TABLE OF CONTENTS

Part I

Introduction ........................................ 1 - 2
Geology and ore deposits .............................. 2 - 4
Summary of general mining plans .............. 4 - 7
Caving Progress of Andes Copper ............. 8 - 9
Waste Stripping .................................... 10 - 11
Ore Removal - South Orebody
South Oxide ........................................ 13 - 22
South Sulfi.de ........................................ 14 - 28
Ore Removal - Central Orebody
Central Oxide ........................................ 29 - 42
Central Sulfi.de ...................................... 43 - 48

Part II

General mining plan ................................ 1 - 2
Size of blocks ....................................... 2 - 4
Location of transfer raise levels .............. 4 - 6
Layout of transfer raise levels ................. 6 - 8
Block development
Drawpoint spacing .................................. 8 - 10
Main transfer raise ................................ 10 - 12
Orebody level ....................................... 13 - 15
Branch raise ......................................... 15 - 17
Undercut level & undercutting procedure .... 17 - 20

Approved by:
Jay A. Carpenter, Director
Mining School of Mines
23 - 28

Timbering ........................................... 29 - 31

Summary of operational facts and figures .... 31 - 34
Acknowledgments and references ............... 35 - 50

In partial fulfillment of the requirements
for the degree of Engineer of Mines

By

MARTIN K. HANNIFAN
# TABLE OF CONTENTS

## Part I

<table>
<thead>
<tr>
<th>Section</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>1 - 2</td>
</tr>
<tr>
<td>Geology and ore deposits</td>
<td>2 - 4</td>
</tr>
<tr>
<td>Summary of general mining plans</td>
<td>4 - 7</td>
</tr>
<tr>
<td>Waste Stripping</td>
<td>8 - 9</td>
</tr>
<tr>
<td>Ore Removal - South Orebody</td>
<td>10 - 13</td>
</tr>
<tr>
<td>South Oxide</td>
<td></td>
</tr>
<tr>
<td>South Sulfide</td>
<td>13 - 22</td>
</tr>
<tr>
<td>Ore Removal - Central Orebody</td>
<td>23 - 28</td>
</tr>
<tr>
<td>Central Oxide</td>
<td></td>
</tr>
<tr>
<td>Central Sulfide</td>
<td>29 - 42</td>
</tr>
</tbody>
</table>

## Part II

<table>
<thead>
<tr>
<th>Section</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>General mining plan</td>
<td>1 - 2</td>
</tr>
<tr>
<td>Size of blocks</td>
<td>2 - 4</td>
</tr>
<tr>
<td>Location of transfer haulage levels</td>
<td>4 - 6</td>
</tr>
<tr>
<td>Layout of transfer haulage levels</td>
<td>6 - 8</td>
</tr>
<tr>
<td>Block development</td>
<td></td>
</tr>
<tr>
<td>Drawpoint spacing</td>
<td>8 - 10</td>
</tr>
<tr>
<td>Main transfer raises</td>
<td>10 - 12</td>
</tr>
<tr>
<td>Grizzly level</td>
<td>12 - 15</td>
</tr>
<tr>
<td>Branch raises</td>
<td>15 - 17</td>
</tr>
<tr>
<td>Undercut level &amp; undercutting procedure</td>
<td>17 - 20</td>
</tr>
<tr>
<td>Isolation</td>
<td>20 - 23</td>
</tr>
<tr>
<td>Ore drawing and extraction control</td>
<td>23 - 28</td>
</tr>
<tr>
<td>Timbering</td>
<td>29 - 31</td>
</tr>
<tr>
<td>Maintenance of blocks</td>
<td>31 - 33</td>
</tr>
<tr>
<td>Table of Comparisons-development work &amp; drawpoint spacing</td>
<td>33-A</td>
</tr>
<tr>
<td>Summary of operational facts and figures</td>
<td>34 - 35</td>
</tr>
<tr>
<td>Acknowledgments and references</td>
<td>36</td>
</tr>
</tbody>
</table>
ILLUSTRATIONS

DEVELOPMENT

Plan of transfer haulage level - 3184 meters elevation- 1
Plan of transfer haulage level - 3112 meters elevation- 2
Plan of transfer haulage level - 3032 meters elevation- 3
Plan of main adit haulage level - 2982 meters elevation- 4
Main raise layouts - Sulfide system----------------------- 5
Main raise layouts - Oxide system------------------------- 6
Grizzly level layouts - Sulfide system-------------------- 7
Grizzly level layouts - Oxide system---------------------- 8
Branch raise layouts------------------------------------- 9
Undercutting level layouts - Sulfide system-------------- 10
Undercutting level layouts - Oxide system--------------- 11
Isolation layouts---------------------------------------- 12

TIMBERING

Haulage drift timbering------------------------------- 13
Haulage chute layout-------------------------------- 14
Early timbering - Sulfide control set system---------- 15
Present grizzly control set - Sulfide system---------- 16
Present grizzly control set - Special, Sulfide system-- 17
Grizzly layout, past and present - Oxide system------- 18
Haulage equipment------------------------------------- 19
The Andes Copper Mine of the Anaconda Copper Company is located at Potrerillos on the western slope of the Andes Mountains in the Province of Atacama, Department of Chañaral, Chile, about ninety-five miles east of the Pacific port of Chañaral.

From 1894 to the present time, Potrerillos has been developed from primitive vein mining methods on a very small scale to producing the world's largest daily tonnage among underground metal mines, and August, 1946, records 100,000,000 metric tons of copper ore delivered to the plant.

The Potrerillos mine required a tremendous investment to bring it to its present producing capacity from the time (1913) William Braden recognized its large-mine possibilities, located and partially explored it before selling the property to the Andes Copper Mining Company in 1916. This company carried out an extensive churn-drilling and underground exploration program, together with test plant work, followed by the underground development of the orebody and construction of a 25,000 ton oxide-leaching, sulfide-flotation plant, smelter and refinery. In addition, a complete camp to house and maintain 5,000 workmen and their families was constructed by the time ore removal started in 1926.
A history of Andes development is a good study of progress in the caving system of mining, since it is a mine planned on ideas formed from the earliest practice of the "block system" and has been developed by a progressive improvement-minded management, taking advantage of local ore-body characteristics allowing system changes without great risk of ore loss or excessive waste dilution. I believe that this study will show many changes and innovations, both major and minor, in the mining layout of the Potrerillos mine that are not in use at other caving system properties.

GEOLOGY

All of the ore is associated with an igneous intrusive called the Cobre Porphyry; a system of stockworks, probably of common origin, intruding in early Tertiary time the Potrerillos formation of limestones (Jurassic to upper Cretaceous), the Cerro Negro limestones and shales (upper Cretaceous or early Tertiary), and overlying andesitic volcanic rocks (early Tertiary).

ORE DEPOSITS

The form and attitude of the two principal orebodies may be generalized as follows:

1. Central Orebody. In plan, this is a rudely elliptical doughnut-shaped orebody, major and minor axes 800 meters and 500 meters respectively. The major axis strikes N65E. About 75% of the inner elliptical area is low grade porphyritic waste. The ore area widens on the west end of the major axis, and there is a circular ore-stockwork (175
meters in diameter) in the low grade waste area and the east end of the major axis. In section, the ore areas narrow and converge with increasing depth, and rake 75°NW, rapidly flattening below 200 meters depth to eventually conform with the dip of the Copiapina thrust-fault (strike N30°E, dip 20°NW), the controlling structure of porphyry intrusion. A typical section of this orebody shows a gravel wash and surface leached-zone of 20 meters depth; an oxide ore zone of 80 meters, the lower 30 or 40 meters of which does not everywhere contain sufficient mineralization to be of ore grade; 100 meters of supergenebly enriched sulfide-ore; 130 meters of weakly enriched sulfide ore, grading into primary sulfide ore below 330 meters depth. Explored to 500 meters depth, this orebody contained an estimated 40,000,000 tons of 1.5 percent (total copper) grade.

The South Orebody. This is a tabular orebody striking N20°E and dipping 65°NW towards the Central Orebody, from which it is separated by 300 meters of porphyritic waste. It is 500 meters along the strike, a wedge in section, showing features similar to the Central Orebody in that the ore width narrows from 90 meters to 20 meters with increasing depth, and the dip flattens rapidly on approaching the Copiapina thrust-fault. A typical section along the dip of this orebody shows 100 meters of oxide ore, 30 meters of leached low-grade
mixed oxide-sulfide material, 100 meters of enriched sulfide ore, 200 meters of weakly enriched primary sulfide ore grading into primary sulfide ore below 350 meters depth. Explored to 600 meters of depth, this orebody contained an estimated 40,000,000 tons of 1.5 percent (total copper) grade.

ORE CHARACTERISTICS AFFECTING MINING

The form of the orebodies varies from a massive body having steep, sharply-defined ore boundaries in the Central Orebody, to a tabular orebody dipping 65° with a highly irregular assay boundary in the South Orebody.

The ore shoots vary from 30 meters to 150 meters in width, and from 10 meters to 300 meters in depth.

The ore character varies from hard, little-fractured porphyry through weak, highly-fractured sedimentary contact ore to soft, wet, gougy zones, in places of such close proximity as to be included in a single block.

The overburden, including such materials as alluvial gravels, leached porphyritic waste, and limestone, varies in thickness from 400 meters to none.

MINING SYSTEM

The initial mining system was planned by members of the Anaconda staff and developed by Greninger, Van Buskirk, Arnold and Newlin, all of whom gained experience in caving practice at Inspiration, Arizona, where the caving-system on a large producing basis started in 1915.
There were various methods of caving ore practiced at the time Andes was developed, all with the same fundamental idea of undercutting a section of ore and allowing it to cave and crush from its own overlying weight in a continuous operation, by drawing out the broken ore from the undercut area through raises to a haulage level whence it was transferred to the plant. The methods differed mainly in the manner of undercutting, weakening of section boundaries, and ore transfer systems.

The engineers who planned the general development of a mining system for Andes decided on a caving system instead of an open pit operation because of the form of the orebodies and the excessive stripping ratio of waste to ore. They chose a block-caving method taken from the Inspiration system with modifications to suit local orebody conditions.

A chronological summary of plans follows:

1. 1918 - Block Caving with a gathering tributary raise system and no intermediate retransfer levels.

