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第二次現地調査キックオフ会議用資料集

DATA COLLECTION SURVEY ON GEOTHERMAL DEVELOPMENT IN RWANDA

1

EXPLANATION OF PROGRESS REPORT

JULY, 2013

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

NIPPON KOEI CO., LTD

Location Map

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Outline of National Electric Development Plan (Chapter 3)

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Outline of National Electric Development Plan (Chapter 3)

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1) Energy demand projections 2008-2020

	2008	2012	2015	2020
Peak power demand (MW)	55	165	700	1,300
Energy demand after losses (GWh)	225	460	1,500	2,010
% households with electricity	6%	16%	35%	60%
% energy consumed by households	38%	64%	75%	83%

(Data source: :National Energy Policy and Strategy, 2011)

2) Additional Power plant up to 2017

- Geothermal : 310.00 MWe
- Others : 801.78 MWe
- Total : 1,111.78 MWe

(Data source: Electricity Development Strategy (2011-2017))

01. Outline of National Electric Development Plan (Chapter 3)

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3) Possible Geothermal Projects by 2017

Expected Commissioning	Responsible	Project	Status	Expected Capacity (MW)
2013	GoR/IPP	Karisimbi Early Well; Head Generation unit	Drilling before end of 2011	10
2014	GoR/IPP	Geothermal I	-	75
2016	GoR/IPP	Geothermal II	-	75
2016	GoR/IPP	Geothermal III	-	75
2017	GoR/IPP	Geothermal IV	-	75
Total				310

(Data source: National Energy Policy and Strategy, 2011)

Summary of Previous Studies on Geothermal Potential (Chapter 4)

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02. Summary of Previous Studies on Geothermal Potential (Chapter 4)

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1) List of Geothermal Areas, Resources Potential, required Work

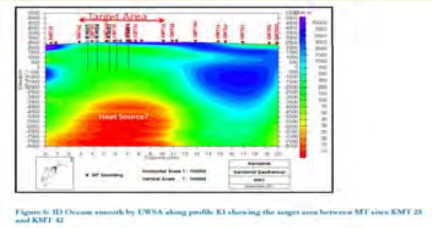
Geothermal Prospect	Karisimbi	Gisenyi	Kinigi	Bugarama	Other area	Total
Approximate Resource Area (km2)	25	30	25	50	20	150
Estimated Development Resource Area (km2)	8	5	4	2	2	
Number of Wells per (km2)	10	10	10	10	10	
Average Well Productivity (MWe)	4	4	3	3	2	
Resource Potential (MWe)	320	200	120	60	40	740
Targeted Generation by 2017	160	150				310
Complete work	Reconnaissance surface studies	Reconnaissance surface studies	Reconnaissance surface studies	No surface studies	No surface studies	
Required work	Detailed geology and geophysics, infrastructure, exploration drilling, production drilling, power plant construction	Detailed geology and geophysics, infrastructure, exploration drilling, production drilling, power plant construction	Detailed geology and geophysics, infrastructure, exploration drilling, production drilling, power plant construction	Reconnaissance surface studies	Reconnaissance surface studies	

(Data source: Ministry of Infrastructure, 2011)

02. Summary of Previous Studies on Geothermal Potential (Chapter 4)

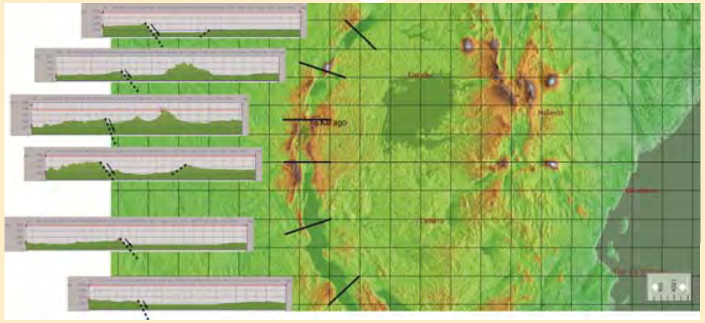
Conclusions of the Previous Studies were reached through "Data and Final Report Validation Workshop in January 2013"

➔Three-3000m deep exploration wells are to be drilled in the Karisimbi prospect



OUR Observation on Geothermal Potential (Chapter 7)

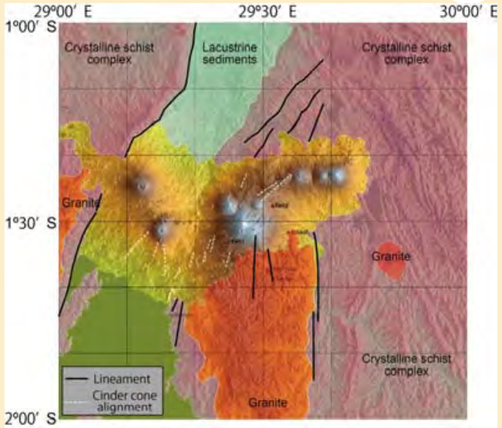
OUR Observation on Geothermal Potential Regional Tectonics



(Data Source: The Study Team)

- Boundaries of the eastern rims of the rift are not always clear.
- ➔ Western Branch of EARV may be less active than Eastern Branch of EARV.
- ➔ Large lakes along the Western Branch of EARV may mask the geothermal manifestation

OUR Observation on Geothermal Potential Regional Tectonics



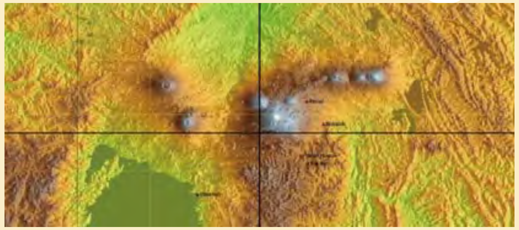
(Data Source: The Study Team)

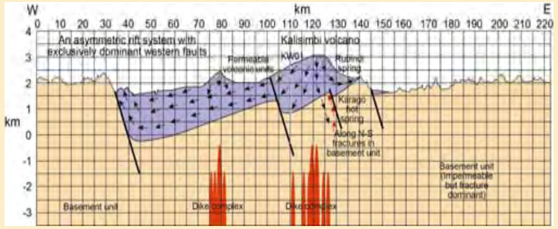
Notable three facts:

1. Three hot springs of temperatures around 70ºC possibly associated with volcanoes,
2. Under tensional stress field,
3. Lineally aligned cinder/scoria cones

➔ Magmatic dikes might have intruded to upper part of the crust.

OUR Observation on Geothermal Potential
Regional Tectonics





- Magmatic dykes might be heat sources.
- Large amount of groundwater in permeable volcanoes might mask geothermal manifestation.

➔The exploratory drilling in Karisimbi will be challenging, but essential to explore the potential.

OUR Observation on Geothermal Potential
Characteristics of Magma – Comparison with Olkaria

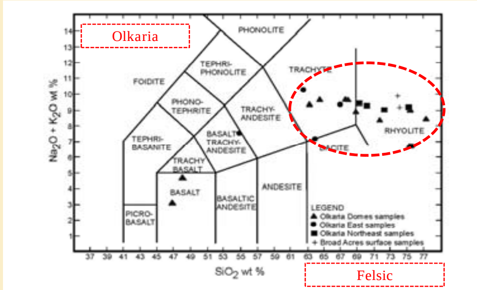


FIGURE 7: Total alkalis silica (TAS) diagram for classification of volcanic rocks using chemical analysis (Les Bas et al., 1989). Data from Olkaria Domes is from the present study, Olkaria East data is from Browne (1984), Olkaria Northeast data are from Omenda (2000), MacDonald et al., (1987) and Black et al (1997), Broad Acres data is from McDonald et al (1987)

Most of rock samples fall in "Felsic".

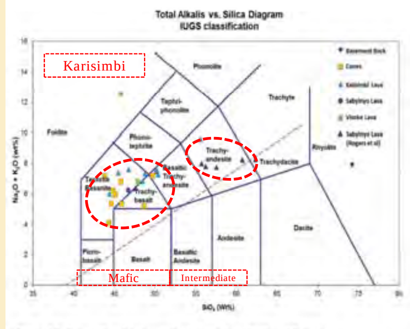


Figure 4.9: Compositional domains of volcanic rocks in Northwest Rwanda.

Most of rock samples fall in "Intermediate" or "Mafic".

OUR Observation on Geothermal Potential
Characteristics of Magma – Comparison with Olkaria

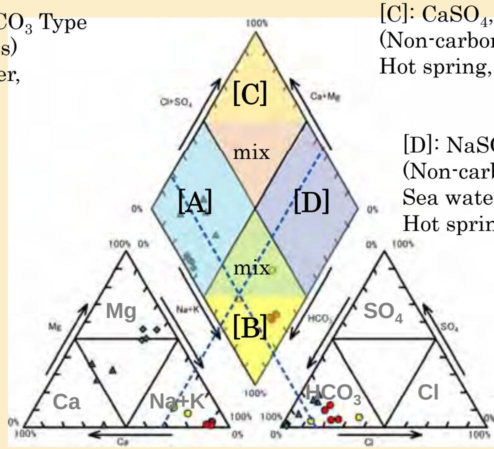
	Classification		
	Mafic (Basic)	⟷	Felsic (Silicic)
1.Specific Weight	Larger	⟷	Smaller
➔Depth in Crust	Deeper	⟷	Shallower
2.Viscosity	Smaller	⟷	Larger
➔Flow-ability	Larger	⟷	Smaller
➔Size of Magma Chamber	Smaller	⟷	Larger
➔Cooling	Quicker	⟷	Slower
3.Radioactive Element	Releasing	⟷	Condensing
➔Self heating ability	Smaller	⟷	Higher
General comparison by constituents with many exceptions in accordance outer conditions			
(Data source : JICA Team)			

➔ Analogy with Olkaria in potential estimation may need consideration of geological back ground.

OUR Observation on Geothermal Potential
Review of Geochemical Data – Graphical Presentation

[A]: $CaHCO_3$, $MgHCO_3$ Type (Carbonate hardness) Shallow groundwater, River water

[B]: $NaHCO_3$ Type (Carbonate Alkali) Deep groundwater



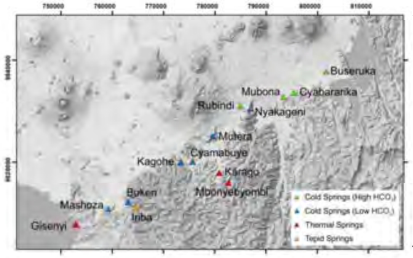
[C]: $CaSO_4$, $CaCl_2$ Type (Non-carbonate hardness) Hot spring, Mineral spring

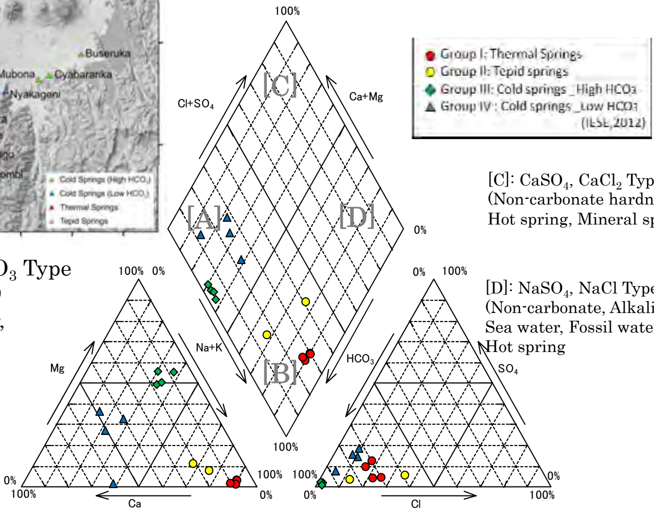
[D]: $NaSO_4$, NaCl Type (Non-carbonate, Alkali) Sea water, Fossil water, Hot spring

Water quality classification by Trilinear Diagram

OUR Observation on Geothermal Potential

Review of Geochemical Data – Graphical Presentation





[A]: $CaHCO_3$, $MgHCO_3$ Type
(Carbonate hardness)
Shallow groundwater,
River water

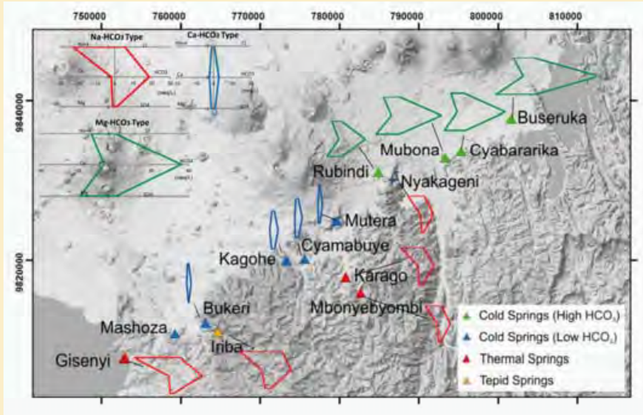
[B]: $NaHCO_3$ Type
(Carbonate Alkali)
Deep groundwater

[C]: $CaSO_4$, $CaCl_2$ Type
(Non-carbonate hardness)
Hot spring, Mineral spring

[D]: $NaSO_4$, NaCl Type
(Non-carbonate, Alkali)
Sea water, Fossil water,
Hot spring

OUR Observation on Geothermal Potential

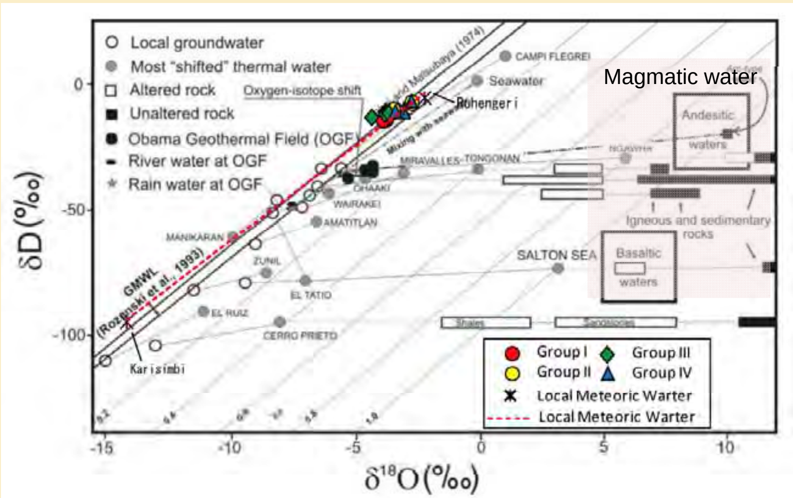
Review of Geochemical Data – Distribution map of Stiff diagram



- Group I and II have similar chemical compositions, which indicate the similar flow process.
- Group IV seems to have short travel time because of the low ion concentration.
- Group III has the longer travel time than Group IV.

OUR Observation on Geothermal Potential

Review of Geochemical Data – Stable Isotopes



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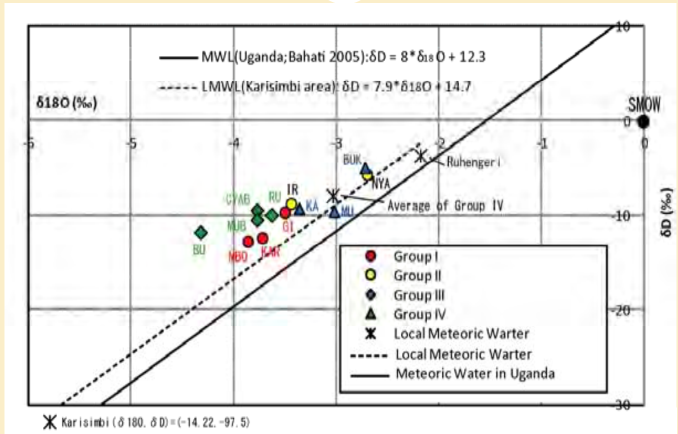
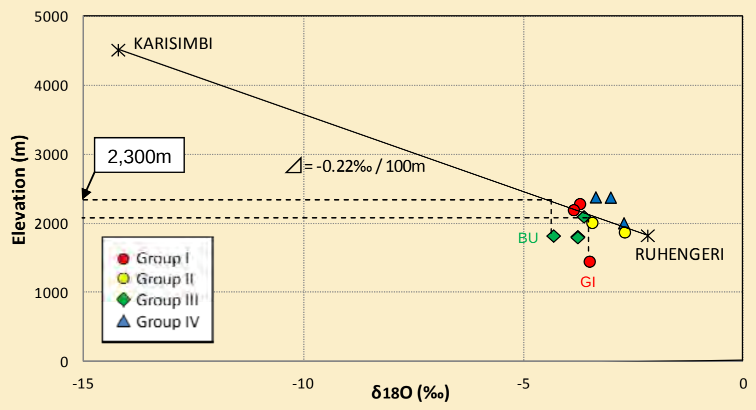
Review of Geochemical Data – Delta Diagram of Rwanda



Local data of precipitation in Ruhengeri(1,830m) and Karisimbi(4,516m) and the average value of shallow groundwater are used for making LMWL.

OUR Observation on Geothermal Potential

Review of Geochemical Data – Estimation of recharge level



Using the Altitude effect of isotope, it is possible to estimate the recharged elevation of groundwater. The regression line is defined asDelta-18O:-0.22‰/100m.

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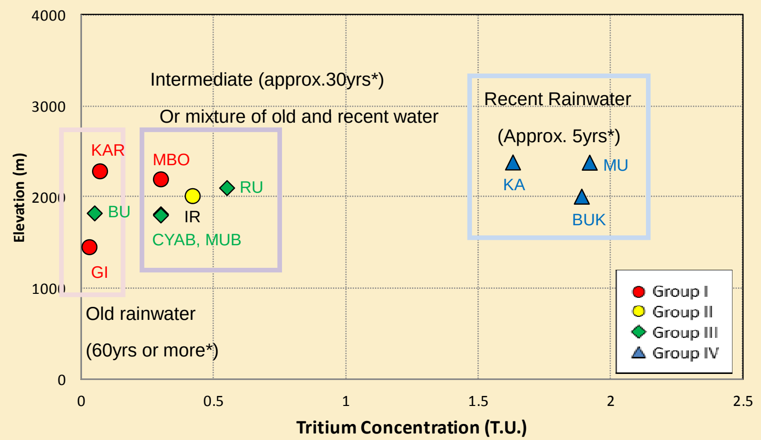
Review of Geochemical Data – Tritium Concentration



OUR Observation on Geothermal Potential

Review of Geochemical Data – Summary of geothermal consideration

	Group-I	Group-II	Group-III	Group-IV
Location	**Gisenyi (GI), Karago (KAR), Mbonyebyombi (MBO)**	**Iriba (IR) , Nyakageri (NYA)**	**Cyabararika (CYAB), Mubona (MUB), Buseruka (BU), Rubindo (RU)**	**Bukeri (BUK), Cyamabuye (CYA), Kagohe (KA), Mutera (MU), Mushoza**
Type of Spring	**Hot**	**Tepid**	**Cold**	**Cold**
	$Na-HCO_3$	**$Na-HCO_3$**	**$Mg-HCO_3$**	**Ca-HCO3**
	Deep groundwater,		**Shallow groundwater, circulated water**	
	Recharged by meteoric water from 2,000-2,500m a.s.l., no influence by magmatic water			
Tritium (short half-time, 12.3 yr)	**Deep, long flow path**	**Deep, long flow path**	**Deep, long flow path**	**Less deep flow path, mixed with groundwater**
	Residence time is more than 60yr	**approx. 30 yr or mixture of old and new water**	**approx. 30 yr or mixture of old and new water**	**approx.5 yr**

Advisory Service Conducted to Date

Hannes san: Please enhance the presentation of this slide, adding other slides will be OK as required!

Advisory Service Conducted

1. Preparation of Application for Geothermal Risk Mitigation Facility
   ➔ Yet to be finalized
2. Advice on Cement Slurry
   ➔ Mixture of silica flour was strongly recommended.
3. Preparation of Drilling Program
   ➔ Draft of the Drilling Program was prepared.
      ➔ Separate explanation by Drilling Engineer

Schedule and Approach

Schedule and Approach

- Overall Schedule (Updated)

Items \ Year/Month	2013					
	3	4	5	6	7	8
Works in RWANDA	1st 12				2nd 22	
Works in Home Countries	3	6			3	
Report	Inception Report		Progress Report		Draft Final Report	Final Report

Note: Works in home countries are intermittent as necessary.

08. Report Preparation

Report	Contents	Submission Schedule
Inception Report (IC/R)	· Review results of recent reports on geothermal potential · Approach of the Study	To be delivered directory to EWSA when the Survey Team is in Rwanda, in the middle of March 2013.
Progress Report (P/R)	· Technical recommendation of well drilling and well tests · Strategy/direction of the well drilling/testing to be agreed upon with the counterpart	To be delivered through e-mail followed by a courier service, toward the end of May 2013.
Draft Final Report (DF/R)	· All outputs of the Study	To be delivered through e-mail followed by a courier service, in end of July 2013
Final Report (F/R)	· All outputs of the Study (comments are incorporated)	To be submitted to JICA Head office, in middle of August 2013

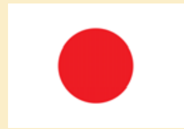
Proposed Activities of the Second Visit in Rwanda

			TAKAHASHI S.	Hannes S	*TERAMOTO M. (NK own fund)*	EWSA Drilling Engineer	EWSA Borehole Geologst
27-Jun	Thu			RKV->AMT, FI502(0740->1240)			
28-Jun	Fri			AMT->KGL, KL535(1100->1905)	HND->DXB,EK313(0130->0705)		
29-Jun	Sat			off work	DXB->NBO,EK719(1045->1445)		
30-Jun	Sun		NRT->DHA,QR805(2230->0330)	off work	NBO->KGL,KQ442(1055->1305)		
1-Jul	Mon	a.m.	DHA->KGL,QR536(0730->1350)	Preparation	Preparation	Special training course in Kigali	On Site
		p.m	**16:00 Meeting with JICA-Rwanda (??)**			Special training course in Kigali	On Site
2-Jul	Tue	a.m.	**9:00 Kick-off Meeting with EWSA (??), Explanation on Progress Report and Schdule (??)**			Special training course in Kigali	On Site
		p.m	Preparation for site inspection (?)			Special training course in Kigali	On Site
3-Jul	Wed	a.m.	**Joint Site Inspection (Karisimbi Drilling Site) for confriamtion of preparation works for drilling**			Special training course in Kigali	On Site
		p.m				Special training course in Kigali	On Site
4-Jul	Thu	a.m.	* Work on site with EWSA Engineers (??) or Small seminor in Kigali ??)			Special training course in Kigali	On Site
		p.m				Special training course in Kigali	On Site
5-Jul	Fri	a.m.	== do ==			Special training course in Kigali	On Site
		p.m				Special training course in Kigali	On Site
6-Jul	Sat	a.m.	off work	off work	off work		
		p.m					
7-Jul	Sun	a.m.	off work	off work	off work		
		p.m					
8-Jul	Mon	a.m.	* Work on site with EWSA Engineers (??) or Small seminor in Kigali ??)				
		p.m					
9-Jul	Tue	a.m.	== do ==				
		p.m					
10-Jul	Wed	a.m.	== do ==				
		p.m					
11-Jul	Thu	a.m.	== do ==				
		p.m					
12-Jul	Fri	a.m.	== do ==				
		p.m					
13-Jul	Sat	a.m.	off work	off work	off work		
		p.m					
14-Jul	Sun	a.m.	off work	off work	off work		
		p.m					
15-Jul	Mon	a.m.	* Work on site with EWSA Engineers (??) or Small seminor in Kigali ??)				
		p.m					
16-Jul	Tue	a.m.	**Preparation for Wrap-up meeting (?)**				
		p.m					
17-Jul	Wed	a.m.	**Wrap -up Meeting with EWSA**				
		p.m	Report preparation	KGL->AST, KL535(2020->0645)	Report preparation		
18-Jul	Thu	a.m.	Report preparation	AMT->RKV,FI503(1400->1510)	Report preparation		
		p.m	Report preparation		Report preparation		
19-Jul	Fri	a.m.	Report preparation		KGL->NBO,KQ471(0900->1130)		
		p.m	Report preparation				
20-Jul	Sat		KGL->DHA, QR539(0950->1805)		NBO->ICN,KE960(1030->0450)		
21-Jul	Sun		DHA->NRT,QR804(0150->1750)		ICN->NRT,KE701(0910->1130)		

Thank you,

Murakoze,

Arigato



DATA COLLECTION SURVEY
ON
GEOTHERMAL DEVELOPMENT
IN RWANDA

INTRODUCTION
of

Technology and Characteristics of Geothermal Drilling

JULY, 2013

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

NIPPON KOEI CO., LTD

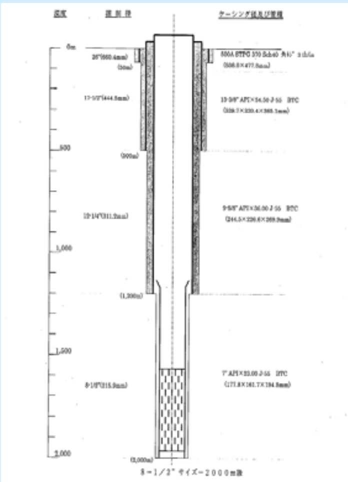
Geothermal Well – Type and Purpose

- Exploratory Well :
  - Preliminary Production Test
    - Investigation for Quantity and Quality of Geothermal Fluid
  - Final Drilling Diameter : 4 ¾ to 7⅝ to 8 ½ in.
- Production Well :
  - Long Usage for Power Generation
  - Final Drilling Diameter : 8 ½ – 12 ¼ in.
- Injection Well:
  - Injection of Hot Water separated from Steam
  - Final Drilling Diameter : 6 ½ in. or more

- *Geothermal Fluid: Steam and Hot Water*

(All wells are usually associated with various in situ testing.)

Example of Casing Program for 2000m class well



Drilling Diameter	Casing Pipe
⌀ 26 in.	⌀ 20 in.
⌀ 17-1/2 in.	⌀ 13-3/8 in.
⌀ 12-1/4 in.	⌀ 9-5/8 in.
⌀ 8-1/2 in.	⌀ 7 in.

(⌀ :diameter)

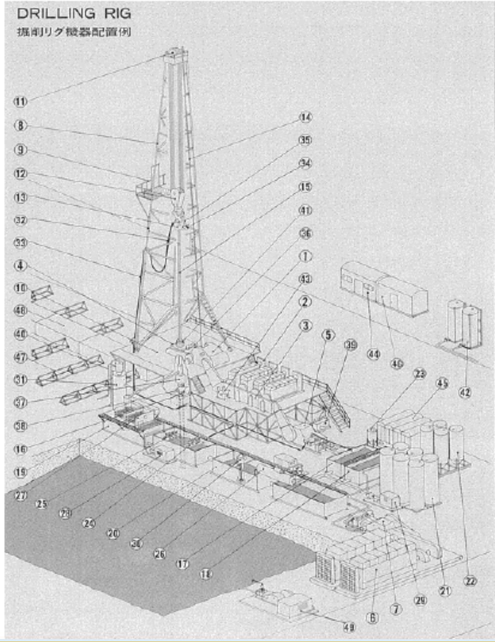
Geothermal Well - Characteristics

- High Temperature (in general)
  - Geological Formation Temperature:
    - Above 200 ℃ for production wells
  - Mud Circulation Temperature:
    - Above 60 ℃
  - Steam Temperature:
    - Above 130 ℃
- Frequent Losses of Mud Circulation
  - Because drilling is conducted to encounter/penetrate fracture zones that contain geothermal fluids.

- *High enthalpy, to be more precise*

Drilling Facilities

- <u>Drilling equipments</u>:
  - Mast, Draw-works, Substructure, Mud Pump, Solid Control Equipments, Cementing Equipment, Cooling Tower
- <u>Drilling Strings</u>:
  - Kelly, Drill Pipe, Drill Collar, Stabilizer, Down-hole Motor, Drilling Jar, Subs, Bit,
- <u>Well-head Equipments</u>:
  - Blowout Preventer, (Drilling Spool, Drilling Valve)



① DRAWWORKS
② DIESEL ENGINE
③ DRIVE GROUPS
④ ROTARY TABLE
⑤ MUD PUMP
⑥ DIESEL ENGINE
⑦ MUD PUMP
⑧ MAST
⑨ PLATFORM
⑩ SUBSTRUCTURE
⑪ CROWN BLOCK
⑫ HOOK BLOCK
⑬ ROTARY SWIVEL
⑭ WORK LINE
⑮ KELLY
⑯ WELLHEAD
⑰ SUCTION TANK
⑱ MIXING TANK
⑲ SHAKER TANK
⑳ SPARE TANK
㉑ MUD TANK
㉒ BARYTE BULK TANK
㉓ SURGE TANK
㉔ DE-SANDER
㉕ DE-SILTER
㉖ DEGASSER
㉗ SHALE SHAKER
㉘ CENTRIFUGAL PUMP
㉙ MIXING PUMP
㉚ MUD AGITATOR
㉛ MUD GAS SEPARATOR
㉜ ROTARY HOSE
㉝ STAND PIPE
㉞ ELEVATOR
㉟ ELEVATOR LINKS
㊱ POWER SLIP
㊲ BLOWOUT PREVENTER
㊳ BLOWOUT PREVENTER
㊴ ACCUMULATOR UNIT
㊵ DRILL PIPE
㊶ KELLY DRIVE BUSHING
㊷ FUEL TANK
㊸ AIR COMPRESSOR
㊹ DOG HOUSE
㊺ CHEMICAL HOUSE
㊻ TOOL HOUSE
㊼ PIPE RACK
㊽ CENTER RACK
㊾ INJECTION WELL PUMP UNIT

Drilling Rig in Operation

Mast

Mast

Hook Block and Elevator

Major Drilling Equipments (1)

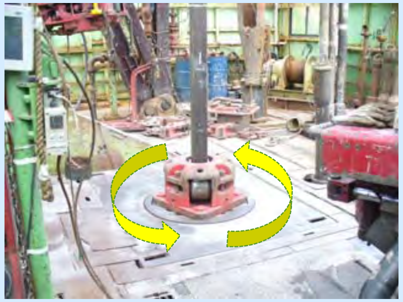
- Draw-works
  - For rotating rotary table and move drill strings up and down,
  - Capacity to depend on the maximum hoisting weight
- Mud Pump
  - Capacity to depend on the well diameter and flow rate
- Solid Control Equipments
  - Shakers, Mud Screen, De-sander, De-silter , and etc.,
- Cooling Tower
  - To cool the circulation mud water

Major Drilling Equipment(2)

- Draw-works
  - For rotating rotary table and move drill strings up and down,
  - Capacity to depend on the maximum hoisting weight

Draw-works

Rotary Table



Major Drilling Equipment(3)

- Mud Pump
  - Capacity to depend on the well diameter and flow rate
- Solid Control Equipments
  - Shakers, Mud Screen, De-sander, De-silter etc.,

Mud Pump

Mud Mixing

Shaker

De-Sander, De-Silter

Environmental Consideration

Mud and Waste Control

Mud waste has to be brought out to designated disposal places.

