CHAPTER 5 DRILLING SURVEY

A drilling survey was performed for the principal purpose of identifying the geological structure and quality of groundwater in the Study area, and the drilling survey to characterize the hydrogeological conditions was conducted by recording hydrological and water quality parameters in the boreholes designated DH-1～DH-14. Pumping tests were performed at each hole designated DH-1～DH-14 to gather hydrogeological data . Water samples were also collected for water quality analysis twice during the study.

5.1 Geological and Hydrogeological Conditions

The geological profile along Wadi Suq is presented in Figures 5.1. The upstream area of Wadi Suq consists of the Effusive rocks, i.e. mainly basaltic rocks of the Ophiolite. In uppermost reaches of the wadi, tailing dam was constructed. Tailings have 30.20 to 30.65 m in thickness and Wadi Sediments can be found at the bottom of the tailings. The lowest part of the tailings consists of garvels ranging in thickness from 0.1 to 0.65 m.

Permeability of the tailings seems to be relatively poor because they consist of well-compacted fine grained materials. On the other hand, the basaltic basement is presumed to have higher permeability.

The geology of the middle stream area of Wadi Suq consists of mainly basaltic rocks. Outcroppings of the Batinah Olistostromes can be seen on a small scale near the point-designated PS-2. These rocks consist mainly of limestone, red colored shale and chert.

Wadi sediments are widely distributed in the downstream area of Wadi Suq. The thickness of the wadi sediments is 17.85 to 28.60 m and consist of sand and gravel. The top bed down to -3.00 m below the surface is loose wadi sediments. Lower beds are calcreted sand and gravel, with the lower half consisting of minute calcreted beds.

Basement rocks consist of the Batinah Olistostromes and Tertiary layers. The Batinah Olistostromes consists of mainly limestone, shale and chert.

Groundwater levels for each drill hole are shown in Table 5.1.

The field pumping tests obtained permeability coefficients ranging from 10^{-3} to 10^{-6} cm/sec. The observed permeability is rather low because the tests were mostly conducted in calcreted sand and gravel zones and in bedrock.

Table 5.1 Groundwater Level in Drill Holes

Drill hole No.	July, 2000 Depth (m)	Nov., 2000 Depth (m)	Drill hole No.	July, 2000 Depth (m)	Nov., 2000 Depth (m)
DH-1A	-32.70	-32.50	DH-7D	-10.20	-9.35
DH-1B	-17.79	-17.53	DH-8S	-16.36	-15.31
DH-2	-7.37	-6.60	DH-8D	-16.16	-15.24
DH-3	-3.45	-2.51	DH-9	-8.22	-7.57
DH-4S	-6.59	-5.61	DH-10	-7.62	-6.85
DH-4D	-5.88	-4.98	DH-11	-10.33	-9.58
DH-5S	-10.64	-9.90	DH-12S	-5.88	-5.20
DH-5D	-8.40	-8.07	DH-12D	-5.87	-5.36
DH-6S	-11.41	-10.54	DH-13	-9.21	-7.85
DH-6D	-11.61	-10.78	DH-14	-9.47	-8.70
DH-7S	-10.19	-9.42			

5.2 Result of Water Quality Analysis

Contaminated seepage from the tailing dam, including salt and heavy metals, is dispersed downstream in Wadi Suq and Wadi Bani Umar al Gharbi to the northwestward of the tailing dam. The quality of groundwater indicated uniform attenuation (dispersion) of Hg, Cd, Cr, As, Ni, Mn, Pb, Cu, Fe, Zn, SO_4, and Cl with the distance downstream from the tailing dam (Figure 5.2 (1)～(2)).

The extent of water contamination designated by the evaluation standards of water quality is confirmed at two areas, namely from the tailing dam to Sagha Village (KM14) and from northwestward of the tailing dam to Wadi Bani Umar al Gharbi (Figure 5.3). Also, a part of the contamination is dispersed all the way to the drill holes of DH-5 and DH-12. However, the relatively high concentrations of SO_4 and Cl at drill holes DH-6 and DH-7 are thought to occur due to natural causes that occur locally.

The mechanism responsible for the secondary peaks in Cd, Pb, SO_4, and Cl concentrations observed far downstream from the tailing dam cannot be explained by natural attenuation or dispersion theories.

A sample of groundwater collected at a depth of 50m at DH-7 was date by analyzing Tritium (^3H). This groundwater sample indicated the age of the groundwater at this location was 27 years (1973), which is before the start of the mine development at Sohar was begun.

