Moisture condition with salinity behind the Dunhuang Mogao Grottoes, China

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Location of Dunhuang, China

Temperature: 9°C
Precipitation: 39.9mm
Evaporation: 4500mm
Climate: Extreme aridity
Mogao Grottoes

Mingsha Mountains

- Daquan River
- 1370m
- 40m

Entrance
aisle
irrigation
Cliff

West

Daquan River
Satellite Image by Landsat5-TM
Water pathway
① River Water
② Rain Water (30mm/year)
③ Irrigation of the Vegetation
④ Moisture movement in the Ground
Geo-environment behind the caves

Pattern diagram of moisture and salinity behind the Mogao Grottoes.
**Definition of electrical resistivity**

\[ R = \frac{V}{I} = \rho \times \frac{l}{S} \]

- \( \rho \): resistivity (\( \Omega \cdot m \))
- \( R \): resistance (\( \Omega \))
- \( V \): voltage (V)
- \( I \): current (A)
- \( l \): length (m)
- \( S \): section area (m\(^2\))

**Electrical resistivity** \( \Rightarrow \) **difficulty of the current flow**
# Factors affecting to the resistivity

<table>
<thead>
<tr>
<th>Factor</th>
<th>Low resistivity</th>
<th>High resistivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degree of water saturation</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>Conductivity of groundwater</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>Amount of conductive mineral</td>
<td>much</td>
<td>few</td>
</tr>
<tr>
<td>Porosity of saturated rock</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>Porosity of dry rock</td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>Temperature</td>
<td>high</td>
<td>low</td>
</tr>
</tbody>
</table>
Electrical resistivity survey
(2011/9/11～23)

Borehole

No30
No1
1.52m
1.17m
149.85m

150m
5m
Electrical resistivity tomography
Electrical resistivity tomography

- Lower resistivity zone
- Line 102
- Line 101
- Line 100
- Borehole 150m
- Line V102
- Line V100
- Color scale: 1000.0 - 500.0 [ohm-m]

Diagram showing resistivity values with color coding and annotation.
The lowest value is 45 Ω・m.
Laboratory experiments

Estimation of the relation between ER and water saturation under changing salt density

A cross-sectional schematic of the Mogao Grottoes
Local soil contains a large amount of salt. Is the low resistivity due to salinity? or due to water?

An electrode device

<table>
<thead>
<tr>
<th>Case</th>
<th>Resistivity (Ω·m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.756 × 10⁻³</td>
</tr>
<tr>
<td>B</td>
<td>1.50 × 10⁻³</td>
</tr>
<tr>
<td>C</td>
<td>3.14 × 10⁻³</td>
</tr>
<tr>
<td>D</td>
<td>16.7 × 10⁻³</td>
</tr>
</tbody>
</table>

The lowest resistivity zone

Degree of saturation (%)
Evaluation of the ER result by RI logging

45Ω・m⇔Sr: 55%
Salt content (0.0167g/g)

Result in Borehole No.3
Locations where soil samples was taken
Results in the surface ground

Distribution of salts in points A, B and C

Mass of salt in 10cm deep from the ground surface in point A and B.
The salt are uniformly distributed in the horizontal direction behind the west wall.
Comparison of the results

- The result of 108 caves and results up to 40cm depth of point C is almost the same.
- The amount of salt behind the Cave 108 is relatively high compared with the amount of salt deeper than 40cm from the surface.
### Estimation of the salinity

\[ w=5\% \]
\[ \frac{0.0167}{(0.05+0.0167)}=0.250(25.0\%) \]
\[ w=4\% \]
\[ \frac{0.0167}{(0.04+0.0167)}=0.294(29.4\%) \]

Salt content \((0.0167\text{g/g})\)

45Ω・m ⇔ \(S_r: 55\%\)

Field survey

Result in Borehole No.3
Estimation of the salinity

\[ w = 5\%, \text{ salt content} = 0.0016g/g \]
\[ \frac{0.0016}{0.05 + 0.0016} = 0.031 (3.1\%) \]

\[ w = 5\%, \text{ salt content} = 0.006g/g \]
\[ \frac{0.0167}{0.05 + 0.006} = 0.107 (10.7\%) \]

Distribution of salts in the Cave 108.
Conclusions

The result of the ER survey and laboratory experiment about the degree of the saturation around the 50m depth correspond exactly to the result of RI logging.

Degree of water saturation and mineral content were evaluated quantitatively.

- The degree of water saturation at the depth of around 50m is 55%.
- Salt content of approximately 0.017g/g is uniformly distributed and the average of the salt density is around 25%.
- Salt content of 0.0016 to 0.006g/g is present just behind the Cave 108.
Thank you for your kind attention