第 6 章　物理探査

6.1　物理探査の概要

地熱開発調査対象地域において、地下の比抵抗構造を把握するために電磁探査の一手法である MT 法探査を実施した。また MT 法で得られたデータの補正を行うために TEM 法探査を実施した。取得データの処理・解析を行い、調査対象地域の比抵抗構造を解明した。得られた地下の比抵抗分布をもとに地質・地質構造を推定し、地熱貯留層モデルの構築・評価および調査ボーリング計画に資する地下深部の物性情報を得た。

6.2　物理探査サイトの選定条件

本調査では、22 の対象地域から 2 サイトを選定し、新規に調達した機材機器を使用して GSE 職員とともに MT 法/TEM 法探査を実施した。

物理探査の対象 2 サイトについては、本報第 5 章にて決定された地熱有望サイトの優先順位の高い順に、Tendaho-2(Ayrobera)および Boseti を選定した（表 5.2.12 参照）。

6.3　調査概要

本調査で実施した MT 法/TEM 法探査の調査内容は以下の通りである。

・調査手法（調査原理および調査方法の詳細は巻末に添付）

リモートリファレンス方式 MT 法探査
セントラルループ方式 TEM 法探査（MT データのスタティック補正）

・調査地域

Tendaho-2 (Ayrobera)地区および Boseti 地区

・調査期間 (第 4 次現地調査)

Tendaho-2 (Ayrobera)地区：2014 年 10 月 16 日～2014 年 11 月 8 日
Boseti 地区：2014 年 11 月 10 日～2014 年 12 月 11 日

・測定点数

Tendaho-2 (Ayrobera)地区：24 点、リモートリファレンス点は Mille に設置
Boseti 地区：30 点、リモートリファレンス点は Koka に設置

・取得データ

MT 法探査：磁場 3 成分(Hx、 Hy、 Hz)、電場 2 成分(Ex、 Ey)の時系列データ
(測定時間：1 測定点当たり 14 時間以上)
TEM 法探査：磁場 1 成分(Hz)の過渡応答データ

・データ処理・解析周波数

MT 法探査：320Hz～0.00034Hz の範囲の 80 周波数
TEM 法探査：リピートレート 237.5Hz、 62.5Hz、 25.0Hz の主に 3 周波数

6.4 調査結果

MT 法/TEM 法探査の調査位置図を図 6.4.1 に、調査対象地域ごとの測定点位置図を図 6.4.2 および図 6.4.3 に示す。測点位置座標一覧表を巻末に添付する。

6.4.1 Tendaho-2 (Ayrobera)地区

(1) MT 法探査

取得データのリファレンス処理を実施し、見かけ比抵抗・位相曲線を作成し、データの品質を確認した。ほとんどすべての測定点のデータについて高周波数域から低周波数域にわたってデータ品質は良好であった。一部測定点のデータでローカル処理では多少ばらつきが認められたもののリファレンス処理を行うことによってノイズの除去が行われ、良好なデータを取得することができた。

図 6.4.2 に示すように本調査で MT 法探査を実施した 2 測線に、これまでに実施された MT 法探査の 6 測線を加えた合計 8 測線について 2 次元インバージョン解析を実施し、比抵抗構造を求め、比抵抗分布断面図を作成した。それらの結果を基に比抵抗分布平面図およびパネルダイヤグラムを作成した。図 6.4.4 に比抵抗分布平面パネルダイヤグラムを示す。比抵抗分布断面図および平面図、測定値と計算値の見かけ比抵抗・位相曲線を巻末に添付する。

Tendaho-2 地区の MT 探査結果から読み取れる比抵抗構造の特徴は以下の通りである。

- 本調査地域の大局的な比抵抗構造は地表から深部に向かって標高-5,000m 程度までは、低-高-低の比抵抗変化を示す。調査地域全体では 1Ωm から 250Ωm 程度までの比抵抗が分布する。
- 標高 200m では 16Ωm 以下の低比抵抗が調査地域全体に広く分布する。特に、南部、西部、東部の一部には 3Ωm 以下の比抵抗が比較的分布する。
- 標高 0m では標高 200m で見られた低比抵抗分布同様、調査地域全体に低比抵抗が分布し、比抵抗値もさらに低くなっている。調査地域の南側で相対的に低比抵抗を示す。
- 標高-700m では調査地域中央に NW-SE 方向に帯状に 16Ωm 以下の低比抵抗が分布する。特に帯の中央部で低比抵抗を示し、6Ωm 以下の低比抵抗の分布が認められる。帯状の低比抵抗分布の両側は 40Ωm 以上の高比抵抗が分布し、帯状低比抵抗分布の境界は比抵抗変化の大きいコントラストを示し、コンターは直線的であり、比抵抗の不連続構造を示唆する。
- 標高-1,500m では標高-700m で見られた NW-SE 方向の低比抵抗帯が継続して認められる。標高-700m の比抵抗分布と比較して、分布性状は類似しているが比抵抗値が全体的に高くなっている。
- 標高-2,500m では標高-700m、-1,500m での比抵抗分布同様、中央部を NW-SE 方向に低比抵抗が帯状に分布する。標高-1,500m との違いは、帯状分布の低比抵抗値が 40Ωm 以上で相対的に高い比抵抗値を示すことである。

- 標高-700m から深部にわたって認められる帯状比抵抗分布の帯幅はほぼ均一で、深部にまで続く低比抵抗のチャンネル構造を示しているが、TDO97 測線付近では低比抵抗帯の幅が多少狭くなり、少しくびれた形状を示すことが特徴的である。
- 各標高の比抵抗分布平面図から、極表層を除く浅部から深部にわたって NW-SE 方向の比抵抗構造の走向が明瞭に認められる。

(2)　まとめ

Tendaho-2 地区の比抵抗構造の特徴をまとめると以下の通りである。

表 6.4.1　Tendaho-2 (Ayrobera)の比抵抗構造の特徴

項目	特徴
比抵抗構造	地表から深部に向かって標高-5,000m まで低－高—低の比抵抗変化
比抵抗値	1ohm-m から 250ohm-m まで分布
不連続構造	調査地域中央部には NW-SE 方向に低比抵抗が、標高-700m から深部にかけて帯状に分布し、低比抵抗のチャンネル構造を形成
	低比抵抗分布で構成されるチャンネル構造とその両端の高比抵抗分布との間の比抵抗変化は急激で比抵抗不連続構造を示唆
	TDO97 測線付近ではチャンネル構造の低比抵抗帯の幅が多少狭くなり、少しくびれた形状を示し、低比抵抗のチャンネル構造を横断する不連続構造を示唆

出典: 調査団

6.4.2　Boseti 地区

(1)　MT 法探査

取得データのリファレンス処理を実施し、見かけ比抵抗・位相曲線を作成し、データの品質を確認した。ほとんどすべての測定点のデータについて高周波数域から低周波数域にわたってデータ品質は良好であったが、BST-501 では低周波域でデータのばらつきが大きく、見かけ比抵抗曲線の勾配に人口の電磁場ノイズの存在を示すような傾きが認められた。これは調査地域北側にある高圧送電線の影響と考えられた。その他の測定点ではローカル処理では中間周波数域から低周波数域にかけて多少ばらつきが認められた測定点が多少あったが、リファレンス処理を行うことによってノイズの除去が行われ、良好なデータを取得することができた。

図 6.4.3 に示すように本調査で MT 法探査を実施した 4 測線ついて 2 次元比抵抗構造インバージョン解析を実施し、比抵抗構造を求め、比抵抗分布断面図を作成した。2 次元比抵抗構造解析においては後述する TEM 法調査の結果より求められたスタティックシフト補正値を 2 次元解析の入力データである MT 法データに適用した。2 次元解析結果を基に比抵抗分布平面図およびパネルダイヤグラムを作成した。図 6.4.5 に比抵抗分布平面パネルダイヤグラムを示す。比抵抗分布断面図および平面図、測定値と計算値の見かけ比抵抗・位相曲線を巻末に添付する。

Boseti 地区の MT 探査結果から読み取れる比抵抗構造の特徴は以下の通りである。

- 本調査地域の大局的な比抵抗構造は地表から深部に向かって標高-3,000m 程度までは、高-低-高の比抵抗変化を示す。調査地域全体では 1Ωm から 400Ωm 程度までの比抵抗が分布する。
- 地表から深度 50m では 63Ωm 以上の高比抵抗が調査地域全体に分布しており、特に北西部

と南部では高いところで 250Ωm 以上の高比抵抗を示す。

- 標高 1,200m では低比抵抗が南部に比較的広く分布し、Berecha 山の北側裾野である地表の標高の高い部分に対応している。この低比抵抗部と北側の高比抵抗分布との境界は比抵抗変化の大きいコントラストを示し、コンターは WNW-ESE 方向で直線的であり、比抵抗の不連続構造を示唆する。
- 標高 500m では低比抵抗が調査地域全体に分布しており、特に、中央部には N-S ないしは NNE-SSW 方向に帯状に 4Ωm 以下の低比抵抗が分布する。調査地域の中心から北側で最も低い比抵抗値(3Ωm 以下)を示す。標高 1,200mで南部に見られた低比抵抗部はこの標高でも認められ、深部に連続した低比抵抗分布である。
- 標高 0m では、標高 500m で認められた帯状の低比抵抗部が同様に認められるが、比抵抗の数値自体は高くなっている。その帯状の低比抵抗分布の両側は相対的に高比抵抗が分布し、帯状低比抵抗分布の境界は比抵抗変化の強いコントラストを示し、比抵抗の不連続構造を示唆する。標高 1,200mで南部に見られた低比抵抗部はこの標高では明瞭ではない。
- 標高-500m では調査地域全体に 25Ωm 以上の比抵抗が分布し、標高 0m と比較して相対的に高い比抵抗分布を示す。局所的に 63Ωm 以上の高い比抵抗を示す部分も見られる。標高 0m で認められた帯状の低比抵抗分布も同様に認められるが、比抵抗の数値自体はさらに大きくなっている。
- 標高-1,000m では、比抵抗分布は標高-500m の分布と性状が類似している。調査地域全体にわたって 25Ωm 以上の比較的高い比抵抗が分布し、標高 500m から見られた NNE-SSW 方向の帯状の低比抵抗分布は不明瞭ながらも認められる。
- 各標高の比抵抗分布平面図から、浅部から深部にわたって比抵抗構造の主な走向は NNE-SSW 方向を示している。

(2) TEM 法探査

MT 法探査を実施したすべての測定点において TEM 法探査を実施した。測定値については、時間ウィンドウの極初期の部分および最後の部分においてデータにばらつきが見られる測定点が数点存在したが、1 次元層構造解析には支障のない概ね良好なデータを取得することができた。各測定点で得られた測定データを用いて 1 次元層構造解析を実施した。ほとんどの測定点で地表から深部に向かって高-低-高の比抵抗変化を示す比抵抗層構造が求められた。この結果を用いて MT 法の見かけ比抵抗・位相曲線を作成し、MT 法探査から求められた見かけ比抵抗曲線のスタティックシフト補正に必要なシフト量を算出した。このスタティックシフト補正値を MT 法で得られた見かけ比抵抗に適用して 2 次元比抵抗構造解析を実施した。スタティックシフト補正値一覧表および TEM 法探査データによる 1 次元層構造解析結果を巻末に添付する。

(3) まとめ

Boseti 地区の比抵抗構造の特徴をまとめると以下の通りである。

表 6.4.2　Boseti の比抵抗構造の特徴

項目	特徴
比抵抗構造	地表から深部に向かって標高-3,000m までは低－高―低の比抵抗変化
比抵抗値	1ohm-m から 600ohm-m まで分布
不連続構造	調査地域中央部には NNE-SSW 方向に標高 500m から深部にかけて低比抵抗が帯状に分布し、低比抵抗のチャンネル構造を形成
	低比抵抗分布で形成されるチャンネル構造とその両端の高比抵抗分布との間の比抵抗変化は比抵抗不連続構造を形成
	Berecha 山の北側裾野である地表の標高の高い部分の地表下には浅部から低比抵抗部が現れ、標高 1,200m において WNW－ESE 方向の比抵抗変化の大きいコントラストを示す。

出典: 調査団

6.4.3　電磁探査結果からみた貯留槽モデル構築上の留意点

電磁探査では、一般に解析して得られた比抵抗分布から地質構造を推定する。地下の比抵抗分布を把握することにより地質・地質構造、物性、地下水や温泉あるいは粘土化帯や変質帯等の有無等を推定することができる。

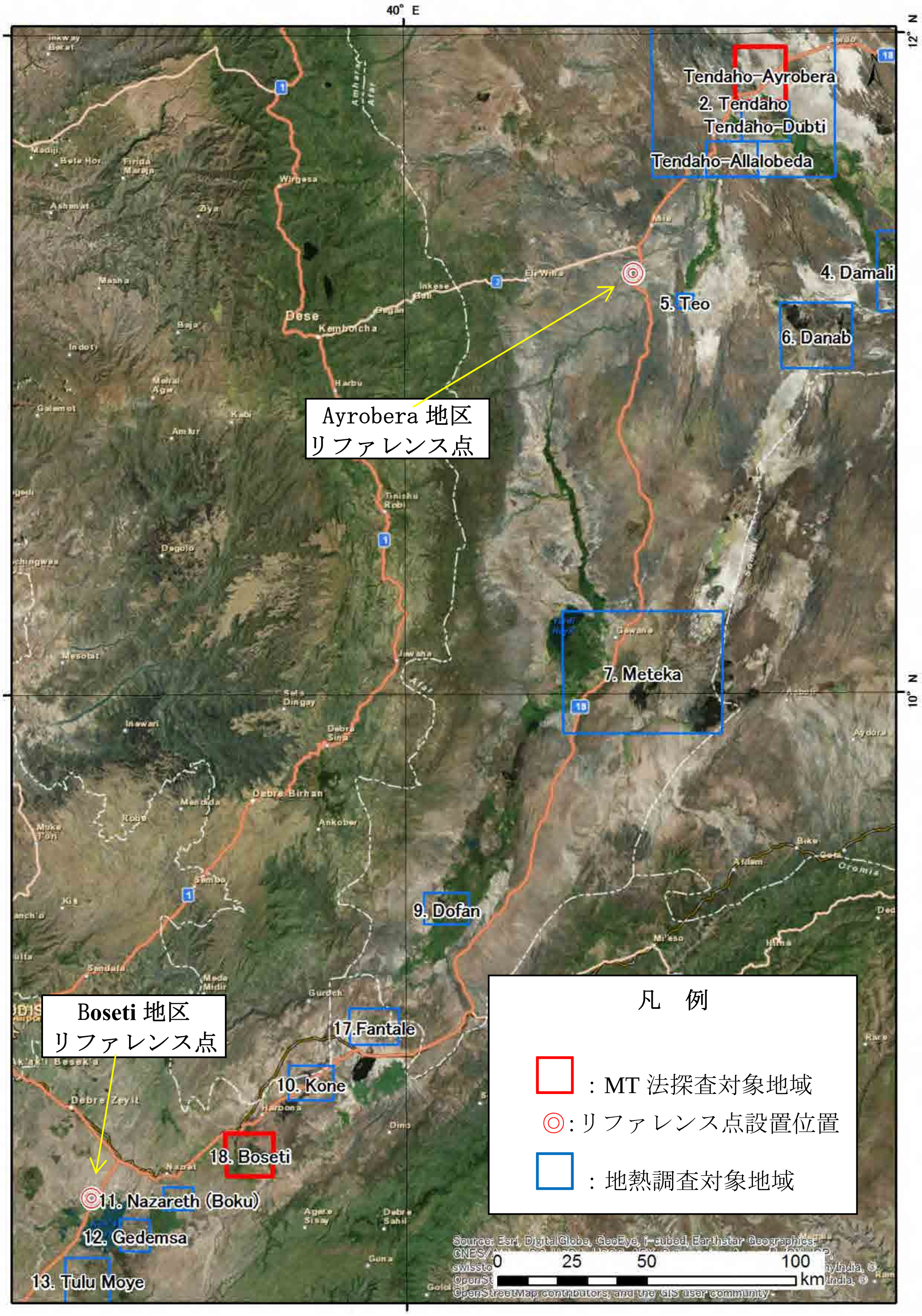
火山地帯の地熱貯留層モデルでは地熱貯留層の上の不透水層は粘土鉱物によると思われる低比抵抗層を形成し、その下の相対的な高比抵抗層が地熱貯留層であるとの考え方がある。高比抵抗層の中でも比抵抗の変化があり、一般に断層破砕帯は高間隙率のため比抵抗値を下げる性質のある流体の存在により、相対的に低比抵抗を示すと考えられる。以上のことを踏まえて各調査地域の比抵抗構造の示唆するものの可能性を推察した。

(1)　Tendaho-2 (Ayrobera)地区

MT 法探査で求められた比抵抗構造の特徴と既存の地質情報および過去の MT 法探査結果より、浅部の低比抵抗は塩分濃度の高い流体を含む堆積層あるいは熱水活動に伴う変質帯、中間部の高比抵抗は主に玄武岩質溶岩類にそれぞれ対応すると推察される。深部の低比抵抗は地熱源に関連する流体を含む領域の可能性が考えられる。本調査地域の特徴的な構造として、NW-SE の走向を示す低比抵抗のチャンネル構造や TDO97 測線付近で低比抵抗帯の幅が狭くなっていることから示唆されるチャンネル構造を横断する不連続部が挙げられる。これらの比抵抗不連続部が地熱貯留層モデルを規制する可能性のある構造として考えられる。

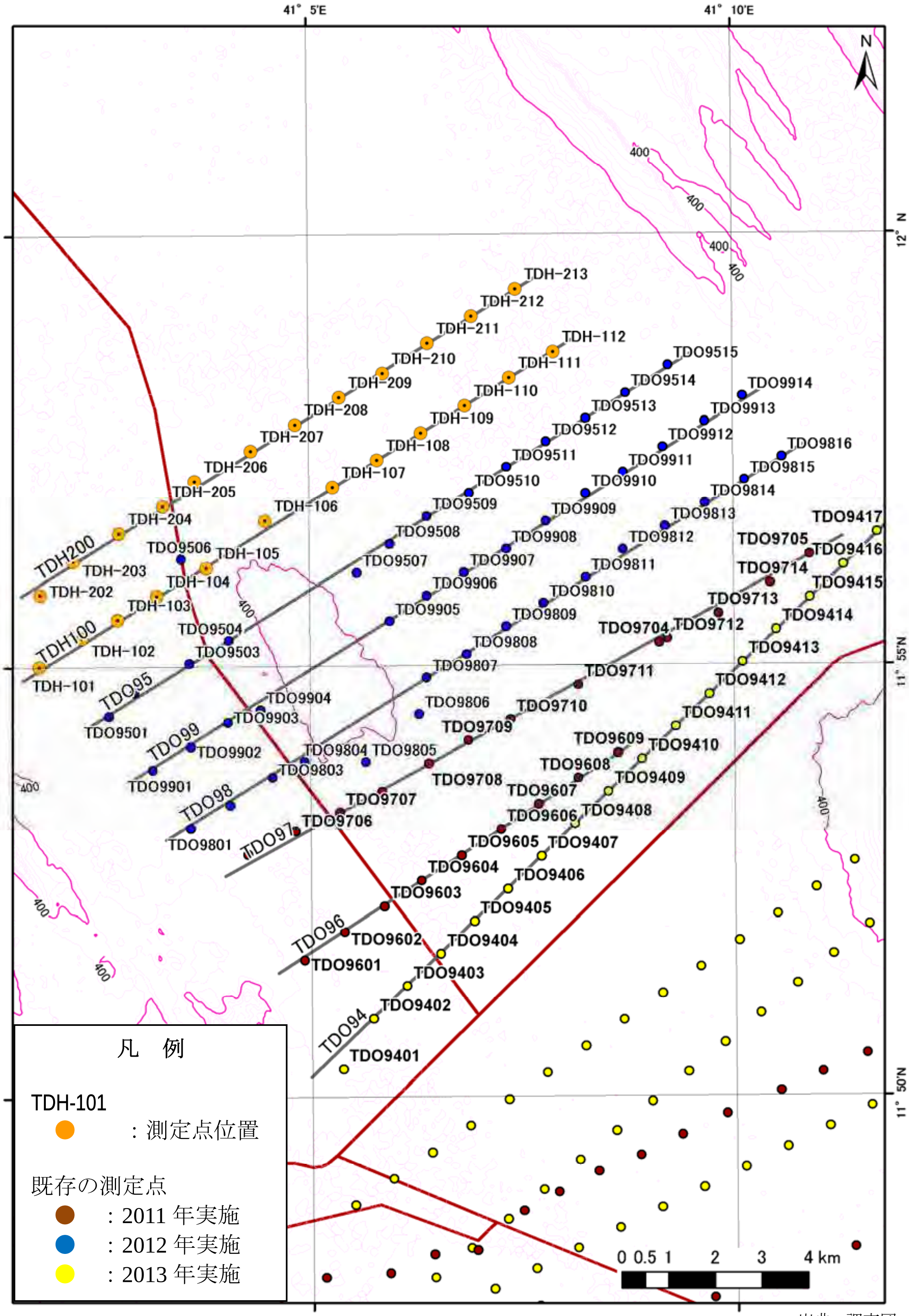
(2)　Boseti 地区

MT 法探査で求められた比抵抗構造の特徴と既存の地質情報より、浅部の高比抵抗は火山岩溶岩類、中間部の低比抵抗は熱水活動に伴う変質帯あるいは高塩分濃度の流体を含む層、深部の高比抵抗は凝灰岩類にそれぞれ対応すると推定される。本調査地域の特徴的な構造として、標高 500m 付近から現れ、NNE-SSW 方向の走向を示す低比抵抗のチャンネル構造や調査地域南部において浅部から現れ、深部に続く低比抵抗部が挙げられる。これらの特徴的な比抵抗構造が地熱貯留層モデルを規制する可能性のある構造として考えられる。



