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Report on A Visit to the United States and Canada

by

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INTRODUCTION

This report touches on certain aspects of the mining industry of the United States and Canada as seen during the visit and is sub-divided into sections on Open Pit Mining, Underground Mining, Mining Research, and so on as listed in the Table of Contents.

The tour started and finished in San Francisco and included United States Bureau of Mines Marine Minerals Technology Centre at Tiburon, California; Kaiser Steel Co.'s Eagle Mountain Mine and Pellet Plant; copper mines and smelters at San Manuel, Ray, Hayden, Morenci, Douglas, Bisbee and Twin Buttes in Arizona; Utah Copper Co.'s operations at Bingham Canyon and the nearby Kennecott and Anaconda research centres in Salt Lake City; various U.S. Bureau of Mines establishments at Denver, Washington D.C., College Park and Minneapolis; iron mines and pellet plants in Minnesota and Michigan and the White Pine Copper Mine. In Canada, sections of the Department of Energy Mines and Resources in Ottawa and Elliot Lake were visited, as well as research centres, open pit and underground mines and treatment plants in Ontario. The tour ended with a visit to the U.S. Bureau of Mines Research Laboratory in Spokane and mines and plants in the Coeur D'Alene and Metaline Falls Areas.

Localities visited in the course of the tour are shown on the map, figure 1. Visits made in the course of the tour are discussed in some detail below under sections of common interest.

OPEN PIT MINING

I. COPPER MINES

(a) Twin Buttes - The Anaconda Company

This mine is in the development stage and is located to the west of Sahuarita, about 20 miles south of Tucson, Arizona.

Over 100 million tons of material have been removed in the last 3 years; the top of the ore is now exposed and installation of the permanent crusher/grizzly system is taking place. The permanent belt conveyors are being fed by temporary spurs to remove overburden lying above this point.

A temporary conveyor system feeding to wagon loading points is in use for overburden removal at the opposite end of the pit, and some of this material has been used to construct walls for future tailing ponds. Scrapers are used in the pit to feed into this system.

Crusher installation at the top of the orebody is at 600 feet below ground surface and the pit will extend to about 1000 feet below this. A life of more than 20 years is anticipated for this operation.

A section of the mine near the permanent conveyor is moving down into ore and is conducted as a shovel and truck operation using 15 cyd bucket Marion Shovels, 100 ton Electra-haul and 80 ton Caterpillar trucks.

Progress is recorded weekly by surveys of benches etc. made each Sunday when the operation is shut down. There are normally 3 survey crews of 3 men each in the pit itself with a further 3 crews on property surveys, road layouts etc. Aerial surveys have been carried out from time to time but are not accepted with confidence by the mine's engineering staff.

The permanent overburden conveyor has been set up on wagon dumped fill. Future plans call eventually for moving this conveyor to spread overburden over a wider area that can be reached by the spreading system at present. Some difficulties may be expected when the conveyor is moved onto the unconsolidated material dumped off the conveyor belt, and it will be interesting to see how this works out in practice.

Because of the large number of earthmoving machines in operation a computerised information system has been introduced to control maintenance requirements and maintain cost data for every machine.

(b) Ray - Kennecott Copper Corporation

Located in a valley about 65 miles north of Tucson, Arizona, the mine has been operated as an open pit since 1955. Expansion of the operation is in progress. A leaching plant to recover copper from chrysocolla is being built to replace the existing leach, precipitation and flotation circuit at the Hayden Mill, 25 miles away. Production is currently at the rate of 24,000 tons of ore per day.

As is normal in an operation that has been going for some time there are a variety of trucks dating from the initial equipment (which appeared to be a 3 axle type of about 60 ton capacity) and including newly developed trucks for evaluation, usually taken on a hire/purchase basis.

Euclid was represented by the 80 ton RX model and a 100 ton experimental model which was being used to ensure that the 80 ton fleet met the guarantee of 85% availability under which they had been sold. These 8 wheel, 2 axle, all wheel drive trucks are articulated in the middle and it may sometimes be disconcerting to drivers when the cab and projecting body move substantially in relation to one another on sharp turns.

The K. W. Dart Company had delivered part of an electric drive truck with 200 ton capacity for trial in the near future. The truck will, however be 23 feet wide (I expect that it had to be made wide to avoid it being too long or high for loading with existing shovels). This extra width may require some revision of standard road widths, and will restrict the use of the truck to certain areas, at least initially.

Tonnage and grade estimates are made from data from vertical diamond drill holes on a 300 foot grid, which are combined by computer into 1000 foot square blocks for the 40 foot bench intervals. All work is done on plan. In forming longer term plans, some allowance is made for varying overburden ratios in determining grade cut-offs. Additional rotary drilling for prospecting doubtful areas is worked into the blasthole drilling pattern. Faces are sampled once or twice per shift to establish which shovels are in ore.

Pits are surveyed manually, a full pickup and reconciliation with the mill weightometer being made once a quarter, but the plans are continuously being updated. The area has been flown on several occasions, but there seems no interest in replacing the manual surveying methods currently in use by aerial surveys.

Introduction of a greater degree of computer control into pit operations has been planned but a major stumbling block has been the difficulty in getting the operating staff to think in terms of the 1000 foot square blocks that the computer operates on. However it is planned to use the computer to give performance targets in terms of tonnage hauled by various trucks over various profiled routes. These haulage route profiles will be supplied by the Engineering Office.

Papers collected at Ray and Hayden are listed in Appendix 1.

(c) Morenci - Phelps Dodge Corporation

This is a long established rail haulage open pit mine in eastern Arizona for which trucks and shovels are now used beyond the limits of rail haulage, i.e. for isolated hills and high spots not warranting railway development and also for making the drop cut to a new level. Production is currently 60,000 tons of ore and 96,000 tons of waste and leach ore per day.

Long term planning is based on polygons round diamond drill holes, originally spaced on 800 foot centres but closed up to 400 foot centres and with additional drilling where required for planning purposes. Day to day control is by the Ore Control Engineer and General Mine Foreman working together. Blast holes are sampled and assays used to provide data for flagging firings as ore, waste or leach.

At quarterly intervals the train and truck factors are adjusted for ore (against mill weightometer) and waste (against survey calculations). Surveying is done by hand and plans continuously updated, so that no major effort is required for reconciliation at the end of each quarter.

The original open pit shovels introduced in 1937 are still at work. Tests are said to indicate that 9 cyd shovels offer no economies over the 6 cyd size. However a 15 cyd shovel is to be tested soon. Some small 10 cyd trucks are used in a quartzite flux pit, and 40 cyd models in a limestone flux pit. 80 cyd models are in use in the pit itself on overburden and waste.

Trains are operated by radio remote control and always driven from the leading end. They are driven from a convenient location opposite the shovel when loading. No brakeman is employed.

Up to the present time there has been no difficulty in filling shovel and train driver jobs from the "understudy" jobs of oiler and brakeman, but remote control of trains and centralized automatic lubrication systems are making these jobs redundant. Some formal training programme is accepted as a necessity in coming years.

An attempt has been made to run a computer system for comparing shovel train and truck performances but this has not yet been made to work satisfactorily. The principal difficulty seems to be associated with the hole punching of cards in the field, and is to be eliminated by a transcription step. The computer is not yet used in planning, but has been applied to verify the statistical adequacy of the 400 foot spacing adopted for drill holes.

Time prevented a visit to the mill and smelter.

Pamphlets and papers collected at Morenci are listed in Appendix 1.

(d) Lavender Pit, Bisbee - Phelps Dodge Corporation

A brief visit was paid to this operation which is located near Douglas, on the Arizona-Mexico border. Originally a rail haulage mine, the Lavender pit has been extended using trucks. The original truck haulage equipment was 20 ton capacity, but this has now all been replaced by 40 ton, and more recently 80 ton capacity units which probably carry 100 tons when loaded with high sulphide ore. All trucks are K. W. Darts.

The largest shovels in use are of 15 cyd bucket size. Productivity ranges from 11,000 tons/shift under good conditions to as low as 4,500 tons/shift in rough limestone. All trucks are radio controlled by a dispatcher in a cabin from whence he has a view of the crusher and all of the older section of the pit. Trucks are individually directed to shovels after dumping their loads, and a tally is also kept.

A monthly review of factors used for ore and waste is made after a month end updating of pit outlines by survey.

Operator training is carried out by truck drivers being instructed one at a time by a foreman appointed for the purpose and shovel operators by oilers being given the opportunity to drive under the supervision of the regular driver.

(e) Bingham Canyon - Utah Copper Corporation

Situated to the west of Salt Lake City, this mine is possibly the largest hard rock mine in the world today. Production is in the range 350,000 - 400,000 tons of material per day, of which approximately 108,000 tons is ore.

The mine was originally all rail haulage, with trestles and tunnels to provide access to benches and dumps on reasonable grades and alignments. In 1963 it was decided to increase copper production by increasing leach plant capacity and using truck haulage for the upper section of the mine where most of the material to be removed is overburden. Any ore mined in this section is hauled down to the rail haulage section and tipped over a bench for re-loading into trains. This down grade haulage of ore is a matter of some concern to pit operating staff in view of the strain placed on braking systems and the possibility of trailer-type units "jacknifing" when roads are slippery.

Ore trains are hauled out through a series of tunnels, assembled in a marshalling yard at Copperton into larger trains for haulage on the main line to the three crushing and grinding mills at Magna, 16 miles away where they are rotary dumped and returned to Copperton.

Waste loaded into rail trucks in subsequently tipped at waste dumps by hydraulic cylinders on truck frames through side opening doors. Some of the waste is limestone and an attempt is made to keep this material separate in view of its adverse effect on the leaching characteristics of dumps.

The motor truck operation started in 1963 with 65 ton Haulpacks and K. W. Darts. The next addition was the 100 ton semi-trailer type K. W. Dart. More recent additions to the fleet have been the articulated Euclid RX model with two axles and all wheel drive and the Electra-haul. One of the Electra-haul units has been equipped with a Solar gas-turbine which weighs only half a ton compared with the 4 to 5 tons of diesels of equivalent horsepower. However, fuel consumption is high and even a 600 gallon tank cannot be relied upon for a full shift of operation. Other 100 ton trucks do about 48 gallons per hour.

Mechanics for the new expansion were trained from within the existing employees in other callings, under an agreement with the union. The training was given in a maintenance shop now used to rebuild major components for replacement. Trucks are operated on a 5 days in service, 2 days in shop, basis. With this regular maintenance, failures during the 5 day service periods are very few. The economics of recapping and retreading tyres are still being explored. An hydraulic machine has been built up for breaking the large tyres off their rims, and tyres are inspected by an experienced foreman. Temperatures range from over 100° F to as low as 15° F below freezing in the winter, but normally between 90° F and 5° F below freezing. An on line computer system is being developed to give data on servicing requirements and costs of the individual units. There were a total of 94 trucks in service at the time of my visit, at least 60 were always available.

Shovels range in size from 15 cyd buckets down, through 12 cyd and 9 cyd to 5-6 cyd. A total of 38 were in service. All the major shovel manufacturers are represented. Bucyrus Erie 60R rotary drills are used in the truck haulage section and 30R rotaries in the rail haulage section. Inclined holes drilled with the 60R replace the practice of drilling and chambering toe holes formerly used.

A computer programme to assist mine planning is being developed. This is based on tonnages and grades in 100 foot square blocks and mines out the orebody in accordance with specified parameters. Some thought is being given to the use of a waste credit for leaching recovery where this is relevant and ultimately to the use of a monetary rather than arbitrary grade cut-off. Drill hole spacing is on 800 foot centres, filled in as required for more detailed planning.

Daily control is by assay of blast hole cutting samples. After firing, hole areas are staked as ore or waste using coloured ribbons. There is no storage in the system supplying the crushers and it is necessary to make some further control of shovels as between type "A" and type "C" ore which

behave differently in the mill. There is little type "B" ore and this is not generally considered in pit planning.

Some consideration is being given to the use of conveyors for handling waste from certain sections of the mine.

Radio control is to be established for the truck haulage operation from a cabin located where practically all the pit can be seen. All trucks will be equipped, as well as supervisors, but drivers of haulage trucks will not be able to talk to one another. Supervisors in the truck haulage area use 2 wheel drive 30 cwt trucks with limited slip differentials. In the rail haulage area where road access is not so good, 4 wheel drive Jeep Station Waggons are used.

Because of the large spread of operations, several points have been established for shift changing and refueling etc; the garage and truck haulage section operational offices have been established beyond pit limits. Several notches cut into the pit provide access to the waste dumps and garage and office area.

The rail haulage dispatcher for the pit is located near the Bingham Canyon entrance whence he has a good view of the pit as a whole. Rail haulage offices are located a few benches lower in the same general area.

Operating staffs are assisted by an Industrial Engineering Group which evaluated proposed new methods and equipment also a Quality Control Group and an Industrial Relations Group. These activities are co-ordinated by the Mine Superintendent.

Pamphlets collected at Utah Copper Co. are listed in Appendix 1.

II IRON FORMATION PITS

(a) Eveleth - Eveleth Taconite Company

The first taconite operation visited was that of the Eveleth Taconite Company, which has been operating for about 2 years and is owned 85% by Ford Motor Company and 15% by Oglebay Norton who also manage it. Initial drilling of the area was at about 1200 foot centres. This was subsequently closed up to 200 foot centres on sections at 300 foot centres.

A contract for a diamond drilling programme to cover a 12 months operating period is let two years in advance, and completed within a few months. Sample analysis takes another few months, but there is usually a six month period available for planning before the next year's work commences. Samples are analysed, Davis tube tests run, magnetic iron and silica determined, together with recovery at various degrees of grinding. Cut off grades are about 17% magnetic iron.

Planning covers 5 and 20 year periods in the long term, and monthly periods in the short term. A conscious attempt is made to take portions of all three types of ore in the pit and by selective mining to maintain as constant a feed to the mill as possible. The annual production of 1.7 million tons of

pellets calls for mining about 5 million tons of ore and a like amount of overburden. The pit works two shifts per day Monday to Friday on ore, one shift per day and five shifts over the weekend on overburden. No work is normally done on the first shift on Sunday.

3 P and H 1600 shovels with 6 cyd buckets are in use and haulage is by a fleet of 50 ton Wabco trucks. A 100 ton K.W. Dart with 700 hp. engine is on trial for compatibility with the 6 cyd shovels. It has a low profile and is over 20 feet wide as a result. Some adjustment to road widths would have to be made if this truck were adopted for permanent use.

Drilling and blasting practice is of particular interest here as the mine is within 1500 feet of a main highway and adjacent to the Eveleth residential area. Blasts of 200-400,000 tons are made two or three times a month. Holes are drilled by jet piercing, the bottoms chambered and loaded with a 25% aluminized slurry explosive. The top 25 feet of hole is stemmed, and blasts are fired against a cushion of 25% of the previous blast to reduce fly rock. Air shock and noise are the principal sources of complaint by private individuals. The company maintains a fixed continuous seismograph and a number of portable shock and noise meters.

On a morning when a blast is planned, the whole Engineering Office staff are split into a number of crews and from 9. a.m. monitor conditions by firing 2 lb charges in selected localities. All crews are in radio contact. A final pilot charge is set off 1 minute before the regular blast firing time of 11.30 a.m., and only if this gives acceptable results is the main blast fired.

Blasts are designed so that there is no more than 14,000 lb of explosive on any one delay and intervals at the back of a blast are shortened to smother fly rock by close sequence of delays and heave action. High energy primacord lines are covered with the jig plant tailings used for stemming, and low energy primacord is used over escarpments where it cannot be covered.

The winter temperature reaches 40° - 50° F below zero in this area. Some of the resulting difficulties include hangups in the load-out tunnel, particularly with fine ore; live bin capacity is much reduced. Bin probes freeze up and bin levels must be monitored by men. Shovel buckets are heated by burning hay or crude petroleum in them before starting work after change of shifts or lunch break. The low temperatures can destroy the magnetism of ceramic permanent magnets, and care is needed in handling and storage where temperatures of 20° F below or lower are anticipated.

Pamphlets from Eveleth are listed in Appendix 1.

(b) Peter Mitchell Mine, Babbitt - Reserve Mining Company

This mine produces 30 million tons of taconite per year and 4 million cyd of overburden. The plant at Silver Bay produces 10 million tons of pellets per year.

The initial drilling of the area was on a spacing of approximately 500 feet. For planning purposes it was closed up to 250 feet. Planning is

based on blast sized blocks (several hundred thousand tons) of ore. The significance of holes in and near blocks is assessed by engineers and an average grade and tonnage assigned to a block. This data is then placed on data cards. Plans are made by manually arranging the data cards in sequence and then running the sequence on a computer to test resulting production patterns for regularity etc.

Surveyors make a pickup of bench toes at the end of each month; calculated volumes are accepted for overburden. Ore is weighed at the product loadout conveyor and the truck factor adjusted accordingly.

An ore control group under the Mine Engineer samples the muckpiles daily. Results are normally available in time for consideration of the next day's operation. A Planning Department revises short term planning on a weekly basis. Plans are updated each quarter to show what remains to be done on a yearly basis. A continuous diamond drilling programme with 2 crews is effective in sorting out "lean" sections (i.e. low in magnetic iron) to leave behind untouched. Greater than normal detailed drilling is often required for this purpose.

The computer at Silver Bay is used for accounting purposes and to a minor extent by the Engineering groups at the mine for manipulating data. Diamond drill logs are recorded within the computer. Davis tube tests are calculated and included for certain set degrees of grind. A letter symbol is used for denoting rock types.