Major Drilling Equipment(5)

Cement Silo Storage

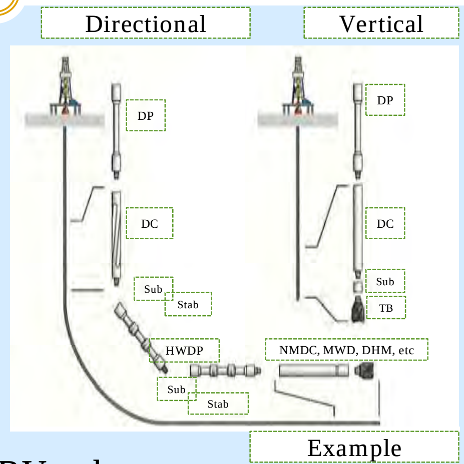
Cement with Silica Flour is pre-mixed at cement factory and delivered to the site

Cooling Tower

For Cooling Drilling Mud

Drilling Strings (1)

a. Kelly (see next slide)
b. Drill Pipe (DP)
   - Heavy Wall Drill Pipe (HWDP)
c. Drill Collar (DC):
   - Spiral Drill Collar
   - Squired Drill Collar
   - Non Magnetic Drill Collar (NMDC)
d. Tricone Bit (TB)
e. DHM, MWD, etc
f. Stabilizer (Stab)
   - Roller Reamer (RR)
g. Subs (joints)– Bit sub, NRV sub, etc.



DHM: Down-Hole-Motor, MWD: Measurement While Drilling, NRV: Non Return Valve

Drilling Strings (2)

Tricone Bit, Stabilizer

Kelly (Rectangular)

Drill Pipe (@9 m)

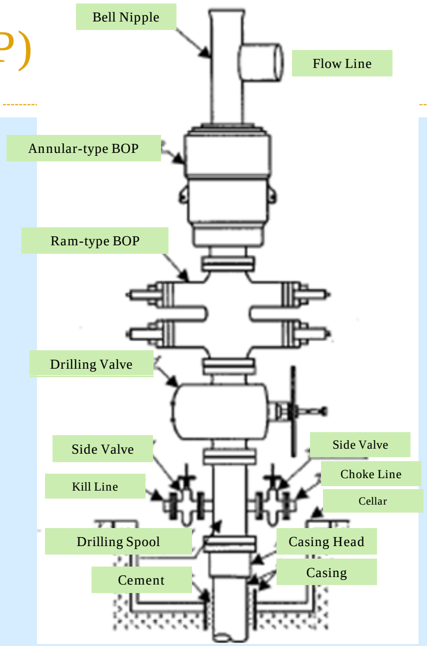
Drilling Strings (3)

Strings for Directional Drilling

Stab. for Sperry Drilling

Strings for Sperry Drilling

Blowout Preventers (BOP)



Blowout Preventers (BOP)

Annular type BOP

Ram type BOP

Drilling Methods

Drilling Methods

Drilling Methods

- Kelly Drilling:
  - Power to be transmitted to drill pipe from rotary table through kelly
- Top Drive Drilling:
  - Power to be transmitted to drill pipe directly from Top Drive System
- Vertical Drilling :
- Directional Drilling:
  - Well to be drilled directionally by controlling the azimuth and inclination
- Mud drilling:
- Aerated Drilling:
  - Air mixed (aerated) fluid forming Foam to be used for drilling
  - Drilling is balanced or slightly under/over

Kelly Drilling

1. Power to be transmitted to drill pipe from <u>rotary table</u> through quadrangle or hexagonal <u>kelly</u>,
2. A drill pipe to be connected to the kelly every time after drilling of the depth of a drill pipe,

3. The drill pipes to be hoisted by "stand"

So called "Stand" is a string of a few drill pipes connected together.

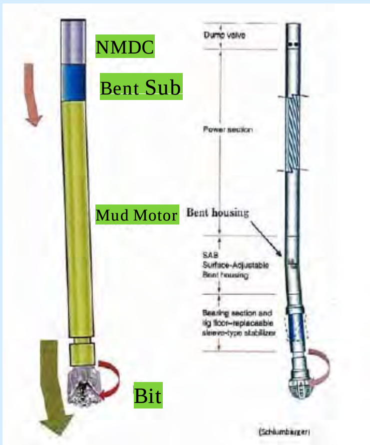
Top Drive Drilling

- Power to be transmitted to drill pipe directly from Top Drive System
- Kelly and rotary table not used
- To hoist drill pipes by "stand"

➔ Merit: one stand (a few drill pipes connected together) is added or replaced when drilling or removing drill pipes; resulting in considerable time saving

Directional Drilling

- Well to be drilled directionally by controlling the azimuth and inclination
  - Drill bit only is rotated by mud motor,
  - Drilling direction is controlled by bent sub or bent housing,
  - Azimuth and inclination in the non magnetic drill collar (NMDC) are monitored.



Bent Housing (Mud Motor)

Measurement of Azimuth and Inclination

1. Single Shot
   - Pictures of gyro magnetic compass in DC is taken on films while not drilling,
   - Rig crew can measure.
2. Steering Tool
   - Azimuth and inclination are monitored continuously by utilizing mud motor
3. Measurement While Drilling (MWD)
   - Position of drill bit is monitored continuously,
   - Special engineering company is employed.

Characteristics of MWD

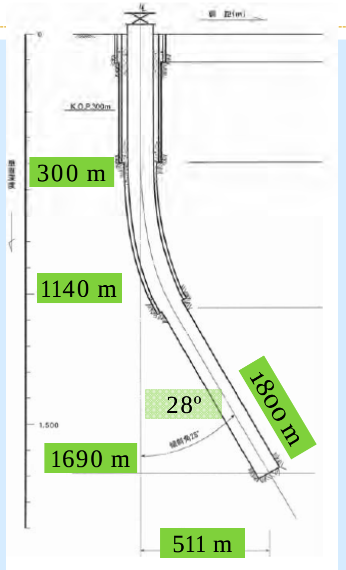
Mechanism

- Sensor : Geomagnetism or gyrocompass,
- Data transmission : Mud Pulse or Electromagnetic Wave

Characteristics

- Almost real time data acquisition,
- Direct information of drill bit position
  - (No calculation/interpretation necessity),
- Direct information of drilling track record and azimuth /direction of bit,
- Considerable time saving together with mud motor and/or top drive system

Example of directional drilling



- Length :1800m
- KOP :300m (Kick off point)
- Interval of changing angle :300-1140m
- Rate of increasing angle :1°/30m
- Directional Angle :28°
- Directional Distance :511m
- Vertical Depth :1690m

Drilling Mud

Drilling Mud

Drilling Mud

Purposes/rolls

- Removing cuttings from well, prevent them from sinking in well;
- Protecting well wall by forming mud wall,
- Keeping reservoir fluid out by over pressure
- Cooling well (Preventing Blowout),
- Cooling drill bit,
- Lubricating drilling strings,
- Controlling ph.
- Powering a mud motor and cleaning the bit

Characteristics Required – Drilling Mud

- Provisions against High Temperature
  - against de-hydration and gelatinization
- Low Density
  - against Lost Circulation

➔ Bentonite plus Other Additives

- **Bentonite** 6-8% (by weight)
- **Additives** :
  Dispersing agents, polymer, ph control chemicals, Anti-bubble and preparations;
  (Thickener, Lubricant, Surfactant, as required)

Drilling Mud Control

- Characteristics (quality and quantity) of drilling mud is monitored, Thereby quality and quantity is controlled.
- Specialized engineering company for mud logging is employed.
- Controlling Items:
  - Specific gravity,
  - Marsh Funnel Viscosity (40 – 45 sec)
  - ph,
  - Sand contents,
  - Quantity of dehydration,
  - Mud wall,
  - Plastic Viscosity (10 -15 Centi Poise)
  - MLB Consumption;
- Monitoring Items:
  - Volume and Temperature of inflow and outflow,
  - Air temperature

Monitoring Items during Drilling

- Borehole conditions
  - Water level
  - Bottom hole temperature
  - Azimuth and Inclination
- Drilling conditions
  - Bit weight
  - Rotation speed
  - Rotary torque
  - Drilling progress rate
  - Pump pressure
- Bit conditions
  - Bit diameter
  - Corn clanking
  - Abrasion of tooth and chip

Aerated Drilling

Drilling mud is mixed with air (aerated), resulting in smaller bulk density of drilling mud.

- Merit
  - No lost mud circulation
  - No damage to the production zone (no cuttings and drilling mud into production zone)
  - Good removal of cuttings, leading to high speed drilling
- Demerit
  - Difficult to maintain air balance
  - Necessary for additional facilities such as compressors, etc.
  - Necessary for anti-corrosion measurement for drill strings

Casing Cementing

Casing Cementing

Casing Cementing

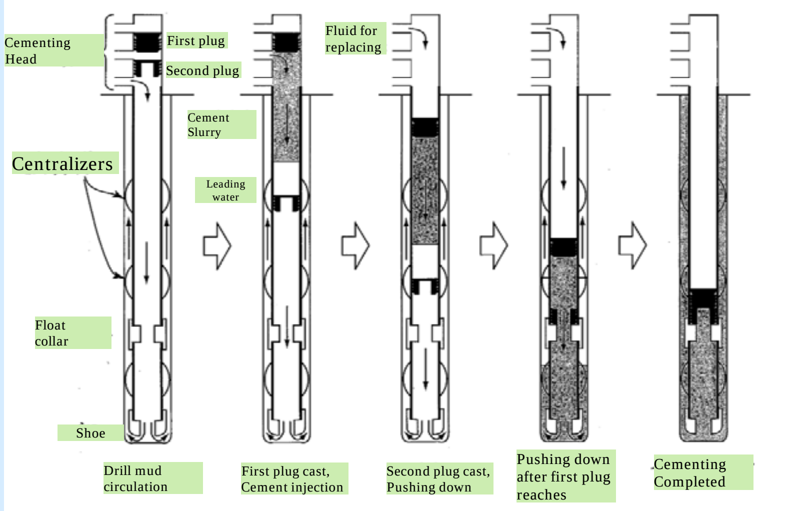
- Purpose of Cementing
  - To support and protect casing pipes
  - To prevent formation liquid from flowing out
- Required Characteristics of Cement slurry
  - To be of low slurry specific weight
  - To develop and maintain proper strength under high temperature conditions
  - To maintain proper fluidity under high temperature conditions

Casing Cementing

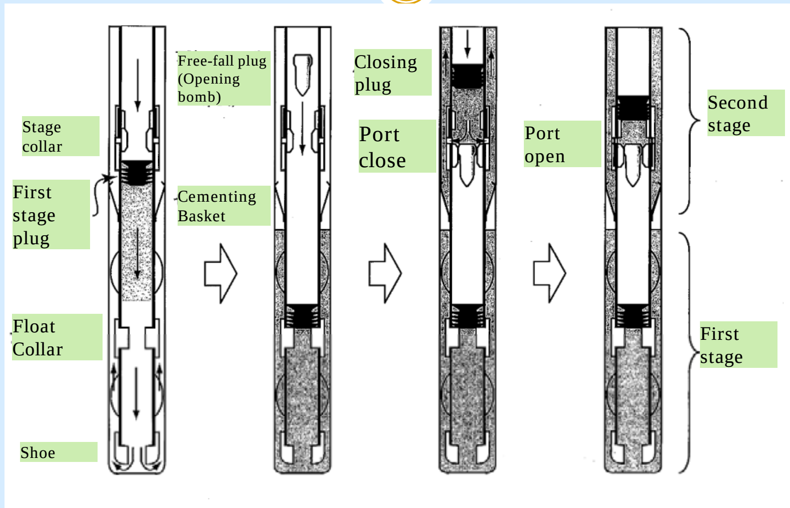
Issues to be overcome

- Continuous injection of large volume cement slurry
- Lost mud circulation to possibly be caused due to density difference between drilling mud and cement slurry
- Cementing Methods
  - Two Plug Method Cementing
  - Two Stage Cementing
  - Liner Cementing
  - Inner String Cementing
  - Tie Back Cementing : Cementing to Tie-Back-Casing fixed onto Liner Casing
  - Top Job Cementing: Injecting cement slurry into the annulus from the surface

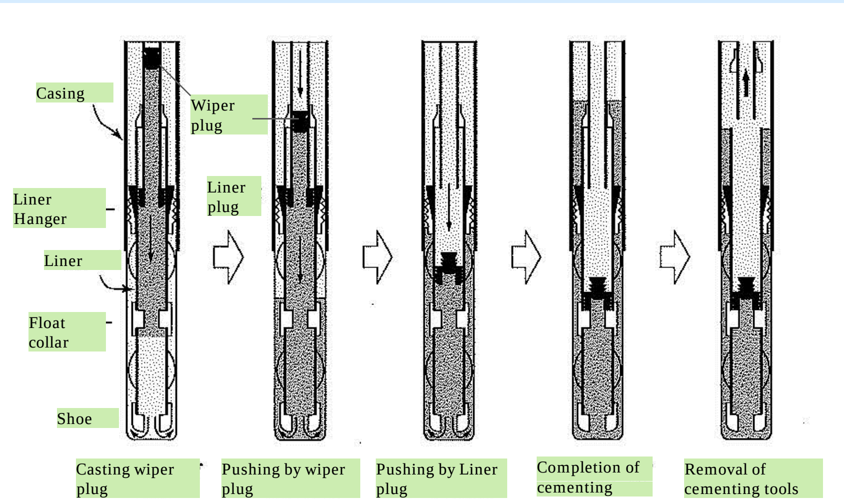
Two-Plug method Cementing



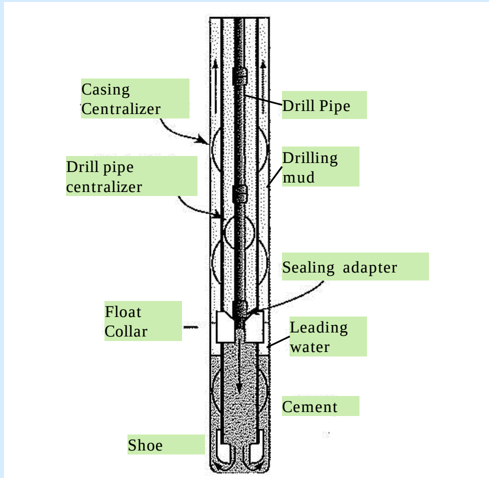
Two-stage Cementing



Liner Cementing



Inner Strings Cementing



Key Points for Good Cementing

- Centering of casing pipe
  - To maintain the casing pipe in the center of the well
- Check the casing shoe bottom
  - Pressurizing after drilling the float shoe
- Sufficient drilling mud circulation
  - Cooling and conditioning of drilling mud
- Continuous Cementing without interruption
- Records of Cementing Works
  - pump pressure, pump rate, density etc.,

Major Troubles during Drilling

Major Troubles during Drilling

Lost Circulation (Loss of Circulation)

Drilling mud is suck into fractures:

Actions to be taken:

- To detect the depth and quantity of the lost circulation
- To apply LCMs (Lost Circulation Materials)
  - To utilize the mixture of several types of LCMs
- To conduct cementing to prevent lost circulation
  - To decide the types of additives to best suite temperatures and other conditions

Countermeasures of Lost Circulation (LC)

Example for a case of mud circulation of about 2000l/min.

- Small loss: Less than several hundreds l/min;
  - To add LCMs to mud water
  - (Loss circulation often naturally stops during drilling)
- Medium loss: about -1,000 l/min;
  - To conduct cementing
  - To conduct a spot application of dense drilling mud mixed with LCMs
  - To inject chemical liquid (ex. Silicate soda)
- Large loss: Larger than 1,0000 l/min;
  - Not to be able to remove the cuttings
  - Sand pack for shallow depths
- All loss of the mud water
  - Sand pack for shallow depths

LC in production zone is to be left untreated unless otherwise decided.

Other Troubles during Drilling

Other Troubles during Drilling

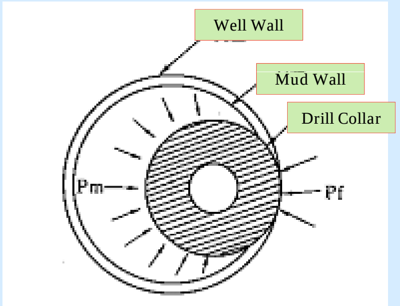
Other Troubles during Drilling

- **Detention**:
  - Drilling strings are detained in the well and not possible to be removed from the well
- **Left behind**:
  - Drilling tools and/or drilling strings are left behind in the well
- **Blowout**:
  - Steam and/or hot water blowout from the well
- **Crushing**:
  - Casing pipes are crushed in the well by swelling of water pocket behind the casings

Detention of Drilling Strings

- Differential Pressure Sticking:
  - Drilling strings are pressed to the well wall
- Wall Collapse:
  - Formation materials in well collapses on to drilling strings,
- Cuttings sedimentation:
  - Cuttings sediments onto drilling strings when stop of drilling and/or lost circulation
- Formation Swelling:
  - Swelling formation detains drilling strings
- Mud sticking:
  - Mud/clay sticks to drilling strings, forming mud cylinder of thick diameter.
- Under Gauge: *(abrasion, wearing)*
- Key sheet:

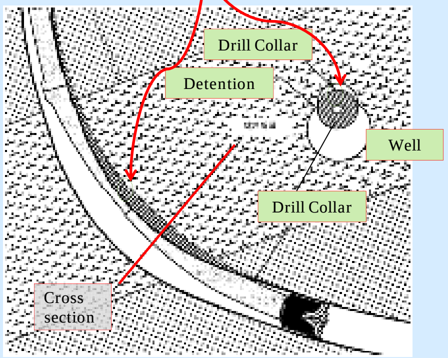
Pressure differential Sticking, Key Seat



Mud Columnar Pressure (Pm)> Formation Pressure (Pf)

Pressure Differential Sticking

Key Seat



Left behind of Drilling Tools

- Cutting-off:
  - Metal fatigue, Corrosion, Washout and etc, causing cutting-off drilling strings.
- Self-screw-releasing :
  - Reverse rotation due to sudden stop of high torque rotation, causing de-touching of connections .
- Falling objects:
  - Bit corn, chip, tools and etc.
- Cutting off of wire and cable

Examples of Tools Damaged

Broken Sub – upper part

Recovered drilling strings by over-shooting

Recovered broken Sub – lower part

Crack on Drilling Pipe

Crushing of Casing

- Casing pipes are crushed into the well due to swelling of water left behind the casing pipe (water pocket), because of rapid temperature raising;

- Key points:
  - No water pockets to be left
    ➔ appropriate cementing,
  - No channeling to be caused
    ➔ appropriate placing of centerizers,
  - To minimize free water in cementing slurry

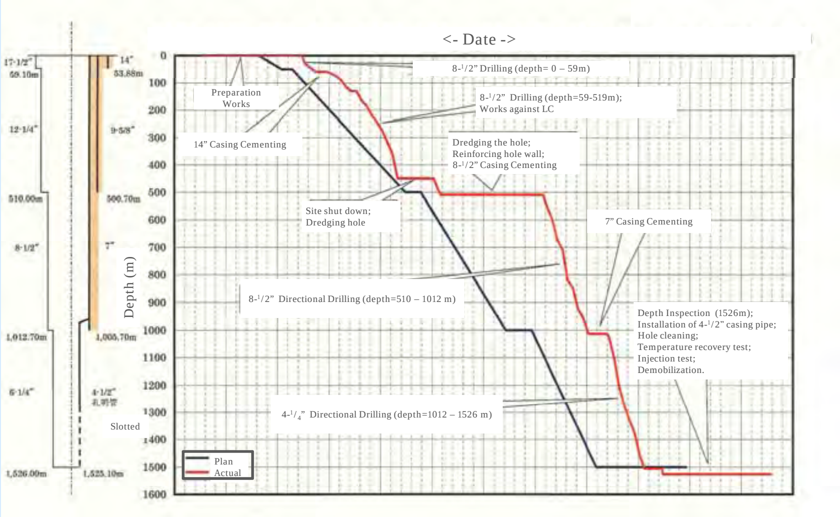
Blowout

- BLOWOUT is violent eruption of hot water, steam, gas and etc. from well

- Key Tokens of Blowout:
  - Rapid falling down of water level caused by the lost circulation
  - Rapid raising up of water level caused by high pressure formation fluid
  - High temperature of drill mud circulation (T>60°C)

Drilling Progress Record

(to be translated into English)



DATA COLLECTION SURVEY ON GEOTHERMAL DEVELOPMENT IN RWANDA

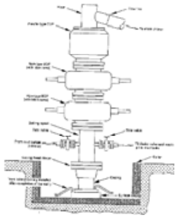
Thank you

ありがとうございます

July 2013

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

NIPPON KOEI CO., LTD



DATA COLLECTION SURVEY
ON
GEOTHERMAL DEVELOPMENT
IN RWANDA

Well Design and Drilling

Hannes Sverrisson, M.Sc. Petroleum Engineering

July, 2013
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)
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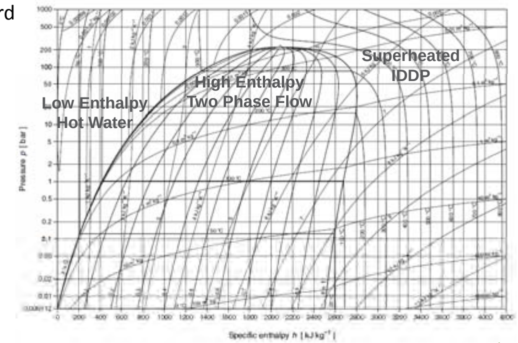
Overview

- Well Design
  - Casings
  - High Enthalpy and Low Enthalpy
- Drilling Programs
  - Drilling Programs
  - Hellisheiði Geothermal Power Plant
  - Well Testing
- KW-01 Drilling Program

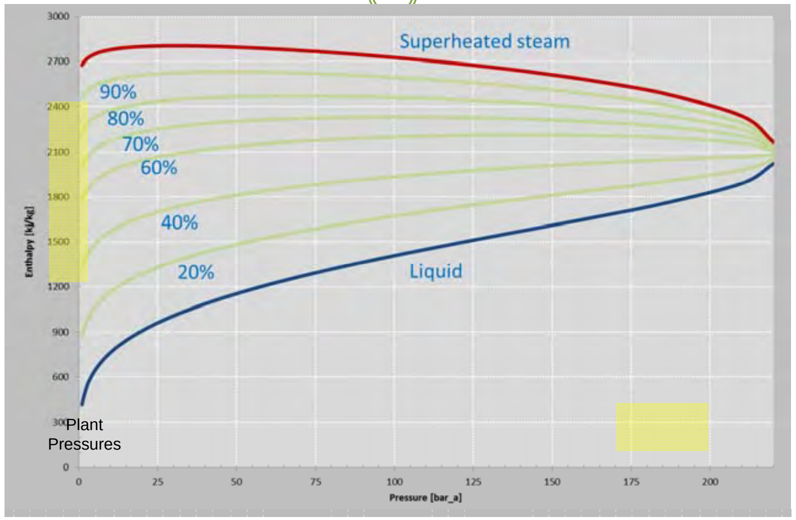
WELL DESIGN

Well Design: Main References

- API Standards:
  - API Standards for casings, BOP, valves, and material
  - Sometimes the API don´t apply because of larger diameters in geothermal
  - Some time Line Pipe material grade used for surface casings
  - Code of Practice for Deep Geothermal Wells
  - NZS 2403:1991, New Zealand Standard
- Steam Tables
  - International Steam Tables
    http://www.international-steam-tables.com/
  - EES
  - Xsteam
    http://xsteam.sourceforge.net/
    - Excel



Well Design: Enthalpy vs. Pressure

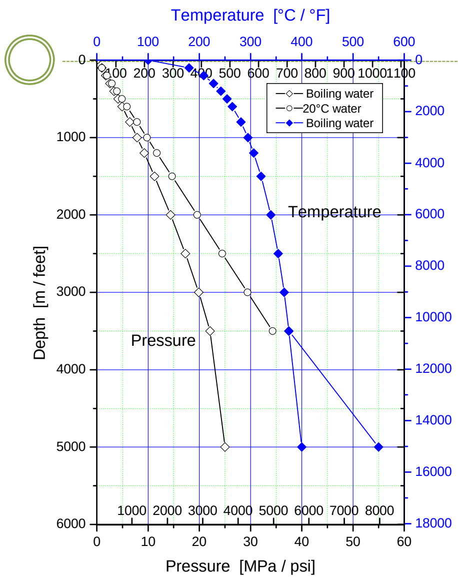


Well Design: Main Points

- High temperatures
- Large borehole and casing diameters
- Collapse risk
- Casing steel grades preferably from low yield steel
- Extreme LOC common
- Low cost drilling fluids and when in the reservoir rock only water with high density polymer
- Usually large targets like fizzures and fault zones and thus, less accuracy needed
- Flashing can occur inside the wellbore
- Limited budget

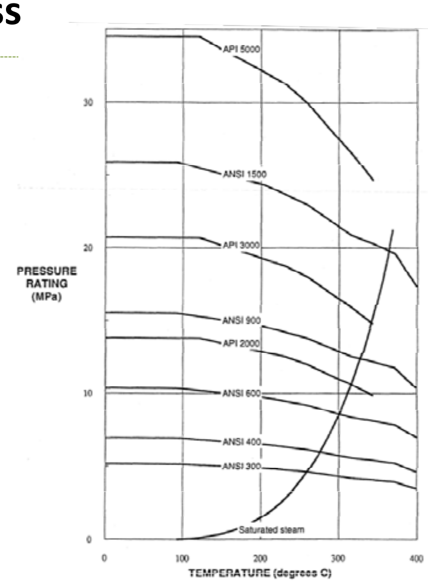
Well Design: Casings

- Determine Temperature
  - Depends on depth
  - Expected enthalpy of reservoir
- Exploration well
  - Expected temperatures from Geologists and surface indicators are „indicators“
- Always keep the well full of water or closed
- Some areas may have blow-out at 100 m depths!
- **Minimize heat cycles from cold to hot and vice versa.**



Well Design: Pressure Class

- Pressure Classes ANSI / PN
  - Cl. 2500 / PN 420
    - Superheated
  - Cl. 1500 / PN 250
    - High Enthalpy
    - API 5000
  - Cl. 900 / PN 150
    - Hellisheiði PP, TVD 1900 m
    - API 3000
  - Cl. 600 / PN 100
    - Low Enth. 2 phase, TVD 1150 m
    - Hot water
  - Cl. 300 / PN 50
    - Hot water
  - Cl. 100 / PN 16
    - Water wells



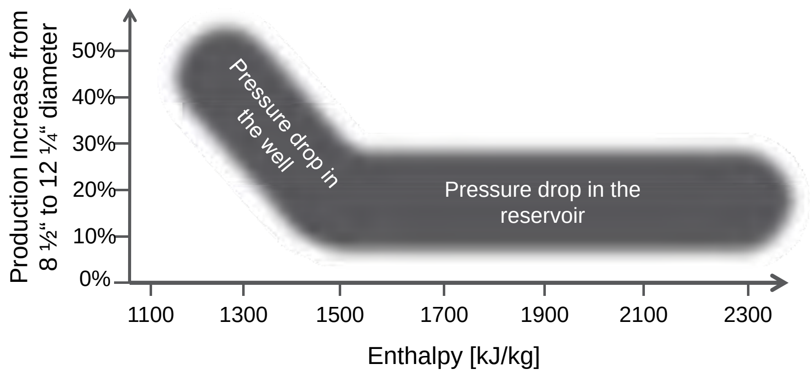
Well Design: Casings

- High temperatures
  - Affects casing material strength
  - Highest temperature expected depends on the reservoir and depth
  - Highest 450° C (IDDP)
- Steel Grades
- K55 or J55
  - Low yield strength
  - High tensile strength
- Line pipe X56 in surface casings
- The casing will yield due to high temperature
- The low yield steel has good corrosion resistance
- Sometimes higher yield casing steel grades may be sold as K55. Then do additional requirements to the API standard

Well Design: Diameter

Low Enthalpy
12 ¼" Production Interval

High Enthalpy
8 ½" Production Interval



Well Design: Narrow and Wide Program Cl. 900

- Wide
  ø12¼" production hole
- ø24½" bit: 26"
- ø18⅝" bit: 21"
- ø13⅜" bit: 17½"
- ø9⅝" bit: 12¼"

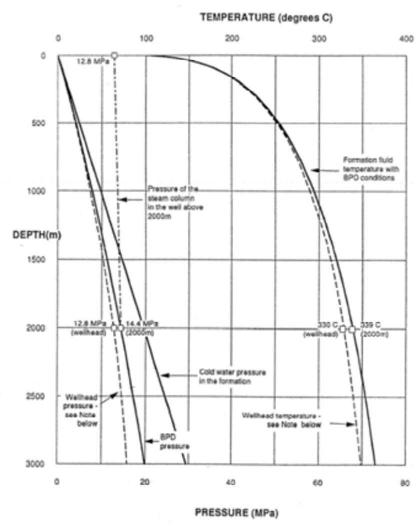
- Well Flange: ø18"
- Master Valve: ø12"
- Expansion spool: ø18" - ø12"

- Narrow
  ø8½" production hole
- ø18⅝" bit: ≥21"
- ø13⅜" bit: 17½"
- ø9⅝" bit: 12¼"
- ø7" bit: 8½"

- Well Flange: ø12"
- Master Valve: ø10"
- Expansion spool: ø12" - ø10"

Well Design: Burst & Collapse

- Burst
  - Empty well with steam column to top
  - Burst at top is bottom hole pressure at section depth at the boiling point, with the weight of the steam column subtracted.
- Cementing procedures
  - Same as in oilfield
  - Usually stab-in cementing used, thus not an issue.
- The reservoir fluid may be saline and with other dissolved minerals which increases density slightly.
- Collapse
  - Avoid trapped water pockets that may heat up and expand
  - Good cementing essential without cement boundaries
  - Free water content of slurry
  - Low density for collapse risk and also to limit risk of fissure break-out



Well Design: Tension and compression

- Temperature difference due to tension needs to be taken up be the cementing
- If casing is badly cemented and loose then for a 1000 m section and 150° C warm up:
  - 1,8 m movement
  - 360 MPa compressive stress if held in place
  - Yield strength of K55 is 379 Mpa
- Minimize warm-up cycles due to tension and compression
  - For compression the K55 material may yield and thus high tension can result when cooled down again.

