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

by

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

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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.

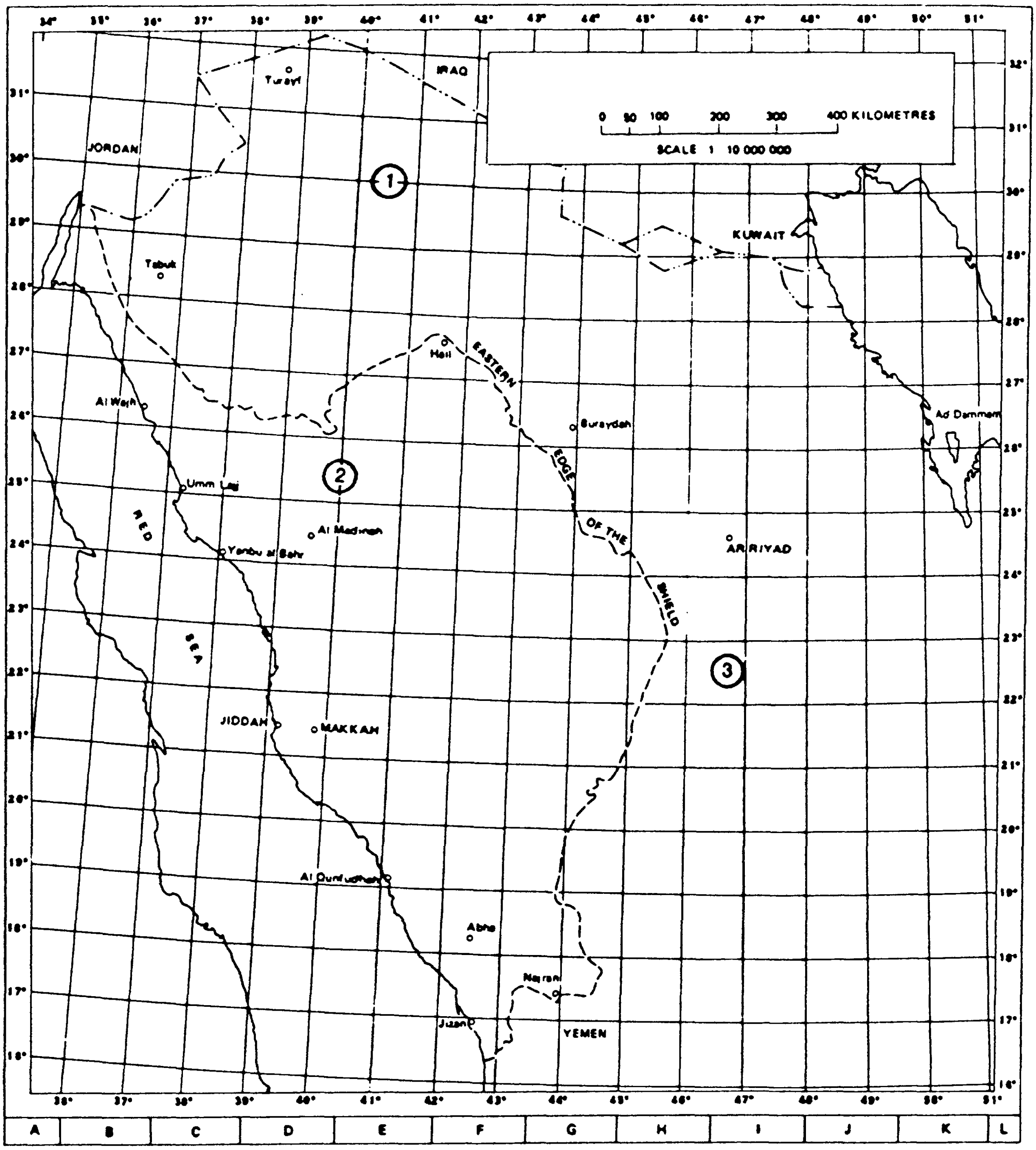


Figure 1.–Index map showing the three study areas, Kingdom of Saudi Arabia: 1) Al Jawf study area; 2) Hanakiyah study area; and 3) Layla study area.

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 (HCO_3), 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

$$\frac{\frac{\text{anions}}{\text{*eq. wt.}} - \frac{\text{cations}}{\text{eq. wt.}}}{\frac{\text{anions}}{\text{eq. wt.}} + \frac{\text{cations}}{\text{eq. wt.}}} \times 100\ \%\ \text{difference}$$

*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.

Constituent/ Parameter	Analytical method	Reference
Sulfate--------	Ion chromatography------------------------	Fishman and Pyen (1979)
Chloride-------	---do------------------------------------	Do.
Fluoride-------	---do------------------------------------	Do.
Nitrate--------	---do------------------------------------	Do.
Calcium--------	Flame atomic absorption spectrophotometry-	Perkin-Elmer Corp. (1982)
Magnesium------	---do------------------------------------	Do.
Sodium---------	---do------------------------------------	Do.
Potassium------	---do------------------------------------	Do.
Lithium--------	---do------------------------------------	Do.
Silicon--------	---do------------------------------------	Do.
Zinc-----------	---do------------------------------------	Do.
Iron-----------	---do------------------------------------	Do.
Manganese------	---do------------------------------------	Do.
Copper---------	Flameless atomic absorption spectrophotometry----------------------	Perkin-Elmer Corp. (1977)
Aluminum-------	---do------------------------------------	Do.
Molybdenum-----	---do------------------------------------	Do.
Arsenic--------	---do------------------------------------	Do.
Uranium--------	Laser excited fluorescence----------------	Scintrex Corp. (1978)
Specific conductance--	Conductivity bridge	Brown and others (1970)
Alkalinity-----	Gran's plot potentiometer titration-------	Orion Research, Inc. (1978)

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.]

Sample	Latitude	Longitude	Ca(mg/L)	Mg(mg/L)	Na(mg/L)	K(mg/L)	Li(µg/L)	SiO_2(mg/L)	Alk(mg/L)
01	29 48 40	39 52 0	270	160	630	112.0	84	22	243
02	29 49 20	39 51 40	27	10	21	14.0	12	16	116
03	29 48 10	39 53 10	27	10	23	13.0	11	15	119
04	29 48 10	40 10 40	50	17	90	6.7	16	15	116
05	29 49 40	40 8 30	60	20	96	8.1	17	14	125
06	29 49 30	40 7 40	88	24	110	8.7	15	16	127
07	29 52 0	40 12 50	101	32	87	14.0	19	14	129
08	29 54 30	40 11 20	78	22	100	8.9	19	15	73
09	29 58 40	40 13 10	125	34	230	31.0	72	25	69
10	29 59 40	40 14 20	31	15	84	12.0	17	14	156
11	30 0 0	40 14 0	125	59	270	26.0	31	15	214
12	30 0 0	40 14 1	46	22	80	14.0	14	12	115
13	30 0 0	40 14 2	65	24	120	14.0	18	21	139
14	29 47 40	39 50 30	150	105	580	70.0	100	14	104
15	29 47 30	39 52 40	79	43	77	50.0	45	19	166
16	29 45 40	39 41 0	51	20	84	17.0	16	19	95
17	29 20 30	40 8 0	31	11	31	7.1	9	13	91
18	29 49 0	39 35 10	39	16	89	16.0	14	17	102
19	29 49 40	39 35 0	32	10	26	12.0	7	17	97
20	29 50 30	39 34 40	40	13	34	13.0	8	17	94
21	30 36 20	40 32 50	29	17	72	19.0	30	15	175
22	30 58 30	41 1 0	15	19	160	42.0	76	23	266
23	30 58 0	41 2 0	15	20	230	48.0	87	22	274
24	30 5 40	40 16 20	56	22	72	8.3	17	12	105
25	30 5 40	40 21 40	62	21	110	11.0	16	12	148
26	30 23 0	40 8 30	76	26	185	8.2	25	14	169

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^{+}-HCO_3^{-}, six Ca_2^{+}-Na^{+}-HCO_3^{-}, six Na^{+}-Cl^{-}, one Ca_2^{+}-SO_4^{2-}, and one Ca_2^{+}-Na^{+}-SO_4^{2-}. 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 (HCO_3^{-})-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.

Sample	SO_4(mg/L)	Cl(mg/L)	F(mg/L)	NO_3(mg/L)	Zn(μg/L)	Cu(μg/L)	Mo(μg/L)	As(μg/L)
01	1,050	911	1.70	130	10	7.3	9.3	<1
02	40	17	.29	<1	<1	2.6	2.9	<1
03	43	20	.29	<1	<1	<1.0	5.5	<1
04	90	165	.47	30	1	1.1	3.9	<1
05	116	120	.67	11	570	1.6	3.6	<1
06	180	200	.17	30	7	1.6	4.4	<1
07	260	150	.20	<1	4	2.0	3.5	<1
08	130	198	4.10	27	15	2.0	5.2	<1
09	550	200	<.10	<1	8	4.2	7.4	<1
10	76	66	1.00	<1	2	14.0	2.2	<1
11	410	529	<.10	36	6	11.0	2.7	<1
12	106	88	1.90	3	28	1.4	3.0	<1
13	198	140	1.30	23	5	3.2	4.1	<1
14	705	550	5.20	27	9	4.8	4.5	<1
15	313	98	7.90	<1	8	2.2	12.0	<1
16	136	99	7.70	<1	5	1.8	4.8	<1
17	39	43	.30	21	27	<1.0	4.9	<1
18	88	101	.34	7	3	1.8	3.1	<1
19	54	20	.24	1	3	1.7	2.7	<1
20	76	55	<.10	3	4	1.2	5.7	1
21	70	69	.35	<1	8	1.7	2.7	<1
22	100	130	1.30	<1	4	7.3	2.5	1
23	100	208	1.50	<1	1	2.9	2.2	<1
24	91	104	<.10	14	9	1.1	2.7	<1
25	120	162	.70	75	6	1.5	4.2	<1
26	184	273	.90	<1	320	1.9	3.8	<1

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 disolved $CO_2$and carbonate complexes in equilibriium 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.

Sample	Fe(mg/L)	Mn(mg/L)	Al(mg/L)	U(µg/L)	Sp.cond.	pH	Temp.C	Char.bal.	Depth (m)
01	.010	.03	.03	2.00	4,100	7.33	23	2.9	30
02	.320	.15	.04	<.10	350	6.87	29	3.2	180
03	.440	.14	.04	<.10	360	6.83	28	1.2	100
04	.010	.03	.03	.88	770	7.05	26	-5.6	100
05	.005	.04	.04	.58	870	7.04	21	5.7	170
06	.020	.01	.04	3.20	1,100	6.89	27	-2.5	120
07	.030	.04	.05	1.90	1,100	7.02	26	.3	140
08	.005	.02	.04	1.50	1,000	7.24	26	.8	100
09	.130	.01	.04	20.00	1,750	6.94	25	4.2	30
10	.005	.01	.08	.40	600	7.27	28	5.4	100
11	.010	.01	.06	7.00	1,850	7.00	25	-7.9	100
12	.040	.02	.03	1.90	690	7.27	27	8.4	150
13	.160	.02	.50	2.60	1,000	7.90	24	.1	10
14	.020	.03	.02	2.80	3,200	7.30	27	14.0	100
15	.070	.12	.02	1.90	1,060	7.06	28	-1.2	200
16	.190	.07	.01	.78	800	6.90	36	4.4	380
17	.005	.01	.04	.74	390	6.90	27	1.5	280
18	.240	.13	.01	<.10	690	6.69	35	7.6	200
19	.150	.15	.03	<.10	390	6.58	35	7.7	200
20	.080	.12	.03	.40	480	6.57	34	1.6	200
21	.780	.08	.01	<.10	590	6.85	38	1.4	680
22	1.900	.06	.02	<.10	920	6.64	48	.8	1,500
23	1.800	.03	.05	<.10	1,200	6.63	49	4.2	1,500
24	.020	.01	.05	3.00	720	7.10	26	8.1	190
25	.010	.01	.03	3.20	950	7.12	25	-4.1	115
26	.030	.01	.03	2.40	1,280	6.97	24	-.5	300

Table 3.--Summary of chemical analyses of 26 water samples from the Al Jawf area.

