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08623

Distr.
LIMITED

UNIDO/IOD.223
19 October 1977

ENGLISH

UNITED NATIONS INDUSTRIAL
DEVELOPMENT ORGANIZATION

GYPSUM MINING AND PROCESSING.

TS/JOR/76/001.

JORDAN.

Technical report: Techniques of gypsum mining and processing

Prepared for the Government of Jordan
by the United Nations Industrial Development Organization,
executing agency for the United Nations Development Programme

Based on the work of Abd Elrahim Marei, expert
in gypsum mining and processing

United Nations Industrial Development Organization
Vienna

id.77-7488

Explanatory notes

References to dollars ($) are to United States dollars, unless otherwise stated.

The following exchange rates are used in the conversion of country currencies to United States dollars:

Country	Currency	Exchange rate per US dollar in 1977
Cyprus	Cyprus pound (£C)	0.413
Jordan	dinar (JD)	0.333
Kuwait	dinar (KD)	0.288
Saudi Arabia	Saudi riyal (SRls)	3.52
United Arab Emirates	United Arab Emirates dirham (U.A.E.D.)	3.95

References to "tons" are to metric tons, unless otherwise stated.

References to "gallons" are to United States gallons; one United States gallon equals 3.785 litres.

The following forms have been used in tables:

A dash (-) indicates that the amount is nil or negligible.

n.d. indicates that the data are not determined.

Totals may not add because of rounding.

The following economic abbreviations are used in this publication:

f.o.b. free on board

c.i.f. cost, insurance, freight

c.f. cost and freight

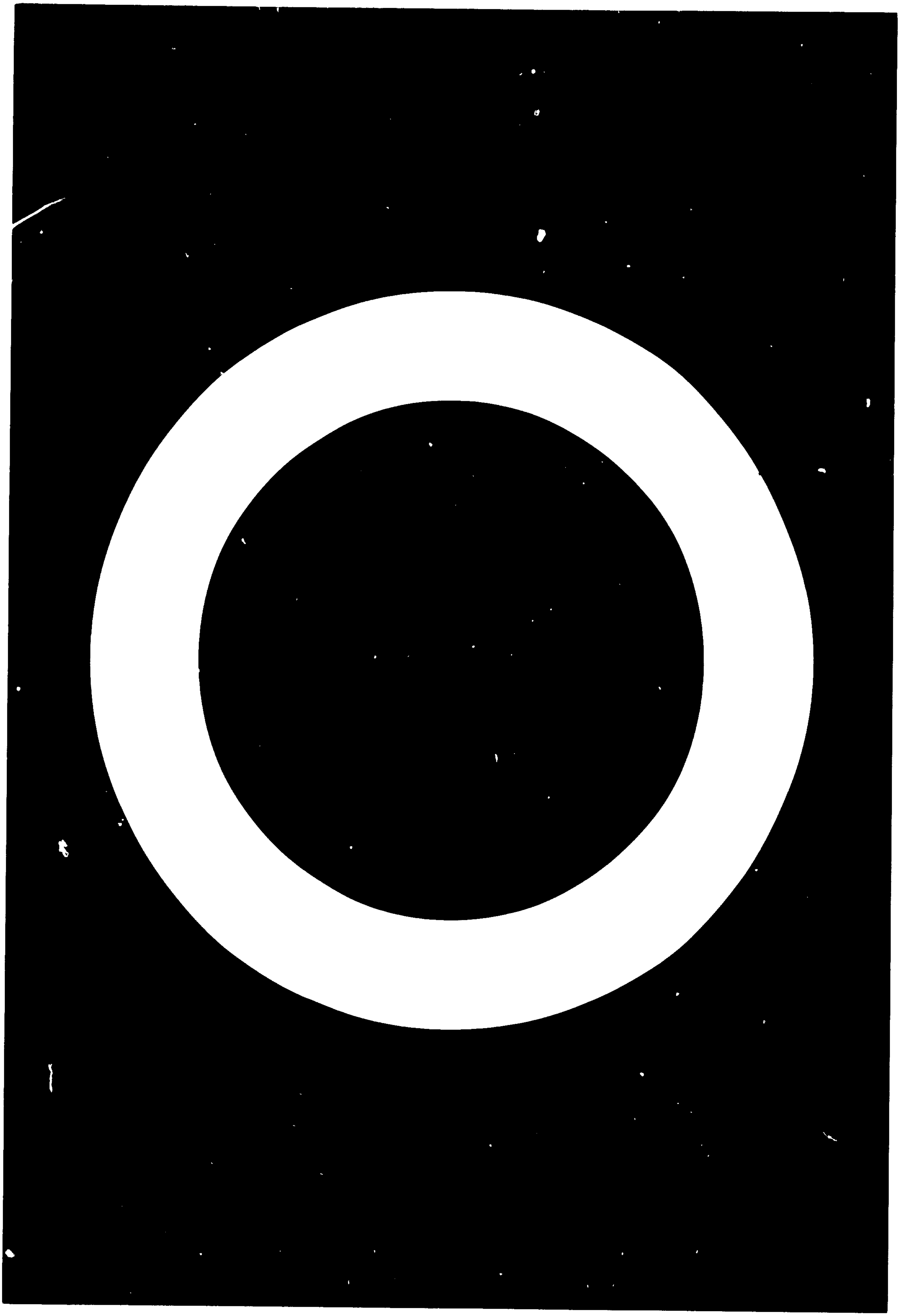
ABSTRACT

This is the report of a mission to Jordan constituting the United Nations Industrial Development Organization (UNIDO) project "Gypsum mining and processing" (TS/JOR/76/001). The Public Mining Co. Ltd (PMC), Amman, was the counterpart agency.

The period of the mission was from 1 September 1977 to 7 October 1977.

There appear to be sufficient reserves of gypsum in the Zarqa River area to support a large-scale mining operation. An analysis of the quality of the gypsum shows it to be high enough to make Jordanian gypsum a marketable quantity. This report considers the markets for Jordanian gypsum and presents financial studies of two methods of gypsum production and two methods of plaster of Paris production. The manufacturing procedures and equipment required for each method are described. Further proposals are made for the production of mixed cement and for the simultaneous production of sulphuric acid and cement. The possibility of using shale-oil from shale deposits in the Lajjan area is also discussed.

Before extensive gypsum mining and processing can start, however, accurate large-scale maps need to be drawn, and the exact extent of the deposits and analysis of the gypsum should be determined.



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This is the report of a mission to Jordan constituting the United Nations Industrial Development Organization (UNIDO) project "Gypsum mining and processing" (TS/JOR/761/001). The Public Mining Co., Ltd. (PMC), in Amman, was the counterpart agency.

The period of the mission was from 1 September 1977 to 7 October 1977.

The PMC was established on 12 May 1975 by the Government which owns 51% of its shares. The main activities of the Company are mining, beneficiating and marketing industrial rock and non-metallic minerals such as gypsum, clay, glass-sand, feldspar, tripoli, travertine, marble and limestone.

The expert's main task was to prepare a development plan and report on the mining and processing of gypsum from the Zarqa River, northwest of Amman. He visited the clay (kaolin) deposits at Mahes and the sand quarry in the same area. He also visited the marble deposits that the Company intends to work.

A complete report was made on the marble deposits but, owing to lack of time, not on the kaolin deposits. Based on his experience, and after much discussion with the staff at the PMC and other companies, the expert made two proposals for developing Jordanian industry: the first, to use the sand for the production of mixed cement; the second, to use the gypsum for simultaneous production of sulphuric acid and cement.

Properties and uses of gypsum

Only a very small proportion of the gypsum produced is used in the crude state. From 5% to 8% of ground gypsum is added to Portland cement to retard its setting time.

Pulverised gypsum, and to some extent gypsum and anhydrite, are applied to the soil as conditioners and fertilizers (land plasters). These materials are of special value in the growing of peanuts, alfalfa, peas and beans. In addition to providing sulphur they promote the assimilation of potash from the soil and they react with unwanted sodium carbonate ("black alkali") deposited by some irrigation waters to form harmless calcium carbonate and sodium sulphate.

Small amounts of raw gypsum are finely ground and used as insecticide carrier, as filler, and as nutrient in the growing of yeast. However, the chief use of gypsum, as plaster, depends on a unique property: when heated to about 175°C gypsum loses three quarters of its water of hydration. On cooling, the resulting hemihydrate (calcined gypsum or plaster of Paris) can be mixed with water and spread, cast or moulded, whereupon it sets to a dense mass of intergrown needle-like crystals. Records of the first use of gypsum plaster are lost in early history. The Egyptians used it on the walls of tombs and it has been utilized for one purpose or another by every civilization since that of ancient Egypt.

Today more than 95% of the gypsum produced is calcined and nearly all the product is used in making gypsum plaster, lath and plaster, and wall board. The welfare of the gypsum industry is thus closely tied to that of the construction industry.

Gypsum plaster, mixed with a fine aggregate such as sand or expanded perlite, is applied as an interior coating to lath, concrete blocks or other backing. A fibre, commonly animal hair, is mixed with the plaster for strength and a retarder is added to extend the setting time to two hours or more.

Retarders are dispersing or deflocculating agents which mechanically hinder the crystallization of the plaster. The most common one is glue made of hoof-meal or low-grade animal hair. Accelerators are coagulators or setting agents that aid crystallization. Among these are potassium sulphate, alum and common salt. The development of retarders and accelerators has been an important factor in increasing the industrial uses of gypsum. The finest grades of white gypsum plaster are used in special applications - ceramics, moulding, dental work and statuary. The post-war construction boom greatly increased the demand for prefabricated gypsum products, especially wall board, sheathing board, lath and tile. These are manufactured in many countries.

The main uses of the plaster of Paris are as follows:

Plastering interior walls and ceilings
Decorating and ornamenting walls and ceilings
For acoustic and decorative ceilings and wall panels
Manufacturing gypsum partition walls
For gypsum cardboard panels

- Reclaiming agricultural land
- For medical purposes
- Manufacturing moulds for sanitary ware and various other purposes
- Casting reinforced roofs (in this case the roofs covered by a thick layer of tar)
- Manufacturing white and coloured chalk
- Manufacturing paints and other chemical products

Advantages of gypsum

Gypsum plaster offers the following advantages:

- No shrinkage when set and dried
- Sets hard quickly to permit continuous production, without needing drying periods between coats
- Attains maximum strength on drying
- Application is independent of weather conditions
- Has high fire resistance
- Absorbs and insulates against sound
- Provides insulation against heat and cold, and so may be used in both hot and cold countries
- Its whiteness can be overpainted with any paint colour
- It is durable and less expensive than most other building materials

Other forms of gypsum plaster include Juss, rough-cast powder and gypsum ores.

Juss is a gypsum of inferior fineness and purity. It is used for plastering the interior walls and ceilings of cheaper dwellings.

Rough-cast powder (crystal) is used externally for plastering buildings. It is distinguished from similar materials by its whiteness and property of sticking and drying. Moreover, compared with other forms, it needs a smaller quantity of cement in the rough-cast mixture.

Gypsum ores are used for reclaiming agricultural land, particularly land with a high saline content. Such ores are used in cement manufacturing as a retarder in a proportion of 3% to 7%.

1. FINDINGS

A. Market

1. World

The United States of America is the largest gypsum producing and consuming country, with 20% and 28% respectively of world totals in 1975. Other leading producing countries include Canada (12% of world production), France (10%) and the Union of Soviet Socialist Republics (8%).

The United States gypsum industry is large and well-integrated, and is dominated by a few major companies. Crude gypsum production is centred in three areas: the Great Lakes, Texas/Oklahoma and California. Gypsum products are made chiefly in the Great Lakes, Texas, California, New York and Florida. Five companies produce almost three quarters of the total United States crude gypsum output. The same five companies also account for 87% of the gypsum products sold.

The estimated United States production of crude gypsum in 1976 was 10.6 million tons and this probably increased by 10% in 1977. It is predicted that 15 million tons will be produced in 1985, and possibly 20 million tons by the end of the century. Recently, imports from Canada (Nova Scotia) have supplied about 30% of overall demand. In the first six months of 1976, 2.7 million tons were imported, compared with 2.4 million tons imported during the same period in 1975. The representative price of crude gypsum in 1975 was $4.85.

Almost one third of the sales of gypsum products by the United States consisted of uncalcined items. Just under 70% of this amount was used in the manufacture of Portland cement. In the first six months of 1976, 1.5 million tons were sold for this purpose. The cement industry demand for uncalcined gypsum could reach 10 million tons annually by the year 2000. Most of the remainder of the uncalcined gypsum sold goes into agriculture.

Some 93% of the calcined gypsum sold in 1975 was used for prefabricated products; a further 5% was used for building plaster and 2% for industrial plaster. Experts predict a significant upturn in wall-board consumption. However, gypsum board products are faced with substitution in many applications by building materials such as cement, concrete-steel, lime mortars, wood and fibreboard. In most other areas in which calcined gypsum is used, no suitable substitutes exist.

Maintaining a competitive advantage is a continuing problem, and although the price edge of crude gypsum is extremely important in uncalcined uses, it is less significant in calcined uses. Industrial research efforts thus generally aim at product development and utilization rather than at mining and milling improvements. Although mining and processing methods are relatively simple and well established and major changes are not expected, a possible development is the greater application of ore-beneficiation practices to low-grade deposits that are located close to gypsum product markets. The greatest developments will occur in the area of utilization, where the competitive pressure of other materials will require products that are improved and adapted to changing building practices.

In several countries, gypsum is recovered and refined as a by-product from chemical plants. In the United States, vast quantities of by-product gypsum have been recovered at fertilizer plants.

United States demand for gypsum is expected to reach 26 million tons in 1985 and some 39 million tons by the end of the century. This would represent a growth rate of 2% annually. World consumption of gypsum is projected to be 93 million tons by 1985, and to reach almost 125 million tons by 2000. Domestic and foreign resources and reserves of gypsum are adequate for any forseeable period: world resources are conservatively estimated at 2 thousand million tons, of which the United States has 350 million tons. Although the domestic resources of the United States are enormous, there are no large deposits near the seacoast where plants tend to use gypsum imported mainly from Nova Scotia.

2. Middle East

Suppliers

Cyprus

Cyprus is a net exporter of industrial gypsum, or plaster of Paris. In 1953, 102,140 tons of gypsum were exported, which was then a relatively large amount. Of this quantity, 7,420 tons was exported to the Middle East.

From 1953 on, the quantity of gypsum exported decreased steadily. The quantities of gypsum exported in 1962 and 1963 were as shown below.

Item	1962		1963	
	Quantity (tons)	Cost (£C)	Quantity (tons)	Cost (£C)
Industrial gypsum	1,905	6,990	1,532	5,345
Raw gypsum	35,099	35,099	45,352	36,197

The Saudi Arabian market was opened to Cypriot gypsum in 1952, when it absorbed 2,875 tons of gypsum. After that the Saudi Arabian market was more or less closed. In contrast, the Kuwaiti, Lebanese and Sudanese markets are still importing Cypriot gypsum.

There are two companies in Cyprus engaged in gypsum exporting:

1. The Gypsum and Plaster Board Company, a branch of the Hellenic Mining Company. This company is responsible for about 75% of the total Cypriot industrial gypsum exports, and uses two kettles for gypsum production.

