JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

No.

MINISTRY OF COMMERCE AND INDUSTRY (MCI)
SULTANATE OF OMAN

THE FEASIBILITY STUDY
ON
MINE POLLUTION CONTROL
IN
SOHAR MINE AREA,
SULTANATE OF OMAN

FINAL REPORT

SUMMARY

DECEMBER 2001

MITSUBISHI MATERIALS NATURAL RESOURCES DEVELOPMENT CORP.
E & E SOLUTIONS INCORPORATION

JAPAN

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ABSTRACT

The abstract of the Study are, as follows:

(Topography, geology, hydrologeology investigation)

- The topography of the Study area mainly consists of the moderate and low relief mountain, hilly land, fans and terraces, alluvial plain and coastal plane.
- Wadi Suq has a river length of 34 km with an average slope of 0.008 (1:125), 275 m in maximum elevation of the wadi, 71 km^2 as the catchment area, and of Wadi Suq, and the mountainous area of the basin occupies approximately 29 km^2. The downstream portion has a gentle slope and forms wide floodplain.
- Wdi Suq is topographically divided into seven subareas, including Subarea 1 to 7.
- The geology of the Study area consist of the Samail Nappe, which is composed of the Ophiolite and Batinah Olistostromes of the Pre-Tertiary, Tertiary Deposits in the eastern part of the area, and Quaternary Deposits.
- The Quaternary Deposits consist of terrace deposits in diluvium, wadi sediments and screes. The Alluvial Terrace Deposits generally is almost consolidated by calcrete, and the permeability is relatively low.
- The dominant directions of faults are northeast to southwest and northwest to southeast. A narrow graven structure from 1 km to 1.5 km wide runs along Wadi al Jizi in an east-northeast to west-southwest direction.

Geochemical investigation)

- High concentration zones of Cd, Pb, Cu, Fe, Zn, and SO_4, which are caused by the smelter and tailings dam, were found by soil investigation and locally dispersed beyond 3 km.
- Leakage of contaminated groundwater in a northwest direction from the tailing dam was confirmed and its impact has reached downstream to Bayda village.
- Leakage of seawater occurred out of pumping station PS-2, and there exists a high chloride concentration zone approximately 400 m in length.

(Geophysical survey)

- In the tailing dam, the specific resistivity basement appears as an almost horizontal line about 30 m under the ground surface with a layer of low specific resistivity spreading horizontally.
- In the middle reach of Wadi Suq exist 50 to 100 m under ground surface, and it is deeper than upper reach of the wadi.
- In the upper and middle reaches, the depth of the basement is distributed almost horizontally from 5 to 10 m below the wadi ground surface.
- In the middle and lower reaches, the basements exist at a slightly deeper depth of about 20 m. However, their form is almost flat on the whole.

(Drilling investigation)

- There exists an aquifer with very shallow groundwater level of –4m upstream of Sagha village. The shallowness of the aquifer in this area is caused by a natural constriction in the topography that results in a damming effect on the groundwater.

- Deep groundwater in DH-4, DH-5 and DH-8 is slightly confined. Compact calcreted sand and gravel beds may act as confining beds.
- Permeability coefficients obtained by the field pumping tests ranged from 10^{-3} to 10^{-6} cm/sec. Permeability is lower in calcreted sand and gravel beds.
- Elevated concentrations of Cd and Pb were observed in seepage out of the tailing dam and slightly higher concentrations were observed in downstream areas until DH-5 and in mine water out of Aarja and Bayda mines. Other areas presented low concentration not exceeding Omani drinking water standards.
- Cl concentration ranged from 45 to 34,578 mg/L with the high concentrations obtained from seepage out of the tailing dam, including its downstream area near DH-5 and northwestern part of the tailing dam.
- All chemical constituents in the shallow and deep groundwater exhibited marked attenuation with distance from the sources. The concentrations generally decreased with distance downstream until approximately the area of borehole DH-5 is reached in Wadi Suq. The entire area form the tailing dam downstream to Sagha village is considered contaminated.
- There exist water quality differences between the deep layer groundwater and that of shallow layer.
- Peak concentrations of Cd, Cr, Pb and Cu are observed at DH-5, while peak concentrations in Mn and Fe were observed at DH-6. The presence of weak natural mineralization in area around DH-5 and -6 seems to be causing elevated concentrations of metals in this area.
- SO_4 concentrations exhibit attenuation with distance downstream from the source and a peak was observed at DH-7 borehole. This sulfate peak may be the result of natural sulfate minerals in the area of DH-7.
- A high concentration peak of Cl was detected at DH-5. This chloride peak could be caused by leakage out of the seawater pipeline.

(Pollutant source investigation)

- High salinity groundwater is flowing out from the tailing dam, and the tailings from the surface to the tailing dam are scattered by wind.
- Wastes were dumped in dumping areas, located in Lasail, Lasail West, Aarja, and Bayda mines.
- Abandoned open pits of Lasail West and Aarja mines are filled by mine water.
- Off-gas is directly discharged out of the main stack after simple dust collection without desulfurization.
- Waste liquid out of tank house is neutralized by hydrated lime after liberating electrolysis to decopper, and finally transported by tank truck to the evaporation ponds.
- Tailings contain a great amount of sulfur, which might produce a lot of acidic water. But it is believed the surplus lime in tailings; calcreted beds and basement rock might act as buffering agents to prevent the onset of acid drainage.
- Wastes of both Lasail and Aarja mines have high sulfur contents ranging between 10 and 13 %. Some of these wastes might produce acidic water with leached heavy metals in the future as oxidation progresses further.
- Aarja mine water contains high concentration of Hg, Na, Ca and Cl is different from shallow layer groundwater in the surrounding area. On the other hand, Lasail West mine water presents slightly

low pH, but has some correlation with the groundwater in the surrounding area.

(Environmental (water quality) investigation)

- pH values are almost neutral.
- Electric Conductivity presented a high value of 7.66 S/m at the tailings impoundment and decreased with distance downstream along Wadi Suq.
- Cd, As, Pb, Cu, Zn, and SO_4 presented higher values at the tailings impoundment, northwest of the tailing dam, and mine water of Aarja and Lasail West.
- Cl presented high concentration at the tailings impoundment, extending to the northwest, and downstream along Wadi Suq.
- Extent of water contamination impact in Sohar mine area is summarized, as follows:
  - Cd, Pb, Cu, SO_4 and Cl as pollutants originate from the tailings dam and are observed downwards along Wadi Suq. The extent of water contamination is limited from the tailing dam to the KM-14 point of Sagha Village along Wadi Suq.
  - A high concentration zone of Cl in the area downstream of Wadi Suq could be influenced by old seawater based on the results of radioactive dating by tritium. The age of this water was estimated at 27 year and contains Cl contamination from before mine development.
  - Contaminated groundwater is leaking toward the northwest out of the tailing dam and is impacting Wadi Bani Umar al Gharbi.
- The groundwater modeling of Wadi Suq was performed using Groundwater Modeling System (GMS) v3.0.
- Steady state simulation results of the Wadi Suq model presented excellent comparison with measured groundwater levels.
- Calculated simulation results of contaminated groundwater showed excellent correlation with measured concentrations obtained by monitoring. In the future, however, further study will be made.

(Air quality investigation)

- The 1-hour average SO_2 concentrations varied from 0.001 ppm (3 $\mu g/m^3$) to 0.835 ppm (2,404 $\mu g/m^3$).
- The 24-hour average TSP concentrations varied from 49 $\mu g/m^3$ to 332 $\mu g/m^3$.
- The 24-hour average PM_{10} concentrations varied from 33 $\mu g/m^3$ to 205 $\mu g/m^3$.
- Measured dustfall masses varied from 0.42 t/km^2/30days to 2.90 t/km^2/30days.
- 24-hour average SO_2 ranged from 19 to 225 $\mu g/m^3$, and exceeded the EEC standard at 2 points.
- The predicted result of ground level concentrations in air showed relatively excellent comparison with measured concentrations. The predicted SO_2 concentration of the ground level for 24-hour is 120 $\mu g/m^3$ as diluted value on west side of the OMCO smelter.