Constituent/ Parameter	Minimum	Maximum	Geometric mean
Ca (mg/L)	15	270	53.7
Mg (mg/L)	10	160	22.9
Na (mg/L)	21	630	97.0
K (mg/L)	6.7	112	16.8
Li (µg/L)	7.0	100	22.3
SiO_2 (mg/L)	12	25	16.1
Alk. (mg/L)	69	274	130
SO_4 (mg/L)	39	1,050	35
Cl (mg/L)	17	911	118
F (mg/L)	<0.1	7.9	0.593
NO_3 (mg/L)	<1	130	4.25
Zn (µg/L)	<1	570	6.70
Cu (µg/L)	<1	14	2.30
Mo (µg/L)	2.2	12	3.96
Fe (mg/L)	0.005	1.9	0.053
Mn (mg/L)	0.01	0.15	0.033
Al (mg/L)	0.01	0.5	0.034
U (µg/L)	<0.1	20	0.752
Specific conductance, µmho/cm	350	4,100	887
pH	6.57	7.90	7.00[1]
Temperature, °C	21	49	28.8

[1] Arithmetic mean

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

Sample no.	Cation	Anion	Sample no.	Cation	Anion
1	Na	SO_4	14	Na	SO_4
2	Ca-Na	HCO_3	15	Ca-Na	SO_4
3	Ca-Na	HCO_3	16	Na	SO_4
4	Na	Cl	17	Ca-Na	HCO_3
5	Na	HCO_3	18	Na	HCO_3
6	Na	Cl	19	Ca-Na	HCO_3
7	Ca	SO_4	20	Ca-Na	HCO_3
8	Na	Cl	21	Na	HCO_3
9	Na	SO_4	22	Na	HCO_3
10	Na	HCO_3	23	Na	HCO_3
11	Na	Cl	24	Ca-Na	HCO_3
12	Na	HCO_3	25	Na	Cl
13	Na	SO_4	26	Na	Cl

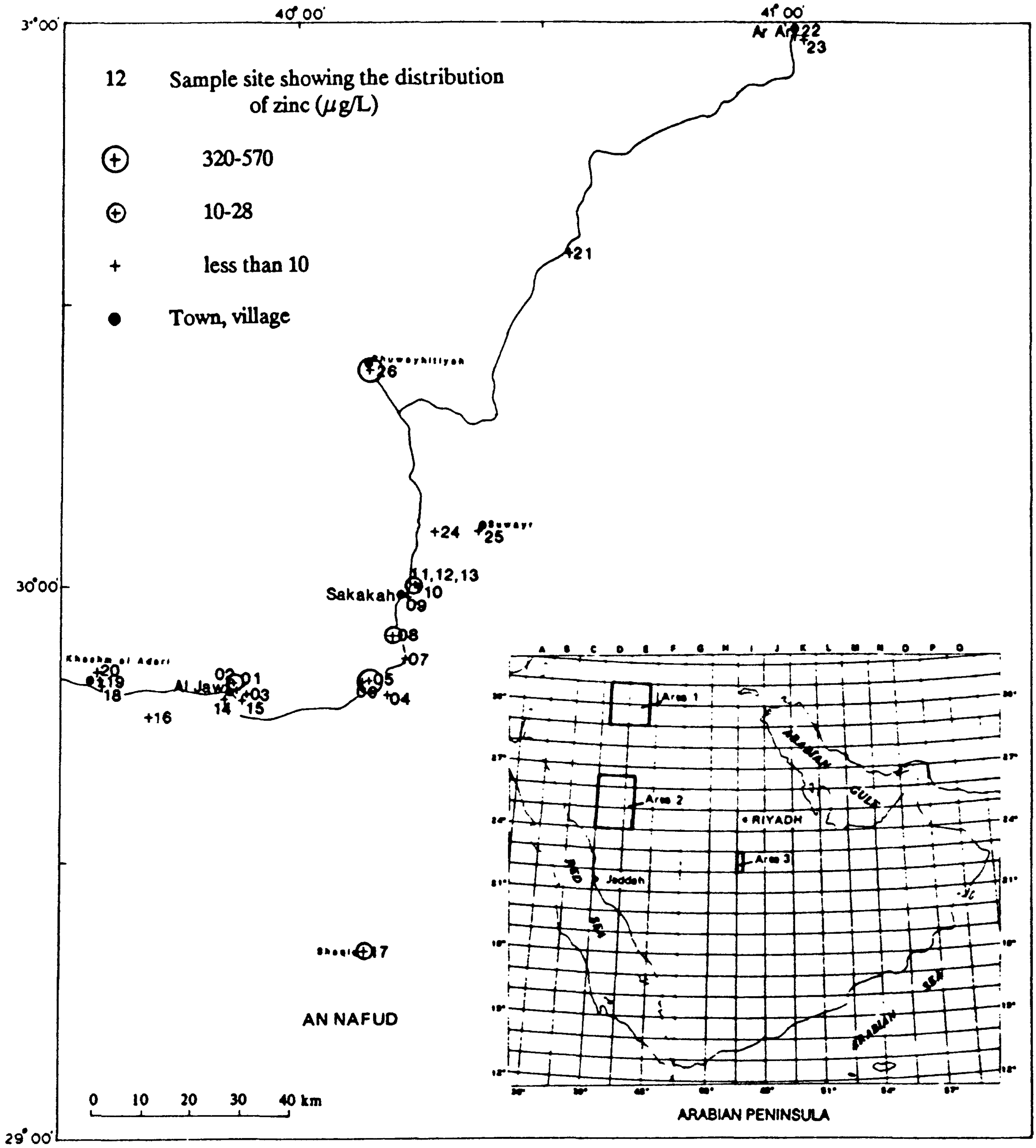


Figure 2.--Distribution of zinc in water, Al Jawf study area 1.

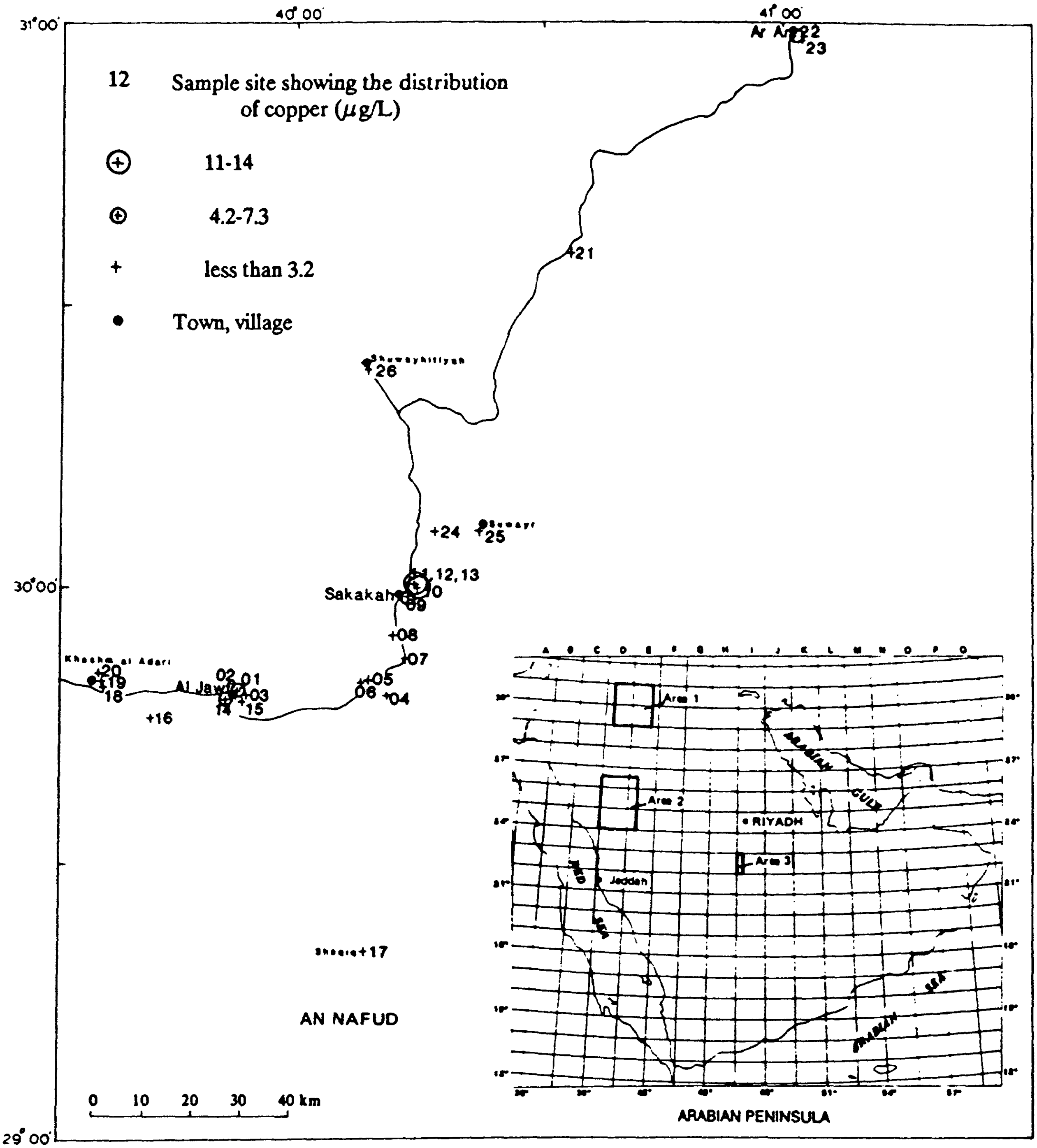


Figure 3.--Distribution of copper in water, Al Jawf study area 1.

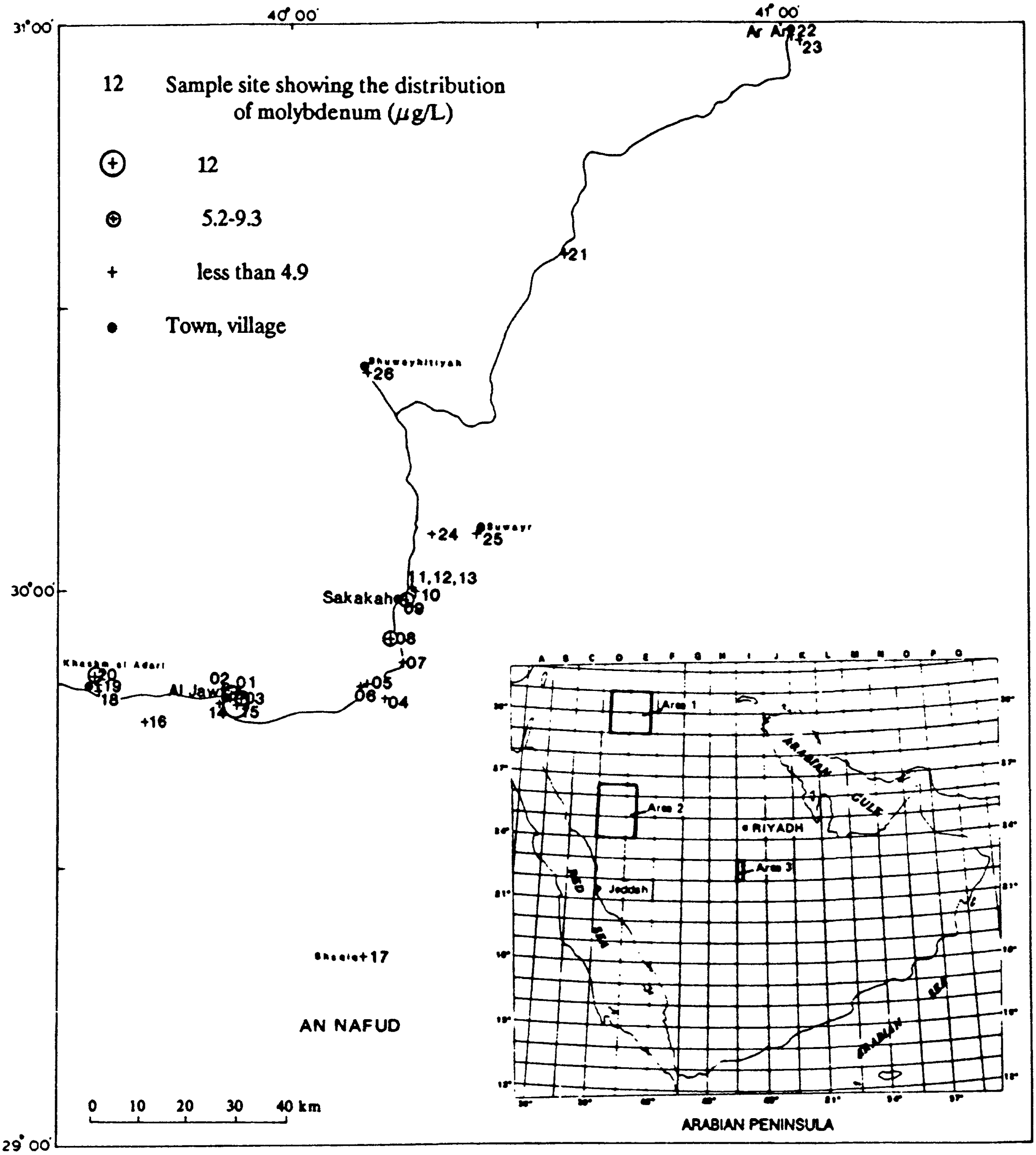


Figure 4.–Distribution of molybdenum in water, Al Jawf study area 1.