2. Limassol Chemical Products. This company is responsible for the remaining 25% of the total Cypriot industrial gypsum exports. Its production depends on ordinary, primitive shaft kilns.

The best industrial Cypriot gypsum produced is reddish in colour due to the presence of iron oxide impurities. Its setting time ranges from 3 to 9 minutes. The chemical analysis of two samples is given below.

Mineral	Sample 1	Sample 2
	(Percentage)	
CaO	33.02	32.84
SO_3	45.10	44.35
SiO_2	0.13	0.22
$Fe_2O_3 + Al_2O_3$	0.08	0.13
MgO	0.21	0.14
Water of crystallization	20.64	21.20
CO_2	0.69	0.47
Total	99.87	99.35

Federal Republic of Germany

Although there have been some offers for gypsum from the Federal Republic of Germany by Kuwait and some Gulf States, its relatively high price prevents it from being competitive.

Iran

Small quantities of Iranian gypsum are exported to Kuwait and the Gulf States. Because of its location Iran prefers to export its gypsum to nearby Kuwait. It is expected that the quantity exported to these countries and especially to Kuwait, will increase when a new gypsum factory is completed. Iranian gypsum is of fairly high quality. Its only defect is its long setting time, which reduces its appeal in the Middle East.

Iraq

Iraq exports its gypsum to the Gulf States and Kuwait. The gypsum is competitively priced, although its quality is not as good as the other gypsum bought in these markets. The gypsum is transported from Iraq by trucks, a journey of about two days. Iraqi gypsum production has been increasing since a new factory was erected.

Lebanon

Lebanese exports of gypsum to the Gulf States were interrupted by the recent civil strife in Lebanon. Gypsum exports are expected to pick up. Lebanese gypsum is of medium quality and is exported by large trucks. The truck journey takes about three days.

Romania

Romanian gypsum is expected to enter the Arabian market because of its quality and competitive price, particularly if the Egyptian and the other high quality gypsum open up a market for such gypsum in these countries.

Saudi Arabia

The National Gypsum Company (NGC) is responsible for the exploitation of a white and rosy gypsum in the central area of Saudi Arabia. Commercial production started in 1963. The plant was established by the Benno-Schilde Company of the Federal Republic of Germany as a turnkey plant.

The plant consists of a high-power crusher, a rotary kiln with a capacity of 120 tons/day, several silos each with a capacity of 200 tons, two mills and an automatic packing machine.

The output capacity was doubled during 1970, when a second rotary kiln was added. NGC is a public stock company capitalized at SRl 12 million. The factory has a modern laboratory for testing raw materials and finished products.

The main products of NGC are as follows:

Plaster of Paris

Juss

Rough-cast powders

"Echostop" acoustic panels (under licence from Gartenmann Company, Switzerland

"Dekora" and "Sentilet" decorative suspended ceiling and wall panels (under license from the SADI Company Italy)

Claustras

Cement floor and wall tiles

Mosaic marble-chip tiles

Cement parapet walls

Cement decorative blocks

The specification of gypsum produced by NGC is compared with the standard DIN 1168 of the Federal Republic of Germany below.

Item	DIN 1 168	NGC specification
Fineness of grain		
Maximum residue on 1.2 mm mesh	15½%	Zero
Maximum residue on 0.2 mm mesh	12½%	1½%
Setting time		
Commencement	8–12 min	5–12 min
Termination	20–60 min	15–60 min
Minimum bonding strength	25 kg/cm^2	52 kg/cm^2
Minimum crushing strength	60 kg/cm^2	142 kg/cm^2
Purity of $CaSO_4 \cdot \frac{1}{2}H_2O$	90%	94%

NGC products cover the local markets throughout Saudi Arabia, and there are some exports to the Gulf States and Kuwait. Yearly sales increased from a modest SRl 691,368 in 1963 to SRl 5,155,287 in 1970. The annual NGC production of plaster of Paris, Juss, and rough-cast powder (crystal) is about 50,000 tons. About 7,500 tons of gypsum are exported to Kuwait and the Gulf States; this quantity represents about 32% of the total annual production. Although Saudi Arabia exports gypsum, it has been importing gypsum plaster. This is due to the distance between the NGC plant and the main market centres, such as Ad Damman (500 km). After 1974 the quantity exported to Kuwait and the Gulf States decreased.

Importers

The total quantity of gypsum imported by the Gulf States from all countries is 10,000-15,000 tons. Saudi Arabian gypsum is preferred, for the following reasons:

(a) The strong relationships and proximity of the countries;

(b) Saudi Arabian gypsum has been bought in the Gulf States for a long time, the Gulf State consumer is thus familiar with the product and tends to prefer it to other gypsum;

(c) The easiness of transport from Riyadh, in Saudi Arabia, by large trucks.

Thus, if there is no deficiency in production or quantity, Saudi Arabian gypsum has a definite edge in the Gulf State market, thanks to its whiteness, high quality and accessibility. However, Saudi Arabian gypsum is the most expensive sold in the Gulf States: a typical sack is priced U.A.E.D. 35-40, while other qualities are sold for U.A.E.D. 22-30, depending on the specific type.

The reasons why gypsum imported from other countries does not compete successfully with Saudi Arabian gypsum are: (a) the distance between exporting countries and the Gulf States means, for example, that Egyptian gypsum takes from five to seven months to arrive; the quality of gypsum is often changed by this delay: the gypsum may be damaged by the humidity of the atmosphere and other causes; and (b) the long period between loading and dispatching may cause the gypsum sacks to be damaged; losses due to such damage may exceed 30%, and repacking gypsum is made expensive by the high prices of sacks and the high labour charges.

Prices. Price competition is very sharp, since every importer is attempting to establish himself. In the Gulf States, clients prefer the gypsum to be delivered to their stores owing to the problems arising at ports when ships arrive late. Egyptian gypsum is sold f.o.b. Some countries, such as Cyprus, Greece and Iran, prefer to send their gypsum c.f. The 1977 gypsum price c.f. was in the range of $75-$85/ton, depending on type, transport and packaging.

United Arab Emirates

The Islamic Bank has started to erect a gypsum plant at Dubai, after geological studies proved the presence of sufficient reserves. Some primary experimental studies were done, and the gypsum proved to be acceptable. A Japanese proposal is now under study. Another gypsum plant is planned at Al -Ain, Abu Dhabi after the erection of a cement factory. There are considerable reserves of gypsum ore in Abu Dhabi and the gypsum importers are encouraging the erection of such a plant.

The following analysis of a sample from the Al-Ain district of Abu Dhabi shows that pure gypsum is present with a moderate anhydrite content:

Item	Percentage
Uncombined water	0.26
Combined water	17.26
Sulphite (SO_3)	47.52
Calculated gypsum content ($CaSO_4 \cdot 2H_2O$)	82.5
Calculated anhydrite content ($CaSO_4$)	15.6
Total gypsum and anhydrite	98.1
Rest	1.9
Total	100.0

Although the quality indicated by this analysis is high, the reserves of gypsum must be calculated before any decision is taken to erect a plant, as the reserves need to be sufficient to serve both the cement and gypsum production.

Exporting gypsum to the Gulf States will be increasingly difficult for the following reasons:

(a) Plastics that replace gypsum decorations are being favoured by consumers for their lightness and effectiveness;

(b) The presence of gypsum ore reserves in the Gulf States;

(c) The difficulties of transporting gypsum by sea (e.g. from Cyprus, Egypt and Romania. The transportation of gypsum by small ships within Kuwait harbour is hampered by the severe monsoon storms, especially in summer.

The following companies import gypsum into the Gulf states:

The Jordanian Organization for General Commerce

Home of Decoration

El Satary

El Latabah

The Abu Dhabi Company for Building Material

Kuwait

Kuwait is an open market with a very commercial environment, since Kuwait imports most of its industrial and agricultural requirements. Kuwait needs gypsum, and it consumes a good proportion of the gypsum exported by several countries including Cyprus, Egypt, Iran, Iraq, Japan and Saudi Arabia.

Kuwait's gypsum consumption ranges from 25,000 to 30,000 tons/year. The gypsum is mainly used for the decoration of buildings and for the adhesion of marble. It is not used in plastering interior walls and ceilings since paper or prepared wood are preferred. Kuwait importers usually like goods to be sent c.f., as all ports (Shuwakha, Shehebi, Elahmadi) are crowded with ships the year round. Most ships wait for at least 2-3 months, which has a very harmful effect on the gypsum because of the humidity, which is very high in Kuwait. It should be noted that the consumer needs to be able to receive particular types of gypsum on a continuous basis so that he can use uniformly coloured and cohesive gypsum throughout the decoration or plastering of a building. It is also important that packing should be perfect in order to avoid gypsum losses during the long period of transportation and handling. High quality kraft paper, or perhaps plastic ply, should be used to prevent damage due to humidity. Gypsum exported to the Kuwait market must be of the best quality in order to be competitive. It must have a high percentage of hemihydrate. Some advertising would help gypsum marketing in Kuwait.

Kuwaiti imports of gypsum from Iraq range from 10,000 to 12,000 tons/year. It is transported by trucks directly to the stores. Transportation time ranges from 8 to 10 hours. The four-ply kraft paper bags used hold 35 kg.

In the first six months of 1976, about 2,000 tons of medium quality gypsum (as regards fineness, whiteness and setting time) was imported from Iran. No gypsum was imported during the last six months of 1976. However, imports should have resumed in 1977 after the erection of a new gypsum plant in Iran. Iranian gypsum is packaged in four-ply kraft paper. It is transported by small boats, and can thus be unloaded within a day, avoiding the delays usually experienced by large boats.

Japanese gypsum is whitened by adding calcium bicarbonate to it; this improves its whiteness, but decreases its setting time. The gypsum is packed in 25-kg polyethylene (plastic) bags covered with four-ply kraft paper, which minimizes losses. The journey from Japan to Kuwait takes three months or more. The price is quoted c.f. About 2,000 tons of Japanese gypsum are imported to Kuwait per year.

Cypriot gypsum is packed in 33 1/3 kg plastic bags covered by four-ply kraft paper. Its whiteness is similar to that of Egyptian gypsum. The journey from Cyprus to Kuwait ranges from 15 to 20 days. About 5,000 tons were imported in 1976.

The price per 33½-35 kg plastic bag of the Cypriot, Egyptian, Iranian and Iraqui gypsum ranges from KD 1.15 to KD 1.35 ($4.6 to $5.4). When there is a shortage of gypsum on the Kuwaiti market, the price may rise above KD 2.00 ($8). However, when there is a glut in the market the price decreases to KD 1.00 ($4). The price per bag of Japanese gypsum is only KD 0.70 ($2.8), partly because of the lower weight per bag (25 kg instead of 33 1/3-35 kg).

The following companies import gypsum into Kuwait:

Nake and Wazzan Company
Anwar el Fteki Company
El Maarifi and Building
Mahmoud Ahmad Nayfoni
The Arabian Building Materials Company
Agnadin Company

Eid el Amir el Turky

Essa + Eid al Bahman

Abd el Mouhsen el Harami

Momen Nader Rageh

The Kuwait Cement Factory (this company takes over 3,000 tons of raw gypsum per month.)

3. Africa

Kenya

Kenya produces about 3,000 tons of gypsum per year. This gypsum is used for construction, for building and as chalk. Kenya probably will not have ability to export gypsum in the near future, as cement production depends on gypsum imported from the United Republic of Tanzania and on native gypsum. Kenya may thus be considered a potential ore market.

Somalia

Gypsum ore is found in Somalia in large quantities as a mixture of gypsum and anhydrite. However, the gypsum industry is unlikely to develop as there is probably a lack of fuel. This market needs further study and attention.

South Africa

South Africa is second among the gypsum-producing countries of Africa (Egypt is first). It produces low-grade gypsum ore which needs special processing, such as washing, in order to reach 80% purity. South African exports go to Malawi, Mozambique and Rhodesia. South Africa imports little gypsum ore.

Sudan

Gypsum ore is found in some areas 40 km north of Port Sudan, where some local companies intend to erect a gypsum plant with a capacity of 50 tons/day. However, Sudan is still considered to be a gypsum importer, as Port Sudan is far from the market centres, and the transportation costs are very high.

United Republic of Tanzania

Tanzanian exports go to Kenya and Uganda. The quantity exported is about 15,000 tons/year. The ore is of low quality, containing not more than 78% of pure gypsum.

Northern Africa

Algeria, Morocco and Tunisia all produce industrial gypsum for internal use. The Libyan Arab Jamahiriya has been an importer of gypsum.

Western Africa

No major gypsum industry is expected to develop here, although the Anglo company is producing gypsum; its production capacity is about 3,000 tons/year.

B. Gypsum in Jordan

Three major gypsum deposits have been identified in Jordan:

(a) Blake and Ionides described gypsum deposits of minable thickness at the northern and southern sides of Wadi Kerak, between Kerak and Dra'a; a 2-3 m thick layer of gypsum was exposed, with the deposits extending for several kilometres in the chalk-marl succession of the Cenomanian;

(b) Ruef and Jeresat recorded gypsum with an overall thickness of 15 m west of the road crossing Wadi Hujib, distributed in beds up to 1m thick within 70 m of the shale-marl-chalk succession of the lower echinoid limestone member (Cenomanian);

(c) Blake and Ionides also found massive gypsum belonging to the Triassic succession exposed in a thickness of about 30 m near the confluence of the Wadi Huni and the Zarqa River.

The only gypsum deposit visited by the expert is the one at the Zarqa River. This report is devoted solely to this deposit. The expert was shown a very high quality crystalline gypsum sample from this deposit.

The gypsum deposit examined forms the low part of the El-Subeihi Hills to the north-west of Amman. The Hills occupy the north-western area of Jordan and lie to the north-east of the Dead Sea. This area is covered by the Amman topographic sheet, which was published on a scale of 1:25-250,000 by the Agronomy and Surveying Department in 1947.

A plane-table mapping of the morphology and topography of the area was carried out by the Public Mining Co., on a scale of 1:1000.

It is recommended also to map the geology of the gypsum deposit area either on the same map mentioned before or on another map with scale 1:2000 or scale 1:500.

Location and communications

The El-Subeihi gypsum deposit lies about 50 km to the north-west of Amman. An asphalt road links Amman with a road to Suweilih (10 km), Subeihi village (a further 22 km) and then Seyhan and Jarreesh (a further 13 km) where the gypsum transported from the quarry is piled. From Jarreesh, a desert road leads to the north and then to the west in the direction of the Zarqa River, where the gypsum deposits are located. The distance between Seyhan and the gypsum deposit is 5 km. The desert road is rough and very hard.

The gypsum area is bounded by the following four co-ordinates:

North	East
177.000	217.400
176.300	217.400
176.300	220.400
177.000	220.400

As the main consumer of the ore is the Jordan Cement Company at El-Fuhais, the main ore transportation route is a desert road from the quarry via Suweilih village to the cement company.

Climate and water supply

The following meteorological averages apply to the area for the period 1966-1975.