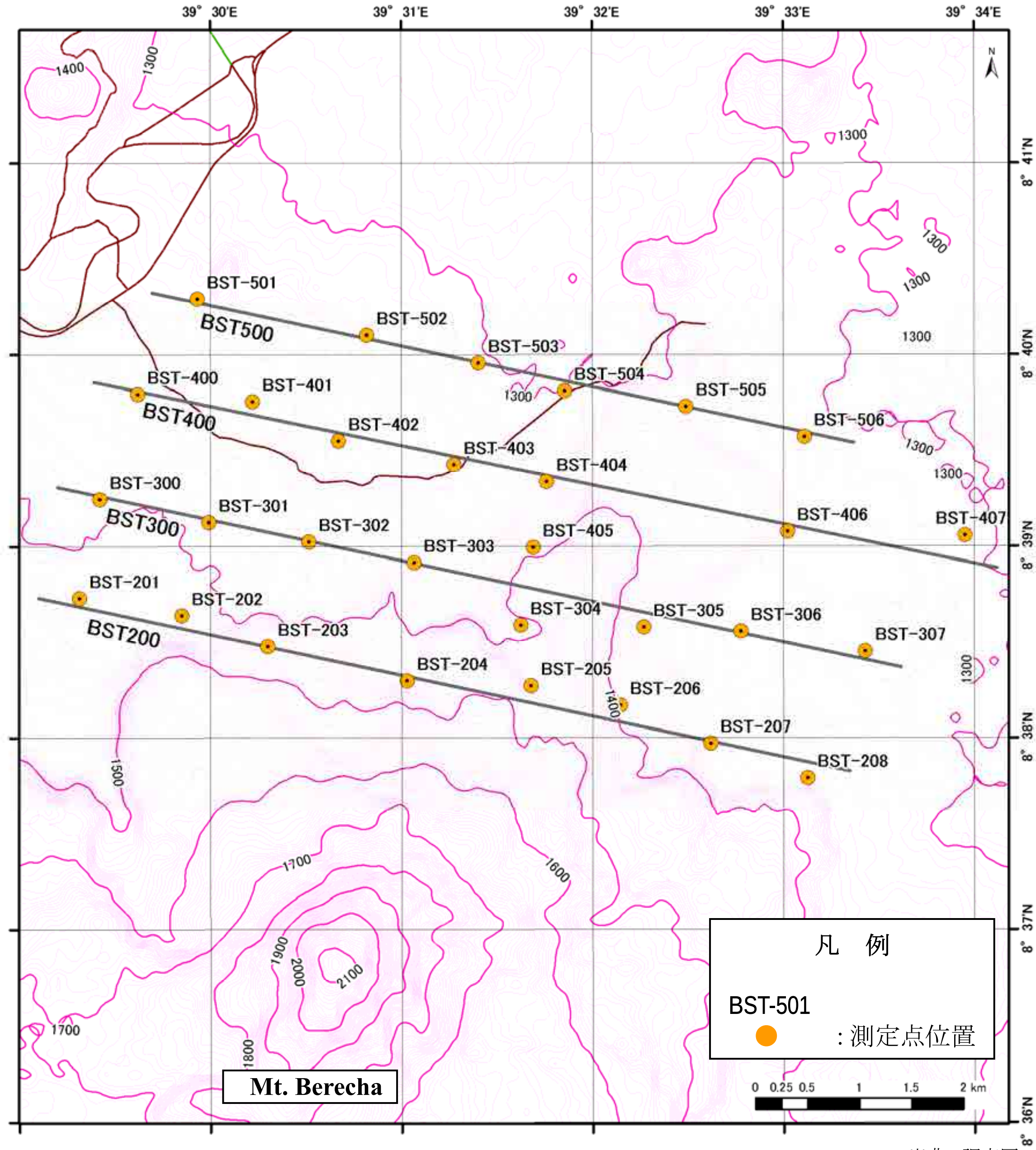
出典：調査団

図 6.4.1　調査位置図



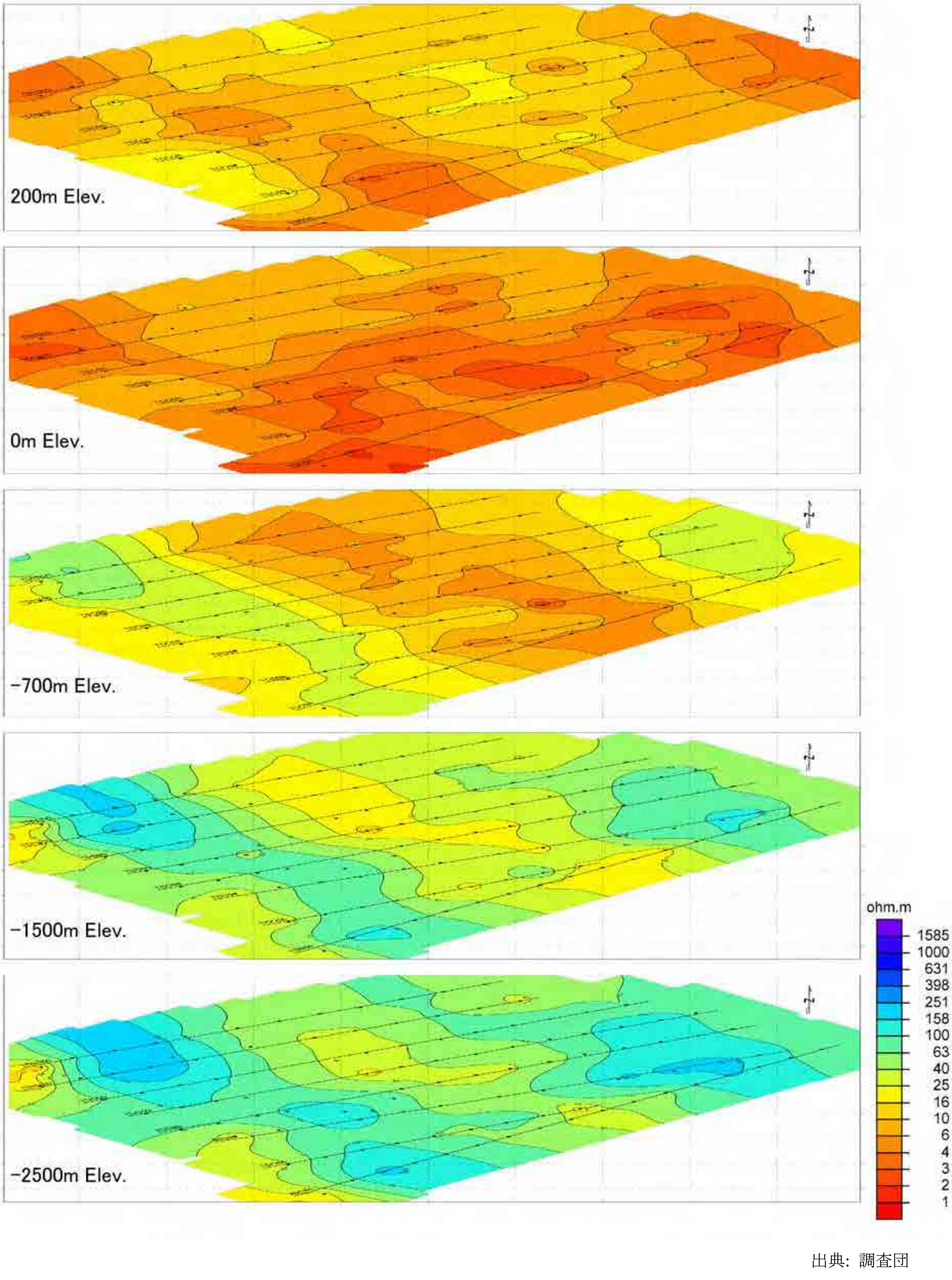
出典: 調査団

図 **6.4.2** 測定点位置図（**Ayrobera** 地区）



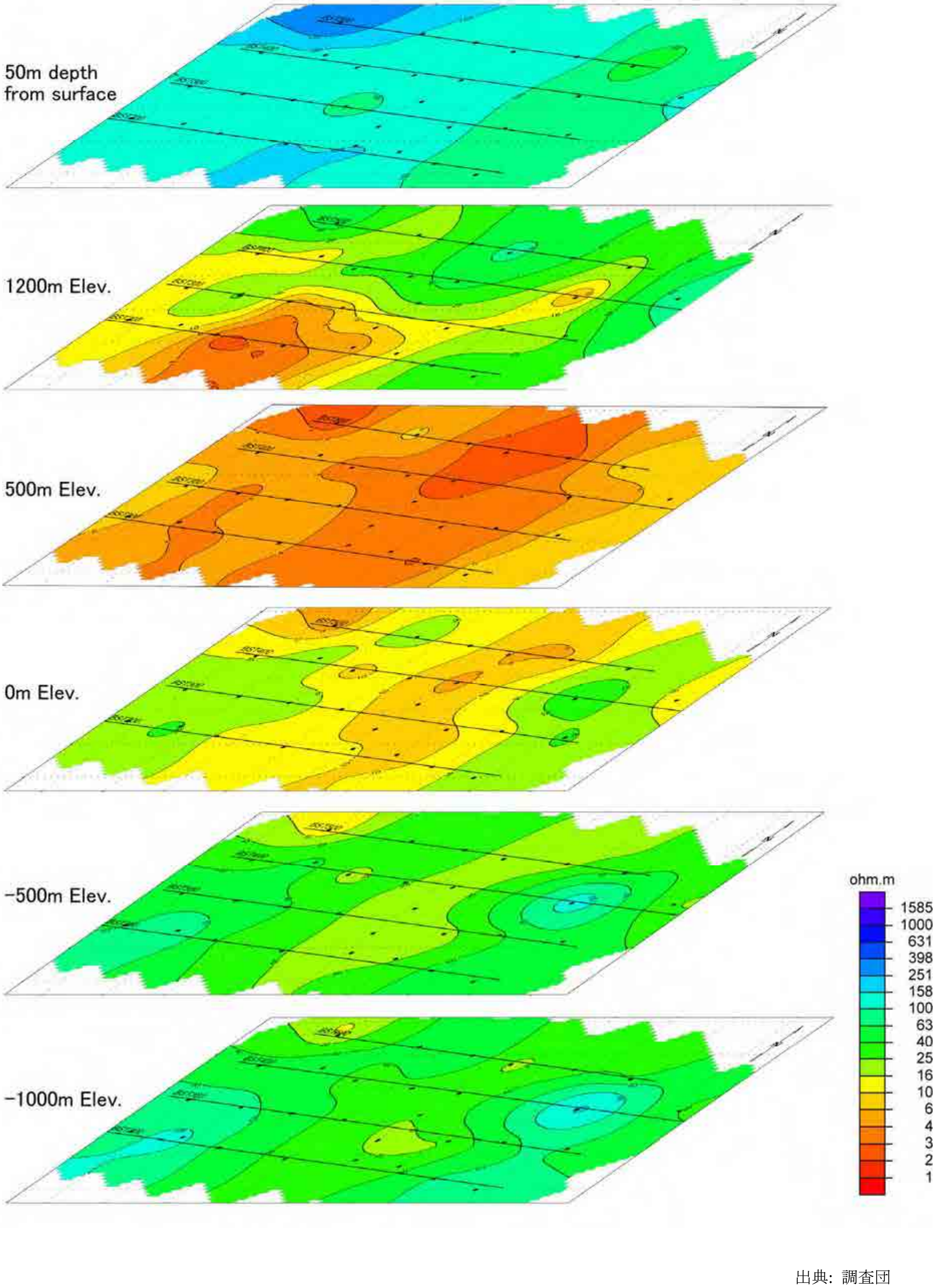
出典：調査団

図 6.4.3 測定点位置図（Boseti 地区）



出典: 調査団

図 **6.4.4**　比抵抗分布平面パネルダイヤグラム **(Ayrobera** 地区）



出典: 調査団

図 **6.4.5**　比抵抗分布平面パネルダイヤグラム **(Boseti** 地区）

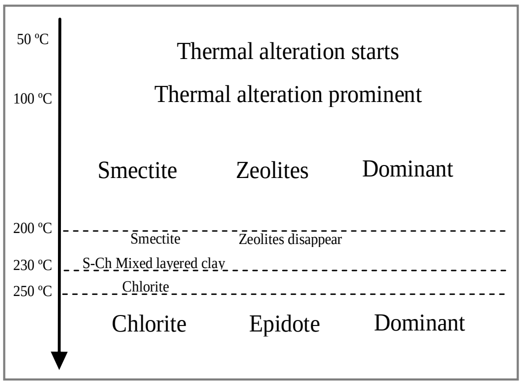
6.5 調査結果の地熱構造的解釈

MT/TEM 探査によって得られる地熱地域の地下比抵抗構造は、多くの場合 3 つのゾーンに区分される。それらは、最上部の上部層、低比抵抗帯、高比抵抗帯である（図 6.5.1a）。ここで上部層とは、地表付近の比較的高い比抵抗値を示す部分である。その下位に低比抵抗帯、高比抵抗帯が区分される。それぞれの層の比抵抗値と変質鉱物・変質帯及び推定温度の関係を表 6.5.1 および図 6.5.1 に示す。

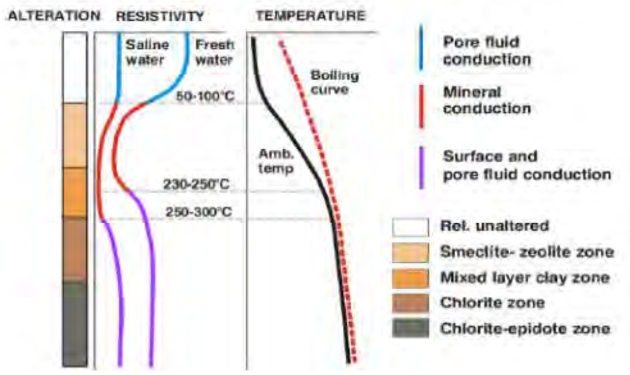
表 6.5.1　地熱地域における比抵抗値と変質鉱物および温度の関係

名称	比抵抗値	変質鉱物・変質帯との関係	推定温度
上部層	数百-数千 ohm-m	<非変質帯> 火山灰、表土堆積物、非変質火山岩等	50-100^{o}C
低比抵抗帯	10 ohm-m（または 5 ohm-m)以下	<粘土化帯（キャップロックに相当）> スメクタイト、混合層粘土鉱物、沸石類を含む変質帯	100-250^{o}C
高比抵抗帯	数十-数百 ohm-m	<緑泥石-緑れん石帯（貯留層に相当）> 緑泥石、イライト、緑れん石（およびガーネット）を含む変質帯	250-300^{o}C

出典・経済産業省ほか(2010)をもとに調査団が加筆



a.　変質鉱物の生成と地温勾配との関係



b.　変質帯と比抵抗値・温度との相関関係

出典: Gylfi et.al. (2012)

図 6.5.1　地熱地域における比抵抗値と変質鉱物および温度の関係

6.5.1 Tendaho-2 (Ayrobera) 地熱徴候サイト

2 次元比抵抗構造インバージョンで得られた結果を元に、海抜 200m, 0m, -700m, -1,500m, -2,500m 毎の解析比抵抗分布平面図を作成した（図 6.5.2）。さらに、代表断面での解析比抵抗分布断面図も合わせて作成した（図 6.5.3）。

図 6.5.2 によると、海抜 200 m と 0 m において、10 ohm-m 以下の低比抵抗帯が広く分布する。また、海抜-700m では NW-SE 方向に低比抵抗帯が発達するがそれ以深では次第に不明瞭となる。NW-SE 方向の低比抵抗構造は、Tendaho Graben の発達方向とも整合しており、顕著に破砕を受けた地層が、その東西に分布する高比抵抗岩体と直線的に接していると考えられる

同サイトの南東約 13km に位置する Dubti (Tendaho-1)サイトでは、1994 年から 1998 年にかけて 6 本の試掘井戸が掘削されており、地質データおよび坑井の温度データが存在する。このうち、本地域の地熱構造を把握するにあたり参考となる TD-1 と TD-2 のデータを表 6.5.2 に示す。

Dubti での MT 探査結果では、5 ohm-m 以下の低比抵抗帯が深度 530 m から 580 m に分布する。また、深度 450 m から 600 m で坑内温度 245 – 250 ºC を記録している。この深度と温度の関係より、Tendaho 地域においては 5 ohm-m を境として、上位の低比抵抗帯はキャップロック、下位の高比抵抗帯は地熱貯留層であると推定することができる。

表 6.5.2　Dubti (Tendaho-1)サイトの試掘井戸データ

変質帯区分	TD-1			TD-2		
	比抵抗値,（測定深度）	温度（測定深度）	変質帯 該当温度.,（測定深度）	比抵抗値,（測定深度）	温度（測定深度）	変質帯 該当温度.,（測定深度）
1)　上部層	高比抵抗	<150 ºC	非変質帯 50-100 ºC , (95 m)	高比抵抗	<150 ºC	非変質帯 50-100 ºC, (50 m)
2)　低比抵抗帯	<5 ohm-m, (580 m)	150 ºC- 250 ºC, (600 m)	粘土化帯 100-250 ºC, (350 m)	<5 ohm-m（530 m）	150 ºC- 245 ºC (450 m)	粘土化帯 100-250 ºC, (280 m)
3)　高比抵抗帯	>5 ohm-m	250 ºC	緑泥石-緑れん石帯 (250-300 ºC)	>5 ohm-m	245 ºC	緑泥石-緑れん石帯 (250-300 ºC)

出典: Aquator (1994),　Aquator (1995)をもとに調査団作成

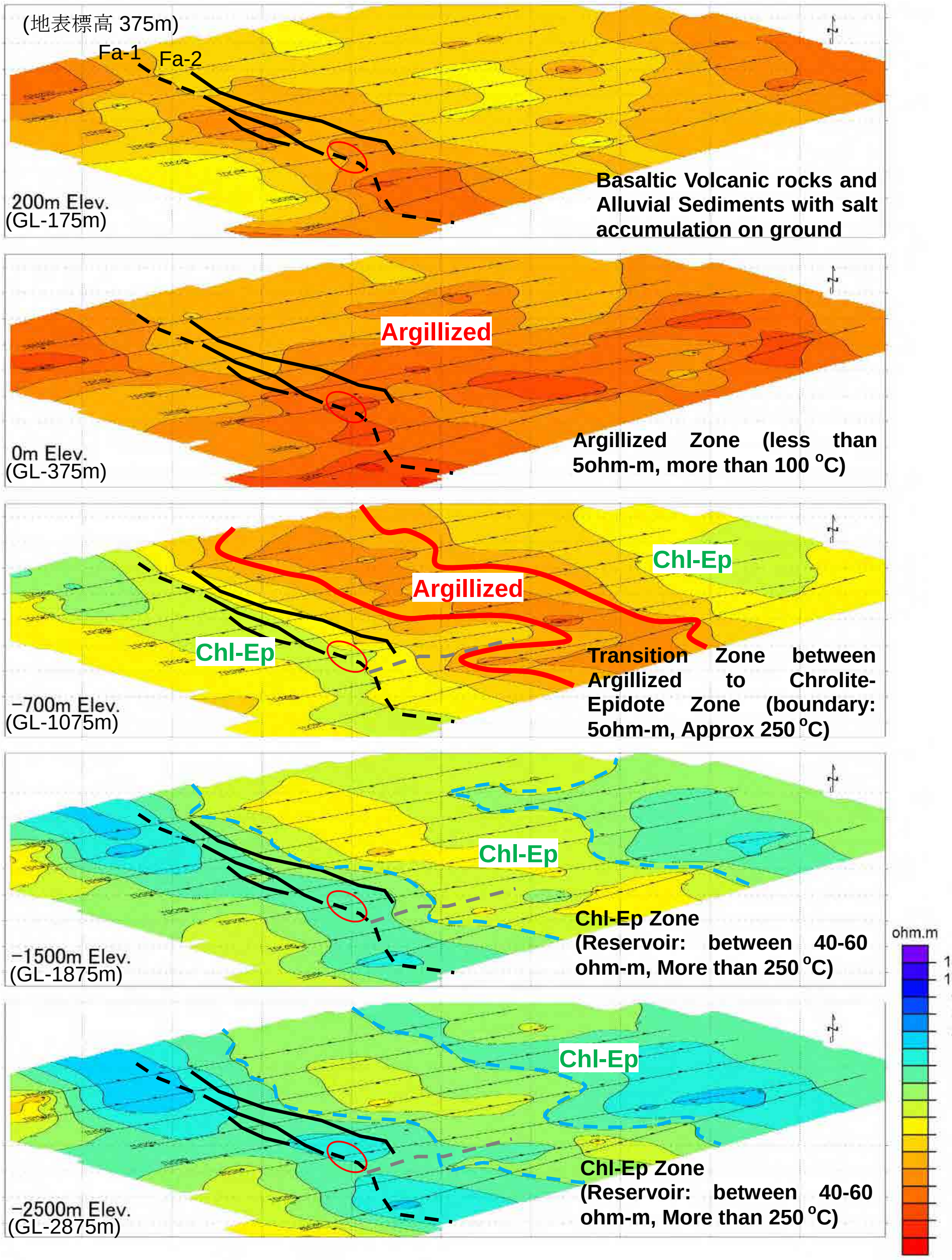
解析比抵抗分布断面図(図 6.5.3)から、低比抵抗帯は断面中央部で発達しており、NW-SE 方向の断層破砕帯の存在が示唆される。またこの破砕帯は、両側を高比抵抗岩体に囲まれ、上部を低比抵抗帯にキャップされた地熱貯留層であると考えられる。5 ohm-m 以下の低比抵抗帯はいわゆるキャップロックであり、深度 300m から 1,200m に分布する。表 6.5.3 に比抵抗分布に基づく各深度の推定温度を示す。

表 6.5.3　比抵抗分布に基づく Ayrobera (Tendaho-2) サイトの推定温度

比抵抗帯	推定される深度および温度		
	比抵抗値	深度 (GL-m)	推定温度
1)　上部高比抵抗帯	10 ohm-m 以上	100 m 以浅	50-100 ºC
2)　低比抵抗帯	5 ohm-m 以下	約 100–500 m	100-250 ºC
3)　高比抵抗帯	5 ohm-m 以上 (約 40–60 ohm-m)	300– 1,200 m 以深	250-300 ºC

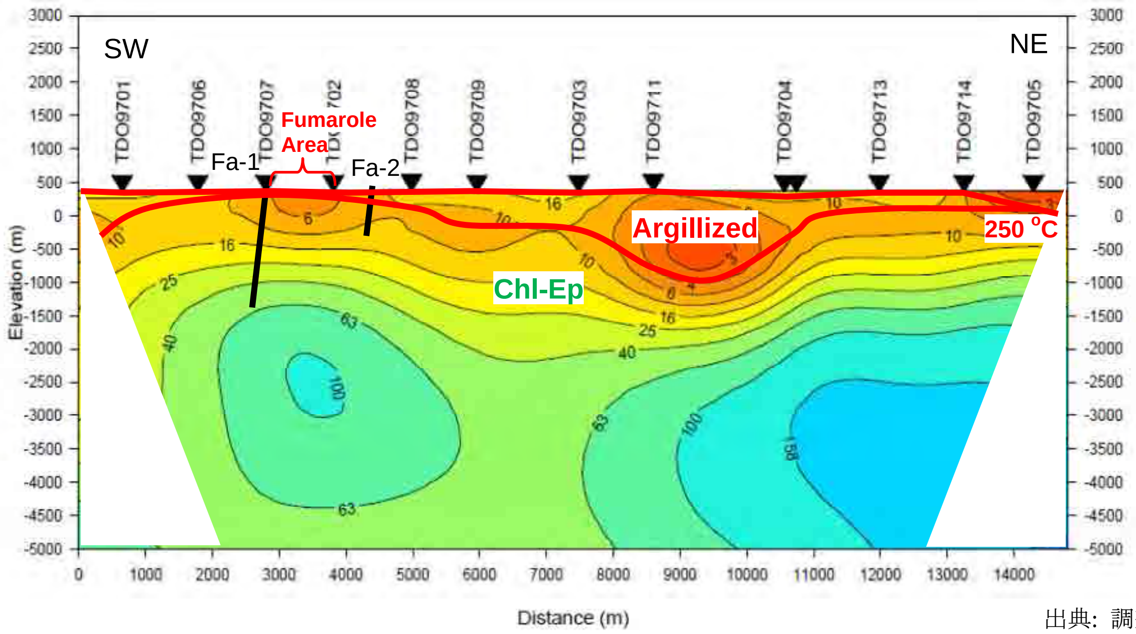
出典: 調査団

地表で噴気が観察される箇所は、想定される貯留層の直上部とずれている。これは、貯留層上部が粘土層により完全に遮蔽されており、噴気は貯留層の縁辺部に発達する小断層にそって噴出していると考えられるためである。



出典：調査団

図 6.5.2 Ayrobera (Tendaho-2)サイト解析比抵抗分布パネルダイヤグラム



出典: 調査団

図 6.5.3　Ayrobera (Tendaho-2)サイト解析比抵抗分布断面図

6.5.2.　Boseti 地熱徴候サイト

2 次元比抵抗構造インバージョンで得られた結果を元に、海抜標高 1,200m, 500m, 0m, -500m, -1,000m 毎の解析比抵抗分布平面図(図 6.5.4)および WNW-SES 方向の断面図を作成した(図 6.5.5)。