Grade	Temperature (°C) 20	100	200	300
API Yield Strength (Factor):				
J/K-55	1.00	0.95	0.95	0.95
N-80	1.00	0.96	0.92	0.88
Tensile Strength (Factor):				
J/K-55	1.00	0.97	1.02	1.07
N-80	1.00	0.97	0.99	0.99
Modulus of Elasticity (10^3 MPa):				
J-55	178	172	168	160
K-55	208	208	200	192
N-80	206	206	200	192

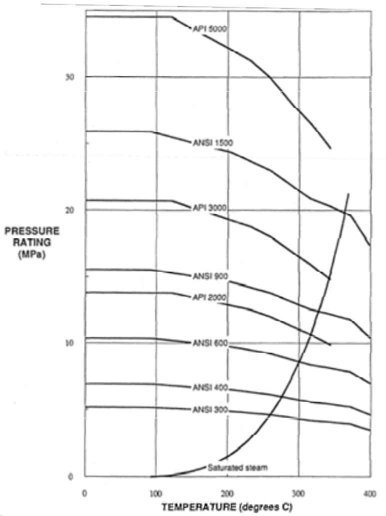
Design factors					
Axial		*Use*	Hoop		*Use*
Tensile	1.5-1.8	*1,5*	Internal yield (burst)	1.5-1.8	*1,5*
Compressive	1,2	*1,2*	Collapse	1,2	*1,2*
Wellhead anchorage	1,5	*1,5*	Inner collapse (outer burst)	1,2	*1,2*

Well Design: Thread

- Choose a thread that is strong in compression as well as tension.
  - Buttress Thread BTC
  - Hydril (IDDP)
- Glue (cement) the top and bottom 3 connections
- Use joint compounds that are rated for the temperature

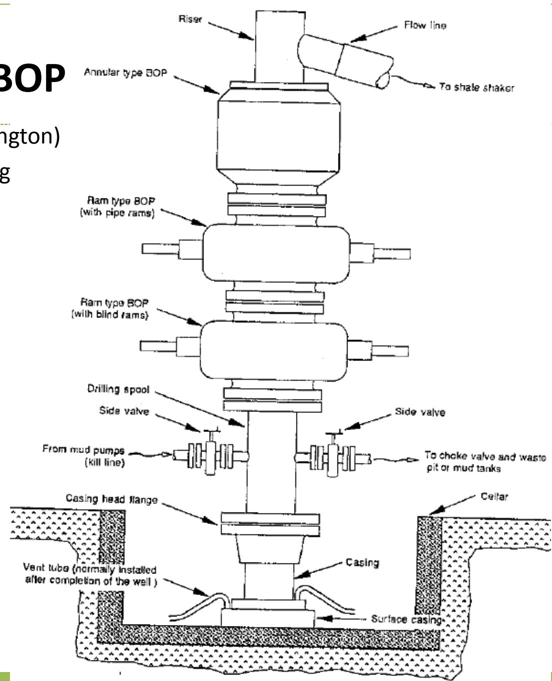
Well Design : Blow Out Preventers (BOP)

- API Standard
  - Functionality test and pressure test API RP 53 prior to drilling out cement
- API 2000
  - Shallow sections (sometimes surface casing)
  - Connects to ANSI 600 Ring Joint Flanges
- API 3000
  - Intermediate sections and often to TD
  - Connects to ANSI 900 Ring Joint Flanges
- API 5000
  - High temperature and deep wells
  - Connects to ANSI 1500 Ring Joint Flanges



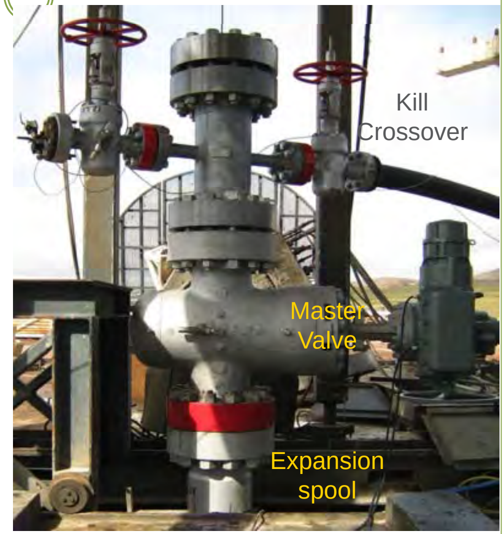
Well Design : BOP

- Rotating head (Washington)
- Drilling spool for killing



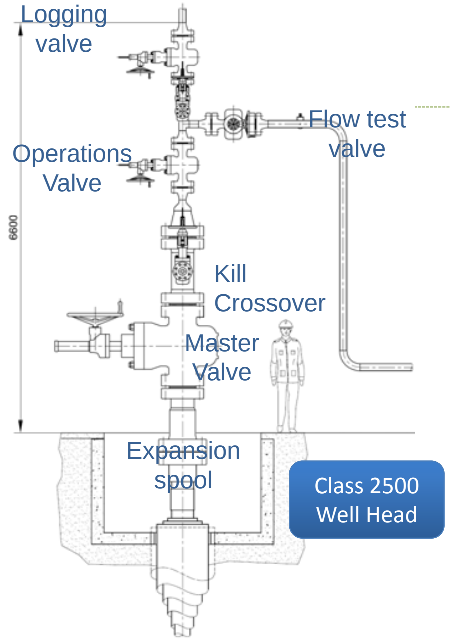
Well Design: Well Heads

- Kill cross-overs no longer used before the master valves
- Master valve used sparingly
  - Operation valve (not expanding) used for connecting to steam gathering or seperator
- Flow control
  - Valves, expensive and usually set once per year.
  - Orifice, cheap and may be changed annually or 2 years.
- Ring Joint Flanges with steel ring gaskets



Well Design: Well Heads

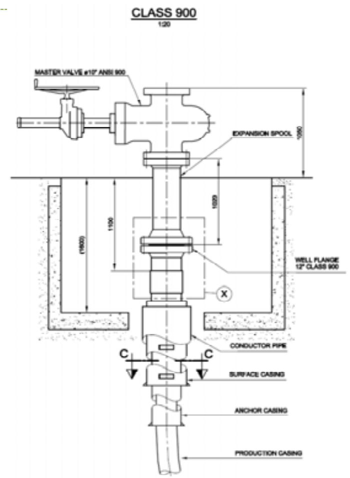
- Testing
  - Always use the operations valve and minimize use of master valve
  - Use a 3“ logging valve for temperature and pressure measurements during flow test
- Design the well head for movement and vibration

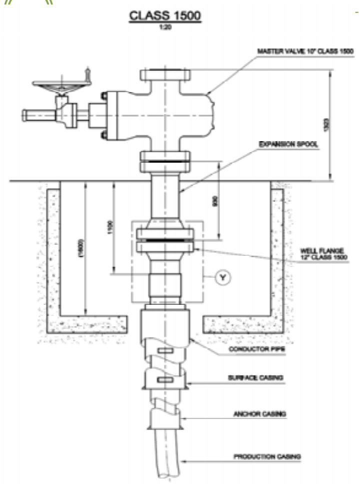


Well Design: Valves and Expansion Spools

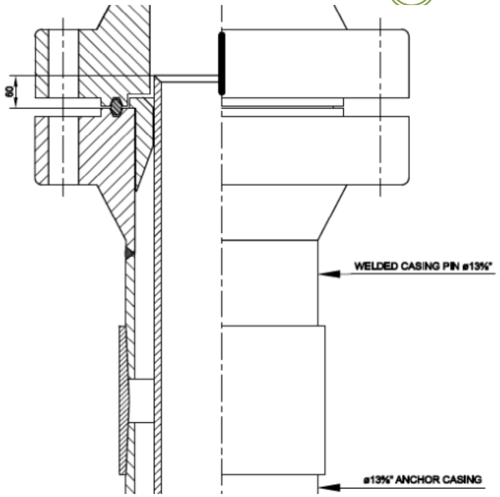
- Preferable to use expanding gate valve type for master valves
  - They seal the valve housing when fully open and fully closed.
- Packing assembly used in high enthalpy wells

Well Design: Valves and Expansion Spools





Well Design: Valves and Expansion Spools



Well Design: Drilling Pad

- At least stack four wells per drilling pad
- Straight or J-type slanted well paths.
  - Usually not more than 35° - 40°
  - KOP 300 – 400 m
  - Maximum departure of 1590 m for a 40° and TD 3000 m
- Blind drilling maybe necessary in the production section
  - Thus, no inclination and azimuth measurements while drilling.
- Accuracy

Category	A	B
Azimuth	±5°	±15°
Inclination	±3°	±12°
Maximum DLS	1,0°/ 30 m	1,0°/ 30 m

Well Design: Cementing

- Preferable to cement with stab-in method
  - Flexible slurry volume
  - Slurry delivered cold downhole
- Monitor cement return in annulus on surface and pressure
- Monitor pressure and expect a break-out due to fissure opening
- If a fissure opens where the slurry escapes
  - Pump water on the annulus to keep the fissure open
  - Switch the cementing method to annulus top down cementing
  - Cement until TOC in annulus is at surface
  - Top up due to subsidance

Well Design: Slurry recipie

- Grade-G with 35% silica flour
  - High density
- Iceland: Portland Cement with 40% silica flour
  - Allows lower density
  - Cheaper and availability
- Monitor pressure and expect a break-out due to fissure opening
- Slurry volume – Rule of Thumb:
  - With caliper msmt. add 25%
  - Without caliper msmt. add 50%
  - Have material on-site for mixing 220% the design volume

Common Slurry, density 1,7:

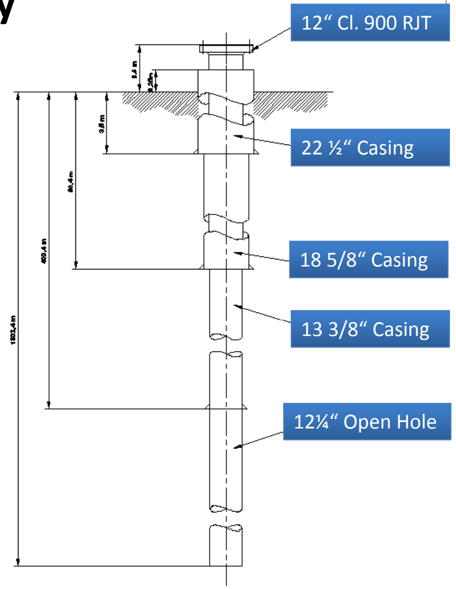
Portland Cement	100 kg
Water	63 kg
Silica 325 mesh	40 kg
Bentonite	2 kg
Tensed Perlite	2 kg
Retarder	0 – 0,5 kg

Well Design: Logging

- Temperature
  - Important factor
  - Use sensitive temperature sensors with accuracy and fast responce
  - The normal oil field temperature sensors are not adequate
- Typical:
  - Last section:
  - Temp. & Press.
  - Azim. & Incl.
  - Spontaneous Pot. (SP)
  - Natural Gamma (GR)
  - Resistivity
  - Neutron-neutron (n-n) (Radioactive)
  - (Vertical Seismic Profiling (VSP), exploration)
- Other:
  - Cement Bond Logging (CBL)
- Well Testing:
  - Temp. & Press.
  - (Flow meter)
  - (Gamma ray)

Well Design: Low Enthalpy

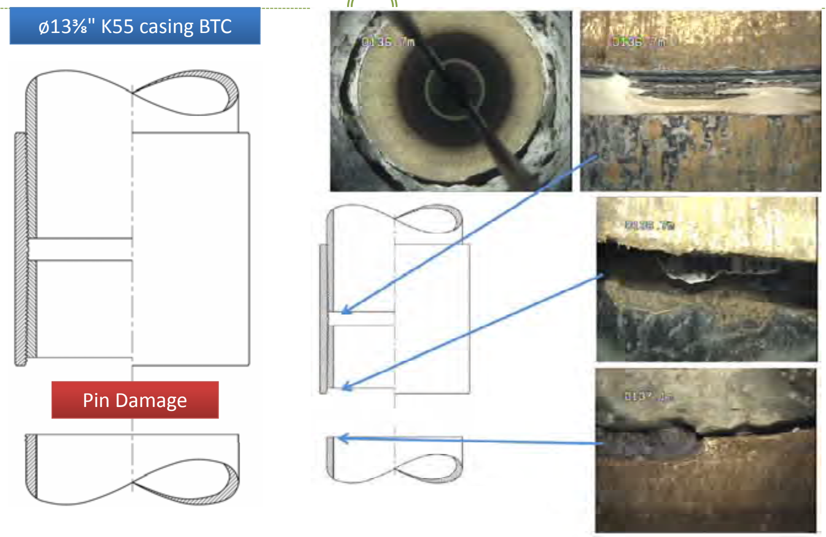
- Wide casing program
  - 12 ¼“ open hole production part
- Production casing 13 3/8“



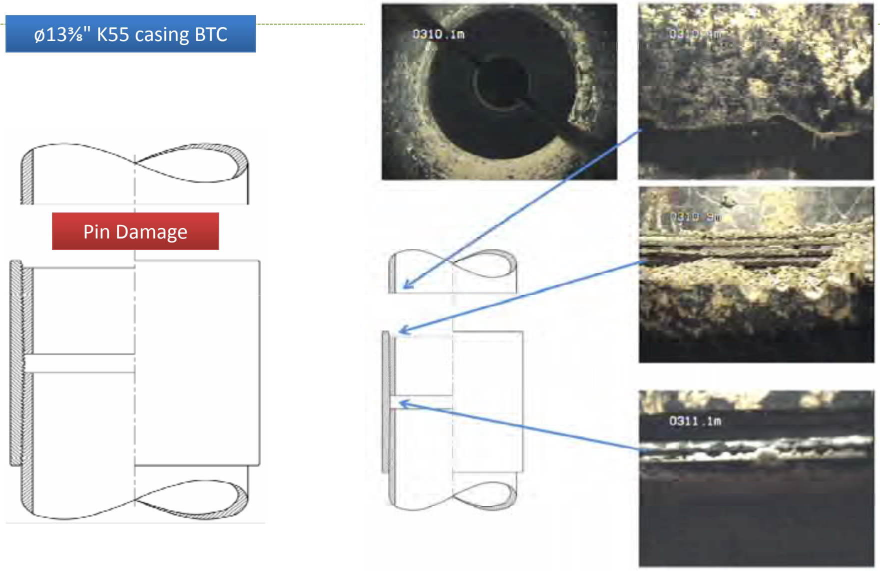
Well Design: Low Enthalpy

- Wide casing program
  - Have space for downhole pump

Well Design: Tension Failures

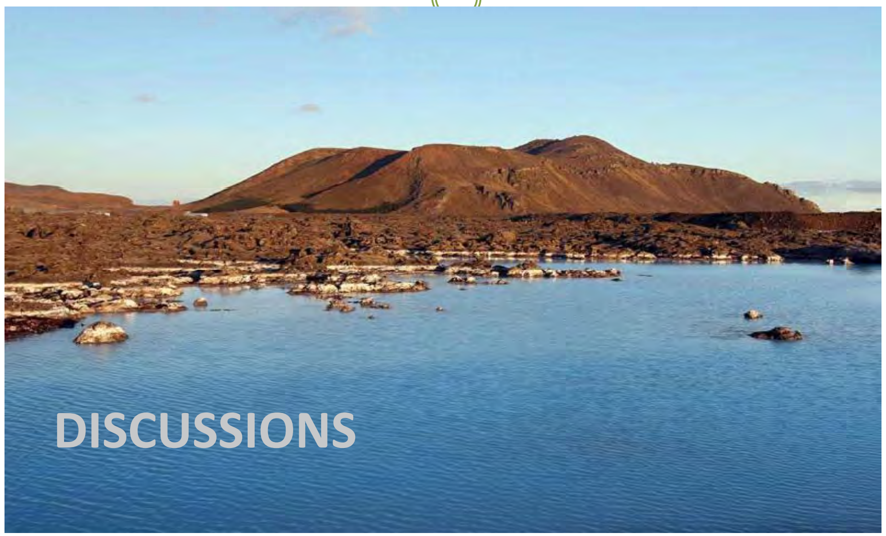


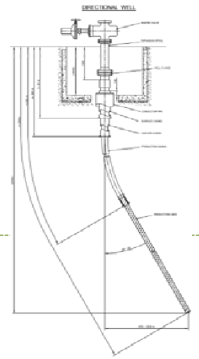
Well Design: Tension Failures



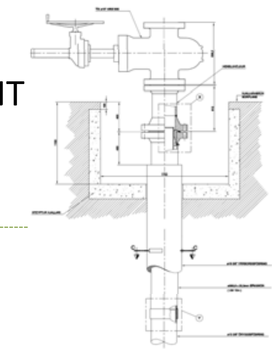
Well Design: Points to Remember

- Use low yield steel to allow yielding and corrosion resistance.
- Cement in one continous and fast flowing procedure and be ready to switch to top down annulus cemeting.
  Lower slug density is beneficial.
- Allow for well head movement and minimize warm-up and cooling cycles.
- Always keep the well full of water and monitor the water table.
- Always close the well when no string is in it.
- Limit drilling ROP and monitor cuttings removal or buildup in the well.





DATA COLLECTION SURVEY
ON
GEOTHERMAL DEVELOPMENT
IN RWANDA



Drilling Programs

Hannes Sverrisson, M.Sc. Petroleum Engineering

July, 2013
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)
NIPPON KOEI CO., LTD

DRILLING PROGRAMS

Overview

- Well Design
  - Casings
  - High Enthalpy and Low Enthalpy
- Drilling Programs
  - Drilling Programs
  - Hellisheiði Geothermal Power Plant
  - Well Testing
- KW-01 Drilling Program

Drilling Programs: Main Points

- Extreme LOC usual occurrence
- Blind Drilling
- Usually large targets and less accuracy needed
- Flashing can occur inside the wellbore
- Lower budgets

Drilling Programs: Extreme LOC

- Have procedure in place for addressing LOC
- LOC material: mica and nut shells with good experience
  - When less than ≈15 l/s
- High losses treated with cementing
  - LOC material added to the cement
  - Prevents the fissure / vain of affecting cementing operations
- May get sealed by cuttings
- Monitor cuttings coming to surface

Drilling Programs: Blind Drilling

- When losses exceed the fluid pumped downhole
- Have procedure for blind drilling or maybe stop drilling
  - the „**objective**“ may have been reached although the „**target**“ has not been
- Cuttings may build up
  - Monitor cuttings buildup by pulling up to the casing and wait for cuttings to settle
  - Wash down and note cuttings buildup in the well by depth difference
  - Slowly remill the cuttings
- Usually no information on azimuth and inclination
  - Continue drilling and check azimuth and inclination at the next bit change

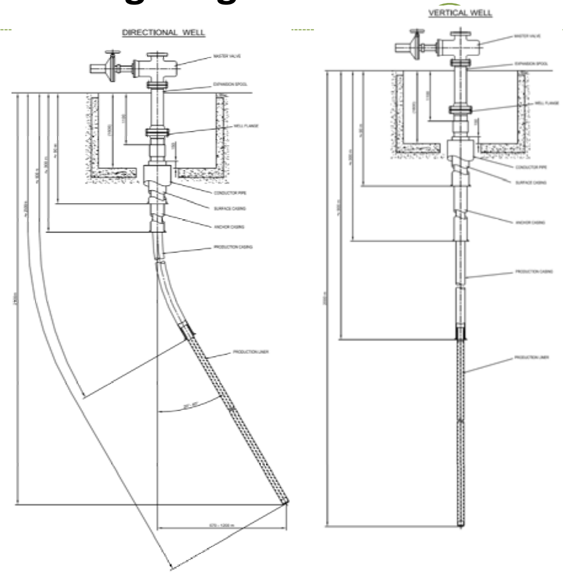
Drilling Programs: Steam Flashing

- Always monitor water level in the well
- Always close the well when no drilling string is inside
- The fluid column is usually enough to prevent steam flashing
- Have backup water if water supply fails
- Have at least 20 ton of Barite available on-site or storage area for killing

Drilling Programs: Stuck String

- Well collapse
- Buildup of cuttings
  - New fissure opens and the water level drops suddenly in the well which collects the cuttings at the fissure

Drilling Programs: Cl. 900 & 1500 Wells



	CLASS 900	
	DRILL BIT	CASING
VALVE		ø10"/900
EXPANSION SPOOL		ø12"-10"/900
WELL FLANGE		ø12"/900
SURFACE CASING	(ø21")	ø18⅝"
ANCHOR CASING	ø17½"	ø13⅜"
PRODUCTION CASING	ø12¼"	ø9⅝"
PRODUCTION LINER	ø8½"	ø7"

	CLASS 1500	
	DRILL BIT	CASING
VALVE		ø10"/1500
EXPANSION SPOOL		ø12"-10"/1500
WELL FLANGE		ø12"/1500
SURFACE CASING	(ø21")	ø18⅝"
ANCHOR CASING	ø17½"	ø13⅝"
PRODUCTION CASING	ø12¼"	ø9⅝"
PRODUCTION LINER	ø8½"	ø7"

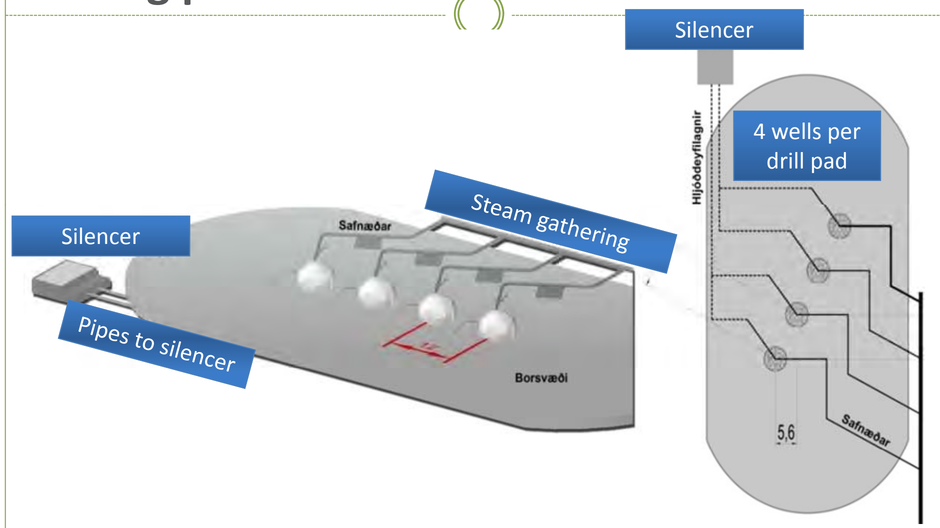
Drilling Programs: Well Testing

- Allow time for warm-up period
- Warm up well head slowly
  - Gas bleeding
- Allow well to eject drilling water
  - 1 – 2 months
- Well testing
  - 2 – 6 months to get general data
- Try to keep the well heads warm until utilized
- Low Enthalpy Wells
  - Air lift maybe needed to lift the water column
  - The well may oscillate

Hellisheiði Geothermal Power Plant

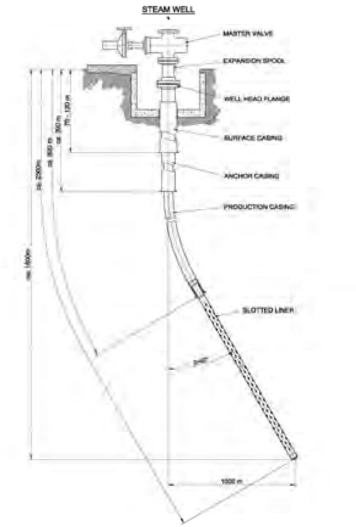
- Electricity Production: 303 Mw_e
  - Delivered @ 220kV
- District Heating: 133 MW_{th}
- 57 production wells
  - Steam 3kg/s @
- 17 injection wells
  - Water kg/s @ 70° C
- 54 groundwater wells / information wells d:9 7/8‘‘
- Well Depth on average 2000 m and length 2300 m
- Well diameter 12 ¼‘‘, 8 ½‘‘ (production part)
- Well pads with 4-6 wells
- Distance between bore holes
  - Surface: ~12m
  - Reservoir: ~500-1200m

Drilling process at Hellisheiði

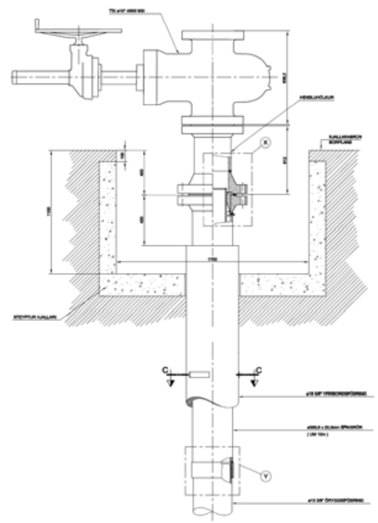


Drilling process at Hellisheiði

- Drilled to reach a temperature (250° C +)
- Target production zone and fractures
- Open hole or slotted liner on production zone
- Three step process for safety
- Class 900, ~100 bar_a pressure at 314° C



Wells – Well Heads, Hellisheiði



Balanced Drilling or Air Drilling

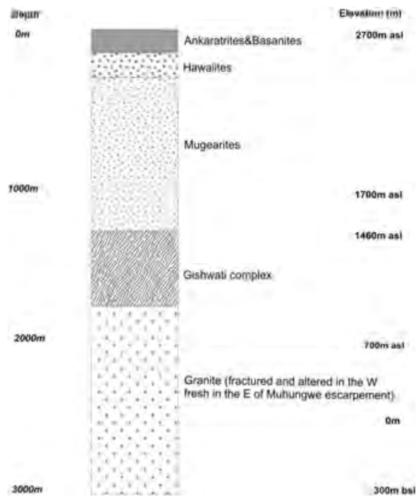
- Pressure is kept in balance with fissures in the formation
- Drilling fluid is foam
- Gains:
  - Better cuttings removal
  - Improved production with less formation damage
- Compared to conventional drilling
  - Cost is +15-30%
  - Production gain depends on the reservoir
  - Formation damage from cuttings possible

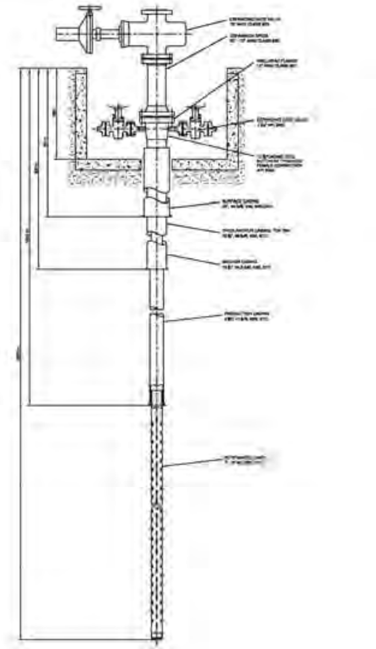
Drilling Programs: Points to Remember

- Always keep the water level high in the well.
- Have enough backup water.
- Expect extreme LOC.
- Total LOC – continue with blind drilling or stop drilling?
- Limit ROP.
- Stack wells per drillpad to lower costs.
- Have prepared written procedures to handle these risks above.