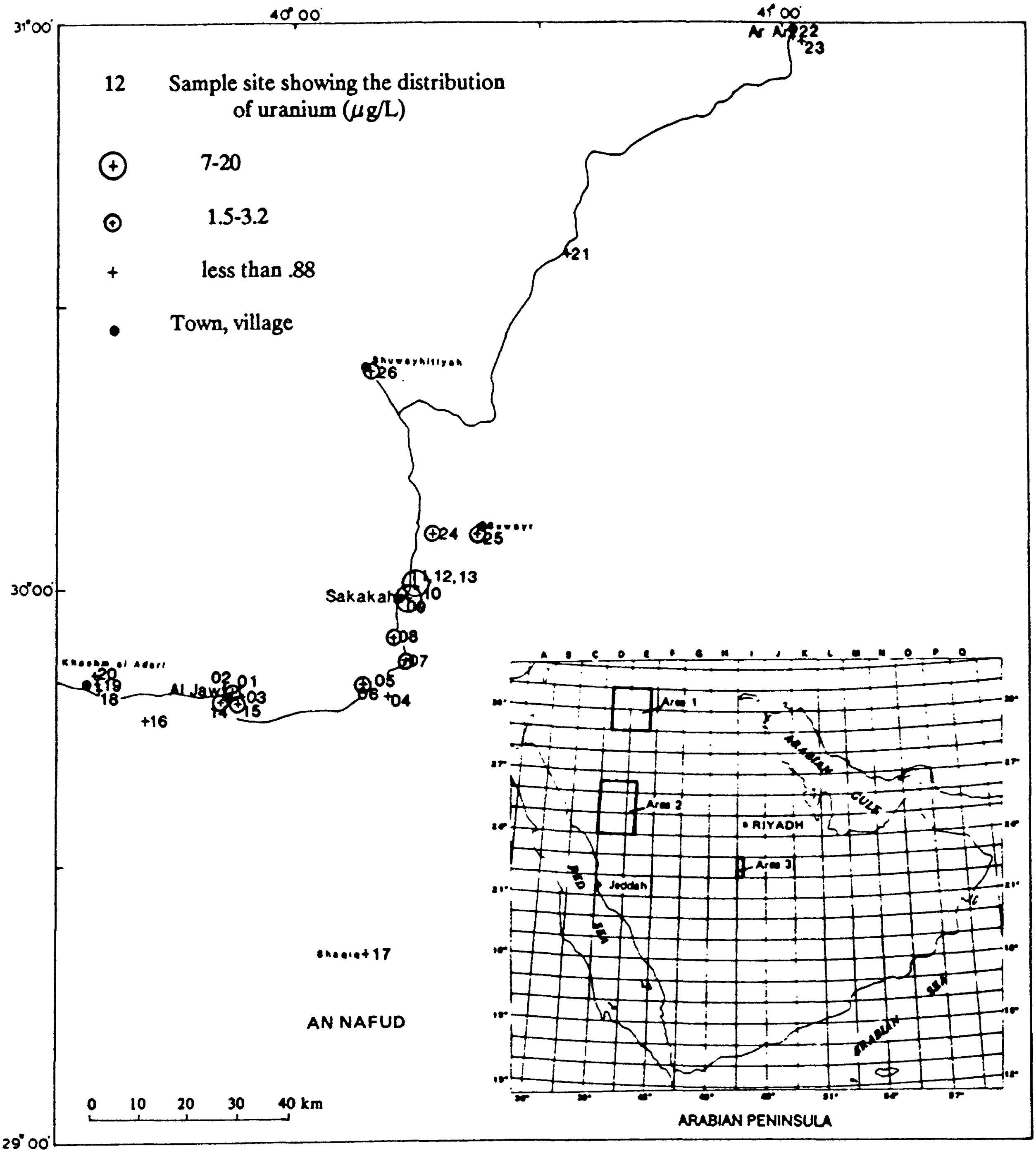


Figure 5.—Distribution of uranium in water, Al Jawf study area 1.

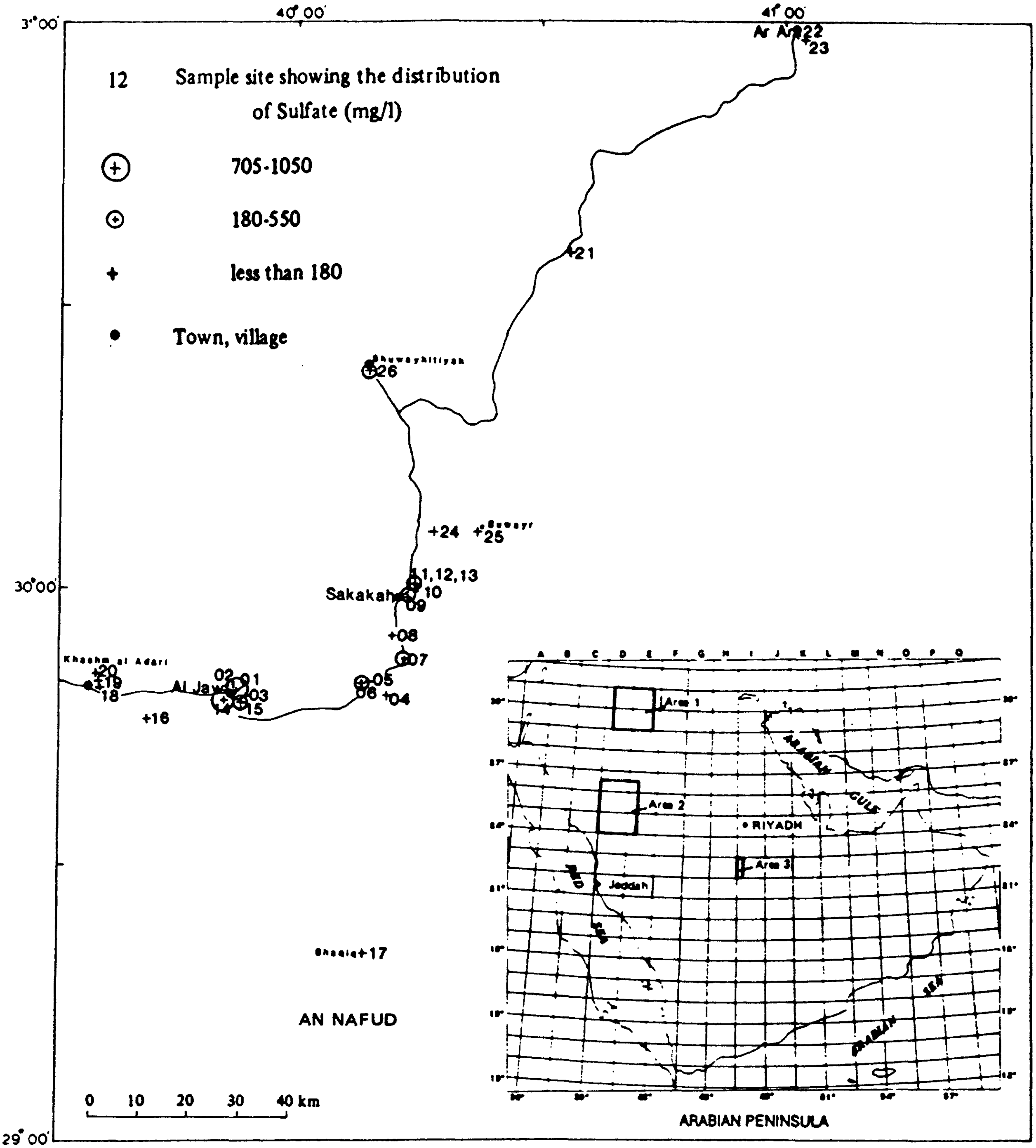


Figure 6.–Distribution of sulfate in water, Al Jawf study area 1.

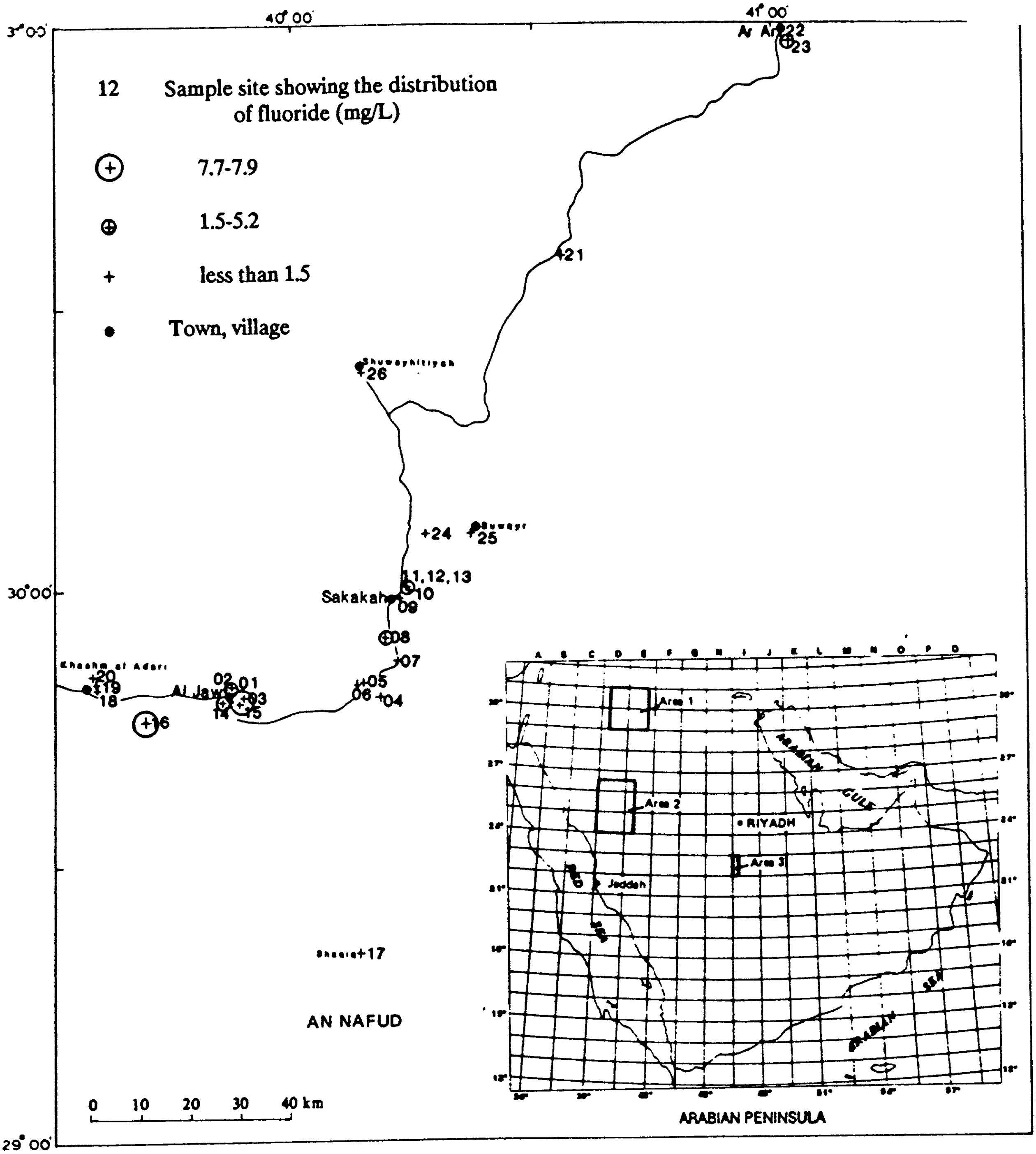


Figure 7.--Distribution of fluoride in water, Al Jawf study area 1.

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.

HANAKIYAH STUDY AREA 2

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.

