THE UNITED REPUBLIC OF TANZANIA

PRE-FEASIBILITY STUDY REPORT
ON
NATURAL SODA DEVELOPMENT IN LAKE NATRON AND RELATED TRANSPORTATION FACILITIES

PART I

August 1976

JAPAN INTERNATIONAL COOPERATION AGENCY

PART Ⅱ

REPORT

ON

NATURAL SODA DEVELOPMENT

ABBREVIATIONS :

t., Mt., *M/t*	....	metric ton
St., *s/t*	....	short ton
wt%	....	weight per cent
$	....	US$

US$1.00 = Tshr 8.16
Tshr 1.00 = US$ 0.122549

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CHAPTER 1 SODA ASH AND NATURAL RESOURCES

1-1 Nature of Soda Ash

Soda ash (sodium carbonate unhydride) is hygroscopic white powder having a molecular weight of 105.99, specific gravity of 2.533, and melting point at 851° C. When dissolved in water, it generates the heat of solution, and presents a considerably strong degree of alkali. The major properties of soda ash are as follows:

Chemical formula:	Na_2CO_3
Molecular weight:	105.99
Chemical equivalent:	53.00
Electro-chemical equivalent:	1.977 g/Ah
Colour and form:	White powder
Specific gravity:	2.533
Hygroscopicity:	Slightly hygroscopic
Specific heat:	0.249 cal/° C. mol (at 20° C)
Melting point:	851° C
Boiling point:	Decomposition
Solubility in 100 g water:	7.1 g (at 0° C) 21.6 g (at 20° C) 45.5 g (at 100° C)
Heat of solution:	-5.9 Kcal/mol. at 100 mol. H_2O

1-2 Application of Soda Ash for Use

The so-called alkali carbonates such as sodium carbonate, sodium bicarbonate, sesqui-sodium carbonate, potassium carbonate, etc. are important industrial chemicals as alkaline raw materials together with caustic alkali. Of the alkali carbonates, the most important is sodium carbonate which is generally known as soda ash.

When compared with caustic alkali such as caustic soda, etc., soda ash presents a weaker degree of alkali: however, being in solid powder form, it is comparatively stable chemically, thereby allowing much easier handling. Soda ash has been utilized since a considerably long time ago. Particularly since the beginning of the 18th century, when the demand for glass, soap, etc. began to increase, inventions were made to produce soda ash by utilizing salt abundantly available. The process was since developed into a synthetic process such as the Leblanc Process, and in 1866, the production of synthetic soda ash was made by the Solvay process. During the early decades of the 20th century, natural soda ash production began in Lake Magadi of Kenya, in Owens Lake and Searles Lake California, and in Green River, Wyoming, U.S.A., etc.

The growth of demand for soda ash was supported by the increase in the application as the raw material for manufacturing glass and soap during the initial stage; however, along with the development of industry, the field of application has been expanded. At present, the major application of soda ash as a raw material covers a wide range as enumerated below:

Production of sheet glass, glass bottles, glass products

Production of soda derivatives such as sodium bicarbonate, sodium silicate, sodium bichromate, sodium sulphite, etc.

Production of inorganic chemicals such as magnesium carbonate, barium carbonate, etc.

Production of chemical seasonings such as sodium glutamate, etc.

Organic synthesis to produce dyestuffs, perfume, pharmaceutical goods, etc.

Production of soap from fatty acid, and as the raw material for other detergents

Production of pulp and paper

Processing such as cleaning, refining, and dyeing of cotton, wool, etc.

Desulfurization of pig iron in steel manufacture

As the water softener for industrial water

As a neutralizing agent

For refining of salt water, oil, fats, etc.

As the blazer for chinaware, enamelware, etc.

For regeneration of rubber

Among the above-enumerated fields of soda ash application, the manufacturing of sheet glass and other glass products is by far the largest soda ash consuming sector. In the industrially advanced countries, more than 50% of the total soda ash consumption is destined to the production of glass-related products. The next largest consumer of soda ash in these countries are the consumption in the fields of manufacturing inorganic and organic chemicals, dyestuffs and detergent.

Table 1-1 shows the demand structure of soda ash of Japan and U.S.A. which are deemed to be representing the general trend of soda ash consumption in the world today.

Table 1-1 Demand Structure of Soda Ash

	Japan			U.S.A.		
	1973	1974	1975	1973	1974	1975*
Plate-glass, glass products	59	57	57	52	55	51
Chemical industry	21	25	25	29	24	27
Paper, pulp	1	1	1	3	7	8
Detergent, soap	1	1	1	4	5	6
Water treatment	18	16	16	4	3	3
Others				8	6	5

* : Estimated

1.3 Quality of Soda Ash

As has been mentioned earlier, soda ash is produced in the form of white hydroscopic powder or granule and is used as a final product in this form. Of various grades of soda ash, those having bulk density of less than approximately 0.8 are called *light soda ash*. *Light soda ash* may sometimes cause loss by scattering in the atmosphere in the form of dust, and thereby sometimes polluting the environment. Therefore, recent trend is an increase in the demand for dense soda ash of higher of approximately 1.2 or more and also having a larger particle size.

As it is not very difficult to obtain high purity soda ash, the industrially advanced countries consume only those grades of more than 99% purity which do not call for a process of eliminating impurities. Further, highly pure soda ash is the most economical alkali source at present.

Table 1-2 Example of Soda Ash Quality

(%)

	Natural soda ash			Synthetic soda ash
	Kenya	U.S.A.		Japan
		A	B	
Na_2CO_3	97.1	99.8	99.8	99.5 min.
$NaHCO_3$	0.05	-	-	-
$NaC\ell$	0.3	0.03	0.02	0.3 max.
Na_2SO_4	0.40	0.07	0.02	0.05 max.
Fe_2O_3	0.035	0.0006	0.0005	0.001 max.
NaF	1.28	0.00	0.00	0.00
H_2O Insol.	0.4	0.0	0.0	0.002

If impurities as salt, etc. are included in soda ash such, accidents may be caused because of corrosion of equipment by the impurities. Also, they may deteriorate the quality and yield of industrial chemicals made of soda ash. Therefore, soda ash containing much impurities is deemed unacceptable to the users.

Particularly in recent years, the problems pertaining to the environmental pollution which has been aggravating along with the development of industrialization have been becoming serious on a global scale. The atmospheric pollution by fluorine which inflicts damages on human skin and the respiratory system is among one of the most serious problems.

The release of fluorine is therefore strictly regulated by the recommendations on the environmental pollution allowance issued by the American Conference of Governmental Industrial Hygienists (ACGIH) or by enactment of laws and regulations in the case of Japan. The presence of fluorine was considered useful in the manufacturing of glass products in the past; however, along with the emergence of the necessity for conserving environmental conditions, the dispersion of fluorine from plants into atmosphere has become intolerable.

Fluorine may intrude into the off-gas during the application of soda ash and eventually leak into the atmosphere if not properly controlled. Therefore, if elimination of fluorine is not properly conducted, the marketing of such soda ash may be greatly handicapped in the world market, particularly in the industrially advanced countries.

1-4 Natural Soda Resources

The existance of natural soda reserves has so far been reported from several places in the world. These reserves are classifeid into two categories, i.e., those existing in the form of sodium salt minerals such as Torona reserves ($Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$), and those existing in the form of brine (a aqueous solution containing carbonate, sulphate, sulphides, and other sodium salts).

The natural soda is found mainly in the U.S.A. and Africa. The already developed reserves are Green River of Wyoming, Lake Owens and Lake Searles of California, and Lake Magadi of Kenya, Africa. The natural soda in the U.S.A. has become the world's largest soda ash supply source.

The soda ash produced at Green River, U.S.A. is a high-grade mineral of Trona composition, and it has been confirmed that the deposit is forming multiple layers at one hundred meters to several hundred meters underground. So far, production of soda ash from this deposit has been carried out at a level of several million tons of products per year, and the deposit is estimated to be several tens of billion tons.

In the Californian deposits, the soda ash production is carried out by using brine pumped up from underground. This brine contains in addition to sodium carbonate, halite, burkeit, borax, etc. Therefore, from the brine, produced at present are soda ash, borax, sodium sulphate, potassium chloride, etc. It is estimated that the brine deposit in terms of soda ash amounts to approximately 500 million tons.

In Africa, the soda ash deposit has been identified in Lake Magadi and Lake Amboseli of Kenya, Lake Makgadikgadi of Botswana, and Lake Natron of Tanzania. Of these, the reserves at Lake Magadi was developed around the turn of this century. The bed of the deposit consists of brine which is the body of the lake water, and the layer of the cristalline Torona which has been formed due to the evaporation of the water content from this brine. In addition to the production of soda ash from the Torona layer, table salt has been produced from the brine. It is estimated that the extent of the reserve amounts to more than 100 million tons in terms of soda ash.

CHAPTER 2 GENERAL SURVEY OF LAKE NATRON

2-1 Outline of Lake Natron

2-1-1 Geographic location and the area coverage

Lake Natron is located in the northern part of Tanzania at 2°20' south latitude, 36°10' east longitude. The lake is located at approximately 460km north-west of Tanga Port on the North Coast of the country, and the northern shore of the lake is adjacent to the border line with Kenya. The shape of Lake Natron is a long oval stretching roughly from north to south, having a east-west width of approximately 20km and north-south length of approximately 50km, with a total area coverage of approximately 900km^2.

2-1-2 Climatic conditions

The temperature and humidity in the vicinity of Lake Natron were measured by the Survey Team which stayed on the shore from 20th November 1975 until 25th November 1975. The maximum temperature was 35.6° C, the temperature difference between daytime and night ranging from 10° C to 20° C. The humidity during the day was 30% to 40%, and approximately 60% at night.

It is necessary to conduct a long-term observation of the climatic conditions around the lake; however, the information made available to the Team reveals that the climatic conditions of this site is as follows:

According to the annual meteorological data (Table 2-1) concerning Lake Magadi which is located at approximately 40km north of Lake Natron, the maximum annual temperature is 37° C, and the minimum at 22° C. The total annual precipitation amounts only to 384mm, and the average annual humidity ranges from 28% to 60%. These data imply that this area is extremely dray.

Further, according to an annual precipitation distribution chart (Fig. 2-2) in the 'Tanzania in Map' (L. Berry, 1971), the annual precipitation in the vicinity of Lake Natron is less than 600mm.

In view of the above-mentioned data, the area around the lake belongs to the 'semi-desert climate' zone, having low precipitation and a high extent of dryness. Therefore, it seems that the speed of evaporation at the lake is extremely high. The Team tried to measure the evaporation speed by sampling the brine from the lake in a small container. However, probably because it was the short rainy season, the evaporation and precipitation were on an approximately the same level due to shower rainfalls which took place almost every day. According to an actual measurement of evaporation conducted by Guest and Stevens in 1951, it is reported that the

Figure 2-1 Location of Lake Natron

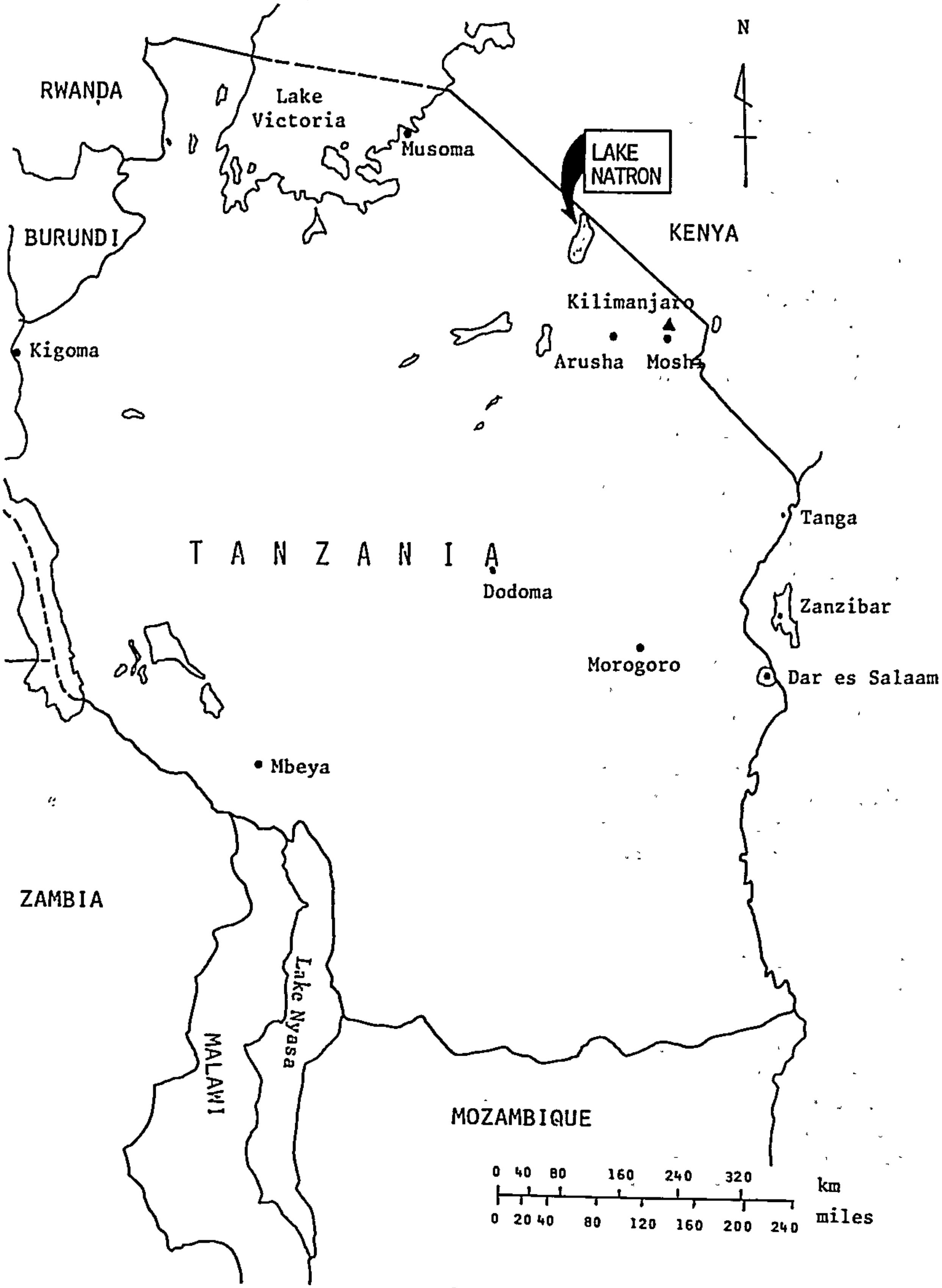
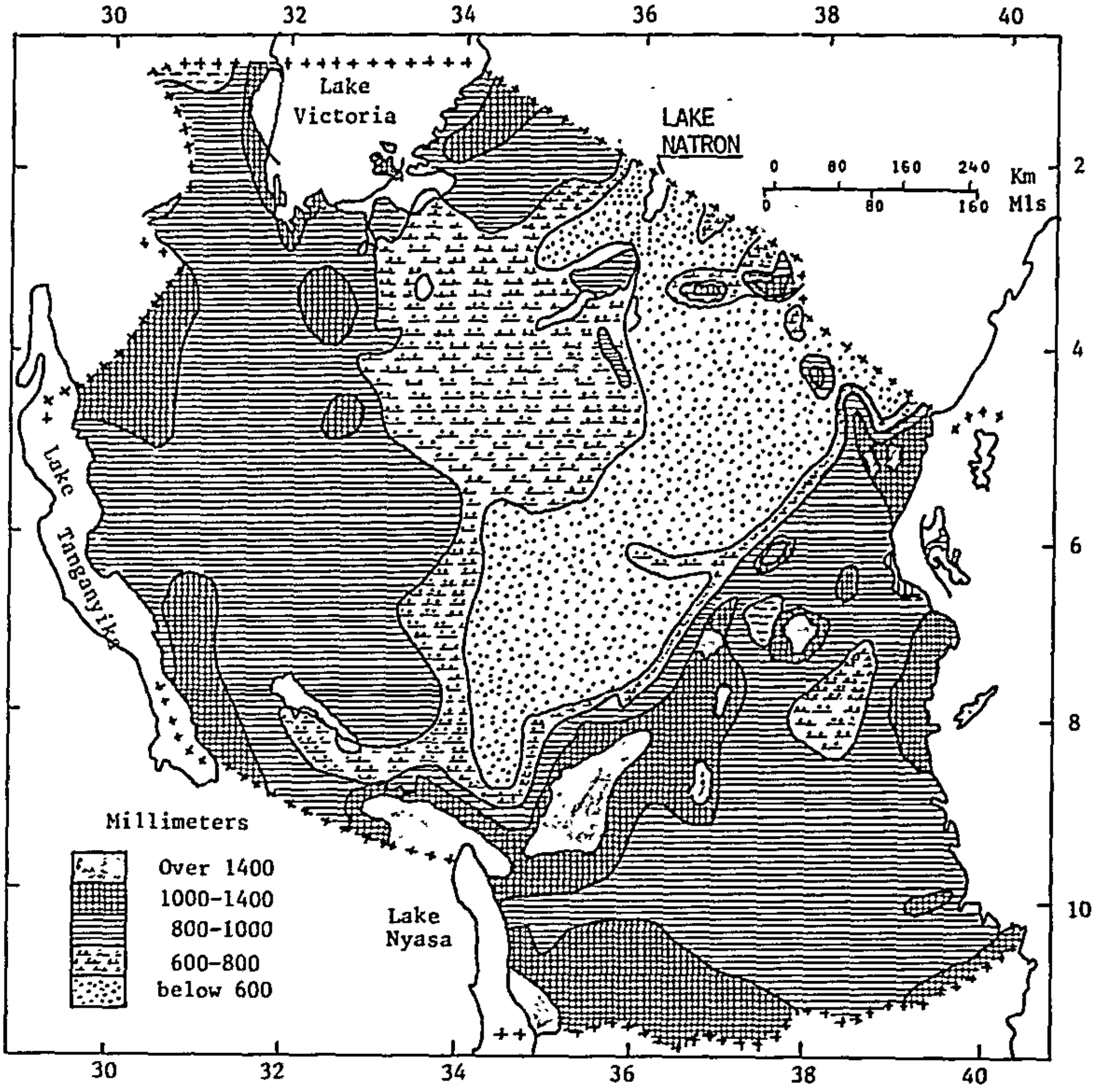


Table 2-1 Climatic Conditions at Lake Magadi

	Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Precipitation (mm)	29	49	63	85	54	9	2	3	3	13	29	45	384
Number of rainy days (day)	6	5	8	13	9	2	0	1	1	3	7	7	62
Maximum temperature (° C)	37	37	37	35	33	33	32	33	35	37	35	35	-
Minimum temperature (° C)	23	24	24	23	23	22	22	22	23	24	23	23	-
Average humidity (%)	28 - 65% (average 32%)												
Maximum annual precipitation in the past	621 mm												
Minimum annual precipitation in the past	153 mm												

'Area Studies in East Africa' (K. J. Hargrave)

Figure 2-2 Annual Precipitation Distribution Chart



Source: Tanzania Map (1. Berry, 1971)

average evaporation was 8.4mm/day, and the maximum at 25.4mm/day. Further, as shown in Table 2-2, the evaporation at Lake Magadi amounts to 3,302mm per year on average.

In terms of daily average figure, the above evaporation corresponds to 9.05mm a day which is almost the same as the evaporation rate at Lake Natron was mentioned before.

Table 2-2 Precipitation and Evaporation at Lake Magadi

Annual average precipitation: 406mm

Annual average evaporation: 3,302mm

(Magadi–The Story of the Magadi Soda Company, M.F. Hill, 1964)

The conditions of climate in the vicinity of Lake Natron exert a profound influence upon the formation of soda crust. They also affect selection of method of crust mining and also selection of the mining site. Further, the precipitation has a close bearing upon the volume of the river water which will serve as the supply source of the water for industrial use. Therefore, instrument shelters for meteorological observation seem imperative in the vicinity of the lake in order to conduct continual and long-range observation of at least temperature, humidity, precipitation, and evaporation.

2-1-3 Topography

Lake Natron is located within the East African Great Rift Valley, and a fault escarpment of 200m to 400m head approaches directly to the wast side of the Lake. On the northeast side, a stepfault gives into an almost flat plateau. On the southeast side of the Lake, the foot of Mt. Gelai (2,942m h.) is stretching. (Refer to Fig. 2-3)

Further, the Lake is included in the volcanic zone, and a number of hot springs are gushing water which forms several streams flowing into the Lake. The volcanoes surrounding the Lake are as follows:

Mt. Gelai on the southeast
Ol Doinyo Lengai (2,878m h.) on the south
Mosonik Hill on the southwest
Mt. Shombole on the north (1,565m h.)
Ol Doinyo · Sambu (2,043m h.) on the northwest

Fig. 2-4 shows the volcanoes surrounding Lake Natron.

Thus, the surrounding area of the Lake is forming a basin, and the Lake is located at its bottom. Therefore, the precipitation tends to flow into the Lake together with the sand, mud, etc. The Lake on the other hand has no river flowing out. In other words, Lake Natron is a closed lake. The valley area of the rivers through which the rainfall flows into the Lake occupies as much as over 100 thousand km^2, so that in-flow amount of the precipitation and sand, mud, etc.

Figure 2-3 Map showing the distribution of younger volcanoes located in and around the African Great Rift System from the Ethiopian border to the northern part of Tanzania

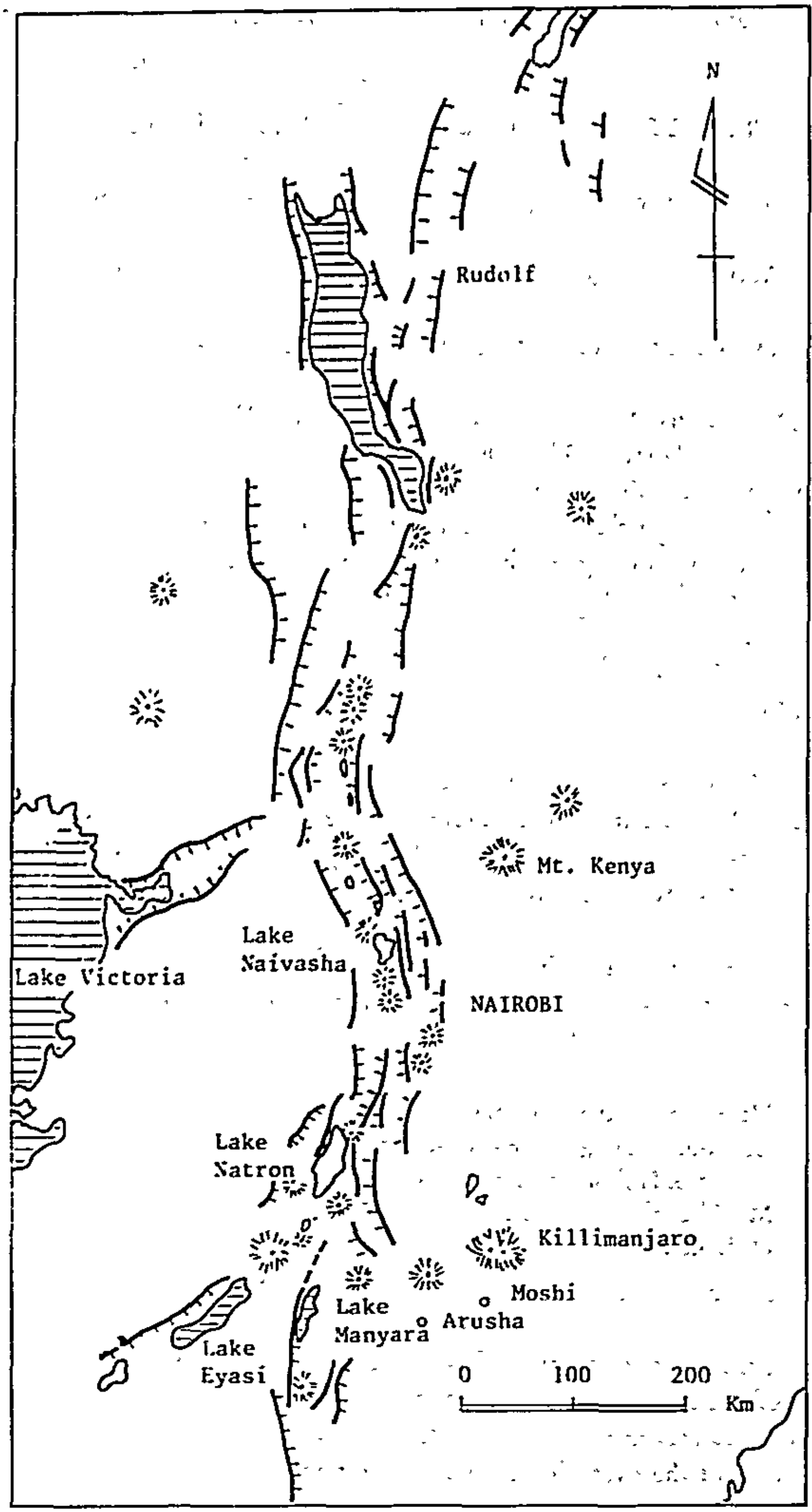
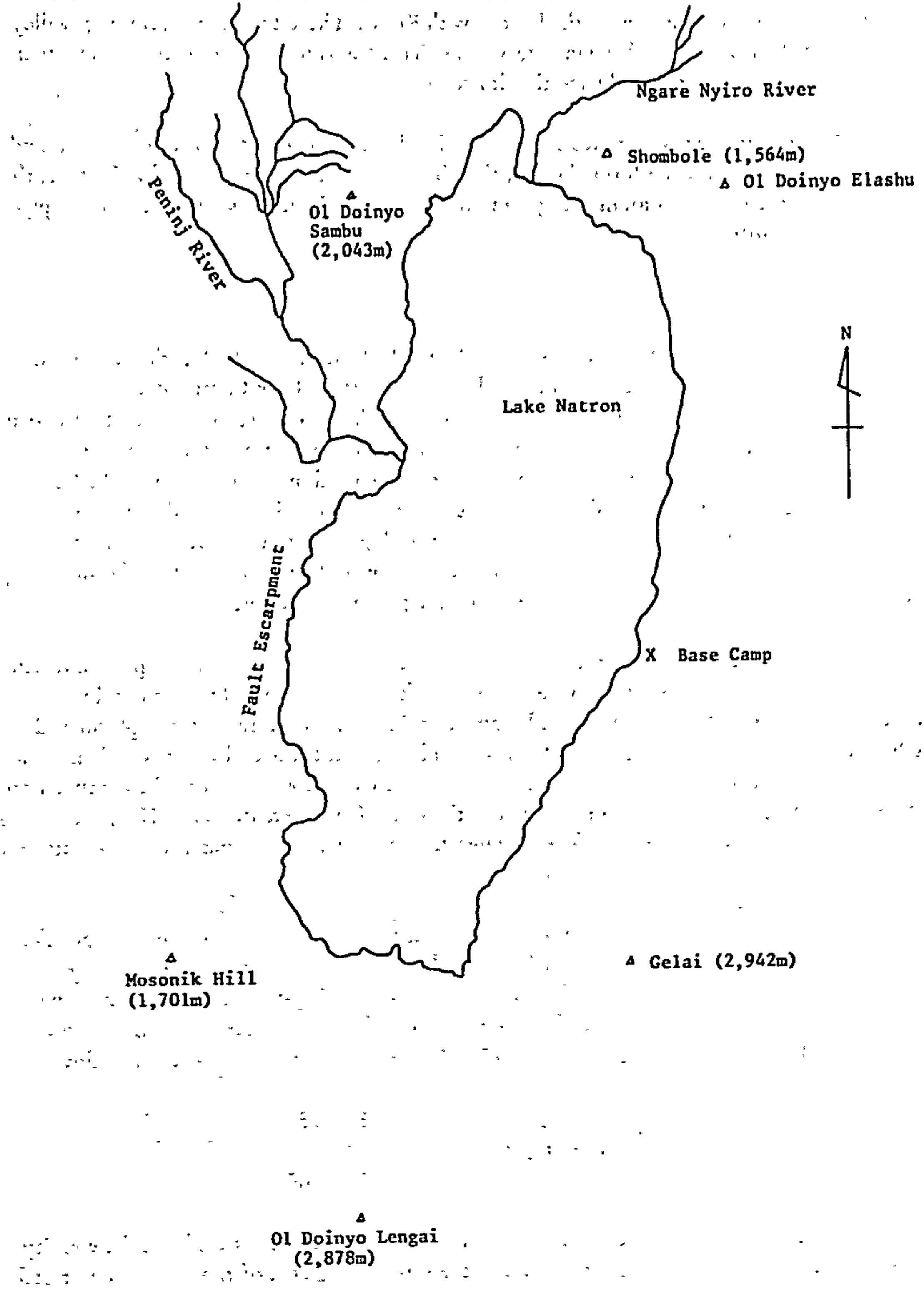


Figure 2-4 Volcanoes Surrounding Lake Natron



into the Lake appears to be considerably high.

Into the Lake, Peninj River flows on the northwest side, while Ngare Nyiro River gives into the Lake after flowing across the border with Kenya. These two rivers have large valley areas, and part of the flow passes through forest areas. This seems to imply that these rivers maintain a certain volume of water even during the dry season.

The river water flowing into the Lake will delay the soda crust formation speed, and the sand, mud, etc. will cover the formed crust, thereby making the mining difficult. Further, the mined crust will consequently contain a large amount of mud, and will rpesent unfavourable problems in terms of quality.

2-1-4 Geology

The paleogeology of the areas surrounding Lake Natron reveals that the geological formation until palaeogene presented a stable land mass consisting of pre-Cambrian rocks. Since the Neogene, a rift fault movement began to take place into the northsouth direction which accompanied the activation of a number of volcanoes. The fault further developed to form a Great Rift Valley, and it seems that the volcanic activities persisted in the meantime. The Ol Doinyo Lengai located on the south side of the Lake is a still active volcano. Following up the fault in the north-south direction, a smaller-scaled fault took place into the east-west direction which were divided into blocks. It seems that concave areas were further formed inside the Great Rift Valley, and one of these areas has become the present Natron Basin.

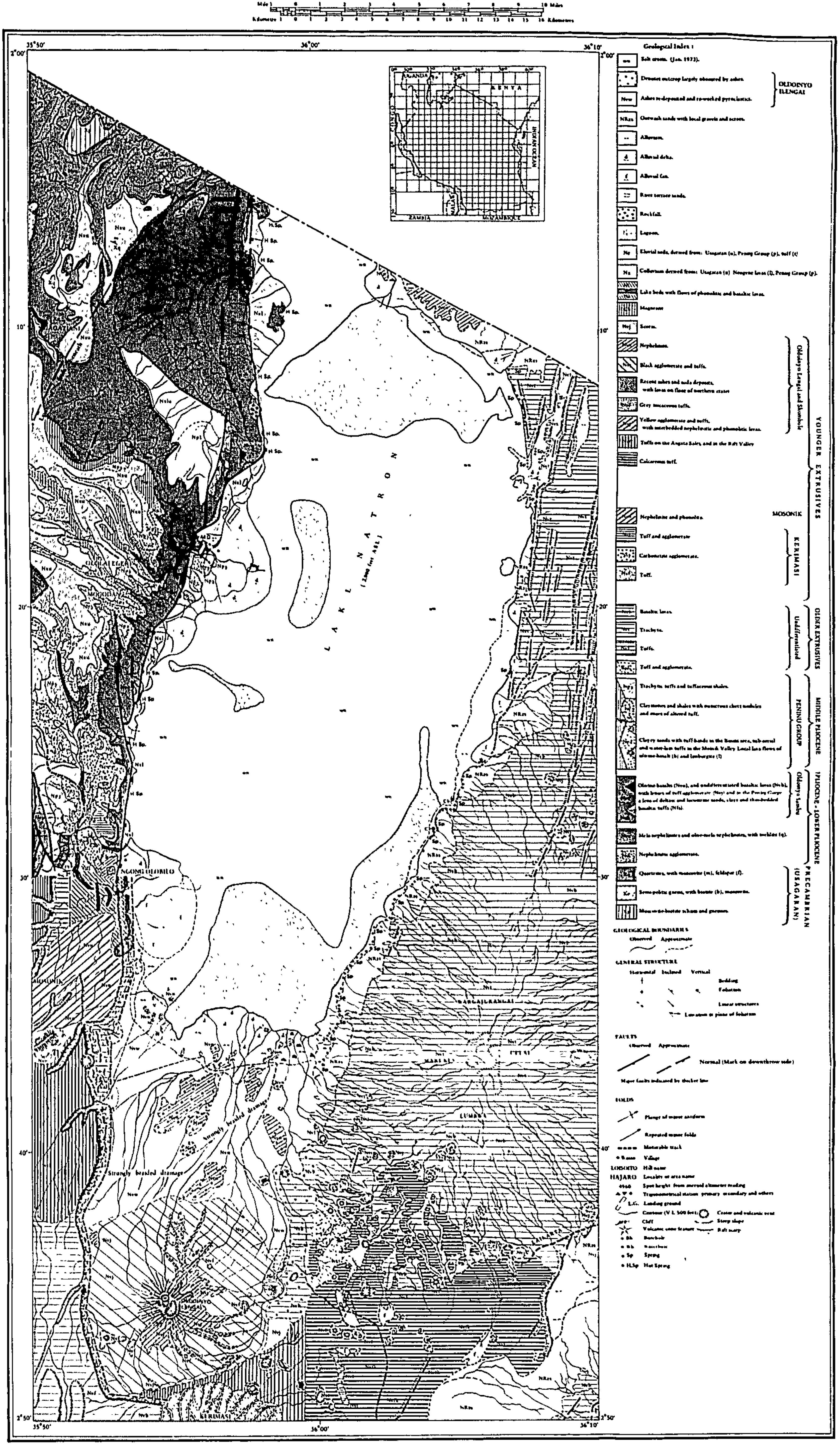
The constituent rocks in the surrounding areas of Lake Natron involve pre-Cambrian basement rock and volcanic rock which were generated after the Neogene. The pre-Cambrian layer which exists now in the form of an old basement rock received severe metamorphism and folding because of the Katanga orogenesis which took place towards the end of pre-Cambrian era and the beginning of Paeozoic era (620 to 485 million years ago). Consequently, the composition of the rock presents Quartzit, Gneiss, etc. Further, the volcanic rock created after Neogene are of Basult, Trachyte, Nephelinite, Tuff, Agglomerate, etc. For the most part, the areas surrounding Lake Natron consist of the volcanic rocks.