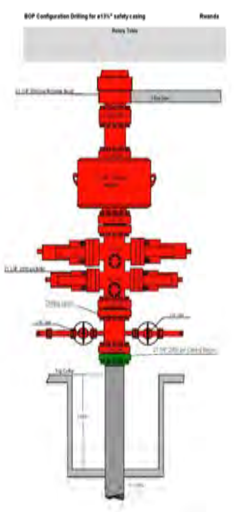
KW-01 DRILLING PROGRAM

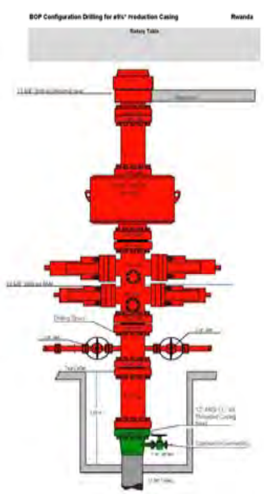
Section		Depth Interval m, TVD-GL	Hole Size	Casing			
				Size	Weight	Grade	Conn.
I	Surface casing	0 - 60	26"	508 mm	10 mm	X56	Welded
II	Anchor casing	0 - 300	17½"	13⅜"	54,5 lb/ft	K55	BTC
III	Production liner	0 - 1200	12¼"	9⅝"	47 lb/ft	K55	BTC
IV	Perforated liner	1170 - 3000	8½"	7"	26 lb/ft	K55	BTC

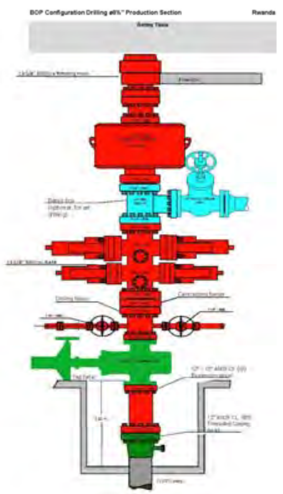




Drilling BOP







Section I – 26” Hole – 508mm Surface Casing to 30 m

- Possible problems
- Cementing Method

Section II. – 17-1/2" Hole -13-3/8" Anchor Casing to 300 m

- Possible problems
- Cementing Method

Section III – 12 ¼" Hole - 9-5/8" Production Liner to 1200 m

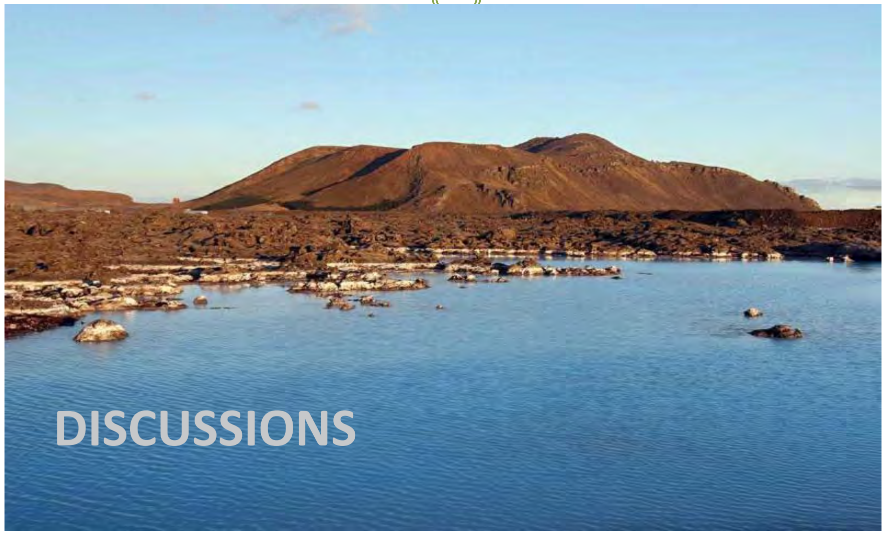
- Possible problems
- Aerated drilling
- LOC zones
- LOC procedures
- Temperature measurement
- Cementing Method

Section IV – 8-1/2" Hole – 7" Perforated Liner to 3000 m

- Possible problems
- Aerated drilling
- LOC zones
- LOC procedures
- Blind drilling
- Temperature measurement
- Liner placement

Estimating Cement Volumes

Casing size and weight	inch	20" 94.0#	13 3/8" 54.5#	9 5/8" 47#
Top, open hole	m	0	55	295
Bottom, open hole	m	60	300	1200
Top casing	m	0	0	0
Casing shoe depth	m	58	298	1198
Casing length	m	60	300	1200
Open section annulus length	m	60	240	900
Displacement casing	lpm	202,68	90,65	46,94
Capacity casing	lpm	185,32	80,64	76,04
Capacity open hole	lpm	342,5	155,2	76
SLURRY VOLUME				
Volume between casings	m3	x	5,7	10,1
Volume between casing and well	m3	8,4	15,5	26,2
Excess slurry (btw casing and well) 60%	m3	5,0	9,3	15,7


DISCUSSIONS

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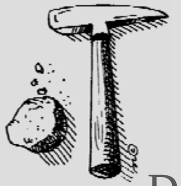


INTRODUCTION of Geological Analysis with Data from Geothermal Drilling

July, 2013

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

NIPPON KOEI CO., LTD

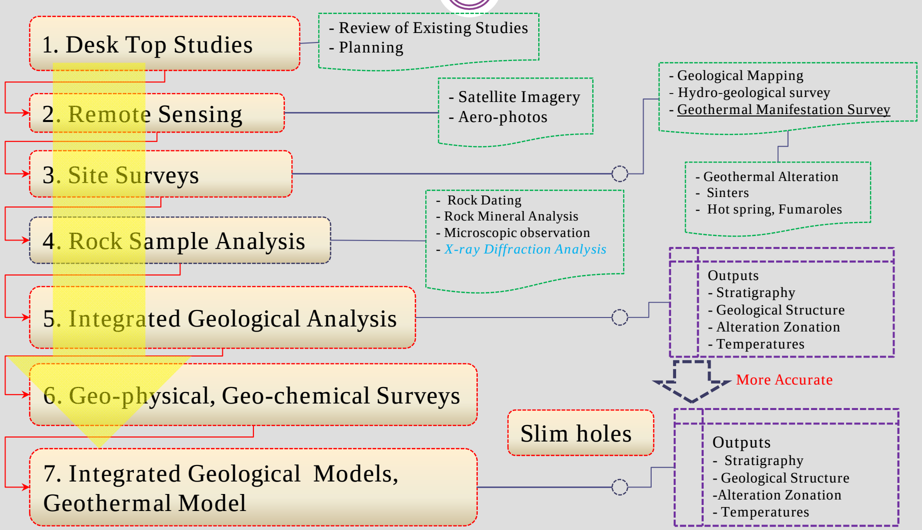
Subjects for Today

1. Outline of Surface Geological Study
2. Geological Study with Drilling Data
    1. Sampling of Drill Cuttings/Rock Cores
    2. Observation of Drill Cuttings/Rock Cores
        - Megascopic, Microscopic
    3. X-Ray Diffraction Analysis
    4. Fluid Inclusion Analysis
3. Rock Classification (TAS)
4. Alteration Minerals

→ Geological Cross Sections

→ Alteration Zonation

Outline of Surface Geological Study



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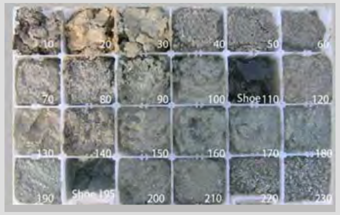
Sampling of Drill Cuttings

1


2


3


Hand with a cup

4


1. Sampling from drill mud system
2. Temporally storage on site
3. Storage in bins after washing
4. Columnar, special display

Rock core sampling and Rock hin section

1


2

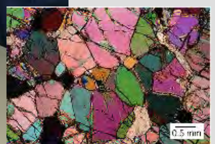

3


4


1. Rock core sample in core box
2. Rock core cut into pieces
3. Rock pieces stuck to a glass being ground
4. Thin section (needs to be ground more)

Microscopic Observation

Stereo Microscope
for drill cuttings observation



An image under polarizing microscope (crossed nicols)

Polarizing Microscope
for thin section observation

Sample Format for Geological Logging

Drilling Geological Log

Location: Well No:
Elevation: Direction:
Total Depth: Logged by:

Alteration Minerals

Location and volume

Depth (m)	Elevation (masl)	Casing Program	Symbol	Rock Name	Color	Description	Formation name		Stereo-scopic observation										LoC	Analyss		
									Sulfur	Quartz	Quartz (euhedral)	Pyrite	Smectite	Calcite	Anhydrite	Laumontite	Epidote	Wairakite		Thin section	X-Ray	Fuild Inclusion
10																						
20																						
30																						
40																						
50																						

- Weathering,
- Hardness,
- Denseness (compact, porous, etc)
- Minerals,
- Alteration (clay, color, etc)
- Special notes, if any,
- others

Photos of cuttings

Sampling Locations

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➔ Geological Cross Sections

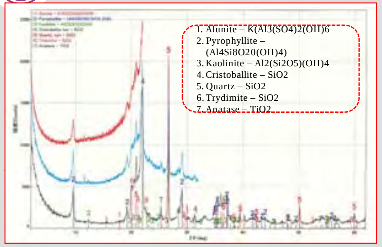
➔ Alteration Zonation

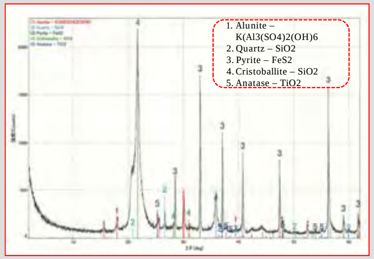
X-Ray Diffraction Analysis

- **Powder X-ray Diffraction (XRD)** is one of the primary techniques to examine the physico-formula compositions of unknown solids.
- **XRD technique** takes a sample of the material and places a powdered sample in a holder, then the sample is illuminated with x-rays.
- **XRD technique** is a powerful tool to identify alteration minerals

X-ray Diffraction Analysis

X-Ray Diffraction Analysis
- Equipment -





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Fluid Inclusion Microthermometry

Definition:

- Fluid inclusions are inclusions in minerals that are filled with fluid (gas and/or liquid), and in a few cases minor amounts of one or more solid phases.
- Fluid inclusions result from defects in the crystals during their growth, which lead to the entrapment of fluid in their surroundings.

Information derived from Fluid Inclusion:

- *Fluid composition,*
- *Salinity of the fluids*
- *Fluid Density,*
- *Temperatures of entrapment*
- *P-T history of the sample*

Interpretation of Reservoir Temperature

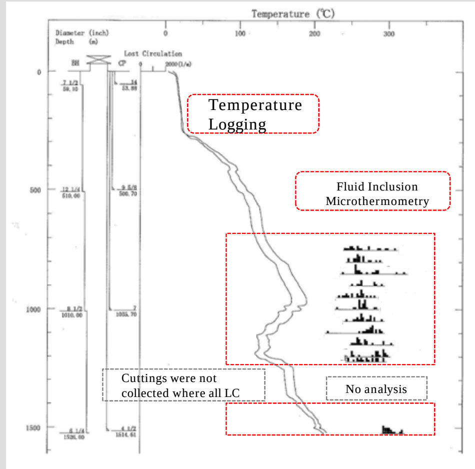
Practical use for geothermal development:

- Fluid Inclusion Homogenization Temperature is measured from minerals in drill cuttings;
- The temperature under which the mineral formed is determined.

Fluid Inclusion Microthermometry

Fluid Inclusion Microscope:.

Microscope with heating and cooling stage attached that allows determination of phase transitions in fluid and gas inclusions.



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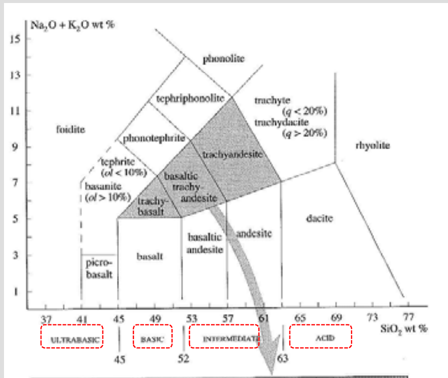
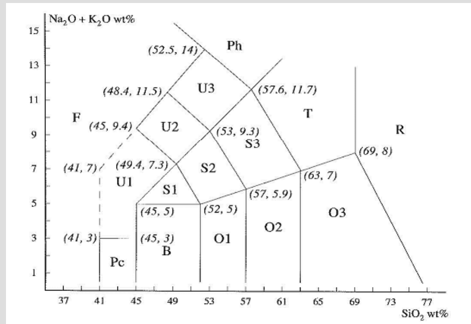
Rock Classification



Further subdivisions of shaded fields	trachybasalt	basaltic trachyandesite	trachyandesite
$Na_2O - 2.0 \geq K_2O$	hawaiite	mugearite	benmoreite
$Na_2O - 2.0 < K_2O$	potassic trachybasalt	shoshonite	latite

←Total Alkali-Silica (TAS) Diagram

▼Field symbols and coordinate points



Rock Classification - Examples

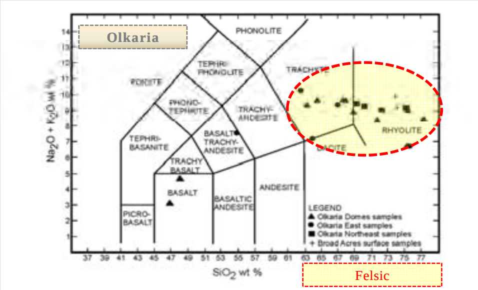


FIGURE 7: Total alkalis silica (TAS) diagram for classification of volcanic rocks using chemical analysis (Les Bas et al., 1989). Data from Olkaria Domes is from the present study, Olkaria East data is from Browne (1984), Olkaria Northeast data are from Omenda (2000), MacDonald et al., (1987) and Black et al (1997), Broad Acres data is from McDonald et al (1987)

Most of rock samples fall in "Felsic".

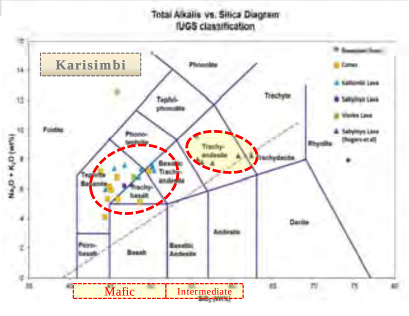


Figure 4.9: Compositional domains of volcanic rocks in Northwest Rwanda.

Most of rock samples fall in "Intermediate" or "Mafic".

Rock Classification

General Characteristics of mafic – felsic magma

	Classification		
	Mafic (Basic)	⟷	Felsic (Silicic)
1.Specific Weight	Larger	⟷	Smaller
Depth in Crust	Deeper	⟷	Shallower
2.Viscosity	Smaller	⟷	Larger
Flow-ability	Larger	⟷	Smaller
Size of Magma Chamber	Smaller	⟷	Larger
Cooling	Quicker	⟷	Slower
3.Radioactive Element	Releasing	⟷	Condensing
Self heating ability	Smaller	⟷	Higher
General comparison by constituents with many exceptions in accordance outer conditions			
(Data source : JICA Team)			

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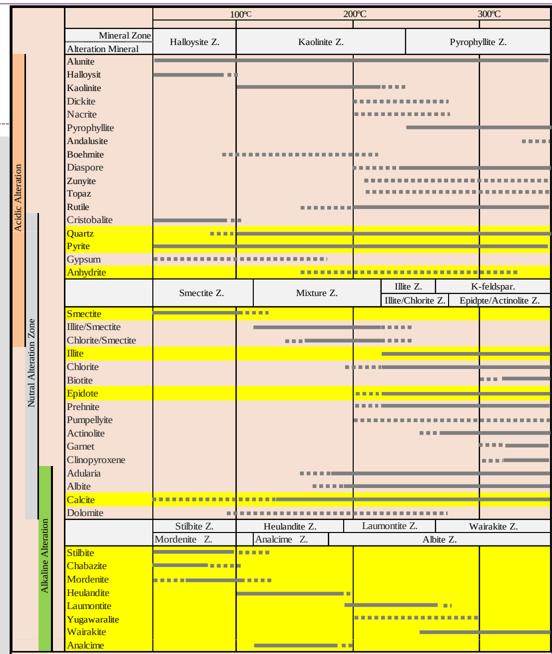
➔ Alteration Zonation

➔ Geological Cross Sections

Alteration Minerals

- Identification of Alteration Minerals is essential for Alteration Zonation,
- This will be useful in interpretation of geothermal structure, used as geothermometers.



After "Companion to Geothermal Power Generation" (2006), originalin Japanese

Pictorial Guide of Some Alteration Minerals

Acidic – Neutral Alteration Minerals

- Pyrite
- Quartz
- Anhydrite
- Smectite
- Illite

Neutral Alteration Minerals

- Epidote

Neutral-Alkaline Alteration Minerals

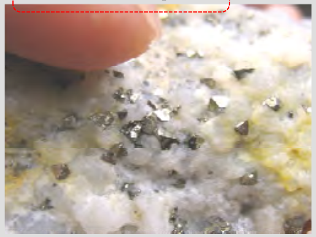
- Calcite

Alkaline Alteration Minerals

- Stilbite
- Chabazite
- Mordenite
- Heulandite
- Laumontite
- Wairakite

Alteration Minerals - Pyrite

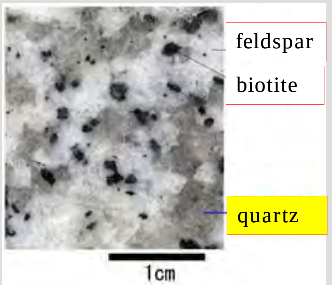
Acidic - Neutral



- Group: Sulfide mineral
- Formula: FeS2
- Crystal S.: isometric
- Cleavage: One-dir, indistinct
- Fracture: uneven, conchoidal
- Mohs scale: 6-6.5
- Luster: Metallic, glistening
- Color: pale Brass-yellow reflective
- Streak: greenish-black to brownish black
- Specific gravity: 4.8 - 5

Alteration Minerals - Quartz

Acidic - Neutral



- Group: silicate mineral
- Formula: SiO2
- Crystal S. : trigonal (low T.), hexagonal (high T.)
- Cleavage: none
- Fracture: conchoidal
- Mohs scale: 7
- Luster: vitreous
- Color: colorless
- Streak: white
- Specific gravity : 2.7

- Not scratch-able by knife (Mohs scale-some 5.5)

Alteration Minerals - Anhydrite

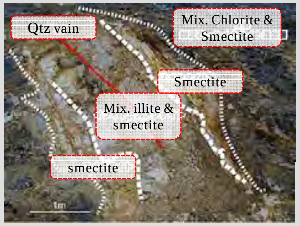
Acidic - Neutral

- Group: sulfate mineral
- Formula: CaSO4
- Crystal S. : Orthorhombic
- Cleavage: 3-dir, perfect
- Fracture: Conchoidal
- Mohs scale: 3.5
- Luster: vitreous, pearly
- Color: colorless, white, blue purple, red
- Streak: white
- Specific gravity : 3.0

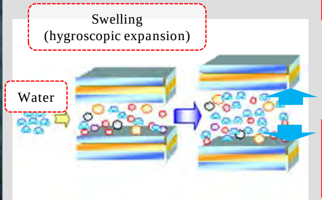
- Scratch-able by knife (Mohs scale-some 5.5)
- No reaction with HCL

Alteration Minerals – Smectite (montmorillonite)

Acidic - Neutral



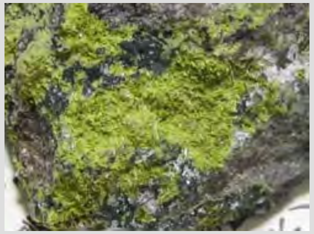
- Clay mineral,
- Powdered state,
- Hydro-thermal alteration or weathered mineral of quartz trachytic, rhyolite rock and/or tuff,



- swelling characteristic -> bentonite

Alteration Minerals - Epidote

Neutral

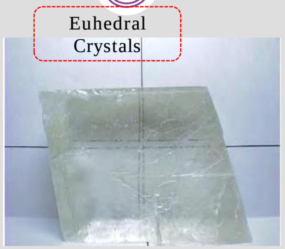


- Group: Silicate
- Formula: $Ca_2Fe^{3+}Al_2(Si_2O_7)(SiO_4)O(OH)$
- Crystal S. : monoclinic
- Cleavage: 1-d, perfect
- Fracture: -Flat regular to uneven
- Mohs scale: 6 - 7
- Luster: vitreous to resinous
- Color: yellowish green, dark green
- Streak: greenish white
- Specific gravity : 3.4

- Not scratch-able by knife (Mohs scale-some 5.5)

Alteration Minerals – Calcite

Neutral - Alkaline

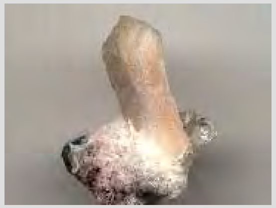


- Group: Carbonate mineral
- Formula: CaCo3
- Cristal S.: Trigonal
- Mohs scale:3
- Cleavage :$\{10\bar{1}1\}$3-d, perfect
- Luster: vitreous
- Color: Colorless, white, Pail yellow
- Streak: white
- Specific gravity : 2.7

- Scratch-able by knife (Mohs scale=some 5.5)
- Bubbled with HCL

Alteration Minerals – Stilbite

Alkaline



- Group: (Zeolite)
- Formula:
  Stilbite-Ca:
  $NaCa_4(Si_{27}Al_9)O_{72}\cdot 28(H_2O)$:
  Stilbite-Na:
  $Na_9(Si_{27}Al_9)O_{72}\cdot 28(H_2O)$
- Cristal S.: Monoclinic , triclinic and orthorhombic
- Mohs scale: 3.5 - 4
- Cleavage :Perfect on {010}
- Fracture: conchoidal or uneven
- Luster: Vitreous
- Color: Usually colorless, white or pink
- Streak: white
- Specific gravity : 2.12 – 2.22

- Notes:
  Decomposed in HCL

Alteration Minerals – Chabazite

Alkaline




- Group: (Tecto-silicate)
- Formula: $(Ca,K_2,Na_2)_2[Al_2Si_4O_{12}]_2 \cdot 12H_2O$
- Cristal S.: triclinic
- Mohs scale: 4 - 5
- Cleavage : distinct/good
- Fracture: irregular/uneven
- Luster: vitreous
- Color: Colorless, white, yellow, pink, red
- Streak: white
- Specific gravity : 2.05 – 2.2

Alteration Minerals – Mordenite

Alkaline



- Group: Zeolite
- Formula: $(Ca, Na_2, K_2)Al_2Si_{10}O_{24} \cdot 7H_2O$
- Cristal S.: Orthorhombic
- Mohs scale:5
- Cleavage : -
- Fracture: -
- Luster: -
- Color: colorless, white, faintly yellow or pink
- Streak: -
- Specific gravity : 2.1

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Alteration Minerals – Heulandite

Alkaline




- Group: Zeolite (tecto-silicate)
- Formula: $(Ca,Na)_{2-3}Al_3(Al,Si)_2Si_{13}O_{36} \cdot 12H_2O$
- Cristal S.: monoclinic
- Mohs scale: 3-4
- Cleavage : one-perfect
- Fracture: -
- Luster: vitreous
- Color: colorless, white orange, yellow, brick-red, green
- Streak: -
- Specific gravity : 2.2

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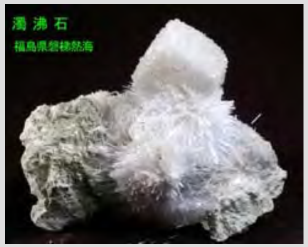
Alteration Minerals - Laumontite

Alkaline





- Group: Silicate
- Formula: $Ca_4[Al_8Si_{16}O_{48}]18H_2O$
- Crystal S. : monoclinic
- Cleavage: 3-dir. perfect
- Fracture: irregular
- Mohs scale: 3-3.5
- Luster: vitreous
- Color: colorless, white, yellow, red, brown etc
- Streak: colorless
- Specific gravity : 2.2-2.3

- In cavity and/or vain
- Powdered in air

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Alteration Minerals - Wairakite

Alkaline

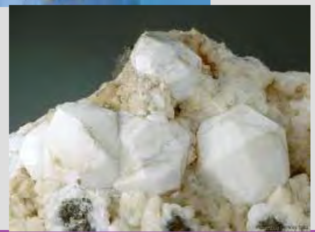



- Group: alumino-silicate
- Formula: $Ca[Al_2Si_4O_{12}]\cdot 2H_2O$
- Crystal S. : monoclinic, trigonal
- Cleavage: -
- Fracture: -
- Mohs scale: 5.5-6
- Luster: vitreous
- Color: colorless - white
- Streak: -
- Specific gravity : 2.26

- Hardly scratch-able by knife (Mohs scale: some 5.5)

Alteration Minerals – Analcime

Alkaline

- Group: Zeolite
- Formula: $NaAlSi_2O_6\cdot H_2O$
- Cristal S.: Cubic; tetragonal, orthorhombic, or monoclinic, pseudo-cubic, with degree of ordering.
- Mohs scale: 5 5.5
- Cleavage : Very poor [100]
- Fracture: Uneven to sub-conchoidal
- Luster: Vitreous
- Color: White, colorless, gray, pink, greenish, yellowish
- Streak: white
- Specific gravity : 2.24 – 2.29

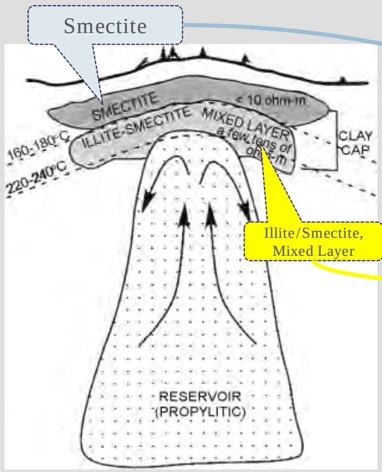
- Notes: Weakly piezoelectric; weakly electrostatic when rubbed or heated

Subjects for Today

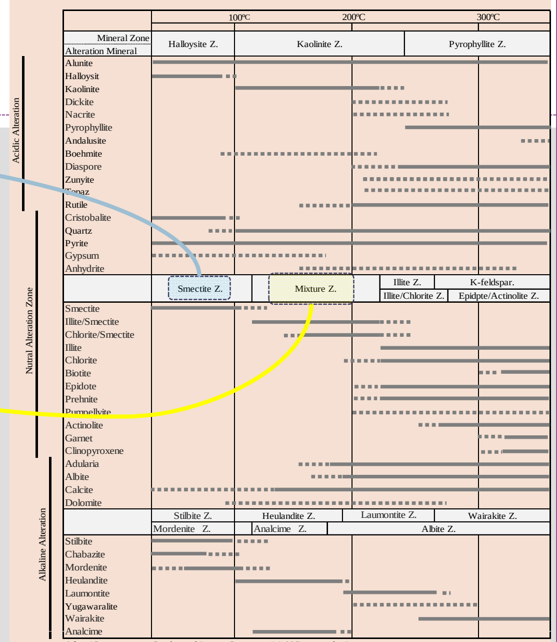
1. Outline of Surface Geological Study
2. Geological Study with Drilling Data
   1. Sampling of Drill Cuttings/Rock Cores
   2. Observation of Drill Cuttings/Rock Cores
      - Megascopic, Microscopic
   3. X-Ray Diffraction Analysis
   4. Fluid Inclusion Analysis
3. Rock Classification (TAS)
4. Alteration Minerals

- ➔ Alteration Zonation
- ➔ Geological Cross Sections

Example of Alteration Zonation (1)

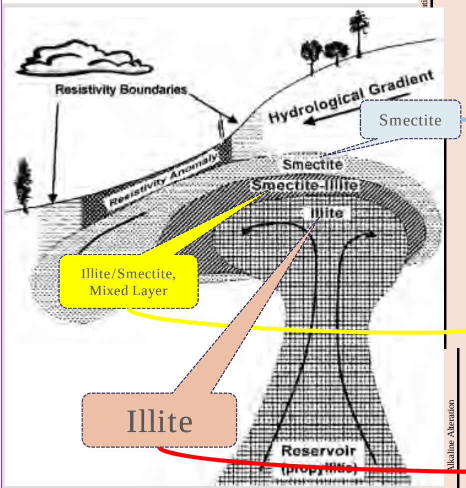


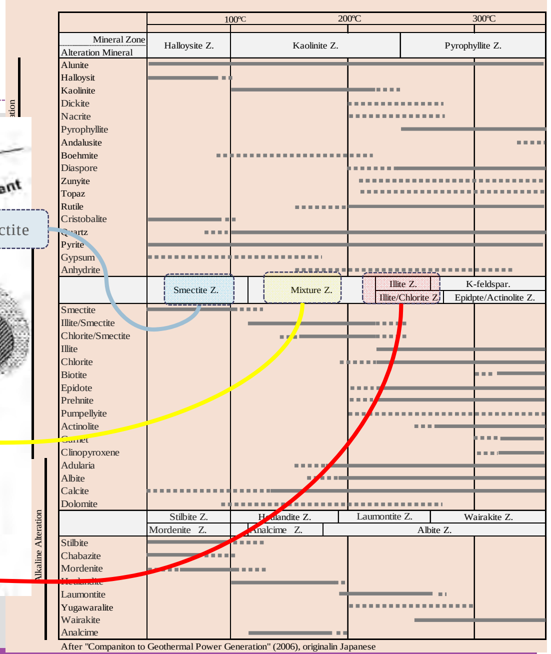
Base Figure: "Conceptual resistivity model of a convective geothermal system (after Oskooi et al., 2005)"



After "Companiton to Geothermal Power Generation" (2006), originalin Japanese

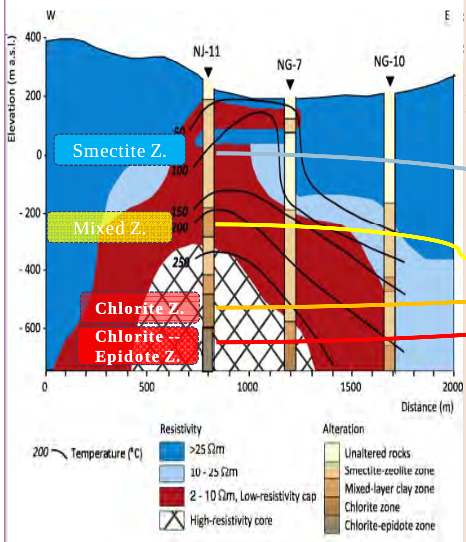
Example of Alteration Zonation (2)

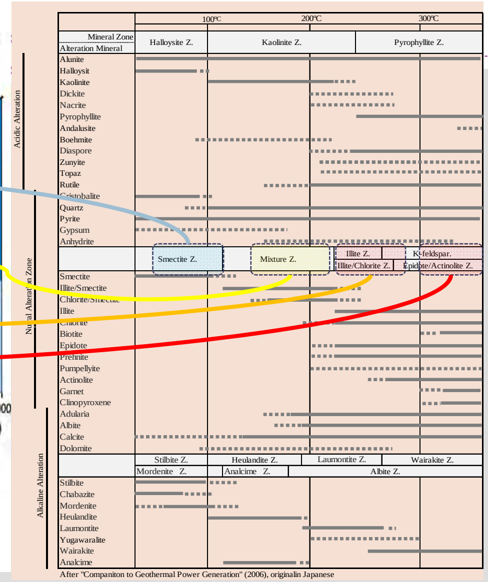




Base Figure: "Generalized geothermal system in a steep terrain (after Anderson et al., 2000)".

