Hydrogeochemical Survey of groundwater for selected areas in the Arabian Shield and in cover rocks, Kingdom of Saudi Arabia

by

J. B. McHugh and W. R. Miller

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

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HYDROGEOCHEMICAL SURVEY OF GROUNDWATER FOR SELECTED AREAS IN THE ARABIAN SHIELD AND COVER ROCKS, KINGDOM OF SAUDI ARABIA

By

J. B. McHugh and W. R. Miller

ABSTRACT

In the spring of 1984, a hydrogeochemical survey was conducted in the Kingdom of Saudi Arabia to test ground water as a sampling medium in exploration for mineral deposits. Eighty-one water samples (mostly from wells) were collected. The samples were analysed for the presence and concentration of major cations and anions, as well as a suite of trace elements. Most of the water samples contained high concentrations of dissolved salts. The majority of the samples showed no significant amounts of the trace elements. A few well-water samples contained moderately anomalous concentrations of zinc, molybdenum, and uranium. These anomalies could be due to salinity effects, contamination, or the proximity of mineral sources. This survey has established some baseline water-chemistry data, especially for the trace metals, which to date have not been reported in ground water in the Kingdom of Saudi Arabia.

INTRODUCTION

In the spring of 1984, a hydrogeochemical survey was conducted in each of three selected areas in the Kingdom of Saudi Arabia (fig. 1). The purpose of the survey was to investigate the possibility of using ground water as a sampling medium in the exploration for mineral deposits, primarily within the cover rocks, but also within the rocks of the Arabian Shield. Three study areas were chosen on the basis of favorable criteria. The criteria used for selection of the three areas were (1) that the area be easily accessible by road, (2) that there be adequate sample density (wells), and (3) that favorable lithologies and (or) structures be present. Two of the selected areas, the Al Jawf and Layla areas, are within the cover rocks. The third selected area, the Hanakiyah area, is located within the Arabian Shield.

The climate of all three areas is hot and arid. Summer temperatures can reach 38° -50° C; annual average rainfall is 0-7 cm per year.
Figure 1.—Index map showing the three study areas, Kingdom of Saudi Arabia: 1) Al Jawf study area; 2) Hanaklyah study area; and 3) Layfa study area.
Hydrogeochemical techniques are useful for geochemical exploration and provide an understanding of geochemical processes active in an area. Background information on applications and limitations of hydrogeochemical techniques can be found in Boyle and others (1971), Cameron (1978), and Miller (1979). Hydrogeochemical exploration represents one of the few potentially useful geochemical exploration techniques in the region because of the presence of a great number of water wells within the cover-rock areas of the Kingdom of Saudi Arabia.

**SAMPLE COLLECTION**

Water samples were collected from 81 sites within the three study areas, 79 from wells and two from springs. Well pumps were powered by gasoline or diesel engines; one was powered by an electrical engine. Samples from three wells had to be obtained using a bucket and rope. Wells with pumps were allowed to flow for five minutes or longer before sample collection. The discharge of most pumping wells was greater than 500 L per minute.

Most of the pumping wells in each study area were sampled, although only a representative number of wells were sampled in several local areas with a high density of pumping wells. Depths of sampled wells in all three study areas ranged from 8-1,500 m and varied in nature from shallow wells that were usually hand dug to deeper machine-drilled wells.

At each locality, a 60-ml sample was collected and filtered through a Millipore HAWP (25 mm, 0.45 μ) filter and acidified with reagent-grade concentrated nitric acid to pH < 2. Water samples were stored in acid-rinsed polyethylene bottles. An untreated 250-ml sample was also collected.

**ANALYTICAL PROCEDURES**

Water temperature and pH were measured at the time of collection. Water samples were shipped to the U.S. Geological Survey laboratory in Denver, Colorado for analysis. The analyses were completed within three months from the date of collection. Determinations of alkalinity (HCO₃), specific conductance, and sulfate, chloride, fluoride, nitrate, and uranium content were conducted on the untreated samples. Concentrations of calcium, magnesium, sodium, potassium, lithium, silicon, zinc, copper, molybdenum, arsenic, iron, manganese, and aluminum were determined on the filtered and acidified samples. The analytical methods used for these analyses are shown in table 1. The chemical analyses, electrical-charge balance, and well depth for the 81 samples are shown in tables 2, 5, and 8.
The electrical-charge balance was calculated for each sample to determine the accuracy of the analyses. The charge balance is calculated by the equation

\[
\frac{\text{anions} - \text{cations}}{\text{eq. wt. eq. wt.}} \times 100 \% \text{ difference} = \frac{\text{anions} + \text{cations}}{\text{eq. wt. eq. wt.}}
\]

*eq. wt. = equivalent weight = molecular weight/charge

The results of the charge-balance calculations indicate that 47 of the samples are within 5 percent of neutrality, 33 samples are within 10 percent of neutrality, and one sample is within 14 percent of neutrality. These results support the analytical results for the major cations and anions.