(Investigation on expansion program for smelter and refinery plant)

- It has been stated that plans for expanding the annual production of OMCO's smelter ranging from 40,000 to 100,000 t/year have been drafted. The JICA Team concluded there is no feasible plan for expansion of the plant at this time.

(Environmental impact investigation)

- Environmental impact investigation was performed by personal interview with local residents, health and medical facilities based on an environmental questionnaire. Consequently, diseases, such as respiratory symptom, decrease of livestock, and some impact on plants and insects were observed.

(Socio-economic survey)

- Population in Sohar prefecture is estimated to be 104,169 persons. Agriculture and fishery are active but industrialization has progressed rapidly in recent years.
- There are 8 communities around Sohar mine with 119 families and 870 residents.
- Areas around mine have suffered from salinization of groundwater and offensive odor etc.
- The results of the interview investigation are, as follows:
    - About half of the interviewee do not the situation of Sohar mine area.
    - Almost all persons who visited Sohar mine area know the existing environmental negative effects.
    - Some of persons think they do not use the land in Sohar mine area, but others may use it.
    - Their willingness-to-pay for improving the environmental condition in Sohar mine area is considered to be reasonable.

(Technical transfer)

- Technology transfer was implemented through cooperative efforts during study, including the practice of on-site training, the explanation of the analysis results with the counterparts, counterpart study and training in Japan and so on.
- Some of the problems experienced in implementing the technology transfer element of the study included a shortage of technical experts within MCI and MMEW and the differences in the social environments between Oman and Japan, but the anticipated object of the study was achieved sufficiently and the study was completed with the sincere attitude and efforts of Omani and Japanese study teams.

(Environmental countermeasures)

- The environmental countermeasures in the Sohar mine area consist of the tailing dam and along Wadi Suq.
- The countermeasures between the tailing dam and Trenches -1 and -2 in Subarea 1 are examined by OMCO. A part of construction of evaporation pond is commenced. The tailing dam will be capped with a bitumen liner material, and the contaminated groundwater at Trenches-1 and 2 will is pumped to and treated at the evaporation pond.
- The contamination countermeasures in Subarea 1, 3, 4, and 5 along Wadi Suq were examined and evaluated.
- The contaminated soil in Subarea 3 is necessary to be extracted by excavation, and the excavated zone should be replaced clean soil. The contaminated soil would be transported to seashore for use as fill material in the construction of seaport facilities.
- The countermeasure alternatives at KM 14 in the Subarea 4 consist of two alternatives, including cutoff trench and pumping wells. During construction of countermeasures at the Subarea 4, measures would be taken to protect the natural gas pipeline and seawater pipeline buried in the wadi gravel, and the highway would have to be temporarily rerouted during construction.
- The countermeasure in the Subarea 5 consists of the pumping wells.
- The contaminated groundwater extracted from the Subarea 4 and/or 5 would be transported and treated at the water treatment facility.

- The contaminated groundwater will be removed the salt and heavy metals in the water treatment system. The treatment system would use a membrane separation technology known as reverse osmosis (RO). The permeate stream would be suitable for domestic or agricultural uses. The permeate stream would either be re-injected into the wadi gravels downstream of KM 14, or provided to local residents for domestic or agricultural purposes.
- The condensed water will send to the evaporation ponds and evaporated at there, and finally will be stocked at warehouse after packed.
- Three assemblages of alternatives were selected based on the engineering judgment and cost evaluation, as 1) Countermeasures-A as thought to be the best overall, 2) Countermeasures-B as thought to be second best overall, and 3) Countermeasures-C as technically thought to be necessary minimum.
- The total cost for the Countermeasures-A are estimated at US$ 11,900,000. The total cost for the Countermeasures-B are estimated at US$ 5,300,000. The total cost for the Countermeasures-C are estimated at US$ 2,500,000. The construction period is 12 months.

(Economic analysis)

- The economic cost of the Countermeasures-A was estimated at US$ 10,120,000, and the yearly financial maintenance cost was estimated at US$ 170,000.
- The value of land would fall since the quality of the dates deteriorates as contamination increases. If the implementation of countermeasures can make the groundwater clean, the fall in land values will be stopped, and may even rise. The benefit for land is calculated at 59,700 R.O./year.
- The number of goats, etc. has dropped drastically. If countermeasures will be taken, the number of goats, etc. will increase. The estimated benefit is 37,500 R.O./year.
- If the countermeasures will be implemented, the cost-saving benefit for supplying with free drinking water by OMCO is calculated at 11,984 R.O./year.
- The estimated mean of willingness to pay was 7 R.O./year for Muscat city and 8 R.O./year for Sohar city. Using the estimated mean of willingness to pay, the total amounts of willingness to pay in Muscat were estimated at 800,000 to 1,000,000 R.O./year. That of Sohar was estimated at 350,000 to 450,000 R.O./year.
- As a result of the economic analysis, IRR is 14.0 %, the present net value is considerably large, and the cost benefit ratio is indicated to be greater than 3.0. Therefore, the recommended countermeasures can be judged to be sufficiently feasible.
- Other benefits, including improvement of existing orchard land, growing of trees in the "Al Ons Nature Reserve", returning of honeybees to the mine area, increasing of tourists, etc. will be obtained after the countermeasures will be implemented.

(Countermeasure project implementation)

- The government should burden for this project, which contributes to the improvement of regional environment. In specialty since the construction cost is necessary for a large amount of money, the government is requested for giving its help to OMCO as much as possible by granting subsidy, borrowing soft loans, etc.
- Although it is desirable that the government should pay construction cost, the assignment of the government subsidy is desired to examine. It is necessary to negotiate on loan conditions for

borrowing from domestic banks. In this case, repayment of capital and interest is sufficiently possible by assigning only 0.01 % of GDP to the projects.

- For the implementation of the countermeasure project, it is necessary to execute making of detailed implementation plans, detailed design works and the construction management and so on. After completion of the countermeasure project, operations and management of the water treatment facilities are very important. There is a good solution to use the technology support scheme by foreign countries as the means that cuts these expenses and moreover can receive technology transfer.

(Countermeasures for the air pollution)

- Wet limestone/gypsum scrubber Flue gas desulfurization (FGD) system is recommended to reduce SO_2 emissions from OMCO. SO_2 removal is approximately 90 % or more.
- If 90 % SO_2 removal FGD system is installed in the OMCO plant, the ambient air quality standard is not violated in the area over 20 km x 20 km surrounding OMCO plant.
- The total installation cost of the wet limestone/gypsum scrubber FGD system into OMCO plant is estimated approximately US$ 20,000,000.

(Environmental monitoring system)

- On the monitoring system in the Sohar mine area, total 40 monitoring locations including the existing monitoring places and JICA Team's 25 new monitoring wells are recommended.
- On the monitoring work, establishing of the standard operating procedures (SOPs) for the water sampling and treatment in the field, chemical analysis in the laboratory, data-analysis technique are recommended.
- Another national ambient air quality monitoring station would be necessary in order to monitor impact of stack emission from OMCO.

(Environmental management system)

- The JICA Team recommends no changes in Oman's current wastewater discharge and drinking water standards. The current Omani standards are consistent with world standards.
- The JICA Team recommends that a permanent liaison position be created within DGM to foster coordination and cooperation between MCI and MMEW.
- The government of Oman has not yet established national ambient air quality standards. US EPA ambient air quality standards (NAAQS) are tentatively used as a substitute for ambient air quality standards of Oman.
- Although MMEW presently only reviews these monitoring data/reports and keep them by filing, development of database system of the data/reports gathered in MMEW will certainly contribute to air quality management policy planning.
- OMCO should develop database system, as the database system is helpful to understand ambient air quality monitoring condition and trend around OMCO area, and effective to make and review air quality management plan.

PREFACE

In response to a request from the Government of Sultanate of Oman, the Government of Japan decided to conduct the Feasibility on Mine Pollution Control in Sohar Mine Area, Sultanate of Oman, and entrusted the Study to the Japan International Cooperation Agency (JICA).

