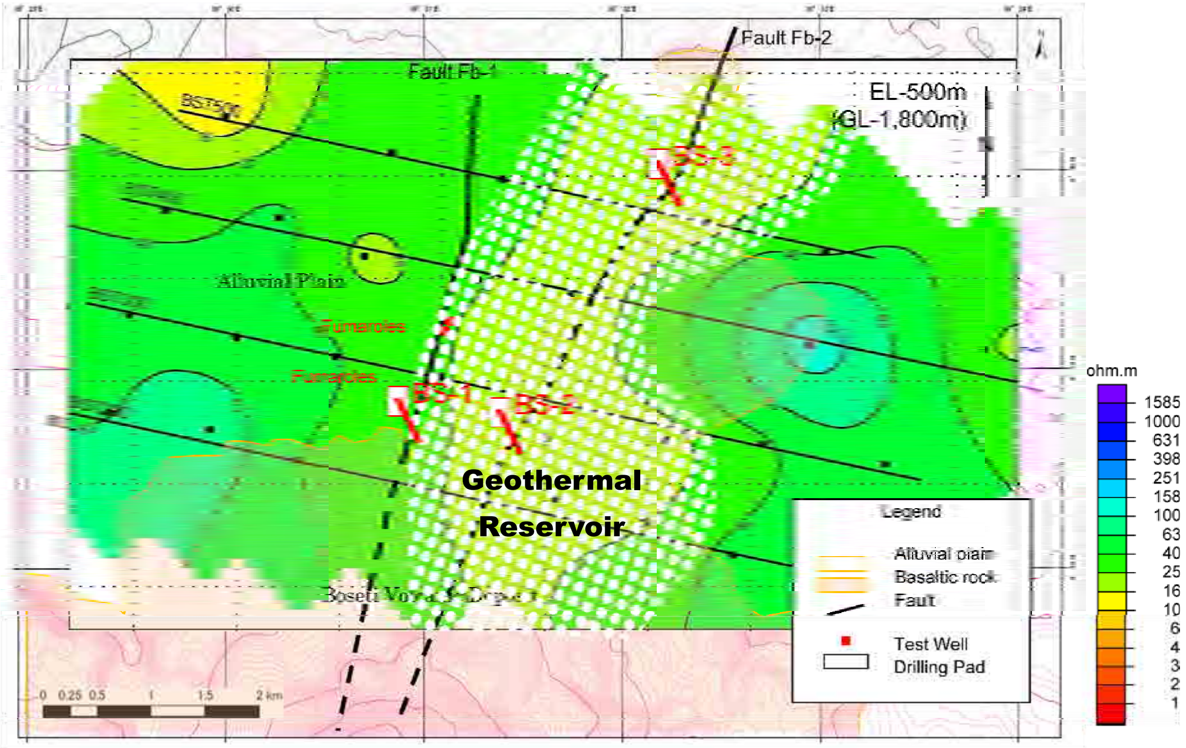
Target Area	Target	Test Drilling
BS-1 Area	NNE-SSW low resistivity zone along Fault Fb-1 where many fumaroles are located.	Directive Well
BS-2 Area	Center of the reservoir (low resistivity zone) along Fault Fb-2 near the volcanic body.	Directive Well
BS-3 Area	Center of the reservoir (low resistivity zone) along Fault Fb-2 where the Fault is clearly observed on the ground.	Directive Well

Source: JICA Project Team

Table 7.3.4 Tentative Specification of Test Well Drilling in Boseti

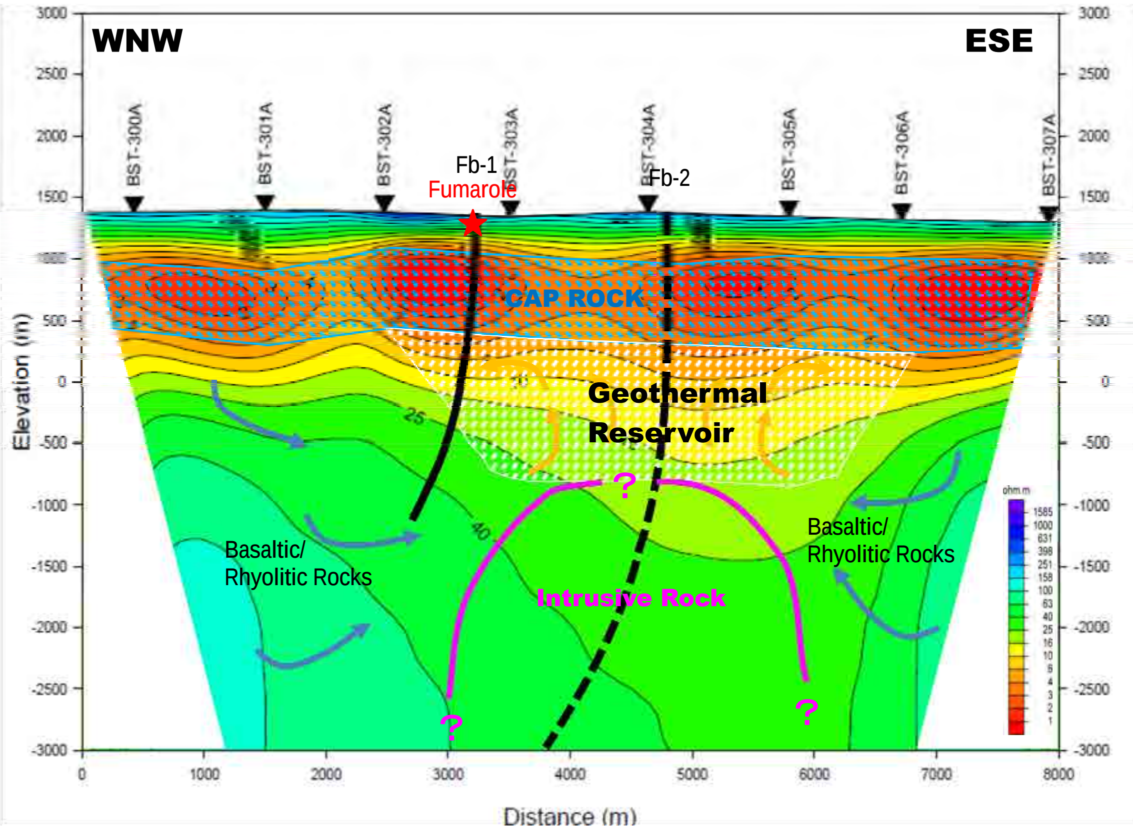
Item	BS-1	BS-2	BS-3
Outline of the target	Aiming at NNE-SSW low resistivity zone along Fault Fb-1.	Aiming at NNE-SSW low resistivity zone along Fault Fb-2.	Aiming at NNE-SSW low resistivity zone along Fault Fb-2.
Location of the target from wellhead	Direction from true North standard : S 30° E, Vertical depth: 1,840 m Horizontal distance: 600 m	Direction from true North standard : S30° E, Vertical depth: 1,840 m Horizontal distance: 600 m	Direction from true North standard : S30° E, Vertical depth: 1,840 m Horizontal distance: 600 m
Approximate depth of the target (GL-m)	1,000–1,840	1,000–1,840	1,000–1,840
Estimated temperature at the target	Approx. 250–300 °C	Approx. 250–300 °C	Approx. 250–300 °C
KOP (kick off point)	800 m	800 m	800 m
Drilling depth to bottom	1,840 m	1,840 m	1,840 m

Source: JICA Project Team



Source: JICA Project Team

Figure 7.3.3 Test Well Drilling Plan in Boseti



Source: JICA Project Team

Figure 7.3.4 Schematic Section of Test Well Drilling in Boseti

7.4 Recalculation of Geothermal Resources and Priority of Geothermal Development

7.4.1 Re-evaluation of Geothermal Potential

Geothermal resources were re-evaluated for Tendaho-2 (Ayrobera) and Boseti geothermal sites based on geothermal conceptual models. Volumetric method was used for re-calculation of geothermal resources as described in chapter 3. Reevaluated reservoir volumes and potentials are shown in Table and Table .

Table 7.4.1 Reservoir Volume Estimated by Geothermal Conceptual Model

Site name	Tendaho-2(Ayrobera)	Boseti
Estimated Reservoir Volume (km^2)	40.0 (12.5)	37.5 (48.6)

( ): Estimated Reservoir Volume in Paragraph 3.5 Source: Project Team

Table 7.4.2 Geothermal Potential Recalculated by Reservoir Volume

Site name	80% Occurrence Probability (MW)	Most Probable (MW)	20% Occurrence Probability (MW)
Tendaho-2(Ayrobera)	120 (47)	180 (100)	330 (230)
Boseti	175 (160)	265 (320)	490 (800)

( ): Estimated Geothermal Resource in Paragraph 3.5 Source: Project Team

Compared with the preliminarily estimated results conducted in a previous section, the re-evaluation resulted in an increase of 80 MW for Tendaho-2 (Ayrobera), and a decrease of 55MW for Boseti geothermal site.

7.4.2 Review of Priority of Geothermal Development

It is noted that the prioritization conducted in Chapter 5 has already reflected these re-evaluated potential resources.

7.5 Drilling Plan

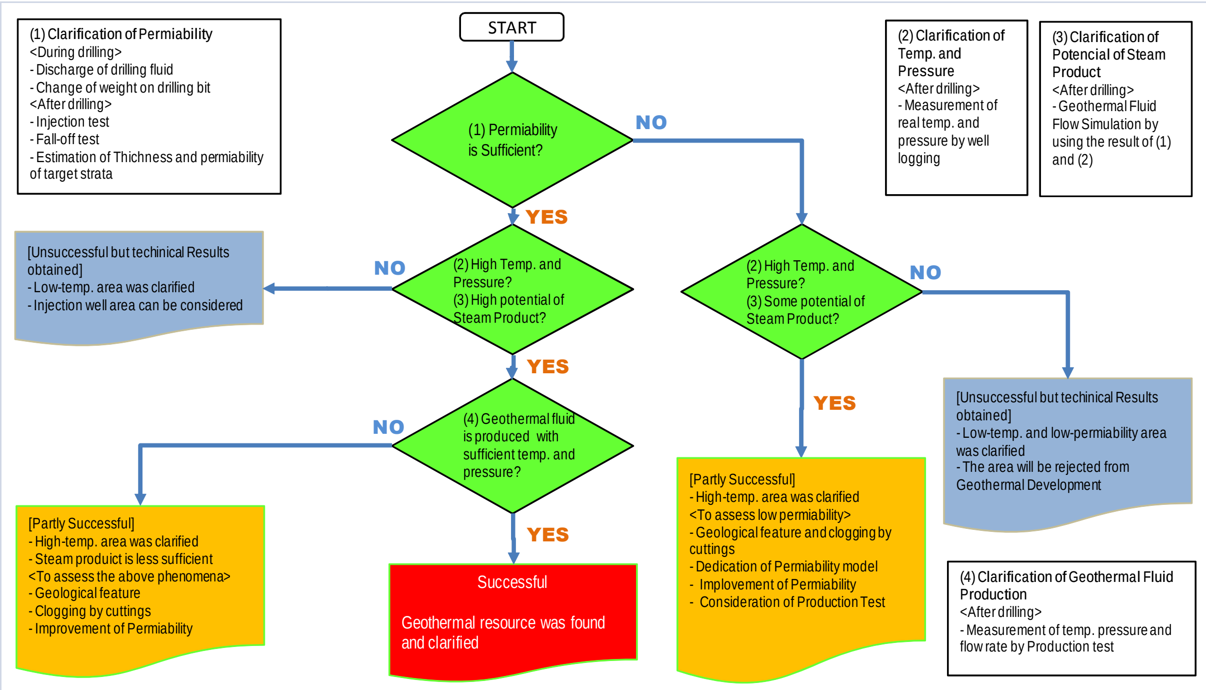
7.5.1 Test Drillings

(1) Purpose of Test Drillings

Test drillings are conducted for examination of geothermal resources from geological, geochemical, and geophysical information. Figure 7.5.1 shows the purpose and method for examination and criteria for successful/ unsuccessful wells.

(2) Types of Test Wells

There are three types of test wells as shown in Table 7.5.1. The wells with the final diameter under 6 in. are called 'Slim Hole'. The drilling cost of smaller diameter test wells are normally cheaper, however, Type 2 or Type 3 should be adopted when directional drilling and/or production test are applied. Also, at least 8-1/2 in. is necessary if the test drilling bore will be used for production afterwards.



Source: JICA Project Team

Figure 7.5.1 Criteria for Successful/ Unsuccessful Wells

Table 7.5.1 Types of Test Drilling

Item \ Size		Type 1	Type 2	Type 3
Depth (m)		1,500	2,000	2,000
Temperature (°C)		200>	350>	350>
Final Diameter (in.)		N～H*	5-5/8”-6-1/4”	8-1/2”
Drilling Type		Spindle	Rotary	Rotary
Coring		All coring	Spot coring	Spot coring
Directional Drilling		N/A	Applicable	Applicable
Testing/ Examination	Temperature Recovery	Applicable	Applicable	Applicable
	Injection Test	Applicable	Applicable	Applicable
	Production Test	1 month>	1 month<	1 year
	Logging	N/A	Applicable	Applicable
Use for Production Well		N/A	N/A	Applicable
Purpose of Drilling		Geological evaluation	Reservoir evaluation by production test	

*N: 78.5 mm, H: 98.2 mm N/A: Not Applicable Source: JICA Project Team

(3) Test Drilling at the Target Sites

For the test drillings in Ayrobera and Boseti, it is recommended to drill with Type 2 or 3 for the purpose of directional drilling to the target at the fractured zone along the faults, and the examination and evaluation of geothermal reservoir by loggings and production test.

7.5.2 Considerations for Test Drilling

There are some considerations while drilling test wells at the target sites, which were pointed out from the geological and geographical characteristics.

(1) Tendaho-2 (Ayrobera) Site

- Attention should be paid for drilling problems such as 'stuck pipes' while drilling soft-sediment formation and pyroclastic formation at a depth from 0 to 50 m.
- It is necessary to prepare enough amounts of drilling water, inhibitor and cement against 'lost circulation' at the formation with fractures and shallow groundwater aquifer.
- Blow-out Preventer (BOP) should be used while drilling. There is a possibility of a blow-out even in shallow formation since shallow geothermal reservoir is observed at a depth of 500 m in Tendaho-1 (Dubti).

(2) Boseti Site

- It is necessary to prepare enough amounts of drilling water, inhibitor and cement against ‘lost circulation’ of drilling water at the formation with fractures in volcanic rocks, boundaries, and shallow groundwater aquifer.
- Attention should be paid for drilling problems such as ‘stuck pipe’ at a depth from 0 to 100 m where alternation of soft-sediment and volcanic rocks are expected.

CHAPTER 8 DATABASE CONSTRUCTION

8.1 Objective and Utilization of the Database

A geothermal database was constructed to systematically store various geothermal data such as geological, geochemical, and geophysical test results as well as information on topography and infrastructures.

"G*BASE", the database software procured for the Geological Survey of Ethiopia (GSE), has been produced by Geothermal Energy Research and Development Co. Ltd., Japan based on Oracle7/8TM exclusively for geothermal-related database, and has been used by various geothermal-related users in Japan. If sufficient information is collected, GSE would be able to conduct reservoir computer simulations in the near future. At such stage, G*BASE can be also utilized for data input into TOUGH2, a geothermal reservoir/groundwater simulator and storage of calculation results widely used worldwide.

8.2 Structure of the Database

The database was constructed using the G*BASE software by digitizing all information for each prospect. The data and information that can be input in G*BASE are summarized in Table 8.2.1.

Table 8.2.1 Database Structure of "G*BASE"

Data Type	Information Examples
Depth (Z, numerical data)	Well logging, lost circulation/feed point. casing program, well direction coordinates, geologic column
2D Discrete data (X, Y, numerical)	Altitude, depth to the top of rock phases, planar distributions of geophysical and geochemical survey
3D Discrete data (X, Y, X; numerical)	Geophysical survey (MT resistivity, vertical electronic sounding, etc.), reservoir simulation results
Chronological data (t; numerical)	Well test, production-reinjection well record, pressure-temp monitoring, geochemistry monitoring, etc.
Mark data	Place name, manifestation point (hot spring, fumaroles), sampling point coordination, volcano
Polygon data	Road, river, lake, facilities, boundary line, geological maps, faults, caldera
Image data (planar or sectional pictorial image)	Satellite imagery, geological maps, geological cross sections, seismic reflection survey, planar section at depths
Geochemical data	Geochemical analysis results

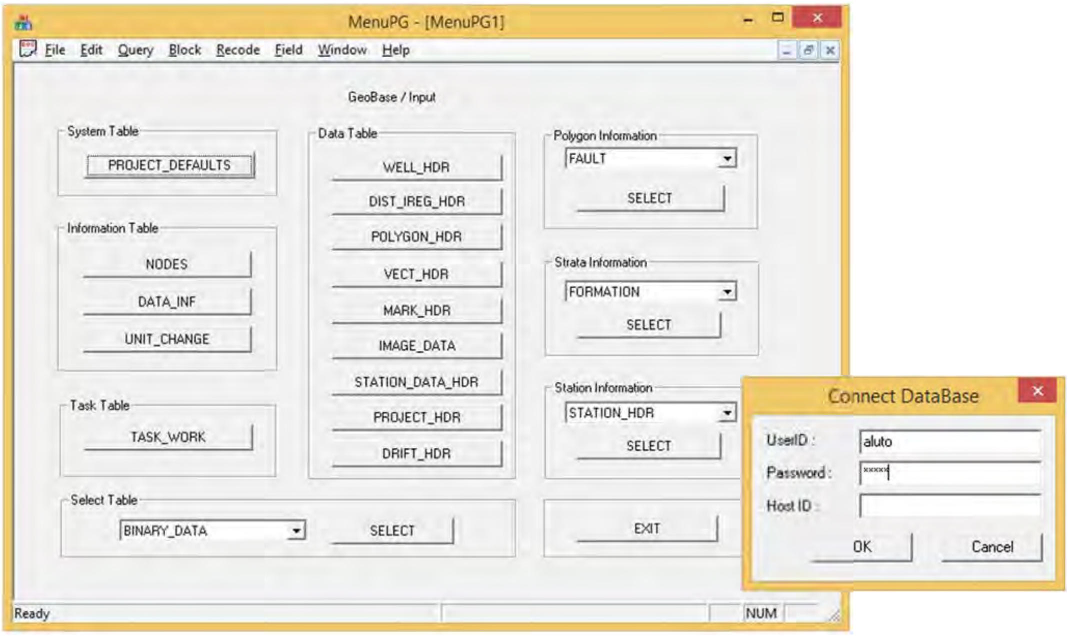
Source: JICA Project Team

Each prospect is given a site ID to input and display data and information of the site in G*BASE. Table 8.2.2 shows the site IDs. Because there are some surveys such as geophysical survey and drilling survey beyond the boundary of prospects in the Tendaho and Aluto areas, three prospects of Tendaho 1~3 and Aluto 1~3 are integrated in one site ID respectively and registered in G*BASE. The startup menu of the database is shown in Figure 8.2.1. G*BASE has several applications that need to be started to input data and information, import geochemical data, display 2-D or 3-D model, and manage the database. It needs to log in with the site ID and password to start the applications, as shown in Figure 8.2.1. The site IDs are shown below and the passwords are provided to each GSE staff separately.

Table 8.2.2 Prospect IDs in G*BASE

Site ID	Geothermal Prospects in the Master Plan
dallol	1. Dallol
tendaho	2. Tendaho 3 (Tendaho-Allalobeda) 21. Tendaho 1 (Tendaho-Dubti) 22. Tendaho 2 (Tendaho-Ayrobera)
boina	3. Boina
damali	4. Damali
teo	5. Teo
danab	6. Danab
mateka	7. Meteka
arabi	8. Arabi
dofan	9. Dofan
kone	10. Kone
nazareth	11. Nazareth
gedemsa	12. Gedemsa
tulumoye	13. Tulu Moye
aluto	14. Aluto 2 (Aluto-Finkilo) 15. Aluto 3 (Aluto-Bobesa) 20. Aluto 1 (Aluto-Langano)
abaya	16. Abaya
fantale	17. Fantale
boseti	18. Boseti
corbetti	19. Corbetti

Source: JICA Project Team



(left: input application, right: login window) Source: JICA Project Team

Figure 8.2.1 Startup Menu of G*BASE

Instructions and training on how to operate G*BASE were given to the GSE staff through training in Japan and on-the-job training (OJT) in Ethiopia so that GSE is able to update the database in Ethiopia. A detailed operations manual for G*BASE, which explains how to import data and display 2-D and 3-D geothermal models, is provided to GSE in a separate volume.

8.3 Data and Information in G*BASE

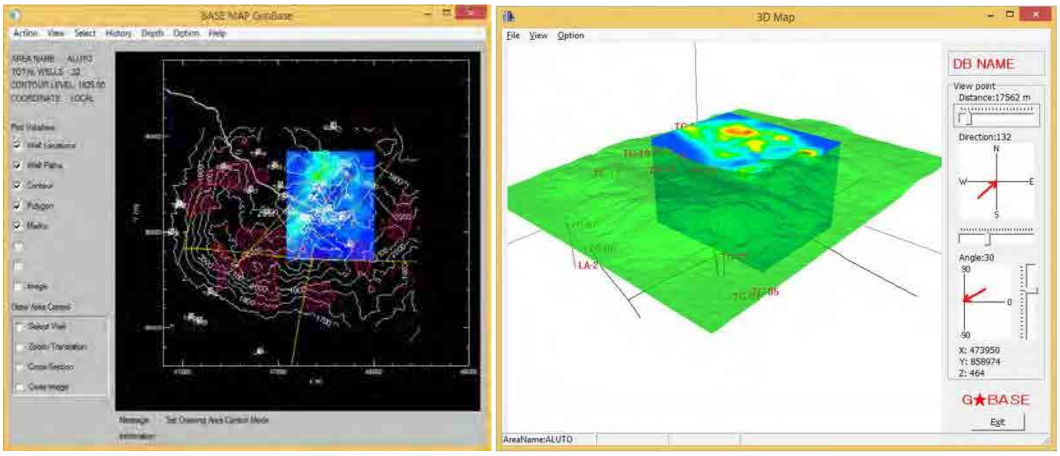
The JICA Project Team constructed the database and input geothermal data provided by GSE and acquired in this study. Table 8.3.1 presents the list of input data and information. A detailed data list showing all data stored in G*BASE is shown in Appendix-7.

Table 8.3.1 Geothermal Data in G*BASE

Classification	Input Data
Basic Information	Topographic Contour
	River
	Lake
	Primary Roads
	Railway
Geological Data	Geological Map
	Fault
	Volcano
	Caldera
Topography (Remote Sensing Data)	Hydrothermal Alternation
	Circular Landform
	Lineament
Surface Survey	Geothermal Manifestation
	Sampling Location
Geochemical	Geochemical Analysis Result
Geophysical	MT/TEM Survey Map
	VES Map
	Magnetic Sounding Map
	Bouguer Anomaly Map
	Microseismic Map
Drilling Well Data	Well Location
	Well Curve
	Casing Program
	Geological Column
	Well Event (Lost circulation point)
Well Logging Data	Temperature Logging
	Pressure Logging
	Well Head Pressure Test
	Injection Test
	Fall-off Test
	Production Test
	Discharge Flow Test
	Inference Test
	Build-up Test

Source: JICA Project Team

The JICA Project Team had imported into the database not only the survey results of this study but also data collected from GSE as much as possible. Using one of the applications in G*BASE, the 2-D and 3-D model can be built as shown in Figure 8.3.1 below. It can be utilized for geothermal reservoir and fluid simulation.



Source: JICA Project Team

Figure 8.3.1 2-D Geothermal Model (left) and 3-D Geothermal Model (right) of the Aluto Area

8.4 Management and Upgrading of the Database

It is necessary that GSE upgrade and manage the database properly when it obtains new geothermal data. Before commencement of this study, existing geothermal data had not been utilized fully by the GSE staff because most of the data were scattered and not accumulated properly. Moreover, there were some missing data (including logging data, acquisition date, test conditions, and data unit, etc.). To avoid the same mistakes, GSE is expected to accumulate all data into the G*BASE database properly. In utilizing the database, GSE should plan further geothermal surveys and drilling programs and simulate several tests of geothermal reservoirs and fluids.

CHAPTER 9 PROPOSED SURVEY UP TO TEST WELL DRILLING

Up until the previous chapters, we have formulated a Master Plan on the Development of Geothermal Energy in Ethiopia, for the nominated 22 geothermal prospects. Among those, we have selected three sites i.e. Ayrobera (Tendaho-2), Boseti and Meteka as high priority sites for development except the sites that have already been committed by other donors or a private firm for development. We conducted geophysical surveys (MT survey and TE-survey) in Ayrobera (Tendaho-2) and Boseti to locate targets of test wells to be drilled for resource confirmation, leaving Meteka for GSE to conduct geophysical survey by themselves. However, it is considered to be a prudent approach that further detailed surface surveys shall be conducted before costly test wells are to be drilled.

On the other hand, we pointed in section 5.5 that a new public organization be needed for integral implementation of geothermal energy development. A similar recommendation is said to have been proposed by IFC.

In this chapter, we will make recommendations on further surface surveys and an approach to creating the new implementation organization.

9.1 Recommendations on Surface Surveys in the Selected Sites

9.1.1 Target sites to be additionally surveyed

In addition to **Ayrobera (Tendaho-2)** and **Boseti,** where we conducted the MT/TEM survey, we propose to include **Butajira** (approximately 150 km southwest from Addis Ababa) in our survey program as a portfolio approach where several sites are to be surveyed in parallel to select the best site for the costly test well site. Butajira was recognized as a seemingly promising site that was accidentally identified in May 2014 while drilling a water well. We measured the temperature of a hot spring at 83.6 ºC; geochemical analysis of the spring water we conducted indicated the temperature would range from 210 to 250 ºC.

9.1.2 Present development status of Butajira

It is noted that the present development status of Butajira is as follows.

- It is found on the GRMF web site that a consultant submitted EoI to GRMF for surface survey; the feedback on the EoI will be sent to the applicant on 6th March, 2015;
- GSE explained that the license section of the Ministry of Mines has not receive any application regarding Butajira geothermal development,
- It is expected that if the application should be accepted, the applicant to GRMF would apply the license to the Ministry of Mines for surface survey.
- At this moment, Butajira could be included in a future program under JICA.

9.1.3 Approach of the additional survey

We recommend to adopt a two step approach, namely the first step is for additional surface survey in the nominated three sites, and the second step is for temperature gradient well drillings.

(1) The first step – surface survey

The first step survey consists of (1) Micro-seismicity survey, (2) gravity survey, (3) Magnetic survey, (4) MT/TEM survey, (5) MT 3D analysis, (6) 2-m depth temperature survey, (7) geological and geochemical survey, and (8) preliminary Environmental and Social Impact Assessment (ESIA).

In Ayrobera, Micro-seismicity, additional MT/TEM survey followed by a detailed 3 D analysis are proposed; In Boseti, a gravity survey and a magnetic survey are proposed for comparison with the MT/TEM information obtained by this Master Plan Project; and in Butajira, a gravity, magnetic and MT/TEM survey are proposed. For all the three sites, a 2 m depth temperature survey is proposed. In addition, geological-geochemical survey and preliminary ESIA will have to be conducted in Butajira if this should be included in the survey of the next step.

Based on those survey together with the results of the existing survey results, one or two candidate sites will be proposed for temperature gradient shallow well survey.

Table 9.1.1 Proposed Additional Surface Survey and TG Wells

Step	Survey Items	Ayrobera	Boseti	Butajira (if additionally requested)	GSE Input		JICA Assistance
					Capacity Building	Equipment	
1st	Micro-seismicity	☑	-	-	- Geologists, - Geophysists, - Reservoir engineers	-	T/C, Survey equipment
	Gravity Survey	(Existing data)	☑	☑		-	T/C, Survey equipment
	Magnetic Survey	(Existing data)	☑	☑		Survey equipment	T/C
	MT/TEM Survey	☑	-	☑		Survey equipment	T/C
	MT 3D Analysis	☑	-	-		-	T/C
	2m Depth Temperature Survey	☑	☑	☑		-	T/C, Survey materials
	Geological and Geochemical survey	done	done	☑	- Geologist, - Geochemist	Labo analysis	T/C, Survey materials
	Preliminry ESIA	done	done	☑	-	-	T/C, (out-sourcing)
2nd	TG wells	At one or two promising site/s			- Drilling service, - Drilling managers, - Geologists, - Reservoir engineers	Drilling machine, Supporting equipment, Drilling crew	T/C, Drilling consumables
3rd	Test Wells	At the most promising site					

Note: TG wells: Temperature gradient wells; T/C: Technical cooperation (Source: JICA Project Team)
ESIA: Environmental, Social Impact Assessment

(2) The second step – Temperature gradient well

At one or two sites that will be selected from the three, drilling of temperature gradient wells is proposed. A depth of about 300 m per a well is proposed taking into consideration the GSE equipment. It is desirable to drill 4 wells in one site.

It is noted that the well-head valve together with BOP shall be fixed to the well to avoid possible blow-out from some of wells.

(3) Third step –Test well

After all the information available and to be made available be integrated examined, test well targets that were proposed in this master plan project shall be reviewed.

9.2 Proposal for on Master Plan Formulation Project on Establishment of EEGeD

9.2.1 Special Purpose Public Entity (Enterprise)

The recommended new special purpose entity temporarily named as Ethiopian Enterprise for Geothermal Energy Development (EEGeD). The mandates of EEGeD may be as follows:

- To undertake the geothermal resource surface survey and test drilling,
- To undertake project feasibility study when necessary for a future business of EEGeD,
- To undertake field development wherever possible, and
- To operate steam production and sales wherever possible.

There may be a possibility that EEGeD may extend its operation to power generation.

The merits of forming EEDeD are as follows:

- EEGeD will be able to concentrate its efforts to geothermal development mainly for the purpose of electricity generation;
- EEGeD will also be able to accumulate its knowledge and experiences within the organization, which will accelerate geothermal development; and
- EEGeD, as the single focal point for geothermal development in Ethiopia, will be able to attract donors' attention, which will make financial arrangement much easier.

9.2.2 Characteristics of EEGeD

The new geothermal-specialized public entity EEGeD shall be financially sustainable once it becomes a fully-fledged operation. It is for this reason that EEGeD shall undertake steam production and sales, thereby ensuring stable revenue.

9.2.3 Proposal for the Master Plan Formulation Project on Establishment of EEGeD

To establish the new enterprise EEGeD, a design of institutional and regulations will be necessary. Even though the final status of EEGeD shall be a financially sustainable organization, there will be a transitional period when the EEGeD may need financial supports until its fully-fledged operation. Thus, we would propose a Master Plan Formulation Project to be implemented. The proposed Terms of Reference is shown in the Table

Table 9.2.1 Proposed TOR of a Master Plan Project on Establishment of EEGeD

1. Rationale for EEGeD
2. Vision and Mission
3. Situation analysis
   (Assessment of human, physical and financial resources)
4. Business model
   (Value chain mapping and ownership structure)
5. Human Resource Development (Organization and staffing)
6. Legal and regulatory framework
7. Geothermal resource development
8. Financial plan
9. Steam Sales Agreement (SSA)
10. Action Plan for Formation of EEGeD

CHAPTER 10 THE WAY FORWARD: CONCLUSIONS AND RECOMMENDATIONS

The Project Team assessed geothermal resources of the nominated 22 sites in Ethiopia based on existing information, remote sensing analysis, field geological and geochemical survey followed by its laboratory analysis, and environmental-social impact assessment. Thereby, the Team formulated the Master Plan on Development of Geothermal Energy in Ethiopia.

Prior to describing conclusions and recommendations, we would first reconfirm and emphasize its significances of the geothermal energy development in Ethiopia:

1. **Geothermal power generation provides reliable electricity supply as base load throughout a year;**
2. **Geothermal energy is supreme to other climate-dependent renewable energies such as wind, solar and/or others;**
3. **Geothermal energy will reduce drought risks of hydropower-dependent Ethiopian power supply;**
4. **Thus, priority has to be given to the earliest and the maximum development of geothermal energy.**

The conclusions and recommendations the Project Team reached are as follows.

CONCLUSIONS

1. The geothermal resources of the target sites are estimated at a 4,500 MW as the most probable occurrence probability (O/P), a 2,100 MW as 80% O/P, and a 10,800 MW as the 20% O/P. This estimation is classified as “inferred geothermal resource” since only surface surveys were conducted for the estimation. This estimation needs to be refined to a level of “indicated or measured geothermal resources” through conducting geophysical survey and test well drilling for formulating more specific development plans.

2. The environmental and social impact assessment identified no significant adverse impacts on natural and social environment with a few exceptions that were eventually ranked at lower priorities.

3. The 22 sites are classified into the five priority groups, i.e. Priority-S, A, B, C and D on the basis of the multi-criteria analysis conducted. The analysis concluded that a 610 MW of the Priority-S should be developed for the period of 2014 to 2018, an approximately 2,800 MW of the Priority A and B for the period of 2019 to 2025, and an approximately 1,100 MW of the Priority-C and D for the period of 2026 to 2037.

4. Among the Priority A and B to be developed for the period of 2019 to 2025, the three sites, i.e. Tendaho-2 (Ayrobera), Boseti and Meteka, are green fields where no other donors or private firms have committed to development. Those three sites were nominated as priority sites for new development.

5. The analysis also concluded that the geothermal sites of the Priority A and B should first be developed prior to some of the wind and solar power generating facilities planed by EEP. EEP presently plans to install an total of an approximately 1,200 MW of wind and solar power facilities by 2018.

6. The financial analysis revealed that the generation cost could be below the present domestic tariff level only when the Priority-A sites are developed with most concessional financing programs such as Japan's ODA loans; The generation cost could then be below the present exporting tariff level when the Priority-A and B sites are developed with more concessional financing programs such as World Bank loans; the generation cost will exceed the both tariff levels if geothermal sites are developed with private funds. In other words, public financing schemes shall be utilized for the geothermal development under the present tariff policy. If private investments are to be promoted, financial and/or institutional supporting policies will have to be established.

7. The geothermal development has to be implemented by a public entity who shall handle projects with public financing schemes. A new public entity named EEGeD needs to be established by merging the existing geothermal related sections in GSE and EEP. Financial sustainability of EEGeD could be maintained by selling steam to the electricity producer (EEP, etc). Private firms, however, should be allowed to participate in any stage of the geothermal energy development.

8. The Project Team identified three priority sites, i.e. Tendaho-2 (Ayrobera) of Priority-A, and Boseti and Meteka of Priority-B, from green fields where other donors or private firms have not yet committed. Out of those three, geophysical survey was conducted in Tendaho-2 (Ayrobera) and Boseti. Based on the geophysical survey conducted, the outer limits of geothermal reservoir were preliminarily inferred for each site; thereby, targets of test wells were proposed.

RECOMMENDATIONS

Geothermal power generation will be of paramount importance as a stable base load energy for the hydropower dependent Ethiopia power supply system, which is susceptible to climate change and unstable in drought years. The Project Team proposes the following recommendations in order to accelerate the geothermal development in Ethiopia.

1. To ensure the smooth implementation of the Priority-S projects that are already committed by other donors or a private firm;

2. To implement, at an earliest convenient, an additional surface survey including temperature gradient wells at Ayrobera and Boseti. In Butajira that was first identified in 2014, surface survey including geophysical survey shall be conducted.

3. To realize, as earliest as possible after the above survey, test well drillings at Ayrobera, Boseti or Butajira wherever deemed to be the most promising;

4. To conduct geophysical survey by GSE at Meteka, were the Master Plan project did not conduct the geophysical survey though it was selected as one of the priority site.

5. To review and update the geothermal resource assessment as further exploration proceeds,

6. To conduct, as an urgent requirement, a master plan project for the establishment of EEGeD; to implement capacity building to EEGeD, at very earliest convenient, in order to accelerate the geothermal development; and

7. To review and update the Master Plan from time to time, since the Ethiopia economy is being rapidly growing and the world economic circumstances are drastically changing.

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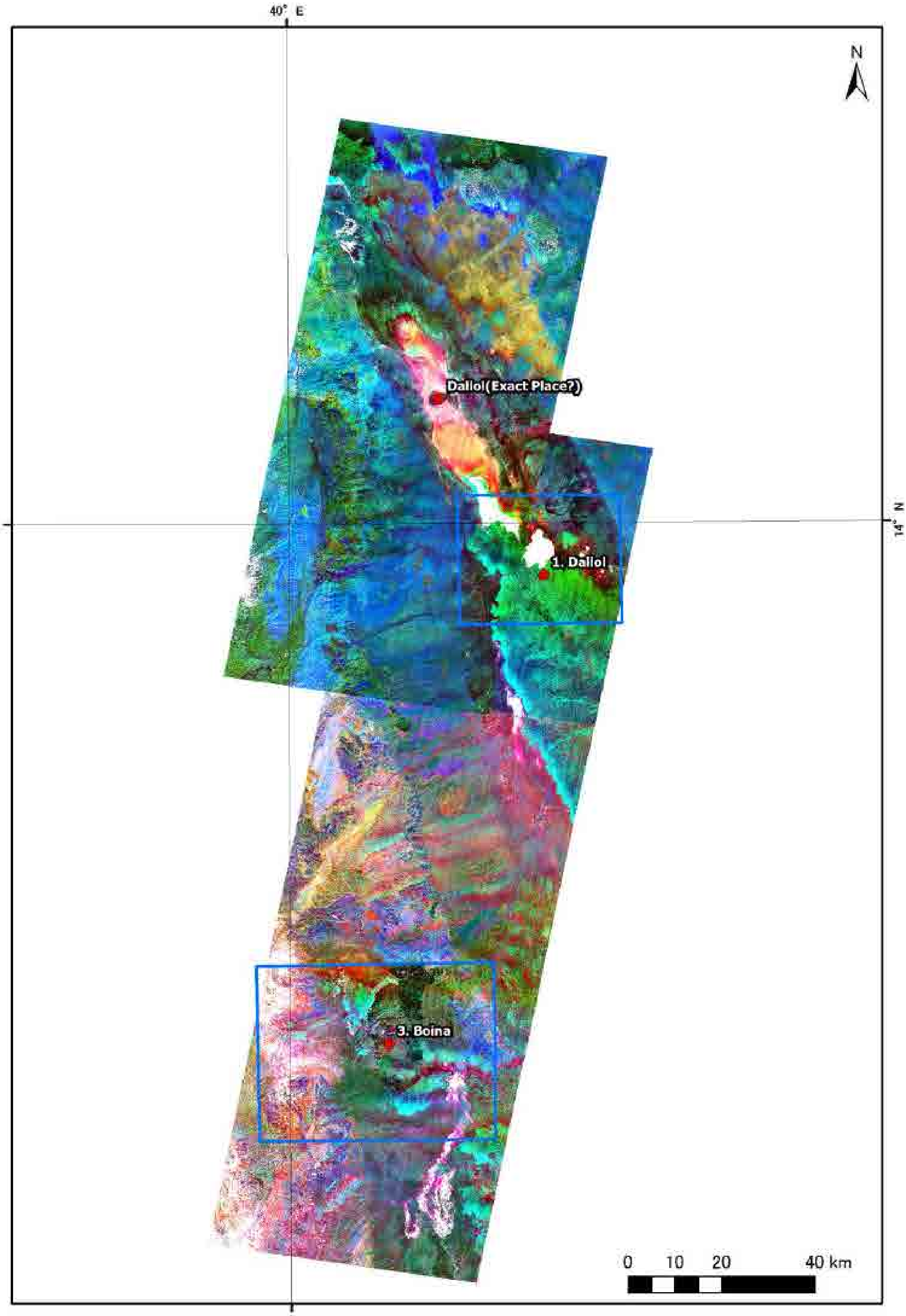
APPENDIX