The volcanic rocks in the surrounding area of the Lake generally present a high alkalinity. The younger the age of volcanic rock is, the higher its alkalinity. In Ol Doinyo Lengai which is considered to be the youngest volcano is presenting eruption of carbonatite consisting of calcium carbonate ($CaCO_3$). According to the results of analysis conducted on the volcanic rocks of this area by Mr. J.M. Mushi, et. al. in 1975, the composition of the rock is as follows:

Sodium oxide (Na_2O):	5% - 15%
Potassium oxide (K_2O):	1% - 6%
Calcium oxide (CaO):	3% - 10%

Because of the existence of new volcanic rock and a number of faults in the vicinity of Lake Natron, numerous hot springs are found in the surrounding area of the Lake as described in above 2-1-3, particularly conspicuously on the west side slope of Mt. Gelai. As the water from

Figure 2·5 GEOLOGICAL MAP OF LAKE NATRON AREA



these hot springs are coming out thorugh volcanic rock of high alkalinity, the water itself also present high alkalinity, thereby generating the soda crust existing in the Lake. The alkalinity examination results of sampled hot spring water are as shown in Table 2-3.

Table 2-3 Alkalinity of Hot Spring Water Samples

Sampling No.	Odour	Turbidity	pH	Alkali (as Na) g/ℓ	Cℓ g/ℓ	SiO_2 mg/ℓ
HW 1	None	11	9.3	2.1	1.5	65
HW 2	″	1	9.1	6.4	1.2	22
HW 3	″	2	9.7	7.5	5.3	48
HW 4	″	400	10.0	4.1	0.9	42
HW 5	″	8	10.1	2.9	5.5	62
HW 6	″	2	8.9	1.1	0.78	23
HW 7	″	5	9.2	2.0	0.57	38

Note: Location of sampling points is shown in Fig. 2-7.

It is likely that the in-flow of water from these hot springs has been continuing for several millions of years, and at the same time, it is possible that other soda crust layers may exist on the lake bottom or underneath the ground of the lake shore owing to the crustal movement which since took place. If such new crust deposits are discovered, in addition to the soda crust layer presently confirmed in the Lake, some other crust mining methods which may be more economical could be recommended. Therefore, it seems necessary to conduct boring exploration, *seismic* exploration, etc. for the purpose of confirming other crust layer deposits in addition to the exploration which is called for in the ground bearing survey for the construction of crust purification plant and for the development of geothermal energy sources.

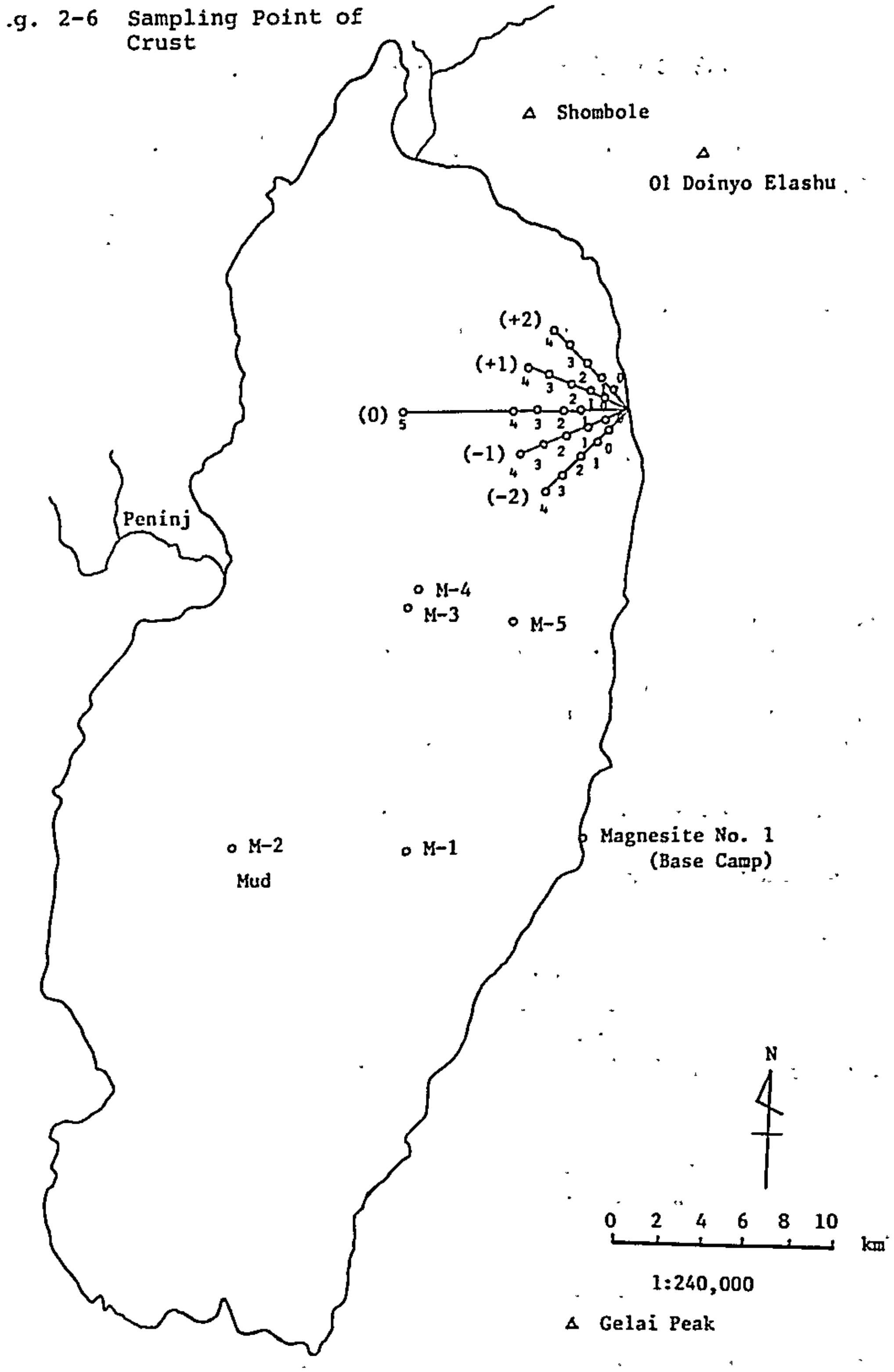
2-1-5 Economic activities in the surrounding areas

The Lake Natron area which belongs to the semi-desert climate zone of scarce precipitation and high dryness does not make favourable living enviornment for human life. Therefore, the population in this area is extremely low. The present community consists of villages of several dome-like huts of Masai Tribe made of mud and wooden shrubs. Masai tribemen are engaged in small-scaled grazing by raising cattles, goats, etc., and economic activities are hardly significant.

The hot spring water of high alkalinity which is flowing into the Lake fosters small fish of several centimeters long; however, the herd seems to be too small to be utilized as fishery resources.

Lake Natron is located approximately 100km east of the Serengeti National Park, and in the surrounding areas of the Lake wild animals such as giraffes, zebras, etc. are living in small herds. A large flock of flamingo lives in and around the Lake; however, these wild animals

Figure 2-6 Sampling Point of Crust



seem to be poor in the variety of species to be developed as a sightseeing attractions.

2-2 Details of the Survey at Lake Natron

The Survey Team conducted surveys on the soda resources, water resources, plant sites, soda crust mining sites, etc. for six days from 20th, November 1975 onwards by establishing a base at Magnesite No. 1 on the east shore of Lake Natron (refer to Fig. 2-6 as to the location of the base).

2-2-1 Survey schedule

The schedule of survey conducted at Lake Natron are as follows:

November 20th:	o Departed from Arusha o Camped on the northeast side of Mt. Gelai
November 21st:	o Arrived at Magnesite No. 1 o Setting up camping base o Overall Reconnuissance of Lake Natron o Evaporation test of brine (continued until November 24th) o Topographic survey on the west side of the Lake
November 22nd:	o Selection of soda resource sampling points o Sampling of soda resources o Survey of river water o Survey of the soda crust distribution status
November 23rd:	o Sampling of soda resource o Survey of river water o Survey for the selection of sites suitable for crust mining and for crust purification plant
November 24th:	o Sampling of hot spring water o Topographic survey (on the east shore of the Lake) o Survey for the selection of site for the crust purification plant
November 25th:	o Departure from Lake Natron o Arrived at Arusha

2-2-2 Lists of survey team members, survey equipments, etc.

The following table stipulates the number of team members and the items of equipments employed for the survey conducted around Lake Natron:

(1) Team members

o Experts (Japanese nationals):	10
o Experts (Tanzanian nationals):	2
o Survey assistants (Tanzanian nationals):	3
o Helicopter pilot:	1
o Car drivers:	7
o Car mechanic:	1
Total	24

(2) Equipment employed for the survey

o Helicopter (3 seater):	1
o Land rover:	7
o Lorry:	1
o Instruments for survey (auger, etc.):	1 set
o Camping equipment (tents, etc.):	1 set
o Fuels for the helicopter and land rovers	
o Food and drinking water	

2-2-3 Survey methodology

(1) Sampling of soda crust, etc.

A total of 90 samples were collected as follows for the purpose of analyzing the composition of soda crust and brine:

Selection was made for 30 spots (as shown in Fig. 2-6) centering on the lake surface point[*] located approximately 20km north of the Magnesite No. 1, and three samples each were collected at selected 30 points unless otherwise specified (one crust sample each from the surface and the lower layer part, plus one brine sample).

Concerning the selection of the sampling points, a base point was set on the shore of the Lake on a map, from which the points were plotted at one kilometer intervals onto the lake surface radially. In order to ensure the access to the sampling points, a helicopter was mobilized, and the identification of the points were carried out by measuring the direction and distance on the basis of the cruising speed and time of the helicopter equipped with a gyrocompass.

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[*]: The point was selected as the 'suitable crust mining area' by a Japanese survey in 1973 covering the whole lake area.

A hand auger was employed as an equipment for extracting the soda crust samples; however, the crust was extremely hard in dry places, thereby presenting difficulties in manual extraction.

The collection of brine sample was carried out by employing a small electric pump which was inserted into holes made by the auger to extract brine by suction.

(2) Estimation of soda deposit

Simultaneously with the collection of the crust samples, etc. as described in the foregoing (1), the thickness of the crust and brine layers was also measured at the sampling points in order to estimate the volume of deposit of the soda resources.

The surface area of the crust was calculated by employing planimeter on a distribution chart compiled by means of simple surveying equipment.

(3) Selection of suitable site for crust purification plant

In order to select the most suitable site for constructing a crust purification plant on the shroe of the Lake, the observation of the topographic formation of the lake shore area was conducted by employing a helicopter, and a site for plant construction was proposed by referring to the geoglogical chart made available.

(4) Selection of mining sites

The crust mining sites were selected on the basis of the thickness of the crust layer surveyed as described in the foregoing (2), as well as the topographic conditions of the Lake area such as the status of river water in-flow into the Lake.

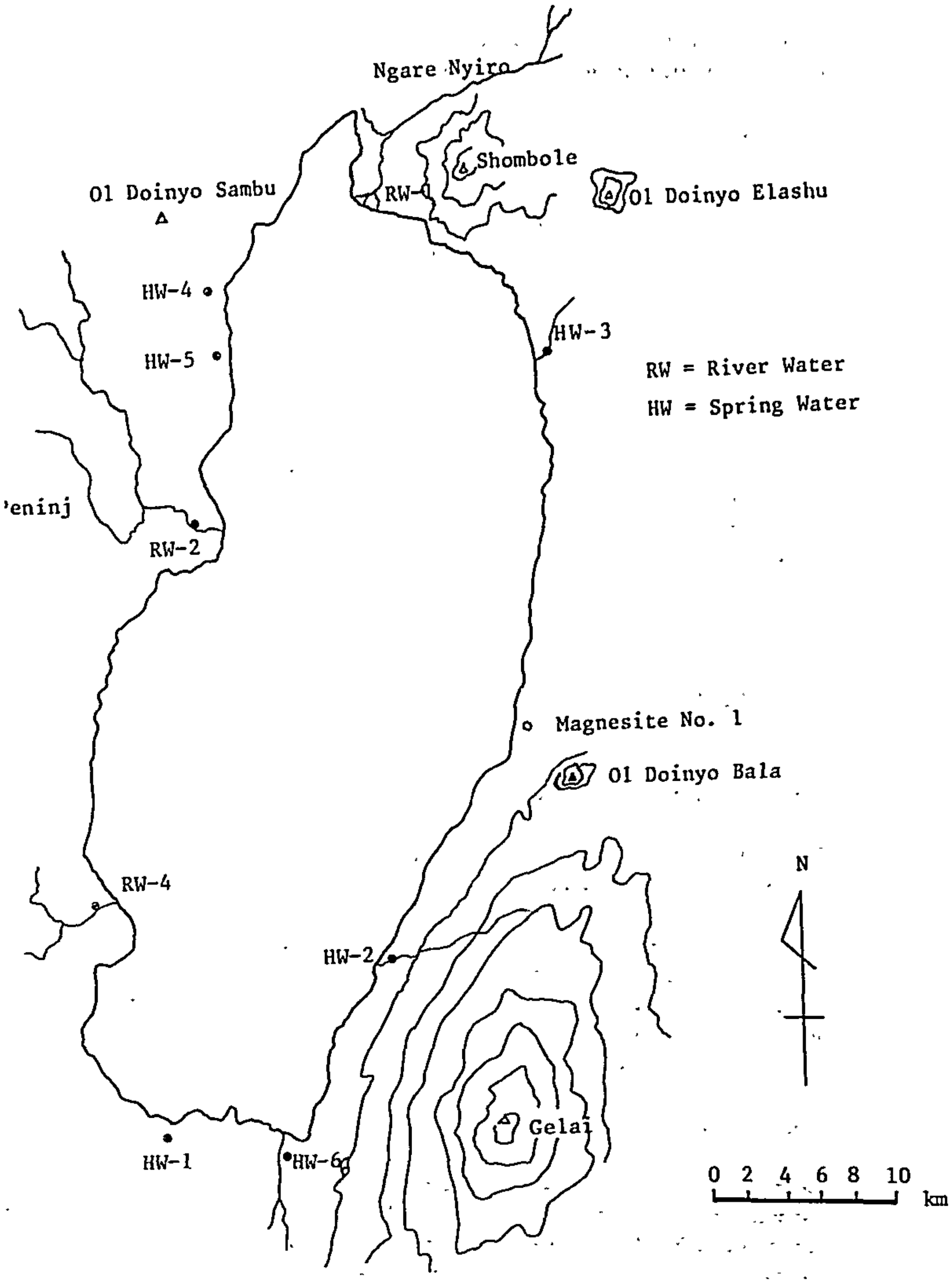
(5) Survey of water sources and the quality of water

For the purpose of surveying the existence of rivers having ample volume of water as the supply source of industrial water for use in the crust purification process to be constructed by the Lake, observation of the geographic and topographic conditions was conducted by employing a helicopter. As a result, measurement of flow amount was conducted as to five selected rivers which were deemed usable as the supply sources. Water samples were extracted for analysis of the quality as process water and also as drinking water. The sampling points of river water and hot spring water are dotted on Fig. 2-7.

(6) Brine evaporation test

In order to study the crust formation process and the crust formation speed, evaproation tests of sample brine extracted from the Lake was conducted by the shore (at Magnesite No. 1). However, no substantial result was obtained because of shower rainfall which took place everyday during the test period.

Figure 2-7 Sampling Point of River Water and Spring Water



2-3 Soda Resources at Lake Natron

2-3-1 Formation of the resources

A number of hot springs are producing streams which flow into the Lake. Of these, the flow amounts were measured regarding the three largest hot springs in view of the in-flow into the Lake. Further, the composition of water samples was also analyzed, and the results were obtained as shown in Table 2-4.

Table 2-4 Examples of Flow Amount and Compsoition of Hot Spring Water

	HW-2	HW-3	HW-6	Total/Average
Flow amount	1,800 m^3/h	400 m^3/h	1,000 m^3/h	Total 3,200 m^3/h
Specific gravity (15° C)	1.005	1.029	1.002	Average 1.012
Total Na_2CO_3	1.47 wt%	1.68 wt%	0.25 wt%	Average 1.13 wt%
$NaCl$	0.20 wt%	0.85 wt%	0.13 wt%	Average 0.39 wt%
Na_2SO_4	0.15 wt%	0.43 wt%	0.09 wt%	Average 0.22 wt%
NaF	0.0075 wt%	0.026 wt%	0.0057 wt%	Average 0.013 wt%
SiO_2	0.000022 wt%	0.000048 wt%	0.000023wt%	Average 0.000031 wt%

The amount of sodium carbonate fed into Lake Natron by the above-mentioned three hot spring sources was calculated as follows:

o	Total hot spring water in-flow amount:	3,200 m^3/h
o	Average specific gravity:	1.012
o	Total Na_2CO_3 content:	1.13 wt%

On the basis of the above figures, the annual in-flow of Na_2CO_3 amounts to approximately 320×10^3 tons as follows:

$$3{,}200\ m^3/h \times 1.012 \times 0.0113 \times 24\ h \times 365\ days \fallingdotseq 320 \times 10^3 t$$

The hot spring water merged into the lake water forms lagoons, and the water evaporates at high temperature and low humidity, thereby accelerating crust formation.

Regarding this crust formation process, an excellent observation was made in a report of a survey conducted in 1973. The following is a quotation from the report:

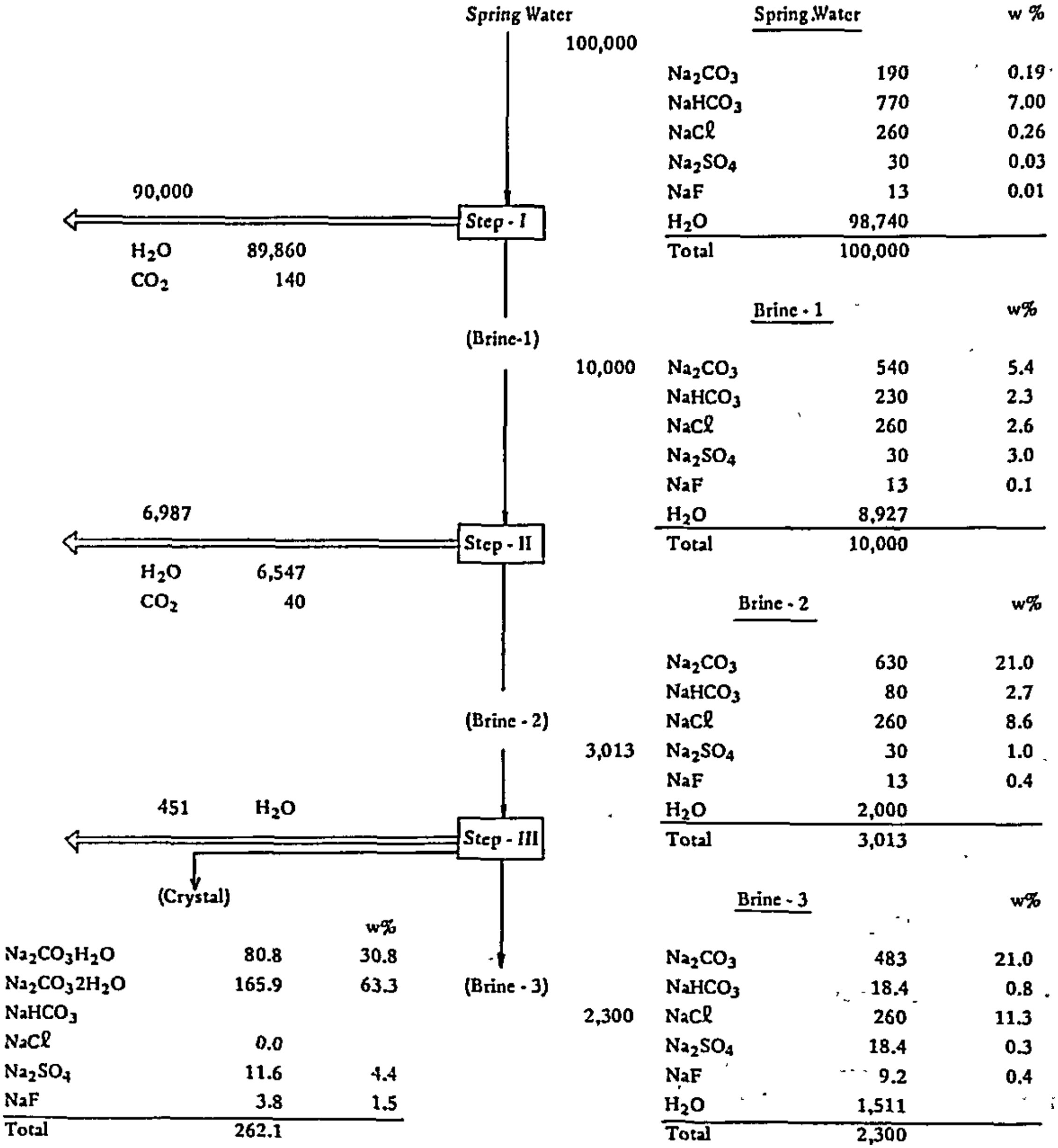
'Fig. III-5 (corresponds to Fig. 2-8 of this report) shows a material balance for evaporation and crystallization which have been taking place in Lake Natron. From the Figure, it can be comprehended how the soda crust has been formed.

Spring water flows into the Lake forming a lot of lagoons. Brine-1 of the Figure indicates that it is concentrated about 10 times (of spring water) through evaporation of Step-I.

As the concentration proceeds further, brine of lagoons becomes a saturated solution with 33 times higher concentration than spring water. This is Step II. Through the procedure of evaporation, sodium bicarbonate contained in Brine-l converts into sodium carbonate. During the process of Step-II to Step-III, crystallization of sodium sesqui-carbonate, sodium mono-hydrate and sodium fluoride takes place in the saturated Brine-2. Sodium chloride, however, is not presumed to crystalize in this stage. Step-III indicates the actual conditions of Lake Natron at this moment.

After all, it is understood from this figure that 2.62 tons of the crystal, that is, the soda crust, and 23.0 tons of soda brine are formed from 1,000 tons of spring water by evaporating about 975 tons of water into the atmosphere.'

Figure 2-8 Material Balance in Natron Evaporation



	Spring Water	w %
Na_2CO_3	190	0.19
$NaHCO_3$	770	7.00
NaCℓ	260	0.26
Na_2SO_4	30	0.03
NaF	13	0.01
H_2O	98,740	
Total	100,000	

	Brine - 1	w%
Na_2CO_3	540	5.4
$NaHCO_3$	230	2.3
NaCℓ	260	2.6
Na_2SO_4	30	3.0
NaF	13	0.1
H_2O	8,927	
Total	10,000	

	Brine - 2	w%
Na_2CO_3	630	21.0
$NaHCO_3$	80	2.7
NaCℓ	260	8.6
Na_2SO_4	30	1.0
NaF	13	0.4
H_2O	2,000	
Total	3,013	

	Brine - 3	w%
Na_2CO_3	483	21.0
$NaHCO_3$	18.4	0.8
NaCℓ	260	11.3
Na_2SO_4	18.4	0.3
NaF	9.2	0.4
H_2O	1,511	
Total	2,300	

(Crystal)		w%
$Na_2CO_3H_2O$	80.8	30.8
$Na_2CO_32H_2O$	165.9	63.3
$NaHCO_3$		
NaCℓ	0.0	
Na_2SO_4	11.6	4.4
NaF	3.8	1.5
Total	262.1	

2-3-2 Distribution of the reserves

The distribution of soda crust is as shown in Fig. 2-9. The distribution was surveyed through the observation of the lake surface from above by a helicopter, and also by the application of simple surveying equipment to the surface of the Lake.

The crust on the surface of the Lake is stretching for 10 to 15km in east-west direction and approximately 25km in north-south direction centering on the central part of the Lake. The area of the crust is approximately 370km^2 which corresponds to about 40% of the area of the whole lake. The colour of crust is either pink or light brown, and the aereal observation of the crust surface revealed a number of patterns similar to a tortoise shell. Surrounding the crust, either lagoon or sedimentation of mud is formed. Comparatively large lagoons are noticed on the southern part and northern tip of the Lake.

According to the results of the present survey, the distribution area of the sedimentation caused by Peninj River mouth towards south and that on the south side of the mouth of Ngare Nyiro River on the south side of the Lake have been noted in comparison to the results of the survey conducted in 1973. The crust distribution status observed during the survey in 1973 is shown in Fig. 2-10.

At the sampling point M-2 shown in Fig. 2-6 existence of crust was reported by the previous survey; however, the present survey confirmed a mud sedimentation of approximately 30cm thickness, underneath which white hard crystallized substance was noted. This crystal seems to be of the same material as the soda crust which covers the Lake.

This seems to have resulted from piling of the mud and sand carried into the Lake in large amounts during the rainy seasons by two major rivers flowing into the Lake, thereby covering the already formed crust, and water has evaporated from the sedimentation. Therefore, it is safely assumed that the crust identified by the previous survey still exists underneath the sedimentation pile. In view of this, it seems necessary to perform boring exploration in order to confirm the crust distribution status more accurately, covering the whole lake including the portions where no direct visual observation of crust was possible.

2-3-3 Composition of the resources

The 30 points as shown in Fig. 2-6 were selected for the purpose of sampling soda crust and brine, the composition of which were analyzed, and samples were collected at each of these points from the surface and the lower layer of the crust unless otherwise specified as far as crust samples are concerned, and one sample underneath the crust regarding the brine. All the collected samples were brought back to Japan, and were used for crust and brine composition analyses through ordinary chemical analyses, as well as X-ray analysis, fluorescent X-ray analysis, colorimetric analysis, and atomic absorption spectrochemical analysis. (The details of the results of these analyses are shown in Tables 2-8 and 2-9.)

Fig. 2-9 Status of Soda Crust Distribution Observed in This Survey

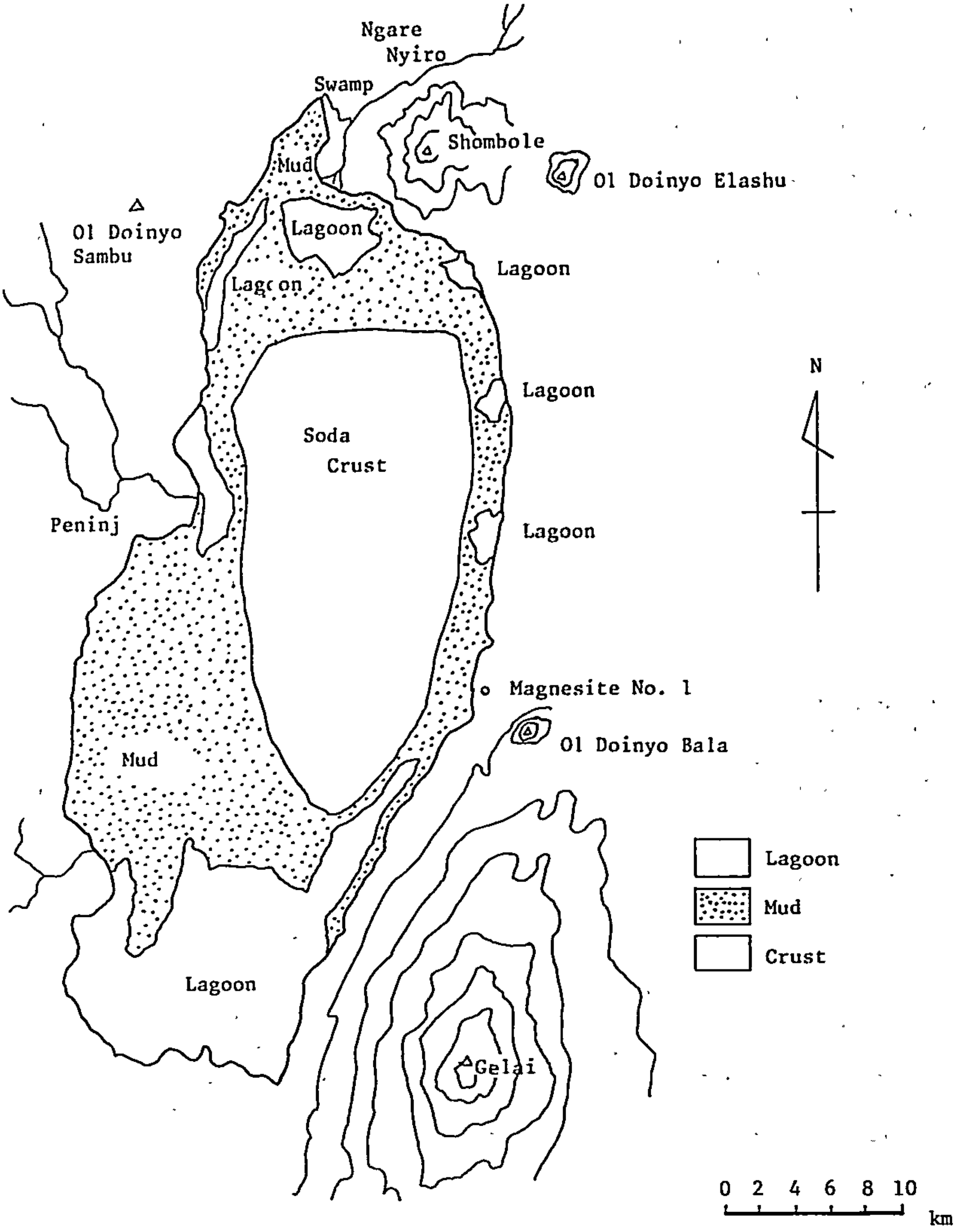
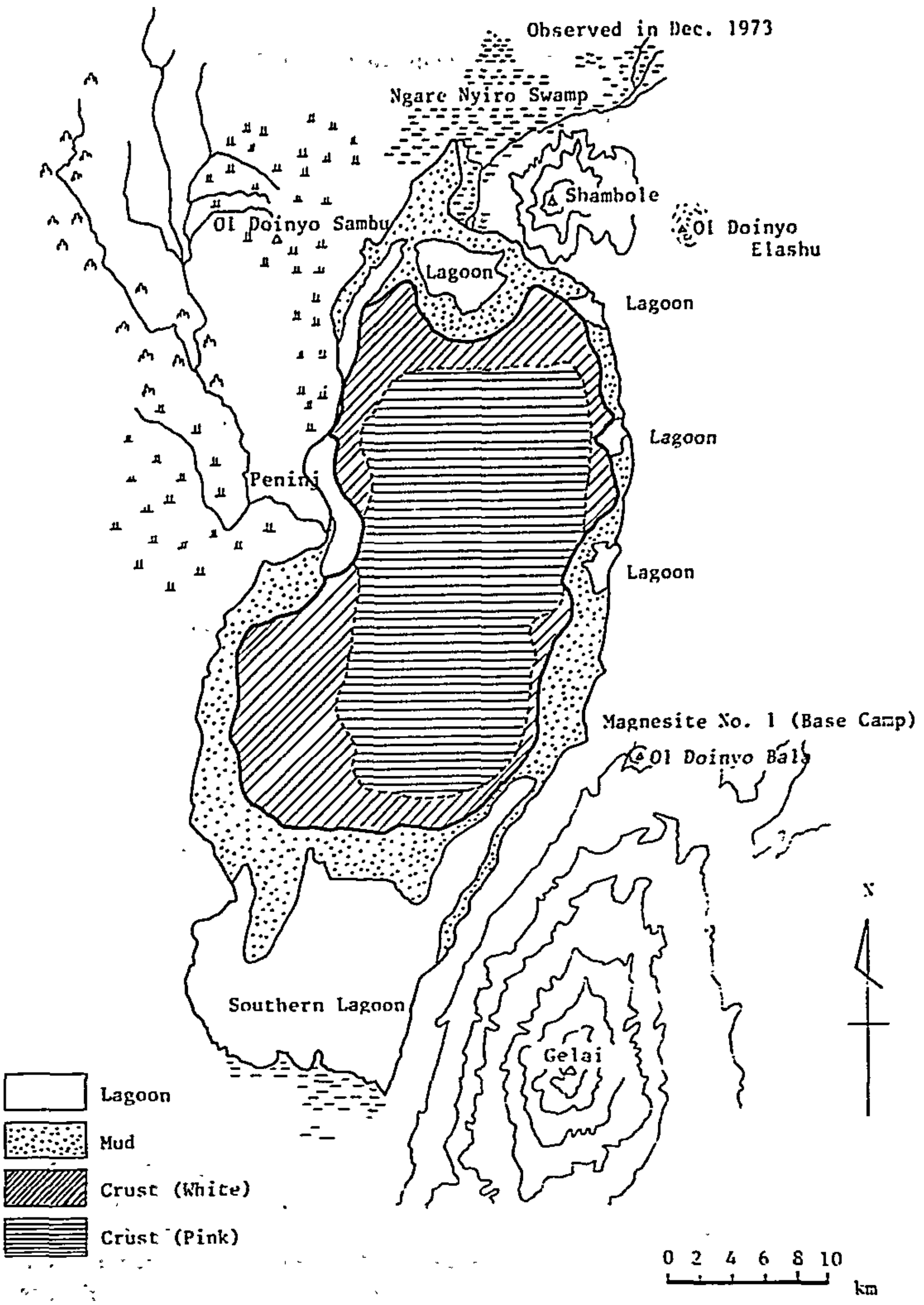


Fig. 2-10 *Status of Soda Crust Distribution Observed in Dec. 1973*



2-3-3-1 Composition of the crust

The average composition of the crust is as shown in Table 2-5.