JICA sent to the Sultanate of Oman a Study Team headed by Mr. Soichiro Matsuzaka of Mitsubishi Materials Natural Resources Development Cooperation between February 2000 and December 2001.

The Study Team held discussions with the officials concerned of the Government of Sultanate of Oman, and conducted field investigation at the study area. After the Study Team returned to Japan, further studies were made and the present report was prepared.

I hope that this report will contribute to the promotion of the project and to the enhancement of friendly relations between two countries.

I wish to express my sincere appreciation to the officials concerned of the Government of Sultanate of Oman for their close cooperation extended to the Study Team.

December 2001

川上隆朗

Takao Kawakami
President
Japan International Cooperation Agency

LETTER OF TRANSMITTAL

December, 2001

Mr. Takao Kawakami
President
Japan International Cooperation Agency
Tokyo, Japan

We are pleased to submit to you the Final Report on the Feasibility on Mine Pollution Control in Sohar Mine Area, Sultanate of Oman.

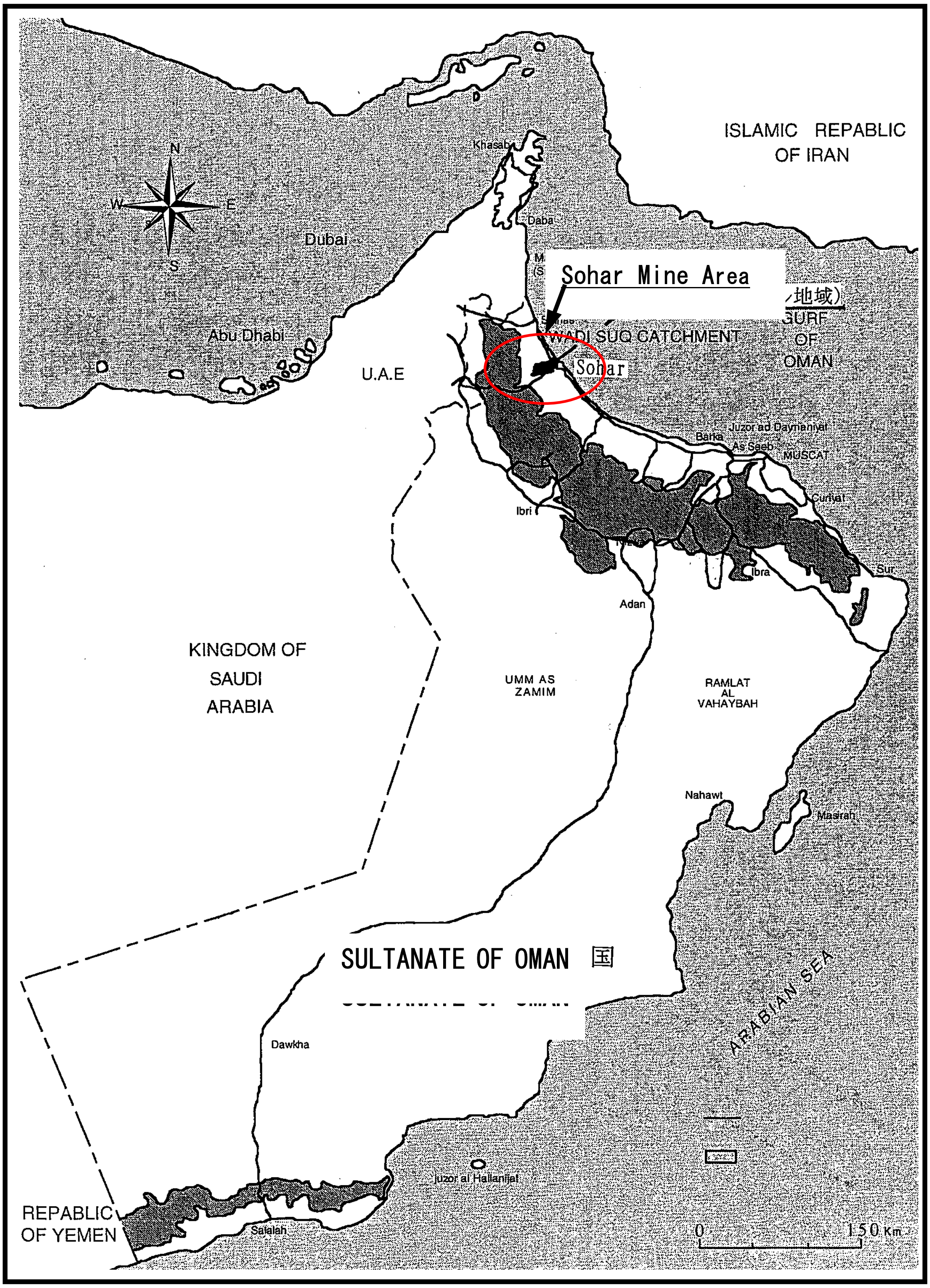
Mitsubishi Materials Natural Resources Development Cooperation and E & E Solutions Incorporation conducted the Study under a contract to JICA, during the period from February 2000 to December 2001. In conducting the Study, we have examined the various environmental aspects related to the mine pollution in the Sohar mine area in the Sultanate of Oman.

We wish to take this opportunity to express our sincere gratitude to the officials concerned of JICA and the Ministry of Foreign Affaires. We would also like to express our gratitude to the officials concerned of the Ministry of Commerce and Industry of the Sultanate of Oman and the Embassy of Japan in the Sultanate of Oman for their cooperation and assistance throughout our field investigations.

Finally, we hope that this report will contribute to further promotion of the project.

Very truly yours,

Soichiro Matsuzaka
Project Manager
Mitsubishi Materials Natural Resources Development Co.



Locality Map

The Feasibility Study on Mine Pollution Control in Sohar Mine Area, Sultanate of Oman

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CHAPTER 1 INTRODUCTION

1.1 Background of the Study

Mining activities in Oman were initiated during the beginning of his Majesty Sultan Qaboos Bin Said's rule together with the opening of a country in 1970. Mineral exploration was actively promoted simultaneously with petroleum and natural gas development. Consequently, Oman Mining Co. LLC. (OMCO) was established in 1978 and development of copper mines in the Sohar districts was commenced. In 1982, operations of the Sohar Mine and Smelter were started. However, the mines were closed in 1994 due to the exhaustion of the copper ore reserves. The copper smelter started toll smelting mainly on consignment in order to compensate for the shortage of domestic concentrate production. This type of smelter operation continues to the present.

The Sohar mining area produced a total of about 15,000,000 t/y of crude copper ore from four deposits named Lasail, Bayda, Aarja, and Lasail West. The entire concentrate production from the on-site dressing plant was supplied to the adjacent smelter. Approximately 11 million tons of sulfide rich tailings from the dressing plant were disposed of in the adjacent tailing dam. The tailing dam was constructed by damming up the shallow valley at the approximate up-stream end of Wadi Suq. In the initial stage of operation, the whole tonnage of industrial water for ore dressing was supplied by seawater. The total amount of seawater used at the dressing plant and then discharged to the tailing dam is estimated to be about 5 million m^3.

At present, salt damage and heavy metal contamination of groundwater have occurred due to seepage from the tailing dam, which is one of the auxiliary facilities of the Sohar mining district. Hence, it is suspected that dispersion of pollution to the lower reaches of Wadi Suq may be occurring. Air pollution damage due to sulfur dioxide (sulfurous acid gas) rich off gas discharged from the operating smelter is occurring also.

Government officials in Oman, such as MMEW have expressed strong interest in the pollution originating from the mining and smelting facilities in the Sohar region and have expressed concern about the dispersion of groundwater contamination and air pollution. Officials are especially concerned about the possible contamination of the series of green belts that run along the coastline of the Gulf of Oman. These green belts comprise the largest agricultural zone in the country and are also densely populated, with Sohar, the third largest city in Oman, at the center. Concerns about the potential impacts of groundwater and air pollution on this densely populated and important agricultural area are taken very seriously.