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

Sample	Latitude	Longitude	Ca	Mg	Na	K	Li	SiO_2	Alk
27	25 16 40	40 36 50	320	105	660	4.3	42	31	85
28	26 0 0	40 49 20	20	6	72	6.4	6	22	167
29	26 0 30	40 51 30	35	13	77	5.1	10	29	218
30	26 1 30	40 52 20	66	22	210	4.5	8	26	122
31	25 55 30	40 42 30	260	150	1,350	9.4	32	35	127
32	25 58 30	40 27 0	18	24	140	4.0	4	31	288
33	24 52 30	40 30 20	250	145	960	11.0	20	31	263
34	24 53 0	40 30 10	111	50	460	4.0	9	28	137
35	24 55 0	40 30 10	450	360	1,560	8.8	24	42	302
36	25 0 30	40 31 50	111	96	340	6.5	10	31	102
37	25 0 0	40 32 30	150	128	440	7.5	10	32	238
38	25 3 20	40 30 50	44	37	210	4.1	5	29	215
39	25 7 0	40 20 0	19	11	130	3.6	9	25	197
40	25 4 0	40 22 0	35	39	190	5.7	8	25	423
41	25 4 30	40 21 0	24	26	150	4.8	7	25	218
42	24 59 20	40 30 0	470	310	940	11.0	18	31	173
43	24 43 20	40 17 30	270	208	560	7.2	27	35	235
44	24 41 30	40 11 0	140	63	100	9.2	6	29	143
45	25 17 0	40 58 30	55	158	240	36.0	12	37	222
46	25 32 0	39 19 0	109	35	210	6.1	11	40	172
47	25 32 49	39 14 2	420	130	1,750	18.0	130	24	62
48	25 44 59	39 16 0	26	51	490	8.4	4	32	410
49	21 57 18	39 25 21	135	76	430	7.9	4	31	88
50	24 3 50	39 4 27	112	28	200	7.8	33	30	92
51	24 30 24	39 44 39	520	140	1,920	10.0	145	21	54
52	24 29 53	39 43 49	420	130	1,760	18.0	130	25	60
53	21 55 25	39 20 8	1,000	700	6,000	3.0	25	34	101
54	21 46 21	39 37 31	39	14	90	1.4	<4	29	110

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 Ca^{2+}-Na^+-Cl^-, one Na^+-$SO_4^=$, and nine Na^+-HCO_3^- 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.

Sample	SO_4(mg/L)	Cl(mg/L)	F(mg/L)	NO_3(mg/L)	Zn(µg/L)	Cu(µg/L)	Mo(µg/L)	As(µg/L)
27	1,040	910	2.50	85	21	9.7	10.0	2
28	24	40	.44	20	1	1.6	7.8	16
29	29	56	1.00	34	5	1.2	6.2	4
30	182	255	.90	14	4	2.4	10.0	4
31	1,220	2,037	2.00	57	20	10.0	9.4	2
32	59	83	.60	31	1	1.9	9.0	2
33	1,140	1,370	3.30	<1	15	5.5	9.0	1
34	470	515	.90	<1	8	6.1	3.9	2
35	1,900	2,420	5.50	282	340	8.4	17.0	1
36	390	450	.90	199	15	3.8	4.1	1
37	479	634	.33	223	4	4.7	3.9	1
38	121	193	1.00	27	4	3.0	7.0	2
39	78	65	.46	27	3	2.8	14.0	2
40	130	170	.90	28	10	3.2	11.0	1
41	103	105	.50	31	2	11.0	12.0	2
42	1,550	1,820	2.30	326	20	6.2	14.0	1
43	337	1,610	1.20	194	21	3.8	8.1	1
44	198	365	.80	22	5	2.1	3.7	3
45	271	528	.50	21	24	4.3	2.2	4
46	194	295	.60	53	10	2.2	9.1	1
47	683	3,090	1.60	143	42	6.7	16.0	<1
48	416	298	.30	40	5	6.0	15.0	2
49	445	660	.60	28	24	4.8	9.7	1
50	192	277	1.30	40	9	1.7	70.0	1
51	777	3,870	1.60	89	22	5.5	75.0	1
52	705	2,644	2.80	141	18	5.4	19.0	<1
53	2,500	9,000	17.00	400	240	30.0	28.0	<1
54	61	86	.30	18	5	1.5	7.1	<1

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

Sample	Fe(mg/L)	Mn(mg/L)	Al(mg/L)	U(µg/L)	Sp. cond.	pH	Temp(°C)	Char.bal.	Depth (m)
27	.040	.02	.03	7.60	3,400	7.25	26	3.2	10
28	.005	.03	.10	1.10	430	7.55	21	.8	10
29	.010	.03	.03	1.60	590	7.66	21	-.4	10
30	.020	.02	.06	2.80	1,240	7.80	30	4.0	8
31	.030	.02	.06	15.00	4,800	7.60	25	-1.0	25
32	.010	.02	.06	1.50	820	7.71	28	1.5	0
33	.090	.02	.05	10.00	5,300	7.20	29	-.3	65
34	.060	.01	.04	4.80	2,500	7.28	28	5.6	30
35	.050	.03	.05	14.00	8,200	7.36	26	1.2	60
36	.020	.02	.02	.90	2,450	7.50	30	5.0	65
37	.030	.02	.02	2.80	3,100	7.38	30	2.9	65
38	.010	.01	.02	.90	1,240	7.54	30	9.5	65
39	.010	.02	.01	1.50	730	7.72	32	3.1	75
40	.030	.02	.01	2.20	1,200	7.61	31	-5.4	65
41	.010	.01	.02	2.20	950	7.68	32	4.1	70
42	.070	.04	.04	3.60	6,500	7.66	32	-.8	70
43	.080	.02	.02	10.00	4,600	7.42	31	-3.6	152
44	.010	.02	.07	1.10	1,700	7.70	30	-1.0	65
45	.020	.01	.03	.18	2,450	7.09	28	5.2	20
46	.005	.08	.05	2.00	2,060	7.54	33	4.7	>80
47	.030	.07	.03	.80	11,500	7.82	27	1.6	74
48	.020	.02	.03	2.20	2,840	8.21	28	5.0	61
49	.010	.03	.07	.78	3,360	7.80	34	3.5	34
50	.005	1.00	.02	13.00	1,900	7.55	33	9.0	42
51	.030	.20	.03	<.10	13,000	7.80	34	-2.6	78
52	.030	.06	.02	.80	11,600	8.12	33	7.9	51
53	.100	.15	.10	1.60	37,000	8.05	33	7.3	22
54	.030	.03	.05	.50	850	8.40	31	9.7	48

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

Constituent/ Parameter	Minimum	Maximum	Geometric mean
Ca (mg/l)	18	1,000	110
Mg (mg/l)	6	700	64.6
Na (mg/l)	72	6,000	392
K (mg/l)	1.4	36	6.8
Li (µg/l)	2.8	145	13.9
SiO_2 (mg/l)	21	42	29.6
Alk. (mg/l)	54	423	156
SO_4 (mg/l)	24	2,500	301
Cl (mg/l)	40	9,000	490
F (mg/l)	0.3	17	1.07
NO_3 (mg/l)	<1	400	42.9
Zn (µg/l)	1	340	10.6
Cu (µg/l)	1.2	30	4.19
Mo (µ3/l)	2.2	75	10.2
As (µg/l)	<1	16	1.54
Fe (mg/l)	0.005	0.1	0.022
Mn (mg/l)	0.01	1.0	0.031
Al (mg/l)	0.01	0.1	0.034
U (µg/l)	<0.1	15	1.94
Specific Conductance, µmho/cm	430	37,000	2,674
pH	7.09	8.40	7.64[1]
Temperature, °C	21	34	29.3

[1]Arithmetic mean

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

Sample no.	Cation	Anion	Sample no.	Cation	Anion
27	Na	SO_4	41	Na	HCO_3
28	Na	HCO_3	42	Na	Cl
29	Na	HCO_3	43	Na	Cl
30	Na	Cl	44	Ca-Na	Cl
31	Na	Cl	45	Na	Cl
32	Na	HCO_3	46	Na	Cl
33	Ca	Cl	47	Na	Cl
34	Na	Cl	48	Na	HCO_3
35	Na	Cl	49	Na	Cl
36	Na	Cl	50	Na	Cl
37	Na	Cl	51	Na	Cl
38	Na	HCO_3	52	Na	Cl
39	Na	HCO_3	53	Na	Cl
40	Na	HCO_3	54	Na	HCO_3