Table 1.—Analytical methods used for water analysis.

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<th>Analytical method</th>
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AL JAWF STUDY AREA 1

The Al Jawf study area is located in the northwestern part of the Kingdom in the vicinity of the towns of Al Jawf and Sakakah (fig. 1). The study area, which measures 160 km (north to south) by 200 km (east to west), lies within cover rocks just north of the An Nafud desert. The area is a low-relief, treeless desert; elevation ranges from 500 to 700 m. Most of the domestic and irrigation water wells are located near the towns of Al Jawf and Sakakah, and are used to irrigate wheat fields and date groves. The cover rocks consist of mostly Devonian to Tertiary age limestone and dolomite, and Paleozoic sandstone (Bramkamp and others, 1963).

Twenty-six well-water samples were collected. Well depths range from 10 to 1,500 m. The town of Ar'ar uses two wells (1,500 m deep) for its water supply. The results of the chemical analyses of the 26 water samples from this area are shown on table 2; the summary of the chemical analyses is shown on table 3.

Table 2.—Analyses for 26 water samples from Al Jawf area.

[N, not detected; <, detected but below the limit of determination shown; >, determined to be greater than the value shown.]

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The waters from the Al Jawf area may be classified according to the dominant cation and anion present (table 4). The area contains the following quantities of water types: seven Na*-HCO₃, six Ca²⁺-Na⁺-HCO₃, six Na⁺-Cl⁻, one Ca²⁺-SO₄²⁻, and one Ca²⁺-Na⁺-SO₄²⁻. Water types reflect the major lithologies of the rocks of the study area.

Specific conductance, which is an approximate measure of dissolved salts, ranges from 350 to 4,100 μmho/cm in the study area, with a geometric mean of 887 μmho/cm. The high concentrations of dissolved salts are probably due to evaporative effects. The bicarbonate (HCO₃⁻)-dominant waters, which include half of the water samples collected in this area, are referred to by the local people as "sweet water" and have the lowest conductivity.

**Table 2.** Analyses for 26 water samples from Al Jawf area—Continued.

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<th>Sample</th>
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<th>F (mg/L)</th>
<th>NO₃ (mg/L)</th>
<th>Zn (μg/L)</th>
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</table>
The pH values measured at the surface range from 6.57 to 7.90, with a mean pH of 6.99. The pH of natural water is controlled by dissolved CO₂ and carbonate complexes in equilibrium with other ions in the solution system. High pH may be due to high-carbonate ions, and low pH may be caused by the presence of sulfides, organic matter, or carbon dioxide. The waters from the study area do not exhibit any unusually high or low pH values.

Samples 22 and 23 had the highest temperatures of the study area (48° and 49° C) and were obtained from 1,500-m deep wells.

Figures 2 through 7 are maps that show the distribution of concentrations of zinc, copper, molybdenum, uranium, sulfates, and fluorides in the study area. Zinc values range from <1 to 570 μg/L (fig. 2), with a geometric mean of 6.70 μg/L. Samples 5 and 26 contain the highest concentrations of zinc (570 and 320 μg/L). Samples 9 and 11 contain significant uranium concentration (20 and 7 μg/L, respectively).

Table 2.--Analyses for 26 water samples from Al Jawf area--Continued.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Fe(mg/L)</th>
<th>Mn(mg/L)</th>
<th>Al(mg/L)</th>
<th>U(μg/L)</th>
<th>Sp.cond.</th>
<th>pH</th>
<th>Temp.°C</th>
<th>Char_bal.</th>
<th>Depth (m)</th>
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<td>.03</td>
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### Table 3.—Summary of chemical analyses of 26 water samples from the Al Jawf area.