1.2 Purpose of the Study

Purpose of the study is as follows:

1) Investigate groundwater contamination and air pollution sources originating from the past copper mining and current smelting activity and identify the contamination and pollution mechanisms;
2) Propose countermeasures that would reduce and control the dispersion of pollutants in the Sohar mining district and execute a feasibility study for the proposed countermeasures;
3) Transfer technology on mine site pollution and its control to the Ministry of Commerce and Industry (MCI) and Oman Mining Co. LLC. (OMCO) who are the Omani counterpart organizations during the study period.

1.3 Objective Area of the Study

The Study area includes Wadi Suq and its surroundings from Falaj al Qabail on the east to Suhaylah village on the west side of the OMCO plant site. This area encompasses approximately 300 km^2 (Figure 1.1).

1.4 Scope of the Study

The Study consists of three stages, including the Basic Study Stage, Detailed Study Stage, and Feasibility Study Stage. To achieve the Study's objectives, the scope of the three stages of the Study consists of the following:

1) Basic Study Stage
   - Hydrogeologic and environmental investigation
   - Geophysical exploration
   - Drilling survey
   - Chemical analysis etc.
   - Examination of hydrogeologic features and contamination mechanism of groundwater
   - Examination of simulation model for the air pollution
2) Detailed Study Stage
   - Hydrogeologic and environmental investigation
   - Drilling survey
   - Chemical analysis etc.
   - Hearing investigation
   - Socio-economic investigation
   - Clarification of water contamination mechanism and simulation of water contamination
   - Simulation of air pollution (sulfur dioxide)
   - Planning of countermeasures for water contamination and air pollution
3) Feasibility Study Stage
   - Conceptual design of countermeasures for water contamination
   - Examination of countermeasures for air pollution
   - Cost estimation for countermeasures of mine pollution

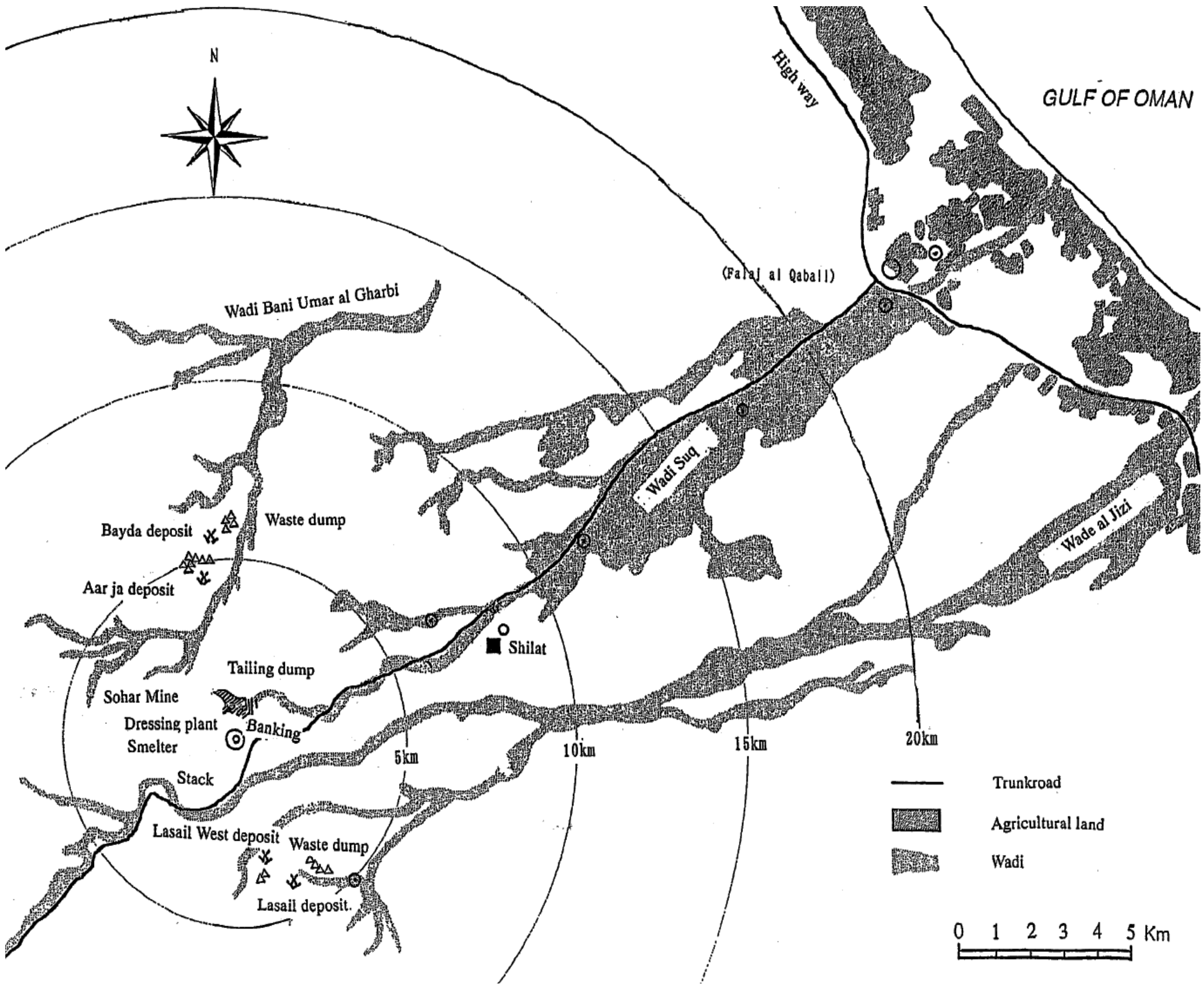

Figure 1.1 Objective Area of the Study

- Clarification of socio-economic, economic and financial analyses
- Evaluation and examination of feasibility of the remedial countermeasures
- Technical transfer related to the study for the Omani counterparts' engineering staff.

1.5 Flow of the Study

The Study was executed according to the flow chart shown in Figure 1.2 (1) and (2).