List of Appendix

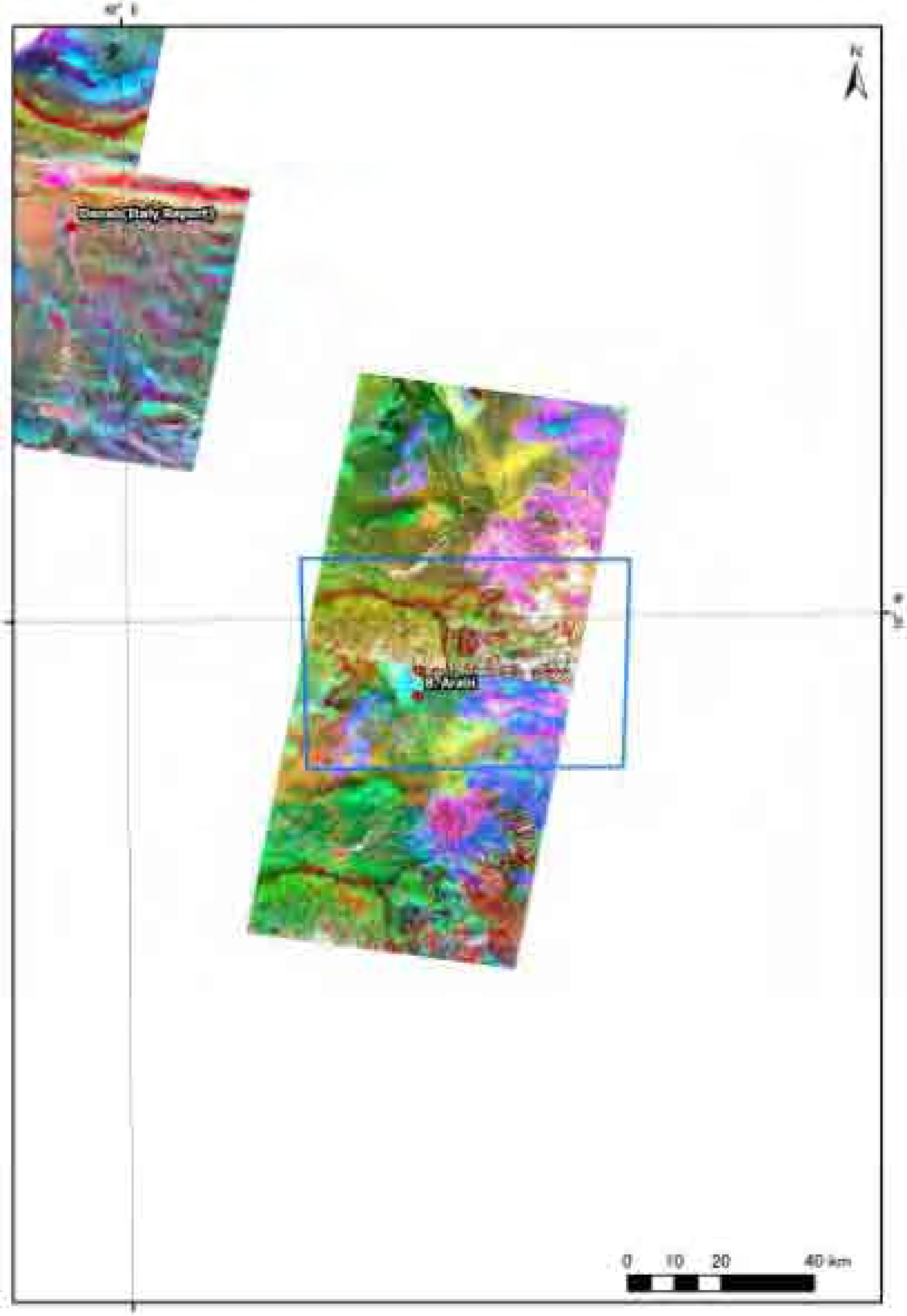
APPENDIX-1

REMOTE SENSING ANALYSIS



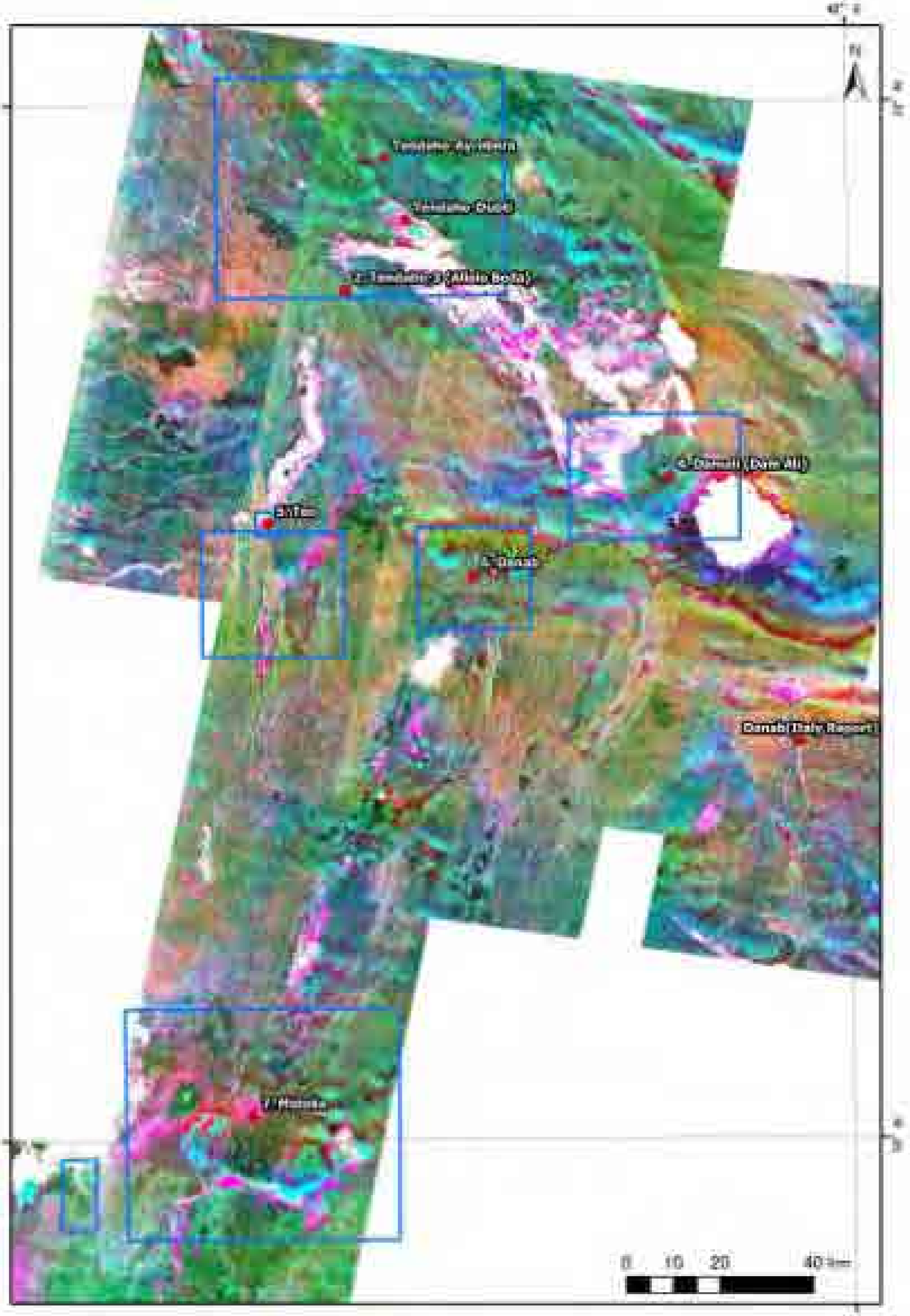
Source: JICA Project Team

Figure A.1.1 ASTER Band Ratio Image of Dallol and Boina Sites



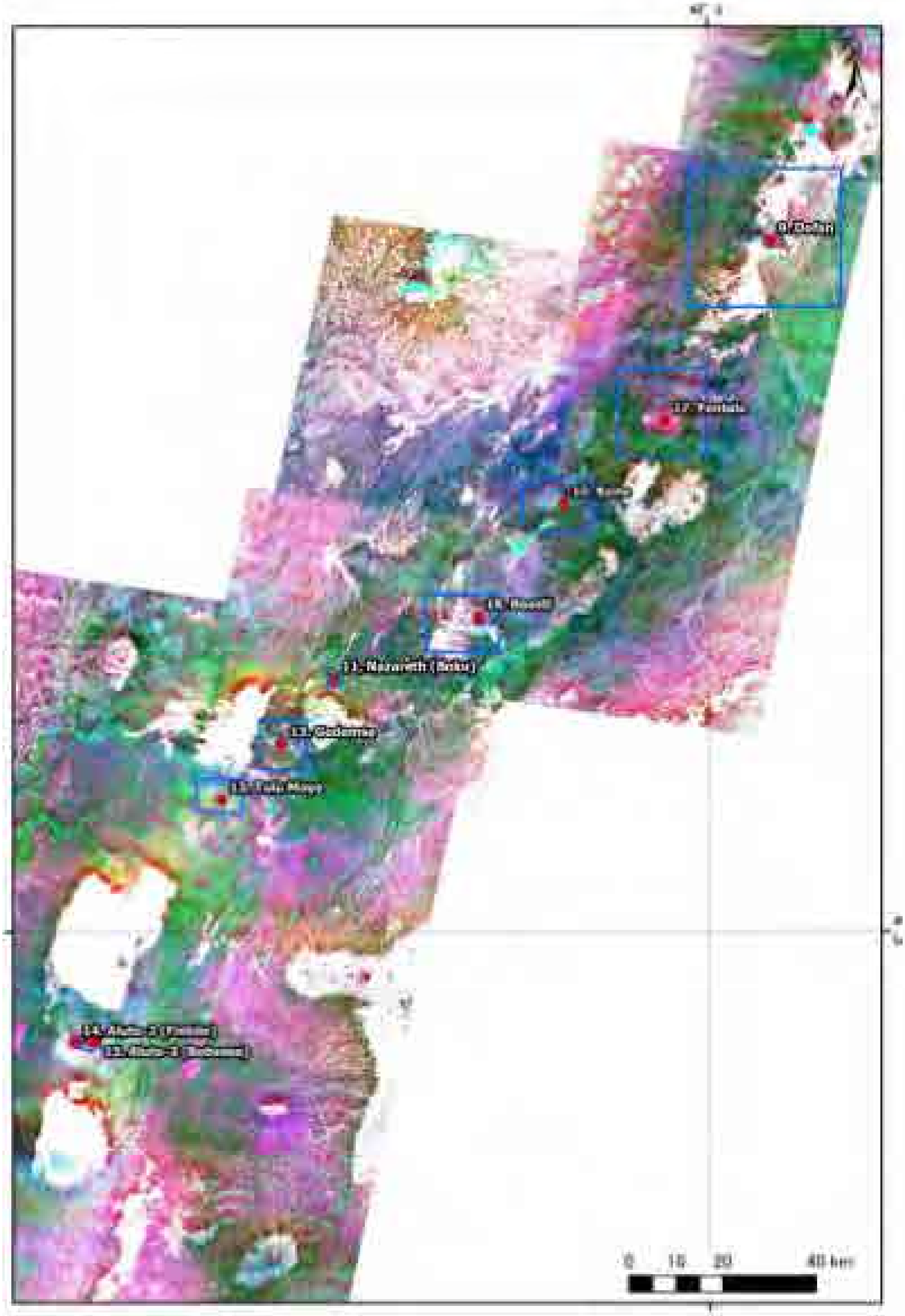
Source: JICA Project Team

Figure A.1.2 ASTER Band Ratio Image of Danab and Arabi Sites



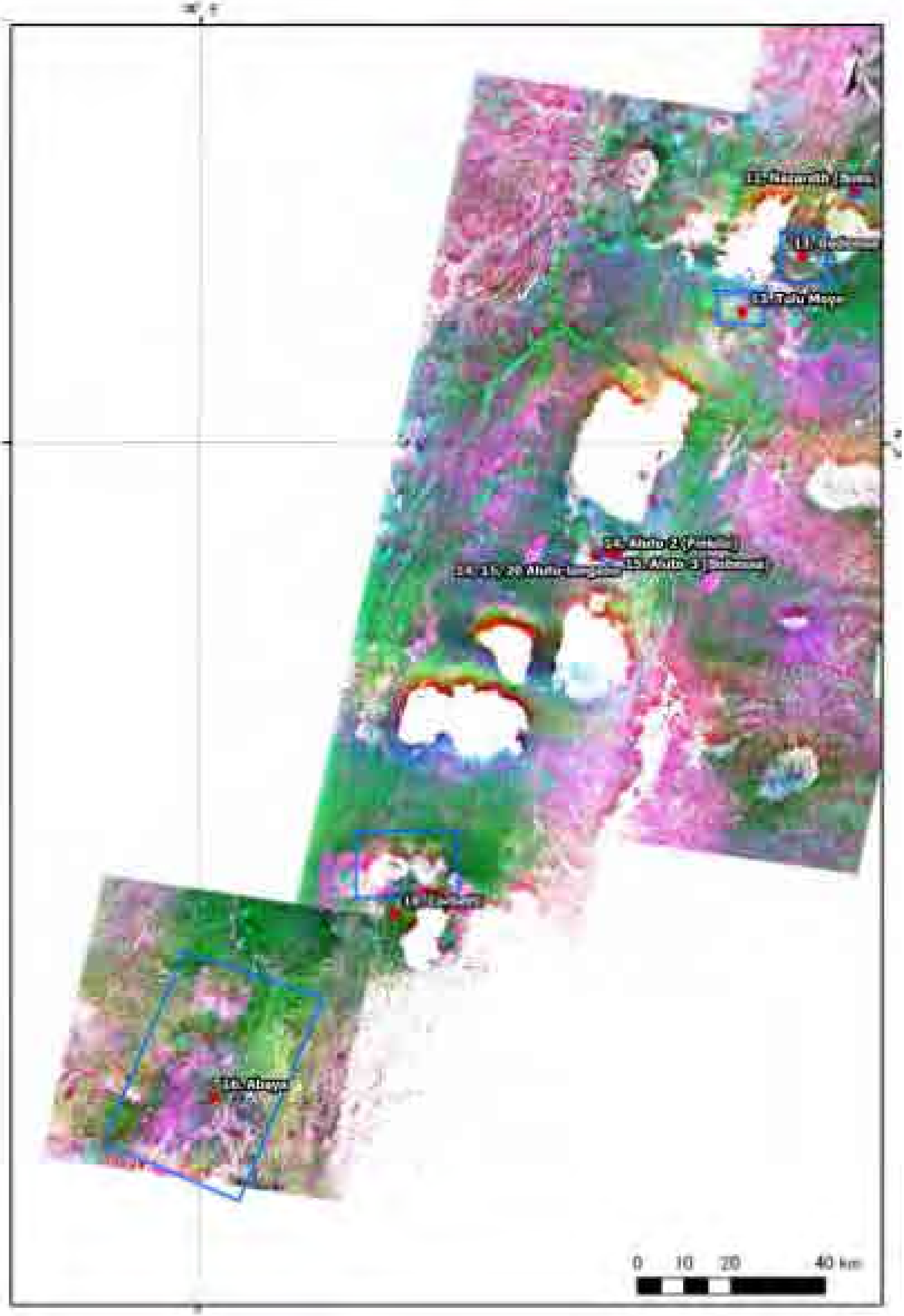
Source: JICA Project Team

Figure A.1.3 ASTER Band Ratio Image of Tendaho, Teo, Damali, and Meteka Sites



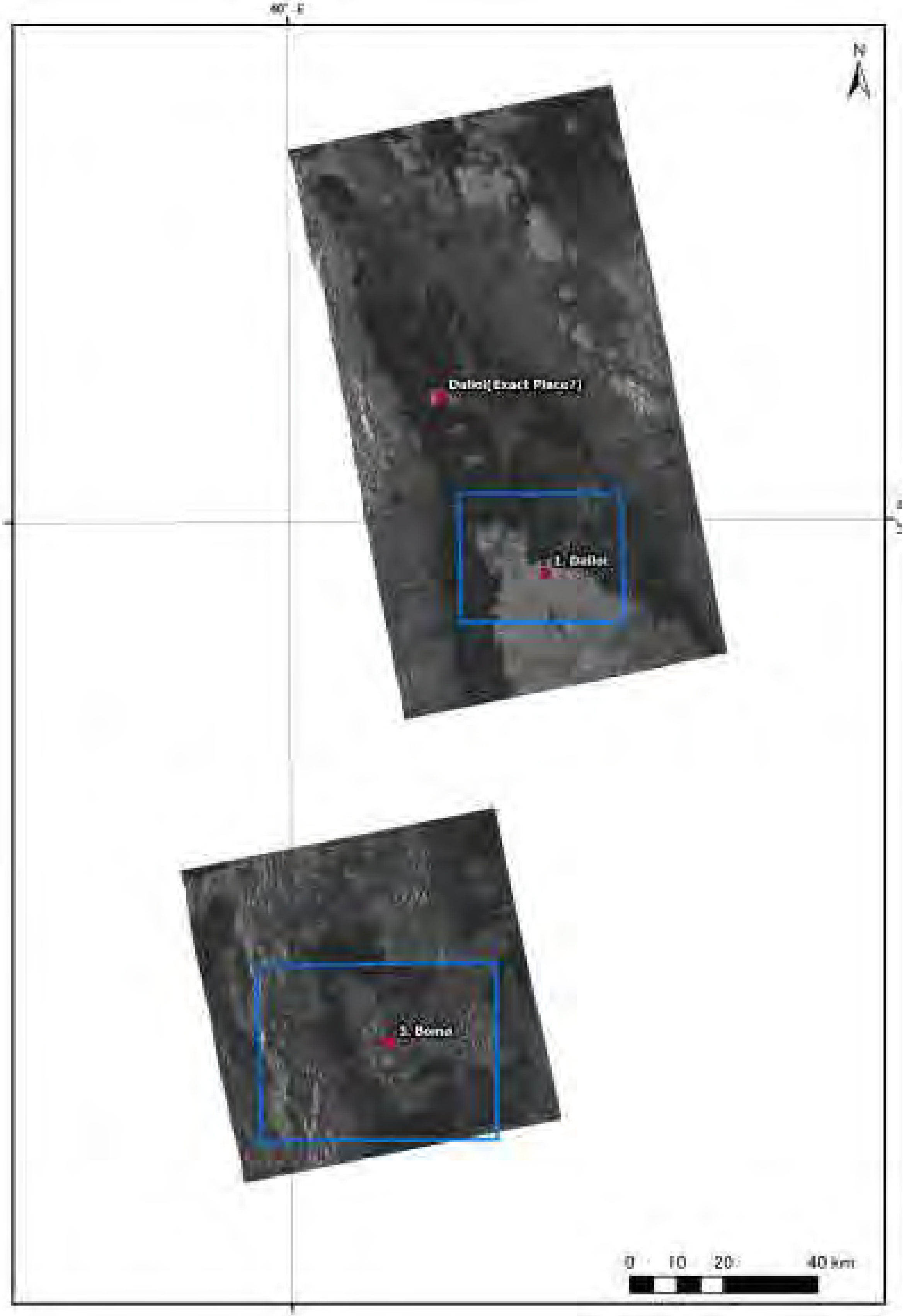
Source: JICA Project Team

Figure A.1.4 ASTER Band Ratio Image of Central Part (Gedemsa and Others)



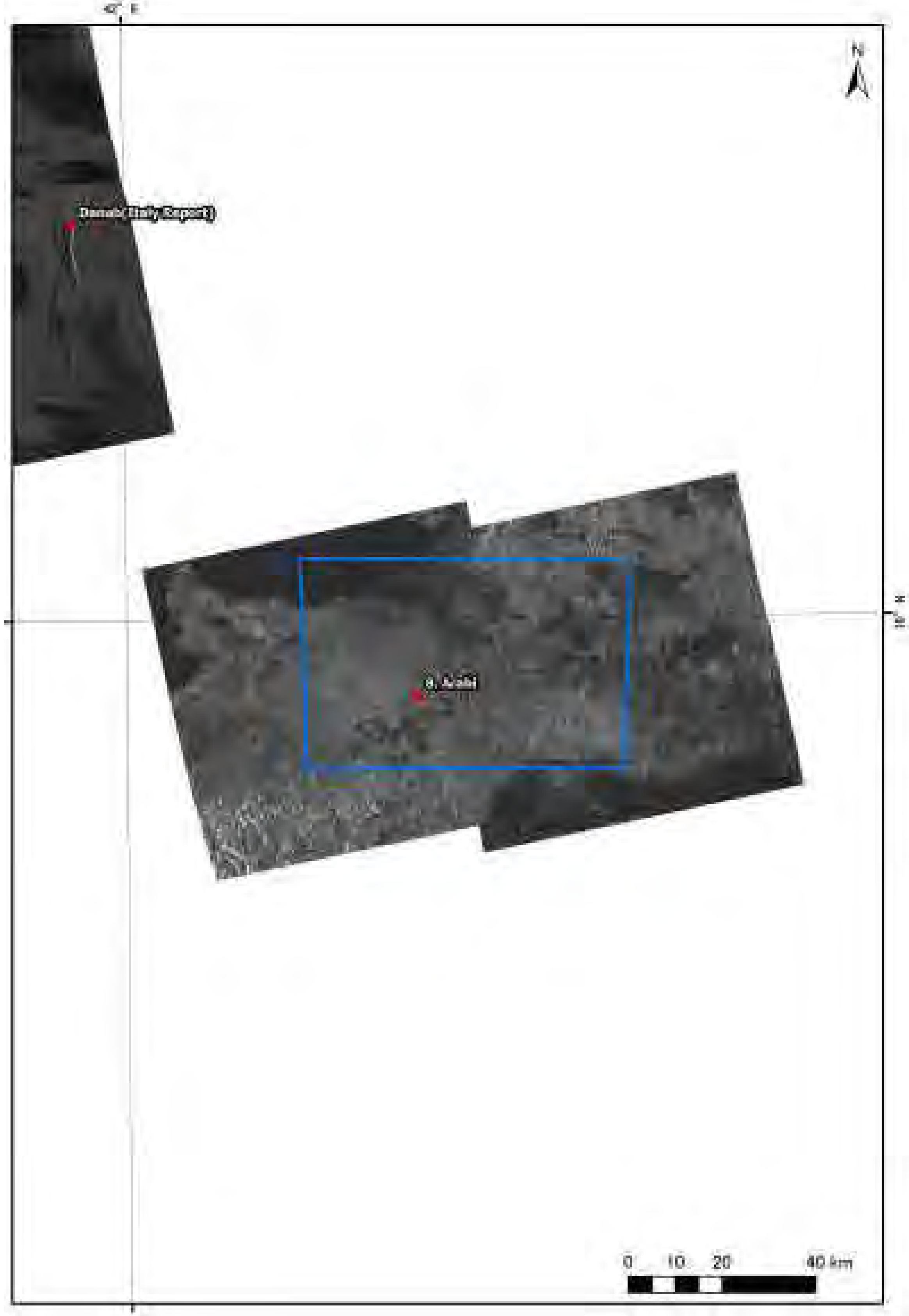
Source: JICA Project Team

Figure A.1.5 ASTER Band Ratio Image of Southern Part (Aluto and Others)



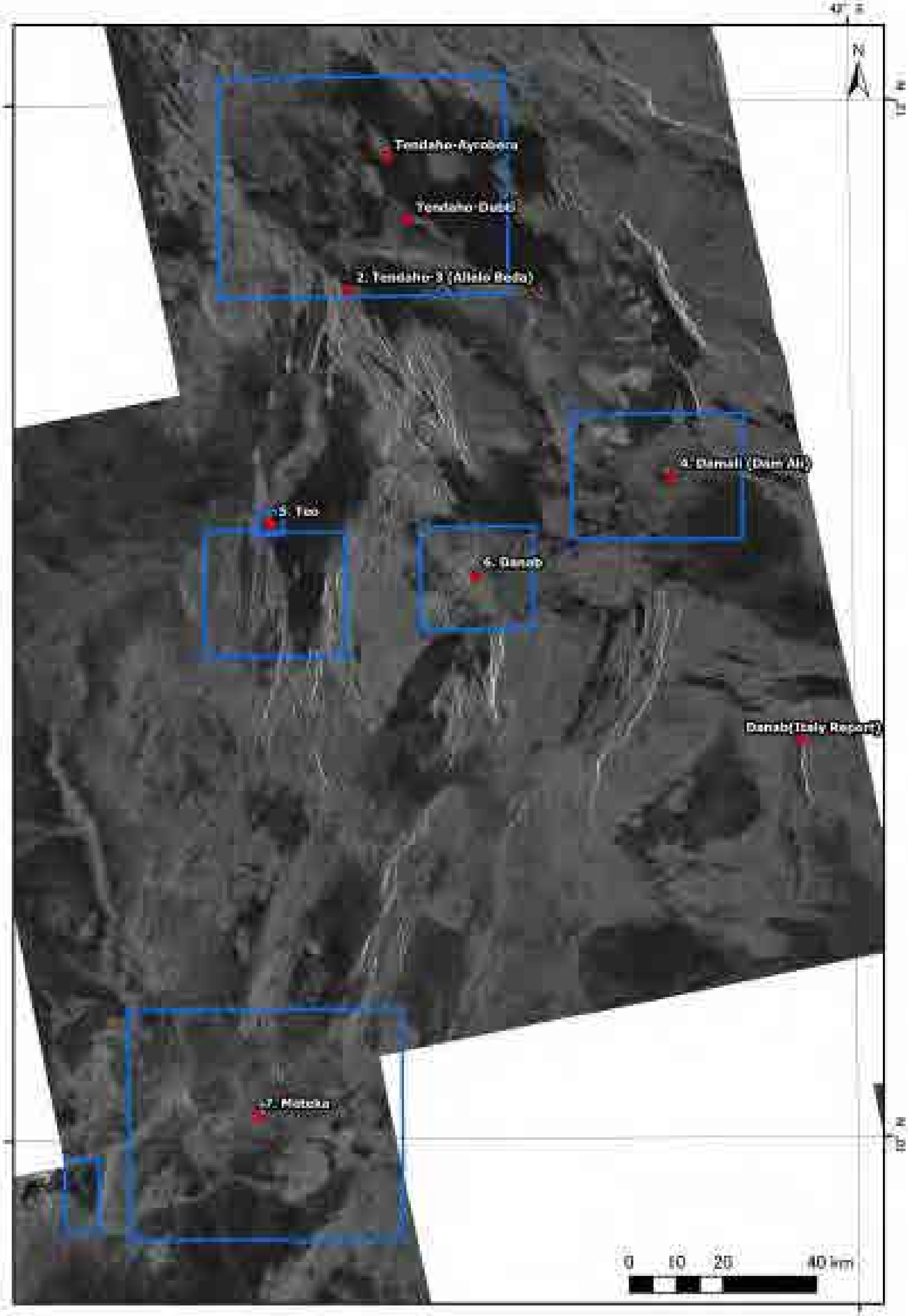
Source: JICA Project Team

Figure A.1.6 PALSAR Mosaic Image of Single Polarized Wave (HH) of Dallol and Boina Sites



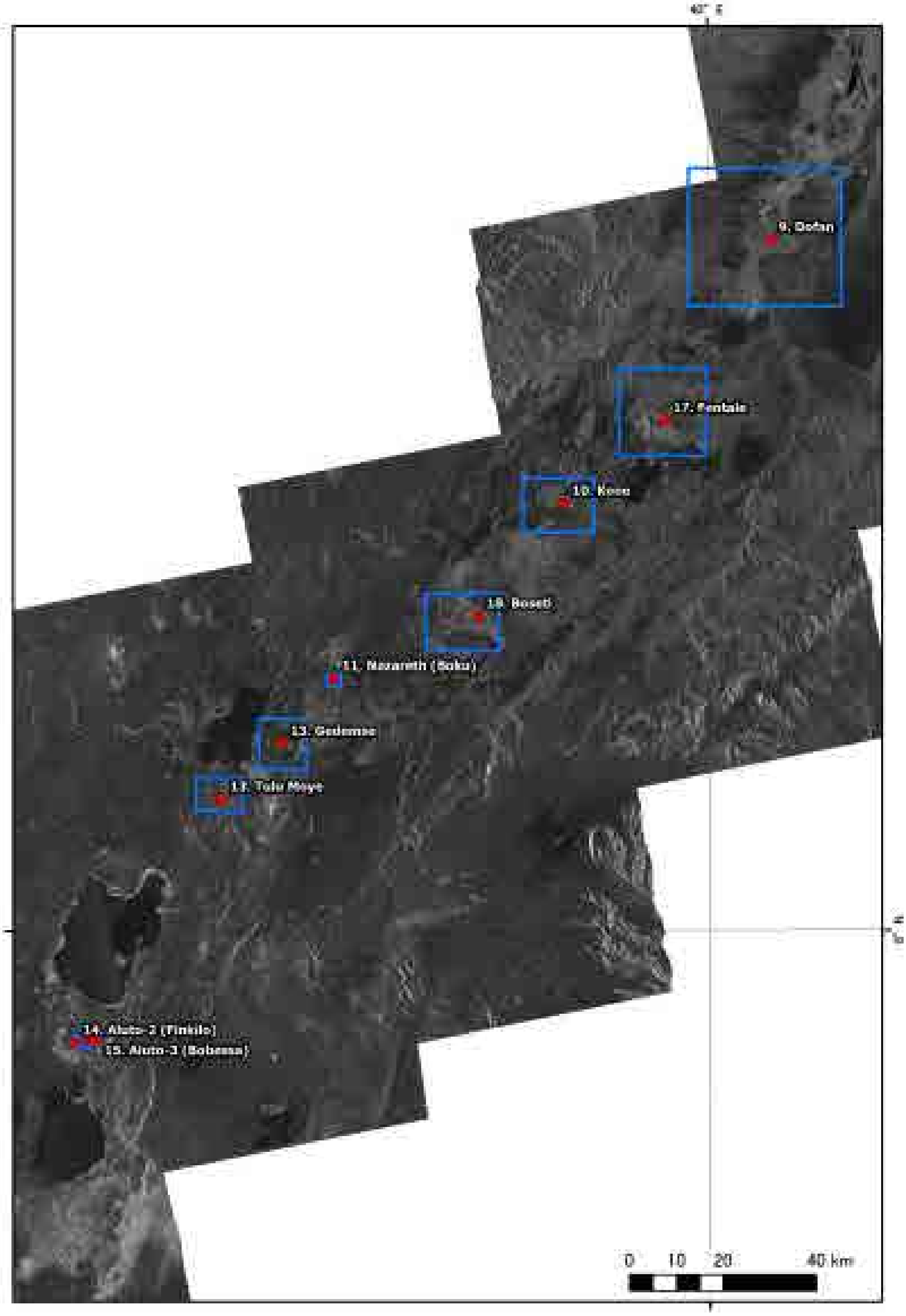
Source: JICA Project Team

Figure A.1.7 PALSAR Mosaic Image of Single Polarized Wave (HH) of Danab and Arabi Sites



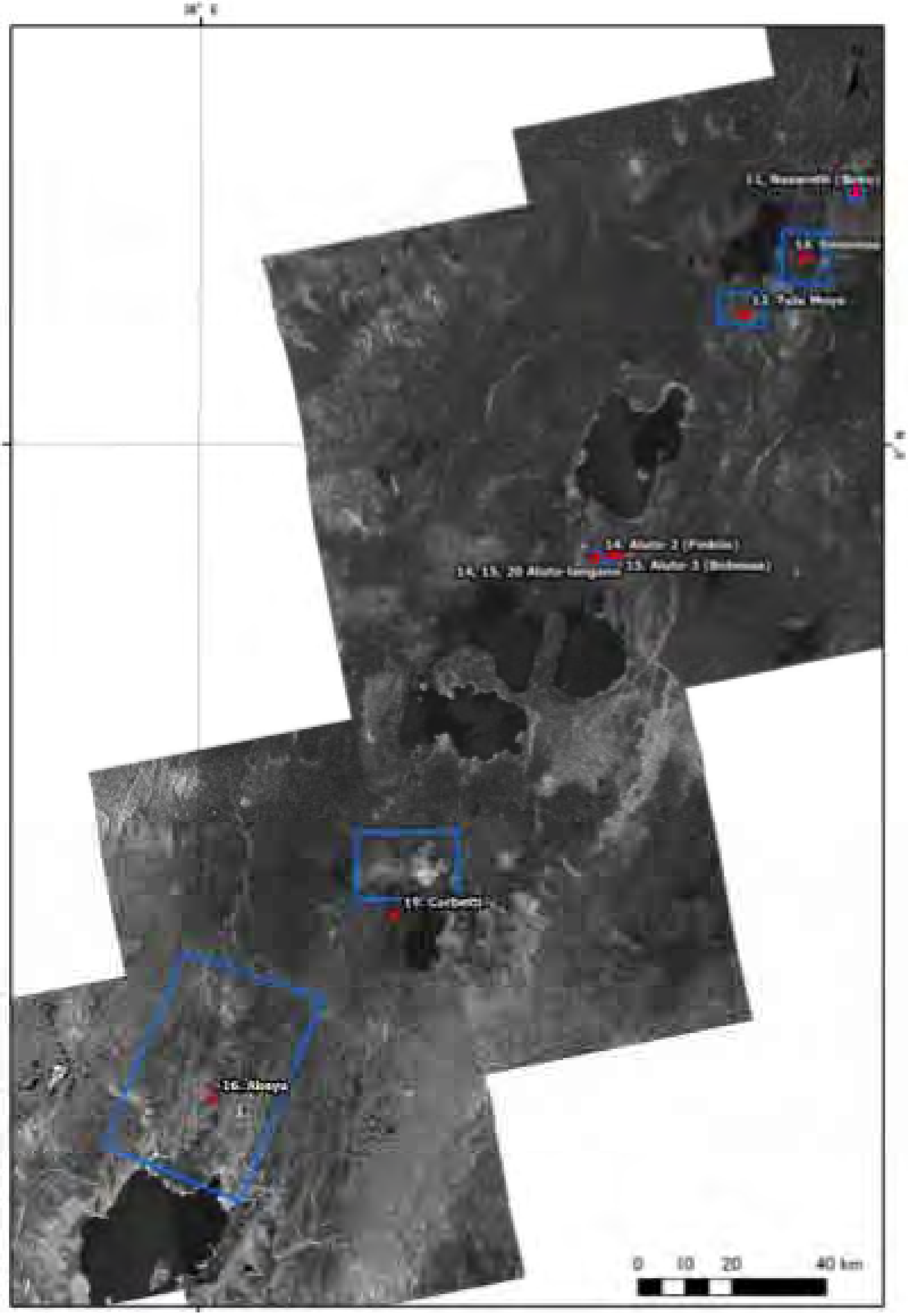
Source: JICA Project Team

Figure A.1.8 PALSAR Mosaic Image of Single Polarized Wave (HH) of Tendaho, Teo, Damali, and Meteka Sites



Source: JICA Project Team

Figure A.1.9 PALSAR Mosaic Image of Single Polarized Wave (HH) of Central Part (Gedemsa and Others)



Source: JICA Project Team

Figure A.1.10 PALSAR Mosaic Image of Single Polarized Wave (HH) of Southern Part (Aluto and Others)

APPENDIX-2

SITE RECONNAISSANCE

Site No. 2	Site Name: Tendaho-3 (Tendaho-Allalobeda)	Regional State: Afar

Satellite Imagery and Route Map

N

0.5 km

Legend
- Surveyed Route
- Fumarole
- Hot Spring
- Other Geological Feature

Center Coord. (WGS84)
Lat: N 11°38'34.29"
Lon: E41°00'58.70"

Surveyed Date:
12 April, 2014

by Google Earth Pro:
http://www.google.com/earth

General Geology
The site is located at the western edge of Manda-Hallaro Graven. Layered basalt and andesite lava of Afar Stratoid are observed (1-4Ma, by V. Accolela et.al. (2008))

Geological Structure, Fault and Others
The site is located along NW-SE marginal fault of Manda- Halaro Graven, associated with minor faults. The height of fault scarp is approx. 200m.

Manifestation
More than 20 hot springs and geysers are found along NW-SE marginal fault within 1 km diameter, showing definite relationship between the faults and manifestations. Whitish gray amorphous silica is deposited around the springs.

Alteration
No alteration was observed at the host rock.

Others
Remote sensing result shows no indication of alteration; due to no alteration minerals were found.

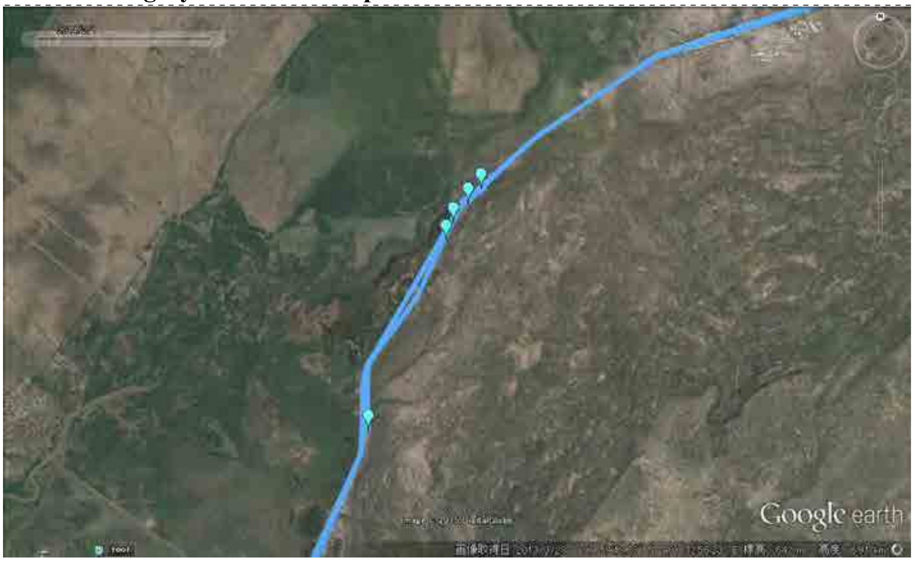
Photos

Overview

Geyser

Site No. 7	**Site Name: Meteka**	**Regional State: Afar**

Satellite Imagery and Route Map



N **0.5 km**

Legend
- Surveyed Route
- Fumarole
- Hot Spring
- Other Geological Feature

Center Coord. (WGS84)
Lat: N 9^{0}59'18.78"
Lon: E40^{0}32'56.33"

Surveyed Date:
08-09 April, 2014

by Google Earth Pro:
http://www.google.com/earth

General Geology
The site is located at the steep fault scarp. Andesite lava and pyroclastic rocks of Afar Stratoid are observed at the fault scarp. Western side is a swampy area where Awash River is flown to the north.

Geological Structure, Fault and Others
The site is located along NE-SW steep but unclear fault; height of fault scarp is approx. 200m. Quaternary volcanoes of Wonji Group are located at approx. 9km east-northeast of the manifestation sites.

Manifestation
Many hot springs are found at the foot of fault scarp distributed within 2km, showing relationship between the faults and manifestations.

Alteration
Amorphous quartz, Calcite in amygdule, and gypsum vain are observed in andesite, indicating low hydrothermal alteration.

Others
Remote sensing result indicated the alteration zone at the Quaternary volcanoes; however the area is dangerous and difficult to reath them.

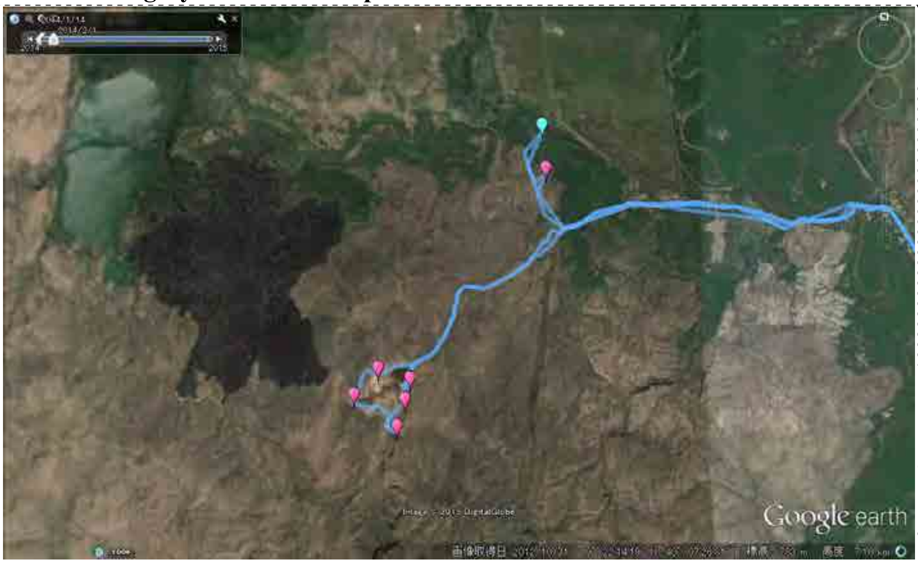
Photos

Hot spring at roadside

Hydrothermal Alteration in rock

Site No. 9	**Site Name: Dofan**	**Regional State: Afar**

Satellite Imagery and Route Map



2.0 km

Legend
- Surveyed Route
- Fumarole
- Hot Spring
- Other Geological Feature

Center Coord. (WGS84)
Lat: N 9^{0}22'14.19"
Lon: E40^{0}07'26.81"

Surveyed Date:
07 April, 2014

by Google Earth Pro:
http://www.google.com/earth

General Geology
The site is geologically located at the center of rift valley, composing the volcanic mountain. Basalt and andesite lava of Quaternary Dofan Basalt is observed.

Geological Structure, Fault and Others
Wonji faults (NNE-SSW faults) are commonly run through volcanic mountain. Wonji Basalt was erupted and covers Dofan basalt in some area.

Manifestation
Many fumaroles are observed at the center of the volcanic mountain, associated with white clay and sulfur. Large hot springs are observed at the northern foot of the mountain.

Alteration
White clay with sulfur is observed around fumaroles, indicates acidic alteration by H_2S in fumaroles gas. The alteration zone is distributed by circle in ground, indicates that piped-shape alteration zone may continue down to the ground.

Others
The alteration zone matched the result of remote sensing results.

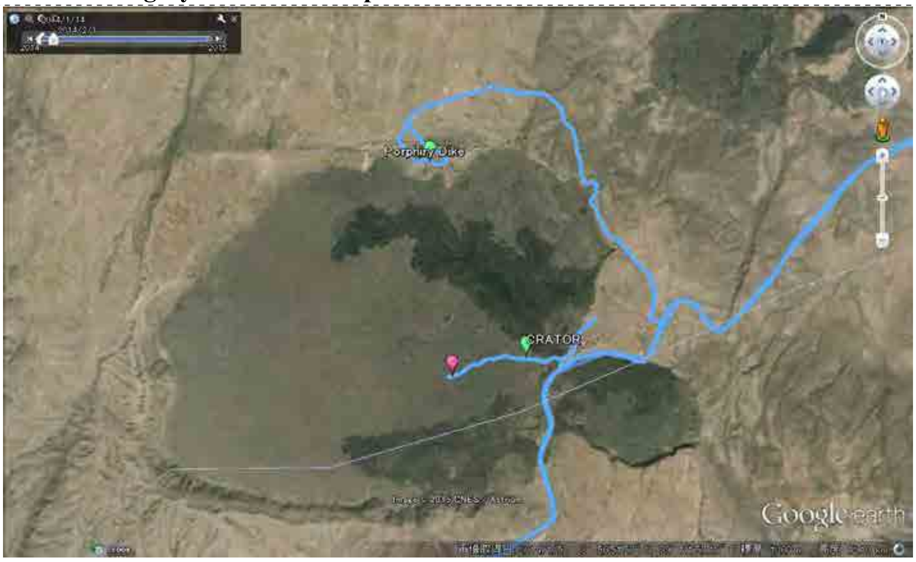
Photos


Overview of Fumarole site


Hot Spring

Site No. 10	Site Name: Kone	Regional State: Afar

Satellite Imagery and Route Map



N **2.0 km**

Legend
- Surveyed Route
- Fumarole
- Hot Spring
- Other Geological Feature

Center Coord. (WGS84)
Lat: N 8^{0}50'51.57"
Lon: E 39^{0}41'57.15"

Surveyed Date:
24, 30 January, 2014

by Google Earth Pro:
http://www.google.com/earth

General Geology

The site is geologically located at the center of rift valley, mainly rhyolitic welded tuffs of Wonji Group are distributed at the area.

Geological Structure, Fault and Others

Distinctive two calderas are observed. Larger caldera is called Kone caldera, (6km x 4km). Small caldera is called Korke caldera (2km x 1km). Outflow of caldera is not found. Wonji faults (NNE-SSW faults) are commonly run through outside of caldera. Wonji Basalt was erupted and filled in both calderas; some of them are very recent.

Manifestation

Very weak fumarole is found at the inside of Kone caldera.

Alteration

No alteration was observed at the host rock.

Others

Remote sensing result shows some clay and chlorite-type alterations at surrounded area; however alteration zone was not found by survey.

Photos

Site Overview (Korke)

Fumarole in Caldera

Site No. 11	**Site Name: Nazreth (Boku, Sodole)**	**Regional State: Oromia**

Satellite Imagery and Route Map

3.0 km

Legend
- Surveyed Route
- Fumarole
- Hot Spring
- Other Geological Feature

Center Coord. (WGS84)
Lat: N 8^{0}26’46.13”
Lon: E 39^{0}19’39.66”

Surveyed Date:
27 January, 2014

by Google Earth Pro:
http://www.google.com/earth

General Geology
The site is located at the south of Nazreth (Adama). Rhyolitic volcanic rocks of Priocene are mainly distributed. The crescent shape ridge (Boko scarp) ridge is located at Boko, may indicate remnant of caldera structure.

Geological Structure, Fault and Others
Wonji faults (NNE-SSW faults) are commonly run through outside of caldera. The eastern part of Boko ridge, Wonji Basalt is erupted with forming volcanic cones.

Manifestation
Sodole hot spring and Boko fumarole is famous; however other manifestation is not common. Boko is located at the foot of Wonji Fault, fumaroles are coming from fractures.

Alteration
Amorphous silica (agate) with clay minerals are found in pyroclastic rock in Boko; it may indicate low-grade alteration or hydrothermal alteration.

Others
Remote sensing result shows no indication of alteration.

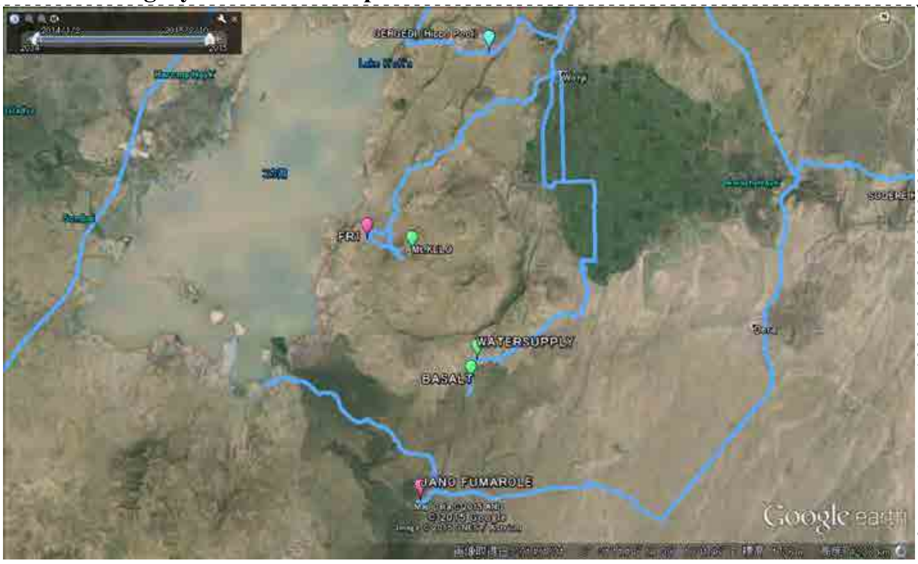
Photos

Fumarole from fractures (Boko)

Hot Spring (Sodole)

Site No. 12	Site Name: Gedemsa	Regional State: Oromia

Satellite Imagery and Route Map



N

5.0 km

Legend
- Surveyed Route
- Fumarole
- Hot Spring
- Other Geological Feature

Center Coord. (WGS84)
Lat: N 8⁰21'11.14"
Lon: E 39⁰10'41.46"

Surveyed Date:
25, 29 January, 2014

by Google Earth Pro:
http://www.google.com/earth

General Geology

The site is located at the southwest of Nazreth town, and east of Lake Koka. The site composed of large caldera (12km x 10km) in Nazret Group and volcanoes inside the caldera.

Geological Structure, Fault and Others

Wonji faults (NNE-SSW faults) are commonly developed at outside of caldera. Wonji Basalt was erupted at north and south of caldera.
Some of Wanji fault continues inside the caldera.

Manifestation

No manifestation was found inside the caldera; only weak fumaroles are found at the western caldera rim. Hot springs and some fumaroles are found at the outside of caldera; that coincide distribution of Wonji fault.

Alteration

Amorphous quartz (agate) was found at welded tuff outcropped at caldera rim, however there is no or few relation with geothermal alteration.

Others

Remote sensing result shows clay alteration at the volcano inside the caldera; however alteration was not found.

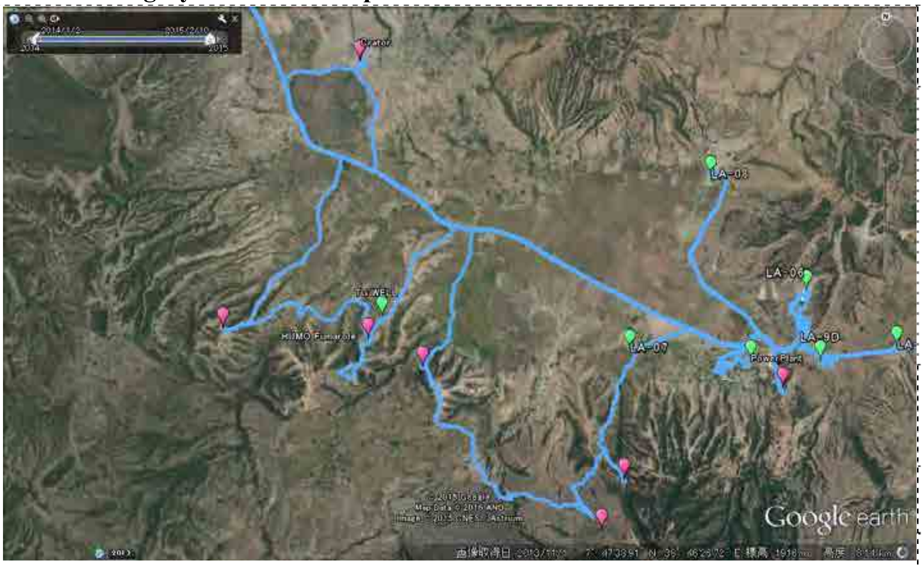
Photos

Weak fumarole from western caldera rim

Hot Spring (Gergedi, Hippo Pool)

Site No. 14	Site Name: Finkilo (Aluto-2)	Regional State: Oromia

Satellite Imagery and Route Map



N

1.0 km

Legend
- Surveyed Route
- Fumarole
- Hot Spring
- Other Geological Feature

Center Coord. (WGS84)
Lat: N 7°47'38.91"
Lon: E 38°46'26.72"

Surveyed Date:
21 January, 2014

by Google Earth Pro:
http://www.google.com/earth

General Geology
The site is located in Aluto volcanic complex and at the west of Aluto-Langano Geothermal site. The area is composed of Quaternary rhyolite lavas and pyroclastic rocks of Aluto Volcanics.

Geological Structure, Fault and Others
The site is located at slope and terrace area inside the volcanic complex. No faults are visible at the site. Small crater with fumaroles and outflown obsidian lava was observed at the northern part of the site

Manifestation
Many fumaroles are observed at the valley at the southern part.

Alteration
Altered clay was observed only at the fumaroles points, indicates very low alteration.

Others
Remote sensing result shows clay alteration in some parts; low-altered pumice tuffs are distributed.

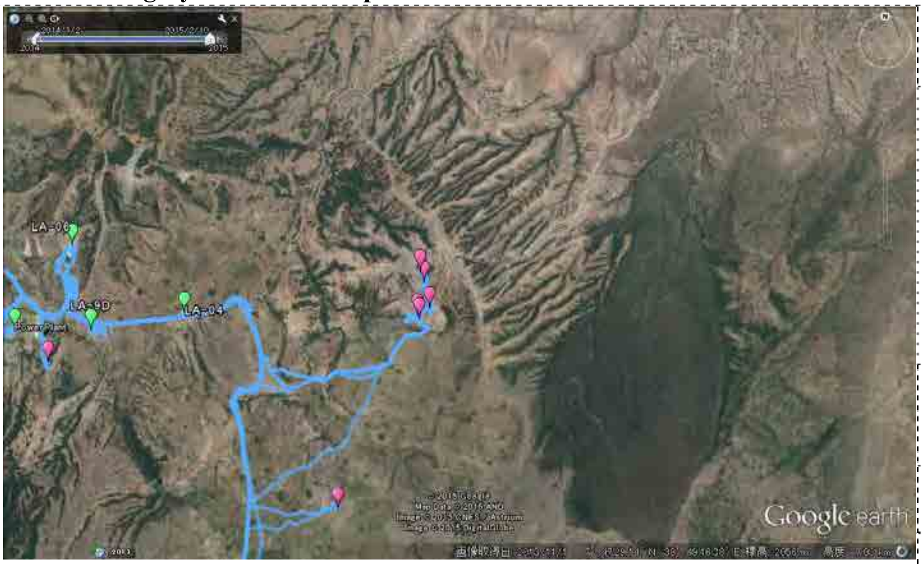
Photos

Overview of Finkilo Site

Fumaroles at the valley

Site No. 15	Site Name: Bobesa (Aluto-3)	Regional State: Oromia

Satellite Imagery and Route Map



N

1.0 km

Legend
- Surveyed Route
- Fumarole
- Hot Spring
- Other Geological Feature

Center Coord. (WGS84)
Lat: N 7^{0}47’29.14”
Lon: E 38^{0}49’16.38”

Surveyed Date:
19-20 January, 2014

by Google Earth Pro:
http://www.google.com/earth

General Geology
The site is located in Aluto volcanic complex and at the east of Aluto-Langano Geothermal site. The area is composed of Quaternary rhyolite lavas and pyroclastic rocks of Aluto Volcanics.

Geological Structure, Fault and Others
The site is located at the eastern part and outside of the volcanic complex. No faults are visible at the site; however the distribution of fumaroles may indicate subsurface faults of NNE-SSW.

Manifestation
Mainly two fumaroles are observed;
1) Active fumaroles area approx. 6km east of Power Plant (Bobesa)
2) Active fumaroles in the valley outside the mountain (Gebiba)

Alteration
Altered clay was observed only at the fumaroles points, indicates very low alteration.

Others
Remote sensing result matched the fumaroles area in Bobesa.

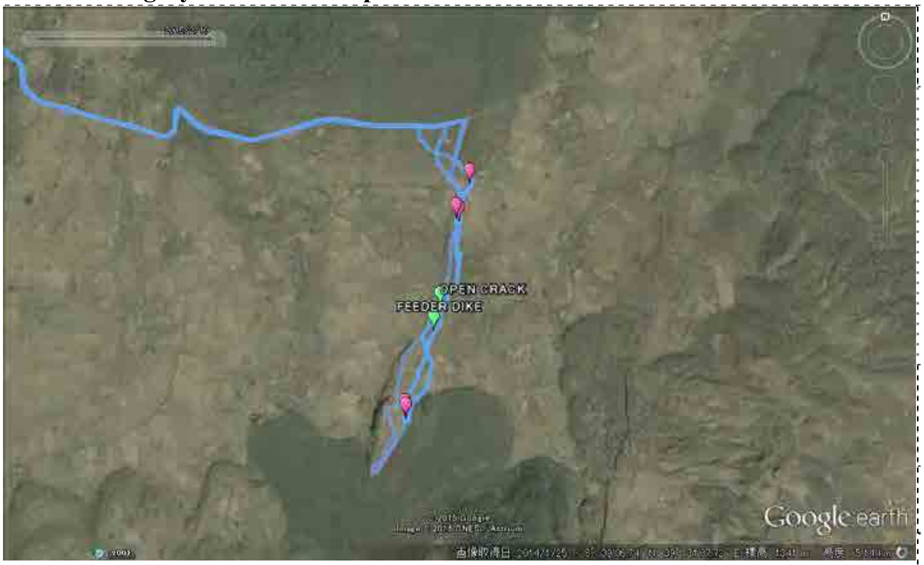
Photos


Overview


Fumaroles from the fractures

Site No. 18	Site Name: Boseti	Regional State: Oromia

Satellite Imagery and Route Map



N

0.5 km

Legend
- Surveyed Route
- Fumarole
- Hot Spring
- Other Geological Feature

Center Coord. (WGS84)
Lat: N 11°38’34.29”
Lon: E41°00’58.70”

Surveyed Date:
12 April, 2014

by Google Earth Pro:
http://www.google.com/earth

General Geology
The site is located at the north of Boseti mountain (Boseti bericha). The area was consisted of basaltic lavas of Wonji Basalt, which was covered by obsidian lava flows outpoured by Boseti Volcano.

Geological Structure, Fault and Others
Wonji Fault (NNE-SSW faults) are commonly developed the area, forming sharp scarps. Boseti mountains coincide with NNE-SSW faults and some obsidian lavas outpoured through the open faults.

Manifestation
Some fumaroles are observed along Wonji Fault in northern part (Kintano) of Boseti Bericha mountain.

Alteration
Altered clay was observed only at the fumaroles points, indicates very low alteration.

Others
Remote sensing result shows some clay and chlorite-type alterations at the eastern foot of the mountain; however no alteration was found by survey.

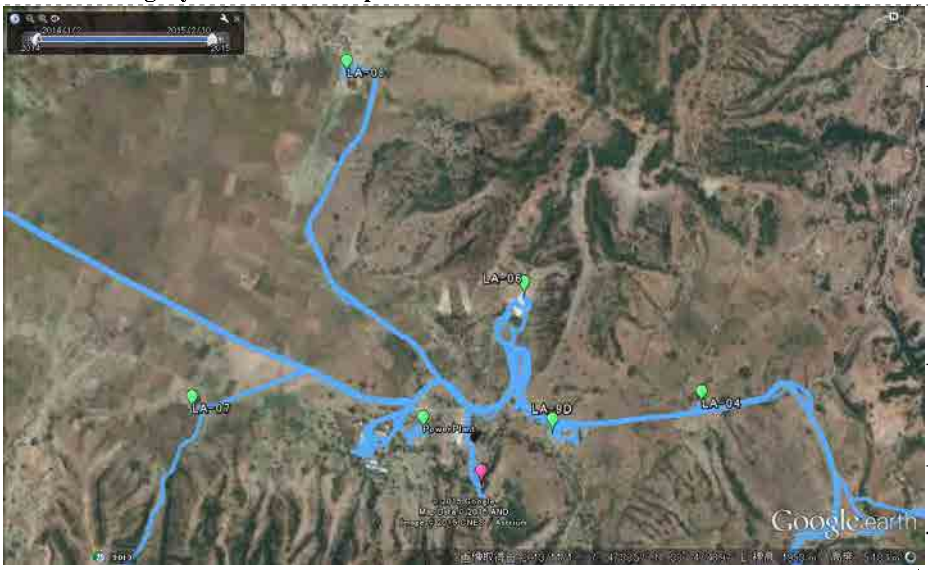
Photos


Overview


Sampling of fumaroles at fault scarp

Site No. 20	Site Name: Aluto-Langano (Aluto1)	Regional State: Oromia

Satellite Imagery and Route Map



N **0.5 km**

Legend
- Surveyed Route
- Fumarole
- Hot Spring
- Other Geological Feature

Center Coord. (WGS84)
Lat: N 7⁰47'38.57"
Lon: E 38⁰47'46.97"

Surveyed Date:
19 January, 2014

by Google Earth Pro:
http://www.google.com/earth

General Geology
The site is located mostly at the center in Aluto volcanic complex. The area is composed of Quaternary rhyolite lavas and pyroclastic rocks of Aluto Volcanics.