Rainfall

Average yearly rainfall	292.7 mm
Highest amount of rainfall in month	235 mm (January)

Temperature

Absolute maximum during the year	41.5°C (July and August)
Absolute minimum during the year	-0.5°C (January)
Monthly mean	16.3°C

Relative humidity

Monthly mean	53%

Wind speed

Monthly mean	6.2 knots
Highest wind speed	69 knots (Amman Airport, January)

The area has very little rain. Some rain usually falls during winter, producing enough water to compensate for that lost by soaking into the wadi alluvium; this water flows on the surface towards the Zarqa River. However, every year heavy showers accompanying thunderstorms also occur. After such heavy rainfall the supply of the river is enormously increased and the quality of water is considerably improved. Some seepage of water occurs in places.

The Zarqa River lies very near to the gypsum quarry at the foot of the northern part of the gypsum deposit. It is normally very small and drains into the River Jordan which lies to the west. The water flow of the Zarqa River is about 2 m^3/sec in the dry season. Water supply will be improved when the King Tallal dam is finished, probably during 1977. The lake formed behind this dam will collect the excess water of the rainy season. This water will be used for irrigation, but with sufficient quantities available for industry and quarrying in the area. The Tallal dam does not at present supply any electric power.

Topography

The area under investigation covers about 10 km^2. It is hilly and mountainous with heights ranging from 100 to 1000 m. There are two main mountains, one with an elevation of about 1000 m, and the other 451 m. The main wadi in the area is at the Zarqa River, which runs from east to west along the northern part of the map.

A narrow wadi runs through the middle sector from south to north, draining the southern sector of the area. The northern sector is drained by three or four very narrow tributaries to the Zarqa running from north to south.

Geology and structure of the Zarqa gypsum deposit

Gypsum carries no fossils and, despite minor differences in texture and composition, gypsum from one deposit is much the same as that from another. The associated rocks are restricted to other evaporites, carbonate rocks and shale. Gypsum is widespread in occurrence, so that only deposits that are readily accessible, flat-lying or nearly so, and at or near the surface, are quarried.

The gypsum deposit at Zarqa was observed to crop out in the form of grayish-white beds along the low-lying parts of the area; the area is covered in many places by wadi wash or shale and then by sandstone or limestone. The thickness of these beds ranges from 20 to 50 m.

The thickness of a section of the gypsum bed observed in the field exceeded 50 m, as the outcropping of the main bed was more than 20 m, and a bore hole drilled at the base of this outcrop penetrated through gypsum to a depth of 30 m. The base of this gypsum bed was not reached, which indicates that the thickness of the gypsum was at least 50 m (assuming that the borehole was not drilled in a slide block). At the foot of the mountain where the Zarqa River passes it was found that the gypsum beds alternate with greyish shale beds. The whole mountain face, especially that by the gypsum outcrops, was covered by wadi debris, the main constituents of which were gypsum rocks. Some of these gypsum rocks were massive and hard. The gypsum is massive, with a greyish colour, which in some cases changes to black at the bedding planes. This black colouration is due to the presence of organic matter remnants. The gypsum contain lenses of soft dark limey clay, and is penetrated by many deep sinkholes and fissures, most of which are filled with shale, clay or alluvial marl.

Debris covers most of the area investigated and this makes it impossible to observe any definite contacts of the layers forming the main rock units (described below). Debris originates mainly from Jurassic limestone, marls, clays, and the lower Cretaceous sandstone. It is formed of rounded cobbles, pebbles, limestone-quartz grains and rounded fragments which are derived from the rock units exposed in the area.

Unsorted recent sediments are deposited in the wadis, consisting mainly of blocks, boulders, and gravels of sandstone, limestone and gypsum, together with sand and mud.

The area under study is situated in the vicinity of the Jordan rift and so it has been strongly affected by structural movement connected with the formation of the Rift Valley. Faulting thus dominates the area. These faults always traverse the area, but, owing to the lack of marker horizons in the rocks of the area studied, it is difficult to identify the faults and their relative movements. There is, however, a minor surface expression of faults in the thick soil cover that develops on the rock units.

Major dips are gentle - generally 10°, mainly to the west. However, at the the western part of the area under study the gypsum shows steep dipping ranging from 30° to 40° to the west. The dipping noted in the field is due to tectonic changes during the early geological periods.

It was stated in a geological report on oil and gas prospects in Jordan (F. Bender, June 1967) that the most extensively exposed rocks in Jordan (including the area investigated), are the upper Cretaceous sediments. These sediments constitute most of the West Jordanian Highlands, as well as most of the Northern Highlands east of the Rift; they cover almost the entire Central Jordanian Plateau as far as the Ras en Naqb escarpment.

The upper Cretaceous sediments begin in the west - and north, north-east, and central - areas of Jordan, and are marked by a fully marine sedimentation which, in contrast to that of the lower Cretaceous, does not contain any coarse clastics.

Alternating limestone, dolomitic limestones, nodular limestone, marls, shales and some chert of marine origin were deposited on top of the lower Cretaceous, while in south-east Jordan the deposition of the varicoloured sandstone continued in a continental environment. The marine nodular limestone unit (= lower portion of Quennell's "Ajlun Group") may exceed a thickness of 450 m in west Jordan; close to the Rift in east Jordan (on the lower course of the Wadi Mujib) it was found to be approximately 300 m, and from there towards south and south-east its thickness decreases to less than 70 m (at Ras en Naqb). Owing to its abundant fossils, the unit is assigned to the Cenomanian stage (Blanckenhorn, and others).

The nodular limestone unit is followed by the echinoid limestones, a mappable unit of alternating thick- and thin-bedded limestones, dolomitic limestones, marly limestones, marls and some shales, with gypsum layers (middle and upper portion of Quennell's "Ajlun Group"). It is approximately 210 m thick in the Zarqa River area, and may be thicker to the west and thinner to the south and east. The upper third of the echinoid limestones shows an increasing sand content as one goes south and south-east from the Wadi Mujib area. According to fossil evidence, the lower part of the echinoid limestone is of the Cenomanian stage, while its upper third, inclusive of its lateral facies equivalent, is the sandy limestone unit. This unit is 780 m thick south of Wadi Mujib, and is placed in the Turonian sandstones.

Several main units are identified in the "Report on the Gypsum Occurrences at Wadi El Huna-Wadi El Azab in the Zarqa River Area" (National Resources Authority). These are the red-spotted grey limestone unit, the brown sandstone unit, the blocky limestone unit and the spotted sandstone and dolomite sandstone unit. The report expresses some doubts that the area is of Triassic age.

Red-spotted gray limestone unit (gypsum-bearing unit)

This unit is restricted to a narrow strip parallel to Zarqa River. It appears and outcrops at the lowermost slope in the east and west sections of Wadi El-Huna. This bed consists of grey-blue thin-bedded limestone and yellowish marl as indicated in the type section. The gypsum deposits are in the form of massive cracked strata with marl and clay intercalations. The dpoisit is not very well exposed as the lower contact is not visible and the upper contact is covered by very thick soil and overburden. The report estimates the thickness of this unit as about 70 m.

Brown sandstone unit

This unit overlies the red-spotted grey limestone unit and outcrops along a narrow strip parallel to the Zarqa River. It consists mainly of yellowish brown, hard, coarse-grained sandstone and is weakly cemented at the lower part. The upper unit is brownish in colour, friable, medium-grained sandstone. The lower contact is defined by the change from light-grained bedded limestone to yellowish-brown sandstone. The upper contact is situated where the brown sandy dolomite is overlain by thick-bedded grey limestone. The thickness of this unit is given as approximately 40 m.

Blocky limestone unit

The limestone forming this rock unit ranges in colour from light brown to pink-brown. It is dense, hard, compact, porcelain-like and conchoidally fractured when broken. The thickness of this unit is approximately 50 m.

Spotted sandstone and dolomite sandstone unit

The lower portion of this rock unit is formed of a yellowish-brown, hard, dolomitic and medium-grained sandstone. The report attributed the dolomitic matrix that forms the cementing material to quartz grains, which are possibly restricted to the surface. The lower and upper portions of this unit are separated from each other by means of a friable sandy and dolomitic layer. The thickness of this layer is about 50 m. The upper portion of this unit consists of sandstone, which is of light yellowish colour, friable and loosely cemented, and medium-grained. The spots found in this unit are due to the presence of iron oxide. The total thickness of the unit is approximately 70 m.

Extent of gypsum deposit

The following terms were used in assessing the extent of the gypsum deposit:

Assured mineral. Ore or deposit of which the mining engineer or geologist can give a definite assurance. It is necessarily a minimun, and not an actual quantity, as statements of assured mineral or deposit are essentially conclusions based upon judgement, and not the result of mathematical calculations.

Indicated reserves. Ore for which tonnage and grade are computed partly from specific measurements, samples or production data, and partly from projections based on geologic evidence. The sites available for inspection, measurements and sampling are too widely, or otherwise inappropriately, spaced to outline the ore completely or to establish its grade throughout.

Inferred reserves. Ore for which quantitative estimates are based largely on a broad knowledge of the geology of the deposit and for which there are few, if any, samples or measurements. The estimates are based on assumptions of continuity or repetition for which there is geologic evidence. This evidence may include comparison with deposits of similar type.

Due to the short visit of the expert, only one borehole was drilled; the only mining works studied were at the quarry, and so the ore reserves were estimated on the basis of outcrops, trenches and the one borehole.

Despite relatively scant information and experimental evidence, there appears to be a huge quantity of gypsum in the area.

Further quantitative analysis is necessary (annex I) in order to estimate assured, indicated and inferred gypsum deposits. The evaluation of ore reserves mentioned in the National Resources Authority report is reasonable and has been used as a basis for the following evaluation.

Eastern block (east of Wadi El-Huna outcrop)

Indicated reserves

Area of deposit	6,750 m^2 (estimated)
Average thickness	35 m (estimated)
Specific gravity	2.32 (measured)

Indicated reserves (specific gravity x area x thickness) in this block are thus 548,100 tons.

Inferred reserves

Area of the deposit	45,000 m^2 (estimated)
Average thickness	35 m (measured)
Specific gravity	2.32 (measured)

Inferred reserves are thus 3,654,000 tons for the eastern block.

Western block (west of Wadi El-Azab outcrop)

This block is divided into a southern and a northern part by a fault running from east to west.

Southern part

Indicated reserves

Length	425 m (estimated)
Width	15 m (estimated)
Thickness	35 m (measured)
Specific gravity	2.32 m (measured)

Indicated reserves for this block are thus 517,650 tons. This quantity could be twice as high, since the width may be as much as 30 m, so the assured reserves are 1,035,300.

Inferred reserves

Length	425 m (estimated)
Width into the hill	50 m (estimated)
Thickness	35 m (measured)
Specific gravity	2.32 (measured)

Thus 1,725,500 tons inferred reserves have been established for the southern part of the western block.

Northern part

Indicated reserve

Due to lack of trenching in this area, indicated reserves could not be estimated.

Inferred reserves

Area of deposit	84,375 m^2 (estimated)
Thickness	10 m (estimated)
Specific gravity	2.32 (measured)

Thus 1,957,500 tons inferred reserves have been established for the northern part of the western block. The total inferred reserves in the western block are as follows:

1,957,500 + 1,725,500 = 3,683,000 tons

The indicated reserves are thus as follows:

548,100 + 1,035,300 = 1,583,400 tons

These quantities could prove to be twice or even thrice as large after the drilling and trenches are completed.

As the gypsum extends underneath the Triassic sandstone unit, this rock could serve as a cap rock for underground mining in the future if there proves to be a sufficiently high demand for this gypsum.

Analysis of gypsum deposit

The gypsum deposits occur at the base of Triassic beds covering olive-green and bluish-gray thin-bedded limestone intercalated with thin marl bands.

The lower contact of the gypsum deposit is not exposed in the area studied. The upper contact also is not well exposed, but only defined by trenches. It consists of marl and ferruginous shaly siltstone. The average thickness of the outcropping gypsum deposit is about 35 m (stated in the report). The deposit is exposed along the Zarqa River in three localities:

East of Wadi El-Huna. This is an area close to the northern edge of the Zarqa River (i.e. north-east of the area investigated).

This outcrop is covered by alluvium and thick soil. The average thickness of the alluvium is more than 14 m. Four trenches were dug in the upper part of this deposit. The bottom contact is inferred. The eastern and western parts of the deposit are not exposed due to faulting.

The results of the chemical analysis carried out by the National Resources Authority are shown below.

Trench number	CaO	SO_3
	(percentage)	
1	31.32	44.69
1	31.86	44.96
1	32.11	45.34
2	32.39	45.03
2	32.18	42.75
3	31.83	44.36
3	37.69	51.30 (anhydrite)
4	32.27	45.62

West of Wadi El-Azab. About one kilometre west of Wadi El-Azab at the southern part of the Zarqa River where the gypsum deposit is located, the gypsum crops out between two faults. The throw of these faults is unknown due to the presence of thick alluvial cover. The lower contact is not visible and the upper contact is characterized by about 2 m of yellow marl. Two trenches were dug in the middle and the upper part of this deposit. The results of the chemical analysis are shown below.

Trench number	CaO	SO_3
	(percentage)	
6	33.91	41.42
6	32.71	40.81
6	31.95	40.62
7	33.98	39.92
7	32.81	44.34
7	31.81	45.56

This area was chosen for quarrying by the Public Mining Company. Quarrying began at the western side of the two trenches mentioned. The quarry is about 200 m from these trenches. Three representative samples were taken from the quarry face, and the results of the chemical analysis of these samples are shown below.

Analysis
(percentages)

Mineral	Sample 2	Sample 1	Sample 3
H_2O	21.75	21.83	23.40
CaO	32.04	32.04	30.96
SO_3	43.33	41.58	40.96
MgO	1.09	1.05	2.94
Na_2O	0.12	0.04	0.04
K_2O	0.04	0.07	0.04
Fe_2O_3	1.35	0.14	0.34
Al_2O_3	n.d		0.13
TiO	0.00		
SiO_2	1.27		

Wadi El-Azab. At Wadi El-Azab, 0.5 km south of the junction of Wadi El-Azab and the Zarqa River, the gypsum outcrop is more likely to be the upper part of the gypsum deposit succession. The thickness of the gypsum outcrop is 3 m. It is grey in colour, covered by 2 m of yellow and light-green marl. One grab sample was taken and analysed. The percentages of CaO and SO_3 were 31.81 and 45.3 respectively.

It should be noted that these results indicate that this sample is a somewhat typical hydrous gypsum sample; however, these data may be misleading unless the other constituents - H_2O and CO_2 - are considered and the percentage of hydrous calcium sulphate in the sample is estimated.

The report also indicated that several grab samples were collected from different localities in the area and sent to the laboratory for chemical analysis and X-ray studies.

The X-ray studies gave the following results:

Gypsum sample number	Results
I	Major gypsum, calcite and minor dolomite
II	Major gypsum, minor calcite and dolomite
III	Major gypsum, calcite and minor dolomite

The results of the chemical analysis of the samples are shown below.

Sample number	SO_3	CaO	K_2O	Al_2O_3
	(percentage)			
I	25.88	22.56	0.0	0.0
II	47.78	34.16	0.0	0.0
III	45.67	33.29	0.0	0.0

Further analysis

The chemical results given in the previously mentioned report of the Natural Resources Authority (although these results are based on very few samples and are not completely analysed) and the expert's visit indicate that this gypsum is of good quality. The gypsum content cannot be estimated exactly, as the percentages of H_2O and CO_2 in the samples were not determined in the analyses given. Therefore, in order to gauge completely the quality and the quantity of the gypsum under study, it is recommended that:

1. A complete network of boreholes be drilled throughout the area under study. The extent of the area to be drilled is to be decided by the exploiter. Drilling will give a better idea of the true thickness of the gypsum deposits.