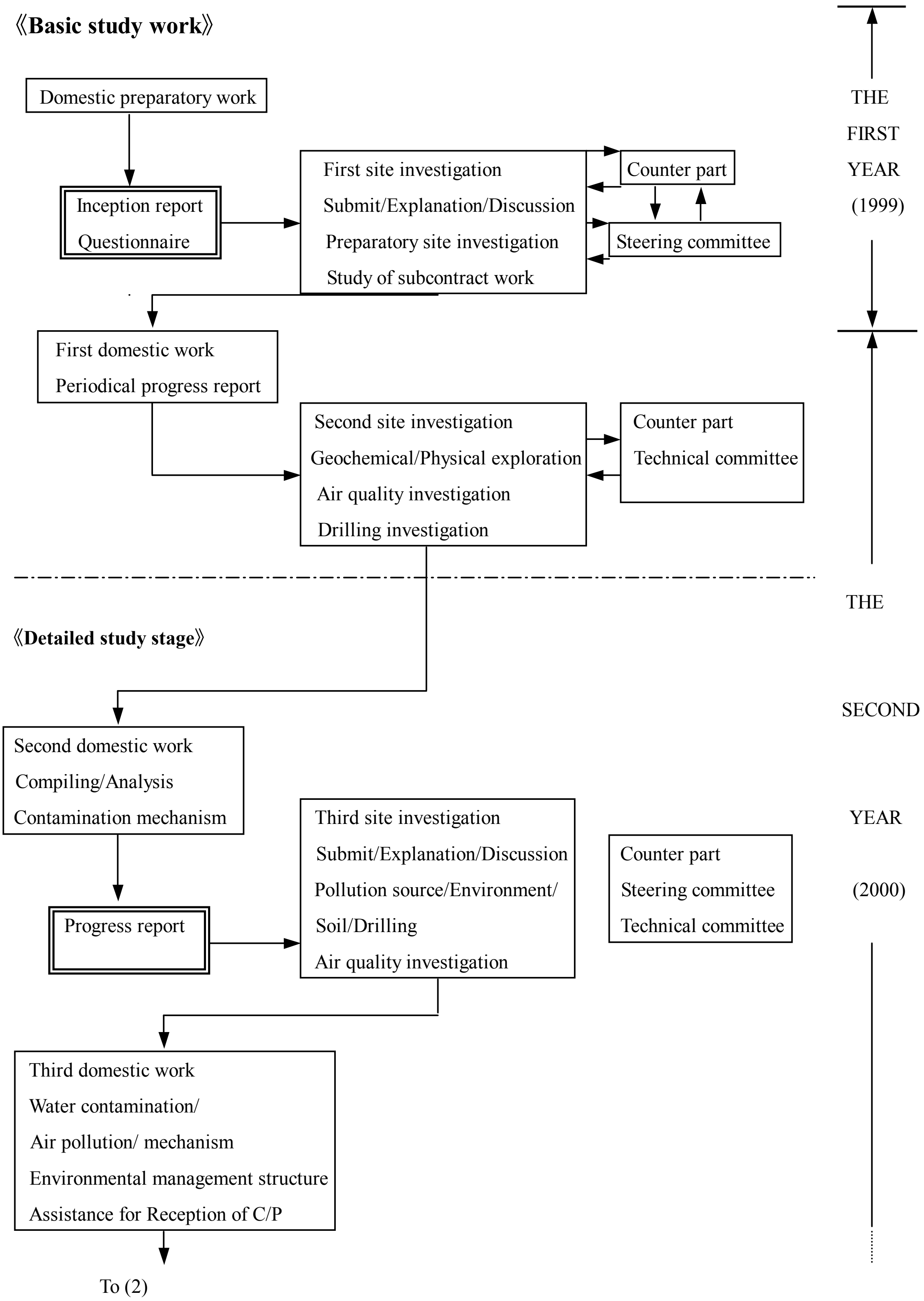

Figure 1.2 Flow of the Study Work (1)

《**Feasibility study stage**》

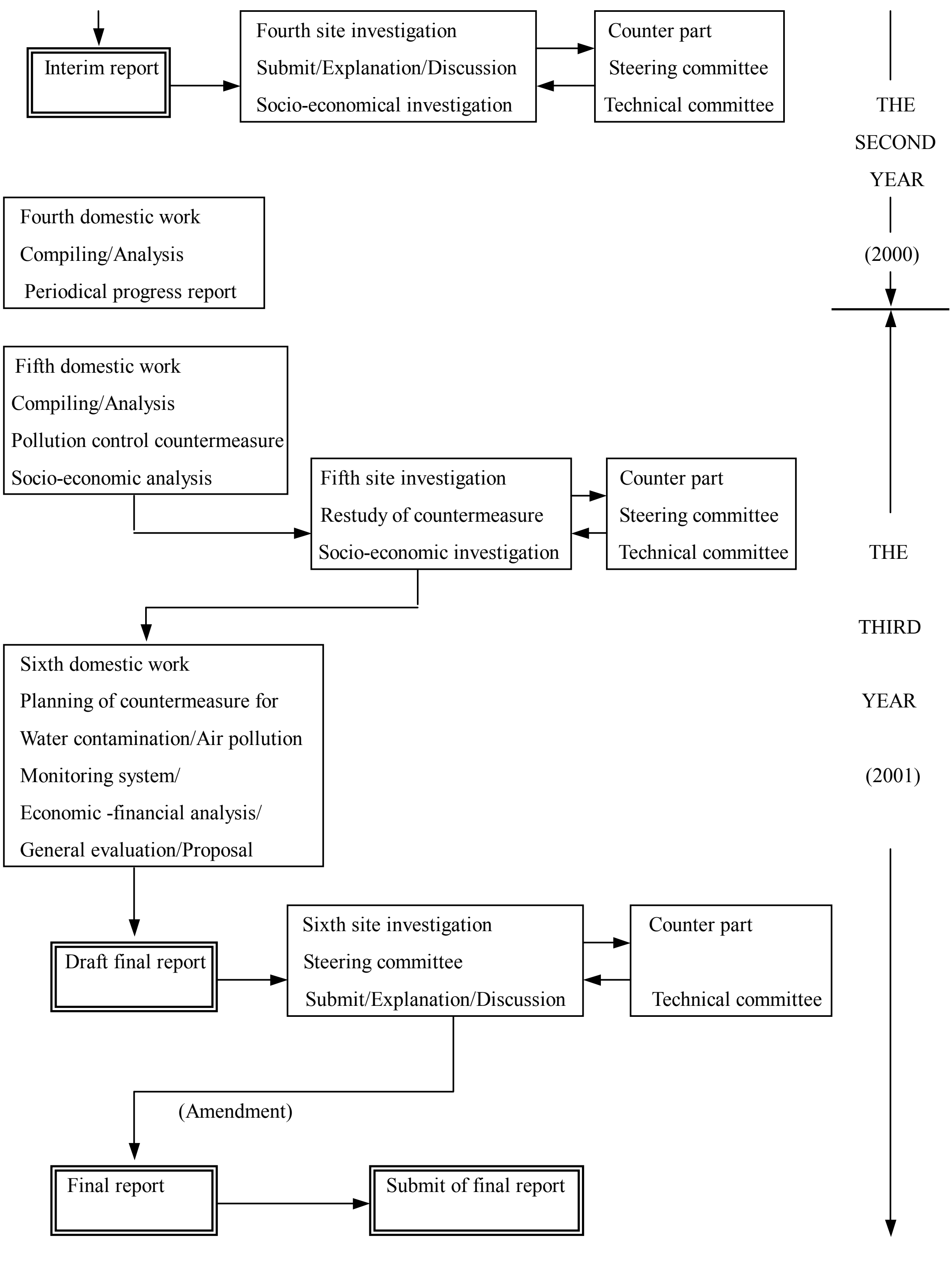

Figure 1.2 Flow of the Study Work (2)

CHAPTER 2 TOPOGRAPHY・GEOLOGY AND HYDROGEOLOGY

2.1 Topography

2.1.1 Topographical Characteristics

The Sohar area is located on east side in northern part of the Hajar Mountains. The topography of the Study area mainly consists of the moderate and low relief mountain, hilly land, fans and terraces, alluvial plain and coastal plane. Wadi Suq is a dry valley, a so-called wadi; and, for the most part, no surface water is found. Wadi Suq has a river length of 34 km with an average slope of 0.008 (1:125). The maximum elevation of the wadi is 275 m. The wadi is 30 m above sea level at Falaj al Qabail in its down-stream area. The upper reaches of Wadi Suq consist of hilly land and locally low to moderate relief mountains. The tailing dam is located in this upper area (Figure 2.1).

2.2 Geology

On the geology of the Study area, the basement rocks consist mainly of the Samail Nappe, which is composed of the Ophiolite and Batinah Olistostromes of the Pre-Tertiary period. Tertiary Deposits are found locally in the eastern part of the area, while terrace deposits and alluvial deposits of the Quaternary period are widely distributed in the eastern part of the area.

On the geological structure, the dominant directions of faults in the region of the Pre-Tertiary and Tertiary Deposits are northeast to southwest and northwest to southwest. A narrow graven structure from 1 km to 1.5 km wide runs along Wadi al Jizi in an east-northeast to west-southwest direction.

2.3 Hydrogeology

2.3.1 Water System

Normally dry riverbeds flowing out from the Study area consist of Wadi Bani Umar al Gharbi, Wadi Suq, and Wadi al Jizi from north to south, respectively. All wadis flow from the west to northeast and east-northeast.

Wadi Suq is 34 km in length with an average gradient of 0.008 (1:125). The maximum elevation of the wadi is 275 m. The altitude at Falaj al Qabail is 30 m in elevation. The total catchment area is 71 km^2 with the mountainous zone of the wadi occupying 29 km^2. The tailing dam located at the uppermost part of Wadi Suq. The hydrological features on Wadi Suq are shown in Table 2.1(1)～(2).