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<th>Constituent/Parameter</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Geometric mean</th>
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<tr>
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<td>Na (mg/L)</td>
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<td>AlK. (mg/L)</td>
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<td>130</td>
</tr>
<tr>
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<td>1,050</td>
<td>35</td>
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<tr>
<td>Cl (mg/L)</td>
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<td>118</td>
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<td>U (µg/L)</td>
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Specific conductance, µmho/cm 350
pH 6.57
Temperature, °C 21

1 Arithmetic mean

### Table 4.—Dominant major cation-anion water types, Al Jawf study area

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<tr>
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<td>Cl</td>
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<tr>
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<td>Na</td>
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<td>Na</td>
<td>Cl</td>
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<td>Na</td>
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<tr>
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<td>Na</td>
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<td>11</td>
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<td>Cl</td>
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<tr>
<td>12</td>
<td>Na</td>
<td>HCO₃</td>
</tr>
<tr>
<td>13</td>
<td>Na</td>
<td>SO₄</td>
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</table>

<table>
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<th>Sample no.</th>
<th>Cation</th>
<th>Anion</th>
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</thead>
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<td>SO₄</td>
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<td>Cl</td>
</tr>
<tr>
<td>26</td>
<td>Na</td>
<td>Cl</td>
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</table>

8
12 Sample site showing the distribution of zinc (μg/L)

- 320-570
- 10-28
- less than 10
- Town, village

Figure 2.—Distribution of zinc in water, Al Jawf study area 1.
Sample site showing the distribution of copper ($\mu g/L$)

- $\circlearrowright$ 11-14
- $\circledcirc$ 4.2-7.3
- $+$ less than 3.2
- $\bullet$ Town, village

Figure 3.—Distribution of copper in water, Al Jawf study area 1.
Sample site showing the distribution of molybdenum (μg/L)

- 12
- 5.2-9.3
- less than 4.9
- Town, village

Figure 4.—Distribution of molybdenum in water, Al Jawf study area 1.
Figure 5.—Distribution of uranium in water, Al Jawf study area 1.
Figure 6.—Distribution of sulfate in water, Al Jawf study area 1.
Figure 7.—Distribution of fluoride in water, Al Jawf study area 1.

12 Sample site showing the distribution of fluoride (mg/L)

• Town, village

7.7-7.9
1.5-5.2
less than 1.5

Sakakah
DISCUSSION OF RESULTS

Half of the samples collected in the study area are bicarbonate-dominant waters that are produced by weathering of the predominant local rock type. The other half of the samples are sulfate-chloride dominant waters that result from the presence of salts that typically form in arid environments, especially in sedimentary rocks.

The high zinc concentrations in samples 5 and 26 could be due to contamination: all the samples were obtained from wells whose plumbing consists of zinc or iron pipes, and, therefore, contamination by these metals is likely. The copper and molybdenum concentrations are low in these waters. The two highest copper values could be due to contamination from the copper pumping equipment.

Samples 9 and 11, collected near the town of Sakakah, contain significant concentrations of uranium. Uranium mineralization in the Sakakah sandstone is possible and warrants further investigation.
The Hanakiyah study area is located about 100 km northeast of Al Madinah (fig. 1) and includes the towns of Hanakiyah and Hulayfah. The study area measures 240 km (north to south) by 200 km (east to west). The area is mostly a low-relief, treeless desert; elevations range from 800 to 1,200 m. Domestic and irrigation wells are usually located around towns and are used to irrigate date groves and wheat and vegetable fields. The rock types in this area are predominantly Proterozoic rhyolite, schist, andesite, granite, granodiorite, Tertiary basalt and andesite, and minor Quaternary gravel, sand, and silt (Brown and others, 1963). Twenty-eight water samples were collected from this area: 27 samples from wells and one sample from a spring (sample 32) in the town of Al Hayit. Well depths range from 8 to 152 m.

Table 5.—Analyses for 28 water samples from the Hanakiyah area.

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<th>Longitude</th>
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<th>Mg</th>
<th>Na</th>
<th>K</th>
<th>Li</th>
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<th>Alk</th>
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The chemical analyses for the 28 water samples from this area are shown in table 5. The summary of the chemical analyses for this area is shown in table 6. Table 7 shows the dominant water type for each sample in the Hanakiyah area. The area contains sixteen Na⁺-Cl⁻, one Ca²⁺-Na⁺-Cl⁻, one Na⁺-SO₄²⁻, and nine Na⁺-HCO₃⁻ waters.

Specific conductance ranges from 430 to 37,000 μmho/cm in the study area, with a geometric mean of 2,674 μmho/cm. The pH values range from 7.09 to 8.40, with a mean pH of 7.64. The high dissolved-salts content in samples with conductivity over 5,000 is probably due to dissolution of surficial evaporite deposits.