Geological Structure, Fault and Others
Total nine (9) geothermal wells were drilled in the area where subsurface faults are expected. Three (3) wells are used for productive well while one (1) well is used for injection well. NNE-SSW fault scarps are observed beside LA-6 and LA-8, considered as Wonji Fault.

Manifestation
Few fumaroles are found besides NNE-SSW fault scarps at the south of Power Plant.

Alteration
Altered clay was observed only at the fumaroles points, indicates very low alteration.

Others
Remote sensing result shows no alteration rock at the surface.

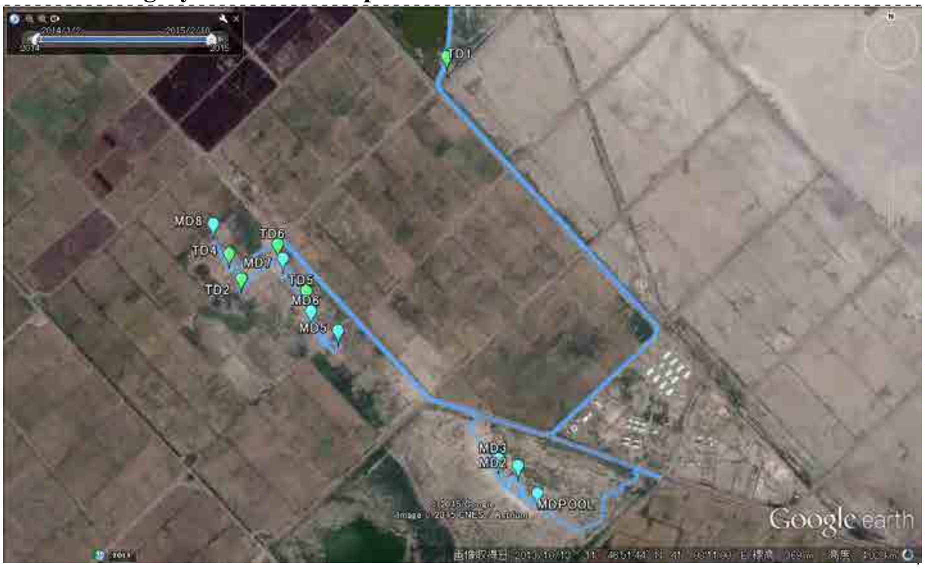
Photos

Fumarole near the power plant

Gas Sampling from LA-6

Site No. 21	**Site Name: Tendaho-1 (Dubti)**	**Regional State: Afar**

Satellite Imagery and Route Map



0.5 km

Legend
- Surveyed Route
- Fumarole
- Hot Spring
- Other Geological Feature

Center Coord. (WGS84)
Lat: N 11^{0}46’51.44”
Lon: E41^{0}08’11.00”

Surveyed Date:
12 April, 2014

by Google Earth Pro:
http://www.google.com/earth

General Geology
The site is geologically located at the center of Manda- Hararo Graven. The site is covered by alluvial sediments supplied by Awash River.

Geological Structure, Fault and Others
No geological structure is found at the site; however mud pools are aligned the direction of NW-SE, which is concordant with the main spreading axis of the Graven. Five (5) test wells were drilled in 1990s’.

Manifestation
More than ten (10) mud pools are aligned at the alluvial plain. The gas with muddy water is continuously bubbled at the mud pools. Some fumaroles are found at around mud pools.

Alteration
No alteration was observed.

Others
Remote sensing result shows no indication of alteration; because of alluvial plain.

Photos

Mud pool (Diameter :10m)

Sampling from test well

Site No. 22	Site Name: Tendaho-2 (Tendaho-Ayrobera)	Regional State: Afar

Satellite Imagery and Route Map

N

0.2 km

Legend

- Surveyed Route
- Fumarole
- Hot Spring
- Other Geological Feature

Center Coord. (WGS84)
Lat: N 11°53’26.28”
Lon: E 41°05’37.76”

Surveyed Date:
14 April, 2014

by Google Earth Pro:
http://www.google.com/earth

General Geology

The site is located at the center of Manda- Hararo Graven and the north of Dubti. Layered basalt and andesite lava, pyroclastic rocks and volcanic sediments of Afar Stratoid are observed (1-4Ma, by V. Accolela et.al. (2008))

Geological Structure, Fault and Others

The site is located at the side between basalt hills and alluvial plain. NW-SE faults are commonly developed in basalt hills.

Manifestation

Ten (10) or more fumaroles are found along NW-SE direction. Fumaroles are spout out directly from the ground. In alluvial plain, fumaroles points originate many mounds.

Alteration

No alteration was found.

Others

Remote sensing result shows no indication of alteration.

Photos

Overview: Mounds in Alluvial Plain

Geyser

APPENDIX-3

VOLUMETRIC CALCULATION METHOD

PROCEEDINGS, Thirty-Ninth Workshop on Geothermal energy Reservoir Engineering
Stanford University, Stanford, California, January 26-28, 2015
SGP-TR-204

A Rational and Practical Calculation Approach for Volumetric Method

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Keywords: volumetric method, typical power cycle process, steam-liquid separation process, adiabatic heat drop, exergy efficiency, available thermal energy function

ABSTRACT

The USGS volumetric method together with Monte Carlo simulations is widely used for assessing the electrical capacity of a geothermal reservoir. However, the USGS method appears not to be easily usable with the probabilistic method. On the other hand, some of prevailing references practice the volumetric method calculations differently from the USGS method; in many cases rational explanations are not necessarily provided. Instead, we herein propose a rational and practical calculation method by reflecting both the steam-liquid separation process at separator and the adiabatic heat-drop process at turbine, together with a rational temperature at condenser; that can be used with Monte Carlo method also. The proposed method enables us to assess electrical capacity by clearly and rationally defined parameters for the equations; resulting in clearer understandings of the electrical capacity estimation of a geothermal reservoir. The proposed method shows an approximate agreement with the USGS method, but gives larger estimation results than the ones given by the prevailing calculation method. This might be attributed to how underground-related parameters should be estimated.

1. INTRODUCTION

USGS (Muffler, L.J.P, Editor 1978) introduced the stored heat method for assessing the electrical capacity of a geothermal reservoir. The equations for the methods are as follows.

$$q_r = \rho C V (T_r - T_{ref}) \quad \text{[kJ]} \quad (1)$$

$$R_g = q_{WH} / q_r \quad \text{[-]} \quad (2)$$

$$q_{WH} = m_{WH} (h_{WH} - h_{ref}) \quad \text{[kJ]} \quad (3)$$

$$W_A = m_{WH} \left[h_{WH} - h_0 - T_0 (s_{WH} - s_0) \right] \quad \text{[kJ] or [kW]} \quad (4)$$

(for a geothermal reservoir temperature ＞ 150℃)

$$E = W_A \eta_u / (FL) \quad \text{[kJ/s] or [kW]} \quad (5)$$

Where q_r is reservoir geothermal energy, q_{WH} is geothermal energy recovered at wellhead, T_r is reservoir temperature, T_{ref} is reference temperature, T_0 is rejection temperature (Kelvin), m_{WH} is mass of geothermal fluid produced at wellhead, h_{WH} is specific enthalpy of geothermal fluid produced at wellhead, h_{ref} is specific enthalpy of geothermal fluid at reference temperature, h_0 is specific enthalpy of fluid at final state, s_{WH} is specific entropy of fluid at wellhead, s_0 is specific entropy of fluid at final state, ρC is volumetric specific heat of reservoir, V is reservoir volume, Rg is recovery factor, W_A is available work (exergy), E is power plant capacity, η_u is utilization factor (that includes energy ratio of steam fraction separated from the fluid and exergy efficiency), F is power plant capacity factor and L is power plant life.

While it is said that this is a good approach from theoretical perspectives, it includes issues to be discussed when used for liquid dominant geothermal fluid recovered at wellhead.

S K. Garg et al (2011) pointed out that the "available work" of USGS methodology is a strong function of the reference temperature, and that the utilization factor (i.e. ratio of electric energy generated to available work) depends on both power generating system and reference temperature. On the other hand, the AGEG Geothermal energy Lexicon (compiled by J. Lawless 2010) described that recovery factor of the USGS method rejects both the fraction of heat below commercially useful temperature and fraction of unrecoverable heat, when used for liquid dominant geothermal fluid. These and other relevant references we reviewed suggest that we should examine utilization factor and/or recovery factor in connection with both of liquid-steam separation process and reference temperature when we use the USGS method for a flash type power cycle using liquid dominant geothermal fluid. The determination of these parameters with considerations on the relations among these, will require proper and deep understandings of geothermal generation system. In addition, we observe that the equation (1) to (4) appear to be imbalancing, because the equations (1) to (3) include two reference-related parameters (T_{ref}, h_{ref}) whereas the exergy equation (4) does not include reference-related parameters in the square bracket. We also observe that the calculations using the USGS equations that include variable T_r dependent-parameters (h_{WH}, s_{HW}), with

Monte Carlo simulations, would be laborious. Thus, we consider that the USGS method would not be easily applicable for assessment of electric capacity of a geothermal reservoir with Monte Carlo simulations.

In place of the USGS method, the different method is being used by many prevailing references for geothermal resource estimations. We name this different method “the prevailing method”. The equation of the prevailing method is given as follows.

$$E = R_g \eta_c \rho CV (T_r - T_{ref}) / (FL) \quad \text{[kJ/s] or [kW]} \quad (6)$$

Where η_c is named as “conversion factor”.

The core term $\rho CV(T_r - T_{ref})$ in the equation (6) is exactly the same as the equation (1) of the USGS method. The theoretical concept, however, appears to be quite different. The prevailing method adopts much higher temperatures such as 150 ºC, 180 ºC or others to the reference temperature (T_{ref}); while the USGS method defines that the reference temperature (T_{ref}) for all cycles is chosen as 15 ºC (i.e. the average ambient temperature of the USA) and the rejection temperature as T_0=40 ºC (i.e. a typical condenser temperature) in the calculation of available work (W_A) of the equation (4). The reference temperature in the prevailing method is sometimes named as the abandonment temperature.

The prevailing method is said to be derived from Pálmason, G. *et al* (1985, in Icelandic). There seems however to have been variations in slecting the temperature (AGEG, 2010 refers to various cases). It is explained sometimes in such a way that it adopts a separator temperature to the reference temperature to exclude the geothermal energy to be abandoned as liquid form that is separated from fluid at separator. Here, a question arises on how the equation distinguishes the steam and the liquid; both separated in the separator at the same temperature; thereafter the liquid is to be abandoned whereas the steam to be used. Another application is that a cut-off temperature is sometimes selected. It would be conceived that the cut-off temperature is included in the equations to exclude non-economically-valuable fluid produced from the reservoir that has already been delineated by practitioners, where the cut-off temperature is understood as the one that defines the outer limit of the reservoir. Here, another question arises on why the cut-off temperature should be included in the equation if the outer limit of the reservoir has already been defined by the cut-off temperature to exclude non-economically-valuable fluid. Both cases above seem to be illogical.

The other different point is that the prevailing method adopts the conversion factor η_c ranging from 0.13 to 0.16 approximately; while the USGS method recommends 0.4-0.45 to the utilization factor η_u defined by the equation (5). *Obiter*, the equation (6) appears to be nothing but expressing a thermodynamic process: the term $R_g\rho CV(T_r - T_{ref})$, ($T_r$ >0 ºC and T_{ref}>0 ºC are assumed here), is the recovered heat energy that is made available when the temperature of fluid changes from T_r to T_{ref}, the fluid that conveys the heat from the reservoir. The term $R_g\rho CV(T_r - T_{ref})$ in the equation (1) of the USGS method expresses the heat energy available at the temperature condition of T_{ref}; in this context, it is clear that the utilization factor η_u was intended to include the steam energy ratio against the recovered energy and the exergy efficiency. On the other hand, it appears not to be clear what efficiencies are included in the conversion factor η_c because inclusion of the T_{ref} of much higher temperature in the equation (6) makes the thermodynamic implication of the equation ambiguous.

Thus, we consider that the prevailing method might be an empirical method based on field wisdom that attempts to assess electric capacity of geothermal reservoir that produces liquid dominate fluid at wellhead by modifying the concept of the USGS method. This is further discussed in the section 6 of this paper.

Instead, we herein propose a rational and practical method that defines the aboveground-related key parameters; that reflects the steam-liquid separation process in the calculations; that can be used with the Monte Carlo method also. The proposed method enables us to select a reference temperature, a recovery factor and a conversion/utilization factor rationally and independently, and separately from consideration of the steam-liquid separation process; that results in clearer understanding of the resource estimation.

2. INTRODUCTION OF AVAILABLE THERMAL ENERGY FUNCTION ζ

We begin our explanation with turbine side; because our primary interest lies on electrical power generation, and for that reason here includes the key point of this paper. We calculate electric energy by using the adiabatic heat-drop concept (or exergy concept) at turbine. This is widely used for design of turbine-generator system. In Figure-1 we illustrated the conceptual model of geothermal generation system we assumed. The electric capacity produced at turbine-generator system is written as;

$$E = \eta_{ex} m_{tbin} (h_{tbin} - h_{tbout}) / (FL) \quad \text{[kW]} \quad (7)$$

or

$$E = \eta_{ex} (q_{tbin} - q_{tbout}) / (FL) \quad \text{[kW]} \quad (8)$$

Where η_{ex} is exergy efficiency, $m_{tb\,in}$ is mass of steam at inlet of turbine, $h_{tb\,in}$ is specific enthalpy at inlet of turbine, $h_{tb\,out}$ is specific enthalpy at outlet of turbine, $q_{tb\,in}$ is thermal energy at inlet of turbine, $q_{tb\,out}$ is thermal energy immediately after turbine.

Here, we introduce the “available thermal energy function” defined by the following equation.

$$\zeta = (q_{tbin} - q_{tbout}) / q_{WH} \quad \text{[-]} \quad (9)$$

Where ζ is the available thermal energy function.

The available thermal energy function (9) we introduced, represents the ratio of the heat-drop at turbine against thermal energy available at wellhead. In other word, it represents the ratio of available thermal energy for electrical power generation against thermal energy available at wellhead.

Combined with the available thermal energy function (9), the equation (8) is rewritten as;

$$E = \eta_{ex}\zeta q_{WH}/(FL) \quad \text{[kW]} \qquad (10)$$

Further, combined with the equations (1) and (2), the equation (10) is rewritten as;

$$E = \eta_{ex}\zeta R_g \rho CV(T_r - T_{ref})/(FL) \quad \text{[kW]} \qquad (11)$$

where

$$\rho C = (1-\varphi)C_r\rho_r + \varphi C_f \rho_f \quad \text{[kJ/(kg}^o\text{C)]} \qquad (12)$$

Where C_r is specific heat of reservoir rock matrix, C_f is specific heat of reservoir fluid, ρ_r is density of reservoir rock matrix and ρ_f is density of reservoir fluid.

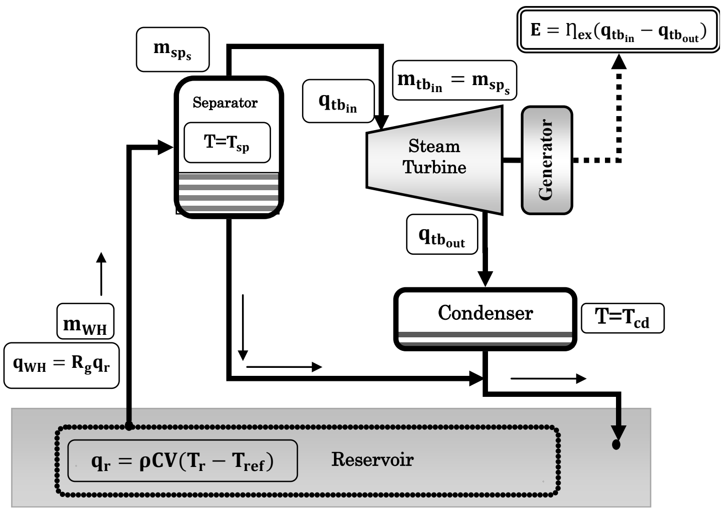

Figure 1 Simplified single flash power plant schematic

The available thermal energy function ζ in the equation (11) exclusively includes the thermal energy of the steam fraction only that is used for power generation. By introducing the available thermal energy function ζ to the volumetric method calculation, we can limit our considerations about utilization factor or conversion factor to turbine-generator related matters; and we can also limit our considerations about recovery factor to underground phenomenon. Thereby, the proposed method enables a rational assessment of electrical capacity of a geothermal reservoir by rationally defined parameters of the equations of the volumetric method.

3. INTRODUCTION OF READILY CALCULABLE EQUATIONS FOR ζ

In this section, we will describe the procedure of how we obtain calculable equations of the available thermal energy function ζ ; and thereafter, we will introduce approximation equations of the available thermal energy function ζ for practical uses, as direct functions of a reservoir temperature T_r .

3.1 Assumptions

We assume that geothermal energy is recovered as saturated and single-phase liquid. This is not only for a simplification of calculation; but also for a reason that S. K. Sanyal et al (2005) pointed out that the “explicit consideration of the two-phase volume in reservoir estimation is not critical”.

We also assume a single flash power cycle with a separator of a typical pressure. Dry steam is assumed at inlet of turbine; wet steam is then assumed immediately after turbine to obtain near-realistic power output. We will assign a typical temperature to condenser, too.

3.2 Determination of "available thermal energy function ζ"

3.2.1 Geothermal energy recovered at the wellhead (q_{WH})

The geothermal energy recovered at wellhead is defined by the equation (3) when the final state of the fluid is the one under the ambient condition. However, since we assume a geothermal power plant of single flash type, the final state of the fluid contributing power generation should be under the condenser condition. We will assume at a later part of this paper the condenser temperature. Thus, at this step of calculation we assume that all the recovered heat at the well head will be sent from the wellhead to the separator.

$$q_{WH_L} = m_{WH_L} h_{WH_L} \qquad \text{[kJ]} \qquad (13)$$

Where $q_{WH\,L}$ is geothermal energy recovered as liquid phase at wellhead, $m_{WH\,L}$ is mass of single phase geothermal liquid produced at wellhead, $h_{WH\,L}$ is specific enthalpy of single phase geothermal liquid produced at wellhead.

3.2.2 Thermal energy at the inlet of the turbine ($q_{tb_{in}}$)

The thermal energy at turbine inlet ($q_{tb_{in}}$) should be the thermal energy of dry steam separated at separator from fluid recovered at wellhead. The following equations give the mass of the steam fraction separated at separator, and to be sent to turbine.

$$m_{sp_S} = \alpha_{sp_S} m_{WH_L} \qquad \text{[kg]} \qquad (14)$$

$$\alpha_{sp_S} = (h_{WH_L} - h_{sp_L}) / (h_{sp_S} - h_{sp_L}) \qquad \text{[-]} \qquad (15)$$

Where $m_{sp\,s}$ is mass of steam fraction separated at separator, $\alpha_{sp\,s}$ is ratio of steam mass fraction separated at separator, $h_{sp\,L}$ is specific enthalpy of liquid fraction separated at separator, and $h_{sp\,s}$ is specific enthalpy of steam fraction separated at separator.

From the above, the thermal energy at turbine inlet is given by;

$$q_{tbin} = m_{sp_S} h_{sp_S} = \alpha_{sp_S} m_{WH_L} h_{sp_S} \qquad \text{[kJ]} \qquad (16)$$

3.2.3 Thermal energy immediately after the turbine($q_{tb_{out}}$)

The dry steam in turbine is losing its thermal energy; and becomes wet steam when exhausted from turbine. The adiabatic heat-drop concepts explains this process. The following equation gives the dryness (quality) of the wet steam immediately after turbine.

$$\chi = (s_{sp_S} - s_{cd_L}) / (s_{cd_S} - s_{cd_L}) \qquad \text{[-]} \qquad (17)$$

Where χ is quality of steam (dryness of steam), $S_{sp\,s}$ is entropy of steam fraction at separator, $S_{cd\,L}$ is entropy of liquid fraction at condenser and $S_{cd\,s}$ is entropy of steam fraction at condenser.

Then the enthalpy of the wet steam is given by;

$$h_{tbout_{SL}} = h_{cd_L} + (h_{cd_S} - h_{cd_L})\chi \qquad \text{[kJ/kg]} \qquad (18)$$

Where $h_{tbout\,SL}$ is specific enthalpy of wet steam immediately after turbine, $h_{cd\,L}$ is specific enthalpy of liquid fraction at condenser and $h_{cd\,s}$ is specific enthalpy of steam fraction at condenser.

Since the same mass as that of the dry steam is exhausted out of turbine, the thermal energy immediately after turbine is given by;

$$q_{tb_{out}} = m_{sp_S} h_{tbout_{SL}} = \alpha_{sp_S} m_{WH_L} h_{tbout_{SL}} \qquad \text{[kJ]} \qquad (19)$$

3.2.3 The available thermal energy function ζ

Replacing the variables of the equation (9) with the equations (13), (16), and (19) gives the following equation.

$$\zeta = \alpha_{sp_S}(h_{sp_S} - h_{tbout_{SL}}) / (h_{WH_L}) \qquad \text{[-]} \qquad (20)$$

With the equation above, we can obtain specific values of the ζ by giving the enthalpies.

3.2.3 Introduction of approximation equations of ζ for practical uses.

Calculation using the variables in the equation (20) for each reservoir temperature is laborious and not readily usable with the Monte Carlo Method. We will then introduce approximation equations of the ζ from the calculation results of the five typical reservoir temperatures, i.e. 180 ºC, 200 ºC, 250 ºC, 300 ºC, and 340 ºC.

For the calculation we assume that the separator pressure is 5 bar (151.8 ºC), because the produced electrical power would be maximum when the separator pressure is around 4 bar to 5 bar. Let us assume the power generation is E=1.00 when the separator temperature is 150 ºC. A simplified calculation for various separator temperatures gives the following results: i.e. when the separator temperature is

120 ºC, 140 ºC, 160 ºC, and 180 ºC; then, electric energy produced at turbine-generator system will be E=0.95, E=1.00, E=0.98, and E=0.88 respectively. R. Dipippo (2008) shows similar results.

We assume typical values for the other factors as follows.

Condenser temperature(T_{cd}) : 40.0 ºC (a typical temperature of condenser)

The results are shown in Figure-2. It confirms that the ζ can be expressed as functions of the reservoir temperate (T_r). The form of the approximation equation is given below.

$$\zeta = 0.0000000127T_r^3 - 0.0000124900T_r^2 + 0.0046543806T_r - 0.4591082158 \quad [\text{-}] \qquad (21)$$

The curve of the equation (21) is shown in the Figure-2. It shows the available heat function ζ will be zero when the reservoir temperature equals to the separator temperature T_{sp} (151.8 ºC). At this state, the recovered fluid no longer flashes in the separator. This temperature shall be "the plant minimum operation temperature" for a flash type system, that is defined only by separator temperature. Note this should be differentiated from "cut-off temperature" that should define the spatial outer limits of the reservoir

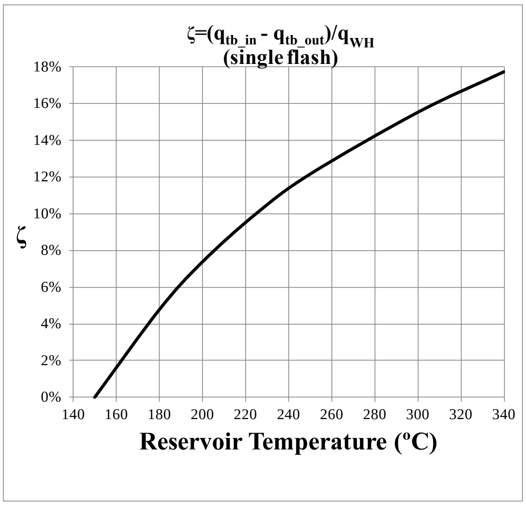

Figure 2: Calculation results of ζ against various reservoir temperatures..

3.3 Selection of Conversion Factor – Turbine-generator efficiency: Exergy Efficiency (η_{ex})

We have started the electric capacity calculation with the equation (7). The coefficient η_{ex} should therefore be defined as:

$$\eta_{ex} = \{E(FL)\} / \{m_{tb_{in}} (h_{tbin} - h_{tbout})\} \quad [\text{-}] \qquad (22)$$

Note that this coefficient η_{ex} is the "functional exergy efficiency (DiPippo 2008, p 240)" that is different from both the "utilization factor η_u" defined in the equation (5) of the USGS method and the "conversion factor η_c" in the equation (6) of the prevailing method; the "utilization factor" will include the energy ratio of steam separated from the fluid and exergy efficiency; the "conversion factor" may include the energy ratio of steam separated from the fluid, Carnot efficiency and exergy efficiency (the "conversion factor" of the prevailing method is not necessarily clearly defined, because the method appears not to be explainable from thermodynamic point of view.)

For the parameters in the right side of the equation (22), we examined the 189 existing geothermal power stations all over the world which are listed in the booklet (ENAA 2013 in Japanese), thereafter, we calculated each exergy efficiency defined by the equation (22). In the calculation, steam dryness was also considered immediately after the turbine. After the calculation, we examined the correlation between the exergy efficiencies and the temperature drops $(T_{tb_{in}} - T_{cd})$ between turbine inlet and condenser. Thereby, we obtained the following approximation equation.

$$\eta_{ex} = 0.163897 \ln(T_{tbin} - T_{cd}) - 0.001766 \pm 0.05 \quad [\text{-}] \qquad (23)$$

Where $T_{tb\,in}$ is temperature of turbine inlet and T_{cd} is temperature of condenser.

The graphical scatter plot showed large variations; we, therefore, added a distribution range of ± 0.05. This is because the actual efficiencies of turbine-generator system depend on many factors that include the efficiency of basic power plant design, resource temperature, concentrations of dissolved gases in the reservoir fluid, the condition of plant maintenance and so on. Nevertheless and for that reason, the approximation equation (22) reflects actual conditions and therefore applicable for the calculation of the volumetric method.

For our case of $T_{tb_{in}}$ = 151.8 ºC, T_{cd} = 40 ºC,

$$\eta_{ex} = 0.77 \pm 0.05 \qquad [\text{-}] \qquad (24)$$

3.3 About Recovery Factor R_g

There are a number of references that discussed on the recovery factor. M. A. Grant (2014) recently pointed out that the past values of recovery factor have been in all cases high in comparison with actual performance. We herein refer to some of the papers we examined.

GeothermEx (2004) describes: "Based on our assessment of more than 100 geothermal energy sites around the world, we have found it more realistic to apply a recovery factor in the range of 0.05 (Min) to 0.2 (Max) without application of a most-likely value".

C.F.Williams et al (USGS open-file Report 2008-1296) describes that the recovery factor "R_g for fracture-dominated reservoirs is estimated to range from 0.08 to 0.2, with a uniform probability over the entire range. For sediment-hosted reservoirs this range is increased from 0.1 to 0.25".

S.K. Garg and J. Combs (2010) describes: "Prior to geothermal energy well drilling and testing, it will not in general be possible to obtain any reliable estimates of reservoir thickness and thermal recovery factor. Since it may eventually prove impossible to produce fluid from a geothermal energy reservoir, the possibility of the thermal recovery factor being zero cannot be discounted during the exploration phase; therefore, the proper range for thermal recovery factor is from 0 to 0.20 (the latter value is believed to be the maximum credible value based on world-wide experience with production from liquid-dominated reservoirs)".

AGEA compiled by J. Lawless (2010) describes: "In fracture dominated reservoirs where there is insufficient information to accurately characterize the fracture spacing, adopt the mean USGS value of 14%, or 8 to 20 % with a uniform probability over the entire range when used in probabilistic estimates". "In sedimentary reservoirs or porous volcanic-hosted reservoirs, of 'moderate' porosity (less than 7% on average), adopt the mean USGS value of 17.5%, or 10 to 25% with a uniform probability over the entire range when used in probabilistic estimate". "In the case of sedimentary or porous volcanic-hosted reservoir of exceptionally high average porosity (over 7%), adopt the empirical criterion of recovery factor 2.5 times the porosity to a maximum of 50%".

M.A. Grant (2014) pointed out that there are a wide range of recovery factors: 3-17 % covers the entire range of observed results. This indicates that any result is subject to an error of at least a factor of 2, or alternatively ± 70%. One conclusion is immediate: past recovery factors have been too high, and comparison with actual performance show that an average value of 10% should be used.

The decision on what values should be chosen is left to professionals in charge, that depends on the site conditions, past experiences and/or degrees of diagnostic confidence. Note that the proposed method enables that <u>the recovery factor can be determined independently from both the liquid-steam separation process and conversion process o</u>f thermal energy to electric energy.

4. EXAMINATIONS OF THE RESULTS

We calculated electric powers per km² (power density) by three different methods of the USGS method, the proposed method and the prevailing method for a comparison purpose with the following parameters.

C_r	= 1.0	[kJ/(kg ºC)]
ρ_r	= 2750	[kg/m^3]
C_f	= 5.0	[kJ/(kg ºC)]
ρ_f	= 790	[kg/m^3]
V	= 2	[km^3], (Reservoir thickness 2 k m)
F	= 0.9	[-]
L	= 30	[years to be converted to second when applied]
R_g	= 0.12	[-]
T_{ref}	= 0.01 ºC (h_L=0 kJ/kg for the proposed method assuming all the recovered heat is sent to the separator)	
	= 20 ºC for the USGS method;	
	= 150 ºC or 180 ºC for the prevailing method	
T_0	= 40 ºC for the USGS method (condenser temperature)	
Conversion factor	η_C	= 0.13 for the prevailing method
Utilization factor	η_U	= 0.45 for the USGS method
Exergy efficiency	η_{ex}	= 0.77 for the proposed method

The results are given in Figure-3. It shows that the proposed method is in good agreement with the USGS method. In addition, it gives similar results to the power density ('the main sequence') presented by wilmarth et al (2014). A deviation from the USGS method is observed at lower side of reservoir temperature. This is because that the USGS method adopts a fixed utilization factor; whereas the proposed method adopts 'the available thermal energy function" that is a function of T_r as shown in Figure-2. This suggests that the utilization factor may have to be smaller than 0.45 when reservoir temperature is lower, though its impact will be negligible.

On the other hand, the Figure-3 shows that the prevailing method is considerably different from both of the proposed method and USGS method.

We calculated the electric capacity by the proposed method, for the four cases of recovery factors of R_g =0.08, 0.12, 0.15, and 0.20. The other parameters remain same as above. The results are shown in Figure-4. It demonstrates that selection of the recovery factor will give a significant impact on the calculation results of electric capacity estimation by the volumetric method. Similarly, the other underground-related factors ρC, T_r and/or V will have similar impacts on the calculation; which must be emphasized.

From the above and since we have defined the aboveground-related key parameters, the significant differences between the prevailing method and the proposed method shown in Figure-3 may be attributed to the definition differences of the underground-related parameters. This is further discussed in the section 6 Discussion of this paper.

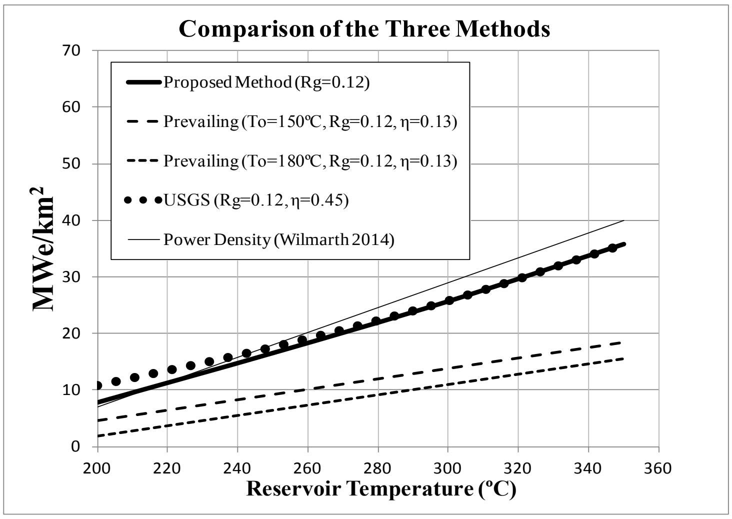

Figure 3: A Comparison of calculated electric power among three methods (Single Flash Power Cycle)

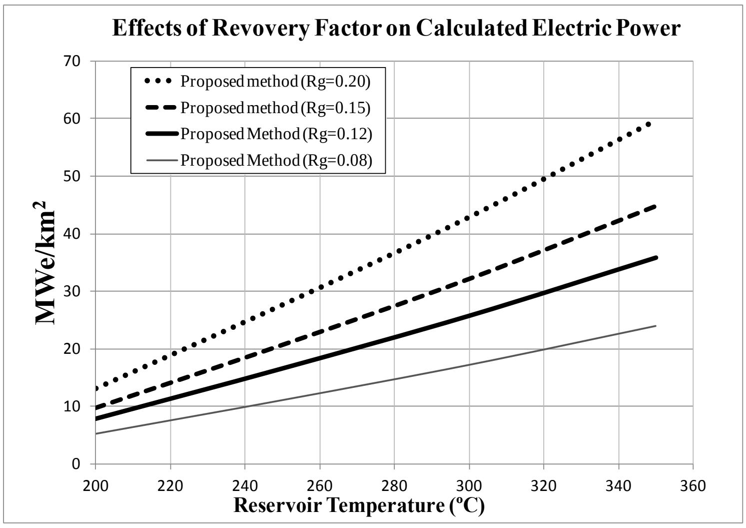

Figure 4: Effects of Recovery Factor on Calculated Electric Power (Single Flash Power Cycle)

5. SUMMARY

We proposed herein a rational and practical calculation approach of the volumetric method by introducing 'the available thermal energy function ζ. The introduction of the available thermal energy function ζ enables us to include the steam-liquid separation process in the calculation equations rationally, which further enables us to examine the underground-related parameters separately and independently from the aboveground-related parameters; i.e the recovery factor and turbine-generator efficiency (exergy efficiency) can be selected independently, without consideration on steam-liquid separation process; thereby, the proposed method realizes rational and practical calculations of geothermal resources of liquid dominant geothermal field; that can used with the Monte Carlo method.

We hereunder summarize the proposed method for a practical use. Assuming saturated single phase geothermal liquid of temperature T_r ºC at wellhead, T_{sp}=151.8 ºC, and T_{cd} =40 ºC, the following equations for the volumetric method will give an estimation result of electricity capacity of a liquid dominant geothermal reservoir if the underground-related parameters are properly selected.

$$E = \eta_{ex} \zeta R_g \rho C V (T_r - T_{ref}) / (FL) \quad \text{[kW]} \quad (25)$$

where

$$\rho C = (1-\varphi) C_r \rho_r + \varphi C_f \rho_f \quad \text{[kJ/(m}^3\text{ ºC)]} \quad (26)$$

$$\zeta = 0.0000000127 T_r^3 - 0.0000124900 T_r^2 + 0.0046543806 T_r - 0.4591082158 \quad \text{[-]} \quad (27)$$

$$T_{ref} = 0.01 \quad \text{[ºC]} \quad (28)$$

$$\eta_{ex} = 0.77 \pm 0.05 \quad \text{[-]} \quad (29)$$

$R_g = 0.05 - 0.2$ proposed by GeothermEx 2004), [-] (30)

or $R_g = 0.08 - 0.2$ or $R_g = 0.1 - 0.25$ proposed by C.F.Williams (2008),

or $R_g = 0 - 0.2$ proposed by S.K. Garg et al (2010)

or $R_g = 0.05 - 0.2$ or $R_g = 0.10 - 0.25$, or R_g =2.5 times the porosity to a maximum 50%, proposed by AGEA (2010).

or $R_g = 0.03 - 0.17$, 0.10 in average proposed by M.A. Grant (2014)

We may adopt different constants for the available thermal energy function ζ and use a different value of η_{ex} when it should become necessary to change, separator temperature and/or condenser temperature. The calculation procedures are given herein the above. Once the equations are given in a spreadsheet, we can examine as many cases as possible about underground related factors together with the Monte Carlo method.

6. DISCUSSIONS

Having summarized the proposed calculation method above, we continue this paper to examine the relationship between the prevailing method and the proposed method. We regard the USGS method ≈ the proposed method in the following discussions, since the theoretical background of the proposed method is almost same, and the both produce similar calculation results,

6.1 Deriving of Approximation Equations of the Proposed Method

Under the conditions of T_{sp}=151.8 ºC and T_{cd}=40 ºC, Figure 3 implies that the variable term $\zeta(T_r - T_{ref})$ in the equation (11) will be a near liner relation with T_r, thus this liner relation is approximated as:

$$\zeta(T_r - T_{ref}) = (0.3312 T_r - 51.911) \quad \text{[liner approximation]} \quad \text{[ºC]} \quad (31)$$

With the equation (31), the equation (11) becomes;

$$E = \eta_{ex} R_g \rho C V (0.3312 T_r - 51.911) / (FL) \quad \text{[KW]} \quad (32)$$

This is further reduced as;

$$E = (0.77 \pm 0.05) R_g \rho C V (0.3312 T_r - 51.911) / (FL)$$

$$E = 0.3312 (0.77 \pm 0.05) R_g \rho C V (T_r - 157) / (FL)$$

$$E = (0.26 \pm 0.02) R_g \rho C V (T_r - 157) / (FL) \quad \text{[KW]} \quad (33)$$

The equation (33) shows that the equation (11) of the proposed method has eventually become the same equation form as the equation (6) of the prevailing method. Note that the second constant 157 should be the T_{sp} (151.8 ºC) as shown in the previous section 3.2.3; the constant 157 here is the one that resulted from the linear approximation shown in the equation (31).

6.2 Discussions on the Approximation Equation of the Proposed Method in connection with the prevailing method

As the conclusion, two constants of the equation (33) are mere the products of the linear approximation, therefore, any discussions on the equation (33) relating with resource estimations would appear to be meaningless or misleading. However, step-by-step discussions would be helpful to reach this conclusion for future possible discussions that may be instigated; thereafter we will discuss on possible reasons of the differences between the prevailing method and the USGS method.

6.2.1 Is the second constant 157 the cut-off temperature?

A number of constants have been proposed for the equation (6) of the prevailing method in various references. The constants in the equation (33) might be considered to be a variety of the equation (6) of the prevailing method. Here are our observations on the equation (33) in connection with the prevailing method.

a. The approximation constant 157 in equation (33) appears to be the one that is sometimes named as "cut-off temperature". However, this has to be named as the "plant minimum operation temperature", at which the fluid no longer flashes in separator of the assumed separator temperature (151.8 ºC) as described in the previous section 3.2.3. The "plant minimum operation temperature" is rather a "plant-related temperature" that shall be differentiated from the "cut-off temperature". The cut-off temperature is defined as "the temperature below which there is no economic value in the fluid - the temperature at which wells cease to flow or it becomes uneconomic to pump them. This defines the outer limits of the resource (M A Grant, *et al* 2011, p 47)." Thus, the cut-off temperature is a "reservoir related temperature". The plant minimum operation temperature shall not be larger or preferably sufficiently lower than the reservoir related cut-off temperature to ensure fluid to flash in the separator. From this point, the approximation constant 157 in the equation (33) shall not be replaced with reservoir-related cut-off temperature that has to be separately decided from field observations. (If the separator temperature should be designed at 180 ºC for an instance, then the second constant in the equation (33) will be 180; however, the first constant has to be changed in accordance to the calculation and approximation shown above.)

b. As mentioned before, such explanation that the cut-off temperature is included in the equation to exclude fluid of no-economic value from the already defined reservoir seems to be illogical and unexplainable. The inevitable possibility that drilling wells may fail to produce useful fluid from the reservoir shall be dealt with the recovery factor or probabilistic approaches.

c. In addition, the cut-off temperature (= T_{ref}) in the prevailing method is commented by M.A. Grant (2014) in such a context that "the different approaches also implies unrecognized assumptions about the physical process controlling reservoir depletion". The "different approaches" here means the ones that assign a cut-off temperature to T_{ref}, that are derived from the Icelandic practice. Our observation on the unrecognized assumptions is that such physical process controlling reservoir depletion seems not to be a matter of T_{ref} to be expressed in the thermodynamic equation. If the temperature of a part of the reservoir is expected to fall down below the cut-off temperature during operation period, it seems to be logical to reduce the value of either the reservoir volume or the recovery factor, or the plant life time for an extreme case.

6.2.2 Is the second constant 157 the reference temperature for the power generation cycle?

a. On the other hand, from a thermodynamics point of view, the equation (33) could possibly be interpreted in such a way that the power capacity E calculated is an energy fraction converted from the recovered heat energy when the temperature changes from T_r to 157 ºC, with adjustment by the multiplier (0.26 ± 0.02) and the divisor (FL). In this context, the approximation constant 157 in the equation (33) is the one that is named as "reference temperature", "rejection temperature", "base temperature" or the like; the temperature in the equation (33) shall be defined as the temperature of the final state of the fluid at a point of a power plant. However, this corresponds to the rejection temperature at the separator, not the final state temperature of the whole power generation cycle as seen above. This constant shall not be regarded as the final state temperature of the power cycle. At the same time, the first constant (0.26 ± 0.02) shall not be defined as a kind of a logically-derived efficiency, though it looks seemingly to be a meaningful coefficient.

6.2.3 What are the fist and the second constants in the equation (33)?

Consequently, we have to come back to the equation (33); whereat, we recall that the both constants 157 and (0.26 ± 0.02) were the mere resultants of the linear approximation. They were derived as the impartible combination under the specific assumptions (T_{sp}=151.8 ºC and T_{cd}=40 ºC). Any of these two constants shall not be examined independently or shall not be changed separately. Those two approximation constants, as it were, are "the virtual reference temperature" and "the virtual conversion factor" of "the virtual geothermal power plant" that is virtualized on the basis of the approximation equation (33), that has been derived through the series of calculations, that does not represent the thermodynamic process of any actual power plant. Thus, discussions on these approximation constants will probably be meaningless and possibly be misleading or even harmful when geothermal resource is estimated by the volumetric method.

6.3 Discussions on the Relation between the Prevailing Method and the USGS Method (≈the Proposed Method)

a. Nevertheless, the equation (33) is simple in form, not many variables included, and thus easy to use with Monte Carlo simulation. The prevailing method appears to have been used by adopting approximate a half value of the first approximation constant (0.26 ± 0.02) and a cut-off temperature similar to the second approximation constant 157 to suit field conditions. Although these constants shall not be allowed to use from the thermodynamic point of view, estimations by the prevailing method have been reported to be in accordance with other more precise estimation methods or field observations (Sarmiento et al 2007, which practices the prevailing method, but appears to have referred to Muffler P., et al (1978) of the USGS method as the methodological base. Similar undistinguishing quotations are seen in other references).

b. At the same time and on the other hand, the USGS method (≈ the proposed method) has been used for resource estimations, although the USGS method gives larger results than the ones of the prevailing method when the same underground-related parameters are given to the both methods as shown in Figure -3. Our observations are as follows.

(i) We have defined the aboveground-related parameters for the proposed method (≈ the USGS method), thus the discrepancy may possibly be due to differences of interpretations on underground-related parameters; i.e. for the resource estimation of the same geothermal field, the practitioners of the prevailing method would propose the $(R_g\rho CV)_{prevailing}$ as their underground-related parameters; whereas the other practitioners of the USGS method (≈ the proposed method) would propose the different parameters $(R_g\rho CV)_{USGS}$; $(R_g\rho CV)_{prevailing} \neq (R_g\rho CV)_{USGS}$.

(ii) The USGS method appears to assume that the all the heat energy relating to $(R_g\rho CV)_{USGS}$ should be extracted at the ground surface, because the method (when R_g=0.12 in Figure 3) gives similar results to the "main sequence" of the power density (Wilmarth *et al*., 2014); the analysis of the power density does not include the information of failed wells. In other words, possibility of well failures may not be included in the USGS method. Geothermal wells however are not always successful to produce useful fluid. Sanyal S.K *et al*. (2012) analyzed 2,528 geothermal wells in 52 field in 14 countries and found that the mean success rate was 68%. At early stages of exploitation the rate varies in a range from 20% to 60 % approximately. If the average drilling success rate should be considered for a resource estimation, the resultant recovery factor would be R_g=0.12 x 68%= 0.08; with this R_g=0.08 the USGS method will come close to the prevailing method of T_0=150 ºC as shown in Figure-4. M.A. Grant (2014) strongly pointed out the past values of R_g have been all cases too high, an average value of R_g=0.10 should be used.

(iii) On the other hand, the prevailing method even with R_g=0.25 is reported to be in good agreement with actual performance (Sarmiento et al 2007). Thus, it may allow localized non-productive zones to be included within the reservoir, by adopting amended constants to the places of the first and second constants of the equation (33) "to calibrate" the results to the actual performance. However, again, it shall not be the constants of the equation (33) but the underground-related parameters such as R_g, V and/or others that shall be examined. In other words, the calculation form of the equation (33) may have falsely diverted our attentions from the underground-related parameters to the aboveground-related parameters or the approximation constants in the approximation equations.

6.4 Closing discussion

(i) All those may be resultants from usage of ambiguously defined parameters, which may has allowed practitioners to adopt various values of not only underground-related parameters (R_g, ρC, V, *cut-off temperature*) but also aboveground-related parameters (T_{ref}, T_{sp}, T_{cd}), with considerations on relations with others as if some of those would be functions of others; such considerations however may sometimes not be necessary if the parameters used should be well-defined.

(ii) Instead, we have introduced the equation (11) with clear definitions of the aboveground-related key parameters, including the flashing process with the typical condenser conditions. The proposed method could allow us to examine the underground-related parameters rationally, being independent from considerations of relations with aboveground-related parameters. The proposed method will also allow us to avoid possible misleading that may be caused by the prevailing method in the form of the equation (33).

(iii) In any cases, it is of paramount importance to use the volumetric method with very careful and prudent examinations and considerations together with clear definitions on the underground-related parameters.

7. CONCLUSION

The USGS method is theoretical, but practice with the equations together with Monte Carlo method seems to be laborious; the prevailing method is somewhat questionable from theoretical point of view. We have herein proposed a rational and practical calculation method for volumetric method for a specific but typical case. We would like to recommend to use the equation (25) because the proposed method enables us to assess electrical capacity by clearly and rationally defined parameters for the equations; thereby we could examine the underground-related parameters, resulting in clearer understandings of the electrical capacity estimation of a geothermal reservoir. Once clearer assessment with the specific but typical conditions of the aboveground parameters has been made, one could extend assessments with other conditions of the aboveground parameters for comparisons. If the aboveground-related parameters T_{sp} and/or T_{cd} should be changed to suit a particular field condition, we could modify the constants of the available energy function.

We have also derived the simplified equation (33) that appears to be the same form of the prevailing method and provides us with a simple calculation procedure. It however masks its theoretical background completely, which may hinder us from proper and deeper understanding of underground related parameters to be used for the volumetric estimation. This may mislead us to unnecessary considerations and/or discussions on the virtual "conversion factor" and/or virtual "reference temperature" of the "virtual power plant" virtualized by the equation (33). We therefore would like to recommend to avoid using this equation (33).

Finally, very careful and prudent examinations and considerations shall be required for determination of underground-related factors, in particular R_g and/or V. If estimation results by the proposed method should not be in accordance with other more precise estimation methods or field monitoring results, the underground related parameters have to be examined. Well drilling success rate could be in cooperated when we determine R_g and/or V.

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APPENDIX-4

ENVIRONMENTAL AND SOCIAL IMPACT ASSESSMENT

Appendix 4.1

Table A.4.1 Major Regulations, Guidelines and Proclamations Applicable to the Geothermal Energy Development Project

No.	Title	No/ Date of Issue	Description
1	Environmental Impact Assessment Proclamation	299/ 31 De, 2002	This Proclamation prescribes that no person shall commence any new development activity under any category listed in any directive issued pursuant to this. Defining the Environmental Protection Authority, requirement of fulfilling EIA requirements by licensing agencies before issuing an investment permit is prescribed.
2	Environmental Pollution Control Proclamation	300/ 03 Dec, 2002	This Proclamation consists of 22 articles divided into 6 Parts: Preliminary (1); Control of pollution (2); Environmental standards (3); Environmental inspectors (4); Offences and penalties (5); Miscellaneous provisions (6), providing various environmental standard.
3	Environmental Protection Organs Establishment Proclamation	295/ 31 Oct, 2002	The proclamation provides the responsibility and roles of the Environmental Protection Authority at central level, Sectoral Environmental Unit at each competent agency and Regional Environmental Agencies at local level.
4	Expropriation of Landholdings for Public Purposes and Payment of Compensation Proclamation	455/ 15 Jul, 2005	This Proclamation grants the power to specified local public bodies to expropriate rural or urban landholdings for public purpose. The Proclamation sets out the procedure of expropriation and provides with respect to compensation (which shall be paid in advance) and appeals. Displacement compensation based on average annual income from land shall be paid to rural landholders that are permanently or temporarily expropriated. Substitute land may be made available.
5	Rural Land Administration and land Use Proclamation, Proclamation	456/ 15 Jul, 2005	This Proclamation provides for a new system of administration for rural land management and use and for sustainable rural land use planning based on the different agro-ecological zones of the country necessary for the conservation and development of natural resources.
6	Ethiopian Water Resource Management Proclamation	197/ Mar, 2000	This Proclamation aims to ensure that all surface and ground waters of Ethiopia are properly protected and managed. The text consists of 33 articles divided into 9 Parts: General provisions (1); Supervising body (2); Inventory of water resources and registry of actions (3); Permits and professional licenses (4); Fees and water charges (5); Servitude (6); Water banks and harmful effect of water (7); Association of water users (8); Transitory provisions (9). All water resources of Ethiopia are declared common property (art. 5). Article 6 sets out the fundamental principles of water management and administration.
7	Solid Waste Management Proclamation	513/ 12 Feb, 2007	This Proclamation makes provision for the management of solid waste and for designation and implementation of solid waste management action plans at the lowest administrative units of urban administrations so as to ensure community participation.
8	Environmental Impact Assessment Procedural Guideline Series 1	Nov, 2003	This is a guideline prepared by Environmental Protection Authority to provide detail procedure for the EIA process in the country.
9	Draft EMP for the Identified Sectoral Developments in the Ethiopian Sustainable Development & Poverty Reduction (ESDPRP)	01 May, 2004	This is a draft guideline prepared by Environmental Protection Authority aiming to provides EMP framework for different sectors.
10	Investment Proclamation	280/ 02 Jul, 2002	This proclamation prescribes detail scheme of foreign investment to enhance the country's development, consisting of 42 articles. This defining the condition and administration for the foreign investment.
11	Council of Ministers Regulations on Investment Incentives	64/ 07 Feb, 2003	This is a regulation prescribes some incentives on the foreign investment such as tax exemption, etc including 18 articles in total.