Working on 40 scale drill hole sections it is possible to obtain an 8 lines/inch computer print out which corresponds exactly with the 5 foot sample interval. These can then be cut up and stuck directly onto 40 scale sections on which holes are plotted and geological boundaries drawn in. Ore reserves could be calculated from these sections if desired. Planning however, as mentioned above, tends to be on blast sized units.

Jet piercing at a nominal 9 inch diameter is the normal drilling medium. The bottom sections of holes are chambered and in wet sections blasted with slurries topped up with the ordinary ammonium nitrate-fuel oil mixture used in dry holes.

A variety of outside contractors are used for placing these explosives and a constant programme of documented comparison is carried out to keep them on their toes and reduce costs to a minimum.

Although the townsite is some distance away from the mine, a portable seismograph and shock meters are placed in the area at blast time, and a weather consultant in Chicago gives a short term local forecast for the blast area.

The one exception to the drilling pattern is the recent introduction of a CP 61R rotary to drill a $12\frac{1}{4}$ inch hole in diabase which, because of its low silica content, doesn't spall easily and resists penetration by jet piercing.

The mine is notable for the great variety of trucks in use. Because

of the dumping arrangements for the 60 inch gyratory cruchers, ore can only be hauled in side tipping semi-trailer trucks. These were originally of about 45 ton capacity when the mine opened in the early nineteen fifties. Since then 85-90 ton trucks of similar configuration by a number of manufacturers have become standard and a 135 ton unit is on trial. Any ore picked up from unusual locations in end dump trucks must be tipped into side tippers for haulage to the crushers.

Trucks for use on overburden are selected after trial and evaluation by the Industrial Engineering Group. As these are normally on a rental/purchase basis during trial, a lengthy trial can mean that it will be economical to purchase the particular rented truck, even though trials may show that other makes and models of trucks are more suitable. The garage staff do not seem dismayed at the wide variety of trucks that results and probably the good spare parts facilities resulting from the large market on the Iron Range is a major factor in this context.

Shovels are usually in the 5 cyd and 11/12 cyd ranges. The two larger shovel types are selected for a particular location more on the basis of their suitability, shovels with double cab arrangements offering increased flexibility for particular circumstances.

The pamphlet collected at Babbitt is included in the list in Appendix 1.

(c) Hoyt Lakes - Erie Mining Company

This operation is approximately the same size as Reserve, annual production being of the order of 10 million tons of pellets. The main difference is that the concentrator and pellet plant are located at the mine site, rather than on the Lake Superior shore, 70 miles distant, as is the case with Reserve.

Haulage of ore in the pit is by rail, rather than by motor truck as at Reserve. Overburden is handled by end dump trucks in the normal way. Operations are scattered over nine different mining areas, including one near the Peter Mitchell Mine at Babbitt.

Initial drilling patterns are closed up to a 200 foot by 300 foot grid for planning purposes, and the usual test programme is carried out on samples. A group of engineers and geologists is responsible for grade control. Geologists visit shovel sites daily. The success of the whole operation depends on good grade control to produce a feed to the mill that will produce good pellets. There is little provision for storage or blending within the mill system itself.

The locomotive haulage system is probably related to the wide spread of operations and the long hauls consequently necessary to the mill. Where ore is not loaded direct to railway trucks, provision is made for end dump motor trucks to load into hoppers with vibrating feeders loading rail trucks. Train control here is by remote radio unit similar to that developed by Phelps Dodge at Morenci, but normal 2 man crews run loaded trains to the crusher. 1800-2000 horsepower locomotives are used singly or in pairs to

haul 9 or 17 car trains.

The basic end dump truck fleet is 85 ton Electra-hauls, backed up by smaller Euclid R45 units.

Blasting practice is generally similar to that at Reserve with continuous evaluation of the service and cost of a number of contractors. Taconite is drilled by jet piercing, but interbedded slate is drilled with a 61R rotary. The latest Hughes tricone bits show some prospect of drilling taconite more cheaply than jet piercing. Tests are continuing.

Shovel practice seems generally conventional but it is apparently normal to use a 16 cyd bucket on the larger units in overburden and an 11 or 12 cyd bucket on the same machine when loading ore.

Pamphlets collected at Hoyt Lakes are listed in Appendix 1.

(d) Ishpeming - Cleveland Cliffs Iron Mining Company

Empire Mine is one of the newer operations, having commenced in 1963. Grinding media costs for a conventional circuit were said to be prohibitive and ore is reduced by autogenous grinding in Hardinge Cascade Mills and pebble mills to 95% - 500 mesh before magnetic separation. Sizing of feed to these mills is apparently uncontrolled. In the pit, about 2 million tons of broken material is carried at any one time and daily production is graded by a geologist largely on grindability. Three basic types of ore are recognised - siliceous, carbonate, and argillaceous, with the latter lying between the other two as far as grindability is concerned. Some degree of blending is achieved in the covered fine ore bin by the tripper on the loading conveyor spreading ore over the length of the bin.

Latest additions to pit haulage equipment have been Wabco 105-110 ton trucks with Dorman engines and electric wheel transmissions. There is a Euclid RX truck but even with added side boards it carries only 85-90 tons. The articulated design seems to be working out satisfactorily in practice. 45 ton and 64 ton capacity trucks from previous purchases are still in use. Normally 1/3rd of the truck capacity is in reserve (under repair or maintenance).

Latest addition to the shovel fleet has been an 11 cyd machine; normally 3 shovels are in use in ore. Overburden is moved by the regular crew when the mill is shut down and at weekends etc.

A 60R rotary drill and some smaller rotaries drill $12\frac{1}{4}$ inch and $7\frac{3}{8}$ inch holes, which are loaded with slurry and ANFO, or all low strength slurry if wet. The top 20 feet of a 45 foot hole is stemmed. The 60R makes 40 feet of hole per hour.

Republic Mine was started some years earlier on a deposit of coarse specular haematite that could be ground with conventional equipment at the time it was started in 1956. Jet piercing (at 20 feet per hour) is used.

The truck fleet is mixed - good trucks from earlier purchases being retained. Tyres are retreaded wherever possible and it is normal to get a

total of 10,000 hours on a tyre including one recapping. A turbine powered Electra-haul is due on the mine shortly for trial purposes.

Papers collected at Ishpeming are listed in Appendix 1.

(e) Kirkland Lake - Adams Mine of Jones & Laughlin Steel Corp.

This operation is located on an outcrop of iron formation in the old gold-mining area of Kirkland Lake. The whole area being mined stretches over a length of 5 miles and five separate pit sites are operated. The iron formation is intersected by acid and basic dykes. Initial diamond drilling on 400 foot centres is closed to 150 foot centres for planning purposes. Sections are used for pit design to get cut off outlines and assess what waste can be taken. This is done by interpolation, balancing profit/ton of ore against cost of overburden handling to get it. The pits are planned around a concept of roads 100 feet wide, with 40 foot wide berms left every 80 feet elsewhere. Only the third cut has so far been taken in the main pit. A model in foam plastic has been constructed and is brought up to date by cutting sections off as they are blasted. The scale appeared to be 40 feet to one inch.

Long term plans covering 5 and 10 year year periods are made to avoid future difficulties. In the short term, the aim is to have shovels operating in both high and low grade material. Every second hole in the blast pattern is sampled and any abnormal rock types noted. After blasting the muck pile is inspected and marked with paint by the geologist to define ore and waste. Sketch maps for individual muckpiles are given to both the foreman and shovel operator.

Diamond drill holes are sampled over 10 foot intervals for total and magnetic iron, silica and Davis Tube test results after a standard grinding period. Areas of refractory ore which resist liberation are thus defined. A geologist is working with the Mill Research Group in an attempt to develop an adequate test for grindability so that when the pit is further opened up it will be possible to provide a steady quality of feed from pit to mill.

Rotary drilling with 9 7/8 inch bits by 50R machines gives 160-200 feet per shift and 1600-2000 feet per bit. 4 feet of subgrade is drilled below the 40 foot bench, on a 22 feet x 24 feet pattern. Holes are loaded with 500 lb. of slurry followed by ANFO in dry holes, or all slurry in wet holes. Secondary blasting is by "sand shots" at present; a drop ball is on order. An older down the hole hammer drill remains in use for perimeter blasting along roadway sides etc. where a smooth wall is desired.

Production is approximately 10,000 tons of ore and 5,000 tons of waste per day. Four 6 cyd P. & H. 1600 shovels are in use, together with 8 of a fleet of 15 Euclid 45 ton trucks. 14 of these are double bogie rear axle type - the other is a single axle truck on hire and currently being evaluated.

Tyres are demounted in a shop in Kirkland Lake. About 10% are retreaded a first time. Sections are replaced in most tyres before they are discarded. Much of the other major equipment repairs are, by contrast, undertaken on the mine.

Provision is made in the ore crushing flowsheet to crush waste to - 5/8 inch for road dressing and for discharging this material from the conveyor feeding the fine ore bins to the outside of the mill building.

The coarse crusher stockpile holds a live storage of almost 12,000 tons. This acts to an extent as a blending pile as it is loaded from a swinging stacker conveyor and provided with 7 vibratory feeders for loading out on the reclaim conveyor. Refer to flowsheets for more details of this piece of equipment.

Pamphlets collected at the Adams Mine are listed in Appendix 1.

III OTHER IRON PITS

(a) Eagle Mountain - Kaiser Steel Corporation

The ore lies in sediments affected by a monzonite intrusion, and is apparently subject to a structural control by small features on a generally dipping bed. There are two main pits - the East, which includes the old Bald Eagle pit and "alluvial" ore; and the Black Eagle pit about 5 miles away, where there is a small pit on "southern" ore separate from that on "northern" ore.

The area is diamond drilled BX wireline, and costs have been reduced from $25 to $12 per foot, including assays and metallurgical testing. Sections on 800 foot spacing are used in calculating what management calls "proved" ore. Additional drilling to reduce the spacing between sections to 200 feet is carried out for planning purposes.

For operational reasons, campaigns of about one week's duration are worked on high and low sulphur ore in the pit. The overburden to ore ratio is about 3 to 1 and about sixty percent of the ore sent for treatment is recovered as concentrate.

Detailed control is by sampling blast hole cuttings. Samplers start at 5 a.m. By noon results of assays are available for planning blasts which take place at 2.30 p.m. at change of shift. Two shifts only are worked in the pit; both pit and mill work a seven day week. Shovel operators can usually grade ore visually on a day by day basis.

Twice yearly an aerial survey is made of the pit. This is used as a check on gross quantities estimated by shovel and truck counts and weighing of ore. A detailed check of ore and waste is made by transferring computer plotted data onto ore reserve cross sections. Overall agreement is good, but the small southern orebody pit at Black Eagle has to be worked by hand.

Some preliminary underground work is being carried out with Wagner ST8 Scooptrams and a Gardner Denver Jumbo with a view to recovering ore from the area between East Pit and Black Eagle. The proposal is to try a caving method using Kiruna Truck type machines for ore haulage.

In the pit, holes are drilled in harder material with Ingersoll-Rand down the hole hammer drills with 9 inch bits, and in softer material with Bucyrus Erie 50R rotaries with 9.7/8 inch bits: Shovels range in size from

12 cyd to 4 cyd bucket capacity, the larger sizes being used on overburden, the others on ore and included waste.

The mine was originally equipped with 3 axle (semi-trailer) 100 ton trucks with mechanical transmissions, and these have been more recently replaced by 2 axle 100 ton units with V12, V16 turbocharged and finally V12 turbocharged engines developing about 1000 hp and driving through Allison torque converters with retarders.

On the industrial side, turnover of labour is low where housing is provided. Much overtime is worked, with hourly rates ranging $3.29 to $4.59 and time and a half for overtime. Daily summer temperatures average 103° F max. and 80° F min. with daily maxima occasionally rising to 117° F and 115° F.

There is less emphasis placed on selective mining now that the blending plant is in operation and sulphur can be eliminated from the pellets during induration, than during the period when the pit was operated as a source of ore only.

The paper collected at Eagle Mountain is listed in Appendix 1.

(b) Shawville - Hilton Mines Ltd.

This operation is about 40 miles west of Ottawa on the Quebec side of the Ottawa River. About 8 million tons of material are moved annually for a production of 900,000 tons of pellets. About 3.6 million tons is crushed, but 1.1 million of this is discarded at about two inch size by dry magnetic cobbing.

The ore occurs here as a skarn deposit. There are some iron sulphides but no other undesirable elements. In the pit there are extensive tongues and dykes of granitic material through a softer schistose ore. Planning is based on plan plotted diamond drill holes on 100 foot centres. Grade and recoverability as shown by Davis Tube tests etc. are also recorded.

All blastholes are sampled, and an attempt is made to keep several hundred thousand tons broken in the pit at all times. Three of a total of five shovels are in use on any one shift and of these two are in ore and one in waste or overburden. Shovel drivers can distinguish visually between ore and waste and call the foreman by radio if conditions depart from what was expected.

The first generation of 22 ton trucks is being replaced by Euclid RX 45 ton trucks and some K.W. Dart 45 tonners originally on hire/purchase for trial purposes. A number of Euclid 2 engine, tandem rear axle, trucks are still in use (model R40). Truck size is at present limited by the arrangements for tipping into the primary crusher - a 36 inch gyratory. There is no storage capacity and the 45 ton trucks must tip in two stages.

In the pit, holes are drilled with Ingersoll Rand Quarrymasters with 7 inch holes on an 18 feet x 18 feet to 22 feet x 22 feet pattern. Bits last 1000-2000 feet. Wet holes are loaded with slurry in the bottom and ANFO above using plastic hole liners with primacord and boosters. Ammonium nitrate received in bags is loaded with a mine operated mix truck. A drop ball is used for secondary breaking.

The Mines Branch of the Canadian Department of Energy Mines and Resources is undertaking a ground support project using cables and concrete beams tied back beyond the failure slip circle and holding the rock by arc mesh. The Freyssinet system is used to hold the cables and beams in place and the whole is instrumented. The object of the experiment is to develop a means of holding steeper pit walls.

It was noted that a conveyor system for loading out cobbed waste onto an elevated dump, had been abandoned because of mechanical difficulties due to the unstable base for the conveyors. Trucks were being used to carry this material away.

There were no papers available giving details of Hilton Mines operation.

SUMMARY - OPEN PIT MINES

Truck sizes continue to increase, and most operations of a number of years standing have three generations of trucks in their fleets: the remnants of previous large fleets, still in economically sound condition; the most recent large addition to the fleet and one or more individual new trucks undergoing evaluation.

Most manufacturers offer 100 ton capacity trucks and larger models to 200 tons are being evaluated in pit trials. Problems in tipping and loading these large trucks with existing facilities and equipment and the width of haul roads will tend to limit the extent to which the biggest trucks can be used, particularly in existing operations. Elsewhere smaller scale operations and selective mining call for smaller units both in shovels and trucks to provide the flexibility required.

Gas turbine engines are being introduced in trucks currently being evaluated, and at least three major manufacturers are offering diesel engines for the 100 ton sizes. Electric transmissions i.e. electric wheels are becoming increasingly popular in the larger sizes.

In the drilling field, bigger and better rotary drills seem to be moving even into the field of taconite drilling, for which jet piercing has been long regarded as the only solution. Holes of 10 to 12 inches diameter are popular for the newer large rotaries.

Pit control methods vary, and although most plants producing iron pellets indicated that they considered a steady feed to the mill important, and went to some lengths to achieve this, only Kaiser Steel had gone to a full blending system, and only one other mine (the Adams at Kirkland Lake) had made much concession in the design of the crushing section to smooth out irregularities in the feed coming from the pit. Weather conditions in the northern United States and Canada are probably significant in this context, in that they discourage the carrying of large stockpiles of broken ore in the open.

Power shovel sizes have been increasing to keep pace with increasing truck sizes. However most operators seem content to rebuild shovels as required rather than retire them, and new shovels are only added as additional capacity is needed. In some of the less arduous conditions, very large front end loaders

are used in times of emergency to replace shovels as primary loading units, but only in the short term.

Blasting practice is almost universally based on ANFO and slurry explosives, with suitable modifications in loading wet holes. In the Iron Range the very competitive nature of the explosives supply business was evident, most companies using two or more contractors in various parts of their pits. In areas where the market is small mines provide their own facilities, rather than depend on explosives suppliers for the actual placing of the explosives.

UNDERGROUND MINES

(a) San Manual - Magma Copper Company

This operation is located about 35 miles north north east of Tucson and is block caving a porphyry copper under a sedimentary series consisting largely of conglomerate, ranging from 0 to 1900 feet in thickness.

The outcrop was sampled and churn drilling carried out on 400 foot centres, later reduced to 200 feet. This was followed by underground development and diamond drilling on sections at 200 foot intervals. Sections are prepared and tonnages and grades calculated by geologists and passed to mine planners for location of openings and detailed scheduling of development.

Control diagrams are prepared to show the percentage of estimated tonnage and grade progressively recovered from each caving block. There is a monthly adjustment from mill weightometer figure back through skip and truck counts to the estimates of tonnage drawn from individual drawpoints. Shiftbosses give written instructions to grizzlymen (who are not on an incentive rate) as to where and how much to draw. The actual "pull" is reported and recorded by the draw clerk.