This plan consisted of:

a. Main adit at elevation 2,982 meters, 5 kilometers long, branching under the orebody into three parallel drifts 49 meters apart.

b. Underground adit storage bins of 1,000 tons capacity equipped to load ore into railroad car trains for transfer to the plant.

c. Oxide ores to be undercut and caved at elevation 3,218 meters, the broken ore to be withdrawn through fingers and grizzlies directly into tributary transfer raises to adit level storage bins. (In advance of oxide ore drawing operations, it was planned to remove waste overburden from the oxide area by caving and withdrawing broken material through raises to retransfer tunnels, then by rocker-dump car trains to the surface camp site).
d. Underlying sulfide ore to be undercut and
caved at elevation 3,061 meters, following
oxide removal, and to be withdrawn through
fingers and grizzlies directly into transfer
raises from the adit level via chutes to
railroad cars.

2. 1920 - Plan 1 was modified to include two intermediate
retransfer haulage levels above the adit, one
at 3,032 meters and the other at 3,184 meters
elevation. This plan consisted of:

a. Main adit at 2,982 meters, 4.7 kilometers
long, branching into two rejoining drifts
under the orebody.

b. Underground adit storage bins of 1,000 tons
capacity.

c. Waste removal to camp site through tunnels
at 3,320 meters and 3,237 meters elevation.

d. Removal to storage dump of South Oxide ore
in order to strip the South Sulfide ore for
early mining. This ore was to be trammed
through the transfer tunnel at 3,320 meters
elevation by 10-ton electric locomotives
and 2.25 cubic meter capacity rocker-dump
cars.

e. Central Oxide ore and upper South Sulfide
ore to be caved and withdrawn through
gathering raises from the retransfer haul-
age level at 3,184 meters elevation follow-
ing waste and South Oxide removal, traming
to be done by 10-ton electric trolley loco-
motives and 5-ton side-dumping Granby car
trains delivering ore to ore passes joining
adit bins.

f. Upper Central Sulfide and middle South Sul-
fide ore to be caved at 3,135 meters elev-
atation, following Central Oxide and upper
South Sulfide removal, the broken ore to be
withdrawn through tributary transfer raises
from the retransfer haulage level at 3,032
meters elevation and trammed by similar
trains to ore pass dumping stations.

g. Lower Central and South Sulphide to be caved
at 3,058 meters elevation following upper
Central Sulfide and middle South Sulfide
removal, and withdrawn through gathering
raises from the 3,032 meters elevation re-
transfer level and delivered to ore bins by
arrangement as in (f).

3. 1933 - Plan 2 was further modified to include a third
intermediate retransfer haulage level at 3,112
meters elevation for withdrawing upper Central
and middle South Sulfide.

Section (f), Plan 2, then consisted of
caving these two ore bodies at 3,135 meter
elevation and withdrawing ore through
gathering raises to the 3,112 meter ele-
vation retransfer level trains which deliver-
ed the ore to branches from adit-bin ore
passes.

These plans, with minor modifications, have been generally
followed to date with the recent addition (1948) of another
undercut level at 2,999 meters elevation, from which Central
Sulfide will be withdrawn through fingers and grizzlies to a
scraper or conveyor belt gathering drift system, delivering
ore directly to railroad cars on the adit level (2,932 meters
elevation).

The following is a general outline of the original layout
and subsequent changes in each of the four principal sections
of the mine, with observations and notes intended to show the
reasons for the major changes and their effectiveness. It may
be noted that similar method and layout changes occur in each
of the four mine sections. No attempt has been made to co-
rrelate these changes, since each represents the adaptation of
an experimental change (usually on a small scale) which has
proven effective and, when feasible, has been adopted through-
out the mine. Credit for these changes in general is due the
mine superintendent and his staff operating at the time of the
change:
WASTE STRIPPING

Original plans called for the removal of 10,000,000 metric tons of overlying waste in advance of oxide ore removal, the material to be used as camp site fill. Waste removal was planned on the basis of maintaining a given oxide mill-heads assay with the mining cost of waste removal and the amount of underlying ore affected estimated in advance to delimit waste areas which could be removed for greater economic efficiency. (See Plan 2-c, page 6).

The general layout was as follows:

A. South Oxide Area

Transfer level - 3,320 meters elevation, 2.45 x 2.45 meters in section with standard chutes at 25 meter intervals.

Grizzly raises - 1,262 meters elevation, 2.45 x 2.45 meter section.

Grizzly Level - 12 meters vertically above transfer level. Grizzly communication drifts were spaced 17 meters apart parallel to the transfer level. Grizzlies were at 25 meter centers over transfer raise openings. From the grizzlies, raises were driven to the surface and waste was removed by mill-holing. Waste was removed from the haulage chutes by 10-ton locomotives and 2.25 cubic meter rocker-dump cars and delivered to a surface dump site. South Oxide waste development workings were planned to be utilized later for South Oxide ore removal. Removal of waste in this area was concluded in January, 1927.

B. Central Oxide Area

1. Rhyolite waste-rock in place.

Transfer level - 3,237 meters elevation, gathering spurs at 30 meter intervals, driven with a 2.45 x 2.45 meter section and chutes spaced at 8.33 meter intervals.
Transfer raises - 1.5 meter diameter, inclined at 45° on 8.33 meter intervals.

Grizzly level - 9 meters vertically above transfer level. Grizzly communication drifts were at 15 meter intervals and parallel to the transfer level.

Branch raises - two per grizzly at center-sides dividing into 3 fingers to the undercut level.

Undercut level - 3,262 meters elevation, 25 meters vertically above grizzlies. Drifts were parallel to grizzly drifts at 7.5 meter centers and crosscuts at 8.33 meter centers. Undercutting was accomplished by drilling and blasting pillars in a retreating operation.

Caved waste was trammed to the camp site from chutes by trains as in South Oxide waste removal. 5,959 square meters were caved in this manner for a total of 354,530 metric tons. Waste removal in this area was concluded in December, 1927.

2. Alluvial gravel.

Transfer level - same as (1).

Transfer raises - at 8.33 meter intervals, inclined 45°.

Grizzly drifts - 3,252 meters elevation, 25 meters vertically above transfer level. From the grizzlies, raises were driven to the surface, and waste (average thickness 5.9 meters) was removed by a mill-holing method later supplemented by scraping.

Broken material was trammed from the chutes to the camp site with trains as in (A). 392,647 metric tons were removed in this area, and the operation was concluded in October, 1926.

3. San Antonio waste section.

Transfer level, transfer raises, grizzly level, and branch raise layout as in (B-1), but development consisted of a single retransfer drift and a single grizzly drift. Undercutting in the weaker ground was done directly from branch raises without developing an undercutting level. 1,254,382 metric tons were removed, and waste removal in this area was concluded in March, 1926.

Since waste removal is not considered as ordinary block caving at Andes, there is no discussion of such
points as block size, timbering, maintenance or operational efficiency.

ORE REMOVAL - SOUTH OREBODY

1. South Oxide 1926 - 1931

Metallurgical convenience dictated that mining be started first on sulfide ore, and it was found necessary to mine and store for future recovery 10,000,000 tons of oxide ore from this area. (See Plan 2-d, page 5). The general layout was as follows:

Transfer Adit - At 3,320 meters elevation, gathering spurs at 34 meter intervals and chutes at 12.5 meter centers. (See South Oxide waste removal).

Main transfer raises - 52° inclination, 1.5 meters diameter, serving one grizzly per chute.

Grizzly drifts - 12 meters vertically above and parallel to the haulage, spaced 17 meters apart with grizzlies at 12.5 meter intervals over main raise openings.

Branch raises - two per grizzly at center sides and branching into a three or four fingered system between grizzly and undercut level, so that each finger served 33-1/3 square meters drawpoint area.

Undercut - located 8 meters above the grizzly level. Drifts (1.5 x 2 meter section) were driven parallel to the grizzly drifts on 8.5 meter centers. These and old exploration crosscuts constituted the undercut preliminary development. Undercutting was accomplished by widening stations and long-hole blasting of elongated pillars in a retreating operation.

Isolation - None. Since waste capping had been removed, no dilution was possible, and removal of ore continued to "day-lighting" of branch raises.

Extraction control - None, except for drawing distribution to effect caving action.

Timbering

LDD (Large Drift Driving) - original driving required little other than standard chute layout at 12.5 meter centers, as ground was firm.
MRD (Main Raise Driving) - original driving required little to none.

GDD (Grizzly Drift Driving) - Grizzlies were constructed of double 10 in. x 10 in. x 15 ft. pine sills, spaced 5 ft. apart with 70 lb. cross rails placed for 10 inch openings. (See Plate 18 - Fig. 1).

Grizzly sets - square sets of 10 inch x 10 inch pine, 5 feet wide x 6 feet high inside measurements.

BRD (Branch Raise Driving) - a window of 10 inch x 10 inch cribbing with a 5 foot inside opening was placed on diagonals in the mouth of the branch raise.

UCD (Undercut Driving) - None.

Maintenance - Although the ground was firm during initial development, crushing due to ore caving as well as lateral movement along fault planes caused by the subsidence of nearby South Sulfide block caving, made necessary considerable later timbering of haulage drifts, main raises, and grizzly drifts. Repair of grizzly sets and branch raise cribbing, because of blasting and movement of coarse ore, was frequent.

South Oxide (1942)

In 1942, additional South Oxide ore was proven, and development proceeded as follows:

Retransfer haulage - The original 3,320 meter elevation adit haulage was utilized, and ore was delivered by rocker-dump car trains to an unlined ore pass from which it was removed on the 3,134 meter elevation level by Granby car trains and retransferred to adit bin ore passes.

Main transfer raises - 50° inclination, single plane branching layout to serve 2 to 4 grizzlies per chute. Spaced at 16 meter intervals.

Grizzly drifts - 31 meters vertically above the haulage adit. The main communications were normal to the haulage and on coordinates halfway between alternate chutes with stub drift communication to grizzlies. Grizzlies were spaced at 16 x 16 meter centers.

Branch raises - 4 per grizzly, arranged in a "V" system so that the intersection of the axes of each pair of branches was located 1 meter beyond either end of the grizzly to avoid flooding of grizzly as occurred in the "center-side" layout. Each branch was developed with three fingers to the undercut level; these fingers were eventually coned to a single large drawpoint during
undercutting operations so that each grizzly drew
from 4 coned branches, each of 64 square meters
drawpoint area. (See Plate 9 - fig. 2 - Ox.).