No.	Title	No/ Date of Issue	Description
	and Investment Areas Reserved for Domestic Investors		
12	The FDRE Proclamation, "Payment of Compensation for Property Situated on Landholdins Expropriated for Public Purposes"	455/ Y2005	This law provides the detail procedure such as expropriation process and compensation standard are prescribed in "the Expropriation of Landholding for Public Purposes and Payment of Compensation Proclamation, Proclamation No. 455/2005".
13	Council of Ministers Regulation, "Payment of Compensation for Property Situated on Landholdins Expropriated for Public Purposes"	135/ Y2007	This regulation provides further detail standard such as compensation standard for the each expropriating asset. This prescribes that land expropriation is implemented by local government, Woreda or Urban administration exclusively for the public purpose and it should be adequately compensated to PAPs. As the principle of the compensation, transferring cost for the asset on the land is compensated for the residential land and 10 times of the annual income which is averaged the incomes in last 5 years is compensated for the farm land. The one of the preferable way, the regulation prescribes that provision of the alternative land which enable to be utilized equal to the previous land.
14	Oromya Regional Administration Council Directives, "Payment of Compensation for Property Situated on Landholdins Expropriated for Public Purposes"	5/ Y2003	Regional regulation on the compensation at expropriation process for the public project.
15	Investment (Amendment) Proclamation	373/ 28 Oct, 2003	This proclamation amended previous Investment Proclamation (2002). This consists of 6 articles including description of investment permit.

Appendix 4.2

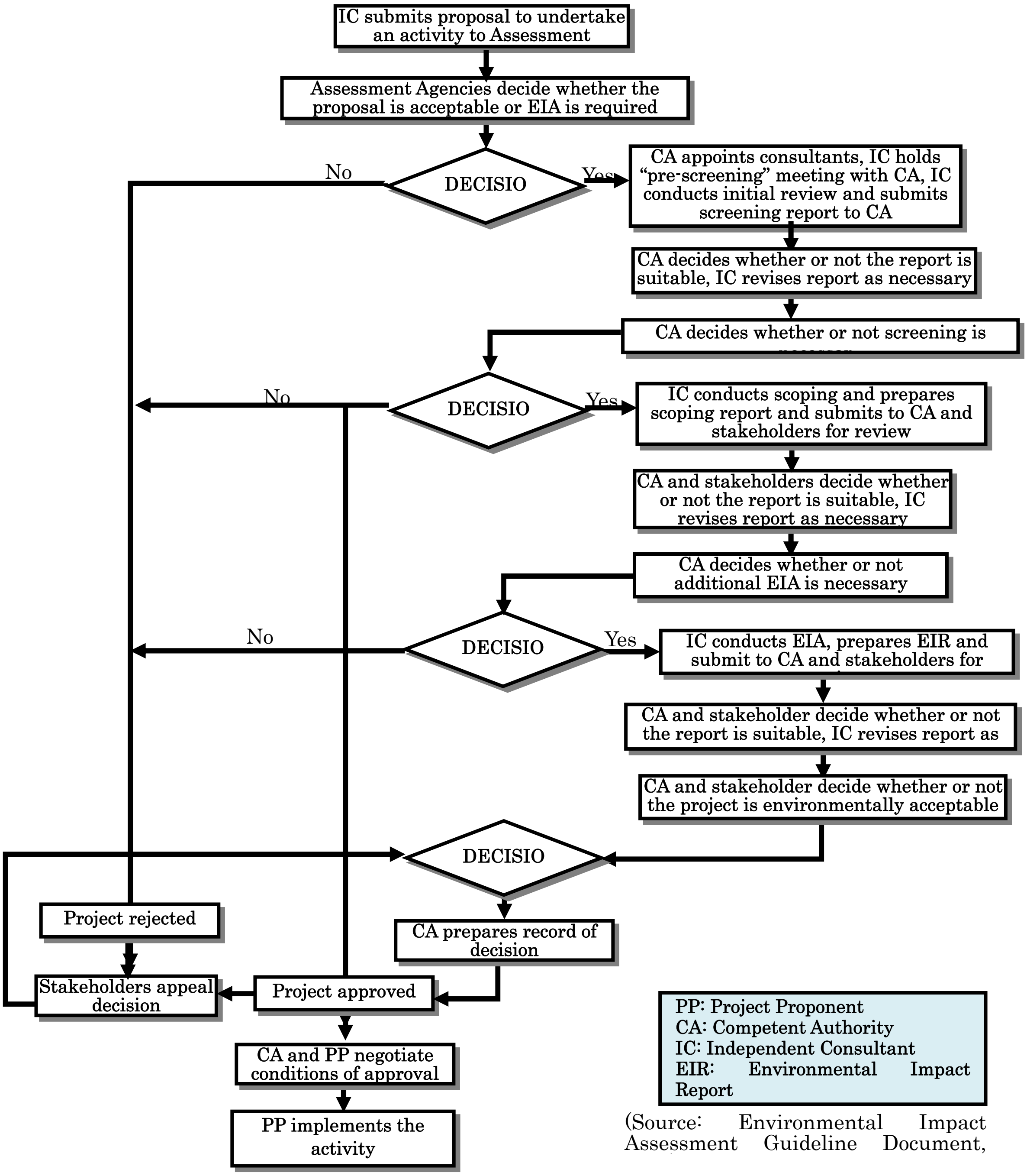


Figure A.4.1 EIA Procedual Flow in Ethiopia

Appendix 4.3

Table A.4.2 Gaps between Relevant Regulations in Ethiopia, JICA Guidelines and World Bank Safeguard Policies Environmental Impact Assessment (EIA)

Aspect	JICA Guidelines for Environmental and Social consideration (April 2010)	World Bank OP4.10	Government Laws	Gaps between JICA Guidelines and Government Laws	Mechanisms to Bridge Gaps
Objectives	To ensure transparency, predictability, and accountability in its support for an examination of environmental and social considerations.	Environmental Assessment (EA) of projects proposed is required for Bank financing to help ensure that they are environmentally sound and sustainable, and thus to improve decision making.	The purpose of the environmental impact assessment serves is to bring about administrative transparency and accountability, as well as to involve the public and, in particular, communities in the planning of and decision taking on developments which may affect them and its environment. Section 15 also specifies public participation and access to the EIA report, and ensures to solicit comments on it. (Environmental Impact Assessment Proclamation 2002_299)	No significant gaps were identified.	None
Procedure of EA	JICA supports and examines appropriate environmental and social considerations undertaken by project proponents etc. to avoid or minimize development projects' impacts on the environment and local communities, and to prevent the occurrence of unacceptable adverse impacts.(1.4)	EA evaluates a project's potential environmental risks and impacts for preventive measures over mitigatory or compensatory measures, whenever feasible.	The law states that environmental impact assessment is used to predict and manage the environmental effects which a proposed development activity as a result of its design sitting, construction, operation, or an ongoing one as a result of its modification or termination, entails and thus helps to bring about intended development; and assessment of possible impacts on the environment prior to the approval of a public instrument provides an effective means of harmonizing and integrating environmental, economic, cultural and social considerations into a	No significant gaps were identified.	None

Aspect	JICA Guidelines for Environmental and Social consideration (April 2010)	World Bank OP4.10	Government Laws	Gaps between JICA Guidelines and Government Laws	Mechanisms to Bridge Gaps
			decision making process in a manner that promotes sustainable development (Environmental Impact Assessment Proclamation 2002_299)		
Criteria of EA	'Environmental and social considerations' means considering environmental impacts including air, water, soil, ecosystem, flora, and fauna, as well as social impacts including involuntary resettlement, respect for the human rights of indigenous people, and so on.(1.3.1) JICA confirms that projects comply with the laws or standards related to the environment and local communities in the central and local governments of host countries; it also confirms that projects conform to those governments' policies and plans on the environment and local communities. (2.6.2) JICA confirms that projects do not deviate significantly from the World Bank's Safeguard Policies, and refers as a benchmark to the standards of international financial organizations; to internationally recognized standards, or international standards, treaties, and declarations, etc.; and to the good practices etc. of developed nations including Japan, when appropriate. (2.6.3)	EA takes into account the natural environment (air, water, and land); human health and safety; social aspects (involuntary resettlement, indigenous peoples, and physical cultural resources); and transboundary and global environmental aspects. EA considers natural and social aspects in an integrated way. It also takes into account environmental action plans; the country's overall policy framework, national legislation, and institutional capabilities related to the environment and social aspects; and obligations of the country, pertaining to project activities, under relevant international environmental treaties and agreements.	Section 2 Definitions specify that "Impact" means any change to the environment or to its component that may affect human health or safety, flora, fauna, soil, air, water, climate, natural or cultural heritage, other physical structure, or in general, subsequently alter environmental, social, economic or cultural conditions. Additionally, Section 6. Trans-Regional Impact Assessment specifies the transboundary aspect of the EIA. (Environmental Impact Assessment Proclamation 2002_299) However, resettlement/relocation of people and animals is also considered as a project which requires the full EIA. (Schedule of 1, Environmental Impact Assessment Proclamation 2002_299; EIA Procedural Guidelines 2003)	Less focus on social considerations, especially involuntary resettlement and indigenous peoples.	The project proponent should adhere to the policies of the financial institutions and consider both environmental and social factors.
EA Instruments	JICA conducts an environmental review in accordance with the project category,	A range of instruments can be environmental impact assessment	Preliminary environmental impact study (or IEE), full environmental	No significant gaps were identified.	Not applicable

Aspect	JICA Guidelines for Environmental and Social consideration (April 2010)	World Bank OP4.10	Government Laws	Gaps between JICA Guidelines and Government Laws	Mechanisms to Bridge Gaps
	and refers to the corresponding environmental checklists for each sector when conducting that review as appropriate.	(EIA), regional or sectoral EA, environmental audit, hazard or risk assessment, and environmental management plan (EMP).	impact study report, Trans-Regional Impact Assessment (SEA), Environmental Management Plan are mentioned (Environmental Impact Assessment Proclamation 2002_299; EIA Procedural Guidelines 2003)		
Environmental Screening	Category A: Project proponents etc. must submit EIA reports. JICA publishes the status of host countries' submission of major documents on environmental and social considerations on its website. Prior to its environmental review, JICA also discloses the following: (1) EIA reports and environmental permit certifications, (2) RAPs for projects that will result in large-scale involuntary resettlement, and (3) IPPs for projects that address issues of indigenous people. Specifically, JICA discloses EIA reports 120 days prior to concluding agreement documents. JICA undertakes its environmental reviews based on the EIA and other documents submitted by project proponents etc. Category B: The scope of environmental reviews for Category B projects may vary from project to project, but it is narrower than that of Category A projects. JICA discloses the following: (1) EIA reports and environmental permit certifications, (2) RAPs for projects, and (3) IPPs for projects that will require measures for indigenous people, when these documents are submitted by project proponents etc.	Category A: A proposed project is classified as Category A if it is likely to have significant adverse environmental impacts that are sensitive, diverse, or unprecedented. For a Category A project, the borrower is responsible for preparing a report, normally an EIA (or suitably comprehensive regional or sectoral EA). Category B: A proposed project is classified as Category B if its potential adverse environmental impacts on human populations or environmentally important areas – including wetlands, forests, grasslands, and other national habitats – are less adverse than those of Category A projects. The findings and results of Category B EA are described in the project documentation (Project Appraisal Document and Project Information Document). Category C: A proposed project is classified as Category C if it is likely to have minimal or no adverse environmental impacts. Beyond screening, no further EA action is	Section 5 Projects Requiring Environmental Impact Assessment specified that 1) Every project which falls in any category listed in any directive issued pursuant to this Proclamation shall be subject to environmental impact assessment. 2) Any directive provided under Sub Article 1 of this Article shall among other things, determine categories of: (a) projects not likely to have negative impacts, and so do not require environmental impact assessment; (b) Projects likely to have negative impacts and thus require environmental impact assessment. (Environmental Impact Assessment Proclamation 2002_299; EIA Procedural Guidelines 2003) More specifically, Schedule 1 of the guidelines has the list of projects that require full EA; Schedule. 2 for the list of projects require a preliminary environmental impact study; and Schedule 3 for the lists of projects that may not require environmental	The preparing of a Resettlement Action Plan (RAP) and an IPP is not mentioned. In the governmental law, there is no equivalent category to JICA's Category FI.	Differences exist in the screening process, namely, the government uses project types and some thresholds to determine the type of the EA report required. Since there is a possible problem that the government does not require a full EIA due to the project type but the JICA considers the scale of impact is significant and categorizes the project A such as rural roads and manufacturing, screening also needs to be done as per the JICA Guidelines.

Aspect	JICA Guidelines for Environmental and Social consideration (April 2010)	World Bank OP4.10	Government Laws	Gaps between JICA Guidelines and Government Laws	Mechanisms to Bridge Gaps
	Category C: For projects in this category, environmental review will not proceed after categorization. Category FI: JICA examines the related financial intermediary or executing agency to see whether appropriate environmental and social considerations as stated in the guidelines are ensured for projects in this category.	required for a Category C project. Category FI: A proposed is classified as Category FI if it involves investment of Bank funds through a financial intermediary, in subprojects that may result in adverse environmental impacts.	impact assessment. (Environmental Impact Assessment Proclamation 2002_299; EIA Procedural Guidelines 2003)		
EA for Special Project Types	Category FI projects: JICA examines the related financial intermediary or executing agency to see whether appropriate environmental and social considerations as stated in the guidelines are ensured for projects in this category. JICA also examines institutional capacity in order to confirm environmental and social asks advice from the Advisory Committee when it is necessary considerations of the financial intermediary or executing agency, and, if necessary, requires that adequate measures be taken to strengthen capacity. The financial intermediary or executing agency examines the potential positive and negative environmental impacts of sub-projects and takes the necessary measures to avoid, minimize, mitigate, or compensate for potential negative impacts, as well as measures to promote positive impacts if any such	*Sector Investment Lending*(*SIL*) During the preparation of each proposed subproject, the project coordinating entity or implementing institution carries out appropriate EA according to country requirements and the requirements of this policy. The Bank's judging criteria are as follows: (a) screen subprojects (b) obtain the necessary expertise to carry out EA (c) review all findings and results of EA for individual subprojects (d) ensure implementation of mitigation measures (including, where applicable, an EMP) (e) monitor environmental conditions during project implementation of *Financial Intermediary Lending* (***FI).*** The Bank requires that each FI screen proposed subprojects and ensure that subborrowers carry out appropriate	Category FI is not mentioned but the emergency operations are categorized under Schedule 3 of the list of projects does not require the EIA. (Environmental Impact Assessment Proclamation 2002_299; EIA Procedural Guidelines 2003)	EA for the FI is not described.	For Category FI projects, the sub-project developer should adhere to the policies of the lending agencies and usually requires the EIA framework.

Aspect	JICA Guidelines for Environmental and Social consideration (April 2010)	World Bank OP4.10	Government Laws	Gaps between JICA Guidelines and Government Laws	Mechanisms to Bridge Gaps
	measures are available. (3.2.1(4)) Measures Taken in an Emergency In an emergency—which means a case that must be dealt with immediately, such as restoration after natural disasters or post-conflict restoration—when it is clear that there is no time to follow the procedures of environmental and social considerations mentioned in the guidelines, JICA reports at an early stage to the Advisory Committee for Environmental and Social Considerations on categorization, judgment of emergency, and procedures to follow, and discloses a result. JICA	EA for each subproject. In appraising a proposed FI operation, the Bank reviews the adequacy of country environmental requirements relevant to the project and the proposed EA arrangements for subprojects, including the mechanisms and responsibilities for environmental screening and review of EA results. *Emergency Operations under OP8.00* The policy set out in OP 4.01 normally applies to emergency operations processed under OP/BP 8.00, *Rapid Response to Crises and Emergencies*. The Bank requires at a minimum that (a) the extent to which the emergency was precipitated or exacerbated by inappropriate environmental practices be determined as part of the preparation of such projects (b) any necessary corrective measures be built into either the emergency operation or a future lending			
Institutional Capacity	JICA provides support for and examinations of the environmental and social considerations that project proponents etc. implement in accordance with Sections 2 and 3 of the guidelines, depending on the nature of cooperation projects. (1.5)	When the borrower has inadequate legal or technical capacity to carry out key EA related functions (such as review of EA, environmental monitoring, inspections, or management of mitigatory measures) for a proposed project, the project includes components to strengthen that	The guidelines state that an Environmental Agency has responsibility to make sure that appropriate support is made available to build capacity and create awareness on EA, etc. (Environmental Impact Assessment Proclamation 2002_299; EIA	Not applicable	Not applicable

Aspect	JICA Guidelines for Environmental and Social consideration (April 2010)	World Bank OP4.10	Government Laws	Gaps between JICA Guidelines and Government Laws	Mechanisms to Bridge Gaps
		capacity.	Procedural Guidelines 2003)		
Public Consultation	Project proponents etc. consult with local stakeholders through means that induce broad public participation to a reasonable extent, in order to take into consideration the environmental and social factors in a way that is most suitable to local situations, and in order to reach an appropriate consensus. JICA encourages project proponents etc. to publicize in advance that they plan to consult with local stakeholders, with particular attention to directly affected people, in order to have meaningful meetings. In the case of Category A projects, JICA encourages project proponents etc. to consult with local stakeholders about their understanding of development needs, the likely adverse impacts on the environment and society, and the analysis of alternatives at an early stage of the project, and assists project proponents as needed. (2.4) Consultations with relevant stakeholders, such as local residents, should take place if necessary throughout the preparation and implementation stages of a project. Holding consultations is highly desirable, especially when the items to be considered in the EIA are being selected, and when the draft report is being prepared. (Appendix 2)	For all Category A and B projects proposed for IBRD or IDA financing, during the EA process, the borrower consults project-affected groups and local nongovernmental organizations (NGOs) about the project's environmental aspects and takes their views into account. The borrower initiates such consultations as early as possible. For Category A projects, the borrower consults these groups at least twice: (a) shortly after environmental screening and before the terms of reference for the EA are finalized; and (b) once a draft EA report is prepared. In addition, the borrower consults with such groups throughout project implementation as necessary to address EA-related issues that affect them.	Section 5.2.1 suggests the project proponent to conduct pre-screening consultation to discuss how best to proceed with the EA between the project proponent and respective environmental or sectoral agencies. However, the details are not given. Section 5.2.6 also describes that a summary of evaluation is made available to the public; and reasons for decision and conditions of approval are made public are considered when reviewing the EIA. (Environmental Impact Assessment Proclamation 2002_299; EIA Procedural Guidelines 2003)	Public consultation is emphasized in the law and guidelines; however, the detailed requirements are not specified, the preliminary screening consultation is not a mandatory, and the public consultation at the later stage is not clearly specified.	Since JICA emphasizes public consultation meetings for stakeholders including indirectly/directly affected persons at the scoping stage and draft final report stage specifically, these need to be complied by the project proponent.

Aspect	JICA Guidelines for Environmental and Social consideration (April 2010)	World Bank OP4.10	Government Laws	Gaps between JICA Guidelines and Government Laws	Mechanisms to Bridge Gaps
	In the case of Category B projects, JICA encourages project proponents etc. to consult with local stakeholders when necessary. (2.4)				
Disclosure	Information about the environmental and social considerations of their projects. JICA encourages project proponents etc. to disclose and present information about environmental and social considerations to local stakeholders. Project proponents etc. disclose information well in advance when they have meetings with local stakeholders in cooperation with JICA. On these occasions, JICA supports project proponents etc. in the preparation of documents in an official or widely used language and in a form understandable by local people. (2.1/1, 6,7) For Category A project, JICA publishes the status of host countries' submission of major documents on environmental and social considerations on its website. Prior to its environmental review, JICA also discloses EIA reports and environmental permit certifications 120 days prior to concluding agreement documents. JICA discloses a translated version of EIA reports, subject to approval by project proponents etc. For Category B project, JICA discloses EIA reports and environmental permit certifications, when these documents	For meaningful consultations between the borrower and project-affected groups and local NGOs on all Category A and B projects proposed for IBRD or IDA financing, the borrower provides relevant material in a timely manner prior to consultation and in a form and language that are understandable and accessible to the groups being consulted. For a Category A project, the borrower provides for the initial consultation a summary of the proposed project's objectives, description, and potential impacts. In addition, for a Category A project, the borrower makes the draft EA report available at a public place accessible to project-affected groups and local NGOs. Any separate Category B report for a project proposed for IDA financing is made available to project-affected groups and local NGOs.	Section 15. Public participation describes that 1) The Authority or the relevant regional environmental agency shall make any environmental impact study report accessible to the public and solicit comments on it. (Environmental Impact Assessment Proclamation 2002_299; EIA Procedural Guidelines 2003) Section 4.3 describe that the consulting firm needs to ensure that Interested and Affected Parties are provided with all means and facilities (e.g. notice, assembly holes, reasonable time, understandable language, fair representation, etc.) enabling them to adequately air their views and concerns. (Environmental Impact Assessment Proclamation 2002_299; EIA Procedural Guidelines 2003)	Public disclosure of the EIA is not specified in the government law or guidelines, though the law requires the EIA report needs to be accessible to interested and affected persons.	JICA discloses the EIA report of category A projects at JICA's website at least for 120 days before signing the LA, which needs to be complied by the Project Proponent.

Aspect	JICA Guidelines for Environmental and Social consideration (April 2010)	World Bank OP4.10	Government Laws	Gaps between JICA Guidelines and Government Laws	Mechanisms to Bridge Gaps
	are submitted by project proponents etc. (Sec.3/3.2/3.2.1/(1), (2))				
Monitoring Implementation	JICA confirms with project proponents etc. the results of monitoring the items that have significant environmental impacts. This is done in order to confirm that project proponents etc. are undertaking environmental and social considerations for projects that fall under Categories A, B, and FI. The information necessary for monitoring confirmation by JICA must be supplied by project proponents etc. by appropriate means, including in writing. When necessary, JICA may also conduct its own investigations. JICA discloses the results of monitoring conducted by project proponents etc. on its website to the extent that they are made public in project proponents etc. (3.2.2/1,2, 7) undertaking environmental and social considerations for projects that fall under Categories A, B, and FI. The information necessary for monitoring confirmation by JICA must be supplied by project proponents etc. by appropriate means, including in writing. When necessary, JICA may also conduct its own investigations. JICA discloses the results of monitoring conducted by project proponents etc. on its website to the	The borrower reports on (a) compliance with measures agreed with the Bank on the basis of the findings and results of the EA, including implementation of any EMP; (b) the status of mitigatory measures; and (c) the findings of monitoring programs The Bank bases measures set out in the legal agreements, any EMP, and other project documents.	Section 8 I. Environmental Impact Study Report requires (i) procedures of self auditing and monitoring during implementation and operation. Section 12. Implementation Monitoring states that the Authority or the relevant regional environmental agency shall monitor the implementation of an authorized project in order to evaluate compliance with all commitments made by, and obligations imposed on the proponent during authorization. (Environmental Impact Assessment Proclamation 2002_299; EIA Procedural Guidelines 2003)	Details of monitoring requirements are not discussed in the law or guidelines.	Since JICA needs to disclose the monitoring results of Category A project at JICA's website, this needs to be complied by the project proponent.

Aspect	JICA Guidelines for Environmental and Social consideration (April 2010)	World Bank OP4.10	Government Laws	Gaps between JICA Guidelines and Government Laws	Mechanisms to Bridge Gaps
	extent that they are made public in project proponents etc. (3.2.2/1,2, 7)				

Source: JICA. 2010. Japan International Cooperation Agency (JICA) Guidelines for Environmental and Social Considerations; World Bank. 2012. Operational Policies; Democratic Republic of Ethiopia. 2002. Environmental Impact Assessment Proclamation; Environmental Protection Agency, 2003. EIA Procedural Guidelines.

Appendix 4.4

Table A.4.3 Gaps between Relevant Regulations in Ethiopia, JICA Guidelines and World Bank Safeguard Policies – Involuntary Resettlement

Aspect	JICA Guidelinesfor Environmental and Social Consideration (April 2010)	World Bank OP4.10	Government Laws	Gaps Between JICA Guidelinesand Government Laws	Mechanisms to Bridge Gaps
Avoid involuntary resettlement	Involuntary resettlement and loss of means of livelihood are to be avoided when feasible by exploring all viable alternatives.	Involuntary resettlement should be avoided where feasible	Not mentioned in the govt. law, though in Ethiopia, land belongs to the State and people can only own usufruct rights over land. (FDRE Constitution)	The first effort to avoid involuntary resettlement is not described.	The project proponent should make an effort to avoid involuntary resettlement where feasible as per the JICA's Guidelines.
Minimize involuntary resettlement	When, after such an examination, avoidance is proved unfeasible, effective measures to minimize impact and to compensate for losses must be agreed upon with the people who will be affected.	Minimize involuntary resettlement by exploring all viable alternative project designs.	Not mentioned in the govt. law, though in Ethiopia, land belongs to the State and people can only own usufruct rights over land. (FDRE Constitution)	The initial effort to minimize involuntary resettlement is not described.	The project proponent should make an effort to minimize involuntary resettlement where feasible as per the JICA's Guidelines.
Mitigate adverse social impacts	People who must be resettled involuntarily and people whose means of livelihood will be hindered or lost must be sufficiently compensated and supported by project proponents etc. in a timely manner.	Where it is not feasible to avoid resettlement, resettlement activities should be conceived and executed as sustainable development programs, providing sufficient investment resources to enable the persons displaced by the project to share in project benefits.	Article 44 No. 2 of FDRE Constitution states that: "All persons who have been displaced or whose livelihoods have been adversely affected as a result of state programs have the right to commensurate monetary or alternative means of compensation, including relocation with adequate state assistance. (Article 44 No.2 of FDRE Constitution) Section 13. Responsibilities of Woreda and Urban Administrations include "pay or cause the payment of compensation to holders of expropriated land in accordance	Mitigation measures for adverse social impacts are required by the govt. law.	Not applicable.

Aspect	JICA Guidelinesfor Environmental and Social Consideration (April 2010)	World Bank OP4.10	Government Laws	Gaps Between JICA Guidelinesand Government Laws	Mechanisms to Bridge Gaps
			with this Proclamation, and provide them with rehabilitation support to the extent possible" (Proclamation 455/2005)		
Screening	JICA classifies projects into four categories (i.e. A, B, C and FI) according to the extent of environmental and social impacts, taking into account an outline of project, scale, site condition, etc. JICA requests that Project proponents etc. fill in the screening form found in Appendix 4; the information in this form will be a reference for the categorization of proposed projects.	The Bank also requires early screening in resettlement planning.	Not mentioned in the govt. law.	Screening is not recognized by the govt. law as a step of resettlement planning.	Not applicable. In practice, it should be done as per the JICA guidelines since the screening format needs to be submitted to JICA when the government requests JICA's assistance.
Categorization	Projects that are likely to have a significant adverse impact on the environment and society are categorized as "Category A" even if they are not included in the sectors, characteristic, or areas on the list. Sensitive Characteristics (1)Large-scale involuntary resettlement	The Bank classifies the proposed project into one of four environmental categories (A, B, C and FI), depending on the type, location, sensitivity, and scale of the project as well as the nature and magnitude of its potential impacts.	Not mentioned in the govt. law.	Not applicable.	The project proponent needs to follow the categorization of JICA Guidelines.
Resettlement plan	For projects that will result in large-scale involuntary resettlement, resettlement action plans must be prepared and made available to the public. In preparing a resettlement action plan, consultations must be held with the affected people and their communities based on sufficient information made available to them in advance.	To cover the direct social and economic impacts that that are caused by the involuntary taking of land and/or the involuntary restriction of access to legally designated parks and protected areas, the borrower will prepare a resettlement plan (RP) or resettlement policy framework . The RP or framework will include measures to ensure that the displaced persons are provided assistance during relocation; provided with residential housing, or	Not mentioned in the govt. law.	RP/framework are not required by the govt. law.	The project proponent needs to prepare a respective RP for the project which involves resettlement or physical or economic displacement according to the requirements of the JICA guidelines.

Aspect	JICA Guidelinesfor Environmental and Social Consideration (April 2010)	World Bank OP4.10	Government Laws	Gaps Between JICA Guidelinesand Government Laws	Mechanisms to Bridge Gaps
		housing sites, or as required agricultural sites; offered transitional support; provided with development assistance in addition to compensation.			
Alternatives	Involuntary resettlement and loss of means of livelihood are to be avoided when feasible by exploring all viable alternatives	Assess all viable alternative project designs to avoid, where feasible, or minimize involuntary resettlement.	Not mentioned in the govt. law.	Alternative considerations are not required by the govt. law.	The project proponent needs to consider alternatives to minimize the scale of the impact according to requirements of the JICA guidelines.
Social assessment	The impacts to be assessed with regard to environmental and social considerations. These also include social impacts, including migration of population and involuntary resettlement, local economy such as employment and livelihood, utilization of land and local resources, social institutions such as social capital and local decision-making institutions, existing social infrastructures and services, vulnerable social groups such as poor and indigenous peoples, equality of benefits and losses and equality in the development process, gender, children’s rights, cultural heritage, local conflicts of interest, infectious diseases such as HIV/AIDS, and working conditions including occupational safety.	Through census and socio-economic surveys of the affected population, identify, assess, and address the potential economic and social impacts of the project that are caused by involuntary taking of land (e.g. relocation or loss of shelter, loss of assets or access to assets, loss of income sources or means of livelihood, whether or not the affected person must move to another location) or involuntary restriction of access to legally designated parks and protected areas.	Not mentioned in the govt. law.	Social assessment is not required by the govt. law for land acquisition.	The project proponent needs to conduct the social assessment for the RP of the project which involves resettlement or physical or economic displacement according to requirements of the JICA guidelines.
Involvement of stakeholders	Appropriate participation by affected people and their communities must be promoted in the planning, implementation, and monitoring of resettlement action plans	Consult project-affected persons, host communities and local nongovernmental organizations, as appropriate. Provide them opportunities	Not mentioned in the govt. law.	Public consultation is not required by the govt. law, though the land acquisition procedure	The project proponent needs to conduct adequate public consultation for the RP

Aspect	JICA Guidelinesfor Environmental and Social Consideration (April 2010)	World Bank OP4.10	Government Laws	Gaps Between JICA Guidelinesand Government Laws	Mechanisms to Bridge Gaps
	and measures to prevent the loss of their means of livelihood.	to participate in the planning, implementation, and monitoring of the resettlement program, especially in the process of developing and implementing the procedures for determining eligibility for compensation benefits and development assistance (as documented in a resettlement plan), and for establishing appropriate and accessible grievance mechanisms. Pay particular attention to the needs of vulnerable groups among those displaces, especially those below the poverty line, the landless, the elderly, women and children, Indigenous Peoples, ethnic minorities, or other displaced persons who may not be protected through national land compensation legislation.		includes issuing some notifications to landholders.	of the project which involves resettlement or physical or economic displacement according to requirements of the JICA guidelines.
Existing social and cultural institutions	The impacts to be assessed with regard to environmental and social considerations. These also include social impacts, including social institutions such as social capital and local decision-making institutions, existing social infrastructures and services, vulnerable social groups such as poor and indigenous peoples.	To the extent possible, the existing social and cultural institutions of resettlers and any host communities are preserved and resettlers' preferences with respect to relocating in pre-existing communities and groups are honoured.	Not mentioned in the govt. law.	Only compensation for land and assets are mentioned in the govt. law.	The project proponent needs to pay attention to ensure the affected persons will not lose existing social and cultural institutions according to the JICA guidelines.
Definition of displaced persons	People who must be resettled involuntarily and people whose means of livelihood will be hindered or lost must be sufficiently compensated and supported by project proponents etc. in a timely manner.	1) those who have formal legal rights to land (including customary and traditional rights recognized under the laws of the country); 2) those who do not have formal legal rights to land at the time the census	Not mentioned in the govt. law, though landholders are defined. (Proclamation 455/2005)	The definition of displaced persons is not clear. Especially, it is not clear whether the entitled displaced persons include	The definition of the displaced persons as per the JICA Guidelines needs to be used by the project proponent.

Aspect	JICA Guidelinesfor Environmental and Social Consideration (April 2010)	World Bank OP4.10	Government Laws	Gaps Between JICA Guidelinesand Government Laws	Mechanisms to Bridge Gaps
		begins but have a claim to such land or assets - provided that such claims are recognized under the laws of the country or become recognized through a process identified in the resettlement plan; and 3) those who have no recognizable legal right or claim to the land they are occupying.		informal occupants.	
Vulnerable group	Appropriate consideration must be given to vulnerable social groups, such as women, children, the elderly, the poor and ethnic minorities, all members of which are susceptible to environmental and social impacts and may have little access to decision-making processes within society.	Particular attention must be paid to the needs of the vulnerable groups among those displaced, especially those below the poverty line, landless, elderly, women and children, ethnic minorities etc.	Not mentioned in the govt. law.	Special resettlement/rehabilitation assistance for the vulnerables is not described in the govt. law.	The project proponent needs to provide additional assistance to the vulnerable groups as per the JICA Guidelines.
Replacement costs	Prior compensation, at full replacement cost, must be provided as much as possible	The methodology to be used in valuing losses to determine their replacement cost	Section 7. Basis and Amount of Compensation states that the amount of compensation for property is calculated on the basis of replacement cost of the property. (Proclamation 455/2005)	No significant gap is observed.	Not applicable.
Capacity building	JICA makes efforts to enhance the comprehensive capacity of organizations and operations in order for project proponents etc., to have consideration for environmental and social factors, appropriately and effectively, at all times	Financing of technical assistance to strengthen the capacities of agencies responsible for resettlement, or of affected people to participate more effectively in resettlement operations.	Not mentioned in the govt. law.	Capacity building is not mentioned in the govt. law.	The project proponent needs to pay attention to capacity building of the person in charge of involuntary resettlement as proposed in the RAP, which is required by the JICA Guidelines/WB OP 4.12.
Grievance	Appropriate and accessible grievance	A grievance redress mechanisms for	Section 11. Complaints and Appeals	Grievance redness	The project proponent

Aspect	JICA Guidelinesfor Environmental and Social Consideration (April 2010)	World Bank OP4.10	Government Laws	Gaps Between JICA Guidelinesand Government Laws	Mechanisms to Bridge Gaps
procedures	mechanisms must be established for the affected people and their communities.	simplicity, accessibility, affordability, and accountability	in Relation states: (a) rural areas and in an urban center where an administrative organ to hear grievances related to urban landholding is not yet established, a complaint relating to the amount of compensation shall be submitted to the regular court having jurisdiction; (b) Where the holder of an expropriated urban landholding is dissatisfied with the amount of compensation, he may lodge his complaint to the administrative organ established by the urban administration to hear grievances related to urban landholdings; and (c) The organ referred to in Sub-Article (2) of this Article shall examine the compliant and give its decision within such short period as specified by directives issued by the region and communicate its decision to the parties in writing; (d) A party dissatisfied with a decision, rendered in accordance with Sub-Article (I) and (3) of this Article may appeal, as may be appropriate, to the regular appellate court or municipal appellate court within 30 days from the date of the decision. The decision of the court shall be final. (Proclamation 455/2005)	mechanism at the project level (i.e. field and headquarters levels) is not specified.	needs to establish the grievance redress mechanism within the project especially at the field level and headquarters levels as per the international practice, which is also required by the JICA Guidelines.
Information disclosure	For projects that will result in large-scale involuntary resettlement, resettlement	Disclose draft resettlement plans, including documentation of the	Not mentioned in the govt. law.	Information disclosure is not specified in the	The project proponent should follow their own

Aspect	JICA Guidelinesfor Environmental and Social Consideration (April 2010)	World Bank OP4.10	Government Laws	Gaps Between JICA Guidelinesand Government Laws	Mechanisms to Bridge Gaps
	action plans must be prepared and made available to the public. In preparing a resettlement action plan, consultations must be held with the affected people and their communities based on sufficient information made available to them in advance.	consultation process, in a timely manner, before appraisal formally begin, in an accessible place and in a form and language that are understandable to key stakeholders.		govt. law.	guidelines to ensure full implementation of actions related to information disclosure which is required by the JICA Guidelines.
Monitoring	After projects begin, project proponents etc. monitor whether any unforeseeable situations occur and whether the performance and effectiveness of mitigation measures are consistent with the assessment's prediction. They then take appropriate measures based on the results of such monitoring.	The borrower is responsible for adequate monitoring & evaluation of the activities set forth in the resettlement instrument.	Not mentioned in the govt. law.	Monitoring is not specified in the govt. law.	The project proponent should follow monitoring requirements of the JICA Guidelines such as internal/external monitoring as well as regular monitoring during implementation of land acquisition and resettlement/post-resettlement evaluation as per the international practices which are required by the JICA Guidelines.

Source: JICA. 2010. Japan International Cooperation Agency (JICA) Guidelines for Environmental and Social Considerations; World Bank. 2012. Operational Policies; Democratic Republic of Ethiopia. FDRE Constitution; Democratic Republic of Ethiopia. 2005. Expropriation of Landholdings for Public Purposes and Payment of Compensation Proclamation; Democratic Republic of Ethiopia. 2007. Council of Ministers Regulations on the Payment of Compensation for Property Situated on Landholdings Expropriated for Public Purposes.

Appendix 4.5

Table A.4.4 Summary of Prospective Geothermal Energy Development Sites

No	Site	Rift locality	Location			Natural and geological conditions	Socioeconomic conditions	Accessibility /Road	Status of geothermal development	Potential Impact
			Region	Wareda	Kebele					
1	Dallol	Afar depression	Afar	Berhale	Ahamed-Ela	Arid and dry land, Harsh climatic condition, Located at lowest depression, Exposed rock surface and sandy soil, Huge deposits of solid salt and salty water bodies, Rich also in other mineral resources such as Sulfur, Potash. No natural and historical points.	• Not residential area, and no social services. Farming or grazing • Availability of water resources: Pond water, 25-30km distance (No water resources nearby), scarcity all year, not safe water (shortage of water)	Accessible, 7km sandy road construction required	Technical studies/or scientific investigation/ at pre-feasibility level (Surface exploration level is lower), No practical activities are currently observed on the sites, The site is used for salt production	(Social) None (Natural) • Gas emission (H_2S) • Water pollution • Change in land use
2	Tendaho-3 (Allelobeda)	Afar depression	Afar	Dubti	Gurmudale	Arid and dry land, Rain fall: 200 – 300mm, Plain topography, Exposed sand soil surface, Hot springs with relatively big volume of water, used for drinking animals and grazing livestock. No natural and historical points.	• Not residential area , and no social services • Availability of water resources: River・Dam (Dubti electric Dam) water, 0.5-2 km distance (water availability high), not safe water • Far from main road • Tribal/minority conflicts • A few unidentified stone tombs are observed	Accessible, About 12km sandy road construction required	Technical studies/or scientific investigation/ at pre-feasibility level (Surface exploration level is lower), WB plans development. The site is either bared or used for grazing	(Social) • Dispossession of grazing land (Natural) • Gas emission • Water pollution • Change in land use • Water use competition
3	Boina	Afar depression	Afar	Erebti	Gira-Ale	Located at the top of mountain, at higher altitude as compared to Dallol, Arid and dry land, Very hot environment, Rain fall: 300 – 500mm, Rugged topography. No natural and historical points.	• Not residential area , and no social services • Availability of water resources: Rain/pond water, 15km-25km distance, April-June scarcity, not safe water (shortage of water)	Poor accessibility, About 40km rugged, rocky, and sandy require construction of road. Far from main electrical grid.	Technical studies/or scientific investigation/ at pre-feasibility level (Surface exploration level is lower), No practical activities are currently observed on the sites, The site is either bared or used for grazing.	(Social) None (Natural) • Gas emission • Water pollution • Change in land use
4	Damali	Afar depression	Afar	Asayta		Harsh environment, Arid and dry land with erratic rain fall pattern, Rain fall: 200 – 300mm, Exposed rock surface with shrub and grass, Located at central Afar depression. No natural and historical points.	• Not residential area , and no social services • Availability of water resources: River water, not safe water	Difficult to access. Far from main electrical grid.	Technical studies/or scientific investigation/ at pre-feasibility level (Surface exploration level is lower), No practical activities are currently observed on the sites, The site is either bared or used for grazing.	(Social) None (Natural) • Gas emission • Water pollution • Change in land use

No	Site	Rift locality	Location			Natural and geological conditions	Socioeconomic conditions	Accessibility /Road	Status of geothermal development	Potential Impact
			Region	Wareda	Kebele					
5	Teo	Afar depression	Afar	Mille		Harsh environment, Arid and dry land with erratic rain fall pattern, Rain fall: 200 – 300mm, Exposed rock surface with shrub and grass, Located at central Afar depression, Hot spring. No natural and historical points.	• Not residential area , and no social services • Availability of water resources: River water, scarcity all year, not safe water	Difficult to access. Far from main electrical grid.	Technical studies/or scientific investigation/ at pre-feasibility level (Surface exploration level is lower), No practical activities are currently observed on the sites, The site is either bared or used for grazing.	(Social) None (Natural) • Gas emission • Water pollution • Change in land use
6	Danab	Afar depression	Afar	Dubti		Harsh environment, Arid and dry land with erratic rain fall pattern, Rain fall: 200 – 300mm, Exposed rock surface with shrub and grass, Located at central Afar depression, Located in the nearby salt flat. No natural and historical points.	• Not residential area , and no social services • Availability of water resources: River water, scarcity all year, not safe water	Difficult to access. Far from main electrical grid.	Technical studies/or scientific investigation/ at pre-feasibility level (Surface exploration level is lower), No practical activities are currently observed on the sites, The site is either bared or used for grazing.	(Social) None (Natural) • Gas emission • Water pollution • Change in land use
7	Meteka	Afar depression	Afar	Gewane	Meteka	Harsh environment, Arid and dry land with erratic rain fall pattern, Rain fall: 200 – 300mm, Low altitude with relatively plain topography, Exposed sand soil surface with scattered shrub and grass, Perennial swamps cover some portion of Meteka (Sensitive wet land), Hot spring for use of bathing, washing cloths/cars. No natural and historical points.	• Located within the village of Meteka Kebele, Residential area with a number of social services • Availability of water resources: Borehole/River water, 0.5km distance water availability high), safe water • Orthodox church (St. Mary Church located • Tribal/minority conflicts	Easy to access	Technical studies/or scientific investigation/ at pre-feasibility level (Surface exploration level is lower), No practical activities are currently observed on the sites, The site is on nearby settlement area.	(Social) • Dislocation of people, dispossession of grazing land, and social services (Natural) • Interference with ecologically sensitive aquatic (Swampy) area (Regional conservation area) • Gas emission • Water pollution • Change in land use
8	Arabi	Afar depression	Somali	Dembel	Arabi	Good environment, Upper Kola climatic conditions, Flat plain topography, Bushed exposed surface with scattered grass vegetation, Big River called Arabi is found along side of the site, An industrial input mineral called Diatomite Earth is identified in the area, Hot spring. No natural and historical points.	• Not residential area , and no social services (about 4km away from residential area of Arabi Kebele) • Availability of water resources: Borehole/River water, 0.5km distance (water availability high), safe water	Difficult to access, About 35km rugged, sandy, and rivers require construction of road.	Technical studies/or scientific investigation/ at pre-feasibility level, No practical activities are currently observed on the sites, The site is used for agriculture and grazing.	(Social) • Dispossession of grazing land (Natural) • Gas emission • Water pollution • Change in land use

No	Site	Rift locality	Location			Natural and geological conditions	Socioeconomic conditions	Accessibility /Road	Status of geothermal development	Potential Impact
			Region	Wareda	Kebele					
9	Dofan	Main rift valley	Afar	Dulecha	Dofan	Good environment, Arid and dry land with erratic rain fall pattern, Rain fall 200 - 300 mm, Closer to Awash River, Relatively flat plain topography, Surrounded by intensively cultivated land and state farm, Sulfur deposits are reported in the area. No natural and historical points.	• Relatively a few people settled but no social services • Availability of water resources: River water, 0.5-1 km distance (water availability high), not safe water • History of tribal/minority conflict	Difficult to access, more than 35 km, rugged, sandy, and river requires road construction	Technical studies/or scientific investigation/ at pre-feasibility level, No practical activities are currently observed on the sites, The site is either bared or for gazing.	(Social) • Dispossession of grazing land (Natural) • Gas emission • Water pollution • Change in land use • Disturbance to surrounding wild life; lion species
10	Kone	Main rift valley	Afar	Fentale	Tututi	Good environment, Lower to Kola climatic condition, Rain fall: 500-900 mm, Flat plain topography, Constantly increasing water covers large surface area of the prospect site; Beseka lake, Intensively cultivated land and sugar factories, Hot spring for bathing. No natural and historical points.	• Not residential area , and no social services • Far from villages, the surrounding area is used for common grazing • Availability of water resources: lake water, 0.5-1 km distance (water availability high), not safe water	Easy to access, 1.5 km sandy road requires construction	Technical studies/or scientific investigation/ at pre-feasibility level (Surface exploration level is lower), No practical activities are currently observed on the sites, The site is either bared or used for grazing.	(Social) • Dispossession of grazing land (Natural) • Interference with ecologically sensitive aquatic (Swampy) area (Awash N. Park) • Gas emission • Water pollution • Change in land use
11	Nazareth	Main rift valley	Oromia	Adam	Boku	Good environment, Hot spring for healing. No natural and historical points.	• A few residential huts around, Hot springs located in the farming plots, Religious/Church • Availability of water resources: Birka/River water, 0.5 km distance, safe water • Orthodox church located	Easy to access	Surface exploration level is lower	(Social) • Dispossession of agriculture and grazing land (Natural) • Gas emission • Water pollution • Change in land use • Biologically/ecologically no significant impacts •
12	Gedemsa	Main rift valley	Oromia	Adam	Gedemsa	Good environment, Moist Wena Dega climatic conditions, More than 900 mm rain fall, Flat topography, Dense shrub land and intensively cultivated land, Suitable soil for agriculture, Water body called Koka lake is available in the surrounding. No natural and historical points.	• Not residential area , and no social services, Surrounded by farming plot • Availability of water resources: River water, 7 km distance, scarcity summer time, not safe water	Accessible, nearly 10 km rugged, Current sandy and rocky earth road requires construction of road	Technical studies/or scientific investigation/ at pre-feasibility level (Surface exploration level is lower), No practical activities are currently observed on the sites, The site is used for agriculture and grazing.	(Social) • Dispossession of agriculture and grazing land (Natural) • Gas emission • Water pollution • Change in land use • Biologically/ecologically no significant impacts

No	Site	Rift locality	Location			Natural and geological conditions	Socioeconomic conditions	Accessibility /Road	Status of geothermal development	Potential Impact
			Region	Wareda	Kebele					
14	Aluto-2 (Altu-Fin kilo)	Main rift valley	Oromia	Zeway	Aluto	Good environment, Dry Wena Dega climatic conditions, Below 700 mm rain fall, Gentle slope topography, Open wooded land & wooded grass land, Closer to two water bodies; Lake Zeway (8 Km south) and Lake Langano (10Km north), Suitable soil for agriculture. No natural and historical points.	• Relatively few people settled but no social services • Availability of water resources: Lake/River water, 7 km distance, not safe water • Adjacent to Aluto-Langano Geothermal project site	Easy to access	Techno-economic feasibility studies are currently, July 2014, studied for existing pilot plant. WB/ICEADA plans MT.	(Social) • Displacement of people, dispossession of agricultural and grazing land (Natural) • Gas emission • Water pollution • Change in land use • Biologically/ecologically no significant impacts
15	Aluto-3 (Aluto-B obessa)	Main rift valley	Oromia	Zeway	Aluto	Good environment, Dry Wena Dega climatic conditions, Below 700 mm rain fall, Gentle slope topography, Open wooded land & wooded grass land, Closer to two water bodies; Lake Zeway (8 Km south) and Lake Langano (10Km north), Suitable soil for agriculture. No natural and historical points.	• Relatively few people settled but no social services • Availability of water resources: Lake/River water, 7 km distance, not safe water • Adjacent to Aluto-Langano Geothermal project site	Easy access	Techno-economic feasibility studies are currently, July 2014, studied for existing pilot plant. WB/ICEADA plans MT.	(Social) • Displacement of people, dispossession of agricultural and grazing land (Natural) • Gas emission • Water pollution • Change in land use • Biologically/ecologically no significant impacts
18	Boseti	Main rift valley	Oromia	Boseti	Geri	Good environment, Moist Wena Dega climatic conditions, Above 900 mm rain fall, Flat topography, Dense shrub land and intensively cultivated land, Suitable soil for agriculture. Forest/green area, Hot spring for healing. No natural and historical points.	• Farming land small residential area • Availability of water resources: Pipe/pond water, 2 km distance, scarcity Jan.- May, safe water	Easy access, 1.5 km earth road, and 12km gravel road upgrading	Technical studies/or scientific investigation/ at pre-feasibility level (Surface exploration level is lower), No practical activities are currently observed on the sites, The site is used for agriculture and grazing.	(Social) • Dispossession of agriculture and grazing land • Limitation of suitable relocation sites (Natural) • Gas emission • Water pollution • Change in land use • Biologically/ecologically no significant impacts

Appendix 4.6

Table A.4.5 Potential Impact at each prospect project site

		Social Environment									Natural Environment							Pollution						
No.	**Project Site**	Involuntary resettlement	Living and Livelihood	Land use and utilization of local resources	The poor, indigenous and ethnic people	Local conflicts of interests	Water usage or water rights and rights of common	Hazards(Risks) (infectious disease such as HIV/AIDS)	Working Conditions	Disaster	Topography and geographic features	Land subsidence	Climate	Soil erosion	Wetlands, rivers and lakes	Fauna and flora and biodiversity	Landscape	Ground water	Air pollution	Water contamination	Wastes	Noise and vibration	Odor	Accidents
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	Dallol			✔														✔	✔	✔	✔	✔	✔	✔
2	Tendaho-3 (Allalobeda)			✔			✔											✔	✔	✔	✔	✔	✔	✔
3	Boina			✔														✔	✔	✔	✔	✔	✔	✔
4	Damali			✔														✔	✔	✔	✔	✔	✔	✔
5	Teo			✔														✔	✔	✔	✔	✔	✔	✔
6	Danab			✔														✔	✔	✔	✔	✔	✔	✔
7	Meteka	✔													✔	✔		✔	✔	✔	✔	✔	✔	✔
8	Arabi	✔		✔														✔	✔	✔	✔	✔	✔	✔
9	Dofan	✔														✔		✔	✔	✔	✔	✔	✔	✔
10	Kone	✔		✔											✔	✔		✔	✔	✔	✔	✔	✔	✔
11	Nazareth	✔														✔		✔	✔	✔	✔	✔	✔	✔
12	Gedemsa	✔		✔												✔		✔	✔	✔	✔	✔	✔	✔
14	Aluto-2 (Altu-Finkilo)	✔		✔												✔		✔	✔	✔	✔	✔	✔	✔
15	Aluto-3 (Aluto-Bobessa)	✔		✔												✔		✔	✔	✔	✔	✔	✔	✔
18	Boseti	✔	✔	✔												✔		✔	✔	✔	✔	✔	✔	✔
22	Tendaho-2 (Ayrobera)																	✔	✔	✔	✔	✔	✔	✔

(Source: JICA Study Team)

Note: The possible impacts rated as B+ are counted.

