STATE OF KNOWLEDGE OF THE GEOTHERMAL PROVINCES OF REPUBLIC OF DJIBOUTI

ARGEOP-C1 Conference
Addis-Ababa, Ethiopia, 24-29 November 2006

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Djibouti, CERD
GEOTHERMAL EXPLORATIONS IN DJIBOUTI

- FIRST PHASE
  - Preliminary field studies
  - Asal rift geophysical studies
  - First geothermal drillings in Asal Rift geothermal area
  - Nord-Goubhnet geophysical studies

- SECOND PHASE
  - Hanlé-Gaggadé exploration (field studies and gradient wells)
  - Hanlé geothermal drillings
  - Asal rift new drillings and geophysics
  - Scaling and corrosion study of Asal rift deep reservoir

- ARCEO PROJECT PHASE
Carte établie par M. J. Varet à partir des levers géologiques de :

(1) MM. F. Barberi, G. Giglia, G. Marinelli, R. Santacroce, H. Tazieff, J. Varet et al. (1971)
(3) MM. L. La Volpe, L. Liner, J. Varet (1973)
(4) MM. F. Barberi, M. Di Paola, G. Giglia, R. Santacroce, J. Varet
(6) MM. R. Bleck, W. Morton, J. Varet (1972)
Formations sédimentaires : MM. F. Gasse (Afar central), M. Teles (Awash moyen, 1972)
Toponymie relevée par M. E. Châdeville.

Chaines volcaniques axiales, à tendance tholéitique
Acid volcanic ranges with tholeitic tendency.

Centres rhyolitiques des marges
Marginal rhyolitic centres

Alignements volcaniques transverses, d'affinité alcaline.
Transverse volcanic alignments (alkaline affinity).

Série stratique de l'Afar (SL)
Afar stratified series

Basaltes du Daïha
Daïha basalts

Rhyolites des Mabia
Mabia rhyolites

Granites hypersthéniques miocène
Miocene peralcaline granites

"Soile" cristallin et couverture Pré-mioéne
Pre-miocene "basement"
GEOLOGY AND SURFACE MANIFESTATIONS

Legend:
- Fumarole
- Spring
- Jurassic and Cretaceous
- Quaternary sediments
- Stratoid rhyolites
- Makla rhyolites
- Gulf basalts
- Stratoid basalts
- Somali basalts
- Recent basalts
- Dalka basalts
- Adolei basalts

Map of geographical locations with various geological and surface manifestation symbols.
HANLE GEOTHERMAL EXPLORATION AREA
Republic of Djibouti

- Hanle plain
- HANLE 1
- HANLE 2
- Lake Abhe
- Gaggade plain
- Lake Asal
HANLE-GAGGADE GEOCHEMICAL STUDIES
(AQUATER-CERD 1983)

- 1. Bicarbonate-earthen-alkaline
- 2. Chlorinated-alkaline
- 3. Chlorinated-alkaline-earth-alkaline
- 4. Chlorinated-bicarbonate-sulfate-alkaline

Mixing of group 1 and 4
ELECTRICAL SURVEY OF HANLE PLAIN
(AQUATER-CERD 1983)
HANLE GRADIENT WELLS

TEWEO1

GARABAYIS2

Coarse alluvium
Fine sand
Mud and silt
Rhyolite
Basalts

452 m

30°C

100°C

130°C

1.3°/100m
43.7°C

Teweo1

2°/100m
121.7°C

Garabayis1

3°/100m
80.8°C

Garabayis2

130°C

30°C

100°C

500m
HANLE EXPLORATION OUTCOMES

- Hanlé 1 (1623 m), 72 °C at 1420 m
- Hanlé 2 (2038 m), 124 °C at 2020 m
- Permeability
  - Hanlé 1: rhyolites, contact rhyolites-basalts, scoriae, dry below 800 m
  - Hanlé 2: basalts, scoriae, dry below 450 m
- Bottom hole core of Hanlé 2: 18.8 My
- Thick crust with 24 °C/km to 36 °C/km
Asal Geothermal area
Republic of Djibouti
SURFACE MANIFESTATIONS AND
GRADIENT WELLS. ASAL RIFT (BRGM-CERD 1973)
GRAVIMETRIC SURVEY. BOUGUER ANOMALY (BRGM 1993)
AMT SURVEY OF THE ASAL RIFT (BRGM 1993)