2. The distance between the boreholes (from east to west)should be in the range 50-75 m from east to west and 20-30 m from north to south. These distances could be doubled if necessary.

3. Deep trenches and pittings should be dug on the gypsum outcrops to show the gypsum beds clearly, especially in the western block. The trenches should be within 50-80 m of each other.

4. The core samples taken from the boreholes should be carefully preserved in special boxes.

5. The complete sections of every borehole and trench should be explained and drawn carefully.

6. Detailed maps of proper scale are needed for the study of the area. These should show the topography and geology of the area.

7. The boreholes and trenches should be located on the newly-surveyed maps.

8. A representative sample taken from a borehole or a trench at every two metres should be analysed.

9. The analysis of any gypsum sample must show the percentage loss on ignition, calcium oxide content, sulphite content, water of hydration and carbon dioxide content; an analysis could also be done of the sodium oxide, potassium oxide, silicon dioxide, aluminium oxide and iron oxide contents. Even just the complete chemical analysis of a representative sample of the gypsum found in the existing borehole or trench would be sufficient.

10. The results of the chemical analysis can be represented on a map with an appropriate scale to show the variation of the chemical changes laterally and vertically. In the same way, the $CaSO_4 \cdot 2H_2O$ content can be displayed by using profile drawings to illustrate any systematic directional variation that exists. These profiles also can show the site where the highest percentage of gypsum is concentrated. The shift from gypsum to anhydrite or to limestone and the relation between these rocks can be demonstrated in this way.

11. The relation between $CaSO_4 \cdot 2H_2O$, $CaSO_4$, $CaCO_3$, NaCl and insoluble residue can be plotted and demonstrated on a chart. The relationship between the corresponding values of these different constituents can be shown, especially that between the anhydrite and calcium carbonate, as there is a good relationship between these two constituents due to one of the minerals replacing the other.

12. Different kinds of representative samples from all types of rock in the gypsum deposit should be carefully studied and examined petrographically. The samples should represent the inclusion of any variation in the mineral constituents, whether vertically or laterally.

13. Some of the previously mentioned samples should be X-rayed and DTA-examined, especially the dolomitic inclusions and hydrite.

From all these data a complete picture of the Zarqa River gypsum deposit can be obtained.

C. Financial study of gypsum production

There are two main methods (annex II) for quarrying gypsum: the first method (A) involves the use of a bulldozer for ripping; the other (usual) method (B) involves the use of a wagon drill and explosives (annex III).

Tables 1, 2 and 3 show the manpower, equipment and fuel costs of the two methods, assuming an annual production of 70,000 tons of gypsum. Using the figures in table 1, the total annual manpower costs can be calculated as follows:

Item	Method A (JD)	Method B (JD)
Annual salary cost of gypsum protion	20,400	29,360
Overtime allowance (10%)	2,040	2,936
Insurance (8%)	1,632	2,349
Annual bonus (one month's salary)	1,700	2,447
Sub-total	25,772	37,092
Supervision (15%)	3,866	5,564
Total	29,638	42,656

A comparison (based on table 2) of the equipment costs of the two methods, including spares for two years, is given below.

Table 1. Manpower costs for gypsum production by methods A and B

Position	Qualifications	Number required A	Number required B	Annual salary (JD) A	Annual salary (JD) B	Percentage devoted to gypsum production A	Percentage devoted to gypsum production B	Value devoted to annual gypsum production (JD) A	Value devoted to annual gypsum production (JD) B
Quarry manager	B.Sc. Engineering or B.Sc. in geology plus at least five years' experience	1	1	3 600	3 600	50	50	1 800	1 800
Foreman	Industrial school plus at least five years' experience	1	1	1 600	1 600	100	100	1 600	1 600
Storekeeper	General certificate of education	1	1	1 200	1 200	100	100	1 200	1 200
Clerk	General certificate of education	1	1	800	800	100	100	800	800
Mechanic	Industrial school plus at least five years' experience	1	1	2 000	2 000	50	50	1 000	1 000
Bulldozer operator	Primary school plus five years' experience	1	1	2 000	2 000	30	10	600	200
Loader operator	Primary school plus five years' experience	2	2	4 000	4 000	60	60	2 400	2 400
Drivers (service truck and car)	Primary school plus five years' experience	2	2	2 000	2 000	100	100	2 000	2 000
Assistant mechanic	Three years' experience	3	3	2 160	2 160	100	100	2 160	2 160
Workers		7	20	5 040	14 400	100	100	5 040	14 400
Guards		3	3	1 800	1 800	100	100	1 800	1 800
Total		23	36	26 200	35 560			20 400	29 360

Note: Salary levels are 1977 estimates.

Table 2. Equipment and building costs for gypsum production by methods A and B

Item	Quantity	Value (JD)	Depreciation (percentage)	Value of annual depreciation (JD)	Maintenance and spare parts (10% of value in JD/year)	Total (JD)	Percentage devoted to gypsum production A	Percentage devoted to gypsum production B	Value devoted to annual gypsum production (JD) A	Value devoted to annual gypsum production (JD) B
Bulldozer	1	80 000	20	16 000	8 000	24 000	30	10	7 200	2 400
Crawler loader	2	70 000	20	14 000	7 000	21 000	80	80	16 800	16 800
Service car	1	5 000	25	1 250	500	1 750	100	100	1 750	1 750
Wagon drill and attachments	1	12 000	10	1 200	1 200	2 400	-	100	-	2 400
Compressor and attachments	1	15 000	25	3 750	1 500	5 250	-	100	-	5 250
Service truck	1	10 000	25	2 500	1 000	3 500	100	100	3 500	3 500
Building and construction	1	30 000	5	1 500	3 000	4 500	100	100	4 500	4 500
Set of quarry tools	1	3 000	50	1 500	-	1 500	20	100	300	1 500
Tanks	3	2 000	20	400	-	400	100	100	400	400
Total		227 000		42 100	22 200	64 300			34 450	38 500

Note: Cost estimates relate to 1977.

Table 3. Fuel, oil and lubricant costs for equipment used in gypsum production by methods A and B

Item	Quantity	Cost of daily consumption per machine (JD)				Total (JD)	Working days		Cost per year	
		Fuel	Oil	Special oil	Lubricants		A	B	A	B
Bulldozer	1	4.0	2.5	1.4	0.6	8.5	75	25	640	210
Crawler loaders	2	4.5	3.5	1.3	0.7	20.0	80	80	1 600	1 600
Wagon drill	1	-	0.2	-	0.3	0.5	-	90	-	50
Compressor	1	1.5	1.3	-	0.2	3.0	-	90	-	270
Service car	1	2.0	1.0	-	0.2	3.2	250	250	800	800
Service truck	1	2.0	1.0	-	0.3	3.3	150	200	500	660
Total									3 540	3 590

Note: Cost estimates relate to 1977, and are taken to be as follows:

Item	Cost (JD)
Solar	0.016 per litre
Benzene	0.060 per litre
Oils	0.550 per kg
Hydraulic oil	0.450 per kg
Lubricant	0.450 per kg

Item	Method A		Method B	
	Part cost	Spares (20%)	Part cost	Spares (20%)
	(JD)			
Bulldozer a/	24,000	4,800	8,000	1,600
Crawler loaders b/	56,000	11,200	56,000	11,200
Service car	5,000	1,000	5,000	1,000
Wagon drill	-	-	12,000	2,400
Compressor	-	-	15,000	3,000
Service truck	10,000	2,000	10,000	2,000
Buildings	30,000	-	30,000	-
Quarry tools c/	600	-	3,000	-
Tanks	2,000	-	2,000	-
Total	127,600	19,000	141,000	21,200

a/ Bulldozer costs are taken as 30% of the total price for method A and 10% for Method B - these are the proportions of time each method would need the bulldozer for.

b/ Crawler loader costs are taken as 80% of the total price for both methods.

c/ Tool costs are taken as 20% of the total price for method A and 100% for Method B.

Table 3 shows the costs of fuels and lubricants required by the project. The costs of explosives (see annex III) are shown below.

Item	Price (JD)
Gelatine	750 per ton (approximately)
Ammonium nitrate powder	120 per ton
Capsules	0.015 each
Safety fuse	0.025 per m

About 100 grams of gelatine will be needed per ton of gypsum produced by method B. The costs per ton will be as follows:

Item	Price (JD)
Gelatine (100 grams)	0.075
Fuse, capsule	0.030
Total	0.105

If ammonium nitrate is used instead of gelatine, the cost of explosives used will decrease by some 60 per cent; some gelatine will also be needed. Thus, using ammonium nitrate, the cost of explosives per ton of gypsum would be JD 0.065, or a total cost per year of 0.065 x 70,000 = JD 4,550.

A calculation of the total capital requirements is given below. The figures are 1977 estimates derived from tables 1, 2 and 3.

	Method A (JD)	Method B
Fixed assets		
Machines and equipment, buildings	127,600	141,000
Spare parts	19,000	21,200
Land	62,000	62,000
Preliminary charges	7,200	7,200
Total fixed assets	215,800	231,400
Working capital (1/3 of annual requirement)		
Salaries	9,900	14,200
Fuel, oil and lubricants	1,200	1,200
Explosives	-	1,500
Rent of land	2,200	2,200
Other expenses	2,000	2,000
Total working capital	15,300	21,100
Total capital	231,100	252,500
Cost of investment		
Interest at 8%	18,500	20,200
Share of one ton of gypsum in cost of investment (÷ 70,000)	0.264	0.289

The annual cost of gypsum ore, calculated from tables 1, 2 and 3 is shown below.

Item	Method A (JD)	Method B (JD)
Depreciation, maintenance and spare parts	34,450	38,500
Salaries	29,638	42,656
Fuel, oil and lubricant	3,540	3,590
Explosives	-	4,550
Price of land (10% of the total price)	6,200	6,200
Rent of land	6,700	6,700
Preliminary charges and other expenses	8,000	8,000
Cost of investment (8% interest)	18,500	20,200
	107,028	130,396
Price per ton of gypsum produced (÷ 70,000)	1.53	1.86

The following should be noted in considering the cost estimates:

1. Inflation is included in the cost of machines, equipment and buildings.

2. The figure given for annual maintenance and spare parts costs includes insurance.

3. In considering the working life of the machines (annex IV), the worst case has been taken - the minimum efficiency at which the quantity of gypsum required can be produced. Production can be increased by over 50% by careful control.

4. The optimal staff level is indicated in table 1.

5. The gypsum ore costs indicated show the costs of gypsum loaded onto the trucks (annex V). The sales price, on board the trucks at the quarry, is taken to be JD 3.40. The net profit per ton of gypsum produced by method A is thus 3.40 - 1.53 = JD 1.87, and the total net profit per year would be 70,000 x 1.87 = JD 130,900. The net profit per ton of gypsum produced by method B is 3.40 - 1.86 = 1.54, for a total annual profit of 70,000 x 1.54 = JD 107,800.

From these calculations method A seems preferable - the ripping method involving a ripper bulldozer with three shanks. The expert has experience of this method in gypsum and limestone production, and feels it to be the best method currently available for the production of soft and medium-hard materials. The big bulldozer recommended here can be used not only for gypsum quarrying, but also for the kaolin, sand and marble quarries of the company on a part-time basis both for production and in removing overburden.

The net profit can be increased by over 20% after the desert road is repaired and asphalted, when the transport tariff will decrease. Trucks will be able to move full loads (30% of the capacity load) direct from the quarry to the cement factory. In the calculations, consideration has been given to the fact that the trucks will carry 80% of the capacity load owing to the quarry being located in a lowland area: trucks will have to cross a mountain with the load against the motor power.

D. Financial study of plaster of Paris production

Manufacture of plaster of Paris

The manufacture of plaster of Paris (annexes VI and VII) is based chiefly on the dehydration of gypsum; the calcination can take place in many different ways, for example, gypsum can be calcinated in ordinary small rotary kilns, like those used in cement production, or in open pans or deep kettles, or under pressure in autoclaves, either with or without water or without pressure in certain salt solutions.

The expert recommends that plaster of Paris production should start at once in Jordan. The Jordanian market can probably absorb about 8,000 tons/year and, as has already been mentioned, Kuwait and the Gulf States would consume large quantities of plaster of Paris made from Jordanian gypsum, which is of high quality and should be able to compete effectively with other imported gypsum. Jordanian plaster of Paris could be transported by means of large trucks, and could reach consumers within a few hours. This would minimize damage to the plaster due to adverse climatic conditions or to repeated handling of the plaster at different places.

Financial study

The calculation which follows is for a plaster of Paris plant with a production capacity of 50 tons/day. There are two main methods of producing plaster of Paris (annex VI). The first method (A) involves the use of an autoclave or kettle to produce plaster with the high quality required in the gypsum and plaster market. The second method (B) involves the use of a rotary kiln with continuous production; ordinary quality plasters are produced.

Tables 4, 5 and 6 show the manpower, equipment and fuel costs of the two methods, assuming an annual production of 15,000 tons of plaster of Paris.

Using the figures in table 4, the total annual manpower costs for both methods (A and B) can be calculated as follows:

Item	Value (JD)
Annual salary cost of plaster of Paris production	36,400
Overtime allowance (10%)	3,640
Insurance (8%)	2,912
Annual bonus (one month's salary)	3,034
Sub-total	45,986
Supervision	4,600
Total	50,586 = 50,600

A comparison (based on table 5) of the equipment costs of the two methods, including spares for two years, is given below.

Item	Method A		Method B	
	Part cost	Spares (20%)	Part cost	Spares (20%)
	(JD)			
Plant equipment	200,000	40,000	80,000	16,000
Buildings	60,000	-	60,000	-
Electrical generator	30,000	6,000	30,000	6,000
Crawler loader[a/]	7,000	1,400	7,000	1,400
Service car	5,000	1,000	5,000	1,000
Truck	15,000	3,000	15,000	3,000
Compressor	3,000	600	3,000	600
Tools	500	-	500	-
Fuel tanks and other tanks	2,000	-	2,000	-
Total	322,500	52,000	202,500	28,000

a/ The crawler loader will serve not more than 20% of its time to heap the gypsum ore into the crusher.