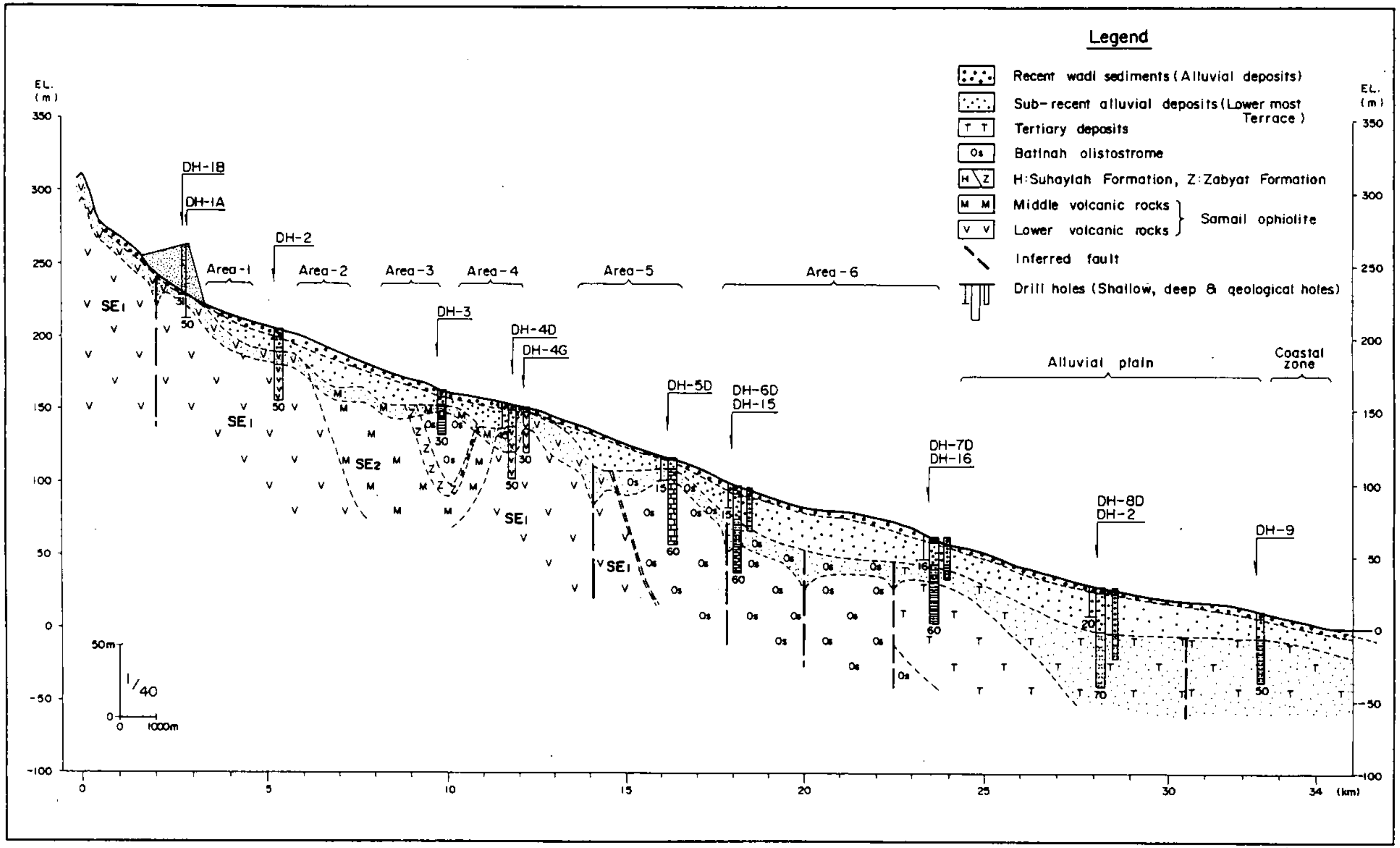
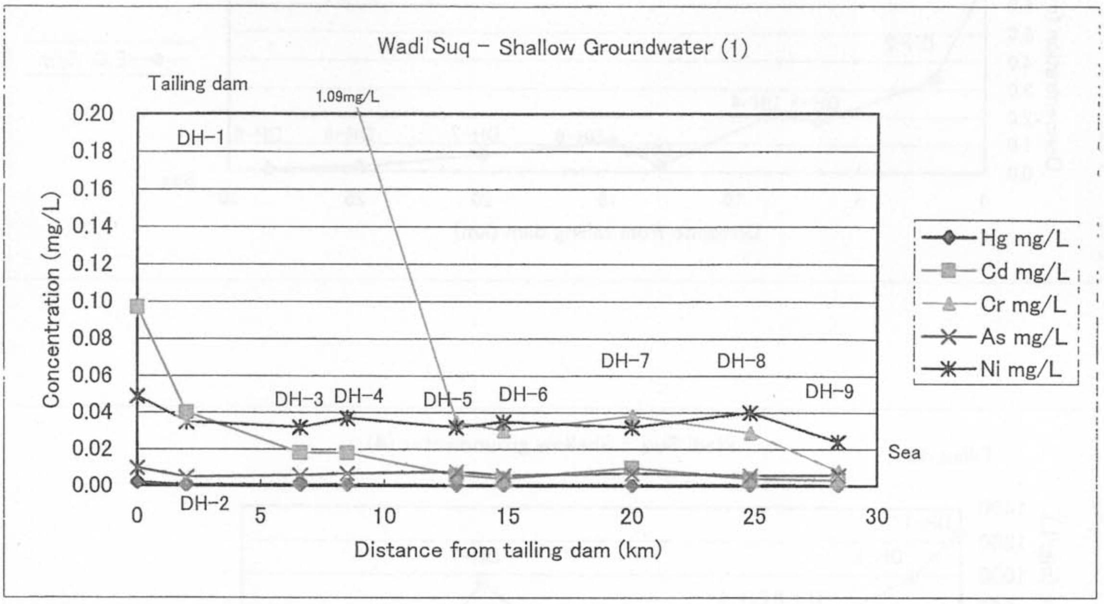