Example of Alteration Zonation (3)





Base Figure: Amason and Flovenz (1992); modified by Liney H. Kristinsdottir et al., (2010)

DATA COLLECTION SURVEY ON GEOTHERMAL DEVELOPMENT IN RWANDA

Thank you

ありがとうございます

July, 2013

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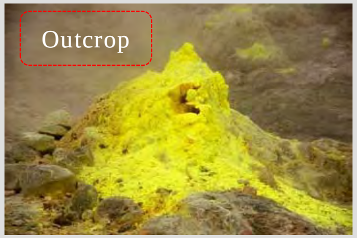
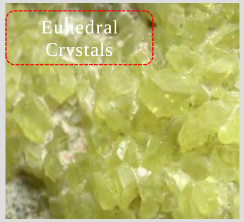
Alteration Minerals - Sulfur





- Group:
- Formula: S
- Crystal S. : various
- Cleavage: -
- Fracture: -
- Mohs scale: 2
- Luster:-
- Color: yellow
- Streak: -
- Specific gravity :
- Good indicator of volcanic activities

DATA COLLECTION SURVEY
ON
GEOTHERMAL DEVELOPMENT
IN RWANDA

INTRODUCTION
of
Well Testing

July, 2013
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)
NIPPON KOEI CO., LTD

Contents

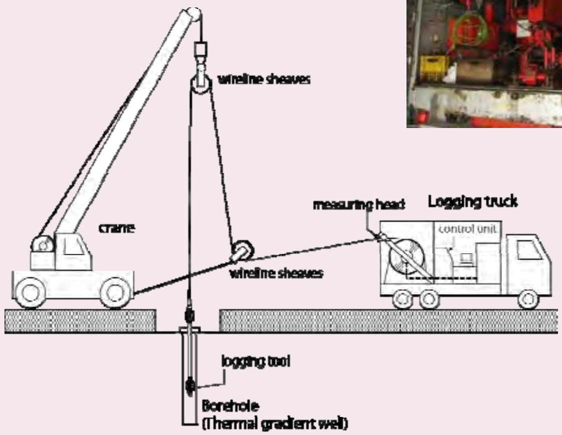
Geophysical Logging

- Physical logging is a physical technique that measures geology and geophysical property in the borehole continuously with an instrument pulling down in the wellbore.
- Core analysis is also the method to investigate the physical properties in the borehole, however, physical properties of core sample may vary according to temperature and pressure condition change after taken from the ground.
- Physical logging has an advantage of being able to obtain in situ properties in the wellbore.

Example of Geophysical Loggings

Methodology	Purpose
Resistivity	Measure the resistivity of the formation.
Spontaneous potential	Measure the electric field underground caused by formation and fluid
Sonic(velocity)	Measure the P wave velocity of the formation
Density	Determine the density of the formation by detecting artificial gamma-ray
Gamma-ray	Examine the distribution of lithofacies and alteration by detecting natural gamma intensity
Caliper	Determine the diameter of borehole
Neutron	Determine the porosity of the formation by measuring the attenuation of a fast neutron

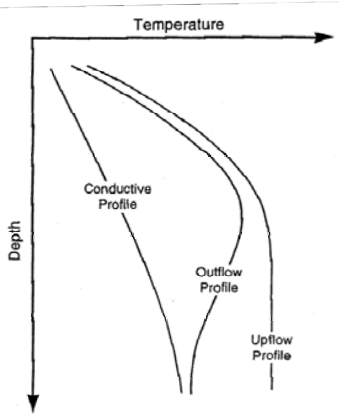
Logging Equipment

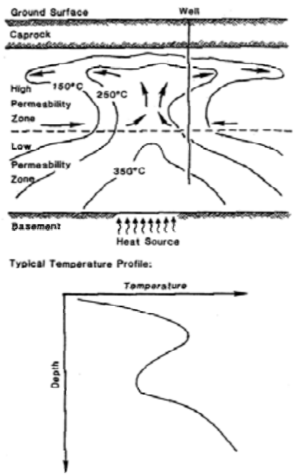


Temperature Logging

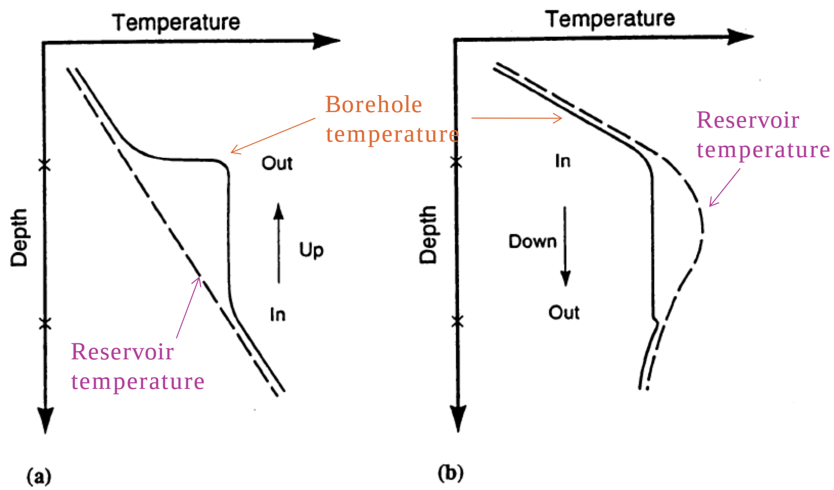
- Temperature information is one of the most important data to obtain at the preliminary survey stage of geothermal development

Temperature profiles in a geothermal reservoir

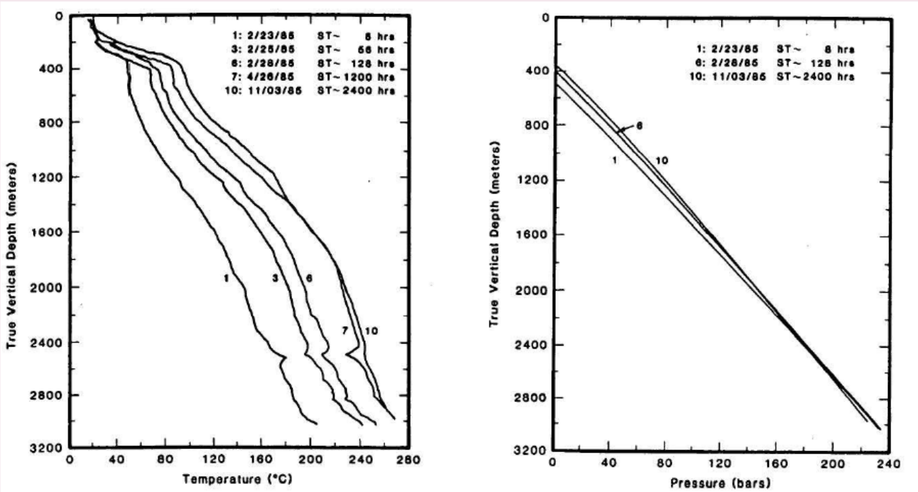




Temperature profile and fluid flow in the wellbore



Temperature logging during warm up



DATA COLLECTION SURVEY ON GEOTHERMAL DEVELOPMENT IN RWANDA

Thank you

ありがとうございます

July, 2013

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添付－6
ICIEDA-ISORの研修プログラム

UNITED NATIONS UNIVERSITY

GEOTHERMAL TRAINING PROGRAMME

June 25, 2013 / LSG-IGH-BSH-DTh-STh

SHORT COURSE ON DEEP GEOTHERMAL EXPLORATION

Organized by UNU-GTP on an ICEIDA-Contract for EWSA, Kigali, Rwanda, June 25-29, 2013

Basic setup: First day: *General introduction of geothermal energy and surface exploration* (for a wider audience), followed by 4 lecture days on *deep geoscientific geothermal exploration and drilling.*

TUESDAY JUNE 25

08:30-09:00 **Registration**
09:00-09:15 **Welcome ceremony – aim of the short course, organization and practical matters**

Geothermal energy overview and project planning: Chairman Uwera Rutagarama, EWSA

09:15-10:00 **Geothermal energy in the world – status and future possibilities**
Ingimar G. Haraldsson, UNU-GTP
10:00-11:00 **Geothermal systems in global perspective**
Dadi Thorbjörnsson, ÍSOR
11:00-11:15 Coffee break
11:15-12:30 **Geothermal exploration and development – from a hot spring to utilization, phases of geothermal development - geothermal project planning**
Björn S. Hardarson
12:30-13:30 Lunch

Geoscientific surface exploration: Chairman Sverrir Thórhallsson, ÍSOR

13:30-14:00 **Geological exploration of geothermal systems**
Björn S. Hardarson
14:00-15:00 **Geophysical exploration of geothermal systems**
Björn S. Hardarson
15:00-15:30 **Chemical exploration of geothermal systems**
Dadi Thorbjörnsson, ÍSOR
15:30-16:00 **Environmental Impact Assessment and pre-development studies**
Dadi Thorbjörnsson
16:00-16:30 **Coffee and discussion**

WEDNESDAY JUNE 26

Drilling and borehole geological studies: Chairman Ingimar G. Haraldsson

09:00-09:30 **Siting of geothermal wells**
Björn S. Hardarson
09:30-11:00 **Geothermal wells and drilling technology I**
Sverrir Thórhallsson
11:00-11:15 Coffee break
11:15-12:30 **Geothermal wells and drilling technology I – cont.**
Sverrir Thórhallsson
12:30-13:30 Lunch

Session continued: Chairman Dadi Thorbjörnsson

13:30-16:00 **Geothermal borehole geology**
Björn S. Hardarson
16:00-16:30 **Coffee and discussion**

THURSDAY JUNE 27

Drilling and logging: Chairman Dadi Thorbjörnsson

09:00-11:00 **Geothermal wells and drilling technology II**
Sverrir Thórhallsson
11:00-11:15 Coffee break
11:15-12:30 **Geothermal wells and drilling technology II – cont.**
Sverrir Thórhallsson
12:30-13:30 Lunch

Session continued: Chairman Sverrir Thorhallsson

13:30-16:00 **Environmental monitoring**
Dadi Thorbjörnsson
16:00-16:30 **Coffee and discussion**

FRIDAY JUNE 28

Flow testing and chemical and environmental monitoring: Chairman Björn S. Hardarson

09:00-10:00 **Flow testing of geothermal wells**
Sverrir Thórhallsson
10:00-11:00 **Chemical sampling and monitoring of geothermal wells**
Dadi Thorbjörnsson
11:00-11:15 Coffee break
11:15-12:30 **Chemical sampling and monitoring of geothermal wells – cont.**
Dadi Thorbjörnsson
12:30-13:30 Lunch

Session continued: Chairman Ingimar G. Haraldsson

13:30-16:00 **Use of geophysical logging in drilling operations and reservoir assessment**
Sverrir Thórhallsson and Björn S. Hardarson
16:00-16:30 **Coffee and discussion**

SATURDAY JUNE 29

Geothermal reporting and case examples: Chairman – Ingimar G. Haraldsson

13:00-13:45 **Geothermal reporting and data handling**
Björn S. Hardarson and Dadi Thorbjörnsson
13:45-14:30 **RIMDrill program**
Sverrir Thórhallsson
14:30-14:45 Coffee break
14:45-16:00 **Case ex.: Exploration and development of the Reykjanes high-temperature geothermal system in SW-Iceland**
Dadi Thorbjörnsson

Conclusions and closing remarks – Chairman: Ingimar G. Haraldsson

16:00-16:30 **Discussion and conclusions**
16:30-17:00 **Closing of the Short Course**
17:00-18:00 Cocktail

添付－7

井戸掘削用水給水施設に関する提出レター

NIPPON KOEI
Challenging mind, Changing dynamics

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102-8539, JAPAN
phone 03-5276- 7239; fax 03-5276-3326
e-mail : a2604@n-koei.co.jp
http://www.n-koei.co.jp

JICA TECHNICAL ASSISTANCE

DATA COLLECTION SURVEY ON GEOTHERMAL DEVELOPMENT IN RWANDA

Date: 9 July, 2013

To: Energy, Water and Sanitation Authority, Ministry of Infrastructure, Rwanda

Your ref. *Our ref.* ***JA12G1014-0709-01***

Sub. Observations on Water Supply Pipe Line

Dear Person in Charge,

Thank you for your arrangement for us to visit the site on 5th July 2013. We visited the in-take site, booster pump station and drilling site. We also observed the pipe placing works.

We noted that the preparation for drilling itself has almost completed and the site representative of the drilling company told they could start drilling shortly.

On the other hand, works for the water supply system was going on at the intake site, and we were informed some more works were still necessary.

As a result of our brief site observation, we note that additional considerations and action may have to be needed for the water supply pipe line. We summarized our preliminary observation and attached hereto for your immediate pursuance.

We are very much pleased to have discussion on this matter as required.

Sincerely yours,

TAKAHASHI Shinya
Team Leader,
Data Collection Survey on Geothermal Development in Rwanda

Form R-007-F1 Issue 0
(1 Sept 2009)

Preliminary Observations on Water Supply System For Drilling

5th July 2013, JICA Team

We obtained various information and our preliminary observations are as follows (the observations might have to be revised should the information obtained not be correct):

1. Basic information we obtained on drilling site.

a. Key information of the key locations

Locations \ Items	Approx. Elevations (m.a.s.l.)	Height difference between the two locations (m)	Distance – pipe line (km)	Pipe diameter (inches)
Tanks at drilling site Kabatwa	2718.8	219.3	9.2	8
Booster site Sashwara	2499.5			
In-take site Lake Karago	2287.8	211.7	9.0	8

b. Pumping plan and pump capacity

- Pumping plan: 150 m^3/hour
- Pump capacity:-

Location \ Item	Flow (m^3/h)	Head (m)	No. of Pumps
Booster site Sashwara	150	268	2 (one for stand-by)
Intake site Lake Karago	155	536	2 (one for stand-by)

It is noted that the pumping head of the pump at the booster station is as half as the one at the In-take site, according to the information given onsite.

c. Water tanks at sites

- 3 x 4,000 m^3/tank. Total of 12,000 m^3.
- Two are completed (except for the piping to and from them), one is under construction.

2. Our preliminary observations

a. Pump capacity

We conducted a preliminary calculation of the water head-loss with Hazen-Williams equation assuming straight pipeline. The results are:

Pipe length (L)		Head loss
(km)	(m)	(m)
7	7,000	52
8	8,000	60
9	9,000	67
9.2	9,200	69
9.5	9,500	71
10	10,000	75
11	11,000	82

As the result, the head loss of a 9.0 – 9.5 km long pipe with a flow of 150-m³/hour is in a range of 70 m.

Therefore the required capacities of pumps are:

	Flow (m³/hour)	Required Pump head (m)	Rated Head of the installed Pump (m)	Note
Booster Pump (Sashwara)	150	288 (219 + 69) or more	268	Capacity of the installed pump is not sufficient to pump at 150 m³/hr.
Intake Pump (Lake Karago)	150	279 (212 + 67) or more	536	Enough capacity

From the above preliminary observation, the pump capacity of the booster station may not be enough to pump up 150 m³/hour of water to the tanks at the drilling site. The actual flow rate may be 120 m³/hour or less.

This is a preliminary calculation and the head loss may be greater than this because there are curves and bends along the pipe line, that will induce additional head loss. The capacity of a booster pump will have to be similar to the one of the pump at the intake, or an joint operation of the two pumps already installed may have to be required.

b. Pipe installation works

There are no pipe-supports used as shown in the attached Figures. There are no air valves seen at apexes or convexes of the pipe line. All those are recommended for a water supply system. The pipe line without proper supports may vibrate, which might cause failure. The pipe line without air-valves will not send water as planed because cross sectional areas will be reduced by compressed air. In addition, mud drain valves may be necessary at concave locations because the water in Lake Karago is muddy.

It is important that this is addressed immeadieatly as it will take at least a week or two to complete the necessary changes.

	
Pipe in the air, support needed	Pipe in the air, supports recommended.
	
Right angle bend; preferably to be exchanged with a long elbow; pipe support recommended.	A bent pipe support recommended.
	
Sharp angle bend; recommended to be exchanged with a long elbow.	Pipe line in the air at Lake Karago; proper pipe support recommended. Approx 30 MPa internal pressure or more.

添付－8

最終掘削プログラム（EWSA作成版）

Energy Water and Sanitation Authority

Avenue du lac Ihema, PO Box 537 Kigali, Rwanda. Tel: + (250) (0)252573666, Fax + (250) (0)252573802

Email: ewsa@ewsa.rw, info@ewsa.rw, ewsa@rwanda1.rw , Website: www.ewsa.rw

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1. Well Information

Area: Kabatwa Sector, Nyabihu District, Northern Province, Rwanda
Field: Karisimbi Geothermal Prospect
Well No.: KW01
Location: UTM E 768622 N 9827891 Elevation: 2675
Target Depth: 3000m (9,800')
Target: Vertical well at Intersection of NE & NW Structures

Hole size	casing	shoe	Comment
26 ''	20'' 94 lb/ft, Grade K55	60m	Cement to surface
17 ½ ''	13 3/8 '' 68 lb/ft, Grade K55, btts	305m	Cement to surface
12 ¼ ''	9 5/8''47 lb/ft , Grade K55, btts	900-1200m	Cement to surface
8 ½ ''	7'' perforated liner	850-1150m to bottom 3000m	Open hole

2. Objectives

- Determine drilling conditions and risks
- Determine the geothermal resource potential.

- Determine chemical characteristics of the reservoir fluids.
- Determine temperature and pressure distribution
- Determine reservoir feed zones
- Determine structural and geological setting to be used for determining the drilling program for the next wells.
- Determine well lithology and mineral alteration
- Determine casing depths
- Determine fluid flow characteristics by discharging the wells
- Drill the wells in safe productive way in the shortest time (Summary in table 1 and Figure 1 below)

Table 1: Drilling depths versus estimated number of days

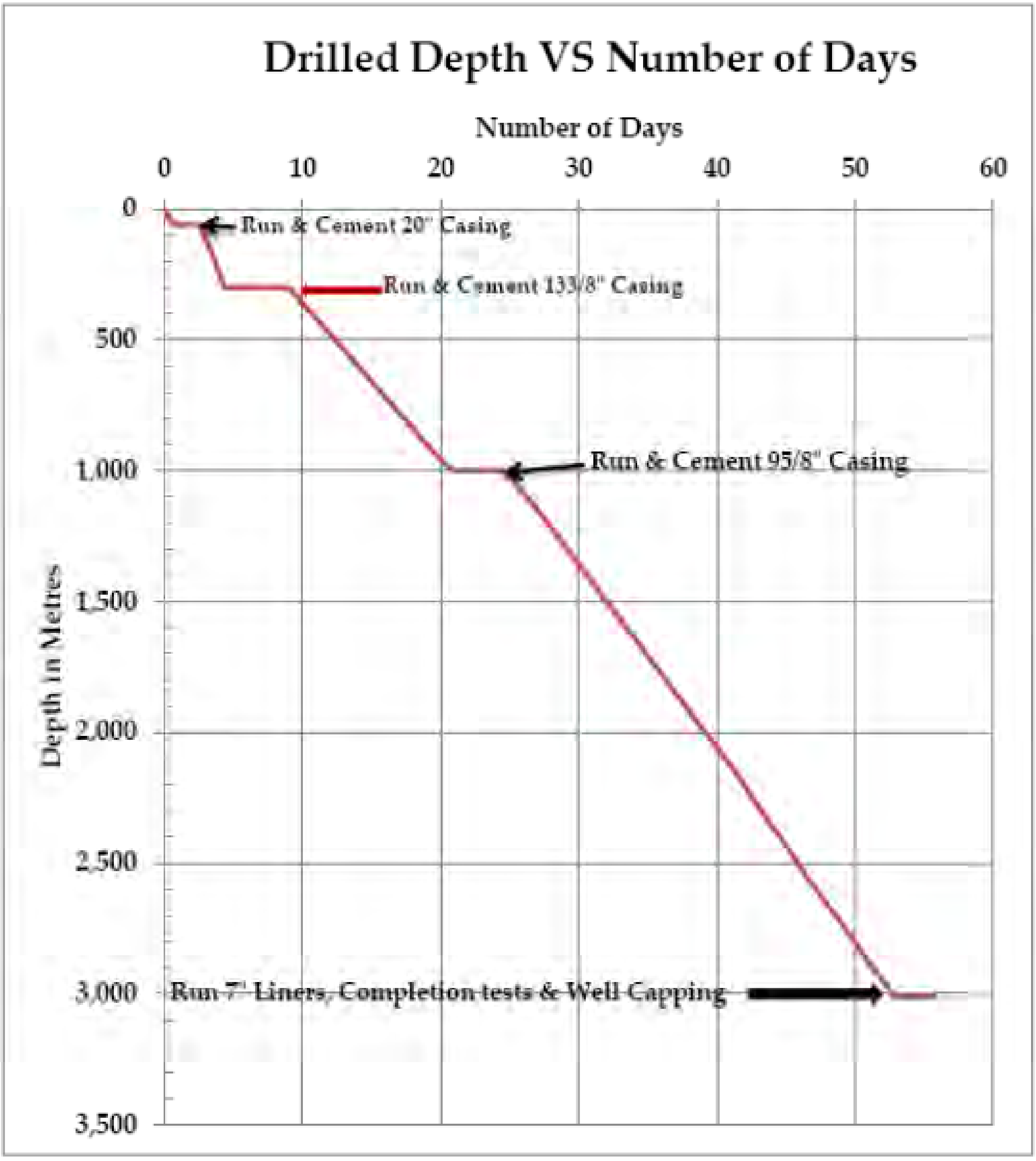

Figure 1: Estimated drilled depths against the number of days

3. Geological setting & rock formations

3.1 Rock formations

0-15 m volcanic rocks

Hard volcanic rocks possibly with some lava caves and loose volcanic bombs erupted from varies episodes of volcanic activity

15-60 m: Volcanic rocks

Expected are hard volcanic layers from different volcanic activity with varying hardness and fracture density. Thin layers of volcanic ash are also expected and may lead cave-ins. Some major lose of circulation is expected. *Drilling with water is recommended if such losses are encountered at shallow depths but this will be determined by both the drilling engineer and Great Wall Drilling Company(GWDC).*

60-90 m Ash and Fractured lava rocks

Soft ash layers mixed with volcanic bombs with intercalation of fractured and fresh lava rocks. Medium hard to hard lava may layer occur with tuff intercalations. The setting of the 60m casing therefore has to be evaluated carefully.

90-400 m Tertiary Lava Rocks

This zone consists of mainly hard unaltered lavas probably with a few intercalations of pyroclastics and ash deposits. Contacts of different lava rocks may be filled with groundwater. This is the zone for the 13-3/8′ casing

400-700 m Altered and fractured lava rocks

Possibly medium to soft altered and fractured lava rocks with intercalations of ash and pyroclastics. We expect a possible of loss of circulation at the contacts of different lava rocks and in the fracture zones.

700-1200 m Lava rocks possibly Trachytes

The trachytes or tertiary volcanics possibly fractured (medium to hard formation). Probably higher degree of geothermal alterations and this could be considered for production casing. Major to Minor losses are expected in fracture zones and at the contacts of the lavas.

1200-2200 m Metamorphosed rocks (and Metasidements)

This zone could be a sequence some lava rocks and metamorphosed rocks composed of Phyllites, Black Shale, Quartzite, Schist and Gneiss. These rocks are expected to have alternating hard and soft formations with good permeability at the contacts of the rocks and fracture zones. Major loss of circulation is expected at contacts of dipping rock units. The formation is medium hard to hard and therefore not much problems are expected except minor losses or partial losses especially when adding the drill pipe and also during bit change. Fractured and altered Schist could be a problem because they are very soft.

2200->3000 m Intrusive rocks

This zone is composed of fractured and possibly altered granite, pegmatite and dolorite. The rock could be highly fractured and therefore losses are expected in this zone. This zone extends to over 3000 m. The formation here is expected to be medium hard to hard. Major losses are expected at fracture or fault zones.

3.2 Sampling

The rock cutting samples should be collected at 2 m interval. Half a litre sample of both inflowing and out flowing drilling fluids shall be collected after every 50 m

interval. Geosweeps should be carried out with the request of the Rig Geologist if mixing of the cuttings is suspected.
NB: Air drilling should be commenced as early as possible to ensure better sample collection and also to avoid clogging the production zones 8 ½" open hole.

3.3 Coring

Cores are required for this well to establish the stratigraphy of the area to be used to determine the drilling program for the next 2 wells. The cores are to be cut at 400m, 700 m, 900m, 1200 m, 1500m, 1800 m, 2400 m and TD, preferably when changing the bits. However, the Rig Geologist might request for additional cores if there is need for more cores based on the quality of the cuttings and changes in formation.

3.4 Casing

The casing depths for the well are outlined below. The formation at the proposed depths is expected to be competent enough for the casing to be set. Hydrothermal alteration mineralogy patterns and clay analyses coupled with SFTT should be monitored as from 400 m. *The Rig Geologist together with the exploration management team (including reservoir engineering after SFTs) to advice on the appropriate production casing depth.*
Surface Casing: **60 m**
Anchor Casing: **305 m**

Production Casing: **900-1200 m**

4.0 Anticipated Drilling Problems

4.1 Surface Hole: 26" (0-60m)

The top part is hard formation with expected lava tubes and caves and therefore cave-in and washout is expected. Major losses are anticipated. Drilling with water/mud is recommended if such losses are encountered. This part is also expected to have boulders and volcanic bombs that cause cave-ins and unstable well conditions.

4.2 Intermediate Hole: 17 ½" (60 – 305m)

The zone could be softer, washouts and cave inns are expected. Major losses of circulations are expected to occur. Therefore drilling with water and high viscosity gel sweeps at every drill pipe connection is recommended. Air drilling is recommended if hole-cleaning problems are encountered.

4.3 Production Hole: 12 ¼" (305-1200m)

This zone contains rocks that are medium to hard. Production casing shall be set at 900- 1200m RKB. Fractured rocks are anticipated and huge losses could occur. Some clay alteration is also expected.

4.4 Main Hole: 8½'' (900-3000m)

The zone between 700-900m could be soft and altered and the clays may swell and care should be taken to avoid clogging the bit. Between 900m and 1200m the zone consists of competent rocks. Between 1200m and 1800m the rock formation is soft to hard and occasionally fractured and some places may experience major losses. Between 1800m and 3000m the formation is medium soft to hard and fractured. Some major losses could occur if fracture zones are encountered. The conditions at the bottom hole may change to soft and temperature increase is anticipated. The drilling results would be monitored and if required deeper drilling may be recommended to maximize on the permeability and therefore increase production. The geologists and the drilling team will advice on the stoppage depth.

5.0 Drilling program

5.1 Move drilling rig and associated equipment to the well site. Completely rig up all accouterments including Top Drive (if available) unit prior to spud.

5.1.1 Conduct pre-spud meeting covering well control, H2S, emergency medical evacuation, safety procedures and well program.

5.1.2 Be sure location is secured with proper burms and ditches prior to spud.

5.1.3 Move in and rig up air compressors with all air lines to rig.

5.1.4 Level mast and center the travelling block with accuracy to avoid drilling of the hole off center

5.1.5 Check the Crown Block Saver before every trip and after every slip-and-cut operation.

5.1.6 Fix the Derrick Escape line to the monkey board and anchored to the ground at no more than 300 from the horizontal before spudding –in

5.1.7 Install direct communications between, tool pusher and drilling supervisor.

5.1.8 Adhere to Drilling Reporting Criteria and safety requirements.

5.1.9 Conduct EWSA/GWDC safety inspection.

5.1.10 Mix mud. Minimum total water delivery rate should be about 20 bbls/min for possible well control. (Mud program)

5.1.11 Drilling Ton-Miles must be calculated and recorded on the log sheets daily.

5.1.12 Rig manager, tool pushers, and drillers must read the drilling program before all major operations. The Rig manager should discuss the program contents and operational procedures with the Drilling Engineer or Drilling Supervisor (EWSA) on duty. The two should proceed to ensure that all necessary preparations for the operation have been made.

NOTE1: If 20″ casing is pre-set, go to step 5.5. Count all drill pipes on location and record before spudding.

5.2 Make up 26″ bit to near bit stabilizer.

5.2.1 Drill 26″ hole to 60m +/-.

NOTE 2

Spud the well with mud and low pump speed to avoid massive washouts. Drill 26′′ hole to about 60m RKB. Use 8′′ drill collars and a 26′′ near bit stabilizer. The over-hole below the expected 20′′ casing shoe depth should be about 2m unless hole cleaning problems are encountered in which case the over-hole should be limited to less than 4m. Run mud with marsh funnel viscosity of 60-80 sec marsh funnel viscosity. If circulations losses are encountered and cannot be regained with LCM materials, drill blind with water and high viscosity gel sweeps at every connection or more frequently depending on the hole conditions.

5.2.2 Wipe hole.

5.2.3 Circulate hole clean.

5.3 Rig up and run 20″ casing and cement in place.

5.3.1 Run 20″ casing equipped centralized 10′ above shoe and first two collars.

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5.3.3 Connect cement head to casing.

5.3.4 Circulate hole clean via casing.

5.3.5 Cement casing in place as per cement program.

a. Condition the hole and spot a high viscosity gel pill on bottom before tripping out

b. Run 20″ OD, 94 Ib/ft casing with an guide shoe.

c. Screw joints together and torque every joint to set mark.

d. Lower casing slowly.

e. Pump water through casing to condition the mud prior to cementing

NOTE 3

In preparation for cementing, the Rig manager, tool pusher and cementing equipment operator will discuss the cementing program with the Drilling Engineer (RG/EWSA) on duty at least three hours before the cement job. The cementing equipment operator will be required to fill in the cement checklist indicating the blended cement available, slurry density, pumped volumes etc. The Cementing Engineer will ensure sample cans are available before cementing commences.

5.4 WOC and rig up flow line.

5.5 Drill 17 ½" hole to 305m plus or minus using mud as a circulating medium. Treat losses with LCM or if severe, use cement plugs. If problem persists notify RG/EWSA office for alternate plan.

Run in hole with a slick BHA consisting of 17 ½'' bit, bit sub and 8'' drill collars to drill out cement. Drill out cement with water at low WOB and rotary speed in order to maintain low rotary torque. Drill ahead to 30m below the casing shoe and then trip out of the hole. Run in hole with a pendulum BHA consisting of the 17 ½'' bit, bit sub, 8" drill collars and 17 ½" blade stabilizer 20m above the bit to drill ahead.