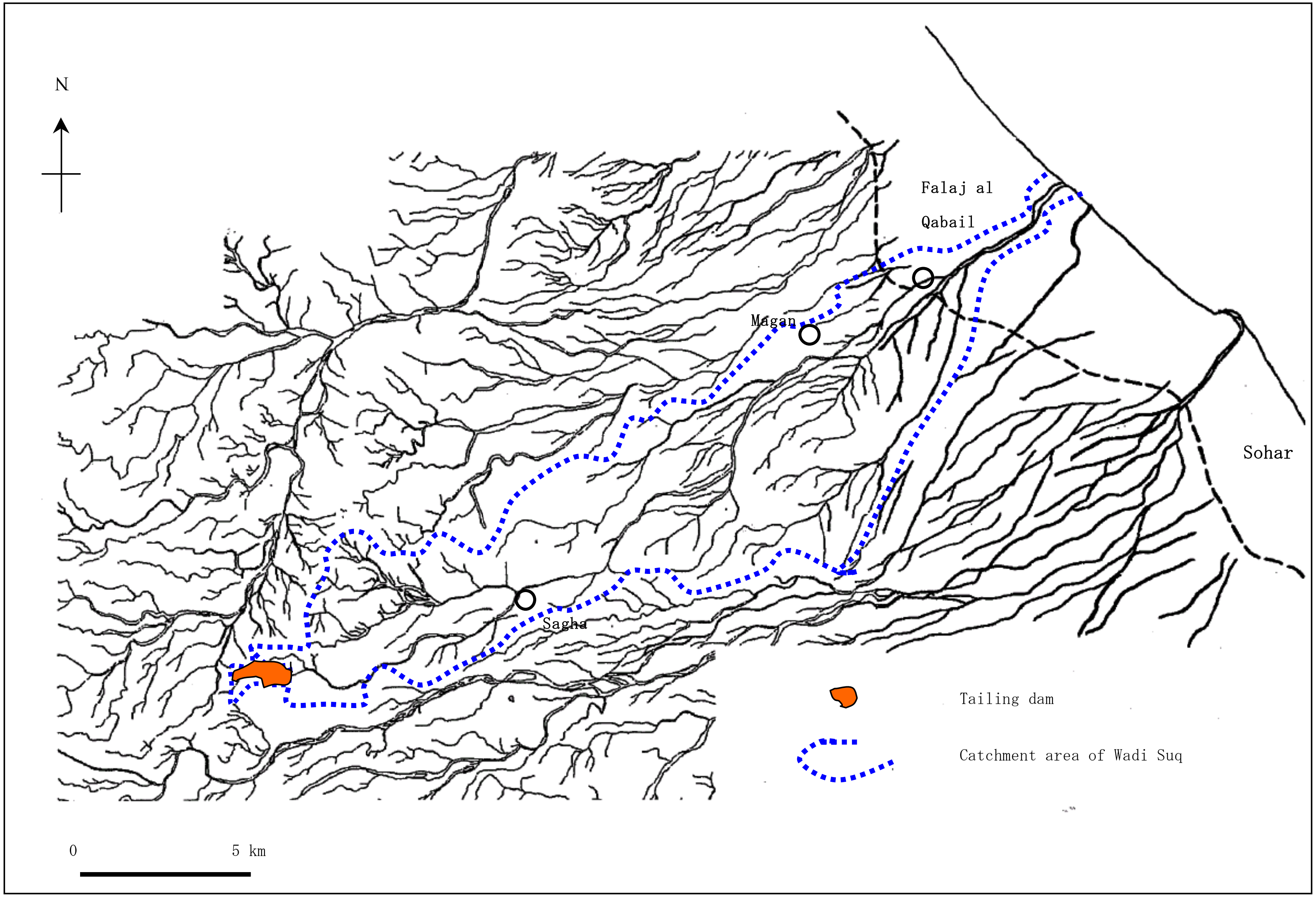

Figure 2.1 Catchments area of Wadi Suq

Table 2.1 Hydrological Features on the Wadi Suq

(1) Situation of Wadi Suq

1. Total river length (m)	34 km		
2. River length (m) and elevation (m)	Location	Length (km)	Elevation (m)
Upper part of Wadi Suq Middle part of Wadi Suq Lower part of Wadi Suq	From top to KM14 (Sagha) From KM14 (Sagha) to Magan (D-7 point) From Magan (D-7 point) to river mouth	12.2 11.3 11.0	312 to 152 152 to 60 60 to 0
3. Total catchments area (km^2)	90.66 km^2 (including main water course area and Tributary-1) 111.81 km^2 (including main water course area, Tributary-1 and -2) 158.16 km^2 (including main water course area, Tributary-1, -2 and -3)		
4. Highest elevation (m)	312 m		
5. Total river gradient (°)	0.5 ° (1/110)		
6. River gradient (°) Upper part of Wadi Suq Middle part of Wadi Suq Lower part of Wadi Suq	From top to KM14 (Sagha) From KM14 (Sagha) to Magan (D-7 point) From Magan (D-7 point) to river mouth	0.7 ° (1/77) 0.5 ° (1/122) 0.3 ° (1/183)	
7. Topographical features Upper part of Wadi Suq Middle part of Wadi Suq Lower part of Wadi Suq	Low relieved mountainous land Hilly land and terrace plane Alluvial plane		
8. Vegetation in the catchments area	Classification : Sub-arid area Vegetation : Very rare		
9. Surface water	No surface water		

(2) On the Subarea along Wadi Suq

1. Tributaries of Wadi Suq	Name	Length (m)	Catchments area (km^2)	
	Tributary-1 Tributary-2 Triburart-3	7.5 14.5 20.9	15.68 21.15 46.35	
2. Sub-areas in main water course of the wadi	Subareas	Location	Length (km)	Area of alluvial plane (km^2)
	Subarea-1	End of Tailing dam to D-5 point	1.5	0.71
	Subarea-2	D-5 point to 6.2 km point	1.5	0.52
	Subarea-3	6.2 km point to D-6 point	2.5	0.89
	Subarea-4	D-6 point to KM14 (Sagha)	3.45	1.02
	Subarea-5	KM14 (Sagha) to D-13 point	4.0	4.87
	Subarea-6	D-13 point to D-7 point	7.35	13.29
	Subarea-7	D-7 point to D-16 point	8.9	18.72
	Total		29.2 km	40.02 km^2

Water is typically pumped from the wells by electric or gasoline powered pumps. Well water is mostly used for irrigation and livestock. Potable water is currently obtained by delivery trucks from OMCO since the mine pollution has affected the quality of the water.

Wadi al Jizi has total length of 75 km, with a catchment area of 1,100 km^2. The altitude at the highest point is 1,567 m and average gradient is 0.021 (1:48). The Study area includes from middle to lower part of the wadi, i.e. from Suhaylah village to Sohar city.

Wadi Bani Umar al Gharbi is 65 km in length with a catchment area of 450 km^2. The altitude at the highest point is 1,452 m and the average gradient is 0.022 (1:45). The middle to downstream reaches of the wadi, i.e. a range from Bayda village to its downstream is included in the Study area. The Aarja and Bayda mines are located along one of the tributaries in the middle stream area.

2.3.2 Water Wells

Water wells are distributed in riverbeds or on alluvial terrace plains along Wadi Suq, Wadi al Jizi and Wadi Falaj al Qabail. The wells are mostly hand dug and range in depth from 6 to 15 m.

CHAPTER 3 GEOCHEMICAL INVESTIGATION

The geochemical investigation was conducted to determine the distribution of chloride (Cl) in soils and wadi sediments.

3.1 Soil (Dustfall) Investigation

The purpose of the soil investigation is to identify soil contamination caused by the deposition of dust from the copper smelter and other sources. And these points are selected at random in zones of 500 m, 1 km, 2 km, and 3 km distance from the smelter. A total of 31 soil samples were collected for the geochemical investigation. Analytical parameters consist of 13 components, including Hg, Cd, Cr, As, Pb, Cu, Mn, Fe, Ni, Sn, Zn, SO_4, and Cl.

By chemical analysis of topsoil samples obtained from the terraces, high heavy metal content, such as Cd, Pb, Cu, Fe, Zn and SO_4, appear to be the result of fugitive dust emissions from the smelter stack. All of these metals appear to be dispersed a central point at the plantsite. Some of these metals are presumed to be dispersing beyond 3 km. Anomalies in the concentrations of Pb, Fe, Ni, SO_4 and Cl can be found around the tailing dam. These anomalies are apparently caused by wind transport out of the tailing dam.