Figure 5.1 Geologic Profile along Wadi Suq



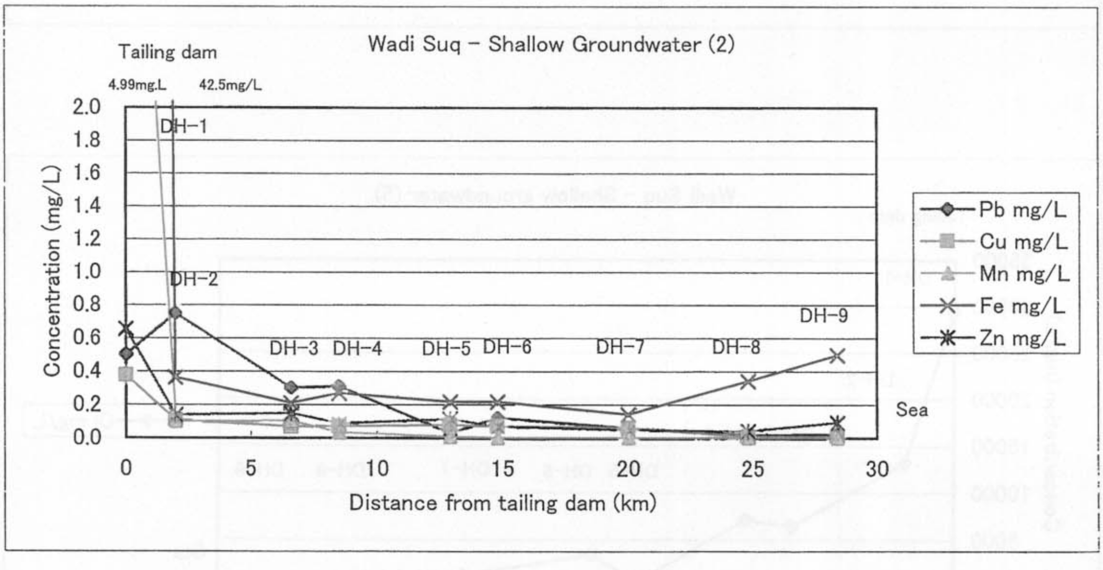
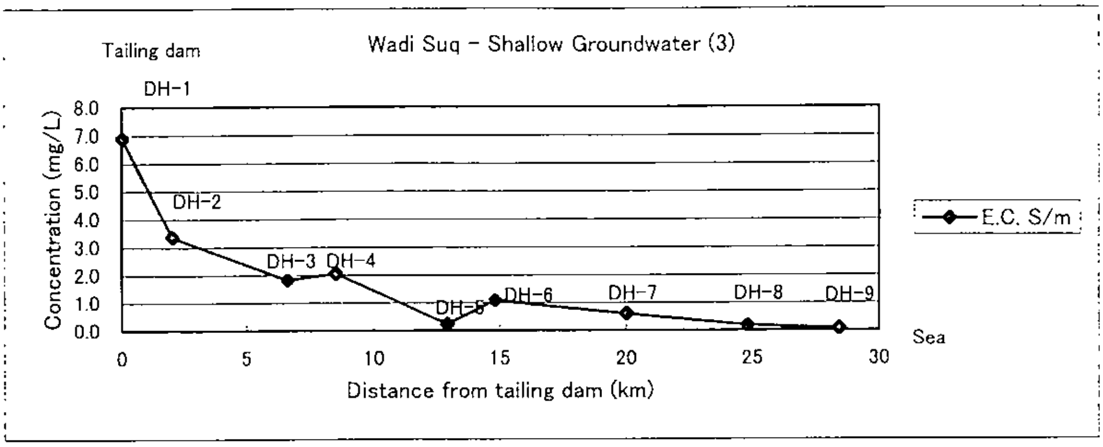
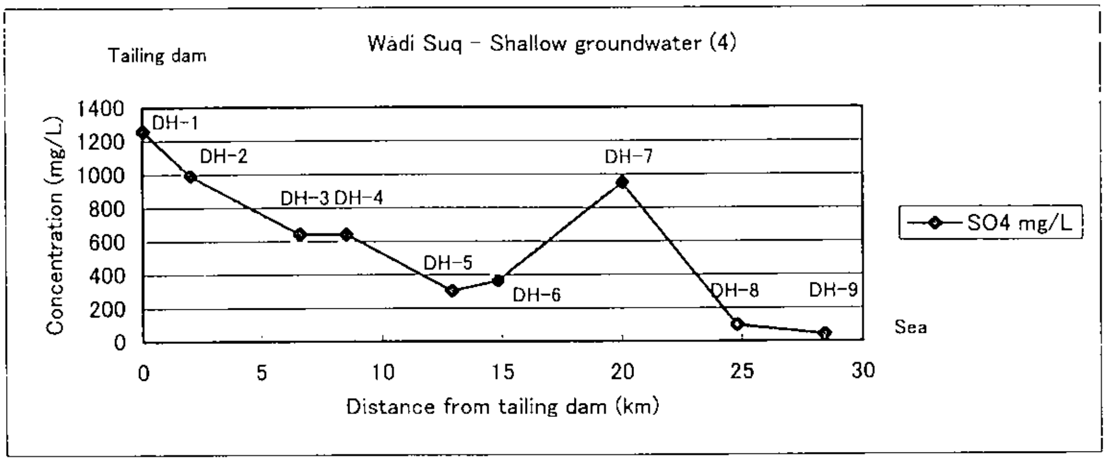


