Assessment of Carbon Dioxide (CO$_2$) Partial Pressures in the Menengai Geothermal Area, Kenya.

Jeremiah Kipngok/ 1st November, 2018 / Kigali Convention Centre.
Outline

• Introduction

• Application of $P_{CO_2}$ to the Menengai Geothermal Field
  o Groundwater boreholes
  o Geothermal wells
  o Gas isotopes

• Conclusion
Introduction

- CO₂ is the predominant gas in geothermal systems, accounting for >90% of the total gases present.
- In geothermal systems CO₂ has different sources but is mainly controlled by hydrothermal minerals.
- Flux of CO₂ in the soil and P\text{CO}_2 in shallow groundwater is a permeability indicator (Chiodini et al., 1998).
- P\text{CO}_2 affects calcite scaling: solubility of CaCO₃ decreases with decrease in P\text{CO}_2.
- Soil CO₂ flux has also been recently proposed as a geothermometric tool (Harvey et al., 2018)
Menengai Geothermal Area

- **Main structures:** Olorongai and Solai structural systems and Menengai caldera ring faults
- **Main rocks:** Peralkaline trachytes with minor/subordinate pyroclastic intercalations
Location of Menengai Geothermal Wells
Probability plots for samples collected by GDC (left) and those by Geotermica Italiana (right)
### P$_{\text{CO}_2}$ of Groundwater Boreholes

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Pop.</th>
<th>N</th>
<th>%</th>
<th>Average</th>
<th>Standard dev. (σ)</th>
<th>Median - 2σ</th>
<th>Median</th>
<th>Median + 2σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>GDC A</td>
<td>9</td>
<td>3.0</td>
<td>0.162</td>
<td>0.0319</td>
<td>0.108</td>
<td>0.159</td>
<td>0.235</td>
<td></td>
</tr>
<tr>
<td>GDC B</td>
<td>110</td>
<td>36.3</td>
<td>0.0464</td>
<td>0.0144</td>
<td>0.0242</td>
<td>0.0443</td>
<td>0.0813</td>
<td></td>
</tr>
<tr>
<td>GDC C</td>
<td>167</td>
<td>55.1</td>
<td>0.0139</td>
<td>0.0102</td>
<td>0.00302</td>
<td>0.0112</td>
<td>0.0415</td>
<td></td>
</tr>
<tr>
<td>GDC D</td>
<td>17</td>
<td>5.6</td>
<td>0.00117</td>
<td>0.000580</td>
<td>0.000412</td>
<td>0.00105</td>
<td>0.00268</td>
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</tr>
<tr>
<td>Geotermica Italiana A</td>
<td>12</td>
<td>12</td>
<td>0.0761</td>
<td>0.0105</td>
<td>0.0572</td>
<td>0.0754</td>
<td>0.0993</td>
<td></td>
</tr>
<tr>
<td>Geotermica Italiana B</td>
<td>28</td>
<td>28</td>
<td>0.0390</td>
<td>0.00767</td>
<td>0.0259</td>
<td>0.0382</td>
<td>0.0565</td>
<td></td>
</tr>
<tr>
<td>Geotermica Italiana C</td>
<td>53</td>
<td>52</td>
<td>0.0117</td>
<td>0.00753</td>
<td>0.00302</td>
<td>0.00982</td>
<td>0.0319</td>
<td></td>
</tr>
<tr>
<td>Geotermica Italiana D</td>
<td>8</td>
<td>7.9</td>
<td>0.00112</td>
<td>0.000697</td>
<td>0.000302</td>
<td>0.000950</td>
<td>0.00299</td>
<td></td>
</tr>
</tbody>
</table>

- The upper limit of the low-$P_{\text{CO}_2}$ populations B, C and D is close to the worldwide maximum soil CO$_2$ pressure of 0.042 bar (Brook et al., 1983).
- The lower limit coincides with the average atmospheric $P_{\text{CO}_2}$.
- Probably processes; decay of organic matter and root respiration, occurring in soils, which are systems exchanging gases with the atmosphere.
High $P_{\text{CO}_2}$ population A: 0.06-0.2 bar suggests a deep source of CO$_2$.