Start up after the 8 months strike shutdown was reported as easy. Where a given area is taking excessive weight, relief can be obtained by heavier draw on adjacent areas. Surface movements beyond the cave area are due to movement on post-ore fault planes. A drawing rate of 18 inches per day gives good results. Drawing of blocks was originally on a checker-board pattern, but following advice from the U.S. Bureau of Mines the pattern has been changed to a flying wedge and will be changed to an en echelon pattern as the opportunity offers. The cut off grade depends on the height of ore above development levels but is usually 0.6% Cu. No credits are allowed for gold silver and molybdenum.

Approximately 130 million tons have been mined since 1956 at 40,000 tons/day rising more recently to 60,000 tons/day. The faulted section of the existing orebody has been bought outright. This lies at greater depth and mining will be complicated by water, heat and higher rock pressures.

Development openings are sampled every 20 feet, drill core on 5 foot intervals and drawpoints once per week, or more frequently if oxide ore or waste starts to appear. The presence of calcite in the gangue means that although low grade ore cannot be leached by the classical acid method, mine water is suitable for plant purposes.

Much of the materials handling section of the mine is automated - refer to pamphlet listed in Appendix 1 for details of concrete supply, ore haulage and dumping etc.

Draw and haulage operations are co-ordinated through a dispatcher (who handles train movements etc. also) by an audio paging system.

Considerable use of non-reinforced concrete for ground support is made on the grizzly level particularly, but in other places also.

(b) White Pine - White Pine Copper Company

Time prevented a visit underground here, but useful discussions were had with the company's manager of research and his staff.

The mine itself came into being following a successful programme of metallurgical research into the recovery of chalcocite and native copper from the ore. This consists of a sedimentary column with two enriched sections of 60 lb Cu/ton and 80 lb Cu/ton. With the present equipment, which needs $8\frac{1}{2}$ feet of headroom, it is not practical to mine the enriched sections separately, nor is it practical to take the whole column at once. Present practice is to mine a total thickness of about 14 feet, leaving portion of the upper low grade material. A room and pillar layout is used.

As work proceeds down the dip, room and pillar mining becomes less attractive. The company is investigating the possibilities of longwall mining and development of low profile equipment to mine the higher grade sections only.

Longwall development to date has been hampered by difficulty in securing a sufficiently rapid face advance. One way of doing this is by pre-drilling long holes parallel to the face and firing these against a buffer pile. Wander in long holes limits face lengths to about 200 feet instead of the preferred 600 feet. A selective cutter along the lines of the South African machine for Banket mining is understood to be under development and giving promise of success.

Mining equipment for the present "full column" room and pillar system includes Joy loaders, 18 cyd articulated trucks, Wagner Scoop-trams ($\frac{3}{4}$, 2 and 5 cyd sizes), twin boom jumbos and a recently developed electro-hydraulic roof bolt drill. Underground layouts are designed to provide for movement of the refuelling and man transport vehicles, which have the greatest dimensions. Tyres are normally recapped several times. Chains have been tried but without any outstanding success. Current proposals include the drilling of a 12 foot diameter shaft for ventilation purposes to about 1800 feet and also the drilling of an 18 foot diameter tunnel below the ore seams as a major haulage drive. The equipment to do this at present on the mine awaiting assembly. The company hopes to develop suitable borers for smaller diameter openings to link the major haulage and the ore seams and for development in ore.

Good work has already been done in rock mechanics and is reported in the paper listed in Appendix 1. As a result of this investigation the room and pillar layouts are oriented with the long axis of pillars parallel to tension

cracks resulting from regional and local tectonic activity. Equipment used in stress field measurements consists of triaxial transducers manufactured by Soiltest to fit an AX hole for overcoring with a six inch hole.

It is felt that it should be possible to use photo-elastic strain gauges cemented to the end of a hole and overcored with the same diameter bit as that used to bore the hole. See comment later on Canadian Mines Branch work in this field.

(c) Sudbury Area - International Nickel Company of Canada

Several underground visits were made at various places in the mines operated by this company.

The first area visited was at the Murray Mine where Wagner ST4A Scooptrams were being used in the development of a Cascade stoping method after the style of that originated in Rhodesia. The orebody is flat lying (45°) with good footwall and ore but an incompetent hanging wall. Footwall access is by ramping down at 20 percent grade between sublevels which are driven almost level. As well as the access decline, each sublevel has a horizontal drive just within the footwall and short turnouts to draw points. Roadways are concreted for easy travelling. A two boom hydraulic jumbo with capacity for 10 foot steel is used for drilling development ends. Ammonium nitrate-fuel oil is the normal blasting agent.

In stoping, rings of holes 20 to 90 feet in length are to be drilled with Atlas Copco ring-drilling rigs, set up so that one man operates two machines. Approximately 210 to 300 feet per manshift is expected from these units.

In this area all haulage during the development stage has been up the ramps to tip into granby cars hauled by trolley wire locomotives. All supplies have been handled into the area by the Scooptrams, which have 5 cyd buckets and heavy duty front axles. It is possible to tip concrete into these buckets from rail cars if the Scooptram front wheels are dug in a bit. It is expected that Scooptram loading rates will reach 1200 tons per shift in this stoping method when the chute system has been completed.

At the Frood-Stobie mine, mechanized cut and fill stoping of a pillar 700 feet by 200 feet was inspected. Production of around 1200 tons per shift is obtained by drilling with a 3 boom jumbo using up holes, except at the stope ends. A Massey-Ferguson tractor with fork lift and platform guards over cab and engine is used for installing the regular pattern of roofbolts and wire mesh. This supporting steel is finally recovered from the ore by magnets after hoisting. It does not appear to cause any difficulty up to this point. Secondary blasting sufficient for loading by the Scooptram is carried out in the stope. The rest of the haulage system can accept rock of this size.

Manways are maintained the size of a square set through the fill, and chutes are circular steel plate sections, $\frac{1}{4}$ or $\frac{3}{8}$ inch thick. Two are used for this area. Cement is added to tailings fill to give a solid mining floor. Cement to sand ratios used in practice vary but something of the order

of 8 of fill to 1 of cement seems optimum. High tyre wear can result if the top rich layer breaks up, thus nullifying any economies obtained by using a leaner mix in this area. Sometimes the bulk of the fill also has cement added at a ratio of about 1 to 30, particularly when placed adjacent to pillar lines.

Raise boring machines have been used to advantage in the programme of production expansion recently engaged upon. Large areas of new ground have been opened up by long ventilation raises which have been completed quickly and without calling upon skilled miners. Conventional methods would have faced high rock temperatures etc. etc. and been very slow. Where large holes are required it is probably cheaper to install a raise-climber machine than to drill a raise and then make special provision to strip it to a larger size and equip it.

Inco have two sizes of Hewitt-Robbins raise-boring machine. The smaller is capable of 3 to 4 foot diameter holes. A 75 h.p. electric motor is used for rotation and the hydraulic system is mounted on the machine's caterpillar chassis. Rods 4 feet long and 9 inches in diameter are used. The larger machine has a 150 h.p. motor for rotation, separate hydraulic system and 5 feet by 10 inch diameter rods, each weighing 140 lbs. Both machines operate by drilling a pilot hole down (12-13 inches in diameter) and then reaming back at final size. A hole 600 feet long was being reamed by the large machine at the time of my visit. Load on the reamer bit should ideally by about 300,000 lb. Progress is of the order of 20 to 30 feet per day with a 2 man crew.

The machine is set up on a bedplate which is carefully installed to surveyors marks for bearing of the raise. After the machine is installed a large perspex clinometer is used to set the inclination and this is checked again after two feet have been drilled.

It is proposed to use raise borers for large drainage holes to control the inflow from the melting of snow in the Frood-Stobie open pit which connects with some of the workings.

On the diamond drilling side, wireline drilling has resulted in excessive deviation and is little used as a consequence. Much drilling is BX size with impregnated bits in an attempt to minimise deviation. Short holes for detailed information are normally drilled EX. Deeper exploration is by holes as long as 4000 feet from sites 6000 feet underground. The Tropari instrument is in regular use for surveys where magnetic effects are not too great.

Organization of the Inco mining complex is based on a system of relatively independent mines. Each group has its own repair shops, surveyors, planners and schedulers, safety and ventilation officers and industrial engineers. The central office at Copper Cliff has a Chief Engineer and planners for reviewing proposals from the groups. Capital Statements for new equipment, major developments etc. come forward from the groups themselves. Longer term budgets and schedules are prepared by the Chief Engineer's staff and reviewed by the Mines Manager and the individual Mine Superintendents.

Pamphlets collected at Inco are listed in Appendix 1.

(d) Sudbury - Levack Area - Falconbridge Nickel Mines Ltd.

Discussions with Chief Mine Research Engineer and his staff were interesting in bringing out the company's philosophy of approach to research.

At Falconbridge itself there is little in the way of new developments to be seen apart from the mine fill plant incorporating provision to add cement, and the detailed scheduling system recently introduced. These and other items will be discussed in the paragraphs below - the visit to the new Strathcona mine at Levack, about 40 miles to the north west, will then be described.

At Falconbridge some brief discussion was held with the mine geologist regarding ore reserve calculations. Tonnages are calculated using level areas assumed to extend half way to the next level or according to a so called "Prismoidal" formula $T = (A + B + \frac{\sqrt{AB}}{2}) \times \frac{h}{3} \times \frac{1}{\text{density}}$. Grade is based on drill hole assays and face samples, weighted appropriately and related to a minimum mining width of 6 feet.

An allowance is then made for dilution due to weak wall rock. In main lode calculations this is allocated according to stope width and in south wall orebodies according to tonnage. After this allowance the block value is recorded on a longitudinal section. Blocks are usually between sections 100 feet apart. Where an orebody is not intersected by adjacent levels tonnages and grade are calculated as above, cut 40% on tonnage and reported as indicated ore.

Working plans and sections are kept on a scale of 20 feet to 1 inch. Diamond drilling continues as required until the geologist feels he has enough data to give the planners an adequate picture of the orebody between levels, by means of 20 scale plans. The layouts are then done by planners and circulated between themselves, the geologists and operating staff until agreement is obtained.

Long term planning is a matter of manipulating the mining sequence for ore reserve blocks. The picture at this mine is a relatively simple one of a single narrow orebody with a clean north wall and irregular offshoots into the south wall.

Consultants were called in for the establishment of a system of short term detailed stope scheduling on which 2 men, previously with the work study group, are continuously employed.

These two men take the operating areas as called for by the longer term plan and in co-operation with the mine captains schedule the work to be done in terms of manpower required for all operations in the cut and fill sequence.

Shiftbosses report back by recording actual dates progress is achieved on the bar charts and plans, as well as the actual number of men employed in the stope and the tonnage mucked out. The Assistant Mine

Superintendent, who is in charge of this scheme, produces a report reconciling the plan and actual performance.

It is reported that benefits are not measurably demonstrated, except that more tonnage is being produced by a smaller crew. Very substantial variations, even from these short term plans, are produced by the effect of good stopes producing very well, and others falling far below expected performance. New stope plans are provided by the Survey Office at the beginning of each monthly scheduling period.

The Strathcona mine is being developed for full production by April 1969. Concentrates from the mill are railed as a slurry in tank cars to Falconbridge for smelting.

The underground visit was made to an area developed for transverse cut and fill stoping with 44 foot stopes and 18 foot pillars, cut out on the footwall to provide access to four stopes for the Wagner ST4A Scooptram being used for loading. There are no chutes in service gangways as the few steel lined 6 foot diameter passes are connected to one or other of two main haulage levels.

On these levels, rakes of 10 12½ ton capacity Grangesberg cars are hauled with trolley wire electric locomotives. One such train will need to be tipped every fifteen minutes when the mine is in full production.

One aspect giving concern is the difficulty of communication between stope and haulage crew. The long free fall of ore in the chutes could lead to packing and major hangups if this contact is not maintained and the stope miners continue to fill into a chute which is already hung up, particularly in view of the Scooptram's high filling rate of 200-300 ton/hour.

Chutes on the main haulage level are placed longitudinally over the centre of the track and under chain control are intended to provide continuous loading of the train as it moves beneath. At present the chain control seems too short to be properly effective and the train crew is spending a disproportionate amount of time on firing hung chutes.

Ore from the Grangesberg dump pocket is fed to a 48 inch x 60 inch jaw crusher and some of the rockbolts and mesh used for stope back support is removed from the ore at this point by the crusher attendant. After crushing the ore is fed to storage bins (2 x 3000 ton capacity) from which it is drawn and fed by conveyor to weighing pockets and finally loaded into skips for haulage to the surface. The feed conveyor is stopped when skip tonnage is reached in the weighing pockets.

Eventually about 40 stopes will be operating. Six ST4A Scooptrams and 5 model ST2 units will be required. The smalled units have only sufficient capacity for average production rates and no reserve to cope with fluctuations in capacity requirements. Production off the two haulage levels is planned to total 6000 tons per day.

Experience to date with Scooptrams has been that some drive shafts and articulated joints have been broken and this may be ascribed to

excessively course muck and to the practice of retaining too sharp an edge at junctions between ramps and levels. Some of the ST4A machines were equipped with hydraulic devices to restrict wheel spin on front axles under difficult conditions.

In the stopes visited selective mucking is practised as the transverse stopes are in an area where there are stringers of ore separated by waste, which is left broken in the stope as far as possible and covered by fill. This could probably not be done with a conventional slusher type stoping operation. Machines will be captive in stopes between levels and it is expected that stopes will extend through two levels.

In another application a Scooptram is being used instead of a train type transfer operation over a distance of 600 feet. The drive will be stripped to provide 6 feet clearance on one side, two feet on the other. A concreted floor will be provided and rail tracks straddled by the Scooptram as it travels to and fro.

At present, cemented tailings fill 1/32 with 1/8 for the top foot is used and from the solid flat floor thus provided up holes, 12 feet long at 65° are drilled by a very simple pneumatic tyred wagon drill. This mounts two muffled 3 inch bore rockdrills on long feeds which consist of an aluminium extrusion with an air piston inside coupled to the machine by a high tensile wire rope. The machine guides and cylinder have been incorporated in the feed shell extrusion. The rig makes 50 to 60 12 foot holes per shift, with one miner operating it.

It is proposed to use a larger carriage and higher back so that the 12 foot holes may be drilled in one pass. This procedure will require different arrangements for securing the back. At present this is done with expansion shell rockbolts (on a 4 foot square pattern) and mesh placed from the muckpile. The present intention is to go to a platform or gantry slung from an Alimak raise climber track bolted along the centre line of the stope and use this for barring down and placing rockbolts and mesh.

These is a high intensity of supervision in this operation. A stope-boss has charge in each stope; there is a shiftboss for approximately every 20 men, mine captains for various areas and finally the Mine Foreman who is invariably professionally qualified.

(e) Elliot Lake - Canadian Denison Mines Ltd.

The orebody on this limb of the overall Z shaped synclinal structure dips at an average of 19° but varies between 5 and 45 degrees on the Denison property.

Rather than follow the contour to maintain grade, the strike drifts used to open up the orebody are driven on line. This practice results in very rapid changes of grade thus limiting the type of equipment that may be used and making the maintenance of good roads more difficult.

The basic equipment used is Clyne diesel trucks rated at 10 tons but in fact carrying only 7 and electric slushers with loading ramps. Strike

headings are driven as 8 foot x 8 foot pilot openings slashed to 25 feet wide and benched with down holes. Jackleg drilling machines are used. Slusher ramps for headings are crawler mounted but permanent structures are built at the entrance to stopes.

Where flatter strike drifts make it possible, Scooptrams (Wagner ST5 model) are used to pick up from a surge pocket in place of the scraper loader and trucks mentioned above. For hauls over 500-600 feet, Wagner 20 ton trucks are loaded by Scooptram.

As the main haulage to hoisting shafts is by conveyor belt all ore is passed through 10 inch aperture grizzlies between trucks and belts. Men with spalling hammers have been for many years the only solution to the breaking of large rocks, but recently a modified down-the-hole hammer drill has been developed, giving a blow of 1000 ft. lb. It has been necessary to strengthen grizzlies where this machine is used.

Another change in practice has been to replace the short holes drilled with a jackleg machine in stoping by long holes drilled out in advance by mounted drifters. This is particularly applicable where the orebody is relatively thick. Roof support is by rockbolts and mesh placed from the muckpile.

Individual headings are mapped geologically and sampled at least every 20 feet. Samples are normally taken in pilot headings of drifts or stopes and extended to the full thickness of the orebody by up and down holes drilled with a Packsack diamond drill. Horizontal holes up to 700 feet are also used in the development of the mine, but these, of course, are of limited value.

The property was tested initially by 30 holes from the surface, and existing mapping in adjacent properties also provides useful data. This information is correlated into trend lines for equal grade and thickenss and this allows some projection into the unexplored area ahead. There is other mineralized material higher in the sedimentary sequence which may be economic to mine at some future stage of higher uranium prices and more advanced technology.

Planning is on a broad 10 year basis with more detailed yearly planning. Some high grading was unavoidable during the period of low contract prices when the mine did manage to continue operating. The intention now is to concentrate on removal of the remaining steeper, high grade, thicker ore and prepare to mine the flatter, lower grade, thinner ore for which Scooptrams will be more suited.

Yearly plans, as approved by the Board of Directors, are used to forecast capital equipment and constructional requirements. The yearly plans are considered at monthly meetings to establish targets of tonnage and grade for each working place, and when considered with manpower efficiencies and stores consumption this is built up to form the Mine Captains' working plans for the month. After six months, the yearly plan is revised in the light of what has actually been achieved.