Drill to a 13⅜" casing depth of about 305m with a bentonite mud allowing 1.5-2m over-hole below the expected casing shoe depth. Run desilter continuously to maintain low mud weight.

If loss of circulation returns occurs attempt to regain it and if the loss cannot be healed, continue drilling blind with water and slug the hole frequently with high viscosity mud pills. Drill with high pumping rates on the hole to clean the hole. In the event that hole cleaning is a major problem, change the drilling fluid to stiff foam.

Ream the hole with the same BHA as used during the drilling operation, prior to running the 13⅜'' casing. The precise casing point will be picked by the Geologist, the rig manager, the drilling engineer on the basis of lithology, lost circulation zones, presence of competent rock

5.5.1 Make up 17 ½" bit on locked DA.

5.5.2 Make up extra stands of pipe and tools standing back in derrick.

5.5.3 Drill 17 ½" hole to 305m +/- as determined by geologist and company man.

5.5.4 Catch 10' grab samples from drill cuttings and monitor for hydrothermal alteration whenever circulation permits.

5.5.5 Check returns for increased salinity and chlorides.

5.5.6 Run MRT's with surveys. ????????????

5.5.7 Log temperatures in and out on tour sheets hourly.

5.5.8 Run drilling jars in all assemblies.

5.5.9 Notify RG/EWSA office if flow-line temperatures exceeds or reaches 65C, or if temperature rise exceeds 10C.

5.5.10 Keep hole straight.

5.6 Continue drilling 17 ½"hole to 305m +/-. Casing will be set in low permeability rock below possible lost circulation zone.

5.6.1 Set and polish off cement plug on bottom if formation is not competent.

5.6.2 Monitor well for flow or gasses.

5.6.3 Use sweeps to clean well bore. Keep close watch on estimated chip velocity in 20″ casing.

5.6.4 Use mud cooler as needed and log when started.

5.7 Circulate hole clean and wipe hole with stiff drilling assembly

5.7.1 Circulate hole clean after wiper trip.

5.7.2 Keep hole full (if possible) and check for excess flow.

5.7.3 Measure out of hole.

5.7.4 Be sure all casing running equipment is ready for use.

5.8 Rig up and run 305m +/- of 13-3/8″, 68 ppf, K-55 Buttress casing equipped with float shoe, float collar placed on top of second joint. Stabilize shoe joint with centralizer placed 3m (10′) above shoe joint, on 1st, 2nd, 3rd collar and every third joint thereafter

5.8.1 Be sure casing is centered prior to cementing.

5.8.2 Run casing at slow speeds to prevent down surge.

5.8.3 Fill casing as required to overcome buoyancy.

5.8.4 Have casing sized to remain off bottom.

5.9 Circulate well clean reducing gel strengths.

5.10 Cement 13-3/8″ casing as cementing program

5.10.1 Monitor cement for fall back.

5.10.2 If cement does fall, locate top of cement, notify RG/EWSA and prepare for high density top job as directed by RG/EWSA

5.10.3 WOC by lab reports and surface samples.

5.11 Screw on 13-5/8" x 13-3/8" 2m SOW well head.

5.12 Install 13-5/8" 2m x 13-5/8" 5m spool with 3" outlets. Install 13-5/8" double gate, 13-5/8" 5m annular and rotating head. Install choke and kill lines.

5.13 Test casing, blind rams, and choke line to 300 psi for low pressure and 1000 psi for high pressure.

5.13.1. RIH and test pipe rams and hydril to 500 psi.
5.13.2. Log results on tour sheet.

5.14 Clean out cement and shoe.

5.15 Drill 12 ¼" hole to 1200m +/- using mud as a circulating medium or aerated fluid as best determined by hole conditions.

5.15.1 Keep hole straight.

5.15.2 Treat loss circulation with LCM. If severe use aerated fluid.

5.15.3 Survey at 90m intervals or as directed.

5.15.4 Catch 10′ grab samples, clean, dry, bag in envelops, and label two complete sets of samples.

5.15.5 Check mud for increased salinity or chlorides.

5.15.6 Monitor well for increase or decrease of flow.

5.15.7 Record depths of loss circulation zones, amount and type of fluid lost in each zone.

5.15.8 Sweep the wellbore every 27m.

5.15.9 Be sure circulation is established and stable prior to setting bit on bottom.

5.15.10Place flapper float in drill pipe on first joint from kelly when starting aerated drilling.

5.15.11Pick up high to shut off pumps on connections

5.15.12Monitor and log any flow or fill on connections and trips.

5.16 After reaching 1000-1200m +/- circulate hole clean (depending on the casing depth).

5.16.1 Make wiper trip to shoe keeping hole full. Check and log any fill on bottom.

5.16.2 Circulate hole clean.

5.16.3 Measure out of hole.

5.16.4 Monitor well closely for flow or gasses.

NOTE: If this section was drilled with aerated fluid due to severe loss circulation, follow steps No. 5.17-5.21, if not skip to step #5.22 and continue.

5.17 POH
5.18 Perform foam cement plug as per attached procedures and cement slurry.

5.19 WOC.

5.20 Release pressure annulus.

5.21 Make up 12 ¼" bit with 3 drill collars and heavy weight drill pipe.

5.21.1 RIH and tag top of cement.

5.21.2 Clean out cement to bottom at 1200m plus or minus.

5.21.3 Monitor well closely for any fluid losses. If loss circulation occurs, re-squeeze as per previous procedure.

5.21.4 If well bore is secure and circulating POH and rig up to run 9-5/8" casing.

5.22 POH, rig up and run 9-5/8" 47 ppf, K-55 buttress thread casing equipped with 9-5/8" float shoe, 9-5/8" float collar placed 80' up from shoe. Centralize casing 3m above shoe, on 1st collar and 3 joints thereafter.

5.22.1 Cement casing as per attached cement program.

5.22.2 WOC.

5.23 Remove BOPE, cut off casing and install 11-3m x 9-5/8" SOW well head with 2 3-1/8" outlets using "Hot-Hed system for stress release when welding on well head and test to 80% of collapse casing pressure.

5.23.1 Install 10-900 Expanding Gate Valve.

5.23.2 Install 10-900 x 10-5m XO spool.

5.23.3 Install 10" 5m double gate.

5.23.4 Install 10" 5m Banjo Box with 12" 5m outlet.

5.23.5 Install 12" flow line to separator with 12" 5m valve to separator.

5.23.6 Install 10" 5m double gate.

5.23.7 Install 10" 5m annular.

5.23.8 Install rotating head.

5.24 Test casing and blind rams to 500 psi for low pressure and 1500 psi for high Pressure test. Hold for 15-20 minutes and log on tour sheet.

5.25 Make up 8 ½″ drilling assembly and RIH to top of cement and clean cement to top of float collar.

5.26 Circulate hole clean and test pipe rams and choke manifold.

5.27 Drill out cement, float collar and shoe.

5.28 Drill 2-3m of new hole and perform leak off test. Squeeze shoe if leak off test is less than 0.6 gradient.

5.29 Drill 8 1/2" hole to 3000m +/- using a circulating medium of a balanced aerated fluid or slightly under-balanced through bit as best determined by hole conditions.

5.29.1 Survey hole as required at 150m intervals and using MRT's.

5.29.2 Catch, clean, dry samples and bag in envelopes. Label two complete sets of samples at 3m intervals to total depth.

5.29.3 Monitor well closely for excess flow and avoid bringing in well if resource or gasses are encountered.

5.29.4 Sweep the well bore with polymer or soap sweeps every 18m or as hole conditions dictate.

5.29.5 Be sure circulation is established and stable prior to setting bit on bottom after connections and drilling ahead.

5.29.6 Pick up high to shut off pumps on connections.

5.29.7 Monitor fluid level and fill on connections or trips.

5.29.8 Be sure flapper float is placed in drill pipe on first joint from kelly when starting aerated drilling.

NOTE: DO NOT USE LCM.

Run in with a slick 6 ¼''BHA with 8 ½''bit to drill out cement with water. Drill out cement with low RPM and WOB maintaining low rotary torque. Drill ahead to 30m below the casing shoe then pull out of the hole.

Run in with a pendulum 6 ¼'' BHA consisting of the 8 ½'' bit with stabilizer 20m above the bit and drill ahead with water.

When the first signs of lost circulation appear, partial or total, switch to aerated water drilling. (See appendix A).

Down hole temperatures may be high and the temperature of the in-going fluid should be maintained at a maximum of 400C, which is the maximum, recommended operating temperature for the pumps. Control of temperature is also critical for extending the bit life.

The cost of drilling detergent is very expensive and as such, it is important that it is used without wastage.

Attempted survey runs without first circulating the hole adequately may result in damaged (burnt) deviation tools. Whenever high temperatures are suspected, a temperature run must precede the deviation survey.
The condition of the bit and the stabilizer should be considered critical in controlling the hole gauge and deviation. A lot of caution should be taken to avoid locked or dislodged cones. Drilling parameters like torque, RPM, and WOB should be monitored closely and if suspiciously high torque is observed, the bit should be tripped out and inspected.

5.30 After reaching TD at 3000m +/-, circulate hole clean.

5.30.1 Make wiper trip to shoe. Check and log any fill on bottom.

5.30.2 Circulate well bore clean.

5.30.3 Monitor well closely for flow or gasses.

5.31 POH and rig up wire-line unit and run P/T survey.

5.32 Make up 8 ½" bit and RIH to make sure well is open and gauged for liner.

5.33 Keep well dead and rig up to run 7" slotted liner.

5.33.1 Use a liner adapter with no slips, and a plain cement guide shoe.

5.33.2 Set liner on bottom and allow for a minimum of 12m lap.

5.34 Prepare for short term flow test.

5.34.1 Remove well head and install second Master valve, Flow testing and testing equipment (See attached flow test program).

5.35 After flow test close Master Valve and secure well.

5.36 Check and tighten all bolts on well head assembly.

5.37 Lay down drill pipe and tools in mouse hole.

5.38 Clean mud tanks.

5.39 Release rig.

5.40 Submit well completion records including: Well record sheet, bit record, casing details, pipe measurement records, well schematic diagram, well head assembly diagram and serial numbers of well head valves to RG/EWSA office before next well is spudded or within one week.

6.0 Production Liner Program

Run 7'', 26lb/ft, K55, BT & C slotted liners with two plain top joints. The slotted liners will be run using a 7” fabricated and modified landing

nipple. The liners will be landed at hole bottom. Run sufficient liners to cover an overlap of two plain joints (about 28m) inside the 9 ⅝'' casing.
NOTE: A drifting tool must be run through the liners while on the racks to ensure that the liners are clear before they are run in hole.

7.0 Well Measurements

Completion tests will be done before the master valve is installed. See appendix D for details.

8.0 Material Transfers

A material Transfer record must accompany all materials transferred from the location or left over at the end of the hole drilling.
KW01
*Prepared By: Stephen Alumasa ONACHA Approved By:*___________________
Reviewed By:____________________ Approved By:___________________

Annex: Cementing

a) Call a safety meeting between the drilling crews and the cementing equipment operators.

b) Cement the casing as cementing program provided by the Drilling Engineer (RG/EWSA).

c) Displace cement with water without plug. If no losses are observed, leave one to one and a half casing of cement not displaced. For this case install a valve immediately before the circulation swage to be used to provide a hydraulic lock after displacement.

d) Wait on cement for 8hrs, or longer if samples have not set, cut off the landing joint and weld on the casing bowl.

e) Nipple up the 21 ¼'' BOP stack consisting of a single blind ram and an annular preventer. Test both the ram and the annular BOP to 300psi for 10 minutes each before drilling out cement at the shoe. Do not drill out cement until after a minimum of 12hrs W.O.C

Casing

1. Circulate and condition mud, then spot a high viscosity gel pill before tripping out. Lay down the stabilizer and rig up to run casing.

2. Run 13⅜'' K-55, BTC, 54.5Ib/ft casing but the top 2 joints to be 68Ib/ft as follows; -

a) Guide shoe – use THREADLOCK

b) One joint of casing –use THREADLOCK

c) Float collar –use THREADLOCK

d) Remainder of casing - no THREADLOCK uses casing dope.

Place casing centralizers as follows; -

a) 1middle of shoe joint.

b) 1 @ 2m above float collar.

c) 1 every 4 casing joints to surface.

3 Run casings no faster than 30 seconds per joint.
4 Landing casing off bottom with the special landing joint such that the screw on bowl will be at the correct height.

4 Install the cementing head loaded with 13⅜'' OD top plug.

5 Confirm that the casing has been landed to the correct position.

6 If no problems were encountered with caving formations during drilling, circulate water at least twice the casing volume with the rig slush pumps. If caving hole problems were encountered during drilling use an additional

10,000 liters of a light gel slurry, about 40 seconds Marsh funnel viscosity. Discuss with the Engineer how best to run the gel slurry.

7 If this stage of hole was drilled with full circulation returns, anchor the casing at the floor. Remember to follow the casing advice on Note 2 above. The chaining is a safety precaution intended to prevent casing floatation and possibly popping out of the hole during cementing operation.

NOTE 3: Cementing should commence as soon as the lines are changed on the rig floor, especially if there were hole problems when drilling.
Cementing

1 Call a safety meeting between the drilling crews and the drilling contractors cementing equipment operators while circulating the hole through the cementing head.

2 Cement casing as per cementing program.

3 Displace the cement slurry with the top plug using water and bump it at a pressure not exceeding 500 psi above final displacement pressure. The maximum allowable pressure before bumping the plug is 2730 x 0.75 = 2047.50 psi. The capacity of the 13⅜'' OD 54.5lb/ft casing is = 80.63 l/m.

4 Bleed off the pressure. Check if the plug holds. If it does not, leave the casing valve closed to provide a hydraulic lock. Bleed off the pressure every two hours until the cement is set or fluid stops flowing out of the casing.

5 Align the casing with the rotary using timber or casing slips between the casing and rotary table.

6 If good cement returns are not obtained, back-fill to surface.

7 In the event that the inner string (Stab-in) method will be used to cement the anchor casing, the EWSA Drilling Engineer on duty will provide the relevant cementing program.

NOTE 4:

a. The chicksan hose and valve used with the cementing head should be left on until the annulus is full of cement. The end of the chicksan line should be placed away from the rotary table to ensure that water does not leak out and get into the casing /casing annulus. For added security, leave the annulus BOP closed at all times after the first back-fill until the annulus is full.

b. WOC for 8hours before backing off the landing joint, longer if samples have not set.

c. Nipple down the 21 ¼′′ BOP stack. Cut off the casing bowl and install the 13⅝′′ 3000 psi Casing Head Flange (CHF).

d. Nipple up the 13⅝′′ BOP stack consisting of a 3000 psi rated Hydril annular and double gate ram preventers.

e. After waiting on cement for a maximum of 12 hours, pressure test rams to 200 psi and 1000 psi for 10min. each. Pressure test the annular preventer to 1000 psi for 10minutes. Flush all circulating lines including the blooie line.

5.3 Phase III – Production Hole Program

5.3.1 Drilling 12¼′′ hole

Run in with a slick BHA consisting of 12¼′′ bit and 8′′ drill collars to drill out cement Drill out cement with water with low WOB and rotary speed in order to have low rotary torque. Pressure test the shoe track using pipe ram to 200psi and 1,000psi for 10min each time. Drill ahead to 30m below the casing shoe and then trip out of the hole.

Run in hole with a pendulum BHA consisting of the 12¼′′ bit, 8′′ drill collars and 12¼′′ blade stabilizer 20m above the bit to drill ahead to the Kick Off Point (K.O.P) of 400m and conduct a survey. Use mud until a loss of circulation returns is experienced then switch over to aerated water (See Appendix A)

At 400m, assemble the angle building (kick off) BHA consisting of 12¼″ bit, NRV sub, mud motor (7¾″), orientation sub, non-magnetic drill collar, three (3) 8″ drill collars, fifteen (15) 5″ OD heavy weight drill pipes and the balance to be 5″ drill pipes. Run in the hole and orient the bit to the specified azimuth and Kick Off using drilling mud as the drilling fluid. The angle should be built at a rate of three (3) degrees per 30 m drilled to a maximum angle of 20 degrees. The deviation surveys will be done at KOP and every single drilled during angle build up. After attaining the maximum angle pull out of the hole and lay down the orientation sub and mud motor.

Change the BHA as needed in maintaining (holding) the angle, Holding the angle, continue drilling ahead carrying out single shot survey every 30 m and later at every 60 to 90 m depending on the observed dog leg severity and drift on the azimuth angle. Use drilling mud or aerated water as the drilling fluid. Alternative assemblies may be suggested by the directional drilling contractor based on the azimuth angle drift due to the presence of magnetite in volcanic formations.

The trajectory profile and directional drilling data is as shown in APPENDIX B attached.

It is recommended that deviation surveys be carried out during bit changes. During all air drilling operations, the corrosion control program outlined under appendix A (attached) must be followed.

The production casing should be set at about 750mRKB. Drill to casing tally depth plus 1.5-2m over-hole. Confirm the casing shoe will be in competent formation with the Geologist. Do wiper trips from the previous casing shoe USING THE SAME BHA and spot a high viscosity gel pill before tripping out.

5.3.2 Production Casing and Cementing Program

1. Run 9 ⅝", 47 lb/ft, K55, BTC as follows: -

a) Guides- use THREADLOCK

b) Shoe joint – use THREADLOCK

c) Float collar – use THREADLOCK

d) Rest of casing –CASING DOPE (NO THREAD LOCK)

2. Place centralizers as follows: -

a) 1 middle of shoe joint – stop collar

b) 1 @ 2m above float collar- stop collar

c) 1 every 4 casing joint to surface –casing collars.

3 Run casing no faster than 45 sec/joint, slower near the bottom.

4 Run the last three joints slowly. Make up the landing joint with a circulating swage and chicksan hose. If fill is encountered, circulate the landing joint to bottom through the swage. If the casing is full, start pumps slowly while raising string to avoid surging.

Circulate casing as advised by Drilling Engineer on duty. If formation problems were encountered during drilling or a lot of fill when landing casing, mix up 10,000 liters of light gel, about 40 seconds marsh funnels viscosity. Discuss how best to run the gel with the Engineer on duty.

5 Land the casing at the correct height with landing joint and ensure that it is centralized with the rotary table.

NOTE 5: Take note of where the 13 3/8′′ casing was landed to ensure that the 9⅝′′ casing is landed correctly.

Cementing

1. Call a safety meeting between the drilling crews and the cementing equipment operators. Cement as per the cement program provided by AOGCL Drilling Engineer.

2. Displace the cement after releasing the top plug with water. Measure the displacement volume using the tanks on the cementing unit. The 9⅝'' OD, 47lb/ft. casing capacity is 38.19lt/m.

3. Slow down the pumping rate over the last 2000 liters of displacement. Bump the plug at no more than 500 psi above the final displacement pressure. Maximum allowable pressure before bumping the plug is 3880 x 0.75 = 2910 psi.

4. Bleed off the pressure. Check if the plug holds. If it does not, leave the casing valve closed to provide a hydraulic lock. Bleed off the pressure every two hours until the cement is set or fluid stops flowing out of the casing.

5. If good cement returns are not obtained, consult the Engineer on whether to flush the casing annulus. Back-fill the casing annulus to surface with cement slurry. Remember to leave the chicksan lines and annular BOP as advised in Note 4.

NOTE 6:
1. Casing: (The Cementing method, will either be inner-string cementing or two stage cementing, shall be advised by AOGCL Drilling Engineer)

2. The erosion shield should fit when the master valve is finally installed. There will be NO NEED to use water to flush the top of the cement away after cement returns are obtained.

3. WOC for 8 hours or until the cement samples have set. Open the annular BOP and back off the landing joint.

4. After WOC for 12 hours, pressure test the blind rams, pipe rams and hydril to 200 psi and 1000 psi for 10 minutes each.

APPENDIX A: Foam and Aerated Water Drilling.

1. Introduction

The objective is to drill the well to enhance production. The use of foam and aerated water drilling is strongly recommended for the production zone. The primary units should not all be used at the same time but mostly two at a time and the booster should be able take all the air from two units.
Compressed Air Systems for the main rig:

2. Foam

Temperature: Return Temperature <800C
Depth: Up to 1500m deep if possible.
Foam is to be utilized as the drilling fluid in the upper, lost circulation sections of the well where temperature and low or nil water inflow conditions allow the establishment of stable foam circulation. An initial fluid concentration of 0.5% soap is to be utilized unless severe heating or poor hole cleaning is evident, in which case the concentration of soap should be slowly increased to 1%. The main cuttings lifting agent is the thick foam and so the driller should check that a strong structure of foam returns is being achieved.
Foam drilling parameters will be approximately:
Air: 10 – 30 m3/min
Soap/water: 80 – 200 l/min

Soap concentration: 0.5% of total water flow (□1.0 L/min).

3. Aerated Water

Aerated water is to be utilized as a drilling fluid from where it becomes impossible to drill with foam due to high temperature or weak return foam structure due to too much water. Water flow rates of 1000 – 2000 lpm for the 12 ¼′′ hole and 800 – 1500 lpm for the 8 ½′′ hole are usually sufficient to provide adequate hole cleaning, bit and hole cooling. Soap concentration of about 0.02% of the water flow rate should be utilized (i.e. about 20 lts/hr of soap in 1500 – 1700 lpm water). The mixture should have standard air (measured volume) to liquid ratios to about 40:1 by volume. This mix may be obtained by using 1500 lpm from the slush pumps and 100 – 200 lpm from the soap pump. Only if returns are sluggish should high soap concentrations be used. Airflow volumes and thus liquid flow volumes fraction necessary to balance down hole formation pressure will be determined by the actual hole conditions. Air volumes will be in the range of 40 – 60 m3/min.

4. Unloading

While there are many methods of unloading the hole, it is recommended that the hole be unloaded from bottom using the minimum strokes on the mud pump. This method is fairly quick and reduces shock waves into the formation to minimum, which could cause sloughing in weak formations.
Use of jet subs is only possible if the water level is high in the casing and the section to be drilled is short. This is because jet subs should not be operated below the casing shoe since they almost always result in washouts.
Ensure that the time periods the bit is left without fluid circulating, while in the hot hole, are kept to an absolute minimum especially if return temperatures are above 400C. This would reduce the heat applied to the elastomer seals in the bit bearings.

5. Record Keeping

The data from the primary and booster compressor air outlets should be collected and recorded. The data includes air temperatures, flow rate and pressure. There is also a Barton meter which records the airflow rate and pressure on a rotating chart from the booster outlet.
Notwithstanding, records of air and water flow, standpipe pressure, and blooie line conditions are to be recorded every hour on the logs as required.
Other drilling related records such as diesel consumption and material used must be properly recorded for future and audit references. Clean and accurate records must be kept at all times.

6. Corrosion control

Once circulation has been established and stabilized, the circulating fluid pH should be maintained at about 10pH using caustic soda. The pH of returns should be checked using litmus paper hourly and recorded on the drilling logs. 5 liters of a 10:1 ratio of Diesel: Coat 415 (Amine film inhibitor) mixture should be put in the drill pipe at every 2 drill pipes connection if the caustic soda is not available. The Tool Pusher should ensure that this is done to minimize chances of twist offs due to hydrogen sulphide embrittlement and oxygen corrosion.
This program must be followed at all times when aerated fluids are in use.

APPENDIX B: KW01

Vertical well but if directional drilling will be done, then the proposed trajectory

1. Trajectory :	Type I (build angle and hold)
2. Kick off Point:	400 m RKB
3. Angle of Inclination:	20 degrees
4. Rate of build:	About 3 degrees per 30 m (100ft)
5. Single shot measurements:	The surveys will be done before kickoff, at KOP, every single drilled, then 30m, 60m, 90m and every 150m drilled.
6. Desired measured depth:	3010m at a TVD of approximately 2840m
7. Target Lateral displacement at TD.	800m

添付－9
第二次現地調査　ラップアップ会議資料集

DATA COLLECTION SURVEY ON GEOTHERMAL DEVELOPMENT IN RWANDA

WRAP-UP MEETING FOR THE SECOND VISIT

17 JULY, 2013

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)
NIPPON KOEI CO., LTD

Location Map

Today's Subject

1. Outline of the Activities Conducted by the JICA Team (Takahashi S.)
2. Observations on Geological Aspects (Takahashi S.)
3. Observations and Recommendations from Hydro-geological Aspects (Teramoto M.)
4. Observations and Recommendations on Water Supply Facility (Takahashi S.)
5. Observations and Recommendations on Drilling Aspects (H. Sverrisson)
6. Schedule of the Team

			TAKAHASHI S. Team Leader/ Geologist	Hannes S Drilling Engineer	*TERAMOTO M. (NK own fund)*
27-Jun	Thu	day		RKV->AMT, FI502(0740->1240)	
28-Jun	Fri	day		AMT->KGL, KL535(1100->1905)	HND->DXB,EK313(0130->0705)
29-Jun	Sat	day		off work	DXB->NBO,EK719(1045->1445)
30-Jun	Sun	day	NRT->DHA,QR805(2230->0330)	off work	NBO->KGL,KQ442(1055->1305)
1-Jul	Mon	a.m.	DHA->KGL,QR536(0730->1350)	public holiday	public holiday
		p.m	**Public holiday in Rwanda**		
2-Jul	Tue	a.m.	**9:30 Meeting with JICA Rwanda office**		
		p.m	**Preparation for the 1st meeting**		
3-Jul	Wed	a.m.	**8:00 Meeting with EWSA at GDU of EWSA, Joint Training Program with ISOR to EWSA**		
		p.m	**Continuation of Joint Training Program with ISOR to EWSA**		
4-Jul	Thu	a.m. / p.m	**Public holiday in Rwanda**		
5-Jul	Fri	a.m. / p.m	Site Inspection (Pumping sites and Karisimbi Drilling Site) for confirmation of preparation works for drilling		
6-Jul	Sat	a.m. / p.m	off work	off work	off work
7-Jul	Sun	a.m. / p.m	off work	off work	off work
8-Jul	Mon	a.m.	Explanation of Geological Survey while Drilling with	Explanation of Drilling Program and Drilling Technology	Explanation of Geo-chemical survey
		p.m	Discussions	Discussions	Discussions
9-Jul	Tue	a.m.	Additional explanation of Geological Aspect	Discussion on Drilling Program with EWSA and RG on site	Site survey
		p.m	Preparation for site visit		
10-Jul	Wed	a.m. / p.m	Site Visit with Equipment provided by ISOR	Joint Discusstion with iSOR and EWSA	Discussions on Geo-chemical survey
11-Jul	Thu	a.m. / p.m	Joint meeting for the finalization of the Drilling Program among EWSA, RG, GWDC and JICA Team on site		
12-Jul	Fri	a.m. / p.m	Site survey (Karago Spring)	Preparation of Site Reports and Materials for wrap-up meeting	Site survey (Karago Spring)
13-Jul	Sat	a.m. / p.m	Site visit of Springs: Buseka, Cyabararika, Rubindi and Cyamabuye; and Bondi volcanic cone	Home work	Site visit of Springs: Buseka, Cyabararika, Rubindi and Cyamabuye; and Bondi volcanic cone
14-Jul	Sun	a.m. / p.m	Site visit of Gyseni spring	Home work	Site visit of Gyseni spring
15-Jul	Mon	a.m. / p.m	Site visits: Karago and Sashwara pump station; Drilling site; Moving to Kigali	Preparation of Site Reports and Materials for wrap-up meeting	Site visits: Karago and Sashwara pump station; Drilling site; Moving to Kigali
16-Jul	Tue	a.m.	**Collecting of additional inforamtion and discsuution with EWSA**		
		p.m	**Prparation for wrap-up meeting**		
17-Jul	Wed	a.m.	**Prparation for wrap-up meeting**		
		afternoon	**14:00 Wrap-up meeting**		
		evening		KGL->AST, KL535(2020->0645)	
18-Jul	Thu	a.m. / p.m	Report preparation	AMT->RKV,FI503(1400->1510)	Report preparation
19-Jul	Fri	a.m. / p.m	Report preparation		KGL->NBO,KQ471(0900->1130)
20-Jul	Sat		KGL->DHA, QR539(0950->1805)		NBO->ICN,KE960(1030->0450)
21-Jul	Sun		DHA->NRT,QR804(0150->1750)		ICN->NRT,KE701(0910->1130)

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Observation on Geological Aspects

- A comprehensive short course for geothermal development was provided to EWSA by UNU-GTP on an ICEIDA-Contract for EWSA from 25 to 29 June 2013 (with a Nordic fund?).
- Follow-up trainings are on-going (as of 16 July) for geological survey and environmental monitoring during drilling; for about six moths.
- JICA Team provided an explanation with emphasis on geothermal alteration; together with confirmation of geological conditions conducted with the EWSA geologist on site.

Observation on Geological Aspects

- A stereo-microscope and polarized microscope, sampling equipment of core-cutting have been provided under the UNU-GTP program.

- The Geology Team of EWSA is almost ready for drilling.