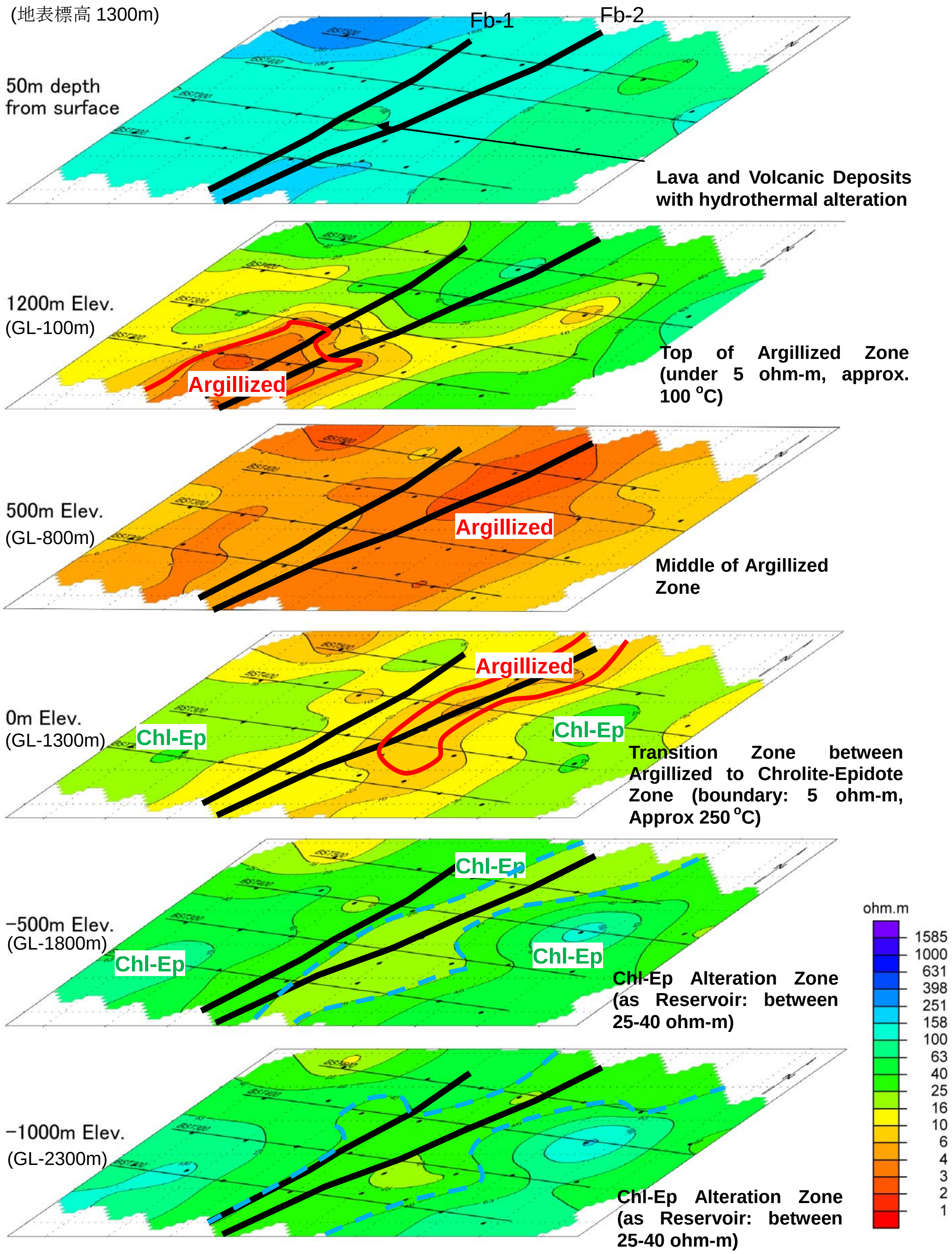
本地域の比抵抗構造は、表層付近の新しい溶岩層に対比される 100 ohm-m 以上の高比抵抗帯、海抜標高 500m に見られる 5 ohm-m 以下の低比抵抗帯、海抜標高 0m で顕著に確認される N-S 方向の低比抵抗帯とそれ以深の高比抵抗帯となっている。比抵抗構造は本地域に特徴的な NNE-SSW 方向の断層構造と調和的であり、低比抵抗帯は断層帯を示すと考えられる。

図 6.5.5 の断面図からは、NNE-SSW 方向の断層を示すと考えられる低比抵抗領域が深部まで広がる。標高 500m-1,000m にキャップロックを示唆する低比抵抗帯が分布し、その上位は表層の高比抵抗帯が存在する。キャップロックの深度は GL-900m（標高 400m-500m ）であり、その下位には地熱貯留層が形成されていると考えられる。表 6.5.4 に比抵抗深度分布から推定される推定温度を示す。

表 6.5.4　比抵抗分布に基づく Boseti サイトの変質帯と推定温度

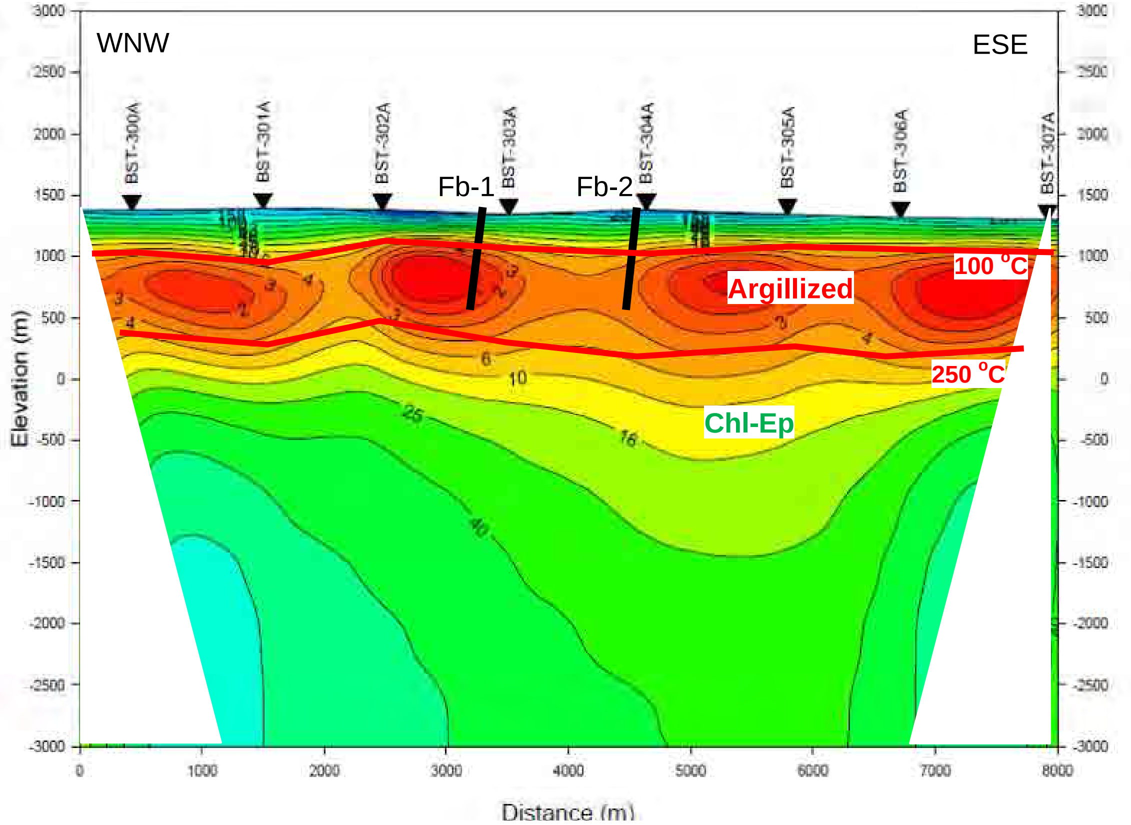
比抵抗帯	貯留層構造推定		
	比抵抗値	深度 (GL-m)	推定温度
1)　上部高比抵抗帯	5 – 150 ohm-m	300-500m 以浅	50-100 °C
2)　低比抵抗帯	5 ohm-m 以下	500 – 900m	100-250 °C
3)　高比抵抗帯	5 ohm-m 以上 (平均 25- 40 ohm-m)	800 – 900m 以深	250-300 °C

出典: 調査団



出典：調査団

図 6.5.4　Boseti サイト解析比抵抗分布パネルダイアグラム



出典: 調査団

図 6.5.5　Boseti サイト解析比抵抗分布断面図

Boseti サイトでも同様に、噴気点は想定される貯留層の縁辺部の断層上に位置している。

第 7 章　予備的貯留層モデル・試掘ターゲットの提案

7.1　はじめに

本章では Tendaho-2 (Ayrobera) および Boseti 地熱徴候サイトの 2 ヶ所について、予備的貯留層モデルと試掘ターゲットの提案を行う。

7.2　Tendaho-2 (Ayrobera)地熱徴候サイト

7.2.1　調査結果の地熱構造的解釈

Ayrobera サイトの地熱貯留層モデルを想定するために必要な地形データや地質調査結果、地化学分析結果および MT/TEM 探査結果は表 7.2.1 のとおりとなる。

表 7.2.1　地表調査結果（地質・地化学・物理探査）から得られる地熱構造

<table>
<tr><th colspan="2">項　目</th><th>記　事</th></tr>
<tr><td rowspan="2">地質</td><td>文献
衛星写真
地質概査</td><td>・ Manda-Harraro 地溝帯に位置する。
・ 基盤は Pliocene-Pleistocene の Afar Stratoid からなり、玄武岩溶岩・火砕岩と堆積岩（細粒砂岩―シルト岩）が分布する。調査地の南西では、Pleistocene の Recent basalt の割れ目噴火による溶岩流が見られる。
・ Ayrobera 周辺では、これらを沖積層が覆い、平原を形成する。</td></tr>
<tr><td>坑井</td><td>・ 約 12km 南方の Tendaho-3 (Dubti)に 6 本の既存坑井が存在する。
・ これら坑井では、深度約 50m ～ 350m で熱水変質粘土、以深では緑泥石-緑れん石が確認されている。前者はキャップロック、後者は高温貯留層を形成している。
<table><tr><th>坑井</th><th>流量</th><th>流体温度</th><th>深度</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
1190-1265m</td></tr></table>・ 調査地南西約 7km の TD-4 坑井では、深度 2,000m 付近までは玄武岩を挟む堆積岩層が、これ以深では玄武岩の溶岩・火山砕屑岩が確認されている。</td></tr>
<tr><td rowspan="2">断裂系</td><td>文献
衛星写真
地質概査</td><td>・ 引張応力場にあり、地溝帯の方向に沿った NW-SE 方向の正断層帯および断裂帯が多数存在している。
・ サイトの南西部に拡大軸があり、SW 方向に傾斜する高角度の断層が発達する。</td></tr>
<tr><td>物理探査</td><td>・ MT/TEM 探査結果では、対象サイトの中央部に NW-SE 方向の低比抵抗帯が、深度 700m から 2,500m に確認される。
・ 重力探査結果では、上記低比抵抗帯を境界として高重力帯（北東）と低重力帯（南西）が分布する。
・ 磁気探査結果では、上記低比抵抗帯を境界として高磁力帯（北東）と低磁力帯（南西）が分布する。（Yohannes L.,2007）
・ 既存坑井 TD-4 から、南西の低重力-低磁力帯は堆積岩が厚く分布している地域と解釈される。
・ MT/TEM 探査で得られた比抵抗帯の分布域は、重力探査および磁気探査で現れた高→低の遷移帯の分布域とほぼ一致していることから、断層帯と推定される。</td></tr>
<tr><td>熱源</td><td>物理探査</td><td>・ 深度 4,000m 程度から比抵抗値の低下傾向がみられ、玄武岩マグマの貫入による温度上昇域の可能性がある。</td></tr>
</table>

流体	衛星写真/地形	・ アワシュ川からの涵養および北方の湿地帯からの涵養が想定される。
	地化学	・ 99.3℃の噴気が確認される（南西地域）。 ・ 想定される地化学温度（シリカ温度）は 240-290ºC である。
	坑井	・ Tendaho-3 (Dubti)での既存坑井(TD-2)では 1.8t/h (13kg/s)、220 ºC の流体自噴が確認されている(DAmore et al., 1997)。
キャップロック	物理探査	・ 5ohm-m 以下の低比抵抗帯が深度 100m ～ 500 m に分布する。これらがキャップロックに相当すると考えられる。
	坑井	・ Tendaho-3(Dubti)の既存坑井では、深度約 50m～約 350m で、2 次鉱物として粘土鉱物および沸石類が確認されている。 ・ この 2 次鉱物の出現深度は約 5 ohm-m 以下の低比抵抗帯と対応する。

出典：調査団

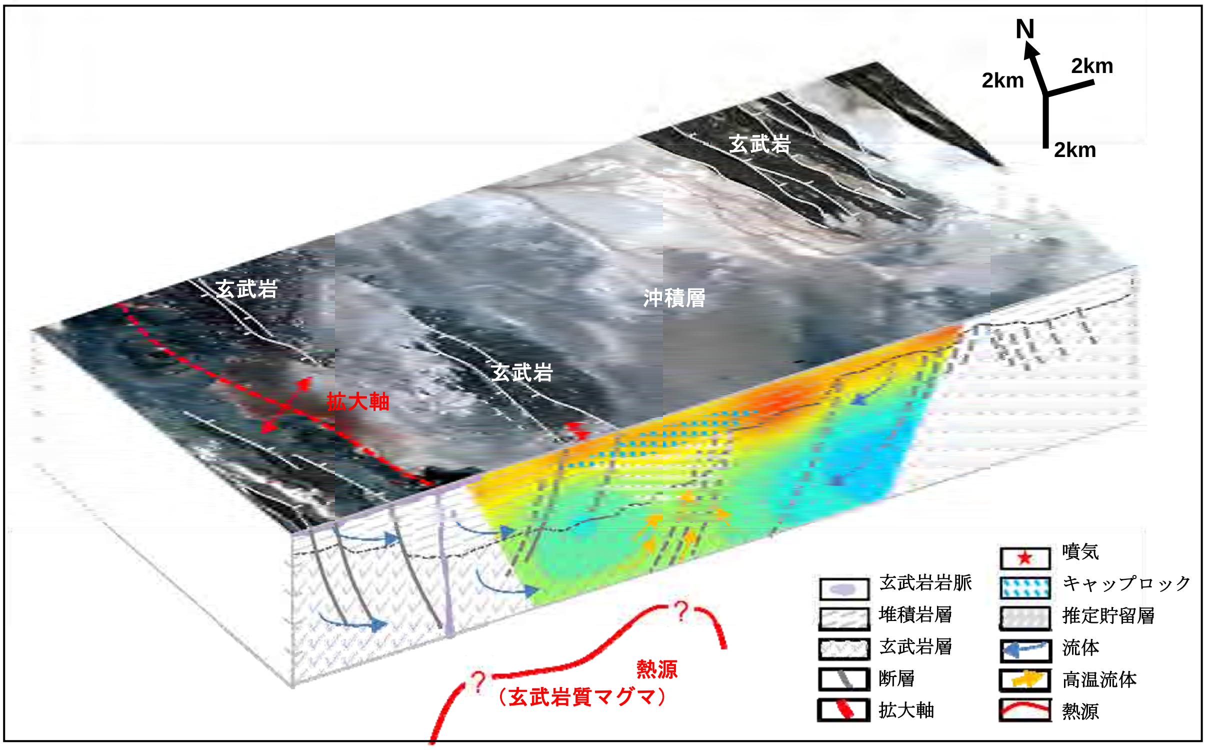
7.2.2 地熱貯留層概念モデル

上記の情報から示される Tendaho-2 (Ayrobera)サイトの地熱貯留層概念モデルの特徴を表 7.2.2 に、概念図を図 7.2.1 および図 7.2.2 に示した。

表 7.2.2 貯留層概念モデル

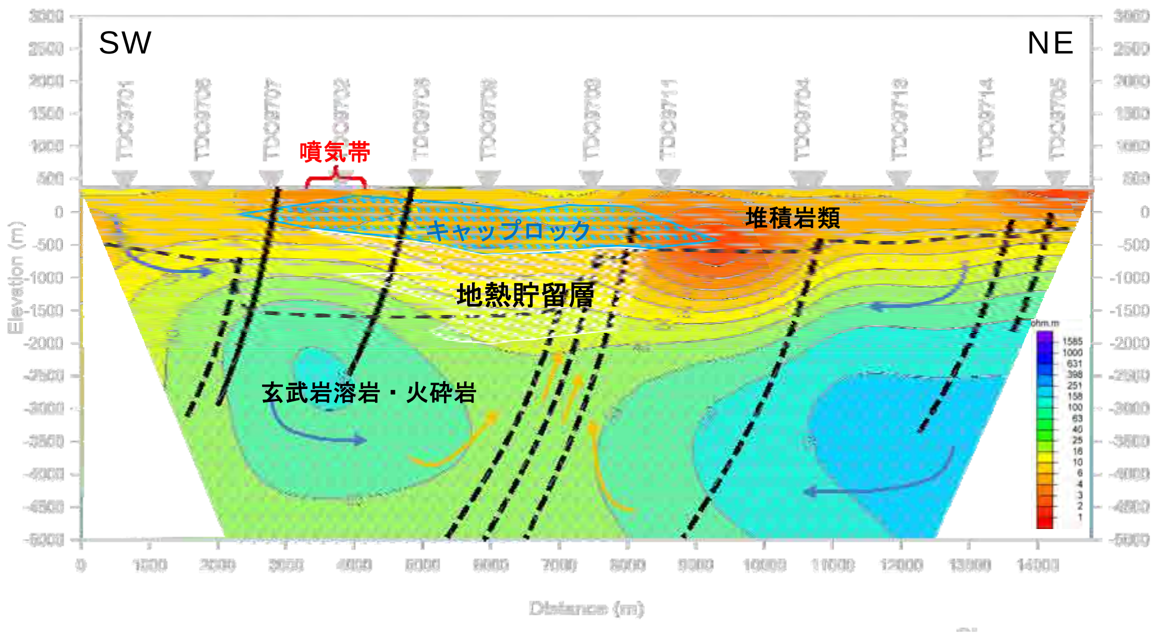
項　目	内　容
貯留層	貯留層は空隙に富む玄武岩および砂岩と考えられる。貯留層の北東縁は玄武岩中の断層帯により明瞭に介され、南西縁は堆積岩中の砂岩層に沿って、細長く何層も分布すると考えられる。キャップロックとして粘土化した変質玄武岩と、細粒砂岩・シルト岩の存在が推定される。
流体	流体はアワシュ川からおよび地表から涵養され、断層帯に規制されて対流している。調査地域中央部で断層帯に沿った上昇域を形成する。
熱源	深度 5-6km 以深に分布する玄武岩質マグマと推定される。

出典：調査団



出典: 調査団

図 7.2.1 Tendaho-2 (Ayrobera)サイト貯留層概念モデル



出典: 調査団

図 7.2.2　**Tendaho-2 (Ayrobera)サイト貯留層概念モデル断面**

7.2.3　試掘ターゲットの選定

前述の貯留層概念モデルから、調査地域のほぼ中央部に北西-南東方向の高温対流域（低比抵抗帯）と、噴気帯周辺の断層帯の貯留層への連続が推定される。これら想定される高温対流域や断層帯に達するためには、深度 2,000m の試掘井が必要と考えられる。現時点で想定される試掘ターゲット、試掘井の諸元を表 7.2.3、表 7.2.4 および図 7.2.3、図 7.2.4 に示す。

表 7.2.3　試掘ターゲット（案）

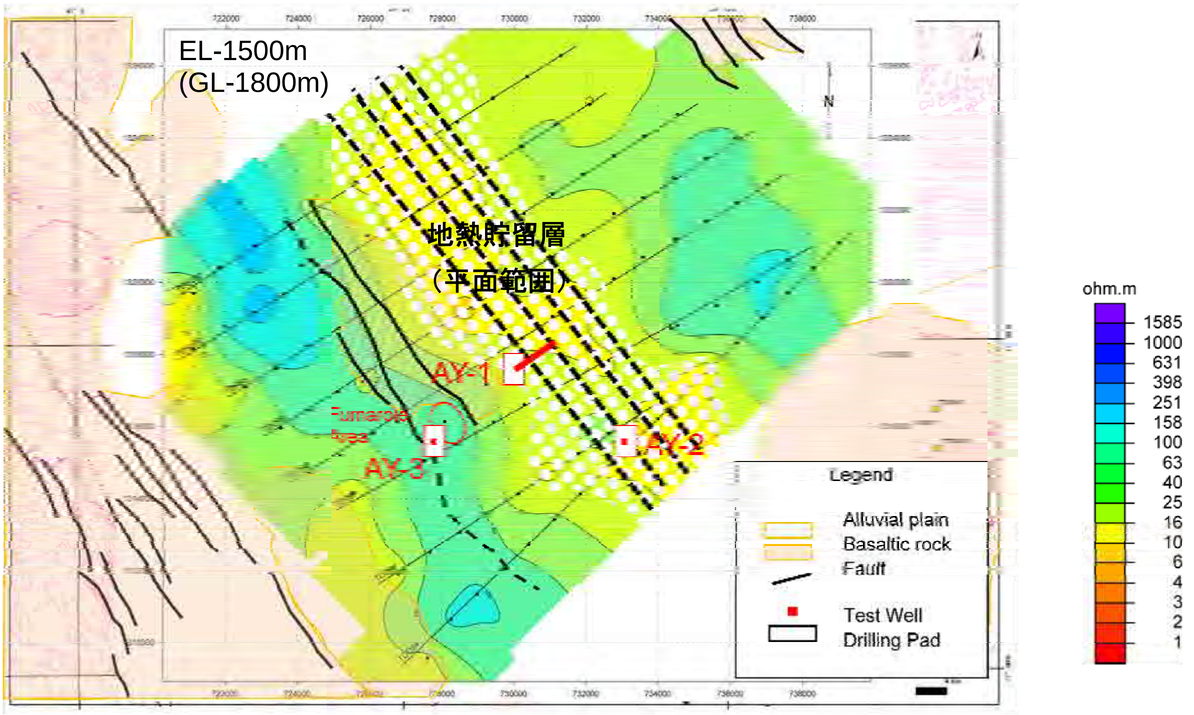
ターゲット・エリア	断裂帯との関係/ターゲット掘削の目的	掘削方法
AY-1 エリア	貯留層（断層帯）中心	傾斜掘削
AY-2 エリア	貯留層（断層帯）中心	垂直掘削
AY-3 エリア	噴気帯	垂直掘削

出典: 調査団

表 7.2.4　試掘井掘削計画（案）

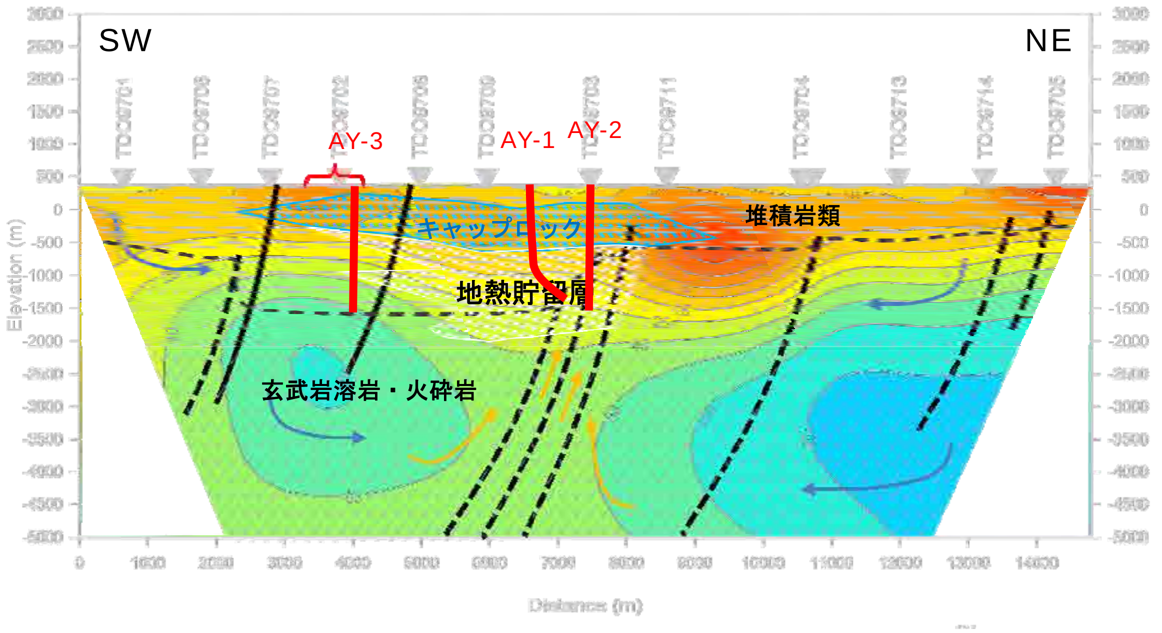
坑井番号 / 項目	AY 1	AY 2	AY 3
ターゲット概要	NW-SE 方向の断層破砕帯	NW-SE 方向の断層破砕帯	NW-SE 方向の断層破砕帯
坑口からのターゲット位置	掘削方向: N 57° E, 垂直深度: 1,840 m 坑井偏距: 600 m	垂直深度: 2,000 m	垂直深度: 2,000 m
掘削方法	傾斜掘削	垂直掘削	垂直掘削
ターゲット深度(m)	1,000 m-1,840 m	1,500 m-2,000 m	1,500 m-2,000 m
ターゲットにおける推定温度	約 250-300 ℃	約 250-300 ℃	約 250-300 ℃
KOP	800 m	–	–
坑井深度	2,000 m	2,000 m	2,000 m