Table 4. Manpower costs for plaster of Paris production by both methods (A and B)

Position	Qualifications	Number required	Annual salary (JD)	Percentage devoted to plaster production	Value devoted to annual plaster production (JD)
Plant manager	B.Sc.Engineering or B.Sc. in chemistry or chemistry and geology plus at least five years' experience	1	3 600	50	1 800
Foreman	Industrial school plus at least five years' experience	1	1 600	100	1 600
Storekeeper	General certificate of education	1	1 200	100	1 200
Clerk	General certificate of education	2	1 600	100	1 600
Mechanic	Industrial school plus at least five years' experience	2	4 000	100	4 000
Loader operator	Primary school plus at least five years' experience	1	2 000	30	600
Drivers (service truck and car)	Primary school plus at least five years' experience	2	2 000	100	2 000
Assistant mechanic and kiln operator	Three years' experience	5	5 000	100	5 000
Workers		20	15 000	100	15 000
Guards		6	3 600	100	3 600
Total		41			36 400

Table 5. Equipment and building costs for plaster of Paris production by methods A and B

Item	Quantity	Value (JD)	Depreciation (percentage)	Value of annual depreciation (JD)	Maintenance and spare parts (10% of value in JD/year)	Total (JD)	Percentage devoted to plaster of Paris production		Value devoted to annual plaster of Paris production (JD)	
							A	B	A	B
Plant equipment and machines (method A)	Complete plant	200 000	10	20 000	20 000	40 000	100	-	40 000	-
Plant equipment and machines (method B)	Complete plant	80 000	10	8 000	8 000	16 000	-	100	-	16 000
Buildings	Plants, stores	60 000	5	3 000	6 000	9 000	100	100	9 000	9 000
Electrical generator	Complete set	30 000	10	3 000	3 000	6 000	100	100	6 000	6 000
Fuel tanks (50 tons) and other tanks	General	2 000	10	200	200	400	100	100	400	400
Crawler loader	1	35 000	10	3 500	3 500	7 000	20	20	1 400	1 400
Service car	1	5 000	20	1 000	500	1 500	100	100	1 500	1 500
Service truck	1	15 000	20	3 000	1 500	4 500	100	100	4 500	4 500
Compressor	1	3 000	20	600	300	900	100	100	900	900
Tools	Set	500	50	250	-	250	100	100	250	250
Totals	Method A	350 500		34 550	35 000	69 550			63 950	39 950
	Method B	230 500		22 550	23 000	45 550				

Table 6. Fuel, oil and lubricant costs for equipment used in plaster of Paris production for both methods (A and B)

Item	Quantity	Cost of daily consumption for machines (JD)					Total (JD)	Total annual cost a/ (JD)
		Fuel	Oil	Heavy oil	Special oils	Lubricants		
Plant equipment	Set	0.5	5.0	16.0	-	3.0	24.5	6 125
Electrical generator	Set	12.0	6.0	-	-	2.0	20.0	5 000
Crawler loader	1	1.0	1.0	-	0.3	0.2	2.5	625
Service car	1	2.0	1.0	-	-	0.2	3.2	800
Service truck	1	2.0	1.0	-	-	0.3	3.3	825
Compressor	1	0.3	0.3	-	-	0.1	0.7	175
							54.2	13 550

Note: Cost estimates relate to 1977, and are taken to be as follows:

Item	Cost (JD)
Solar	0.016 per litre
Benzene	0.060 per litre
Oils	0.550 per kg
Hydraulic oil	0.450 per kg
Heavy oil	8.000 per ton
Lubricant	0.450 per kg

a/ The working year is taken as 250 days.

Table 6 shows the costs of fuels and lubricants required by the project.

A calculation of the total capital requirements is given below. The figures are 1977 estimates derived from tables 4, 5 and 6.

Fixed assets	Method A	Method B
	(JD)	
Plant equipment, cars, buildings and machines	322,500	202,500
Spare parts	52,000	28,000
Land (estimates)	60,000	60,000
Preliminary charges	8,000	8,000
Total fixed assets	442,500	298,500
Working capital (one-third of annual totals)		
Salaries	16,862	16,862
Fuel and oil	4,450	4,450
Other expenses	3,000	3,000
Total working capital	24,312	24,312
Total capital	466,812	322,812
Cost of investment		
Interest at 8%	37,345	25,825

Given an annual production of 15,000 tons, the cost of investment per ton for method A is $\frac{37,345}{15,000}$ = JD 2.5 and, for method B $\frac{25,825}{15,000}$ = JD 1.7.

The annual cost of plaster of Paris production, calculated from tables 4, 5 and 6, is shown below.

Item	Method A	(JD)	Method B
Raw gypsum	36,000		36,000
Depreciation and maintenance	63,950		39,950
Salaries	50,586		50,586
Fuel, oil and heavy oil	13,550		13,550
Price of land (10% depreciation)	6,000		6,000
Packaging	37,500		37,500
Other expenses	8,000		8,000
Cost of investment (8% interest)	37,345		25,825
Total	252,931		217,411

Given an annual production of 15,000 tons, plaster made by method A costs $\frac{252,931}{15,000}$ = 16.862 JD/ton, and plaster made by method B costs $\frac{217,411}{15,000}$ = 14.494 JD/ton.

The following should be noted in considering the cost estimates:

1. Inflation is included in the cost of machines, equipment and buildings.

2. Estimates are based on 300 working days per year. Under conditions of perfect control and with good maintenance of the plant machinery, 325 working days could be possible. In the latter case, the production would be 10 ton/day higher, and costs would be about 10% lower.

3. The ideal staff level is indicated in table 4. If the plant is situated near to the quarry, supervisory, administrative, financial and technical staff could serve both the quarry and the plant.

4. The cars and the trucks can serve both the quarry and the plant.

5. The truck could transport the raw material.

6. The depreciation of the plant equipment is set at 10%. That is, all machines and equipment are taken to have a life of only 10 years although the machines could probably serve for more than 15 years, which would make the costs lower than calculated.

7. If the cost of investment interest at 8% is taken into account about JD 2.5 should be added for Method A and JD 1.8 for method B.

The quantities and the prices of plaster imported by Jordan in 1976 are as follows:

Source	Imports (tons)	Value (JD)	Price/ton (JD)
Belgium	130	4,445	34.20
Germany, Federal Republio of	127	4,900	38.11
Italy	1	18	18.00
Lebanon	225	3,715	16.52
Turkey	40	1,528	38.20
	523	14,606	

The mean price of plaster imported to Jordan c.i.f. is about JD 28.00, not including any tax or duty or transportation within Jordan.

No study of the gypsum and plaster market had been made by the Company. To bridge this information gap, specialist shops were contacted, as well as specialists in gypsum marketing. It was found that gypsum was sold on the Amman market for JD 40.

It thus appears that the company could sell its plaster products for at least JD 25. The net profit to be gained in marketing the plaster in Jordan is calculated below.

Sales price per ton	JD 25
Sales price for total production	15,000 x 25 = JD 375,000
Production cost	= JD 217,411
Net profit	375,000 - 217,411 = JD 157,589

The tariff for transporting plaster from Amman to Kuwait and the Gulf States ranges from JD 6 to JD 14 according to the season. The tariff increases during the winter orange season, since it is preferred to transport oranges rather than any other cargo during this season. This is good for marketing Jordanian plaster, which should ideally be transported from the end of March to the beginning of October, and not in the orange marketing season. If the tariff for transporting plaster to Kuwait and the Gulf States is as low as JD 6, Jordanian plaster could compete effectively with the other plaster imported to these countries. The decision to market Jordanian plaster abroad should be taken after the precise tariff and market sizes have been ascertained.

E. The manufacture of plaster-board

After a study of the market, a kettle for the production of hemihydrate should be erected beside the rotary kiln. This will necessitate the manufacture of plasterboard which needs high quality hemihydrate (annex VIII).

The procedure for producing such boards is described below.

The approximate quantities of material used for producing one square metre of plaster-board 95 mm thick are as follows:

Item	Quantity
Plaster ($CaSO_4 \cdot \frac{1}{2}H_2O$)	6.5–7 kg
Water containing 1% paper	5.5–6 kg
Adhesive	5 cm^3
Special cardboard	2.04 m^2
Starch	0.04 kg

Other additives, such as retardants, accelerators, glass fibre and foam may also be required. The heat requirement will be some 19,000 KJ. Some 0.2–0.3 kWh should cover the power and light requirement. Operation personnel per shift would be 6–8 workers.

Plaster preparation

The hemihydrate produced by a kettle or autoclave is drawn from its main storage silo and passes to an intermediate silo. From this silo, it is transported by a belt conveyor (on which it can be metered by weight) to a mixing screw. In this screw the water (in the correct water/plaster ratio), hemihydrate and additives are mixed together. The additives control the setting time of the plaster as well as the other qualities of the finished boards. The mixing screw leads to a mixer where the plaster, water and additives are homogenized to form a uniform plaster paste. To the water/plaster ratio needed for the paste certain disintegrated paper fibres, starch and foam are added according to the required properties of the product.

Forming

The outer sides of the plaster core consist of two cardboard covers. These covers are supplied from special rolls with 1.8 m diameter. From these rolls, the lower cardboard cover passes through tensioners, trimming shears, heaters and scoring machines to the forming table upon which the plaster paste flows at the appropriate speed. The lower cardboard cover has bent edges, which determine the thickness of the board. The upper cardboard cover, which is coated on both sides with adhesives, passes over the moulding cylinder from above and thus completes the cardboard coating of the plaster core. The plaster-board, while still soft then passes over setting belts (rubber belts) where it is given its final shape by means of smoothing bars before being driven over an open roller table to the knife. This divides the plaster-board into the dimensions required and leaves sharp edges. The cutting is controlled electronically. The cut boards are transported through a cross-conveyor to an automatically controlled input device (a deck drier). This drier is heated directly by steam or heat transfer oil or indirectly by gas or light fuel oil. The boards stay in the ventilated hot zones for about an hour, during which the excess water used in preparing the plaster paste is slowly expelled from the plaster core.

After drying, the boards are bundled together in pairs with adhesive tape covering the end faces, and stored in a storage shed.

F. Production of mixed cement

The Jordan Cement Company currently produces only ordinary Portland cement. This is done by adding 10%-13% pozzolan to 83%-86% clinker and about 4% gypsum (used as a retardant). Such cement complies with the specifications of ordinary Portland cement, and can be used for all construction purposes. However, for uses that do not require high strength cement, such as tile and brick making and plastering, mixed cement can be used.

Mixed cement was first produced on a large scale at the beginning of this century, initially for the manufacture of very large concrete blocks used in dam construction, particularly in the United States. Many countries started mixed cement production during the Second World War, and have been continually increasing production since. Such countries include Argentina, China, Egypt, Malaysia and Romania.

The particular type of mixed cement produced depends on the needs of the country and the availabilities of additive material. Typical additives to the cement clinker are: sand of high purity and silica content (over 90% silica); limestone; basalt; pumice; pozzolanic materials; and slag.

Jordan is rich in sand quarries. The General Public Mining Company has its own sand quarry in Mahes, 7 km from the cement company. The expert found the silica content of the sand there to be very high - above 90%. The production of mixed cement in Jordan would thus be based on adding up to 25% silicic sand to about 70% Portland cement clinker and approximately 5% gypsum ore.

All the materials - the clinker, sand and gypsum - need to be ground together in cement mills to a fineness of not less than 3,000 cm^2/g. The results obtained from grinding these materials show that the sand grains act as a grinding medium on the clinker.

Production of mixed cement does not affect the rate of consumption of the lining and the grinding media by more than 10% above the wear normally found in the cement without sand. The production rate of the cement mill will decrease (because mixed cement is harder) by 20%-25% compared with normal Portland cement produced with a fineness of 2,500 cm^2/g. As the normal Portland cement produced in Jordan is ground to Blaine 3,000 cm^2/g, the production rate of the cement will decrease by only 10%-15%. One of the benefits of using sand in mixed cement production is its ability to remove the coating of residue on the liners and the grinding media. This is why mixed cement is usually produced for periods after the superfine cement production.

Some research into mixed cement production in Jordan is being done. Further research should also cover the following experiments and tests:

1. The chemical analysis of the clinker and sands used in the tests should be carried out first. (The same clinker should be used in all the experiments - say, 250 kg taken from the same source.)

2. The grain size distribution of the sand is required.

3. The insoluble residue of the sand used should be determined.

4. The clinker should be tested with different percentages of sand - say 10%, 15%, 20% and 25%.

5. The clinker (good quality) should be crushed small enough to pass a 10 mm screen.

6. These percentages (10%, 15%, 20%, 25%) of sand are ground with the appropriate percent of clinker and gypsum in a small vibratory ball mill

to the required Blaine 3,000 cm^2/g and also to Blaine 3,500 cm^2/g.

7. The grindability curves for the test samples are required. Clinker gypsum (normal cement) should be used as a blank for comparison.

8. After grinding to the required Blaine the mill must be discharged carefully with all the grinding media into a clean pot. The grinding media and mill should be cleaned thoroughly before being used for another test.

9. The mill is repeatedly charged, taking into consideration the time required to grind the mixture to the required Blaine and from time to time and within the grinding period a sample can be taken from the mill to test its fineness.

10. The chemical analysis of the ground product should be determined, especially the insoluble residue for all the samples tested.

11. A sample can be taken from every ground meal to be physically tested according to the following specifications:

Fineness

Retained percentage on sieve No. 170

Expansion

Initial and final setting time

Compressive strength of the mortar 1 (1 cement: 3 sand) for 1 day, 3 days, 7 days, 28 days, 3 months, 1 year (the mean value of 3 cubes is required). After all the results are obtained of the comparison of three-months compressive strength with the same normal cement a decision can be taken to carry on some semi-industrial tests in the cement mill

G. The simultaneous production of cement and sulphuric acid

Portland cement is manufactured in most countries by mixing limestone or marly limestone with other material containing silica, alumina and iron oxide. These raw mixes are burnt at the clinkering temperature and the resulting clinker is ground with gypsum, so as to produce Portland cement. The thermal decomposition of calcium carbonate used in the raw mix will yield calcium oxide and carbon dioxide. The latter gas is of no economic importance.

The production of cement from gypsum or anhydrite by using the Muller-Kühne process leads to the formation of sulphur dioxide which is dissociated from and yielded by the gypsum. This gas is used in the manufacture of sulphuric acid and, since sulphuric acid is one of the fundamental raw materials of the chemical industry, is economically very important. The importance of sulphuric acid to the chemical industry is often compared with that of steel to heavy industry. The amount of sulphuric acid produced is used as a scale to judge the development of the chemical industry of a given country.

The constant increase in the consumption of sulphur and sulphuric acid has been making it necessary to find new raw material sources.

During the First World War, when the supply of Spanish pyrites to the Federal Republic of Germany was stopped, attention was paid for the first time to the immense reserves of sulphur stored in the large deposits of gypsum and anhydrite.

The problem of producing the sulphur dioxide from gypsum was considered even earlier. The first patent in this field was an English one claimed in 1847 by Tilghman. Tilghman's method was to carry water vapour through an incandescent bed of gypsum, generating CaO, SO_2 and O_2 and also a small amount of SO_3. Many patents have since been applied for, but none were industrially feasible.

To decompose gypsum directly by dissociation rather high temperatures are required, which make this kind of processing uneconomical. Therefore further research was directed towards decomposing gypsum at lower temperatures, employing such additives as aluminosilicates and iron oxide, which enter into chemical reactions with the calcium oxide as one of the dissociation products of gypsum.

On this basis, W.J. Mueller in 1915 started research that had the first satisfactory results. The outcome of Mueller's activity is the so-called cement patents of the Bayer Company, known later as Badische Anilin und Soda Fabriken. These patents protected the processing of sulphuric acid from gypsum, simultaneously generating cement clinker as a by-product. The Bayer gypsum/sulphuric acid method is based on grinding gypsum or anhydrite together with a component consisting of aluminosilicates and iron ore plus a certain quantity of coke, before burning this mixture in a rotary kiln to produce cement clinker. Instead of the carbon dioxide obtained in the normal clinker-burning process (which is usually expelled through the kiln stack), the Bayer process generates valuable sulphur dioxide, converts it into sulphuric acid, and simultaneously produces standard-quality cement clinker as a by-product.