Table 2-5 Average Composition of Crust

$Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$	60.3 wt%
$Na_2CO_3 \cdot H_2O$	30.7
NaCl	5.45
Na_2SO_4	2.80
NaF	1.37
$CaCO_3$ (total)	0.14
Insoluble matter in acid	0.15
Fe_2O_3	0.0237
Ti	0.0046
K	0.0014
V	0.0016
Mn	0.0004
Cr	0.00002
Zn	0.0031
Ba	not detected
Li	not detected
Br	0.015
I	0.002
SiO_2	0.19
B	0.006
P_2O_5	0.03
COD *	0.10

*: Chemical Oxydant Demand

The major components of the crust are sesqui-sodium carbonate ($Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$) and hydride of sodium carbonate ($Na_2CO_3 \cdot H_2O$), these two together comprizing approximately 90wt% of the total components. The rate of these two major components varries from one sampling point to another, and also depends on whether the sample was collected from the surface or the deeper layer of the crust. A general trend is noted that the rate of sodium carbonate is highly in the case of crust samples collected from the surface layer. This implies that the decomposition of sodium sesqui-carbonate into sodium carbonate has progressed more in the surface layer where the opportunity of coming into contact with atmosphere is higher.

Apart from sodium sesqui-carbonate and sodium carbonate, the contained elements are salt (NaCl), Sodium sulphate (Na_2SO_4), and sodium fluoride (NaF), together with a slight amount of calcium, potassium salt, silica, etc. The content of heavy metals was only slight.

2-3-3-2 Composition of the brine

The average composition of brine is as shown in Table 2-6.

Table 2-6 Average Composition of Brine

T-Na_2CO_3	20.1 wt%
Na_2CO_3	19.3
$NaHCO_3$	1.3
NaCl	11.2
Na_2SO_4	0.69
NaF	0.25
Fe_2O_3	0.0005
Ti	0.00017
K	0.41
V	0.000003
Mn	not detected
Zn	0.000004
Cr	0.0000007
Ba	not detected
Li	not detected
Br	0.034
I	0.002
SiO_2	0.10
B	0.011
P_2O_5	0.07
COD*	0.05

*: Chemical Oxydant Demand

In the case of brine, in comparison with crust, the concentration of sodium chloride, potassium salt silica, phosphates is considerably high as against the sodium carbonate concentration.

In view of solubility, sodium carbonate (Na_2CO_3), sodium chloride (NaCl) and sodium fluoride seem to have almost reached the saturation point. Therefore, sodium chloride and sodium fluoride are crystallized in the crust. Table 2-7 shows the mutual solubility data of $NaF\text{-}NaCl\text{-}Na_2CO_3\text{-}H_2O$ at 25 C and 50°C.

The measurement conducted at Lake Natron revealed that the temperature of the brine was 36°C to 38°C, and the specific gravity was 1.3g/cm^3 on average. In the case of brine, like crust, the colour was either pink or light brown. This seems to be due to the pink halophilic bacteria contained in the brine as an organic substance which is represented as COD (Chemical Oxidant Demand) in the chart of analysis results.

2-3-4 Volume of the reserves

2-3-4-1 Thickness of the crust and brine layers

The thickness of the layers of crust and brine was measured at the points shown in Fig. 2-6 in order to obtain data for estimating the volume of the deposit of soda resources in Lake Natron. A hand auger was employed for the survey. Because of this, it was difficult to confirm as to whether or not crust layer still existed at a portion much lower than the point which was deemed as the bottom of the Lake. Therefore, the layer thickness measurement was conducted to only these crusts which existed above the layer which was deemed to be the bottom of the Lake.

The thickness of the crust and brine naturally varies from point to point; however, the thickness became smaller as the point approaches shore of the Lake in both cases of crust and brine. In the vicinity of the lake shore, there were some points where no brine existed and crust was contacting directly the bottom of the Lake.

The results of the measurement of the thickness of crust and brine are shown in Tables 2-12 and 2-11.

The average of the thickness of the crust in 28 sampling points and that of the brine in 20 sampling points were respectively 43cm and 35cm. Regarding the thickness of the crust, it was 18cm thicker than the average thickness of 25cm which was the result of the survey conducted in 1973. It is likely that the crust formation progressed over the last two years; however, there is not concrete proof to support this assumption. Therefore, in order to know the crust formation speed at Lake Natron, it is suggested that the measurement of crust thickness be conducted at regular intervals at the same measuring point.

Table 2-7 Solubility in System NaF-NaC -Na_2CO_3-H_2O

Points	Composition of saturated solution (in wt. %)					Composition of dry salts (in wt. %)			d	Solid phases
	NaF	NaCl	Na_2CO_3	Total salts	H_2O	NaF	NaCl	Na_2CO_3		
						Temperature 25°			d_4^{25}	
C	0.40	26.37	0	26.77	73.23	1.40	98.51	0	1.1993	NaF · NaCℓ
	0.38	23.70	4.17	28.33	71.67	1.34	83.94	14.72	1.2254	
	0.30	21.41	8.17	29.88	70.12	1.00	71.65	27.35	1.2507	
	0.24	18.50	11.81	30.55	69.45	0.70	60.55	38.66	1.2745	
	0.23	16.14	19.68	32.05	67.95	0.72	50.36	48.92	1.2973	
H	0.23	15.17	17.30	32.70	67.30	0.70	46.30	52.01	1.3097	NaF + NaCℓ + $Na_2CO_3 \cdot 7H_2O$
	0.26	12.80	18.43	31.49	68.51	0.82	40.65	58.53	1.3044	NaF + $Na_2CO_3 \cdot 7H_2O$
Q	0.27	11.71	19.04	31.02	68.98	0.87	37.75	64.38	1.3013	NaF + $Na_2CO_3 \cdot 7H_2O$ + $Na_2CO_3 \cdot 10H_2O$
	0.33	10.90	19.21	30.44	69.56	1.08	35.81	63.11	1.3011	NaF + $Na_2CO_3 \cdot 10H_2O$
	0.40	10.53	19.15	30.08	69.92	1.33	35.01	63.66	1.3011	
	0.39	10.41	18.62	20.42	70.58	1.32	35.30	63.20	—	
	0.64	5.47	19.18	25.23	74.71	2.53	21.63	75.84	—	
E	0	15.30	17.40	32.70	67.21	0	46.66	53.34	—	NaCl + $Na_2CO_3 \cdot 7H_2O$
	0.07	15.32	17.40	32.79	67.21	0.22	46.72	53.06	—	
						Temperature 50°			d_4^{50}	
	0.27	24.78	2.99	28.02	71.98	0.96	83.36	10.68	1.2093	NaF + NaCl
	0.23	22.31	6.78	29.28	70.72	0.78	76.19	23.03	1.2336	
	0.23	19.67	11.55	31.45	68.55	0.73	62.55	36.72	1.2673	
N	0.23	18.30	13.47	32.00	68.00	0.72	57.18	42.10	1.2785	NaCl + NaF + $Na_2CO_3 \cdot H_2O$
	0.32	8.85	22.67	31.84	68.16	1.00	27.80	71.20	1.3043	NaF + $Na_2CO_3 \cdot H_2O$
	0.33	6.04	34.98	31.35	68.65	1.00	19.26	79.68	1.3115	
	0.33	2.42	28.60	31.35	68.65	1.00	7.72	91.23	1.3326	
P	0	18.37	13.63	32.0	68.00	0	57.41	42.59	1.2808	NaCl + $Na_2CO_3 \cdot H_2O$

G.A. Lopatkina Journal of Applied Chem. of the U.S.S.R., 32 2644-50 (1959)

Table 2-8 The Result of Analysis on Composition of Soda Crust

Sampling pt.	Na_2CO_3 wt.%	$NaHCO_3$ wt.%	NaCℓ wt.%	Na_2SO_4 wt.%	NaF wt.%	$CaCO_3$ wt.%	Insol. Mat. in HCℓ wt.%	T. Moist wt.%
*1								
+2- 0A	27.1	13.7	3.83	0.91	0.60	5.60	18.4	27.7
0B	-	-	-	-	-	-	-	-
1A	34.8	22.2	4.64	2.07	0.97	0.05	0.1>	35.2
1B	25.6	16.3	3.58	0.36	0.54	3.30	15.3	29.3
2A	35.8	25.4	3.44	3.66	1.17	0.20	0.1	29.6
2B	25.5	14.3	4.17	0.64	0.48	3.30	14.4	32.3
3A	37.5	26.7	3.53	0.61	0.18	0.49	1.2	30.2
3B	31.9	13.0	4.20	0.38	0.39	3.20	14.3	33.7
4A	38.1	24.7	3.27	0.46	0.19	0.31	0.9	31.4
4B	28.6	12.0	3.92	0.31	0.53	2.17	15.3	29.7
+1- 0A	32.3	11.6	4.27	1.10	0.46	4.30	13.2	30.5
0B	28.0	13.0	3.60	0.79	0.38	4.38	16.1	25.4
1A	41.0	23.1	3.01	3.94	1.06	0.28	0.2	27.1
1B	31.1	14.9	4.17	1.03	0.48	2.57	7.8	34.0
2A	39.3	24.3	3.04	1.10	0.34	0.07	0.1	31.9
2B	40.8	26.7	2.67	1.02	0.34	0.12	0.1	28.2
3A	38.8	28.7	2.84	1.66	0.55	0.21	0.1>	27.0
3B	36.5	26.1	3.52	1.87	0.38	0.14	0.1>	30.8
4A	32.9	20.5	3.60	8.75	1.91	0.04	0.1>	34.5
4B	-	-	-	-	-	-	-	-
0- 0A	-	-	-	-	-	-	-	-
0B	-	-	-	-	-	-	-	-
1A	38.8	21.0	4.13	7.32	1.89	0.06	0.1>	26.8
1B	37.3	24.9	3.78	1.12	0.09	0.22	0.4	31.6
2A	39.0	22.9	4.49	4.87	1.26	0.02	0.1>	27.1
2B	35.8	23.6	3.88	3.43	1.33	0.07	0.1>	31.0
3A	37.0	20.3	4.37	3.18	0.85	0.03	0.1	34.5
3B	37.8	20.8	3.28	9.89	2.77	0.03	0.1>	25.9
4A	-	-	-	-	-	-	-	-
4B	40.6	19.2	3.83	5.58	1.78	0.03	0.1>	29.2
5A	47.1	11.9	4.69	1.75	0.49	0.03	0.1	34.3
5B	42.2	12.8	4.93	2.42	0.61	0.16	0.2	36.6
-1- 0A	50.6	12.2	3.29	5.06	1.24	0.10	0.1>	27.6
0B	27.0	11.2	3.34	0.54	0.33	6.47	23.0	22.9
1A	41.3	24.3	3.88	3.10	0.88	0.08	0.05	25.3
1B	39.8	21.7	4.18	1.92	0.50	0.55	2.0	25.6
2A	42.5	18.4	3.57	4.29	1.23	0.06	0.1>	29.0
2B	37.8	20.1	4.54	3.50	1.00	0.09	0.1>	32.5
3A	43.5	13.2	5.41	4.67	1.24	0.09	0.1>	31.4
3B	41.8	21.0	3.08	4.26	1.18	0.07	0.1>	28.6
4A	40.8	19.3	6.16	3.31	0.97	0.05	0.1>	29.5
4B	36.1	25.0	5.02	5.51	1.78	0.04	0.1>	26.9
-2- 0A	41.1	23.3	4.01	6.43	2.41	0.04	0.1>	22.8
0B	41.8	25.1	4.05	4.01	1.90	0.05	0.1>	23.2

Sampling pt.	Na_2CO_3 wt.%	$NaHCO_3$ wt.%	$NaC\ell$ wt.%	Na_2SO_4 wt.%	NaF wt.%	$CaCO_3$ wt.%	Insol. Mat. in $HC\ell$ wt.%	T. Moist wt.%
1A	40.2	27.6	3.92	0.96	0.21	0.05	0.1>	26.5
1B	41.7	27.4	3.27	2.25	1.22	0.08	0.1>	23.9
2A	42.9	20.7	4.11	3.70	1.43	0.05	0.1>	27.6
2B	43.2	19.2	4.98	3.64	1.05	0.07	0.1>	27.7
3A	40.6	26.2	3.87	5.30	1.88	0.02	0.1>	22.3
3B	39.6	27.0	3.69	2.28	1.00	0.07	0.1>	26.9
4A	41.3	21.8	4.15	3.84	1.27	0.05	0.1>	26.2
4B	-	-	-	-	-	-	-	-
M - 1A	43.8	17.2	5.02	3.00	1.08	0.20	0.5	28.6
1B	42.8	16.9	5.08	2.90	0.87	0.27	1.5	29.1
*2								
M - 2A	12.5	2.8	3.13	0.36	0.61	3.39	39.8	23.8
M - 2B	29.0	17.9	1.82	0.21	0.19	2.55	25.0	14.8
M - 4A	59.0	13.5	3.93	3.86	1.62	0.02	0.1	18.1
4B	40.9	28.0	5.57	3.18	1.16	0.04	0.1>	21.5
M - 5A	37.1	32.9	3.79	0.45	0.37	0.07	0.1>	25.5

*1	A:	Surface layer
	B:	Bottom layer
*2:	M2-A	Mud on surface layer
	B	Sample from lake bottom

Table 2-9 The Result of Analysis on Composition of Brine

Sampling pt. *	Na_2CO_3 wt.%	$NaHCO_3$ wt.%	$NaC\ell$ wt.%	Na_2SO_4 wt.%	NaF wt.%	$CaCO_3$ wt.%	Insol. Mat. in Water wt.%
+2- 0	18.5	3.2	10.88	0.59	0.19	0.26	4.0
1	19.6	1.7	9.11	0.65	0.24	0.01	0.3
2	20.6	1.6	9.33	0.74	0.29	0.04	1.0
3	17.8	3.3	7.85	2.08	0.30	0.13	2.2
4	17.1	2.4	7.17	1.40	0.52	0.02	0.8
+1- 0	19.8	1.5	11.25	0.63	0.21	0.03	0.1
1	20.0	1.2	11.24	0.65	0.32	0.01	0.2
2	20.6	1.3	10.12	0.79	0.31	0.01	0.2
3	18.0	2.1	8.97	1.18	0.39	0.01	0.2
4	19.0	1.2	9.11	1.07	0.41	0.01	0.2
0- 1	21.1	1.3	10.14	0.61	0.27	0.11	4.0
2	20.2	1.2	10.92	0.60	0.28	0.01	0.3
3	20.6	1.3	10.27	0.68	0.27	0.01	0.1
4	19.6	1.1	11.61	0.59	0.19	0.01	0.1
-1- 0	21.0	1.0	10.74	0.62	0.17	0.09	2.1
1	20.4	0.2	11.86	0.60	0.26	0.01	0.1
2	21.2	0.3	11.12	0.62	0.27	0.01	0.4
3	19.2	0.2	13.12	0.55	0.21	0.01	0.1
4	19.3	0.1	13.12	0.50	0.26	0.01	0.1
-2- 0	20.3	1.4	11.23	0.65	0.16	0.01	0.3
1	20.6	1.0	10.48	0.74	0.21	0.01	0.2
2	18.4	1.2	12.52	0.60	0.13	0.02	1.0
3	18.8	0.9	13.02	0.50	0.15	0.01	0.2
4	19.1	0.8	12.92	0.58	0.12	0.01	0.1
M- 1	17.1	0.7	14.63	0.52	0.20	0.01	0.1
M- 3	15.7	1.4	15.29	0.49	0.20	0.01	0.1
M- 3B	23.8	6.0	11.40	1.50	0.62	0.11	1.6
M- 4	16.8	1.5	13.80	0.44	0.20	0.01	0.1
M- 5	20.0	1.6	10.28	0.75	0.29	0.01	0.1

*: 70cm from lake surface

Table 2-10 Results of Analysis of Metallic Contents in Natural Soda (Crust, Brine)

Lot		Fe ppm	Ti ppm	K %	V ppm	Mn ppm	Cr ppm	Zn ppm	Ba %	Li ppm	Br %	I %	SiO_2 %	B %	P_2O_5 %	COD %	$NaHCO_3$ %	Water content (Adjusted by sodium bicarbonate)
Crust	-1-OB	120	72	0.04	1.1	5	0.3	30	0.04 or less	5 or less	0.009	0.003	0.19	0.005	0.02	0.11	24.0	24.4
	-2-3B	100	35	0.09	2.4	8	0.2	3	0.04 or less	5 or less	0.009	0.002	0.17	0.003	0.02	0.08	26.8	24.7
	0-4A	28	25	0.09	1.0	2	0.2	65	0.04 or less	5 or less	0.011	0.001	0.12	0.005	0.02	0.10	18.3	27.4
	M-3A,B	40	29	0.27	1.2	2	0.2	9	0.04 or less	5 or less	0.023	0.001	0.15	0.006	0.05	0.08	5.7	27.2
Brein	-2-O	50	19	0.29	0.4	0.5 or less	0.09	0.4	0.03 or less	3 or less	0.024	0.002	0.10	0.005	0.05	0.04		
	-2-3	10	14	0.36	0.3	0.5 or less	0.06	0.3	0.03 or less	3 or less	0.029	0.002	0.09	0.011	0.06	0.05		
	0-4	3	17	0.27	0.3	0.5 or less	0.06	0.5	0.03 or less	3 or less	0.023	0.001	0.07	0.010	0.04	0.04		
	M-3	7	18	0.73	0.3 or less	0.7	0.08	0.3	0.03 or less	3 or less	0.058	0.002	0.16	0.017	0.12	0.07		

2-2-4-2 Estimation of the deposit of sodium carbonate

On the basis of the weight of the crust observed on the surface of Lake Natron, and that of the brine existing thereunder, the deposit of sodium carbonate may be calculated as follows:

(1) Crust

Crust area: $370\ km^2$

Average thickness of crust: 43 cm

Average specific gravity of crust: 1.0

Weight of crust: $370km^2 \times 0.43m \times 1.0Mt/m^3$
$= 159 \times 10^6 Mt$

Weight of sodium carbonate: $159 \times 10^6 Mt \times 0.687$ *
$= 109 \times 10^6 Mt$

*: Composition ratio obtained from the average composition rate of crust in terms of dry Na_2CO_3

(2) Brine

In most places the Lake, brine exists underneath the crust; however, in some points close to the shore of the Lake, brine sometimes does not exist. Therefore, it is assumed that the brine existing area corresponds to 80% of the crust area.

Brine area: $370km^2 \times 0.80 = 296km^2$

Average thickness of brine: 35 cm

Average specific gravity of brine: 1.3

Weight of brine: $196km^2 \times 0.35m \times 1.3$
$= 134.6 \times 10^6 t$

Weight of sodium carbonate: $134.6 \times 10^6 t \times 0.201$ *
$= 27.0 \times 10^6 t$

*: Composition ratio obtained from the average composition rate of crust in terms of dry Na_2CO_3

The deposit estimates of sodium carbonate (Na_2CO_3), salt ($NaCl$), sodium sulphate (Na_2SO_4), and sodium fluoride (NaF) are shown in Table 2-11.

Table 2-11 Amounts of Resources Contained in Crust and Brine

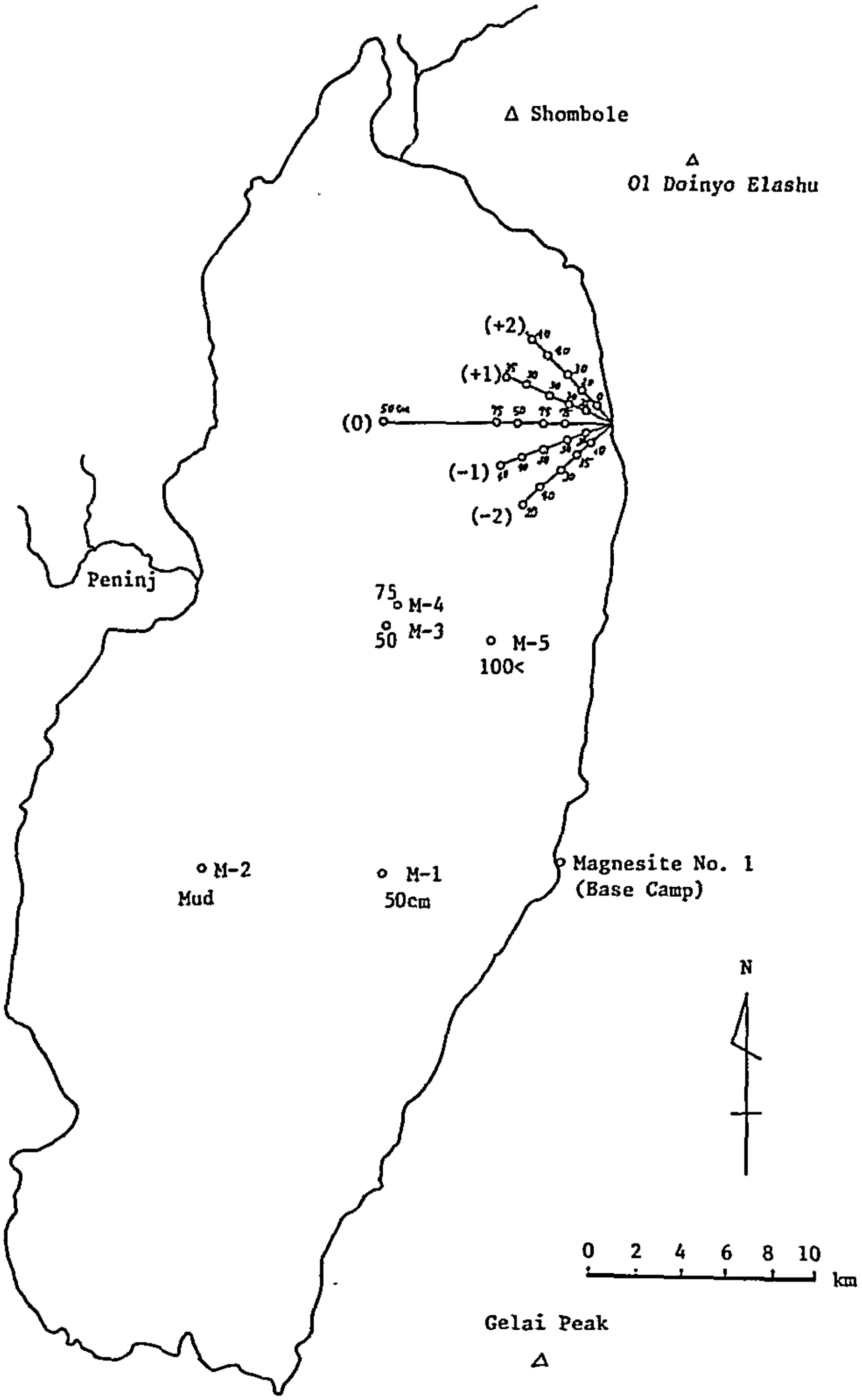
(Unit: 10^6 t)

	Crust	Brine	Total
Na_2CO_3	109	27	136
$NaCl$	8.7	15	23.7
Na_2SO_4	4.5	0.9	5.4
NaF	2.2	0.3	2.4

Table 2-12 Thickness of Crust and Brine

Sampling Point		Colour of Crust Surface	Thickness of Crust (cm)	Thickness of Brine (cm)	Depth of Lake (cm)
1	-2- 0	Red Brown	10	–	10
2	1	Yellow	35	5	40
3	2	Pink - Yellow	30	30	60
4	3	Pink - Yellow	40	40	80
5	4	Pink - Yellow	20	85<	105<
6	-1- 0	Pink - Yellow	20	–	20
7	1	Pink - Yellow	30	–	30
8	2	Pink - Yellow	50	–	50
9	3	Pink - Yellow	70	35<	105<
10	4	Pink - Yellow	40	55	95
11	0- 1	Pink - Yellow	75	–	75
12	2	Pink - Yellow	75	–	75
13	3	Pink - Yellow	50	25	75
14	4	Pink - Yellow	75	20	95
15	5	Pink - Yellow	50	55	105
16	1- 0	Pink - Yellow	25	30	45
17	1	Pink - Yellow	30	40	70
18	2	Pink - Yellow	30	45	75
19	3	Pink - Yellow	35	35	65
20	4	Pink - Yellow	35	45	80
21	2- 0	Brine	(–)	(25)	(25)
22	1	Pink - Yellow	20	15	35
23	2	Pink - Yellow	30	20	50
24	3	Pink - Yellow	40	40	80
25	4	Pink - Yellow	40	25	65
26	M- 1	Pink - Yellow	50	–	–
27	M- 2	Mud	(–)	(–)	(0)
28	M- 3	Pink - Yellow	40	30	70
29	M- 4	Pink - Yellow	75	30>	105<
30	M- 5	Yellow - Yellow	105<	–	105<
Average		Total/n	43.5 (n=28)	34.8 (n=20)	67.2

Figure 2-11 Sampling Point (and Thickness of Crust Layer)



CHAPTER 3 SELECTION OF THE PLANT SITE

3-1 Factors Affecting the Site Selection

Generally, a number of factors must be taken into consideration when selecting a site for constructing a plant. In the case of selecting a plant site for soda ash puridication, the following points must be particularly taken into account:

(1) Means of transportation and transportation cost

Detailed explanations is made in other volume of this report regarding the transportation means of crust which is the raw material as well as products. In any case, both the raw material, crust and the product, soda ash are vulnerable to causing chemical reaction, thereby requiring full attention in selecting the means of trasnportation. When the amount of transportation of the raw material and that of the product are compared, it is necessary to trasnport 2 tons of raw materials against 1 ton of the product. This is due to the fact that 2 tons of raw material is necessary to produce 1 ton of purified product.

(2) Possibility of securing water for industrial use

In order to process a million tons per year of soda ash, 20,000 tons per day of process water is necessary.

(3) Environmental conservation

The crust excavated from Lake Natron contains impurities such as sodium sulphate (Na_2SO_4), sodium fluoride (NaF), etc., so that the discharged water and residue turned out from the purification process involve a danger of polluting the environmental plant sites if discharged without treatment.

Particularly, fluorine contained in sodium fluoride (NaF) is extremely harmful to human health. It damages the skin and respiratory tissues of human body. Therefore, a vast extent of investment is necessary to construct suitable treatment facilities to prevent environmental pollution caused by the exhausts and emissions.

(4) Possibility of securing labour force

Necessary labour force to produce a million tons of soda ash per year is estimated to be 358 persons at plant site. Proper arrangements must be made to secure this labour force.

3-2 Plant Site

The following three locations were selected as the possible sites for constructing the purification plant. The following paragraphs will cover the feasibility study of these sites by taking into consideration these factors of selection described in the foregoing 3-1:

(a) Tanga
(b) Arusha
(c) Natron Lake side

3-3 Study of the Site

3-3-1 Tanga

Tanga is one of the leading ports of Tanzania, and therefore has a great advantage in the case of exporting the product, and for the transportation of either heavy oil or coal which will be used as the energy source for the purification process. However, when producing a million t/y of soda ash, it is necessary to transport two million tons per year of crust from Lake Natron which is approximately 460km away from Tanga. Even if the road or railway or both means of transportation cost of raw material will inevitably become extremely high when compared with the transportation cost of the product.

Tanga has a fertilizer plant, etc. and has the third largest population in the country next to Dar es Salaam, and Zanzibar. Therefore, the securing of labour force will present no serious problem (refer to Table 3-1, population structure by sex and age).

If a plant is to be constructed in Tanga with a current population of 60 thousand, it will be imperative to install treatment facilities for discharged water, residue, etc. which will be emitted from the process, in order to protect the environmental conditions. Such an installation will naturally call for a large amount of investment.

3-3-2 Arusha

Arusha is a beautiful urban area having a population of more than 30,000, and the land area of the city and the suburbs covers 115km^2. The area was designated as one of the national parks in 1970, and is attracting a great number of foreign tourists as one of the bases for sightseeing trip covering northern Tanzania. It goes without saying that proper attention must be paid to the conservation of the environmental conditions if the soda plant is to be constructed in this area.

Further, Arusha has no large river to ensure supply of water. Therefore, the securing of the water must depend entirely upon underground water. The conditions of under-water must be confirmed by geological surveys; however, in any case, damage may be inflicted upon the agricultural products and vegetation of this area if underground water utilization is carried out for the process.

3-3-3 Lake Natron

As has already been mentioned in 2-1, the population in the vicinity of Lake Natron is extremely small, thereby presenting a problem in securing labour force. However, as the raw material soda crust is mined from the Lake, it would be unnecessary to transport crust which will call for transportation cost twice as high as the product, if the purification plant is constructed by the lake. Therefore, the weight of transportation cost in the product price will be greatly reduced.

Further, the exhausts from the plant can be returned to the Lake after simple treatment, so that any special treatment equipment such as required in the other plant sites will become unnecessary. Such a feeding-back of the residue will not damage the natural environment in the area. Further, Peniji River is slowing into the northwestern part of the Lake, while Ngare Nyiro River is coming into the Lake on the north. It seems highly likely that the water available from these rivers can be used as for industrial water throughout a year.

A problem in the case of constructing the plant on the shore of Lake Natron is the difficulty in securing ample labour force necessary for the production. Therefore, it will be necessary to induce surplus labour from various urban areas inside Tanzania to emigrate into this area, together with building proper living environment for the workers and their dependants.

3-4 Suggested Sites for the Plant Construction

3-4-1 Finalization of the site selection

As the alternative sites for plant construction, (a) Tanga, (b) Arusha, and (c) Lake Natron area were selected. As a result of comparative examinations of these alternatives, it seems that Lake Natron area is superior to the other two from both economic and sociological viewpoints.

3-4-2 Finalization of the sites in the vicinity of Lake Natron

The next step of the study is to examine the optimum site for the plant construction within the Lake Natron area. As the basis for selecting the construction site, the following items must be taken into consideration:

(a) Geographic and topographic conditions

(b) Distance between the plant site and crust mining site.