Figure 5.2 Relationship between Distance from Contaminant Source and Water Quality (1)





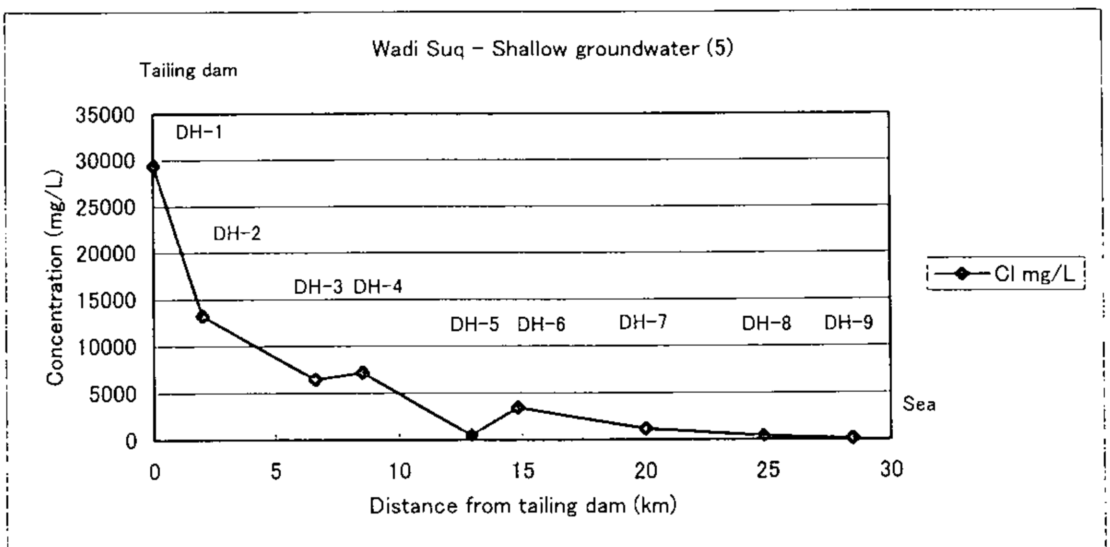


Figure 5.2 Relationship between Distance from Contaminant Source and Water Quality (2)