Distribution maps showing concentration of zinc, copper, molybdenum, uranium, sulfate, and fluoride can be seen in figures 8-13. Samples 49, 53, and 54 are located two degrees directly south of sample 50 and could not be placed on the distribution maps.

Table 5.—Analyses for 28 water samples from the Hanakiyah area—Continued.

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Table 6.—Summary of chemical analyses of 28 water samples from the Hanakiyah area

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<th>Maximum</th>
<th>Geometric mean</th>
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<td>Mg (mg/l)</td>
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<td>Na (mg/l)</td>
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<tr>
<td>K (mg/l)</td>
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<td>6.8</td>
</tr>
<tr>
<td>Li (μg/l)</td>
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</tr>
<tr>
<td>SiO₂ (mg/l)</td>
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<td>29.6</td>
</tr>
<tr>
<td>AlK. (mg/l)</td>
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<td>156</td>
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<td>SO₄ (mg/l)</td>
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<td>U (μg/l)</td>
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¹Arithmetic mean

Table 7.—Dominant major cation-anion water types, Hanakiyah study area.

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<th>Cation</th>
<th>Anion</th>
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<td>Na</td>
<td>HCO₃</td>
<td>43</td>
<td>Na</td>
<td>Cl</td>
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<td>Na</td>
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<td>Cl</td>
<td>45</td>
<td>Na</td>
<td>Cl</td>
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<td>HCO₃</td>
<td>54</td>
<td>Na</td>
<td>HCO₃</td>
</tr>
</tbody>
</table>
Sample site showing the distribution of zinc (μg/L)

- 240-340
- 20-42
- less than 20
- City, town

Figure 8.—Distribution of zinc in water, Hanakiyah study area 2.
Figure 9.—Distribution of copper in water, Hanaklyah study area 2.
Sample site showing the distribution of molybdenum (µg/L)

- 70-75
- 14-28
- less than 12
- City, town

Figure 10.—Distribution of molybdenum in water, Hanaklyah study area 2.
Sample site showing the distribution of uranium (µg/L)

- 13-15
- 3.6-10
- less than 2.8
- City, town

Figure 11.—Distribution of uranium in water, Hanaklyah study area 2.
Sample site showing the distribution of sulfate (mg/L)

- 1900-2500
- 683-1550
- less than 500
- City, town

Figure 12.—Distribution of sulfate in water, Hanakiyah study area 2.
Figure 13.—Distribution of fluoride in water, Hanakiyah study area 2.
DISCUSSION OF RESULTS

Nine samples collected from areas underlain by Tertiary basalt and andesite were bicarbonate-type water. The remaining 19 samples were chloride-sulfate type water that resulted from concentration of surficial salt.

Zinc concentrations are due to evaporative effects or contamination from galvanized pipe. The high zinc concentration in sample 35 could be due to a possible mineral source. The copper values are low or are due to evaporative effects, except for sample 41. Sample 41 has a copper concentration of 11 µg/L, which could be from contamination or a mineral source. Molybdenum values are mostly low. Higher values are probably due to evaporative effects, except for samples 39, 41, and 50. These samples may indicate the presence of a mineral source. Uranium concentrations of 1-2 µg/L are normal background values due to chemical weathering of igneous rocks and evaporative effects, and are not considered significant. The high nitrate concentrations in several of the samples could be due to contamination from waste or fertilizer.
LAYLA STUDY AREA 3

The Layla study area is located south of Riyadh (fig. 1). The area includes the towns of Layla, Al Badi, and Suwaydan. The study area, which measures 90 km (north to south) and 50 km (east to west) lies within cover rocks just east of Jibal Tuwayq. The area is a low-relief, treeless desert, with elevations ranging from 500 to 800 m. Most of the irrigation wells are used to irrigate wheat fields. The cover rocks of this area are Jurassic anhydrite and gypsum, Cretaceous limestone, and Quaternary gravels (Bramkamp and others, 1956).

Table 8.—Analyses for 27 water samples from the Layla area.

[N, not detected; <, detected but below the limit of determination shown; >, determined to be greater than the value shown; elemental concentrations in mg/L, except Li, which is in /g/L]

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</table>
Twenty-seven water samples were collected from the study area; all but one were obtained from domestic or irrigation wells. Well depths range from 16 to 400 m. Sample 78 was collected from a small lake fed by springs.