Appendix 4.7

Table A4.6 Potential Impact at Activities at Project Phase

No	Likely Impacts	Overall Rating	Planning/Designing Phase				Construction Phase		Operation Phase
			Resettlement	Land Acquisition	Change of land use for the	Well drilling and testing	Land Clearing	Facility construction	Operation of the geothermal power plant
Social Environment									
1	Involuntary resettlement	**C-**	**C-**	**B-**					
2	Living and Livelihood	**B-**		**B-**					
		B+						**A+**	**A+**
3	Land use and utilization of local resources	**B-**			**B-**				
		B+							**B+**
4	The poor, indigenous and ethnic people	**D**							
5	Local conflicts of interests	**D**							
6	Water usage or water rights and rights of common	**D**							
7	Hazards(Risks) (infectious disease such as HIV/AIDS)	**D**							
8	Working Conditions	**D**							
9	Disaster	**D**							
Natural Environment									
10	Topography and geographic features	**B-**					**B-**	**B-**	
11	Land subsidence	**B-**							**B-**
12	Climate	**B-**							**B-**
13	Soil erosion	**B-**							**B-**
14	Wetlands, rivers and lakes	**B-**						**B-**	
15	Fauna and flora and biodiversity	**B-**				**B-**	**B-**	**B-**	**B-**
16	Landscape	**D**							
17	Ground water	**C-**				**C-**		**C-**	
Pollution									
18	Air pollution	**B-**				**B-**		**B-**	**B-**
19	Water contamination (Water use & Water contamination)	**B-**				**B-**		**B-**	**B-**
20	Wastes	**C-**				**C-**		**C-**	**C-**
21	Noise and vibration	**B-**				**B-**		**B-**	
22	Odor	**C-**				**C-**		**C-**	**C-**
23	Accidents	**B-**				**B-**		**B-**	**B-**

(Source: JICA Study Team)
<Rating>
A-: Serious impact is expected, if any measure is not implemented to the impact.
B-: Some impact is expected, if any measure is not implemented to the impact.
C-: Extent of impact is unknown (Examination is needed. Impact may become clear as study progresses.)
D : No impact is expected.
A+: Remarkable effect is expected due to the project implementation itself and environmental improvement caused by the project.
B+: Some effect is expected due to the project implementation itself and environmental improvement caused by the project.

Appendix 4.8

Table A4.7 Name of offices and Personnel Visited for Baseline Data Collection and Stakeholder Consultation

Name	Responsibility/Profession	Woreda
Health office		
Amin Homo	Human Resource Head	Berhale
Desta Fisha	Health Promotion and Disease Prevention	Erbati
Demissie Shibiru	Planning Head	Boseti
Mitiku Basie	Health Expert	Boseti
Lubaba Yimer	Health Administrator	Boseti
Adem Nur	Health Expert	Alolbeda
Degu M/Mariam	Disease Prevention Expert	Dulech
Tegegne Biftu	MSH Head	Gedemsa
Hizquiel G/Kidan	Health Expert	Arabi
Alemayehu Siyoum	Nurse	Boku
Tegegne Biftu	Nurse	Boku
Fassika Terefe	MCH Expert	Boku
Mohamod Ali	Disease Prevention Expert	Zeway
Abdela Oliso	Family Health Expert	Zeway
Biruk Fekede	Family Health Expert	Metehara
Anwar Awol	Rur. Water & Sanitation Expert	Bahri
Kedir Awol	Water & Energy Head	Asayta
Aychew Gedefa	Irrigation Expert	Gewane
Culture and Tourism Office		
Abdulwad Kasim	Commu. And Info. officer	Zeway
Hamid Wolo	Commu. Desk Head	Dubti
Tadele Gemechu	Tourism Culture Rese. Officer	Gewane
Elias Tirkiso	Cul. Tour. Commu. Head	Dulecha
Jafar Jemal	Project Plan Head	Nazreth
Education Office		
Abdurahman Arin	Exoert	Arabi
Hassan Bereken	Desk Head	Arabi
Bati Girma	Expert	Nazreth
Jafar Jemal	Project Plan Head	Nazreth
Jemal Gededa	Human Resource Head	Boseti
Birhanu Yimer	Human Resource Head	Boseti
Mulugeta	Educ. Quality Head	Bahri
Tulu Gemechu	Expert	Zeway
Jemo Draro	Expert	Zeway
Shugete Gunechu	Expert	Zeway
Tibebe Qumbi	Expert	Zeway
Guro Gobe	Educ. Officer Head	Zeway
Biruk Nigussie	Educ. Expert	Gewane
Finance Economy and Divt. Office		
Legesser Feyisa	Finance and Eco. Expert	Boseti
Kedir Hassen	Animal Market Officer	Dulecha
Yasin Mohamod	Finance Officer	Dulecha
Demissie Argaw	Gri. Input Expert	Dulecha
Tewodros Yitsedal	Crop production Expert	Dulecha
Ahmod Jemal	Extension Worker	Dulecha

Different Office representatives		
Ali Ahmod	Kebeke Chair	Dubti
Ebrahim Husien	Woreda Chair	Berhale
Gifta Yose	Woreda Head	Gewane
Tadelle Diridssa	Woreda Head	Arabi
Girma	Grievance Handling Head	Arabi
Jemu Gemeda	Deputy Woreda Head	Zeway
Teshite Jarso	School Head	Nazreth
Mulugeta Gonfa	Woreda Council	Boseti
Asebir	Grievance Handling Head	Nazreth
Habtamu	Deputy Grievance Handling	Boseti
Anggetu Daba	Committee	Boseti
Birra Rorissa	Grievance Handling	Gedemsa

Table A4.9 Names of Representatives in Community Consultation

Site	Name	Age	Status
Afar			
Tendaho	Shiek Mohamod	53	Religious leader
	Amila Kahsim	35	Woman
	Ali Khasim	28	Youth
	Hamad Ali Dula	52	Elderly
Dallol	Mohamod Ali	52	Elderly
	Hussien Mohamod	40	Religious leader
	Hussien Edris	20	Youth
	Halima Moha	40	Woman
Dofan	Oumar Abhab	66	Religious leader
	Ebrahim Shiek	43	Community leader
	Ali Hamad	60	Elderly
	Abato Humad	40	Resident
Erati	Abdulkrim Mohamod	40	Community leader
	Ayish Kedir	35	Woman
	Ali Baba	30	Youth
Meteka	Abadi Ali	37	Woman
	Halale Ali	27	Youth
	Medina Qumar	27	Resident
Oromia			
Aluto 2	Birke Feleta	87	Elderly
	Rufe Jilio	40	Woman
	Gemede Abu	25	Youth
	Gebo Barti	35	Resident
Aluto 3	Barke Fileto	64	Elderly
	Gereda Abo	66	Religious leader
	Shalo Azemach	25	Youth
Boku	Biru Hawaz	58	Religious leader
	Genet Melka	25	Woman
	Katema Wagjira	30	Youth
	Negewo Lema	36	Edir Chair
Boseti	Beada Tufa	60	Religious leader
	Dadi Gube	77	Elderly

	Mezgebua Babsa	28	Woman
Gedemsa	Danse Jelila	46	Community leader
	Dadi Shire	38	Woman
	Girma Aboye	24	Youth
	Belete Meojne	42	Resident
Somali			
Arabi	Ahmod Awol	55	Peace committee
	Shiek Abdu	70	Religious leader
	Adel Suluye	55	Elderly
	Deqa Yenus	45	Woman
	Ahmod Berreh	23	Youth

APPENDIX-5

CALCULATION OF EIRR

Tendaho-1 (Dubti) Project

Geothermal Plant

Installed capacity	280	MW
Plant factor	90	%
Station use	9	%
Economic life	30	years
Generated energy	2,208	GWh
Sales energy	2,009	GWh
Construction cost	1,888.2	M$
O&M cost	10.9	M$/yr

Annual investment (real term at 2012 price, million $)

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Plant construction	326.5	652.9	108.8																														
Supplemental drilling				12.3	9.6	9.6	12.3	9.6	9.6	12.3	9.6	9.6	12.3	9.6	9.6	12.3	0.0	9.6	9.6	12.3	9.6	12.3	9.6	9.6	12.3	9.6	9.6	12.3	9.6	9.6	12.3	9.6	9.6
Total	326.5	652.9	108.8	12.3	9.6	9.6	12.3	9.6	9.6	12.3	9.6	9.6	12.3	9.6	9.6	12.3	0.0	9.6	9.6	12.3	9.6	12.3	9.6	9.6	12.3	9.6	9.6	12.3	9.6	9.6	12.3	9.6	9.6

Alternative Diesel Plant

Installed capacity	351	MW
Plant factor	67	%
Station use	4	%
Economic life	15	years
Generated energy	2,093	GWh
Sales energy	2,009	GWh
Unit construction cost	800	$/KW
Construction cost	285.2	M$
Fuel cost	0.171	$/kWh
O&M cost	0.009	$/kWh

Annual investment (real term at 2012 price, million $)

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Initial investment	42.8	213.9	28.5																														
Reinvestment																42.8	213.9	28.5															
Total	42.8	213.9	28.5													42.8	213.9	28.5															

Economic Feasibility

Cost/benefit stream

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Cost																																	
Investment	326.5	652.9	108.8	12.3	9.6	9.6	12.3	9.6	9.6	12.3	9.6	9.6	12.3	9.6	9.6	12.3	0.0	9.6	9.6	12.3	9.6	12.3	9.6	9.6	12.3	9.6	9.6	12.3	9.6	9.6	12.3	9.6	9.6
O&M				10.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	326.5	652.9	108.8	23.1	9.6	9.6	12.3	9.6	9.6	12.3	9.6	9.6	12.3	9.6	9.6	12.3	0.0	9.6	9.6	12.3	9.6	12.3	9.6	9.6	12.3	9.6	9.6	12.3	9.6	9.6	12.3	9.6	9.6
Benefit (avoidable cost)																																	
Investment cost	42.8	213.9	28.5													42.8	213.9	28.5															
Fuel cost				357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8	357.8
O&M cost				18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8
Total	42.8	213.9	28.5	376.7	376.7	376.7	376.7	376.7	376.7	376.7	376.7	376.7	376.7	376.7	376.7	419.4	590.6	405.2	376.7	376.7	376.7	376.7	376.7	376.7	376.7	376.7	376.7	376.7	376.7	376.7	376.7	376.7	376.7
Net benefit	▲283.7	▲439.0	▲80.3	353.5	367.0	367.0	364.4	367.0	367.0	364.4	367.0	367.0	364.4	367.0	367.0	407.2	590.6	395.6	367.0	364.4	367.0	364.4	367.0	367.0	364.4	367.0	367.0	364.4	367.0	367.0	364.4	367.0	367.0

EIRR (real term)	31.7%

Source: JICA Project Team

Table A.5.1 Calculation of EIRR (Tendaho-1)

Aluto-2 (Finkilo) Project

Geothermal Plant

Installed capacity	110	MW
Plant factor	90	%
Station use	9	%
Economic life	30	years
Generated energy	867	GWh
Sales energy	789	GWh
Construction cost	437.0	M$
O&M cost	4.4	M$/yr

Annual investment (real term at 2012 price, million $)

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Plant construction	131.1	262.2	43.7																														
Supplemental drilling				0.0	9.6	0.0	0.0	12.3	0.0	9.6	0.0	0.0	9.6	0.0	0.0	12.3	0.0	9.6	0.0	0.0	9.6	0.0	12.3	0.0	0.0	9.6	0.0	0.0	12.3	0.0	9.6	0.0	0.0
Total	131.1	262.2	43.7	0.0	9.6	0.0	0.0	12.3	0.0	9.6	0.0	0.0	9.6	0.0	0.0	12.3	0.0	9.6	0.0	0.0	9.6	0.0	12.3	0.0	0.0	9.6	0.0	0.0	12.3	0.0	9.6	0.0	0.0

Alternative Diesel Plant

Installed capacity	140	MW
Plant factor	67	%
Station use	4	%
Economic life	15	years
Generated energy	822	GWh
Sales energy	789	GWh
Unit construction cost	800	$/KW
Construction cost	112.1	M$
Fuel cost	0.171	$/kWh
O&M cost	0.009	$/kWh

Annual investment (real term at 2012 price, million $)

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Initial investment	16.8	84.0	11.2																														
Reinvestment																16.8	84.0	11.2															
Total	16.8	84.0	11.2													16.8	84.0	11.2															

Economic Feasibility

Cost/benefit stream

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Cost																																	
Investment	131.1	262.2	43.7	0.0	9.6	0.0	0.0	12.3	0.0	9.6	0.0	0.0	9.6	0.0	0.0	12.3	0.0	9.6	0.0	0.0	9.6	0.0	12.3	0.0	0.0	9.6	0.0	0.0	12.3	0.0	9.6	0.0	0.0
O&M				4.4		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	131.1	262.2	43.7	4.4	9.6	0.0	0.0	12.3	0.0	9.6	0.0	0.0	9.6	0.0	0.0	12.3	0.0	9.6	0.0	0.0	9.6	0.0	12.3	0.0	0.0	9.6	0.0	0.0	12.3	0.0	9.6	0.0	0.0
Benefit (avoidable cost)																																	
Investment cost	16.8	84.0	11.2													16.8	84.0	11.2															
Fuel cost				140.6	140.6	140.6	140.6	140.6	140.6	140.6	140.6	140.6	140.6	140.6	140.6	140.6	140.6	140.6	140.6	140.6	140.6	140.6	140.6	140.6	140.6	140.6	140.6	140.6	140.6	140.6	140.6	140.6	140.6
O&M cost				7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4
Total	16.8	84.0	11.2	148.0	148.0	148.0	148.0	148.0	148.0	148.0	148.0	148.0	148.0	148.0	148.0	164.8	232.0	159.2	148.0	148.0	148.0	148.0	148.0	148.0	148.0	148.0	148.0	148.0	148.0	148.0	148.0	148.0	148.0
Net benefit	▲ 114.3	▲ 178.2	▲ 32.5	143.6	138.3	148.0	148.0	135.7	148.0	138.3	148.0	148.0	138.3	148.0	148.0	152.5	232.0	149.6	148.0	148.0	138.3	148.0	135.7	148.0	148.0	138.3	148.0	148.0	135.7	148.0	138.3	148.0	148.0

EIRR (real term)	31.1%

Source: JICA Project Team

Table A.5.2 Calculation of EIRR (Aluto-2)

Tendaho-2 (Ayrobera) Project

Geothermal Plant

Installed capacity	180	MW
Plant factor	90	%
Station use	9	%
Economic life	30	years
Generated energy	1,419	GWh
Sales energy	1,291	GWh
Construction cost	725.0	M$
O&M cost	7.2	M$/yr

Annual investment (real term at 2012 price, million $)

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Plant construction	217.5	435.0	72.5																														
Supplemental drilling				0.0	9.6	9.6	0.0	12.3	0.0	9.6	9.6	0.0	12.3	9.6	0.0	9.6	0.0	12.3	9.6	0.0	9.6	12.3	0.0	9.6	0.0	12.3	9.6	0.0	9.6	12.3	0.0	9.6	0.0
Total	217.5	435.0	72.5	0.0	9.6	9.6	0.0	12.3	0.0	9.6	9.6	0.0	12.3	9.6	0.0	9.6	0.0	12.3	9.6	0.0	9.6	12.3	0.0	9.6	0.0	12.3	9.6	0.0	9.6	12.3	0.0	9.6	0.0

Alternative Diesel Plant

Installed capacity	229	MW
Plant factor	67	%
Station use	4	%
Economic life	15	years
Generated energy	1,345	GWh
Sales energy	1,291	GWh
Unit construction cost	800	$/KW
Construction cost	183.4	M$
Fuel cost	0.171	$/kWh
O&M cost	0.009	$/kWh

Annual investment (real term at 2012 price, million $)

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Initial investment	27.5	137.5	18.3																														
Reinvestment																27.5	137.5	18.3															
Total	27.5	137.5	18.3													27.5	137.5	18.3															

Economic Feasibility

Cost/benefit stream

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Cost																																	
Investment	217.5	435.0	72.5	0.0	9.6	9.6	0.0	12.3	0.0	9.6	9.6	0.0	12.3	9.6	0.0	9.6	0.0	12.3	9.6	0.0	9.6	12.3	0.0	9.6	0.0	12.3	9.6	0.0	9.6	12.3	0.0	9.6	0.0
O&M				7.2		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	217.5	435.0	72.5	7.2	9.6	9.6	0.0	12.3	0.0	9.6	9.6	0.0	12.3	9.6	0.0	9.6	0.0	12.3	9.6	0.0	9.6	12.3	0.0	9.6	0.0	12.3	9.6	0.0	9.6	12.3	0.0	9.6	0.0
Benefit (avoidable cost)																																	
Investment cost	27.5	137.5	18.3													27.5	137.5	18.3															
Fuel cost				230.0	230.0	230.0	230.0	230.0	230.0	230.0	230.0	230.0	230.0	230.0	230.0	230.0	230.0	230.0	230.0	230.0	230.0	230.0	230.0	230.0	230.0	230.0	230.0	230.0	230.0	230.0	230.0	230.0	230.0
O&M cost				12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1
Total	27.5	137.5	18.3	242.1	242.1	242.1	242.1	242.1	242.1	242.1	242.1	242.1	242.1	242.1	242.1	269.6	379.7	260.5	242.1	242.1	242.1	242.1	242.1	242.1	242.1	242.1	242.1	242.1	242.1	242.1	242.1	242.1	242.1
Net benefit	▲190.0	▲297.5	▲54.2	234.9	232.5	232.5	242.1	229.9	242.1	232.5	232.5	242.1	229.9	232.5	242.1	260.0	379.7	248.2	232.5	242.1	232.5	229.9	242.1	232.5	242.1	229.9	232.5	242.1	232.5	229.9	242.1	232.5	242.1

EIRR (real term)	30.8%

Source: JICA Project Team

Table A.5.3 Calculation of EIRR (Tendaho-2)

Aluto-3 (Bobesa) Project

Geothermal Plant

Installed capacity	50	MW
Plant factor	90	%
Station use	9	%
Economic life	30	years
Generated energy	394	GWh
Sales energy	359	GWh
Construction cost	201.1	M$
O&M cost	2.0	M$/yr

Annual investment (real term at 2012 price, million $)

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Plant construction	60.3	120.7	20.1																														
Supplemental drilling				0.0	0.0	9.6	0.0	0.0	0.0	0.0	9.6	0.0	0.0	0.0	0.0	0.0	12.3	0.0	0.0	0.0	0.0	9.6	0.0	0.0	0.0	0.0	0.0	12.3	0.0	0.0	0.0	0.0	9.6
Total	60.3	120.7	20.1	0.0	0.0	9.6	0.0	0.0	0.0	0.0	9.6	0.0	0.0	0.0	0.0	0.0	12.3	0.0	0.0	0.0	0.0	9.6	0.0	0.0	0.0	0.0	0.0	12.3	0.0	0.0	0.0	0.0	9.6

Alternative Diesel Plant

Installed capacity	64	MW
Plant factor	67	%
Station use	4	%
Economic life	15	years
Generated energy	373.7	GWh
Sales energy	358.7	GWh
Unit construction cost	800	$/KW
Construction cost	50.9	M$
Fuel cost	0.171	$/kWh
O&M cost	0.009	$/kWh

Annual investment (real term at 2012 price, million $)

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Initial investment	7.6	38.2	5.1																														
Reinvestment																7.6	38.2	5.1															
Total	7.6	38.2	5.1													7.6	38.2	5.1															

Economic Feasibility

Cost/benefit stream

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Cost																																	
Investment	60.3	120.7	20.1	0.0	0.0	9.6	0.0	0.0	0.0	0.0	9.6	0.0	0.0	0.0	0.0	0.0	12.3	0.0	0.0	0.0	0.0	9.6	0.0	0.0	0.0	0.0	0.0	12.3	0.0	0.0	0.0	0.0	9.6
O&M				2.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	60.3	120.7	20.1	2.0	0.0	9.6	0.0	0.0	0.0	0.0	9.6	0.0	0.0	0.0	0.0	0.0	12.3	0.0	0.0	0.0	0.0	9.6	0.0	0.0	0.0	0.0	0.0	12.3	0.0	0.0	0.0	0.0	9.6
Benefit (avoidable cost)																																	
Investment cost	7.6	38.2	5.1													7.6	38.2	5.1															
Fuel cost				63.9	63.9	63.9	63.9	63.9	63.9	63.9	63.9	63.9	63.9	63.9	63.9	63.9	63.9	63.9	63.9	63.9	63.9	63.9	63.9	63.9	63.9	63.9	63.9	63.9	63.9	63.9	63.9	63.9	63.9
O&M cost				3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4
Total	7.6	38.2	5.1	67.3	67.3	67.3	67.3	67.3	67.3	67.3	67.3	67.3	67.3	67.3	67.3	74.9	105.5	72.4	67.3	67.3	67.3	67.3	67.3	67.3	67.3	67.3	67.3	67.3	67.3	67.3	67.3	67.3	67.3
Net benefit	▲52.7	▲82.5	▲15.0	65.3	67.3	57.6	67.3	67.3	67.3	67.3	57.6	67.3	67.3	67.3	67.3	74.9	93.2	72.4	67.3	67.3	67.3	57.6	67.3	67.3	67.3	67.3	67.3	55.0	67.3	67.3	67.3	67.3	57.6

EIRR (real term)	30.7%

Source: JICA Project Team

Table A.5.4 Calculation of EIRR (Aluto-3)

Tendaho-3 (AllaloBeda) Project

Geothermal Plant

Installed capacity	95	MW
Plant factor	90	%
Station use	9	%
Economic life	30	years
Generated energy	749	GWh
Sales energy	682	GWh
Construction cost	402.4	M$
O&M cost	4.0	M$/yr

Annual investment (real term at 2012 price, million $)

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Plant construction	120.7	241.5	40.2																														
Supplemental drilling				0.0	13.1	0.0	0.0	10.5	0.0	0.0	10.5	0.0	0.0	13.1	0.0	0.0	10.5	0.0	0.0	10.5	0.0	0.0	13.1	0.0	0.0	10.5	0.0	0.0	13.1	0.0	0.0	10.5	0.0
Total	120.7	241.5	40.2	0.0	13.1	0.0	0.0	10.5	0.0	0.0	10.5	0.0	0.0	13.1	0.0	0.0	10.5	0.0	0.0	10.5	0.0	0.0	13.1	0.0	0.0	10.5	0.0	0.0	13.1	0.0	0.0	10.5	0.0

Alternative Diesel Plant

Installed capacity	121	MW
Plant factor	67	%
Station use	4	%
Economic life	15	years
Generated energy	710.0	GWh
Sales energy	681.6	GWh
Unit construction cost	800	$/KW
Construction cost	96.8	M$
Fuel cost	0.171	$/kWh
O&M cost	0.009	$/kWh

Annual investment (real term at 2012 price, million $)

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Initial investment	14.5	72.6	9.7																														
Reinvestment																14.5	72.6	9.7															
Total	14.5	72.6	9.7													14.5	72.6	9.7															

Economic Feasibility

Cost/benefit stream

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Cost																																	
Investment	120.7	241.5	40.2	0.0	13.1	0.0	0.0	10.5	0.0	0.0	10.5	0.0	0.0	13.1	0.0	0.0	10.5	0.0	0.0	10.5	0.0	0.0	13.1	0.0	0.0	10.5	0.0	0.0	13.1	0.0	0.0	10.5	0.0
O&M				4.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	120.7	241.5	40.2	4.0	13.1	0.0	0.0	10.5	0.0	0.0	10.5	0.0	0.0	13.1	0.0	0.0	10.5	0.0	0.0	10.5	0.0	0.0	13.1	0.0	0.0	10.5	0.0	0.0	13.1	0.0	0.0	10.5	0.0
Benefit (avoidable cost)																																	
Investment cost	14.5	72.6	9.7													14.5	72.6	9.7															
Fuel cost				121.4	121.4	121.4	121.4	121.4	121.4	121.4	121.4	121.4	121.4	121.4	121.4	121.4	121.4	121.4	121.4	121.4	121.4	121.4	121.4	121.4	121.4	121.4	121.4	121.4	121.4	121.4	121.4	121.4	121.4
O&M cost				6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4
Total	14.5	72.6	9.7	127.8	127.8	127.8	127.8	127.8	127.8	127.8	127.8	127.8	127.8	127.8	127.8	142.3	200.4	137.5	127.8	127.8	127.8	127.8	127.8	127.8	127.8	127.8	127.8	127.8	127.8	127.8	127.8	127.8	127.8
Net benefit	▲ 106.2	▲ 168.9	▲ 30.6	123.8	114.7	127.8	127.8	117.3	127.8	127.8	117.3	127.8	127.8	114.7	127.8	142.3	189.9	137.5	127.8	117.3	127.8	127.8	114.7	127.8	127.8	117.3	127.8	127.8	114.7	127.8	127.8	117.3	127.8

EIRR (real term)	29.1%

Source: JICA Project Team

Table A.5.5 Calculation of EIRR (Tendaho-3)

APPENDIX-6

GEOPHYSICAL SURVEY

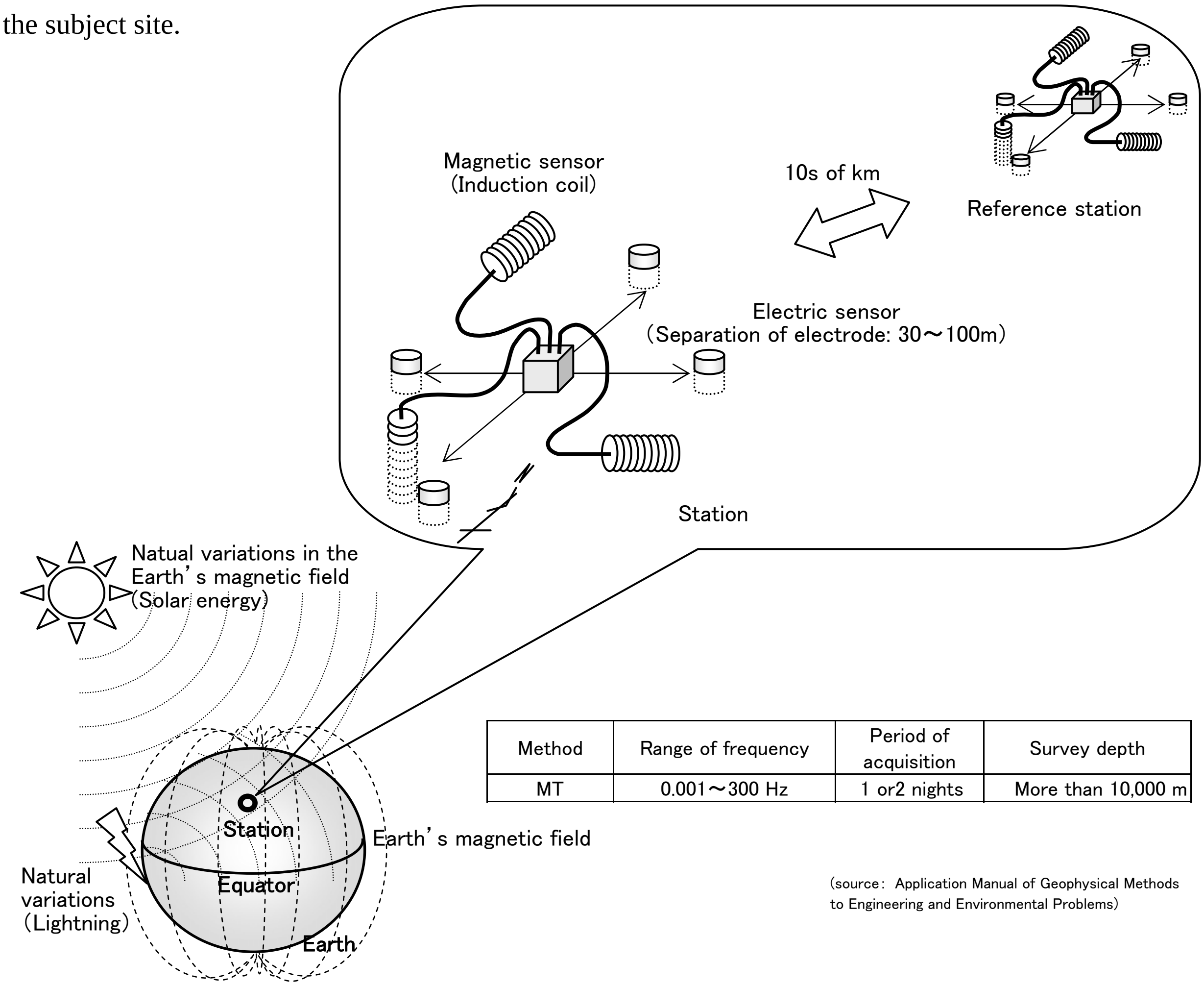
A6.1 Outline of Methodology

A6.1.1 MT Survey

(1) Principle of Method

MT (Magnetotelluric) method observes the earth's magnetic field and telluric current in nature with magnetic and electric sensors to investigate underground structures. MT method can investigate more than 10,000 m deep.

The term "MT method" is an abbreviation for magnetotelluric method, derived from the combination of the earth's magnetism and telluric currents . It denotes a survey method using the earth's telluric currents produced in the ground by variations of the earth's magnetic field (Figure A.6.1).The earth's magnetic field changes naturally and is thought to be due to the earth's magnetic oscillation, less than 1Hz, driven by solar activity and the earth's magnetic pulsation, more than 1Hz, produced by lightning. MT method observes these activities in the frequency range between 0.001Hz and 1,000Hz. Observation is commonly carried out overnight when the noise level is low. The remote reference method eliminates the noise at survey points. It uses an observation result at a reference station more than 50km away from the subject site.



Method	Range of frequency	Period of acquisition	Survey depth
MT	0.001～300 Hz	1 or2 nights	More than 10,000 m

Figure A.6.1 Schematic diagram of principles of MT method

The electromagnetic wave is attenuated gradually while it enters ground surface and penetrates underground. MT method is some of the

The skin depth where the energy intensity decreases to 1/e (about 0.37time) of the intensity at ground surface is regarded as a rule of thumb of the exploration depth for MT method.

The skin depth δ (m) depends on resistivity of ground ρ (ohm-m) and frequency f (Hz) of electromagnetic wave and is estimated as the following equation.

$$\delta = \sqrt{\frac{\rho}{\pi f \mu}} \cong 503\sqrt{\frac{\rho}{f}}$$

Where μ is electric permeability.

This equation shows that the higher the resistivity and the lower the frequency, the deeper the exploration depth into the ground. About MT method in the frequency range of 300 ~ 0.001Hz, the resistivity of 10ohm-m indicates the skin depth of about from 92m to 50km. It is said that the exploration depth of MT method is about 2-1/2 (≒0.707) of the skin depth.

As the variations of the earth's magnetism and telluric currents in low frequencies like the micropulsation affected by solar activity are observed for MT method, the measurement has to be carried out overnight when the culture noise level is low at least for one night. However at MT measurement, the variations of the earth's magnetism and telluric currents are small and it is difficult to distinguish those signals from noises. The remote reference station is set up at the far place from the survey site and where noise is low and the measurement is carried out at the survey station and the remote reference station simultaneously. The variations of observed signals at the survey station which have the correlation with data at the remote reference station are recognized as correct signals and those signals reduce affection of noise to acquired data. This technique is called the remote reference method.

The resistivity is the electrical property obtained from the electromagnetic or electric surveys including MT method. The definition of resistivity is electric resistance per unit of length with electric current flowing through the unit cross section area. This means, the apparent resistivity value is different depending on the directions of the measurements in case of layered underground or fracture rock. In other words, the resistivity shows anisotropy. MT method routinely measure this apparent anisotropy of resistivity differently from electromagnetic surveys except for MT method or electric surveys. For example, in case of the survey for fault, the resistivity in parallel with the strike direction of fault is TE mode and that of the orthogonal direction of the strike is TM mode.

In MT method, generally **Hx** as magnetic field and **Ex** as electric field in NS direction (x axis) and **Hy** and **Ey** in EW direction (y axis) are observed. Bold characters mean complex number. The definition of impedance tensor **Z** is expressed as the next equation with the relationship of magnetic and electric field.

$$\begin{pmatrix} \mathbf{E}_x \\ \mathbf{E}_y \end{pmatrix} = \mathbf{Z}\begin{pmatrix} \mathbf{H}_x \\ \mathbf{H}_y \end{pmatrix} = \begin{pmatrix} \mathbf{Z}_{xx} & \mathbf{Z}_{xy} \\ \mathbf{Z}_{yx} & \mathbf{Z}_{yy} \end{pmatrix}\begin{pmatrix} \mathbf{H}_x \\ \mathbf{H}_y \end{pmatrix}$$

The resistivity is related to the mutually-perpendicular components Zxy and Zyx of impedance tensor. Therefore 2 orthogonal directions of the resistivity are obtained in MT method. If x axis is rotated from NS direction to another, each component value of impedance tensor Z is varied. It means that by using the impedance tensor Z calculated from the observed data at NS and EW directions, the resistivity at arbitrary direction can be estimated.

(2) Measurement Method

Figure A.6.2 shows the schematic drawing for deployment of MT data acquisition system in the project. For data acquisition, MTU-5A system of Phoenix Geophysics (compatible with MT/AMT) was used and 2 components of the electric field and 3 components of the magnetic field were observed as time series. at each station.

The Pb-$PbCl_2$ non-polarized electrodes PE4 of Phoenix Geophysics were used at the measurement of the telluric current and according to the condition of each station, the dipole of 50~100m range was selected. The 2 directions of the dipole were NS and EW direction referring the magnetic north as standard. The electrodes were buried with water and bentonite to reduce contact resistivity in the hole of about 30m depth.

At the measurement of the magnetic field, the induction coils MTC-50/80 of Phoenix Geophysics were used to observe the magnetic field in the direction of NS and EW (magnetic north as standard) and verticality.

The remote reference stations were set up at more than 60 km far from the survey sites. The measurements were conducted simultaneously at the survey station and the remote reference station for more than 14 hours overnight and the survey equipment were moved and set up at next station during daytime. At the beginning of each survey, the calibration was executed to test magnetic sensors and decide coil coefficients.

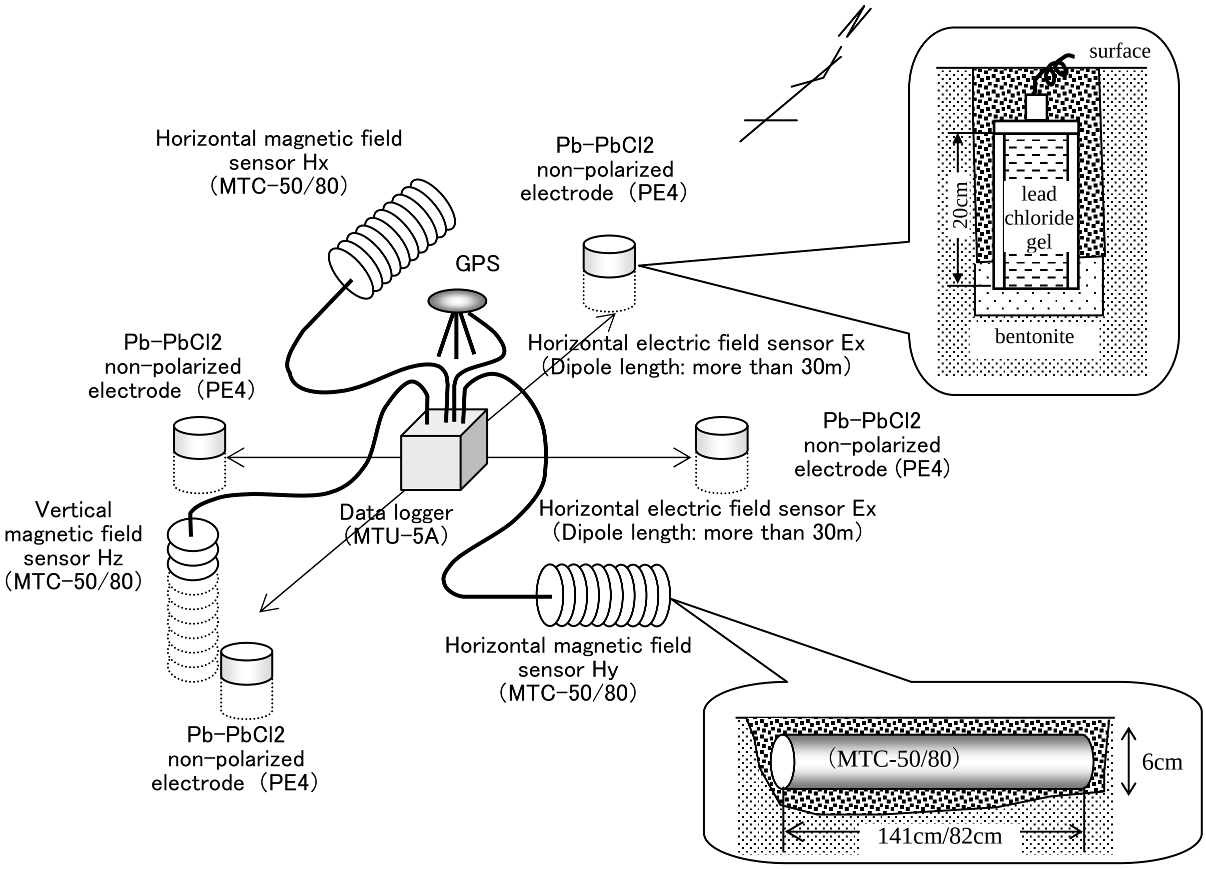


Figure A.6.2 Schematic drawing for deployment of MT data acquisition system

(3) Data Processing

The time series data including 3 components of magnetic field and 2 components of electric field acquired by data logger were moved to the laptop computer soon in the field after finishing the measurement. each component of the time series data was processed by Fourier transform and each power spectrum at every frequency f (Hz) was obtained. The spectral ratios of horizontal magnetic field Hx(f) and Hy(f), electric field Ex(f) and Ey(f) compose each component of impedance tensor Z(f) at every frequency. The mutually-perpendicular resistivity ρxy(f), ρyx(f) and phase difference $\Delta\phi$xy(f), $\Delta\phi$yx(f) were computed from the impedance tensor Z(f) using the next equation.

$$\rho_{xy}(f) = \frac{1}{2\pi f\mu}\left|\mathbf{Z}_{xy}(f)\right| = \frac{1}{5f}\frac{\left|\mathbf{E}_x(f)\right|}{\left|\mathbf{H}_y(f)\right|},\quad \Delta\phi_{xv}(f) = \phi\{\mathbf{H}_y(f)\} - \phi\{\mathbf{E}_x(f)\}$$

$$\rho_{yx}(f) = \frac{1}{2\pi f\mu}\left|\mathbf{Z}_{yx}(f)\right| = \frac{1}{5f}\frac{\left|\mathbf{E}_y(f)\right|}{\left|\mathbf{H}_x(f)\right|},\quad \Delta\phi_{xv}(f) = \phi\{\mathbf{H}_y(f)\} - \phi\{\mathbf{E}_x(f)\}$$

Where,

f: frequency (Hz), π: the ratio of the circumference of a circle to its diameter, μ: magnetic permeability

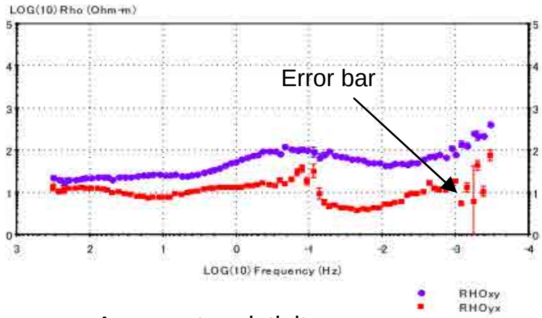
$|\mathbf{E}_x(f)|$、$|\mathbf{E}_y(f)|$: intensity of electric field (V/m), $|\mathbf{H}_x(f)|$, $|\mathbf{H}_y(f)|$: intensity of magnetic field (nT)

$\phi\{\mathbf{E}_x(f)\}$, $\phi\{\mathbf{E}_y(f)\}$: phase of electric field (degree), $\phi\{\mathbf{H}_x(f)\}$, $\phi\{\mathbf{H}_y(f)\}$: phase of magnetic field (degree)

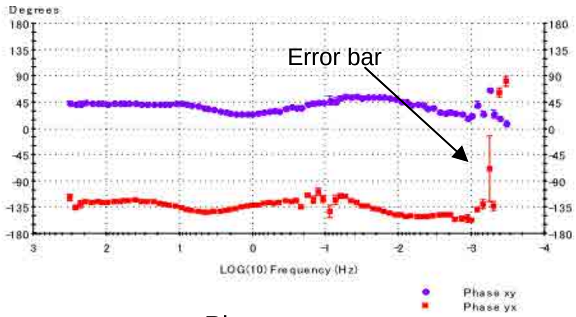
Calculated resistivity ρxy(f) and ρyx(f) mean exact resistivity in case that the ground resistivity is equal. Actually, as they mean approximate resistivity because of the unequal ground resistivity, it is called "apparent resistivity" in MT method. Phase difference is called "phase" ϕxy(f), ϕyx(f). An example of apparent resistivity and phase curve is shown in Figure A.6.3.

In the project, the observed time series data were divided to 20 segments and each apparent resistivity and phase is calculated at every segment. 20 processed values were obtained at every frequency and statistically

mean and variance are calculated and variance is expressed as error bar on apparent resistivity curve or phase curve. Generally, it is desirable and means high quality to have low scatter, moderate curvature and well-joined frequency-band curve segments. Data processing by using only the observation data at survey station is called local processing. In the project, after downloading data to the laptop computer, the local processing was done and data quality of the observed data was estimated with the apparent resistivity and phase curve.



Apparent resistivity curve



Phase curve

Figure A.6.3 An example of an apparent resistivity and phase curve

About data processing of this survey, at 80 frequencies in the range between 320Hz ~ 0.00034Hz of MT data, each impedance tensor Z(f) was computed.

After the field survey finishing, by using the acquired data at remote reference station, the remote reference processing technique was applied to the acquired data at survey stations to remove local noises. A concept of remote reference processing is given in Figure A.6.4. Both the observed data and the remote reference data have artificial electromagnetic noises generated by power lines, residences, and traffic of vehicles etc. in circles of Figure. If the distance between the survey site and the remote reference station is fully far, the correlation of the signal is good and at the same time, noise shows no correlation. Therefore after cross-correlation data processing, the processed data without noise are created.

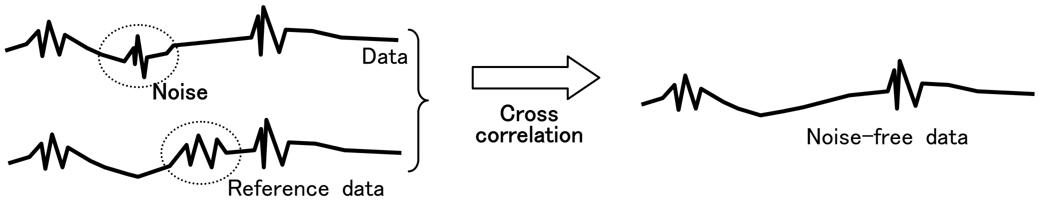


Figure A.6.4 A concept of remote reference processing

SSMT2000 software of Phoenix Geophysics was used for a series of remote reference data processing technique. The processed data were edited by selecting the segment with high S/N at every frequency so that the apparent resistivity and phase curves have small error bar and smooth curvature. For edit, MT-editor software of Phoenix Geophysics was used.

(4) Data Analysis

As mentioned above, the apparent resistivity ρxy(f) and ρyx(f) computed through data processing just indicate the mean value of resistivity to the exploration depth (about 0.707times skin depth). 2D inversion analysis was executed using apparent resistivity and phase curves to infer the resistivity structure.

For data analysis, considering the comprehensive strike direction of the survey site, profiles were set up and y axis was put in the direction of the profile and x axis was put in the perpendicular direction of the profile.

Impedance tensor was rotated and the apparent resistivity from the combination of electric field of x direction and magnetic field of y direction as TE mode (parallel to structure) and the apparent resistivity from the combination of electric field of y direction and magnetic field of x direction as TM mode (perpendicular to structure) are computed respectively and used for 2D inversion as input data.

In 2D inversion , under the assumption that the resistivity structure doesn’t change and continue infinitely in the direction perpendicular to profile, 2D resistivity model is computed automatically so that the response of 2D resistivity model fits to the observed impedance. The resistivity value of each cell in the resistivity model is calculated from all apparent resistivities of the profile by non-linear least squares method. As apparent resistivity of adjacent survey station and adjacent resistivity cell are considered, a relatively continuous model is obtain as reasonable analysis result.

In the project, 2D resistivity inversion analysis was executed using WinGLink of Schlumberger Inc. which has an function of 2D inversion. The cross section of profile is composed by the elements of finite element method for model calculation and resistivity cells combined by elements. The size of the element and the resistivity cell are made enough fine at shallow zone and larger to the direction of marginal and deep zone.

And next, the homogeneous model of 100 ohm-m resistivity is used as initial model and the response of resistivity model by finite element method was computed at each survey station. Comparing the calculated apparent resistivity with the observed apparent resistivity, the iteration of correcting resistivity was continued until RMS (abbreviation of Root Mean Square) error becomes less than the threshold.

A6.2.2 TEM Survey

(1) Principle of Method

TEM method is an abbreviation for transient electromagnetic method. It means a method that observes the transients of magnetic field after turning off an input artificial magnetic field (Figure A.6.5).

An artificial magnetic field is transmitted in a vertical direction when an electric current flows in an electric square loop on the ground (transmission loop). The loop may be rectangle or circle. When the electric current is turned off, a secondary electric current starts in the ground in a circle to maintain the input magnetic field. This current gradually spreads under the ground further. This current is called the eddy current, or often called "smoke ring" comparing to the smoke loop from cigar. The input artificial magnetic field decays in time and its rate is less where the resistivity is low. The resistivity of the subsurface is estimated by measuring the decay of the artificial magnetic field by an induction (receiver) coil. The decay immediately after stopping the current signal (early time response) indicates resistivity at shallow ground and the late time response resistivity at deeper parts.