(c) Distance between the plant site and water sources for industrial use

  (1) On the west shore of the Lake, Peninj River is flowing into the Lake, thereby making it extremely advantageous to secure the source of water supply; however, Ol Doinyo Sambu Moutain approaches quite close to the Lake on the north side of Peninj River. A fault of the Great Rift Valley is standing on the south side of

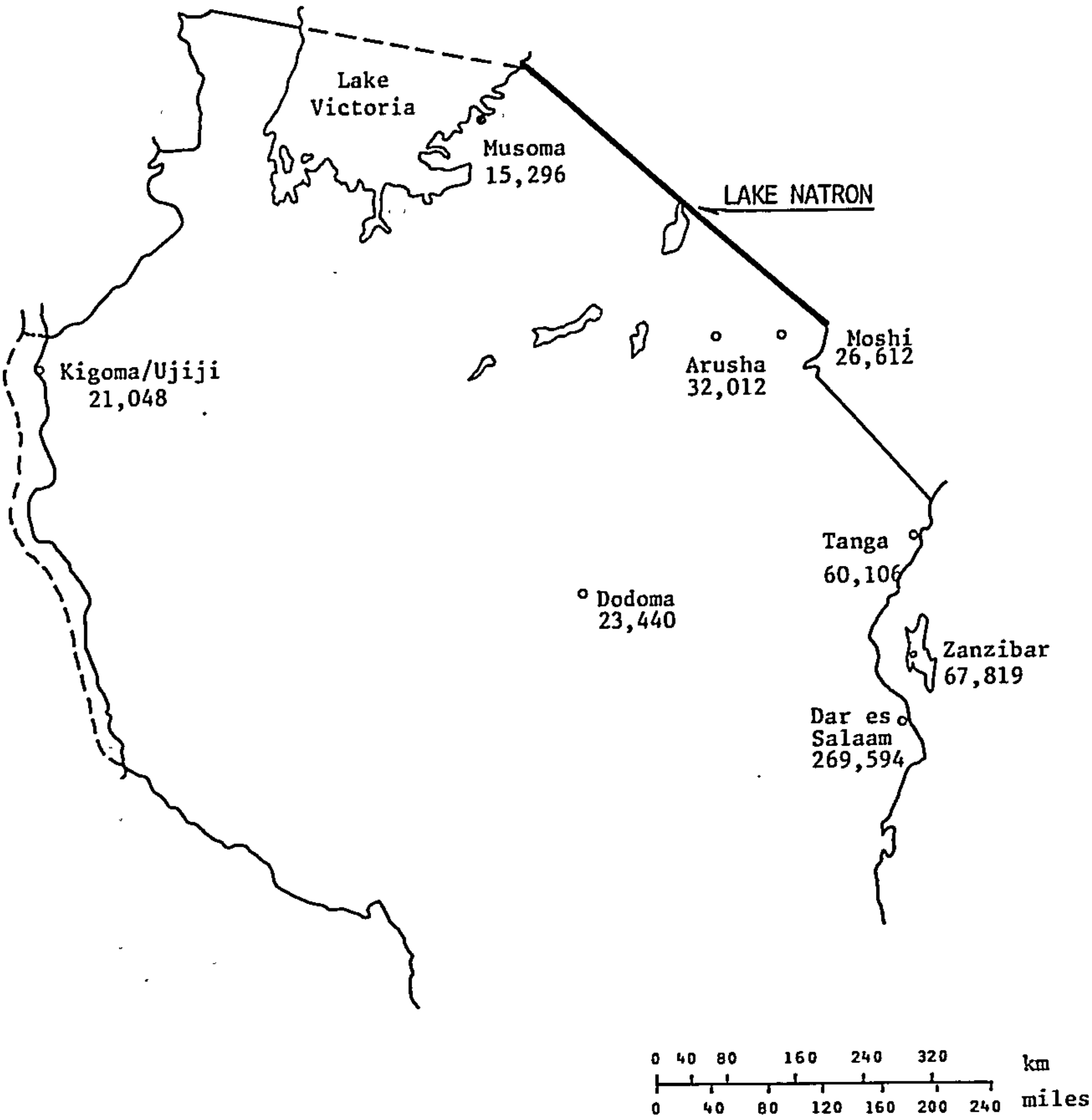
Table 3-1 Population Structure by Sex and Age

(Unit: Persons)

Name of Cities	Sex	Age Total	0-4	5-9	10-14	15-19	20-34	35-49	50-64	65-	N.S.
Dar es Salaarm	Male	148,547	19,849	14,199	10,208	14,299	52,811	26,186	7,727	3,142	126
	Female	121,047	20,191	15,411	9,471	13,616	40,157	14,378	4,964	2,784	75
	Total	269,594	40,040	29,610	19,679	27,915	92,968	40,564	12,691	5,926	201
Tanga	Male	32,582	4,508	3,600	2,883	3,360	9,216	5,810	2,152	994	59
	Female	27,524	4,518	3,921	2,561	3,007	7,962	3,505	1,338	677	35
	Total	60,106	9,026	7,521	5,444	6,367	17,178	9,315	3,490	1,671	94
Arusha	Male	18,137	2,742	1,992	1,446	2,176	6,169	2,488	749	346	29
	Female	13,875	2,522	1,936	1,206	1,663	4,310	1,468	486	262	22
	Total	32,012	5,264	3,928	2,652	3,839	10,479	3,956	1,235	608	51
Moshi	Male	14,934	2,149	1,534	1,270	2,137	4,826	2,064	635	271	48
	Female	11,678	2,169	1,539	1,001	1,530	3,574	1,206	416	228	15
	Total	26,612	4,318	3,073	2.271	3,667	8,400	3,270	1,051	499	63
Musoma	Male	7,845	1,218	897	668	747	2,574	1,199	348	175	19
	Female	7,451	1,310	1,017	712	962	2,120	746	355	215	14
	Total	15,296	2,528	1,914	1,380	1.709	4,694	1,945	703	390	33

Source: The United Republic of Tanzania 1967 POPULATION CENSUS Volume 2 published by Bureau of Statistics, Ministry of Economic Affairs and Development Planning in 1970.

Figure 3-1 Population Distribution of Major Cities in Northern Tanzania



the river. Therefore, it is rather difficult to secure a wide and flat land area necessary for constructing a plant on the west shore of the Lake.

(2) The northern part of the Lake presents no difficulty in securing of water supply because of the in-flow of Ngare Nyiro River; however, Mt. Shombole is soaring close to the lake shore, and an accumulation of mud and a lagoons are covering the northern lake area. Therefore, it seems that this part of the Lake is not suitable as a site for mining crust. This signifies that if a plant is constructed in this area, the distance between the site and the crust mining point which will be set somewhere in the lake will be great and crust transportation becomes more difficult.

(3) On the south shore of the lake a flat land area is available; and accumulation of mud and a lagoon stretches widely over the Lake in this area, thereby making the distance to the crust mining point great. Also, this part of the Lake does not have any source of water supply in the vicinity.

(4) The southern portion of the east side of the Lake also has a flat land area which is a part of the foot of Gelai Peak. This area slso lacks the water supply source, and the existence of lagoon and mud accumulation in the Lake is also frequent. These conditions therefore will make the distance between the plant site and the crust point great.

(5) The topographic conditions of northern part of the east side of the Lake offer a continued stepfault, while flat lands necessary for plant construction is abundantly available. As weill be mentioned in detail later, the crust in the Lake in the vicinity of this area is comparatively thick, and seems to facilitate the mining and the transportation of crust when compared with the other crust points.

    The shortcoming of this area is the difficulty in securing industrial water source. The supply of water must depend on either Peninj River or Ngare Nyiro River, so that installation of pipelines, etc. will be necessary in order to secure the water supply.

In view of the above comparative observation of various areas surrounding Lake Natron, it seems most desirable that the plant be constructed on the flat land of the stepfault existing on somewhat northern part of the east side of Lake Natron after summing up all the advantages and disadvantages of the environmental conditions. Fig. 2-3 shows the selected alternative sites for plant construction.

3-5 Proposed Site for Crust Mining

As shown in Fig. 3-3, the mud accumulation portion and lagoon parts of the Lake have been excluded from the selection of crust mining points in view of the obvious disadvantage in crust distribution. The crust mining points have therefore been selected from the part of the

Figure 3-2 Selection Candidate Sites for Plant Construction at Lake Natron

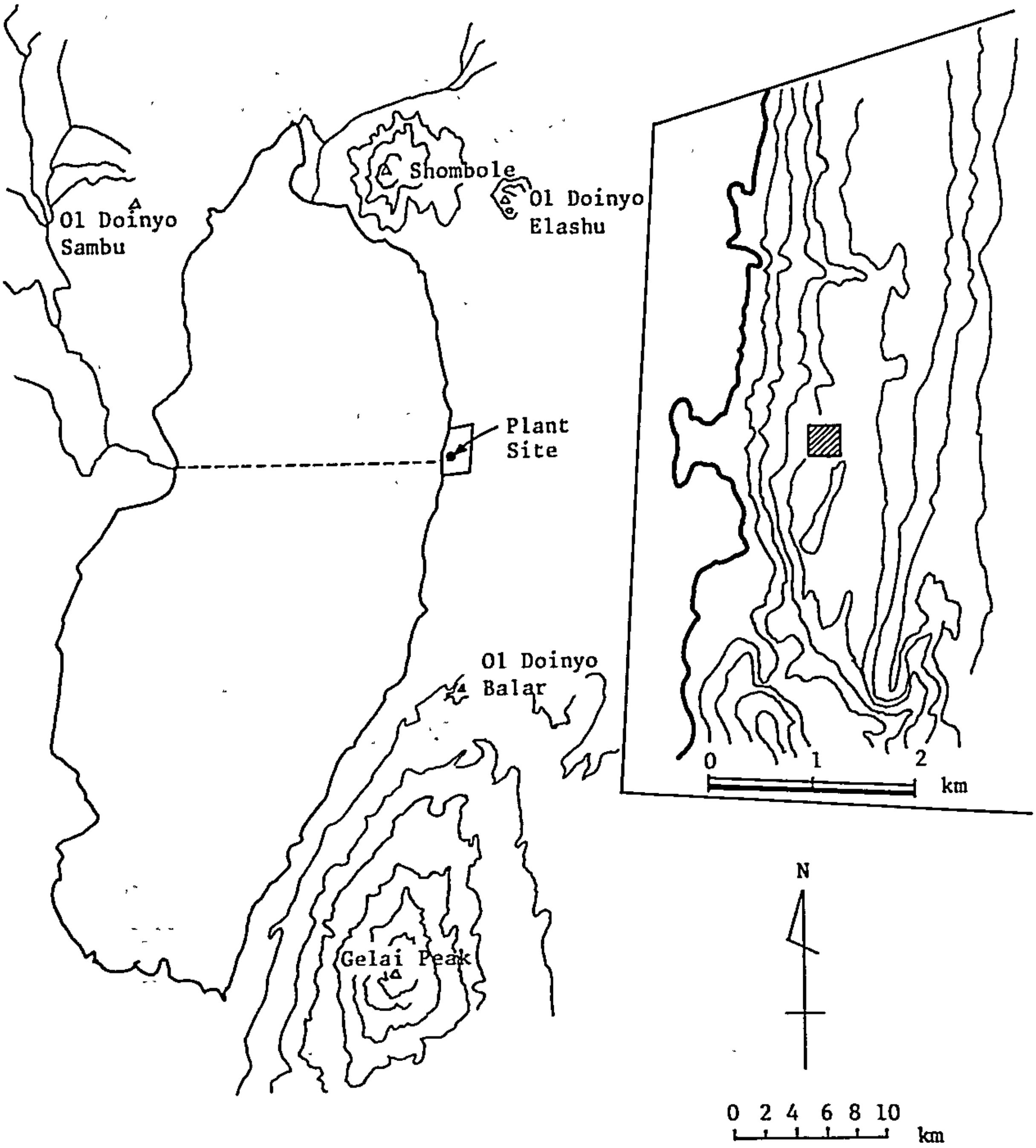
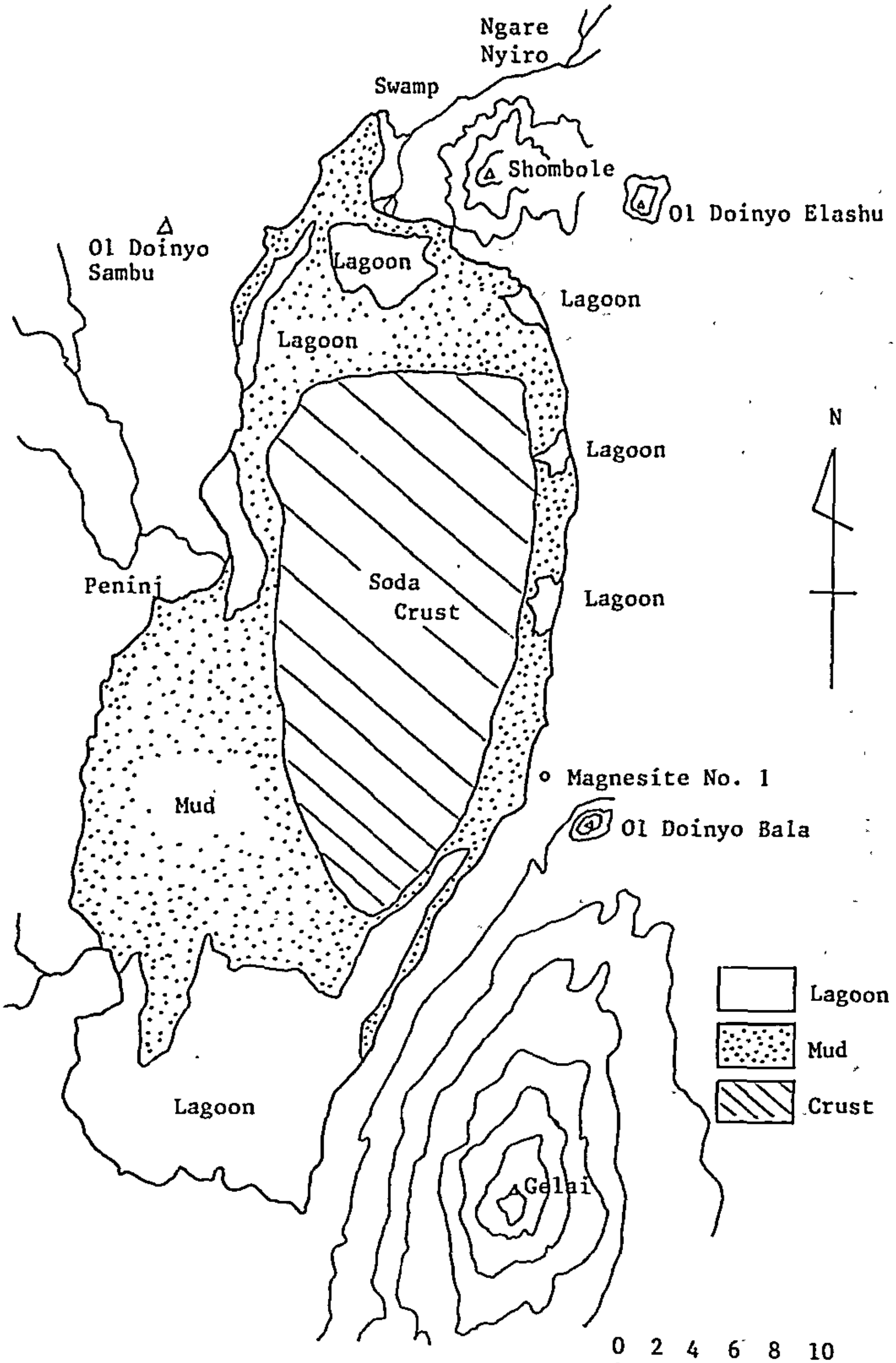


Figure 3-3 Distribution Chart of Soda Crust at Lake Natron



crust area which is visible on the surface of the Lake. It is also possible that other crust layer exists on the bottom or underneath the bottom of the Lake. Depending upon the future confirmation of the existence of such crust layers, more suitable crust mining points may be selected.

However, the present survey did not involve examination of the lake bottom or the underground portion of the lake shores by means of boring, etc. Therefore, the selection of the mining points has been based only on the exposed area of the crust in the Lake.

From the viewpoint of mining of crust, the advantage will be greater if the crust layer is thicker and the sodium carbonate (Na_2CO_3) contents are higher. Therefore, the measurement of the crust thickness and the analysis of the crust composition were conducted. The obtained results are shown in Tables 2-12 and 2-8 respectively. Although the thickness of the crust varies from point to point, there is no significant difference in view of the contents of sodium carbonate (Na_2CO_3) among the selected points. Therefore, if the selection is based only on the thickness of crust layer, the most advantageous point for future mining of crust is the area towards the east shore from the mid point of the Lake viewed directly towards east from the mouth of Peninj River. This site is comparatively close geographically to the already discussed site for constructing the purification plant which is on the east shore of the Lake. The selection of these two sites, one for the plant and another for crust mining, will facilitate crust transportation, thereby providing advantage in view also of raw material crust transportation cost.

3-6 Feasibility of Conveyance of Raw Material Crust through Pipelines

In this section, studies will be made regarding the feasibility of long-distance transportation of raw material crust through pipelines on the assumption that the soda ash purification plant is constructed on a site geographically away from the crust mining site, for instance the case of constructing the plant in Arusha, etc.

When transporting the raw material crust through pipelines, it is necessary to make the crust into slurry after mixing it with brine. It is accepted that the mixing ratio of brine and crust be 7 to 3 approximately. Therefore, for transporting by this means 1 ton of crust, it would be necessary to move the slurry of approximately 3 tons. This presents a question as to whether or not this method of transportation is actually effective in view of the transportation efficiency.

The crust turned out from Lake Natron is soft and fragile. Therefore, the crust will become fine powder during transportation, thereby increasing the viscosity. Table 3-2 shows a result of experiment on the chronological changes in the slurry viscosity when the Natron crust was mixed and stirred with the brine which was also sampled from the Lake. As shown in this table, the viscosity in two hours after mixing becomes as high as 458 C.P. Unlike the slurry transportation of coal and water, etc. the soda crust transportation by this method will cause a great increase in the electrical power consumption, thereby deteriorating the economy of the operation.

Table 3-2 Example Data on Slurry Viscosity

	Soda crust and brine	Saturated water solution of sodium carbonate and sesqui-sodium carbonate	Coal and water
Raw solution viscosity	6.28 c.p.	2.42 c.p.	1.00 c.p.
(minutes)			
0	7.67	3.42	1.00
20	–	–	1.35
30	40	137	–
40	–	–	1.56
60	79	152	1.96
90	238	155	–
120	458	163	–

CHAPTER 4 PLANT DESIGN

4-1 Mining of Crust

4-1-1 Mining commencement location

As shown in Fig. 4-1, the mining of crusts is proposed to be started at the point 4km away from the lake shore on the south side of the water in-take pipeline from Peninj River which located on the opposite shore of the plant construction site.

4-1-2 Mining volume and mining area

Tables 4-1 and 4-2 show the results of preliminary calculation of the crust mining quantity and the crust mining area to obtain necessary amount of raw material crust to produce soda ash at an production capacity of a quarter million t/y, half a million t/y, and one million t/y on the assumption that the average soda crust thickness if 40cm, the apparent specific gravity 1.0, unit consumption of the crust 2.0, and at 300 days annual operation.

Table 4-1 Crust Mining Quantity

(Unit: 1,000 t)

Production scale of soda ash	Annual mining	Monthly mining	Daily mining
250,000 t/y	500	42	1.7
500,000 t/y	1,000	83	3.3
1,000,000 t/y	2,000	167	6.7

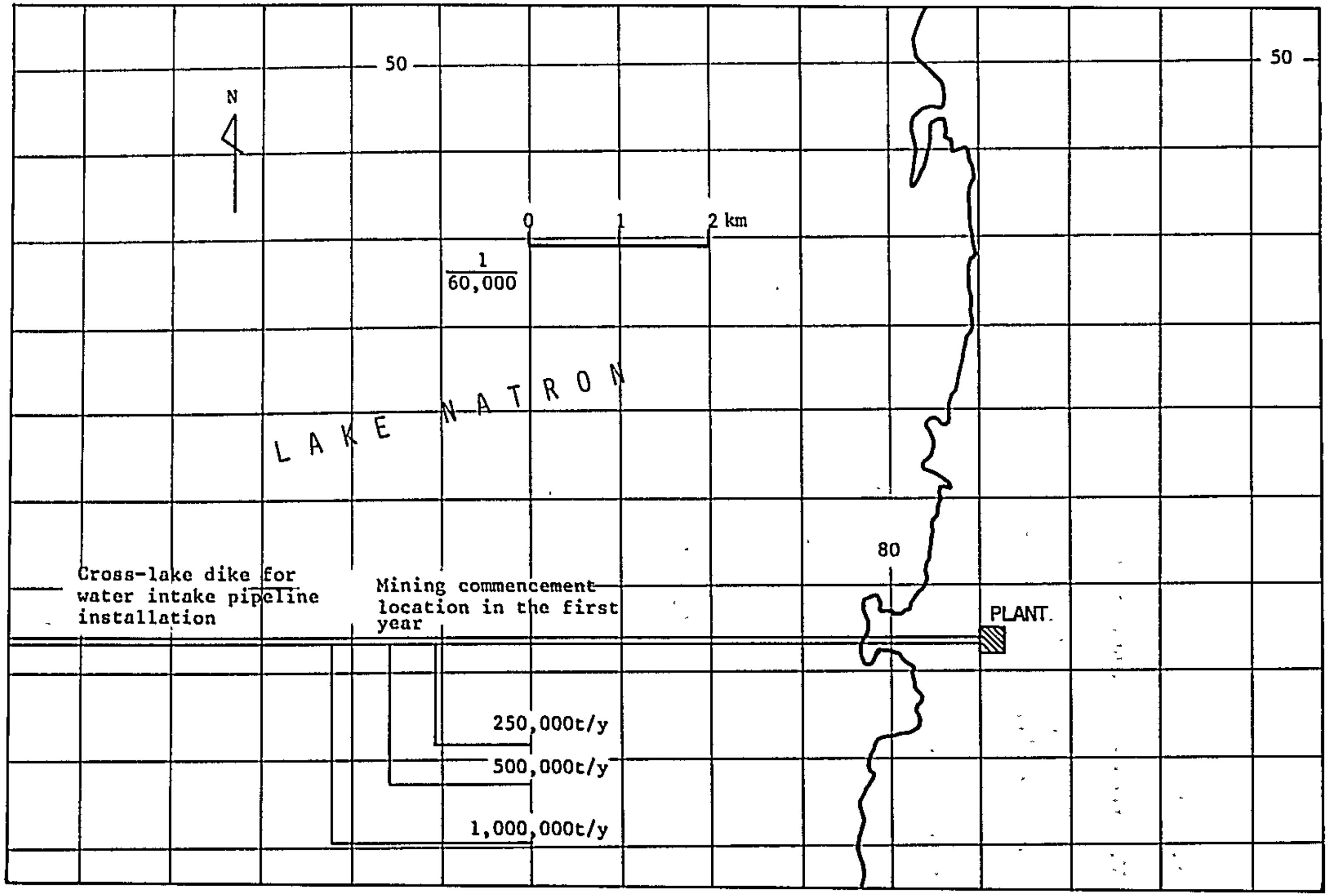
Table 4-2 Crust Mining Area

(Unit: 1,000 m^2)

Production scale of soda ash	Annual mining	Monthly mining	Daily mining
250,000 r/y	1,250	104	4.2
500,000 t/y	2,500	208	8.3
1,000,000 t/y	5,000	417	16.7

The crust mining area is illustrated in Fig. 4-1.

Figure 4-1 Mining Commencement Location and Area



4-1-3 Method of mining

This section discusses, the available method of crust mining from Lake Natron.

(1) Dredger method

This method is presently employed at Lake Magadi for crust mining. Direct application of this dredger without modification seems rather difficult. Certain modifications in the mining system are therefore necessary.

In the Dredger method, the crust collected by a bucket dredger is screened and divided into coarse grains and fine grains through vibrating screens. The coarse substances are treated by crushers and then mixed with the fine grains. Soda brine is added to the mixture to produce slurry for pipeline transportation.

In the case of Lake Natron, the slurry transportation pipeline is installed along the new constructed embankment in parallel to the water-intake pipeline which stretches towards the plant from the west. The pipeline is fixed on the surface of the embankment. On the other hand, the pipeline stretching towards the south is set on the floats in order to allow free movement. The soda slurry is fed into an arc-shaped sieve which separates crust from brine. The separated crust is transported on a belt conveyor to the crust yard, while brine being returned to the Lake through a pipe.

This method seems to be most suitable if the crust layer thickness is larger, and if the shifting of the dredger is not frequent. However, in the case of Lake Natron, the depth of water is approximately one (l) meter, and therefore makes it difficult to float a dredger. Further, as the crust layer is not thick, the mining area par day is as large as 8,300 m^2 (in the case of producing 500,000 t/y soda ash production). This naturally requires easy mobility of the dredger.

Thus, when adopting the Dredger system at Lake Natron, it is necessary to develop a dredger of amphibious use with high maneouvrability.

(2) Cut and pull method

By this method soda crust is cut into predesignated size of blocks, thereby floating the blocks on soda brine. This soda crust is then pulled to the in-take piping dike which crosses through the Lake. After de-watering the crust blocks by means of a crane, either belt conveyors or dump trucks are employed to transport them to the crust yard installed on the shore. If this method is to be employed, the width and the bearing capacity of the piping dike must be designed accordingly.

This method seems to be rather suitable for the crust mining operation at Lake Natron where the thickness of crust layer is not so great.

(3) Dry method

This method involves the sectioning of the Lake area by means of mud, gravel, etc. to prevent the in-flow of river water or hot spring water from outside in order to evaporate the soda brine by the heat of the sun. If the heat of the sun alone is insufficient to effect brine evaporation, pumps are employed to take the water out of the section in order to facilitate the evaporation drying. Thus dried crust is mined by on-land mining machines to transport the crust to the yard by belt conveyors. The disadvantage of this method is the fluctuation of the mining operation efficiency affected by the weather conditions.

(4) It seems necessary to effect the long-term meteorological observations, evaporation tests, boring exploration, physical exploration, etc. in order to clarify the weather conditions in the vicinity of Lake Natron, the depth of the Lake, the status of the lake bottom and the existence of further soda crust layers underground. Depending upon the results of these surveys, it would be possible to pinpoint the optimum site for crust mining and to select the most effective method of mining.

For the estimation of the plant cost and production cost in this survey, the Dredger Method is adopted as the basis.

4-2 Soda Ash Purification Process

4-2-1 Natural soda ash purification process

Prior to conducting a scrutinization of the purification processes to produce soda ash from the soda crust at Lake Natron, an outline explanation will be made in the following paragraphs regarding the purification processes of natural soda ash which have already been commercialized in the U.S.A. and Kenya.

(1) Natural soda ash purification process employed in the U.S.A.

The outline of the soda ash purification process employed at Green River, Wyoming, U.S.A. is as follows:

The raw ore of Trona excavated from levels of several hundred meters underground consists of comparatively high purity trona substances containing 8% to 10% of water insoluble matter. An example of the composition is shown in Table 4-3.

The trona ore excavated from underground is roughly crushed and then calcined at 500 to 600 C. The organic matters contained are burnt off and the trona is decomposed into crude soda ash in the calcination. The crude soda ash is dissolved into water to effect sedimentation separation of the water insoluble substances. Then, the solution is filtered and passes through activated carbon treatment. By this time, the organic substances and water insoluble substances, originally contained in the trona ore are almost

Table 4-3 Example of Composition of Trona Raw Ore at Green River, Wyoming, U.S.A.

Trona content ($Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$)	91.2 %
Fe_2O_3	0.009 %
NaCl	0.16 %
Na_2SO_4	0.12 %
Water insoluble matter	8.48 %

completely eliminated. The solution of the refined soda ash is concentrated in an evaporating crystallizer to crystallize sodium carbonate monohydrate crystal, which is separated and washed by a centrifuge. The monohydrate crystal is dried by a dryer. The soda ash delivered from the dryer is then screened to be made into the final product. The purity of thus produced soda ash is as high as 99.8%. An example of the quality specifications of this product is as shown in Table 4-4. The purification process is shown in Fig. 4-2.

Table 4-4 Example of Quality of Specification Natural Soda Ash at Green River, Wyoming, U.S.A.

Na_2CO_3	99.8 %
$NaHCO_2$	–
NaCl	0.02 %
Na_2SO_4	0.02 %
Fe_2O_3	0.0005 %
NaF	0.00
Water insoluble matter	0.00

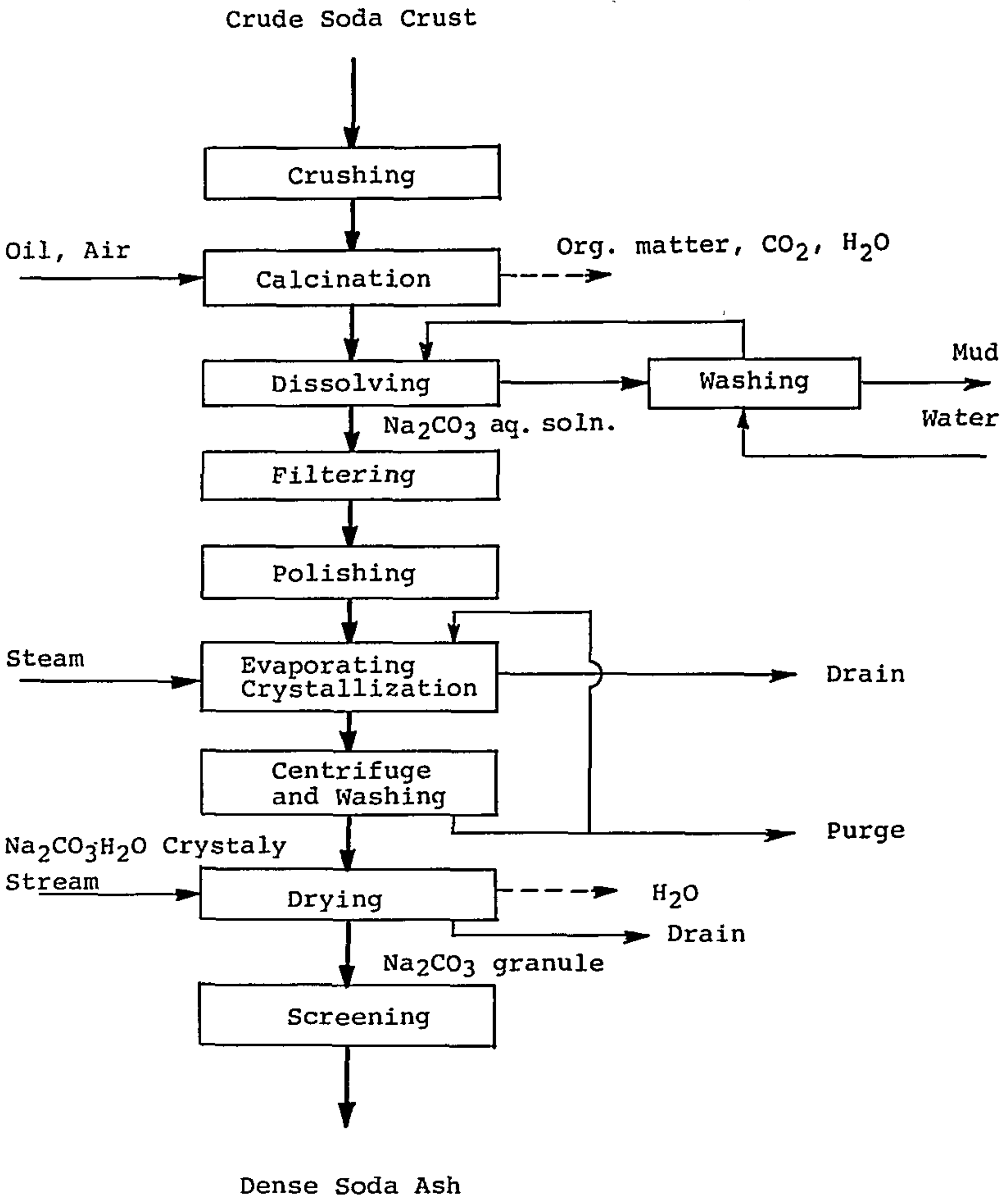


Figure 4-2 Torona Soda Ash Purifying Process

(2) Natural soda ash purification proces employed at Magadi, Kenya

Dredgers are employed to collect the raw ore which mainly consists of trona from Lake Magadi. The dredgers are floating on the brine and are shifted to points suitable for collecting trona.

The raw ore collected by the dredgers is coarsely crushed in crushers and transported to the plant standing on the lake shore in the form of brine slurry. Filtration of the slurry is effected in the plant, thereby washing out and separating the adhering mud, salt, etc. Then, the separated and washed raw ore is calcined at 600 C in order to burn the contained organic substances, and also to decompose the trona into soda ash.

It is reported that the purity of thus purified soda ash is approximately 97%, which is lower than the purity of American natural soda ash or synthetic soda ash. Further, Magadi ash contains approximately 1% of sodium fluoride which is causing quality problems. An example of quality specifications of Magadi as shown in Table 4-5. The purification process is illustrated in Fig. 4-3.

Table 4-5 Example of Quality Specification Natural Soda Ash of Magadi, Kenya

Na_2CO_3	97.1 %
$NaHCO_3$	0.05 %
NaCl	0.3 %
Na_2SO_4	0.40 %
Fe_2O_3	0.035 %
NaF	1.28 %
Water insoluble matter	0.4

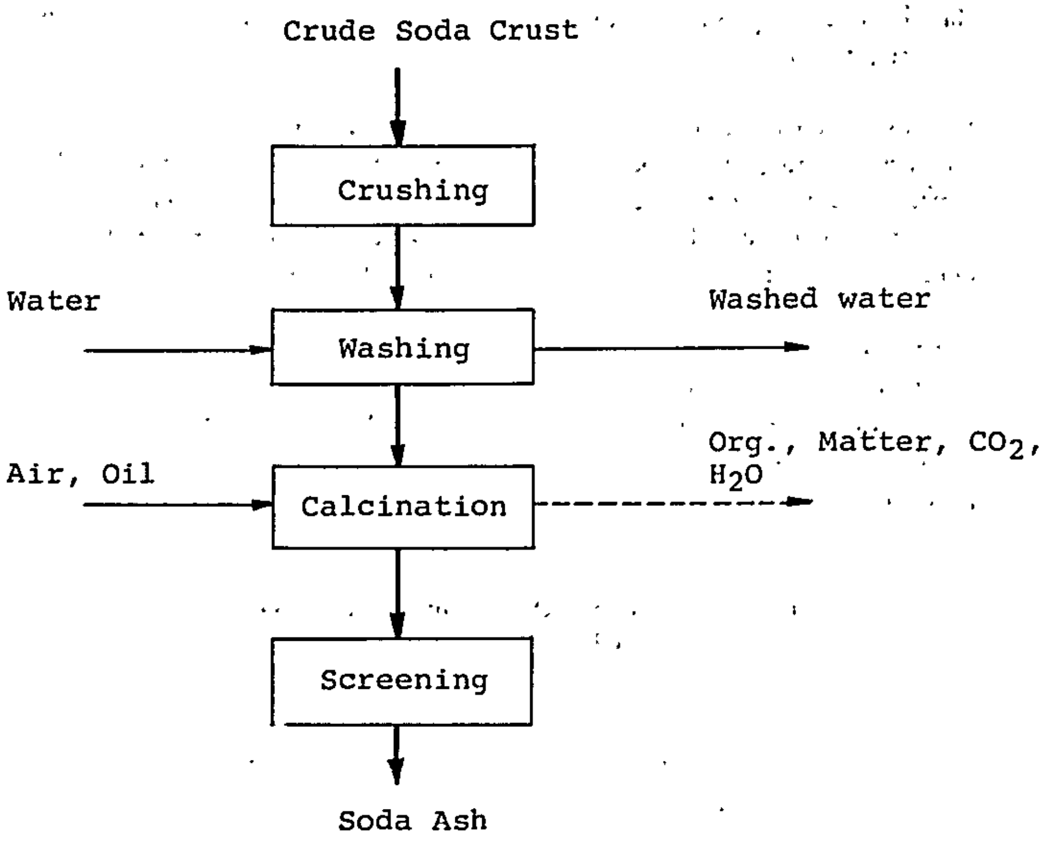
4-2-2 Basic concept of design of a purifying process for natural soda ash available at Lake Natron

The following basic points are taken into consideration when designing a purifying process of the soda crust at Lake Natron.:

(1) Quality of the products

The soda crust available at Lake Natron contains organic substances presenting pink and

Figure 4-3 Purifying Process of Magadi Soda Ash



yellow brown in colour, and also includes sodium fluoride, sodium sulphate, sodium chloride, heavy metals, water insoluble substances, etc. Further, it seems inevitable that mud and brine are accompanied from the bottom of the Lake when mining the crust. In order to sell in the international market a large amount of soda ash as much as 250,000 tons, 500,000 tons, or even 1,000,000 tons per year, it is imperative that the purification of soda ash must be effected to a level of purity comparable to that of synthetic soda ash or American natural soda ash. Therefore, the process for removing these impurities must be incorporated into the design.