Three survey crews are engaged in development work and one on stope surveys, marking up long hole drilling and so on.

(f) Wallace, Idaho - Galena Mine of ASARCO

This is a relatively small mine, employing 210 men of whom 24 are staff. Production capacity is being raised from 500 tons/day to 800 tons/day. The ore consists of tetrahedrite in a sericitic gange. The cut off grade is thought to be 30 ozs. silver per ton.

Neither the Raise Boring Machine nor the Alimak Climber was in use at the time of my visit. Their experience with these machines had not been entirely happy, partly due to the fact that the raise boring had been carried out on a cost plus contract. Some useful pilot hole work for shaft extension had been done by the borer, but in the conditions in this area the four foot diameter raise is often not big enough from the ventilation point of view. The mining methods normally used call for a raise divided into ladderway, hoist and two ore chutes, and it is simpler to do this as one major development job rather than strip out and equip a bored raise. Often, because they are on line, raises bored in narrow veins will be outside the ore for part of their length. Valuable geological information is thus lost.

The bottoms of a number of bored raises were inspected and it was apparent that they stood much better than raises driven by conventional techniques. Some minor fretting only was apparent, and that at the edges of the hole where joint planes were tangential to the circumference.

Raise borer holes are surveyed by photographic methods, using instruments placed in the rods. This of course gives dip only unless the instrument in placed and retrieved using oriented rods.

In normal mining practice raise timbering is preserved during mining and timbered off at each lift for filling. A 1 to 8 cement sand mixture is used as a topping on each pour of fill, as well as over sill timber. This is supported by stulls resting in brackets hung from rockbolts in the wall and protected by cedar squeeze blocks against damage during rockbursts to which the mine is subject.

The bursting is violent failure of isolated blocks on joints, and is due essentially to the relation between joint and fault systems and the direction of principal stress. The stoping sequence has been adapted to meet this circumstance, retreating from the eastern boundary of the property.

Conventional flatback cut and fill stoping with vertical blast holes in narrower sections and horizontal blast holes in wider ones is used. Ore is scraped to chutes with $7\frac{1}{2}$ h.p. air operated hoists.

Ground support in drifts etc. makes use of slotted plates fixed in a regular pattern using rockbolts, and making provision for a slotted plate headpiece between the rings of plates placed every 6 or 7 feet, the length of a normal drift round. 4 foot and 6 foot expansion shell (Pattin "D" type) bolts are used.

(g) Wallace - Hecla Mining Company - Star Mine

A visit was made to this company in view of their experience with raise boring machines.

The machine used here is a Robbins 42R which is capable of boring up or down. It has found favour because ground conditions at depth are such as to prevent the conventional timbered raise being holed through the full 300 feet from one level to the next. The borer is not used in the upper levels where conventional practice has the advantages noted in the discussion on the Galena mine.

On lower levels, stopes are worked blind with service and ventilation openings carried up through fill. The bored raises are used to maintain major ventilation circuits and for this purpose their smooth surface and self supporting characteristics make them particularly suited.

The borer has also been used for orepasses, pilots for shaft extensions etc. Where larger sized holes are required the Alimak Raise Climber has been found to give good results.

The raise borer they used is sled mounted and has provision for placing wheels below it for moving long distances. Caterpillar tracks are only useful for short moves in their view. The machine is carefully set up for bearing on a concrete footing in the usual way. Angle is set by using a bricklayers level on a template made of $\frac{3}{4}$ inch plywood to give the required dip.

In operation the key to cost is reduction of bit costs and this is achieved by proper thrust so that cutters operate well but the hole does not deviate excessively, as it will at higher thrusts.

Hunting, or variation in rotational speed is considered to be due to the tearing effect of the cutters in softer rock. The effect is alleged to be absent in hard rocks with their balanced cutter layout on the reamer of 2 + 2 + 4. The limitation of the equipment with 8 inch rods is thought to be 800 feet. A 10 inch rod string would permit greater depths. Rods are limited to 4 feet long to lessen the headroom required.

The paper on raise boring collected at this mine is listed in Appendix 1.

(h) Kellogg - The Bunker Hill Company

The mine operates through 17,500 feet of adit (the Kellogg Tunnel) to an area of a variety of vein types, the larger and higher grade orebodies having been mined in past years. Veins and stringer zones contain the bulk of the remaining ore.

Grade control is directed toward determining cut off points in those of the stopes which are generally close to marginal grade. Samples of 7 to 10 truck composites are analysed, and in the stopes themselves loader drivers take samples and make up a shift sample from the various faces.

Shiftbosses also take samples and thus acquire some ability to visually evaluate faces. Assays for samples lodged in the afternoon are available the following morning. Cut off value is based on a 5 month moving average of variable costs plus say $4 or $5.

The section of the mine examined included that where Atlas Copco Autoloaders were being used in the stoping of low grade flatly dipping orebodies. A 10 foot square checkerboard pattern of pillars is used for back support. World Mining for May 1967 at page 46 contains a description of this stoping Method. The larger Cavo 310 four wheel drive loader has been tried and gives much better tyre life. A major item of wear is the 15 feet of hose adjacent to the loader and this is being dealt with by using a separate hose for this section, and making sure that ample spare pieces are available. It is this section which is often run over by the loader during its first movement away from the face. Additional support for the loader drive pinion has been found necessary, but otherwise the loaders seem to work well.

A test stope using square sets on 8 foot centres is being developed. It is hoped that this will permit the use of a loader in square set stoping. The normal 6 foot set spacing is too restricted. Indications to date are that the 8 foot spacing will prove successful. Loaders of this type appear to have a maximum effective hauling distance of 350 feet. They are regarded as better than scrapers, even in open stopes, but sollars are desirable in heavier high grade ore.

There is a mine model in the office which covers an area about 3 miles by 2 miles. It makes use of taut piano wires to represent co-ordinate lines and support the perspex sheets on which details of each level are set out.

The pamphlet collected at this mine is listed in Appendix 1.

(i) Metaline Falls - Pend Oreille Mine.

The mine operates on an orebody consisting of irregular bunches of galena and zinc blende distributed throughout the Reeves - Macdonald Limestone which in this area forms a plunging anticline. Some of the openings into the mine have had to be sealed because the Boundary Dam on the Pend Oreille River has raised the water level more than two hundred and fifty feet. The constructing authority installed a new sump and pumping station in the mine and also made provision to discharge water from the bottom of the dam should a major mine flood develop. In spite of these added costs, the dam site appears to have been sufficiently attractive to carry the additional costs involved in making some provision for the mining companies.

Ore is hauled from the mine by conveyor belt, which is loaded with ore previously crushed to -3 inches. A new crusher station and belt extension is currently being constructed. In the lowest section of the mine, not yet serviced by the belt, ore is spalled through grizzlies and hauled in skips in the continuation of the conveyor drift which is declined at 10-12°. The present bottom of the mine is about 2,200 feet vertically below the adit entrance, and 3 miles by road away.

Stoping is based on practice at the Eagle Picher Mine in the Tri-state lead mining district.

Machines in use include a two boom jumbo mounted on an Eimco Traxcavator chassis and carrying three inch bore Gardner Denver drifters using a twelve foot feed to drill twelve foot holes. Loading is by Traxcavators and haulage by 12 ton Euclid trucks equipped with side on driving positions and headlights front and rear. These have replaced the original equipment of 10 ton Dart trucks.

A 12 cyd Joy transloader is being tested as a replacement (at $70,000) for a loader and two trucks ($90,000). The machine has the additional advantage of using one man instead of three.

Difficulty has been experienced with the exposed hydraulic connections which are a source of many delays for repairs. The drive axle has had to be replaced with a heavy duty unit and the wheels now extend beyond the frame of the machine. Tyre wear is not regarded as a problem with 600 hours life on the drive axle tyres and 1500 hours on the bucket axle ones.

The machine is a bit too large for some of the more confined working places, and its long rigid length (it can twist and move in a horizontal plane to steer, but is rigid in the vertical plane) may impose strains in close quarters also.

Present mine production is at a reduced rate of 4,000 tons per week, using 2½ or 3 loading crews on a one shift, five day week. Previous full production was at 2,400 tons/day.

Ore is sought by diamond drilling and also by percussion drilling using a single boom jumbo on an old Traxcavator chassis. Holes are usually spread out in fans in both directions. Cuttings are panned off at 8 foot intervals to select sections for assay. A small teflon coated pan is used for this purpose.

Results of drilling are plotted on 50 scale working plans, kept as composites for particular grid sections of the mine. All levels are expressed in terms of feet above sea level and spot reduced levels on backs and floors indicate the relative positions of openings in the vertical direction. Where one stope overlaps another, the lower stope outline is dotted.

A cut off grade of 2% combined lead and zinc is used; the normal zinc to lead ratio is 50/50. At present one man visually assays truck loads (by examining the pile in front of the loader) and directs individual loads as ore or waste. Samples are taken to maintain the accuracy of the grader's judgement.

The ground stands well and backs give little trouble. An hydraulic boom mounted on a truck and supporting a basket at the end gives access to backs about 17 feet up. Headings are normally driven about 16 feet x 16 feet and the backs made secure with rockbolts where necessary. In stoping the ore is followed by placing drifts at the top of the known ore outline and

slashing and benching down until the bottom of the ore is reached. Stope heights formed in this way are normally 16 to 20 feet, but have been as much as 100 feet in certain areas.

Supervisors travel in diesel converted Willys Jeeps and International Scouts as well as the conventional diesel Landrover. Maintenance crews use retired Dart haulage trucks converted to flat beds for their transport. Vehicle maintenance jobs requiring less than a day are usually carried out underground. Longer jobs are carried out in the surface shops. Major overhauls are carried out on the mine. Two thirds of the new tyres coming out of service are suitable for recapping.

A pamphlet describing the Boundary Dam was obtained while in this area and is listed in Appendix 1.

(j) Salmo - Jersey Mine - Canadian Exploration Ltd.

This is a deposit of galena and blende in limestone somewhat similar to the Pend Oreille mine which is about 20 miles away.

The mine area is well above river level however, and the deposit itself is more flat lying. The limestone bed outcrops on several sides of the mountain. Ore is hauled out of the mine in diesel-engined rubber tyred trucks. A separate occurrence of scheelite in a skarn deposit was mined by the company under contract to the United States Government in the early nineteen fifties.

The search for ore follows the same general lines as at the Pend Oreille mine. Diamond drill holes at 100-150 foot spacing are used to search for ore ahead, while major development openings are mined by the heading and bench system.

Acutal stoping, however, tends to be carried out by conventional jackleg and scraper methods, using rubber tyred equipment for loading and hauling, as well as driving the main headings and handling supplies. Where practical chutes with overcut arc gates, air operated, are used to load trucks direct, but elsewhere rubber tyred front end loaders are used to load trucks. A Wagner ST5A Scooptram is also in use.

For drilling in headings a three boom jumbo with Gardner Denver drifters on 12 foot feed shells is used to drill 12 foot rounds. This is mounted on a tractor chassis.

The loaders used are Cat966B models with limited slip differentials. Some have been modified by making buckets narrower to reduce spillage in loading the smaller haulage trucks which are 8 ton Koehring Dumptors.

Erlau alloy steel chains have been fitted with success to both loaders and Scooptrams. Their advantage lies in reducing tyre costs from something of the order of $10 to $2.5 per hour. With tyres and chains costing about $1,000 per wheel, tyre life has been increased many times over the 300 hours previously obtained and chain life is incomplete at more than 2,700 hours.

Haulage units consist of fourteen Dumptors mentioned above, with two manual transmission Euclid trucks rated at 12 tons and two KW Dart tractor-trailer units rated at 15 tons. These larger trucks are used on the longer hauls from orepass chutes etc.

Access to the backs, which rarely exceed 80 feet is obtained by means of two truck mounted hydraulic controlled platforms locally called "giraffes". The smaller has a 45 foot reach, the larger 85 feet. Particularly in the case of the larger unit, good floor conditions are essential and it is necessary to prepare the floor with a bulldozer before this machine may be used.

Waste crushed to two inches is used on roads; fines build up adequately from spillage etc.

With production running at 40,000 tons per month a 5 day 2 shift week is run on production, and few spare faces are available. The mill can accept reasonable grade fluctuations without much loss of efficiency, and in cases where very high grade ore is encountered it is stockpiled on the surface and fed into the crusher gradually, a few shovel loads at a time.

Loader drivers and miners are on a contract basis, but truck drivers are not.

As various trucks and tractors have been retired they have been rebuilt into special items of equipment. One of the more useful of these is a 50 h.p. triple drum slusher hoist mounted on a tracked tractor chassis, which is used for opening out stopes from headings before the face is far enough away to make a permanent installation at the heading possible.

SUMMARY - UNDERGROUND MINES

The trend in the United States and Canada is undoubtedly toward increasing the mechanization of mining with the object of decreasing the labour element in production costs. This is due in part to the militant labour unions (most companies visited in the United States had been affected by lengthy strikes in the past twelve months) and to a growing realization that underground mining is becoming less and less attractive to the bulk of the labour force, who are finding more congenial employment elsewhere.

There was a natural tendency for some companies to be deeply involved in research because they depend on solution of problems to remain in production as mining conditions become more difficult and their higher grade ore is exhausted.

In the case of the Sudbury area, the resources are well known, and the money is available to meet the technical challenges that increased production brings forward. The big advantage of a large scale production is that the equipment manufacturers can see a worthwhile market in developing special equipment for these operations. Elsewhere it is largely a matter of piecemeal addition of equipment as previous generations wear out or increased production is required. Here methods must more often be

modified to suit the characteristics of the available equipment, or rather the application is limited by these factore.

Where ample headroom is available there seems little difficulty in adapting surface trucks and loaders to underground conditions. It is in cases where headroom is limited that special equipment must be developed. Probably the most successful of these items is the Wagner Scooptram, which is available in a variety of sizes but seems most popular in a bucket size of 5 cyds.

There is also a field for smaller items of equipment for use in preparatory development for large scale blasthole methods and for stoping in confined areas where support by square sets is necessary or irregularities of the orebody makes scraping unattractive.

The ideal in supervisors vehicles in trackless mining areas does not yet seem to have been evolved. It will be interesting to see how the Landrovers being introduced at Canadian Denison perform in what must be regarded as arduous conditions.

Only one company appeared to be using chains on loaders with any success, and it will be of interest to see whether this successful application leads to a wider spread use of what appears to be a valuable piece of auxiliary equipment.

The general conclusion reached is that there is probably scope for a more rational approach to equipment development, at least in the areas where there are common problems.

MINING RESEARCH

The functions of sections of mining companies which bear this title vary substantially from company to company. In many cases, as well as equipment and mining method development for existing operations, responsibility for evaluation of new prospects rests with this part of an organisation.

(a) Salt Lake City - The Anaconda Company

This section of Anaconda is housed in a new prestige building constructed specially for the Mining Research Division and the Western United States Geological Office. There is provision for core storage, mineralogical and petrological laboratories, assay laboratories (chemical and X-ray), metallurgical laboratories (bench scale flotation etc.) and so on, as well as library facilities. It is not yet fully staffed.

The Mining Research Division has responsibilities for new mine evaluation as well as surface and underground equipment and mining method development and testing. Machines are on test at a number of mines and a two year period is regarded as the minimum that will give significant results.

The development with the Unit Rig Manufacturing Company of the Electra-haul truck for the Butte open pits is an example of the kind of work carried out. Some of these trucks are in use at Anaconda's Chucquicamata mine also, as well as by other companies.

Developments thrown up in discussion included the Bucyrus Erie 60R rotary drill which they feel can cope with any drilling condition. It has a much greater capacity than the 50R model which was somewhat limited. The large Dart front end loader (17½ cyd bucket) was mentioned as a substitute for a 6 cyd shovel at 1/3rd to 1/2 the capital cost, but with a much shorter total life.

The question of bench height was also discussed. The use of front end loaders raises the question of whether the present limitations should be accepted without question. Apparently some high bench mines operate in South America - occasional burying of a shovel does not seem to destroy these operators' enthusiasm for this method. Modern blasting techniques such as pre-splitting could make high benches safer.

Liquified natural gas is being considered as a fuel for trucks. 40lb/sq. inch pressure and low temperature is required for storage on the vehicle.

Underground techniques mentioned included the use of raise borers and high pressure (125 lb/sq. inch) air for drilling.

The Division collects information by clipping or copying from journals etc. and building up their own technical files which are quite specific - separate files are kept for particular diesel engines or pieces of equipment, mining methods etc. Journals are covered thoroughly and not kept for long. Brochures, plans and correspondence are also incorporated in these files.

The Director of Research (Richard M. Stewart) usually visits prospects during the exploration stage when it is apparent that a new mine is possible. Data supplied by the geologists is used to work out valuations based on a number of metal price levels. Data on the metallurgy of new mine ores is supplied from the Metallurgical Research Laboratory at Tucson. It is left to management then to decide what to do about any given potential mine in the face of their financial commitments and other prospects. Anaconda has an expansion budget of $70 million annually with the object of increasing copper production from the present level of 600,000 tons per year to 900,000 tons per year by 1972.

Computers are not used to any great extent in the work of the Division at present, but the difficulty seems to lie with the variety of projects, each different, that present themselves. Nevertheless it was noted that several of the more junior members of the Division were absent at a computer school at the time of my visit.

(b) <u>Salt Lake City - Kennecott Copper Corporation</u>

The Mining Research group of this company is located with the Metallurgical Research Section in a building within the University grounds.