As the cost of the heat necessary to dissociate the gypsum or anhydrite can be charged to two commercial products - sulphuric acid and cement clinker - this process turns out to be very profitable.

The increasing need in Jordan and the surrounding developing countries for both cement and sulphuric acid, and the presence of huge amounts of gypsum in Jordan (possibly over 10 million tons at Zarqa River, Kerak and Mujib) mean that serious consideration should be given to the establishment of a new plant. The study for establishing such a plant ought to begin after drilling and testing the area confirms ore reserves of not less than 10 million tons in the Zarqa River, Kerak and Mujib.

Existing plants

There is one plant in Austria. Czechoslovakia is contemplating the erection of a plant to exploit the huge Czechoslovak anhydrite deposits; here the intention is to employ shaft kilns to get a higher concentration of sulphur dioxide in the exit gases. At present there are two sulphuric acid/cement plants in France (at Miramas and Saint Chamas) and two plants in the Federal Republic of Germany (at Leverkusen and Wolfen). In 1952, one plant was erected in Poland (at Wizow); another plant was under construction in Busko, but construction work was stopped after large deposits of sulphur were discovered in Tarnobrzeg. There are three plants in the United Kingdom (at Billingham, Merseyside and Widness) and one in the Union of Soviet Socialist Republics (at Artemowsk).

Economic considerations

At present about 10 plants produce suphuric acid and cement simultaneously, and are responsible for 2%-3% of world production of sulphuric acid. However, with the exploitation of pyrite deposits for sulphuric acid production, there is a constant decrease in the deposits. The cement/sulphuric acid process thus has a good chance of being used increasingly, particularly in those countries where anhydrite or gypsum is available but where sulphur ores cannot be obtained.

The yield of cement clinker obtained by reacting calcium oxide with aluminosilicates and iron decides the profitability of the process. When calculating production costs during simultaneous acid-clinker production, clinker is considered a by-product and its cost is then deducted from the total production cost of the sulphuric acid. The yield ratio of sulphuric acid to clinker is roughly 1:1 by weight. A recent (1977) price for sulphuric acid is $60.75 per ton (100% sulphuric acid). Given cement prices, a production cost calculation can easily be performed.

The investment costs for a cement/sulphuric acid plant are roughly four times higher than those for a conventional pyrites roasting plant with the same production capacity of sulphur dioxide. But when the clinker value is considered, the production costs prove to be considerably lower than those of a conventional pyrites roasting process.

Fuel

There is oil shale in the Lajjun area near Quatrana in central Jordan. If this is exploited, the oil content could help to heat the raw mix in the kiln. Fischer's assay shows that the average yield of shale oil is 28.1 gal/ton. The reserves so far established at Lajjun are estimated to contain a potential 420 million barrels[1/] of shale oil. Lajjun is about 90 km from Amman.

The coke needed for reduction can be imported. The raw mix meal of the constituents can be estimated after the oil shale is completely analysed. The calorific value of this oily shale should be estimated.

Conclusion

From this preliminary study, it appears that sulphuric acid and cement could be produced from gypsum reserves at the Zarqa River, or the Karak and Mujib areas using the Muller-Kühne process. First, however, the assured reserves of gypsum in one of the gypsum areas must be established as being more than 10 million tons. The production of sulphuric acid and cement would naturally reduce the dependence of Jordan on imports of these materials. The best location for such a plant is near to the cement factory in Amman, between the gypsum quarry and the phosphate mines. The oil shale would be transported about 90 km. The Al Karak area is another possibility, where the plant would be adjacent to all the raw materials - gypsum, oil shale, and phosphate ore.

1/ One barrel is 42 US gallons.

Other industries could be envisaged after the erection of this plant: superphosphate production, and the production of sodium fluorosilicates.

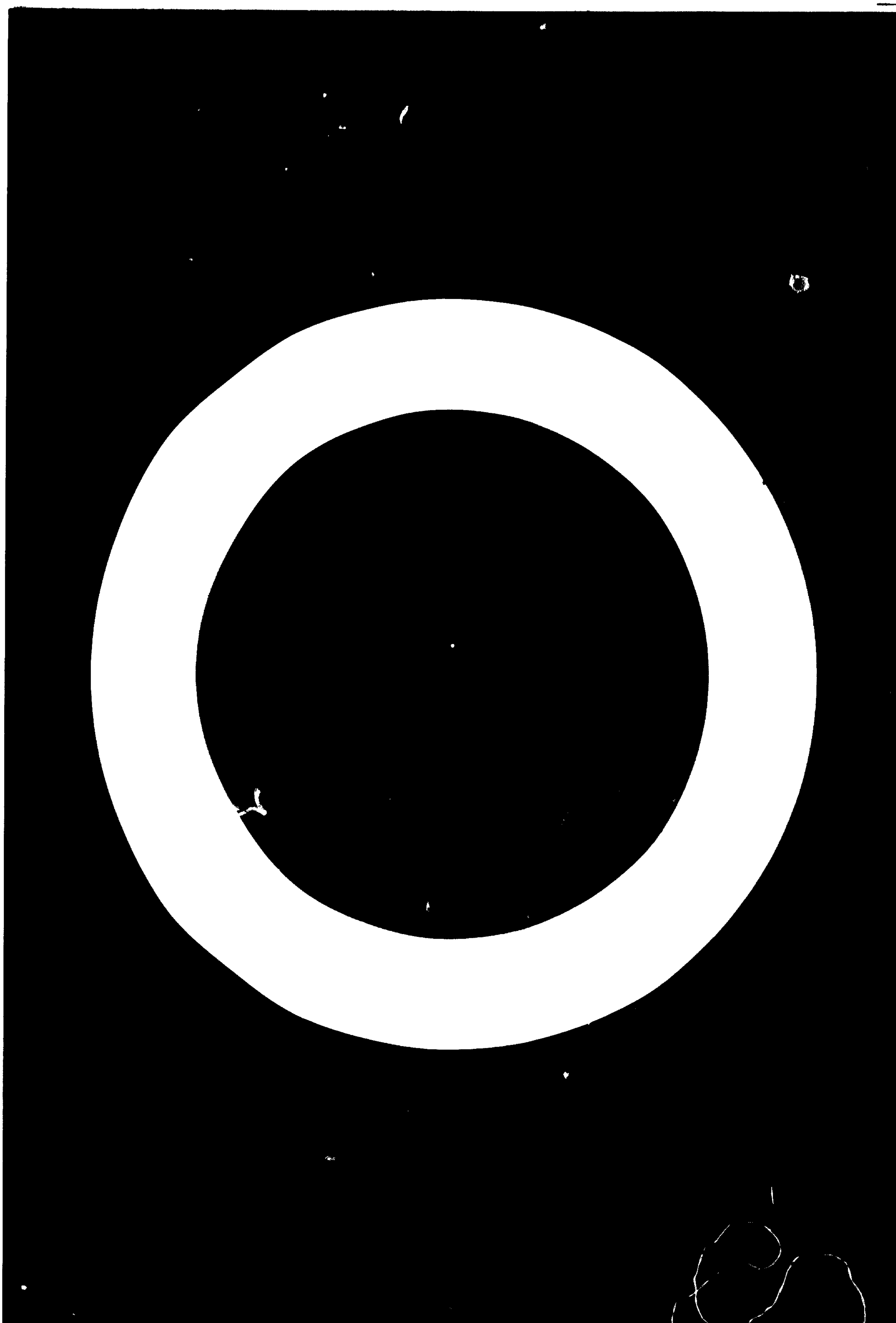
Superphosphate

Production is as follows: 600 kg of raw phosphate (triple-phosphate) is automatically weighed into a reacting basin, into which 500 kg of sulphuric acid is pumped. The mixture is stirred for about five minutes. At the end of the process, one ton of superphosphate is produced. A sulphuric acid concentration of 70% is required for superphosphate production.

Sodium fluorosilicate

This product is important in the glass and enamel industries, and as an antifire material. Raw phosphate contains constituents other than the triple-phosphate, including calcium carbonate, magnesium carbonate, calcium iodate and calcium fluoride. In sodium fluorosilicate production,the fluoride-containing constituents are reacted with sulphuric acid, giving hydrogen fluoride and silicon tetrafluoride. These compounds are then brought together in washing towers for 12 hours, to produce 20% hydrofluorosilicic acid. The acid is neutralized with 23% soda and the sodium fluorosilicate is separated by centrifuge.

As such a project would require a rather large investment, it should be undertaken by the Public Mining Company, the Jordan Cement Company, the Jordan phosphate Company, and the General Mining Company together.



Annex I

METHODS OF EVALUATING THE EXTENT OF GYPSUM DEPOSITS

The evaluation of gypsum deposits is based on one of the following methods:

Arithmetic mean

This is the quickest approximate method in the evaluation of mineral deposits. The arithmetic mean of the thickness of the positive boreholes is multiplied by the area covered by the gypsum deposits as estimated from the surveyed map. The resultant quantity is the estimated gypsum quanitity in cubic metres. By multiplying this quanitity by the specific gravity of the gypsum in this area (estimated as 2.32 by the National Resources Authority), the quantity in tons is obtained. This is not the best method.

Area of influence of every positive borehole

This is one of the most accurate and therefore most recommended methods. The area of influence of each borehole is calculated; the chemical analysis of each sample represents a midpoint between two successive boreholes. The whole area covered by the gypsum is thus divided into "areas of influence" around boreholes. When each of these areas is multipled by the thickness of gypsum in the borehole it surrounds and by the specific gravity, the tonnage is obtained. The total gypsum can be calculated by using this method as can the absolute content tons of $CaSO_4.2H_2O$.

The data are tabulated in a table with the headings such as those shown by way of example below.

Block No.	Thickness	Area of influence	Volume of influence	Tonnage	Assay (% of $CaSO_4.2H_2O$)	Absolute content

The average percentage assay can be obtained by dividing the total absolute content by the tonnage obtained from the table, multiplied by 100.

$$\text{Average assay} = \frac{\text{Absolute content}}{\text{Tonnage}} \times 100$$

Also, Volume of influence = area of influence x thickness of gypsum and Absolute content = assay x tonnage.

Profile method

Profiles can be drawn representing the whole area along the north-south direction including every borehole met with. The area covered by the gypsum deposits can be calculated for each profile, and the average between two successive profiles can be calculated by adding the values for the two areas and dividing by two. When the result is multiplied by the distance between the two profiles and by the specific gravity, the tonnage of gypsum enclosed between the two profiles is obtained.

The gypsum in the whole area can be evaluated and calculated by this method. The date is then tabulated in a table like the one below.

Block No.	Tonnage	Average assay	Absoluts content of $CaSO_4:2H_2O$

$$\text{Average assay} = \frac{\text{Absolute content of } CaSO_4\cdot 2H_2O \times 100}{\text{Tonnage}}$$

After calculating the exploitable reserves, the following must be taken into consideration:

- Any unexploitable area containing buildings or agriculture could be excluded
- The exploitation areas (i.e. quarries) should also be excluded
- The absolite anhydrite in the geological reserves should be calculated and excluded

Annex II

QUARRYING METHODS AND EQUIPMENT

Introduction

The word "quarrying" is often used to indicate only the process of loosening the rock, but is also a collective name for a series of operating stages. For the gypsum, these start with the delivery of the gypsum at the crusher, sieve or ball mill.

Quarrying in its collective meaning can include clearing, stripping and grubbing. Clearing is the cutting of trees and undergrowth and their disposal. Pulling up stumps and roots is termed grubbing. Stripping is the shallow excavation and removal of topsoil containing organic matter. When the topsoil is to be re-used (e.g. when laying pipes) it may be stored nearby. Clearing and grubbing are especially necessary where graders and scrapers are to be used. Roots and small brush interfere with all machines except power shovels and drag-line excavators, whioh do their own grubbing.

Grubbing by hand is uneconomical, but is still practised in cold regions where, for example, winter frosts can loosen stumps and thus lessen the removal work once large roots are cut by hand.

When blasting stumps, dynamite is used to get rid of the roots. Initially a hole is made through the roots; a seoond charge is exploded at least two feet below the surface of the ground and close against the tap root. In the Jordanian deposits, even though some parts of the overburden soil are cultivated, it is not necessary to clear the soil of roots and trees.

Loosening

It is economical to loosen the heavy soils or overburden of the Jordanian deposits by scarifiers or rippers. Hard and compact overburden is loosened by using low-grade dynamite. Holes should be drilled at 45° to the vertical, unless they are drilled in high banks. Horizontal holes are effective in the face of a bank.

The thickness of overburden deposits has a certain influence on its removal. A thick bed of overburden can usually be quarried in one bench. This results in cleaning the advancing fronts. In the case of the present gypsum quarry, or of any other quarry operating in the area, the stripped material (soil, clays and marls) should be dumped at the faulted area where the gypsum disappears. However, if quarrying begins elsewhere, the waste soil (overburden) should be dumped in the drainage wadi - the Zarqa River wadi, Huda wadi, or Azab wadi, where no gypsum deposit is found.

Ripping

A bulldozer can be used for the loosening of soft to medium-hard highly stratified or laminated limestone, shale or gypsum. Such a bulldozer has a bulldozer blade in front and a ripper outfit behind it. The ripper outfit is composed of a movable beam with 1-3 shanks which can be lowered and forced into the ground. When the bulldozer moves forward the shanks plough through the top layer of the deposit to a depth of about 30-90 cm. When the area is ripped, the bulldozer pushes the loosened material into heaps that can be loaded by shovels or loaders.

This method is cheapest when the material is soft and easily crumbled under pressure as in the Public Mining Company gypsum deposit. It is the loading by shovels or loaders that keeps the cost of the material at the crusher very low. The cost of this method can be as little as 30%-40% of the traditional one, involving blasting, loading by shovels and handling by ordinary quarry dumpers.

However, when the rock is hard and relatively unstratified, the output of the ripper is low. When reaching 400-500 ton/h (ripped and bulldozed to piles) ripping usually can not compete with blasting in costs. Under severe conditions the life of even the biggest bulldozer may be as short as 4,000 hours - cases are known where a tractor of the biggest size had to be written off in one year.

Bulldozers are well-suited to work on wet, slippery overburden and on overburden with stones and roots. They are hardy machines. Although they are built in many sizes, only those with an engine power over 125 hp should be considered as suitable for stripping work. The capacity of a bulldozer falls rapidly with the transporting distance. For instance, a 200 hp bulldozer can move 225 m^3 of loose material per hour over a distance of 25 m, but only 65 m^3 of loose material per hour over 100 m.

A bulldozer is particularly useful when there is a downward-sloping bank over which the removed overburden can be pushed. Such a bank may consist of the overburden itself. Among the other uses of a bulldozer are after blasting, to remove loose material or to push it into heaps and to clean and prepare roads.