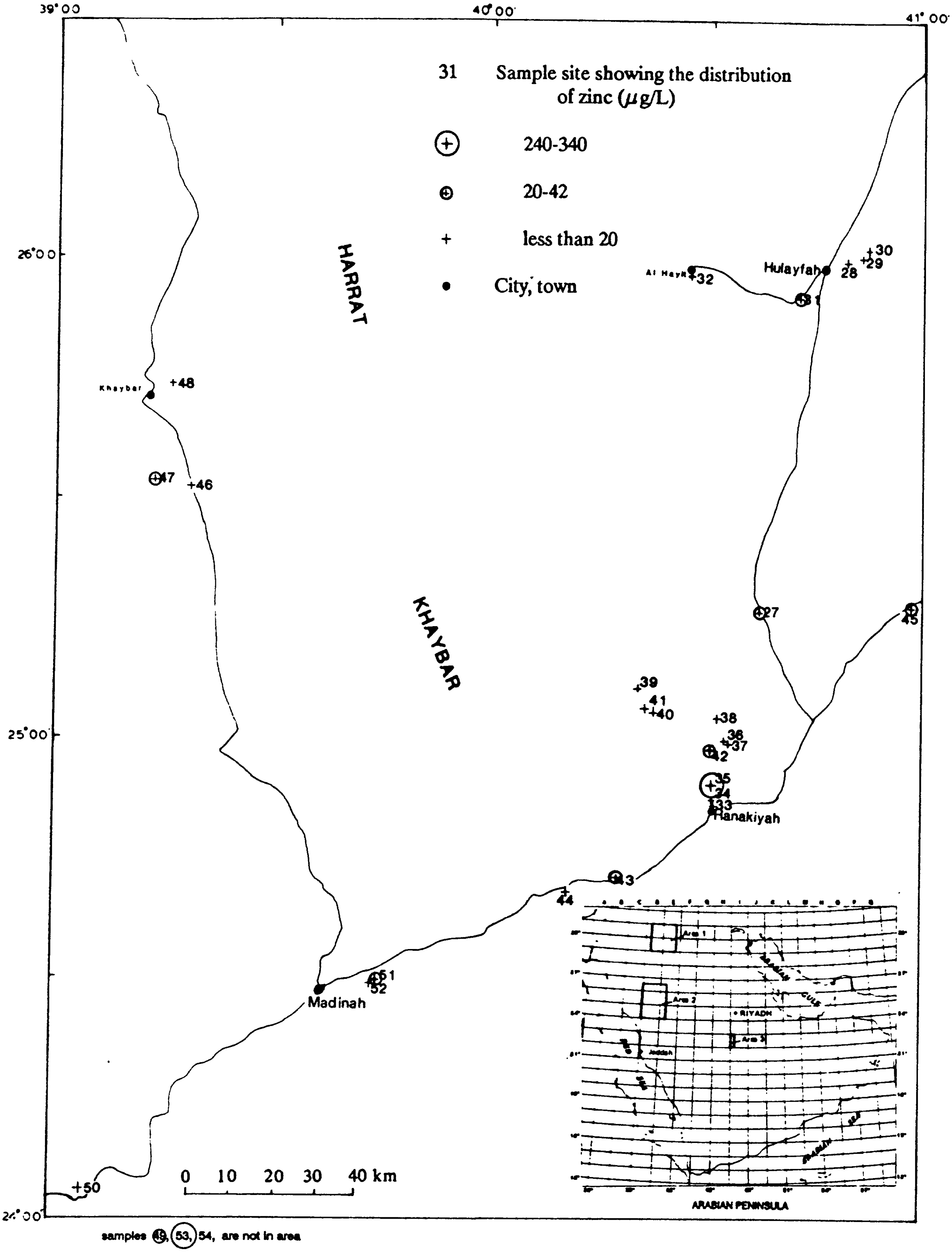
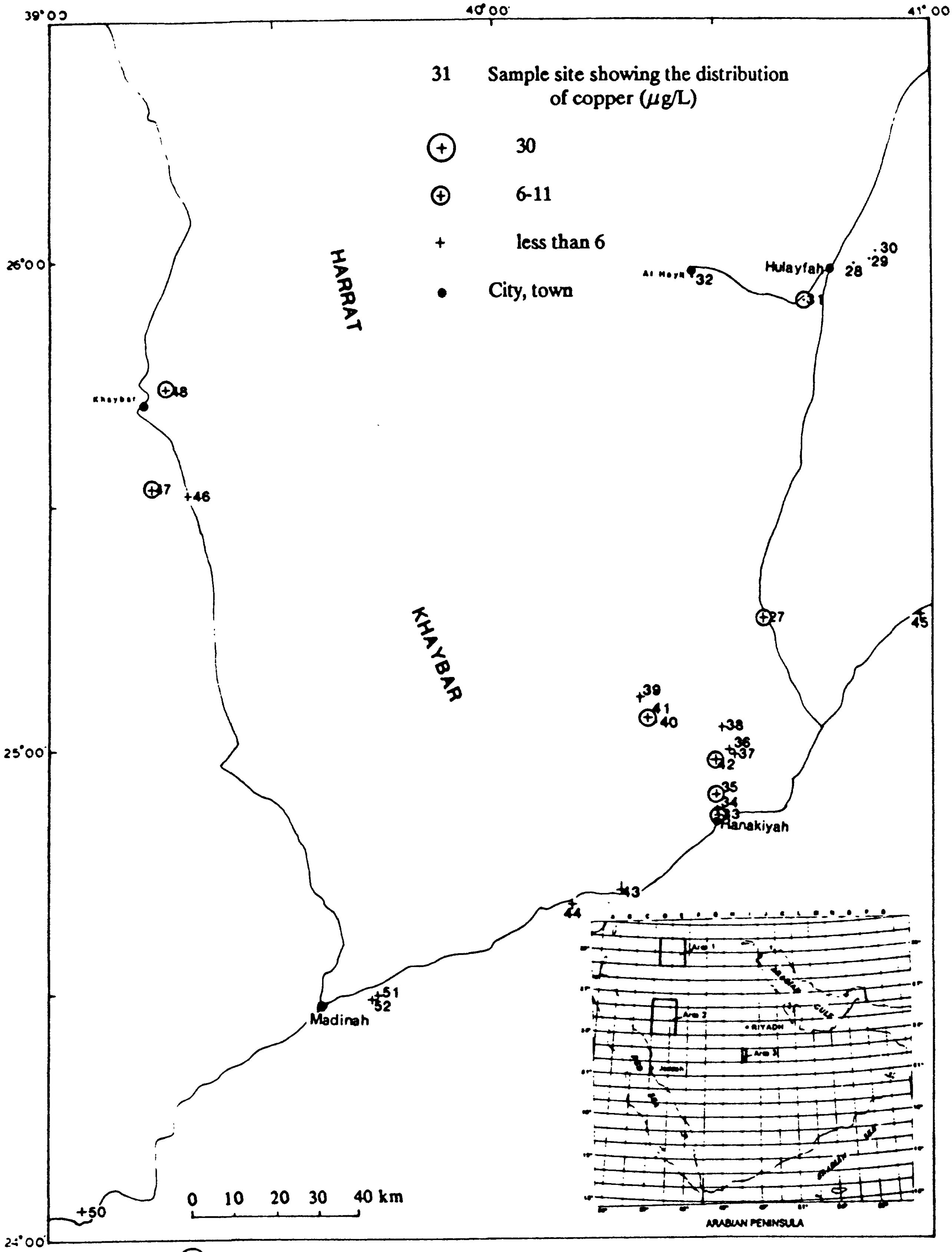
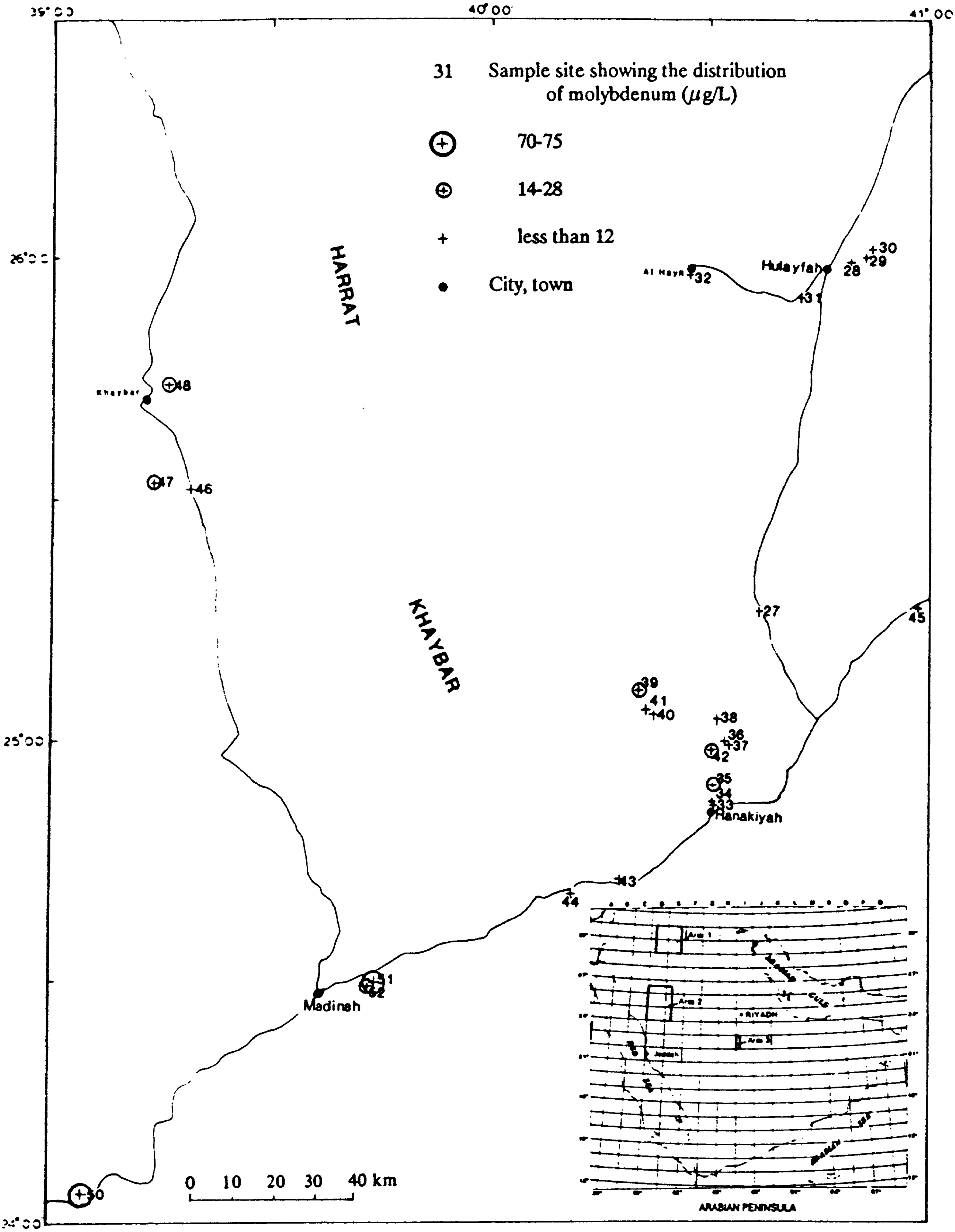


Figure 8.–Distribution of zinc in water, Hanakiyah study area 2.



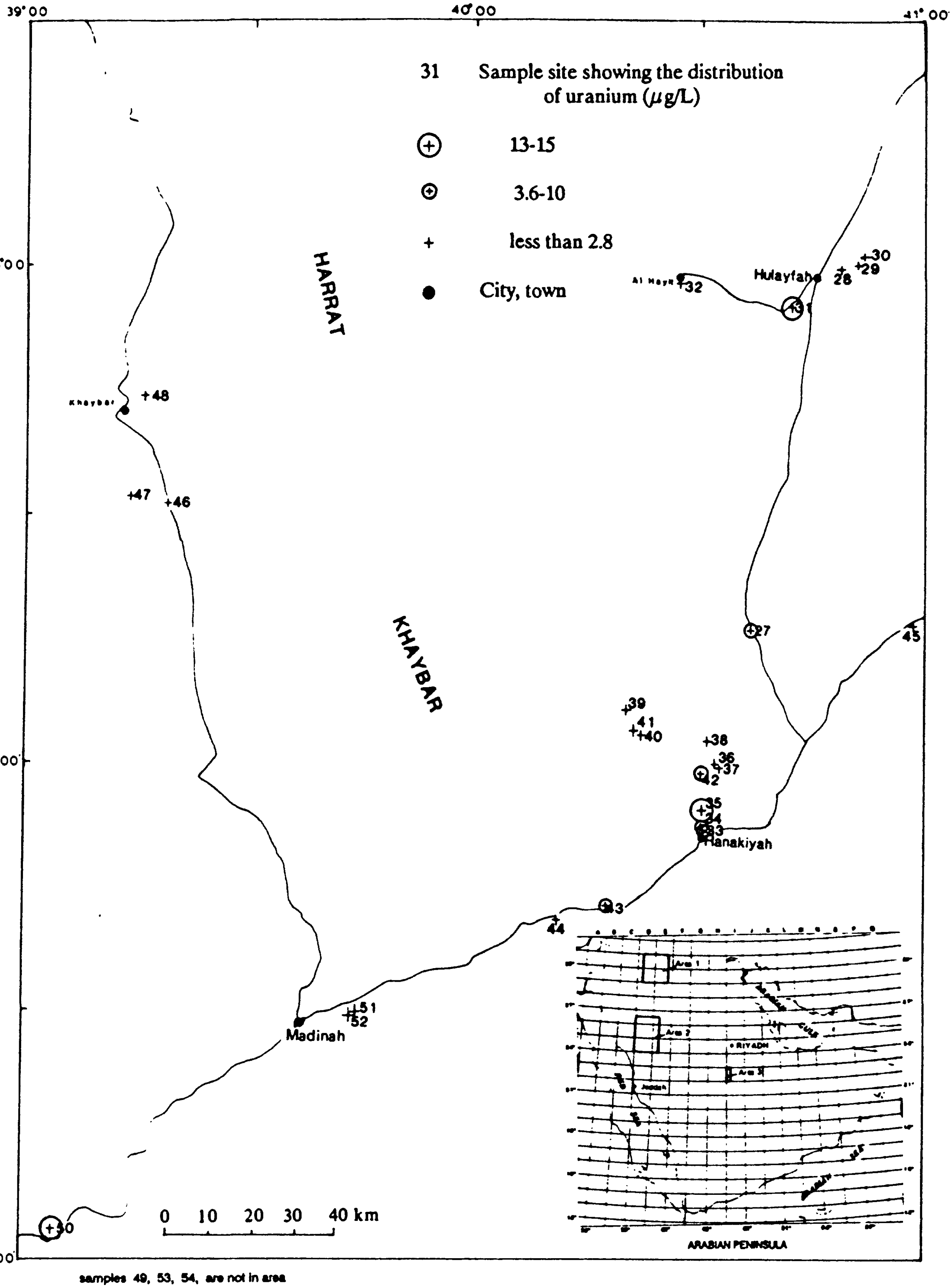
samples 49, (53,) 54, are not in area

Figure 9.--Distribution of copper in water, Hanakiyah study area 2.