3.2 Salt Concentration in the Soil

Samples of wadi sediments and alluvial soil along the wadis around the tailing dam were collected and analyzed to identify leakage of salt from the tailing dam.

In order to identify leakage of salt from the tailing dam, sampling points were limited to the wadi. All small and large-scale valleys around the tailing dam were selected as sampling points. The sampling points selected in Wadi Suq extended especially far downstream in order to determine the extent of contaminant dispersion compared with background levels.

Summary of the analytical result is as follows:

- Chloride concentrations fluctuate in an extremely wide range, from 106 to 146,500 mg/kg.
- Background concentrations in the Study area range from 106 to 180 mg/kg. These background concentrations appear consistent with results of chloride concentrations from the soil dust fall.
- High chloride concentration areas more than 5,000 mg/kg consist of downstream side of the tailing dam, PS-2 point, upstream of KM 14 (Sagha Village), and upstream of Aarja Village (Figure 3.1).
- Cl anomaly along Wadi Bani Umar Al Gharbi is assumed that the leakage out of the tailing dam migrates to the north side through fractures.
- Seepage from the tailing dam permeates downstream, and chloride concentrations become higher immediately downstream of the tailing dam.

- OMCO's seawater pumping station PS-2 is located just upstream of KM 14 (Sagha Village). It has been reported that seawater leaked from the pump station during its operation.

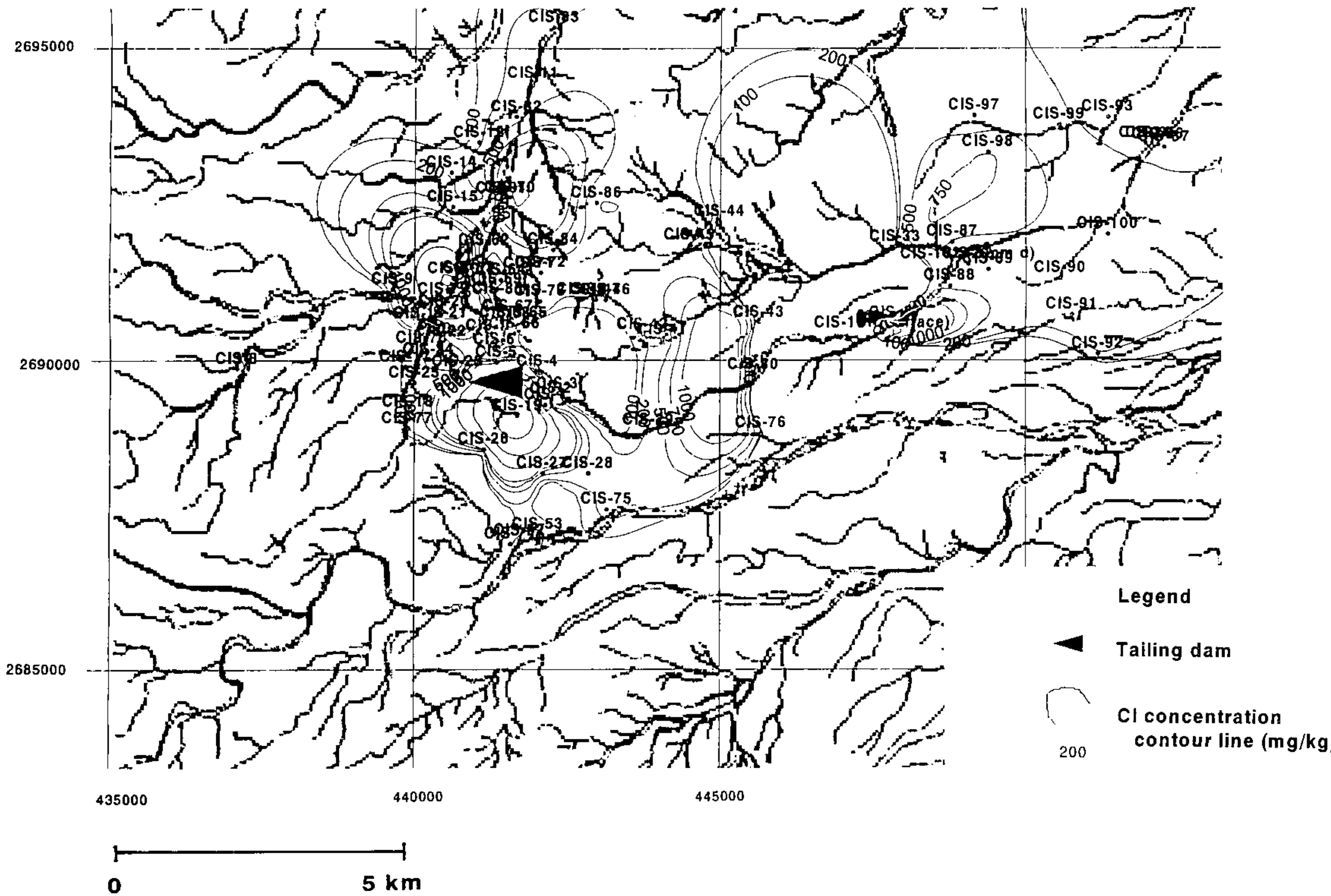

Figure 3.1 Concentration Contour Map of Cl in the Soil

CHAPTER 4 GEOPHYSICAL SURVEY

The purpose of the geophysical survey is to identify the underground structure of the basement, assess the current conditions of the basement rock, evaluate the distribution and characteristics of the loose sediments, and investigate groundwater conditions and groundwater quality. In order to accomplish this purpose, Nano-Transient Electromagnetic Method (Nano-TEM) with micro-gravity methods are expected to be effective.

4.1 Nano-TEM Survey Method

Ten Nano-TEM survey lines were programmed in the upper, middle and lower parts of Wadi Suq. Measurement intervals for each survey line were set at 20 m.

Summary of survey result is shown as below.

- In the cases of the measurement lines L-1 and L-2 passing through the tailing dam located in uppermost reach of Wadi Suq, the specific resistivity basement appears as an almost horizontal line about 30 m under the ground surface with a layer with low specific resitivity spreading horizontally over the basement (Figure 4.1).
- Measurement line L-3 is located downstream of measurement lines L-1 and L-2. In this case, a low resistivity layer cannot be found, but a relatively low resistivity zone is distributed almost horizontally from approximately 10 m below the wadi ground surface to the deep part of a terrace. It can be inferred that there exists a basement with high resistivity under the low resistivity zone.
- Under measurement lines L-4 and L-5 in the middle reach of Wadi Suq, high resistivity basements exist 50 to 100 m under the ground surface, relatively deep compared with the upstream lines.
- High resistivity basements under measurement lines of L-6, L-7 and L-8 located in the middle to lower reaches of Wadi Suq exist 50 to 100 m under ground surface at almost the same elevation as the basement in the middle reach of the wadi. Resistivity values associated with the high resistivity basement under the measurement line L-8 are lower by almost half compared with measurement lines L-6 and L-7. Similarly, resistivity values of the low resistivity zone are relatively low, having zone thickness of about 30 m.

4.2 Gravity Survey

Gravity survey work was carried out at a total 13 measurement lines, i.e. 12 lines in upper to lower reaches of Wadi Suq and 1 line near Bayda village in Wadi Bani Umar al Gharbi. A micro (Precise: less than 2 μ gal) gravity meter of Lacoste D-type (Lacoste & Romberg Co. made in USA) was used to make the gravity measurements.

Summary of survey result is shown as below.

