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REPORT ON LÖKKEN COPPER MINE, NORWAY

Compiled following a visit by J. H. Shillabeer between August 3rd and September 26th, 1964

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The writer is happy to record his gratitude for the interest and hospitality shown him during his stay at Lökken Mine. He would also like to thank the IAESTE Organization for arranging the visit.

J. H. Shillabeer, October, 1964

All data is given in metric units and the following conversions may be of use:-

1 m.	=	3.281 ft.
$1m^2$	=	$10.765 ft^2$
1 km	=	0.622 miles
1 kg	=	2.205 lb.
1 tone	=	0.985 long tons
$1 m^3/min$	=	35.25 c.f.m.

Norwegian currency is in Kroner and øre where 100 øre = 1 Kroner. The rate of exchange is slightly less than 20 Kroner to the Pound Sterling.

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INTRODUCTION

(a) General -

The Lökken Mine is owned and operated by the Orkla Grube-Aktiebolag (Orkla Mining Company Limited), a large and well established Norwegian mining and finance house. From 1931 until 1962, the mine had been engaged in the production of a coarse lump ore ranging in size from ¾" to 5" for the manufacture of sulphur and copper matte in the smelters operated by the Company at Thamshaven. As a result of the discovery of the French natural gas deposits, a new raw material for sulphuric acid was found, thus causing a sharp decline in the price of sulphur. Hence, since 1962, the mine has produced a bulk concentrate of copper sulphides, all of which is now exported to Northern Germany. The sulphur smelters have now been closed down and replaced by plant producing ferro silicon.

From an initial peak production of about 100,000 tones annually in the early 1920's, production rose to the record of 562,000 tones in 1937. After difficulties during the Second World War, production remained steady at around 500,000 tones per year during the 1950's, and at that time, the average price of the product was 250 Kroner per tone. Today, production has been greatly reduced and is now steady at around 230,000 tones annually while the price of the concentrate has fallen to only 95 Kroner per tone.

(b) Location

Lökken Mine is situated near the River Orkla in the southern Tröndelag, some 70 km. south of Trondheim. (Figure 1.). In connection with its mining interests at Lökken, the Company has constructed and operates its own hydro-electric scheme and 25 km. electric railway - the first to be built in Norway. The ore is transported by rail to Thamshaven on the Trondheimsfjord from where it is exported to Germany. There are also road connections to Thamshaven, Trondheim and to the south. Airport facilities are available at Trondheim.

(c) Climate

The weather in the South Tröndelag may be compared with that of North West Scotland. The overall topography is somewhat similar and while the area experiences the benefit of the Gulf Stream, a heavy annual precipitation arises from the depressions which continually sweep inland from the North Atlantic.

The total average annual precipitation is 926 m.m. and most of this falls as snow from mid October to March or April. The absolute maximum depth of snow in the valley at this time of the year is about 1.5 m., and the annual average temperature at 8.00 a.m. is +2.65°c.

Temperatures can however, range between $+27^{\circ}c$ and $-30^{\circ}c$ in one year.

(d) History and Background

Saxon

It is not recorded when the deposit was discovered, but ~~Prussian~~ immigrant miners were probably the first to work the deposit at Lökken. The first licence to mine was granted on June 24th 1655 to the Lökken Copper Mine Company. This company operated the deposit as a copper mine for some 200 years with varied success; it had one smelter at Svorkmo 7 kms. to the north and another at Grutsaeter, some 15 kms. to the south east. In 1777 flooding caused work to be abandoned in the lower levels, but work was continued in the upper parts of the mine until 1845 when all activity ceased and the mine became filled with water. At that time flooding proved to be an insoluble problem. It was not until 1904 when the present company was formed with Norwegian and Swedish capital that dewatering was begun and power plant and a railway constructed; this work lasted 18 months. A new shaft was sunk during the first World War. The increasing demand for sulphuric acid at that time and until recently, made pyrites the more important part of the ore values.

It will be appreciated that Lokken Verk is a closely knit rural community with a very strong mining tradition. However, this region has no history of militant unionism borne out of poverty which is to be found in certain industries in Great Britain. Workers at Lökken have always been well paid by Norwegian standards, and it would appear that the company has always persued a highly benevolent policy towards its workers. It is interesting to note that in 1962, when the fall in the international price of sulphur forced a radical programme of rationalisation upon the company, the reduction in labour force was achieved with the minimum of discord and the maximum of co-operation.

The company owns much of the land in the Lökken area and almost all the housing accommodation - which is provided at an exceptionally low rental. It has also provided a church, cinema-club and holiday resort and amongst its many other activities subsidizes ~~operates~~ the local bus company. This aspect of the report is discussed further under "welfare".

GEOLOGY

(a) General

The Caledonian orogeny is something more than 300 years old, it being mostly composed of Cambro-Silurian sediments and volcanics with some parts the remnants of older rocks i.e. the greenstone. The mountains obtained their structure at the end of the Silurian - and during the Devonian ages, they were probably of a similar size to the Alps as we know them today but in the intervening time have been highly denuded and now only the very oldest parts remain.

The Lökken territory (in the wider sense) is at the middle of the whole geological system which is known as the Trondheim region. A table is given showing a schematic representation of the succession in the Lökken rocks.

Lower Ordovician volcanic greenstone dominates the Trondheim region and it lies conformably over the Röros succession. The orogenic folding which began later - the Trondheim orogeny - caused a break in the succession. Much evidence of earth movement can be seen today in conglomerates and breccia formations - Hovinggruppen (middle and upper Ordovician), Silurian strata are not observed in the Lökken area.

During the mountain forming process, the original rocks became exposed to changes in stress and temperature and were radically altered. The area now forms a typical syncline with the youngest part, Hovinggruppen, at the middle of the basin. The rocks are often strongly folded with the axes running east-west, plunging gently to the east in the western parts and gently west around Lökken. There is a culmination a short distance east from Lökken and from there it falls again to the east in the eastern part. The Limb of the syncline dips generally steeply or moderately so to the north. The great fault at Reisfjell (7 km.) in the "gabbro-massif" must especially be mentioned. Thrusts greater than the one at Reisfjell are not often found in Norway.

As stated previously, the greenstone mass dominates the region mostly forming the heighest mountains the Hovinggruppen slates, phyllites, and altered limestones form the lowlands with rounded hills of porphyry.

FIGURE II

System	Age in Mill. years	Lökken Area Subdivision	Rock Types
	.350		
Silurian			
	390		
Ordovician		Hovinggruppen Bymarksgruppen	Conglomerates, sandstones, Limestones etc. Mostly greenstone
	470		
Cambrian		Rorosgruppen	Mostly phyllites
	550		

The greenstone is remarkably spread in the Caledonian, both in the lower and middle Ordovician. In the Lȯkken region the greenstone is the dominating part of the Lower Ordovician Bymarksgruppen and also the ore bearing formation.

(b) Local Geology - The Lökken Area

The Lökken region in the wider sense occupies an area of something like 250 square miles in the west of the Trondheim system. In Lökken is found the largest of the many occurences of cupriferous pyrite existing in the Trondheim region. The area under discussion here is the Lokken area in a restricted sense, i.e. the immediate surroundings to the mine. Here the rocks belong to the Stören sub-division of Bymarksgruppen and mostly comprise andesitic to basaltic greenstones, remarkably poor in acid pyrite, and metamorphosed in the greenschist or lower epidote facies. The greenstones are partly schistose and partly massive: the latter type may often be observed as pillow lavas. Although the more massive and compact types of greenstone may be considered as metamorphosed lavas, the greenstone schists probably represent sediments and tufs which are often rich in acid pyrite.

It is probably quite certain that the greenstone is of submarine origin because of the existance of pillow lavas in all but the lowest horizons, and because they occur with other rock types of submarine origin such as altered limestone, jasper and quartzites. The pillow lava themselves are almost always of greenstone composition.

The colour of the greenstone varies from light grey through green to black (the most altered types).

Alteration of the greenstone has taken place especially near the ore, the most common feature being carbonisation by CO_2 bearing solutions especially resulting in the leaching of calcium. Close to the ore bodies can be found evidence of more complete metasomatic action involving the addition of other substances: nearest the ore the rocks contain large amounts of quartz, chlorite and some sericite. A change in the proportions of these three minerals takes place progressing away from the orebody - in the middle zone sericite and chlorite are together the chief components, while in the outer zone sericite is the main mineral. Always quartz is present in large quantities. It has been concluded that metasomatism involved the addition of SiO_2, K_2O and H_2O. Many of the altered rocks are impregnated with sulphides in some degree - dominantly pyrite with some zinc blende.

In addition to the jasper, metalimestone and quartzites mentioned above, other sedimentary rocks in the Støren group comprise sedimentary pyrite ("Vasskis", see below) and arkosic quartzites; quantitatively all these types are of minor significance.

There are two types of intrusive rock in the Lokken area: the gabbro masses, and the quartz keratophyres. The gabbro exists in three large bodies which show great similarity, they are all coarse-grained and are usually composed of basic plagioclase (epidote), and altered pyroxene (colourless hornblende).

The dominant tectonic feature of the Lokken area is the folding which has taken place along an axis striking west north west.

(c) Ores

The Lokken ores occur as concordant bodies in the greenstone which also contains layers of sedimentary pyrite ("Vasskis", which has very little copper).

A clay gouge some 20 - 25 cm. in thickness was discovered in the mine some time ago and this has been identified as a thrust plane dipping at some 20° to the west-northwest (striking perpendicularly to the tectonic folding axis). At the surface, the outcrop of the thrust plane can be traced for some distance (see map) and it probably marks the upthrusting of the block of ground to the east-southeast which lies above the ore.

The fully known ore bodies are below the thrust plane at some distance in the eastern parts of the mine, while in the west they peter out into "tails" against the gouge. While the origin of the ores is the subject of considerable controversy at the moment, it would seem that their position was closely controlled by tectonic conditions. It seems reasonable to suppose that a zone of weakness was created in the bend in the greenstones in which they occur (the culmination) by a layer of "Vasskis" already there, and that the thrust plane would produce an area of stress relief in which the ore bearing fluids might gather. Parts of the deposit are near the overlying gabbro (see section, figure 4), but this is now thought to be not directly connected with its origin.

Syngenetic "Vasskis" is not mined today. The epigenetic deposits are cigar shaped lenses, their major axis are always parallel to the fold direction in the country rock. At Lokken, three ore bodies have been worked, they are called Hovedgrubben (the main mine, Indien (the India), and Bakindien (Behind the India). Wall rocks generally dip 45° to the north, while the ore-bodies have an east-west strike with a northerly dip and the long axes plunge at about 9°. Hovedgruben is by far the largest. Bakindien is the smallest: the size ratio being 30:3:1.

In the east near the original outcrop, the ore-bodies are parallel to each other but they converge westwards. Hovedgruben has a length of about 2½ km. The other two ore-bodies gradually converge to the west, but Bakindien disappears about 1150 metres from the outcrop.

Indien too peters out, at some 1700 metres from the outcrop, before it can join Hovedgruben.

The mineralogical composition of the three ore bodies is not the same, and in Hovedgruben too there is a considerable random variation in both hardness and chemical composition. Towards the footwall the ore is usually extra hard with more quartz and less copper than usual while the richest parts seem to be at the centre of the cross section. In crushed parts which may be found near faults the copper content is especially low, but usually very rich copper ore exists nearby, thus possibly indicating the presence of sulphur bacteria in the past. Bornite as well as chalcopyrite may be found in these areas.

Magnetite bearing zones have been found east and west of Wallenberg shaft (cross-section 3, figure 4) and these are impregnated with pyrite. Their exact origin is an unsolved problem.

To the east in the hanging wall of Hovedgruben is a breccia body having a strike length in excess of 200 metres and thickness of some 100 metres (see cross-section 1, Figure 4.) The breccia is mostly fractured greenstone cemented with copper bearing pyrite (approx 4% Cu.) This has been mined since the earliest times and the workings constitute something of a spectacle today.

An analysis table of the ore is given in figure 14.

Along the footwall is found a band of "Vasskis" which is large in area but thin - it is usually a few centimetres to about 1 metre in thickness, seldom more. The sulphur content is from 20 to 40% and there is little or no copper and zinc, trace elements like selenium which are found in the ore are notably absent from the "Vasskis" also. Interbedded with this sedimentary pyrite are thin layers of jasper, chlorite and graphite schists, and magnetite bearing chlorite rock.

Obviously any hypotheses on the origin of the ore at Lökken will be necessarily complex, however, recent workers think they have identified pseudomorphs of pillow lavas in the ore which may point to replacement of the greenstone by metasomatic action in the zone of reduced pressure mentioned earlier.

History of Ore Prospecting at Lökken

Between 1906 and 1920 an extensive diamond drilling programme was carried out and this defined the main features of the ore-bodies. In all, some 78 holes were drilled with a total length of 14,650 m. Since this period work has been confined to exploration for new ore-bodies in the immediate area. During the last 29 years, geophysical methods have been applied and some 150 km^2 have been studied.