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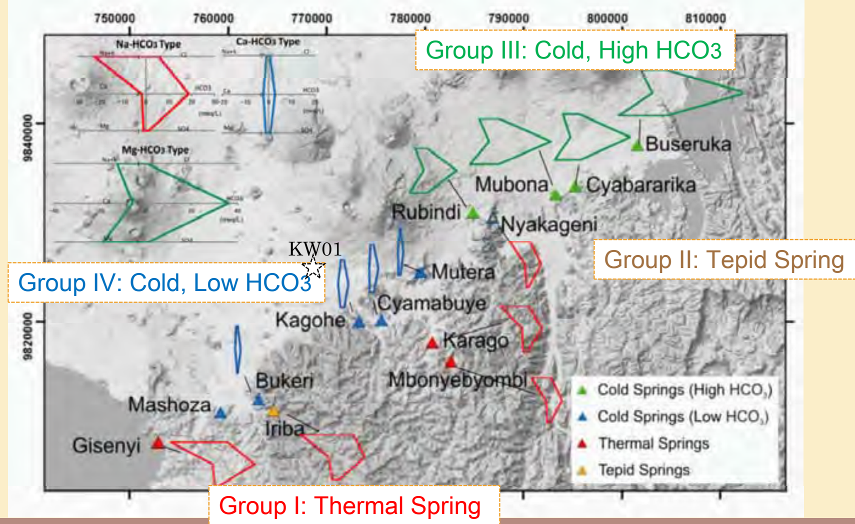
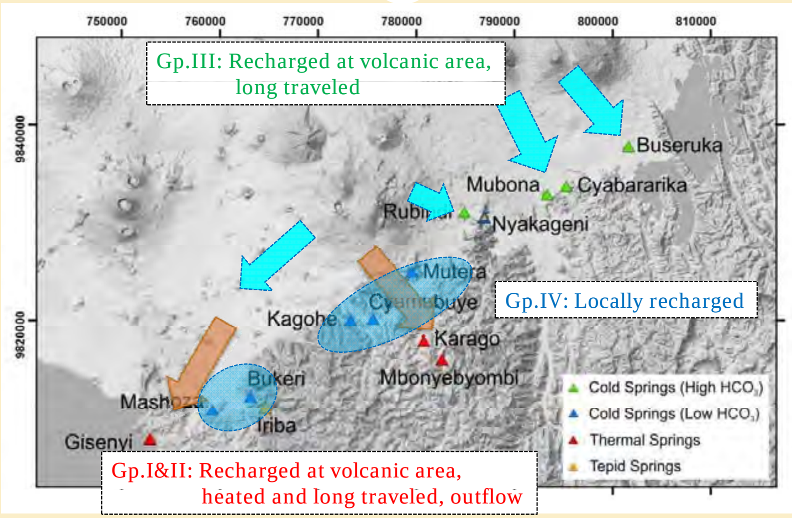
Hydrogeological Field Survey

- JICA team had a hydrogeological site survey in Virunga volcanic area guided by Mr. Jean Claude and Mr. Jean Damour from EWSA on 12-14 July.
- Visited hot springs (Karago and Gisenyi) and cold springs (Buseruka, Chababarika, Rubindi and Cyamabye) for further understandings of groundwater and hydrothermal flow systems in the area.
- Consider influence on water resources from geothermal project.

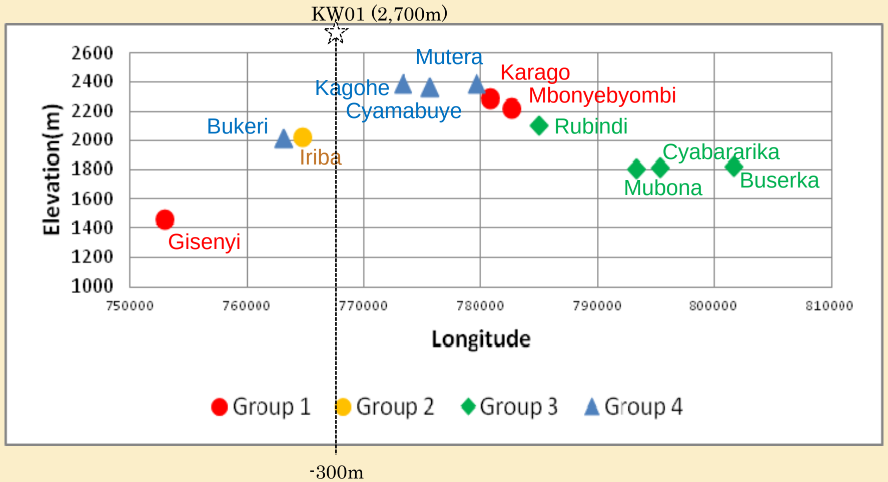
Hot and Cold Springs in Virunga Area



Recharge and Flow of Hot and Cold Springs



Elevation of Springs



Host Rock of Hot and Cold Springs

Group	Name	Elevation	Host Rock
1	Karago	2288	basement rock
	Gisenyi	1455	basement rock
	Mbonyebyombi	2220	basement rock
2	Iriba	2016	basement rock
3	Rubindi	2104	volcanic rock
	Mubona	1803	volcanic rock
	Cyabararika	1816	volcanic rock
	Buseruka	1823	volcanic rock
4	Kagohe	2385	basement rock
	Cyamabuye	2361	volcanic rock
	Bukeri	2010	basement rock
	Mutera	2383	basement rock

Hot Spring from Basement Rock (Group I)

Karago

- T:67.9℃, EC:0.8mS/cm, pH:**
- Environment: Bank of Lake Karago
- Usage: minor use

Gisenyi

- T:73.4℃, EC:2.7mS/cm, pH:7.0
- Environment: Small peninsula, bank of Lake Kivu
- Usage: Bath, Washing, Tourism

Cold - Low HCO3 Spring from Basement Rock (Group IV)

Cyamabuye

- T:16.3℃, EC:0.4mS/cm, pH:6.5
- Environment: Tea vegetation
- Usage: Water resource

Cold - High HCO3 Spring from Volcanic Rock (Group III)

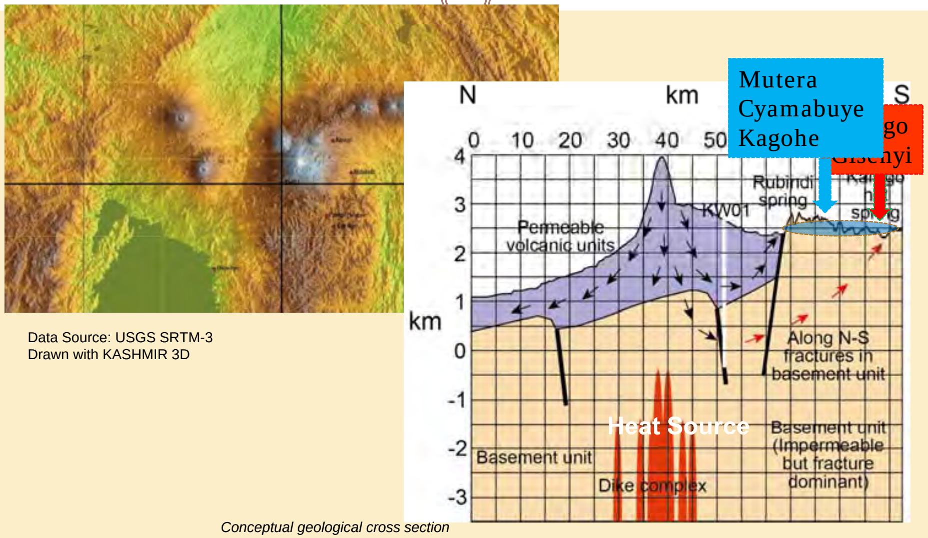
Buseruka (/ Cyabararika)

- 1) T:18.5℃, EC:2.7mS/cm, pH:6.2
- 2) T:15.7℃, EC:0.4mS/cm, pH:6.9
- Environment: near boundary of lava flow and granite basement
- Usage: Water resource for local

Rubindi

- 1) T:18.9℃, EC:2.0mS/cm, pH:6.2
- 2) T:17.7℃, EC:0.2mS/cm, pH:7.5
- Environment: near boundary of lava flow and granite basement
- Usage: Main water resource (Mutobo water treatment plant) of type 2) water

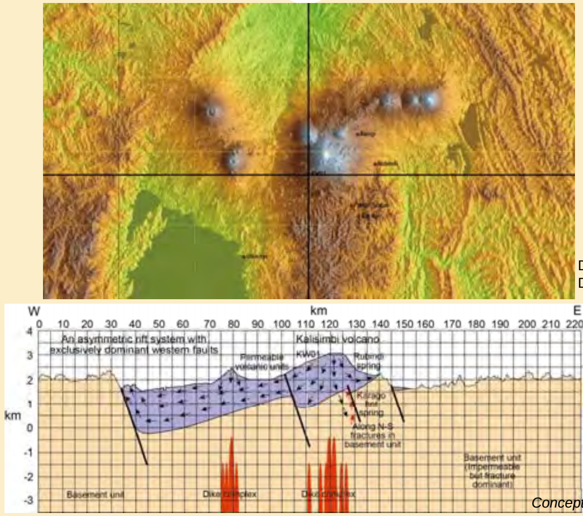
Schematic Flow Model of Groundwater
N-S Cross Section (Spring from Basement Rock)



Data Source: USGS SRTM-3
Drawn with KASHMIR 3D

Conceptual geological cross section

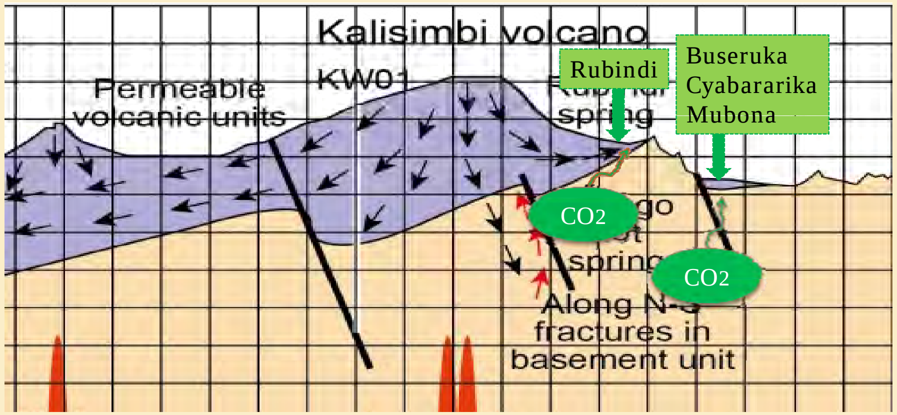
Schematic Flow Model of Groundwater
E-W Cross Section (Spring from Volcanic Rock)



Data Source: USGS SRTM-3
Drawn with KASHMIR 3D

Conceptual geological cross section

Schematic Flow Model of Groundwater
E-W Cross Section (Spring from Volcanic Rock)



Conclusions

Group	Name	Water Type	Main Usage	Interaction from project
I , II	Gisenyi Karago	Hot Deep water	Washing, Bath Tourism	Medium •Possibly same reservoir as geothermal resource •But not very big influence because of the long distance from drilling area
III	Rubindi Buseruka Cyabararika Mubona	Cold High HCO3 Deep water	Main water resources for public	Small-Medium •Different catchment area and different reservoir •Need assessment
IV	Mutera Cyamabuye Kagohe	Cold Low HCO3 Shallow	Water resources	Small •Different reservoir and groundwater system

Today's Subject

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Water Supply Facility

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Key Information

Items / Locations	Approx. Elevations (m.a.s.l.)	Height difference between the two locations (m)	Distance – pipe line (km)	Pipe diameter (inches)
Tanks at drilling site Kabatwa	2718.8	219.3	9.2	8
Booster site Sashwara	2499.5			
		211.7	9	8
In-take site Lake Karago	2287.8			

Design water flow: 2000 l/s (120 s.cu.m/hour) from the contract

Pump Capacity

Item / Locations	Flow (m^3/h)	Head (m)	No. of Pumps
Booster site Sashwara	155	268	2 (one for stand-by)
Intake site Lake Karago	155	536	2 (one for stand-by)

Observation on Water Supply Facility

23

1

Results of Head Loss Calculation

Pipe length (L) (km)	Pipe length (L) (m)	Head loss (m)
7.0	7,000	35
8.0	8,000	40
9.0	9,000	45
9.2	9,200	46
9.5	9,500	47
10.0	10,000	50
11.0	11,000	55

2

Results of the Calculation

Item / Locations	Flow (m^3/hour)	Required Pump head (m)
Booster Pump (Sashwara)	120	265 (219 + 46) or more
Intake Pump (Lake Karago)	120	257 (212 + 45) or more

3

Pump at Booster site (Sashwara)	Flow (m^3/h)	Head (m)
Rated (seen on plate)	155	268
Check in the Capacity Curves of the Pump	120	?

Conclusions

- Calculated head losses are low estimation.
- Pump capacity should be large enough.
- ~~Joint operation by the two pumps may be required.~~

Valves on Water Pipe line

24

- A non-return valve and a gate valve with T- branch was being fixed at each pumping station on 16 July.

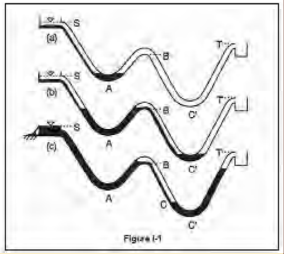
↑ Above: at Karago lake

←Left: at Booster station

Valves on Water Pipe line

25

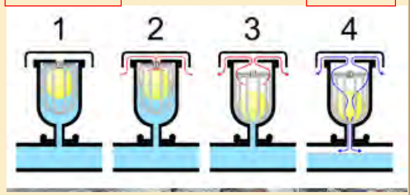
- The JICA Team was informed that procurement of air-valves has been made, and will be made available within days.
- It is understood the pumping will commence before fixing the air valves.



Our Recommendation:

- The JICA Team would warn EWSA against operating the pumps before fixing the air valves.

Valve closed | Air out | Air In



Valves on Water Pipe line

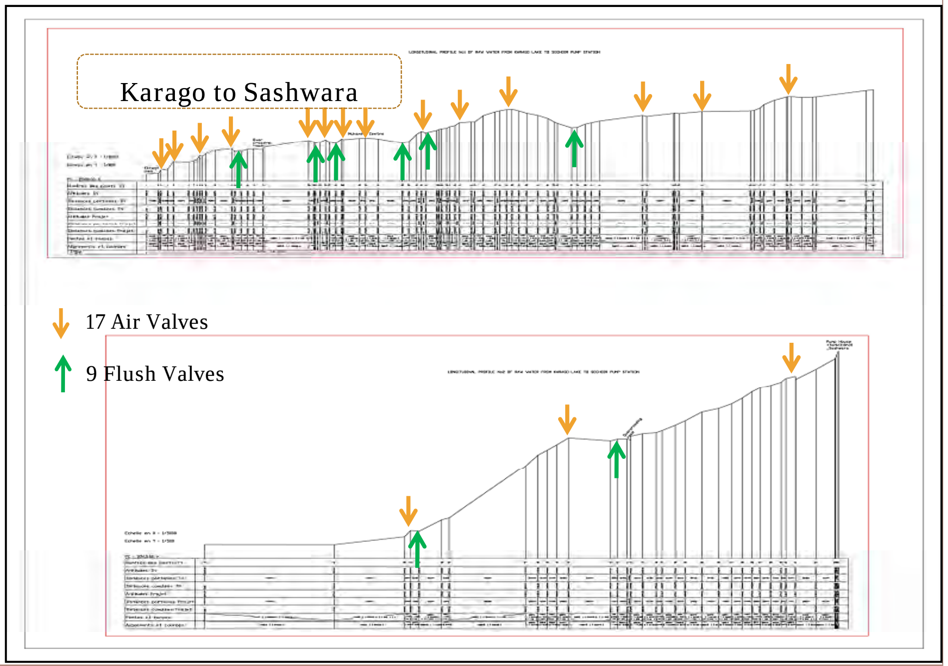
26

- Mud flash valves will be required at concave locations, because water of Karago Lake is presently very muddy.
- Mud flash valves may be fixed later.
- Sieves are recommended in front of pump intakes.

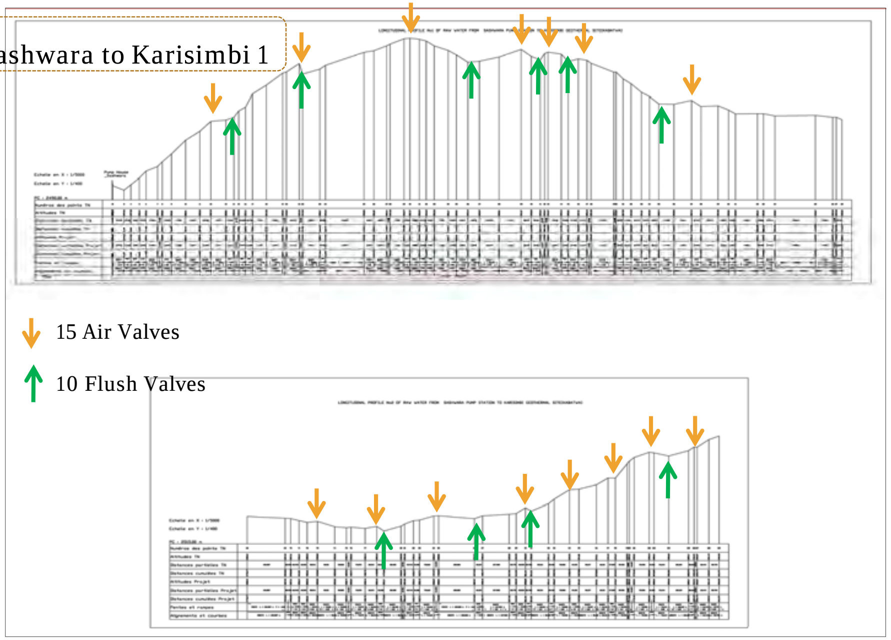
- Other Consideration for pump stations:

Automatic on-off switch is recommended at each pump station to avoid dry operation.

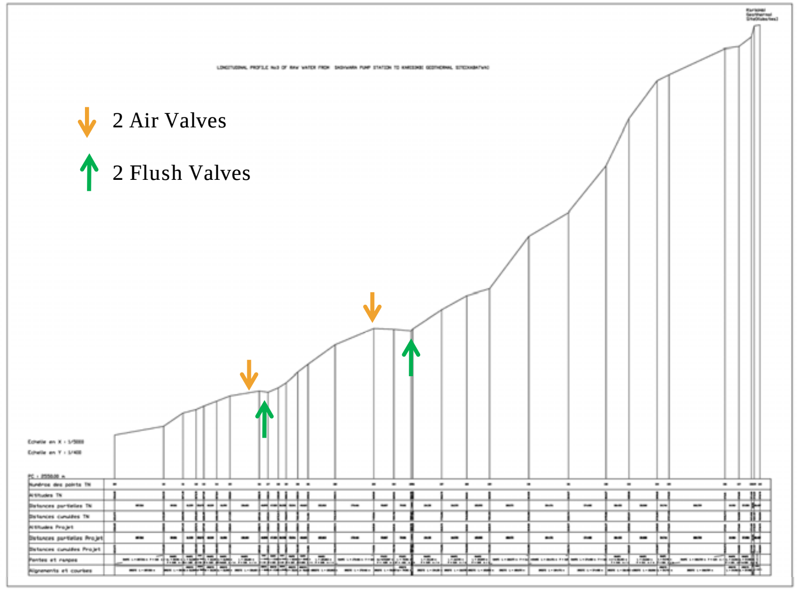
- Approximate locations of air valves and flush valves preliminarily suggested are in the f0llowing figures.
- This may be a minimum requirement
- Exact locations shall be decided on site.



Sashwara to Karisimbi 1



Sashwara to Karisimbi 2



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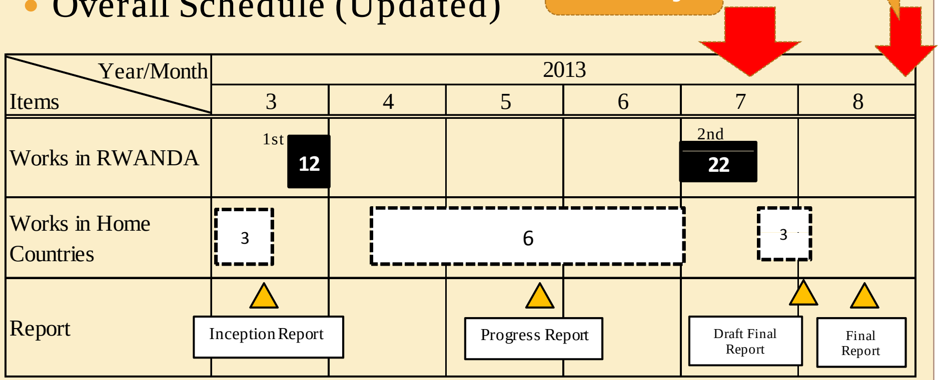
Schedule and Approach

End of our Contract

Today

- Overall Schedule (Updated)



Note: Works in home countries are intermittent as necessary.

08. Report Preparation

Report	Contents	Submission Schedule
Inception Report (IC/R)	· Review results of recent reports on geothermal potential · Approach of the Study	To be delivered directory to EWSA when the Survey Team is in Rwanda, in the middle of March 2013.
Progress Report (P/R)	· Technical recommendation of well drilling and well tests · Strategy/direction of the well drilling/testing to be agreed upon with the counterpart	To be delivered through e-mail followed by a courier service, toward the end of May 2013.
Draft Final Report (DF/R)	· All outputs of the Study	To be delivered through e-mail followed by a courier service, in end of July 2013
Final Report (F/R)	· All outputs of the Study (comments are incorporated)	To be submitted to JICA Head office, in middle of August 2013

DATA COLLECTION SURVEY ON
GEOTHERMAL DEVELOPMENT
IN RWANDA

Thank you,
Murakoze,
Arigato

DATA COLLECTION SURVEY ON GEOTHERMAL DEVELOPMENT IN RWANDA

1

Well Design and Drilling

Hannes Sverrisson, M.Sc. Petroleum Engineering

17 JULY, 2013

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

NIPPON KOEI CO., LTD

Overview

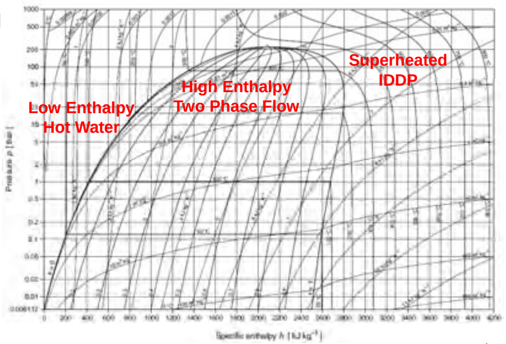
- Well Design
  - Casings
  - High Enthalpy and Low Enthalpy
- Drilling Programs
  - Drilling Programs
  - Well Testing
- KW-01 Drilling Program

Most Important in

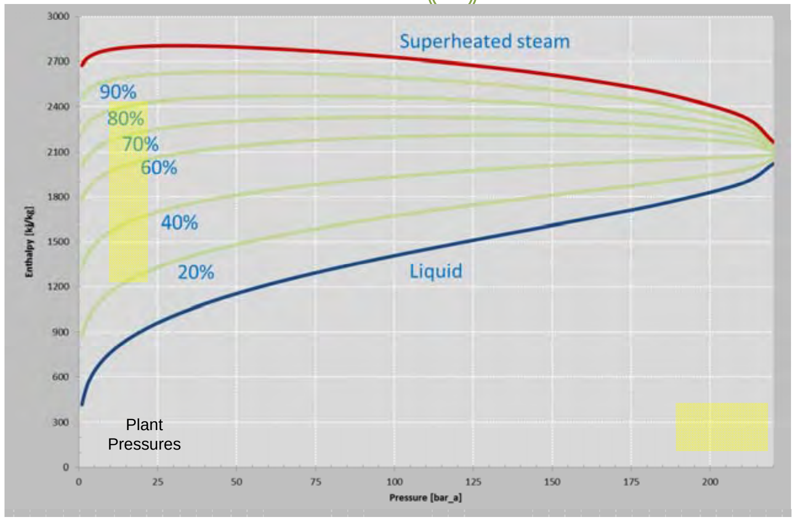
WELL DESIGN

Well Design: Main References

- API Standards:
  - API Standards for casings, BOP, valves, and material
  - Sometimes the API standards don´t apply because of larger diameters for geothermal applications
  - Sometimes Line Pipe material grade used for surface casings
  - Code of Practice for Deep Geothermal Wells
  - NZS 2403:1991, New Zealand Standard
- Steam Tables
  - International Steam Tables
    http://www.international-steam-tables.com/
  - EES
  - Xsteam
    http://xsteam.sourceforge.net/
    - Excel



Well Design: Enthalpy vs. Pressure

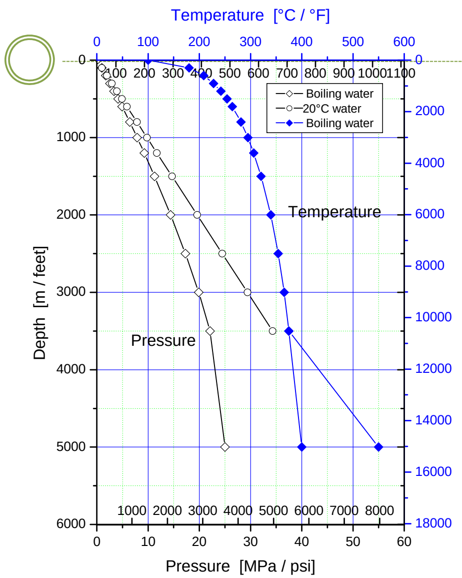


Well Design: Main Points

- High temperatures
- Large borehole and casing diameters
- Collapse risk
- Casing steel grades preferably from low yield steel
- Extreme LOC common
- Low cost drilling fluids and when in the reservoir rock only water with high density polymer
- Usually large targets like fizzures and fault zones and thus, less accuracy needed
- Flashing can occur inside the wellbore
- Limited budget

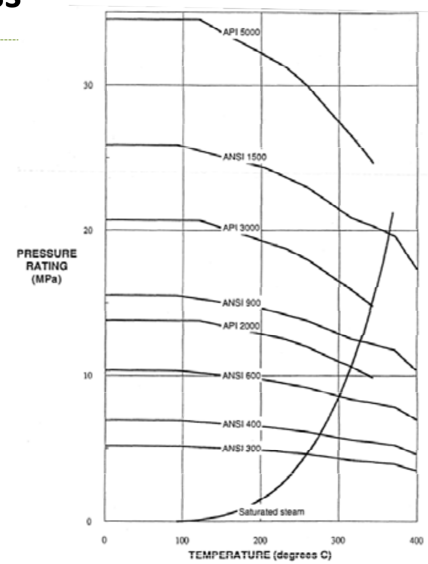
Well Design: Casings

- Determine Temperature
  - Depends on depth
  - Expected enthalpy of reservoir
- Exploration well
  - Expected temperatures from Geologists and surface indicators are **„indicators“**
- Always keep the well full of water or closed
- Some areas may have blow-out at 100 m depths!
- **Minimize heat cycles from cold to hot and vice versa.**



Well Design: Pressure Class

- Pressure Classes ANSI / PN
  - Cl. 2500 / PN 420
    - Superheated
  - Cl. 1500 / PN 250
    - High Enthalpy
    - API 5000
  - Cl. 900 / PN 150
    - Hellisheiði PP, TVD 1900 m
    - API 3000
  - Cl. 600 / PN 100
    - Low Enth. 2 phase, TVD 1150 m
    - Hot water
  - Cl. 300 / PN 50
    - Hot water
  - Cl. 100 / PN 16
    - Water wells



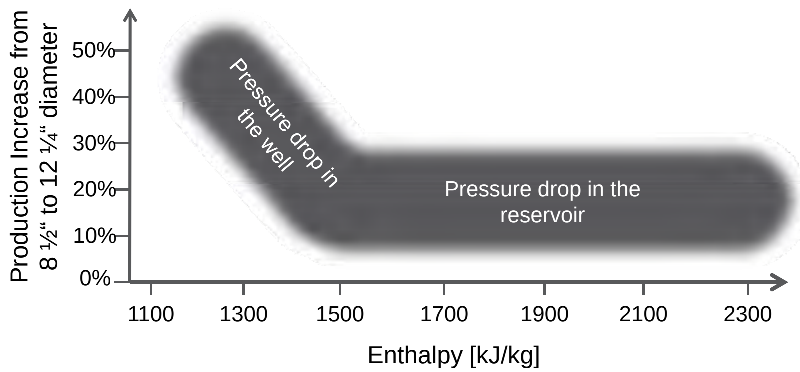
Well Design: Casings

- High temperatures
  - Affects casing material strength
  - Highest temperature expected depends on the reservoir and depth
  - Highest encountered 450° C (IDDP)
- Steel Grades
  - K55 or J55
    - Low yield strength
    - High tensile strength
  - Line pipe X56 in surface casings
  - The casing will yield due to high temperature
  - The low yield steel has good corrosion resistance
  - Sometimes higher yield casing steel grades may be sold as K55. Then do specific requirements to the API standard when purchasing

Well Design: Diameter

Low Enthalpy
12 ¼“ Production Interval

High Enthalpy
8 ½“ Production Interval



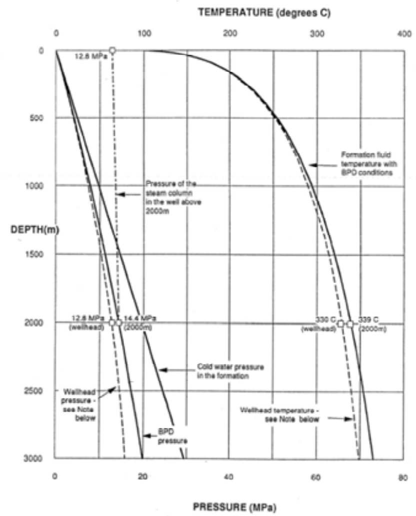
Well Design: Narrow and Wide Program Cl. 900

- Wide
  <u>ø12¼“ production hole</u>
- ø24½“ bit: 26“
- ø18⅝“ bit: 21“
- ø13⅜“ bit: 17½“
- ø9⅝“ bit: 12¼“
- Well Flange: ø18“
- Master Valve: ø12“
- Expansion spool: ø18“ - ø12“

- Narrow
  <u>ø8½“ production hole</u>
- ø18⅝“ bit: ≥21“
- ø13⅜“ bit: 17½“
- ø9⅝“ bit: 12¼“
- ø7“ bit: 8½“
- Well Flange: ø12“
- Master Valve: ø10“
- Expansion spool: ø12“ - ø10“

Well Design: Burst & Collapse

- <u>Burst</u>
  - Empty well with steam column to top
  - Burst at top is bottom hole pressure at section depth at the boiling point, with the weight of the steam column subtracted.
- Cementing procedures
  - Same as in oilfield
  - Usually stab-in cementing used, thus not an issue.
- The reservoir fluid may be saline and with other dissolved minerals which increases density slightly.
- <u>Collapse</u>
  - Avoid trapped water pockets that may heat up and expand
  - Good cementing essential without cement boundaries
  - Free water content of slurry
  - Low density for collapse risk and also to limit risk of fissure break-out



Well Design: Tension and compression

- Temperature difference due to tension needs to be taken up be the cementing
- If casing is badly cemented and loose then for a 1000 m section and 150° C warm up:
  - 1,8 m movement
  - 360 MPa compressive stress if held in place
  - Yield strength of K55 is 379 Mpa
- Minimize warm-up cycles due to tension and compression
  - For compression the K55 material may yield and thus high tension can result when cooled down again.