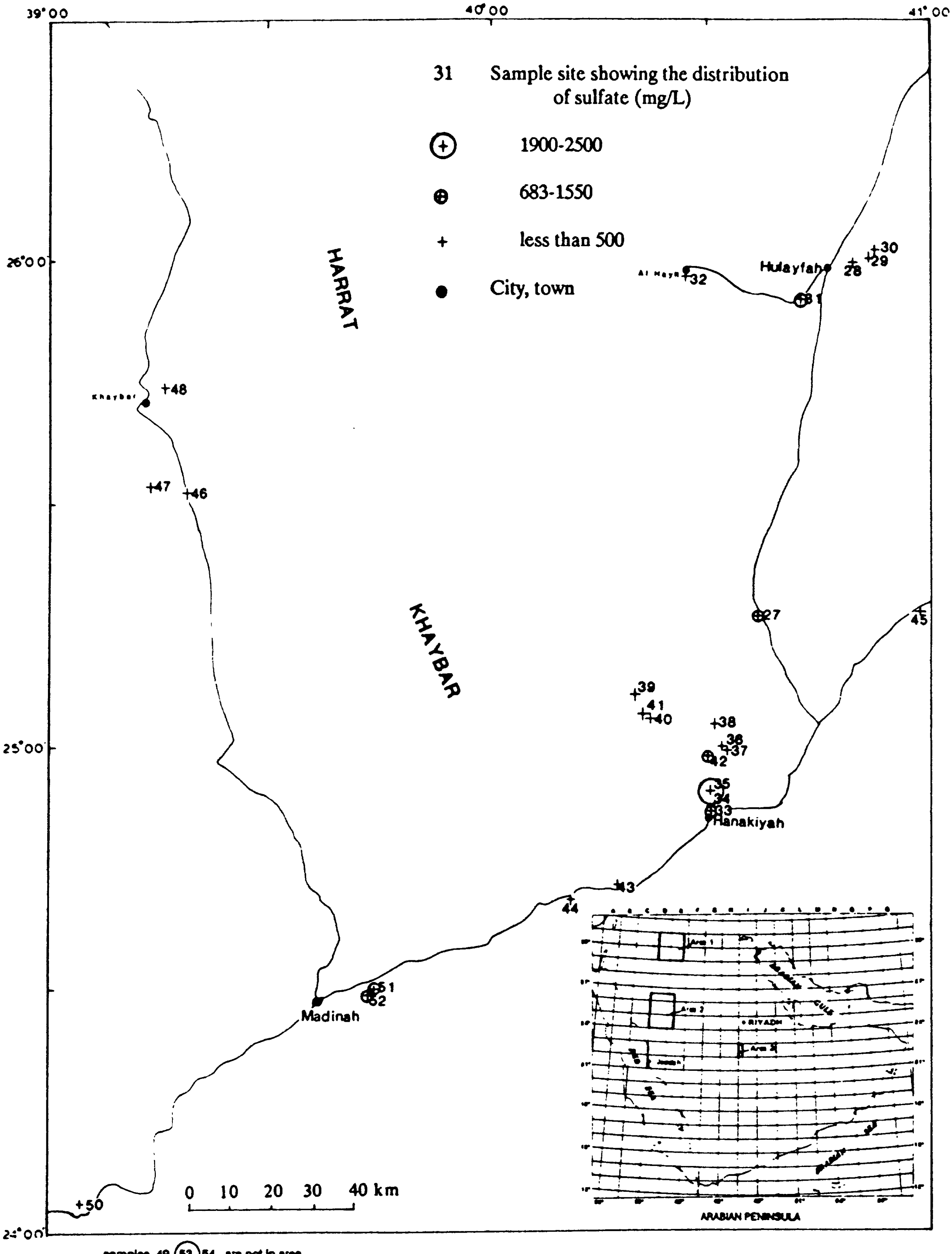
samples 49, 53, 54, are not in area

Figure 10.--Distribution of molybdenum in water, Hanakiyah study area 2.



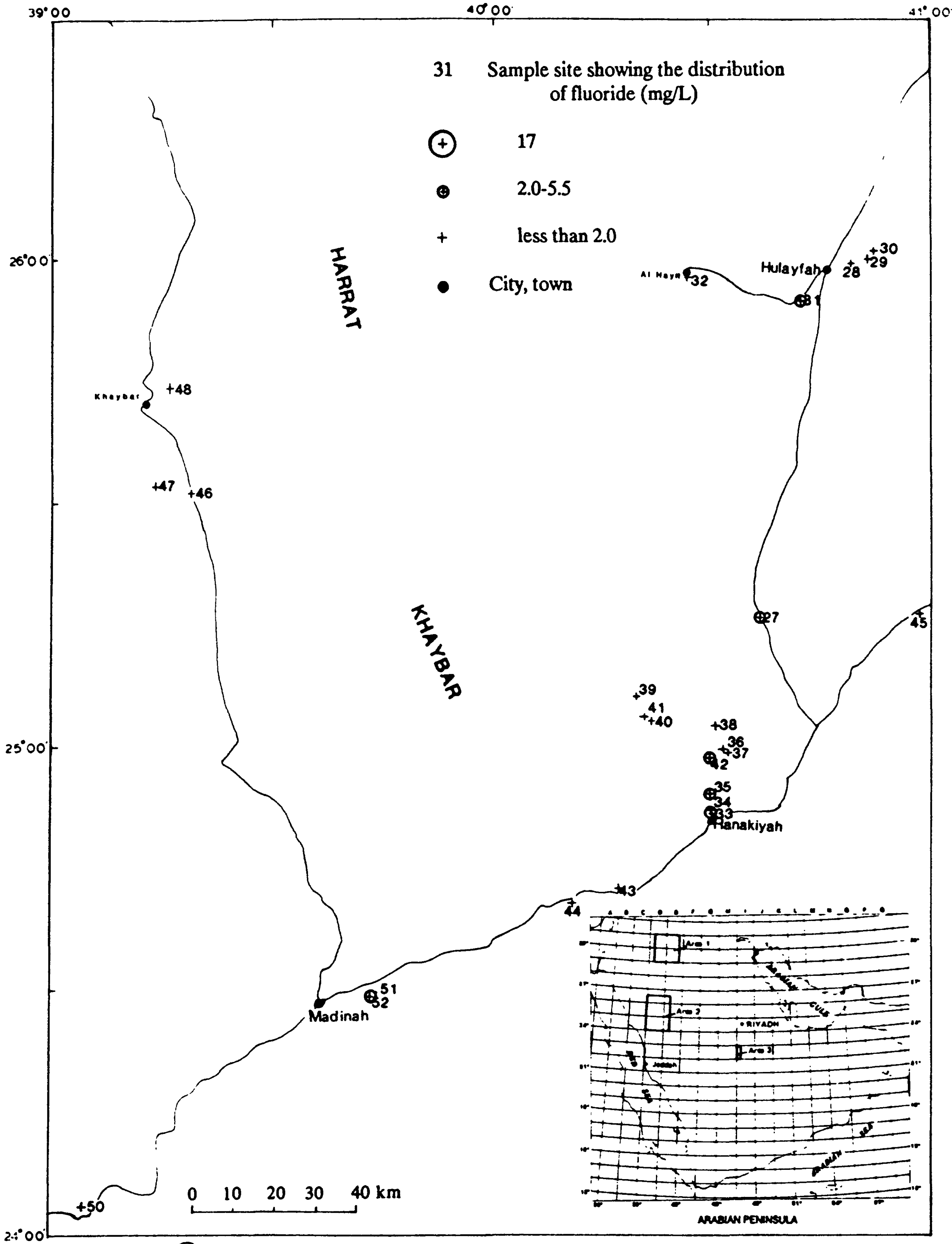
samples 49, 53, 54, are not in area

Figure 11.–Distribution of uranium in water, Hanakiyah study area 2.



samples 49, (53,) 54, are not in area

Figure 12.–Distribution of sulfate in water, Hanakiyah study area 2.



samples 49, (53,) 54, are not in area

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 µg/L.]

Sample	Latitude	Longitude	Ca	Mg	Na	K	Li	SiO_2	ALK
55	22 22 0	46 45 50	178	70	150	6.5	47	21	98
56	22 22 30	46 46 0	240	86	220	6.8	50	21	182
57	22 23 40	46 46 10	500	150	470	12.0	125	25	64
58	22 24 10	46 46 40	520	143	290	15.0	125	23	198
59	22 25 20	46 46 10	540	128	530	9.1	94	25	143
60	22 26 50	46 45 50	290	88	140	7.6	64	20	141
61	22 27 20	46 45 10	300	72	230	6.7	47	20	128
62	22 28 50	46 46 0	210	69	140	5.5	46	21	152
63	22 29 20	46 45 20	164	44	130	5.0	39	18	69
64	22 40 0	46 46 0	600	68	63	5.7	80	21	57
65	22 31 30	46 42 40	207	43	100	3.4	20	17	60
66	22 25 20	46 44 0	320	66	200	6.4	44	18	172
67	22 25 10	46 43 0	84	31	43	4.1	21	16	146
68	22 34 0	46 31 30	52	27	55	4.0	17	17	86
69	22 14 30	46 42 50	242	110	240	15.0	56	18	76
70	22 13 30	46 42 10	330	126	300	11.0	60	17	189
71	22 13 10	46 43 10	560	77	91	7.8	84	28	55
72	22 11 50	46 41 30	400	170	400	15.0	82	18	178
73	22 7 0	46 37 30	250	88	130	9.7	50	20	68
74	22 1 50	46 35 0	290	118	300	27.0	81	18	131
75	22 4 0	46 39 20	450	186	1,350	33.0	120	21	213
76	22 5 40	46 42 30	510	115	210	12.0	105	21	106
77	22 2 50	46 39 0	570	104	120	6.7	115	21	109
78	22 9 0	46 42 0	640	104	93	8.5	120	36	116
79	22 16 20	46 44 30	260	83	120	7.2	42	25	59
80	22 15 40	46 44 0	188	50	77	6.0	32	19	179
81	22 14 0	46 45 30	570	185	260	13.0	175	40	67

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^{-}, and one Na^{+}-SO_4^{-} waters.

Specific conductance has a range of 780 to 6,600 μmho/cm in the study area, with a geometric mean of 2,413 μmho/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.
[Elemental concentrations in mg/L, except for Zn, Cu, Mo, & As, which are in μg/L]

Sample	SO_4	Cl	F	NO_3	Zn	Cu	Mo	As
55	490	230	.8	16	7	3.4	8.3	<1
56	610	395	.9	32	8	5.0	6.6	<1
57	1,520	655	1.2	29	16	7.3	18.0	<1
58	1,300	406	1.7	19	17	5.8	19.0	1
59	1,210	800	1.0	92	15	6.5	18.0	<1
60	615	264	.9	104	7	3.9	10.0	<1
61	610	363	.9	110	8	4.1	12.0	<1
62	578	192	.5	<1	10	5.1	7.0	1
63	452	133	.3	36	10	4.6	5.9	<1
64	1,490	94	1.2	<1	95	3.6	13.0	<1
65	310	250	.9	120	8	2.1	6.3	<1
66	615	322	1.0	220	6	4.8	13.0	1
67	141	56	.5	13	7	1.8	5.6	1
68	128	97	.3	14	4	1.0	3.3	<1
69	860	360	.6	27	7	6.8	10.0	<1
70	1,080	441	.9	22	9	6.5	13.0	<1
71	1,450	157	1.5	<1	13	6.9	15.0	<1
72	1,550	479	1.3	<1	10	7.7	16.0	1
73	830	170	.6	42	15	4.4	7.5	<1
74	1,080	330	.8	36	6	6.6	17.0	<1
75	2,370	965	1.3	<1	14	13.0	21.0	1
76	1,400	264	.2	<1	32	6.5	16.0	<1
77	1,390	149	1.1	<1	22	5.6	15.0	<1
78	1,590	146	2.9	<1	10	4.6	19.0	<1
79	600	243	.7	41	9	3.9	8.6	<1
80	345	159	1.3	38	4	2.1	6.6	1
81	1,680	540	.4	<1	21	7.6	21.0	1

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

Sample	Fe(mg/L)	Mn(mg/L)	Al(mg/L)	U(μg/L)	Sp.cond.	pH	Temp.C	Char.bal	Depth (m)
55	.03	.02	.01	4.40	1,700	7.11	28	7.0	65
56	.03	.02	.04	4.00	2,300	7.75	29	2.6	65
57	.04	.04	.03	5.60	3,750	7.56	27	5.9	16
58	.07	.02	.02	3.80	3,450	7.55	30	9.4	65
59	.12	.04	.03	8.00	4,100	7.40	29	8.2	25
60	.07	.02	.02	2.60	2,250	7.50	29	7.3	80
61	.10	.04	.02	2.80	2,450	7.36	30	7.4	50
62	.04	.03	.03	5.00	1,850	7.41	30	5.8	50
63	.04	.03	.02	4.40	1,460	7.30	29	8.4	70
64	.16	.03	.03	2.00	2,600	7.00	29	5.3	400
65	.03	.04	.01	3.20	1,650	7.58	29	5.4	55
66	.03	.04	.02	3.70	2,500	7.43	29	3.5	120
67	.02	.04	.02	1.50	790	7.54	33	10.0	230
68	.02	.03	.02	1.50	780	7.38	27	2.0	90
69	.04	.03	.03	4.00	2,500	7.00	27	3.7	40
70	.05	.03	.03	3.60	3,100	7.17	28	2.4	50
71	.11	.03	.03	1.40	2,700	7.00	27	4.0	40
72	.03	.03	.04	4.60	3,800	7.08	27	3.1	40
73	.03	.03	.02	4.40	1,950	7.11	28	3.6	40
74	.02	.03	.02	4.20	2,900	7.25	27	4.8	27
75	.05	.05	.06	11.00	6,600	7.24	26	9.7	50
76	.05	.03	.04	3.00	3,200	7.07	26	7.4	20
77	.44	.04	.06	.16	3,000	7.00	28	9.7	60
78	.04	.04	.03	1.60	3,050	8.01	22	6.7	0
79	.04	.02	.02	3.20	2,050	7.17	28	9.2	30
80	.02	.02	.02	2.00	1,500	7.23	29	5.5	30
81	.12	.03	.04	5.00	3,900	7.07	27	3.9	40