The chemical analyses for the 27 water samples collected from this area are shown in table 8; the summary of the chemical analyses for this area is shown in table 9; table 10 shows the dominant water type for each sample in the Layla area. The area contains seventeen Ca\(^{2+}\)-SO\(_4\)^{2-}, nine Ca\(^{2+}\)-SO\(_4\)^{2-}, and one Na\(^+\)-SO\(_4\)^{2-} waters.

Specific conductance has a range of 780 to 6,600 \(\mu\text{mho/cm}\) in the study area, with a geometric mean of 2,413 \(\mu\text{mho/cm}\). The pH values range from 7.00 to 8.01, with a mean pH of 7.30.

Distribution maps showing concentration of zinc, copper, molybdenum, uranium, sulfate, and fluoride are shown in figures 14-19.

**Table 8.—Analyses for 27 water samples from the Layla area—Continued.**

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Table 8.—Analyses for 27 water samples from the Layla area—Continued.

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<th>U (µg/L)</th>
<th>Sp.cond.</th>
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<th>Temp. C</th>
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Table 9.—Summary of chemical analyses of 27 water samples from the Layla area

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1Arithmetic mean

Table 10.—Dominant major cation-anion water types, Layla study area

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</table>
Sample site showing the distribution of zinc (μg/L)

- 95
- 15-32
- less than 15
- Town, village

Figure 14.—Distribution of zinc in water, Layla study area 3.
Sample site showing the distribution of copper ($\mu g/L$)

- 13
- 6.5-7.7
- less than 5.8
- Town, village

Figure 15.—Distribution of copper in water, Layla study area 3.
71 Sample site showing the distribution of molybdenum (μg/L)

- 21
- 15-19
+ less than 15

- Town, village

Figure 16.—Distribution of molybdenum in water, Layla study area 3.
Sample site showing the distribution of uranium (μg/L)

- 8-11
- 4.0-5.6
- less than 4.0
- Town, village

Figure 17.—Distribution of uranium in water, Layla study area 3.
Sample site showing the distribution of sulfate (mg/L)

- 2370
- 1210-1680
- less than 1100

- Town, village

Figure 18.—Distribution of sulfate in water, Layla study area 3.
Sample site showing the distribution of fluoride (mg/L)

- **+** 2.9
- **♀** 1.0-1.7
- **+** less than 1.0
- **●** Town, village

Figure 19.—Distribution of fluoride in water, Layla study area 3.
DISCUSSION OF RESULTS

All the samples collected were sulfate-type waters, reflecting the dissolution of gypsum and anhydrite from rocks of the area. Zinc values are typically low. High concentrations reflect contamination from galvanized pipe. Sample 64 (95 µg/L zinc) could possibly represent a mineral source. Most of the copper values are low; the higher values are probably due to evaporative effects. Molybdenum concentrations are due to the effects of concentration of salts, except for samples 64, 67, 77, and 78. Molybdenum values for these samples may be due to mineral sources. All uranium values are due to the effects of evaporation.

CONCLUSIONS

Water samples were collected from three study areas in the Kingdom of Saudi Arabia; two of the areas are located within cover rocks and the other area lies within the rocks of the Arabian Shield. The samples were analysed for the content of major cations and anions, plus a suite of trace elements. Most of the waters are high in dissolved salts. Most trace elements are preferentially concentrated in this type of water. Two samples from the Al Jawf area may reflect uranium mineralization, and seven samples from the Hanakiyah and Layla areas reflect the possible presence of molybdenum-bearing mineral sources.

The study is inconclusive as to the effectiveness of water as an exploration medium in Saudi Arabia. It has provided some basic water data, especially for trace-element content. More hydrogeochemical studies are needed to reach a conclusion concerning the possible use of water as an exploration medium. Hydrogeochemical interpretation should be used in conjunction with an understanding of the geology and structure of study area.

ACKNOWLEDGMENTS

Special thanks go to Paul Togans of the U.S. Geological Survey Mission in Jeddah, for his field assistance, and to A. H. Handy, Joint Commission on Economic Cooperation, Riyadh, for his special assistance on the project. Thanks are also due to Robert J. Kamilli and Rick Carten for their technical reviews of the paper. This paper is based on work conducted by the authors under a work agreement with the Saudi Arabian Deputy Ministry for Mineral Resources.

DATA STORAGE

All results obtained in this study are contained in this report; therefore, no Data File was established.

No updated information was added to the Mineral Occurrence Documentation System (MODS) data bank and no new files were established.
REFERENCES CITED