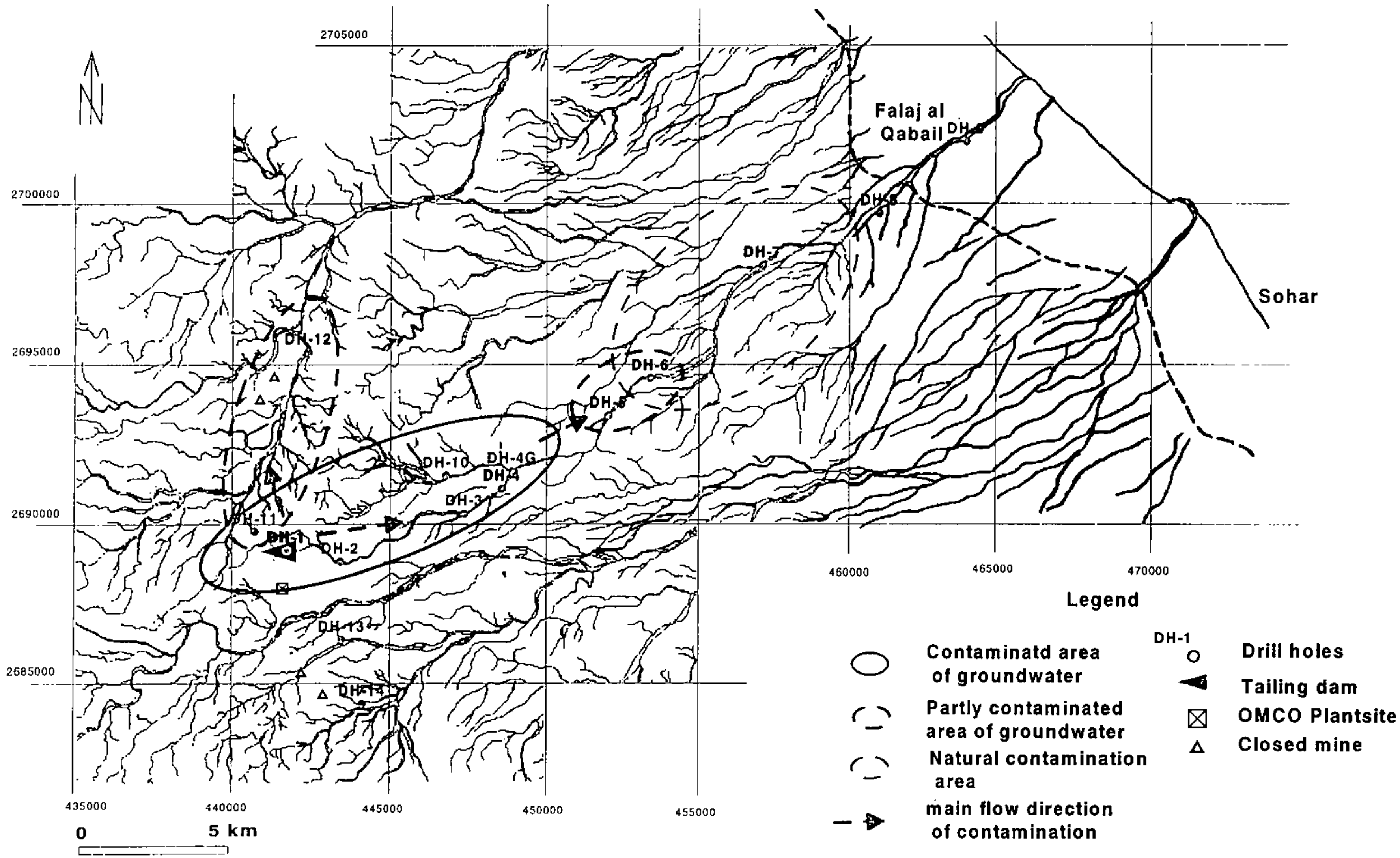


Figure 5.3 Extent of Groundwater Contamination

CHAPTER 6 CONTAMINATION SOURCE INVESTIGATION

Contamination sources related to the Sohar mine area consist of the tailing dam, the area around PS-2 pumping station, waste dump areas, abandoned mines, abandoned open pits, the copper smelter, and evaporation ponds.

6.1 Tailing Dam

The top layer consists of fine particles, having thickness of 2 to 10cm. The fine tailings from the surface are scattered by wind in every direction out of tailing impoundment (Figure 6.1).

Tailings were sampled during the drilling investigation to execute a leaching test. Since tailings contain a great amount of sulfur, they have a very strong acid potential. The NNP of the tailings ranged between 360 to ~ 840 t (tons as $CaCO_3$/1,000 t of tailings) indicating that there is a potential to create between 360 and 840 t of acidity from each 1,000 t of tailings, if all the sulfur is oxidized. Effluent obtained from the oxidized surface layer of the tailings showed a pH 2 to 3.

The seepage from the tailings dam exhibits elevated metal concentrations, such as Cd and Pb, exceeding the Omani standards, especially for cadmium and lead.

6.2 PS-2 Pumping Station

Seawater for the dressing plant was pumped up from Majis Jetty and a considerable amount of seawater leaked at booster pumping station PS-2. The JICA team confirmed the fact that contaminated soil with high salt concentration still exists in the area upstream of PS-2, and is distributed for about 200 to 350m along the wadi. Cl concentrations in groundwater in the hand dug at PS-2 and bore hole DH-3 ranged from 6,000 to 6,500 mg/L (Figure 6.2). A high Cl concentration zone was formed for about 300m in length around the PS-2 area and that this zone is limited to the top thin layer only.

6.3 Waste Dump Areas

Mine wastes were deposited in dumping areas around each abandoned mine, including Lasail, Lasail West, Aarja and Bayda (Figure 6.3). The sulfur content of Lasail Mine waste is relatively high, as much as 10 to 13 % due to pyrite mineralization. The Maximum Potential Acidity (MPA) is also high, ranging from 320 to 420 t per 1,000 tons. However, the net neutralization potential is slightly lower. The pH value of the effluent exhibits strong acidity of 3.4 to 3.7 with high dissolved metals concentrations from the low grade ore. Greenish gray colored basaltic country rock with less pyrite mineralization is believed to have neutral effluent with low dissolved heavy metal ions, based on other experience. It is presumed that a part of waste might produce acid drainage containing leached heavy metals in the future as a result of continued oxidation.