It would at first appear that the geology of the Lökken area would be particularly amenable to the various electrical methods available since the Lokken ore has a resistivity down to 0.01 ohm.cm. while the surrounding rocks have a resistivity which is much higher (10^6-10^7 The overburden is both thin and weakly conducting. Interpetration of the anomalies obtained is however complicated because of extensive occurences of "Vasskis" and graphite schists which both have low resistivity and give marked electromagnetic indications. Diamond drilling must be resorted to in order to aid the work of interpetration and corrolation especially in connection with indications at depth.

Electromagnetic methods have been largely used, alternating current is fed into the rocks both inductively and conductively by means of large loop cables and earthed cables with electrode separations of up to 10 km. It has been found that the size of the primary layout and its orientation towards the mass of rock to be investigated are of extreme importance, especially when surveying at depth. Deep indications observed on one layout may be totally absent in others.

Electromagnetic surveying from aircraft has been carried out, using large earthed cables for both airborne inductive energizing and current supply. Indications from the "Vasskis" and graphite schists were defined but the method is not thought to be readily applicable to Lökken requirements.

Electromagnetic measurements have also been made in diamond drill boreholes from the lower levels in the west of the mine. This has been of use in giving indications of conducting ores on either side and in continuation of the boreholes. Irregular and displaced ores may best be studied by this means. From boreholes in the mine electrical potential measurements have been found useful in providing correlation data between intersections in various holes and obtaining information on the extent of the intersections. In recent years, gravity measurements have been made to some extent from exploratory workings in the mine and these too have proved useful. Some positive anomolies in gravity measurements have been connected with high epidote concentrations in the greenstone nearby.

At present, exploratory work is being carried out from (surface) diamond drill boreholes, some 5 - 6 km to the north-west. The geophysical prospecting work carried out in the mine area predicted the occurence of the new ore body but could give few certain indications of its extent; diamond drilling has also proved its presence. Work is now concentrated on completion of the new sub-level shaft in order that drifts may also provide further exploratory information.

It is the writers opinion that seismic geophysical methods might have found some useful application in the Lokken area because the greenstone, graphite schists and ore all have marked differences in both density and hardness. He has learnt, however, that these methods are not employed in Norway at all.

SURFACE LAYOUT

(a) The Machine Shops

This portion of the surface plant is situated in the "new block" together with the offices, and stores. Here is the main part of the service facilities at Lökken Verk and together with the separate machine shop at the ore dressing plant a policy of a large degree of independence from outside suppliers is persued, this being largely as a result of high transport costs. Some of the machine tools now at the Wallenberg shaft site were recently moved from older machine shops near Gammelsjakten headframe to form the new centralised service and repair installation. While this would seem to be an entirely satisfactory move, since few machines are now in operation in Gammelgruben, the writer feels that there could be more co-operation between the dressing plant and the mine on this aspect - it would probably lead to a more economical division of labour.

At Wallenberg there is no division in accommodation for repairing and machining. There are three large shops, all situated on the ground floor of the new block: the electrical shop, machining and fitting shop, and the forging and welding shop. The building is of excellent quality and very well designed - the shops all present a pleasant light and airy aspect (very little artificial illumination is required during daylight hours). Unlike similar plant that the writer has experienced in England, heating and ventilation have been well thought out and yet adequate access has been preserved.

Few of the machine tools to be found at the Wallenberg centre are particularly modern or highly sophisticated, but it is felt such types would be superfluous when the large variety of work that is normally undertaken is considered. All machines appear to be well maintained and adequately utilised.

A list of the chief machine tools at Wallenberg is given below. From his little experience of the subject, the writer would feel that while all the machines are adequately used, perhaps two of the older and smaller capacity lathes could be desposed of and be replaced by a modern type of swivel head milling machine - this could be justified in terms of the greater degree of flexibility available with these machines.

The chief machine tools at Wallenberg service centre are:-

Quantity	Make	Type	Purpose	Capacity
1	Varnamo (Sweden)	-	Planing and simple milling	small
1	Wanderer (Germany)	IAU	Simple milling	medium
	Brodene Simdt (Sweden)	AS12	Lathe (semi-auto)	2m between centres
1	Himktens (Sweden)	CA50	Lathe (old, no auto)	c.1.7m " "
1	Taylor (England)	GK2-10	" " " "	5 ft." "

Quantity	Make	Type	Purpose	Capacity
1	Brodene Simdt (Sweden)	AS10	Lathe (fairly modern, not automatic)	c. 1.7 between centres
1	" " "	AS4	Lathe (old, smaller diameter)	" " "
1	Norton (U.S.A.)	L295	Grinding, (modern, conventional chuck, not very flexible)	Medium capacity
1	James Shipman (England)	310	Grinding, (hydraulic feed)	Small, fine work
1	Landis (U.S.A.)	-	Face turning lathe (old)	c. 9" diameter
1	Asquith (England)	-	Radius arm drilling	2m. radius, $2\frac{1}{2}$" max. diameter
2	Ingersoll Rand	-	Stamping, cutting, drill sharpening	-
2	Coak fired compressed air, hand forge			
1	Nazell (U.S.A.) Compressed air press			
1	Peddinghaus (Germany)	-	Stamp cutter	45 m. diameter round section 50 m. square m.s.
1	Hoffman (Denmark) electrical rolling machine			2 metre
1	Nibbler (Sweden		sheet metal cutter	8 mm. M.S.
4	Norio (Norway)	STA 450	arc welding (hand)	
	Miscellaneous gas welding (hand)			
1	Norvarex (German) gas welding and cutting (remote/semi. auto) new			

A total of 34 men are employed in the machining and fitting departments. The majority of surface and underground fitters work on the day shift with all the machine tool operators. There are eight electricians employed at the mine, these are all employed on the day shift. A small skeleton staff of fitters is maintained on the two back shifts and if required, further workers are called up by telephone to assist them, most work however, is held over until the following day shift.

(b) Offices

All the offices at Wallenberg are situated in the new block as mentioned previously. All the higher engineers and officials of the company have separate office accommodation in the head office block which is in Lökken town itself. At Wallenberg, there are offices for the mine captain, shift bosses, time keeper and store supervisors. These are all adequate in size and again, appear to be well designed with good ventilation and heating. It may be mentioned that together with the offices are provided shower facilities and changing rooms for the mine officials, visitors, and also the fitting staff. There is also a very pleasant dining room available for the surface workers and also for any entertaining that may be required to be done.

(c) Stores

Six men are employed in the stores office and their responsibilities include both the issuing and the ordering of equipment. There are also three storemen and one transport worker attached to this department. Because of the isolated nature of the mine from its suppliers, a very large stock is carried at all times, indeed the majority of the surface buildings are devoted to storage. The surface layout plan (Figure 5) indicates the distribution of the various storage facilities at the mine, and in particular, the covered storage space available. It should be noted that the small parts and spares store in the new block is on two floors.

(d) Lamp House

This is situated between the older winding house and the new block at the entrance addit to Wallenberg shaft. This is an old building of wooden construction that is sufficient in size for todays requirements. Unlike lamp cabins in England, the miners are not responsible for making sure that their own lamps are recharged and so there is no need to cater for large numbers of people passing through the house in a short space of time. The cabin staff maintain lamps, issue and receive them daily and operate the recharging system. Each man has two lamps issued to him which he uses on alternate days, thus ensuring that each battery is fully charged when taken out. The total capacity of the cabin is 405 lamps and it is staffed by one man.

(e) The Saw Mill

Although little or no timber is required for support purposes at Lökken mine, considerable quantities are consumed every day for a multitude of purposes e.g. two or three fully grown pine trees every day for "bombing sticks". Other large consumers include transport of heavy equipment underground, loading box repairs, ladderways and hoist runners in raizes etc. The new shaft is being lined and equipped completely with local timber. It will thus be seen that there is a considerable daily consumption of timber and to provide for this, a full sized saw mill is provided - this is sited to the south east of the "new block". The writer is not familiar with the method adopted to describe saw mill capacity and thus it must suffice to say that it is the biggest he has seen anywhere and would be capable of handling the largest sizes of timber available locally. In the same building there are also two other smaller rotary saws and a planing machine. Two men are normally employed here. To provide for the timber requirements of the mine and washery plant, the company owns much of the surrounding forest land. Some 1,000 cubic metres of timber are consumed annually.

(f) Wood Preservation Kiln

Situated to the west of the Wallenberg site is the wood preserving kiln, here some 75% of the total timber consumed is impregnated with "Boliden Salt" (an arsenic compound). After packing with sawn timber, the pressure is reduced and then a solution of "Boliden Salt" is introduced under pressure. The total time for the operation is approximately 1½ hours and when completed, the timber is stacked in the open air to dry. To minimise risks encountered from handling the preserving medium, operators are provided with special rubberised protective clothing and separate washing facilities.

(g) Compressed Air Plant

Compressed air for consumption below ground is supplied from compressors to the Wallenberg hoist house and also from compressors at Fearnley shaft top. It would seem that the company intends a gradual run down of compressors at Fearnley shaft while installing new plant at the Wallenberg site.

The main compressed air lines from Wallenberg are of 12" and 10" diameter, welded steel construction, while for the smaller branch or service lines, P.V.C. tubes of Larges (Norway) manufacture are used to a great extent. The two compressor plants are connected by a 6" main underground.

A list of the compressors installed is given below. At Wallenberg shaft:-

1 Ingersoll Rand type XLE	delivering	$58m^3$/min,	rated	350 h.p.
2 Homar	"	$75m^3$/min,	"	560 h.p.
1 Flottman	"	$25m^3$/min,	"	100 h.p.
1 Atlas type AR7	"	$49.3m^3$/min,	"	350 h.p.
1 Sullivan	"	$12m^3$/min,	"	80 h.p.
1 Atlas type ER6	"	$30.4m^3$/min.	"	215 h.p.

At Fearnley Shaft:-

2 Ingersoll Rand	delivering	$30m^3$/min,	rated	200 h.p.
1 " " (1907 vintage)	"	$15m^3$/min	"	100 h.p.
1 Flottman	"	$25m^3$/min	"	" "

N.B. Delivery pressure is 7 kg/cm^2.

The author is of the opinion that excessive use is made of compressed air in the mine, admitedly for some mining operations, compressed air is indispensable, but it is felt that in some cases, e.g. for pneumatically operated railway junctions, pneumatic scraper winches, pneumatic raise hoists and ventilation venturis etc., its use could be avoided and a more economical source of power used, e.g. electricity. Also on principle, the writer is not in favour of static compressors with the miles of large diameter main lines that they necessarily require and their inherant water condensation problems and so, it is to be hoped that development in the new ore body will be accompanied by the application of mobile or semi-mobile compressors.

APPENDIX II

The New Shaft and Development

The New Shaft and the development work to be associated with it have provided opportunities for the study and use of some newer departures in mechanised mining engineering. [It is possible that the timing of this operation could have been better adjusted to the life of the older parts of the mine. For some years, the new ore body has been known to exist and there were no reasons to prevent the development beginning earlier; had this been the case, much of the necessary capital investment required could have been more easily absorbed and set off against the lower mining costs of stoping (as against pillar extraction). Today, there is no longer any stoping work.]

Before starting excavation, work was carried out to define the planes of principle stress and to obtain some forecast of the rock pressures to be encountered. From these investigations, it was possible to design and orientate the shaft to give the best resistance to stress, minimise scaling of the sides, and aid blasting to some extent. The original dimensions were an ellipse of major axis 4.30 m. and minor axis 2.76 m. this has now increased to 4.90 m. x 2.90 m. by scaling and reached a stable condition. The cross sectional area is now approximately 12 $m.^2$.

A simple, single stage sinking platform was designed and built at Lökken. This was primarily for drilling purposes and had 4 drilling machines suspended by their air legs from a peripheral ring below it. The size of the ring, length of air legs and the round of holes were so designed that in positioning each drill, the correct angle was obtained automatically.

The greenstone proved difficult to blast conveniently using the generally accepted cone types of sinking round and these were soon abandoned in favour of a "Vannkut". This was basically a double SLIPING ROUND. the shaft bottom being divided into two halves, one half being blasted and cleaned out before drilling on the second commenced. The average pull per round was 1.60 m. It would seem to be the tendency of the greenstone to cling together, even when broken (very useful in other circumstances where natural arching can be accommodated), that caused the difficulties in blasting and mucking. This was expected to occur from experience elsewhere in the mine, consequently, much consideration was given to the mucking technique to be employed. After gaining information from the mines in many parts of the world, the Cryderman machine was selected as being most suitable. This provided the very necessary digging action and was sufficiently manoeuverable to cope with the uneven profile of the shaft bottom.