Undercut level - Located 10 meters above grizzlies.
Drifts and crosscuts were driven at 8.3 meter cen-
ters, and undercutting was accomplished by widening
stations and long-hole blasting of pillars along with
coning of branch raises in a retreating operation.

Isolation - None, since no capping existed, ore removal
continued to "daylighting" of branch raises. This
was later supplemented by surface plugging and
barring down to remove remaining ore between cones.

Extraction control - None, except for drawing dis-
tribution to effect caving action.

Timbering
LDD - Little other than standard chute layout.
MRD - None.
GDD - All-steel grizzlies; sills of 8 in. x 8 in.
steel H-beams 14 feet long, notched to re-
ceive 70 lb. cross rails spaced for 16 inch
openings. The sills were supported on 70 lb.
cross rails at ends and center. No grizzly
sets were used, as ground was firm and
locations of branch raises effectively con-
trolled flooding. (See Plate 18 - fig. 2).

BRD - None.
UCD - None.

Maintenance - Branch raise wear due to ore drawing re-
quired occasional repair. This generally consisted
of raising the complete grizzly sufficiently to
prevent flooding, but leaving enough head-room for
a grizzly man to work comfortably. In slabbing
ground, some reinforced concrete arches were built
in branch raise entries at the end of the grizzly
to prevent flooding, and supporting piers of con-
crete for grizzly sills were built when main raise
wear or sloughing made it necessary.

This layout prevailed through blocks SO 2, SO 3 and
SO 5. In 1946, SO 6 was developed as follows:

South Oxide 1946

Retransfer haulage - The same, but with chutes at
18 meter intervals.

Retransfer raises - 50° inclination, with a "V"
branching layout in two intersecting planes, to
serve 2 or 4 grizzlies on 18 x 18 meter centers.
Grizzly drifts - 31 meters vertically above the
haulage level. The main communications are normal to the haulage and on coordinates halfway between chutes with stub drift communication to grizzlies, so that all grizzly communication drifts are between the planes of main raises.

Branch raises - 2 per grizzly developed in a "V" layout as before with the axes joining 1 meter beyond the end of the grizzly opposite the communication entry. Each branch is developed into 4 fingers before reaching the undercut level and eventually coned to a single drawpoint of 64 square meter area as part of the undercutting operation. (See Plate 9 - Fig.2-Ox.).

Undercut level - located 9 meters above grizzlies. Drifts and crosscuts were developed at 12.5 meter centers so arranged that each undercut pillar has a finger opening from the underlying branch raise on each of its four corners. Undercutting was accomplished by joining the branch fingers into a single coned drawpoint with supplementary plugging from the undercut level of any remaining solid points in a retreating operation.

Isolation - None, as no waste capping existed.

Extraction control - None, except for drawing distribution to effect caving action.

Timbering
LDD - Standard chute layout only.
MED - None.
GDD - All-steel grizzlies as before described.
BKD - None.

Maintenance - Occasional raising of grizzlies, concrete arches at branch raise entries, and concrete pillars for sills, when necessary, as before described.

2. South Sulphide 1926

Following earliest South Oxide waste and ore removal, the mining of the upper zone of the South Sulphide orebody started. The general layout was as follows: (See Plan 2-e, Page 6).

Retransfer haulage level - 3,184 meters elevation, 2.45 x 2.45 meters in section, with gathering spurs at 33.33 meter intervals. Standard chutes were
placed alternately at 6.25 meters and 9.37 meters to conform to Granby car lengths.

Main transfer raises - 54°30' inclination, 1.5 meters x 1.5 meters section, branching in a single plane to serve grizzlies spaced 8.33 meters apart.

Grizzly level - 13.23 meters above the haulage. Communication drifts were parallel to the haulage and spaced at 16.67 meter centers with a "through-grizzly" layout, grizzlies placed at 8.33 x 8.33 meter centers, each serving 2 control sets.

Branch raises - 2 per grizzly at center sides, each branch inclined 47° for 4.47 meters to a control set from which 4 fingers extended 5.5 meters to the undercut level. Each finger served a drawpoint area of 17.4 square meters. (See Plate 9 - Fig. 1-S.).

Undercut level - The initial block (Stope A) was developed with undercutting drifts parallel to the grizzly drifts and only crosscuts on the block boundaries with a few more in between to facilitate communication and supply on the undercut level. Undercutting was accomplished by driving stub crosscuts into the elongated pillars 4.5 meters long and using these stubs as stations for long-holing. Blasting of long-holed pillars proceeded in a retreating manner diagonally across the block. (See Plate 10 - Fig. 1).

This system was changed in succeeding blocks (Stope B) to drifts and crosscuts at regular 8.3 meter intervals with undercutting accomplished by widening stations and long-holing the square pillars, blasting in a retreating operation across the block.

Isolation - None was used in the initial block, but later blocks had a full panel of raises at 45° on 12 meter centers, forming a checkerboard on each solid boundary vertically up to the ore limit. (See Plate 12 - Fig. 1).

Extraction control - Drawing of ore in this initial operation was under the direction of the geology department. Written orders were issued by the chief geologist with approval of the mine superintendent, and supervising bosses carried this data together with copies of the graphic chute charts maintained in the mine office to date within one week of extraction operations.
Underground, ore drawing was checked on both the grizzly and haulage levels by two ore-checkers. Each grizzly had two small blackboards on which was posted weekly the amount of ore to be drawn from each branch raise in a given week, and bi-weekly the grade of ore being drawn from each branch. Drawing, insofar as possible, was maintained evenly distributed over the block; but crushing and repair work made branches inoperable at times, and a continual compromise between opposing requirements was necessary.

Timbering

**LTD** - Standard chute sets with the intervening spaces supported by standard haulage sets (10 inch x 10 inch timber) at 1.5 meter centers.

**MRD** - Generally lined with 6 x 12 inch cribbing (3.5 feet inside) with 3.5 x 3.5 inch angle iron protection against wear. (See Plate 5 - Fig. 2).

**GDD** - Communications were supported by 3-piece (10 x 10 inch timber) framed sets at 1.5 meter centers. In heavy ground some reinforced concrete or masonry lining was tried, but later abandoned as unsatisfactory. Grizzlies - double 10 x 10 inch sills with 60 or 70 lb. cross rails spaced for 10 inch openings.

Grizzly sets - originally a 3-piece segment set, later abandoned for square sets of 10 x 10 inch timber; 6 x 5 feet inside measurements. (See Plate 15).

**BHD** - Lined with 6 x 12 inch cribbing, 3 feet inside measurement with angle iron protection up to the control set.

Control set - A framed square set of 10 x 10 inch timber, 5 feet 8 inches x 5 feet 8 inches inside measurements with double 10 x 10 inch caps and chutes of 3 inch planks in each of the 4 sides. 3 sets of 6 x 12 inch cribbing were placed in each finger raise of the control set chutes.

**UCD** - Light, temporary sets in weaker ground.

Maintenance - Crushing, wear and blasting made necessary much repair of cribbing in fingers, branches and main raises. Control sets and grizzly sets also demanded much maintenance. Haulage drifts required little repair.

Because of excessive maintenance, the original block size of 200 x 70 meters was reduced to 200 x 50 meters, then to 100 x 50 meters, and subsequent blocks were developed with smaller areas consistent with extraction requirements as a means of limiting the area requiring...
maintenance at any given time. Later, blocks were developed with the undercut at 3,627 meters elevation (83 meters above haulage), but the layout of blocks except for longer main raise sections remained the same. With a subsequent lowering of the required mill-head's assay, undercutting was done on a lower elevation in the same area, utilizing as much as possible of the previous main raise layout. Grizzly drift, branch raise, and control set system was used as before.

Since the South Sulfide dips at 65°, it was necessary to limit the lift mined to avoid taking excessive footwall and hanging wall waste while withdrawing the ore with a block caving system. Original development of a lower elevation South Sulfide section was begun in 1930 following the removal of upper South Sulfide ore. This section was developed from the 3,032 haulage drift through long gathering raises as follows: (See Plan 2-f, Page 6).

South Sulfide 1930

Retransfer level - 3,032 meters elevation with gathering spurs at 100 meter intervals. Ore to be withdrawn from standard chutes and delivered by 10-ton electric motors and Granby car trains to adit bin ore passes.

Retransfer raises - 25 meter intervals, 46° inclination, full lined with 6 x 12 inch cribbing and angle iron protection. Extensive communication raises and subdrifts for servicing raises were provided.

Grizzly level - at 3,125 meter elevation (93 meters above haulage). A "through-grizzly" communication drift layout and timbered as in upper South Sulfide section.

Branch raises - developed with control set layout and 4 fingers per set to undercut; also timbered as in upper South Sulfide section.

Undercut level - 10 meters above grizzlies. Developed with drifts and crosscuts at 8.5 meter centers.

Isolation - Developed with a full panel checkerboard of raises at 45° inclination on 12.5 meter centers on all the solid boundaries.
This development was abandoned when one block was nearly ready for undercutting, because experience in a similar block layout of the Central Sulfide had by this time (See Central Sulfide CS-1,2, pages 29-31) proved that the difficulty of running ore through long transfer raises made this type of development impractical. It was therefore decided to divide the Central Sulfide and South Sulfide orebodies above the 3,032 meter elevation haulage into two lifts by driving a second retransfer level at 3,112 meter elevation (See Plan 3, page 7). This haulage level was extended to the South orebody in 1939 and mining continued there as follows:

South Sulfide 1940

Retransfer level - 3,112 meters elevation with gathering spurs at 25 meter centers. (This spacing to utilize former development workings of blocks developed from the 3,032 meter elevation retransfer level).

Retransfer raises - 50° inclination. Developed on alternating 6.25 meter and 9.37 meter spacing (to accommodate Granby cars) with 3 branches per chute in the plane of the main raise to serve grizzlies at 5 meter intervals. Alternate raises were inclined to serve grizzly drifts equally spaced 7.81 meters apart. (See Plate 5, fig. 3).

Grizzly level - 3,131.5 meters elevation, 19 meters above haulage. A "through-grizzly" layout with grizzlies at 5 meter intervals, and drifts 7.81 meters apart in the plane of main raises. (See Plate 7, fig. 2).

Branch raises - 2 per grizzly at center-sides, 6.20 meters long, inclined 50°, 1.5 meters diameter, coned at the undercut level to 2 meters. Each branch served 21 square meters of drawpoint area. (See Plate 9, fig. 2-S).