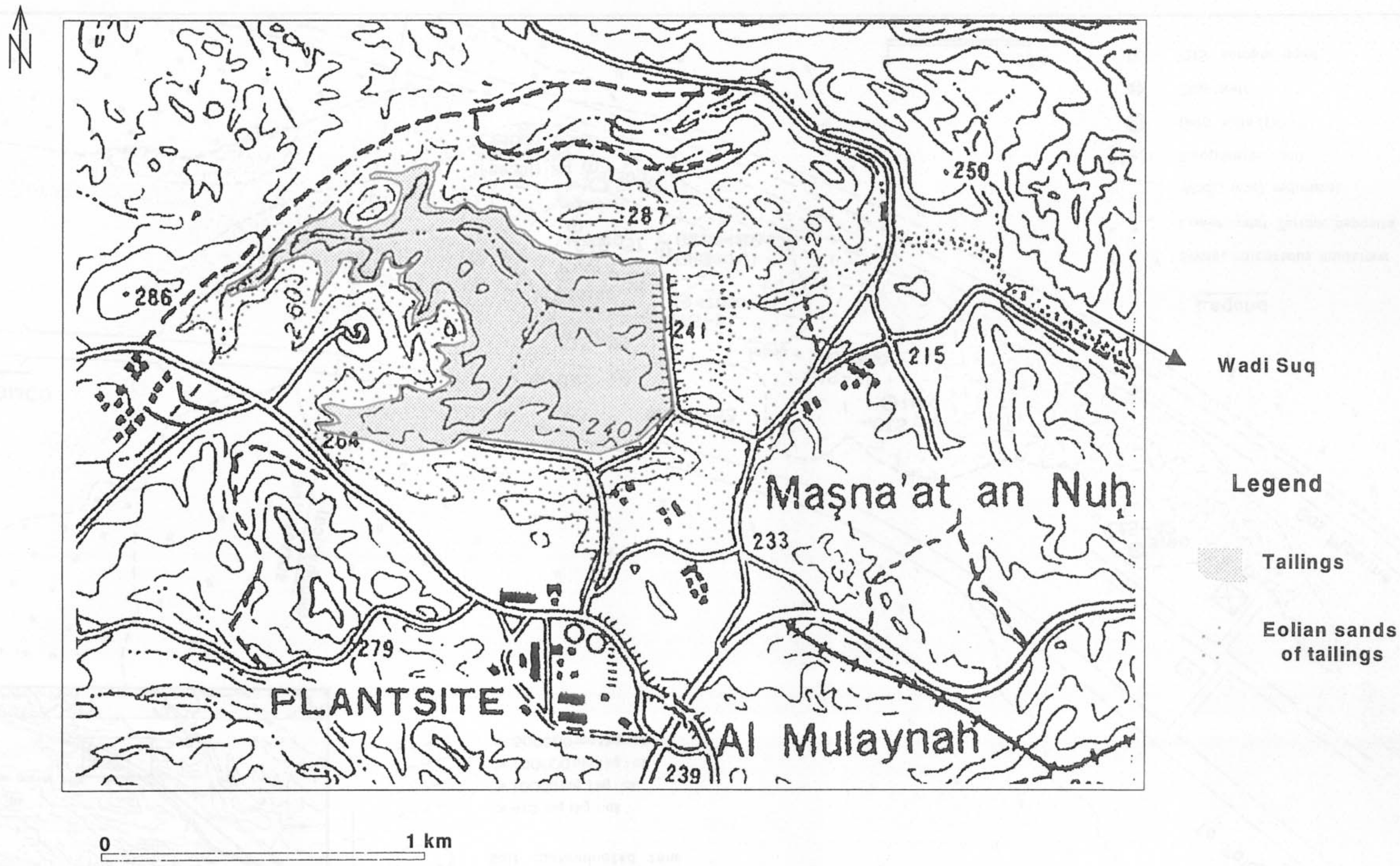


Figure 6.1 Scattered Distribution map of Tailings

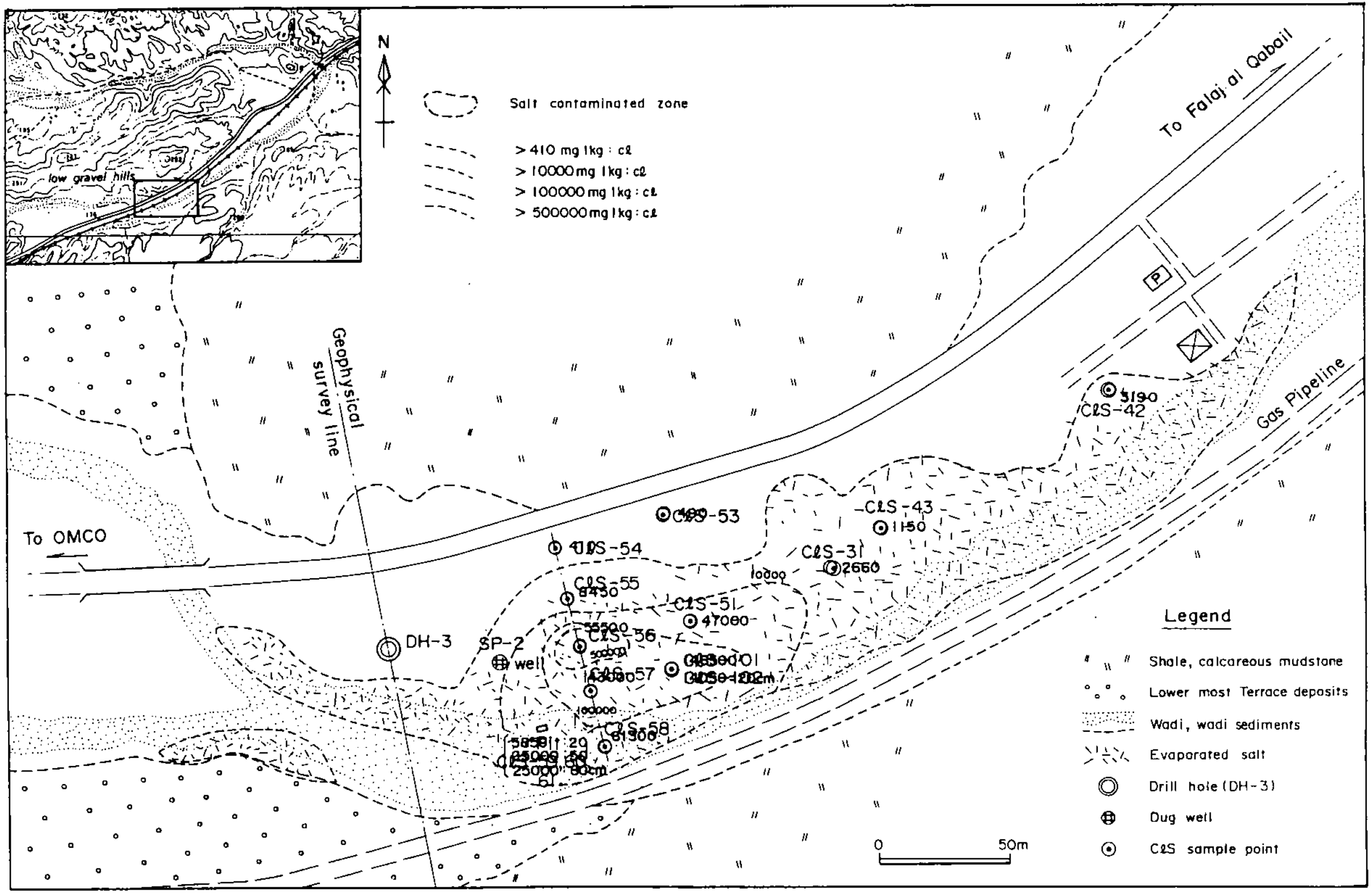


Figure 6.2 Cl Concentration Contour Map in the Soil at SP-2 Point

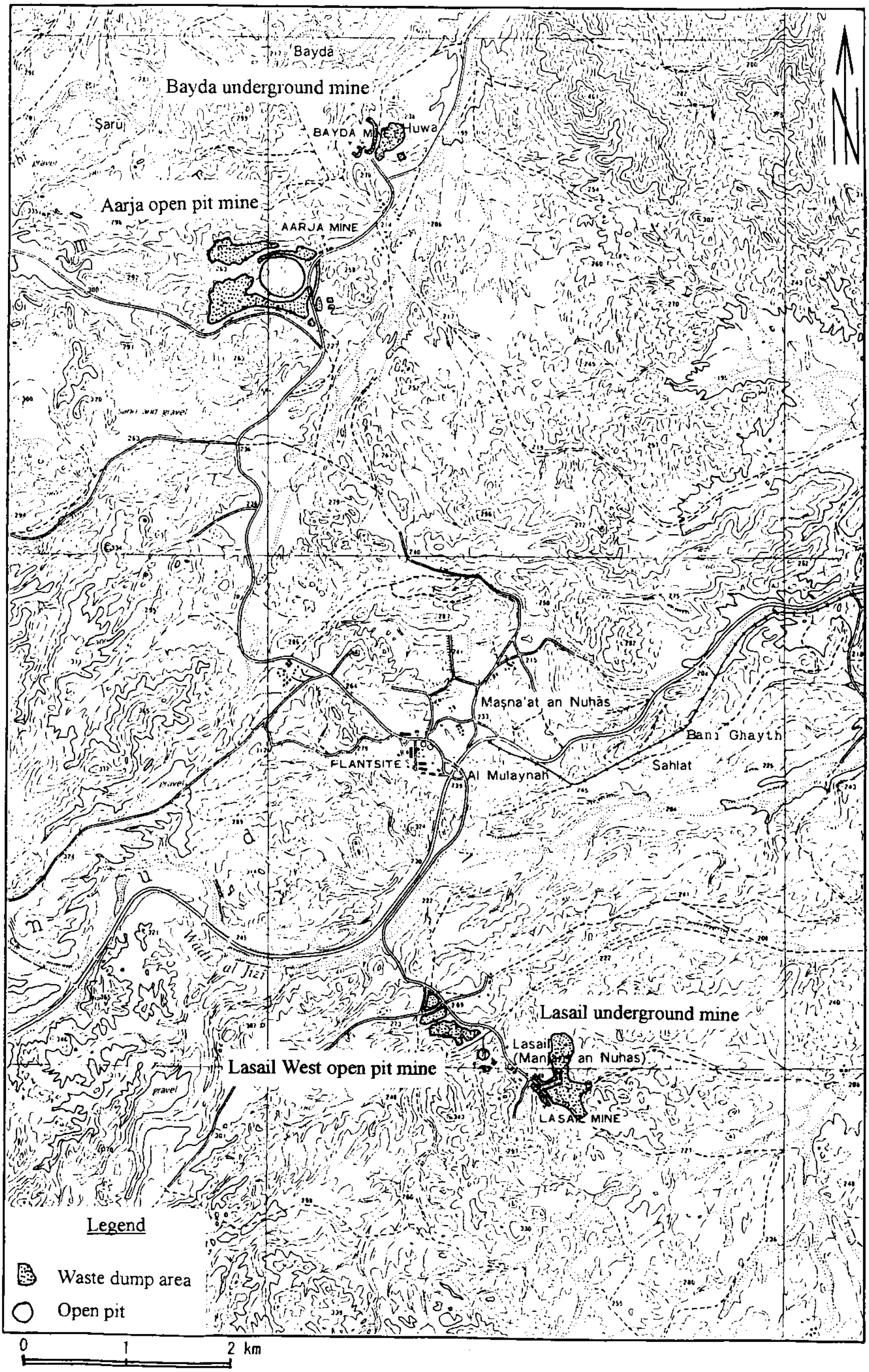


Figure 6.3 Distribution of Mine Wastes

The sulfur content in waste from the Lasail West Mine ranges from 0.16 to 20.09 % for barren country rock and rocks containing low-grade ore, respectively. The MPA of the low-grade ore is very high ranging up to 627 t of acidity per 1,000 t of waste. However, the barren waste presented a low MPA of 5 to 36 t per 1,000 t. The differences in the MPA of the different rock types can be partly explained by the degree of oxidation that has already taken place. In the materials exhibiting low MPA, much of the sulfur may have been previously oxidized.

The sulfur content in Aarja Mine waste ranges from 0.84 in low grade country rock to 29.16 % in rocks containing oxidized low-grade ore. The MPA of the low-grade ore is very high at 911 t per 1,000 t. However, the barren waste exhibited a low MPA of 26 to 144 t per 1,000 t. The reason for the lower MPA in the barren materials is that the initial sulfur content is low and much of the initial sulfur content is already oxidized. It is also presumed that a part of the waste might produce acid drainage containing leached heavy metals in the future if pyrite oxidation continues to occur.