Table 9.--Summary of chemical analyses of 27 water samples from the Layla area

Constituent/ Parameter	Minimum	Maximum	Geometric mean
Ca (mg/L)	52	640	302
Mg (mg/L)	27	186	86.0
Na (mg/L)	43	1,350	174
K (mg/L)	3.4	33	8.52
Li (μg/L)	17	175	62.3
SiO_2 (mg/L)	16	40	21.1
Alk. (mg/L)	55	213	109
SO_4 (mg/L)	128	2,370	790
Cl (mg/L)	56	965	259
F (mg/L)	0.2	2.9	0.818
NO_3 (mg/L)	<1	220	10.4
Zn (μg/L)	4	95	10.9
Cu (μg/L)	1	13	4.65
Mo (μg/L)	3.3	21	11.1
Fe (mg/L)	0.02	0.44	0.048
n (mg/L)	0.02	0.05	0.03
Al (mg/L)	0.01	0.06	0.026
U (μg/L)	0.16	11	3.05
Specific conductance(μmho/cm)	780	6,600	2,413
pH	7.0	8.01	7.30[1]
Temperature (°C)	22	33	28

[1]Arithmetic mean

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

Sample no.	Cation	Anion
55	Ca-Na	SO_4
56	Ca-Na	SO_4
57	Ca-Na	SO_4
58	Ca	SO_4
59	Ca-Na	SO_4
60	Ca	SO_4
61	Ca	SO_4
62	Ca	SO_4
63	Ca	SO_4
64	Ca	SO_4
65	Ca	SO_4
66	Ca	SO_4
67	Ca	SO_4
68	Ca-Na	SO_4
69	Ca-Na	SO_4
70	Ca-Na	SO_4
71	Ca	SO_4
72	Ca-Na	SO_4
73	Ca	SO_4
74	Ca-Na	SO_4
75	Na	SO_4
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77	Ca	SO_4
78	Ca	SO_4
79	Ca	SO_4
80	Ca	SO_4
81	Ca	SO_4

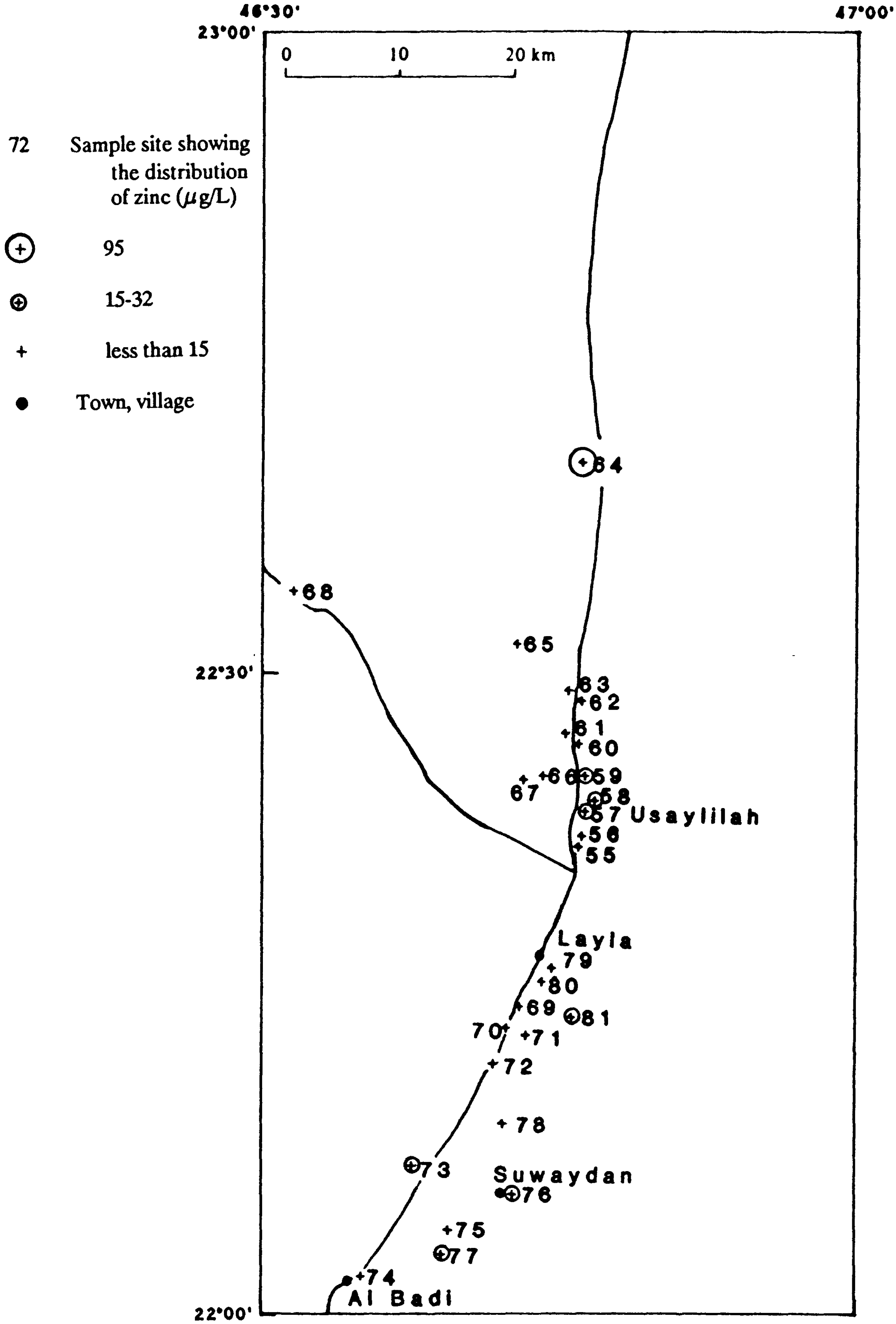

Figure 14.--Distribution of zinc in water, Layla study area 3.

72 Sample site showing the distribution of copper (μg/L)

⊕ 13

⊙ 6.5-7.7

+ less than 5.8

● Town, village

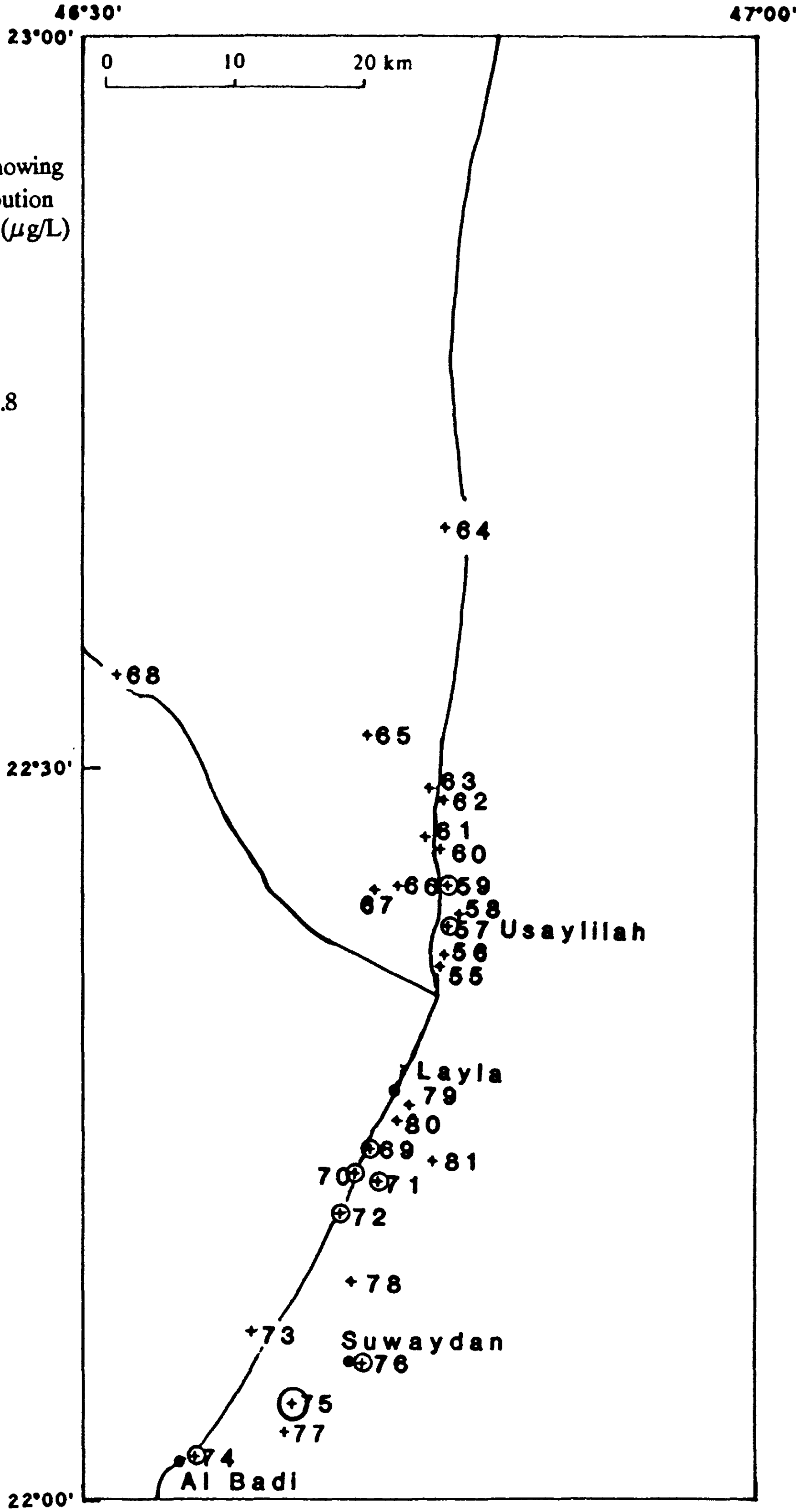

Figure 15.--Distribution of copper in water, Layla study area 3.

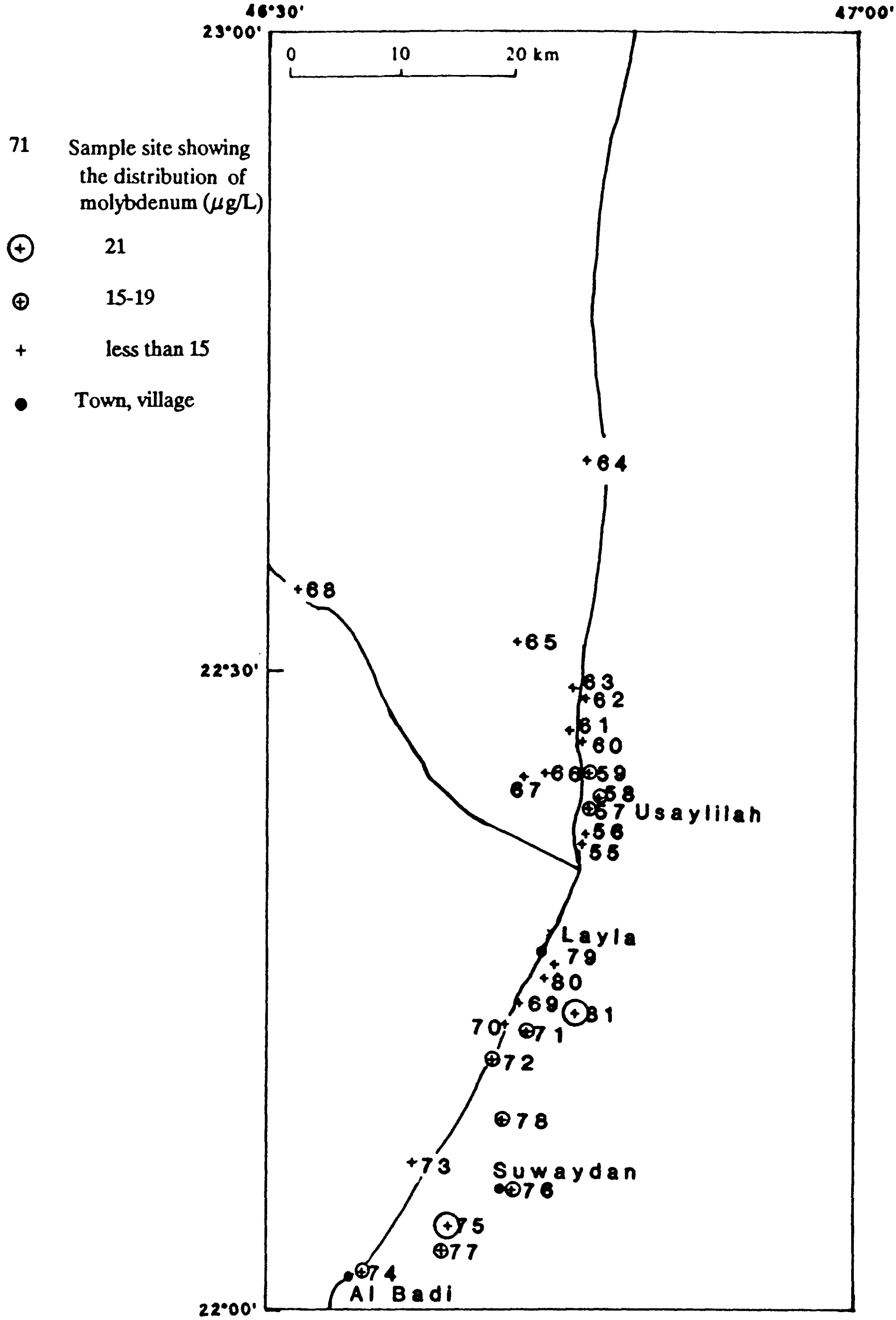

Figure 16.--Distribution of molybdenum in water, Layla study area 3.