Undercut level - Drifts and crosscuts were driven at 7.5 x 7.8 meter centers. Undercutting was accomplished by widening stations & long-hole blasting.
in a retreating operation. (See Plate 10, fig. 3).

Isolation - Instead of full panel isolation, this work was now confined to the corners of a given block, so that solid boundaries had isolation workings covering about 50% of the vertical plane up to the ore limit. This development usually consisted of a vertical raise at the corner of a block with an intersecting system of raises driven at 45° inclination on 10 meter centers with subdrifts at 17 meter elevations. (See Plate 12, fig. 3). Since the average block area was now limited to 50 or 60 meters in either dimension, isolation workings extended, generally, from the block corner 15 meters along both vertical boundary planes, and, as these raises and drifts were advanced, the character of the ground was judged and more or less isolation work was done accordingly. If the ground was too weak to stand without support, isolation work was abandoned; if medium ground was encountered, the plan of raises and subdrifts was followed to completion, time permitting; and if very hard ground was encountered, raises and drifts were supplemented by short shrinkage stopes on one or all of the subdrifts together with sidestabbing rounds at the raise intersections to further weaken the corner's boundary.

Extraction control - Drawing of ore was now under the charge of an extraction foreman with approval of the mine superintendent. Graphic chute charts were continued, but underground checking was limited to one ore-checker on the grizzly level. The grizzly set blackboards were discontinued, but daily orders were issued by the extraction foreman to the section foremen, who gave identical orders to the ore-checker and shift bosses concerning the amount and distribution of ore to be pulled. Ore-checkers kept a daily record of the quantity pulled from each branch, roughly estimated by raise-fulls calibrated into carfuls or tons, which information was posted in the geological office, and from it the graphic chute charts kept up to date. Daily assays were taken from grab samples of cars pulled from a given haulage of a given block, supplemented, when desired, by special samples taken from particular branches or areas of a given block. This information was made available to the mine staff, ore-checkers and shift bosses.

Timbering

LDD - Standard chute sets with the intervening space supported where necessary by 8 x 8 inch standard big drift sets at 1.5 to 2.5 meter centers, depending on the character of the ground.

MRD - None, except where former communications weakened the main raise sections, necessitating necks of 3 x 10 inch cribbing.

GDD - 3-piece 8 x 8 inch unframed sets at 1.5 meter
Grizzlies - 5 x 10 inch x 10 foot sills spaced 42 inches apart with cross rails (70 lb.) spaced for 12 inch openings held in place by space blocks and 2 x 10 inch planks. Grizzly set - unframed square sets constructed of 10 x 10 inch solid, 8 x 8 inch solid or made up of plank and block, depending on character of ground. The set was 6 feet x 6 feet 6 inches x 42 inches inside measurements and provided with a stop-rail, to control the ore, held in place by angle iron "U's" in front of each branch raise. No cribbing windows were used, but old timber was placed as a filler between grizzly-set posts and the drift sides to block the set, as well as to serve as a "muck-buffer". (See Plate 16). BRD - None. UCD - None, except for stulls and headboards where necessary.

Maintenance - Light, since ground was firm. Where crushing occurred, steel caps were placed on repaired sets. Diagonal supports under grizzly set caps and stull supports under drift caps were effective in maintaining original sets. Light lagging was used where needed (1 x 6 inch plank), which allowed the ground to give without breaking the posts or caps when minor weight occurred. A fill of old timber between the ground and the grizzly set post was effective in avoiding broken posts due to blasting or coarse boulder blows, and center collar braces on caps were effective in preventing the same causes from breaking caps. Little difficulty was encountered because of branch raise or main raise wear, and practically no haulage drift repair was necessary except for minor repairs to chutes.

This layout prevailed through South Sulfide 6 - 1A, 1B, 2A, 2B, 3A, 3B and 4A. In addition, during this period about 2,000,000 tons of pyritic material for the acid plant were mined from the South Sulfide hanging wall through the 3,185 meter elevation re-transfer level with a similar block layout.

In 1944, SS 7 and SS 5 were developed as follows:

South Sulfide 1944

Retransfer haulage drift - The 3,112 meter elevation haulage, but gathering spurs were driven at 30 meter centers, and chutes were placed at regular 12.5 meter intervals.

Retransfer raises - 12.5 meters apart, 50° inclin-
ation, developed with 4 branches per system in the same plane to serve grizzlies at 7.5 meter intervals. With this layout, the chutes still conformed to Granby car length, although main raises were all in vertical planes; hence they were easier to drive and had less tendency to hang up. With only 2 branches per side, instead of 3, the main raise section was stronger. (See Plate 5, fig. 6).

Grizzly Level - 19.5 meters vertically above haulage. A "through-grizzly" layout in the plane of the main raise spaced 12.5 meters apart with grizzlies at 7.5 meter intervals. (See Plate 7, fig. 4).

Branch raises - 2 per grizzly at center-sides. Each branch was driven about 1.3 meters in cross-section and divided into 4 fingers before reaching the undercut level if the ground was firm; if not, as many of the 4 as could be driven with safety. In advance of, or in conjunction with, undercutting, these fingers were coned together to form a final branch with a drawpoint area of 47 square meters. (See Plate 9, fig. 3-3).

Undercut Level - 7 meters above grizzly level. Developed with drifts at 6.3 meter intervals, and crosscuts at 7.5 meter intervals so arranged that each pillar formed was centered over the division point of a branch raise, and each finger broke on a corner of the pillar above. This system permitted of more undercutting with stopers, as the process of coning the branch raise fingers practically resulted in undercutting the overlying pillar, and remaining solid points were removed with a minimum of long-holing and plugging. Undercutting, in general, was accomplished by a combination of long-holing, with no preliminary widening of stations, and coning of branch raises in a retreating cycle of operations. The amount of long-holing from the undercut level depended on the character of the ground, which governed the amount of stoper work that could be safely done during undercutting operations. (See Plate 10 - fig. 5).

Isolation - Vertical and inclined raises with subdrifts concentrating on block corners.

Extraction control - As in South Sulfide - Page 18.

Timbering - Similar to that described under South Sulphide 1940, pages 18 and 19, except that larger and stronger pillar support as a result of greater drawpoint spacing lessened the amount of timbering required on the grizzly level. It
was possible under this system to omit sets between grizzlies that formerly would have been necessary.

Maintenance - Same as before, but greater pillar support resulted in less crushing of grizzly drifts and consequently less repair was necessary. Each grizzly serving a greater drawpoint area resulted in more tonnage drawn per grizzly, but the stronger pillar layout counteracted greater wear, and little repair, due to branch or main raise wear, was necessary. The usual broken posts, caps and rails of the grizzly sets because of blasting and boulder blows were handled in the manner previously described. Excessive widening of branch raises because of wear or sloughing was effectively combatted by enlarging the grizzly set; that is, by use of longer posts and caps the set was again blocked to solid ground. Thus, the principal members of the set were removed from the area of blasting or boulder blows. (See Plate 17).

South Sulfide 1946

Following middle South Sulfide removal, a lower elevation (3,062 meters) South Sulfide undercut was developed with the general layout as follows. (See Plan 2-g, pages 6 and 7).

Retransfer haulage drifts - 3 meters elevation with gathering spurs at 33 meter centers to utilize early development workings on this level. Chutes at alternate 6.25 and 9.37 meter centers.

Retransfer raises - Same as SS 1-2-3-4-6, (page 17), but the weak ore-footwall zone necessitated cribbing a major part of the main raises.

Grizzly drifts - Same as SS 1-2-3-4-6, page 17.

Undercut level - Same as described under South Sulfide, (page 18).

Dut the weak ore-footwall zone necessitated cribbing a major part of the main raises.

Timbering LDD - Part of this development was through very weak, wet, gougy footwall sediments, and timbering was heavy. Special haulage drift sets (10 in. x 10 in. pine) having a
wider post batter (2-1/4 in. per foot) with side bridges of diagonally cut 10 x 10 in. pine, and cap bridges of 10 x 10 in. pine were placed in this ground at 1 meter intervals. Side lagging was light - 1 x 6 in. planks mounted with the ends spotted on the inclined planes of the wedge-shaped side bridges - so that the side pressure could move or break the lagging without breaking the main set. This timbering has been effective to date, with a minimum of maintenance necessary. (See Plate 13, fig. 2).

MRD - A major part of this development was through the weak, wet, gougy footwall sediments. The sections of the main raises in this type of ground were cribbed with 3 x 10 in. cribbing, 42 in. inside measurement and framed so that cribbing was spaced 2 in. apart, and no angle iron protection was used. This timbering wore out or was crushed out before extraction was complete and was replaced by 5 in. x 10 in. cribbing of an outside section large enough to fit the ground.

GDD - Although the grizzly level of this block was in weaker ground than previous South Sulfide blocks, the same method of timbering was used, and to date a minimum of crushing has been encountered.

BRD - None, except for a few very weak branches which could not be driven without support. These were cribbed, starting from two (2) horizontal 10 in. x 10 in. sills spaced 1.5 meters apart in the mouth of the branch at the level of, and normal to, the grizzly caps. A vertical section of cribbing 5 ft. inside measurement was carried to the undercut level interspaced apart 2 in.

UCD - None.

Maintenance - To date, no excessive crushing nor wear has resulted other than to main raise cribbing, repaired as described, and the usual minor repair jobs have sufficed. This development layout is being carried through to SS 10, but succeeding blocks are planned on the layout of SS 7 and 5; that is, chutes at 12.5 meters, grizzlies at 12.5 x 7.5 meter centers, branch raises divided into fingers and coned during undercutting to a 47 square meter drawpoint, and undercutting to be accomplished chiefly with stopers.

No plans have been made to date for the removal of ore underlying the 3,062 meter elevation undercutting level in the
ORE REMOVAL--CENTRAL OREBODY

1. Central Oxide 1927

The earliest Central Oxide ore producing block (CO 1) was a gathering tributary raise system from the adit bins to the 3,257 meter elevation undercut, with no intermediate retransfer ore haulage (see Plan 1-c, page 5), developed as follows:

Transfer raises - 3 of the adit bin ore passes (1.5 x 2 meter section, inclined 60°13') were extended to the retransfer level at 3,185 meters elevation, at 44.12 meter intervals. Over each of these openings a pony set was built and main raises driven to east and west at 45° inclination. These raises were branched and planed to north and south in such a manner that there were 20 grizzlies tributary to each ore pass on 16.67 x 11.03 meter centers.