Grade	Temperature (°C) 20	100	200	300
API Yield Strength (Factor):				
J/K-55	1.00	0.95	0.95	0.95
N-80	1.00	0.96	0.92	0.88
Tensile Strength (Factor):				
J/K-55	1.00	0.97	1.02	1.07
N-80	1.00	0.97	0.99	0.99
Modulus of Elasticity (10^3 MPa):				
J-55	178	172	168	160
K-55	208	208	200	192
N-80	206	206	200	192

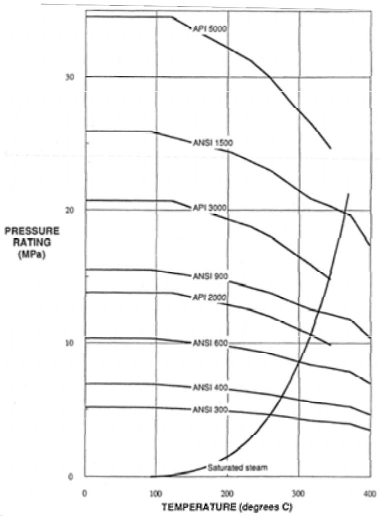
Design factors					
Axial		*Use*	Hoop		*Use*
Tensile	1.5-1.8	*1,5*	Internal yield (burst)	1.5-1.8	*1,5*
Compressive	1,2	*1,2*	Collapse	1,2	*1,2*
Wellhead anchorage	1,5	*1,5*	Inner collapse (outer burst)	1,2	*1,2*

Well Design: Thread

- Choose a thread that is strong in compression as well as tension.
  - Buttress Thread BTC
  - Hydril (IDDP)
- Glue (cement) the top and bottom 3 connections
- Use joint compounds that are rated for the temperature

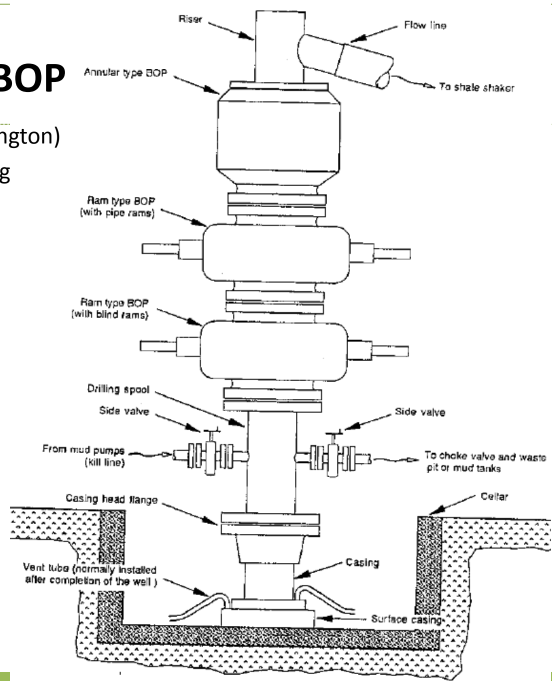
Well Design : Blow Out Preventers (BOP)

- API Standard
  - Functionality test and pressure test API RP 53 prior to drilling out cement
- API 2000
  - Shallow sections (sometimes surface casing)
  - Connects to ANSI 600 Ring Joint Flanges
- API 3000
  - Intermediate sections and often to TD
  - Connects to ANSI 900 Ring Joint Flanges
- API 5000
  - High temperature and deep wells
  - Connects to ANSI 1500 Ring Joint Flanges



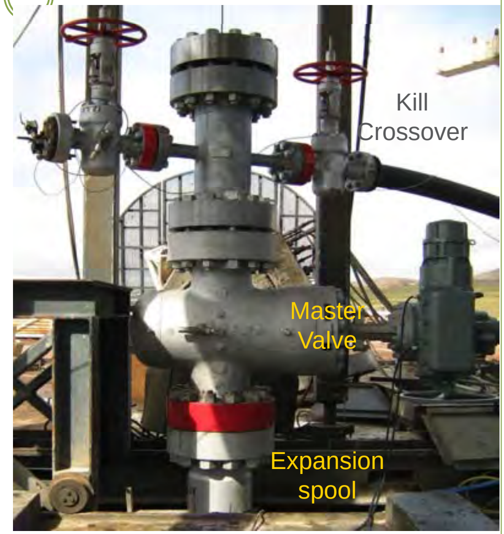
Well Design : BOP

- Rotating head (Washington)
- Drilling spool for killing



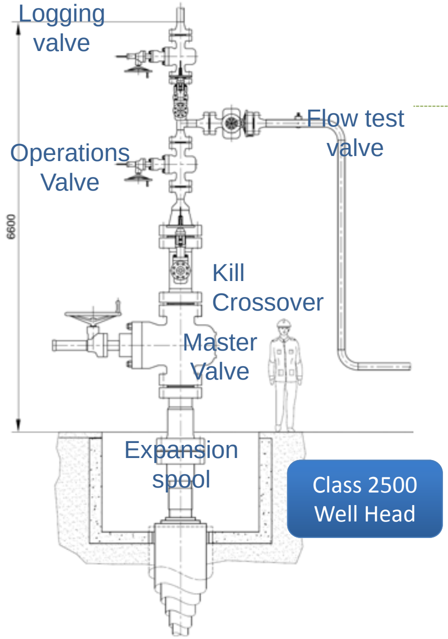
Well Design: Well Heads

- Kill cross-overs no longer used before the master valves
- Master valve used sparingly
  - Operation valve (not expanding) used for connecting to steam gathering or seperator
- Flow control
  - Valves, expensive and usually set once per year.
  - Orifice, cheap and may be changed annually or 2 years.
- Ring Joint Flanges with steel ring gaskets



Well Design: Well Heads

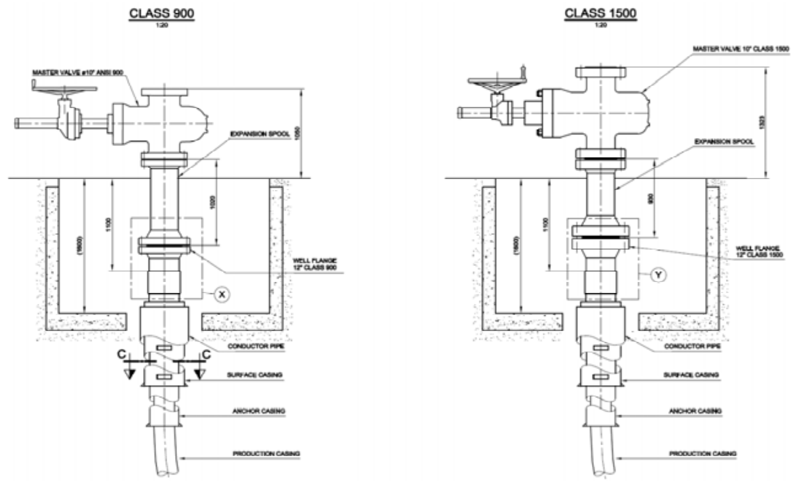
- Testing
  - Always use the operations valve and minimize use of master valve
  - Use a 3“ logging valve for temperature and pressure measurements during flow test
- Design the well head for movement and vibration



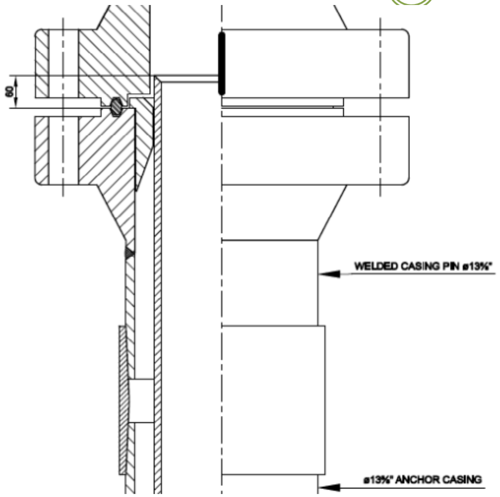
Well Design: Valves and Expansion Spools

- Preferable to use expanding gate valve type for master valves
  - They seal the valve housing when fully open and fully closed.
- Packing assembly used in high enthalpy wells

Well Design: Valves and Expansion Spools



Well Design: Valves and Expansion Spools



Well Design: Drilling Pad

- At least stack four wells per drilling pad
- Straight or J-type slanted well paths.
  - Usually not more than 35° - 40°
  - KOP 300 – 400 m
  - Maximum departure of 1590 m for a 40° and TD 3000 m
- Blind drilling maybe necessary in the production section
  - Thus, no inclination and azimuth measurements while drilling.
- Accuracy

Category	A	B
Azimuth	±5°	±15°
Inclination	±3°	±12°
Maximum DLS	1,0°/ 30 m	1,0°/ 30 m

Well Design: Cementing

- Preferable to cement with stab-in method
  - Flexible slurry volume
  - Slurry delivered cold downhole
- Monitor cement return in annulus on surface and pressure
- Monitor pressure and expect a break-out due to fissure opening
- If a fissure opens where the slurry escapes
  - Pump water on the annulus to keep the fissure open
  - Switch the cementing method to annulus top down cementing
  - Cement until TOC in annulus is at surface
  - Top up due to subsidance

Well Design: Slurry recipie

- Grade-G with 40% silica flour
  - High density
- Iceland: Portland Cement with 40% silica flour
  - Allows lower density
  - Cheaper and availability
- Monitor pressure and expect a break-out due to fissure opening
- Slurry volume – Rule of Thumb:
  - With caliper msmt. Add 35%
  - Without caliper msmt. Add 60%
  - Have material on-site for mixing 220% the design volume

Common Slurry (density 1,7):

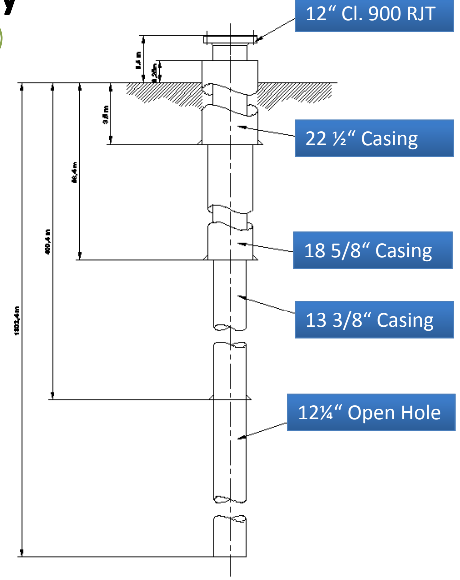
Portland Cement	100 kg
Water	63 kg
Silica 325 mesh	40 kg
Bentonite	2 kg
Tensed Perlite	2 kg
Retarder	0 – 0,5 kg

Well Design: Logging

- Temperature
  - Important factor
  - Use sensitive temperature sensors with accuracy and fast responce
  - The normal oil field temperature sensors are not adequate
- Typical:
  - Last section:
  - Temp. & Press.
  - Azim. & Incl.
  - Spontaneous Pot. (SP)
  - Natural Gamma (GR)
  - Resistivity
  - Neutron-neutron (n-n) (Radioactive)
  - (Vertical Seismic Profiling (VSP), exploration)
- Other:
  - Cement Bond Logging (CBL)
- Well Testing:
  - Temp. & Press.
  - (Flow meter)
  - (Gamma ray)

Well Design: Low Enthalpy

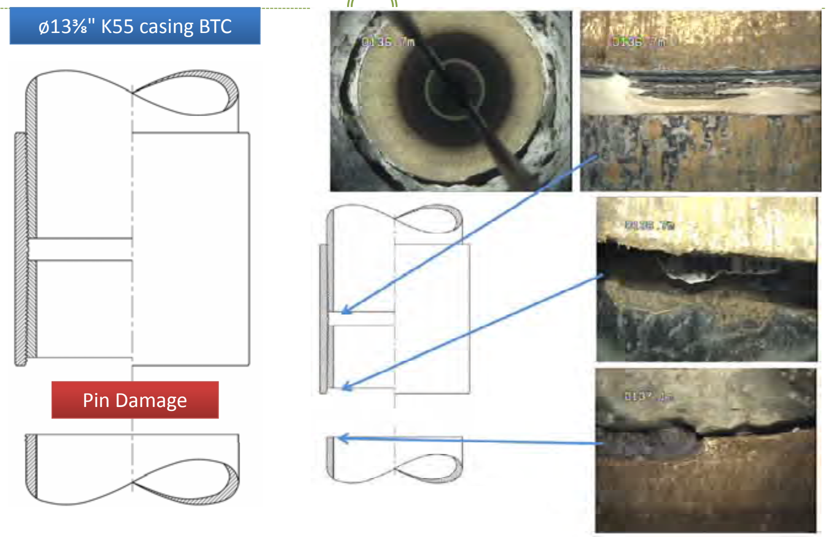
- Wide casing program
  - 12 ¼" open hole production part
- Production casing 13 3/8"



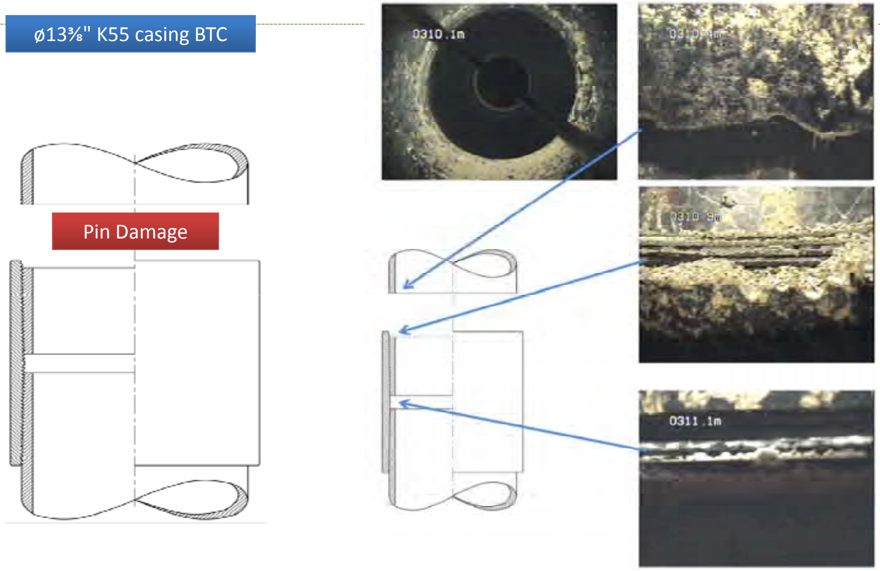
Well Design: Low Enthalpy

- Wide casing program
  - Have space for downhole pump

Well Design: Tension Failures



Well Design: Tension Failures



Well Design: Points to Remember

- Use low yield steel to allow yielding and corrosion resistance.
- Cement in one continous and fast flowing procedure and be ready to switch to top down annulus cemeting. Lower slug density is beneficial.
- Allow for well head movement and minimize warm-up and cooling cycles.
- Always keep the well full of water and monitor the water table.
- Always close the well when no string is in it.
- Limit drilling ROP and monitor cuttings removal or buildup in the well.

Most Important in

DRILLING PROGRAMS

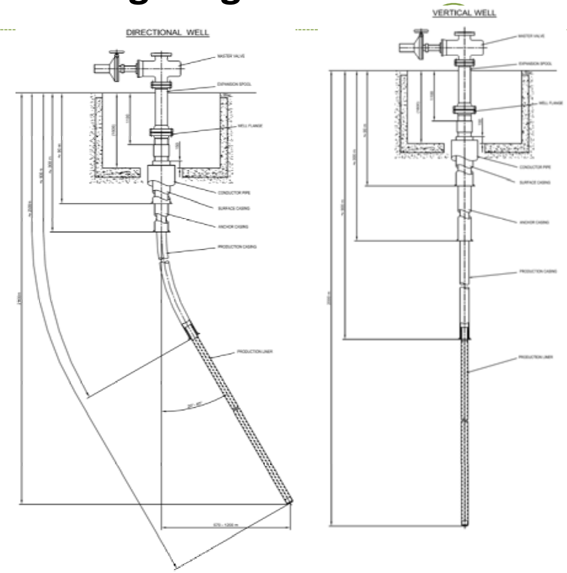
Overview

- Well Design
  - Casings
  - High Enthalpy and Low Enthalpy
- Drilling Programs
  - Drilling Programs
  - Well Testing
- KW-01 Drilling Program

Drilling Programs: Main Points

- Extreme LOC usual occurrence
- Blind Drilling
- Usually large targets and less accuracy needed
- Flashing can occur inside the wellbore
- Lower budgets

Drilling Programs: Cl. 900 & 1500 Wells



	CLASS 900	
	DRILL BIT	CASING
VALVE		ø10"/900
EXPANSION SPOOL		ø12"-10"/900
WELL FLANGE		ø12"/900
SURFACE CASING	(ø21")	ø18⅝"
ANCHOR CASING	ø17½"	ø13⅜"
PRODUCTION CASING	ø12¼"	ø9⅝"
PRODUCTION LINER	ø8½"	ø7"

	CLASS 1500	
	DRILL BIT	CASING
VALVE		ø10"/1500
EXPANSION SPOOL		ø12"-10"/1500
WELL FLANGE		ø12"/1500
SURFACE CASING	(ø21")	ø18⅝"
ANCHOR CASING	ø17½"	ø13⅜"
PRODUCTION CASING	ø12¼"	ø9⅝"
PRODUCTION LINER	ø8½"	ø7"

Drilling Programs: Extreme LOC

- Have procedure in place for addressing LOC
- LOC material: mica and nut shells with good experience
  - When less than ≈15 l/s
- High losses treated with cementing
  - LOC material added to the cement
  - Prevents the fissure / vain of affecting cementing operations
- May get sealed by cuttings
- Monitor cuttings coming to surface

Drilling Programs: Blind Drilling

- When losses exceed the fluid pumped downhole
- Have procedure for blind drilling or maybe stop drilling
  - the „**objective**“ may have been reached although the „**target**“ has not been
- Cuttings may build up
  - Monitor cuttings buildup by pulling up to the casing and wait for cuttings to settle
  - Wash down and note cuttings buildup in the well by depth difference
  - Slowly remill the cuttings
- Usually no information on azimuth and inclination
  - Continue drilling and check azimuth and inclination at the next bit change

Drilling Programs: Steam Flashing

- Always monitor water level in the well
- Always close the well when no drilling string is inside
- The fluid column is usually enough to prevent steam flashing
- Have backup water if water supply fails
- Have at least 20 ton of Barite available on-site or storage area for killing

Drilling Programs: Stuck String

- Well collapse
- Buildup of cuttings
  - New fissure opens and the water level drops suddenly in the well which collects the cuttings at the fissure

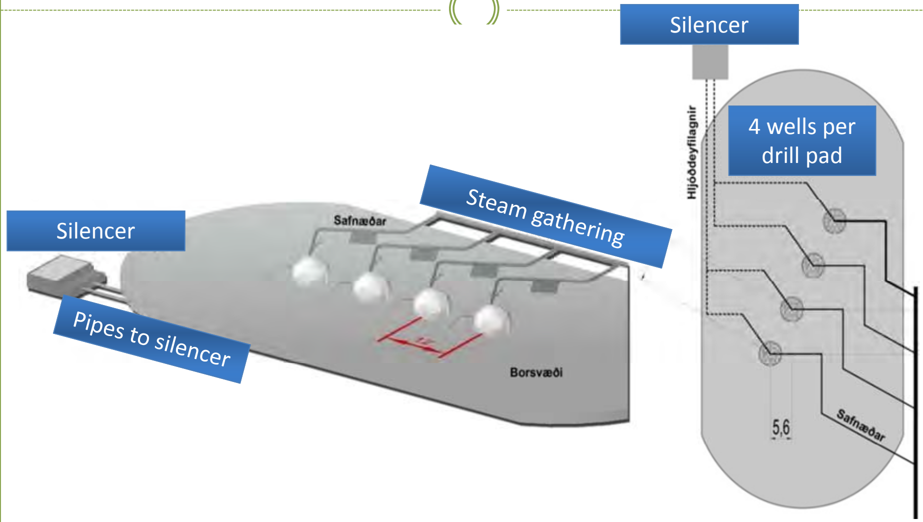
Drilling Programs: Well Testing

- Allow time for warm-up period
- Warm up well head slowly
  - Gas bleeding
- Allow well to eject drilling water
  - 1 – 2 months
- Well testing
  - 2 – 6 months to get general data
- Try to keep the well heads warm until utilized
- Low Enthalpy Wells
  - Air lift maybe needed to lift the water column
  - The well may oscillate

Hellisheiði Geothermal Power Plant

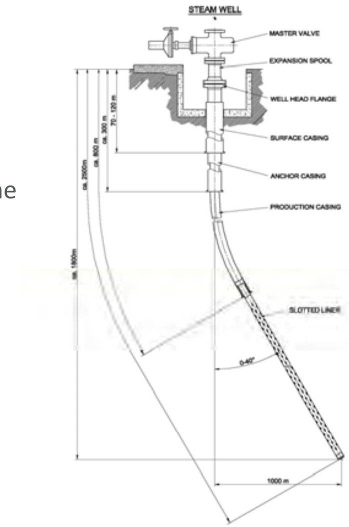
- Electricity Production: 303 Mw_e
  - Delivered @ 220kV
- District Heating: 133 MW_{th}
- 57 production wells
  - Steam 3kg/s @
- 17 injection wells
  - Water kg/s @ 70˚ C
- 54 groundwater wells / information wells d:9 7/8‘‘
- Well Depth on average 2000 m and length 2300 m
- Well diameter 12 ¼‘‘, 8 ½‘‘ (production part)
- Well pads with 4-6 wells
- Distance between bore holes
  - Surface: ~12m
  - Reservoir: ~500-1200m

Drilling process at Hellisheiði

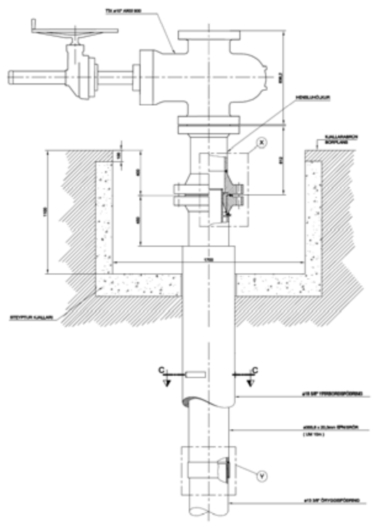


Drilling process at Hellisheiði

- Drilled to reach a temperature (250° C +)
- Target production zone and fractures
- Open hole or slotted liner on production zone
- Three step process for safety
- Class 900, ~100 bar_a pressure at 314° C



Wells – Well Heads, Hellisheiði



Balanced Drilling or Airated Drilling

- Pressure is kept in balance with fissures in the formation
- Drilling fluid is foam or airated drilling mud
- Gains:
  - Better cuttings removal
  - Improved production with less formation damage
- Compared to conventional drilling
  - Cost is +15-30%
  - Production gain depends on the reservoir
  - Formation damage from cuttings possible

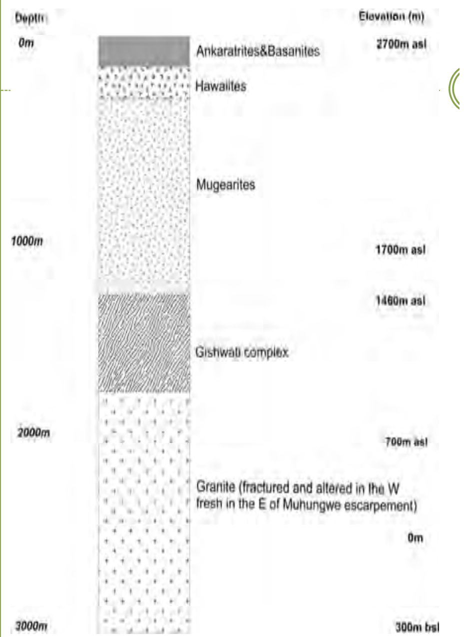
Drilling Programs: Points to Remember

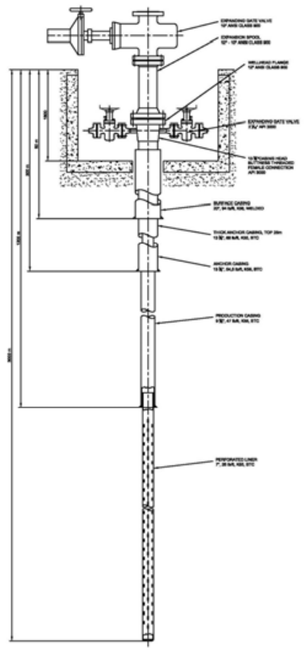
- Always keep the water level high in the well.
- Have enough backup water.
- Expect extreme LOC.
- Total LOC – continue with blind drilling or stop drilling?
- Limit ROP.
- Stack wells per drillpad to lower costs.
- Have prepared written procedures to handle these risks above.

The First Exploration Well

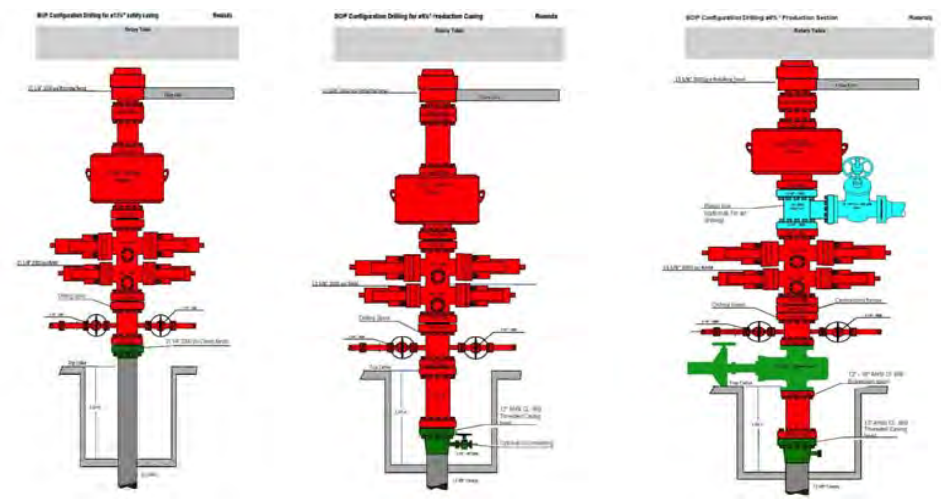
Kabatwa

KW-01 DRILLING PROGRAM





Drilling BOP

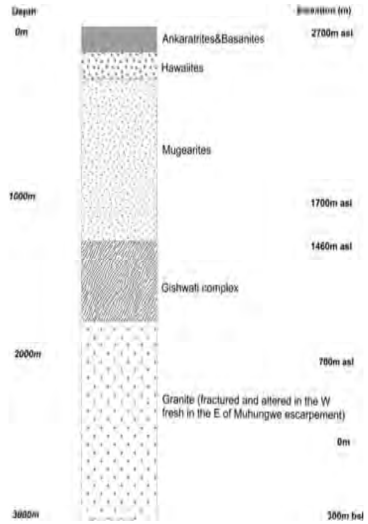


Section I – 26” Hole – 508mm Surface Casing to 30 m

- Possible problems
- Cementing Method

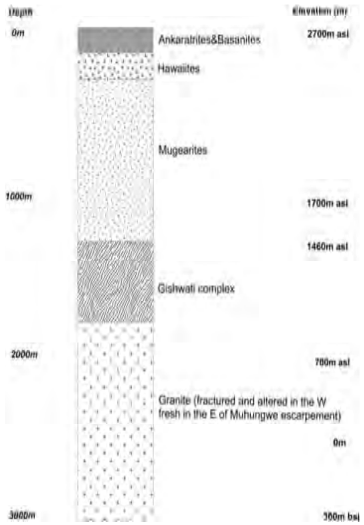
Section II. – 17-1/2” Hole -13-3/8” Anchor Casing to 300 m

- Possible problems
- Cementing Method



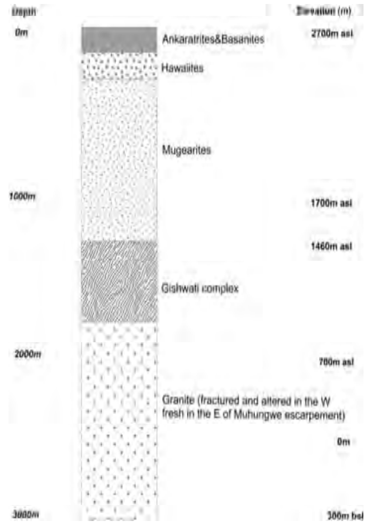
Section III – 12 ¼” Hole - 9-5/8” Production Liner to 1200 m

- Possible problems
- (Aerated drilling)
- LOC zones
- LOC procedures
- Temperature measurement
- Cementing Method



Section IV – 8-1/2” Hole – 7” Perforated Liner to 3000 m

- Possible problems
- Aerated drilling
- LOC zones
- LOC procedures
- Blind drilling
- Temperature measurement
- Liner placement



Estimating Cement Volumes

Casing size and weight	inch	20" 94.0#	13 3/8" 54.5#	9 5/8" 47#
Top, open hole	m	0	55	295
Bottom, open hole	m	60	300	1200
Top casing	m	0	0	0
Casing shoe depth	m	58	298	1198
Casing length	m	60	300	1200
Open section annulus length	m	60	240	900
Displacement casing	lpm	202,68	90,65	46,94
Capacity casing	lpm	185,32	80,64	76,04
Capacity open hole	lpm	342,5	155,2	76
SLURRY VOLUME				
Volume between casings	m3	x	5,7	10,1
Volume between casing and well	m3	8,4	15,5	26,2
Excess slurry (btw casing and well) 60%	m3	5,0	9,3	15,7