Altitude -100m

Altitude -200m

Altitude -300m
EM SURVEY OF THE ASAL RIFT (BRGM 1993; ORKUSTOFNUN 1988)
Br VERSUS Cl IN ASAL RIFT ZONE

- Lake Asal
- Sea water
- Deep reservoir
- Shallow reservoir
- Korili spring
- Other springs
MAJOR ELEMENTS VERSUS Li (San Juan et al. 1990)

- Ca/Cl.10
- Na/Cl.10
- Mg/Cl.10
- Li/Cl.10^4

Legend:
- Lake Asal
- Sea water
- Deep reservoir
- Shallow reservoir
- Korili spring
- Other springs
$\delta^{18}O$ VERSUS $\delta^D$ IN ASAL RIFT AREA

- Sakalol
- Korili

- Hot springs
- Cold springs
- Lake Asal 1974
- Lake Asal 1979
- Sea water

$\delta^D = \delta^{18}O + 10$
Temperature profiles – Asal geothermal area

<table>
<thead>
<tr>
<th>Well</th>
<th>Depth (m)</th>
<th>Temp. Max (°C)</th>
<th>Temp. Gradient (°C/100m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>1145</td>
<td>261</td>
<td>18</td>
</tr>
<tr>
<td>A2</td>
<td>1554</td>
<td>235</td>
<td>14.3</td>
</tr>
<tr>
<td>A3</td>
<td>1316</td>
<td>280</td>
<td>15.51</td>
</tr>
<tr>
<td>A4</td>
<td>2013</td>
<td>345</td>
<td>15.2</td>
</tr>
<tr>
<td>A5</td>
<td>2105</td>
<td>360</td>
<td>15.2</td>
</tr>
<tr>
<td>A6</td>
<td>1761</td>
<td>280</td>
<td>12.75</td>
</tr>
</tbody>
</table>
Interpretative cross section of Asal rift Geothermal area

ASAL 3

1316 m

ASAL 4

Asal series

Stratoid series

Dalha basalts

2013 m

ASAL 5

2105 m

Legend:
- Alluviums
- Clays
- Hyaloclastites
- Rhyolites
- Basalts
- Trachytes

Scale: 500 m
Production curves of ASAL 3

Production curve of ASAL 1
Scale deposits in 6 inches production line
Asal 1 geothermal well (BRGM-CERD 1981)

180 µm
Spharelite

Sulphide deposits
300 m depth

Baryte x3000
Silencer deposits
Asal 3 well testing data

**Drawdowns. ASAL3**

- 155-225 ton/h
- 300-357 ton/h
- 225-300 ton/h
- 79-130 ton/h

**Multirate drawdown. ASAL3**

\[
\frac{1}{Q_N} \left( \frac{(P_i - P_{wf})}{Q_N} \right)
\]

**Injectivity test. ASAL4**

**Multirate drawdown. ASAL6**

\[
\frac{1}{Q_N} \left( \frac{(Q_j - Q_{j-1}) \log (t - t_{j-1})}{(P_i - P_{wf})} \right)
\]
HYDRODYNAMIC PROPERTIES OF THE DEEP RESERVOIR IN ASAL RIFT ZONE

**ASAL3 Drawdown tests**

<table>
<thead>
<tr>
<th>Wt ton/h</th>
<th>ΔQ ton/h</th>
<th>Wt ton/h</th>
<th>ΔQ ton/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>79 - 130</td>
<td>51</td>
<td>15.6</td>
<td>-5</td>
</tr>
<tr>
<td>Multiple</td>
<td></td>
<td>15.9</td>
<td></td>
</tr>
<tr>
<td>155 - 225</td>
<td>70</td>
<td>15.7</td>
<td>-5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.7</td>
<td></td>
</tr>
<tr>
<td>225 - 300</td>
<td>75</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>300 - 357</td>
<td>57</td>
<td>13.4</td>
<td>-5</td>
</tr>
</tbody>
</table>

**ASAL3 recovery tests**

<table>
<thead>
<tr>
<th>Wt ton/h</th>
<th>ΔQ ton/h</th>
<th>Wt ton/h</th>
<th>ΔQ ton/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>357 - 0</td>
<td>357</td>
<td>7.3</td>
<td></td>
</tr>
<tr>
<td>87 - 0</td>
<td>87</td>
<td>5.8</td>
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</tbody>
</table>