Extensive communication manways and subdrifts were driven to service ore passes and tributary raises. (See Plate 6, fig. 1).

Grizzly level - Elevation 3,247 meters, 240 meters above the ore bins. Grizzly communications were driven as a "through-grizzly" system 10.67 meters apart with grizzlies at 11.03 meter intervals. (See Plate 6, fig. 1).

Branch raises - 2 per grizzly at center-sides, each branch dividing into 3 fingers before reaching the undercut level. These fingers were not coned as a final operation into a single drawpoint but remained as 3 separate drawpoints of 26 square meters area, each branch thus serving 78 square meters area.

Undercut level - 3,257 meters elevation, 10 meters above the grizzly level. Development consisted of drifts at 6.3 meter intervals with a few crosscuts for communication and supply. Undercutting was accomplished by widening stations in the form of stub-drifts, long-holing and blasting in a retreating operation. (See Plate 11, fig. 1).

Isolation - None, as no overburden remained after waste stripping.
Extraction control - None, except for draw distribution to effect caving action, and extraction continued to "day-lighting" of branches.

Timbering - Trunk ore passes were 1.5 x 2 meters inside, lined with 8 in. x 8 in. steel H-beams and 6 in. wood fillers concreted in place. Control doors of manganese steel, air operated, were provided on 40 meter vertical intervals. (Sections of these ore passes are still in use for ore transfer). From the pony set, tributary raises were lined with 6 in. x 12 in. cribbing with 8 in. x 8 in. steel H-beam fillers 1 meter square inside measurement.

GDD - Grizzly set was originally a 3-piece segment set (See SS, page 13), later changed to square sets of double 10 x 10 in. pine 5 ft. wide x 6 ft. high inside measurement. Grizzlies - double 10 x 10 in. x 15 ft. pine sills spaced 5 ft. apart with 70 lb. cross rails spaced for 10 in. openings.

BRD - A window of 10 in. x 10 in. cribbing with a 5 ft. inside opening was placed on diagonals in the mouth of the branch raise. (See SO page 10).

Maintenance - Although the ground was firm, much repair of cribbing in transfer raises and branch windows was necessary. Grizzly sets required repair because of wear and blows from blasting and movement of coarse ore.

This layout was used for ore removal in 3 areas, CO 1-2-3, but was replaced by a block caving system with chute and retransfer haulage layout at 3,184 meters elevation as follows: (See Plan 2-e, Page 6).

Central Oxide 1935

Retransfer haulage level - 3,184 meters elevation. Standard chutes were placed at 11 meter intervals.

Retransfer raises - 11 meters apart, inclined 50° with branches in the same vertical plane to serve grizzlies at 16.6 meter intervals in the plane of chute coordinates. A communication drift was provided at 3,202 meters elevation to service main raises at the intersection of the first branch. (See Plate 6, fig. 2).

Grizzly level - 3,212 meters elevation, parallel to and 28 meters vertically above the haulage level.
Grizzly communication drifts were developed with a "through-grizzly" layout spaced 10.6 meters apart and grizzlies at 11 meter intervals. (See Plate 8, fig. 1).

Branch raises - 2 per grizzly at center-sides and developed as above with 3 fingers to the undercut. The individual fingers served a 26 square meter drawpoint, each branch serving 78 square meters of undercut area.

Undercut level - 9 meters above the grizzly level. Developed with drifts only at 8.3 meter intervals and one fringe drift for communication and supply. Undercutting was accomplished by driving stub-drifts into elongated pillars to form long-hole stations followed by long-holing and blasting in a retreating cycle of operations. (See Plate 11, fig. 1).

Isolation - None; since waste had been removed by stripping, ore drawing continued to "day-lighting" of branches.

Extraction control - None, except for drawing distribution to effect caving action.

Timbering

LUD - Standard chute sets with the intervening space supported by 10 x 10 in. standard haulage sets at 1.5 meter centers.

MBD - Full lined with 6 x 12 in. cribbing, 42 in. inside measurement, with angle iron protection.

GDD - Same as initial CO blocks, except that cross rail spacing was changed to 12 in. openings.

BRD - Same as initial CO blocks with a window of cribbing.

Maintenance - Though little crushing occurred, heavy maintenance of main and branch raise cribbing was necessary because of blasting and movement of coarse ore. Also grizzly sets required frequent repairs for the same causes.

This layout was continued through blocks CO 2 - 3 - 4 except for variations such as 3 main raise branches per side because of a bigger interval between haulage and grizzly levels, 58 to 66 meters vertical distance. Also, to utilize waste stripping development for ore extraction, there were some variations in the grizzly level layout.
In 1939, CCO5 was developed as follows:

Retransfer haulage level - 3,184 meters elevation as before. Standard chutes were placed at 25 meter intervals.

Retransfer raises - 50° inclination, with main branch and back-over branches subdivided in a "V" system so that a single chute served 4 to 6 grizzlies on 12.5 x 16.5 meter centers out of plane with the chute coordinates. A communication subdrift was provided at 3,208 meters elevation to service main raises at the lowest branch junction. (See Plate 6, fig. 3).

Grizzly level - 73 meters above the haulage. Communication drifts to grizzlies were developed in a "T-off" system, the main communication being parallel to the haulage with stub crosscuts to grizzlies. (See Plate 8, fig. 2).

Branch raises - 2 per grizzly at sides near the end of the grizzly opposite the communication drift entry. Branches were developed with 3 fingers to the undercut level. Each finger served 37 square meters of drawpoint area and each branch, 111 square meters of area. (See Plate 9, fig. 1-Ox.).

Undercut level - 9 meters above grizzly level. Drifts and crosscuts were driven at 0.3 x 6.5 meter centers, and undercutting was accomplished by widening stations, long-holing and blasting in a retreating operation as before described. (See Plate 11, fig.2).

Isolation - None; as no capping existed in this area, ore drawing continued to "day-lighting" of branches.

Extraction control - None, except for drawing distribution to effect caving action.

Timbering

LDD - Standard chute sets with some standard haulage sets to support intervening space where ground required it.

MED - None. Cribbing was eliminated as ground was firm.

GDD - Grizzlies - 10 in. x 10 in. x 15 ft. pine sills spaced 1.5 meters apart with crossrails (70 lb.) spaced for 14 in. openings. Communication drift timbering was omitted, as ground was firm, and no grizzly sets were used as the location of the branch raises prevented flooding of grizzlies.
Maintenance - With this type of development little maintenance was found necessary, and despite large tonnage drawn through individual branches and main raises, wear did not cause failure of raises except where ground was weak. Some difficulty was encountered by flooding of grizzlies as branch raises were, and stop rails in hitches were placed to combat this. Also, main raise sloughing in weaker ground caused the loss of entry drifts in some cases, since the entries were in the same vertical plane as the intersection of the "V" branches of the main raise system. Short concrete necks were built above chutes in the main raise to counteract wear of the large tonnage drawn per chute (100,000 tons). In general, only minor grizzly and chute repairs were necessary during the life of this block.

Central Oxide 1940 - 1941

Blocks CO 6-7-9-11 followed with a similar type of layout except for a major change in branch raise development, grizzly construction and maintenance methods.

Grizzlies - All-steel construction. Sills were 8 x 8 in. x 15 ft. steel H-beams spaced 5 ft. apart and supported at the ends and center by 70 lb. cross-rails set in hitches. The 70 lb. grizzly crossrails were fixed in place by wooden spacer blocks set in the web of the rail and nailed in place with a 2 in. x 10 in. plank to provide 16 in. openings. (See Plate 18, fig. 2).

Branch raises - 2 per grizzly in a "V" layout so that the intersection of the 2 branches centered in a stub-drift at 1 meter beyond the end of the grizzly opposite the communication drift entry. Each branch was divided into 3 fingers before reaching the undercut level, and coning of the 3 fingers into 1 large drawpoint was done little by little as the fingers plugged during ore drawing operations, eventually resulting in a single large drawpoint per branch, serving 104 square meters of undercut area. (See Plate 9, fig. 1-0x.).

Maintenance - Where branch raise wear or slabbing of brow occurred to the extent of flooding a grizzly, the complete grizzly was raised sufficiently to again give brow protection and still leave sufficient head room for the grizzly man to work. Also, in
some cases, concrete arches were placed at the branch raise entry to grizzly to reinforce the brow, and concrete piers were built beneath the sills where the ground was too weak for ordinary cross rail support.

**Central Oxide 1942**

In 1942, CO-14 was developed with a similar type layout but with a major change in the grizzly level communication system and undercutting method.

**Grizzly level** - Developed with a "T-off" layout, but the main grizzly communications were located normal to the haulage and halfway between chute coordinates. From this communication drift, stub-drift entries were driven to grizzlies so that all communication drifts were located out of the planes of main raises. This effectively solved the problem of main raise wear or sloughing destroying grizzly entry drifts, and increased the safety during blasting operations. (See Plate 6, fig. 4; also Plate 8, fig. 3).

**Branch raises** - Developed as before, but each branch was divided into 4 fingers and the coning of these fingers to a single large drawpoint was now accomplished as part of the undercutting operation. (Final drawpoint area, 104 square meters per branch). (See Plate 9, fig. 2-Ox.).

**Undercutting** - The major part of undercutting was now accomplished by stopers in coning the branch raise fingers to a common drawpoint, and a minimum of long-holing and plugging completed the operation. This method resulted in cheaper, faster undercutting, and as the ground was firm, no sacrifice of safety was made. (See Plate 11, fig. 3).

This layout has been followed through to date, and has proved most satisfactory in economical development and extraction, and requires very little maintenance other than the previously described raising of grizzlies and construction of branch raise entry arches and concrete piers to support sills where required during ore drawing operations.
The earliest Central Sulfide blocks were developed from the 3,032 meter elevation retransfer haulage level with long tributary raises to a grizzly level at 3,130 meters elevation serving an undercut level at 3,138 meters elevation. (See Plan 2-f, page 6). The layout was as follows:

Retransfer level - 3,032 meters elevation, standard haulage section, with gathering spurs at 34 meter intervals. Standard chutes were placed at 12.5 meter intervals.