Loosening of rook gypsum by drilling and blasting

An alternative method of loosening gypsum consists of drilling and blasting rock. A quarry with a large output usually requires loaders with large shovels, bulldozers and hauling units. In order to utilize these rationally, blasting should produce piles big enough to permit the full use of the loaders and a block size small enough to permit loading. Blasting should yield the largest possible amount of rock per metre of a borehole and per kilogram of explosives employed. As the amount of blasted rock per metre of a borehole is a function of size, depth, burden and spacing between boreholes, these elements have to be balanced carefully so as to give the maximum output. Many other factors make drilling and blasting operations complicated for a quarry operator. An account of the interaction of these factors is contained in U. Langefors, Rock Blasting.

Drilling

When opening a quarry, small benching is often used for the initial period. This requires a light, hand-held drill that can easily be moved around on a sloping quarry face. The same type of equipment is also used when preparing benches for big-hole drilling, when drilling for selective blasting and sorting of a series of gypsum bands interbedded with other second-quality gypsum, and when drilling for secondary blasting. The most common of such drills weigh some 18-25 kg. They use integral steels, and the drill depth seldom exceeds 3-4 m. The output is roughly 150 tons per machine shift.

For medium-sized quarries operating with benches, light or heavy wagon drills are used. These work with coupled drill-rods, usually to depths of 10-20 m, and use drill-bit sizes of up to 100 mm. They are mounted either on wheels or on bands, depending on the size of bit and type of store. The output is some 300-500 tons per machine shift for the light wagon drills, and some 500-1,000 per machine shift for the bigger ones.

For quarries operating on beds large enough to permit large-sized blasting, heavy machines are used. Such machines are capable of fast drilling to depths of up to 25-30 m. They use coupled drill-rods and drill-bit sizes of up to 200 m, and they can produce 3,000-5,000 tons per machine shift. They are self-propelled and mounted on bands, and usually carry their own compressors. They may perform rotary drilling, percussion drilling or a combination of both. Percussion drilling may be performed by having the drill work on the top rods or at the lower end of the rods - termed "down-the-hole" drilling. Since the performance of the down-the-hole drilling machine is rather low at the traditional air pressure of 7 kg/cm^2, it is stepped up by increasing the air pressure to as high as 20 kg/cm^2. Different types of bits are used (cross bits, wing bits, button bits and cone-roller bits).

The hand-held drills and the light and heavy wagon drills get their air supply from mobile or stationary compressors. The mobile compressors usually have a capacity of either 7 m^3/min or 17 m^3/min. The bigger size is usually capable of running two heavy wagon drills, four light wagon drills, or seven hand-held drills. Stationary compressors are usually used in large-sized quarries with stable working conditions. These are placed in a compressor house from which the air is piped through a single pipeline. The cost of air from a stationary compressor is usually only three quarters of that from a mobile compressor.

Annex III

EXPLOSIVES

Introduction

In 1875 Alfred Nobel followed his invention of dynamite by that of "blasting gelatine" - a mixture comprising 92% nitroglycerine and 8% collodion cotton. This is still the most powerful industrial explosive.

Lower strength explosives were invented a few years later, in whioh sodium and ammonium nitrate were mixed to NGA. A wide range of explosives based on these substances has sinoe been developed. In 1935 a variety of factory-mixed blasting agents consisting mainly of ammonium nitrate in varying densities were introduced in the United States. "Akremite" was developed in 1954-1955 and gave way to the "on-side" mixing of various types of blasting agents. Since then a growth in the usage of this family of fertilizer-grade ammonium nitrate carbonaceous mixture (generally abbreviated as NCN or as popular type AN/FO) has lead to the recent development of metallized slurries.

Quarry blasting

Explosivee are used for the breaking of stone. The charges are placed in the rock in such a position that their energy is utilized to the full. Before placing charges, however, holes must be drilled in carefully chosen positions and at precise depths. The modern tendency in explosive practice is to drill inclined holes, rather than vertical ones, whenever this is possible with the drilling equipment available.

Quarrying using small diameter holes

The modern concept of quarrying is that as far as possible the rock should be broken to the required size by the primary blast. Jackhammers are used for short-hole drilling; previously holes were placed in a random fashion and explosive was detonated in each hole individually by means of a safety fuse. The modern tendency, however, is to drill holes in a regular pattern, insert the explosive and detonate the holes in a group, either electrically or with detonating cord. The usual practice is to limit the depth of jackhammer holes to 4.5-5.5 m, even though they can be drilled deeper. This reduces problems connected with the handling of drill-steel, removal of drill cuttings and the like.

Stone faces greater than 5.5 m can be broken by employing a combination of vertical, inclined and horizontal slat holes. Using an additional line in the face - frequently referred to as half-uppers - permits a face of say 8 m to be broken up. For good fragmentation, the sets of holes should be spaced 1-1.5 m apart. A large tonnage of rock may be broken in one blast by drilling many sets of holes with additional rows of vertical holes to be fired slightly after the others. Cartridges of explosives 2.9 cm (1 1/8 in.) in diameter or greater should be employed for charging these holes. The holes should be charged in a continuous column to within approximately 1 m of their mouths. It is of course essential that the holes should be fired electrically or by a detonating cord. Short-delay detonators arranged to relieve the burdens on the holes in sequence in most cases produce better blasting, including improved fragmentation, less vibration, less noise and lower explosive ratio.

The wagon drill

The wagon drill is perhaps more commonly used for drilling in the manner described above than the jackhammer, it can comfortably drill 6-7 m in average ground. It can drill to greater depths using special techniques. Depending on conditions, explosives placed in wagon drill holes can be expected to break up quarry faces approximating to the heights providing 2 m diameter explosives are employed. The drill patterns would normally be repeated at intervals of 2-2.5 m for good fragmentation. The quarry floor including the toe, should be cleaned before the drilling of the bottom holes can commence, so that loose rocks do not fall on the men drilling below.

When blasting dense rocks, the holes are generally changed with a high-strength gelatinous explosive such as ammonium gelatine 60%; for softer rocks, it is better to use lower density explosives. The charging procedure is to drop from one to three cartridges in the drill hole and tamp them in position by means of a jointed wooden tamping stick or long plastic tamping hole. In this way the hole is column-loaded to within 1-1.2 m of the surface.

Operations generally aim to minimize the need for secondary blasting, since its direct and indirect effect on total costs is very high. Ideally the proportion of secondary breaking should be kept within the limit of 2% of the total tonnage. Even in the best of open-cut operations, some secondary breaking is always necessary.

High explosives are usually used in production. Nitroglycerine (NG) is the main industrial explosive, although ammonium nitrate (AN) as the oxiding element in blasting agents has recently gained tremendous significance.

Nitroglycerine is a yellow, oily, transparent liquid made by reacting nitric acid with glycerine. In this liquid form, it is too sensitive to be handled safely. It is therefore converted into a more convenient gelatinous (plastic) solid by the addition of 8% gun-cotton to form "Blasting Gelatine", or by the addition of other explosive agents (to form lower strength dynamite and gelatine). The chief difficulties experienced in using nitroglycerine are as follows: nitroglycerine (a) requires careful handling; (b) is easily ignited; (c) freezes at 12.8°C as crystal; (d) is sensitive to shock; and (e) is poisonous.

The main constituents of explosives are listed below.

Chemical	Chemical formula	Function	Remarks
Nitroglycerine	$C_3H_5(NO_3)_3$	Explosive base	Liquid, very sensitive, requires careful handling
Ammonium nitrate	NH_4NO_3	Explosive base and oxygen carrier	Explodes alone, soluble in water
Sodium nitrate	$NaNO_3$	Oxygen carrier	Soluble in water
Wood dust	-	Explosive retarder	

Calculation of boring and explosive requirements

The following table shows the relationship between the depth of borehole and the quantity of rocks produced at the first and subsequent explosions as well as the quantity of rocks yielded.

Value of W	Volume of rocks at the 1st explosion	Volume of rocks in Distance W	N numbers of explosion Distance 2 W
0.75 a	$0.56a^3$	$0.56\ Na^3$	$0.56(N+(N-1))\ a^3$
0.50 a	$0.25a^3$	$0.25\ Na^3$	$0.25(N+(N-1))\ a^3$
0.33 a	$0.11a^3$	$0.11\ Na^3$	$0.11(N+(N-1))\ a^3$
0.25 a	$0.06a^3$	$0.06\ Na^3$	$0.06(N+(N-1))\ a^3$

Where: W = the line of least resistance (shortest distance from borehole to face); a = depth of drill hole; N= number of boreholes.

To ensure the complete efficiency of explosions, the distance between the face and the first series of boreholes or the second series will be 4 m, but the distance between two boreholes 5 m. Then the amount of gypsum produced from one borehole

= 15 x (4x5) x 2.3 = 690 ton

where 15 = depth of the borehole

4x5 = area of borehole

2.3 is the relative density of gypsum.

According to the production needed every month the number of boreholes can be drilled and charged. This number can be estimated by the engineer responsible for the gypsum quarry.

<u>The quantity of dynamite used in a borehole</u>

The charge length for one borehole = a - 1.2 W

a = 16 m

W = line of least resistance = 4.5 m approximately

Thus, the charge length for a borehole = 16-(1.2 x 4.5)

= 16 -5.4 = 10.6 m

= 11 m approximately = 420 in.

From this the dynamite charge can be proportionally distributed in 11 m length for every borehole. It is known that for the production of one ton gypsum, especially that under study, 100-120 gm dynamite is required.

So the quantity of dynamite needed to produce 700 ton from one drilled borehole is as follows:

= 700 x 120 g = 84,000 g = 84 kg; or 700 x 100 = 70,000 g = 70 kg

The diameter of the borehole can be increased or decreased according to the relative density of the dynamite or other explosive to be used.

Annex IV

MACHINES AND EQUIPMENT REQUIRED FOR THE GYPSUM PROJECT

The expert recommends that a larger bulldozer serve as a ripper and dozer in the different quarries e.g. gypsum kaolin sand, limestone, marble etc. The bulldozer will be used part time in these quarries.

Bulldozer

This should be a typical crawler, equipped with a straight and hydraulically tilted blade. The blade and edge should be made of high tensile steel with high resistance to wear. The tracks' shoes should have the same features of blade and edge material and should be self-locking. The bulldozer should have a four stroke diesel engine with a cooling system suitable for tropical conditions, and a flywheel power of at least 280 hp. A heavy-duty dry-type cleaner with centrifugal pre-cleaner is also required.

Wheel loader

The wheel loader should be a crawler loader with articulated frame steering to permit excellent manœuvrability and high stability. The bucket fitted to the machine should have a serrated (toothed) edge, so as to be suitable for stone quarrying. The main specifications of a two-wheel loader are as follows:

Item	Minimum value
Operating weight	14 tons
Bucket capacity	2 m^3
Maximum dumping height at full lift and 45° discharge angle	2.5 m
Maximum reach at full lift and 45° discharge angle	0.96 m
Engine	
Diesel, naturally aspirated four-stroke cycle	
Heavy duty air-cleaners	
Flywheel power	150 hp

The power for (a) drilling; (b) chain feed movement of the rotation motor; and (c) the elevating spindle is provided by similar gear motors. Each of the three gear motors is reversible, which means that they can be used for clockwise or anticlockwise rotations.

The rotation motor mounted on the chain feed must have the ability to produce impacts during the rotation - the turning of the drill bit. The air consumption with a down-the-hole drill is approximately 5.5 m^3/min.

Wagon drill

The wagon drill is used for drilling large bore-holes (up to 85 mm in diameter) down to depths of 60 m. The design and equipment of the machine must be geared to the many requirements of rock drilling. Its main application is in quarrying soft, medium-hard and hard rocks.

A mobile compressor is required. This should be of the screw type, and have a rate of displacement of discharge of 15 m^3/min. The compressor should be fitted with a chassis that can take a maximum speed of 80 km/h. The chassis is mounted on a trailer with four pneumatic tyres. Spares should include a pneumatic rock drill and and a reasonable supply of drill bits, extension rods and coupling sleeves.

Crusher

The crusher is a hammer mill, which is used for crushing soft and medium-hard raw materials. The crusher can serve as primary and secondary grinding machine for such raw materials. It must be noted that feed granulometry and the mill dimensions as well as the fineness degree of the finished products are dependent upon each other to some extent. The screening-grate opening governs the size of the finished product. The hammers should be suspended so as to swing freely. When they meet with a very strong resistance, the pendulum-like suspension permits them to move far enough backwards to escape serious damage. The crusher should be protected against damage caused by tramp iron (wedges, levers, nails etc.), which can accidentally enter with the feed. The crushing machine should have a capacity of 15-25 tons/hour, and the diameter of the gypsum grains should be in the range of 2-5 mm. A vibrating-shute transporter carries the crushed gypsum to the base room of a bucket elevator, from which it is transported to two bunkers or silos. These bunkers can be made of steel or concrete. The capacity of the bucket elevator should be 10-15 ton/h, and the storage capacity of each bunker should be 150 tons. From the bunkers, the ore gypsum is directed to a table-feeder by means of a cylindrical tube containing a flapdoor. The table-feeder is also equipped with a rotating flap that can be directed so as to control the quantity of gypsum ore that passes to the kiln inlet.

The firing room should have an arched roof and be of the dimensions 4 x 3 x 4 m. This room is lined with fire bricks having an alumina content of at least 40%. The area surrounding the flame should be built like a chamber and be lined with 80% high alumina refractories. This chamber is the burning room. The burning room is fitted with a small side door which is used for maintenance. Near the fuel-pipe hole there is another hole fitted with heat-resistant coloured glass through which the kiln operator can monitor the flame and the refractories. The burning room is equipped with a thermo-couple, which shows the inside temperature. From the burning room, the indirect heat and temperature is directed towards the kiln inlet, where it meets the gypsum coming from the table feeder along a heat-resistant steel tube. The temperature of the burning room is about 750°C. It can be lowered or raised according to the quality of the plaster produced.

Heavy oil is used as fuel. It is directed by injecting air into it. This air is produced by a high-speed fan.

The kiln

The kiln described here is of the rotary type. It is cylindrical, 5.5 m in length and 1.2 m in diameter. The cylinder is of heat-resistant anti-abrasion steel about half an inch thick. The kiln shell is rotated by means of an electric motor. It rotates freely on rollers fitted on both side of the kiln. The kiln is also equipped with a thermo-couple, which shows the inside temperature.

The kiln shell is not brick-lined, but is fitted with durable steel crosses and lifters, which distribute the gypsum feed uniformly over the cross section of the kiln. The rock is rearranged several times during each rotation of the kiln. At the same time, the gypsum moves along the kiln in the direction of the heating gases, the velocity of which changes the rock pneumatically according to particle sizes. This regulates the different calcining times required for each size grade.

Initially, during calcination, the outer layers of the gypsum particle lose their water of crystallization. This reduces the forces that bond the outer layers to the rock core, so that the material that is rapidly conveyed to the outlet is in the form of a pulverulent abraded material, entrained in the hot gas stream. Larger gypsum particles are exposed for a longer time to the hot gas stream, and require increasingly longer calcining times to achieve a thorough calcination to hemihydrate (compared with the smallest grain sizes). The raw gypsum used in this process must be more than 85% pure.

After the gypsum is calcined it flows out of the kiln exit to the dust chamber.