As with Anaconda, this group carries out evaluations of new projects as well as mining methods and equipment. They also carry out some applied research in rock mechanics in collaboration with the United States

Bureau of Mines.

Their main research activity in this field has been the slope stability study carried out at Ely in Nevada. An instrumented pit slope has been steepened and the next step is to undercut the wall to failure using a long tunnel coyote blasting technique. For details of this project refer to the paper already listed in Appendix 1. The safe steepening so far carried out has made an additional 3 million tons of ore available.

Other projects have included the study of an instrumented wedge type failure. In this case the pit was cleared shortly before failure occurred on the basis of conclusions reached by a study of microseismic activity using a transducer and counter. Sound velocity contouring of an open pit bench was carried out in the quiet of the recent strike period to determine areas where harder rock would require a different drilling and blasting pattern to that normally employed. The technique is less easy to apply under operating conditions because of the resulting noise.

New equipment is rented from manufacturers and its potential application within the company studied. Some routine work such as layouts and design for new properties is carried out also by this group.

A computer available at the Kennecott Centre is used to do some of the basic data manipulation in new project evaluation, such as reviewing exploration programmes and establishing the statistical accuracy of ore estimates. The head of the group Mr. J. Halls (whose title is Consulting Mining Engineer, Western Research Centre) is preparing a paper on project evaluation techniques used by the group. It is related to Incremental Evaluation; and he hopes to present it to both the IMM and AIME.

(c) White Pine - White Pine Copper Company

The company maintains a very considerable effort in the field of research. This probably stems from original company policy, in that it was a programme of metallurgical research that led to the establishment of the operation in the first place.

In discussion with Mr. L. A. Garfield it was learnt that substantial sums both in capital and wages, salaries and other expenditure were budgeted for research each year by the company. He ascribed the continued successful operation of the company to a forward programme of research to meet the problems that could be foreseen.

At the time of my visit there was a major effort in rock mechanics, in which four engineers and seven technicians were engaged. Other research was being carried out in rock breaking field directed toward a continuous mining process, equipment development in shaft and tunnel boring and mining equipment for low headroom operations, and in metallurgy in the removal of portion of the silver from the copper produced. There is apparently a market for copper with about 12 ozs. silver per ton, but their normal production contains 30 ozs. per ton, and a greater return is possible if the 18 ozs. not required can be recovered and marketed separately.

White Pine's parent company has bought a share of the Dashaveyor

modular transport system and remnants of the trial installation at the crusher site were still to be seen. A full scale system is being constructed to transport 10,000 tons daily on two shifts from the new South Shaft, five miles away. This will follow ground contours between the two sites. Current plans call for a single main track with loading and unloading loops at each end and 4,000 feet of double passing track at the centre of the system. Eight sub-flights of six modules each are to be used in each of two major flights and it is probable that these modules will each be one and a half ton capacity, i.e. larger than the one ton units in the original installation. The new installation, which will be completely covered from the weather, is described at pages 11 and 12 of Mining Engineering for May, 1968.

The research group at White Pine has its own group of miners and others to work out special techniques and carry out the necessary trials demonstrating the success of these techniques to ensure their ready acceptance by operating groups. At present the group makes its own estimates of unit costs in calculating the economics of new equipment or methods. However, an Industrial Engineering group is being set up to establish standards and targets and this information will then be used for estimating purposes.

(d) Sudbury - Falconbridge Nickel Mines Ltd.

The Chief Mine Research Engineer, Mr. J. C. Wilson outlined the major programmes being carried out by the company.

A continuing programme of extensometer and other measurements is in progress at Strathcona (a new mine) and cemented tailings stope fill is being compared to uncemented fill by a series of convergence measurements between the walls of filled stopes.

The research group makes its own estimates of cost benefits of new equipment and techniques using basic data from the Work Study group who manage an extensive incentive system based on the concept of standard hours for particular jobs.

The research group has access to the Falconbridge-McIntyre Library and Information Service in Toronto - apparently run jointly by these two mining groups. The Information Service is a computer based index of useful articles put forward by staff members of the contributing companies. Abstracts and serial numbers are issued in books with supplements for frequent updating. Subject indexes are renewed yearly with four monthly supplements. Author indexes are apparently on the same basis. Some company reports are classified Confidential. The Service can be asked for particular articles by telex and copies are despatched by return mail. The Service seems to be used basically by searching the indexes and then asking for copies of particular articles not contained in the collection of journals held within the group at Falconbridge.

Some equipment development is carried out in conjunction with manufacturers or their representatives. Mr. J. Clark, of Jarvis-Clark of North Bay, called during my visit. His company is the Canadian agent for the Wagner company. With Falconbridge they have developed a hose-reel compressed air operated loader, somewhat similar to the Scooptram, but only 5 feet wide and with a bucket capacity of about 1 ton. The Jarvis Clark Company has also developed an articulated, diesel, four wheel drive, three boom jumbo (under the name "Paramatic") for use as a complement to the Scooptram type of loader, with basically similar characteristics as far as road surface capability and geometry is concerned.

(e) Sudbury - International Nickel Company of Canada Ltd.

Equipment evaluation etc. seems to be managed by the central office. As Inco represents a substantial market, some manufacturers are prepared to produce non standard lines specifically for Inco's requirements as established after a period of evaluation of standard lines. For instance, all their large fleet of Wagner ST4A Scooptrams have heavy duty front axles to suite the heavy sulphide ore.

(f) Elliot Lake - Denison Mines Limited

New equipment evaluation is apparently a function of the Industrial Engineering group at this mine. The system followed is to study the available standard equipment, select the most appropriate and then if necessary co-operate with the manufacturers in the redesign of suggested equipment.

(g) Sheridan Park - International Nickel Company of Canada, Limited

This research establishment is, because of the company's expansion programme, at present more concerned with evaluation of new discoveries than doing much in the way of research and development.

Facilities at the unit are described in the booklet listed in Appendix 1.

The group was originally situated at Copper Cliff and suffered through being too close to operations to escape from involvement in day to day problems. It is subdivided into sections covering geology, ore dressing and mineralogy, and processing by pyro hydro and vapo metallurgical methods. There is also a small product development group, which is particularly aimed at uses for nickel in the mining industry. There is a "miniplant" area suitable only for small scale pilot plant work - there are suitable facilities for larger scale work at Port Colbourne.

Initiation of research projects was discussed with Dr. O'Neill, in charge of the Laboratory. Proposals for projects are considered by the group leaders within the laboratory, and searches of in house and world wide literature made to obtain background information. Following this preliminary examination, Dr. O'Neill and a committee select projects for further work. Progress is reviewed and eventually operating and capital cost estimates for introduction of the processes thus developed are made with assistance from project engineers at Copper Cliff and Port Colbourne.

Dr. O'Neill expressed the view that as the prospect evaluation work permitted, more attention would be given to on line computer control of plants. He felt that a developing lack of interest on the part of plant operators would make this imperative in the longer term.

(h) United States Bureau of Mines, Department of the Interior

An organization chart of the Bureau of Mines was collected at Tiburon, California - see Appendix 1.

Research in Coal, Petroleum, Metallurgy and Mining is carried out under the leadership of four directors, each responsible to the Assistant Director, Minerals Research.

Discussions with Dr. T. Howard, in charge of Mining Research covered the basic philosophy behind the Bureau's involvement in this field. A number of publications (see Appendix 1) give a fuller exposition of his thinking on this matter.

The basic idea was put forward that although in the historic past the primary and overriding consideration in design of mining systems has been maximum profit, population pressures and a growing awareness on the part of the public of a need for increased attention to conservation through wise use of all the values of the land and environment are establishing additional requirements which future mining systems must meet. Lacking the long term profit incentive inherent in forest and agricultural land conservation, mine operators are unlikely to mount research toward meeting the requirements of these future mining systems beyond the extent required to meet regulations imposed to protect the public interest. In these circumstances it is proper for the Government itself to take the lead in this field, bearing in mind that public and mine operator priorities in mining systems requirements will be different.

The whole mining research effort of the Bureau has been based on this thinking. Laboratories in various parts of the country have particular specialties, and all have both scientific and technological groups whose interests overlap, but are intended to prevent the natural bias of the leader of a particular programme from resulting in an unbalanced development of either one aspect in relation to the other.

At Denver, there are two groups, one for ground control rock mechanics and the other for evaluation of deposits and systems engineering - i.e. the grouping of new subsystems into a whole. At Pittsburgh the specialties are environmental studies and materials handling, while at Minneapolis the interest is in rock mechanics from the material disintegration point of view. Spokane is engaged in studies of ground support which overlap to some extent with Denver's ground control. The Marine Minerals Technology Centre also contains science and technology groups, though it is less closely integrated with the conceptual programme outlined above.

The Bureau's approach to mining research then is a long term one. They consider their programme as consisting of work which the average mining company will not consider doing. Anaconda and Kennecott are among the more noteworthy exceptions. Otherwise "research" means short term application work only directed toward cost reduction of traditional methods.

Within the framework of the above philosophy Dr. Howard is convinced that an important breakthrough will not be achieved by research directed toward mining the same tonnages of ore and waste at slightly reduced cost, but by making an attempt to reduce the quantity of waste handled, perhaps by short range geophysics to define ore boundaries before mining, or by some method of continuous selective mining made possible by low profile machines capable of working in hard rock, or even sorting machines operating close to the face. The concept of reduced interference with the original environment of a mineral deposit will lead, Dr. Howard feels, to a return to underground mining.

Urban pressures are leading to more services being placed underground and this in turn is leading to a greater interest in underground openings for purposes other than mining. The increased research effort in this field that will result will no doubt have important benefits in the mining context.

Dr. Howard's 1965 paper also discusses the significance of other Bureau activities in relation to Mining Research. He emphasizes the importance of the Mineral Resource Development Division's studies to permit the establishment of research priorities and the selection of mineral resources for attention so that production should come from deposits which will result in maximum national benefit. He considers that such studies should provide sufficient information about resource characteristics and environments to allow the systems

engineering group to develop models of typical physical, economic and social situations. The Health and Safety Division will, he feels, have a part of play, not only in the synthesis of new and safe subsystems and systems but also in the undertaking of research in safe and healthy conditions.

Within the above broad framework of a Government Research Programme intended to put it ahead of Industry in developing mining systems that will be fully compatible with the public interest, the various Research Centres visited will be discussed in some detail in the following paragraphs.

(i) Tiburon - Marine Minerals Technology Centre

The Centre's programme is oriented toward heavy metals, particularly gold. Last year's cruise by R. V. Virginia City was to Shell Company's offshore prospects in Alaska.

Basically the effort is being concentrated on the evaluation phase, though Mr. M. Criuckshank has done some investigation of potential mining costs. Refer to the paper listed in Appendix 1 for details.

In order to provide an introduction to the offshore environment, provision is made for company nominees to take part in the general programme of the Centre, on payment of a $25,000 annual participation fee.

There are a number of group leaders covering such aspects of the overall programme as evaluation and identification of deposits, drilling systems, mining systems and metallurgy.

A cruise to the Coronado Bank (off San Diego) is intended this year for evaluation of techniques on a phosphorite deposit in 600 feet of water. A second cruise to heavy mineral deposits of the Pacific North West coast is also scheduled.

Drilling techniques tried last year were the Becker (pile-driver type) Drill using driven casing and reverse circulation and the Sonico vibrator, also with a reverse circulation recovery system. The latter equipment is being modified to use a kelly for casing rotation and a wireline corebarrel to recover an in situ sample. Both machines are carried on the Virginia City and used from a retractable A frame and platform.

Problems were encountered in drilling during last year's cruise due to the presence of large stones, and hard and varying materials. Experience indicated that the Sonico drilling system led to losses due to migration of gold particles in the fluidized bed, and that present sampling systems generally led to the samples taken being excessively disturbed. A major addition to the vessel's equipment this year is a system to record all drilling variables as well as a voice commentary by the driller to ensure collection of all relevant data.

The metallurgical group has been responsible for the sample treatment plant which is used to reduce the large volume of material recovered by the drilling systems in use. Final reduction of concentrate was achieved last year by experienced gold panners, and colours weighed on a gimballed balance. The lower deck of the research vessel Virginia City is modified as required for the sample treatment plant and chemical laboratory.

The ship is to continue to use a conventional anchoring system for positioning during drilling. In the Coronado Bank exercise a radar system using 2 shore beacons will give 3 ft. accuracy at 200 miles for vessel location.

The paper collected at this Research Centre is included in the list in Appendix 1.

(j) Denver - Ground Control Rock Mechanics etc.

A number of Bureau of Mines Divisions are located at Denver. There is an administrative group covering the area west of the Mississippi as well as the Rock Mechanics and Systems Engineering Research groups, and elements of the Mineral Resources Development Division and Health and Safety Division.

Some brief discussion was held with officers of the Mineral Resources Development Division. Their work includes field evaluations in Wilderness Areas, collection of statistics either from or on behalf of State Administrations and collection of information by correspondence and personal contact for the Minerals Yearbook.

The work of the Mineral Resources Development Division is assisted by a desk type computer - the Olivetti-Underwood Programma 101. This machine will do calculations such as regression analysis, chi square tests, produce statistical parameters such as variance, correlation co-efficient etc. It costs about $4000. Programmes are stored as plastic cards with magnetic characters. Programmes are put into the machine by passing the appropriate plastic card through a slot and the data by a conventional keyboard. The machine is then put in motion and prints out the answers resulting from the programme that has been put in. The machine will perform the normal reductions of survey data as well as the other jobs listed above and many others of a similar degree of complexity. I believe that AMDEL has such a machine in their Adelaide Laboratories.

The group had a relatively small library and leant upon other libraries within the Denver Federal Centre such as that of the United States Geological Survey. Journals were displayed after circulation to the interested people, and then only selected ones each month. A system of location cards is used to speed up the recall of books previously borrowed outside on inter-library loan. The United States Industrial Arts Index is used for journal items and the U.S. Library of Congress cards for text book indexing. U.S. Bureau of Mines Catalogues of Publications are used as the index to Bureau publications.

As at Tiburon, the Rock Mechanics Research group is divided into Science and Technology sub-groups.

Dr. Panek leads the Technology sub-group and he maintains a programme of stress measurements in mines designed to build up data for design projects in the future. He uses flat jacks and pressure cells, the latter being sometimes used to monitor changes over a period by building up pressure and observing the change with time.

The borehole camera developed was in the process of having its auxiliary equipment rebuilt. The picture data is recorded on tape as well as displayed on a monitor screen - it can be replayed later as required.

An inclinometer has also been developed which provides for continuous logging of a special casing to record movement of ground along the hole as mining progresses. Here the signal is recorded on paper tape.

The Science sub-group is headed by Dr. Duval. His studies include model work using plastics and polarization techniques for which a much cheaper diffused light system has been developed to replace the lens system usually employed.

The laboratories are equipped for triaxial testing, and a new 20 ton

hydraulic press will make creep testing possible. This machine can take samples as big as a cube of 20 inch side. This is big enough to permit insertion of gauges and overcoring etc.

One of the subjects being examined is the effect of top and bottom confining stresses on pillars. This may permit the use of somewhat slimmer pillars than usual with the same degree of safety.

Work has been carried out on surface stresses in dimension stone quarries. The effect of daily temperature variations is apparent to a depth below surface of as much as 5 or 6 feet. Yearly variations are yet to be examined. Surface stresses may vary as much as 1000 to 1500 lb/in^2 with temperature.

A further full scale slope stability test is planned for one of the U.S. Borax Company's open pits. This has such a long face that results will be relatively free of effects from the other sides of the pit - a major defect of the Kimbley study carried out with Kennecott and mentioned above.

Recent work in the use of micro scale rock noise to monitor ground conditions has led to a replacement of humber of events by quantity of energy involved as the criterion studied. This results from consideration of the fact that these events are related to pieces of rock ranging in size from cubes of side one inch to one thousendth of one inch. High frequencies are suppressed within tens of feet of their origin. P and S waves are related and with a number of observation points it is possible to use string diagrams to correlate measured distances and determine the origin of recorded events on the spot in the field.

Papers collected are listed in Appendix 1. Cost data on North Dakota lignite are reported by Van Sant to be as applicable today as in 1959.

(k) Minneapolis - Twin Cities Mining Research Centre

This Laboratory was in a state of flux with a redirection of the programme in the new financial year being planned. The work of the station as a whole is directed toward rock disintegration aspects of rock mechanics, but it also has an "extra-terrestrial resources" programme added. A pamphlet collected covers the various items of equipment and facets of the programme quite adequately. This is a reprint from Engineering and Mining Journal 1968. See Appendix 1.

I was escorted round the laboratories by Mr. Dallaforino who appeared to be the senior technician whose specialty was strain gauges. I gained the impression that in spite of his natural bias the Centre did lean heavily on strain gauges for its instrumentation.

As at other Centres there are separate science and technology sub-groups. One section of the technology sub-group had a responsibility for systems analysis, others covered hydraulic and mechanical fragmentation.

The science sub-group contains sections interested in rock physics, fabric analysis, thermal and electrical properties, chemical fragmentation and

explosive fragmentation.

One of the more interesting pieces of equipment used by the fabric analysis group was a microscope linked to a TV camera which permits analysis of the mineral content by scanning the picture for a given degree of intensity and summing the area as a proportion of the whole field of view.

Sample preparation is carried out by a radial arm drill using diamond core bits selected in co-operation with the Longyear company.

Papers collected at this centre are listed in Appendix 1.