The sulfur content in Bayda Mine waste was rather low, ranging from 0.1 to 0.67 %, indicating the wastes might be in the final stages of sulfur oxidation. This situation coincides with field observations. The MPA of the low-grade ore is as low as 4 to 21 tons per 1,000 t. Based on leaching test results, seepage from the Bayda waste piles exhibits neutral pH and low metals concentrations. Hence, the potential for this material to leach metals in to storm runoff and local groundwater appears to be relatively low.

6.4 Underground and Open Pit Mined-out Areas

Open pit mine water samples were taken from Lasail West and Aarja three times during the Study, i.e. June, September and November 2000 to check water quality. Analytical results of the mine water are described as below.

- The Aarja pH ranged from weakly acidic to neutral at 5.8 to 7.45 and pH of Lasail West mine water was somewhat higher.
- Electric Conductivity presented a stable range from 0.23 to 0.75 S/m. Values at Aarja was higher.
- Cd concentrations ranged from 0.01 to 0.09 mg/L with the higher values observed at Aarja.
- As concentrations ranged from 0.003 to 0.006 mg/L and did not exceed the Omani drinking water standard (0.05 mg/L).
- Pb concentrations ranged of 0.07 to 0.01 mg/L and did not exceed the Omani drinking water standard (0.1 mg/L).
- Cu concentrations ranged from 0.07 to 2.37 mg/L with the higher values observed at Lasail West.