KOP: 傾斜掘開始地点(Kick-Off Point)　出典: 調査団



出典: 調査団

図 7.2.3　Tendaho-2 (Ayrobera)サイトの試掘井掘削計画平面図



出典: 調査団

図 7.2.4　Tendaho-2 (Ayrobera)サイトの試掘井掘削計画断面図

7.3 Boseti 地熱徴候サイト

7.3.1 調査結果の地熱構造的解釈

Boseti サイトの地熱貯留層モデルを想定するために必要な地形データや地質調査結果、地化学分析結果および MT/TEM 探査結果は表 7.3.1 のとおりとなる。

表 7.3.1 地表調査結果（地質・地化学・物理探査）から得られる地熱構造

項 目		記 事
地質	地質	・ 鮮新-更新世の Nazareth 層群に属する玄武岩~流紋岩溶岩・火砕岩と堆積岩（礫岩－砂岩）からなる。 ・ Boseti 火山、Boseti 北方の表層に見られる玄武岩溶岩、および Boseti 火山の噴出物である黒曜岩は、Nazareth 層群の上位に不整合で重なる Wonji 層群（更新世）に区分される。
断裂系	衛星写真 地質	・ 大地溝帯の方向に沿った NNE-SSW 方向の正断層帯が多数発達している。
	物理探査	・ 対象サイトの中央部に NNE-SSW 方向の低比抵抗帯が、深度 800m から 2,300m に確認される。 ・ この低比抵抗帯の方向は地表での断層帯の方向と一致する。
熱源	地質	・ 中央部に確認される NNE-SSW 方向の断層(Fb-2)に沿って溶岩が上昇・噴出したことが地形解析結果から判読される(Korme et.al., 1997)。
	重力探査	・ Boseti 火山の下部深度約 2,000m に高密度帯の存在が推定され、貫入岩体と考えられる。(D.G. Cornwell et al., 2006)
流体	地化学	・ 地熱徴候として噴気が NNE-SSW 方向の断層にそって確認される。 ・ 想定される地下温度は約 170-220℃（クラス C）。
キャップロック	物理探査	・ 5ohm-m 以下の低比抵抗帯が深度 800m～900m に分布する。これらがキャップロックに相当すると考えられる。

出典：調査団

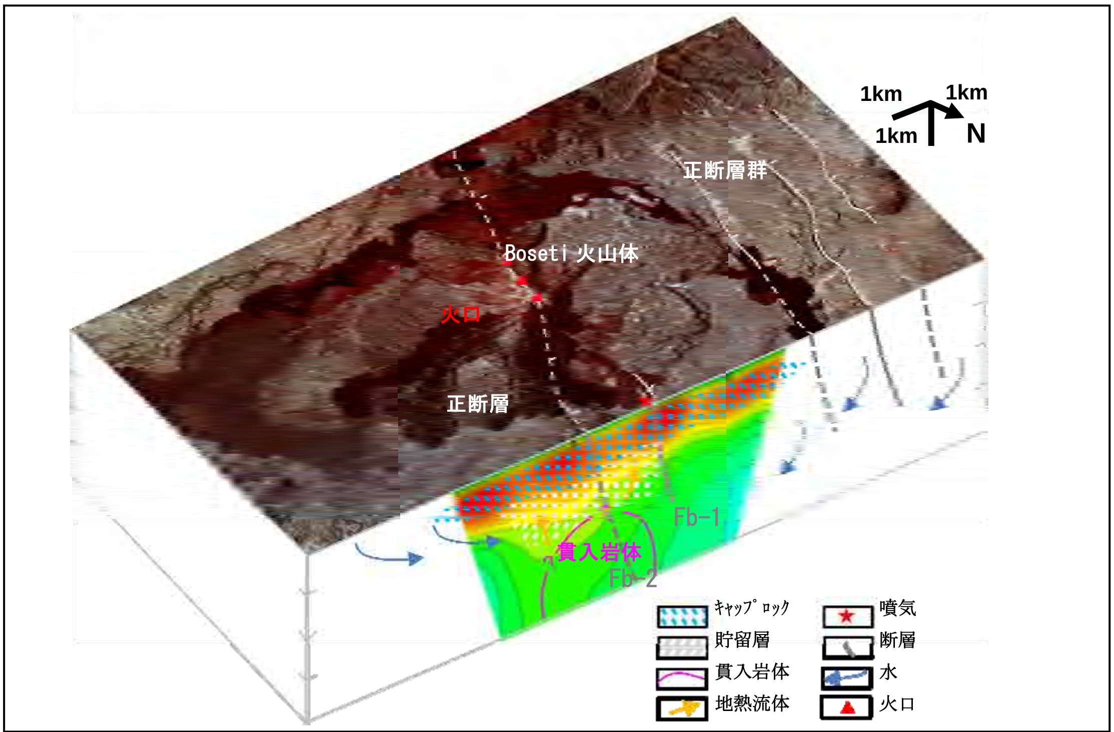
7.3.2 地熱貯留層概念モデル

上記の情報から示される Boseti サイトの地熱貯留層概念モデルの特徴を表 7.3.2 に、概念図を図 7.3.1 および図 7.3.2 に示した。

表 7.3.2 貯留層概念モデル

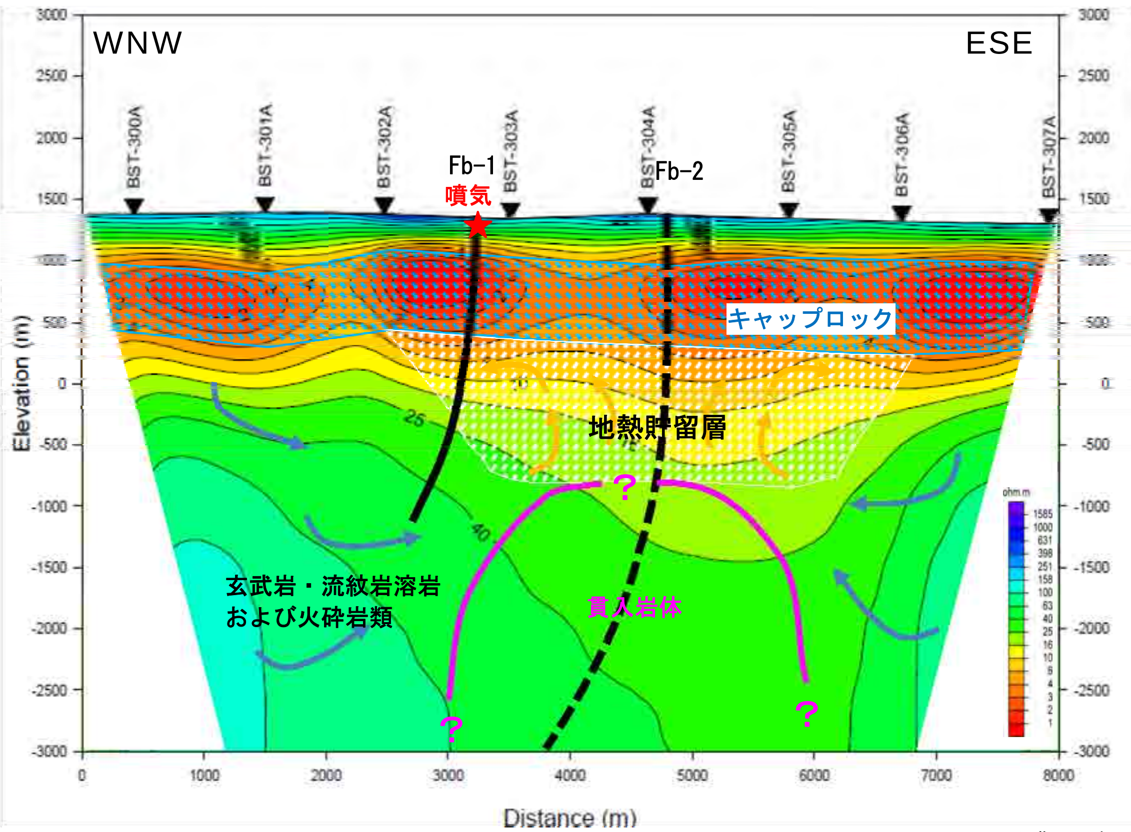
項 目	内 容
貯留層	貯留層は調査地域中央部に位置する NNE-SSW 方向の深部断裂に沿った玄武岩および流紋岩質火山岩類、および堆積岩が推定される。貯留層の両側は亀裂が少なく、高角度の断層、断裂等で規制されていると考えられる。キャップロックとして、玄武岩および流紋岩質火山岩類が変質した変質粘土化帯の存在が推定される。
流体	地表、および Nazareth 層群中に存在する帯水層からの供給が考えられる。断層帯に規制されて対流しており、調査地域中央部で上昇域を形成する。
熱源	深度約 2,000m に存在する、NNE-SSW に伸びた貫入岩体が想定される。

出典：調査団



出典: 調査団

図 7.3.1　**Boseti** サイト地熱構造貯留層概念モデル



出典: 調査団

図 7.3.2　**Boseti** サイト貯留層概念モデル断面

7.3.3 試掘ターゲットの選定

前述の地熱構造モデルから、地表に連続する NNW-SSE 方向の明瞭な断層（Fb-1, Fb-2）と、その下部に高温対流帯（低比抵抗帯）が想定される。この高温対流帯は断層に沿って、Boseti 火山の山体に向かって南方に伸びていることが想定される。熱源として Boseti 火山活動に関連する貫入岩体の存在が示唆されることから、火山体に近づくにつれて貯留層の温度も高くなることが予想される。これら想定される高温対流域や断層に達するためには、深度 2,000m の試掘井が必要と考えられる。現時点で想定される試掘ターゲット、試掘井の諸元を表 7.3.3、表 7.3.4 および図 7.3.3、図 7.3.4 に示す。

表 7.3.3 試掘ターゲット（案）

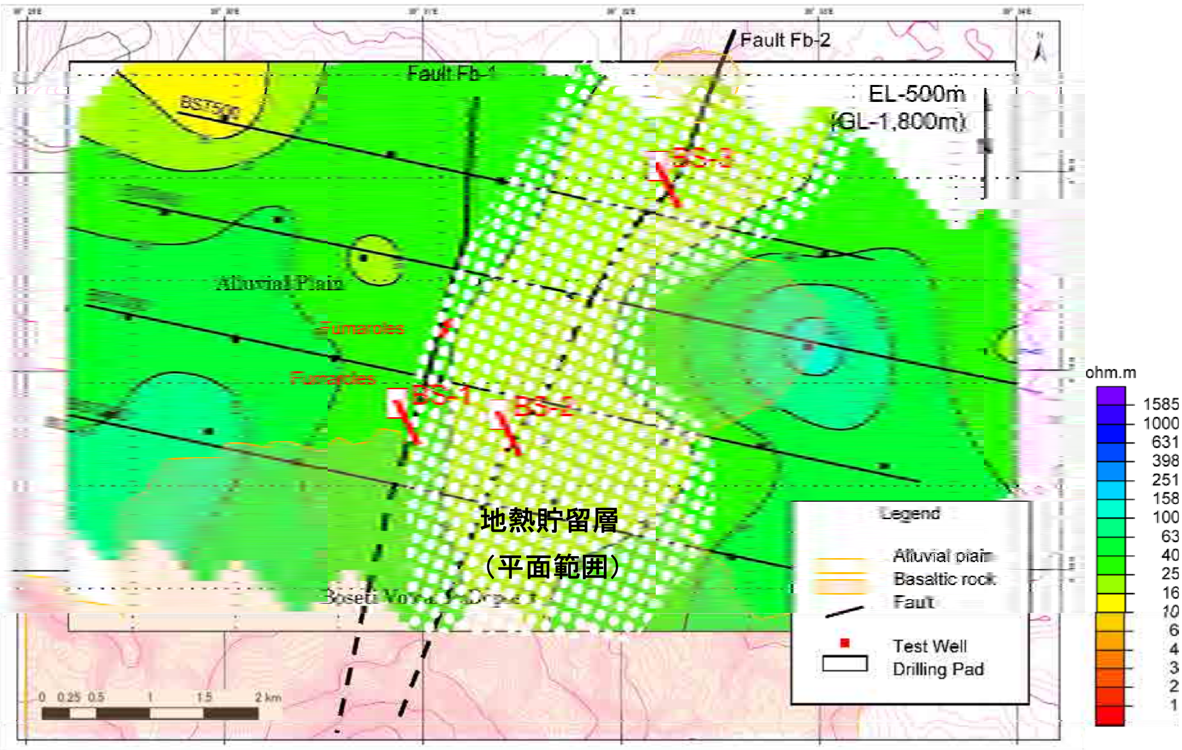
ターゲット・エリア	断裂帯との関係/ターゲット掘削の目的	掘削方法
BS-1 エリア	貯留層外縁の地熱兆候（噴気）を生ずる断層	傾斜掘削
BS-2 エリア	貯留層（破砕帯）の中心、溶岩に被覆されるも火山体に近い地点	傾斜掘削
BS-3 エリア	貯留層（破砕帯）の中心、地表で明確に確認できる地点	傾斜掘削

出典: 調査団

表 7.3.4 試掘井掘削計画（案）

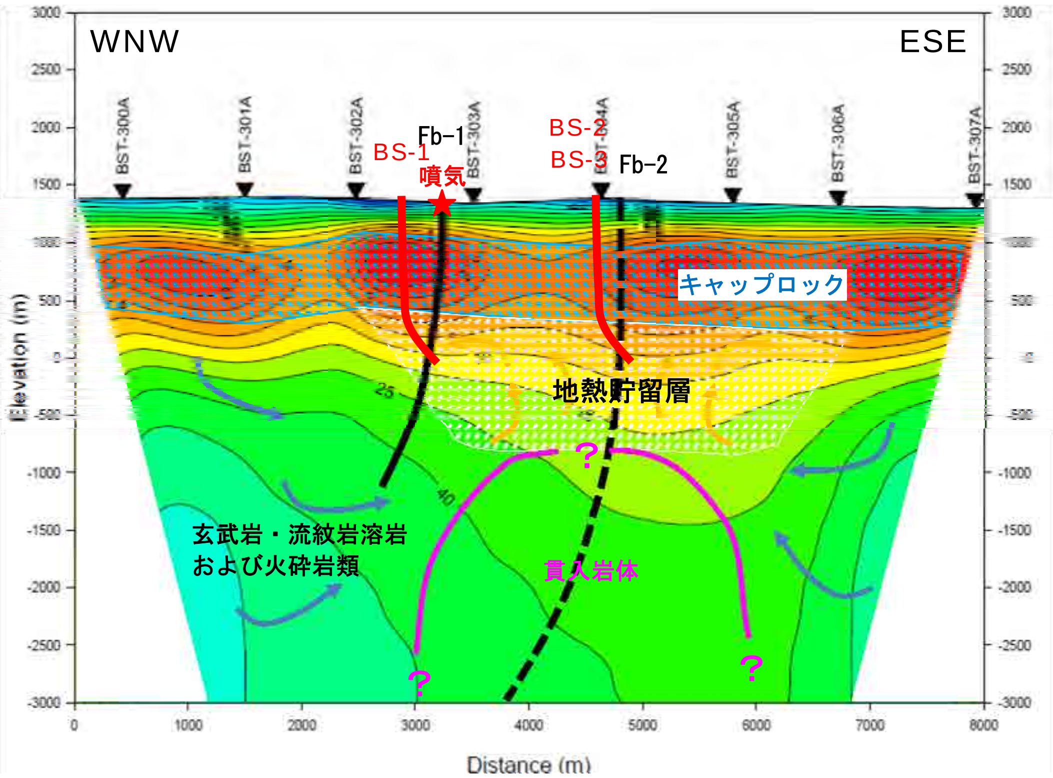
坑井番号 項目	BS 1	BS 2	BS 3
ターゲット概要	噴気帯が存在する NNE-SSW 方向の断層破砕帯(Fb-1)	調査地域中央部 NNE-SSW 方向の断層破砕帯(Fb-2)	調査地域北部 NNE-SSW 方向の断層破砕帯(Fb-2)
坑口からのターゲット位置	掘削方向 S 30°E, 垂直深度: 1,840 m 坑井偏距: 600 m	掘削方向 S 30°E, 垂直深度: 1,840 m 坑井偏距: 600 m	掘削方向 S 30°E, 垂直深度: 1,840 m 坑井偏距: 600 m
掘削方法	傾斜掘削	傾斜掘削	傾斜掘削
ターゲット深度(m)	1,000 m–1,840 m	1,000 m–1,840 m	1,000 m–1,840 m
ターゲットにおける推定温度	約 250–300 °C	約 250–300 °C	約 250–300 °C
KOP	800 m	800 m	800 m
坑井深度	2,000 m	2,000 m	2,000 m

KOP: 傾斜掘開始地点(Kick-Off Point) 出典: 調査団



出典：調査団

図 7.3.3　**Boseti** サイトの試掘井掘削計画平面図



出典：調査団

図 7.3.4　**Boseti** サイトの試掘井掘削計画断面図

7.4　地熱資源量・開発優先順位の再検討

7.4.1　地熱資源量の再評価

作成した地熱概念モデルを用いて、Tendaho-2(Ayrobera)および Boseti サイトにおける貯留層の容積を推定し、地熱資源量の再評価を行った。資源量の計算には 3 章で述べた容積法を用いた。地熱概念モデルより推定した貯留層容積を表 7.4.1 に、資源量の計算結果を表 7.4.2 にそれぞれ示す。

表 7.4.1　地熱概念モデルから推定した貯留層容積

サイト	Tendaho-2(Ayrobera)	Boseti
貯留層容積(km^2)	40.0 (12.5)	37.5 (48.6)

( )内数値は 3.5 節の最可能容積　出典: 調査団

表 7.4.2　地熱資源量再計算結果

サイト	生起確率 80% (MW)	最頻値 (MW)	生起確率 20% (MW)
Tendaho-2(Ayrobera)	120 (47)	180 (100)	330 (230)
Boseti	175 (160)	265 (320)	490 (800)

( )内数値は 3.5 節の計算結果　出典: 調査団

3.5 節での計算結果と比較すると、最頻値については Tendaho-2(Ayrobera)サイトで 80MW 増加、Boseti サイトでは 55 MW 減少する結果となった。

7.4.2　開発優先順位への影響

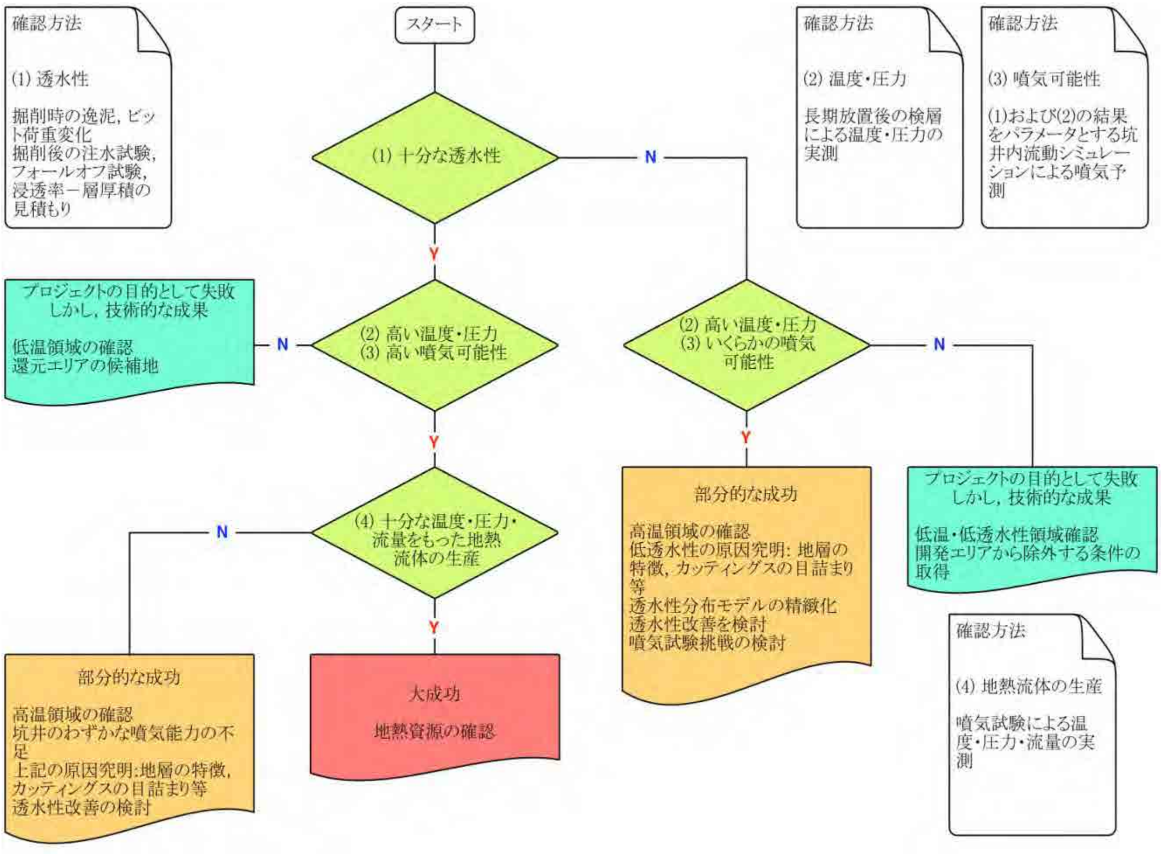
前述のように、地熱概念モデルにより地熱資源量は更新された。一方、貯留層温度に関しては 3.4 節で推定した値からの更新はない。そのため、発電原価の更新もなく、開発優先順位は表 5.2.12 で示した順位のままとなる。

7.5　試掘計画の概要

7.5.1　試掘の概要

(1)　試掘の目的

地熱貯留層の資源量評価を目的として、前述の試掘ターゲットに向けて坑井を掘削し、地熱開発有望地の地下構造および地熱流体の性状を調査する。試掘井での確認項目と確認方法、および成功と失敗の判断基準を図 7.5.1 に示す。



出典: 調査団

図 7.5.1　試掘井の確認項目と判断基準

(2)　　地熱調査井の種類

調査井は、試掘の目的によりいくつかの仕様から選択することが可能である。標準的なタイプは下表に示す 3 種類がある。このうち、最終口径が 6 インチ程度以下の坑井（Type-1 および Type-2）をスリムホールと呼ぶ。小口径の調査井掘削は相対的に安価に押さえることができるが、傾斜掘削および長期の噴出試験を行う場合は Type-2 以上、また生産井への転用を考える際は Type-3 以上の口径での掘削が必要となる。

表 7.5.1　調査井の分類

Item \ Size		Type-1	Type-2	Type-3
Depth (m)		1,500	2,000	2,000
Temperature(°C)		200>	350>	350>
Final Diameter (inch)		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	1month>	1month<	1year
	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: 78.5mm, H: 98.2mm N/A: Not Applicable 出典: 調査団