Particularly, in view of the requirements for the environmental conservation in the soda ash utilizing industries, the employment of soda ash containing a high extent of sodium fluoride is stringently regulated. Therefore, a process for removing sodium fluoride from the soda crust is indispensable in the design. However, the removal of sodium fluoride calls for extremely highly sophisticated technology, and there has been no example of commercialized plant under this process. Toyo Soda Manufacturing Co., Ltd. of Japan has been continually carrying out studies and researches on the subject of natural soda ash purifying for these several years. The following paragraphs will describe a study on the designing of Lake Natron soda ash purifying process on the basis of findings and results of Toyo Soda's research.

(2) Environmental conservation

Attention must be paid to the prevention of adverse effects to the residents and vegetation of the area surrounding plant-site. The pollution preventive provisions are, for example the prevention of flying of dust from the calciner, dryers, and soda ash screens, as well as the return of low soda content water to the Lake after effecting the sedimentation of the residue in a sedimentation ponds as far as plant discharged water is concerned.

(3) By-products

The soda crust available in Lake Natron contains 2.80wt% of sodium sulphate and 1.3wt% of sodium fluoride respectively. The soda brine contains 11.2wt% of sodium chloride. Although it may be theoretically possible to recover these contained substances in the form of by-products; it seems likely that a vast extent of investment will be necessary to recover these by-products with a sufficiently high purity acceptable in the market. Therefore, the commercialization of these by-products seems economically unfeasible. In other words, production of sodium sulphate, sodium fluoride or table salt as commodities by utilizing the soda crust will not support this soda ash project. Therefore, the examination of the by-product recovery process will be excluded from the scope of the study on selecting the purification process of soda ash.

4-2-3 Prerequisite conditions for process design

The prerequisite conditions for designing a purification process of the dense soda ash from the soda crust in Lake Natron are as follows:

(1) Production capacity

The annual production capacity of dense soda ash shall be based on 500,000 tons, and the design of the process includes an allowance for future expansion of the production capacity up to 1,000,000 tons per year. A case of 250,000 ton annual capacity has also been included within the scope of the study.

(2) Operation days

Due to the necessity for rendering maintenance of the facilities, and also in view of the possibility of unpredicted trouble in operation, it seems physically impossible to run the plant for 365 days a year. Therefore, in order to cope with the maintenance service and treatment of occasional and unpredicted malfunctioning of the plant, necessary spare parts must be stored and repair shop has to be installed. At the power generation plant, emergency power source equipment must be installed in order to increase a numbe of operation days. On an assumption that all these provisions are made, the number of annual operation days in set at 300. The running of the plant is based on 24 hours continuous operation.

(3) Composition of the raw material

The soda crust sorted in the yard after being excavated from Lake Natron is deemed to contain 25wt% of brine. It has also been assumed that the compositions of crust and brine will be as follows:

o Soda crust composition (Dry basis)

$NaHCO_3 \cdot Na_2CO_3 \cdot 2H_2O$	62.08 wt %
$Na_2CO_3 \cdot H_2O$	28.08 wt%
NaC1	0.51wt%
Na_2SO_4	3.03 wt%
NaF	1.13 wt%
Mud	5.10 wt%

o Brine composition

Na_2CO_3	20.00 wt%
NaC1	13.01wt%
Na_2SO_4	0.80 wt%
NaF	0.41 wt%
H_2O	65.78 wt%

4-2-4 Soda ash purifying process

Flowsheets of the proposed purifying process are shown in Figs. 4-4 and 4-5. The following paragraphs explain the outline of the process.

(1) Washing

The soda crust mined at the Lake will be piled in the yard from where it is fed into the washing process by means of belt conveyors.

Nearly all of the sodium chloride accompanying the soda crust, and part of the contained sodium sulphate and sodium fluoride as well as part of the accompanying mud are removed through two stages of a spiral washer.

(2) Calcination

Prior to being fed into the calciner, the moisture is removed by a centrifuge in order to enhance the heat efficiency of the calciner. Thereafter, the crust is fed into the calciner at a rated amount.

In the calciner, the crust is burnt directly with combustion gas of heavy oil to effect the following chemical reactions.

$$Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O \longrightarrow \frac{3}{2} Na_2CO_3 + \frac{1}{2} CO_2\uparrow + \frac{5}{2} H_2O$$

$$Na_2CO_3 \cdot H_2O \longrightarrow Na_2CO_3 + H_2O\uparrow$$

As shown above, sesqui-sodium carbonate ($Na_2CO_3 \cdot HaHCO_3 \cdot 2H_2O$) decomposes at 200 to 350°C,while sodium carbonate monohydrate ($Na_2CO_3 \cdot H_2O$) at 60 to 100°C, thereby both turning into sodium carbonate unhydride (Na_2CO_3). The organic matters contained in the crust are decomposed at 400 to 800°C. If the heat is increased above 800°C. the sodium carbonate itself starts to melt. Therefore, the most suitable range of calcination temperature is from 500 to 600°C. Nearly all of the contained organic substances can be removed at the above temperature.

The gas exhausted from the calciner contains fine powder of sodium carbonate. Therefore, a multi-cyclone and a scrubber must be installed to remove the dust. The gas must be released into the atmosphere after it is burnt.

Temperature of the crude sodium carbonate at the exit of the calciner is approximately 600°C. Therefore, before feeding the raw sodium carbonate to the hopper for storage, it is fed to a rotary cooler in which the sensible heat is recovered by cooling the temperature to approximately 200°C with combustion air.

(3) Dissolving

The crude soda ash is fed at a constant rate to the dissolver from the hopper and is dissolved into the process water, thereby making a crude soda solution. The insoluble mud is separated by gravity in the primary settler, and the overflow of the clear solution alone is fed into the treater. The mud slurry removed from the bottom of the primary settler still contains sodium carbonate. In order to recover this content, the slurry is fed into the secondary settler in which it is washed by the process water. The soda content thus recovered in the secondary settler is again returned to the dissolver in the form of weak solution of soda and is used as process water for dissolving the crude sodium carbonate which is newly supplied from the hopper. The mud slurry in which the soda content becomes extremely low is fed into the sedimentation pond.

(4) Purification

In order to remove the impurities such as sodium fluoride, heavy metals, etc, contained in the crude soda solution, chemicals are fed to the treater and the solution is stirred for a predesignated time. Then, the mud containing the added chemicals, sodium fluoride, etc. is removed at the third settler, vacuum filter and the pressure filter. This mud is also diluted by the waste water emitted from the crust washing process, and then fed into the sedimentation pond. At the sedimentation pond, mud and other solids is gravitated to the bottom, and the clear solution alone is sent back into the Lake.

The soda solution from which the mud is eliminated, still contains a limited amount of organic substances in spite of the burning in the calciner. In order to eliminate those, the soda solution is fed to the activated carbon adsorption tower. The solution is thereafter fed to the crystallizer.

(5) Crystallization

The type of the crystallizer to be employed in this process is a triple-effect evaporating crystallizer. The slurry formed in the crystallizer is circulated between the external heat exchanger and the crystallizer itself by pumps. The pressure of the crystallizers is kept vacuum by condensing the steam generated from the third crystallizer with a barometric condenser, and by further sucking the uncondensed steam with a steam ejector. The cooling water used in the barometric condensor is recycled between the cooling tower and the condensers. An amount of water corresponding to the loss from the circulating system has to be supplied in order to cover the evaporation and blow down losses. It is also necessary to purge part of water from the system to avoid the accumulation of impurities. The process water requirement can be minimized if the cooling tower is installed.

The inside of the first crystallizer is kept at 100°C, and 648 Torr pressure, the sodium carbonate monohydrate crystal is produced while approximately 117°C steam is fed into the heater. Both the steam from the power plant, pressure of which is further reduced from 10kg/cm^{2}G at 190°C and the steam recovered from the condensate of the dryer can be fed to the crystallizer.

The inside of the secondary crystallizer is kept at 77°C, and 265 Torr pressure. While the steam generated in the primary crystallizer is fed to the secondary crystallizer, further crystallization takes place in the secondary crystallizer.

The inside of the third crystallizer is kept at 50°C and 77 Torr pressure. Again, further crystallization takes place in the third crystallizer where the steam recovered from the secondary crystallizer is fed. Flow of the steam adopted here is parallel to that of the solution to be concentrated. Thus, the heat energy is effectively utilized.

It is necessary to control the soda crystallization ratio at an adequate level in order to avoid coprecipitation of sodium fluoride which can cause the contamination of the crystals. In this procedure the sodium fluoride content inside the crystals can be reduced, it is necessary to condense sodium fluoride into the mother liquor to reduce the sodium fluoride content in the crystals.

Then, the crystals of sodium carbonate monohydrate are separated from the mother liquor by means of centrifuge, and most of the mother liquor is fed back to the crude sodium carbonate dissolver. The mother liquor is then fed again to the crystallization section after being defluorized in the purification process. In order to prevent the accumulation of sodium sulphate or sodium chloride in the process, a part of the mother liquor is exhausted outside the process.

If the crystallization ratio is set at a lower level and the recycle amount of the mother liquor is increased, further it becomes possible to further reduce the sodium fluoride contents in the crystals; however, excessive increase of the recycle is not economically advantageous.

In view of the specification of the product, it is necessary to so operate the crystallizer that the grain size of dense soda ash is controlled within a range from 100 to 600 micron.

(6) Centrifuge and washing

As the crystal of sodium carbonate monohydrate accompany very small amount of sodium chloride, sodium fluoride, and sodium sulphate, separation and washing is effected at the centrifuge in order to remove these adhering substances.

(7) Drying

The crystals of sodium carbonate monohydrate which has already been washed in the previous process are then fed to the steam tube dryer which is a cylindrical shell having a heating tube bundle inside. The shell is set at an angle of approximately 1/100 slanting, and is rotating at 6 to 7 r.p.m. motivated by a motor. The crystals of sodium carbonate monohydrate fed into the steam tube dryer moves towards the outlet of the dryer while repeating spiral movements and evaporating the water. As the drying proceeds, the adhering and crystal water are generated in the form of steam which is sucked by a fan to be removed from the dryer.

The temperature of the condensate of the steam fed to the heating tube is as high as approximately 180°C. Low pressure steam of 124°C can be recovered from this condensate by means of flush tank, and can be fed to the crystallizer. The remaining condensate is fed back to the power plant.

(8) Screening

The purified dense soda ash coming out from the dryer is processed by the screen in order to regulate the size of crystal grains, and then stored in a silo. The dust of soda ash is apt to fly into the atmosphere. Therefore, it is necessary to protect the working environment by sacking the dust through a fan.

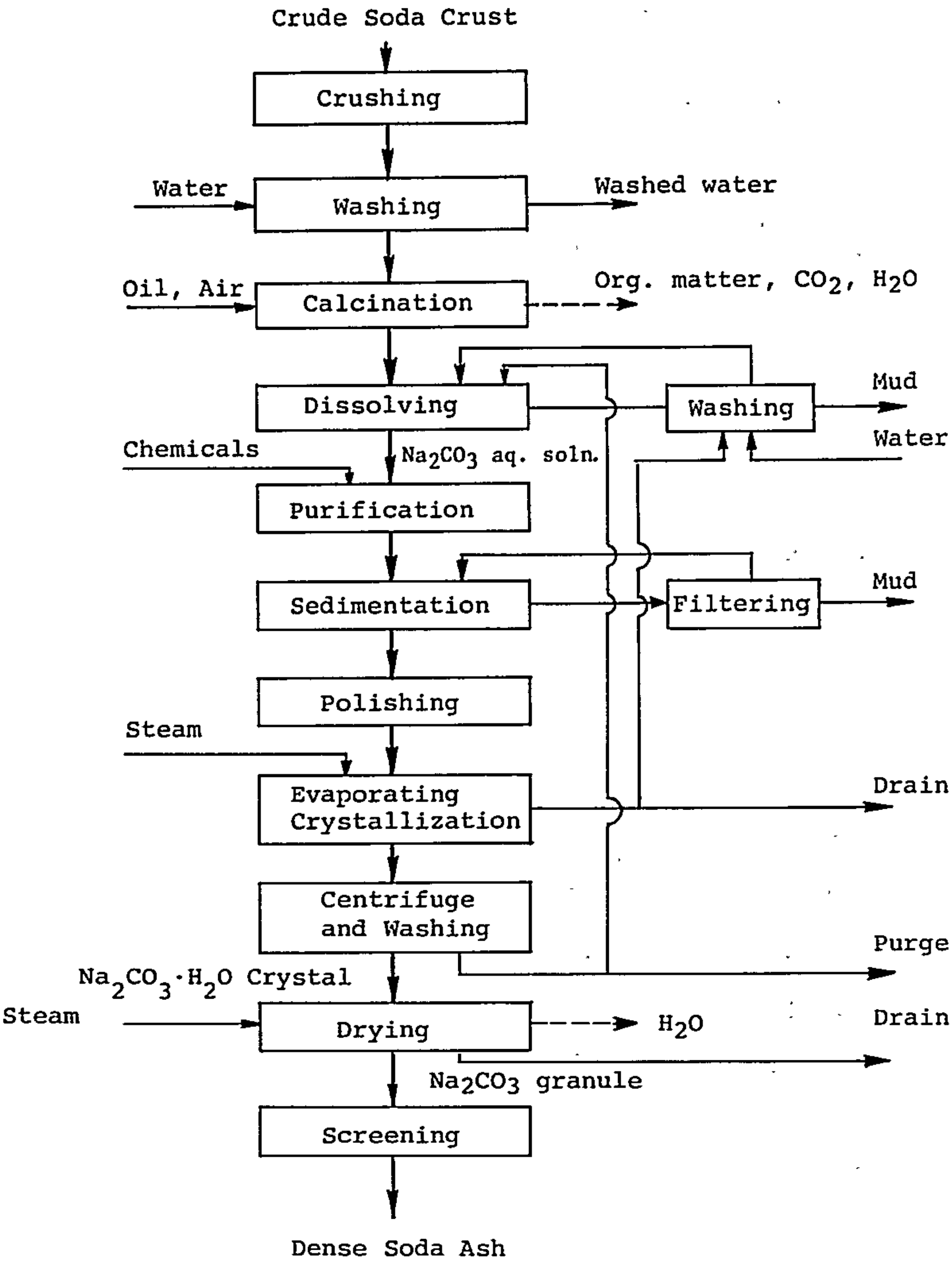
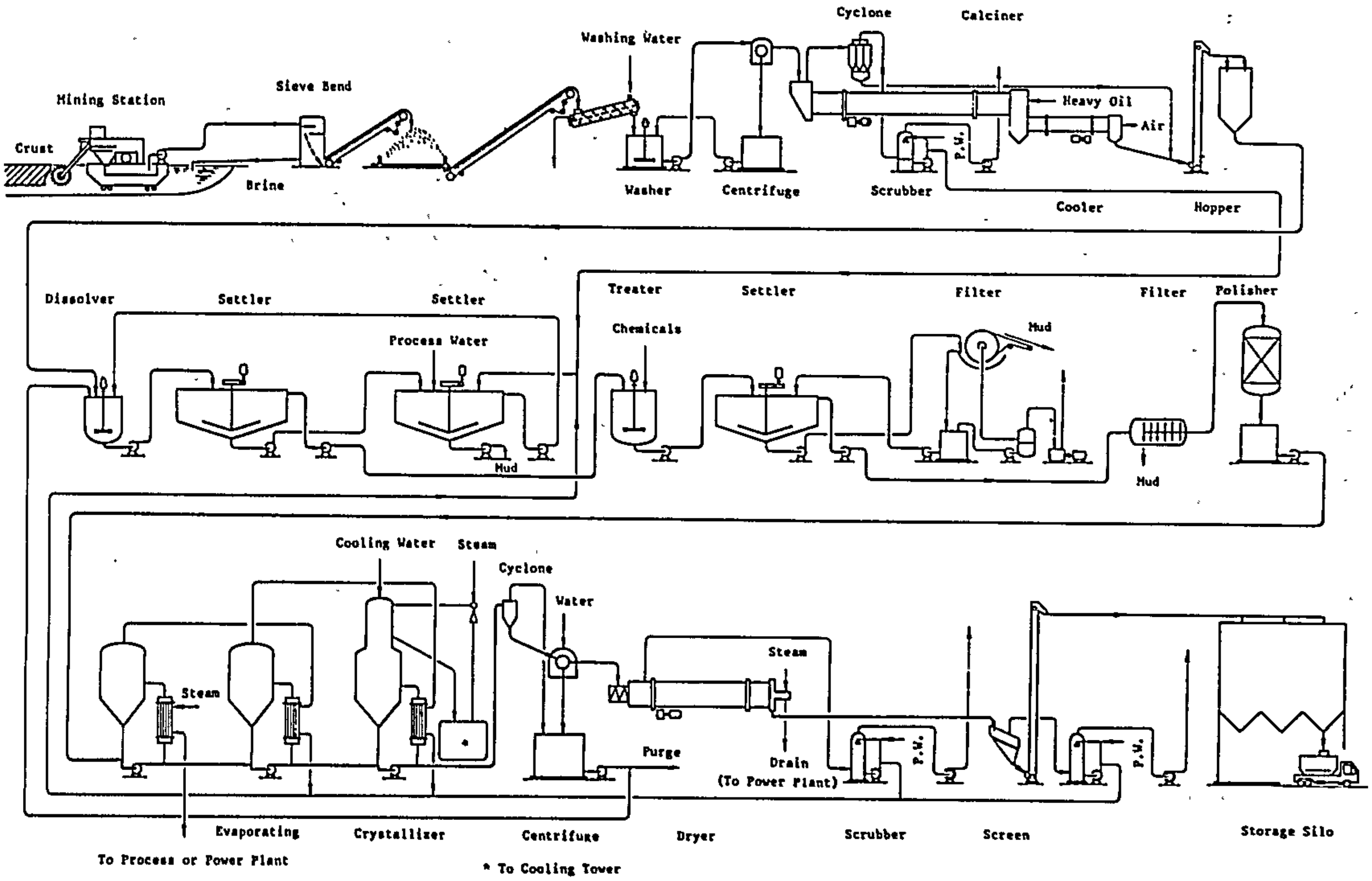


Figure 4-4 Flow Sheet of the Purifying Process for Natron Soda Ash

Figure 4-5 Flow Chart of Soda Ash Production from Natural Soda Crust



4-2-5 Quality and unit consumption of tch product

(1) Quality

On the basis of the laboratory experiment results, the quality of dense soda ash produced by the designed process is estimated to be as follows:

Na_2CO_3	Approx.	99w%
NaCl	Max.	0.5w%
Na_2SO_4	Approx.	0.7w%
Naf		100 to 200 p.p.m.
Bulk density	Min.	$1.0 g/cm^3$

In order to estimate the product quality more accurately, it is necessary to perform pilot plant tests.

(2) Unit consumption

On the basis of the designed process, the unit consumptions of the raw materials and the utility is calculated as follows.

It should be noted here, however, the following unit consumption figures may be revised to a certain extent based on the detailed design to be effected in the future.

Soda crust (dry)	2 t/t. Na_2CO_3
Process water	6 t/t. Na_2CO_3
Heavy oil	0.20 t/t. Na_2CO_3
Steam (393°C, 70 kg/cm^2G)*	1.58 t/t. Na_2CO_3
Electric power**	144 KWH/t.Na_2CO_3
Chemicals	6.24 $/t. Na_2CO_3

*: Heavy oil necessary for the steam generation is included in the above unit consumption of heavy oil.

**: The steam necessary for generating electrical power is included in the above unit consumption of steam.

4-2-6 Main machinery and equipment

On the basis of the designed process, Table 4-6 shows the machinery and equipment necessary for constructing the plant by the different soda ash production scale (250,000 t/y, 500,000 t/y, and 1,000,000 t/y).

Table 4-6 List of Major Machinery and Equipment

	250,000t/y	500,000t/y	1,000,000t/y
Mining Section			
Bucket dredger	1	1	2
Crusher, screen	1	1	2
Slurry transportation facilities	1 line	1 line	2 lines
Sieve band	3	3	6
Purifying Plant			
Crust washer	2	4	8
Calciner	1	2	4
Rotary cooler	1	2	4
Crude soda hopper	1	2	4
Dissolver vessel	1	1	2
Mud settler	2	2	4
De-fluorization purification facilities	1 line	1 line	2 lines
Crystallizer-heat exchanger	1	1	2
Centrifuge	10	18	36
Dryer	1	2	4
Screen	2	3	6
Product silo	1	2	4
Scrubber	3	4	8

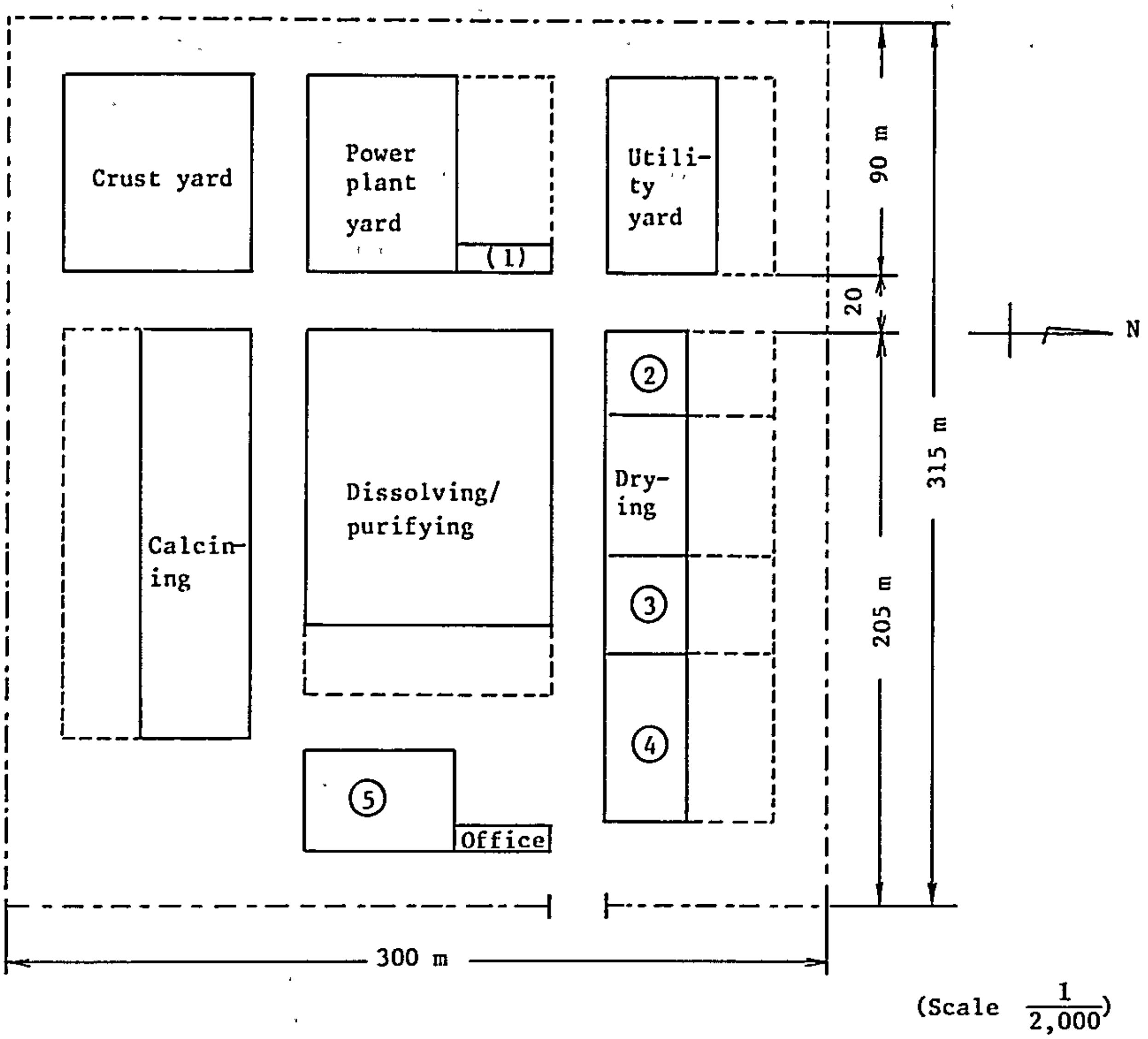
Other machinery and equipment	Intermediate tanks, surge tanks, stirring machines, pumps, fans, blowers, belt conveyors, bucket conveyors, chain conveyors, cyclons, heat exchangers, burners, steam ejectors, truck scales, instrumentation		
Utility Facilities			
Water intake	1 line	1 line	1 line
Water feeding equipment	1	1	2
Pond	1	1	2
Coagulation/sedimentation facilities	1	1	2
Cooling tower	2	3	6
Tap water treating equipment	1	1	1
Heavy oil storage equipment	1	2	3
Compressed air generation equipment for instrumentation	2	2	3
Power Plant			
Boiler water treating equipment	1 line	1 line	2 lines
Boiler	1	1	2
Power generator	1	1	2
Power distributing equipment	1 line	1 line	1 line
Emergency power equipment	1	1	1

4-2-7 Plant layout

The dark lines in Fig. 4-6 illustrate the plant layout in the case of producing 500,000 t/y of soda ash. The layout takes into account the future expansion in order to meet the future increase of the production capacity up to 1,000,000 t/y. The plant expansion portions are shown by dotted line.

The land for the plant stretches 315m into east-west direction, and 300m into south-north direction, having a total land area of 94,500m^2.

Figure 4-6 Outline of Layout for Natural Soda Purification Plant



1 Electricity room
2 Crystallization
3 Screening
4 Product silo
5 Repair shop, spare parts storage

☐ : 500,000 t/y

⬚ : 1,000,000 t/y

4-3 Utility

4-3-1 Utility consumption

The table 4-7 shows the daily consumption of necessary water, heavy oil, electric power and steam in the case of producing 500,000 t/y of soda ash from the soda crust of Lake Naton under the process described in the foregoing 4-2:

Table 4-7 Utility Consumption Per Day

(When producing 500,000 t/y of soda ash)

Utility	Consumption
1. Water	10,600t
(1) Process water	10,000t
Soda purifying process	4,170t
Boiler	1,300t
Cooling water	3,330t
Others	1,200t
(2) Tap water	600t
2. Heavy oil (Fuel oil)	340t
(1) Calciner	150t
(2) Boiler	190t
Power generation	25t
Dryer	165t
3. Electrical power	240MWH
(1) Crust mining	24MWH
(2) Soda purifying	163MWH
(3) Others	52MWH
(4) Household	1MWH
4. Steam (70kg/cm^{2}G, 393°C)	2,630t

4-3-2 Service water plan

4-3-2-1 Water sources

As a result of survey for the existence of river or spring water resources having an ample amount of water for this project in the vicinity of Lake Natron, it has been revealed that Ngare Nyiro River on the north and Reninj River on the west of the Lake have been confirmed together with hot spring water flowing into the Lake from several directions.

(1) Water amount

As a result of survey, the amount of water, both Ngare Nyiro and Peninj Rivers, totals approximately to 76,000^3/d which is an ample amount for producing 1,000,000 tons of soda ash per year.

However, as the water amount survey was carried out after the beginning of the minor rainy season, it is not positively guaranteed as to whether an ample amount of water will be available throughout a year. In order to confirm the available water amount throughout the year, it is necessary to conduct the water flow survey continually for a long period (at least for two to three years), especially to measure the water amount during dry seasons.

On the other hand, water amount surveys were conducted on several hot springs which were considered to have abundant amount of water yield (points HW-2, HW-3, and HW-6 in Fig. 2-7). As a result, it was found out that points HW-2 and HW-6 yields 43,200m^3/day and 24,000 m^3/day, respectively. Although the available amount of water is smaller than the above-mentioned two rivers, the actual water amount is ample for carrying out the projected soda ash purification project.

(2) Water quality

In order to confirm as to whether or not the water from these sources are fit for use as process water and tap water, 7 samples were taken from Ngare Nyiro River, Peninj River, and the hot springs in order to carry out water quality analysis. The obtained results are shown in Table 4-8.

According to the results of the analysis, the hot spring water showed high degrees of alkali and chlorine concentrations, thereby making it difficult to be used as industrial water.

As has been discussed above, river water is superior to hot spring water both in terms of quality and quantity. Thus, either Ngare Nyiro or Peninj River seems to be a suitable source for securing the water supply.

In view of the results of analysis of the water quality of these two rivers, the water of

Table 4-8 Analysis of River Water and Spring Water

Sampl-ing No.	Colour	Odour	Turbi-dity	pH	S. G. 15°C	Free Solids g/ℓ	T-Alkali (as Na) g/ℓ	Cl g/ℓ	SiO_2 mg/ℓ	$CaCO_3$ mg/ℓ	SO_4 g/ℓ	Fe mg/ℓ	*Mn* mg/ℓ	Cu mg/ℓ	F g/ℓ
RW 1	Light yellow brown	None	50	8.4	0.997	0.2	0.07	0.02	55	50	0.05	2.4	0.40	0.35	0.014
2	Light yellow	•	2	8.1	0.998	0.2	0.05	0.01	22	100	0.04	0.5	0.33	0.38	0.007
HW 1	Light yellow	•	11	9.3	1.019	0.1	2.1	1.5	65	20 or less	1.2	1.0	0.33	1.68	0.13
2	None	•	1	9.1	1.005	0.1 or less	6.4	1.2	22	20 or less	0.10	0.2	0.33	1.65	0.034
3	•	•	2	9.7	1.029	0.1 or less	7.5	5.3	48	20 or less	3.0	0.3	0.33	1.65	0.12
4	Yellow brown	•	400	10.0	1.014	0.2	4.1	0.9	42	20 or less	2.3	5.0	0.68	1.45	0.072
5	Light yellow	•	8	10.1	1.008	0.1	2.9	5.5	62	20 or less	1.4	0.5	0.33	1.25	0.058
6	Light yellow	•	2	8.9	1.002	0.1 or less	1.1	0.78	23	20	0.06	0.3	0.35	0.63	0.026
7	Light yellow	•	5	9.2	0.998	0.1 or less	2.0	0.57	38	60	0.12	0.3	0.38	0.35	0.010

Ngare Nyior River showed a higher degree of turbidity, thereby requiring constant removal of the turbid substances. This will naturally enhance the water clarifying cost to a certain extent. On the other hand, if Peninj River is selected to be the source of water intake, a water route crossing Lake Natron must be constructed. On the other hand, water intake from Ngare Nyiro River requires only an on-land pipeline up to the plant site. This being the curcumstance, the water intake from Ngare Nyiro River will be lower in construction cost by approximately US$2 million than the case of securing water from Peninj River. This certainly makes Ngare Nyiro River much more advantageous as the source of securing water in view of economy.

It should also be noted that Ngare Nyiro River flows through the territory of Kenya, and the area in the vicinity of the mouth of this river is geographically close to the border line between Kenya and Tanzania. Therefore, it seems that a negotiation is in order between these two countries when actually utilizing the water of this river. In view of the fact that no negotiation has been conducted between the two countries regarding the utilization of the Ngare Nyiro River water, it is recommended at the present stage that Peninj River be selected as the source of water supply in spite of its economical disadvantage to a certain degree.

4-3-2-2 Water for household consumption

As shown in the results of the water quality analyses, the fluorine level is high in both cases of Penjinj and Ngare Nyiro River, thereby requiring installation of de-fluorization treatment facilities in order to improve the water quality to be used as the drinking water. For reference, the Japanese regulation stipulates that the standard water quality regarding fluorine concentration for drinking water is 0.8 ppm or less, while the WHO (World Health Organization) stipulates the standard concentration at 1.0 ppm or less.

Generally speaking, a long continued intake of fluorine in extremely small quantities by human being may present an adverse effect to teeth and bones which are the calcified systems which are most sensitive to the effects of fluorine. According to Smith and Hodge[1], the teeth will present a fluorine poisoning symptom of spots if the fluorine level in drinking water reaches approximately 2 ppm. Also, according to McClure et al.[2], hardening and brithleness of bones may develop if the daily fluorine dosage attains 4 to 5mg although the symptoms vary depending on the duration of the intake, weather conditions, nutrition conditions, etc. of the subject.

1) Smith, F.A. and Hodge, H.C.: (1959)
Indiana Univ. Press. P. 1 - 37

2) McClure, F.J. and Linkins, R.C.: (1962)
Fluoride Drinking Water P. 392 - 394
U.S. Dept. of Health Education and Welfare Public Health Service
Bethesda Maryland.