A temporary hoist was designed and constructed at Lökken for the sinking operation. This is a double drum hoist, with a maximum unbalanced load of 7,250 kg. It is driven by a 220 h.p. D.C. electric motor and is manually controlled. Drum diameters are 2.2 m.

Sinking of the shaft has now been finished and equipping is nearing completion. It is being fully lined with timber and the skip runners are also of timber (12" x 10" local pine). The shaft was sunk with labour drawn from the mine: teams of only four men per shift were employed, although working was on three shifts and seven days per week.

Much of the future of Lokken mine depends on the success or failure of this project and so it is obvious that development of the new ore body must be pressed forward rapidly. For this purpose, one high speed drilling rig has already been purchased and experience is being gained with it. A second is likely to be obtained later. This machine is illustrated in plates 1 and 2. It incorporates the Atlas Copco BM 30 auto-feed and ladder type beds with three machines mounted on one horizontal arm to the left of the central winch pillars and one machine to the right similarly mounted. Each machine is laterally positioned by simply moving it by hand along the arm while vertical movement is by hand and air operated winches. The rig is anchored to the roof by two compressed air operated pistons. The combination of high drilling capacity and simplicity are the big advantages of this rig: apart from the drilling machines themselves there are practically no sophisticated pieces of machinery which can break down.

A typical round of holes which has been found suitable for drilling with this rig is shown in Figure 26., with two operators and a total length of 743 m. to be drilled the total time for this operation is well under 2 hours. Thus no longer can it be stated that it is the drilling time which controls the tunnelling cycle.

Obviously, an efficient method of cleaning must be employed if the drilling rig is to be utilised to the full and this presents something of a problem, as a tunnel becomes longer and transport of the ore takes longer. This particular aspect of the tunnelling cycle has been at least partially overcome by the construction of a modified "Boliden Scraper Train". In the train to be employed at Lökken, the scraper runs along a special track on top of the wagons and does not load directly into the train. This is accomplished by using an Eimco 21 (diesel, long arm type) overshot loading machine. The scraper train is shown diagrammatically in Figure 27.

It is interesting to note that (only sufficient) ore has been ~~proved~~ indicated (by diamond drilling) ~~to supply work for about one year.~~ It is hoped to be at least. This is sufficient however to cover the capital cost of shaft sinking, development, and all the new machine installations; thus this whole project is an experiment and while typical of the mining industry as a whole, such a gamble is not truly consistent with the latter day character of Lökken Mine. However, it is pleasant to end this report by dealing with a project which in some ways marks a return to the traditional pioneering spirit of the early history of mining at Lökken.

APPENDIX III

Bibliography

1. Mines in South and Central Norway - F. M. Vokes, Oslo 1960

2. Geology of Norway - O. Holtedahl (ed.) Oslo 1960

3. Lökken Verk Pyrites Mine - J. McCafferty (Mine and Quarry Engineering, March 1956)

4. Lökkenfeltetets geologi - C. W. Carstens; 1951 - Norsk Geol. Tidsskr.

5. Lökken Verk, en Norsk Grube Gjennom 300 År, 1954 Orkla Grube A/B

It may be noted however, that the heat transfer from the compressors at Wallenberg is sufficient to provide all the heating that is necessary in the bath houses and offices throughout the year.

(h) Bath Houses

There are three bath houses at Wallenberg and their position will be noted from the surface layout plan (Figure 5). These buildings are not modern and so perhaps this may explain why they are not of the standard one has come to expect today; they are adequate however.

The total accommodation is for about 300 men, the original idea was probably to house each shift separately in a block of its own but this no longer applies today. Separate locker facilities are not provided with a "Clean" and a "Dirty" side but hanging space is sufficient for each man. Although the supply of hot water is more than plentiful, the emphasis is placed on washing facilities rather than showers - there being only eight showers per block i.e. per 100 men. Unless an increase in the labour force is planned, improvements in these facilities are not necessary.

MINING METHODS

(a) General

At Lokken, mining is now concentrated upon work in the Hovedgruben ore body. Indien is now completely worked out, extraction being nearly 100%. In Bakindien, there remains a few pillars to be extracted and these will probably be worked at some future date.

In every part of the mine, the ore and country rock is both hard and competent. Unlike some pyrite ores in Norway, the Lökken ore provides a good roof at all times and though fractures may appear, there is little danger attached to them, provided the usual simple precaution of down loose is taken. Because of the strong tendency of the rock to hang together and form natural arches, stressing and a degree of pillar crushing can usually be predicted with some certainty by the more experienced members of the staff.

Since the mine was re-opened in 1904, stoping has been by shrinkage methods which seem to be well suited to the conditions. Little work remains to be done in the stopes except drawing off the broken ore, most extraction is now from pillars. At this time, most work is concentrated on extracting pillars to the west of Wallenberg shaft and this is usually done by long hole blasting. By working in both easterly and westerly directions simultaneously towards two pillars of low grade ore, it is hoped to attain a high percentage of extraction by taking all but these two pillars. This is further described later.

As a general rule, it has not been found necessary to fill the empty stopes; there being no shortage of land on which to dispose of waste ore. A few stopes have, however, been filled and these are situated below the lake (Fargali-vann); this was done to prevent any marked subsidence and the danger connected with it of flooding. Effects of mining can be seen at the surface in some places where cracks of up to 1 metre have appeared and small blocks of land have dropped a few metres. This has caused little inconvenience as the angle of draw seems very steep and only woodland is situated above the orebody where the subsidence has occurred.

The sulphur ore produces a very acid mine water, PH up to 2.5, and a little decomposition of the broken ore in the stopes results, but this is not serious as the quantity of water is not large. Very little or no gas is evolved.

It is necessary to control the grade of the run of mine ore quite carefully at just a little under 2% copper in order to meet the designed requirements of the dressing plant. Hence, because of the need for grade control, careful planning is necessary and mining is not confined to just a few working places.

customers

(b) Layout and Development

Three shafts have been used up to the present in order to develop the deposit:-

Gammelshakten (The Old Shaft) is vertical and only 235 metres deep. It remains from the early history of the mine and was sunk in the ore; for part of its length it passes through old open stopes. Today, it is used for winding men and materials to the few working places (e.g. pump stations) in the old part of the mine.

Fearnley shaft is situated near the old shaft in the east and is an incline shaft at 45° to the vertical. Driven from the ore dressing plant near the outcrop, it intersects the ore at about 250 metres and continues to 320 metres. It is equipped with 3 ton skips for ore hoisting and is maintained regularly, but seldom used today.

Wallenberg is the main shaft through which all the ore and most of the men and materials are wound. It is situated some 1,100 metres to the west of the outcrop and about 100 m. in the footwall of Hovedgruben. Begun in 1914, sinking was soon held up for a time by labour disputes and lockouts until a contract for sinking was obtained by the Americal Longyear Company of Minneapolis, their 64 man team began work in August 1915 and had sunk to the 380 m. horizon in 16 months. Wallenberg is now 480 metres deep, is 4 m. x 6 m. and is timber lined. There are five compartments in the shaft, two being for 5-tons capacity skips, two for cages carrying men and materials (double deck, capacity 28 men), and one for pipes, cables, ladderway etc. All runners are necessarily of timber because of the effects of mine water corrosion. Skips are of the side tipping type and are operated in balance.

Primary crushing is done underground and Figure 6 illustrates the arrangements for ore handling and storage. There are pockets for both crushed and uncrushed ore, capacities 500 m^3 and 700 m^3 respectively. The ore is crushed to a -200 m.m. product by two 36" x 42" Buchanan jaw breakers, the feed to these machines being controlled by compressed air operated chutes.

In all, eight levels have been driven at vertical intervals of 40 or 50 m. but today most of the production comes from the 430 m. level. The layout will be readily understood from Figure 28. The full car haulage was driven at about 7 m. from the deposit while the empty car roadway was driven in or below the ore to the north. These two main drifts are connected by cross-cuts at 13.5 m. intervals. Production from the western development is brought directly to the shaft along another drift which was driven to reduce congestion. These drifts are of 2.80 x 2.65 m. dimensions.

(c) Stope Preparation

It should be noted that while no new stopes have been developed for the last year or two, this description of stope preparation in the Hovedgruben ore body will largely apply to that which will be used in the new ore body in the future, should conditions permit. At present most of the production comes from pillar extraction.

In preliminary development, the ore body is split into units of 27 metres along the major axis, each unit containing one stope (19 metres wide) and one pillar of 8 metres. Stopes extend the full width of the ore body. When extraction was begun between the 380 and 430 metre horizons, it was believed that the increased rock pressures at the western end of the ore body demanded a greater degree of support and so for a time, stopes were modified to 16 metres and pillars to 11 metres. This was not found to be necessary and later stopes were again made 19 metres wide.

From the loading cross-cuts on the 430 metre level which are approximately 2.3 x 2.8 metres, raizes (2 x 2 metres) are driven at about 45° towards the base of the ore body where the footwall of the ore body is less than about 15 metres from the main cross cuts, these drawhole raizes are driven in pairs from special loading platforms at 8 metre intervals in the cross cuts. About 8 metres below the footwall, the drawholes are opened out into cones with sides at approximately 45°. The loading platforms are a type of rigidly built "Chinaman Chute" and a scraper is normally installed on each platform to assist loading into the wagons.

Where the cross cuts are more than 15 metres from the base of the ore, raizes are excavated some 15 to 25 metres apart and these are driven to about 8 metres below the base of the ore. Here they are connected by pairs of cross cuts which are 13.5 metres apart and 2 metres square. Each raize is enlarged, where necessary, to provide a capacity equal to that of two loading shifts (about 700 tonnes). Every cross cut is driven parallel to the base of the ore and is equipped with electrically operated scrapers manufactured by Norsk Mek. Verksted, Sala or Hollman's and of 15 to 50 h.p. Wherever possible, the scraping distance is kept down to about 40 metres and the levels slope down in the direction of scraping. In early development, these levels were grizzley levels, but this has been abandoned in the interests of efficiency and safety. From each scraper cross cut draw holes are put up at 8 metre intervals to the base of the ore and are opened out to leave cones with side angles of about 45°.

Depending on the width of the ore body at that point, one or two raizes for ventilation and travelling are driven in every second pillar at about 50°. Each raize is approximately 1.6 metre square and is equipped with a compressed air winch.

When all preparation has been completed up to this point, a slice 3 metres thick is removed from the base of the stope over its whole area. At this stage only about one cubic metre of ore is extracted per metre drilled since a small lump size is required - for this the men are payed at a flat rate per metre drilled. Only enough ore is drawn off at this stage to provide an adequate working height i.e. about 1.5 to 2 metres. When this has been completed, normal extraction may commence.

Unfortunately, it is not possible to give examples of the design of rounds used in stope preparation. If an analysis could be made, this would undoubtedly prove more than interesting but the subject in itself would demand a great deal of study. A few general observations must suffice. Because of the variable nature of the ground and partly due to the experience of the miners, no set drilling patterns are laid down. This appears to be entirely reasonable to the author, but what is difficult to understand is the use of a low power ammonium nitrate explosive demanding a large amount of drilling. Even taking into account the very hard nature of the ground, it is difficult to believe that, for example, in an end 2.0 x 1.6 metres pulling 1.3 metres as many as 25 holes are necessary, with 10 or 11 holes in the centre cut. Surely the use of a normal 60% dynamite, in spite of its slightly higher cost, would produce a nett saving? The official reason for the use of this ammonium nitrate explosive (Geomit) is that it is safer, apparently workers are in the habit of drilling into - or near - unwashed sockets: Geomit does not remain active after blasting. Why the usual safety procedures, following the use of a dynamite explosive as used in other mining fields can not be applied with some measure of supervision, remains a mystery.

(d) Stoping Practise

A flat back is carried at all times in the stope; a double overhand benching technique is employed, the bench thickness being limited to 1.5 metres to prevent large pieces of broken ore being lost and later jamming the drawholes. Drill holes are 4 metres long and thus 4 - 5 cubic metres of ore are broken per metre drilled. The drilling pattern is again left to the initiative of the individuals working, in the stope who are paid on the basis of the number of cubic metres broken per month. This is about 2,000 cubic metres/month/2 man team. Each man is required to undertake some secondary blasting and an allowance is paid for this. Stoping machines are the Atlas Copco BBE12DK high frequency (4,800 b.p.m.) type and these are air leg mounted (See appendix 1 for description). Every drill hole is fully charged over its entire length with Geomit explosive (mentioned earlier), this is an ammonium nitrate-nitroglycerine (10%) - trinol explosive in powdered form. Initiation is by safety fuse and standard detonators; the resulting explosive factor is between 25 and 30 g.m./tonne mined.

As in any normal shrinkage method, some 35% of the broken ore is drawn off while breaking ground in order to provide an adequate working height. Stoping is continued upwards to within 8 metres of the next main level where a capping pillar is left. Should the height of the stope become excessive, then extra support is gained by leaving a cross pillar (i.e. parallel to the major axis of the ore body) which is later extracted.