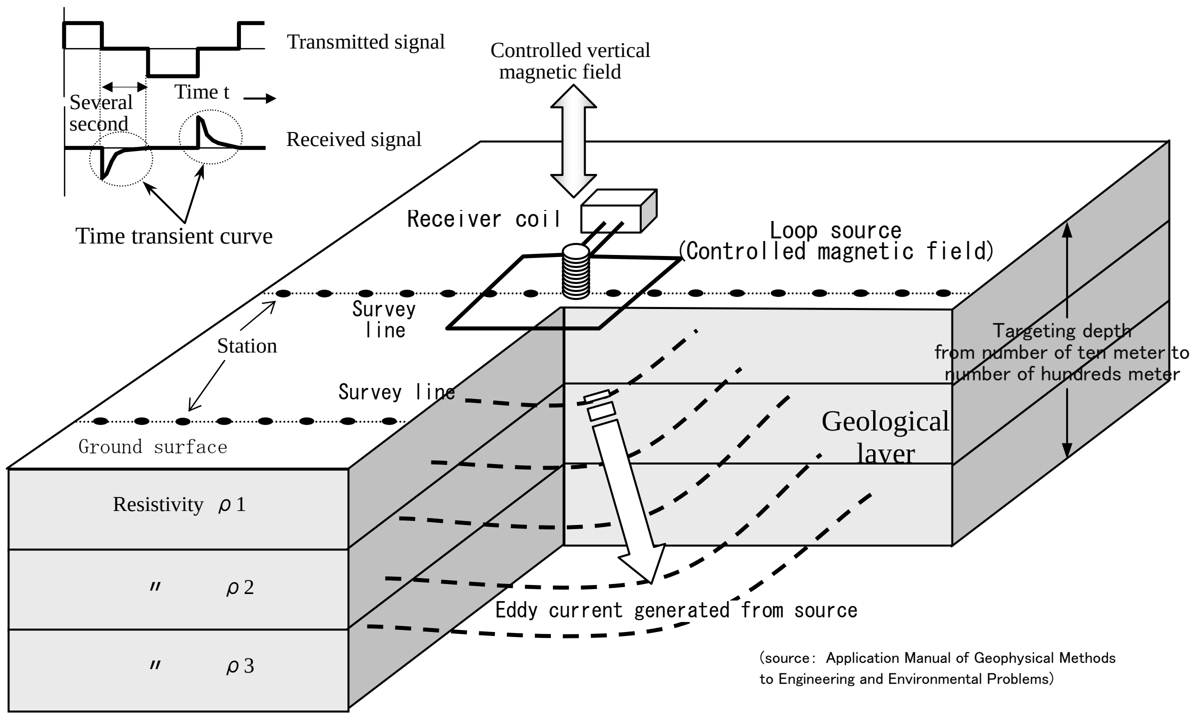


Figure A.6.5 Schematic diagram of principles of TEM method

Especially, TEM method is useful to the structure which shows low resistivity (high conductance) due to groundwater, argillation, weathered deep layer, alteration etc.

The diffusion depth δ (m) is regarded as a rule of thumb of the exploration depth for TEM method and it is estimated as the following equation.

$$\delta = \sqrt{\frac{2t\rho}{\mu}}$$

Where, ρ: ground resistivity (ohm-m), t: time after turning off the primary field (sec), μ: magnetic permeability

This equation shows that the higher the resistivity and the longer the time, the deeper the exploration depth into the ground.

It is difficult to investigate the structure under the distribution of low resistivity with electric methods at the survey site where low resistivity distributes such as argillation or alteration at the shallower zone. But TEM method is available to investigate deeper zone. Especially, in the survey site where argillation or saline groundwater exists at the surface layer TEM method is suitable.

(2) Measurement Method

In the project, TEM method is used for static correction of MT data. As about 100m is needed as exploration depth, 40m square loop was set up on the ground and the current was passed by the portable transmitter to induce magnetic field. After turning off the current, the transient response of magnetic field was measured by the induction coil in the center of the loop for a few times in central loop system. Figure A.6.6 shows the survey schematic drawing for deployment of TEM data acquisition system in the project. PROTEM CM HP system of Geonics Limited was used and the transient response of vertical magnetic field was measured at each station. The transmitter current is about 1A, the number of time windows is 20, the number of stacks is more than 10 times and 3 kinds of the repeat rate 237.5Hx, 62.5Hz and 25.0Hz were mainly used. TEM measurement system of Phoenix V8 was used, too at several stations in Boseti site to make the survey period short. In this case, 200m square loop was used as transmitter source.

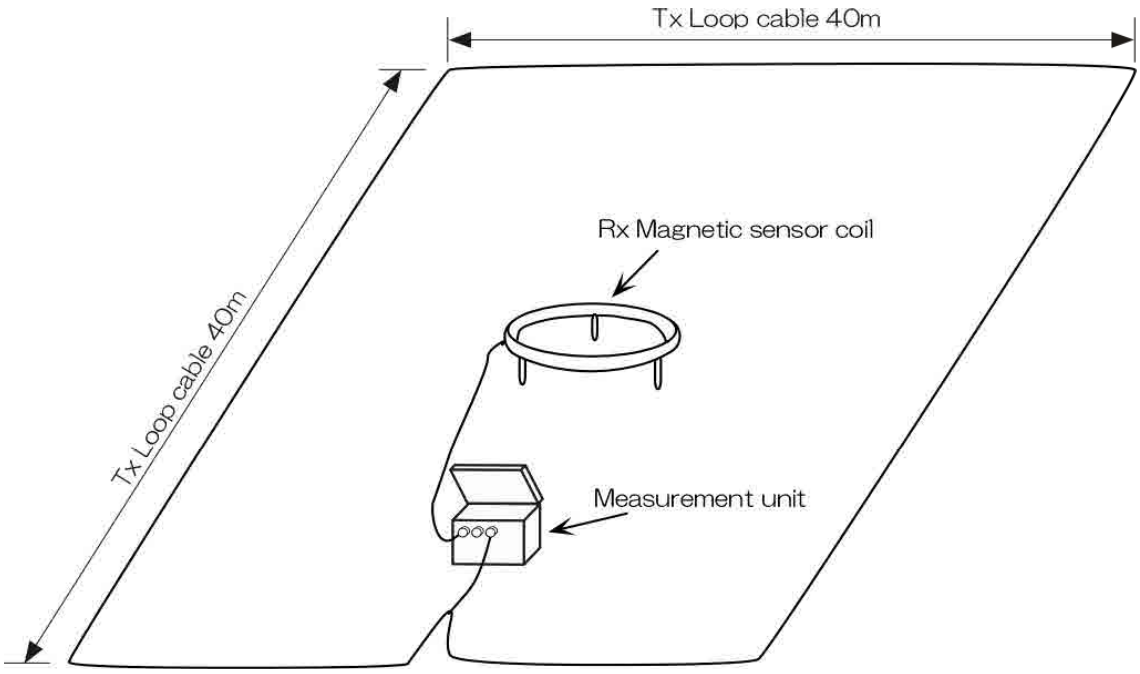
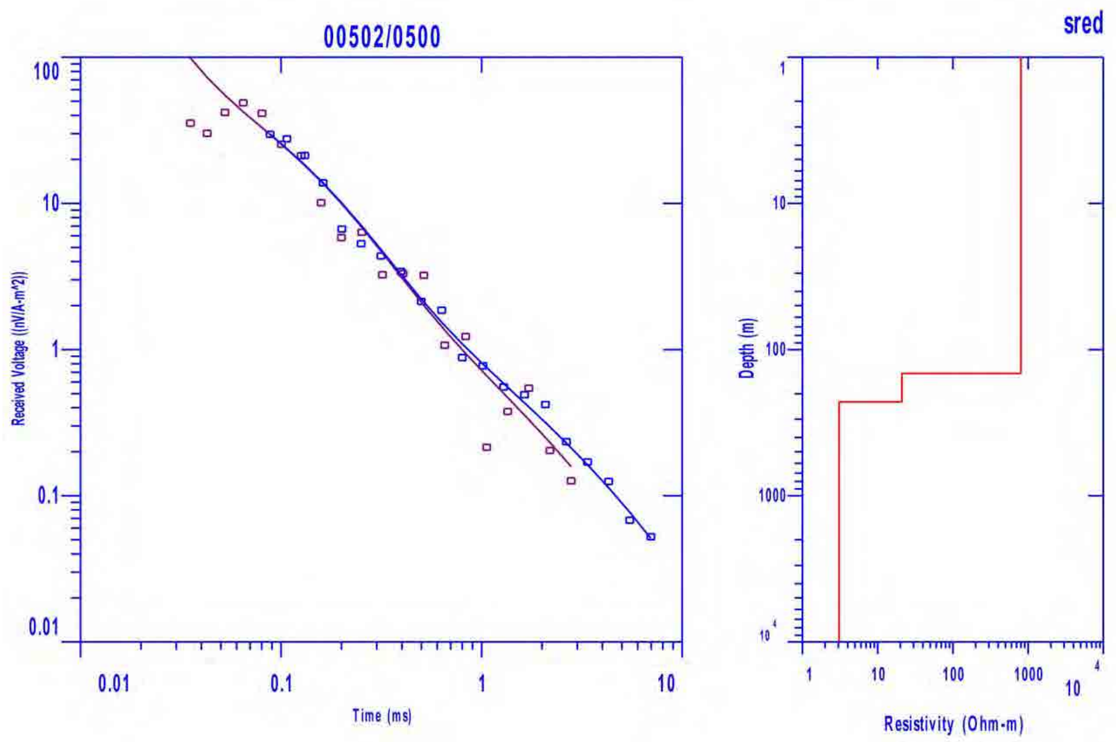


Figure A.6.6 Schematic drawing for deployment of TEM data acquisition system

(3) Data Processing and Analysis

The 1D inversion analysis was carried out from the acquired TEM data. The analysis software is IX1D of Interpex Limited. At each survey station, 5 or 6 layers structure was assumed and the values of resistivity and layer's thickness of the 1D layered model was obtained by 1D inversion analysis so that the transient response of the 1D layered model fitted the observed transient response. An example of the acquired TEM data and the result of 1D layered inversion analysis is shown in Figure A.6.7.



Observed data: □ and calculated curve: solid line (left) and 1D inversion result (right)

Figure A.6.7 An example of TEM data analysis

(4) Static Correction of MT data

An important feature in the data processes with MT method is static shift. The apparent resistivity curve in Figure A.6.8 contains a static shift caused by a local resistivity anomaly in the shallow ground near the survey station. Before starting the analysis, it is necessary to move the apparent resistivity curve back to its normal position, where it would be without the anomaly. A qualitative process is used for this purpose, incorporating shallow resistivity information by resistivity or other electromagnetic methods like TEM, or the difference in a pair of apparent resistivity of higher frequency band.

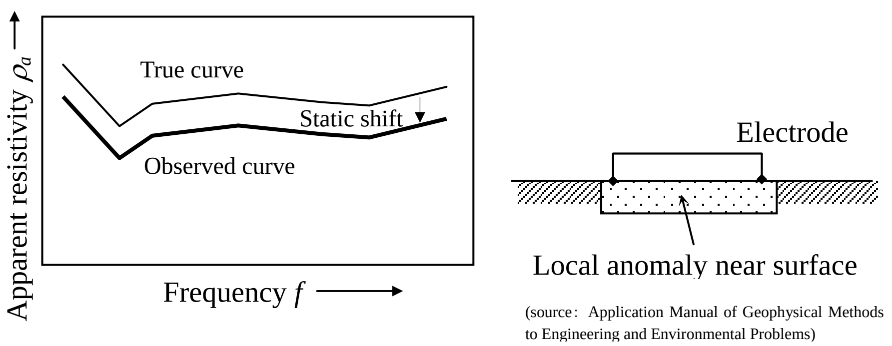


Figure A.6.8 Static-shift due to a near-surface anomaly

In the project, TEM measurement was taken at the same station as MT measurement and 1D inversion analysis for TEM data was executed. By using the result of the analysis, the static correction was applied to MT data. MT response of the analyzed 1D model calculated and the apparent resistivity curve of MT data was shifted so that the curve of MT data in the highest frequency match MT response curve from 1D data analysis of TEM. The list of shift value for each station is at the back of the report.

A6.2 Results of the Survey

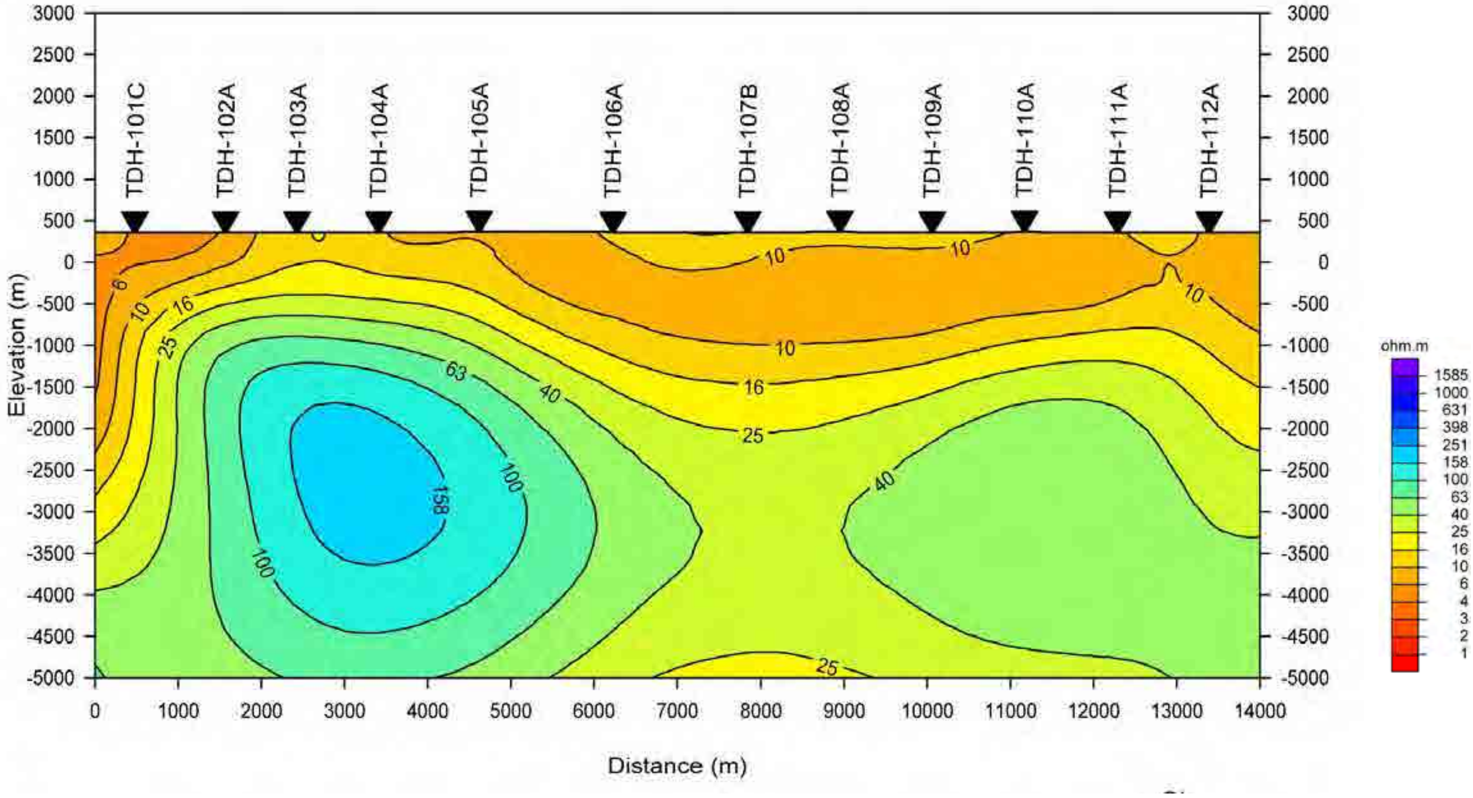
Result of the Survey at 2 sites are attached herewith.

Locations of MT stations (Tendaho-2[Ayrobera] site)

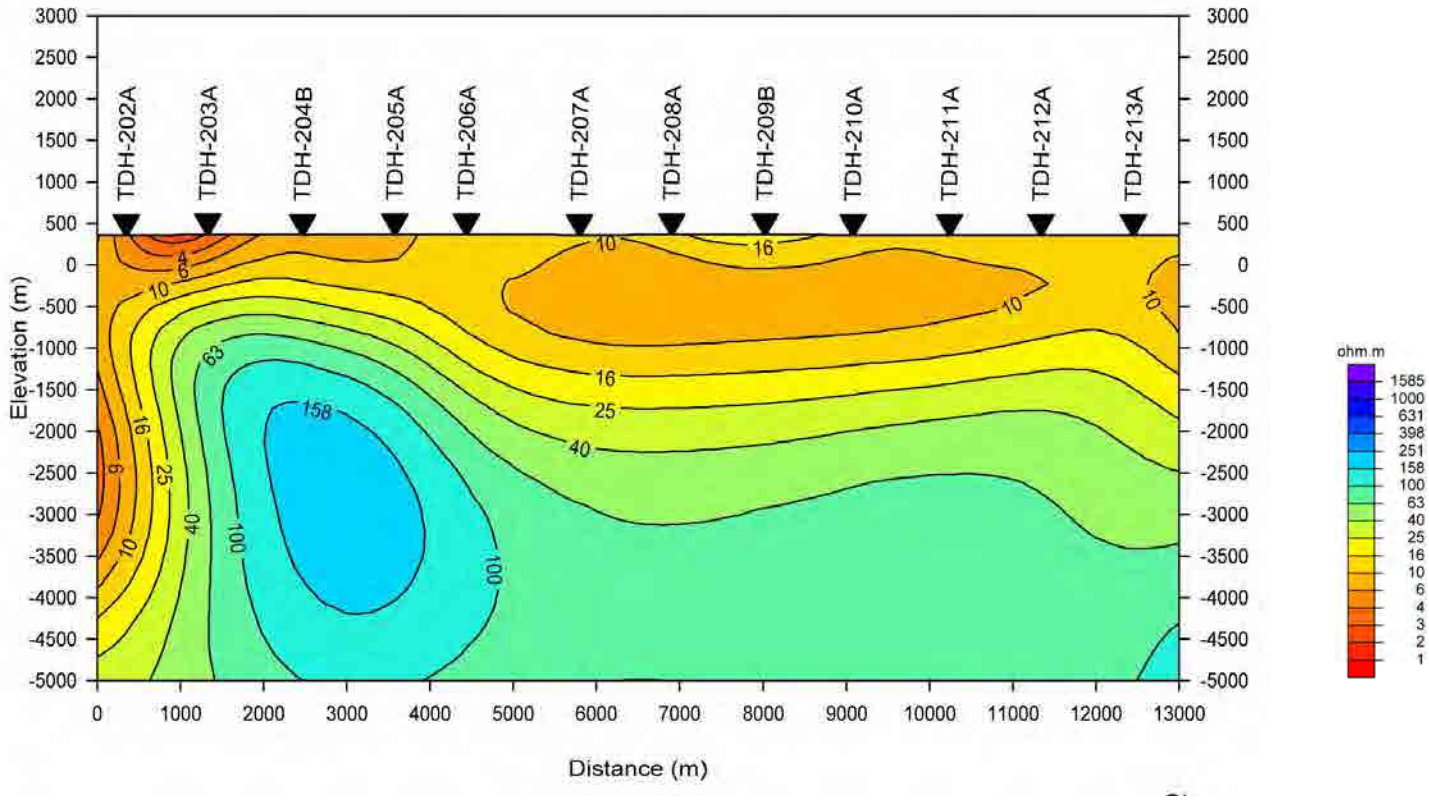
Station	Coordinate (WGS84)		Elevation (m)
	Latitude	Longitude	
TDH-101	11°55'0.4"	41°1'48.6"	356
TDH-102	11°55'20.2"	41°2'18.9"	360
TDH-103	11°55'33.1"	41°2'44.2"	358
TDH-104	11°55'49.4"	41°3'11.9"	361
TDH-105	11°56'8.6"	41°3'47.0"	366
TDH-106	11°56'41.3"	41°4'28.7"	365
TDH-107	11°57'4.4"	41°5'17.0"	363
TDH-108	11°57'23.3"	41°5'48.2"	366
TDH-109	11°57'42.1"	41°6'19.5"	356
TDH-110	11°58'0.8"	41°6'50.8"	366
TDH-111	11°58'20.0"	41°7'22.2"	357
TDH-112	11°58'38.1"	41°7'53.3"	365
TDH-202	11°55'50.5"	41°1'49.4"	359
TDH-203	11°56'13.7"	41°2'13.0"	369
TDH-204	11°56'33.1"	41°2'45.4"	365
TDH-205	11°56'51.8"	41°3'16.8"	368
TDH-206	11°57'9.1"	41°3'39.2"	368
TDH-207	11°57'29.8"	41°4'19.0"	364
TDH-208	11°57'48.2"	41°4'50.5"	366
TDH-209	11°58'6.9"	41°5'21.9"	373
TDH-210	11°58'23.4"	41°5'52.8"	362
TDH-211	11°58'44.5"	41°6'24.4"	361
TDH-212	11°59'3.2"	41°6'55.6"	357
TDH-213	11°59'22.1"	41°7'26.9"	360
TDH-900 (MT-Ref: Mille)	11°16′37.0″	40°42′16.0″	512

Locations of MT stations (Boseti site)

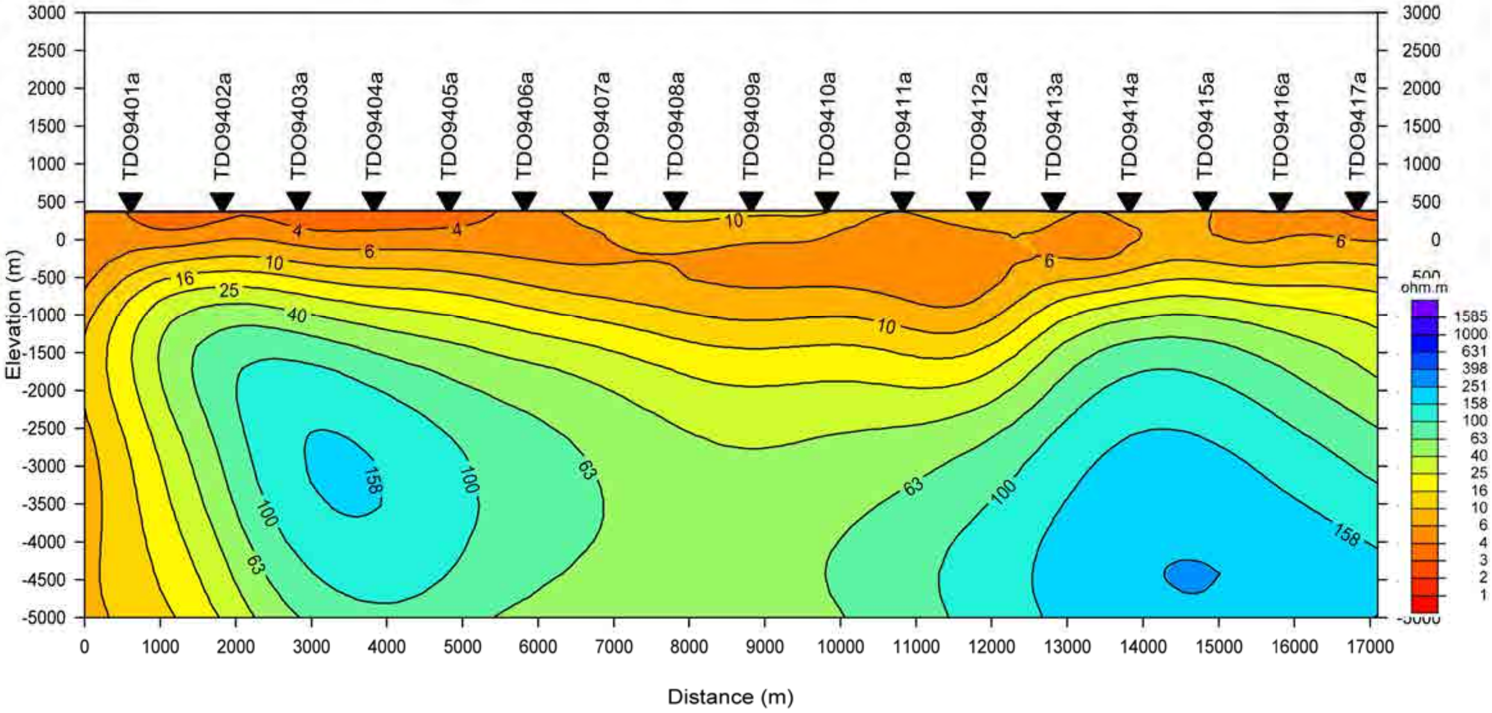
Station	Coordinate (WGS84)		Elevation (m)
	Latitude	Longitude	
BST-201	8°38'43.8"	39°29'19.0"	1411
BST-202	8°38'38.4"	39°29'51.1"	1405
BST-203	8°38'28.7"	39°30'18.1"	1463
BST-204	8°38'17.8"	39°31'1.9"	1428
BST-205	8°38'16.2"	39°31'40.8"	1456
BST-206	8°38'10.2"	39°32'8.9"	1391
BST-207	8°37'58.3"	39°32'37.3"	1339
BST-208	8°37'47.5"	39°33'7.8"	1327
BST-300	8°39'14.8"	39°29'25.4"	1383
BST-301	8°39'7.6"	39°29'59.6"	1395
BST-302	8°39'1.5"	39°30'31.1"	1386
BST-303	8°38'55.0"	39°31'4.2"	1355
BST-304	8°38'35.3"	39°31'37.6"	1392
BST-305	8°38'34.7"	39°32'16.2"	1350
BST-306	8°38'33.4"	39°32'46.8"	1319
BST-307	8°38'27.1"	39°33'25.8"	1305
BST-400	8°39'47.8"	39°29'37.3"	1365
BST-401	8°39'45.4"	39°30'13.4"	1376
BST-402	8°39'33.2"	39°30'40.4"	1353
BST-403	8°39'25.7"	39°31'16.7"	1320
BST-404	8°39'20.4"	39°31'45.8"	1316
BST-405	8°38'59.7"	39°31'41.5"	1384
BST-406	8°39'4.8"	39°33'1.5"	1304
BST-407	8°39'3.6"	39°33'57.2"	1302
BST-501	8°40'17.6"	39°29'56.0"	1341
BST-502	8°40'6.3"	39°30'49.3"	1322
BST-503	8°39'57.5"	39°31'24.3"	1301
BST-504	8°39'48.8"	39°31'51.4"	1301
BST-505	8°39'43.9"	39°32'29.5"	1303
BST-506	8°39'34.4"	39°33'6.8"	1303
BST-900 (MT-Ref: Koka)	8°28'30.7"	39°2'27.5"	1647



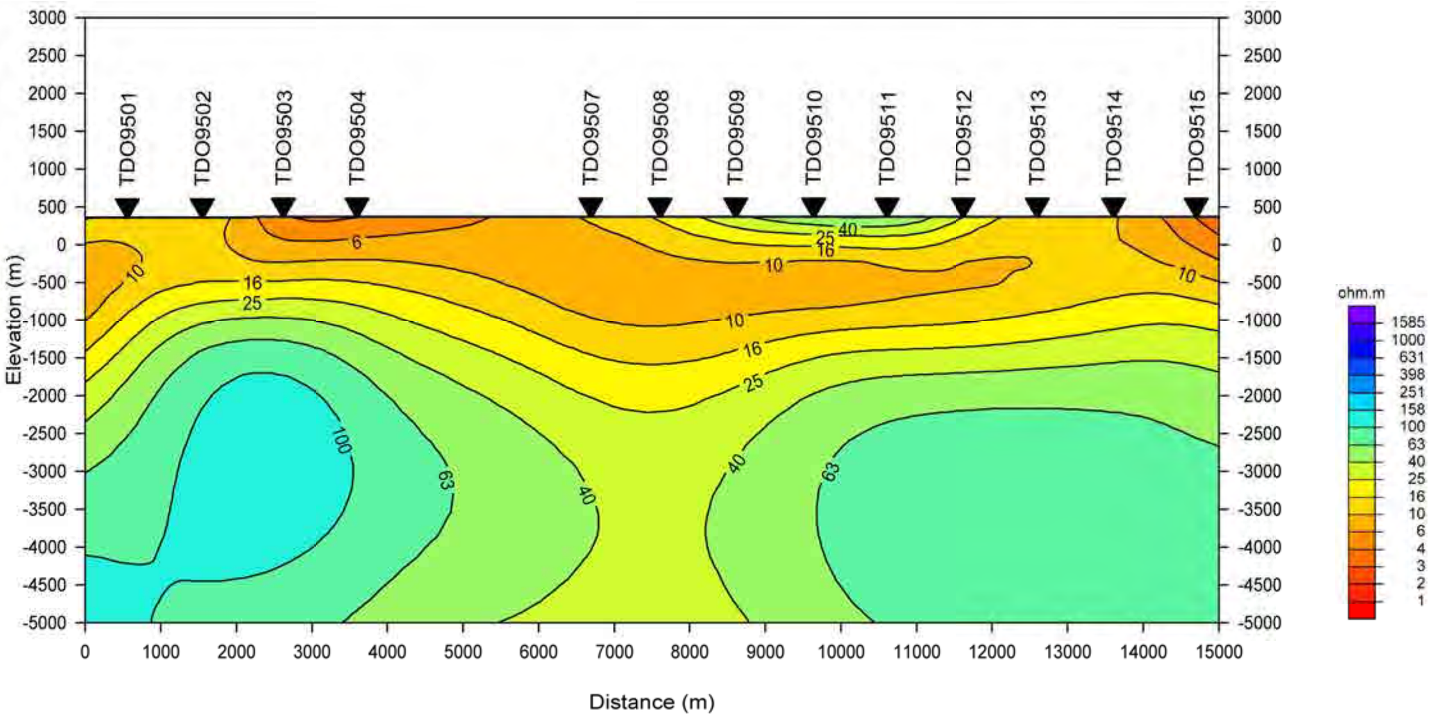
Resistivity cross section at profile 'TDH100'



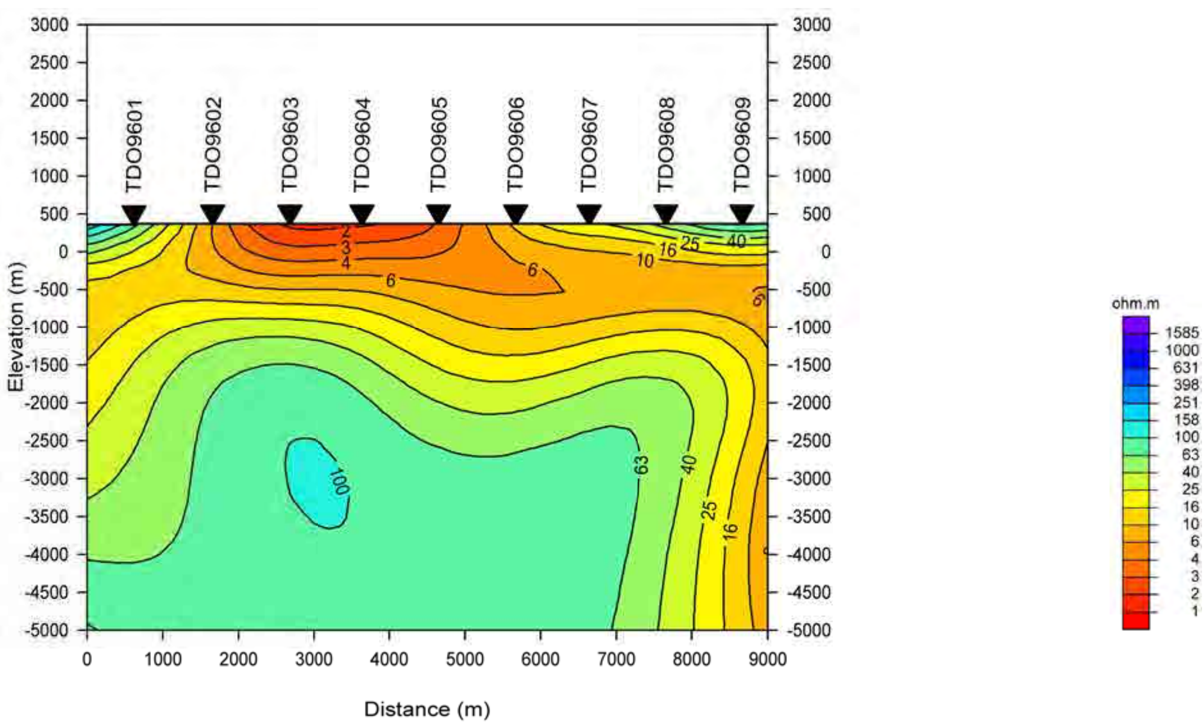
Resistivity cross section at profile 'TDH200'



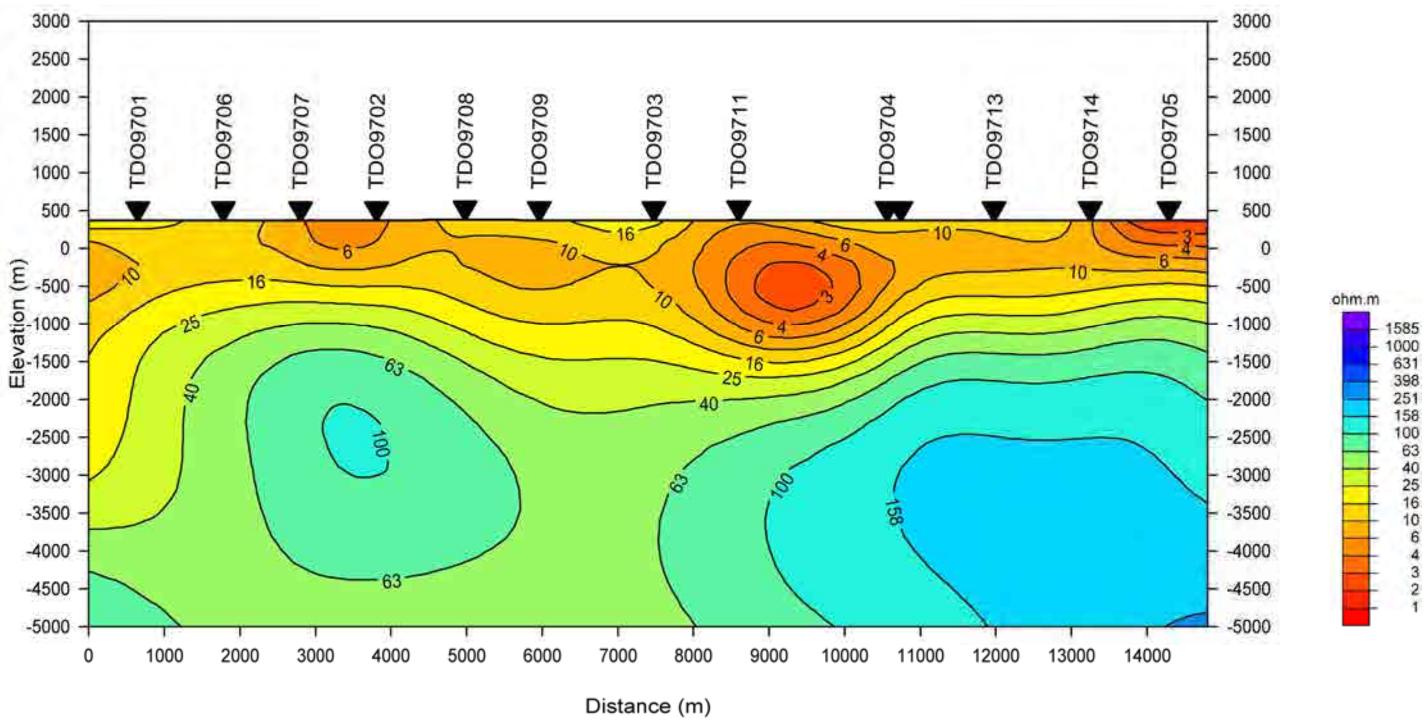
Resistivity cross section at profile 'TDO94'



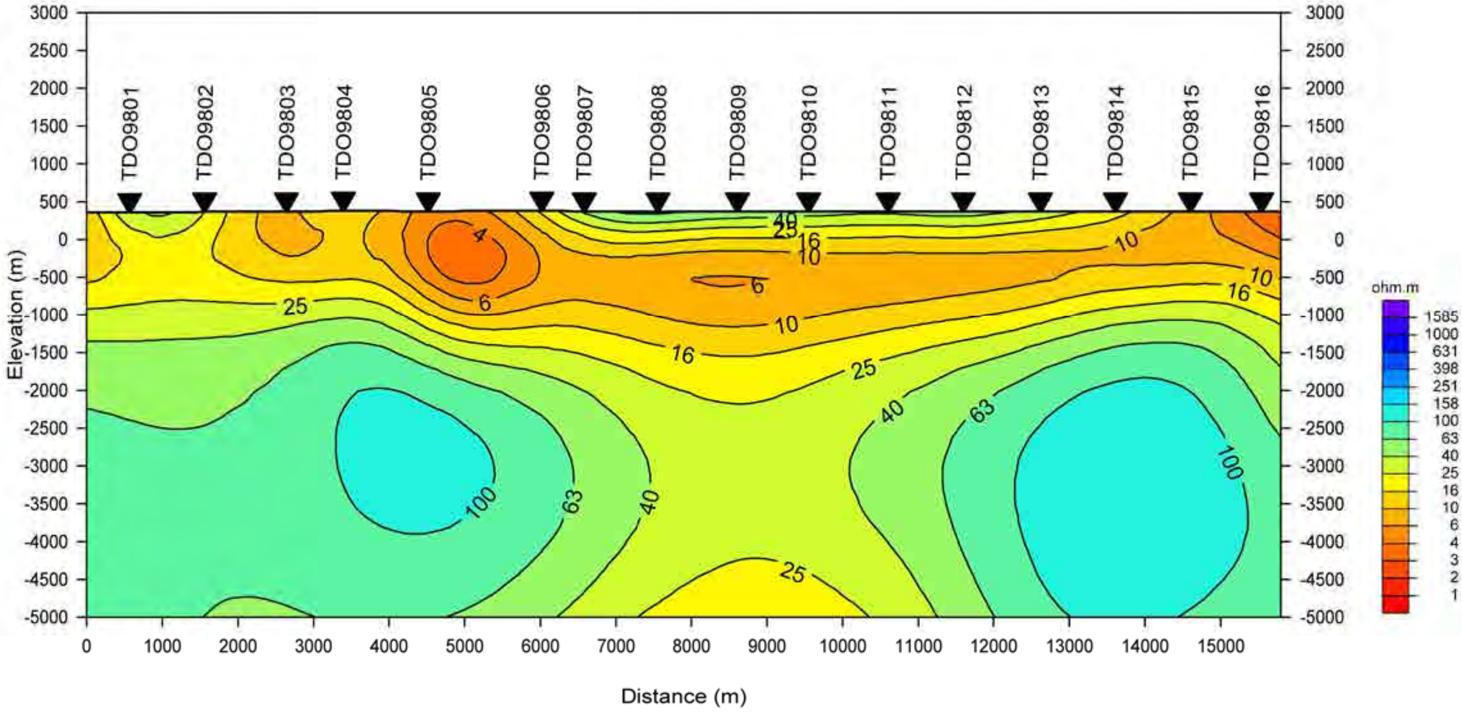
Resistivity cross section at profile 'TDO95'



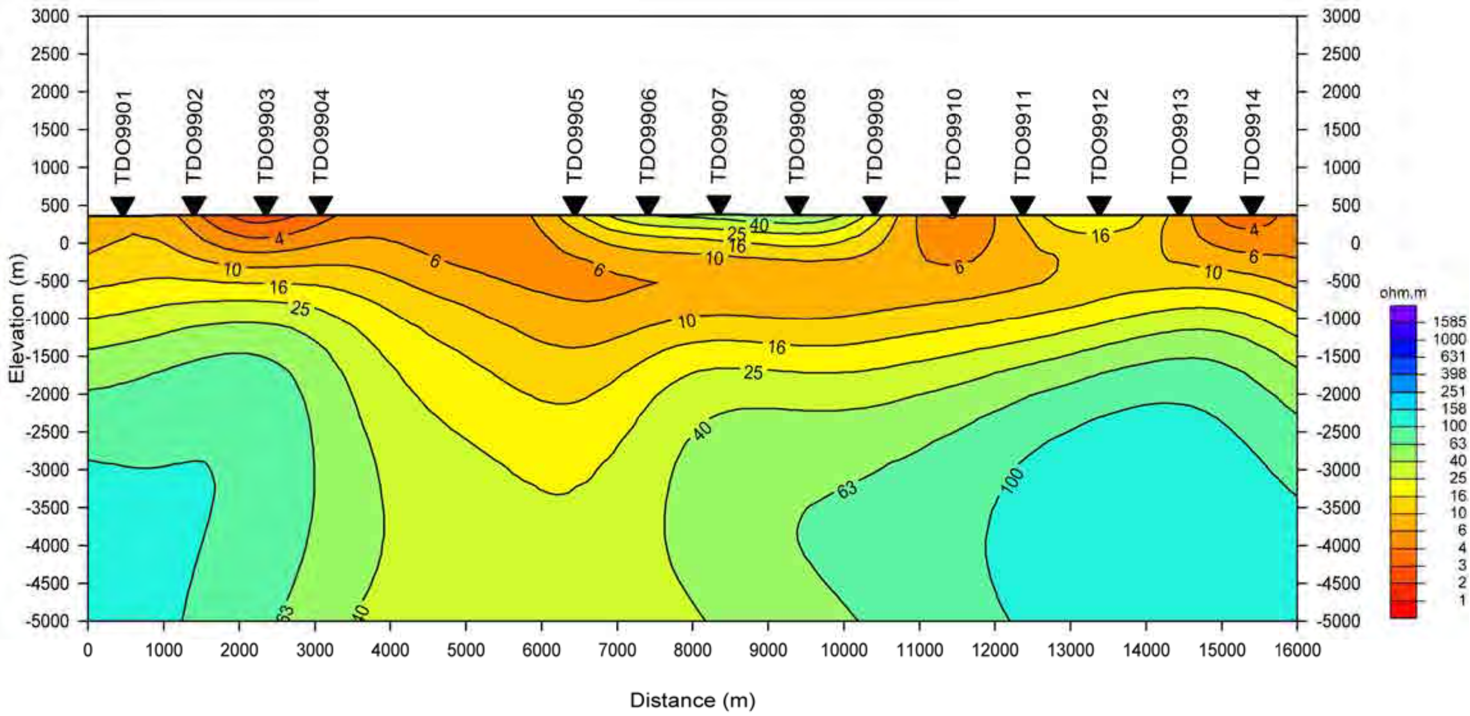
Resistivity cross section at profile 'TDO96'



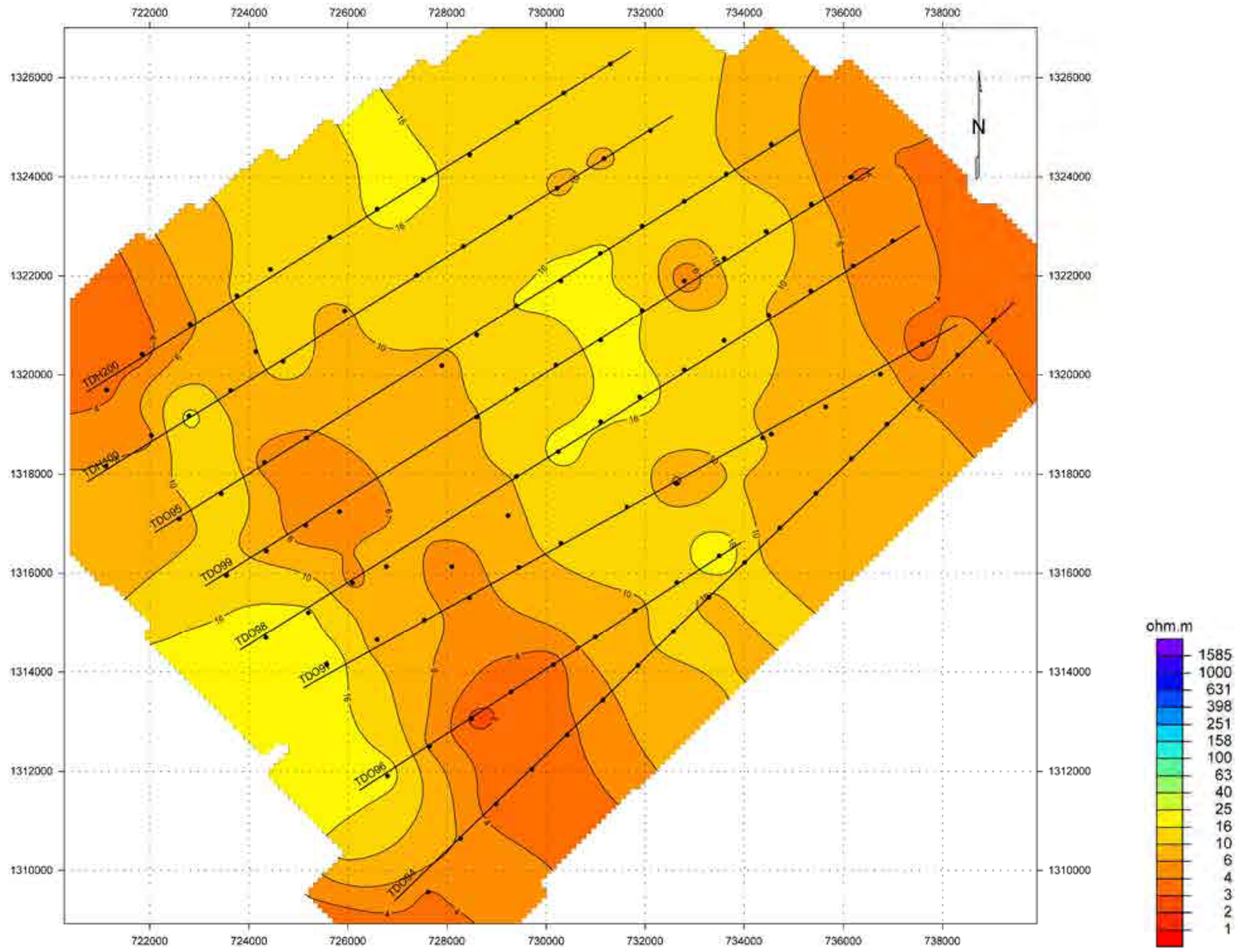
Resistivity cross section at profile 'TDO97'



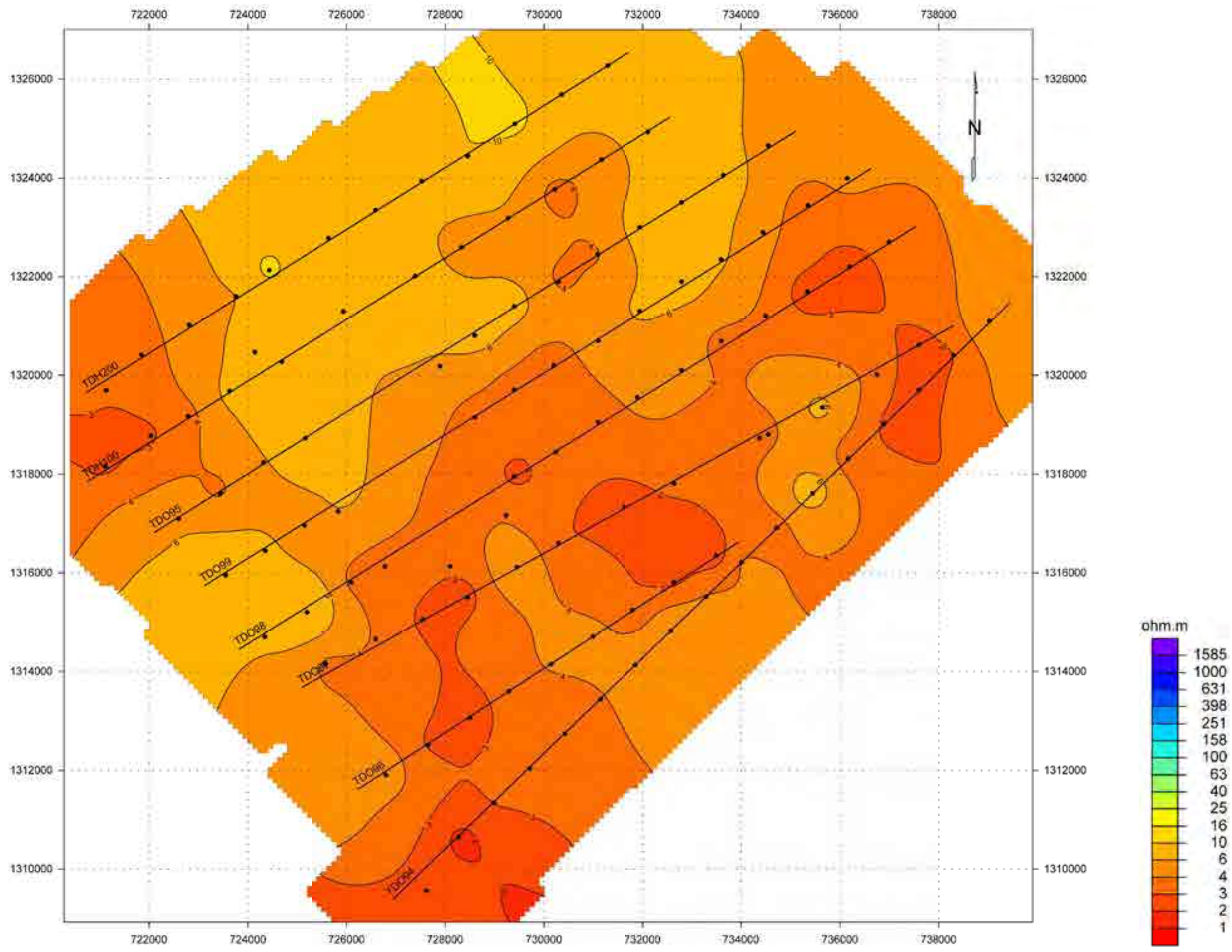
Resistivity cross section at profile 'TDO98'