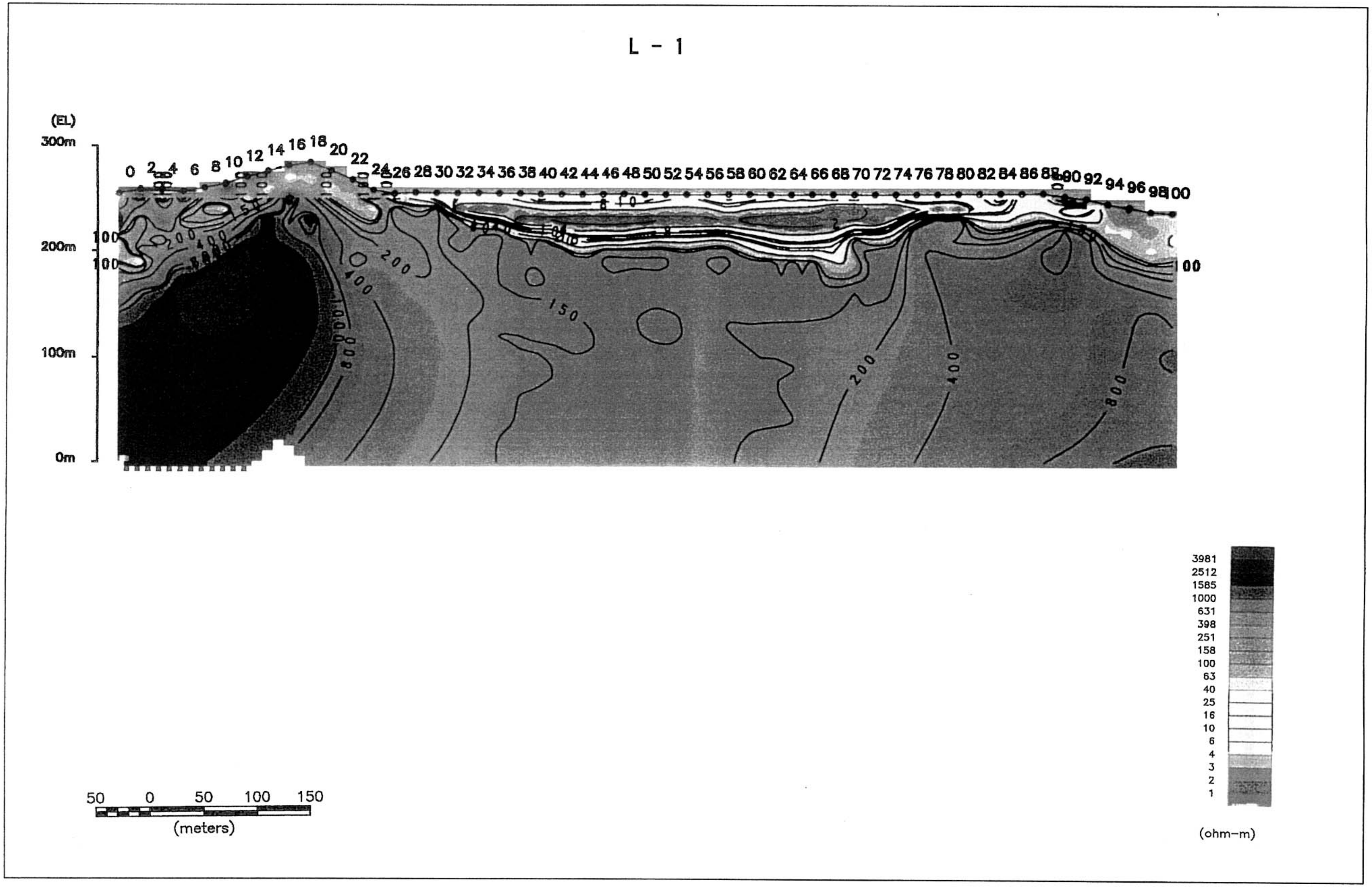

Figure 4.1 Resistivity section analyzed by Nano-TEM Geophsical Survey

- Under measurement lines of L-1 and L-2 in upper stream of Wadi Suq, basement is deemed to exist about 30 m under the ground surface in tailing dam (Figure 4.2).
- Under the measurement line L-3 located downstream of L-1, a landform like a valley can be found on a large scale.
- Under the measurement lines of L-4 and L-5 in the upper and middle reaches of the wadi, there exists an almost flat, relatively shallow basement with ranging from 5 to 10 m below ground surface.
- Under measurement lines L-6, L-7 and L-8 in middle to lower reaches of the wadi, the tendency that the basements exist at a slightly deeper depth of about 20 m. However, their form is almost flat on the whole.

LINE-1

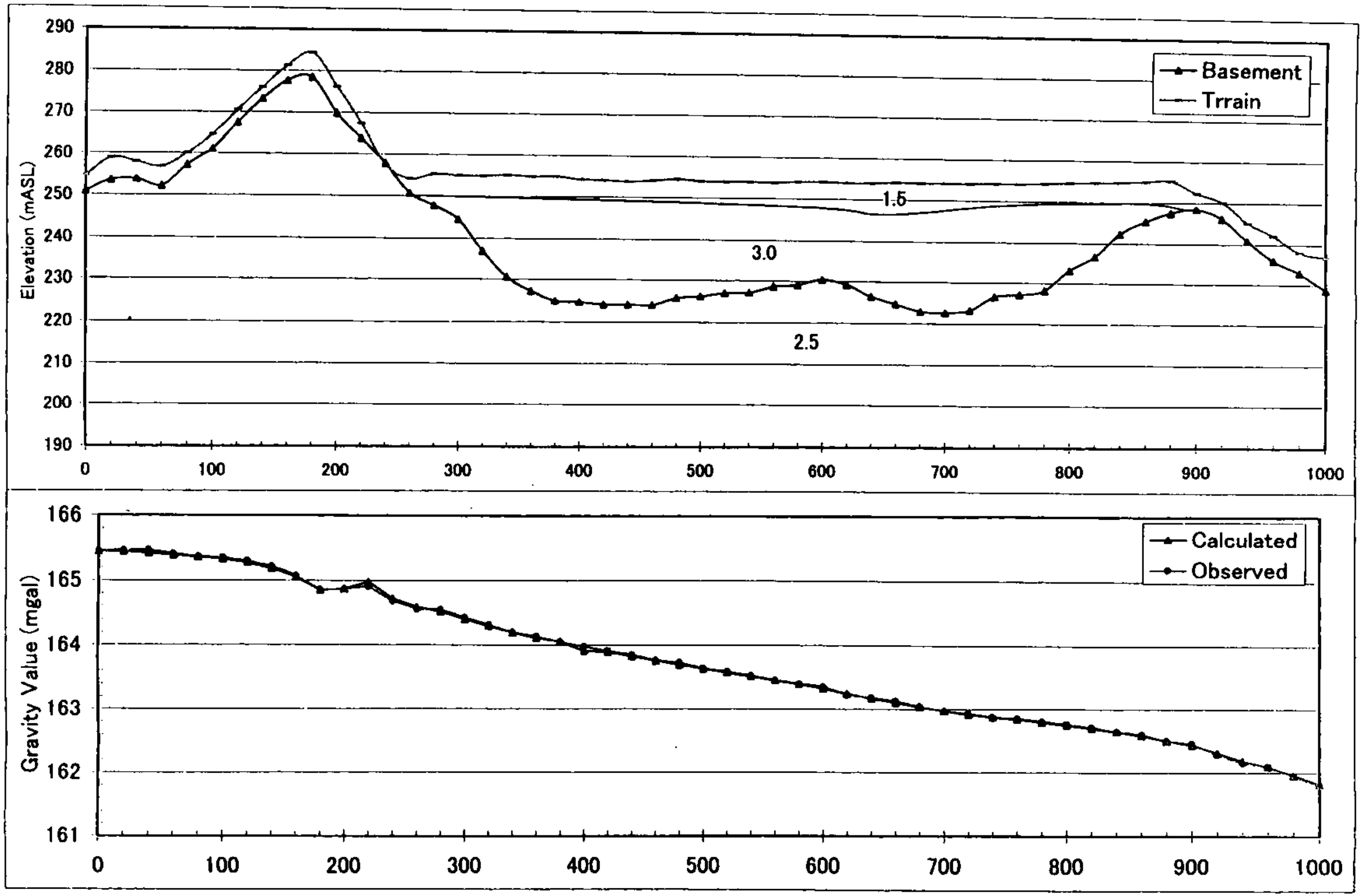

Figure 4.2 Gravity Profile by Sectional Analysis