Retransfer raises - 50° inclination, 1 x 1 meter section branched to serve grizzlies at 10 meter intervals on the 3,130 meter elevation grizzly level, all in the same vertical plane. The west side chute of a pony set and its tributary main raise system served six grizzlies of one block, and the corresponding system on the east side served grizzlies of another block. Communication subdrifts were provided to service the junction points of main raise branches, and at the uppermost communication level (elevation 3,112-18 meters) each main raise branch was provided with a control door, and the space above the door to the grizzly was used as a measuring pocket for the control of ore drawing. (See Plate 5, fig. 1).

Grizzly Drifts - 98 meters above the haulage level. The grizzly communication drifts were developed as a "through-grizzly" layout, spaced 12.5 meters apart in the planes of the main raise systems. (See Plate 7, fig. 1).

Branch raises - 2 per grizzly at center sides. Each branch was inclined 45° for 3,125 meters vertical distance to a control set from which 2, 3 or 4 fingers extended to the undercutting level. (See Plate 9, fig. 1-s).

Undercut level - 9 meters above the grizzlies. Drifts and crosscuts were driven at 12.5 meter centers, and undercutting was accomplished by the usual widening of stations, long-holing and blasting in a re-treating cycle of operations. (See Plate 10, fig. 1 & 2).
Isolation - Each of the 50 meter width blocks was planned to have isolation on the north, south and east panels. Since the west side was adjacent to the San Antonio fault, none was necessary there.

Isolation workings consisted of a full panel checkerboard of raises at 45° inclination on 12 meter centers as before described in the South Sulphide. (See Page 13). (See also Plate 12, fig. 1 & 2).

Extraction control - As previously described in the South Sulphide, page 13, except that the measuring pockets were used to check tonnage drawn from each branch instead of calibrated raisefuls. Running of ore in long raises was difficult, costly, and slow; and heavy maintenance made ore drawing distribution difficult.

Timbering

LHD - Standard haulage sets at 1.5 meter spacing with standard chute sets at 12.5 meter centers.

MED - Timbered with 6 x 12 in. cribbing 3-1/2 ft. inside measurement, and reinforced in the lower sections with 8 x 8 in. steel H-beam fillers, and 3-1/2 in. angle iron in the upper sections as a protection against wear.

GDD - 3-piece 10 x 10 in. framed sets at 1 meter centers.

Grizzlies - double 10 x 10 in. sills with 70-lb. crossrails spaced for 10 in. openings. Grizzly set - square sets of 10 x 10 in. timber, 6 ft. x 5 ft. inside dimensions; caps and sills were generally doubled. (See Plate 15).

BRD - Cribbing, control set and details were the same as in South Sulphide. (See Page 15).

Maintenance - Heavy maintenance was necessary in main-raise, branch-raise, and finger-raise cribbing. Crushing due to the proximity of the San Antonio fault on the west side demanded heavy repair of the control sets and on the grizzly level. Ore removal through long raises entailed much supervision, blasting of hangups, etc., and it was not possible to maintain production requirements with the system.

Blocks CS 1-2-3-4-5 were partially or completely developed with this layout, but ore withdrawal operations were only carried through CS 1 and 3, when, in 1933, it was decided to drive a third retransfer level for the handling of this upper Central Sulphide ore. (See Plan 3, page 7, and South Sulphide, page 15).
Development then continued as follows:

2. Central Sulfide 1934

Retransfer level - 3,112 meters elevation, standard haulage section, connected to dumping stations on ore passes to adit level bins with gathering spurs at 30 meter intervals. Standard chutes were placed at alternate 6.25 meter and 9.37 meter centers to accommodate Granby car trains.

Retransfer raises - 50° inclination, developed with 6 branches in the same plane to serve grizzlies at 5 meter centers; alternate raises were inclined so that the grizzly drifts served were regularly spaced 7.8 meters apart. (See Plate 5, fig. 2).

Grizzly level - 20 meters above the haulage level. Grizzly communication drifts were developed on a "through-grizzly" layout in the planes of main raises regularly spaced at 7.8 meters with grizzlies at 5 meter intervals. (See Plate 7, fig. 2).

Branch raises - 2 per grizzly at center-sides, driven 2.97 meters at 45° (to end of cribbing window), then 4.18 meters at 78° to undercut level. The tops of raises at the undercut level were coned to 2 meters diameter. Each branch served 19.5 square meters drawpoint. (See Plate 9, fig. 2-s).

Undercut level - 6 meters above the grizzly level. Drifts and crosscuts were driven at 7.8 x 7.5 meter centers. Undercutting was accomplished by widening stations, longholing and blasting in a retreating cycle of operations. (See Plate 10, fig. 3).

Isolation - Full panel checkerboard on solid boundaries. (See Plate 12, fig. 1 & 2).

Extraction control - As described under South Sulfide, page 18.

Timbering

LDD - Standard chute sets with the intervening space supported by 10 in. x 10 in. standard haulage sets at 1.5 meter centers.

MRD - Fully lined with 6 in. x 12 in. cribbing 42 in. inside measurement with angle iron protection. (See Plate 5, fig. 2).

GDD - Square framed grizzly sets of 10 in. x 10 in. timber, 5 ft. x 6 ft. x 42 in. inside measurement. Generally doubled caps and sills with 70 lb. cross rails spaced for 12 in. openings. The intervening space between grizzlies was supported by 3-piece framed
sets of 10 in. x 10 in. timber at 1.5 meter centers.

BRD - A window of 6 in. x 12 in. cribbing 5 ft. inside measurement was placed on diagonals from the grizzly set. No control set was used, as each branch raise drew ore directly from the undercut, and a stoprail on the grizzly set was used for ore drawing control.

UCD - Light temporary timber.

Maintenance - Crushing in localized areas demanded heavy maintenance, and cribbing of main raises and branch windows required frequent repair because of blasting of hangups, wear and crushing.

This layout, in general, prevailed for sulfide blocks until 1943, except for the following important changes in development details:

Timbering practice - Changed after 1936 to the use of lighter and less timber, as follows:

LDD - In ground strong enough to stand, drifting was planned so that the back was arched and left unsupported. Where timbering was necessary, 8 in x 8 in. standard haulage sets or sets made of plank and block were placed as far apart as possible, 1.5 to 2.5 meters. Standard chute sets were built of lighter timber where ground permitted, resulting in a saving of 519 bd. ft. of timber per chute. In strongest ground, the posts of the standard chute layout were eliminated, and the chute was supported by caps set in hitches. Backlagging, where used, was 2 in. x 10 in. plank and side lagging, used only in weakest ground, was of 1 in. x 6 in. plank.

MRD - None, except in ground too weak to stand. Here, 3 in. x 10 in. (42 in. inside measurement) cribbing was placed 2 in. apart with no angle iron protection.

GDD - Grizzlies were constructed of 5 in. x 10 in. x 10 ft. sills with 40 lb. rails spaced for 12 in. openings, held in place by space block and plank. Main raise openings below grizzlies were driven with a vertical section and small enough to provide support for grizzly sills. Where ground was weak, cross supports of 8 in. x 8 in. timber set in hitches were placed below grizzly sills. Grizzly sets were unframed 8 in. x 8 in. solid timber or of plank and block construction 6 ft. x 6-1/2 ft. x 42 in. inside measurement, or, if the ground was weak and the drift section enlarged excessively in driving branch raises (driven before timber was placed, where possible), higher sets
were placed to fit the ground. All sets were
blocked to solid ground, both sides and back,
with a fill of old timber. 1 or 2 stop rails
were placed at the entry to branches for draw­ing control depending on the height of the set.
(See Plate 16 & 17). The space between grizzlies
was left unsupported in stronger ground and sup­ported where necessary with light drift sets.
Back lagging was 2 in. x 6 in. plank and side
lagging, 1 in. x 6 in., used only where ground
was weak. Light willow pole lagging was used
successfully when available.

BRT - None. Windows of cribbing in branch raises
were eliminated as unnecessary in 1937.

UCD - None, except for stulls and headboards where
necessary for safety.

Isolation - In 1938 the full side panel checkboard system
of raises at 45° was changed to corner vertical
raises with short subdrifts and connecting raises
on corners only, as described under South Sul­
face, (Page 18). (See Plate 12, fig. 3).

Main raise - In 1940, main raises were redesigned so that
all branches terminated in a vertical section at
least 2.22 meters long, below the grizzly sills,
then planing to 50° to the haulage chutes, result­
ing in less grizzly support failure. (See Plate 5,
fig. 4).

Maintenance - Localized crushing demanded maintenance,
gerenally after middle life of block withdrawal
operations. To increase the life of the sets as
crushing appeared, diagonal braces were placed
under grizzly caps, and stulls under drift caps.
Extra collar braces were placed to combat side
pressure. Where branch raise wear or sloughing
enlarged the opening excessively, grizzly sets
were increased in size by placing longer posts
and caps in order that the set could again be
blocked to solid ground out of the area of bould­
er blows and blasting. Where complete failure
of sets occurred because of crushing, the drift
was redriven and retimbered with 10 in x 10 in.
timber, usually after a period of time sufficient
for the crushing action to subside and the broken
material to partially consolidate.

Main raise wear or sloughing below the sills in
weaker ground was combatted successfully by
placing elliptical barrel forms and pouring a
concrete neck for a few feet below the sills, re­
inforced and tied to solid ground with old drill
steel set in plug-holes. Where crushing caused
main raise failure, the raise was cribbed with
3 in. x 10 in. cribbing of section as large as could be placed without removing solid ground. Haulage drifts required little maintenance, and isolated cases of crushing were effectively supported by "doubling-up" sets.

With this general layout and subsequent changes, Blocks CS 2-4-5-6-7-8-9-10-11-12-14-15-16-17-18-21-22-23-24-25-26-27-28-29-35 and 36 were mined from the 3,112 meter elevation retransfer haulage system.

Blocks CS 50-51-52-53-54-55-56-57-58-60-61-63 and 68, mined from the 3,032 meter elevation retransfer haulage, were also mined with substantially the same layout, except that the retransfer haulage spurs for these blocks were spaced at 34 meter intervals, resulting in a 10 meter interval between the two grizzlies served by the adjacent outside branches of main raises on a given coordinate. This interval was covered by drawpoints formed by driving branch raises in the form of centers from these grizzlies, but had the undesirable effect of decreasing ventilation and communication entries, as well as weakening the protecting pillar of these grizzlies with a third branch raise.