4-3-2-3 Water treatment equipment

Water will be fed to the reservoir inside the plant through a pipeline from Peninj River, at the mouth of which a water intake station will be installed. The station will consist of a water intake, water duct pipe, sedimentation pond, and pump room. The pipeline will be installed on a road to be constructed across Lake Natron. The supplied river water will be treated at coagulation/ sedimentation facilities where chemicals will be added in accordance with the level of the water quality, thereby sedimenting and removing the free solids.

The clear water will be distributed to each of the processes as process water, cooling tower make-up water, and raw water for tap water, for boiler make-up water.

In order to prepare tap water, the raw water will be further treated by a defluorization equipment in order to reduce the fluorine concentration to a level less than 1.0ppm. The treated water will then be processed by a filter to eliminate the remaining fine solids and bacteria. Then, chlorine will be added to thoroughly sterilize the water before it is distributed as drinking water.

Regarding boiler water, the fine solids remaining in the raw water will be completely removed by a filter, and then treated by a water purifying device in order to remove substances of hardness origin (Ca^{++}, Mg^{++}, etc.) which are dissolved in the water and will cause scale accumulation inside the boiler system as well as to remove the anions such as SO_4^{--}, Cl^-, etc. which will cause corrosion.

Deoxidization agent and boiler cleaning agent will be further added to the water thus produced before being fed into the boiler.

The make-up water of the cooling tower is the clear water produced in the coagulation/ sedimentation station and is pumped to the cooling tower where it is chemically treated. The water thus produced is circulated as cooling water.

As to the process water, the clear water produced in the coagulation/sedimentation station will be directly fed into the purifying plant.

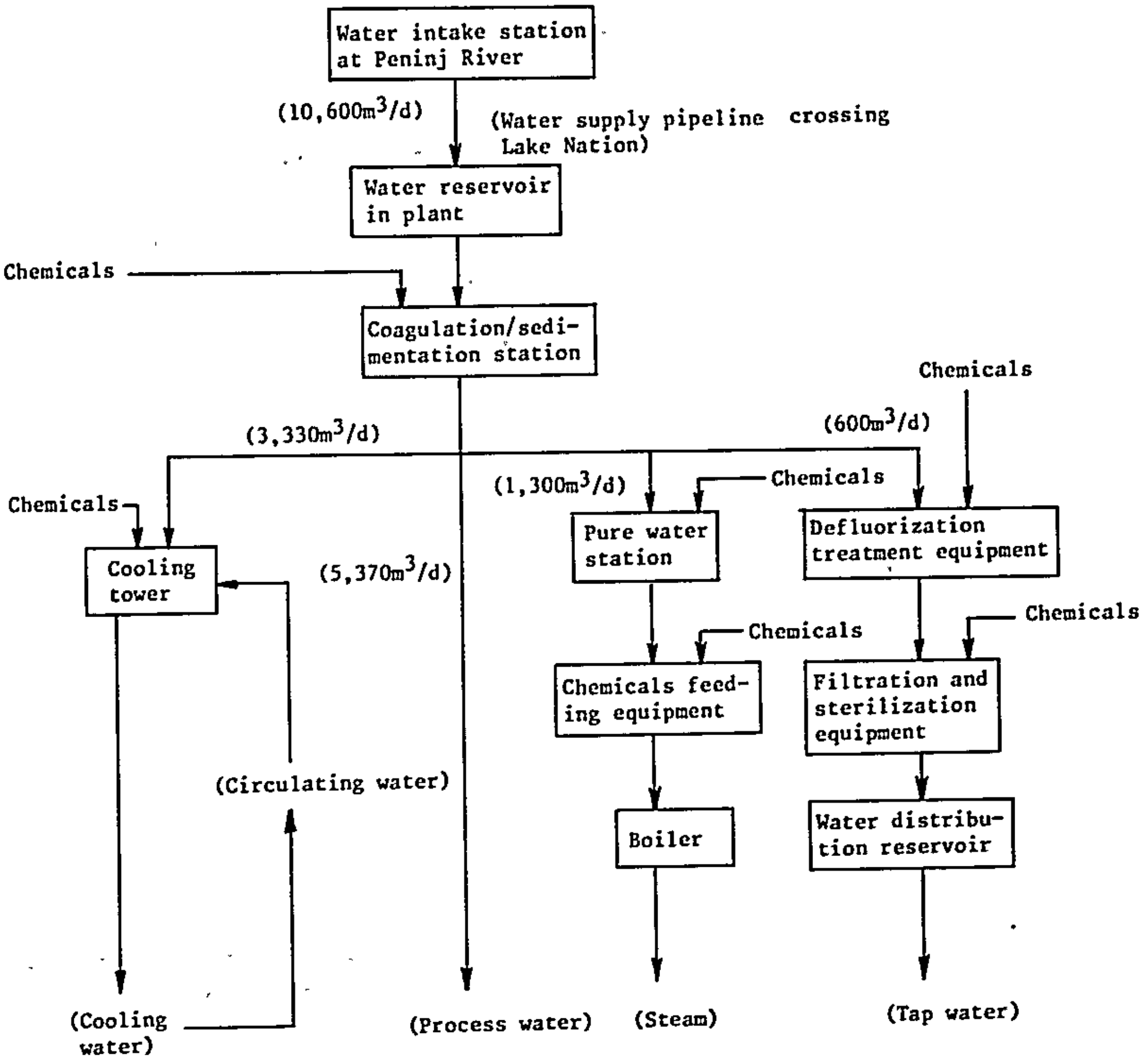
Fig. 4-7 shows the flow diagram and the necessary water amount for the above-explained water treatments.

4-3-3 Steam

For the soda ash producing process, 2,250t/d (at 190°C, 10kg/cm^{2}G) of process steam is necessary. The high pressure steam generated in the boiler at an amount of 2,630t/d (393°C, 70kg/cm^{2}G) is flushed to 10kg/cm^{2}G in a back-pressure turbine to generate necessary electrical power for the plant.

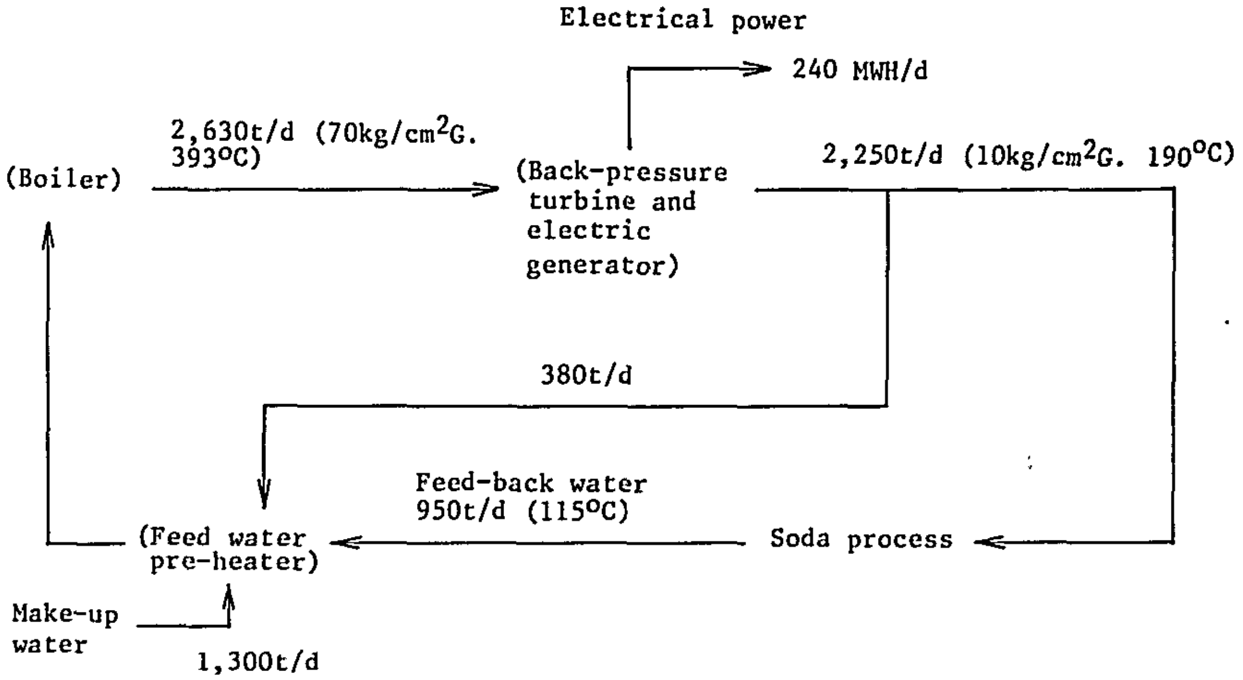
The exhaust steam is almost entirely used as process steam in the above-mentioned process, and the remaining steam is designed for effective use in pre-heating the boiler feed water.

Figure 4-7 Flow Diagram of Water Treatment



The flow diagram of tch system is shown in Fig. 4-8.

Figure 4-8 Flow Diagram of Steam Utilization



4-3-4 Energy Sources

4-3-4-1 Electric power

The following scrutinization is conducted to determine as to whether the electric power to be used by the soda ash process should be entirely purchased externally or entirely dependent on the in-plant electric power generation.

(1) Correlation between the electric power and the steam required in the soda ash process

It has already been mentioned that a large amount of steam is necessary in the process of soda ash. Therefore, even if the electric power is entirely purchased externally, it would still be necessary to install a boiler inside the plant in order to secure the necessary amount of steam. Further, if the necessary steam amount is secured, it would be possible to generate the entire electric power necessary for the plant, and the steam of almost the same amount as that used for the power generation will be directly usable as process steam.

In other words, the steam in an amount of 2,630t/d (in the case of producing 500 thousand t/y of soda ash) indispensable for the soda ash process will also be, at the same time, usable for power generation.

Therefore, external purchasing of electric power without utilizing the steam which can also be used for power generation is an extremely uneconomical scheme.

(2) Availability of the necessary electric power through contract with outside supply sources

When purchasing the electric power externally, the most advantageous scheme would be to purchase the power from Arusha and Moshi in view of such factors as the distance to be covered by power transmission lines.

However, the present power generation capacity at Arusha and Moshi is respectively 88.8 MWH/d and 237.6MWH/d, of which the consumption at present is respectively 88.8 MWH/d and 45.6 MWH/d. Therefore, the surplus electric power amounts to only 192 MWH/d.

On the other hand, in order to produce 500 thousand t/y of soda ash, the necessary electric power consumption is 240 MWH/d, thereby inviting a power supply shortage of 48 MWH/d.

(3) Comparison of electric power unit cost

The contract unit price of electric power at Arusha is ¢2.38/KWH, and to transmit this power to Lake Natron will cost ¢0.39/KWH with even disregarding the discharged loss which takes place during transmission. Therefore, the purchasing unit cost at Lake Natron will be ¢2.77/KWH. On the other hand, in the case of an in-plant power generation by utilizing either heavy oil or coal as fuel, the electric power unit price will be, as will be described later, ¢2.18/KWH (when using heavy oil) and ¢2.83/KWH (when using coal).

Therefore, when heavy oil is used as fuel, the cost of in-plant electric power generation would be more advantageous by ¢0.59/KWH than the scheme of purchasing surplus electric power from Arusha.

In view of the above points, it is desirable that an in-plant electric power generation station be installed to secure the electric power necessary for the soda ash process.

The unit cost of purchased electric power from Arusha and the cost of transmission from Arusha to Lake Natron can be preliminary calculated as follows for the case of producing 500,000 tons of soda ash per year:

(a) Unit Charge of External Power Supply in Arusha

Contracted power	10,000 KVA	
Basic charge (for contracted power)	0 to 40 KVA	$122.55
	40 KVA or over	2.45 $/1KVA
Unit charge for power consumption	0 to 240 MWH/d	1.47 ¢/KWH
Discount for high voltage acceptance	4% on unit charge	
Fuel surcharge	30% of above amount	

On the above assumptions, the power unit cost at Arusha will be as follows:

Basic charge

$$[\llbracket(\$122.5)(10^2) + (10{,}000 - 40\text{KVA}) \times (2.45)(10^2)\rrbracket(12)] / (500{,}000\ \text{t/y})(144\text{KWH/t}) = 0.42\ ¢/\text{KWH}$$

Unit charge (incl. discount)

$$(1.47¢/\text{KWH})(100\text{-}4/100) = 1.41\ ¢/\text{KWH}$$

Fuel surcharge

$$(0.42 + 1.41)(0.30) = 0.55\ ¢/\text{KWH}$$

Total 2.38 ¢/KWH

(b) Power Transmission Cost, Arusha - Lake Natron

Transmission and sub-station facility cost	$1.93 \times \$10^6$
Substation facility operators	11
Depreciation of facilities	20-year straight-line
Maintenance	3% on construction cost
Taxes and insurance	2% on book value
Interest on facilities	10% on book value
Unit labour cost	1,078.43 $/y
Power consumption	240 MW/d
Plant operational rate	300 d/y

On the above assumptions, the unit price of power at Lake Natron is as follows:

Labour cost

$$(1{,}078.43\ \$/\text{y})(11) / (300\ \text{d/y})(240 \times 10^3\text{KWH/d}) = 0.02\ ¢/\text{KWH}$$

Depreciation

$$(\$1.93 \times 10^6) / (20\ \text{y})(300\ \text{d/y})(240 \times 10^3\ \text{KWH/d}) = 0.13\ ¢/\text{KWH}$$

Maintenance
(\$1.93 x 10^6) (3%) / (300 d/y) (240 x 10^3 KWH/d) = 0.08 ¢/KWH

Tax and insurance
(\$1.93 x 10^6) (2%) (1/2) / (300 h) (240 x 10^3 KWH/d) = 0.03 \$/KWH

Interest on facilities
(\$1.93 x 10^6) (10%) (1/2) / (300 d/y) (240 x 10^3KWH /d) = 0.13 ¢/KWH

Total 0.39 ¢/KWH

For the case of producing 500,000 t/y of soda ash, the power unit costs in the case of effecting in-plant power generation by using heavy oil and coal as fuel can be preliminary calculated respectively as follows:

(c) Electric power unit cost when using heavy oil as fuel:

Power station construction cost	\$6.96 x 10^6
Operators (incl. boiler operators)	18
Heavy oil consumption	25 t/d
Heavy oil unit price	73.53 \$/t
Water consumption	1,300 t/d
Water unit price	0.30 \$/t water

The power unit cost on an assumption that all the other conditions are the same as the above (b) will be as follows:

Proportional cost

Heavy oil cost
(25 t/d) (73.53 \$/t) / (240 x 10^3 KWH/d) = 0.77 ¢/KWH

Water cost
(1,300 t/d) (25/190*) (0.30 \$/t) / (240 x 10^3 KWH/d) = 0.02 ¢/KWH

Sub total 0.79 ¢/KWH

Fixed cost

Labour cost
(1,078.43 \$/y) (18) (25/190)* / (300 d/y) (240 x 10^3 KWH) = 0.04 ¢/KWH

Depreciation
(\$6.96 x 10^6) / (20 y) (300 d/y) (240 x

10^3 KWH/d = 0.48 ¢/KWH

Maintenance
($6.96 x 10^6) (3%) / (300 d/y) (240 x 10^3 KWH/d) = 0.29 ¢/KWH

Tax and insurance
($6.96 x 10^6) (2%) (1/2) / (300 d/y) (240 x 10^3 KWH/d) = 0.10 ¢/KWH

Interest on facilities
($6.96 x 10^6) (10%) (1/2) / (300 d/y) (240 x 10^3 KWH/d) = 0.48 ¢/KWH

Sub total 1.39 ¢/KWH

Total 2.18 ¢/KWH

* The total water consumption at the power plant and the number of operators have been proportionally allocated on the basis of the rate of the heavy oil consumption in the electric power generation (25 t/d) and in the steam generation (165 t/d).

(d) Electric power unit cost when using coal as the fuel:

Power station construction cost	US$7.70 x 10^6
Operators (including boiler operators)	26
Coal consumption	46 t/d
Coal unit price	US$ 66.67/t

Breakdown

Unit price at mine:	US$30.64/t
Transportation from mine to Arusha	US$26.96/t
Transportation from Arusha to Lake Natron	US$6.50/t
Cost of transshipment at Arusha and unloading at Lake Natron	US$2.57/t

Quality of the coal

Water content	8%
Ash content	10%
Volatile content	27%
Solid carbon	60%
Sulfur	0.8%

Ash softening temperature	over 1,230°C
Grain size	More than 40% passing 1/4" screen, maximum 1" or less
Heat generation	7,800 Kcal/kg (high grade dry coal)
Water unit price:	US$0.31/t

The power unit price on an assumption that all the other conditions are the same as those in the above (c) is as follows:

Proportional Cost	
Coal cost (46 t/d) (66.67 $/t) / (240,000 KWH/d)	= 1.27 ¢/KWH
Water cost (1,300 t/d) (46/300*) (0.31 $/t) / (240,000 KWH/d)	= 0.03 ¢/KWH
Sub total	1.30 ¢/KWH
Fixed Cost	
Labour cost (1,078.43 $/y) (26) (46/300*) / (300 d/y) (240,000 KWH/d)	= 0.03 ¢/KWH
Depreciation ($7.70 x 10^6) / (20y) (300 d/y) (240,000 KWH/d)	= 0.54 ¢/KWH
Maintenance ($7.70 x 10^6) (3%) / (300 d/y) (240,000 KWH/d)	= 0.33 ¢/KWH
Tax and insurance ($7.70 x 10^6) (2%) (1/2) / (300 d/y) (240,000 KWH/d)	= 0.10 ¢/KWH
Interest on facilities (7.70 x $$10^6$) (10%) (1/2) / (300 d/y) (240,000 KWH/d)	= 0.53 ¢/KWH
Sub total	= 1.52 ¢/KWH
Total	2.83 ¢/KWH

* The total water consumption at the power plant and the number of operators have been proportionally allocated on the basis of the rate of the coal consumption in the electric power generation (46 t/d) and in the steam generation (254 t/d).

4-3-4-2 Fuels

Heavy oil and coal may be employed fuel for generating steam necessary in the soda ash purification process. The following compares the economic advantages of these two fuels:

(1) Preliminary calculation of steam unit price when using heavy oil as the fuel:

Boiler construction cost	$\$6.17 \times 10^{6}$
Heavy oil consumption for generating steam for soda process	165 t/d
Process steam generation amount	2,250 t/d
Heavy oil unit price	$\$73.53/t$
Boiler water consumption*	$1{,}300\ t/d \times \frac{165}{190}$
Water unit price	$\$0.30/t$
Labour cost*	$1{,}078.43\ \$/man.\ y \times 18 \times \frac{165}{190}$

* *The boiler water consumption and the labour cost are proportionally allocated according to the rate of the heavy oil consumption in the electric power generation (25 t/d) and the heavy oil consumption in the steam generation (165 t/d).*

The steam unit cost in accordance with the above conditions is as follows:

(a) Proportional cost

Heavy oil cost

$$165\ t/d \times 73.53\ \$/t\ \frac{1}{2{,}250\ t/d} = 5.39\ \$/t$$

Water cost

$$(1{,}300\ t/d \times \frac{165}{190} \times 0.30\ \$/t\ \frac{1}{2{,}250\ t/d} = 0.15\ \$/t$$

Chemicals 0.03 $/t

Proportional cost Sub total 5.57 $/t

(b) Fixed cost

Labour cost

$$(1{,}078.43\ \$/man.y \times 18 \times \frac{165}{190}) \times \frac{1}{300\ d/y \times 2{,}250\ t/d} = 0.02\ \$/t$$

Depreciation

$$(\$6.17 \times 10^{6}) \times \frac{1}{20\ y} \times \frac{1}{300\ d/y \times 2{,}250\ t/d} = 0.46\ \$/t$$

Maintenance

$(\$6.17 \times 10^6) \times 3\% \times \frac{1}{300\ \text{d/y} \times 2{,}250\ \text{t/d}}$ = 0.27 \$/t

Tax and insurance

$(\$6.17 \times 10^6) \times 2\% \times 1/2 \times \frac{1}{300\ \text{d/y} \times 2{,}250\ \text{t/d}}$ = 0.09 \$/t

Interest on facilities

$(\$6.17 \times 10^6) \times 10\% \times 1/2 \times \frac{1}{300\text{d/y} \times 2{,}250\ \text{t/d}}$ = 0.46 \$/t

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Fixed cost Sub total 1.30

Steam unit price total (a) + (b) = 6.87 \$/t. steam

(2) Preliminary calculation of steam unit price when using coal as fuel:

However, the coal used here is assumed to be the same quality and the same price as that used for power generation.

Boiler construction cost	$\$13.67 \times 10^6$
Heavy oil consumption for generating steam for soda process	254 t/d
Process steam generation amount	2,250 t/d
Coal unit price:	\$66.67/t
Boiler water consumption*	$1{,}300\ \text{t/d} \times \frac{254}{300}$
Water unit price	\$0.31/t
Labour cost*	$1{,}078.43\ \$/\text{man.y} \times 26 \times \frac{254}{300}$

*: The boiler water consumption and the labour cost are proportionally allocated according to the rate of the coal consumption in the electric power generation (46 t/d) and the coal consumption in the steam generation (254 t/d).

The steam unit cost in accordance with the above conditions is as follows:

(a) Proportional cost

Coal cost

$254\ \text{t/d} \times 66.67\ \$/\text{t} \times \frac{1}{2{,}250\ \text{t/d}}$ = 7.52 \$/t

Water cost

$(1{,}300\ \text{t/d} \times \frac{254}{300} \times 0.31\ \$/\text{t} \times \frac{1}{2{,}250\ \text{t/d}}$ = 0.15 \$/t

Chemicals = 0.03 \$/t

Proportional cost Sub total 7.70 \$/t

(b) Fixed Cost

Labour cost

$$(1.078\ \$/\text{man. y} \times 26 \times \frac{254}{300} \times \frac{1}{300\ \text{d/y} \times 2.250\ \text{t/d}} = 0.04\ \$/\text{t}$$

Depreciation

$$(13.67 \times 10^{6}) \times \frac{1}{20\ \text{y}} \times \frac{1}{300\ \text{d/y} \times 2.250\ \text{t/d}} = 1.01\ \$/\text{t}$$

Maintenance

$$(13.67 \times 10^{6})\$ \times 3\% \times \frac{1}{300\ \text{d/y} \times 2.250\ \text{t/d}} = 0.61\ \$/\text{t}$$

Tax and insurance

$$(13.67 \times 10^{6})\$ \times 2\% \times 1/2 \times \frac{1}{300\ \text{d/t} \times 2.250\ \text{t/d}} = 0.20\ \$/\text{t}$$

Interest on facilities

$$(13.67 \times 10^{6})\$ \times 10\% \times 1/2 \times \frac{1}{300\ \text{d/y} \times 2.250\ \text{t/d}} = 1.01\ \$/\text{t}$$

Sub total 2.87 $/t

(3) Table 4-9 is a summary of the results of the preliminary calculations conducted so far:

Table 4-9 Comparison of Steam Unit Price Between The Utilization of Heavy Oil and Coal as Fuel

Unit: $/t steam

	Heavy oil	Coal	Balance
(a) Proportional cost	5.57	7.70	2.13
Fuel cost	5.39	7.52	2.13
Water cost	0.15	0.15	0
Chemicals	0.03	0.03	0
(b) Fixed cost	1.30	2.87	1.57
Labour cost	0.02	0.04	0.02
Depreciation	0.46	1.01	0.55
Maintenance	0.27	0.61	0.34
Tax and insurance	0.09	0.20	0.11
Interest on facilities	0.46	1.01	0.55
Total	6.87	10.57	3.70

As is evident in Table 4-9, coal is extremely uneconomical when compared with heavy oil. The main reasons for this is that the coal mine is located geographically for away from Lake Natron, thereby raising the transportation cost, consequently increasing the purchasing unit price at the plant, and also that the construction cost of boiler when using the coal is more than twice as high as the cost of boiler construction in the case of using heavy oil, whereby making the fixed cost higher.

When using coal, the cost becomes higher by US$3.70 than the case of using heavy oil for generating 1 ton of steam necessary for the soda ash process. This signifies that the production cost of 1 ton of product becomes higher by approximately US$5.8 (i.e., US$3.70/t. steam x 1.58t. steam/t. product)

(4) The following paragraphs shall study the necessary cost level of coal at which coal can quality itself as an alternative fuel for heavy oil:

In this case, the quality of the coal to be employed is as follows:

Water content	8%
Ash content	10%
Voratile content	27%
Stable carbon	60%
Ash softening temp.	1,230°C or over
Grain size	1/4 screen-pass, 40% or over Max. 1" or less
Heat generation	7,800 Kcal/kg (high grade dry coal)

The power plant construction cost, etc. will be as follows when using this coal to generate 240 MWH/day of electric power and 2,250 t/d of process steam (corresponding to the power consumption and steam consumption at the time of producing 500,000 t/y of soda ash):

	Heavy oil burning	Coal burning	Balance
Construction Cost x $\$10^6$	13.13	21.37	8.24
Operators (persons)	18	26	8
Fuel Cons. (t/d)	190	300	110

Depreciation of construction cost	20-year straight line
Maintenance	3% on construction cost
Interest	10% on book value
Tax and insurance	2% on book value
Labour unit cost	1,078.48 $/man. y
Heavy oil unit price	73.53 $/t

Coal-converted value of heavy oil unit price:
(190/300) (73.53 $/t. oil) = 46.56 $/t. coal

Fixed cost difference

Labour cost
(1,078.48 $/man. y) (8) / (300 d/y) (300 t/d) = 0.10 $/t. coal

Depreciation
($8.24 x 10^6) / (20 y) (300 d/y) (300 t/d) = 4.58 $/t. coal

Maintenance
($8.24 x 10^6) (3%) (300 d/y) (300 t/d) = 2.75 $/t. coal

Tax and insurance
($8.24 x 10^6) (2%) (1/2) (300 d/y) (300 t/d) = 0.92 $/t. coal

Interest on facilities
($8.24 x 10^6) (10%) (1/2) / (300 d/y) (300 t/d) = 4.57 $/t. coal

Total 12.92 $/t. coal

In order to make coal an alternative fuel for heavy oil, the coal price delivered at plant must be reduced to as follows:

US$46.56 – US$12.92 = US$33.64/t. coal

Further, it should be noted here that the above-mentioned price calculation does not include the costs for the facilities for coal storage and delivery. Therefore, the necessary price level of coal will have to be further reduced.

In the case of using coal, a large amount of ash as residue (30 t/d) will be by-produced, therefore, it is necessary to consider the ways and means to dispose the ash.

4-3-4-3 Feasibility of hydroelectric power generation at Peninj River

On the basis of the 76,000 m^3/day of flow amount which has been discovered through this survey, a 7 MWH/d electric power generation will be possible if hydroelectric power generation is conducted by constructing a dam having an effective head of 50 mH at the mouth of Peninj River in order to secure electrical power source for the plant.

Also, the average annual electric power generation will be 46 MWH/d on an assumption that the flow area of Peninj River is approximately 1,000 km^2, annual precipitation at 400 mm*, and water flow coefficient at 50%. The level of such power generation is drastically lower than the 240 MWH/d power consumption necessary for producing 500,000 t/y of soda ash. Therefore, such a power generation scheme is completely insufficient for electric power supply source of the plant.

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*: The annual precipitation of 384 mm at Magadi has been applied here.

4-3-4-4 Feasibility of geothermal power generation

Lake Natron is situated in the East Africa Great Rift Valley, and has a number of volcanoes in the surrounding area. On the south side of the Lake, Ol Doinyo Lengai volcano, etc. are still occasionally active. Therefore, it seems there is a possibility of carrying out geothermal power generation.

According to an example of development recently made in Japan, the unit cost of geothermal power generation is approximately ¢2.5 to ¢2.7/KWH, which is lower than the unit price (¢3.8 to ¢3.9/KWH) of hydroelectric power generation or steam power generation. Internationally, it is accepted that geothermal power generation generally brings about electric power unit price lower than that of hydroelectric power generation or steam power generaiton.

Such a survey on the possibility of developing geothermal energy sources seems meaningful for an energy importing country such as Tanzania. However, such a survey will call for an enormous cost and several years of study period. Generally, geothermal energy development is often carried out by other countries of the world as an independent energy project apart from other industrial plans. Therefore, it is recommended that the proposed geothermal energy source survey by conducted as a separate project indepnendently from the soda ash development feasibility study. In this report, only the indications are made regarding the necessary subjects of geothermal power generation survey as shown in Table 4-10.

Table 4-10 Necessary Survey Items for the Development of Geothermal Electric Power Generation

(1) Outline Survey (for 2 to 3 months)
- 1-1) Clarification of the site conditions
- 1-2) Confirmation and scrutinization of Tanzanian governmental projects
- 1-3) Survey for formulating future plans (collection of existing data and information, analyses and studies of the collected data and information.
- 1-4) Preparation of aerial photographs and analyses thereof

(2) Detailed Survey (1 to 2 years)
- 2-1) Geological survey (geology, geographic structures, structural lines, water permeation layer survey, etc.)
- 2-2) Survey on the gorund surface symptoms (volcanic craters, gas eruptions, hot springs, eruption amount, temperature, chemical composition, range of metamorphic area, metamorphic minerals, types of clay and distribution of volcanic crafers, gas eruptions, hot spring, metamorphism and clay, etc.)
- 2-3) Survey on abnormal ground temperature (temperature survey of 1 to 2m underground, ultra-red ray survey, measurements by test drills of 50 to 100m depth, etc.)
- 2-4) Hydrological survey (precipitation, river water, underground water, water circulation, etc.)
- 2-5) Gravity exploration

2-6) Electrical exploration
2-7) Magnetic exploration
2-8) Geochemical exploration

Through the above explorations, surveys will be made on the geological underground structures, metamorphic area, existing of hot water, etc.

Boring

(3) Test Wells (1 to 2 years)
    3-1) Boring of first test wells (simultaneously: survey on the rock core, slime, electrical layer survey, temperature measurement, pressure of erupted materials, their temperatures and their chemical compositions, and other necessary measurements to evaluate the geothermal heat source)
    3-2) Boring of second test wells (600-800mm x 4 wells)

(4) Production Well (1 to 2 years)
    4-1) Boring of production wells for measurement (refer to measurement 3-1)
    4-2) Design of pilot power plant (preparation of various characteristics of wells for this purpose)
    4-3) Boring of production wells for test power generation (1,000m x 2 wells)

(5) Test Power Generation (1 to 2 years)
    5-1) Installation, operation and administration of pilot power plant
    5-2) Compilation of a feasibility report (technical and economic evaluations, outlook on the future, planning, design, economic viability, etc.)

4-4 Required Manpower for Plant Operation

Table 4-11 shows the necessary number of personnel for the operation of the excavation, purifying plant, utility plants, and power plant. The following points have been taken into account in calculating the necessary number of personnel:

(1) As the production of soda ash by the purifying process is deemed to be one of the typical facility-intensive operations, reference has been made to the similar plants which are presently in operation. It has been assumed there that the plant shall be operated continuously for 24 hours a day with the operators attending on a 3-shift, together with an addition of 20% of the necessary manpower to be allocated as the auxiliary crew for holidays.

(2) In view of the fact that the present status of Tanzania is different from that in industrially advanced countries where the similar operations are undertaken in the form of industrial complexes. In view of this fact, the number of maintenance crew has been estimated to be much more numerous than in the case of the industrialized countries.

Table 4-12 shows a summary of the number of personnel required at the plant, the transshipment base, and the shipment base at Port Tanga.