(3) 対象地での試掘

本調査で選定した地熱候補地（Ayrobera および Boseti）で掘削する調査井は、断層破砕帯のターゲットに向けた傾斜掘削、および掘削後に十分な期間の噴出試験を行い、貯留層評価のために必要な検層を行うことから、少なくとも Type-2 以上の口径での掘削を提案する。

7.5.2 試掘時の留意事項

本調査で選定した地熱候補地での試掘実施の際はいくつかの留意点が挙げられる。地質・地形等の現地状況から想定される主な留意点は以下のとおりである。

(1) Tendaho-2 (Ayrobera)

- 深度 0～50m の未固結堆積物や下位の火砕流堆積物など崩れやすい地層の掘削時は坑壁崩壊が起こる可能性があり、この場合の抑留トラブルなどに留意が必要である。
- 亀裂や浅部地下水層での逸泥の発生が考えられる。掘削水の確保と、十分な量の逸泥防止剤の準備、およびセメントによる対策をとれるよう準備が必要である。
- 隣接する Tendaho-1(Dubti)地域では地下 500 メートル付近に浅層熱水帯水層の存在が確認されており、地熱ターゲット以浅であっても被圧された熱水層に遭遇する可能性があり、BOP（暴噴防止装置）を使った掘削が必要である。

(2) Boseti

- 火山性砕屑物や火山岩の亀裂、岩相境界、または浅部地下水層などで逸泥が発生するおそれがある。十分な掘削水の確保と、十分な量の逸泥防止剤の準備、およびセメントによる対策をとれるよう準備が必要である。

  地表付近から深度約 100m の間に、火山岩に挟まれて厚さ数 10m の未固結堆積物の存在が予想され、掘削中に孔壁崩壊が起こる可能性がある。この場合の抑留トラブルなどに注意が必要である。

第 8 章　データベース構築

8.1　構築の目的と活用方法

地熱データベースは、各種地質、地化学、物理探査等の地熱データを、地形データや既存インフラとともに体系的に格納することを目的に構築した。

本調査団は、地熱データベースとして、地熱技術開発株式会社製のデータベースソフトウェア「G*BASE」を GSE に供与した。G*BASE は、Oracle7/8TM をベースにし、本邦の地熱事業者等関係者に頻繁に利用されているソフトウェアである。GSE は、各種調査により近々地熱サイトの必要な情報を揃え、貯留層を解析するためのシミュレーションの実施が可能となる。シミュレーションには、G*BASE の機能を使用し、世界中で地熱貯留層シミュレーションや流体シミュレーションに使用されている他相流解析コード「TOUGH-2」へのデータのインプットや計算が可能である。

8.2　データベースの構造

データベースは、各サイトのすべての情報を数値情報化して、G*BASE ソフトウェアへ格納し、構築した。G*BASE に格納可能なデータ・情報を表 8.2.1 に示す。

表 8.2.1　G*BASE データベースの構造

データ種別	Information Examples
深度情報テーブル （Z, 数値情報）	検層、坑井地質、逸泥・フィードポイント、ケーシングプログラム、坑跡座標等
二次元離散データ （X,Y, 数値情報・・・）	標高、岩相頂部深度、物理探査・地化学調査等の平面分布等
三次元離散データ （X,Y,Z, 数値情報・・・）	物理探査（MT 法比抵抗分布、微小地震震央分布）、貯留層シミュレーション結果等
時系列データ （t, 数値情報・・・）	坑井試験、生産・還元記録、圧力・温度モニタリング、地化学モニタリング等
点データ	地名、地熱徴候地点（温泉・噴気）、サンプル採取位置、火山
ポリゴンデータ	道路、河川、湖沼、施設区画、境界線、地質図、断層、カルデラ等
イメージデータ （平面または断面位置, 画像イメージ）	衛星画像、地質平面図、地質断面図、反射法地震探査深度断面図等
地化学調査	地化学分析データ

出典: 調査団

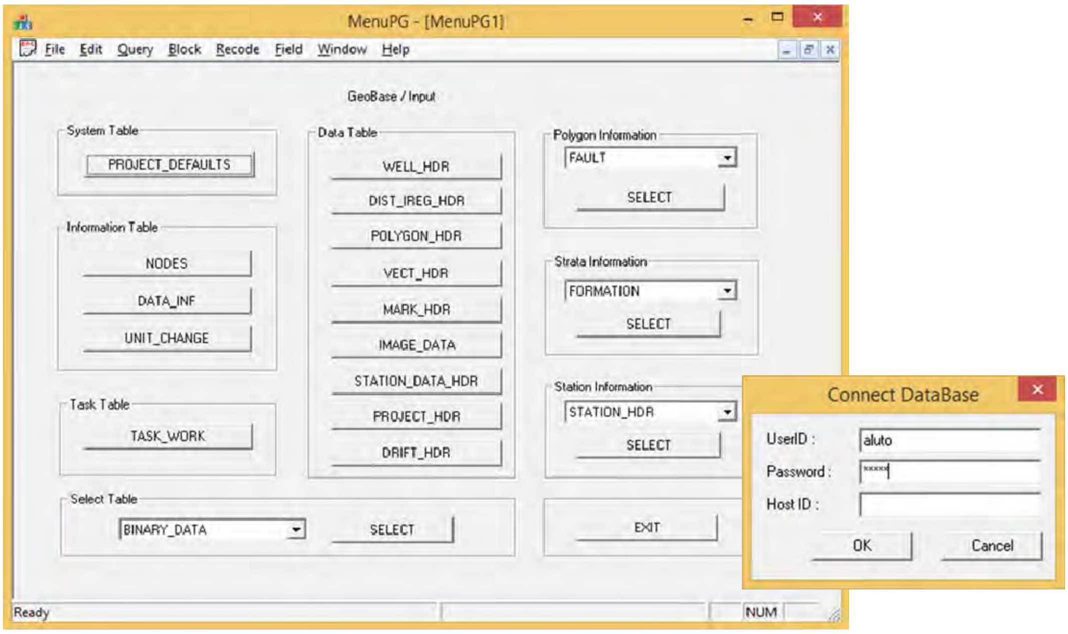
G*BASE において、各サイトにはサイト ID が割り当てられ、データ入力や表示に必要となる。表 8.2.2 にサイト ID の一覧を示す。Tendaho 地区と Aluto 地区では、本マスタープランの地熱サイト区分に跨る物理探査や井戸掘削等の調査が存在するため、Tendaho-1～3 の 3 つのサイトと Aluto-1～3 の 3 つのサイトはそれぞれ Tendaho と Aluto の一つのサイト ID に統合して G*BASE に登録した。データベースのスタートアップ画面を図 8.2.1 に示す。G*BASE は、データ・情報

の登録、地化学データの入力、2 次元表示、3 次元表示、データベースの管理等の別にいくつかのアプリケーションが存在し、用途に応じそれらを起動する必要がある。図 8.2.1 に示すようにサイト ID とパスワードを入力してアプリケーションにログインする。下記に示すサイト ID のほかに、パスワードについては別途 GSE 担当者に引き渡し済みである。

表 8.2.2　G*BASE におけるサイト ID

サイト ID	本マスタープランにおける地熱サイト
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

出典: 調査団



出典: 調査団

図 8.2.1　G*BASE スタートアップ画面

(左: 登録画面, 右: ログイン画面)

G*BASE の操作方法については、本邦研修やエチオピア現地での作業において、GSE が独力で更新できるよう、GSE 職員に教育、研修を行ったほか、データの入力方法や 2 次元・3 次元地熱モデルの表示方法を詳細に説明した G*BASE の取扱説明書を GSE に提供した。本報告書の別冊資料にも添付する。

8.3 G*BASE 内のデータおよび情報

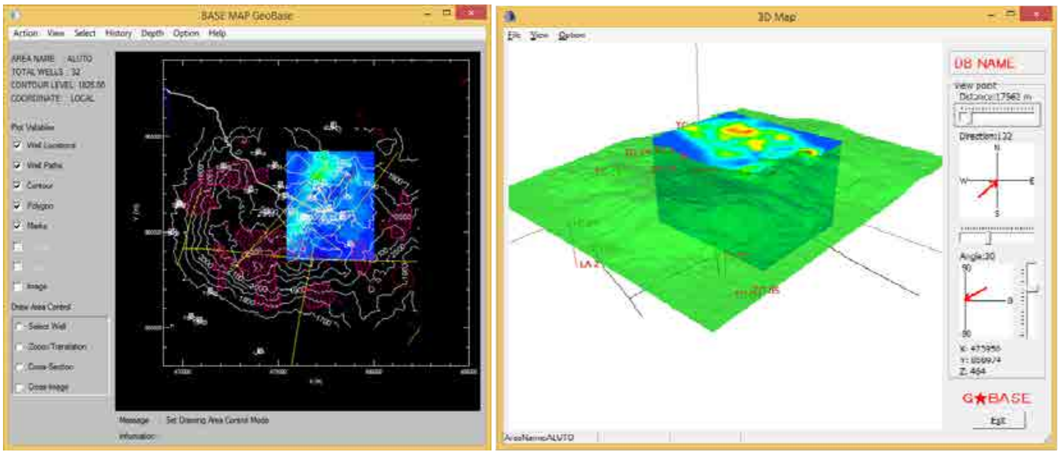
JICA 調査団は、GSE により提供された地熱データや本調査の調査結果を入力し、データベースの構築を行った。表 8.3.1 に入力したデータ・情報種類の一覧を示す。G*BASE に格納した詳細なデータリストを巻末に収録する。

表 8.3.1 G*BASE に登録した地熱データおよび周辺情報

分類	入力データ
基本情報	地形コンター
	河川
	湖沼
	主要道路
	鉄道
地質データ	地質図
	断層
	火山
	カルデラ
地形解析データ (リモートセンシングデータ)	熱水変質帯
	環状地形
	リニアメント
地表調査結果	地熱徴候
	サンプル採取地点
地化学調査結果	地化学解析結果
物理探査結果	MT/TEM 探査結果
	VES 探査結果
	電気探査結果
	ブーゲー異常探査結果
	微小地震探査結果
坑井データ	井戸位置
	井戸軌跡
	ケーシングプログラム
	地質柱状図
	透水イベント (逸泥個所)
井戸検層データ	温度検層
	圧力検層
	坑口圧力測定
	インジェクション試験
	フォール・オフ試験
	噴出試験
	流量計測
	干渉試験
	ビルドアップ試験

出典: 調査団

JICA 調査団は、本調査結果とともに、GSE から収集したデータを可能な限りデータベースに格納した。G*BASE 内のアプリケーションを使用し、2 次元および 3 次元の地熱モデルの作成が下記の図のように可能であり、地熱貯留層や地熱流体のシミュレーション等に活用可能である。



出典: 調査団

図 8.3.1　Aluto 地区の 2 次元地熱データ表示 (左) と 3 次元地熱データモデル表示 (右)

8.4　データベースの管理・更新

GSE は、新規に地熱データを取得した際には、適切にデータベースを更新し、管理していく必要がある。本調査開始前は、ほとんどの地熱データは分散しており、適切に蓄積されていなかった。そのため GSE 職員によって十分に活用されることがされず、更にデータの中には、検層データや試験日時、試験条件、単位などが紛失しているものもあった。このような過ちを避けるためにも、GSE は、G*BASE に全てのデータを適切に蓄積し、データベースを更新していくことが望まれる。また同時にデータベースを活用し、次期地熱調査や井戸掘削を計画し、地熱貯留層や流体に関する各種シミュレーションを実施していくことが望まれる。

第 9 章　試掘までの地表調査提案

前章まで、調査対象の 22 地域において実施した現地調査および解析に基づき地熱開発マスタープラン策定した。これらの調査に基づき、現在開発が進行中ないしは他ドナーあるいは民間企業が開発を表明している地点を除いた地点から、今後優先的に開発を進めていく必要がある地熱開発有望地点を 3 地点選定した。それらは、Tendaho-2 (Ayrobera)、Boseti および Meteka である。このうち、Tendaho-2 (Ayrobera)および Boseti では、本マスタープラン調査の一環として GSE と協働で物理探査を実施した。これに基づき予備的な貯留層モデルを推定して掘削ターゲットを提案した。Meteka 地域は別途我が国から GSE に供与された物理探査機器を使用して GSE が独自に調査を実施することが期待される。一方、今回物理探査を実施した 2 地点については、試掘調査を実施できる段階となったが、その資金調達に時間を要する場合には、試掘をより確実なものとするための追加調査を実施することが望まれる。

また、本マスタープランプランでは、地熱開発を促進するためには、現在各組織に分散している地熱開発担当部署を一組織として統合することを提案している（第 5.5 節）。IFC も同様の提案をしているようである。設立に向けた具体的な道程を示す必要がある。

本章では、より確実な試掘調査に資するためにさらなる地球科学的調査を提案するとともに、新たな組織を立ち上げるために必要な調査内容を提示する。

9.1 追加地表調査項目の提案

9.1.1 追加地表調査対象地点

追加地表調査対象地点としてマスタープランで選定した 2 サイト Tendaho-2 (Ayrobera)と Boseti の他に、Butajira（アジスアベバの南西約 150 km）を加えることを提案する。Butajira は首都アジスアベバに近くアクセス条件も良好で、フラッシュタイプの導入が可能な資源が賦存すると想定される。石油やガス等の採掘業界では、資源を確保する確率をあげるために複数の有望地点の資源調査を同時に行うという Portfolio Approach が採用されている。地熱開発では石油やガスほどの大きな採算性は期待できないが、可能な限り同様のアプローチを採用することが望まれる。

Butajira では、水井戸が掘削さており、本件の現地調査が終了していた 2014 年 5 月に深度約 200m から熱水が噴出したと報告されている（GSE には当時撮影された動画がある）。その後、調査団が現地を訪問して概略調査を行った結果、温度 83.6℃の温泉が確認され、その温泉水の地化学的分析から推定される貯留層温度は 210℃～250℃と推定された

9.1.2 Butajira サイトの開発現況

Butajira サイトの開発現況は下記の通りである。

- GRMF のウェブサイトによれば、英国のコンサルタントが Butajira サイトを地表調査の対象として GRMF に EoI を提出している。2015 年３月上旬時点では、EoI の審査結

果は公表されていない。
- GSE の説明では、調査権の認可を担当する鉱山省には、Butajira サイトにかかる調査権取得の申請は提出されていないとのことである（2015 年 3 月上旬現在)。
- GSE の説明では、EoI が GRMF に採用されて実際の調査を行う場合には、鉱山省に調査権を申請しなければならないとのことである（GRMF への EoI 提出は特にエチオピア側の了解を必要としない)。
- 現在の段階では、Butajira を JICA の調査対象に追加することが可能である。
- 以上より、Butajira を JICA の調査対象外とする積極的な理由はないと考えられる、

9.1.3 追加地表調査のアプローチ

次の 2 段階の調査アプローチを提案する；すなわち、第一段階では物理探査などの地表調査を実施して試掘調査範囲を絞り込み、続く第二段階で深度の浅い構造試錐調査（深度 300m 程度）を行って、試掘調査地点とターゲットの確定をおこなう。各段階における各サイトの調査内容を表 9.1.1 に示す。

(1) 第一段階 — 地表調査

第一段階は、次の調査を行う：(1) 微小地震観測調査、(2) 重力探査、(3) 磁気探査、(4) MT/TEM 探査、(5) 比抵抗 2 次元解析、(6) 2-m 深度地温分布調査、(7) 地質地化学調査、あるいは(8) 予備的環境社会影響調査(ESIA)。調査対象サイトによって、実施済みの調査が異なるので、以下の方針に従う。

Tendaho-2 (Ayrobera)では、ARGeo や本調査によって重力探査や磁気探査、MT/TEM 探査など各種地表調査が行われている。これに加え、微小地震調査や比抵抗 3D に資するための精密 MT/TEM 探査および比抵抗 3D 解析を行う。Boseti では、本件調査によって MT/TEM 探査を実施している。これに加え、Ayrobera で行われたような重力探査や磁気探査を実施する。また、Butajira においては、現在のところ実質的な調査は行われていないため、地質地化学調査から始めて、MT/TEM 探査、重力探査、磁気探査を実施する。また、以上の 3 サイトの全てのサイトにおいて 2-m 深度地温分布調査を行う。さらに、Butajira においては、予備的な環境社会影響評価調査を実施して地熱開発を促進するに当たっての影響を調査しておく必要がある。

これら第一段階の調査結果から、構造試錐調査を実施するサイトを 1～2 サイト選定する。

(2) 第二段階 — 構造試錐調査（地温勾配測定用浅深度調査井）

選定されたサイトにおいて、GSE が保有するトラックマウント式調査用試錐機で掘削可能な深度約 300m の構造試錐調査を実施する。主な調査目的は、地温勾配測定、地質状況確認である。地質状況確認においては、特に熱水変質粘土の生成の有無および程度を確認するものとする。構造試錐調査は、1 サイトにおいて約 4 井掘削することが望まれる。

なお、かつて Tendaho-1 (Dubti)で掘削された試掘井では、深度 500m 程度において熱水に遭遇していることから、坑口バルブと BOP の設置が不可欠である。

表 9.1.1 追加調査の提案

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

(3) 第三段階 — 試掘

第一、第二段階の調査結果に基づき、本マスタープランで予備的に提案した試掘実施サイトおよび試掘ターゲットを見直す。それに基づき試掘を実施する。試掘では、調査孔を利用して電気検層や噴気試験など可能な調査を行う。

9.2 EEGeD 設立マスタープラン調査の提案

9.2.1 地熱開発特別目的公社の設立

新たに設立を提案する地熱開発特別目的会社の名称を仮に「エチオピア地熱エネルギー開発公社 Ethiopian Enterprise for Geothermal Energy Development (EEGeD)」とする。EEGeD の所管業務を下記の通り提案する。

- 地熱地表調査及び試掘を行う。
- 蒸気開発を行うことができる。
- 蒸気販売ないし発電事業を行うことができる。
- 蒸気販売ないしは発電事業まで行うは場合事業可能性調査を行うことができる。

EEGeD を設立する利点は下記の通りである。

- EEGeD は、主に発電を目的とした地熱エネルギー開発業務に専念することができる。

- EEGeD は、地熱エネルギー開発に関する物的知的資源を組織内に蓄積することができ、地熱開発促進に寄与することができる。
- EEGeD は、エチオピア国における地熱開発を担当する単一の公的機関として、各ドナーのフォーカルポイントとしての役割を果たし、開発資金の調達が容易となる。

9.2.2 EEGeD の特徴

新たに設立する EEGeD は、最終的には財務的に持続可能な組織となる必要がある。財務的に持続可能な組織とすることで、組織の運営や経営並びに技術革新への意欲が維持されるものと考える。調査団が EEGeD の業務として含めることを提案する蒸気販売は、この目的のために必要不可欠である。ただし、設立当初は、事業収入が見込めないため補助金等の措置が必要となり、段階的に独立採算公社に変容できるようなプログラムの提案が必要である。

9.2.3 EEGeD 設立マスタープランプロジェクトの提案

地熱開発特別目的公社の設立に当たっては、組織設計や法制度の整備が必要である。また、記述の通り、独立採算となる公社を最終形態の組織運営形態とはするものの、上記販売が開始されるまでは、収入が見込めないので経過措置が必要である。このため、EEGeD 設立マスタープランプロジェクトの実施を提案する。その業務内容(ToR)を下記の通り提案する。

表 9.2.1 EEGeD 設立マスタープランプロジェクト TOR の提案

1. EEGeD 設立趣旨 Rationale for EEGeD
2. ビジョンおよびミッション Vision and Mission
3. 現況分析（人的、物的、財務的資源の分析）
   Situation analysis (Assessment of human, physical and financial resources)
4. 事業形態(価値連鎖確認、オーナーシップ構造)
   Business model (Value chain mapping and ownership structure)
5. 人的資源開発（組織、要員）
   Human Resource Development (Organization and staffing)
6. 法制度枠組整備 Legal and regulatory framework
7. 地熱資源開発計画 Geothermal resource development
8. 財務計画　Financial plan
9. 蒸気販売計画　Steam Sales Agreement (SSA)
10. EEGeD 設立のためのアクションプラン Action Plan for Formation of EEGeD

第 10 章　結論と提言

エチオピア国の 22 ヶ所の調査対象地域における既存資料調査、リモートセンシング調査、現地地質・地化学調査、地質地化学室内分析および環境社会配慮概略調査に基づき、地熱資源量評価を行った。加えて、第 5 章で定めた開発優先順位に従いエチオピア国における地熱開発マスタープランを策定した。

結論と提言を記述する前に、エチオピア国において地熱開発を促進する意義についてまず確認したい。

1. 地熱エネルギーは、年間を通じて安定した電力を提供することができる。
2. 地熱エネルギーは、電力供給源として風力や太陽光などの他の再生可能エネルギーに優れている。
3. 地熱エネルギーは、水力発電に依存するエチオピア国の旱魃時における電力不足リスクを軽減することができる。
4. このため、地熱エネルギーの早期かつ最大限の開発を優先する必要がある。

本マスタープランプロジェクトの結論と提言は以下の通りである。

【結　論】

1. 地熱資源量評価の結果、対象地域の地熱資源量は最頻値で約 4,200 MW と見積もられる。生起確率 80%および 20%の資源推定量はそれぞれ 2,100 MW、10,800 MW と見積もられる。ただし、殆どの対象地域では地質地化学等の地表調査のみ実施されているため、この評価は「推定された（Inferred）」レベルの地熱資源量（Geothermal resource）であることに留意しなければならない。より具体的な開発計画の策定には、物理探査ならびに試掘調査を実施して、この推定量を「提示された（Indicated）」ないしは「測定された（Measured）」レベルの資源量評価に引き上げる必要がある。

2. 環境社会配慮にかかる予備的現地調査の結果、国立公園に立地する地点や、住民摩擦が想定される地点を除く大部分の地熱徴候地点で、環境社会に対する重大な影響はないと判断される。

3. 種々の要素に基づいて地熱徴候地域の開発優先順位付けを行い、開発優先順位のランクを優先度の高い順に Priority-S, A, B, C および D とした。その結果、開発計画として、短期計画（2014－2018）では、既に開発がコミット・実施されている Priority-S の約 600 MW を開発対象とし、中期計画(2019 – 2025)では Priority-A と B の約 2,400 MW(累計約 3,000 MW)、および長期計画(2026-2037)では Priority-C と D の約 1,100 MW (累計約 4,100 MW)を提案した。

4. 中期計画のPriority-AとBのうち､まだ開発がコミット･実施されていない地点は､Priority-AのTendaho-2 (Ayrobera)とPriority-BのBosetiおよびMetekaの3地点である。このため、新期開発地点の選定はこれら3サイトが優先されるとした。

5. EEPCoのマスタープランでは2018年までに合計1,200 MWの風力発電所や太陽光発電所の建設が計画されているが、経済分析の結果ではPriority-AとBの地熱発電所が風力・太陽光発電所に対して経済的に優れる結果となった。このため、風力・太陽光発電所の建設に先行して地熱発電所の建設を優先できるとした。

6. 現行の電気料金施策を前提として財務的考察をおこなった結果次の通りとなった。(i) 国内向け電力供給を前提とすると、融資条件が有利な円借款を活用してPriority-Aを開発する場合にのみ、発電原価が現行の国内向け平均電気料金以内に収まる。(ii) 電力輸出を前提とした場合、世銀の融資や円借款を用いてPriority-AとBを開発する場合はコストは現行の電気輸出価格を下回る。(iii)しかし、民間企業が投資する場合は発電原価は現行輸出価格を上回る。これらの結果、地熱発電所の建設には融資条件が有利な公的資金を投入する必要があることが判明した。民間資金を導入するためには、各種既存の支援制度の活用ないしは新たな支援制度の設立が必要である。