**ASAL4 injectivity test**

<table>
<thead>
<tr>
<th>Wt ton/h</th>
<th>ΔQ ton/h</th>
<th>Wt ton/h</th>
<th>ΔQ ton/h</th>
</tr>
</thead>
<tbody>
<tr>
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<td>51</td>
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<td>57</td>
<td>13.4</td>
<td>-5</td>
</tr>
</tbody>
</table>

**ASAL6 Drawdown tests**

<table>
<thead>
<tr>
<th>Wt ton/h</th>
<th>ΔQ ton/h</th>
<th>Wt ton/h</th>
<th>ΔQ ton/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>79 - 130</td>
<td>51</td>
<td>15.6</td>
<td>-5</td>
</tr>
<tr>
<td>Multiple</td>
<td></td>
<td>15.9</td>
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<tr>
<td>300 - 357</td>
<td>57</td>
<td>13.4</td>
<td>-5</td>
</tr>
</tbody>
</table>

**ASAL4 injectivity test**

<table>
<thead>
<tr>
<th>Q m3/h</th>
<th>Wt ton/h</th>
<th>ΔQ ton/h</th>
<th>kh dm</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>0.6</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>After injection</td>
<td>0.28</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
PRESSURE BUILD-UP MEASUREMENTS. ASAL3

- Build-up décembre 1987
- Build-up mars 1990

- Production 1st period of 1st phase
- Production 2nd period of 1st phase
- Production 2nd phase
- Before production 1st phase
- Before production phase 2
- 77 days after stop production phase 1
- Estimated by build-up after phase 2 production
- Before production phase 2

Graphs showing the relationship between pressure at 1100 m depth and total flow ton/h.
DEEP RESERVOIR RESULTS IN ASAL
- Reservoir recognized by ASAL1, ASAL3 and ASAL 6 in the same area
- Temperature 260 °C to 280 °C
- Reservoir: Dalha basalts (9 - 4 My), 1050 m to 1300 m
- ASAL 3 production:
  - Initial characteristics: total mass flow 360 t/h for 12.5 WHP
  - Kh: 6.3 dm
  - TDS in the reservoir: 116 000 ppm
  - Scaling in the well (6 to 10 mm): sulphides (PbS, ZnS)
  - Scaling in surface equipment: amorphous Si with Fe and Mn
  - Severe decrease of the production rate
  - Decrease of the bottom hole pressure: 3.5 bars

ASAL INTERMEDIATE RESERVOIR
- Recognized on all Asal geothermal wells but not yet studied
- Reservoir: Top of Stratoid series and the bottom of Asal series
- Located between 300 m and 600 m
- Temperature 130 °C to 190 °C
- TDS: 50 g/l
NORD-GOUBHET AND ARTA GEOPHYSICAL SURVEYS (BRGM 1983; GEOTHERMICA 1982)
LAKE ABHE AND OBOCK GEOTHERMAL PROSPECTS
GROUNDWATER THERMAL ANOMALIES
DJIBOUTI AQUIFER
CONCLUSIONS

- HANLE-GAGGADE BASINS ZONE
  Drilling results not conclusive in Hanle basin
  Exploration by drilling not completed
  Need for new geophysical surveys as EM, AMT
  Reevaluate possibility of new drillings

- ASAL RIFT ZONE
  Deep reservoir of high enthalpy demonstrated in ASAL1 area
  Lateral extension of deep reservoir not yet evident
  Permeability and circulations controled by fractures
  Major problem of scaling still to resolve
  Geophysical surveys describe complex structures of reservoirs
  Fairly good understanding of fluids origins based on geochemistry and isotopes

  Shallow reservoir medium enthalpy preliminary significant results
  Shallow reservoir likely to have good extension
PERSPECTIVES FOR GEOTHERMAL DEVELOPMENT

- **ASAL RIFT ZONE**
  - Complete exploration for the deep reservoir extension
  - Solutions for the scaling problem of the deep reservoir
  - Complete EM survey of Asal rift zone
  - Study feasibility of the mineral extraction from the deep reservoir high TDS fluid
  - Realize exploration with drillings in the shallow reservoir
  - Develop both reservoirs for electricity production

- **OBOCK ZONE**
  - Realize geophysical surveys with EM and AMT methods
  - Realize geochemical and isotopic studies on the hydrothermal manifestations
  - Exploration drillings
  - Feasibility study

- **LAKE ABHE AND GAGGADE ZONES**
  - Realize geophysical surveys with EM and AMT methods
  - Realize geochemical and isotopic studies on the hydrothermal manifestations
  - Exploration drillings
  - Feasibility study
Thank you