Central Sulfide 1943

In 1943, CS 34 was developed from the 3,112 meter elevation haulage with the same layout but eliminating every other main raise and its corresponding grizzly and branch raise system as an experiment to observe the effect of wider drawpoint spacing in sulfide ore mining. This block lay directly beneath an area cleared of waste and oxide by previous mining, so that overburden was no consideration in caving the block.
until ground subsidence caused by ore removal from the block increased the surface cave slope-angle such as to bring adjoining waste into the area. This block was developed as follows:

Retransfer haulage drift - 3,112 meters elevation, standard chutes were placed at 15.6 meter intervals.

Retransfer raise - 54° - 30' inclination. These raises were developed with a single back-over branch per main raise system in the same plane at 60° inclination, and all branches had a vertical section below the grizzly sills 2.5 meters long. Raises were placed on 15.6 meter coordinates branched to serve grizzlies at 10 meter intervals. (See Plate 5, fig. 5).

Grizzly level - 18 meters vertically above the haulage level. Grizzly communication drifts were developed with a "through-grizzly" layout on regular 15.6 meter intervals, grizzlies 10 meters apart. (See Plate 7, fig. 3).

Branch raises - 2 at center-sides, driven 5.9 meters at 45° from grizzly center, then subdivided into 3 fingers 5.17 meters long at 51°-30' to the undercut level. These fingers were coned to a single drawpoint in advance of and in conjunction with undercutting operations. Each branch served 78 square meters of undercut area. (See Plate 9, fig. 5).

Undercut level - 9 meters above the grizzly level. Drifts and crosscuts were developed on 7.8 x 10 meter centers, so placed that the 3 fingers of each branch broke on 3 corners of a pillar. Undercutting was accomplished by a combination of Leyner longholes and stoper coning of branch raises with no widening stations. This resulted in cheaper, faster undercutting. Since the ground was firm, and no crushing occurred, little difficulty and no sacrifice of safety was encountered with this method. (See Plate 10, fig. 4).

Isolation - As before described, concentrating on solid boundary corners.

Extraction control - As described under South Sulfide, (page 18).

Timbering
LDD - Standard chute sets with few sets necessary to support the interval between chutes.
MRD - None.
GDD - Grizzly sets and grizzlies as described on page 32 (Central Sulfide). A small drift set at each end of the grizzly set proved sufficient support for the intervening space, as the ground remained firm for the life of the block and communication drifts stood unsupported.

BRD - None.

UCD - None.

Maintenance - Very light and none due to crushing. Stronger pillar support effectively avoided crushing, and maintenance consisted of repairing caps or posts broken by boulder blows or blasting. Where branch raises were excessively large, grizzly sets were placed to fit the ground. Despite increased tonnage handled by the individual branch raises and main raises, none wore sufficiently to require more than minor repairs as described.

Central Sulfide 1944

In 1944, CS 37 (3,112 meter elevation haulage) and CS 64 (3,032 meter elevation haulage) were developed, following the idea of wider spacing but with a smaller drawpoint area than block CS-34, as in these blocks overburden had to be considered. The layout was the following:

Haulage level - Standard chutes at regular 12.5 meter intervals.

Retransfer raises - 50° inclination at 12.5 meter intervals. These raises were developed with one back-over branch per side to serve grizzlies 7.5 meters apart. Each branch terminated in a 4.5 meter vertical section below the grizzly sills. (See Plate 5, fig. 6).

Grizzly level - 20 meters above the haulage level. Grizzly communication drifts were developed on a "through-grizzly" system spaced on regular 12.5 meter intervals with the grizzlies 7.5 meters apart. (See Plate 7, fig. 4).

Branch raises - 2 per grizzly at center-sides. Each branch was driven 4.4 meters at 45°, then divided into 4 branches (less, if ground was weak), each 4.8 meters long at 54° 30’ to the undercut. These fingers were eventually coned to a single drawpoint during undercutting operations. Each branch served 47 square meters of drawpoint area. (See Plate 9, fig. 4-s).
Undercut level - 7 meters above the grizzly level. Drifts and crosscuts were developed on 6.25 x 7.5 meter centers so arranged that the 4 fingers of a branch raise broke on the four corners of the pillar above. Undercutting was accomplished chiefly by coning the fingers to a single drawpoint nor supplemented by as much Leyner long-hole work and jackhammer plugging from the undercut level as was necessary to complete the removal of pillars. Some difficulty was encountered because of crushing of undercut pillars during undercutting operations, and present practice is to drive only 2 diagonally opposite fingers of a branch as initial work; the other 2 to be driven as part of undercutting work in order to maintain stronger undercut pillar support during development and undercutting operations. (See Plate 10, fig. 5).

Isolation - 4s before, concentrating on solid corners.

Extraction control - As described under South Sulfide, page 18).

Timbering

LDD - Standard chute sets with the intervening space supported where necessary with 8 in. x 8 in. standard haulage sets or sets of plank and block at 1.5 to 2.5 meter intervals.

MED - None.

GDB - Grizzly sets and grizzlies as described under Central Sulfide, page 32. The intervening space between grizzlies was timbered, where necessary, with light unframed sets.

BED - None.

UCD - None.

Maintenance - Light, and none due to crushing, despite the crushing of undercut pillars during undercutting operations. All repair was caused by boulder blows, blasting, or wear of branch and main raises. This was handled in the manner described under Central Sulfide, page 33. Although the tonnage removed per individual branch and main raise was greater than in former Central Sulfide blocks other than CS 34, branch raise and main raise wear demanded only minor repairs during the life of the blocks.

Blocks CS 65 and 66 have been mined from the 3,032 elevation haulage level with this same layout. Although it is commonly thought in caving practice that dilution control is lessened with wider drawpoint spacing, extraction efficiency
was good in these blocks, no ore loss occurred and dilution with overburden was kept at a minimum despite its appearance as early as 10% of block extraction. It is my belief that careful control, aided immeasurably by no grizzly nor communication drift failure because of crushing (avoided by strong pillar support in this system), makes up for any control lost by wider spacing. The limit to which this is true is not definitely known and can only be proven by trial.

Central Sulfide 1946

In 1946, block S 2 was placed in ore-production. This block was developed with a change in grizzly level layout and grizzly spacing, as an experiment to observe the effectiveness of a "T-off" grizzly level layout in sulfide blocks. The grizzlies were spaced to serve drawpoint areas intermediary in size between the 19.5 square meters and 47 square meters system. The block was developed as follows:

Retransfer haulage - 3,112 meters elevation haulage level, with standard chutes at 9.375 meter intervals.

Main raises - The same as described under CS 37-64 (page 36), except that the interval between raises was changed to 9.375 meters. (See Plate 5, fig. 6).

Grizzly level - Grizzly communication drifts were developed with a "T-off" layout, 20 meters above the haulage level. Main communications were parallel to the haulage drift and 15 meters apart with stub drift entries to grizzlies on 9.375 meter intervals, and no "through-grizzly" connections from one communication drift to the next. A fringe drift at each end of the block in solid ground served as main communication entry and ventilation drift. (See Plate 7, fig. 6).

Branch raises - The same as described under CS 37 (page 36), and final coned branch served 31.6 square meters of drawpoint area.

Undercut level - 7 meters above the grizzly level.
Drifts and crosscuts were developed on 9.375 x 7.5 meter centers. Undercutting was accomplished as before, by stoper coning of branch raises and supplementary plugging and long-holing from undercut level, where necessary. (See Plate 10, fig. 6).

Isolation - As before, concentrating on corners.

Extraction control - As described under South Sulfide, (page 18).

Timbering
- LDD - Standard chute sets with those in firmer ground placed on caps in hitches, omitting posts. Intervening space was timbered as necessary, but stood chiefly unsupported.

BRD - None.

MRD - None. Two per grizzly at center-sides, staggered.

CDD - Grizzly sets and grizzlies as described under Central Sulfide (page 32).

BED - None.

UCD - None.

MDD - None.

Maintenance - Although some crushing of undercut pillars occurred during undercutting operations, and to a lesser degree, crushing transferred to the grizzly level, the supporting pillars were not destroyed, and minor repair sufficed. To date, this block has required little maintenance, although in weaker ground than average mine rock. Extraction efficiency is not yet known, as the block is still in production, but present indications are good, and the layout is considered worth further trial.

In order to recover Central Sulfide ore located below the 3,032 meter elevation haulage level, blocks are at present being developed from the lowest elevation mine haulage, the Main Adit, as follows: (See Plan 3, page 7).

Haulage level - 2,982 meters elevation, 3.05 x 3.25 meters section, to accommodate the 40-ton Ingoldsbay ore cars used on the mine-to-mill railroad. Gathering spurs are spaced at 72 meter intervals. Scraper drifts - 2,985 meters elevation, (4 meters above the base of the main adit rails). These drifts are 1.80 x 2 meters section and spaced 12.50 meters apart, normal to the gathering spurs, and driven with an in-line arrangement so that 1 hoist can serve 2 scraper drifts, each 35 meters long.

-39-
Transfer raises - Driven on one side of the scraper drift only, 1 meter diameter circular section, on a 45° inclination from the center of the scraper drift floor for 3.53 meters, then vertically for 3.50 meters to the grizzly level. These are regularly spaced 7 meters apart in planes normal to the axes of the scraper drifts.

Grizzly level - 2,992 meters elevation, 6 meters above the scraper drift floor. Developed on a "T-off" system with the main communication drifts normal to the scraper drifts at 14 meter intervals. Stub drift entries to grizzlies are located 12.5 meters apart. A fringe drift is provided for grizzly drift communication along 2 edges of the block.

Branch raises - Two per grizzly at center-sides, developed as in blocks CS 37-64-05 and 66, previously described - a 4 finger system eventually coned during undercutting operations into a single drawpoint area serving 44 square meters.

Undercut level - 7.5 meters above the grizzlies. Drifts and crosscuts are located at 7 x 6.25 meter centers. Undercutting is accomplished chiefly by the coning of the 4 fingers of branch raises, completed with a minimum of Leyner long-holes and jackhammer plugging where necessary, from the undercut level, in a retreating operation.

Isolation - As in previous blocks, concentrating on corners with vertical raises and a system of 45° raises and subdrifts up to the 3,032 meter elevation haulage.

Extraction control - As before described under South Sulfide (page 18), except that the amount of ore drawn daily from individual branches is calculated from railroad cars filled instead of calibrated transfer raisefuls as in ordinary blocks.