Table 4-11 Plant Manning Chart

Production capacity Item	250,000 t/y	500,000 t/y	1,000,000 t/y
1. Plant site			
(1) Plant manager	1	1	1
Clerical	1	1	1
(Sub-total)	(2)	(2)	(2)
(2) Clerical Dept.			
Chief	1	1	1
General Affairs	3	3	3
Accounting	4	4	4
Sales/delivery	6	6	6
Female clerical	3	3	3
(Sub-total)	(17)	(17)	(17)
(3) Production Dept.			
Chief	1	1	1
Female clerical	1	1	1
Foreman	2 x 3.6 → 8	8	8
*Plant operator	70	103	156
Power plant operator	7 x 3.6 →26	26	10 x 3.6 →36
(Sub-total)	(106)	(139)	(202)
*Remarks:			
Breakdown of			
Plant operators			
Mining process	9 x 2 →18	9 x 3.6 →33	15 x 3.6 →29
Calcination process	4 x 3.6 →15	5 x 3.6 →18	8 x 3.6 →29
Purifying process	4 x 3.6 →15	6 x 3.6 →22	8 x 3.6 →29
Crystallization process	3 x 3.6 →11	4 x 3.6 →15	6 x 3.6 →22
Drying process	3 x 3.6 →11	4 x 3.6 →15	6 x 3.6 →22
(Sub-total)	(70)	(103)	(156)
(4) Engineering/repair Dept.			
Chief	1	1	1
Female clerical	1	1	1
Chemical engineer	2	2	2
Mechanical engineer	2	2	2
Electrical engineer	2	2	2
Instrumentation engineer	2	2	2
Analysis engineer	3	3	3
Maintenance/repair			
Foreman	3	3	3
Engineer (electrical)	15	20	30
Engineer (mechanical)	7	10	15
Engineer (instrumentation	7	10	15
(Sub-total)	(45)	(56)	(76)

Item	Production capacity	250,000 t/y	500,000 t/y	1,000,000 t/y
(5)	Gate guard/fire fighting team	3 x 3.6→11	11	11
(6)	Clinic	2	2	2
(7)	Storage Dept.			
	Froeman	1 x 3.6→4	4	4
	Measurer	1 x 3.6→4	4	4
	(Sub-total)	(8)	(8)	(8)
(8)	Labour			
	Office	2	2	2
	Shipment	13	15	20
	Plant	5	6	9
	Maintenance	5	6	9
	(Sub-total)	(25)	(29)	(40)
	Plant site total			
	Employees	191	235	318
	Labour	25	29	40

Table 4-12 List of Personnel

Item / Production capacity	250,000 t/y	500,000 t/y	1,000,000 t/y
1. Plant site			
(1) Plant manager	1	1	1
(2) Section chief	3	3	3
(3) Office clerks	13	13	13
(4) Engineers	11	11	11
(5) Foreman	15	15	15
(6) Skilled workers	29	40	60
(7) Plant operators	70	103	156
(8) Power plant operators	26	26	36
(9) Measurers	4	4	4
(10) Gate guard/fire fighting crew	11	11	11
(11) Clinic	2	2	2
(12) Female clerical	6	6	6
(Sub-total)	(191)	(235)	(318)
Labour	25	29	40
2. Arusha base			
(1) Manager	1	1	1
(2) Female clerical	1	1	1
(3) Shipment	4	4	4
(4) Repair	5	5	7
(Sub-total)	(11)	(11)	(13)
Labour			
(1) Loading/unloading	17	34	34
(2) Car drivers	50	101	200
(Sub-total)	(67)	(135)	(234)
3. Tanga Port			
(1) Manager	1	1	1
(2) Female clerical	1	1	1
(3) Transportation/sales	7	7	7
(4) Repair	5	5	5
(Sub-total)	(14)	(14)	(14)
Labour			
(1) General labour at office	1	1	1
(2) Packing/loading	44	59	74
(Sub-total)	(45)	(60)	(75)
Grand total			
Employees	216	260	345
Labour	137	224	349

CHAPTER 5 PLANT COST AND PRODUCTION COST

In this chapter, calculations of the investment cost for the plant, and production cost are conducted based on the process explained in Chapter 4. A long period will be necessary to effect the implementation and completion of the project, because it is necessary to conduct studies of several problems and preparation of the various procedures as described in the Construction Schedule mentioned in the separate volume of this Report. Therefore, the estimation of the costs have been made by taking the present point as the basis, and on an assumption that the increase in the construction cost, equipment cost, etc., and the increment in the sales price of the products, will be roughly linked to the progress of the inflation rate.

The basic viewpoint of this project is the production facility installation of soda ash at a capacity of 500,000 t/y with a provision for a possible future expansion of the capacity up to 1,000,000 t/y. Scrutinizations are also made regarding a scheme involving a production capacity of 250,000 t/y.

Estimations are not conducted in this chapter regarding the cost for constructing the accommodation facilities for the employees necessary for the operation of the plant (hospitals, post offices, schools, etc.). This chapter therefore limits its scope to the plant facilities alone.

5-1 The Investment Cost for the Plant

5-1-1 Preconditions for calculating the plant cost

The following points have been taken into consideration in calculating the plant cost.

(1) The prices of the machinery, equipment, and materials have been based on the standard prices in Japan as of February, 1976.

(2) Most of the machinery, equipment, and materials will be procured in Japan from where these will be transported via oceans. However, cement and house building materials shall be procured locally.

(3) No import duty shall be imposed upon the machinery, equipment, and materials.

(4) The ocean freight have been calculated by both the weight tonnage and the measurement tonnage, and the higher of the obtained figures has been adopted for the calculation. The ocean freights were calculated individually for the machinery, equipment and material items and then accumulated. Regarding the base ocean freight, it is assumed that liners shall be employed for the voyage.

(5) The inland transportation cost of the machinery, equipment and the material in Tanzania is calculated by the accumulation method of the individual figures, and is added to the

plant cost. In the case of the 500,000 t/y scheme, it is estimated to be US$1,047 x 10^3.

(6) The labour cost for the plant construction which is calculated on the basis of the following ratio of the personnel is also added to the plant cost.

Foreign personnel (A)	Foreign personnel (B)	Labour
20%	70%	10%

The above data have been based on a calculation basis for the labour cost employed by a certain project in the subject area. The Foreign personnel (A)stands for construction supervisors (the cost pertaining to this personnel consisting of salary, general administration cost, and absence fee); the Foreign personnel (B) is construction workers (cost consisting of wages, travel allowances, meals, insurance, and taxes); the Labour is construction workers (relative costs being the same as for the Foreign personnel(B)).

Therefore, in the case of the 500,000 t/y, the personnel cost amounts to US$52,893 x 10^3.

(7) Concerning the living accomodations for the employees, it is assumed that the housing accomodation facilities consisting of two-storeyed apartment houses will be installed with an average construction cost of 2,990 T. Shr/m^2. In order to cover the future improvements in the standard of living per-head (per-household) occupancy of 100 m^2 is adopted in the calculation.

The future improvements in the standard of living have been estimated as follows:

Chief personnel :	20% over the standard
General employees :	On the standard
Labour :	20% below the standard

(8) The following assumptions have been made regarding the engineering fee, process development fee, etc.:

Engineering fee, work supervision fee:	US$20 x 10^6
Production development fee, basic engineering fee:	US$5 x 10^6

Also, the production development fee includes the cost pertaining to a scheme for establishing a pilot plant in a foreign country.

The outline of the pilot plant is as follows:

Production capacity:	1 t/d soda ash

Facility cost: US$1,167 x 10^3
Necessary personnel: 20 persons
Raw material crust: 200 tons for 3-month operation
Required time for completion: 2 years including the construction and operation

It seems rather difficult to excavate the 200 tons of the crust in Lake Natron and to transport them to the pilot plant at an earlier stage of the project due to the fact that no infrastructures which will support the project will be available. Future scrutinization on how to obtain the crust seems necessary.

(9) Concerning the mining process, several problems are left for future discussion as described in the foregoing Chapter 4. However, for the purpose of this Report, it is assumed that dredgers will be employed.

5-1-2 Calculating the plant cost

On the basis of the above assumptions, preliminary calculations are conducted regarding the investment cost for a production plant with a capacity of 500,000 t/y. The obtained results are shown in Table 5-1. Table 5-2 shows the results of studies on the 250,000 t/y and 1,000,000 t/y schemes. Table 5-3 summarizes the results of three cases.

Table 5-1 Plant Cost

500,000 t/y scheme (Unit: $\$10^3$)

		CIF	Construction cost	Total
(1)	Plants	38,427	43,777	82,204
	Excavation	2,610	3,140	5,750
	Calcining	11,980	13,520	25,500
	Purifying	7,763	8,767	16,530
	Crystallization	6,570	7,427	13,997
	Drying	5,180	6,027	11,207
	Screening/storage	4,323	4,897	9,220
(2)	Untitlities	7,840	10,830	18,670
	Water intake/cooling water tower	1,843	4,830	6,673
	Power plant	5,997	6,000	11,997
(3)	Auxiliary facilities (offices, laboratory, repair shop, warehouses)	1,197	1,616	2,813
(4)	Company housing (264 houses)	-	9,503	9,503
(5)	Engineering fee, etc.	25,000		25,000
	Engineering and supervision			20,000
	Process Development and Basic Engineering			5,000
(6)	Total	72,464	65,726	138,190

Table 5-2 Plant Facility and Construction Cost

(Unit: $\$10^3$)

	250,000 t/y			1,000,000 t/y		
	CIF	Construction cost	Total	CIF	Construction cost	Total
(1) Plants	25,377	28,837	54,214	64,100	71,937	136,037
Excavation	2,417	2,970	5,387	4,923	5,937	10,860
Calcining	6,773	7,654	14,427	21,007	23,713	44,720
Purifying	5,450	6,217	11,667	13,170	14,023	27,193
Crystallization	4,940	5,583	10,523	9,770	11,040	20,810
Drying	3,020	3,267	6,287	8,237	9,317	17,554
Screening/storage	2,777	3,146	5,923	6,993	7,907	14,900
(2) Utilities	7,470	10,737	18,207	14,107	17,390	31,497
Water intake/cooling water tower	1,583	4,857	6,440	2,270	5,563	7,833
Power plant	5,887	5,880	11,767	11,837	11,827	23,664
(3) Auxiliary facilities	1,090	1,500	2,590	1,353	1,790	3,143
(4) Company housing		7,773	7,773		12,907	12,907
(5) Engineering fee, Process development, etc.	25,000		25,000	25,000		25,000
Engineering and supervision			20,000			20,000
Process development and basic engineering			5,000			5,000
(6) Total	58,937	48,847	107,784	104,560	104,024	208,584

Table 5-3 Plant Cost Comparison

(Unit: $\$10^3$)

	250,000 t/y	500,000 t/y	1,000,000 t/y
Purifying plant	54,213	82,203	136,037
Utility	18,207	18,670	31,497
Auxiliary facilities	2,590	2,813	3,143
Company housing	7,773	9,503	12,907
Engineering fee, process development, etc.	25,000	25,000	25,000
Total	107,783	138,189	208,584

5-1-3 Cost of facility renewal after the completion of 20-year depreciation

The renewal of the plant facilities is necessary when this project life is considered to be 30 years, which is discussed in economic evaluation of the General Volume of this report, as the life of the plant facilities is limited to 20 years.

On the basis of the present cost factors, the plant renewal cost to be undertaken in 20 years from the start of operation onwards on an assumption of proper execution of daily maintenance, will be calculated as follows:

Renewal cost:	50,000 t/y;	US\$25 $\times 10^6$
	1,000,000 t/y;	US\$33.3 $\times 10^6$

No consideration has been made to the scheme for producing 250,000 t/y of soda ash for the reason that this scheme will not be in existence in 20 years from the start of operation.

Facilities to be renewed:

Full set of mining facilities, bucket elevators, trough chain conveyors, belt conveyors, fans, pumps, centrifuges, screens, full set of instrumentation, vehicles (for construction and maintenance work), machinery for repair work.

5-2 Production Cost

5-2-1 Preconditions for preliminary calculation of the cost

In order to calculate the production cost, the cost calculation standards normally employed by enterprises have been adopted here. Therefore, the simple interest calculation is adopted after the start-up of the production. However, before the start-up, the compound interest calculation is adopted, as a period is required to start the operation of the plant from the commencement of the project.

The depreciation is counted over an extremely long period (20 years), therefore, the production cost is calculated on the basis of a long-term average.

The preconditions for the cost calculations discussed in this section are as follows:

(1) The assessed value of the raw material crust shall be zero.

(2) According to the result of the comparative studies for heavy oil and coal in Chapter 4, the fuel shall be heavy oil, and the unit price of the heavy oil is set at 600 T.Shr/t which is the official price of the commodity in Tanzania.

(3) Regarding the depreciation, a straight-line depreciation over 20 years, which is the limitation of the mechanical service life of the machinery and equipment, is adopted as mentioned earlier.

(4) Concerning the construction cost, a long-period (10 years) will be necessary from the commencement of the project until the start of the operation of the plant as shown in the Construction Schedule because of the nature of this project. Therefore, the interest portions of the process development fee, engineering fee, equipment cost etc. which will be paid in advance of the start of the operation, is added to the plant cost on the basis of compound interest calculations.

(5) It is scheduled that the actual commencement of the production will be ten years after the start of the project implementations. But taking advantage of the long duration, it is possible to train Tanzanian personnel to become skilled workers. Therefore, it is assumed that the task required for the operation of the plant will be entirely undertaken.

Therefore, the number of foreign supervisors at the time of the test operation has been set at 8 persons who will stay at the plant for the first three years, and three of them will remain stationed from the fourth year ownards. The relative cost of supervisors is already included in the general administration cost.

(6) The labour cost consists of the cost pertaining to the foremen, operators, and labour in the production line. Regarding the other workers, the labour cost is included in the

Table 5-4 Model Wage Schedule of Tanzania

	Model Wages	50,000 t/y Scheme
(1) Engineer		
(a) Chief	44,600 T.shr/y	Chief 5 (including hygiene)
(b) Senior	36,000	
(c) Engineer	25,000	Engineer 24 (including general affairs,etc.)
Average	36,000	
(2) Mechanics		
(a) Super intendant	33,000	
(b) Inspector	23,000	
(c) Foreman	14,000	Foreman 15
Average	24,300	
(3) Artisan		
(a) Skilled artisan	8,800	Operator etc. 173
(b) Artisan	5,700	Guard & firefighting 11
(4) Clerical	7,800	Clerical 7
(5) Subordinate		
(a) Urban	4,600	
(b) Rural	2,800	Labour 29
(6) Casual laboures (rural)		
(a) Daily paid	2,300	
(b) Labourers	2,800	

general administration cost. As far as the wage standard is concerned, the model wage schedule effected in Tanzania as shown in Table 5-4 has been employed.

(7) The personnel required at the plant site is already mentioned in Chapter 4. A summary of the personnel requirements according to the model wage schedule of Tanzania is shown in Table 5-5.

Table 5-5 List of Plant Personnel

	250,000 t/y (person)	500,000 t/y (person)	1,000,000 t/y (person)
Chief	5	5	5
Engineer	24	24	24
Foreman	15	15	15
Operator	129	173	256
Artisan	11	11	11
Clerical	7	7	7
Labour	25	29	40
Total	216	264	358

5-2-2 Estimate of the production cost

On the basis of the above assumptions, the production cost is estimated regarding the scheme for 500,000 t/y production. The obtained results are shown in Table 5-6. Table 5-7 shows a comparison of the costs between the 250,000 t/y and the scheme including the future expansion allowance up to 1,000,000 t/y.

5-3 General Observation

An overall comparison, which includes plant cost (including the interest), production cost, operational cost per year, and required manpower, is shown in Table 5-8.

(1) Total plant cost, including the interest, amounts to an extremely large sum, for example US$173 x 10^6 at the scheme of 500,000 t/y production.

The plant cost per ton of products is calculated to be US$250 at a capacity of 1,000,000 t/y, US$346 at 500,000 t/y, and US$558 at 250,000 t/y.

Therefore, the efficiency of investment depends on the scale of production.

(2) Therefore, the rate of the fixed costs, (consisting of depreciation cost, plant facility interests, and repair cost) occupied in the production cost is very high.

(3) Therefore, the effects of the operational rate heavily influences the production cost.

Table 5-6 Production Cost Estimation (at Plant Site)

Production capacity: 500,000 t/y

		Unit consumption T/t	Unit price $/t	Consumption in value $/t	Annual consumption in value 10^3 \$/y
Productional cost					
1.	Crust	2.0			
2.	Fuel oil	0.2	73.5	14.7	7,350
3.	Chemicals			6.3	3,140
	Sub total			21.0	10,490
Fixed cost					
4.	Labour cost	Foreman 8	14,000 T.Shr	0.3	163
		Operator 129	8,000 "		
		Labour 29	2,800 "		
5.	Repair cost	Plant cost x 3%/y		10.4	5,188
6.	Depreciation cost	Plant cost x 1/20		17.3	8,647
7.	Taxes, insurance	Plant cost x 2%/y x 1/2		3.5	1,729
8.	Facility interest	Plant cost x 10%/y x 1/2		17.3	8,647
9.	Operational interest	Target sales price x 10%/y x 1/4 (FOB $80/t)		2	1,000
10.	General administration cost				
	Labour cost	Administration department 98 labour cost		0.4	175
	Others	Production cost x 5%/y		3.8	1,900
	Sub-total			55.0	27,449
	Grand total			76	37,939

Table 5-7 Comparison of Production Costs

	250,000 t/y		500,000 t/y		1,000,000 t/y	
	Unit p. $/t	Ann. con. in value 10^3 \$/y	Unit p. $/t	Ann. con. in value 10^3 \$/y	Unit p. $/y	Ann. con. in value 10^3 \$/y
Raw material, fuel	21.0	5,246	21.0	10,490	21.0	20,983
Labour cost	0.5	126	0.3	163	0.2	236
Repair cost	16.7	4,184	10.4	5,188	7.5	7,511
Depreciation	27.9	6,974	17.3	8,647	12.5	12,519
Tax, insurance	5.6	1,395	3.5	1,729	2.5	2,504
Facility interest	27.9	6,974	17.3	8,647	12.5	12,519
Operational interest	2	500	2	1,000	2	2,000
General administration cost						
Labour cost	0.7	163	0.4	175	0.2	196
Others	5.4	1,346	3.8	1,900	3.1	3,074
Total	107.7	26,908	76	37,939	61.5	61,542

Table 5-8 Overall Comparison of Plant Cost and Production Cost

	250,000 t/y	500,000 t/y	1,000,000 t/y
Plant cost $(10^3\ \$)$	139,462	172,909	250,343
Plant cost	107,783	138,189	208,584
Interest	31,679	34,720	41,759
Production cost $(\$/t)$	107.7	76	61.5
Operation cost $(10^3\ t/y)$	11,065	17,916	32,000
Personnel requirements	216	264	358

For example, an operational rate reduced by 10% will increase the production cost by US$4 (5.2%) at the scheme of 500,000 t/y.

The influence by the decrease of operational rate is much more serious than the decrease in other factors. This correlation is illustrated in Table 5-9 and Figure 5-1.

(4) In addition, the investment cost for the plant also heavyly influences the production cost. For example, investment cost reduced by 10% (if possible) will reduces the production cost by US$4.8 (6.3%) at the scheme of 500,000 t/y. This correlation is shown in Table 5-10 and Figure 5-2.

Table 5-9 Correlation between Plant Cost and Production Cost

	250,000 t/y	500,000 t/y	1,000,000 t/y
Operational rate			
100%	107.7	76	61.5
90	115.2	80	63.9
80	125.2	85.6	67.4
70	138.7	93.3	72.6
60	157.1	104.3	80.1
50	183.9	120.5	91.5
40	225.2	145.9	109.7
30	295.3	189.6	141.3
20	437.7	279.2	206.7
10	869.1	552.1	407.1

Fig. 5-1 Correlation between Plant Cost and Production Cost

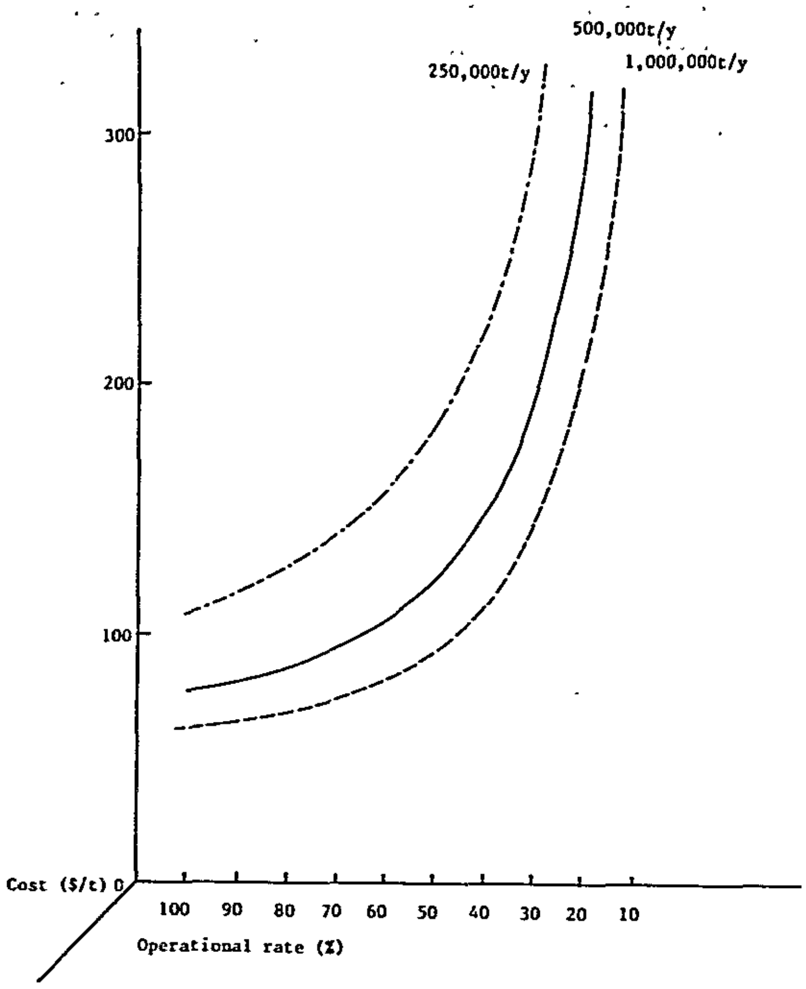
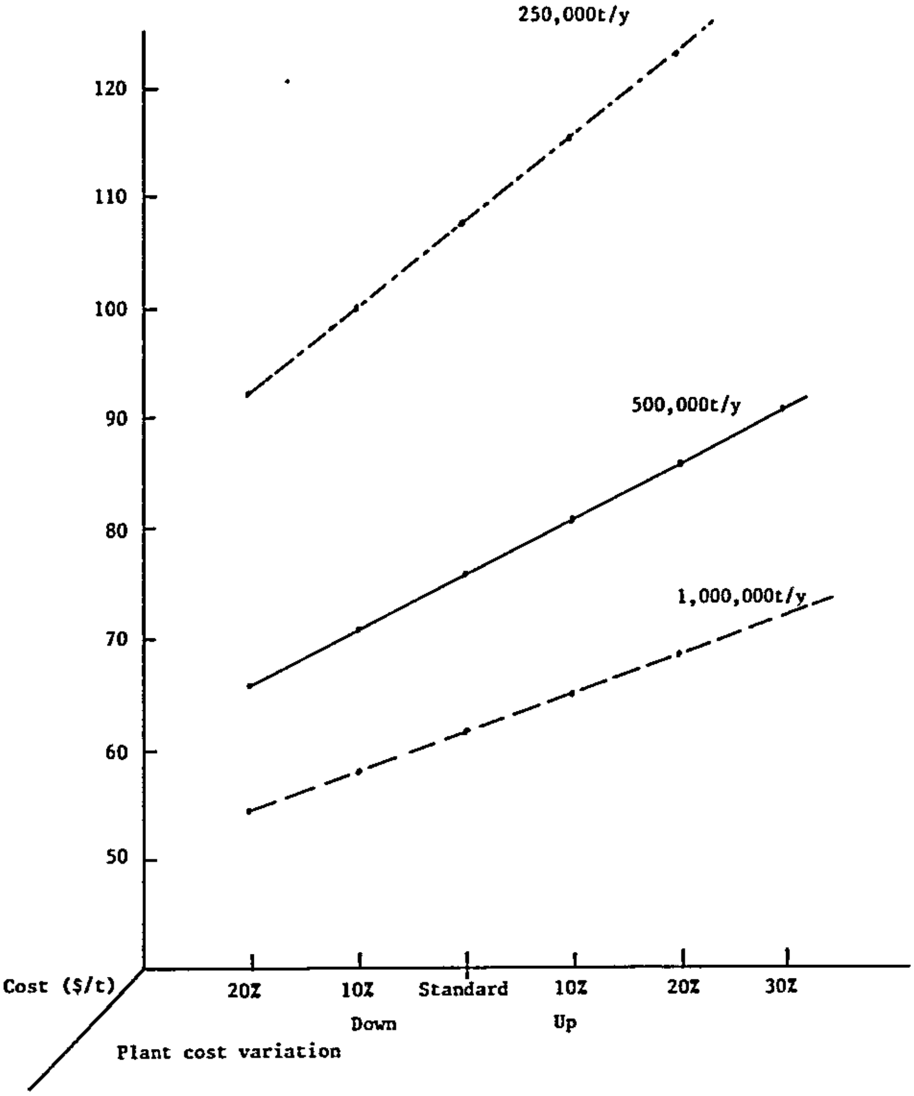


Table 5-10 Changes in Production Cost due to Variation in Operational Rate

	250,000 t/y	500,000 t/y	1,000,000 t/y
Construction cost 10^3 \$	139,462	172,909	250,343
20% down	92.1	66.3	54.5
10% down	99.8	71.2	58
As planned	107.7	76	61.5
10% increase	115.5	80.9	65
20% increase	123.3	85.7	68.5
30% increase	131.1	90.6	72

Fig. 5-2 Changes in Production Cost Caused by Variations in Operational Rate



CHAPTER 6 STUDY OF SUPPLY-DEMAND AND THE PRICE OF SODA ASH

6-1 Production of Soda Ash

6-1-1 Past trend of soda ash production in the world

The soda ash production in the world has been increasing year after year; however, the growth rate itself has been showing a downtrend in recent years. This has been mainly due to a drastic fall in the demand for soda ash, after the energy crisis in 1973 particularly in highly industrialized countries where the majority of worldwide soda ash consumption for industrial use such as for manufacturing glass materials, chemical industrial products, etc. is being made.

Although no complete statistics regarding soda ash production and consumption are available at present, Table 6-1 shows statistical data compiled by the United Nations covering a period from 1965 to 1973. This table is not a direct quotation of the U.N. data, but modified and revised by incorporating other statistics compiled by the OECD.

It is evident, however, that the above statistical data are by no means a representation of the status of the worldwide soda ash production. There still are a number of parts where no production statistics are available, and no stipulation has been made regarding several ash producing countries such as Korea, China, Iran, the U.K., etc. However, as a comparatively reliable information regarding an estimate ocncerning the worldwide soda ash production as of 1970, the data shown in the following Table 6-2 have been made available.

Table 6-1 Production of Soda Ash in the World

Unit: 10^3t

Year Country	1965	1966	1967	1968	1969	1970	1971	1972	1973
Japan*	736	806	877	1,018	1,170	1,237	1,285	1,307	1,363
Taiwan	17	29	36	35	38	43	N.A.	N.A.	N.A.
India	322	350	359	396	422	446	479	486	470
Pakistan	34	32	32	58	63	68	78	77	74
Belgium	237	258	271	276	282	321	350	N.A.	N.A.
Denmark	3	3	3	2	2	2	1	1	1
France	1,089	1,126	1,084	1,127	1,330	1,419	1,421	1,466	1,529
W. Germany	1,165	1,190	1,158	1,275	1,327	1,334	1,351	1,397	1,422
Greece	1	1	1	1	1	N.A.	N.A.	N.A.	N.A.
Italy	563	594	674	669	660	662	664	N.A.	N.A.
The Netherlands	142	134	161	176	197	224	241	258	257
Norway	27	27	27	24	26	25	21	20	** 19
Portugal	26	30	32	39	40	88	97	128	** 141
Spain	224	232	245	267	315	333	444	374	441
Sweden	1	1	1	1	1	1	1	1	N.A.
Bulgaria	223	226	218	225	265	300	301	291	247
Czechoslovakia	63	66	76	86	99	104	114	120	122
E. Germany	682	657	642	635	606	676	714	721	780
Poland	602	609	615	624	628	644	669	709	710
Rumania	350	370	384	471	595	582	601	665	677
U.S.S.R.	2,728	2,815	3,011	3,128	3,289	3,485	3,629	3,850	4,149
Yugoslavia	93	94	98	100	109	113	105	117	129
U.S.A. (Synthetic)	4,238	4,425	4,180	3,972	3,844	3,859	3,745	3,792	3,331
***(Natural)	N.A.	N.A.	N.A.	N.A.	2,545	2,560	2,736	2,957	3,514
Brazil	75	94	92	100	106	N.A.	N.A.	N.A.	N.A.
Chile	10	10	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Colombia	21	20	28	20	52	N.A.	N.A.	N.A.	N.A.
Mexico	122	140	225	288	316	316	319	347	382
Kenya	83	112	105	117	103	160	161	164	206
Total	13,877	14,451	14,617	15,130	18,431	19,002	19,527	19,248	19,964

Note: By the United Nations Statistical Year Book except for the Following:

*: By Japanese Governmental Statistics

**: By OECD Statistics (The Chemical Industry--OECD)

***: Figures obtained by substracting the synthetic side ash amounts of the U.N. Statistics from the OECD Statistics

Table 6-2 Estimated Total Production of Soda Ash in the World in 1970

Unit: 10^3t

Japan and Asia	1,800
West Europe	5,880
U.S.S.R. and East Europe	5,910
North America	6,430
Latin America	520
Africa	160
Others	1,500
Total	22,200

The past trends of soda ash production is observed as shown in the following Table 6-3 regarding several representative countries where the soda ash production records have been particularly high:

Table 6-3 Soda Ash Production Amounts in Large Producing Countries

Unit: 10^3t

Year / Country	1965	1970	1973
Japan	736	1,237	1,363
India	322	446	470
France	1,089	1,419	1,529
West Germany	1,165	1,334	1,422
East Germany	682	676	780
Poland	602	644	710
Rumania	350	582	677
U.S.S.R.	2,728	3,485	4,149
U.S.A.	*5,743	6,419	6,845
Total	13,417	16,242	17,945

*: Estimated

As is evident from the tables above, the soda ash production achieved by the countries stipulated in Table 6-3 occupies more than 70% of the total world production. Further, the average annual growth rate of production over a five-year period from 1965 to 1970 was 3.9%, and the rate over the following three years was 3.3%.

On the basis of the above observation, it seems that the past trend of soda ash production has not been consistent, but evolved with some fluctuation, and that the growth rate of total production by all the soda ash producing countries in the world prior to 1970 was approximately 4%, while the rate fell to approximately 3% thereafter as a general trend. In other words, the worldwide total production in 1965 and 1973 by taking the year 1970 as the base year and by taking the above annual growth rates as the bases, may be estimated as follows:

1965:	18,240,000 tons
1970:	22,200,000 tons
1973:	24,260,000 tons

The above estimates imply that the annual average growth rate over a nine-year period from 1965 to 1973 was 3.6%.

On the basis of the above, together with some other pertinent information, the 1973 United Nations Statistics may be revised as shown in Table 6-4.

Table 6-4 Soda Ash Production in 1973 by Countries

Unit: 10^3t

Japan	1,365	Spain	441
* Taiwan	45	* Sweden	1
* South Korea	100	Bulgaria	247
* China	1,100	Czechoslovakia	122
India	470	East Germany	780
Pakistan	74	Poland	710
Iran	15	Rumania	677
* Belgium	400	U.S.S.R.	4,149
Denmark	1	Yugoslavia	129
* U. K.	1,550	U.S.A. (Synthetic)	3,331
France	1,529	U.S.A. (Natural)	
West Germany	1,442	* Brazil	110
* Greece	2	* Chile	10
* Italy	700	* Colombia	60
Netherlands	257	Mexico	382
Norway	19	Kenya	200
Portugal	141	Others	203
*: Estimated		* Total	24,260

6-1-2 Estimation of the total production of soda ash at present

In 1974, energy price hike took place owing to the oil crisis, thereby inviting an extremely drastic production reduction of soda ash during the last half of the year. The reports from various countries concerning soda ash production are not sufficient as yet; however, according to some information, it seems that the production growth rate in Japan, France, West Germany, and U.S.A. are as shown in Table 6-5.

Table 6-5 Soda Ash Production and Growth Rates Over Previous Year in 1974

	Production	Growth rates
Japan	1,327 10^3 Mt	- 2.64 %
France	1,564	2.29
West Germany	1,456	2.39
U. S. A.	6,850	0.07

Except for some regions, it is generally accepted that the oil crisis affected all the countries of the world almost equally. Therefore, it is reasonable to estimate that the production growth rate of soda ash must have been reduced to approximately 2% which is much lower than the 3% annual average level achieved in tle previous year.

On the other hand, in 1975, in order to control the global inflation caused by the oil crisis, all the countries in the world undertook a governmental policy of suppresing the total demand. Therefore, it is forecast that, on the basis of the reports made by the OECD member countries, the worldwide mining and manufacturing industrial index will be reduced by at least 10%. It is difficult to presume that the production of soda ash is free from such an effect. The average annual growth rate of worldwide mining and manufacturing index was 6.5% from 1963 to 1972 according to the U.N. statistics. On the other hand, the soda ash production growth rate per year was 3.6% during the same period. Judging from the correlation between these two rate figures, it seems that the soda ash production must have fell by 5%.

Therefore, the worldside total production of soda ash in 1974 and 1975 is respectively estimated at 24,750,000 tons and 23,510,000 tons.

	Soda ash total production	Rate of growth over previous year
1973:	24,260,000 tons	–
1974:	24,750,000 tons	2%
1975:	23,510,000 tons	- 5%

6-1-3 Forecast on the future suppliability

Natural soda ash is mainly produced in the U.S.A. and Kenya, with a certain extent of output achieved in Syberia, U.S.S.R. The rest of the production carried out by the other countries consists for the most part of synthetic soda ash which accounts for approximately 85% of the total soda ash production of the world according to certain statistical data as of 1973.

The information regarding the expansion trend of soda ash production capacities in various countries of the world from 1975 onwards has so far been highly fragmental; however, a forecast can be made from the collected information that the future expansion of new production facilities for soda ash production, particularly in the case of synthetic soda ash, will become gradually difficult in general, especially in those countries where industrialization has attained a certainly high level. This prediction of gradual increase in the difficulty in enhancing supply capacity of soda ash is based on the following reasons:

At first, the legal regulation is increasingly tightened to cope with the pollution problem i.e., the contamination of the surroundings caused by the emission and effluent from the plants. Therefore, the amount of investment for providing the pollution control facilities increases to protect the neighbouring local communities in the form of controlling the discharge of calcium chloride waste solution, sulfite gas from energy generation facilities, nitrogen oxide gas from stackes, etc. These will certainly make it more difficult to procure suitable sites for constructing new plants.