7. 上記財務的分析の結果、地熱開発実施体制は原則として公的機関が主導する必要があると結論される。ただし、現存組織制度の枠組みでは円滑な地熱資源開発は困難であると考えられる。このため、既存のGSEとEEPの地熱関連部門を単一機関として独立させ、初期調査から蒸気生産販売までを担当する公社（Enterprise）の設立が必要であるとした。これを、EEGeD（Ethiopia Enterprise for Geothermal Energy Development）と仮称する。地熱資源開発の主目的が電力開発であることに鑑み、EEGeDは水資源･エネルギー省の傘下とし、また、EEGeD は蒸気生産販売を電力生産部門へ販売することで、その財務的持続可能性を確保する必要があるとした。ただし、この組織の設立は、電力生産部門での民間資金による地熱開発を妨げるものではないとも結論した。

8. 開発が優先される地熱徴候地点Priority-AとBの内、民間ないしドナー支援がなされていない地点は、Priority-AのTendaho-2 (Ayrobera)とPriority-BのBosetiおよびMetekaの3地点である。このうち、優先順位に従ってTendaho-2 (Ayrobera)とBosetiにおいて物理探査を実施した。調査の結果、両地点において断裂系に起因すると考えられる地熱貯留層の存在を推定した。この調査結果に基づき、試掘ターゲットを選定した。また、試掘の仕様の概要を定めた。

【提　言】

エチオピア国における地熱発電は、気候変動などによって電力供給が不安定となる水力発電を補い、かつ他の再生可能エネルギーに安定性で勝るベース電源となる。このため、積極的に開発を進めていく必要があり、その実現のため以下の提言をする。

1. 本マスタープランで Priority-S に分類した、民間ないしドナー支援で現在開発が進められている地熱電力開発を滞りなく推進すること。

2. 本調査で物理探査を実施し、かつ試掘ターゲットを提案した Tendaho-2 (Ayrobera)および Boseti 地点において、速やかに追加地表調査を実施して貯留層モデルの精度を高めること。また。2014 年に新たに地熱徴候地点として確認された Butajira 地点において、地質地化学調査に加え、物理探査を実施すること。

3. 上記 3 サイトにおいての追加調査終了後、最も有望なサイトにおいて速やかに試掘を実施すること。

4. Priority-B としたものの、本マスタープラン調査では物理探査の対象地域に含めなかった Meteka 地点において、速やかに物理探査を実施して、地下貯留層構造を推定し、試掘計画を立案すること。

5. 今後の調査の進展に従い、本調査で評価した地熱資源量を逐次改定していくこと。

6. エチオピア国の地熱開発を促進するために、新公社 EEGeD を早期に創設し、かつ速やかな実施能力向上プログラムの立案と実施を行うこと。

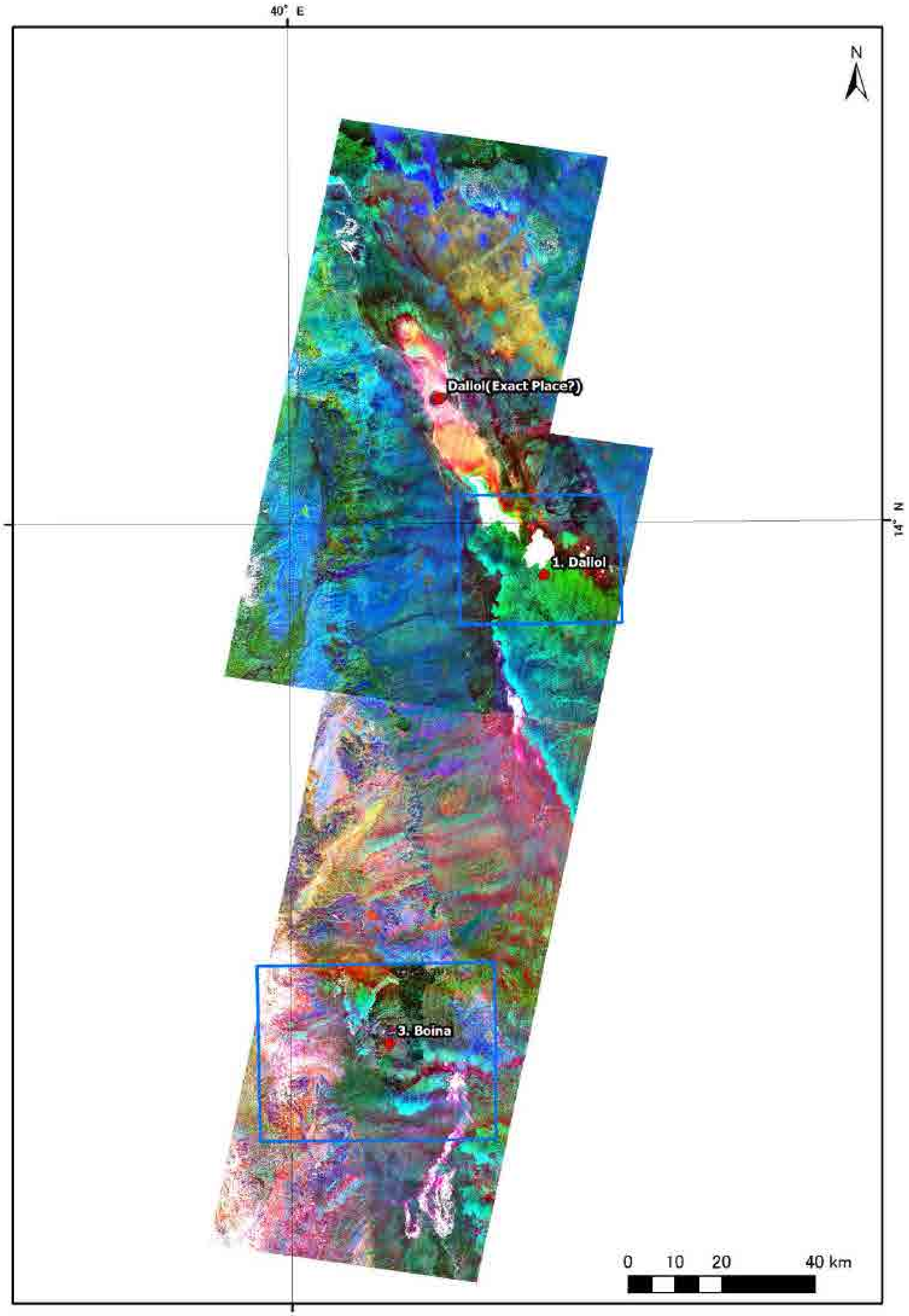
7. エチオピア国は近年、経済成長が著しく、また世界経済情勢も急速に変化している。したがって、本マスタープランを適宜見直していくこと。