(1) Spokane - Mining Research Laboratory

The work of this laboratory is concerned with ground support aspects of rock mechanics. Unlike the U.S.B.M. research centres the distinction between science and technology is not very clearly drawn.

Programmes are well described in the Open House brochure produced at the end of 1967 and listed in Appendix 1. They include research on rock bolting, including explosive anchors and developments of the shell type anchor.

There is an extensive programme on the consolidation of tailings as fill, including development of a vibrator (about to be used in the field by Hecla Mining Co.) and of electro osmosis techniques which have produced densities of as much as 125 lb/cu.ft. The possibility of developing additives to expand fill in situ so as to pre-stress the fill against compression by the walls is being actively explored. This experimental work has led to development of considerable experience in the soil mechanics testing field as a way of evaluating improvements to fill.

The group has had some experience in determining stress fields underground. In their view the technique of using and interpreting results from end of hole patch type strain gauges is not yet sufficiently developed, and where ground conditions are good enough they use the more conventional U.S.B.M. pattern triaxial gauge with overcoring.

In areas where rocks are under high stress it has taken up to 4 months work to get enough acceptable data to determine the stress field in one location, using the 6 inch overcoring technique. Under such conditions of less competent rock they are developing a much larger scale technique using circumferential instrumentation of a development end, and measuring the change that takes place in increasing the size of the end from say a large bored relief hole, or a post hole cut, up to 3 feet in diameter.

Another interesting line of research is the attempt to estimate artificial support requirements based on a continuous recording of deformation of the rock surrounding a tunnel type opening preceeding during and following its excavation. In the experiments the excavated tunnel is loaded by jacks, hydraulic props etc. to control wall rock deformation, and the loading required compared with that predicted from the initial deformation rate measured as the opening was created.

In the field of actual support of openings by artificial means, the laboratory is playing its part in the development of appropriate sub-systems for Project Badger (an exercise in rapid excavation) and the heavy metals project. Their part in the latter is concerned with mining alluvial gravels in California, for which some form of spiling will almost certainly be required.

Another section within the laboratory has been concerned with the production of a manual for tailings dam construction. As well as collection of data on techniques presently adopted, the research group concerned has explored the possibility of using a computer programme to carry out analysis of tailings dam stability according to Bishop's method. This gives a result in pure number terms - 1 is stable, less than 1 will fail, more than 1 will be stable to a proportionately greater degree. Projects are under way to develop a background of measurements that will provide appropriate number values to include in the analysis for various tailings materials. Modified soil mechanics techniques are being used.

(m) Ottawa - Canadian Department of Energy Mines and Resources

My contact in the Department was Mr. Alexander Tait, who after some years with private industry and the United Nations has now joined the Department to work in a newly created section for international assistance in the minerals field. An organization chart of the Department is included in the pamphlets listed in Appendix 1. Some discussions were held with officers in both the Mineral Resources Branch and the Mines Branch.

The Mineral Resources Branch alone totals about 80 people, of whom 30 would be professional officers. They carry out commodity studies in some detail, have a group for internation aid administration (mentioned above) and are also developing techniques in mineral economics in their special projects group.

Within the Mines Branch, a general discussion was held with its head Dr. Convey. I also had a discussion with Dr. Coates, in charge of the Branch's programme in rock mechanics. He said that the emphasis in their programme was changing from much laboratory testing of rock specimens to work on interpretation of results. This is being carried out by a mathematical approach, starting with the assumption of a simple situation and extending it to a 3 dimensional picture and inserting discontinuities. Some laboratory work will be necessary to provide basic data. This may include velocity measurements.

Dr. Coates feels that much good work can be done with borehole extensometers, dial gauges etc. He also expressed the view that the need to overcore with a 6 inch bit made the U.S.B.M. borehole deformation gauge impossibly expensive on deep holes. He sees no difficulties in making the type of gauge, which permits overcoring with the same diameter bit as that with which the hole is bored (i.e. the patch type), give acceptable results.

Within the Mines Branch generally, political implications lead to a wide spread of work over many commodities and areas. However, work is confined to research into problems, rather than provision of consultative advice, and wherever possible cost-benefit studies are used in selecting projects to be undertaken in the light of the limited resources available.

Dr. Convey mentioned the good relations that exist between the Mines Branch and the Canadian Mining Association. Sponsorship of projects was possible through the Association that couldn't be accepted direct from companies.

A press cutting from the Northern Miner included in the list in the Appendix gives details of the proposed Advisory Council for Research in the Mineral Industries, which is to be established in Canada.

A paper by Dr. Coates prepared in October, 1967 gives some greater detail of the projects undertaken and philosophy behind their selection.

(n) Elliot Lake - Mines Branch Research Laboratories

This group is housed in what was previously a simgle mens' mess at the Nordic Mine at Elliot Lake. There is a staff of about 30, mostly engaged on ground support rock mechanics work.

The main piece of equipment is a 4 million lb. capacity compression testing machine which can be programmed to produce desired stress/strain relations. The machine is coupled to a typewriter to produce a digital output as required.

The laboratory is engaged on work with the 4 wire borehole extensometer, and with patch type strain gauges for overcoring with BX thin wall corebits. Some data on these gauges, developed in South Africa was brought back - see Appendix 1. It is recognised, however, that the U.S.B.M. triaxial gauge with 6 inch diameter overcoring is preferable where conditions are too dirty to permit the cementing of gauges to hole bottoms.

The group studying rock breakage are using two impact breaker type machines. The machine for small particles operates in a vacuum to avoid complication from windage effects. Tough rocks like diabase and limestone seem to absorb large quantities of energy with little further breakage effect on repeated passes through the machine. The reason for this has not yet been explained with any degree of certainty.

Work on dusts has so far been confined to the use of the dust chamber to compare the various dust measuring instruments. The comparison is based on results using 24 different dusts at six different concentrations. The results are still being evaluated, but the general conclusion drawn was that only limited correlation between instruments obtains.

Future work will include an attempt to remove by filtration radon daughter products adsorbed on dusts in Elliot Lake mines. Apparently certain areas can present a real health hazard when left idle at low ventilation flows for any substantial length of time.

The Laboratory has direct remote connection to an IBM1620 computer in Toronto, but only through a keyboard - there is no facility to send data already on punched tape. The Departmental computer is available by mail to Ottawa, and this service takes about 1 week. The isolation of the Centre in Elliot Lake is reduced by the Information Centre presently being developed involving both the Mines Branch Library and the Laboratory. Through

information officers and Telex links it is planned to provide the Department, industry and the universities with access to the latest research information in the relevant fields.

(o) Toronto - The Mining Association of Canada

A general discussion on aspects of Mining Research was held with Dr. W. R. Horn who is the Research Co-ordinator for the Association. He acts as a co-ordinator between various sections of the industry in the broadest sense.

Dr. Horn is a chemist by training and was brought in from outside the industry in order to ensure a fresh and unbiased outlook in this newly created position. He is responsible to and supported by a sub-committee of the Mining Association, most of whom are at "Chairman of the Board" level. There is a second committee of alternates to the above sub-committee whose members are at a "Vice President in Charge of Research and Development" level. In addition there is an advisory committee for each of the following fields: materials handling; rock breaking; ground support. These are called together as required. Other committees to cover other fields may be set up.

Broadly speaking, the task of the Research Co-ordinator as set out by his top level committee is to upgrade the technical competence of the mining industry. Activity by the Co-ordinator in metallurgical research is developing slowly, but as research in this field is generally on a fairly sound basis there is not the same urgent need for action as in mining.

Dr. Horn produces a technical bulletin on recent developments, based on information supplied by the Engineering Index abstracting service in the United States.

Like Dr. Howard of the U.S. Bureau of Mines, Dr. Horn thinks that a major breakthrough is required in the field of rock excavation. The use of mechanical tunneling machines is a step in this direction, and in line with the view that Dr. Horn expressed to the effect that energy was the one resource with which we could afford to be prodigal. He feels that too much emphasis in the past has been placed on reducing energy requirements in mining to a minimum. Dr. Horn referred to the recent successful Symposium on Tunneling; and to the extent to which underground excavation for construction purposes is going to increase in the near future, with the side effect of providing funds for research in related fields which will be of benefit to mining. Another view expressed by Dr. Horn was that transportation of broken rock might soon be a bottleneck in view of the progress being made with rock breaking techniques.

In the field of co-operation with equipment manufacturers, Dr. Horn said that he felt that there was room for very worth while progress here. He mentioned the North East (of the United States) Maintenance Association dialogues which are intended to ventilate the users' experience in maintaining equipment supplied by electrical equipment manufacturers, and to thus contribute to the design of improved equipment by removing "bugs" and servicing difficulties. By such dialogues it should be possible to give mining machinery manufacturers the confidence to develop new and more satisfactory designs in the knowledge that these were in line with what industry wanted.

As regards the more basic kind of research project, Dr. Horn felt that these should be carried out by the universities. Rock breaking; ground support and systems research and development should be carried out as well as the environmental studies so favoured by Professor F. T. M. White. Eventually he hopes that a National Mining Research Institute will develop along the lines of the Pulp and Paper Research Institute at Montreal. In such an Institute (following the suggested pattern) Industry, Government and the Universities would have a voice in the management of research and its funding. University staff could work part time in the Institute and higher degrees could be obtained from appropriate research projects carried out within it.

A pamphlet obtained from Dr. Horn is included in the list in Appendix 1.

SUMMARY - MINING RESEARCH

The United States Bureau of Mines has an imaginative programme designed to put the Government in a position to evolve the new technology necessary to cope with future conflicting interests in the exploitation of mineral resources. With some notable exceptions such as Kennecott, Anaconda and White Pine, companies in the United States seem content to continue with a less imaginative kind of programme, designed to get the most out of conventional equipment or that evolved by American or overseas manufacturers.

In Canada, the Government plays a less active role in research, but still makes some valuable contributions to the sum of useful knowledge. The Industry, through its creation of a position of Research Co-ordinator of the Mining Association of Canada, has shown that it is aware of the potential of an active and co-ordinated programme to assist in meeting the challenges of the future. Individual companies, as in the United States continue to direct their attention to equipment evaluation and improvement and the adaption of new techniques to their own requirements. The need for increased production from known substantial resources creates a unique condition for useful research in the Sudbury Basin nickel mining area, and will probably also do so in the Elliot Lake area in the future.

METALLURGICAL RESEARCH AND ASPECTS OF THE TOUR

To an extent this is covered already by the various sections describing visits to mines where mills and smelters were also visited, and visits to some of the metallurgical research centres. Some of the more important or unusual aspects are discussed in the following paragraphs.

(a) Ray and Hayden - Kennecott Copper Corporation

The mill at present uses a leach, precipitation and flotation (LPF) process to deal with refractory ore. Sponge iron produced in Bruckner kilns is used for the precipitation. This process will be superceded by a plant using a sulphuric acid leach of the ore containing chrysocolla followed by electro-winning.

The Hayden smelter is fairly conventional. Mechanical tuyere punching is used in their converters. Propane gas is used instead of green tree trunks for "poling". Oxygen has been used in the smelting process, but with mixed

success due to the high cost of oxygen brought from Los Angeles by truck and difficulties in dealing with the high iron slag thus produced which is not suitable for retreatment in the relatively inflexible reverberatory furnace system that their limited scale of operation provides.

The sponge iron plant uses a fluosolids reactor to roast pyrite concentrate. The resulting iron oxide is mixed with coal and processed in a counter current gas fired rotary kiln. Unless conditions are rigidly controlled, balls build up (3ft. diameter!) and some ringing develops at the burner end. The kiln must be shut down to remove balls using a chain net basket. There is much leakage of fine iron oxide; it is a most unpleasant plant to work in and all concerned will be glad when it is finally shut down. It is interesting to note that calcium sulphids is used in the LPF circuit at Morenci. I did not see this part of the Morenci plant, however, so could not compare the two.

(b) Douglas - Phelps Dodge Corporation

The smelter at Douglas, as well as concentrates from Phelps Dodge's Arizona mines also treats direct shipping ore (3-5% Cu) from Bisbee, cement copper from various sources, small quantities of other direct shipping ore and Pima mine copper concentrates. Scrap copper from the West Coast and as far east as the Mississippi is also treated. Practically all this material arrives by rail.

Sample splitters in the various transfer systems provide for determination of head values of various batches of material. Cement copper is handled separately because it is so wet, and is usually trucked direct to the bedding area by small motor truck.

Because of the variety of feed sources, an extensive system provides for making 8 beds by the usual process of an overhead conveyor belt dumping system and a full face recovery system using a plough. Smelter feed averages 12% copper.

Because of its high sulphur content the material from beds goes to Herreshof furnaces, and thence to the three reverberatory furnaces that are in operation. One is being rebuilt with a basic suspended arch in lieu of the earlier design incorporating a sprung silica brick arch.

There is no recovery of SO_2 and for this reason, production has to be cut during the critical 8 weeks of the vegetable growing season in the irrigated areas of the nearby Hot Sulphur Springs Valley. Only 2 furnaces are used on day and afternoon shift and one on night shift at this time. Even so rain or dew can serve to carry down SO_2 and damage crops under certain atmospheric conditions.

A small sponge iron plant is in operation to produce precipitant for the copper leaching system at Bisbee. Converter slag made by blowing matte without additional fluxes is granluated and stored. It is then fed as required into a rotary kiln for preheating and then into a fluid bed type reactor where reformed natural gas produced in an adjacent generator reacts with the slag to give a product containing 56% metallic iron and 6% copper. Difficulties are usually traced to too long a retention time in the reactor

which results in slagging and channelling. Plant capacity is quite small - possibly 1 ton per hour.

Reformed natural gas is used instead of green poles for refining purposes in the smelter anode casting furnaces.

(c) Bisbee - Phelps Dodge Corporation

The leaching and precipitation system here is made more difficult than usual by the high pyrite content of the ore. The plant consists of a series of concrete vats and launders serviced by a mobile crane on rubber tyres.

Coarse scrap (old car bodies etc) at $15 to $20 per ton is used in the first 4 vats and is consumed largely in the ferrous-ferric reaction in rich solution. The sponge iron produced at Douglas is used in the next part of the system, consisting of V shaped launders with provision for agitation by compressed air. At intervals the air is turned off, remaining coarse particles flushed out and the launder recharged and returned to the circuit. The remainder of the vats are charged with fine scrap such as baling wire from valley farms or shredded tin cans (the latter at $53 per ton). Vats are flushed at invernals via launders to the drainage floor where the cement copper is dried for shipment to Douglas.

(d) Bingham Canyon - Utah Copper Division of Kennecott

The extensive dump leaching system here has been modernized to increase production in recent years. Little trouble is taken with dump construction apart from the segregation of limestone.

Both sets of company designed cone precipitators are now used as primary units. Some copper is recovered from the base of the cones, the rest from the thickener underflow. These two products are combined and dewatered on leaf filters before being discharged to a conveyor belt for shed storage or direct loading.

Thickener overflow is pumped back to the various dumps where it is supplemented by melting snow in spring and early summer. The strength of solution seems little affected by the use of fresh water or recirculated solution, or by the number of times it is recirculated as was discovered during the recent 8 month strike.

The steel plant at Provo, Utah, provides steel scrap (shredded cans) at $55 per ton from a nearby preparation plant. Scrap is handled from rail trucks by crane and conveyor belt to the cones which are of wood stave and stainless steel construction. Pregnant solution enters at 150 lb/in^2 at the bottom of the cones, and 2 tons scrap are needed for 1 ton of precipitates.

(e) Magna - Utah Copper Division - Kennecott

The recent expansion has been achieved by building a new crushing and grinding mill (Bonneville) with a capacity of 28,000 tons per day. Pulp gravitates to the Magna and Arthur mills for flotation with pulp from

crushing and grinding circuits at these mills. The ore milled in these three plants totals 108,000 tons per day. A general flotation concentrate is made first and the molybdenite separated by flotation after roasting at 500°F to destroy reagents and tarnish copper mineral surfaces to oxides.

At the smelter three reverberatory furnaces are fed direct with green concentrates and flux, and the resulting matte blown in converters, 1 of which is used as a holding furnace. The refining step known as "poling" is still carried out in the anode furnaces using green trees. Propane gas has been tried but leads to excessive quantities of black smoke being made. There are difficulties with patent rights in using reformed gas, so plain natural gas is being tried with some success.

The use of oxygen is an established practice and the Lindhe company is currently installing a tonnage oxygen plant to supply the smelter's requirements. Until the recent expansion programme called for increased throughput, smelter staff were not keen on the use of oxygen. As well as increased capacity, (by smelting increased quantities of concentrates in the converters) the use of oxygen gives an off gas richer in SO_2 and results in higher recovery in sulphuric acid with less atmospheric pollution. When a concentrate handling system is installed to make full use of the converters' capacity to handle concentrate it is expected that only two reverberatory furnaces will need to be kept in operation.

(f) Eagle Mountain - Kaiser Steel Corporation

The main feature of this plant is the existence of two blending piles which take the strain out of selective mining and permit maximum advantage being taken of the economies possible with big equipment. Campaigns of a week's duration are run on high (>0.4%) and low sulphur ore. There is a separate blending pile for each type. About 60% of plant feed reports as concentrate.

Magnetic concentrators are used to produce pellet plant feed. Gravity concentrating methods (jigs and heavy media) are used to produce lower grade non-magnetic concentrates for Kaiser Steel's plant at Fontana. Some tailings from magnetic separators are also of high enough grade for this purpose. Some of the gravity plant product used as ore contains as little as 53% iron with 3 to 6% sulphur.