- SO_4 concentrations ranged from 1,102 to 2,046 mg/L with higher values observed at Aarja.
- Cl concentrations ranged from 100 to 842 mg/L with much higher values observed at Aarja. It is presumed that brine from the tailing dam may be mixed with the Aarja mine water.
- As a whole, Aarja mine water contained higher dissolved components, especially higher values for

Hg, Na, Ca, and Cl. On the other hand, Lasail West water exhibited lower pH values and higher copper content. There was little indication of seasonal fluctuations in any of the analytical parameters observed at either of the mine pools.

6.5 Copper Smelter

There is neither an acid plant nor a desulfurization plant at the smelter. The off-gases of the electric furnace and converter are directly discharged from the main stack after simple dust collection by dust chambers consisting of balloon type ducts.

- Concentration of sulfur dioxide : 1 to 4 % fluctuating widely by cycles of Slag forming and blister forming stages
- Amount of sulfur dioxide gas discharged : 38,682 t/year of 1999, = 5.417 t/h = 1,895 m^3/h
- Dust concentration : 0.3 to 0.45 g/m^3
- Amount of dust discharged : 1 to 2 t/day
- Dimensions of main stack : 2.16 m ϕ (I.D)x 100 mH
- Designed velocity of off-gas for the main stack: 14.1 m/sec = 51.6 m^3/sec = 185,908 m^3/h

Based on method devised by Sutton and Pasquill, the maximum ground level concentration and its occurring distance were estimated as 0.47 ppm and 6.9 km, respectively.