以上

添付資料

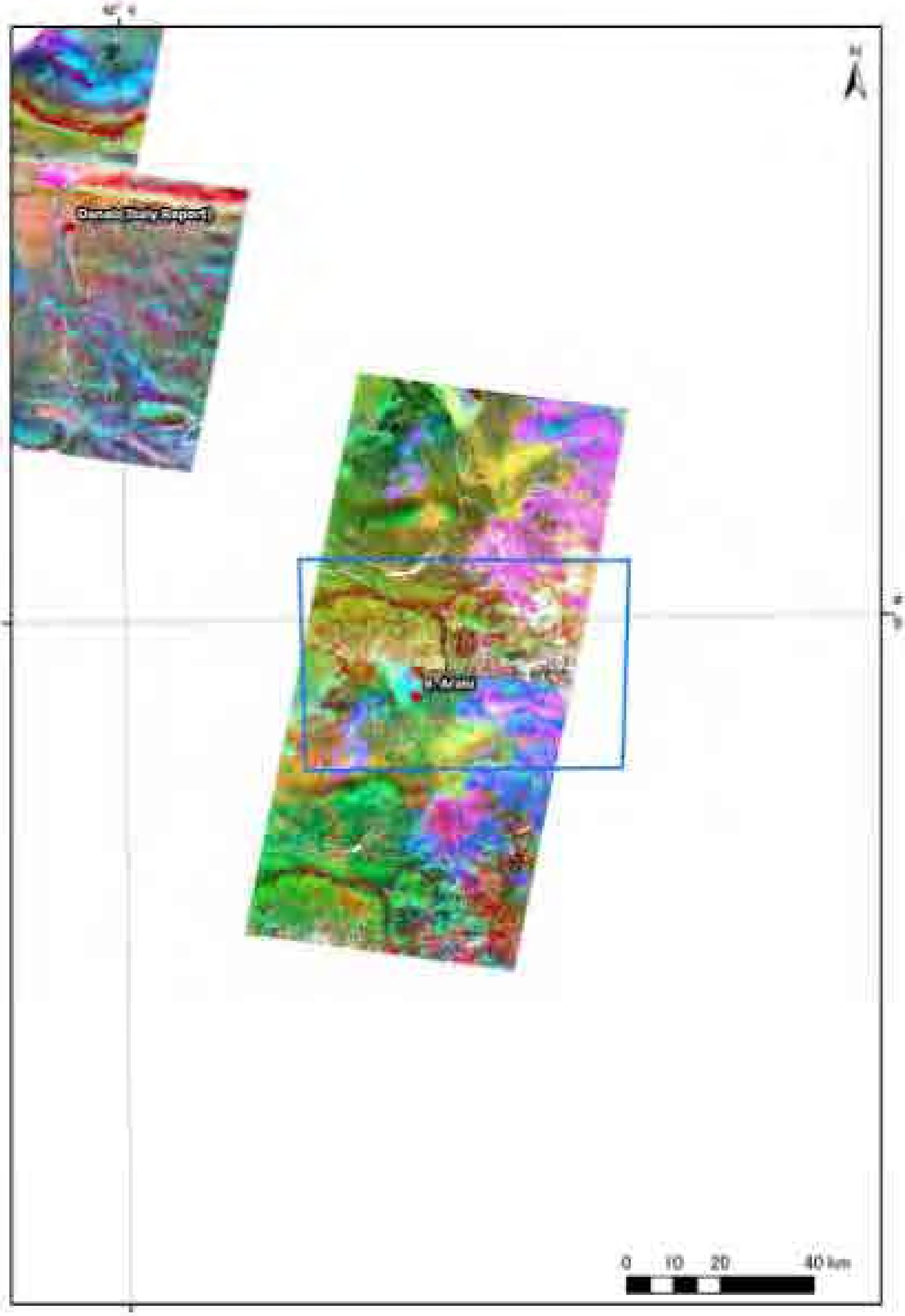
APPENDIX-1

リモートセンシング画像解析



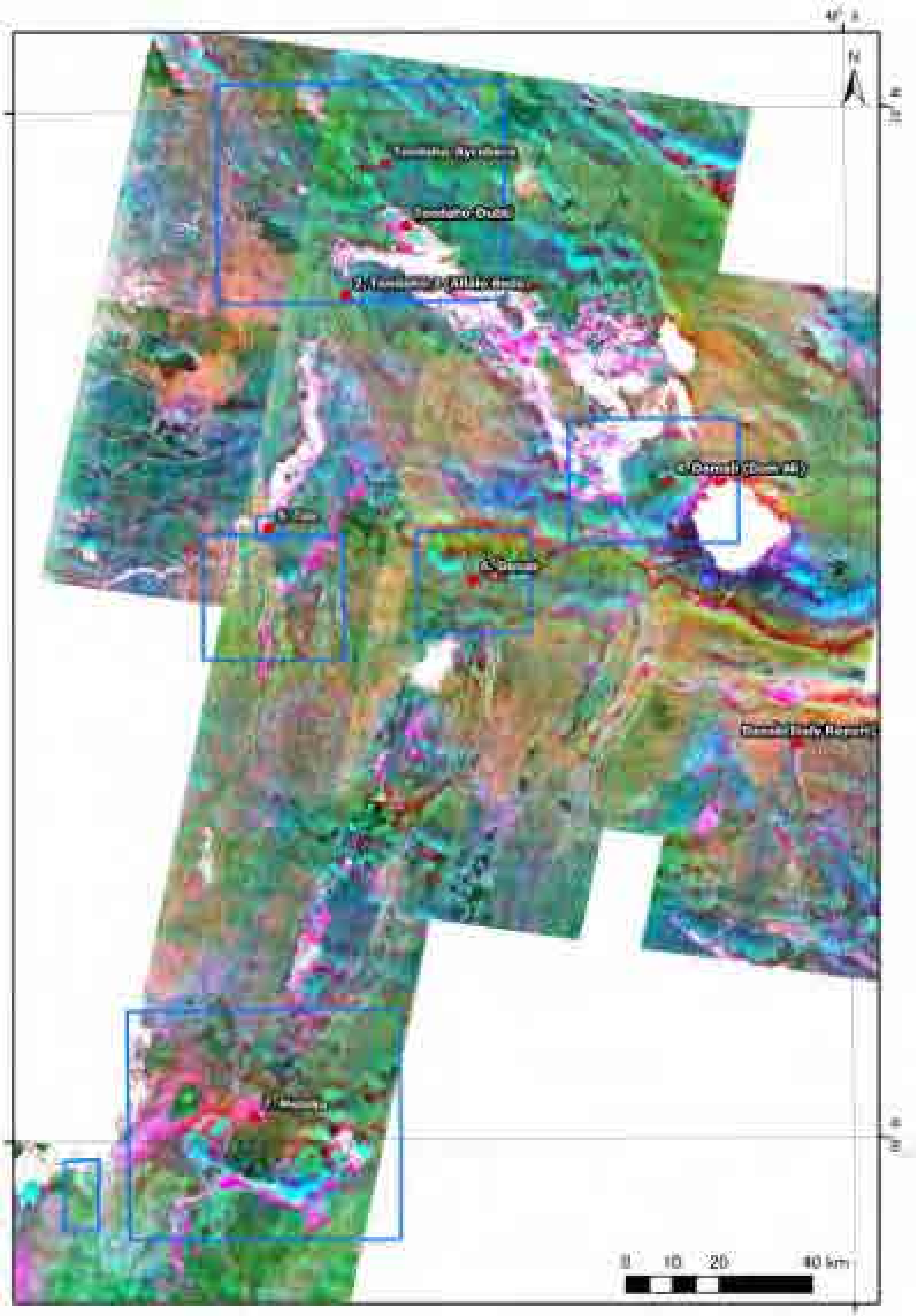
出典：調査団

図 A.1.1 **Dallol**、**Boina** サイトの **ASTER** データ処理画像



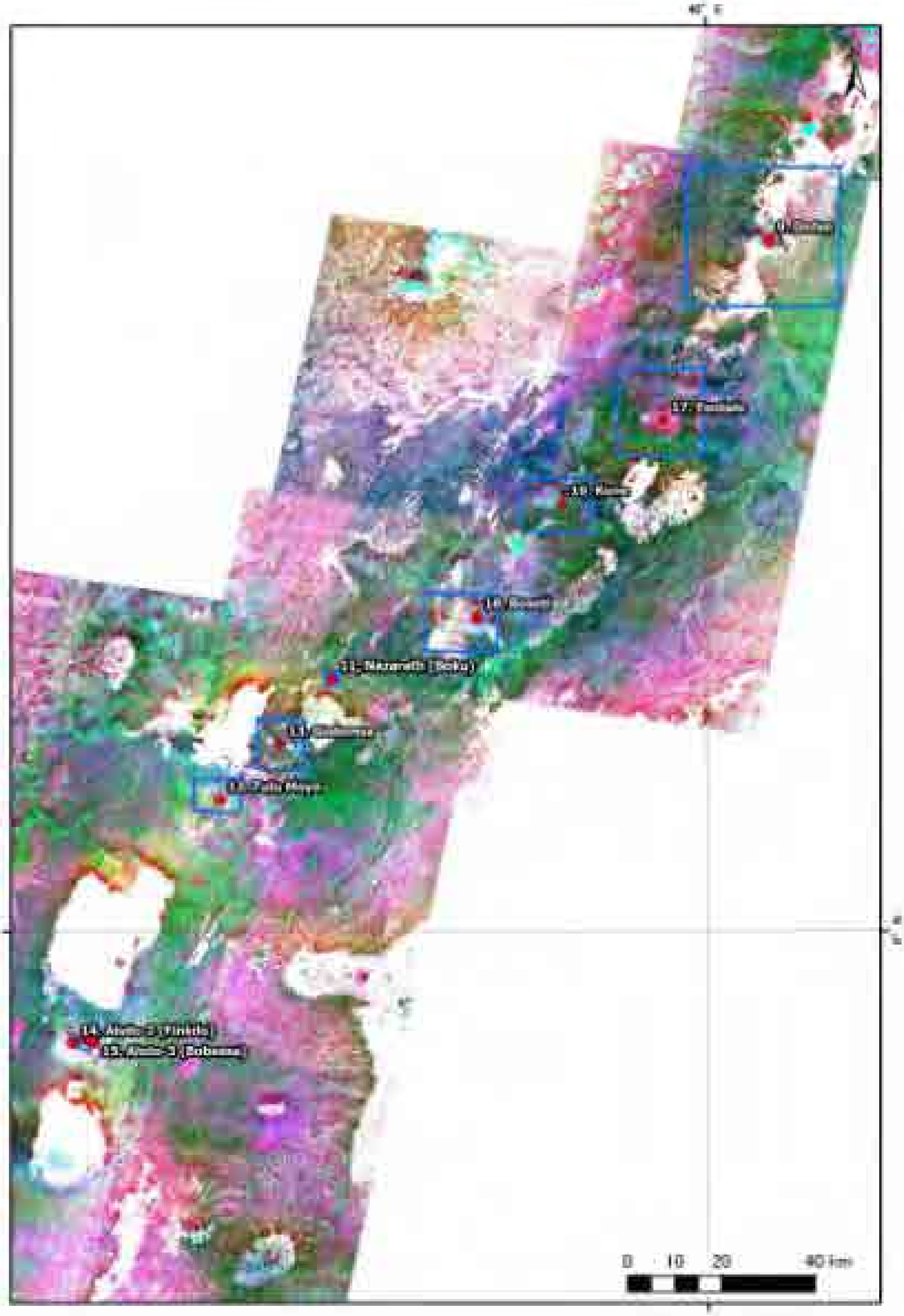
出典：調査団

図 **A.1.2　Danab**、**Arabi** サイトの **ASTER** データ処理画像



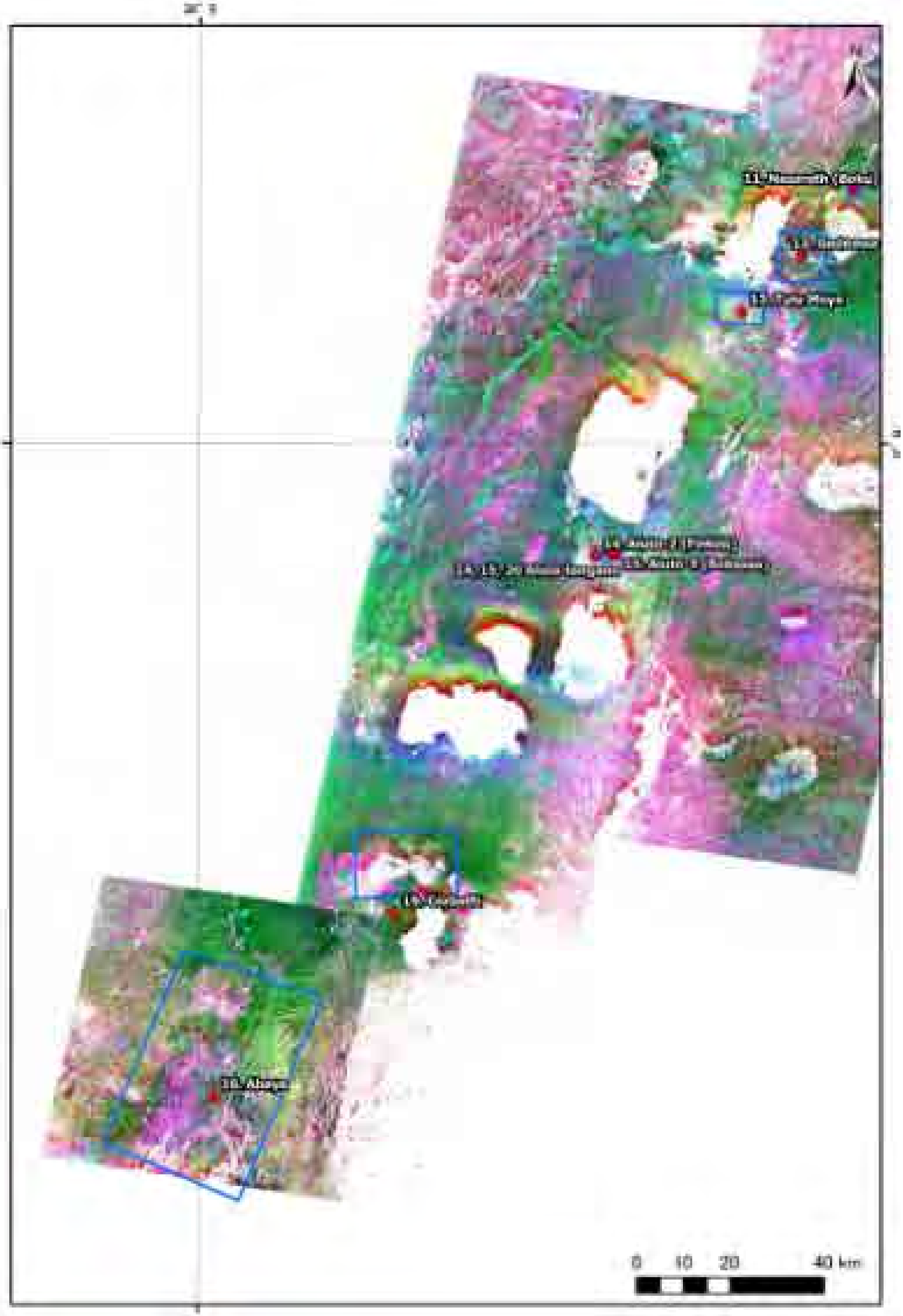
出典：調査団

図 A.1.3　**Tendaho、Teo、Damali、Meteka** サイトの **ASTER** データ処理画像



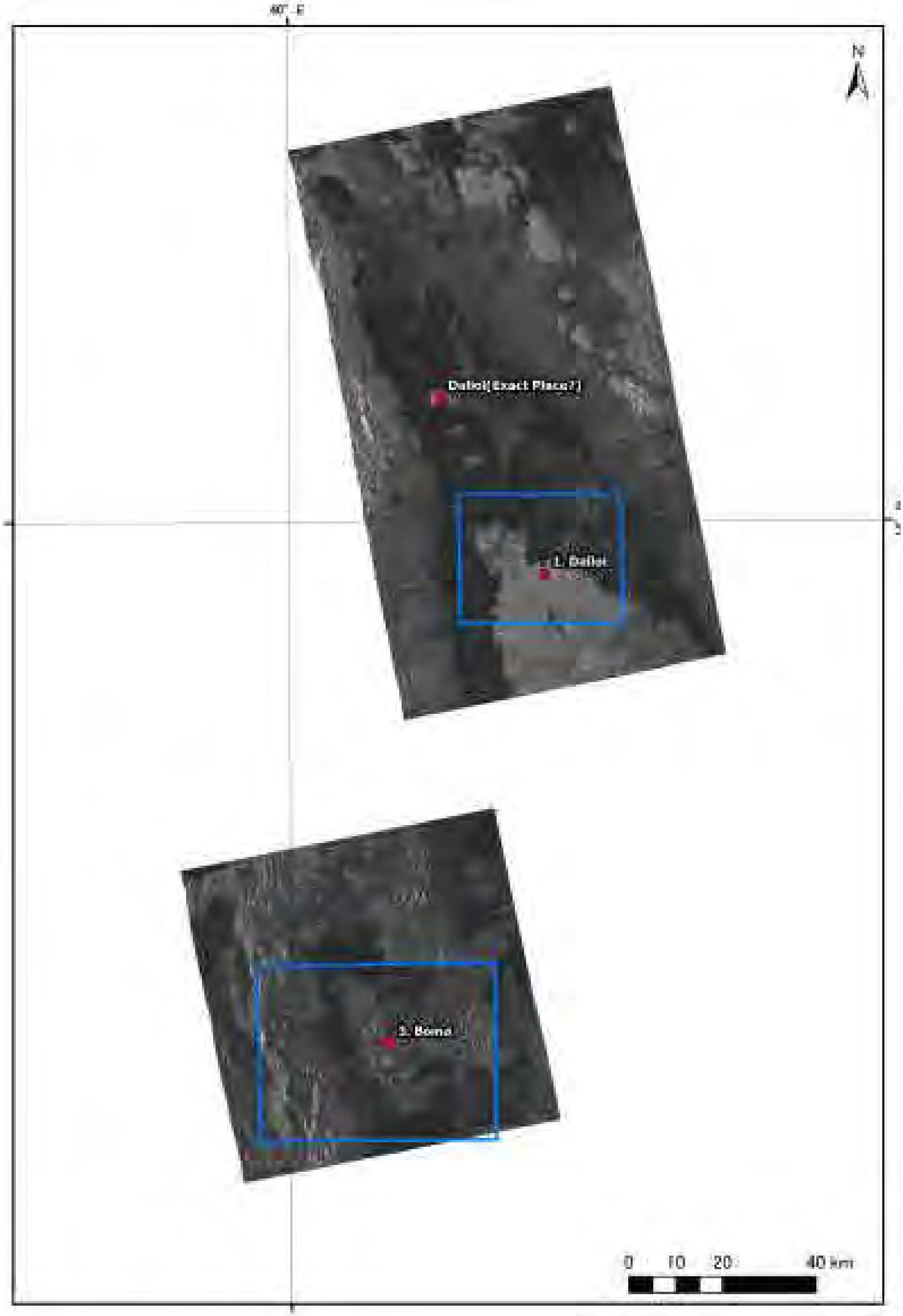
出典：調査団

図 **A.1.4**　対象地域中央部の **ASTER** データ処理画像



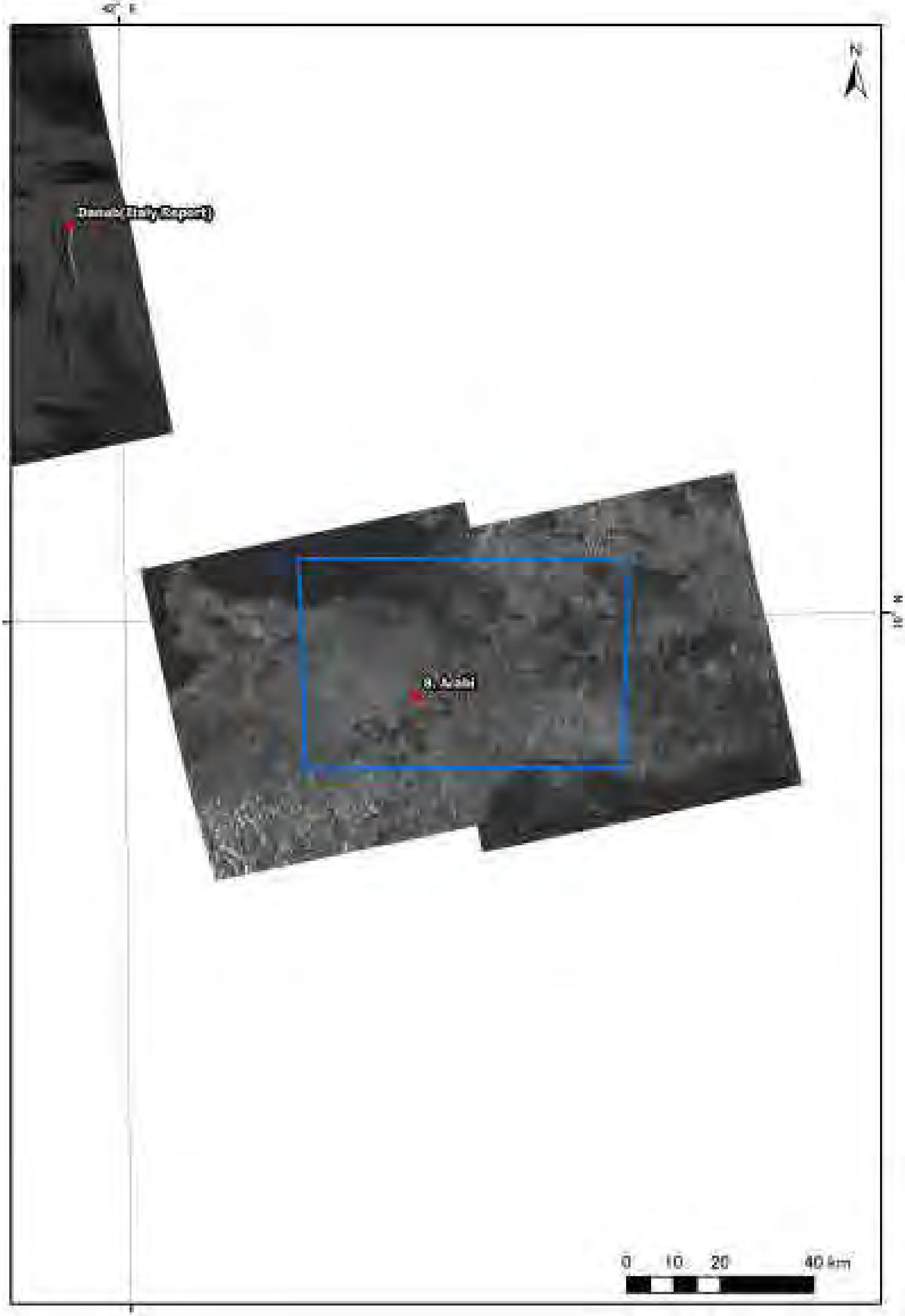
出典：調査団

図 **A.1.5**　対象地域南部の **ASTER** データ処理画像



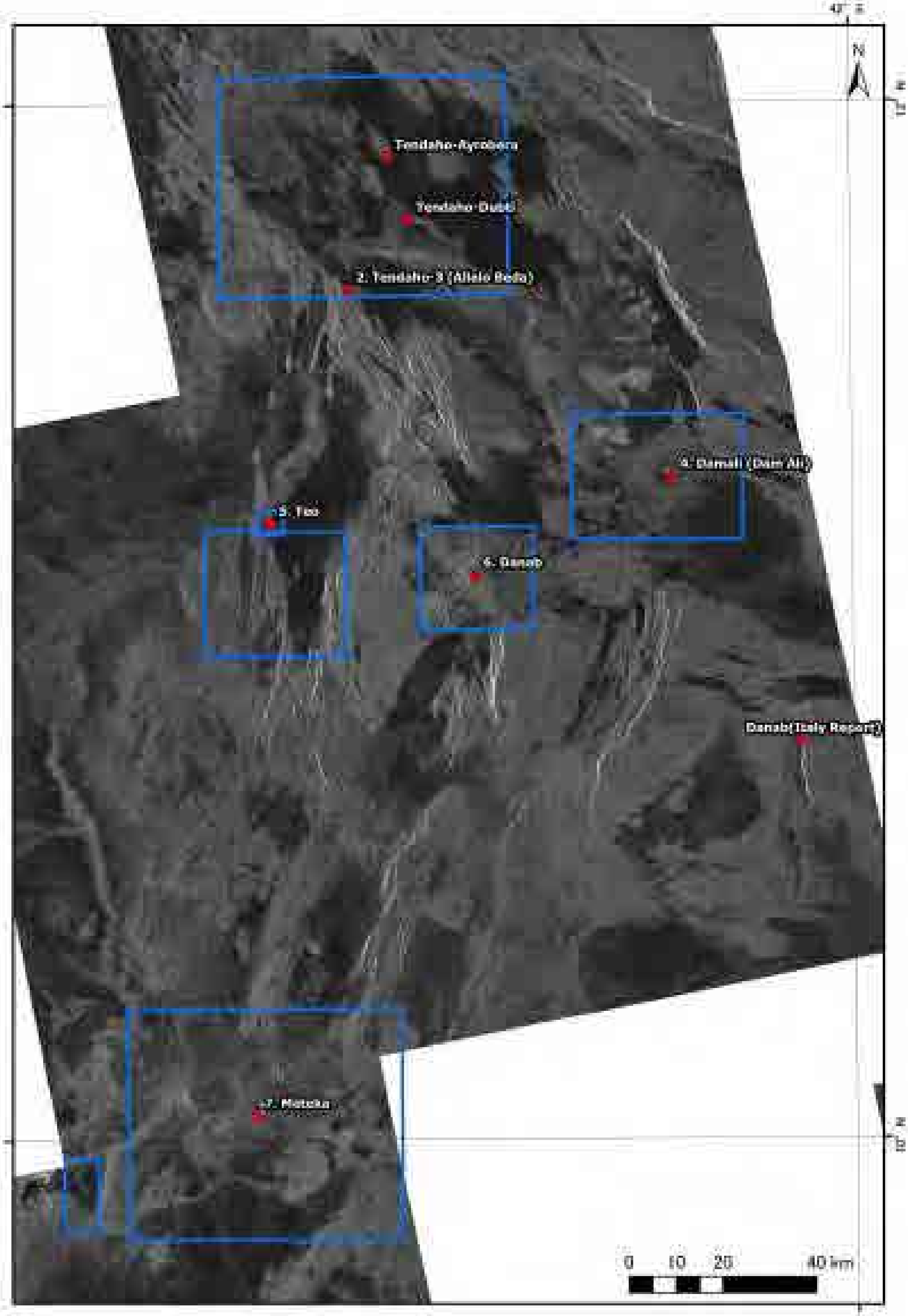
出典：調査団

図 A.1.6　Dallol、Boina サイトの PALSAR 単偏波(HH)モザイク画像



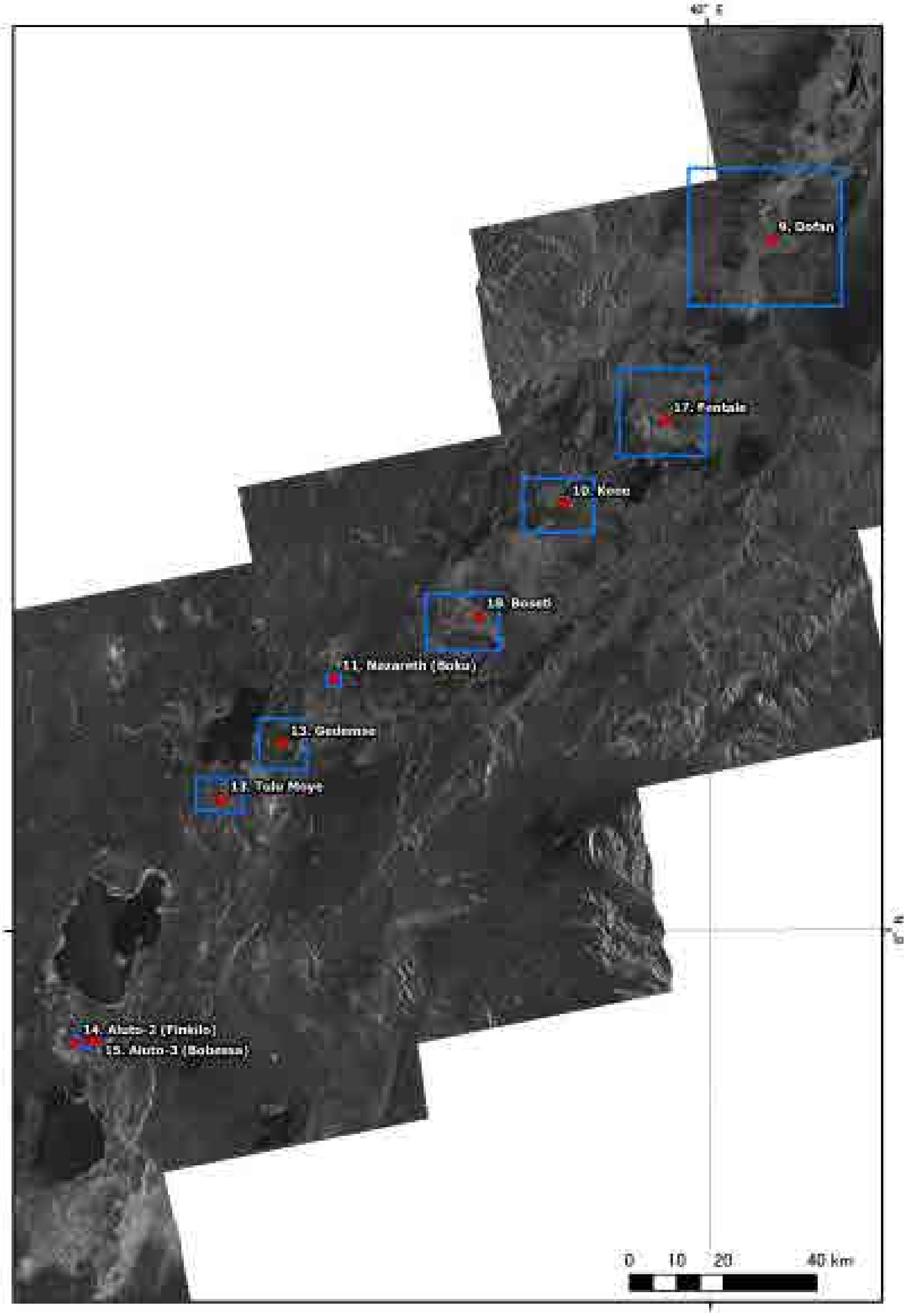
出典：調査団

図 **A.1.7　Danab**、**Arabi** サイトの **PALSAR** 単偏波**(HH)**モザイク画像



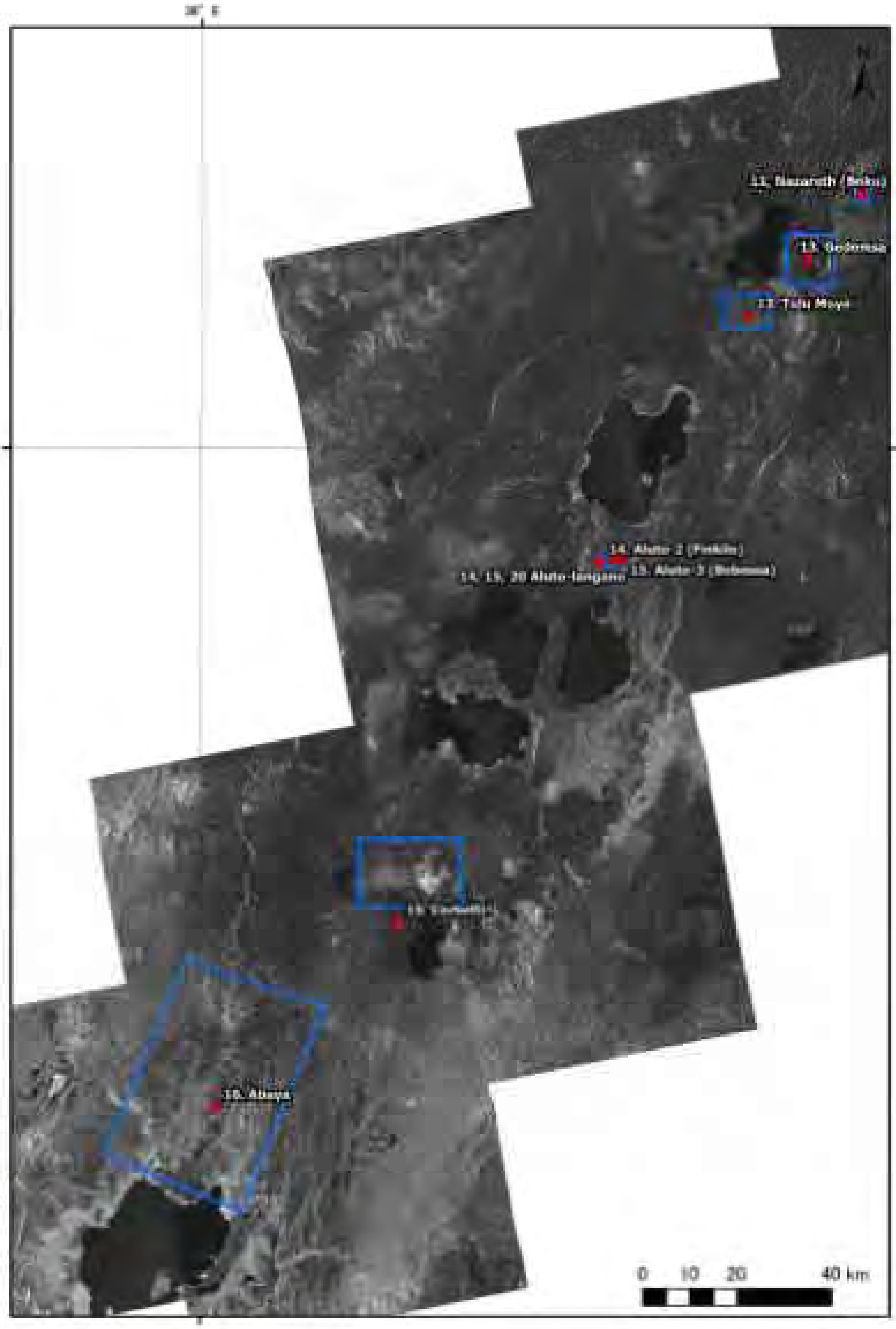
出典：調査団

図 **A.1.8　Tendaho**、**Teo**、**Damali**、**Meteka** サイトの **PALSAR** 単偏波**(HH)**モザイク画像



出典：調査団

図 **A.1.9**　対象地域中央部の **PALSAR** 単偏波**(HH)**モザイク画像



出典：調査団

図 **A.1.10**　対象地域南部の **PALSAR** 単偏波**(HH)**モザイク画像

APPENDIX-2

現地調査票

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.

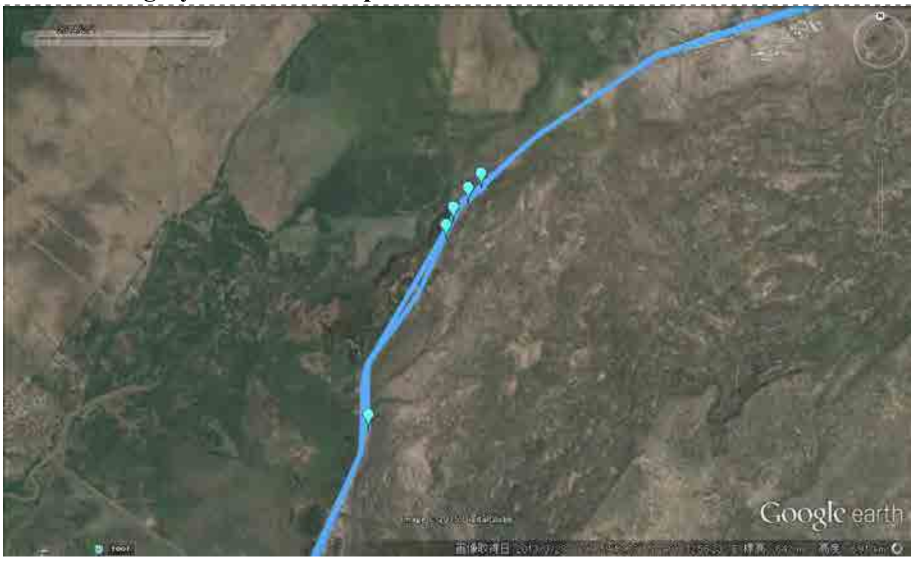
Photos

Overview

Geyser

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

Satellite Imagery and Route Map



0.5 km

N

Legend

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

Center Coord. (WGS84)
Lat: N 9°59'18.78"
Lon: E40°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.

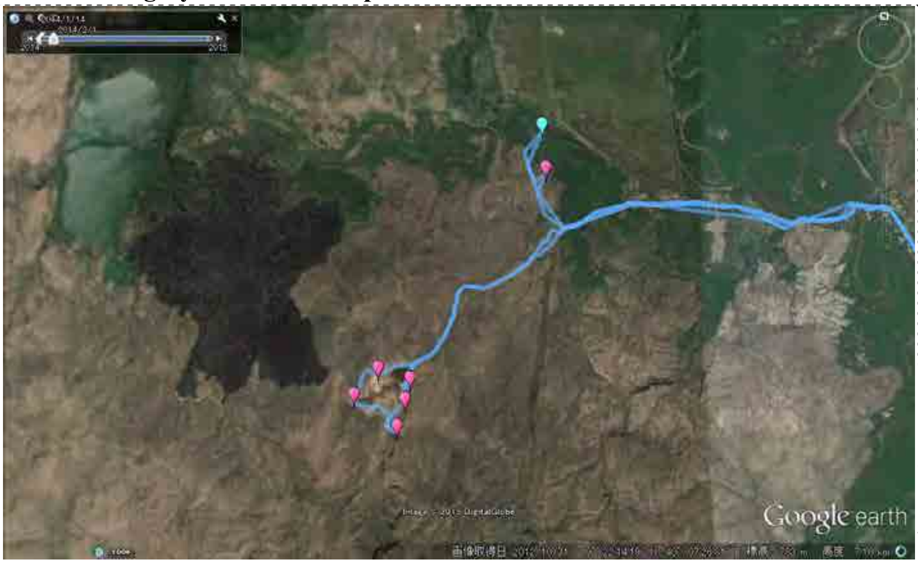
Photos

Hot spring at roadside

Hydrothermal Alteration in rock

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

Satellite Imagery and Route Map



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.

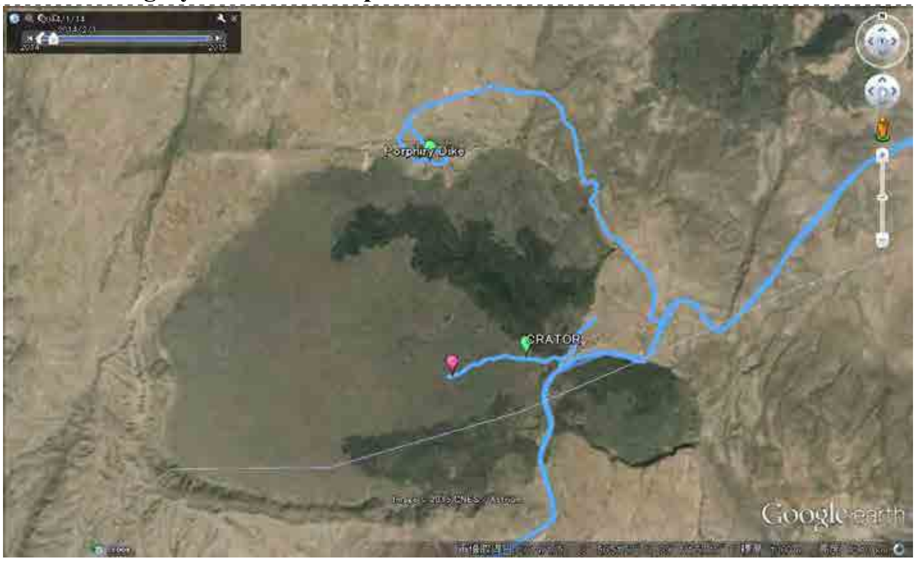
Photos

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

N
3.0 km

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

Center Coord. (WGS84)
Lat: N 8°26'46.13"
Lon: E 39°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.