The pellet plant produces essentially for the Japanese market. Sulphur not removed during concentration is burnt out during the hardening process. Bentonite is added to the concentrate ground to 65% - 400 mesh to obtain adequate ball structure and the pellets hardened on a travelling grate, gas fired, with a capacity of 400 tons/hour. After cooling the pellets are screened, and off size pellets that fail to meet the Japanese contract specifications are sent to Fontana.

(g) Shawville, Quebec - Hilton Mines Ltd.

After cobbing at a relatively coarse size, ore is further crushed and ground to 90% - 325 mesh before further wet magnetic separation. Concentrate is balled in drums after adding bentonite.

Shaft furnaces consume about 640,000 BTU per ton of pellets, have an area of 7 feet by 14 feet with a residence time of 4 hours and capacity of 55 ton/hour. The fuel oil is burnt in combustion chambers on either side of the furnace.

A feature of the operation is the apparently substantial quantities of fired pellets that are recirculated to "control excessive reaction in the furnace". This practice may explain the apparently high fuel consumption of the shaft furnaces of this plant.

The pellets are screened to assure a constant size range in the pellets shipped. Offsize pellets are reground and recirculated.

A number of instruments and automatic controls aimed at producing a better pellet are being installed by the Ramsey Electronics Company. One of these systems is concerned with maintaining a closer control over the water addition to ball mills.

(h) Eveleth - Eveleth Taconite Company

This is a small operation in which the Allis - Chalmers grate-kiln process is used for hardening pellets. Provision has been made to double production with a minimum of trouble and expense.

Little difficulty has been experienced with the concentrating section. Kiln linings have not lasted as well as expected due to unforeseen cold/hot/cold cycling. An 8 day shutdown every 4 months seems enough for the necessary kiln and other pellet plant maintenance. The counter current gas fired kiln requires 750,000 BTU per ton of pellets. Ring formation within the kiln appears accentuated by poor pellets producing excessive dust. A gun using 8ga. shotgun shells and special pellets is used to break up rings.

(i) Hoyt Lakes - Erie Mining Company

The milling process at Erie is fairly conventional, the main item of interest being a system of upgrading concentrates by screening out +325 mesh material using mechanically rapped screens and regrinding and concentrating this material. The process is worth an additional 7 to 10% in grade or production.

The whole operation of the mill is controlled by 1 operator per shift with a few attendants. It is fully automated and remotely controlled. A Honeywell H610 computer accumulates shift tonnages etc. and generally handles all the necessary data acquisition. It also prints out additional data where values are beyond selected limits and indicate an "out of control" condition. There are 36 parallel lines of rod mills, ball mills and concentrators.

Pellet hardening is by shaft furnace. Fuel consumption is much lower than the grate-kiln system (only 450-500,000 BTU/ton pellets), but furnace operation is much more sensitive. They have 27 units for a 10 million ton annual production; 1 or 2 of these are always out for repairs. There is much more materials handling equipment and a significantly larger number of operators than in a grate kiln plant of similar capacity.

(j) Ishpeming, Michigan - Cleveland Cliffs Iron Ore Company

The Empire mine is a relatively new operation. The magnetic taconite ore is very abrasive and only development of autogenous grinding made it possible to reduce the grinding cost sufficiently for it to be economically attractive.

There are 16 lines of Hardinge Cascade Mills and pebble mills grinding to 95% - 500 mesh before magnetic separation. Concentrates are pelletized with the addition of 14lb/ton bentonite and hardened in 2 Allis - Chalmers grate-kiln units consuming 600-700,000 BTU as natural gas per ton of pellets. This fuel produces less tendency to ring than fuel oil.

The Republic plant operates on a non-magnetic taconite feed. After initial grinding and flotation of a hematite concentrate, this concentrate is reground and gangue silica is removed by a hot flotation process. The final concentrate must be ground finer for pelletizing.

As at Empire, the grate-kiln process is in use, but there appeared to be much greater crusting in the kiln than at Empire.

There is a pilot plant installation near the Pioneer Mine in the Palmer area. This is large enough to operate at 10 tons per hour. Runs on Robe River ore had just been completed and the plant was being reconstructed to do trials of ore from the Tilden mine area, which will be Cliffs' next development in Michigan.

The pilot plant equipment includes an 18 ft. diameter balling disk, a full size balling drum and a half ton/hour model of the grate-kiln system itself built by Allis-Chalmers. There is ore dressing equipment also, capable of being arranged for half ton/hour as well as the larger scale 10 tons/hour plant. Autogenous grinding equipment of appropriate size is available within the plant.

In Ishpeming itself, Cleveland Cliffs maintains a Metallurgical Research Centre under Mr. E. W. Lindroos. The laboratories are equipped for bench scale tests of flotation, grinding, magnetic separation (Davis Tube) and for pellet testing both at room and elevated temperatures. A controllable atmosphere pot furnace is also available for small scale pelletizing tests.

There is appropriate supporting staff in chemical analysis and mineralogy with the necessary equipment.

A number of students are employed in summer to replace technicians on leave. Where possible students in technical courses work on specific projects under direction so that they can do a worth while project and bring it to a conclusion while at the laboratory.

The work carried out by the laboratory produces process specifications and estimates of operating costs (reagents, power etc.) for new projects. The project engineering staff do estimates of actual capital costs. The final design and construction of new plant is usually let out on contract and operating personnel are brought in toward the end of the construction phase so as to be ready for start-up.

(k) Kirkland Lake - Jones & Laughlin Mining Company

The mill is a fairly conventional magnetic operation, with cobbing at coarse size to remove waste and wall rock dilution, followed by crushing, grinding and magnetic separation. As a final step (added recently) silica is removed from the concentrate by flotation to produce a concentrate containing 66% Fe and 6% SiO_2, sized 93% - 325 mesh and fine enough to pelletize when 18 lb/ton of bentonite has been added.

The mill has a central control room; but is not automated. Some density gauges etc. are included to aid the operators in maintaining control. Extensive use of Linatex rubber is made to combat abrasion on magnetic separator drums, pipe bends etc.

As a means of securing better blending of the feed to the pellet plant grate, the bentonite-concentrate mixture is circulated through storage bins before finally being sent to the balling drum. In spite of some build up, the operators of this plant have continued the use of the magnetic tail pulley on the belt feeding the grate. This is considered to be of value in laying green pellets on the grate as gently as possible to minimize damage.

There has been little difficulty with kiln refractories except at the discharge end. Damage here has resulted in bricks being replaced by castable refractories, and the area is now adequately maintained by the use of a refractory gun as required. Some considerable growth of rings etc. is tolerated within the kiln, and it is found that these generally fall off as a result of cooling when the kiln is shut down for weekly maintenance. No use is made of a gun to shoot off ring formations. Some difficulties are encountered in the rotary cooler due to hot and cold cycling inherent in its design. The cast refractory presently in use will be replaced by bricks, and this is expected to make adequate provision for expansion and contraction and eliminate further trouble.

Chips screened from the cooled pellets are shipped separately and used as sinter plant feed.

It was interesting to note that although it was possible to operate gates at the railway truck loading bin in the automatic mode, experience had shown that manual operation was quicker, and resulted in less wear and tear on the gates which opened and shut rapidly as the specified weight was approached when in automatic mode.

(l) Sudbury - International Nickel Company of Canada

Ore for the concentrator arrives from outside mines in railway trucks and some attempt at blending is made in the truck tipping sequence. Total Sudbury area ore-dressing capacity is 80,000 tons per day including outlying mills at Levack and Frood-Stobie which produce bulk concentrates only. These are railed to the main plant at Copper Cliff for further processing.

Pyrrhotite is removed by electromagnetic separators and copper concentrates are made by flotation. The aim is to keep thses two products clean. The nickel flotation concentrate is made last and has iron and copper

impurities present to a much greater degree. Copper concentrate is smelted to blister copper in a conventional smelter using Herroshof furnaces for a partial roast. These furnaces are being replaced by fluid bed reactors. Oxygen enriched air is employed. Blister copper is moved in hot metal cars to the electrolytic refinery where it is poled (using green trees rather than gas for this step) and cast into anodes for refining.

The pyrrhotite concentrates go through an ammonia leach process before being pelletized.

The nickel concentrate is smelted to produce a matte of stoichiometric composition for the nickel and copper, and then poured into moulds to cool slowly over about 4 days. Segregation of the copper and nickel sulphides takes place; gangue material collects at grain boundaries. The whole is crushed and subjected to a conventional ore dressing flotation process. Copper sulphide goes back into the copper smelter converters while nickel sulphide is roasted in a fluid bed reactor to produce 75% or 90% nickel oxide for sale or further processing at either Port Colbourne or England. Other impurities eventually finish up in the copper refinery.

A Philips 1212 X-ray fluorescence unit is used for routine copper and nickel determinations and for scanning drill core samples to determine whether wet assays are required.

The operators claim that the disc pelletizer used on the final nickel sulphide product is better than a drum in that any cycling can be picked up and controlled more rapidly. This is partly because the whole process is clearly visible.

The smelter complex uses about 1200 tons/day of oxygen, made on site by Canadian Industries Limited. The result of its use has been to increase roasting capacity (2 fluid bed roasters with oxygen equal 6 Herreshof furnaces without) and also to produce a gas richer in SO_2 which can be used for acid making, thus reducing atmospheric pollution. As much acid is made as the Northern Ontario market can absorb, for this reason. Most of the area about Copper Cliff and Sudbury is bare of vegetation because after damage by past emissions it has not been able to regenerate under prevailing climatic conditions. There is much bare rock, even in unaffected areas, and the soil cover appears thin. Recent domestic plantings are even now damaged occasionally by fumes and the company is obliged to pay compensation for this.

At the iron plant, pyrrhotite is roasted in fluid bed reactors and then changed to magnetite in a rotary kiln. Off gases are used for acid manufacture or diluted and discharged. Canadian Industries Limited operate all the acid plants associated with the International Nickel Company's smelter.

The kiln product is leached with ammonium carbonate to remove nickel and copper. These two are separated by precipitating the copper as sulphide and this is returned to the copper smelter. The nickel-ammonium complex remaining in solution is decomposed. Nickel oxide produced at this stage is highly reactive and suitable for making other nickel salts.

The remaining iron oxide, now sized at 90% - 325 mesh is combined with 10lb/ton bentonite and balled and fired on a travelling grate. It is

intended to add the same amount of lime in the near future with a view to obtaining better pellet structure. Pellets contain 67-68% iron, but also 0.15% nickel and this is sufficient to limit the market for the material.

Pellets are screened after cooling, the oversize being used for side and hearth layers on the grate, the undersize being reground. Normally 80% of the pellets made fall in the range of $+\frac{1}{4}$ inch $-\frac{3}{8}$ inch.

The main effect of the iron plant installation has been to allow greater copper and nickel production at Copper Cliff itself, as the largest part of the burden of iron which was previously slagged in the smelter has been removed by the ore dressing processes outlined above.

(m) Sudbury Area - Falconbridge Nickel Mines Ltd.

The mill at Falconbridge dates from the mid nineteen-thirties, and some additional equipment has been added to increase capacity. After grinding to 60% - 200 mesh, copper and nickel sulphides are recovered in one concentrate by flotation, and pyrrhotite in another. The latter is reground to 90% - 325 mesh, and refloated to produce a further copper-nickel sulphide concentrate and a pyrrhotite concentrate. After cleaning on drum and belt type electromagnetic separators the pyrrhotite goes to a fluid bed roasting plant. The resulting iron oxide is pelletized for use in iron blast furnaces.

The copper-nickel sulphide concentrates are mixed with concentrates from mills at other mines such as Strathcona near Levack and sintered with fluxes, reverts, flue dust, etc. This sinter is charged hot into blast furnaces; the resulting matte is blown to white metal and run into moulds. This material is sent to Norway for further processing.

A new iron plant is under construction. This is to produce not pellets but a sponge containing 90% iron and 1.15% nickel which it is expected will command a better market than the pellets currently produced.

The smelter does not seem to have been subject to much modernization. No SO_2 is recovered, nor is there any use of tonnage oxygen. Some changes may be required to cope with additional production from Strathcona mine which will increase production from 70 million to 100 million pounds of nickel annually.

At Strathcona the new mill is operating and being worked up to the ultimate level of real time computer control. At present only the read-out analogue system is in use and this is not yet completely reliable. The mill is operating under manual centralized control.

Signals in the form of current from the various transducers are put across resistances and the voltage drops measured are taken as the input to the computer system. This has the advantage that there is no interference with the usual visual display system while the computer system is being worked up. At the time of my visit every 5 minutes there was a printout of variables in both the parallel (A and B) circuits. X-ray fluorescence is to be used to monitor 15 different product streams. Previous research work at the nearby Hardy concentrator has solved the problems of this part of the system and it is expected to be operating in a few months. Magnetic flow and gamma density

gauges are being used to measure quantities flowing. Grinding mill sound will also be monitored.

Pebble mills are used in the circuit, and the grinding section is separated from the flotation section by the control room area. A remote TV link permits observation of the secondary crushing system grizzly from within the control room.

(n) Elliot Lake - Denison Mines Ltd.

Although time did not permit a mill inspection it was possible to discuss their underground uranium leaching programme. The company is now recovering yttrium by ion exchange in addition to its normal uranium recovery.

Leaching is limited because the mine pumping system has little additional capacity beyond the water that the mine is already making. Only an additional 100 gals. per minute can be added.

It was originally discovered that the mine water was corrosively acid, then that it had uranium in it and finally that bacteria were responsible for the accelerated leaching of uranium.

Current practice is to use garden sprinklers to spray at 5 gals/minute for one shift, using about 5 locations to cover a stope. In order to prevent damage to rockbolts, sprinklers are so adjusted as to not wet the back. Recycling is practiced, depending on the grade of solution coming out. The pH decreases from 8 to 2 as the fresh water travels through the stope. Water finally drains to the sump which itself is an old stoping area and takes a little more uranium into solution here. On pumping to the surface, the water is fed into the milling system at the crushers. 15-20,000 lb. of U_3O_8 are recovered each month by this means.

Nutrient solutions are not apparently effective. Rubber hoses are left in stopes between cycles. Some areas of the mine have been blocked off with bulkheads and are not accessible - others have a poor ventilating current and because of high radioactivity masks must be worn. A crew of 4 men working one shift operate the leaching system.

(o) Kellogg - Bunker Hill Company

Time did not permit a visit to the mill, but the smelter was visited briefly.

The superintendent, Mr. Kroll, had visited Port Pirie, and some practices developed there were in use at Bunker Hill. Some Port Pirie metallurgists had been at Bunker Hill to observe operations of their zinc recovery plant prior to construction of the slag fuming plant at Port Pirie.

Smelter feed came from 57 different sources last year, including Australia. There are storage bins for most of the differing materials in stock at any given time. From these a calculation (on the basis of slag composition) is made of the blend likely to get the optimum result from the available raw material. A bedding floor is available to take 4 x 800 ton

piles, and these are built by adding the appropriate quantities of material via a conveyor belt and tripper. After sampling, any correcting quantities required are added, and the system moves on to build the next pile.

The reclaimer with its harrows and ploughs is mounted on a monorail and takes the full face of the piles in sequence. The material is then sintered.

The blast furnaces are fed with coke and sinter transferred by conveyor belt - only occasional major surges are encountered as a result of feeding in this unusual way.

Pure silver and silver bullion containing gold are made from zinc crusts produced during the Parkes Process for recovery of precious metals. Final dezincing of the lead bullion follows the normal Port Pirie vacuum process.

The smelter also produces leaded and deleaded zinc oxide from the slag fuming process, antimonial lead, crude cadmium sponge and zinc sulphate.

(p) College Park - Metallurgy Research Centre

This was the only Bureau of Mines Metallurgy Research Centre visited. I met Mr. C. Rampacek in charge of the Centre and had discussions with his project co-ordinators.

Mr. Munson has charge of a programme in electrostatic and electromagnetic separation. Work on wet magnetic separation is concerned with changing the shape of various pieces of the separator. He feels that more of the potential of magnetic separation may be realized when the improvement obtained by pre-exposure of particles to high intensity flux for a few seconds before being placed in the gradient of the separating field is explored.

Mr. Munson also has charge of the bacterial leaching programme of Dr. Ezekiel and of another group who are responsible for estimating process costs. They obtain their data from equipment manufacturers, exchanges with operators, published information, with wage rates obtained from the Department of Labour and Industry and power and water rates from the appropriate utility companies.

Dr. Campbell has a group working on broadening the scope of the X-ray spectroscope to take in the lighter elements. They are also developing "down-the-hole" and surface scanners, with the object of ultimately covering all the elements. More sensitive detectors and better neutron sources (californium 238 for example) are being evaluated in connection with this programme. The group works in conjunction with Hazen's section of the Systems group (in Denver) who are concerned with deposit evaluation.

Dr. Moss' group is to work in the field of surface chemistry - they are changing over from an investigation of yttrium as a semi conductor. They plan to carry out chemical bond studies (relevant to flotation collectors) and are also working on theoretical aspects of the packing of spheres, extending from predictions based on the geometry of the packing to consider the effects

of different forces and varying shapes. The techniques to be used for bonding studies include total internal reflection, infra red studies of vibrations at the ends of long chain molecules, etc.