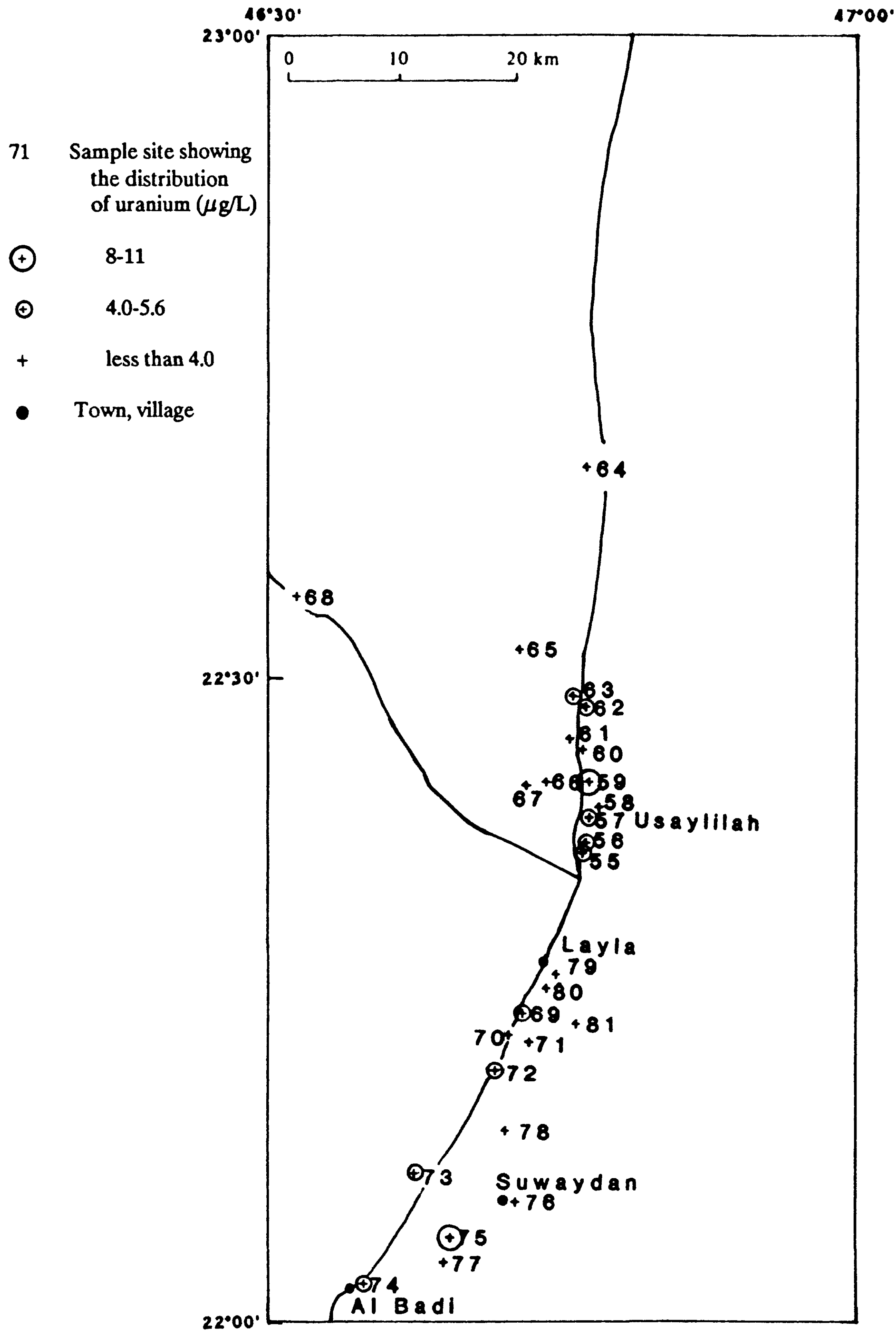

Figure 17.--Distribution of uranium in water, Layla study area 3.

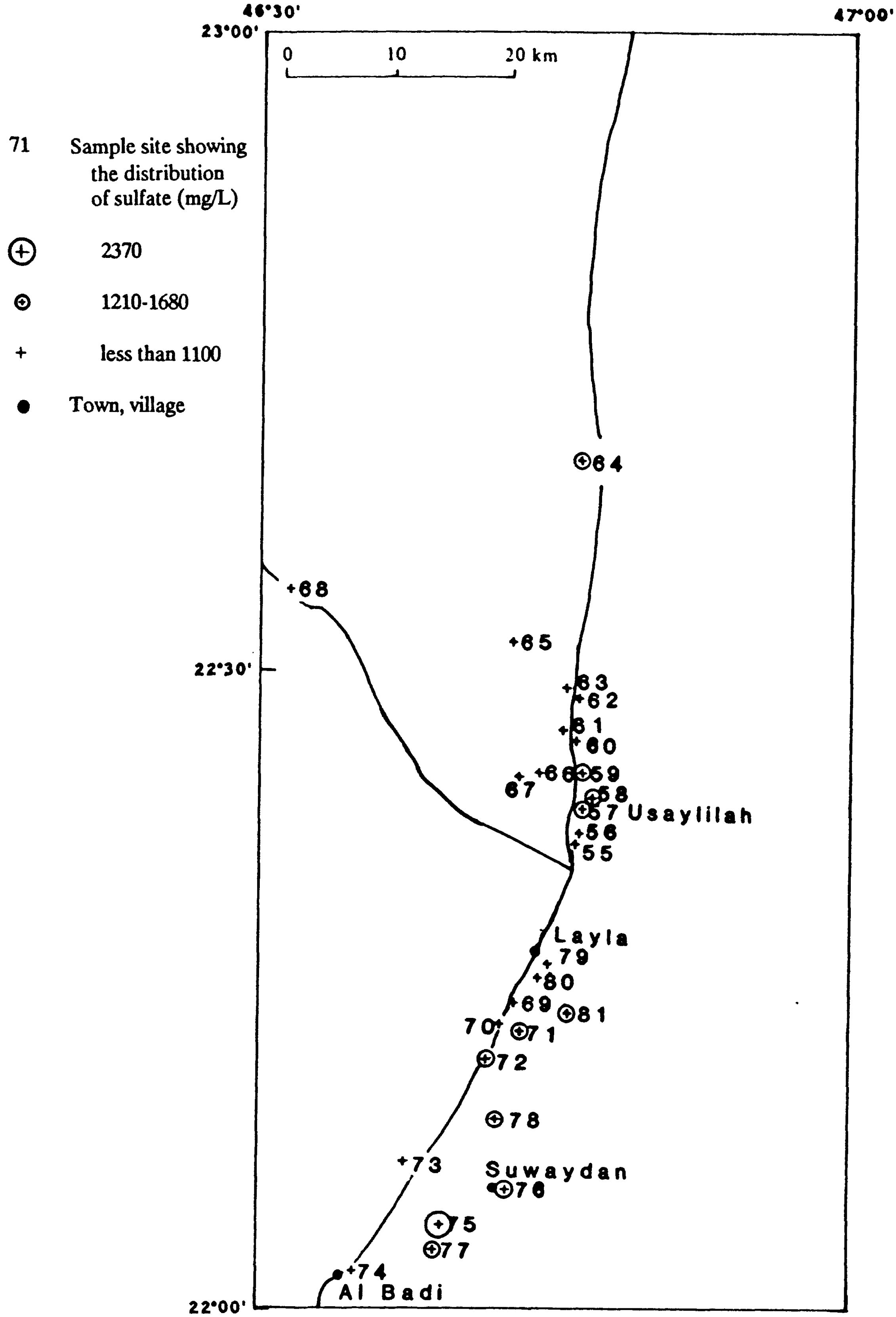

Figure 18.--Distribution of sulfate in water, Layla study area 3.

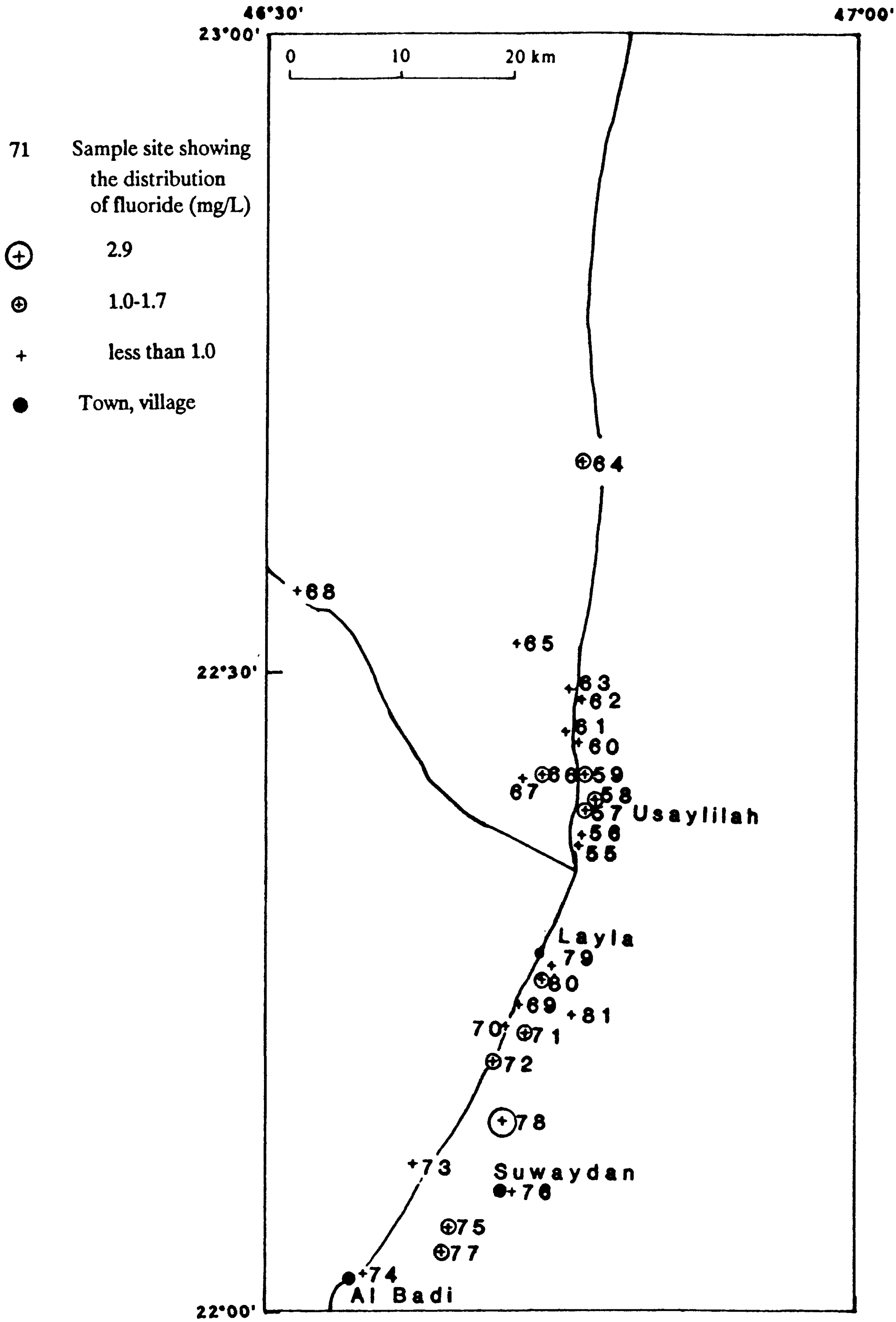

Figure 19.--Distribution of fluoride in water, Layla study area 3.

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

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DATA STORAGE

All results obtained in theis 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.

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