Another reason is the continued increase in the plant construction cost and labour cost.

The following paragraphs will describe an observation on the possible changes which will take place in the soda ash supply capacities in the future within the framework of some information made available so far:

(1) Japan:

According to statistics compiled by the Ministry of International Trade and Industry, the existing soda ash production capacity is approximately 1,550,000 t/y, a level which has been unchanged for several years in the past. Japan is known for having extremely strict pollution control regulations. Also, the Japanese pattern of soda ash production is for the most part in the form of joint production with ammonium chloride for use as fertilizers. Therefore, it is important for the industry to consider the balance between the production of these two of commodities. Therefore, it is predicted that the scale of future expansion in the soda ash production capacity will be controlled to a low level, thereby gradually increasing the degree of dependency upon importation.

(2) The Asian region:

It seems that the total production capacity at present owned by India, Korea, Taiwan, Pakistan, Iran, etc. is approximately 980,000 to 1,000,000 tons per year.

In India, it is envisaged by the Government that the total soda ash production be increased to 1,100,000 t/y by 1978/79 which falls to be the last year of the Fifth Five Year Plan. In order to attain this goal, an increment of the present capacity by approximately 450,000 tons will be necessary. However, at present, an expansion project covering an annual capacity of 144,000 tons is being implemented at only one plant. In view of the lack of any other expansion project in this country, it seems likely that the discrepancy between the governmental project target and the actual operation capacity will be kept unchanged for the future. At any rate, it is planned by the authorities that nearly all the expansion portion in the production of soda ash will be allocated to meet the increment in the domestic demand.

In Pakistan, the presently undertaken capacity increase projects total to 65,000 to 75,000 t/y; however, no clarification has been made regarding the target years of completion. In addition, the Government is studying the feasibility of a joint project participated by the member countries of ASEAN.

(3) West Europe:

The Netherlands and Belgium have announced soda ash production expansion projects. In Belgium, Solvay is formulating an expansion project amounting to approximately 400,000 t/y, however, it seems that the project is suffering from several problems chiefly pertaining to the environmental conservation. Solvay, ICI and other major manufacturers in West Europe are reported to have been positively studying the increment in the production capacity of synthetic soda in order to cope with the future increase in the demand for soda ash.

(4) East Europe:

The soda industry of East European Countries in general is inclined to depend on soda ash, the U.S.S.R. being a prototypical example. Although the figures are unconfirmed, a report reveals that a new soda ash plant was placed on stream in the Sterlitamak industrial complex towards the end of 1974.

Poland has also commenced construction of a soda ash plant having an annual production capacity of 460,000 tons.

An information also relates that a certain plant in Bulgaria had signed a contract for an expansion project covering 400,000 t/y.

(5) U.S.A.

In this country, no new construction of synthetic soda ash plant has been made since 1935. Instead, the synthetic soda ash plants have been close one after another along with the increase in the production of natural soda ash purified from an enormous amount of trona deposited in Wyoming and California States, and also in line with the intensification of the pollution control regulations. During a period from 1974 to 1975, the close-down of synthetic soda ash plant capacity totalled to 1,022,000 t/y. As a result, the present level of synthetic soda production capacity is reduced to 2,583,000 tons per year approximately.

Regarding natural soda ash on the other hand, the production capacity as of August, 1975 was 5,139,000 t/y. Further, an expansion amounting to 675,000 t/y was implemented during the same year, thereby making a total planned production capacity of 5,814,000 t/y. This accounts for approximately 70% of the total American soda ash production capacity of 8,397,000 t/y.

It is predicted that synthetic soda ash plants will be consecutively closed because of the plant becoming obsolescent, hike in the energy cost, the intensification of pollution control standards by the American Government regarding calcium chloride waste solutions and consequential bulging of investment required for installing the treatment facilities, etc. It is generally observed that the discontinuation of synthetic soda ash production will further increase during 1976-1977, so that by 1980 the synthetic soda ash production will be entirely discontinued all over the U.S.A. On the other hand, the production capacity of natural soda ash will keep increasing in the future. It is announced in this country that three plants will accomplish an expansion of a total of 2,115,000 t/y by 1977. Further, during 1977-1978, another plant will complete an expansion totalling 900,000 t/y. In consideration of new expansion projects which will be announced in the future, it is likely that the total soda ash production capacity of the U.S.A. by the end of 1978, encompassing both natural soda ash and the remaining synthetic soda ash productions, will be 11,250,000 t/y. During a 2-year period until 1980 thereafter, the natural soda ash production will be increasing on one hand, the synthetic soda ash production will be cut as mentioned above on the other hand. Therefore, the actual increment in the production capacity will not be very great. In other words, as far as the U.S.A. is concerned, the planned production capacity increase amounts to 2,853,000 t/y from 1975 up to 1980.

(6) Latin America and Kenya

Brazil, Argentina, etc. are formulating capacity expansion projects totalling 433,000 tons to be completed by around 1978.

Kenya seems to have an existing production capacity of 250,000 t/y at present. It has been reported that the manufacturer has already decided upon a project for doubling the production capacity in order to cope with the future increase in the demand for the ash.

At present, the formulation of future projects by various countries is being delayed because of the insufficiency in clarifying an outlook on the recovery and restoration of the international economy. Therefore, the above paragraphs has to be based upon incomplete and fragmental information regarding the soda ash industry of the world.

At any rate, it is estimated that the soda ash production capacity increment completed by 1980 all over the world will be at least 4,690,000 t/y. However, this figure is deemed to be the so-called rated capacity. Therefore, respective operational rates must be incorporated when studying the actual supply capacity. In Japan, U.S.A., etc., the operational rates in the past recorded a level as high as over 87%. Therefore, if the capacity rate of these two countries are estimated to be 90% the supply capacity will be 4,220,000 t/y.

Soda ash production is oriented towards large-scaled production in view of the fact that the operation itself is highly facility-intensive. and also in view of the pattern of utility consumption. The economy of the production also depends on the scale of the operation. At the same time, excessive installation of production facilities will extremely deteriorate the cost merits. Therefore, the production and supply schedule must always be geared closely to the demand forecast. From this viewpoint, it is reasonable to state that the production capacity expansion projects as mentioned above is a reflection of the tightening of supply capacity which took place in 1974. This point is also supported by the observation of the past trend of soda ash prices which will be described later.

Therefore. the soda ash supply capacity of the world till 1980 is estimated to be approximately 28,970,000 t/y which is a total sum of 24,750,000 t/y as of 1974 when the production facilities were fully in operation and 4,220,000 tons mentioned above. Also, the formulation of a forecast in this respect up to 1985 is extremely difficult due to the lack of reliable information at present.

However, it is likely that active expansion of production capacities will be undertaken in the East European countries, the U.S.S.R. in particular, and also that the general growth in the worldwide demand for the ash will be covered by the projects on the reinforcement of the self-sufficiency system in the mid-advanced countries and by projects on the supply expansion based on the advantage of the past achievement of production and marketing in the industrially advanced countries. It is conjectured, on the other hand, that some of the industrailly advanced countries will suffer from tohe difficulties in establishing the self-sufficiency attainment programmes because mainly of the environmental problems concerning the production of synthetic soda ash by the Solvay process.

It is deemed to be highly unlikely that supply increase of some other alkali products, in competition with the supply of soda ash will create a serious problem in the alkali demand field. Therefore, this point will not be treated in this report.

6-2 Trend of Demand for Soda Ash

6-2-1 Possibility of clarifying the demand for soda ash

The demand for soda ash consists of various fields of demand in which it is consumed. In other words, the total demand for soda ash is a total accumulation of those generated in the fields of demand, the major ones being the glass industry, chemical industry, pulp and paper industry, detergent industry, etc. Therefore, it is necessary to clarify the individual trend of these demand fields in order to assess the future trend of the soda ash demand as a whole. However, it is physically impossible to conduct a study in this respect covering all the versatile sectors.

Also, the demand for soda ash exists not only in the developed countries but also in the semi-developed and developing countries as well because of the versatility of application of soda ash as the alkali source. This signifies that, an accurate clarification of the demand trend of this commodity on a worldwide scale will require observation of the demand trend in some over 100 countries in the world. Within the framework of the present survey, such work was absolutely impossible.

In addition to the above, adequate clarification of the demand trend of soda ash is made further difficult because of the insufficiency of statistics regarding the demand or consumption of soda ash in many of the countries or at a number of international markets. The accuracy of statistical data regarding soda ash varies greatly from country to country. Nevertheless, it is possible to collect a certain amount of data regarding the scope of production, exports, and imports. However, regarding the scale of domestic demand or consumption, there are still a number of countries in which no reliable records are available.

Under such a circumstance, it seems most practical to base the observation upon the 'past trend of production amount' in order to study the future soda ash demand trend. Regarding the correlation between the trend of demand and trend of production, it is assumed in this study that production will evolve commensurate with the evolution of the demand unless some extreme restraints exist in the production capacity, i.e., the supply capacity.

The trend of the supply capacity in the world over some 10 years in the past, a shift from the conventional synthetic soda ash production towards natural soda ash has been steadily progressing in the U.S.A. which is the largest producer and exporter of soda ash. This is one of the important trend in the production aspect. There is no report so far that some extreme soda ash supply shortage took place in the world in the past.

As far as demand is concerned, there is no instance either during the past ten years or so, that an revolutionarity new field of demand for soda ash was developed.

In short, as far as the observation of supply-demand balance of soda ash in the past is concerned, the trend of production almost directly represents the trend of demand. Therefore, the studies made in the following paragraphs will be based upon the past production trend, together with an incorporation of the trend of import amounts in various soda ash importing countries.

6-2-2 Past trend of the demand

The estimated amount of the total soda ash production in the world from a 9-year period form from 1965 to 1973 was, as stated in above 6-1-1, ranges from 18,240,000 t/y to 24,260,000 t/y, thereby displaying a continual increase. The demand for soda ash therefore increased by a total of approximately 6,000,000 tons over the 9 years, so that the average annual rate of growth of demand is approximately 3.6%.

However, a closer observation reveals that an annual average of approximately 4% was recorded for five years until 1970 on one hand, the annual rate was reduced to approximately 3% during the following three years thereafter. In other words, the general trend shows an increase in the absolute production amount with a downtrend in the growth rate.

For reference, the worldwide growth rate of mining and manufacturing industry during the same period was registered at approximately 6.5% per year. Therefore, the elasticity value of soda ash demand growth rate as against that of mining-manufacturing industrial production is slightly over 0.5. This implies that the soda ash consuming ifeld, such as glass industry, pulp and paper industry, and chemical industrial fields which require soda ash, displayed only a modest extent of growth in contrast to the machinery manufacturing industry, metal processing industry, which registered an extremely rapid growth during the same period.

Japan, as an example of country-wise observation, showed a trend as stipulated below. These figures were obtained by adding the production amount and import amount together and then subtracting the export amount on the basis of the statistical data. These figures seem to imply approximate figures of the domestic consumption achieved in Japan.

1970:	1,206,000 tons
1971:	1,237,000 tons
1972:	1,238,000 tons
1973:	1,344,000 tons

This implies that the growth of domestic consumption of soda ash during this period in Japan was approximately 3.7% per year.

Examples of France and West Germany, as shown below, reveal the annual average growth rate of approximately 4.2% and approximately 1.8% respectively, thereby both showing an uptrend, yet the growth rates vary greatly each other.

	France	West Germany
1970	996,000 tons	1,322,000 tons
1971:	1,017,000 tons	1,348,000 tons
1972.	1,022,000 tons	1,387,000 tons
1973:	1,131,000 tons	1,395,000 tons

6-2-3 Actual records by exporting countries

There are a number of soda ash exporting countries. However, the number of perpetual exporting countries is comparatively small.

The exporting countries are the U.S.A., France, West Germany, the U.K., the Netherlands, the U.S.S.R., Japan, etc. These exporters are, at the same time, large consummers of soda ash is the world.

The case of Kenya is rather outstanding. The estimated domestic market scale of this country for soda ash is approximately 20,000 tons per year; however, the existing production capacity is 200,000 tons 250,000 tons which is far greater than the domestic consumption. Approximately 200,000 tons of ash is being exported from Kenya. This clearly shows that the soda ash production conducted in Kenya was started and is conitnuing as an export-oriented industry obviously based on the indigenous natural soda ash resources.

It is noteworthy in recent years that East European countries such as Rumania, Bulgaria, Poland, etc. are becoming exporters of soda ash. The synthetic soda ash in these countries are invariably produced by employing the Solvay process. By effectively utilizing the indigenous salt, these countries have been gradually expanding the scale of production until they have come to possess the export surplus capacity.

These exporters are at the same time importers in some cases. West Germany, the Netherlands, the U.S.S.R., Japan, etc. are the major ones of the dual-character countries. This implies that the extent of imports and exports of these countries are affected by the international price trend, the nature of long-term contract supply, ragional convenience, etc., thereby making it rather difficult to simply categorize them as either pure importers or exporters.

Table 6-6 shows the export records of the major ash exporters of the world.

Table 6-6 Export Records of the Major Ash Exporters of the World

Unit: 10^3t

Year / Country	1970	1971	1972	1973	1974
U. S. A.	305	397	436	386	512
France	423	404	445	399	389
West Germany	70	59	68	92	61
U.S.S.R.	70	90	74	64	75*
Kenya	157	150	145	202	140
Japan	67	70	87	30	181
Total	1,092	1,170	1,255	1,173	1,358*

* : Estimated

The total of exports and imports conducted by the EC member countries of West Europe reveals the following figures as of 1974:

Export total:	840,000 tons
Import total:	377,000 tons
Export – Import:	463,000 tons

Approximately 500,000 tons of soda ash flowed out of the EC boundary in 1974. As for the nonmembers of the EC in West Europe, Sweden and Norway, both are significantly important soda ash importers.

The records of exports conducted by Kenya as an example of heavily export-oriented country is as shown in Table 6-7.

The reason for the decrease in the export from Kenya in 1974 from the previous year's level is understood to be the general stagnation in soda ash export market in the world, and also the lack of efficiency in the domestic transportation of the commodities in the same year.

Table 6-7 Records of Exports Conducted by Kenya

Unit: 10^3t

Year Country	1972	1973	1974
(Africa Sub total)	(23)	(23)	(22)
Madagascar	1	-	3
Congo	4	1	-
Ethiopia	3	3	3
Mozambique	10	11	6
Nigeria	-	2	3
Sudan	1	1	1
Swaziland	3	-	1
Zambia	-	4	5
Others	1	1	0
(The Middle and Near East Sub total)	(20)	(23)	(13)
Iran	1	7	0
Israel	12	14	12
Jordan	0	0	1
Lebanon	6	1	0
South Yemen	1	1	0
(Asia Sub total)	(82)	(128)	(48)
Malaysia	7	11	14
Singapore	11	19	18
Ceylon	2	0	0
China	20	29	0
Taiwan	0	0	2
Hong Kong	6	5	4
India	2	1	0
Indonesia	2	17	6
Thailand	15	38	0
Japan	17	8	4
(Oceania and Others Sub total)	(19)	(27)	(56)
Total	144	201	139

6-2-4 Actual records by importing countries

Among numerous soda ash importers, particularly large ones are Sweden, Denmark, Finland, all of which are advanced industrial countries, together with the Republic of South Africa. Among the developing countries on the other hand, Argentina and the Philippines are outstandingly large importers. All these countries are depending entirely upon importation regarding the supply of soda ash.

Among the developed countries such as India, Pakistan, Mexico, Brazil, etc. are also depending upon importation because of the shortage of supply capacity of indigenous soda ash production. These countries are therefore producer-importer nations.

The actual records of soda ash importation are as shown in Table 6-8.

Table 6-8 Records of Imports by Major Importing Countries

Year / Country	1972	1973	1974
Sweden	134	131	113
Denmark	75	75	70
Finland	87	74	70*
Belgium	60	62	60
West Germany	58	67	94
U.S.S.R	465	271	166
Rep. of South Africa	na.	na.	200*
The Philippines	na.	na.	80*
Argentina	180	148	165
Total	-	-	1,018*

* : Estimated

6-2-5 Outlook on the future demand

Since the oil crisis which took place towards the end of 1973, the world economy experienced a negative growth in 1974 and 1975. In December, 1975, the OECD announced the real GNP trend of seven countries, the U.S.A., West Germany, the U.K., France, Italy, Canada, and Japan. According to this announcement, the annual average growth rate of the economy from1960 to 1973 was 5.5%, while in 1974, the rate fell to -0.6%. In 1975, the six countries except Japan registered negative growth, thereby making the total average growth at -2.25%.

Regarding a forecast for 1976, the OECD predicts that the U.S.A. will recover to 5.75% level, and the total rate of these seven countries will turn to a positive growth at a rate of 4.25% per year.

After the economic recession several years after 1973, it is forecast that the world economy will enter into a period of stable growth again after due adjustment and coordination. It is generally predicted that the average rate of economic growth of the industrially advanced countries in the new period will be approximately 4% which is lower by one point than the 5% growth rate during the decade of 1960s.

According to an announcement made by the United Nations, the growth of GDP from 1950 to 1960 was on an average of 4.5% per year, and from 1960 to 1970 was 5.2% per year, while during a 15-year period from 1970 to 1985 it will be 4.7% per year. (According to this estimate, the breakdown of the growth rates during this 15-year period consists of 4.2% as a total of the developed countries, 6.0% as a total of the developing countries, and 5.5% by the centrally planned countries. The structural ratio of GDP in 1985 by the above-mentioned blocks is estimated to the situation prevailed in 1970, the developed countries will show a fall by 5.0 point, while the developing countries will register an increase by 2.6 point, the centrally-planned countries will grow by 2.5 point)

The above paragraphs described a macroscopic forecast on the world economy.

As one of very scarce forecasts made in individual fields of soda ash consumption, the following paragraphs will describe the demand forecast for sheet glass products compiled in Japan in 1975.

The total production of sheet glass conducted by Japan occupies approximately 15% of the total world production, approximately 67% of which is consumed in construction, approximately 19% in the automobile industry.

From 1960 to 1970 the demand for sheet glass in Japan exceeded the growth rate of GNP. However. during a 5-year period from 1970 onwards, the demand fell to a level approximately the same as that of GNP. It is now forecast that the future demand for sheet glass will be below the growth rate of GNP because of several constraints in the above-mentioned major fields of consumption. As a result, it is predicted that the growth rate will be 4.2% approximately during a period from 1976 to 1980.

Examples of forecasts concerning soda ash itself for five to ten years from now onwards are rather scanty, however, in the U.S.A., the forecast of 3% per year, which was predicted two years ago as the growth rate up till 1980, has now been modified and a general prediction on the average annual growth rate up till 1980 is only 2% at the present stage.

On the other hand, some forecasts predict that West Europe and Japan will display a growth rate of approximately 1 point higher than the American prediction. When the developing countries which are showing higher levels of growth rate than those of developed countries are taken into consideration, the world demand level for soda ash up to 1985 is likely to evolve on an annual level of 3%. However, in 1976 and 1977, a rather rapid uptrend is likely as a temporary reaction to the drastically and suddenly deteriorated economy in the previous years. Therefore, with this point in view, the annual growth rate up to 1985 is tentatively set at 4% for the purpose of calculation with a provision that the rate during a period from 1978 to 1985 will be 3%. The obtained results are shown below. (Regarding the 1975 demand, the estimated production for the same year has been applied.)

1975: 23,510,000 tons
1980: 27,790,000 tons
1985. 32,230,000 tons

As is evident from the above, the total world soda ash demand will attain a level of 30,000,000 tons during the first half of the decade of 1980s, while in the mid 1980s the figure will be increased to 32,000,000 tons.

6-3 Forecast on Supply Demand Balance

6-3-1 Supply demand balance on worldwide level

In view of the forecasts made in the foregoing regarding the future trend of world's demand for soda ash the supply capacity in 1980 will be 28,970,000 tons which exceeds the demand level of 27,790,000 tons. In other words, it is likely that no supply shortage will take place as of 1980.

However, the demand during the middle part of the decade of 1980s, in 1985 for instance, is estimated to be 32,000,000 tons. Therefore, approximately 3,000,000 tons of new development of production capacity will become necessary in addition to the supply capacity estimated for 1980. Therefore, during the decade of 1980s, production capacity expansion projects or new plant construction by a new-comer manufacturers are likely to be formulated.

6-3-2 Supply-demand balance in export market

The foregoing paragraphs will discuss the supply-demand balance of soda ash on a worldwide basis. On the basis of the records by exporters described in 6-2-3, and that of the importers stated in 6-2-4, the world's trade amounts of soda ash is approximately 2,500,000 tons per year, of which approximately 500,000 tons is estimated to be distributed in the EC member countries and other East European nations. Therefore, if this European distribution amount is exempted from the total, the world's soda ash trade amount will be approximately 2,000,000 tons. This implies that the world soda ash trade amount accounts for approximately 8% of the world s total soda ash production.

In the case of Kenya which is an export-oriented country, approximately 200,000 tons of soda ash was shipped in 1973. This corresponds to approximately 10% of the total trade amount. The destinations of the soda ash exportation from Kenya were mainly the countries in Africa Middle East and Asia. Of these, importers, even the largest ones imported only 40,000 tons or less so that the amount of the shipment to individual countries was rather limited. Therefore, it is clear that the soda ash exportation from Kenya was widely distributed to a number of importing countries.

In order to forecast the supply-demand balance in the export market, it is necessary to conduct a much more detailed scrutinization away from the forecasts of supply-demand balance on a worldwide market level because of the above special characteristics of soda ash trade.

The first point to be noted is that the present importing countries may find soda ash importation unnecessary because of the intensification of the indigenous supply, and in some cases, the country may even appear in the scene of international market as an exporter. Argentina, the Philippines, etc. and some other developing countries will turn themselves to be such countries in view of the presently formulated domestic production projects.

On the other hand, even the industrially advanced countries having ample capacity to cover the domestic demand may very well be compelled to depend upon importation because of reasons such as the aggravation of environmental pollution problems, difficulties in selecting sites, problems in raw material supply, all of which may lead to closing of some of the existing production facilities, or because of impossibility in expanding the production capacity in spite of growth in the domestic demand for soda ash. In such cases, these countries will give a considerable impact upon the soda ash import-export market of the world.

In the U.S.A.. new construction and expansion of several production facilities with an average capacity of some 1 million tons per year each have been progressing during the last half of 1970s. Such a progress is possible in America where several million tons of domestic market and approximately 500,000 tons per year of export market.

For other countries to study large-scaled new production capacity expansion projects of 500 000 tons to 1,000 000 tons, the following points must be carefully studied especially when such expansions are export oriented:

To secure competitive quality and price in the export markets particularly in relation to the position of worldwide supply-demand balance,

Confirmation of the form of the shipments (either bulk shipment or in bags) in accordance with the level of industrialization on the part of importing countries,

To clarify as to whether or not the quantitative balance at the export-import market will have sufficient allowance to absorb the input of a new and large amount of supply,

Around the middle of the decade of 1980s, the world's total demand for soda ash will attain a level of 32,000,000 tons. However, the extent of trade in the export-import markets at the same period is estimated to show no great excess over a range from 2,000,000 tons to 3,000,000 tons. Therefore, when formulating a new project for the production of soda ash, it seems imperative to carefully study the size of the available export market by properly allocating the production to both domestic and overseas outlets.

6-4 Trend of Price of Soda Ash

6-4-1 Past price trend

Regarding the future trend of the soda ash price in the worldwide market, it seems adequate to mainly observe the price trends displayed by the U.S.A. for the purpose of this report. As is evident from the description made regarding soda ash exporting countries earlier, the U.S.A. has been leading the world's soda ash export market for a considerably long time in both quality and quantity. Particularly, it seems that the trend of the natural soda ash production conducted by this country has been and is giving the most significant impact upon the worldwide soda ash export market.

The trend of the domestic soda ash prices in the U.S.A. from 1955 until recent years on an FOB factory basis is as shown in Table 6-9.

Table 6-9 Trend of American Domestic Soda Ash Price on FOB Factory

Year	S/t	M/t
1955	($28.)	$30.80
1956	($30.-)	$33.10
1957	($32.-)	$35.30
1969	($33.-)	$36.40
1972	($35.50)	$39.20
1975	($42.-)	$46.20
1976	($47.-)	$51.70

As shown in the above trend, the price increase was rather moderate until 1975 when the price was boosted by approximately 12%, followed by approximately 11% in 1973.

For reference, the domestic price trend in Japan, France, and West Germany are as shown below on the basis of FOB factory, converted into US dollars per metric ton.

Year	1971	1972	1973	1974	1975
Japan	57	67	90	114	
France	42	44	49	58	67
West Germany	57	66	73	93	102

Here again, an uptrend is noted from 1971 onwards, with an acute price hike since 1974 quite clearly.

Export prices quoted by the major soda ash exporting countries generally show a level higher than the domestic price levels, and a concerted price increase is noted in 1974. Regarding the former phenomenon, the major reason is the comparatively high instances of exports in small-quantity or in bags, and regarding the latter the price increase was due to the confusion of the price systems due to the oil crisis which affected the world since 1974.

6-4-2 Recent price trend

In 1975, the U.S.A. announced an upward revision of the soda ash price, so that the price level as of the beginning of 1976 was approximately US$57 on FOB factory which previously was approximately US$52. The major source of supply of soda ash in the U.S.A. is the natural soda ash produced in Wyoming which is in the western part of the country. On the basis of the FOB factory price in Wyoming, it is estimated that the FOB port-of-export price per metric ton of soda ash is within a range from US$75 to US$80 after adding the inland freight and shipping cost from the factory to the port of export on the West Coast. (The FOB factory price in the eastern part of the country sometimes show a high level of US$80; however, this quotation does not seem to be a generally applicable to the case of exportation, and therefore shall be excluded from the scope of the present study.)

Regarding the competitiveness of the export prices, the final comparison must be made on the basis of the landed price at the importing countries. Such a comparison will involve a considerably time consuming work of ocean freight calculations, etc. Therefore, the present study will not specify the destination countries of soda ash exportation.

6-4-3 Future price trend

The American prices of soda ash is showing an uptrend as described above, and it is also reported that another price revision will be made upwards sometime mid-1976. In any case, the production cost of natural soda ash is inevitably increasing in the future owing to the hike in the energy cost and labour cost, together with the increase in the inland transportation cost. These factors will directly affect the export prices of soda ash.

However, it seems that a temporary over-supply of soda ash is inevitable during several years from 1976 onwards because of the increment in the soda ash production capacity in the U.S.A. This being the circumstance, it is unlikely that any conspicuous and drastic price increase will be effected in several years to come.

CHAPTER 7 SUMMARY

7-1 Summary of Technical Aspects

7-1-1 Soda ash resources at Lake Natron

As a result of the present survey, it has been confirmed that Lake Natron has a reserve of at least 136 million tons of soda resources in terms of sodium carbonate in the form of crust mainly consisting of sesqui-sodium carbonate and monohydrate of sodium carbonate, and also in the form of brine mainly consisting of sodium carbonate and salt. However, as a problem in view of quality, sodium fluoride contents are noted, particularly at an average of 1.37 wt% in the crust. This high sodium fluoride content is noted as a major problem.

The deposit of the soda source reserves was estimated through the present survey mainly centering on the crust and the brine. It is likely that the estimation of the reserve will be further increased by far if clarification is made regarding the conditions and the status of the lake bottom and underground of the area surrounding the lake. Depending on the clarification of the complete picture of the deposit, the method of mining may become different from the proposed ones in this Report. Therefore, it is deemed necessary to undertake boring exploration of the lake bottom and the lake surrounding areas.

The climatic conditions at Lake Natron are noted to belong to the semi-desert climate characterized by high temperature and low humidity. These natural conditions actually constitute the source of energy for the generation and formation of the natural soda ash, and also these climatic situation will influence the re-formation of the crust after the mining. Therefore, it is deemed necessary to conduct meteorological observations (precipitation, evaporation, wind directions, wind velocity, temperature, humidity, etc.) throughout a year from now onwards, together with the survey regarding the conditions of the lake (conditions during rainy and dry seasons, the crust re-formation speed, etc.).

7-1-2 Mining and purification processes of natural soda

In order to turn the natural soda ash resources available at Lake Natron into products marketable in the international market, it is necessary to conduct the mining and purifying of the raw materials. At the lake, slurry made by mixing the crust and brine will be mining, and this mining will be conducted by covering an area of $5km^2$/y in the case of producing 1,000,000 t/y of soda ash in product at locations several kilometers offshore the lake from where the mining slurry will be transported to the shore by means of pipeline or through other methods.

The site for constructing a plant to purify thus collected raw material soda ash has been selected as being the most suitable location at the northeast shore of the lake. The selection was made on the basis of such factors as raw material transportation, availability of industrial water, environmental conservation, available labour force, etc. This site is closest to the deposit area of the resources and was also accessible in view of the product transportation.

The purification process consists of several stages of operation such as washing, calcining, dissolving, purifying, crystallization, separation, washing, drying, screening, etc. The major problem in this process is the removal of sodium fluoride.

On the basis of the above factors, design was made for a process for producing 500,000,000 t/y of the purified product, together with two other schemes, one for 250,000 t/y production and another for 1,000,000 t/y production. However, further technological development efforts are deemed necessary regarding the actual application of the techniques for the removal of the above-mentioned sodium fluoride.

This process requires process water, heavy oil, steam, and electrical power. It also calls for chemicals to be applied for the removal of the impurities. In order to employ coal in place of heavy oil, it is necessary to reduce the coal cost in general, the cost of transportation in particular. It is therefore necessary to conduct further study regarding the ways and means to make coal usable in view of points such as the transportation cost reduction, quality problems (particularly the softening temperature of the soda ash content, alkali concentration, etc.), the method of disposing of the combustion residue, etc.

7-2 Summary of Economic Aspects

7-2-1 Scale and cost of soda ash production amount

For the study of the scale of soda ash production, a scheme for making 500,000 t/y was taken as the basis, together with the examinations of two other schemes, one for 250,000 t/y and another for 1,000,000 t/y.

As a result, the construction cost was estimated to range from approximately US$100 million to over US$200 million as shown below including the plants, utility facilities, auxiliary facilities, and the inermediary and shipment bases:

250,000 t/y scheme:	US$ 90 million
500,000 t/y scheme:	US$124 million
1,000,000 t/y scheme:	US$208 million

The production cost naturally varies depneding upon the scale of production. The calculations revealed that the cost of the products at FOB plant at Lake Natron ranges as follows. from approximately US$59 to US$86 per ton of product.

250,000 t/y scheme:	US$ 86.37/Mt
500,000 t/y scheme:	US$ 66.27/Mt
1,000,000 t/y scheme:	US$ 59.83/Mt

The schedule of manning of personnel necessary for the operation of the purifying plant and the related facilities is estimated as follows:

250,000 t/y: (employee: 216, worker: 137) Total 353
500,000 t/y: (employee: 260, worker: 224) Total 484
1,000,000 t/y: (employee: 345, worker: 349) Total 694

7-2-2 Trend of supply-demand and price of soda ash

As of 1975, the world's total production of soda ash is estimated to have been approximately 23.5 million tons. In 1975, the general situation of the international soda market was showing a slight extent of over-supply. It is also forecast that for a five-year period from 1975 onwards, the supply-demand balance will be eased to a certain extent owing to the expansion of the production capacity implemented in the U.S.A. and in other countries.

Further, it is predicted unlikely that serious gap between supply and demand will be created during the decade of 1980s in view of the past trend of the balance. In other words, the worldwide demand growth on average will be approximately 3% per year, and the production facility expansion will be carried on commensurate with such a progress of demand.

Above paragraphs describe a macroscopic forecast by viewing the world as a whole unity. As it is estimated that the size of the export market for soda ash occupies approximately 10% of the whole world market, thorough examinations must be effected regarding the future scale of the import demands, if an export-oriented soda ash production is to be projected.

By so doing, it is imperative to ascertain whether or not the export market is substantially large enough to absorb the additional supply from the new soda ash produciton.

Regarding the trend of price, it is necessary to conduct studies as to the export price competitiveness in comparison with the American soda ash which has been and is assuming the leading positions in soda ash export market of the world. The present level of FOB Export Port price of the American natural soda ash ranges from US$75 to US$85 per ton. This American price level will be a important criterion for the comparison of export competitiveness.

It goes without saying that in practice, the comparison of cost competitiveness must be conducted after adding the transportation costs up to the ports of the export destination countries.

7-2-3 Marketability of Tanzanian soda ash

In order to examine the marketability of the Tanzanian soda ash, the key-point will be the conformation of the export competitiveness in view of the above-mentioned market situation. It is therefore necessary to carry out comparative studies concerning the FOB Tanga prices. However, it is not possible in this section of report to effect proper judgement on this point because of the lack of the inland transportation cost factors from Lake Natron to Port Tanga, and the shipping cost at the port. However, the US$86 level in the case of the 250,000 t/y production scheme is absolutely prohibitive. Therefore, the cases worthy of further study as a project are the 500,000 t/y and the 1,000,000 t/y scheme.

In the case of the latter, the export competitiveness of the product prices will be enhanced; however, the major issue here will be the possibility of consuming the product as much as 1 million tons per year in the market.

On the other hand, if the scheme is for manufacturing 500,000 t/y of the product, the feasibility becomes comparatively higher in respect to the quantity of the output into the market. However, in view of the price, the price of the product will become higher by slightly over US$6, i.e., approximately by 10% over the standard level of competitiveness, thereby making the reduction of the competitiveness of Tanzanian ash inevitable.