Mr. Schlain leads a group engaged in studies related to plating and corrosion. Provision exists to carry out basic work in an inert atmosphere, and to evaluate electrode raw materials such as lignite in a Hall-Heroult cell. Work in progress includes testing of porosity and adhesion of deposits, and the study of decomposition products on the surface of the deposits. Activities which have been going on for some time in the more conventional fields of immersion studies, potential studies in various solutions and bimetallic systems in air as well as inert atmospheres are to be continued.

Mr. Caldwell leads a group concerned with the recycling of material, particularly scrap. Generally speaking automobile engine blocks go to Japan. Body scrap is used in the United States but the copper content limits the amount that can be accepted by any one plant. A sodium sulphate + carbon treatment has been developed for body scrap to eliminate copper and recover it as a sulphide matte. Tin is not removed by this process. Another problem being examined is the separation of aluminium tops from tin can bodies in de-tinning plant feed, as the aluminium not only consumes large quantities of sodium hydroxide but also produces too vigorous a reaction in the bath. Other work includes the removel of antimony from lead battery scrap etc.

About four miles away there is another laboratory where a programme of recovery of values from domestic hard wastes is being undertaken. Only domestic refuse incinerators with rotary kilns achieve complete burnout. Chain grate machines leave considerable unburnt material. The programme has applied normal ore dressing techniques to this material for the recovery of tin cans, coarse iron, fine iron and mill scale, glass and non ferrous metals. A process separating clear from coloured glass could produce a high grade feed replacing cullett and also a feed for glass wool production. There is an immediate local problem in that Washington D.C. is running out of space for garbage dumping and development of an acceptable alternative is urgent.

Pamphlets received in the course of this visit are listed in Appendix 1.

GENERALIZATION ON METALLURGY

Metallurgical research groups operated by the larger companies seem to be oriented toward carrying out the necessary technical evaluations required in the assessment and development for production of new properties. Elsewhere, the problems of getting greater capacity from existing installations and to a lesser extent atmospheric pollution problems have been the major influences on research that has been carried out. There seems little basic research at all being carried out by the companies themselves.

I suspect that there may be more of this kind of research sponsored directly or indirectly by companies and carried out at Universities and Research Institutes such as Battelle.

However, possibly the major basic research appears to be carried out by the United States Bureau of Mines and its Canadian counterpart in the Department of Energy Mines and Resources. Probably the Canadian work is more

directed toward lowering costs in Canadian Industry, while the U.S.B.M. has in its long term objective an element strongly directed toward reducing atmospheric pollution, and generally having in mind the needs of all sections of the community, not just the plant operators.

SAFETY IN LABORATORIES

As the opportunity offered, enquiries were made regarding the operation of Laboratory Safety Committees or their equivalents.

At Kennecott's Research Centre in Salt Lake City bench and small pilot scale ore dressing facilities are available, together with bench scale pyrometallurgical equipment and supporting analytical facilities. The Safety Committee here consists of the Building Supervisor, the Assistant Superintendent (Metallurgy) and the Chemist. All new staff members receive an appropriate briefing on joining the Centre.

At Cominco's Laboratory at Sheridan Park, the work carried out is mainly in secondary metallurgy of lead and zinc. There is a Safety Committee which includes the Building Supervisor and the Chief of the Office Staff which carries out monthly inspections. The responsibility however, rests on a Safety Officer who has had wide experience in the field covered by the Laboratory. The Building Supervisor has apparently some useful experience at the technical level and has available the services of one of the suitably qualified members of the staff as Building Engineer for more complex problems.

New staff are briefed on safety matters by the Building Supervisor in the course of an introductory tour of the building. All machines have safety rules and operating instructions posted on them and may not be operated by unauthorized (i.e. untrained) persons.

Experience in the Laboratory to date has been that most injuries are due to cuts and burns. Safety spectacles must be worn in the laboratory and workshop areas by all employees. Accidents related to equipment have been limited to floodings relating to hose failures and inadvertent operation of safety showers. The main hazard is felt to be in location of electroplating baths in an upper floor laboratory.

International Nickel's Laboratory at Sheridan Park was designed by the architects in conjunction with a laboratory design consultant from the United States. However, the following faults have become apparent.

(a) Not all sinks have independent traps.

(b) There is some recapture of exhaust air by other air intakes.

Safety showers have been provided at most laboratory doorways with the rose fitting flush with the ceiling and a chain pull alongside to set them off. However, there was no provision to deal with the water from these showers, and few of the operations observed suggested any need for them.

The responsibility for safety rests with the leaders of the various groups, who are expected to have short group discussions (maximum duration 10 minutes) on safety topics from time to time.

Probably the major hazard lies in vapometallurgical work on carbonyls, and provision is made for emergency operation of the fume extracting system from this particular laboratory in the event of failure of the normal power supply. Safety spectacles are normally worn in all laboratories and other protective equipment as required.

In the Denver Mining Research Centre there is a safety committee of expert and non expert members who make periodic inspections.

At the College Park, Maryland, Metallurgical Research Centre there is a Committee which makes a monthly inspection of all laboratories and submits a written report (a sample copy was obtained - see Appendix 1) to the Research Director. It is up to individual supervisors to correct unsafe conditions. A copy of the Bureau of Mines Employees Accident Prevention Handbook was also obtained at this centre. New employees receive two days indoctrination which includes aspects of safe working practice. The Handbook mentioned above expressly requires the establishment of safety committees in Bureau of Mines establishments and states that their function should be to serve as advisory boards to assist overall conduct of the safety programme.

OFFICE OF MINERALS EXPLORATION - U.S.G.S.

This is attached to the United States Geological Survey rather than the Bureau of Mines, and the officer in charge, Mr. Frank Johnston, has been associated with this programme for many years.

A set of documents, including the Annual Report to June 30th, 1967 was obtained - refer to Appendix 1. The programme is at present restricted to a maximum contract of $250,000, and is allocated approximately $1 million per year. Most projects are now small and there has been little recent success with these. Earlier larger scale projects were more successful, and a ratio of $42 worth of ore for $1 spent is claimed, though there is doubt as to whether all the ore making up the $42 total would be recoverable under current economic conditions.

Larger companies are not really any longer eligible, but some small operators finance their share in participating projects with funds made available by larger companies in exchange for option agreements.

Not many banks will give finance for this sort of work. Johnston says the reference to bank refusal in the application form refers to days of the post war Reconstruction Finance Corporation when bankers claimed R.F.C. was taking potential clients away from them.

It is Mr. Johnston's view that few if any prospects were left undeveloped to avoid royalty by postponing the date of production commencement. Most of the applications are currently for gold, silver, copper, mercury and platinum. There is also one nickel prospect (in Maine). Work directed toward production such as preparation for stoping, proving ore reserves, and excavation of large, production-sized shafts and adits is generally excluded.

In general the O.M.E. may require submission of financial statements to indicate that applicants don't have reserves put away that could be used in

financing the exploration in question. However, the Office does not require capital used in a business to be committed where failure of a programme would lead to loss of a means of earning a living, or a home etc. Generally similar conditions apply where companies are concerned.

GENERAL CONCLUSIONS FROM TOUR

Summaries having been incorporated in the various sections of the report, it is unnecessary to repeat them all again here. However it is appropriate to list for emphasis some of the more important points as follows:

(a) Australian mining companies seem to be well up with their American and Canadian counterparts in adopting newly developed equipment and techniques for use in Australian mines. Possibly the one and inevitable disadvantage is that the design and development sections of the major equipment manufacturers are not so directly available to them for consultation on equipment modification and development.

(b) In research, the very positive approach of the United States Government and its commitment to the idea of being ahead of industry in the technology required to ensure that maximum public benefit is obtained from that country's mineral resources is worthy of note and makes an interesting comparison with the Canadian approach where the Government makes a substantial positive contribution to the technical progress of the mineral industry.

(c) The Mining Association of Canada's appointment of a Research Co-ordinator to upgrade the technical competence of the mining industry and the proposed appointment of a National Advisory Committee on Mining and Metallurgical Research are two examples of the machinery which Australia might usefully consider for co-ordination of research in the growing Australian mineral industry.

APPENDIX 1

PAPERS AND PAMPHLETS

Ray and Hayden - Kennecott Copper Corporation

Metz, R. A. 1966 History and Geology of the Ray Copper Deposit, Ray, Arizona.

Anon. 1963 Flow Process Chart; Concentrator at Hayden, Arizona.

Simpson, D. L., Ensign, B. H., and Marquardson, K. F. 1968 The Design of the Process and Facilities for the Recovery of Copper Silicate Ores at Ray Mines Division, Kennecott Copper Corporation.

Pickering, I. G. 1968 Project Sloop - A Concept of Mining in the Years to Come.

Coburn, James L. 1968 On-Stream X-ray Analyzer at Concentrator Operations, Hayden, Arizona.

Sewell, G. P. 1968 Changes in Milling Practices at Hayden

Morenci - Phelps Dodge Corporation

Anon. 1964(?) Phelps Dodge Corporation, Morenci Branch, Morenci, Arizona.

Moolick, R. T. and Durek, J. J. 1966 The Morenci District in Geology of the Porphyry Copper Deposits of Southwestern North America

Bingham Canyon; Magna - Utah Copper Corporation

Anon. 1965 The Utah Copper Story Utah Copper Corporation

Anon. 1962 Flow Process Data Arthur Concentrator, Utah Copper Corporation.

Broadbent, C.D. 1968 Slope Stability Programme of Kennecott Copper Corporation. Western Mining Divisions Engineering Department.

Eveleth - Eveleth Taconite Company

Anon. 1965 This is the Eveleth Taconite Company

Anon. 1966(?) Minnesota's Iron Mining Industry

Anon. 1965(?) Pictorial Flowsheets - Fairlane Plant (Fine Crusher, Concentrator, Pellet Plant)

Babbitt - Reserve Mining Company

Anon. 1965(?) Reserve Mining Company - Peter Mitchell Mine, Babbitt, Minnesota.

Hoyt Lakes - Erie Mining Company

Anon. 1968(?) This is Erie Mining Company

Anon. 1968 Erie Times (House Magazine)

Ishpeming - Cleveland Cliffs Iron Company

Boyum, B. H.	1964	The Marquette Mineral District, Michigan
Anon.	1964(?)	Empire Iron Mining Company (Brochure and simplified flowsheets)

Adams Mine - Jones and Laughlin Steel Corporation

Anon.	1964(?)	Ore into Pellets at the Adams Mine
Anon.	(?)	Pictorial Flowsheets and Summary of Geology - Adams Mine.

Eagle Mountain - Kaiser Steel Corporation

Anon.	1967	Kaiser's Eagle Mountain Project - from Pit to Premium Pellet

San Manuel - Magma Copper Company

Anon.	1968	General Information Booklet, Magma Copper Company, San Manuel Division

White Pine - White Pine Copper Company

Parker, Jack	1966	Mining in a Lateral Stress Field at White Pine

Sudbury Area - International Nickel Company of Canada Ltd.

Anon.	1962	Flow Chart of Company Operations

Wallace - Hecla Mining Company

Hendricks, R. S.	1967	Raise Boring Methods and Performance

Kellogg - The Bunker Hill Company

Anon.	(?)	A Story of Progress - from Mines to Metals

Metaline Falls - Boundary Dam

Anon.	1966	Seattle City Light's Boundary Project

Sheridan Park - International Nickel Company of Canada Limited

Anon.	1967	Inco Process Research

United States - Bureau of Mines

Anon.	1966	Organisation Chart, Bureau of Mines
Howard, T. E.	1965	The Bureau of Mines Mining Research Programme (Draft)
Howard, T. E.	1967	Mine Systems Design : The Next Effort will Focus on Tunnelling.
Howard, T. E.	1967	Rapid Excavation

United States - Bureau of Mines (cont.)

Howard, T. E.	1968	Outlook for Faster Tunnelling
Cruickshank, M. J. Romanowitz, C. M. and Overall, M. P.	1968	Offshore Mining - Present and Future
Van Sant, J. N. and Ellman, R. C.	1959	Methods and Costs of Mining Lignite in North Dakota
U.S. A.E.C. etc.	1967	Sloop
U.S. A.E.C. etc.	1967	Summary of Sloop
U.S. A.E.C.	1967	Press Release on Sloop
Anon.	1968	Bibliography on Secondary Metals Project
Anon.	1968	Bibliography on X-ray Spectrography, Electron Probe Microanalysis and X-ray Diffraction
Anon.	1958	Employees Accident Prevention Handbook
Ezekiel, W. N.	1967	Genesis of the Society for Industrial Microbiology
Anon.	1956	Conference Minutes on Microbial Research Programmes of the U.S. Bureau of Mines
Anon.	1957	Press Release on Microbial Research in the Bureau of Mines.
The Staff, U.S. Bureau of Mines	1968	U.S.B.M. Examines Exotic Ways of Breaking Rock
Anon.	1968	Organisation Chart - U.S.B.M. Research
McWilliams, J. R.	1966	The Role of Microstructure in the Physical Properties of Rock
Anon.	1967	Spokane Mining Research Laboratory - Open House

Canada - Department of Energy Mines and Resources - Mines Branch

Anon.	1968	Delay in Forming Mineral Industry Research Board. Northern Miner May 23rd.
Coates, D. F.	1967	Mining Research Centre - Progress Report
Anon.	1967	Equipment for Leeman Stress Measurements

Toronto - The Mining Association of Canada

The Mining Association of Canada	1967	What the Mining Industry Means to Canada, 1967.

United States - United States Geological Survey - Office of Mineral Exploration

Office of Minerals Exploration	1967	Second Annual Report
U.S. Congress	1958	Public Law 85-701 Financial Assistance for Exploration
U.S. Congress	1967	Regulations for Obtaining Federal Financial Assistance
U.S. Geological Survey	1965	Application Form for Financial Assistance in Minerals Exploration
Office of Minerals Exploration	1967	Questions and Answers on Exploration Assistance

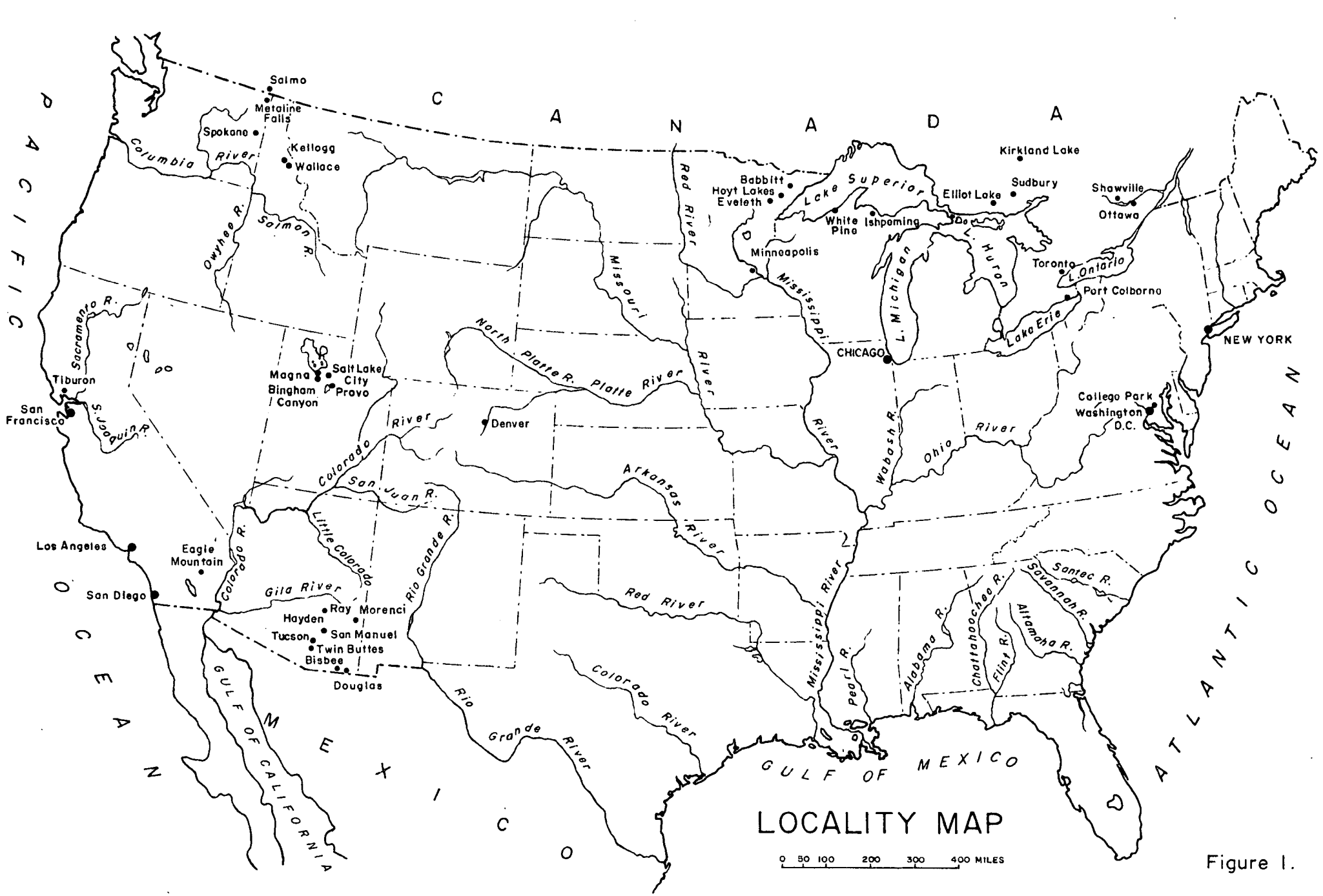

Figure 1.

To accompany Record 1968/99.

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