Reference should be made to Figures 7 & 8 for typical stope layout diagrams.

(e) Stoping by Long Hole Blasting

The Hovedgruben ore body has a projection extending some 24 metres below the 430 metre level, it is some 200 metres long with a maximum width of 16 metres at its upper end. Since the ore here is extra hard with a larger proportion of quartz, it was possible to use open stoping similar to the Noranda method of long hole mining. Today, this part of the ore body is no longer mined and loading of ore from pillars is now the only activity there; the method was however highly successful and may be employed again in the future should conditions in the new ore body demand. Some 4 to 5 years ago, when this ore was being mined, Craelius compressed air diamond drilling machines with 46 mm. diameter coring bits were used.

The ore was worked between two levels at 430 and 456 metres, the latter being connected to the main haulage road by an incline direct rope haulage. The two levels were connected at each stope by a scraper drift parallel to the base of the ore delivering to a "Chinaman Chute" in the 456 m. level. Boxhole chutes were driven from the scraper drift to the base of the ore and a raize driven from one of these chutes up the centre of the stope to the hanging wall and connecting with a drift at the upper level where the drilling machine was situated. This raize was then widened by slabbing from its sides to form a slot 3 metres wide extending the full length of the stope along the footwall. Widening was then continued along this slot by means of vertical fan pattern drill holes.

Figure 9 gives a diagram of the method.

Longhole blasting in these stopes was found to give increased productivity and greater safety (keeping the men working in undisturbed ground all the time). Overall costs were about the same as conventional drilling methods; an average of 32 tonnes were broken per metre drilled with an explosive factor of about 25 tonnes/kg of explosive. Blasting yielded about 5,000 tonnes from each side of the slot. Broken ore was loaded straight away to keep a free face for further blasting.

(f) Pillar Extraction by Conventional Drilling Methods

Pillar extraction by this means is not undertaken until all work in the adjoining stopes is complete, the stopes remain full of broken ore in order to afford a measure of support and thus help avoid any serious bursting. A sub-level method of extraction is employed, the level interval being 6 to 8 metres depending on conditions and a raize 1.6 m. square is driven near the footwall to connect these. Each sub-level is driven 2.0 x 1.6 metres the full length of the pillar and a chamber is excavated between the raize and the footwall to accommodate the scraper units installed there.

Broken ore from the tunnelling and other excavations is scraped into the raise and so passed to the loading chutes in the main level below. When all the sub-level cross cuts are complete, then extraction may commence.

In the top sub-level, a room is excavated near the end of the sub-level of such a size that some 2 metres of solid ore are left on the top and at each side. From this room holes with a maximum length of 4 metres are drilled in all directions and then fired simultaneously. The broken ore is then allowed to remain while retreating 8 metres along the sub-level where a new room is excavated, the process is then repeated along each sub-level in turn until the whole pillar is broken. See figure 10.

Pillar extraction in this manner yields some 2,000 tonnes/month when loading by scraper.

(g) <u>Pillar Extraction by Long Hole Blasting</u>

Pillar extraction by long hole blasting contributes a significant proportion to the output of the mine. Here again, the pillars are attacked by a sub-level method, but in this case, the adjoining stopes are emptied of broken ore before blasting - to provide the necessary free face. Figure 11 illustrates the long hole blasting method.

From a raise near the footwall sub-level, cross cuts are driven at a vertical interval of approximately 16 metres; these levels are equipped with scrapers in the same manner as with the conventional drilling procedure. Where the pillar size allows, sub-level cross cuts 2.80 metres square at 16 metre vertical intervals are driven the full width of the pillar at right angles to the sub-levels. In each of these short cross tunnels, the drilling machine is set up in three positions in order to drill a vertical fan pattern of holes. Atlas Copco BBC 45 machines are used to bore holes of 2" diameter, 10 to 12 holes in each set up, with ⅔ of the length drilled upwards and ⅓ downwards.

The entire pillar is normally blasted in one operation - a recent blast yielded approximately 70,000 tonnes of ore. At present a new Norwegian blasting agent named GEL is being studied for use with automatic charging machines.

(h) <u>Pillar Extraction - General Programme</u>

As stated previously, most pillar extraction is being carried out to the west of Wallenberg shafts. By working in both easterly and westerly directions towards two low grade pillars, which ultimately will probably be left, it is hoped to obtain a high overall degree of extraction.

Long hole blasting methods are being utilised to an ever increasing extent and this technique offers advantages both in economy and control of rock pressure on the pillars. Because of the great tendency of the ore to form strong natural arches, it is normal practise to release any stress, and tendency to crush, on the pillar to be worked by removing a large horizontal slice from its top by long hole blasting methods before work commences.

The removal of this slice has the effect of throwing the stress onto adjoining pillars by the arching effect. It should be remembered that at least one of the adjoining stopes must be empty to provide a free face for later blasting. As more pillars are extracted in this part of the mine, the increasing rock pressures in advance of extraction have demanded that now two pillars be de-stressed simultaneously to throw the pressures well in front of the working places.

(i) Explosives used at Lökken

All the explosive substances employed at Lökken are manufactured by the Norske Sprengstoff Fabrik Company near Oslo and the transport regulations enforced in Norway may have some influence on their choice. The regulations concerning ammonium nitrate explosives containing less than 10% dynamite are far less demanding.

For "bombing", "bulldozing" and other secondary blasting, a straight dynamite must of course be used; this is called "Gummidynamit" and is a type containing 32% nitro-glycerine.

For most other blasting purposes "Geomit", a 10% dynamite, ammonium nitrate based explosive is used. In long hole blasting and where electric detonators are used, "Stern Dynamit", a 60% straight dynamite is also employed as an initiator.

The choice of Geomit, which has been used at Lökken since before the Second World War, has been criticised in an earlier section. A summary of the chief properties of the explosives used is listed below:-

	Geomit	Gummidynamit	Stern Dynamit
Composition	10% dynamite ammonium nitrate trinol	32% nitroglycerine	60% nitroglycerine
Rate of detonation	5,700 m/sec.	6,300 m/sec.	7,500 m/sec.
Gas Evolved	865 l/kg	850 l/kg.	805 l/kg.
Work factor (probable explosive effect)	450 ton m/kg.	495 ton/kg.	550 ton/m/kg.

To-day, there is a tendency to increase the amount of blasting initiated by electric detonating, especially with millisecond delays. In experimental work with the new tunnelling rig (see appendix II), millisecond delays have been found especially successful, somewhat surprisingly, in connection with "burn" type cuts i.e. Coromant and cylinder cuts. Their use has shown great advantages over half second delay detonators in overcoming natural breaks in the strata like pillow lava, faults and dykes - the depth of cut being usually 2.4 m.

(j) Support

The condition of the ore and the wall rock is such that very little artificial support is required anywhere. Very little timber is used for this purpose; rock bolts have been used considerably for many years, these are both types viz: 1"diameter expansion shell and wedge type. It should be made clear that these form only occasional support and are not usually introduced in any set pattern, they are used both with and without sections of steel mesh. Bolts are normally tensioned to about 12 tons tension, using drilling machine adaptors.

It would appear that by careful design of the working layout at Lökken, it is possible to transfer nearly all of the resulting stresses to the strata and so here rock bolts are only used for the purpose of preventing small pieces of loose from falling - where they are used there is no sign of any major breaks in the rock. Rock bursts do not present a problem at Lökken.

HAULAGE

(a) Loading and Discharging Arrangements

Somewhat inevitably with the rather diffuse method of mining employed owing to the necessity for careful grade control, it has not been possible to make any useful method study of the ore transport system. For the same reason, all of the ore transport is carried out with locomotive haulage. In general, it can be stated that empty car trains pass along the main haulage roads on the hanging wall side of the ore body and full trains return to Wallenberg shaft along the footwall haulage roads.

Trains are loaded from the "Chinamen" chutes or compressed air operated loading boxes in the cross cuts and discharged into main grizzleys on each level near Wallenberg shaft. In some places, loading is by overshot loaders from draw points - e.g. sill pillar mining operations.

(b) Trains

Side tipping Granby wagons of 1.75 m^3 (about 5 tons) capacity are used in sets of eight or sixteen wagons underground. All wagons were constructed in the mine workshops. In the author's opinion, the sizes of wagons and trains are well suited to requirements - larger units can not be usefully employed without a more concentrated form of mining and much widening of existing haulage roads.

Where possible, tracks have been graded to give the ideal gradient, but banking of tracks on bends was not apparent.

15 Locomotives of the battery and combined battery - pantograph types are used underground, of these eight were constructed in the mine workshops. Of these, six locomotives are of 17 kw. and the remaining of 25 kw. rating, the weight - including battery - for both types is approximately 6 ton. The remaining locomotives are of Braun-Bonveri or Siemens manufacture and are of 25 kw. rating. Speed underground is limited to 6 km/h.

On the surface railway connecting Wallenberg headframe and the ore dressing plant, two Brown-Boveri (2 x 16 kw motors each) and one Siemens (2 x 7.7 kw motors) pantograph type locomotives are in operation. Each has been modified so that it may be loaded from three loading boxes simultaneously and by remote radio control. Thus only one man instead of the original crew of two per train is now required. One Ruston Bucyrus diesel locomotive is also employed on general duties on the Wallenberg site.

HOISTING

(a) General

Only the hoists which are in use, or which will be used in the future will be described.

Today all the ore and most of the transport of men and materials is through Wallenberg shaft. Fearnley shaft is still fully maintained, although rarely used, while Gommelsjakten is used for winding a few men and materials to the old workings e.g. to the pump station and reservoir there. The new hoist being installed in the new shaft will be described.

In Norway, the control of winding practise is left to the discretion of the mine inspectors - few regulations being laid down. However, both the Swedish and German shaft winding regulations are applied in most cases.

(b) Wallenberg men and materials hoist

This is a double clutched drum winder operating on the Ilgner Ward-Leonard system. It was manufactured by the KEMA Company of ~~Sweden~~ Germany and was installed in 1956; at that time it was not clear if the shaft would need to be deepened in the future and so the hoist was designed to operate to a depth of 550 m. instead of the present 480 m. Special provision has been made to allow both the skips to be wound up to a depth of 100 m. and stored there when not being used (on the night shift) in order that corrosion of the cages by the extremely acid water in the deeper part of the shaft may be minimised. The brakes are of the mechanical and compressed air type. Two sets are provided for each drum - "manoeuvering" and safety brakes - with both brakes in operation, the rope tension is limited to 19,500 kg. The clutch employed is compressed air operated and is of the eccentric gear type mounted on the main shaft inside the drums. Motive power is derived from a 400 kw. D.C. electric motor.

Other data:-

Drum diameter - 4.0 m.
Number of persons in cage - 28 on two decks
Maximum unbalanced load - 4,800 kg.
Maximum load possible (with counter-balancing) - 6,000 kg.
Rope diameter - 36 mm., 114 strands, regular lay
Breaking strain - 67,200 kg.
Rope weight - 4.5 kg./m.
Maximum speed = 6 m/sec.
Maximum acceleration = 0.6m/sec^2.

(c) Wallenberg Ore Hoist

This machine is essentially the same as when originally installed by the A.S.E.A. Company of Sweden in 1916. It was however, completely rebuilt in 1955 and at that time, was fitted with a modern Siemens air amd mechanical braking system. It is a ~~single~~ double drum hoist winding on the Ilgner Ward-Leonard system between the 480 m. level and surface only. Skips are of 5 ton capacity and of the side tipping type. The drive is taken from two 350 h.p. electric motors.

Other useful data is given below:-

- Maximum speed - 7.3 m/sec.
- Weight of skip - 4 tons
- Load - 6 tons/skip
- Maximum acceleration - 0.8 m/sec^2
- Maximum retardation - 1 m/sec^2
- Drum diameter - 4.6 m.
- Rope diameter - 46 mm. (6/19/1) regular lay
- Shaft capacity - approx. 250 skips/shift or 1,500 tons (per shift)

(d) The New Shaft Hoist

This is a small friction hoist winding only one counter balanced skip, with a double deck cage above, and has been supplied by the A.S.E.A. Company. During the writer's visit, this machine was in the process of being installed - the whole operation being expected to take between 3 and 4 weeks.

Like many friction hoists today, this is to be fully automatic when used for hoisting ore and to have push-button selection for man riding and materials transport.

Unfortunately, the writer did not have the opportunity to make a close inspection of this hoist and so little more than performance data can be given:-

- Depth of wind - 630 m. to start, 930 m. capacity - hoisting to surface
- Capacity - 150 ton/hour, 110 tons/ hour
- Load - 11 tons/skip
- Weight of skip and cage - 13.5 tons
- Counter weight load - 18 tons
- Drum diameter - 2.75 m.
- Ropes - 4, 34 mm. (6/19/1) warm galvanised, regular lay.
- Weight of ropes - 11 tons main, 11 tons tail ropes
- Safety factor - 7.2
- Maximum speed - 6.2 m/sec.
- Maximum acceleration - 0.6 m/sec^2
- Drum bearing stress - 20 kg/cm^2 (max)
- Motor - 600 h.p. A.C. with D.C. braking, supplied by A.S.E.A.