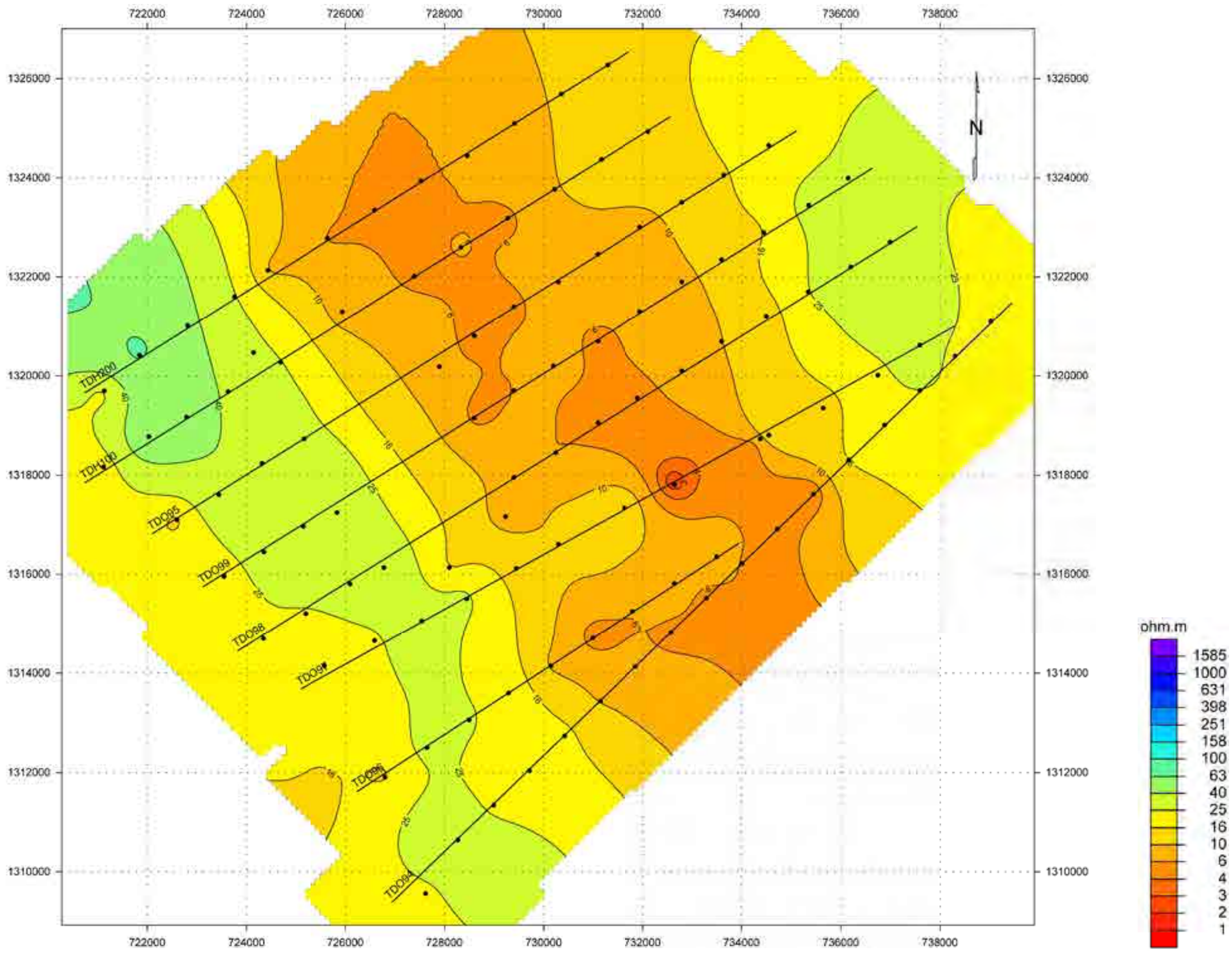
Resistivity cross section at profile 'TDO99'



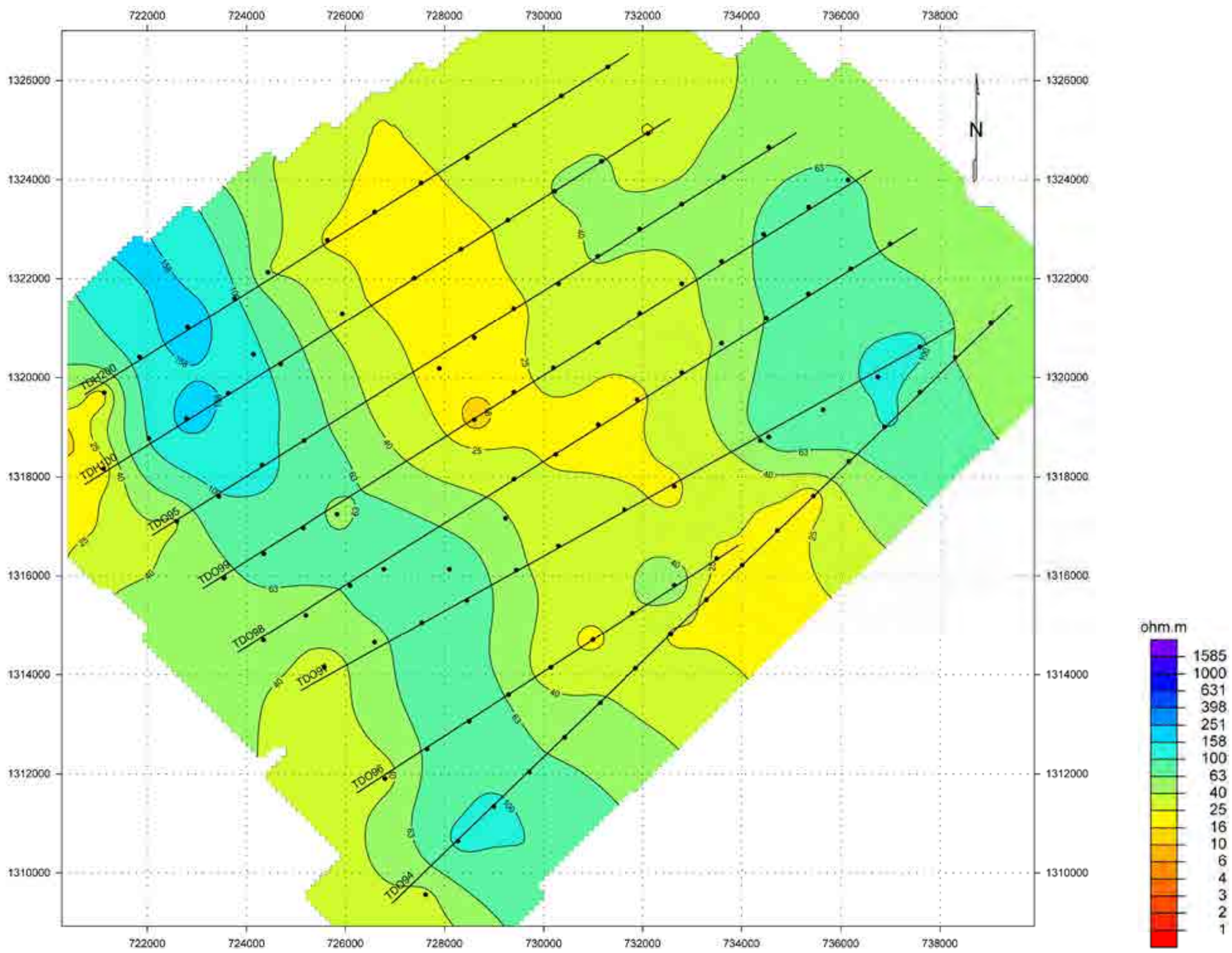
Resistivity (2D Model) at 200 m Elevation



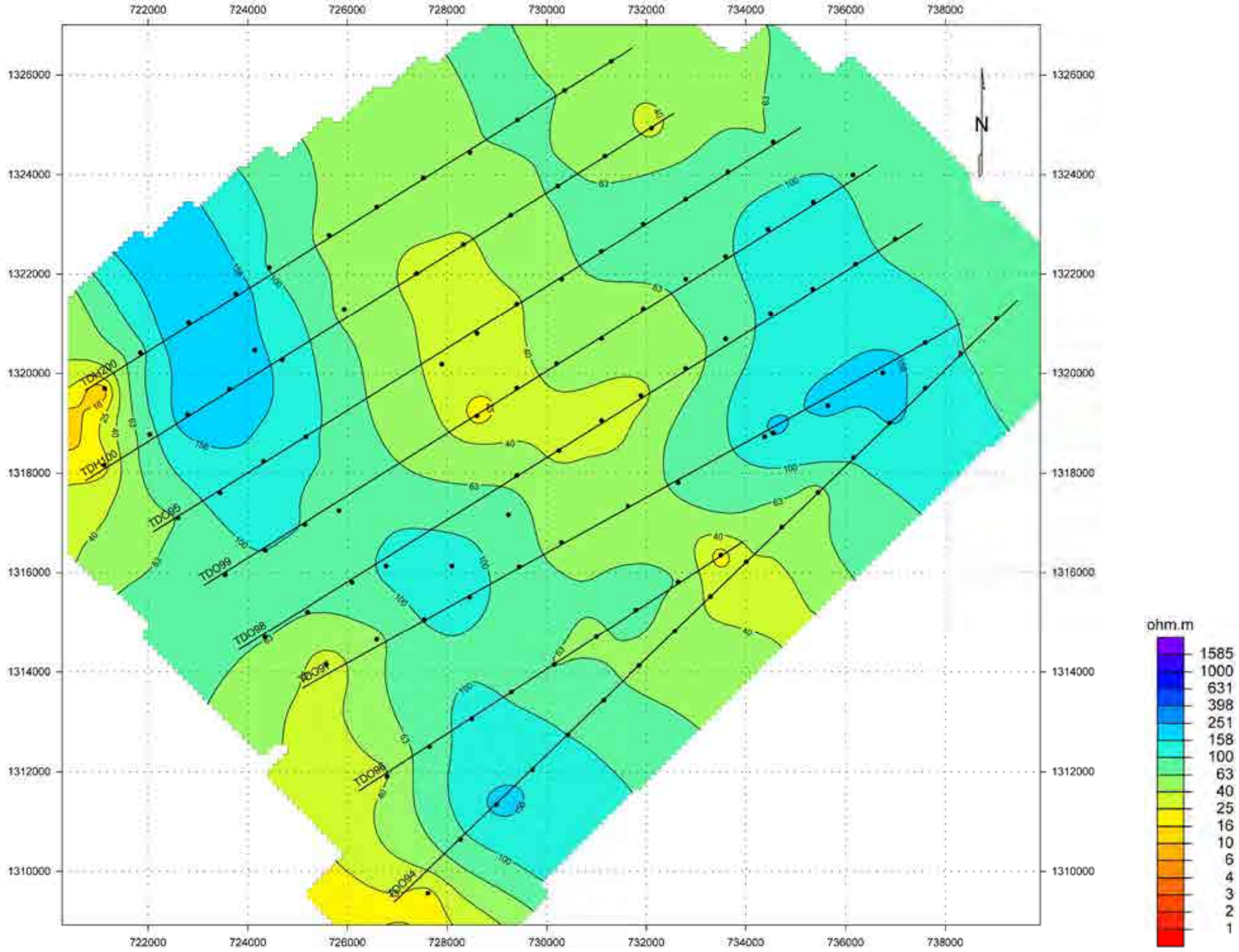
Resistivity (2D Model) at 0 m Elevation



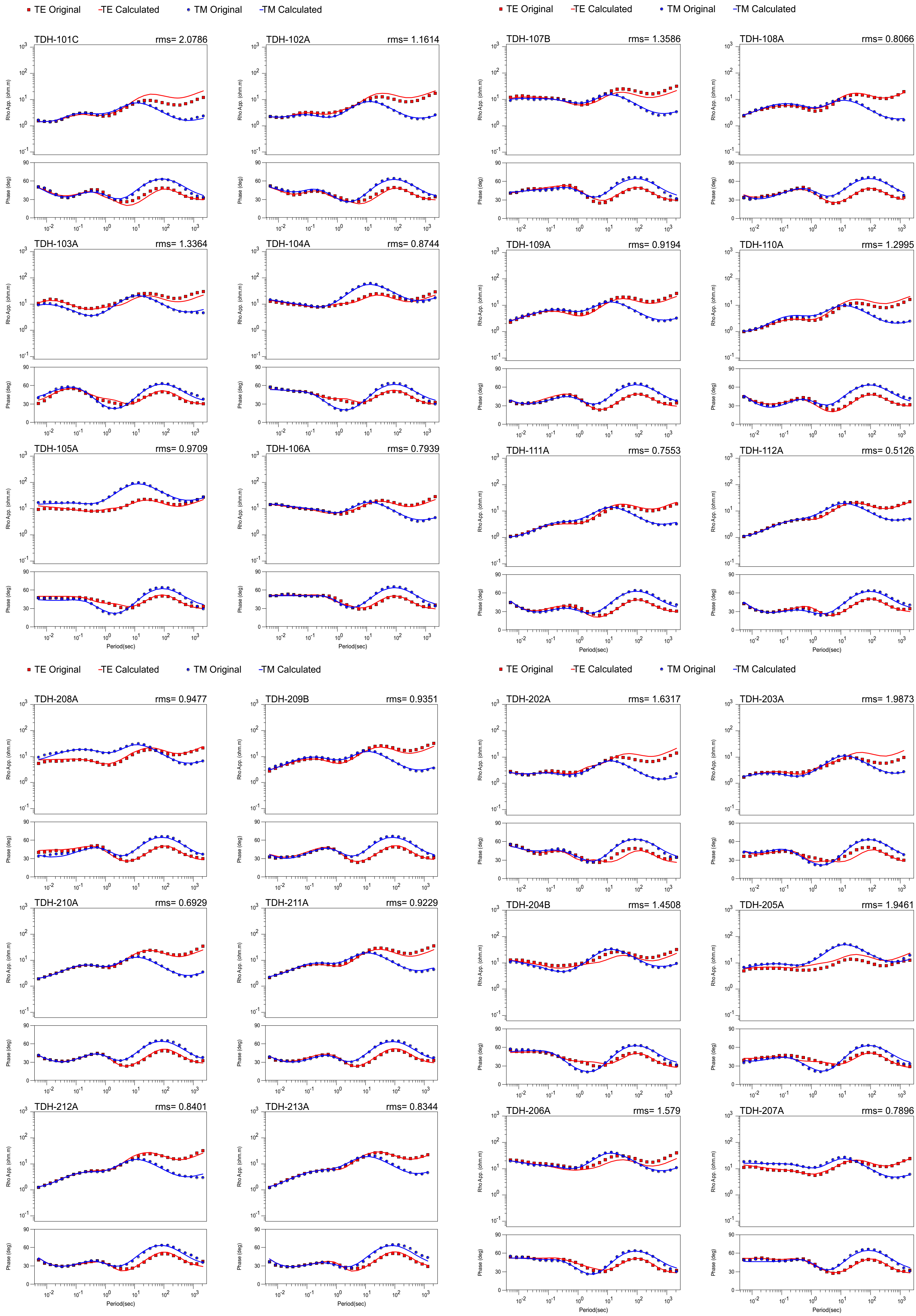
Resistivity (2D Model) at -700 m Elevation



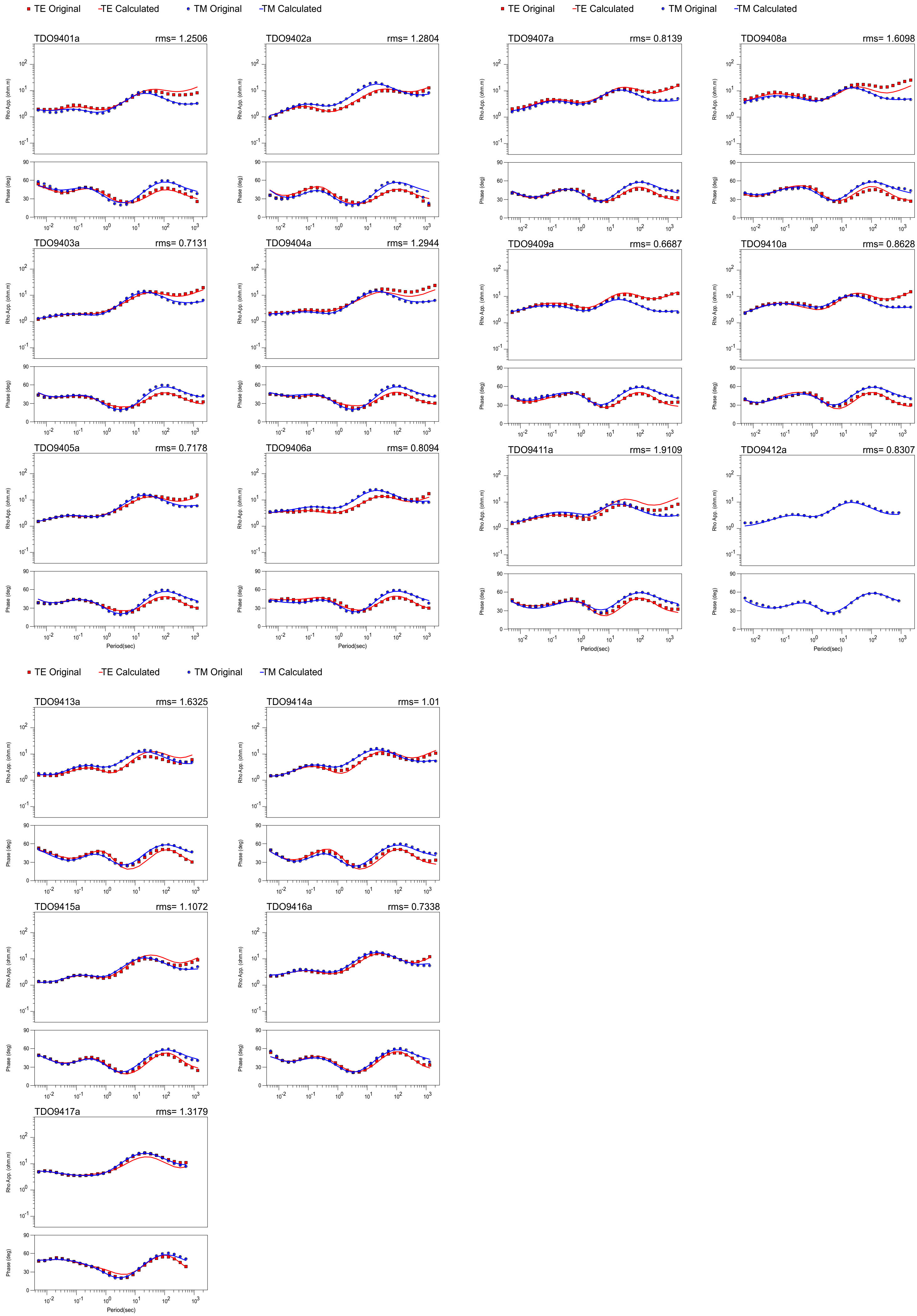
Resistivity (2D Model) at -1500 m Elevation



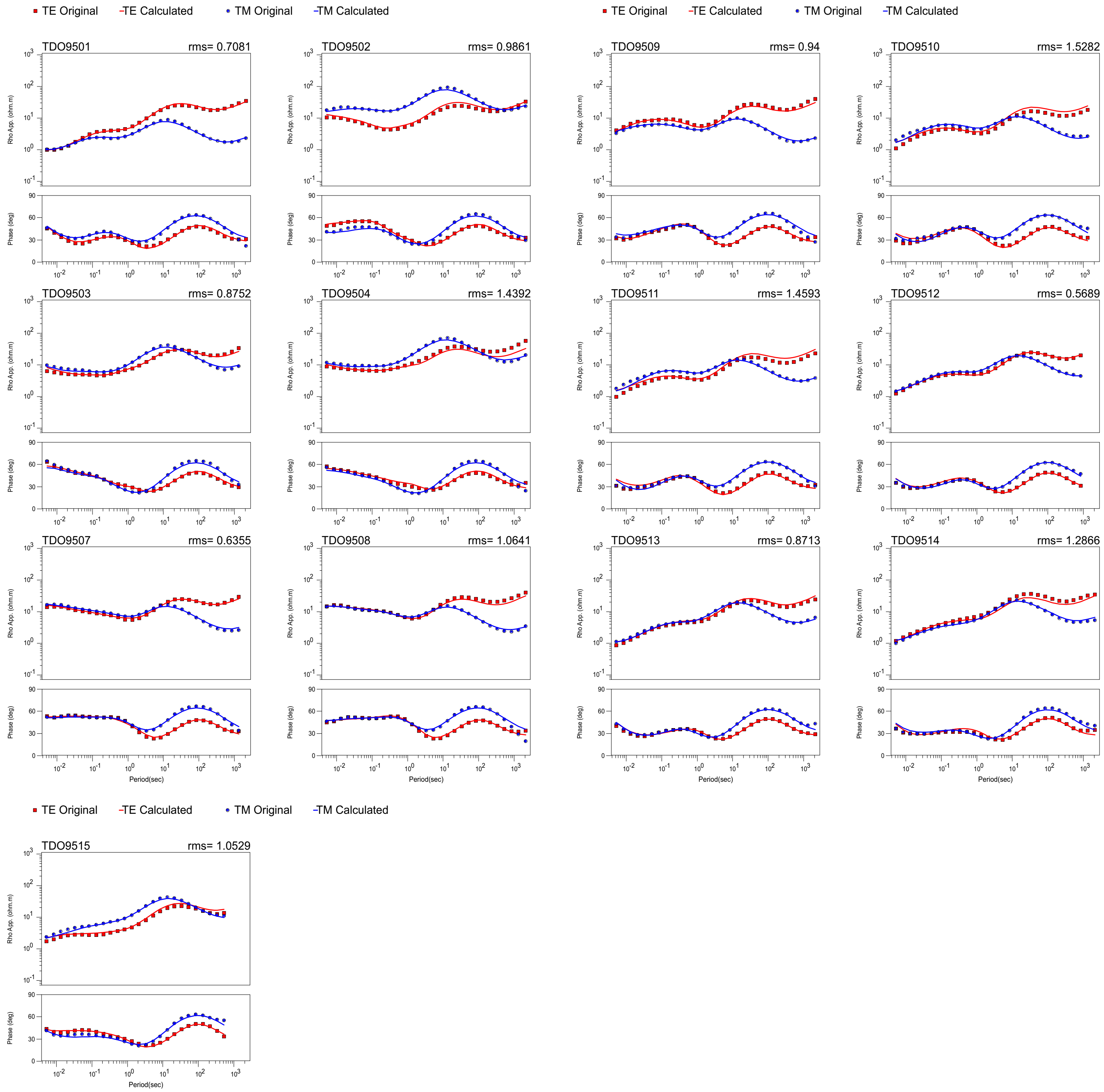
Resistivity (2D Model) at -2500 m Elevation



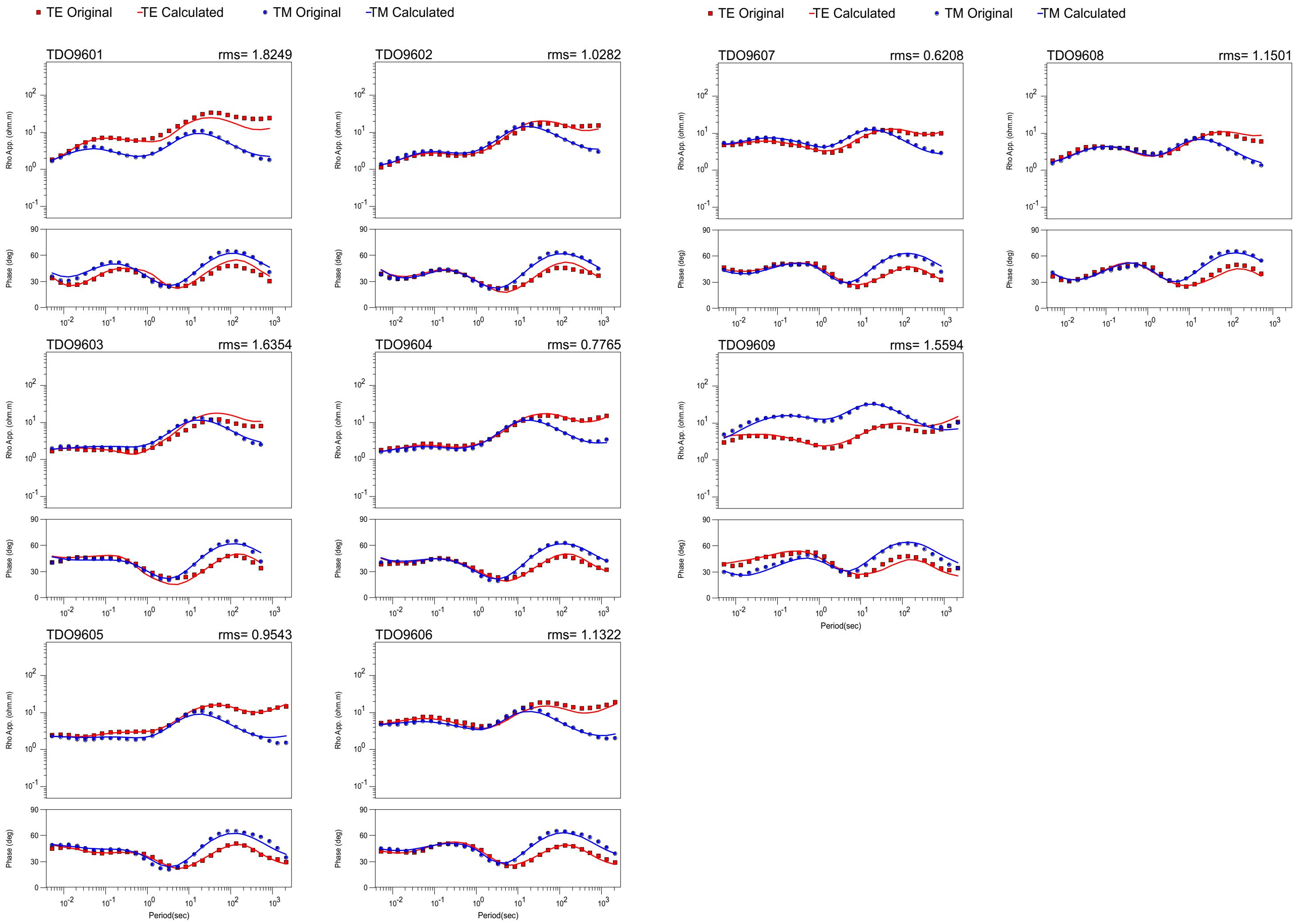
Apparent resistivity and phase curve at profile TDH100 and TDH200



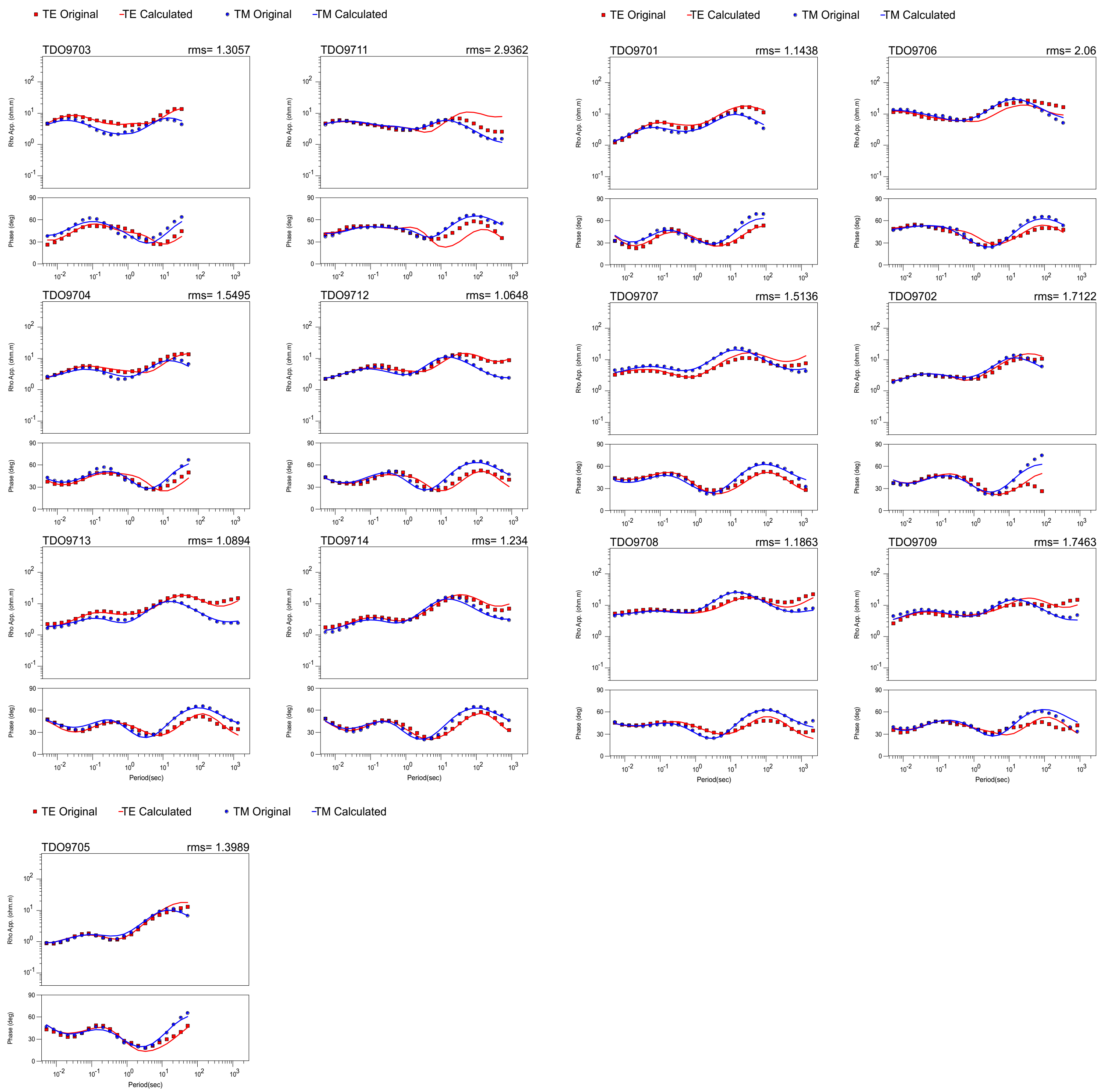
Apparent resistivity and phase curve at profile TDO94



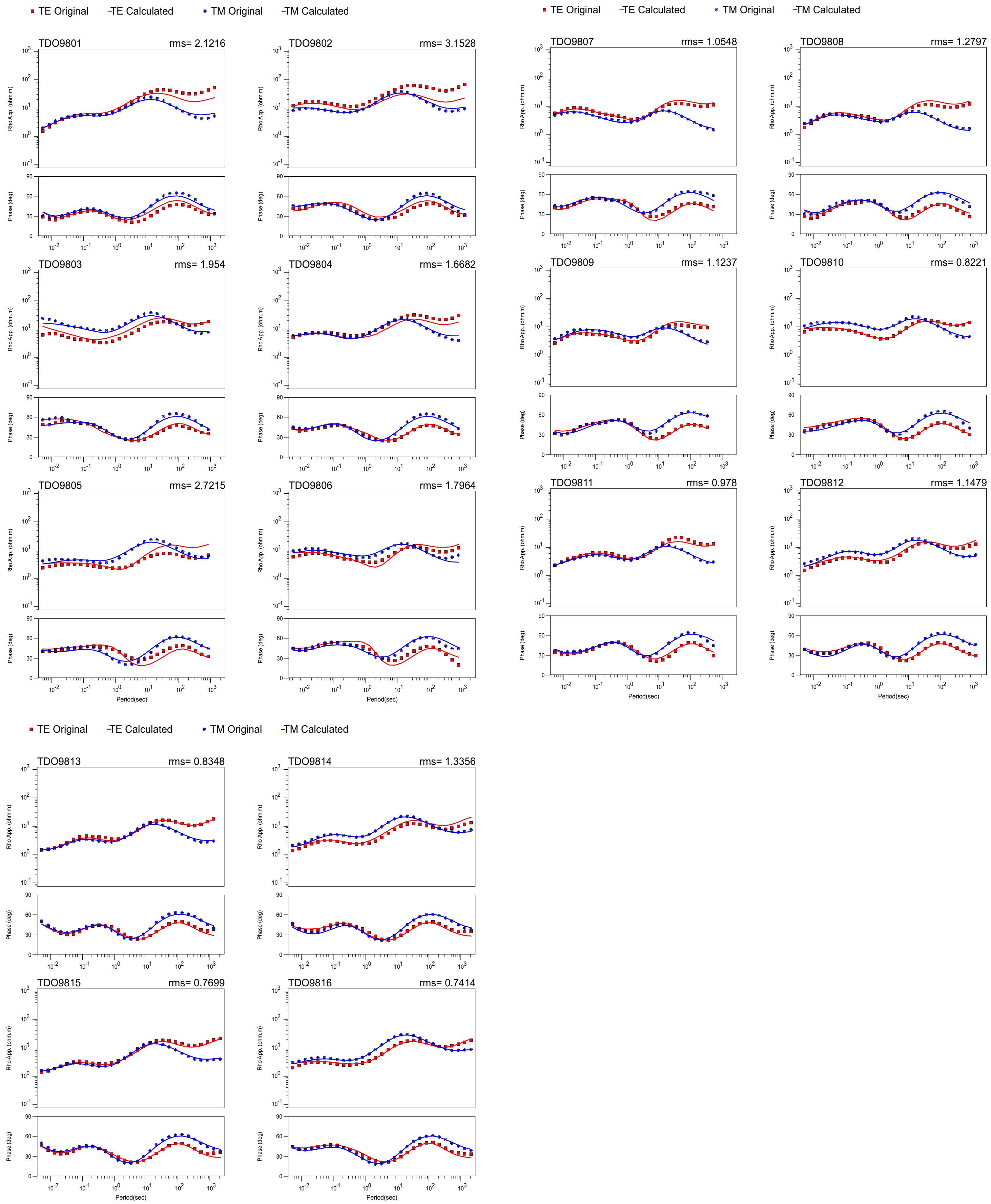
Apparent resistivity and phase curve at profile TDO95



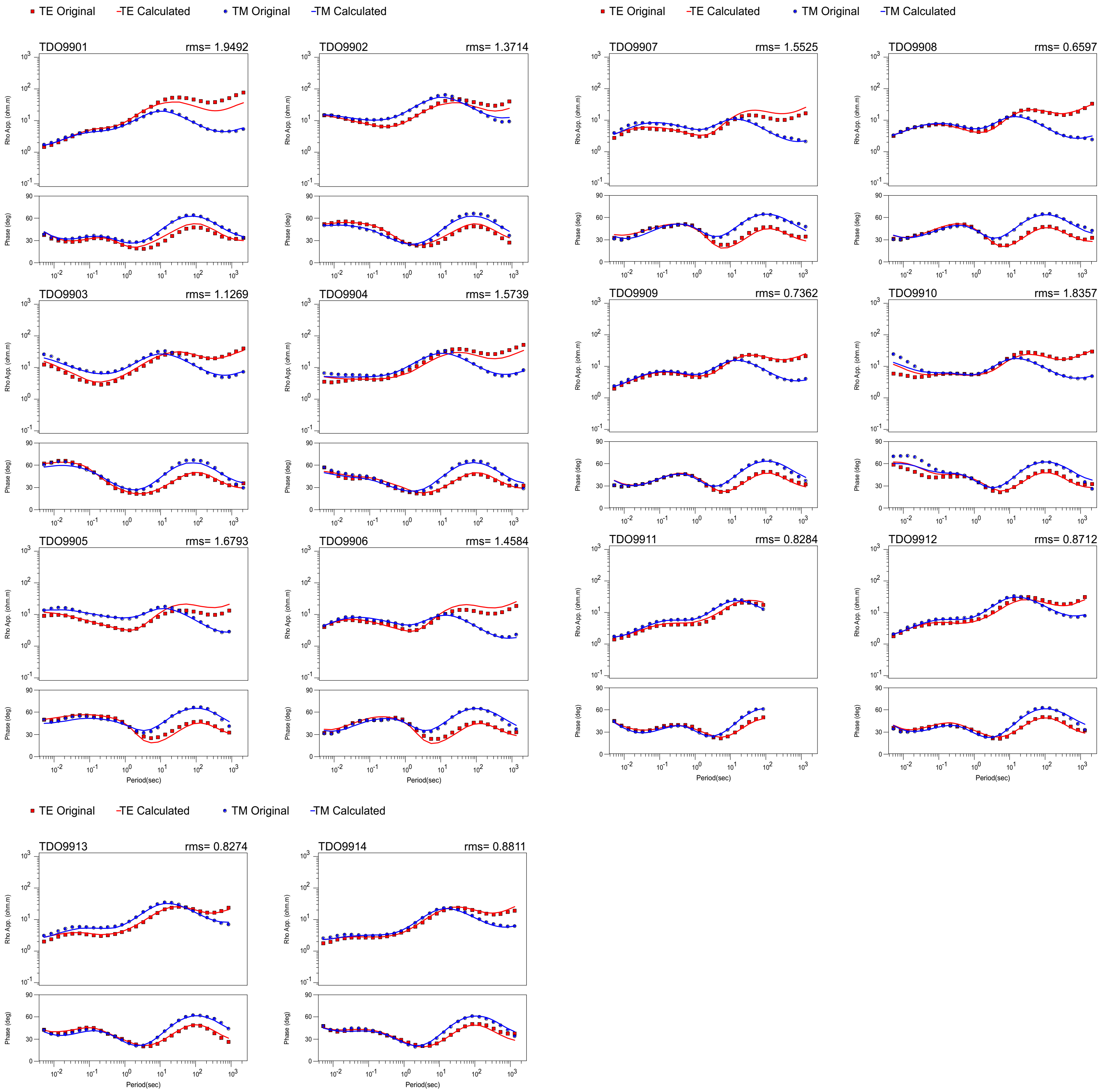
Apparent resistivity and phase curve at profile TDO96



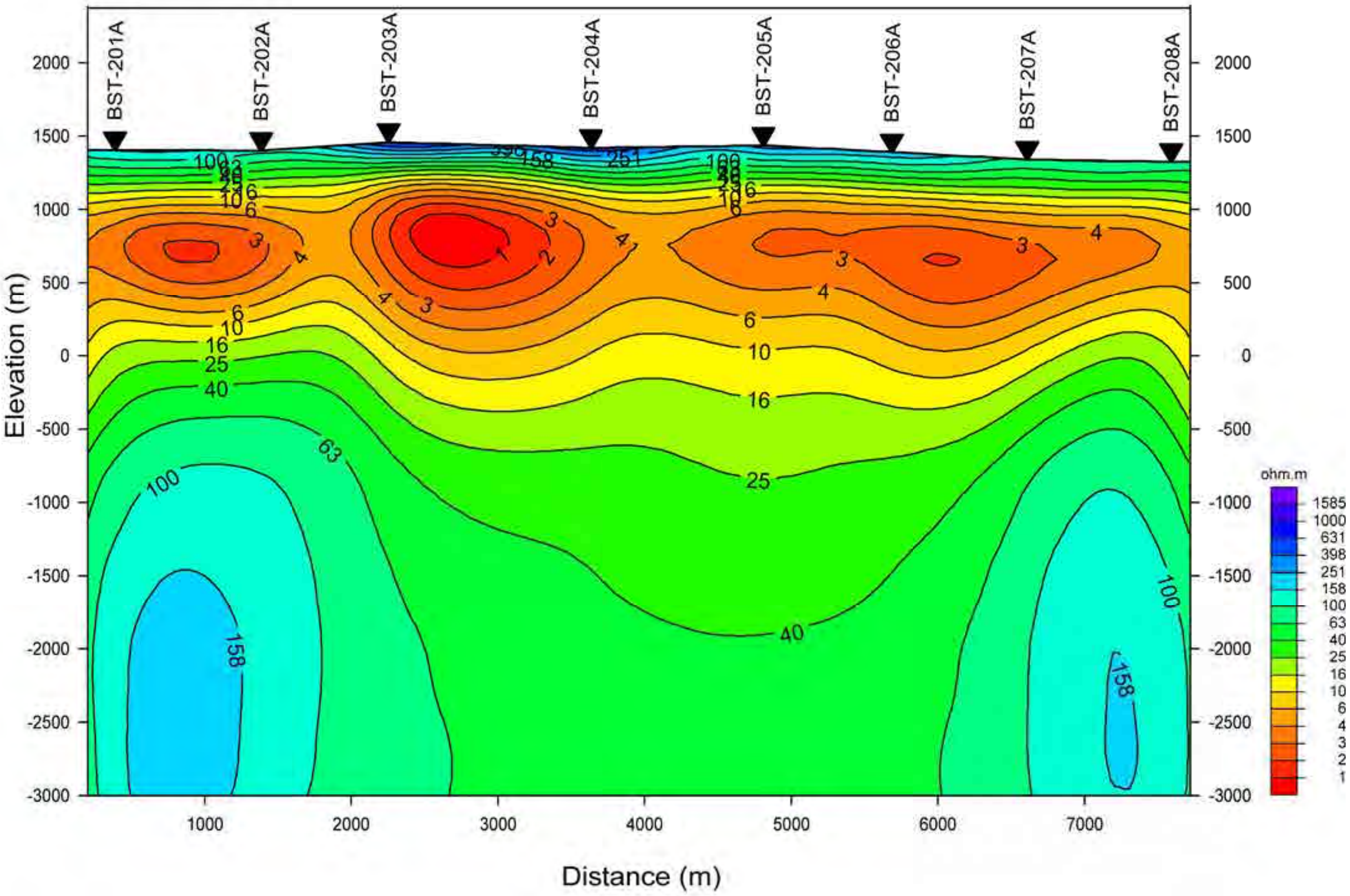
Apparent resistivity and phase curve at profile TDO97



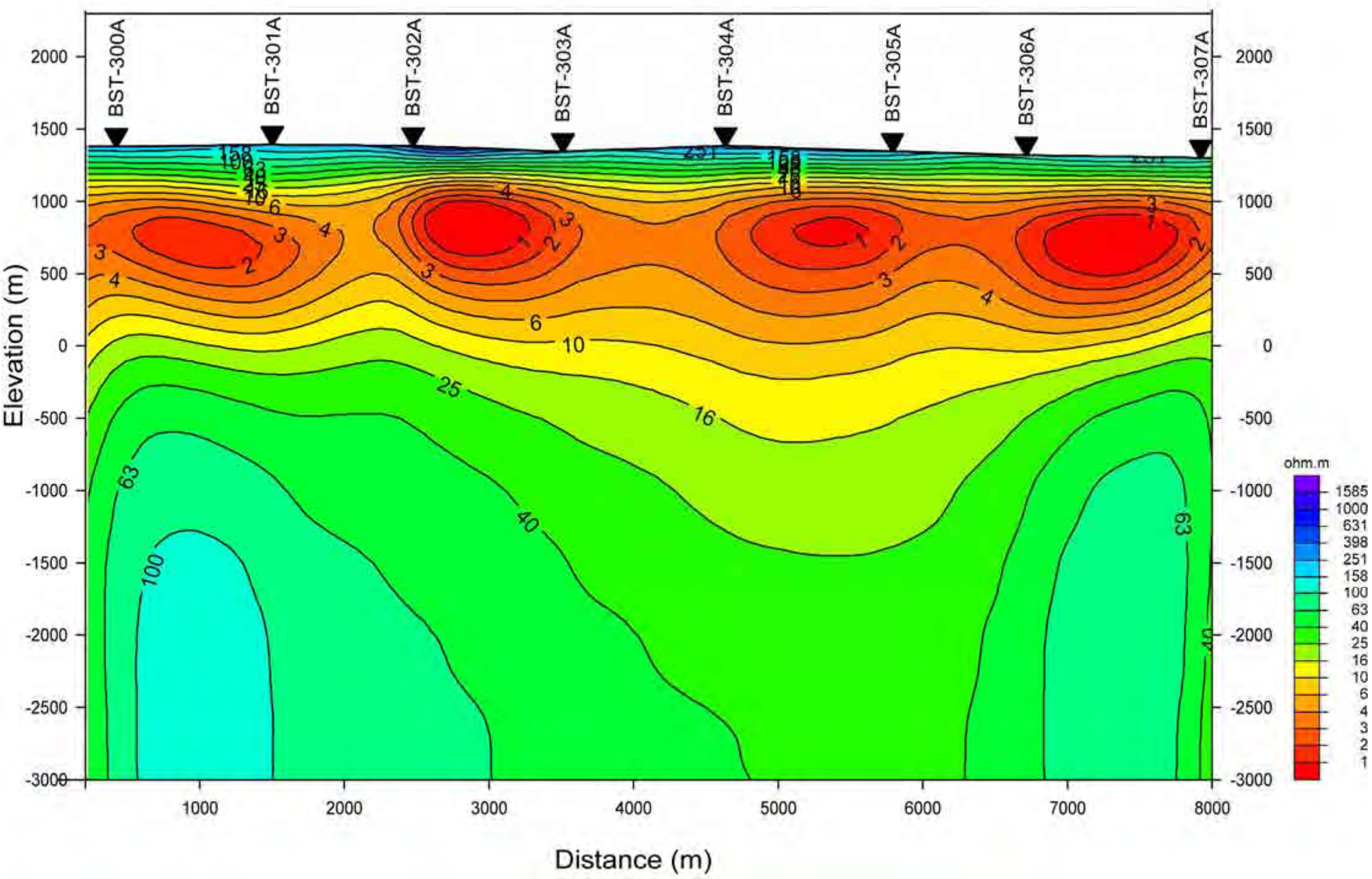
Apparent resistivity and phase curve at profile TDO98



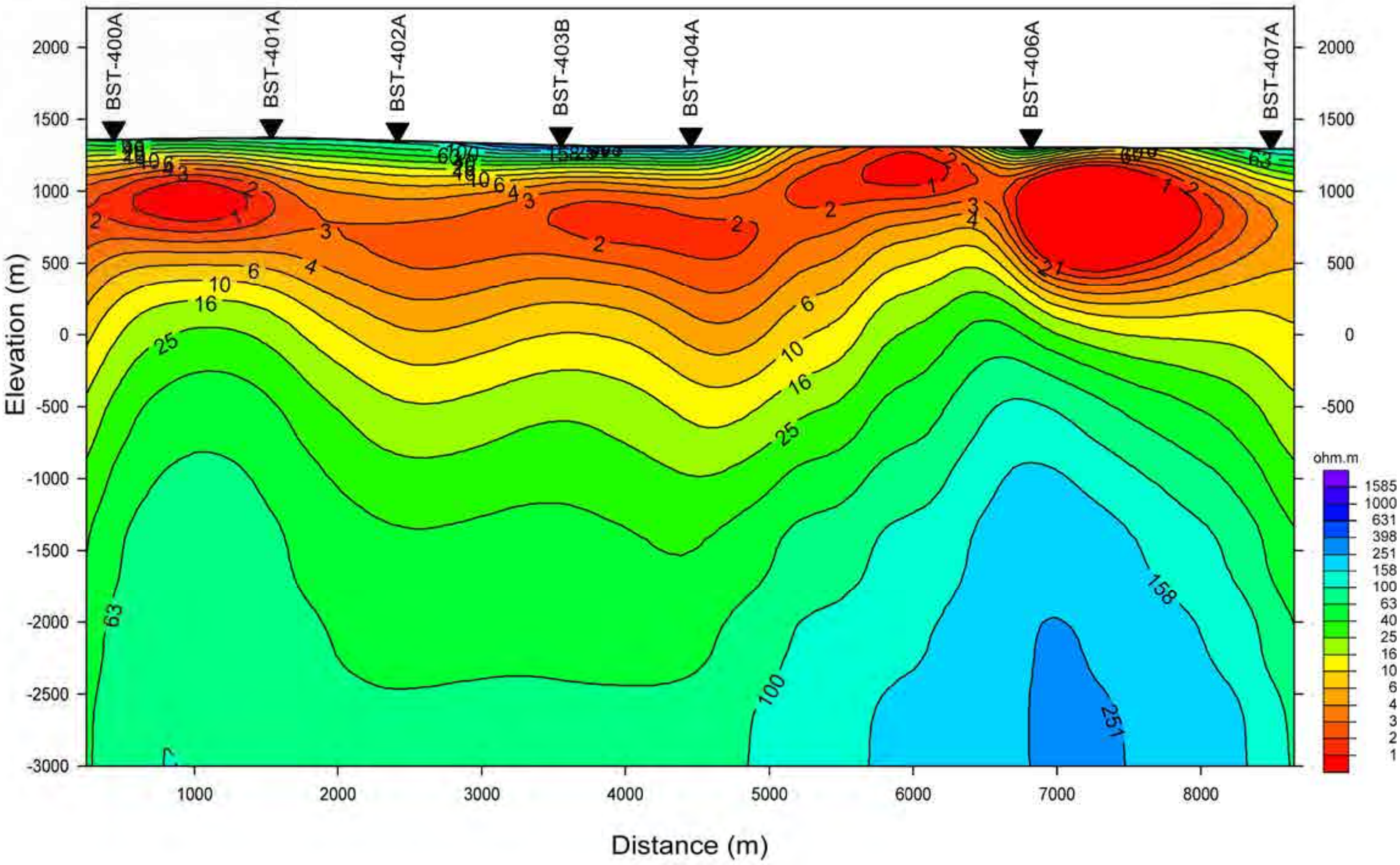
Apparent resistivity and phase curve at profile TDO99