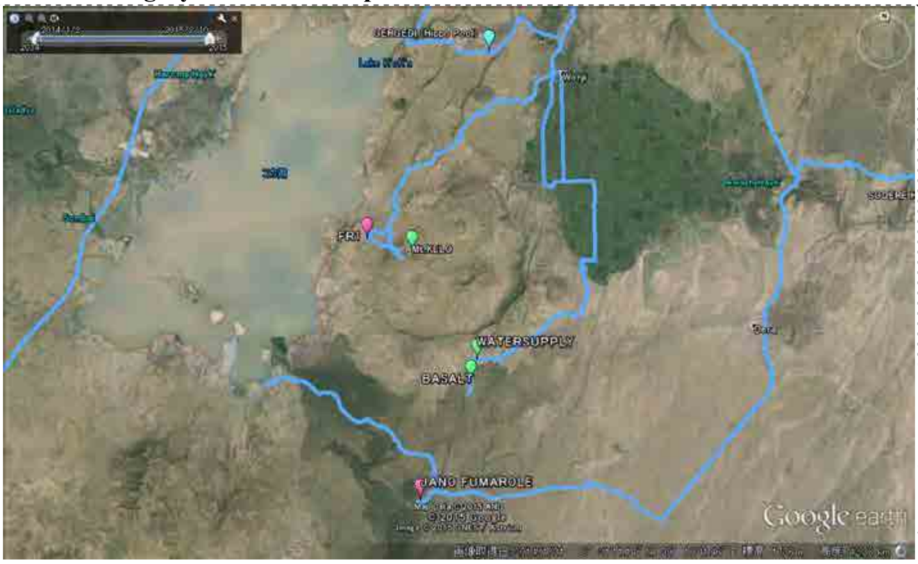
Photos

Fumarole from fractures (Boko)

Hot Spring (Sodole)

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

Satellite Imagery and Route Map



Legend

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

Center Coord. (WGS84)
Lat: N 8°21'11.14"
Lon: E 39°10'41.46"

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.

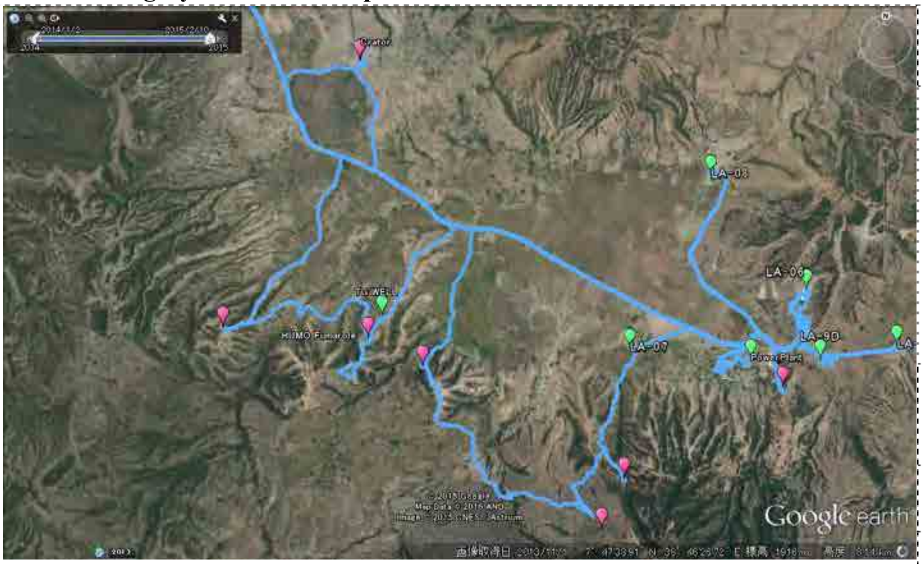
Photos

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^{0}47’38.91”
Lon: E 38^{0}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.

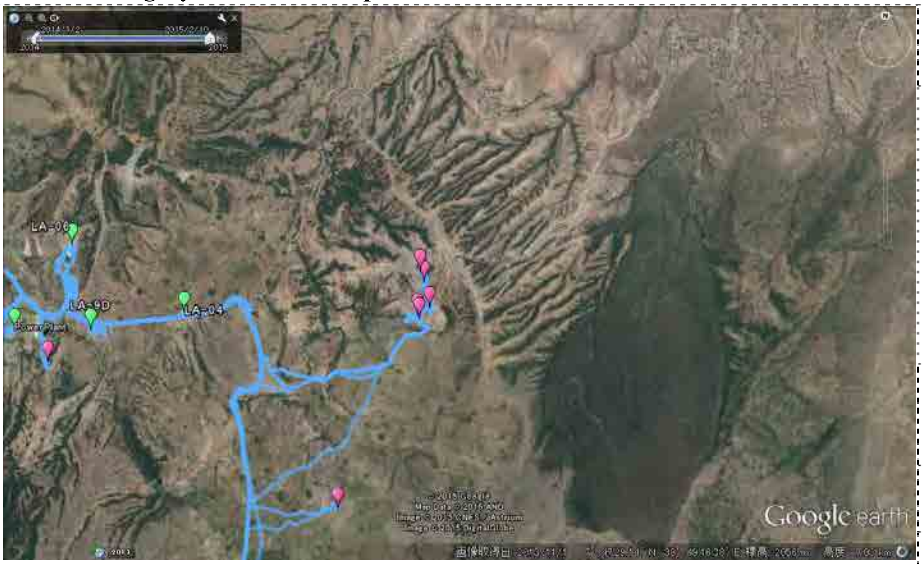
Photos


Overview of Finkilo Site


Fumaroles at the valley

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

Satellite Imagery and Route Map



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.

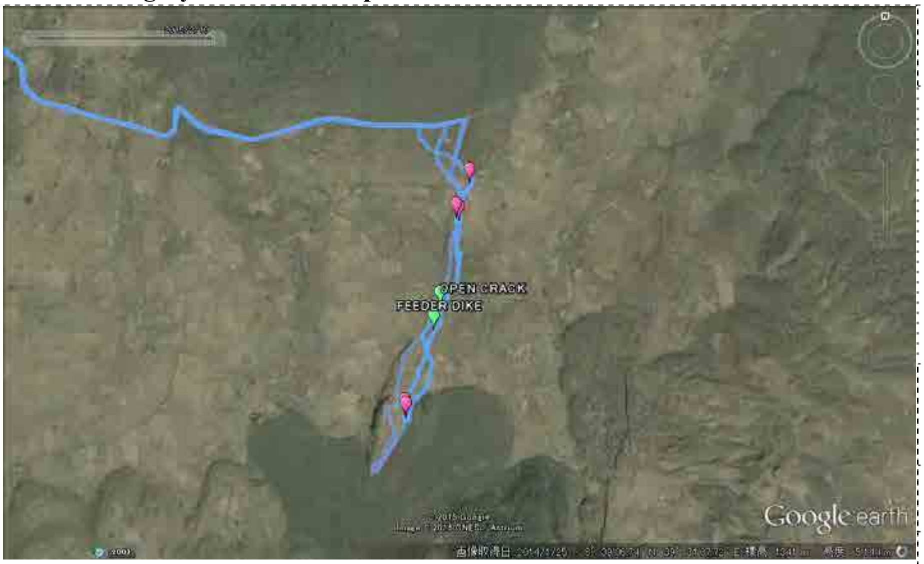
Photos

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^{0}38'34.29"
Lon: E41^{0}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.

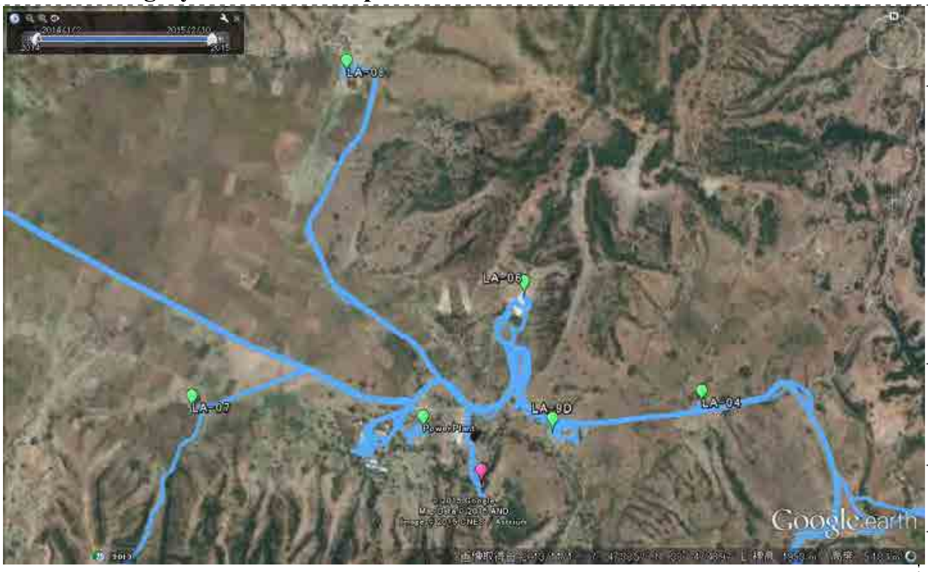
Photos


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 7^{0}47’38.57”
Lon: E 38^{0}47’46.97”

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.

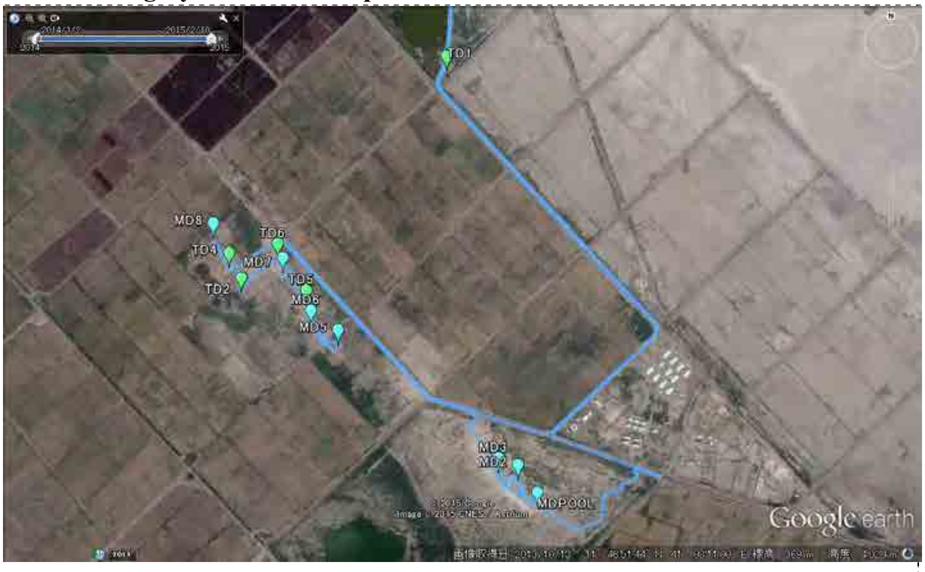
Photos

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



N **0.5 km**

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

Center Coord. (WGS84)
Lat: N 11°46'51.44"
Lon: E41°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^{0}53’26.28”
Lon: E 41^{0}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

容積法計算方法

「合理的実用的な容積法計算の提案」

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.

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

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;

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

or

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

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.

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

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.

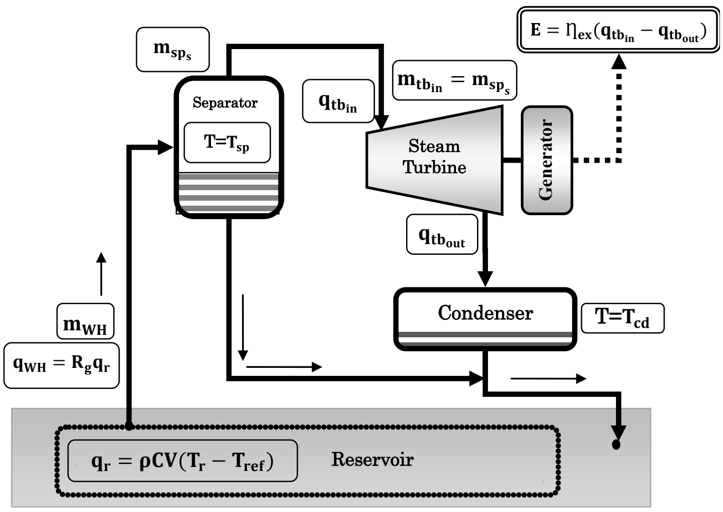

Figure 1 Simplified single flash power plant schematic

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;

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

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 <u>in the separator</u>. 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

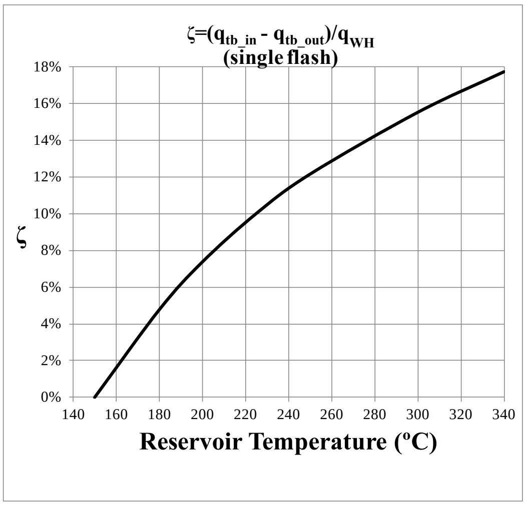

Figure 2: Calculation results of ζ against various reservoir temperatures..

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" <u>will</u> include the energy ratio of steam separated from the fluid and exergy efficiency; the "conversion factor" <u>may</u> 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 the recovery factor can be determined independently from both the liquid-steam separation process and conversion process of thermal energy to electric energy.

4. EXAMINATIONS OF THE RESULTS

We calculated electric powers per km^2 (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.

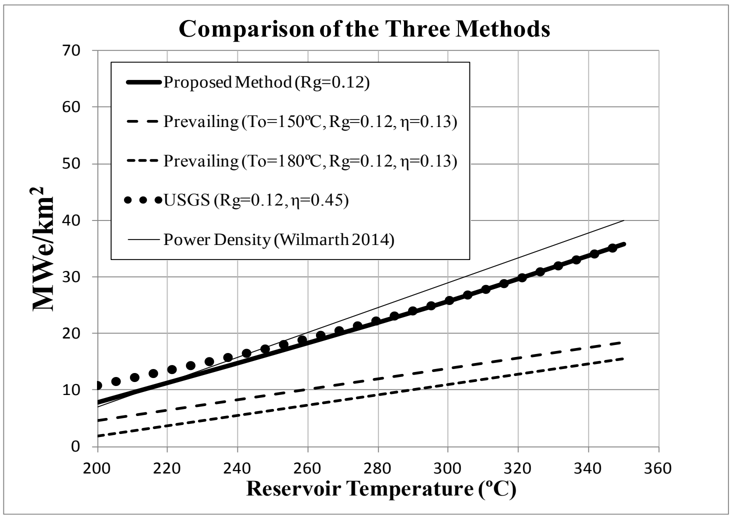

Figure 3: A Comparison of calculated electric power among three methods (Single Flash Power Cycle)

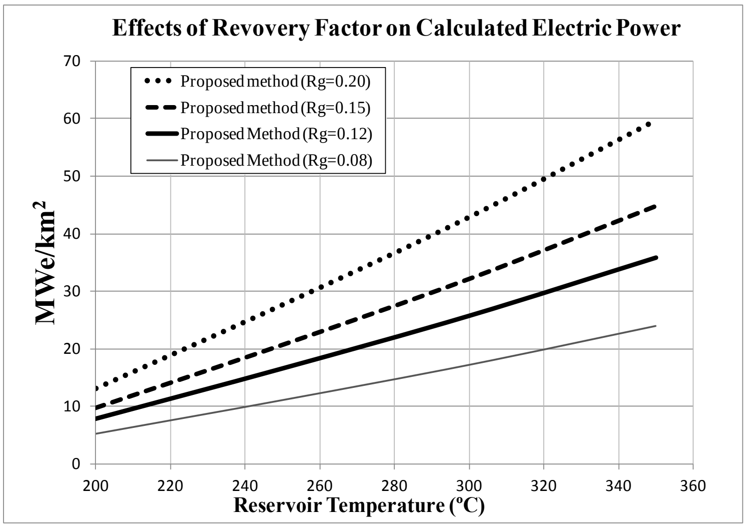

Figure 4: Effects of Recovery Factor on Calculated Electric Power (Single Flash Power Cycle)

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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EoD

APPENDIX-4

環境社会影響評価

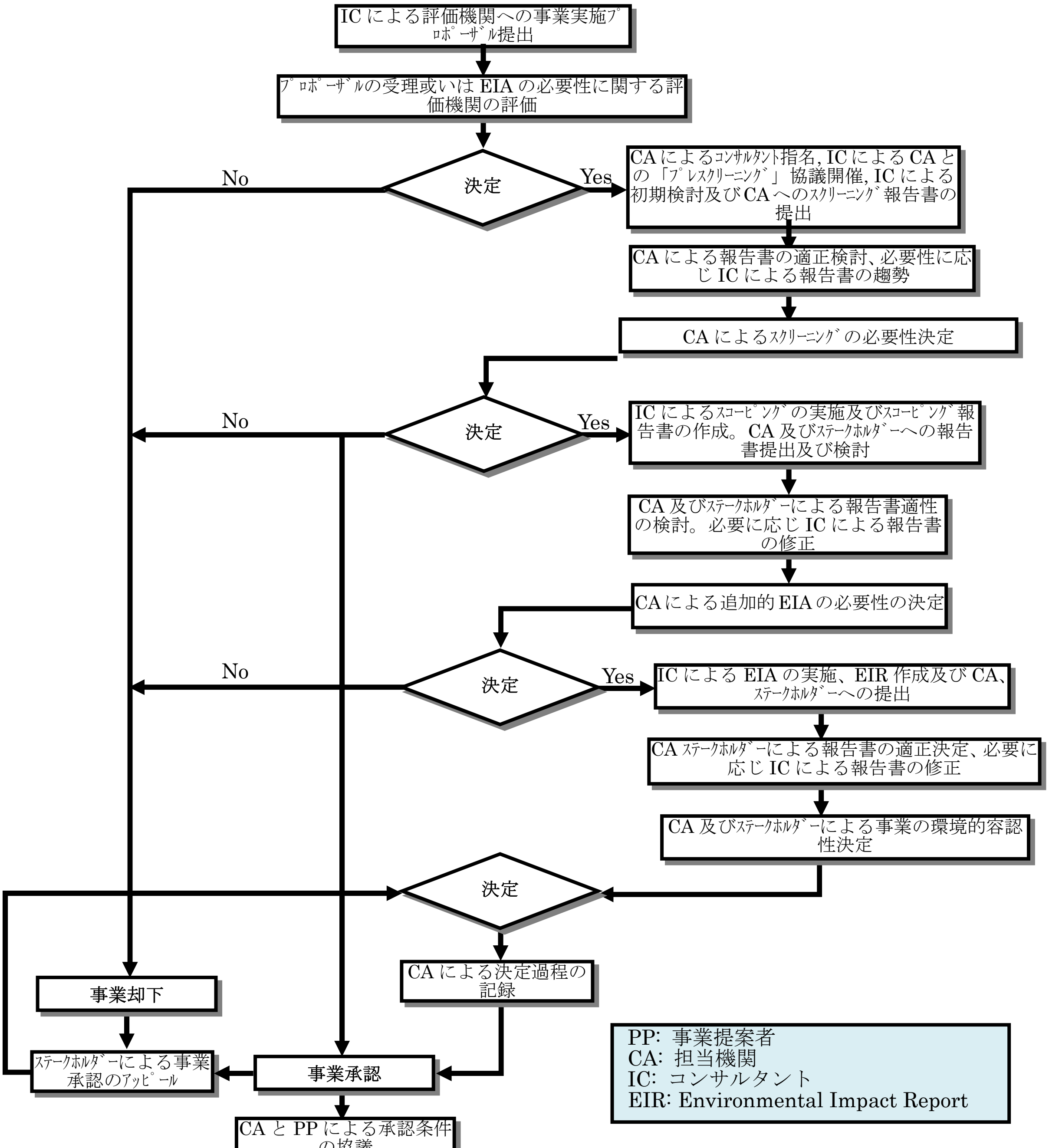
Appendix 4.1

表 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	64/ 07 Feb, 2003	This is a regulation prescribes some incentives on the foreign investment such as tax exemption, etc including 18 articles in

No.	Title	No/ Date of Issue	Description
	Investment Incentives and Investment Areas Reserved for Domestic Investors		total.
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



(Source: Environmental Impact Assessment Guideline Document, 2000)

図 **A.4.1**　エチオピアにおける **EIA** 手順

Appendix 4.3

表 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 decision making process in a manner that promotes sustainable development (Environmental Impact Assessment Proclamation 2002_299)	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
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, and refers to the corresponding environmental checklists for each sector when conducting that review as appropriate.	A range of instruments can be environmental impact assessment (EIA), regional or sectoral EA, environmental audit, hazard or risk assessment, and environmental management plan (EMP).	Preliminary environmental impact study (or IEE), full environmental impact study report, Trans-Regional Impact Assessment (SEA), Environmental Management Plan are mentioned (Environmental Impact Assessment Proclamation 2002_299; EIA	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
			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 C: For projects in this category, environmental review will not proceed after categorization.	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 required for a Category C project.	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 impact assessment. (Environmental Impact Assessment Proclamation 2002_299; EIA Procedural Guidelines 2003)	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 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.	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.			
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 measures are available. (3.2.1(4)) Measures Taken in an Emergency In an emergency—which means a case that	*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 EA for each subproject. In appraising a proposed FI operation, the Bank reviews the	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
	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	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	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 Procedural Guidelines 2003)	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
		includes components to strengthen that capacity.			
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,	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
	and when the draft report is being prepared. (Appendix 2) 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 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
	For Category B project, JICA discloses EIA reports and environmental permit certifications, when these documents 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	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
	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)				

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

表 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	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
		provided assistance during relocation; provided with residential housing, or 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	Consult project-affected persons, host communities and local	Not mentioned in the govt. law.	Public consultation is not required by the govt.	The project proponent needs to conduct adequate

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
	promoted in the planning, implementation, and monitoring of resettlement action plans and measures to prevent the loss of their means of livelihood.	nongovernmental organizations, as appropriate. Provide them opportunities 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.		law, though the land acquisition procedure includes issuing some notifications to landholders.	public consultation for the RP 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	1) those who have formal legal rights to land (including customary and traditional rights recognized under the	Not mentioned in the govt. law, though landholders are defined. (Proclamation 455/2005)	The definition of displaced persons is not clear. Especially, it is	The definition of the displaced persons as per the JICA Guidelines needs to be

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
	compensated and supported by project proponents etc. in a timely manner.	laws of the country); 2) those who do not have formal legal rights to land at the time the census 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.		not clear whether the entitled displaced persons include informal occupants.	used by the project proponent.
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

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
					JICA Guidelines/WB OP 4.12.
Grievance procedures	Appropriate and accessible grievance mechanisms must be established for the affected people and their communities.	A grievance redress mechanisms for simplicity, accessibility, affordability, and accountability	Section 11. Complaints and Appeals 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	Grievance redness mechanism at the project level (i.e. field and headquarters levels) is not specified.	The project proponent 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.

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
			court shall be final. (Proclamation 455/2005)		
Information disclosure	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.	Disclose draft resettlement plans, including documentation of the 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.	Not mentioned in the govt. law.	Information disclosure is not specified in the govt. law.	The project proponent should follow their own 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

表 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

表 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

表 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

表 A.4.7 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

表 A.4.9　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

EIRR 計算

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

Tendaho-1 (Dubti) Project

Geothermal Plant

Installed capacity	280	MW
Plant factor	90	%
Station use	9	%
Economic life	30	years
Generated energy	2,206	GWh
Sales energy	2,009	GWh
Construction cost	1,088.2	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

表 A.5.2 Calculation of EIRR (Aluto-2)

Aluto-2 (Finkilo) Project

Geothermal Plant

Installed capacity	110	MW
Plant factor	90	%
Station use	9	%
Economic life	30	years
Generated energy	857	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
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
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

Year	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Plant construction																
Supplemental drilling	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	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
Initial investment	16.8	84.0	11.2														
Reinvestment																16.8	84.0
Total	16.8	84.0	11.2													16.8	84.0

Year	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Initial investment																
Reinvestment	11.2															
Total	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
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
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
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
Benefit (avoidable cost)																	
Investment cost	16.8	84.0	11.2													16.8	84.0
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
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
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
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

Year	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Cost																
Investment	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	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	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	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
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
Total	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	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

表 A.5.3 Calculation of EIRR (Tendaho-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

表 A.5.4 Calculation of EIRR (Aluto-3)

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	65.2	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

表 A.5.5 Calculation of EIRR (Tendaho-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