(e) Shaft Maintenance

All ropes and shafts are inspected daily and this includes sheaves and winding drums too. Most of the hoist safety devices are operated at least once per week, the remainder once per month. No regular programme is carried out for rope capping - this is merely done when required i.e. every three to four months. Routine electrical and mechanical maintenance of hoisting gear is usually carried out on every Saturday afternoon shift.

Both electrical and mechanical maintenance procedures at Wallenberg and on the new shaft hoist have been facilitated by fitting electrical fault finding indicators. Those on the Wallenberg hoists are not large but nevertheless experience has shown them to be of considerable value. This system is of much use in the weekly maintenance of safety devices as each unit is interlocked with a corresponding indicator light on the hoist control console and the hoist can not be operated until the light is extinguished by correction of the fault or safety mechanism.

(f) Hoist Safety - General Notes

The mine inspectors require that for all the important mechanical parts of ore and transport hoists, the safety factors should be between 5 and 10; rope safety factors are of the order of 7. The maximum decelleration is regulated in comparison with the maximum static load - this has the effect of determining the minimum allowable brake size. When retardation is greater than 4 m/sec. then it is forbidden for the rope tension to exceed three times the maximum static load, and when less than 4 m/sec. the limit is twice the maximum static load. With friction hoist gear, the maximum acceleration or retardation is limited to 1.9 $m/sec.^2$

It is required that in Norway, all hoist brakes should be air and mechanically operated post type and of course, fail-safe in operation. Two complete sets of brakes must be provided for each hoist; one set for everyday use and one set as emergency brakes. The writer is not necessarily convinced that the choice of the air and mechanical system is the best - certain advantages may be gained from use of the hydraulic and spring system such as the elimination of "grabbing" due to the inertia of the weights in the post type; this may be of vital importance where Koepe winders are used. The emergency brakes constitute the main line of defence in the event of a hoisting emergency and it is possible that too much reliance is put upon this aspect when other devices are available e.g. in the event of overwinding there is no provision for automatically detaching the rope(s) from the skip or cage and thus the brakes are the only means of preventing such an accident. A drop in the pressure of the compressed air supply, the gear box oil pressure, a loss of rope tension, overspeed of more than 20% or an over-run, all serve to actuate the emergency brakes automatically. It should be noted that this has the effect of only increasing the brake area and does not increase the rope tension above the maximum permissable.

Solenoids are placed in the shaft at the required positions to ensure that acceleration and retardation begins at the correct points and similar devices are fitted to the mechanical position indicator to prevent over-winding. Electronic recording of all shaft signals is also used as an added safety measure.

In addition to the safety devices noted above, the usual precautions associated with friction winders are to be fitted to the new shaft hoist e.g. automatic rope creep compensation, automatic tread wear indicators, tail rope, trip wire etc.

Samples of all hoisting ropes are analysed for stress control after every second rope capping operation in the case of drum hoists.

VENTILATION

(a) General

On the subject of ventilation it proved particularly difficult to obtain any useful detailed information. It is the writer's sincere opinion that insufficient attention is paid to this aspect of the mine and that some careful study would produce a not inconsiderable financial saving. Legislation in Norway does not require the taking of periodic ventilation measurements and the overall control of environmental conditions is left to the initiative of the Government Inspector. However, the writer must point out that ventilation is adequate and effective throughout the mine - it is merely the method of ventilation and it's apparent cost which leaves something to be desired.

For the reasons given above only, a general and non-detailed appreciation of the system can be given as neither ventilation survey nor economic data were available.

(b) Fans

Specifications of the various fans employed are included below.

The two main fans are situated at the top of the downcast ventilation raise at the western end of the ore body. These fans work in parallel and each deliver 72,400 m^3/h(42,200 cfm.) Both fans are identical and were manufactured by the Swedish Svenske Fekt Fabriken Company in 1958; they are two stage axial flow fans driven by 40 h.p. (160 A at 220 v.) electric motors at 1,450 r.p.m. The useful water guage is 120 m.m.

A booster extraction fan of 36,000 m^3/h (20,950 cfm.) capacity is installed in the Wallenberg head frame. This is driven by an 11 Kw (38A at 220 v.) electric motor at 1,450 r.p.m. and has a useful water guage of 22 m.m. It is a single stage axial flow type fan.

A considerable number of auxilliary fans are used underground; during the last war it became necessary to construct such fans in the mine workshops and this practise has been continued ever since. A few radial flow type fans have been made but the majority are of the axial flow type. The most recent batch of 16 was made in 1957 and they have the following specification:-

Capacity 180 m^3/min (105 cfm.), diameter 0.5 m., speed 3,000 r.p.m., Motor 5 h.p. 220 v. electric.

All main fans are fully automated, and receive routine maintenance once every week.

(c) Ventilation Circuit

Throughout the mine, it is policy to ventilate the workings with fresh air passing along the footwall side and return air along the hanging wall. Many cross-cuts and raises have auxilliary fans to assist the circulation

Fresh air is brought down the ventilation shaft at the western end of the deposit and then passes along the 380 m. and 430 m. levels. Air on the 380 m. levels is split upwards and downwards from stopes 23 and 24 and thus is used to ventilate the 340 m. level and the subsequent stopes and pillar workings towards Wallenberg shaft. Air from these levels is then drawn upwards through Wallenberg shaft.

Some air is taken from Wallenberg shaft into the stopes immediately to the east of the shafts and is then returned to Wallenberg along the 300 m level. However, most of the air ventilating the area to the east of Wallenberg is drawn from Fearnley shaft. It is passed along the 300 m. level and then upwards through the stopes of Gommelgruben and thence returns to Gommelsjakten where a small booster fan is situated in order to assist ventilation. Some air from the 300 m. level is passed downwards along a small incline raise into stope 19 and then along the 340 m. level for a short distance before going down the 380 m. level. Here it is sent to Wallenberg shaft and then used to ventilate the crusher room before joining the upcast air. The remaining return air in the eastern side from both Wallenberg and Fearnley shafts is drawn out to the surface by a small fan at the top of an old ore pass system some 150 m. to the east of Fagerlivan Lake.

The ventilation circuit is shown on the mine section (Figure 28) to be found in the folder at the rear of this report.

(d) <u>Comments</u>

(i) The ventilation of the mine in the piecemeal manner described above, is to be deplored. By using two forcing fans in parallel (at the western end of the deposit), insufficient useful water guage is developed to ventilate even the western end of the ore body without the additional extracting fan at Wallenberg shaft. The duties of the two main forcing, and the Wallenberg fans are all quite small and thus it would appear that a more efficient solution to the problem would be to employ two slightly larger fans in series.

(ii) It would at first seem better to ventilate with the majority of the air passing down Wallenberg shaft and then split it east and west. This can not be easily done because of freezing complications and the formation of icicles in the shaft. It would probably be more suitable however, to site the main ventilation unit at Wallenberg shaft top (this would need little underground construction work), employing two slightly larger capacity fans working in series. Thus all other surface fans could be dispensed with.

(iii) The change mentioned in (ii) above would require the fitting of s several regulators which presents no great problem. At present there is only one ventilation regulator in the whole mine. Regulators would be required at the bottom of the western incline ventilation shaft to give suitable proportions of air along the 380 to 430 levels and for splitting some air from the 380 m to 340 m. level. The crusher room would be ventilated with air from the 430 m. level to the west and this would require a door near the 430 m. shaft station to prevent air from going directly up the shaft.

Air from Fearnley shaft should all be passed to the 300 m. level and thence be split onto the 340 m. and 380 m. levels before joining the upcast air in Wallenberg shaft. Air from Gommelshajkten should be passed along the 200 and 240 m. levels before joining the downcast air in the old ore pass (regulation probably required at this point) and then be sent along the 300 m. level to Wallenberg shaft.

(iv) The wastage of air into Bakindien and the western end of Indien ore bodies is pointless and these should be sealed off near Wallenberg shaft. There is no gas problem to cause any complications over this.

(v) An excessive number of auxilliary fans are used in the cross cuts and these may be substantially reduced by experimentation with regulating doors.

(vi) It is often necessary to use two auxilliary fans in a pair of scraper cross cuts when these are being worked. This is unavoidable if the dust is to be adequately controlled. However, where a fan is situated it is not necessary to use venturi ventilators for the same purpose as is common practise provided short lengths (often 8 ft would suffice) of flexible ventilation tubing are available.

DRAINAGE

(a) General - Disposal and Storage

The subject of drainage presents some special problems at Lökken, due largely to the considerable acidity (pH approx. 2.4) of the mine water. This has necessitated the construction of a special wooden pipeline some 30 km. long in order to dispose of the annual surplus of mine water into the sea near Thamshaven. An underground reservoir of about 40,000 m^3 capacity has been made by daming off an old open stoping area near Gommelsjakten. This provides reserve capacity to meet the winter demands from the washery and to keep the pipeline free of ice during cold weather; water from the mine reservoir remains at a constant temperature of 10.1°c throughout the year and thus is particularly useful for these purposes. Further water storage capacity is provided by several small lakes situated around the mine.

(b) Corrosion

The acidity of the mine water remains at its high level throughout most parts of the mine where water is found in any quantity. However, some seasonal variation in the pH values has been noted and this effect is found particularly in parts of the mine near the clay gouge. It has been observed that the acidity reaches a maximum in late Spring when the quantity of water passing through the mine is at its greatest and is a minimum when the water quantities are least. It is supposed some form of sulphur bacteria present in the overburden are responsible.

Obviously anti-corrosion precautions must be taken in the mine when dealing with this acid water. Underground drainage pipes are made of an almost corrosion free steel of composition 18% Cr, 10% Ni and 1.5 - 2.5% Mo. A similar metal is used on all pump components, valves etc. in contact with the water. Corrosion by abrasion does not present a serious problem.

Some trouble has been experienced in recent years with the wooden pipeline to the sea as a result of corrosion. The pipeline was only constructed at the beginning of the last decade, after many development trials and served well for a time. However, during development testing, account was not taken of the increased stress in the steel restraining hoops caused by swelling of the timber as it became saturated with water. These steel hoops were covered with a thick protective layer of bitumen before being put in place but this was squashed aside by the increased stress. In the last few years, many thousands of hoops have had to be replaced at great expense - these new ones have been further protected by covering with polythene sheets in addition to bitumen. During his stay, the writer did suggest that plastic bonded steel might have provided a possibly cheaper alternative but this had not been investigated. Polythene sheeting is also used to protect such things as railway lines and loading boxes which must remain unused for a while after installation.

For some time, in particularly wet places, it has been found cheaper to use expendable railway track in very acid situations rather than track constructed of corrosion free steel alloys.

(c) Pumping Circuit

Pump stations are located on the 480, 450, 430 and 300 m. levels. Water from the most western districts of the mine is collected by gravity at the pump station on the 480 m level and then pumped up to the 430 m. level. Here it flows by gravity in open ditches in the main footwall transport drive to the Wallenberg shaft pump stations. Water draining through most of the ore body to the west of Wallenberg is collected in the cross cuts and south transport drive, on the 450 and 430 m. levels and runs in ditches to the Wallenberg shaft pump stations. Pumps at the 450 m. level raise the water to the 1,500 m^3 pump sump at the 430 m. level, there is a reserve capacity of 2,040 m^3 at this point. From the 430 m. level pump station, the water is raised up an incline raise to the 300 m. level by a total of five pumps; 2 De Laval PPL 14A5, 4 rotors centrifugal pumps rated 2,000 l/min against a maximum head of 162 m. at 2,950 r.p.m. for 103 nett h.p. and 3 De Laval PPK 24A4 centrifugal pumps rated 900 l/min against a maximum head of 157 m. at 2,950 r.p.m. for a nett h.p. of 52½. This water passes eastwards along the 300 m. level in open ditches, where further water is collected from the higher levels to the 300 m. pump station near the bottom of Fearnley shaft. At this station there is a total sump capacity of 1,700 m^3 in two sumps of 730 and 970 m^3. capacity. Water is pumped to the main reservoir at the 200 m. level from here and the reservoir overflow is also allowed to drain down to the 300 m. level through Fearnley shaft. From the same pump station, water is pumped to the 120 m. level and then passes out to the surface along an addit near the washery - there being a further 3,000 m^3 storage capacity on this level.

At the 300 m. level pump station there are 2 De Laval PPL 14A5 pumps and 3 of the smaller PPK 24A4 pumps. At other installations in the mine, pumps of many varieties are employed, however, all are of approximately 600 l/min capacity and are centrifugal types, either constructed at Løkken or rebuilt as combinations of older types. The pumps at each station are connected in parallel and a large reserve capacity exists at each point. All pumps are fully automated.