Dust chamber

The dust chamber is a small room with a central partition. This central partition is equipped with chains or steel sheets to oppose the gypsum grains or gypsum dust escaping with the air flow. The roof of the chamber is equipped with an exhauster, which is used for air suction. The bottom of the dust chamber is conical in shape, so as to collect the plaster of Paris that comes out of the kiln exit. The conical sections lead to chutes, through which the gypsum is transported by means of screw conveyors. In this way, the gypsum is conveyed to the bottom of a bucket elevator. The bucket elevator lifts the gypsum up to two bunkers, which supply the ring or roller mills. Ring mills and roller mills are described below.

Percussion-ring mill

The ring mill has a rigid cast-iron casing and a door. The casing houses the grinding element, which is a disc furnished with high-grade steel percussion-studs. The disc rotates rapidly between tooth-shaped grinding rings of wear-resistant steel, which are fastened to the inner side of the door and which have slots for the passage of the material to be ground. The material enters through an inlet on the outside of the door.

The charged material is ground gradually until it has the desired fineness and can leave the mill through the screen or grate. The fineness of the finished product can be predetermined by the use of screens with suitable perforations. Magnets should be mounted in the mill inlet to prevent tramp iron from entering.

If a finished product of particular fineness, or even powder, is required, the mill should be operated in conjunction with a high efficiency fine air separator. In this case, the perforation of the screen should be wider than normal, to let through coarser parts during the operation. After the ground material has left the mill, a bucket-elevator raises it up to the air separator, which eliminates the fines while the grits are returned to the mill for further grinding.

A typical ring mill capacity is 20 tons/hour.

Roller mills

Instead of the ring mill, a roller mill can be used for grinding purposes. Such a mill can be operated automatically (it can be fitted with a feed-temperature and air-quantity controller), which reduces the operator requirements. The design and grinding principle of the roller mill are really very simple: three big grinding rollers are arranged at fixed points above a rotating grinding bowl or table. The contact pressure for the grinding is set at three points by pre-tension of the springing system. The springing forces are transmitted to the three grinding rollers through a pressure-ring. The pendulum-like suspended grinding rollers adapt themselves exactly to the momentarily present raw material and to the height of the layer. The pendulum-like suspension prevents the grinding components from being damaged should bigger foreign or tramp parts enter the mill.

Drying takes place according to air sweep principle: the drying gas enters the mill through a nozzle or air-port ring around the grinding table, and is used for both drying and transportation of the pulverized material to the air classifier and to the product separators.

The mill should be easily adjustable and have a low rate of wear and tear (less than 0.2 g/ton of finished product). It should also be equipped with a device to eliminate tramp parts in the feed.

The ground gypsum is transported by means of a screw conveyor to a bucket elevator, which lifts it up to two main bunkers. The capacity of each bunker is 100 tons. From these bunkers the gypsum is transported in bulk. The gypsum becomes aerated during transport to the packing machine by bucket, worm and particularly by fluidized conveyors.

Automatic-valve bag-packing machine

A bag-packing machine will have a packing hopper, the height of which will depend on the bulk density of the material to be handled. The machine can be run by a single operator. When the operator slides the empty bags onto the filling spouts he presses a contact with his free hand to start the filling process. The machine is set so that the filled bags can be removed by hand from the filling spouts. This means that each filled bag remains on the filling spout and on the saddle underneath for a short space of time thereby giving excess air an opportunity to escape and allowing the material to settle. This is especially important for the clean filling of gypsum.

Machine capacities are in the range 800-1,000 bags/hour (= 320-400 tons/hour).

The driving motors have a power of 7.5 kW at 1,500 r.p.m., with a tension rail. The amount of air required to operate the valves is 5.4 Nm^3/h, which should be at a pressure of 5-6 bar. A stationary compressor should thus be associated with the packing machine plant. After the bags have been filled with plaster, they are transported by belt conveyor, either for storage or for loading onto trucks. A storage space with a capacity of 300 tons will be required. The stored gypsum must be well sheltered against rain and humidity, which damage the plaster by making it set. The plaster for local use can be packed in three paper layers (3-ply paper). Plaster for export should be packed in six paper layers (6-ply paper). In some cases a polyethylene or plastic layer is used to protect the packed plaster against humidity.

Annex V

LOADING

One worker can normally load 1 m^3 of broken ground in 50-60 minutes (= 2.5 tons every 50 minutes, or 17 tons per shift), provided the truck is close to the work area. The rate of manual loading decreases as the distance of piled rock from the truck increases. On average, a man can load some 10 tons a shift at a distance of 10 metres. Hand-loading is slow, and thus is used only when mechanical loaders cannot be employed.

The basic function of mechanical loaders is to grab loose-lying mined or heaped rock and to move it to the other transportation facilities.

The principal factors governing the technological parameters of mine or quarry loaders are the prevailing conditions at the quarry: the rock hardness, cross-sectional area of the working, angle of dip, dust conditions, the dump size etc. Mechanical loaders can differ in the way they transfer the load to the transportation facilities (transfer can be direct or step-wise), in the construction of the carrier mechanism or chassis (it can be wheel-mounted. caterpillar mounted, it can have walking arrangements or use rope traction), and in the method of travel (self-propelled, or otherwise). These differences serve as a basis for classifying mechanical quarry loaders.

In the previous section, loading was described in some cases, as being an integral part of the digging. Usually, however, loading is a distinct operation, which is performed after the stone has been properly prepared. After primary and secondary blasting, the stone is in the form of piles at the foot of the front. Loading is usually performed by shovels, but lately other types of equipment have been introduced, such as front-end loaders, wheel loaders and traxcavators. Shovels are manufactured with bucket volumes ranging from 0.33 m^3 to 150 m^3. The most commonly used shovel sizes in large limestone quarries are in the range of 4-6 m^3. It should be noted that the block size of the blasted or ripped material will influence the choice of shovels, loaders and hauling equipment.

Front-end loaders

Front-end loaders and similar equipment are increasingly being used as substitutes for shovels, even in quarries with coarsely shot material. However, just as front-end loaders have developed into bigger units, traditional shovels have undergone an evolution. New types can have static controls, hydraulic operation and wrist action. This sometimes makes it difficult to judge which would suit a special job best.

Numerous job studies have been performed to clarify the situation. Mobility is the biggest asset of the front-end loader, which is thus preferred for supplying stone from several points in a quarry or for selective loading. The shovel is preferred for loading of a more stationary kind, especially of coarsely shot material. It has been shown that the average output of a 4.2 m^3 (5 yd^3) loading is about equal to a 2.5 m^3 (3 yd^3) shovel and that the cost per ton of the 4.2 m^3 loader would roughly be the same as that of a 2.9 m^3 (3.5 yd^3) shovel. The weak point in the economy of the loader is its short life - only some 8,000 hours, compared with 20,000 hours for a shovel.

The front-end loader is also used as a combination of loader and hauler and as such can work economically over distance of up to 100 m. It is used to feed mobile chutes or mobile crushers at the quarry front.

Annex VI

GYPSUM PLASTERS

There are many cementing materials that consist mainly of calcium sulphate, which is produced by partial or complete dehydration of gypsum ($CaSO_4.2H_2O$). Natural gypsum deposits provide the raw material for production of plaster of Paris. Gypsum is also produced as a by-product in the manufacture of fertilizers. Sulphuric acid and cement can be produced by the reduction of raw gypsum, particularly the anhydrite, in special kilns. A type of flooring plaster is made of anhydrous calcium sulphate formed as a by-product in the manufacture of hydrofluoric acid, together with an accelerator.

The different kinds of gypsum plaster are classified in BS 1191 : 1955 as follows:

Class A, plaster of Paris;
Class B, retarded hemihydrate gypsum plaster;
Class C, anhydrous gypsum plaster;
Class D, Keen's plaster.

When finely ground gypsum is heated to about 150°C in shallow, open iron pans, or deeper shallow kettles, the product obtained is the hemihydrate ($CaSO_4.\frac{1}{2}H_2O$), usually mixed with some unchanged gypsum and some hard-burnt material. This product is called "ordinary" plaster of Paris. It sets quickly, since the presence of unchanged gypsum accelerates the setting time. When a small percentage of retardant is added, normally 0.1% of keratin, the rate of crystallization is inhibited and the set is retarded for an hour or two. This is termed retarded hemihydrate gypsum plaster. Another method used for dehydrating gypsum to the hydrate is to heat gypsum in an autoclave under pressure at about 130°C; this produces plaster that requires little water for mixing and that possesses a high degree of strength.

If calcination is carried out at a higher temperature than that used to to produce hemihydrate, the remaining water of crystallization is lost: at first a soluble, and then an insoluble, anhydrite is formed. Soluble anhydrite, which forms the basis of the anhydrous gypsum plasters is produced occasionally when the temperature is allowed to rise to 190°-200°C. This product is very hygroscopic - it absorbs water vapour very rapidly to form the hemihydrate. When soluble anhydrite is heated to higher temperatures its reactivity steadily diminishes until, at a temperature of 600°C, the product becomes relatively inert. This inert product is insoluble anhydrite. Before it can be used as an accelerator, a suitable catalyst must be added to it in order to render it reactive.

Keene's plaster is usually prepared by calcining gypsum in lump form in a kiln at a dull red heat. About 0.5%-1% of potash alum or potassum sulphate is usually added, but mixed accelerators such as ferrous or zinc sulphates with potassium sulphate are also occasionally used.

Lime also acts as a promoter, although it is a less active one. When gypsum is clacined at 1,100°-1,200°C the gypsum is partially dissociated into sulphur trioxide and lime, leaving free lime dispersed in the product to act as an accelerator of setting time. This forms the traditional very low-setting flooring plaster known as Estrich Gips.

Despite extensive study, the chemistry of the gypsum transformation products has still not entirely been elucidated. The temperature at which gypsum is transformed to hemihydrate in water is 97°C. In an atmosphere of low humidity, however, dehydration occurs at much lower temperatures. This is also true in solutions of salts, in which the water has a reduced vapour pressure. Thus, in saturated magnesium chloride solution the temperature is as low as 11°C.

During the setting of plaster, the total solid volume decreases. There is an overall expansion of the mass caused by the manner of crystal growth, and this is a valuable property when sharp casts in moulds are required. For some uses, however a material with a low-setting expansion is desirable, such as can be obtained from low-expansion hemihydrate plasters.

Annex VII

THE MANUFACTURE OF PLASTER OF PARIS

Plaster of Paris with special specifications and special quality requirements is produced using a gypsum kettle. The raw material (gypsum) can be either in the form of fine particles or of dust. This is transported to the kettle in batches by means of a belt conveyor, chain conveyor, plate conveyor, feeding table (rotary discharge), special screw conveyor or bucket elevator. The choice of the conveying system depends on the properties of the feed gypsum. The interval between feed times is usually from 20 to 45 minutes per batch, depending on the size of the kettle.

Method of operation

For the most economical operation of high performance kettles, the feed material should be pre-dried and ground to the required fineness. This can be conveniently achieved by a preliminary process with grinding, air-separating drying mills. It is advisable to fill the kettle automatically by means of a screw conveyor that can be adapted to transport amounts suitable for a given filling time. The feeding is accompanied by continuous stirring by an agitator. The quantity of feed material required will depend on the time material remains in the kettle.

The kettle can be heated either with liquid or gaseous fuel. A simple and easy-to-operate oil-firing unit should be used. The hot gases passing through the pipes around the container are partially returned to the generator. This method of operation provides an indirect exchange of heat between the material and the flue gas, which ensures that the material is uniformly calcined, given careful heat treatment.

At the end of the calcining process the content of the kettle is emptied into a discharge hopper. The duration of heating of the gypsum depends on the nature of the raw gypsum. For cold gypsum that has not been dried or dehydrated previously, a time of 3-4 hours can be expected for one batch. Only 2-2½ hours are required for the calcination of pre-dried and dehydrated gypsum. The batch may even be ready in 1-1½ hours if gypsum which has previously been burnt in a kiln is being calcined.

The plaster of Paris produced by using the kettle method has good working properties with a low proportion of anhydrite.

As a greater quantity can be mixed to provide a uniform material, high strength can be obtained in prefabricated building elements made from this plaster. The properties of plaster with a purity of more than 85% $CaSO_4 \cdot 2H_2O$ (with impurities not affecting the properties of the plaster) are as follows:

Item	Value
Initial setting time	15–20 min
Final setting time	35–45 min
Bending strength	Over 50 kg/cm^2
Compressive strength	Over 130 kg/cm^2
Brinell hardness	Over 170 kg/cm^2

The dimensions and output of gypsum kettles produced by two major companies of the Federal Republic of Germany are compared below. The first table gives performance data related to pre-dried finely ground gypsum.

The performance data relate to pre-dried finely ground raw gypsum at a temperature of 70° to 80°C.

The figures of output refer to pre-dried and pulverized gypsum at temperature of 80° to 85°C.

Size and output of Büttner-Schilde-Haas AG
and Gebrüder Pfeifer AG
gypsum kettles

Büttner-Schilde-Haas AG

Manufacturer's model number	External diameter (m)	Overall height without drive (m)	Output (tons/day)
2.5	2.4	3.9	23
3.2	2.4	4.4	29
4	2.8	4.6	35
5	2.8	4.8	42
6.3	2.8	5.5	52
8	3.4	5.6	63
10	3.4	6.2	80
12.5	4.0	6.2	106
16	4.0	6.9	131
20	4.0	7.6	154

Gebrüder Pfeiffer AG

Manufacturer's model number	External diameter (m)	Overall height without drive (m)	Approximate output (tons/day)
100	1.4	3.0	12.5
112	1.5	3.3	16
125	1.7	3.75	20
140	1.9	4.25	25
160	2.12	4.75	32
180	2.36	5.3	40
200	2.65	6.0	50
225	2.8	6.7	63
250	3.2	7.5	80
280	3.6	8.5	100
320	4.0	9.5	125

Production of hemihydrate using an autoclave

Here the gypsum is crushed into small sizes from about 2 to 3 inches. Patches of this crushed gypsum are introduced inside an autoclave under steam pressure. Hemihydrate is prepared and produced by cooking gypsum by autoclaving under steam pressure. The autoclave is a closed container. The cooking of gypsum is done when the raw gypsum is heated in the autoclave for several hours in contact with steam pressure. Many designers design the autoclaves with various steam pressures, temperatures, and periods of time at which the gypsum is transformed to hemihydrate. According to Perederit hemihydrate is prepared by autoclaving gypsum lumps at a pressure of 1.3 atmosphere at 124°C for a period of six hours with drying after autoclaving for two and half hours at 120°C under the normal pressure. The particle size of raw gypsum has some effect on the production of hemihydrate. In the German Democratic Republic they produce hemihydrate by introducing two-inch gypsum lumps in an autoclave at 5 atmosphere pressure. The autoclave temperature is about 100°C. The size of the gypsum lumps must be well controlled to obtain the proper hemihydrate.

Annex VIII

ASTM STANDARD SPECIFICATIONS GOVERNING GYPSUM AND GYPSUM PRODUCTS

1. Standard Methods for "Chemical Analysis of Gypsum and Gypsum Products". Designation: C 471-75.

2. Standard Specification for Gypsum. Designation: C 22-50. (Reapproved 1974)

3. Physical Testing of Gypsum Plaster and Gypsum Concrete. Designation: C 472-73.

4. Inorganic Aggregates for Use in Gypsum Plaster. Designation: C 35-70.

5. Standard Specification for Gypsum Wallboard. Designation: C 36-75.

6. Standard Specification for Gypsum Concrete.

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