Example: Winsor borehole (west of Menengai; highlighted) has a $P_{\text{CO}_2}$ of about 0.13 bar.
Menengai Geothermal Wells: Effect of $P_{\text{CO}_2}$

- NCG in Menengai averages about 3.5% by weight in tested wells.
- Generally, CO$_2$ produces high-pressure, gas-driven geothermal systems.
- pH and $P_{\text{CO}_2}$ were calculated using a mineral-solution equilibrium model with the aid of EQ3 software package.
- Calculations using WATCH computer code give slightly higher values/estimates due to the implicit assumption (in WATCH) that a single reservoir zone contributes to production.
- The effect of $P_{\text{CO}_2}$ on boiling of two-phase fluids was also assessed.
Menengai Geothermal Wells

Average pH and \( P_{\text{CO}_2} \) values for the reservoir liquids met by a number of Menengai wells

<table>
<thead>
<tr>
<th>Well</th>
<th>Discharge Tests Dates</th>
<th>Reservoir pH</th>
<th>( P_{\text{CO}_2} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>MW-01</td>
<td>Until May 2012</td>
<td>7.09±0.10</td>
<td>8.4±4.6</td>
</tr>
<tr>
<td></td>
<td>Sept 2012 - November 2012</td>
<td>6.72±0.12</td>
<td>53.2±31.5</td>
</tr>
<tr>
<td></td>
<td>Sept 2013 - April 2014</td>
<td>6.95±0.16</td>
<td>19.1±12.8</td>
</tr>
<tr>
<td></td>
<td>January - April 2015</td>
<td>6.77±0.16</td>
<td>49.5±63.5</td>
</tr>
<tr>
<td>MW-01A</td>
<td>October 2014 - March 2015</td>
<td>6.76±0.15</td>
<td>39.6±30.2</td>
</tr>
<tr>
<td>MW-03</td>
<td>October 2012 - June 2013</td>
<td>7.47±0.11</td>
<td>1.1±0.6</td>
</tr>
<tr>
<td>MW-04</td>
<td>October 2011 - March 2012</td>
<td>7.47±0.11</td>
<td>10.4±4.8</td>
</tr>
<tr>
<td></td>
<td>March - April 2012</td>
<td>7.06±0.16</td>
<td>10.4±8.5</td>
</tr>
<tr>
<td>MW-09A</td>
<td>January - March 2015</td>
<td>7.11±0.22</td>
<td>11.7±14.8</td>
</tr>
<tr>
<td>MW-12</td>
<td>Until May 2013</td>
<td>7.00±0.26</td>
<td>20.3±24.0</td>
</tr>
<tr>
<td></td>
<td>March - May 2014</td>
<td>6.90±0.29</td>
<td>32.3±31.8</td>
</tr>
<tr>
<td>MW-19</td>
<td>April - July 2014</td>
<td>7.30±0.26</td>
<td>2.9±2.8</td>
</tr>
<tr>
<td>MW19A</td>
<td>February - April 2015</td>
<td>7.25±0.21</td>
<td>4.2±4.6</td>
</tr>
<tr>
<td>MW-20A</td>
<td>December 2014 - February 2015</td>
<td>7.78±0.28</td>
<td>0.3±0.4</td>
</tr>
</tbody>
</table>
Menengai Geothermal Wells

Curve 1: Measured temperature and pressure (hydrostatic) during discharge of the wells; Curve 2: Temperature and pressure of saturated vapor for pure H₂O. Arrows indicate possible aquifers.
Menengai Geothermal Wells

MW-09C

MW-12

Pressure (bar-abs)

~1650 m depth
~1850 m depth
~2250 m depth
~980 m depth
Depth: 1600 m
~1950 m depth

Temperature (°C)

Temperature (°C)
Menengai Geothermal Wells

MW-18A

MW-19

Pressure (bar-abs)

Temperature (°C)
Menengai Geothermal Wells

MW-19A

- ~1300 m depth
- ~1700 m depth
- Well bottom

MW-21A

- Depth: 1680 m
- Depth: 2000 m

Pressure (bar-abs)

Temperature (°C)
Gas isotopes: \(^{3}\text{He}/^{4}\text{He}\) and \(\delta^{13}\text{C}\) values of \(\text{CO}_2\)

- The main origin \(\text{CO}_2\) is the mantle.
- Thermogenic contribution is possible.
- Calcite precipitation at temperatures lower than 193°C is invoked.
High $P_{CO_2}$ values in Menengai groundwater boreholes is associated with a deep (mantle) source of CO$_2$.

$P_{CO_2}$ anomalies in groundwater could contribute to mapping structures and possible presence of geothermal reservoirs.

The presence of CO$_2$ in significant proportions in the NCG in Menengai geothermal fluids considerably affects boiling and phase conditions in the geothermal reservoir and the wells.

Modelling of the Menengai reservoir should factor in the effects of carbon dioxide in the model.

Determination of $\delta^{13}$C values of CO$_2$ and CH$_4$ is recommended in future works.
Acknowledgments

- GDC for the data used in this work
- The contributions of Luigi Marini and other co-authors.
Thank you for your attention