While the pumping system as a whole was observed by the author to be extremely effective, the anomolous situation at the 300 m. level must be noted. Having expended some considerable power in raising approximately 35,000 m^3 per year to the 200 m. reservoir, it seems somewhat pointless to collect water (3,300 m^3/year) from this stage about 100 m. below in order to pump it to the surface. The quantity involved is quite small but should have been taken into account at the design stage.

The main underground reservoir represents some six weeks capacity at absolute maximum demand. Daily readings of the water levels in the lakes on the surface, in the main reservoir, and of the water flowing along the 430 m. level. Amongst other things, these are used to keep a careful study of the rate of drainage (from the lakes into the mine.)

The disposition of the pump stations is indicated on the mine section plan (Figure 28) in the pocket at the back of this report and a quantity flow diagram (Figure 12) is also included.

LIGHTING

(a) Permanent Lighting

In common with some other aspects of mining in Norway, no minimum standards of illumination are defined in the mining regulations; this is left to the discretion of the local inspector of mines.

At Løkken, a variety of types of lamp are employed, these include normal incandescent filament flourescent, and sodium types; incandescent filament types of lamp, usually 150 w., are gradually being replaced and now form only a minor part of the illumination. Sodium lamps are situated at one point only in the mine i.e. the entrance addit to Wallenberg shaft. Here they are essential to combat the high density mist formed by the slow moving upcast air meeting the outside atmosphere. The inherant disadvantage of sodium vapour lamps regarding their long warm up period, does not apply here because they are rarely switched off. The majority of permanent lighting is from Phillips 40 w. flourescent tube lights which appear to be equipped with flame-proof chokes. Where this type of lamp has been installed, the general standard of lighting is very good, but perhaps they could be used more extensively. Flourescent lights are only installed in the underground office, workshops, rest rooms, crusher rooms, and shaft stations; the writer feels that they could also be usefully employed in such places as main railway junctions near the shaft and at the tipping grizzleys.

Shifting NB.

(b) Cap Lamps

There is a total of 405 cap lamps at Løkken Mine. 180 of these are of the M.S.A. K1 PMX type (battery capacity 13 amp hours at 4.85 v. and 1.0A), and there is a similar number of M.S.A. type P3E lamps (11 amp hours at 1.1A and 3.65 v.). The remainder of the lamps (45) are of the Edison R4 type.

POWER SUPPLY

(a) Sources and Distribution

The availability of inexpensive electrical power from hydro-electric power stations in Norway is exemplified by the sources from which electricity for Lökken is drawn.

Orkla Grube A/B owns two small hydro-electricity power stations to the north of Lökken at Sagberg and Skjenald near Thamshaven and most of the power consumed is drawn from these. Additional facilities are provided by the new government owned power plant at Aura on the west coast. Power, at national grid voltages, is received at the main transformer station at Thamshaven and from there is transmitted at 28 kv. to Lökken Mine. There is a second power line connecting directly with Skjenald at a tension of 16 kv. The main transmission line to the washery from the transformer station at the mine is at a tension of 21 kv. and is then reduced to 220 v. before use. High voltage transmission at the Wallenberg surface site and underground is at a tension of 14.5 kv., it being transformed to 220 volts before consumption.

The sources of electrical power are summarised in Figure 13.

(b) Tariff

As might be expected, electrical power in Norway is readily available and cheap. Lökken Mine pays for the power consumed at a flat rate of 3.2 øre/kwh. All power is bought directly from the supply department of Orkla Grube A/B who then arrange separately for payment to the government for any power received from them. The overall rate of 3.2 øre/kwh is made up as follows:-

	2.7 øre/kwh for transmission and manufacture
	0.3 øre/kwh for profit
	0.2 øre/kwh for tax
Total	3.2 øre/kwh

It should be noted that neither charges for maximum demand nor load factor are found necessary in Norway.

THE TREATMENT PLANT

(a) The Nature of the Ore and Major Dressing Problems Encountered

From the ore data sheet (Figure 14), it will be seen that pyrites, chalcopyrite, sphalerite and quartz are the chiefly occuring minerals. Magnetite and bornite are found mostly in local concentrations in the ore body, in the run of mine ore the magnetite proportion is not expected to rise above about 5%. The ore is extremely fine grained and homogeneous with a grain size of 0.01 - 0.1 mm., it being believed that this is at least partly due to the fact that metamorphism of the region was only slight and hence little recrystalisation could occur.

This fine grained nature and the quartz content result in an extremely hard ore (thought to be the hardest mined anywhere in the world today), which has always presented difficulties in crushing. It is only recently that suitable crushers have been made available in order to produce a fine sized concentrate economically - especially important today that the smelting plant is no longer available and a -4 m.m. product is demanded for export.

The only other special difficulty, a minor one, found in dressing the ore, is when unusual concentrations of chlorite occur in the Run of Mine; this tends to destroy the medium in the sink-float plant.

41.5%

It is required that today's export product should be a bulk concentrate of approximately 41% Sulphur and 2% copper with a particle size of less than 4 m.m.

ORE DATA SHEET (Figure 14)

Mineralogical Analysis:-

Pyrites	70 - 75%
Chalcopyrite	6%
Sphalerite	3 - 4%
Gold	0.2 gr/tonne
Silver	16 gr/tonne
Insoluble	10 - 15%
Magnetite	0 - 5%

Average Composition of the Product:-

41.5% S.	0.05% As.
38% Fe.	0.002% Pb.
13% insoluble	0.01% Cd.
2.0% Cu.	0.09% Co.
1.8% Zn .	16 gr/tonne Ag.
	0.2 gr/tonne Au.

Chemical Analysis (Average for Year Ended December 1963)

Main product	41% S.	2% Cu
R.O.M. ore	30% S.	
Hand picked product	40.6% S.	
Sink-float "	41.6% S.	
Jig "	38.3% S.	
Flotation "	45.6% S.	
Magnetite Flotation Product	44.9% S.	62% Fe.

NB!

(b) General Description of Flow Sheet

Please refer to Figure 15.

After primary crushing below ground, ore of -200 mm. is received at the plant from a light railway and weighed. It is then passed through a hand picking unit (one man) where the larger pieces of waste are removed before the ore is sent to a set of three storage bunkers. Here a certain separation is affected by means of a knife attachment fitted at the transfer point above the bunker, the finer material is allowed to by-pass the next crushing stage where coarse ore from two of the three bunkers is reduced to -150 mm. size. Dust from these crushers is removed in the cyclone unit (made at the mine), shown in Figure 16, and added to the flotation feed. From this point, the material passes by conveyor belt to a 60 mm. screen where the larger material is passed to a second hand picking unit where six men are normally employed (three per belt). Waste rock material from here, together with that from the sink-float unit is removed by conveyor belt and is at present used for road construction. After hand picking, the ore is passed to two Hadfield jaw crushers and reduced to -60 mm. size and then conveyed to a short head 5½ ft. cone crusher working in closed circuit with a 20 mm. screen. Below this 20 mm. screen is a second screen of 4 mm. size and from here the ore is passed to a short head 5½ ft. (fine) cone crusher in closed circuit with a 54" Gyradisc crusher. Some of the ore is reduced to -4 mm. in the short head fine crusher, but that which is not is removed on a second 4 mm. screen and passed to the Gyradisc crusher. This crusher is supplied by an automatic feed from it's storage bunker which can also feed the short head crusher to avoid overloading. Reference to the relevant part of the flow diagram will make this clear and emphasise that the two crushers together form one closed circuit with two 4 mm. screens. This arrangement ensures that there is absolutely no chance of any +4 mm. ore passing to the export silos and it also improves the nett capacity of the crushers. Finally the ore is weighed before being stored.

The -60 mm. material separated before the hand picking stage, is removed and placed in a series of four silos by a system of belt scraping, it is then screened on two double deck screens where -2 mm., 2-4 mm., and 4-60 mm. fractions are divided. 4-60 mm. ore is fed to two more ore pockets and below these the 4-6 mm. size material is screened out and also any magnetic ore is removed here by a magnetic roller at the transfer point. The remaining 6-60 mm. material is passed through the sink-float unit to join the material in the short head cone crusher circuit.

The 2-4 mm. ore which is removed from the sink-float feed is passed to the jigging unit where it is fed from a bunker to the machine as required. The product is dropped into collecting tanks before passage to the Lowenheilm dewaterer, the drying kiln, and export silos.

-2 mm. ore may be passed, either directly to be classified before milling and flotation together with the 4-6 mm. material, or it may be passed through a hydrocyclone and a washing table when required as medium for the sink-float process.

There are three classes of ore which may be passed to the flotation unit, these are the -2 mm. and 4-6 mm. screened out before the sink-float ore pockets and also the 6-60 mm. magnetic ore removed after the ore pockets. The "ordinary flotation" will be discussed first.

The large 54" spiral classifyer acts as a collector for all -6 mm. non magnetic ore except that which is jigged. From the classifyer, the slurry is passed, via a storage tank to the milling plant. Here two ball mills are working in parallel, the second in closed circuit with a spiral classifyer. Fine material from the mills (approx. -60 mesh) is sent to a series of settling tanks together with the fines product from the large spiral classifyer, slimes being removed from these tanks and pumped to the slimes dam in the valley below. During the summer months, slimes are reworked and added to the flotation circuit at the large classifyer. The fines are then pumped to a conditioning tank of the Denver type, where pine-oil and xanthate are added, and then to the flotation cells. A flow diagram of the cells is given in Figure 17, and this should be self explanatory. It should be noted that the use of two scavenger cell batteries in parallel is only a matter of convenience and of no particular design importance. The concentrate, together with that from the magnetite flotation, is then settled, filtered and dried in a kiln, weighed and removed to the export silos.

Magnetic ore, removed at the sink-float stage, is crushed in a 3' standard head cone crusher and then removed to an ore pocket. It is then milled in a 6' x 12' ball mill in closed circuit, with a hydrocyclone. The fine product, again approx. -60 mesh, passes through a chemical conditioning tank and then into the magnetite cell battery. Float from this battery passes into the "ordinary floation" circuit and the "waste" material to the magnetic separators. It is then filtered to about 7% water content and sent to the export silos after weighing.

(c) Description of Equipment Installed in the Plant

1. The Sink-Float Process

Crude ore of -60 to +4 mm. is concentrated in a shaking trough plant of the Swenson type, developed by the Stripa Mining Company of Sweden. Built by the Swedish Kopperberg Company, who take a royalty of 25 ø per tonnes, it is the only one of it's type i.e. employing an antogenous medium, in use in Norway at the present time; thus some further explanation of it's design and installation is required.

The crude ore has a content of about 20% rock material resulting a sulphur content of approximately 33%, separation in the sink-float plant results in a concentrate of circa 41% sulphur, with a recovery rate of some 98%. The pyrite medium (-4mm.) has a specific gravity range of 4.35 to 4.55, thus producing a separating density of 2.95 to 3.15.

The designed capacity of the plant is 40 t/h, but the unit can be worked successfully at a feed rate of some 50 t/h if required. As will be seen from the flow diagram, there are two sink-float troughs in parallel, the first was installed in 1955 and the second in 1956, without interruption in production.

From a crude ore bin of 50 tonnes capacity, the material is passed via a vibrating feeder, manufactured by Jeffrey Taylor, and of the 4DL (18" x 60") 50 - 100 tonnes/hour capacity type, to a preparing screen. This screen is an Allis Chalmers low head vibrating screen (3' x 8'), geared to 945 r.p.m. and driven by a 6.3 kw. at 1,430 r.p.m. motor. Wash water for this unit is obtained from the overflow of the medium cone. By rubber belt conveyors, the ore is passed to the shaking trough which is of 4,000 x 700 mm. overall dimensions; it is vibrated at 400 strokes/min. (Stroke length ¾") by a 15 kw. electric motor. The trough is sub-divided into four equally sized compartments, into which water is sprayed from below, through the two bottom plates. These are suspended screens of 10 mm. (upper) and 3 mm. (lower) spaced 2 mm. apart and are used to effect the removal of any slimes in the medium, which are passed direct to the 54" classifyer and thence to flotation. Spray water from below at a pressure of 10 kg/cm^2 is used to clear the bottom plates of any larger sized particles. It has been found that in practise a solid bed of sink material should be maintained for effective separation, this also serves to protect the bottom plates from excessive wear. Control of the bed is by the quantity of water supplied - both in the medium and in the individual supply to each of the four boxes in the trough. On leaving the trough, the ore (sink) is separated from the waste (float) by means of a horizontal plate or knife, the height of which is adjustable according to feed rate. From the trough, both sink and float are passed directly to a drain and wash screen; this being an Allis Chalmers Low head 3 x 20 mm. vibrating screen (4' x 16') working at 940 strokes/min. and driven by a 6.3 kw. (at 1,430 r.p.m.) electric motor; spray water is obtained from the medium cone overflow. Here medium is removed and returned to the cone by a Landswerk P.G. 20-375, rubber lined, centrifugal pump. This has a capacity of 6,000 l/min. against a head of 11 m., it is driven by an electric motor of 65 h.p. at 950 r.p.m. The medium cone is of 5 m. diameter, height 5.25 m. and volume 35 m^3 and normally contains some 5 tonnes of medium. There is a balanced medium return linking the cone with a sump tank below the drain and wash screen. Power consumption of the plant is some 2.5 kwh/tonne.