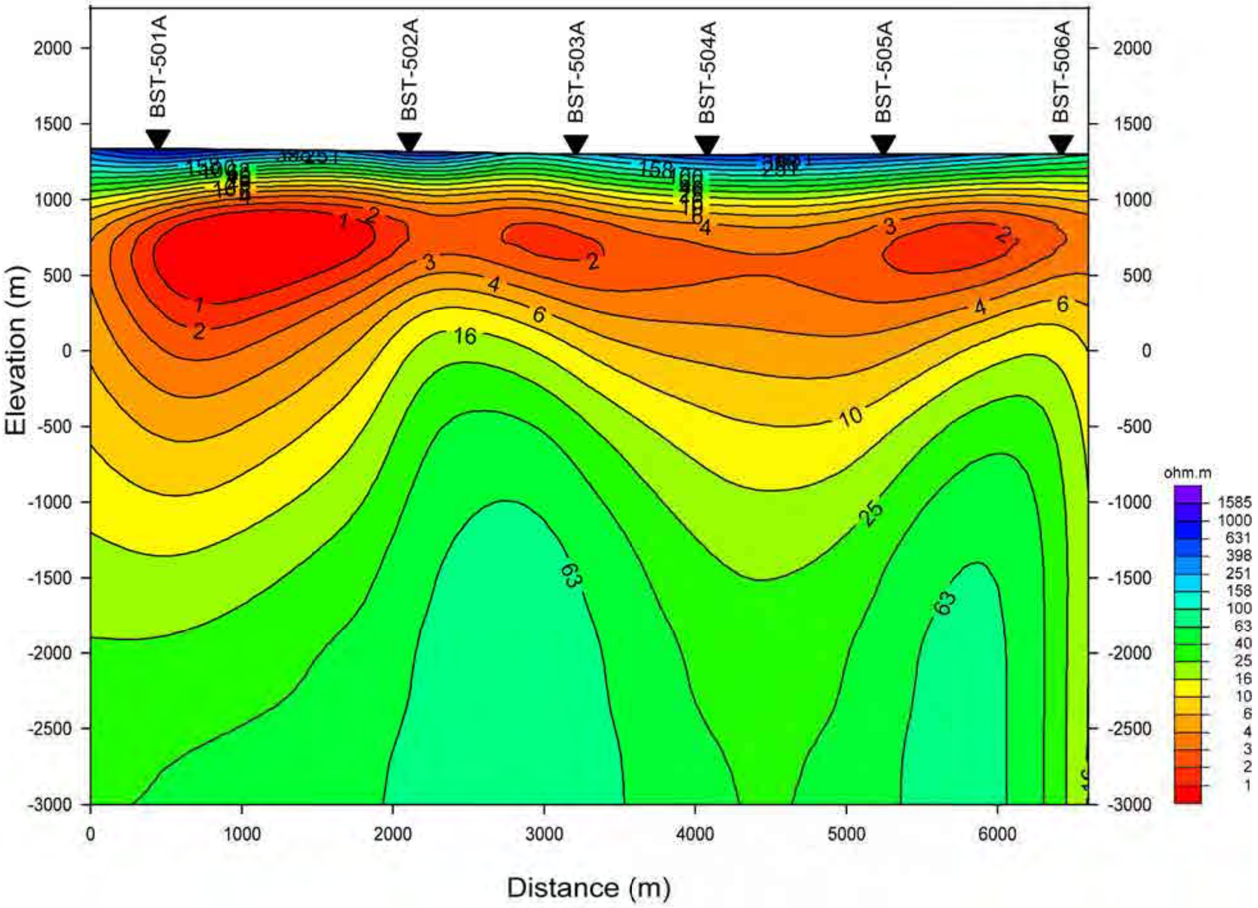
Resistivity cross section at profile 'BST200'



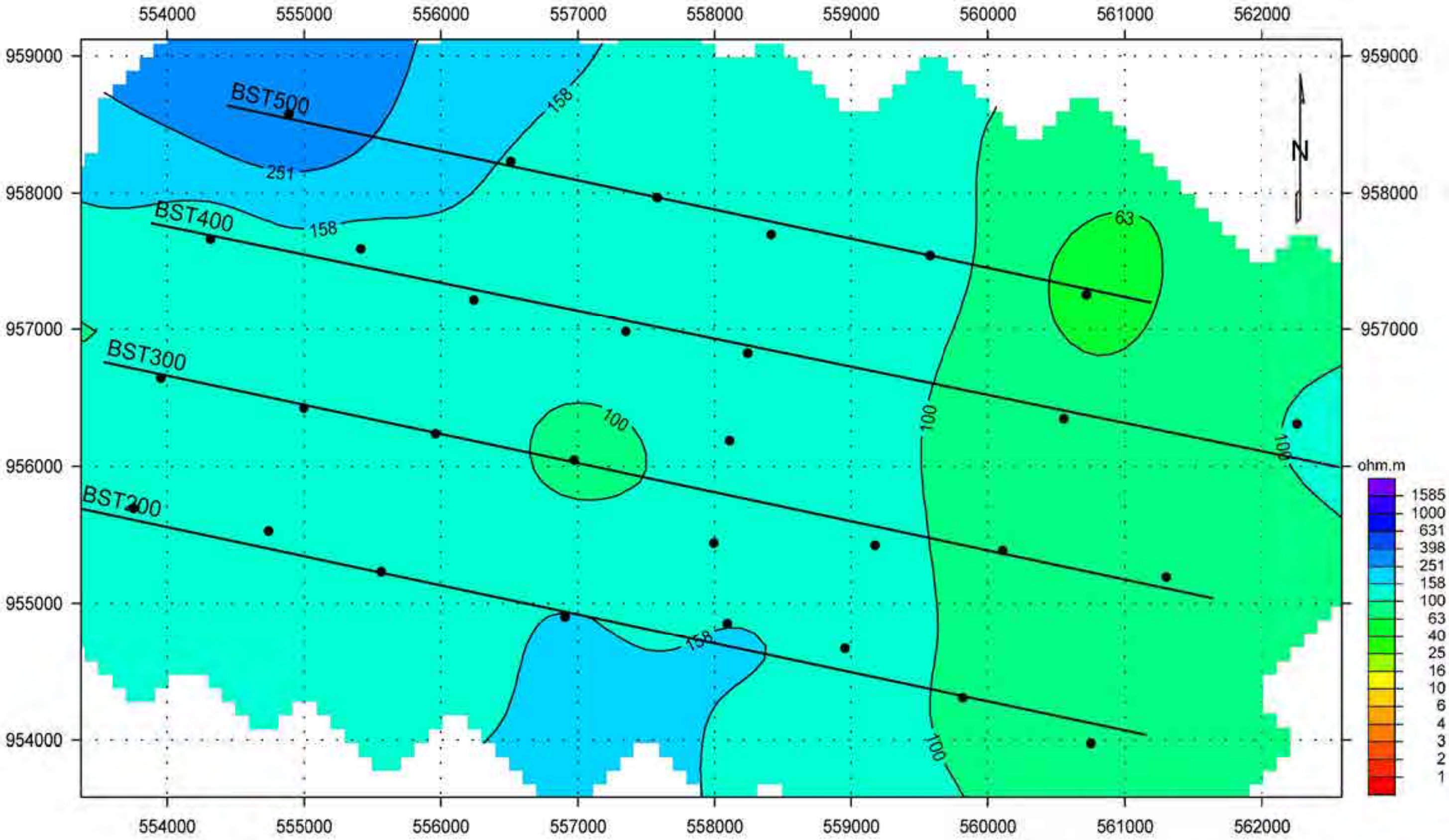
Resistivity cross section at profile 'BST300'



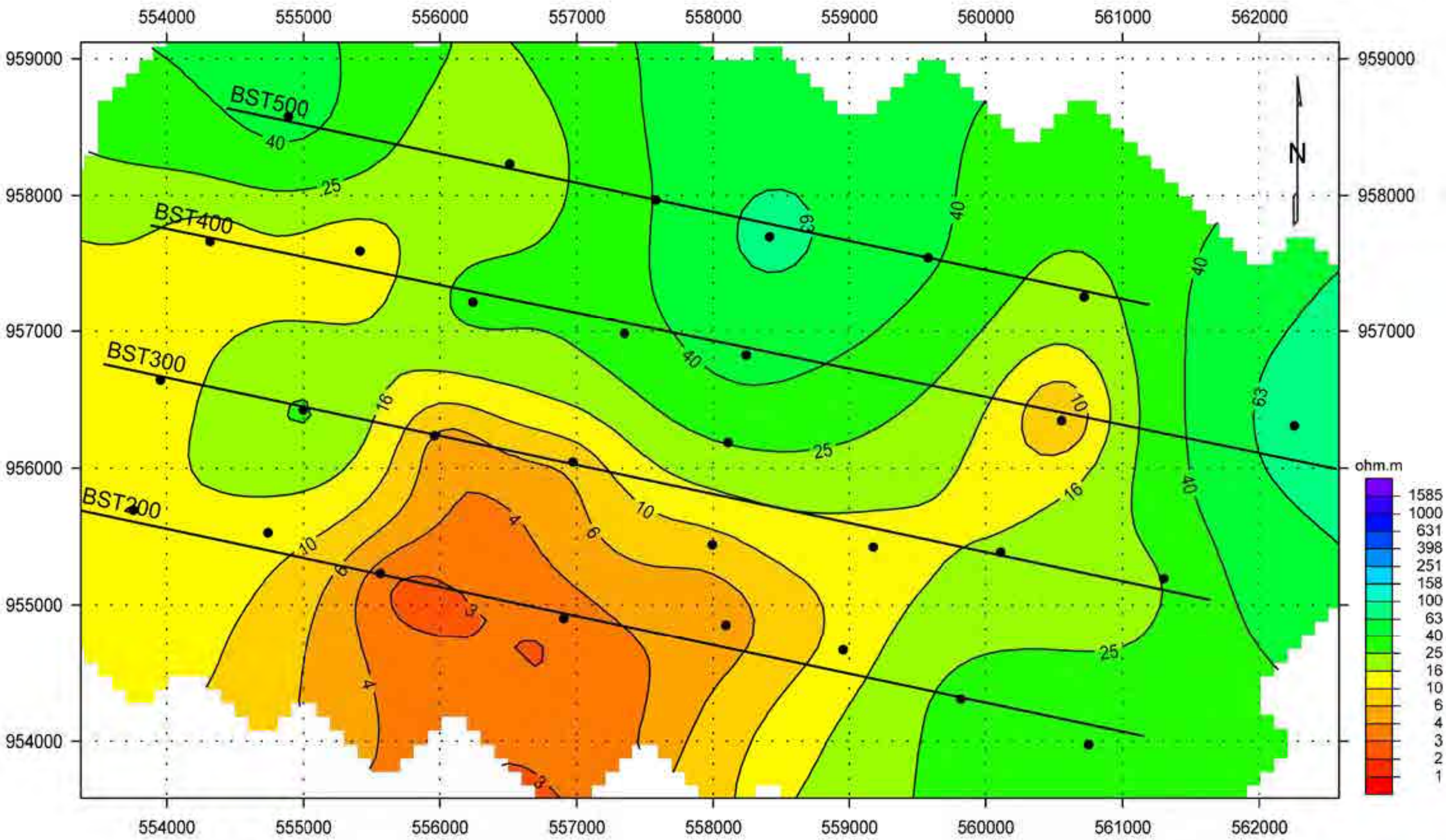
Resistivity cross section at profile 'BST400'



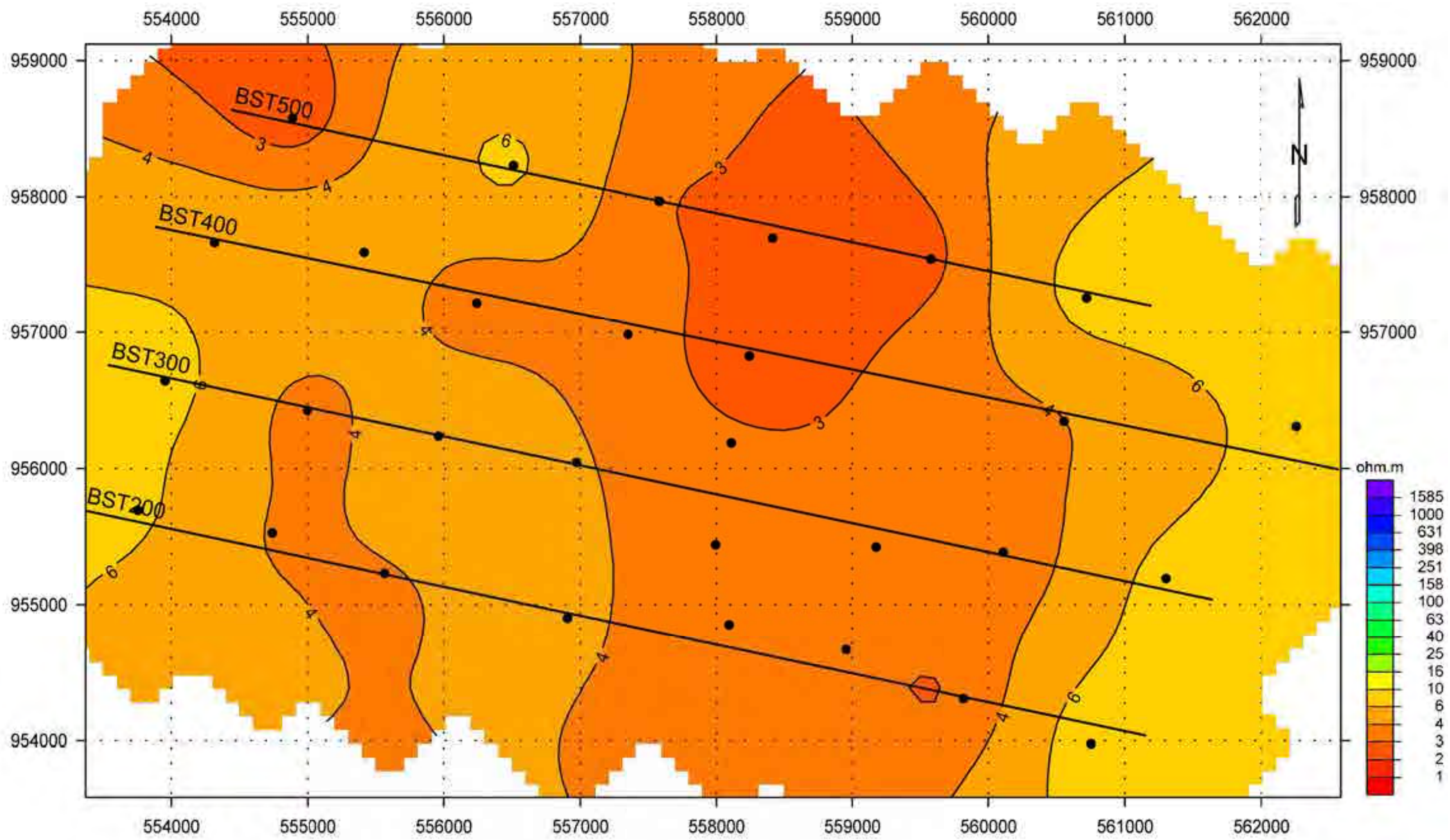
Resistivity cross section at profile 'BST500'



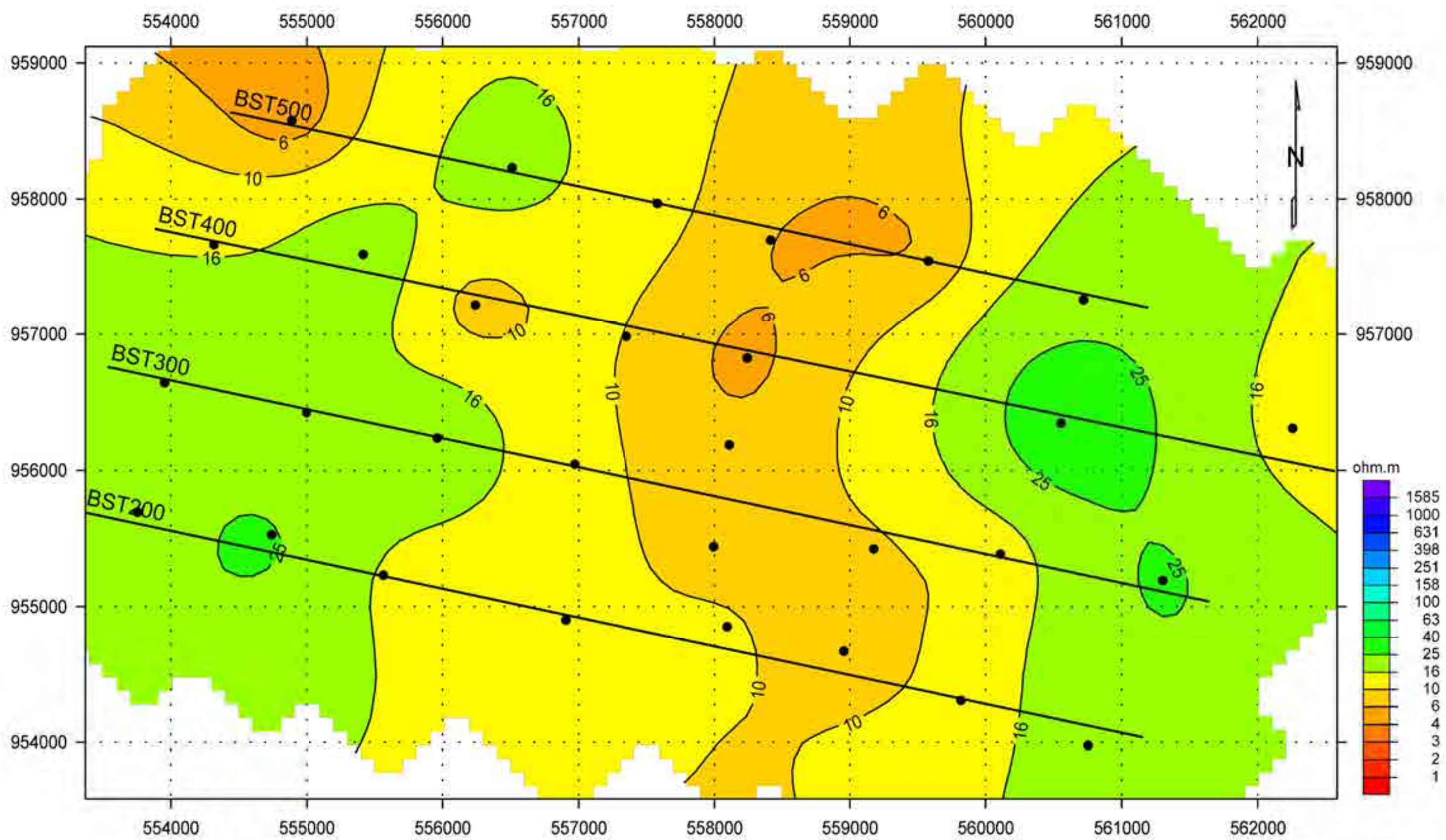
Resistivity (2D Model) at 50 m Depth



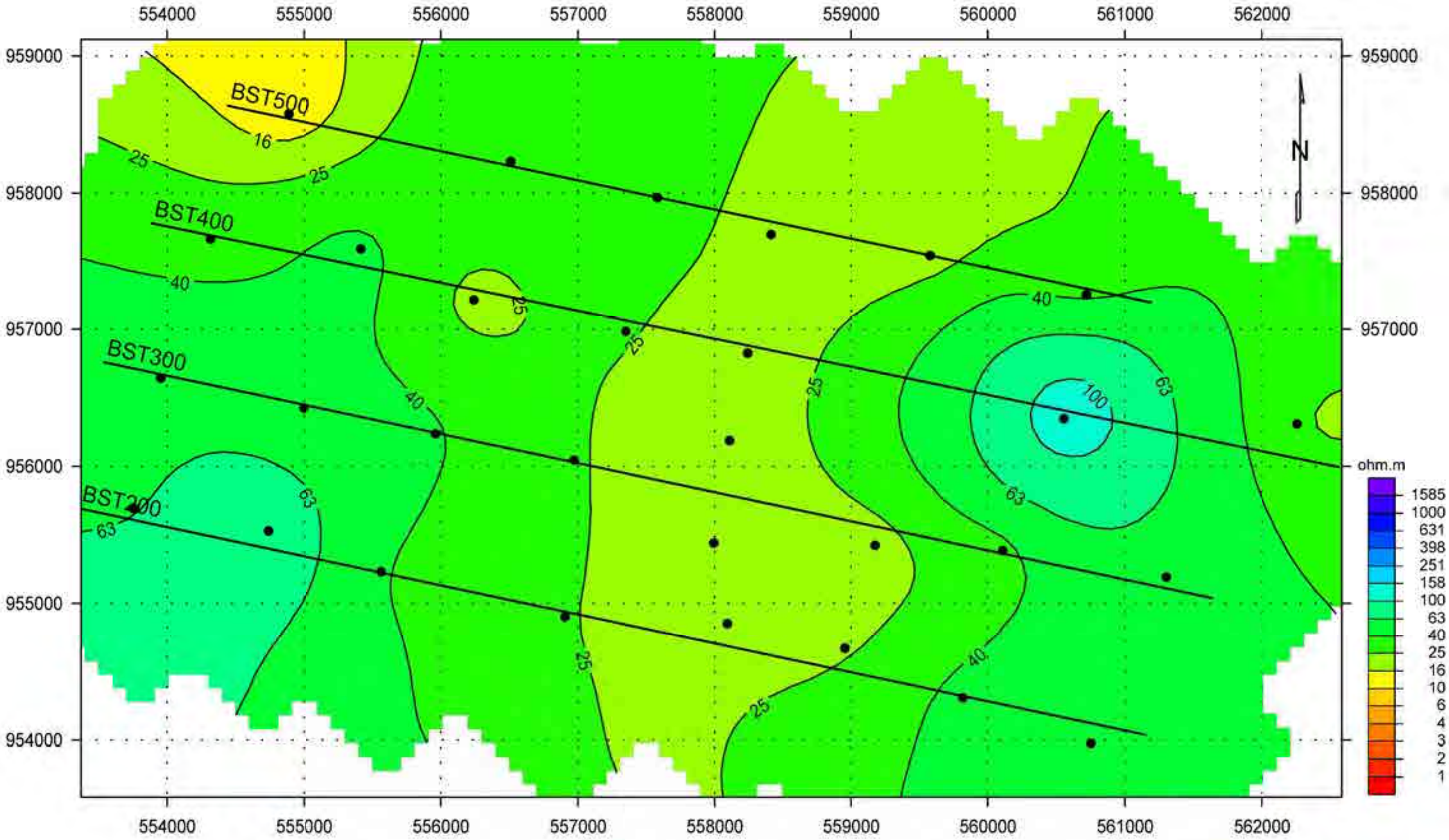
Resistivity (2D Model) at 1200 m Elevation



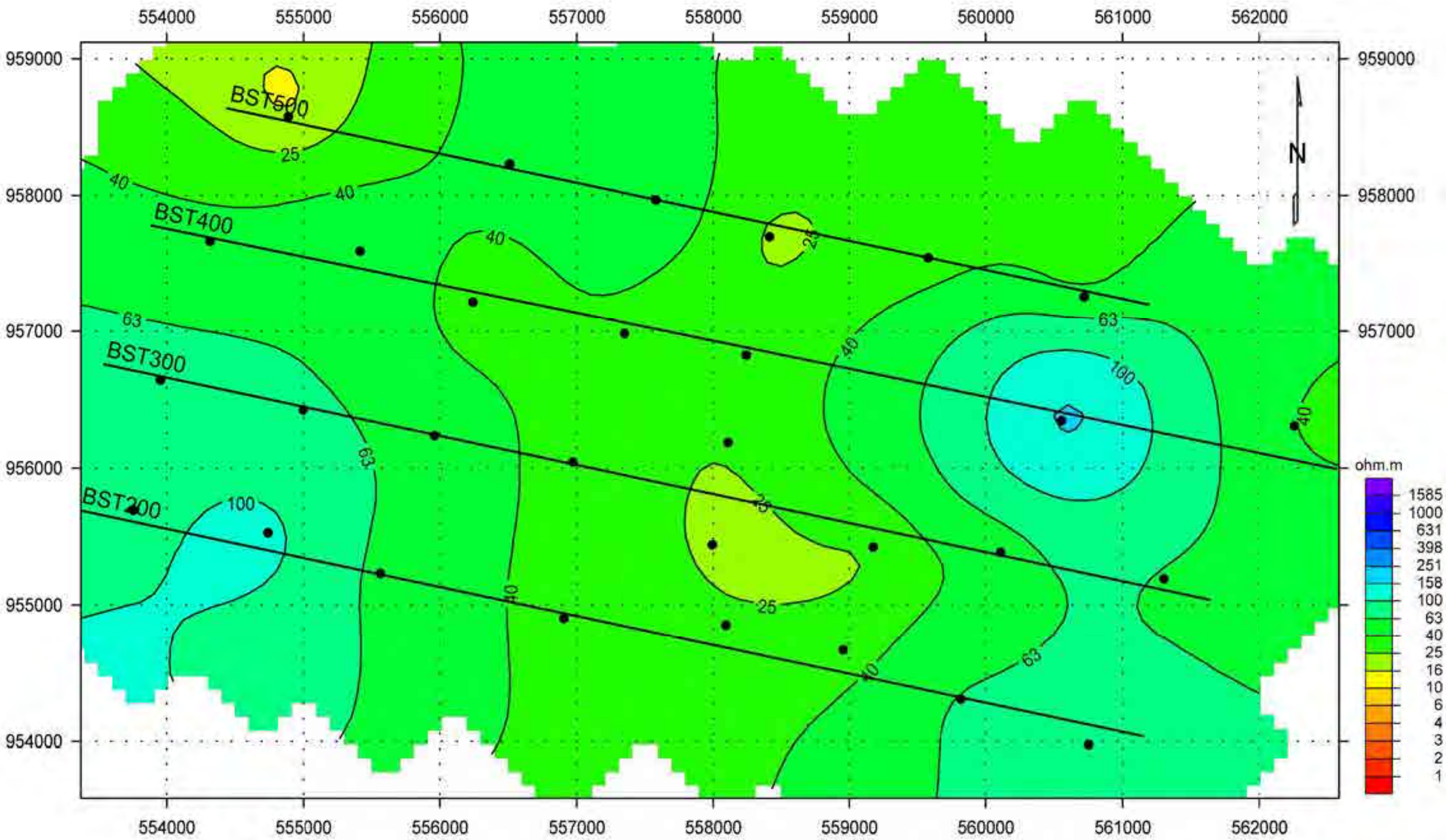
Resistivity (2D Model) at 500 m Elevation



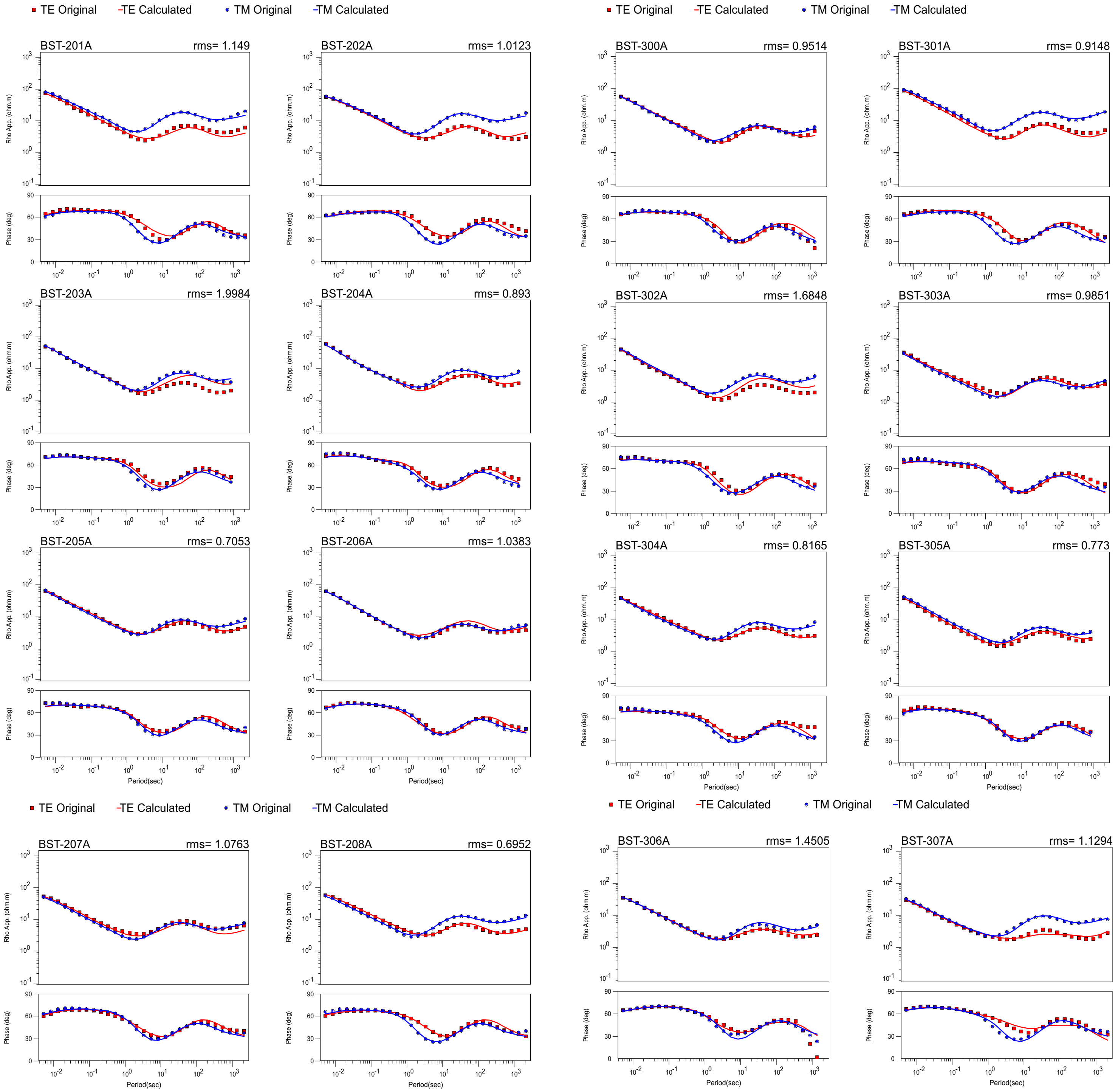
Resistivity (2D Model) at 0 m Elevation



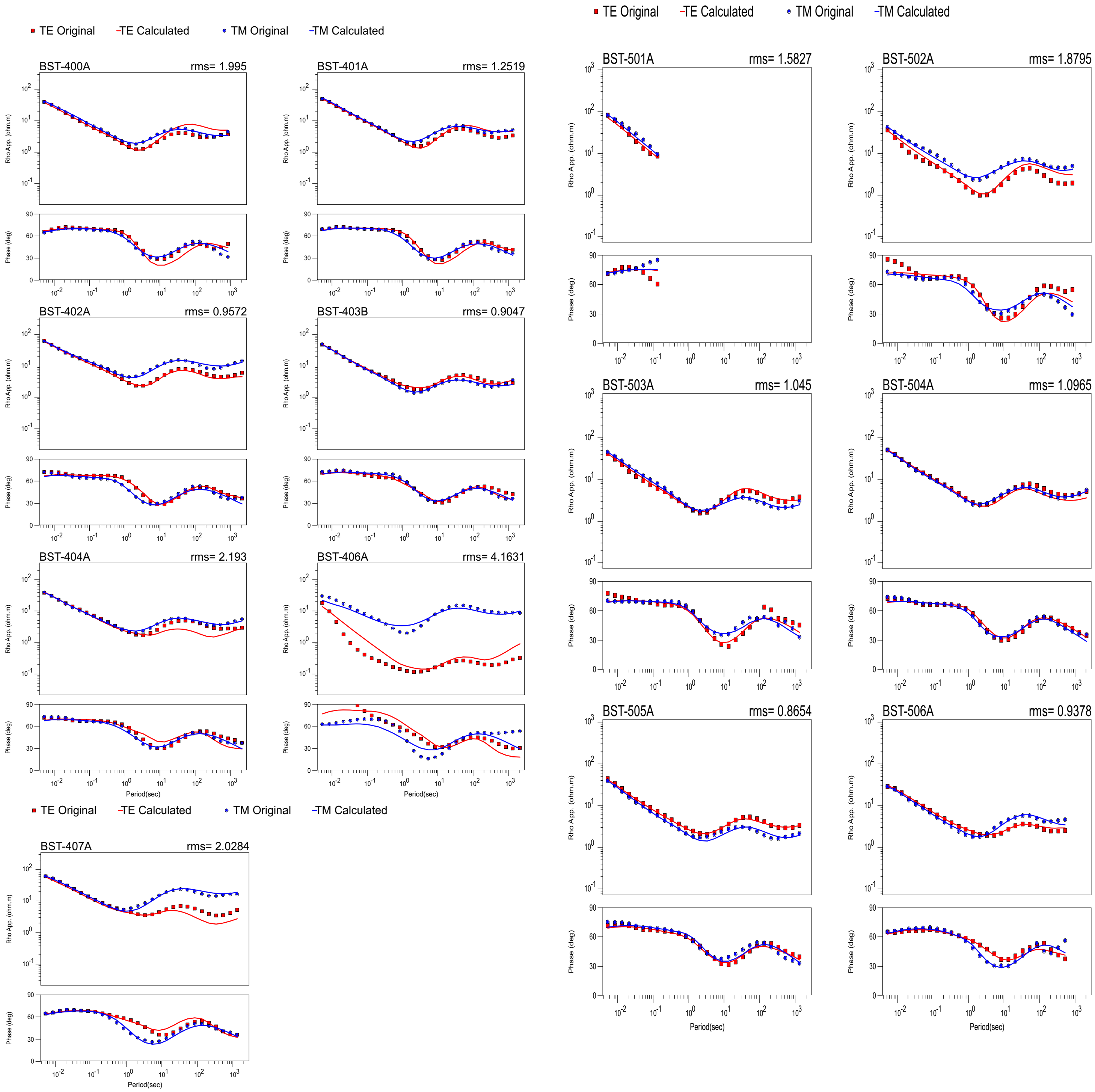
Resistivity (2D Model) at -500 m Elevation



Resistivity (2D Model) at -1000 m Elevation



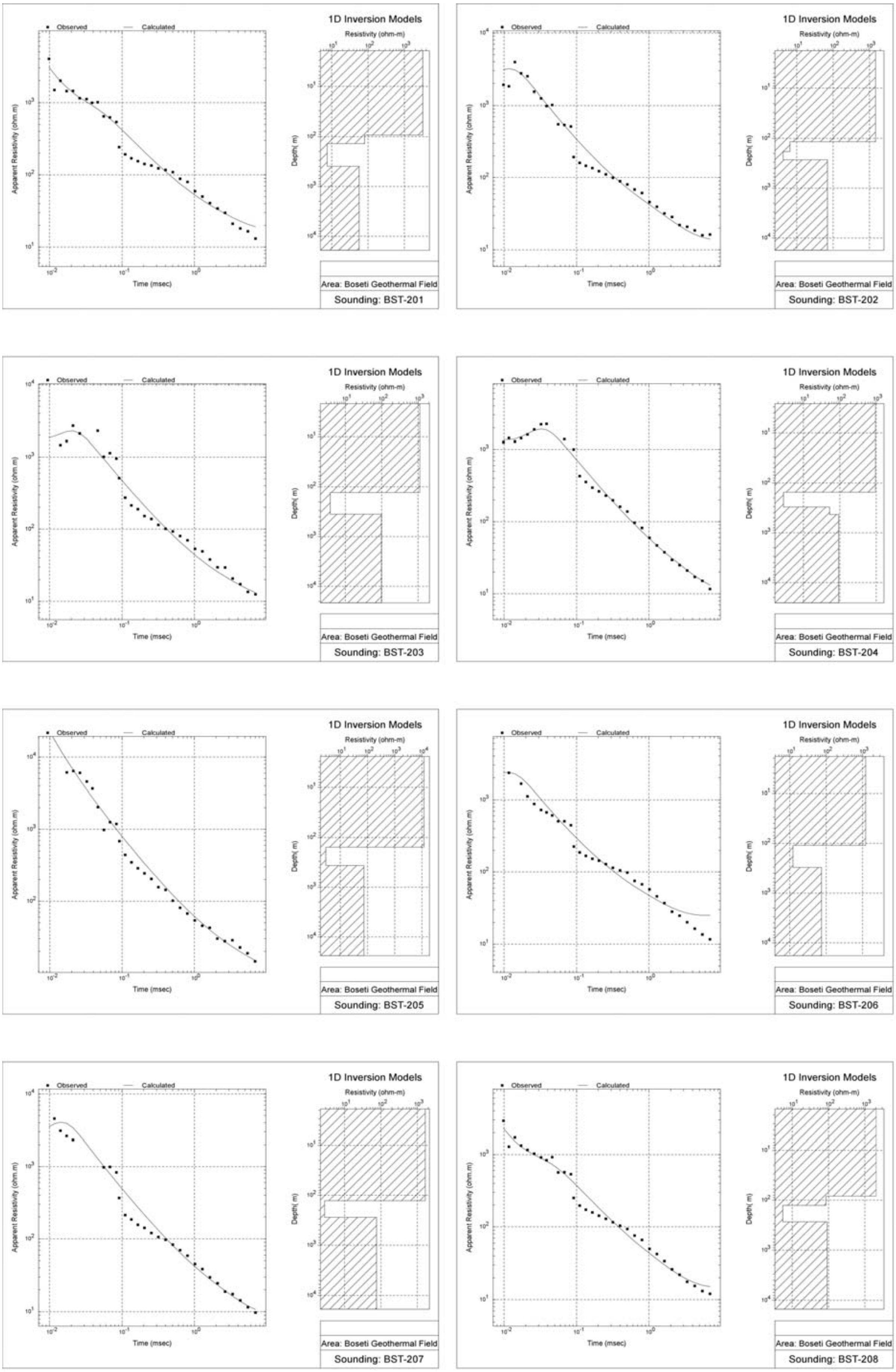
Apparent resistivity and phase curve at profile BST200 and BST300



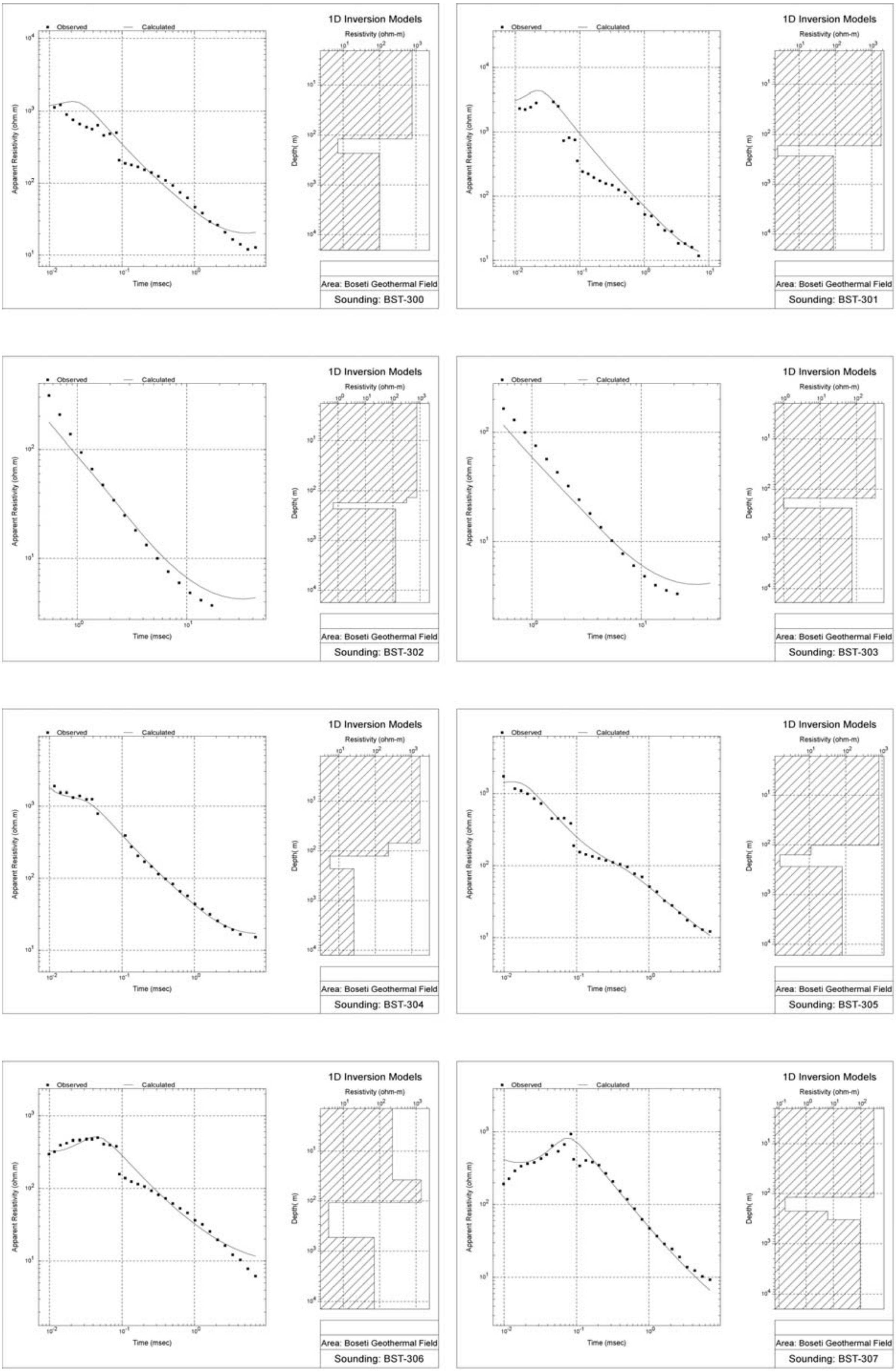
Apparent resistivity and phase curve at profile BST400 and BST500

Offset values for static correction

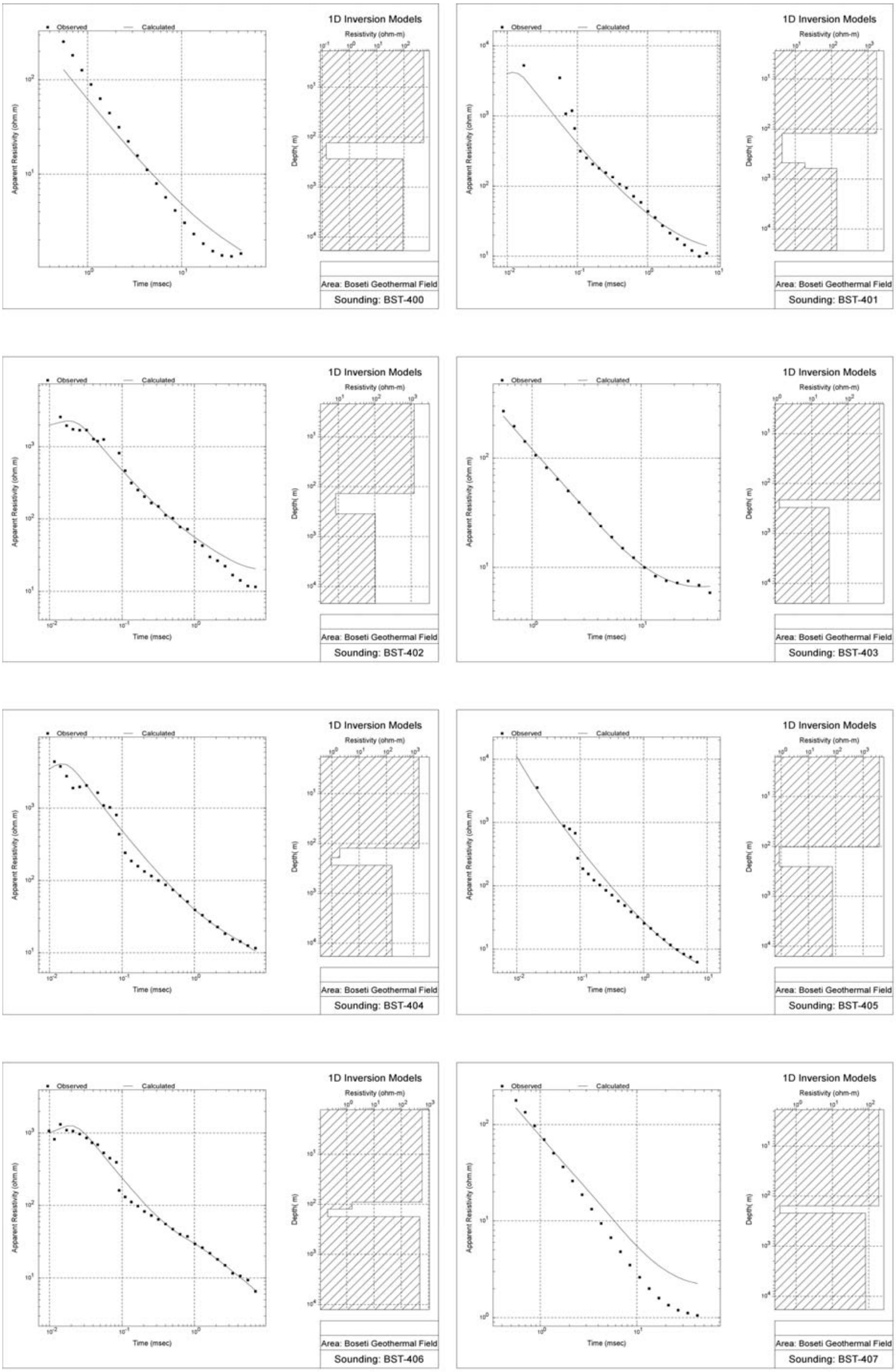
Station	Static Shift (xy)	Static Shift (yx)	Station	Static Shift (xy)	Static Shift (yx)
BST-201	0.329	0.190	BST-400	0.295	0.284
BST-202	0.330	0.258	BST-401	0.192	0.271
BST-203	0.799	0.384	BST-402	0.301	0.299
BST-204	0.454	0.871	BST-403	0.516	1.000
BST-205	0.477	0.273	BST-404	0.683	1.000
BST-206	0.638	0.527	BST-405	1.064	0.539
BST-207	0.241	0.252	BST-406	0.408	0.305
BST-208	0.161	0.298	BST-407	0.499	0.462
BST-300	0.363	0.270	BST-501	0.572	1.000
BST-301	0.536	0.641	BST-502	0.300	1.000
BST-302	0.271	0.300	BST-503	1.364	0.813
BST-303	0.170	0.377	BST-504	0.371	0.557
BST-304	0.521	1.000	BST-505	0.142	0.547
BST-305	0.238	0.257	BST-506	0.318	0.089
BST-306	0.595	0.334			
BST-307	0.363	0.199			



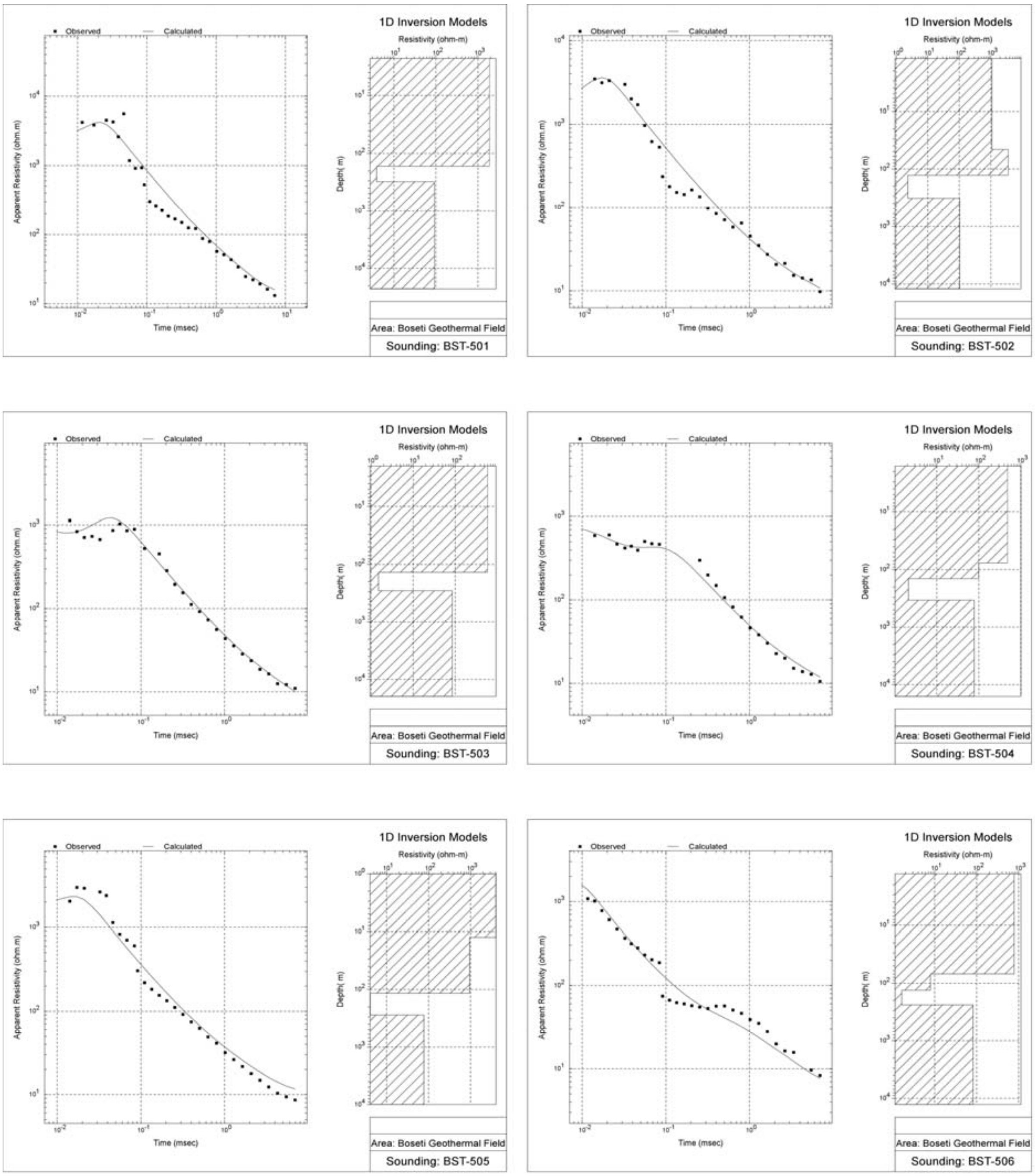
TEM survey results of 1D inversion analysis (BST200)



TEM survey results of 1D inversion analysis (BST300)



TEM survey results of 1D inversion analysis (BST400)



TEM survey results of 1D inversion analysis (BST500)