Normal labour is one or two men per shift, repairing and maintainence included. The material consumption is listed as follows:-

Pump:-	1 impeller per 45,000 tonnes
	1 sideplate 45,000 tonnes
	1 casing 90,000 tonnes
Separator:-	1 set bottom plates per 40,000 tonnes
Preparation screen:-	1 set plates per 5,000 tonnes
Wash screen:-	1 set plates per 10,000 tonnes

Cost distribution is approximately:-

Labour	15%
Power	5%
Repairs	50%
Royalty	30%

Figure 18 is a diagram of the Sink-Float Plant:

2. <u>The Jigging Plant</u>

This installation remains from the time when large size "melting stone" was produced: the finer fraction of the ore being separated by means of several jigs designed by the Company and known as the Orkla type jig. Now only one remains and this is used to treat the 2-4 mm. fraction only.

It is a two compartment jig with a piston and screen in each compartment. The screen has apertures of ½" and supports a ragging layer of iron balls some ¾" in diameter. Reference should be made to Figure 19. for a diagram of the jig. Capacity of the jig is approximately 8 tonnes/hour.

3. <u>The Flotation Plant</u>

The detailed flow sheet for the flotation plant is given in figure 17. Each cell is of the Denver "sub a" No. 24 variety and is driven by a 5.2 kw. (950 r.p.m.) motor. From two of the four 2.5 m. diameter Denver conditioner tanks, where the chemical reagents are added (approximately 50 gm/h. sodium ethyl xanthate and 250 gm/h. pine oil), the slurry is pumped directly to the flotation cells. These are arranged in two batteries of six rougher cells and four of four scavenger cells, each, also one battery of six handling the crushed magnetic product from the sink-float plant.

<u>Main dimensions, power consumption and manufacturer of the other equipment, where available, are listed below:-</u>

4. <u>Screens</u>

60 mm.	Single plate shaking screen, manufactured on site. Driven by a 6.3 kw. (1,430 r.p.m.) electric motor.
20 mm. and 4 mm.	Double deck vibrating screen manufactured by Gutehoffnumgshütte (~~Sweden~~) Type Z. 1.25 x 3.0 m., 6.3 kw at 1,430 r.p.m. electric motor. Two installed.
Sink-Float preparation screen:	Allis Chalmers low head vibrating screen (3' x 8'), speed 945 strokes/min. Motor 6.3 kw at 1,430 r.p.m. Apertures 5 mm. and 8 mm. diameter.
Sink-Float wash screen:	Allis Chalmers low head vibrating screen (4' x 16') speed 940 strokes/min. motor 6.3 kw at 1,430 r.p.m. Apertures 3 x 20 m.m.

4 mm. Krupp-sikt Resonanse-sikt. Motor 7.5 kw at 1,425 r.p.m.

5. Jaw Crushers

Hadfield 36" x 24" jaw crushers, capacity 250 tonnes/hour, motor 85 kw. at 720 r.p.m. Two installed.

Hadfield 24" x 13" jaw crushers, capacity 60 tonnes/hour, motor 35 kw at 720 r.p.m. Two installed.

6. Cone Crushers

Symons 5½ short head cone crusher, capacity 110 tonnes/hour, reducing to -20 mm. size. Motor 210 kw at 750 r.p.m.

Symons 5½' short head fine crusher, speed 485 r.p.m. reducing to -4 mm. size. Motor 160 kw at 740 r.p.m.

Nordberg Gyradisc 54" cone crusher. Motor 160 kw at 725 r.p.m.

7. Pumps

Dorrco sugepumpe. Motor 1.85 kw at 1,420 r.p.m. (flotation feed) Two installed.

Sala SPV 260. Motor 10 h.p. at 970 r.p.m. (magnetic flotation)

Sala SPV 300 Motor 10 h.p. at 1,440 r.p.m. (flotation tailings)

Landsmark PG 20-375. Motor 48 kw at 1,470 r.p.m. pumping 6,000/min. at 1,000 r.p.m. against a head of 11 m. (sink float medium return)

8. Mills

6' diameter x 8' Grondal mills. speed 19 r.p.m. motor 100 h.p. at 970 r.p.m. Two installed.

6' diameter x 12' Grondal millx. Motor (Siemens) 160 kw at 740 r.p.m.

9. Filters

Dorr Oliver 3 discs, 1.83 m. diameter, speed ¼ r.p.m.

Eimco, 6 discs, 6' diameter.

10. Kiln

Length 10 m. inside diameter 1.5 m. speed 4 r.p.m. motor 17 h.p. at 1,455 r.p.m.

Bay Oil Burner, motor 1 h.p. max. oil feed of 70 k.g./hour. (i.e. 40 k.g./tonne feed)

11. Dewaterer

Lowenheilm type F4-3 speed 500 r.p.m. Motor 5 h.p. at 1,430 r.p.m.

12. Flotation cells

Denver "Sub-A" no. 24, cells 43" x 43", motors 5.2 kw. at 950 r.p.m. 34 installed.

13. Feeder (to sink-float)

Jeffrey Taylor 4DL Vibrating feeder 18" x 60". Capacity 50-100 tonnes/hour.

14. Storage Capacity (Ore Pockets)

A list of the situations of the main ore storage points, together with their capacity in tonnes and hours is given below:-

Stock pile - 3,000 tonnes, -2 days.
At first jaw crushers - 500 tonnes, 8 hours
Handpicking - 500 tonnes, 17 hours
Buffer bins (0-60 m.) - 500 tonnes, 15 hours
Sink-float - 100 tonnes; 4¾ hours (2 hours at maximum capacity)
Jigs - 50 tonnes, 4 hours at maximum capacity (intermitant running only)
Mill Bins - 200 tonnes, 25 hours
Magnetite mill bin - 100 tonnes, 65 hours
Silos: For flotation concentrate - 4,000 tonnes,
For magnetic ore concentrate - 1,500 tonnes
For export ore - 12,000 tonnes

(d) Treatment Plant Labour

In addition to the engineer in charge and the design engineer, there are in all 82 workers employed in the ore dressing plant. The distribution of labour is given below:-

1 overforeman
1 administrative foreman
1 flotation foreman
1 service foreman
2 production chargemen
3 service chargemen (each with a team of 3 technicians)
1 service chargeman (team of 5 men), heavy repairs and new installations. (day shift only)
1 carpenter chargeman (team of 4 carpenters)
3 women cleaners
1 technical student (office, design)
1 office man (pay clerk)
1 assistant to chief engineer (Office)

Total service and ancilliary 30
The remaining 52 are plant operators.

The distribution of operators between shifts is not permanently defined. It should be noted that no restrictive practises are operated by the Union: each plant operator may be called upon to assist in service or repairs should the need arise

(e) Layout of Treatment Plant

The ore dressing plant is housed in the original concrete building built in 1913. Being one of the few buildings on the property not constructed of timber, this has proved to be a distinct disadvantage. The architecture was designed to meet the needs of that time and has since demonstrated it's inflexibility; this, together with the topography (a steep slope) has restricted the scope of any alterations demanded by changing equipment. A simplified plan of the main building is shown in Figure 20. Unfortunately, this plan gives no indication of the difficulties encountered in ore transport within the plant. Under these cramped conditions, where belt conveying demands many transfer points and units of small capacity delivering over short distances, the writer would suggest that a greater proportion of the smaller sized fractions could be more adequately dealt with in some cases, as a slurry moved under the action of gravity . A note of this and other improvements thought necessary by the writer will be found under "general observations".

It is the policy of the company that no more than the minimum of spares and equipment should be imported, (at least partly due to the high freight costs), therefore the treatment plant includes a well equipped machine shop containing five lathes, three milling machines and one grinding machine, besides numerous other miscellaneous machine tools. While all the machines appear to be of pre-1939 vintage, they are well maintained and are large enough to undertake any of the major re-conditioning jobs which may be demanded of them in the plant. There is also a hand forge for two men and a welding shop. Although of approximately the same age as the main building, it may be pointed out that the machine shop affords ample accommodation for the machines, is well laid out, light and airy.

Office and bath facilities are also available on the site, these may be described as adequate but no more. Offices are provided at the plant for the chief engineer, his assistant engineer, the overforeman and also a general office.

Unfortunately, no overall plan of the layout was made available during the writer's visit.

(f) Analysis Procedure

Samples are taken at various points in the separation process and analysed for the proportions of sulphur and copper. Whether bulk or individual samples are taken depends on the daily requirements of the engineer in charge. Daily records of the results for each shift worked are kept and also circulated freely to all responsible personnel.

Details of the sampling procedure in each part of the plant are given below:-

(i) Flotation - Normally samples are taken at hourly intervals by the operator(s) in charge of the flotation plant, who are also responsible for preparing the specimens. Tests are made of feed, tailing and concentrate on both the ordinary and magnetite flotation (including the magnetic separators). In addition to sulph ur and copper content, records of feed rate, proportion of solids in the feed, xanthate and pine-oil feed rates, and magnetic iron in the magnetite cells are kept.

(ii) Sink-float - Here sampling is broadly similar to that in the flotation plant except that samples are taken every half hour during production.

(iii) Crushing Circuit - Shovel samples are taken at the transfer point below the last ore pocket, where all the -4 mm. ore is collected before being passed to the export silo, once during each interval that the transfer is operating (approximately once in a twenty minute interval)

(iv) Jig - Samples are taken from the slurry reservoir below the jig at the point where ore is transferred to an ore pocket before dewatering in the Lowenheilm machine. Since the water level in the reservoir below the jig must be kept constant while it is in use, ore is normally passed to the dewatering unit in intervals of about 20 minutes. The flow rate at this time is necessarily high and so shovel samples are taken every two to three minutes.

(g) General Observations

a. It is the impression of the writer that excessive labour is employed in the treatment plant as a whole and that the amount of work expected from each man could be substantially increased. This, however, is a most difficult subject to tackle since the many redundancies resulting from the closure of the smelting plant and loss of demand for "melting stone" have not yet been forgotten. It must be remembered also that the town of Lökken Verk is almost wholly dependent on the mine and that there is practically no alternative employment in the area. Any change in the labour force must therefore be considered very carefully, but ideally a cut of some 15 to 20% in labour should be made and this without any change in the installations. Particularly noticeable was the excessive number of men retained for maintenance work, while it must be the policy to undertake the larger routine service jobs simultaneously to minimise any halts in production, it should be possible to programme the routine maintenance so that a smaller total of men is required, and yet provide a reserve for emergency work. Here a greater degree of co-operation between mine and treatment plant service personnel could be justified; at present both units are completely independent. The absence of restrictive practises would also help to assist this change. In return for this demand of a higher output per man, the average wage could be improved substantially above the somewhat low figure of 6.35 Kr. per hour.

b. The policy suggested in section a. could be taken further by the introduction of some form of remote or automatic control of plant. At present there is virtually none; even centralising the controls at each stage in the plant would result in a great improvement in efficiency. All sampling is at present undertaken by hand and here especially automatic units must be installed as quite spurious results occur not infrequently through probably no negligence on the part of the operators.

c. Hand sorting of ore must now be regarded as both costly and old fashioned. At present nearly 50% of the ore is separated on the basis of hand picking alone - this remains from the time of "melting stone" production - and thus a change to some other form of selection would improve the grade of the product considerably. It is only recently however, that economic means of crushing this extremely hard ore to a suitable size have become available.

An increase in the jigging or sink-float capacity would appear to be a possible solution to this problem. Of these two alternatives, jigging may be prefered because space is restricted and installation costs would probably be lower. At present the company is persuing development tests on a jig supplied by Denver Company (U.S.A.).

d. Transport of ore within the plant has already been mentioned as a problem. As facilities have been changed to meet the new requirements of a changing demand, considerable ingenuity has had to be employed in order to accommodate it in the restricted space available. This aspect of the plant would demand a long and very careful study and any improvements which may result would probably only be marginal.

e. In recent years, it has been policy to re-treat the slimes in the summer months of June, July and August. It was noticed that the capacity of the settling tanks is not quite high enough for this when the mine is on full production.

f. It is thought that the chemical conditioners are not essential to the successful running of the flotation unit, as the time required for the pine oil and sodium ethyl xanthate to be absorbed is short.

g. The capacity of the Dorr Oliver type drum filter used to dry the magnetite product after separation, would seem excessive as it is only required to run for several hours each week.

h. It is an anomoly remaining from the past, when more than 20% of the run of the mine ore was separated on jigs, that today 2-4 mm. ore is jigged while 4-6 mm. ore is milled. This will undoubtedly be altered when the change from hand picking is made.

(ii) Labour new chapter

1. Sources and supply - As stated in the introduction, the majority of the mining labour at Lökken is of local stock and there is a strong tradition of mining in the area in spite of the mine closure at the end of the last century - because of this long break in production, most of the miners are in fact from farming families. An increase in the labour force is not envisaged and so the company is not concerned about the future supply. While most of the qualified engineers have been recruited from all parts of Norway, it is company policy to select certain of the outstanding workers

for special training to fill the need for foremen and shift bosses. An association of the Norwegian Mining Companys' (Norsk Arbeidsgever Forening) has provided a school in Trondheim for this purpose where the potential mine officials follow a full time course of study for 18 months. There is a second similar school in Oslo which is not normally used by the Company trainees.

2. <u>Terms of engagement</u> - There is no written employment agreement between the individual worker and his employer, but both are protected by an extensive agreement governing wage levels and terms of employment between the mining companys' association and the Union (Norsk Arbeidsleder Forbund). However, on engagement, a worker is required to sign two agreements governing welfare facilities, housing etc. and also the explosive regulations. The Company is not legally compelled to make redundancy compensations, but this is usually subject to consultations between the union and the company at the time. As in Great Britain, medical and unemployment contributions are paid jointly by employee and employer.

3. <u>Wage Levels and Method of Payment</u> - In Norway, miners are paid at approximately the same rates as other manual workers, and receive rather less than in England, although they probably have more "fringe" benefits (see welfare). An underground contract worker can expect to receive a maximum of about 360 Kr. (£18) per week, from which, income tax (about 19-20% for a married man with two children), national insurance and medical contributions must be made. At present the company is paying Kr. 2.20 per man-hour in national insurance and medical contributions. Examples of typical contract rates are given below:-

Stoping - now paid on cubic extraction: Kr. 1.10 to 1.50/m^3
Long hole boring - Kr. 3/hour + Kr. 1.75/m. + Kr. 0.50 at every 2m. over 6m.
Sub-level tunnelling - one man per face, two day cycle - Kr. 90/m. + Kr. 10 for cleaning (by scraper), explosive costs Kr. 1.50 and 2.00 per kg. drill steels Kr. 10.

It is perhaps interesting that the hourly rates of pay of non-contract workers are increased proportionately with the cost of living (this is approximately the same as in England)

All workers are paid in cash on a monthly basis, with an advance of Kr. 100 (£5) per week.

4. <u>Welfare</u>

Perhaps the most important of the benefits afforded to the workers at Lökken, is their cheap housing - rents vary between Kr. 25 and 35 per month. The quality of housing seems to be most reasonable, with two or three bedroomed wooden houses, all houses have bathrooms and the main services. Recently a few workers have expressed the wish for independence and are now purchasing their houses from the Company. Heating and travelling allowances are paid by the Company and in addition, each man is permitted to cut a certain amount of the company owned local timber annually.

1 Workers have three weeks summer holidays per year with full pay. However, there is no free medical service provided.

It may be as a result of the excellent political climate existing between the Unions and the Company, that several valuable properties have been presented to the workers as gifts; these include a large community hall, holiday home, and an extensive open rifle range.

5. The Unions - The Norsk Arbeidsmans Forbund is the section of the national industrial union, the Lands Organisasjon (L.O.) to which all miners and contractors in Norway belong. The membership of the L.O. is approximately 530,000 or 14% of the population, while that of the Arbeidsmans Forbund is about 30,000. Mine Officials are members of the Norsk Arbeidsleder Forbund.

There is no history of militancy in the mining unions as in Great Britain, and consequently it would seem that a more progressive attitude of co-operation is persued at all levels. Negotiations normally take place in a cordial atmosphere and restrictive practises do not exist in the industry.

Unfortunately, little factual information was made available on this subject - possibly because of the rather different perspective in which the Unions are viewed in Norway. It undoubtedly merits further study as indicated by our own T.U.C. leaders' recent interest in the Scandinavian trade union movement.

ADMINISTRATION

(a) Structure

Orkla Grube A/B is a well established and reputed house, whose interests today are mostly concentrated in shipping and finance. The Company does not appear to have any other major investment in mining but does, however, own the recently completed ferro silicon plant at Thamshaven.

The managing director, together with his board of directors, are responsible for the financial control of Lokken mine and for approving major policy decisions. Each of the four branches of the company (the mine, ferrosilicon plant, shipping and finance) have their own managers, who control the day to day administration. At Lökken Mine, the mine manager is a qualified mining engineer of some standing in Norway, he is assisted by construction, mechanical, mining and electrical engineers. The electrical departments at the mine and also at the ferro silicon plant are controlled jointly. The construction department has only one engineer in charge and from him the command goes directly to his three foremen. Both the electrical and mechanical departments have second (surface) engineers who pass on the command to the foremen.

The mine management is somewhat more complicated. There are both a first and second mine engineers, but these work in close co-operation and the chain of command here from the manager is not clearly defined. From the second engineer the command passes through the mine captain and hence to the shift bosses. There is also another engineer, non-qualified, reporting to the first mine engineer and manager jointly, who specialises chiefly in safety, ventilation, dust, and electrical blasting.

The ore dressing plant has an engineer in charge, a washery "captain" or over-foreman and from them the command is passed to the foremen. The research and design engineer reports jointly to the manager and dressing plant engineer.

Figures 21. and 22. summarise the management structure in both Orkla Grube A/B and at Lökken.

SAFETY

(a) Safety Organisation

The so called safety engineer (see Figure 22.) is responsible for the safety organisation in the mine, on the surface and in the ore dressing plant. In each of these places, he is assisted by workers' safety committees consisting of one foreman and two workers with the safety engineer as chairman. Members of the committees are elected on a yearly basis and meetings are held monthly; terms of reference are the analysis and discussion of any accidents which occur and to consider any improvements suggested by the workmen. This system seems to function quite well in spite of relying on word-of-mouth distribution of the committees' deliberations. All committees meet at off-shift times and members receive full overtime pay for attending. A second committee exists for the financial assessment of improvements suggested by workers - both in the safety and production fields - the minimum financial reward the committee can give is Kr.50. An annual open meeting of the Lökken division of Orkla Grube A/B is held to receive reports for the year, elect new safety committees, etc.

(b) Training

With the relatively small number of men employed at the mine, it has been possible to ensure that everyone attains a certain minimum standard in first aid and rescue work soon after joining the mine. The course is of 10 hours duration, workers are paid overtime for attending and a certain amount of training in rescue work is given, in addition to the usual first aid teaching. There is also a team of about twenty men (mostly surface based workers like fitters and electricians) who are trained in the use of breathing apparatus; practises are held once every month. More training and practise in rescue work is not required since a great deal of the every day work in the mine requires skills in such situations as may occur frequently in rescue e.g. the use of pulley, wooden temporary supports, slings, and also rock climbing.

(c) Safety Equipment

Fully equipped rescue stations are provided throughout the mine (approximately one for each area controlled by a shift boss). Each station is linked to the shift bosses' underground control office by an independent signalling system for which a special code has been devised. Stations are provided with a comprehensive first aid kit, wooden splints, a nylon climbing rope, mechanical jack, hammer, axe, a steel sledge type stretcher suitable for hoisting up raize ladderways, and a rubber wheeled stretcher wagon. The possibility of fires occurring is not great and so fire fighting equipment is not provided here but only in the transformer stations.

Breathing equipment is kept in the shift boss control office which is near Wallenberg shaft at the 430 m. level. Here one oxygen recirculating type, one compressed air, and one tube aspirator are kept. Further supplies are stored on surface.

Personal safety equipment includes hard hats, and reinforced boots or shoes for which the worker is required to pay two thirds of the cost; safety glasses are issued free of charge when required, while industrial gloves are issued at the rate of one free pair per year. Up to three free pairs of overalls per year are issued to men working in particularly acid water conditions. Plastic safety visors for helmets are available on request free of charge as are safety belts and similar articles.

The mine ambulance is always available at the Wallenberg shaft surface on the day shift and may be called up by telephone at a moments notice on the other two shifts.

(d) Reporting of Accidents

It is required that all accidents, even of the most minor sort be reported to the government inspectors. In the first instance, the report is written by the shift boss in charge of the area, where the accident occurred and to this are added reports of the inspectors and the local doctor. Fatal accidents require a more thorough going investigation which involves the police and the chief inspector of mines.

(e) Safety Statistics

The accident trends on the national scale are shown in Figure 23., while the accident rates for all the major mines in Norway are given in Figure 24.

These comparisons are somewhat misleading because there is not nationally co-ordinated policy for the analysis of statistics from each mine. Hence Orkla Grube is indicated in a false position, it is sincerely believed that Lökken Mine is one of the safest in Norway. It should be noted that the safety campaign at Lökken was begun approximately 2½ years before the national campaign was opened and that comparisons made on the basis of accidents causing a loss of more than four working days (i.e. the more serious ones over which there can be no differences in recording) shows Lokken in an excellent position: Unfortunately, the Company would not release this (unofficial) comparison.

A full breakdown of the accidents at Lökken for the latest available year (1962) is given in Figure 25. Here the most significant point is the high incidence of accidents caused by slipping and tripping - the majority inevitably occurring in the shrinkage stopes. The large number of accidents involving eyes ought to be reduced; it is far too high.

(f) Dust

Lökken ore contains a high proportion of quartz and thus in the past there was a high incidence of respiratory diseases. This situation no longer exists, due partly to the considerable efforts of the mine doctor who has been in a unique position to study the respiratory effects of dust over a period of more than 25 years. The last new cases of silicosis developed some 15 years ago in the immediate post war period.

Routine chest Xrays are taken at three year intervals, more frequently with special cases; as no regular dust sampling is required by law, control has now reached the stage that the dust situation in many parts of the mine can be predicted from the analysis of Xrays.

Dust samples are only taken in places where counts are thought to be high, for this purpose an M.S.A. Midget Impmger instrument is used - it has been found that the medical investigations and this instrument agree very closely in most situations. No maximum permissable dust counts are stipulated by law, but the practical danger limit is believed to lie in the region of 700 p.p. c.c.

Recent dust control work has been centred on the ore dressing plant and a considerable improvement in the working environment there has been reported.

Some interesting publications on dust control at Lökken Mine can be obtained from the Norwegian Medical Association.

APPENDIX I

Drilling Machines

The BBE 12 is a rotary percussive, pusher leg machine which has been developed by the Atlas Copco Company of Sweden, especially for the very hard pyrite ore at Lokken. It is only by using this machine with the most modern type of tungsten carbide tipped, integral steel drill rods that the ground can be economically penetrated today. A lift of 10 - 15 m. is required to make the use of tungsten carbide bits economical for drilling use. This proved difficult to attain, but success was obtained after 7 years of testing. Previously the life of all ordinary carbon steel drilling rod forged with a six-pointed double tapered bit, was only of the order of 1 inch in the ore. Today, drill steel life is of the order of 18 - 19 m. but with some 12 - 15 sharpenings as the tips become blunted, after between 1.3 and 1.5 m.

The BBE12 machine has a cylinder diameter of 75 m.m., a stroke of 25 m.m., a speed of 4,800 b.p.m. and it revolves at 300 r.p.m. The weight of the machine is 24 k.g. Free air consumption at 85 p.s.i.g. is approximately 166 c.f.m.

For drilling in the greenstone strata around the ore body, the Atlas Copco BBC 22 Lion machines are used, although they are being replaced to some extent by the Puma. Somewhat contrary to their reputation, these machines have proved both rugged and efficient and thus are popular, with their operators. They are used to a considerable extent for long hole drilling in the greenstone, where holes of a length less than 8 m. are required. These machines have standard rotation i.e. on the return stroke, and are used in connection with ordinary $\frac{7}{8}$" hexagon drill steels.

Piston stroke and diameter are both of 70 m.m., giving 2,050 b.p.m. The weight of the machine is 29.1 kg. and the free air consumption 155 c.f.m.

Atlas Copco Puma (BBC 16W) machines with the BMN 30 auto-feed attachments, are fitted to the new four machine drilling rig which is described in Appendix II. These machines (Puma) are essentially similar to the Lion but a few differences exist as noted below:-

Piston diameter	-	70 m.m. (Puma and Lion)
" stroke	-	55 m.m. (Puma), 70 m.m. (Lion)
Impacts per minute	-	2,300 (Puma), 2,050 (Lion)
Weight	-	26.8 kg. (Puma), 29.1 k.g. (Lion)
Free air consumption	-	131 c.f.m. (Puma), 155 c.fm. (Lion)