Scraping equipment - The motive power for the 54 in. Westco scrapers are 30 or 50 horsepower electric double-drum tugger hoists mounted on short wheel base 36 in. gauge turn table mounts. These hoists are equipped with 3/4 in. cable. Idler sheaves and tail-pulley are 12 in. anchored in drill holes by wedge eye-bolts.

Timbering - To serve as a base for the hoists, 4 sills of 8 in. x 8 in. x 16 ft. timber are placed across the haulage drift with the ends in the floor of opposite scraper drift entries. Scraper chutes are built upon them by placing 6 ft. cross ties side to side, leaving an opening 36 in. x 48 in. over the center of the haulage drift. Upon these are nailed
30 lb. rails 6 in. apart, parallel to the scraper drifts. Outside rails are 30 ft. long and bent at either end on a 30 in. radius. These are placed 36 in. apart on either side of the discharge opening to serve as a track for the turn-table hoist mount. Between these are nailed 13 ft. rails bent in like fashion, and the curved ends of all rails are set in a concrete block at the scraper approach end. 2 cross rails beneath the floor rails are located to serve as an anchor for fastening down the hoist with a turnbuckle attachment. Side boards are 3 in. x 10 in. plank.

**SDD** - No support is necessary, as ground is hard. "Jingle-bars" (8 in. x 42 in. poles) are hung by chains from a cross rail held in place by wedge anchor-bolts cemented in place in the mouths of transfer raises to control the flow of ore into scraper drifts.

**GDD** - Grizzlies are constructed with 5 in. x 8 in. x 10 ft. sills placed 42 in. apart with 70 lb. cross rails spaced for 12 in. openings and held in place by space block and plank. As the ground is hard, in general no grizzly sets are placed, and to control ore drawing, stop rails are attached by chains to wedge anchor-bolts cemented in drill holes in the branch raise entries.

**BRD** - None.

**Maintenance** - The initial block is still in an early stage of production, and no maintenance has been necessary. No crushing of extraction openings has occurred to date.

As an experiment, one scraper drift in this block is provided with a 30 in. rubber conveyor belt system instead of scrapers. The layout of scraper drifts, grizzly drift, branch raises and undercut in this area is unchanged, but the transfer raises from conveyor drift to grizzlies are driven on a 50° inclination from the center back and parallel to the conveyor drift, so that ore will flow in the direction in which the belt travels. The drive mechanism and pulleys are mounted on steel and concrete bases, and ore is transferred by the belt directly into the Ingoldsby cars.
Additional blocks in this area are being developed with minor changes planned, but to date no plans have been made for the removal of ore underlying this area.
PART II

1. Size of blocks

The following is a discussion of block caving practice at Andes, based on the foregoing historical study of its development together with data and ideas derived from seven years of study, observation and practice at this property, during which time 65,000,000 metric tons of copper ore have been extracted from the Potrerillos mine.

General Mining Plan

Any plan of development of a block caving system should follow the three guiding principles of any successful operation; namely, safety, efficiency and productive capacity.

The general development plan must consider the character of the orebody to be caved and its division into blocks of a size consistent with successful practice. This largely determines the location and layout of transfer systems to withdraw ore from the undercut area. In general, the following are of major importance:

A. Size and shape of orebody. This controls the location and layout of ore transfer levels, ore passes, and the orientation of blocks.

B. Character of ore. This controls the size of blocks, the drawpoint spacing, the amount of isolation weakening necessary to promote caving, the amount of timbering necessary for support of openings, and the productive capacity of a block until it is at least 50% extracted.

C. Overburden. This determines the drawpoint spacing
and the degree of control necessary for efficient extraction.

See pages 2, 3 & 4, Part I, for a discussion of the character of the Andes orebody.

1. Size of blocks

The horizontal area of a block is limited by the caveability of the ore and overburden, and in rough proportion varies directly as the hardness and fractural character of the ore, in that the block must be of sufficient area to cave freely when undercut and small enough to avoid excessive crushing and consequent maintenance of extraction openings. Andes blocks as large as 200 meters x 70 meters and as small as 30 meters x 30 meters have been caved, but, as a compromise between free caving and maintenance costs, present practice is to limit sulfide blocks (soft and friable ore with overburden) in general to 60 x 60 meters, and oxide blocks (harder ore and no overburden) to 100 x 50 meters.

The vertical height of a block is limited by the depth of the orebody and its dip, as well as the character of the ore. At Andes, the oxide blocks are designed to take all of the ore in a single lift with overburden generally not a problem. Blocks average 80 meters in height. Sulfide blocks have been caved with an average ore back as small as 30 meters with an overburden of 400 meters, and as large as 110 meter ore back with 200 meters of overburden, but, where possible, blocks are limited to 60 - 80 meters of ore back. The overburden averages from 20 meters to 200 meters depth. Successful practice at this and other mines using the block...
caving system has shown that 100 meters of vertical ore height is the greatest lift practicable where the character of the orebody allows a choice of block height. The following considerations bear out this statement:

Maintenance work increases with the volume of ore drawn from a given area. This is a result of the wear of extraction openings and the frequent crushing effect of the overlying "live" weight remaining when the block has caved to its vertical limits and shearing along boundaries is complete, usually when extraction has proceeded to 50% or more. When the latter occurs, time of extraction operations becomes an important factor in maintenance costs, as extraction openings must be maintained to continue production.

Extraction efficiency depends on effective caving and dilution control. Since the problem of dilution generally arises when blocks are 20 - 30% extracted, its control is simpler in blocks of medium height with less ore affected in a given block. Ore loss because of poor caving is not so critical in blocks of medium height, especially if the area is again mined from lower horizon blocks whose boundaries do not conform to previously mined blocks above. The ore tied up in pillar supports and drawpoint cones is mined from lower horizon blocks, and the lowest blocks may be planned so that extraction openings lie below the ore horizon.

Because of crushing and abrasive action, there is an increase of fines in the ore as the volume of ore drawn from a block increases, with a consequent increase of dust
in the atmosphere of the working levels as extraction proceeds. This is undesirable for both safety and health considerations.

The disadvantages of a smaller vertical height of blocks are increased development costs by duplicating the extraction openings on a lower horizon; and, to a minor degree, the additional amount of secondary ore breaking on grizzlies. However, these disadvantages are offset by lesser maintenance costs, improved extraction efficiency and better working conditions.

2. Location of transfer haulage levels

These levels are determined by the location of ore horizons, the location of the mine-to-mill transfer system and the vertical height of blocks, together with the length and inclination of transfer raises (grizzly to haulage chute) consistent with successful practice.

Since Andes was developed with an adit mine-to-mill transfer level, the location of intermediary transfer haulage levels was controlled by the location of the oxide ore horizon and the vertical height of sulphide ore above the adit level. Although the south ore body is flatter in dip than the central ore body, transfer levels are extensions located on the same elevation in order to utilize the same ore pass system. (See Plates 1, 2, 3, 4).

Oxide transfer haulage level - 3,184 meters elevation. This level served blocks with grizzly levels located in the footwall zone of the oxide ore horizon from 28 to 78 meters vertical distance above the haulage with main trans-
fer raises designed on a 50° inclination. This also served for the withdrawal of upper South Sulfide. (See Page 16).

Sulfide transfer haulage levels - 2,982 meters elevation (mine-to-mill adit), 3,032 meters elevation, and 3,112 meters elevation. Earlier development in the South Sulfide had blocks designed so that the transfer level served blocks with grizzly levels located from 13.23 meters to 83 meters vertically above the haulage. Main transfer raises were designed on a 50°-30' inclination. Later development consisted almost entirely of blocks designed with grizzly levels 19-20 meters vertically above the haulage. The main transfer raises were inclined 50° or 54°. Most recently developed blocks from the 2,982 meter elevation mine-to-mill adit level are designed with a scraper drift system in order to utilize the lowest elevation mine haulage level as an ore transfer system for mining a maximum height of ore remaining below the 3,112 meter elevation haulage blocks.

In general, practice has shown that the location of transfer haulage levels with respect to grizzly levels of blocks served by them, using a gathering main transfer raise system, is variable to suit local conditions, but the minimum practicable difference of elevation is 18 to 20 meters. This height provides sufficient pillar support for haulage drifts and allows room for a branching main raise system of strong design with an inclination
from chutes to grizzlies of not less than 50° with ample
coverage of the grizzly area and ample ore storage for
car loading efficiency. Excessively long gathering raise
systems, as well as ore transfer raises flatter than 50°
have been conclusively proven impracticable. (See South
Sulfide, page 17, Central Oxide, page 23, and Central
Sulfide, page 29).

With the general mining plan decided upon, the
problems concerned with developing the intermediary trans­
fer haulage levels and individual blocks for safe,
efficient ore removal at a rate to meet production re­
quirements follow.

3. Layout of Transfer Haulage Levels

There are two types of transfer haulage layouts at
Andes. (See Plates 1, 2, 3, 4).

a. Converging system - The main line haulage drifts
to ore pass dumping stations are driven as two
fringe drifts; that is, outside and on either
side of the ore body. These converge at the
dumping stations and are joined by gathering
drifts crossing the ore body at intervals
which are determined by the area of individual
blocks and by main transfer raise design. With
this layout, ore trains are loaded from gather­
ing drift chutes and deliver their loads via
one fringe drift to ore passes and return by
the other fringe drift; all trains, loaded or
empty, being routed in a common direction.

b. Branching main line system - The main line to
ore pass dumping stations is located outside
of the ore body and spur drifts are driven
from it at intervals under the orebody. With
this layout, ore trains are loaded from the
spur drift chutes and deliver their loads to
ore passes via the main line, returning empty
by reversing along the main route.

The converging system is much to be preferred, in
that it is more flexible, provides better ventilation,
increases the daily producing capacity of a given drift 100% or more, and requires less control for safe routing of traffic than does the single main-line system. Its application is limited, however, by the proximity of producing and future blocks to existing ore passes and the greater initial drift driving with respect to the ore tonnage involved.

All transportation systems of either design at Andes are driven a standard size to accommodate the Granby car trains. Track is 40 lb. rail placed at 1 meter gauge on crossties at 80 cm. intervals. Curves have 30 meter radii. Safety features include centrally controlled electric signal light systems, buzzer warning signals where necessary on curves, ample electric lighting, and telephone communication between gathering drifts, grizzlies, switchman and dispatcher. Safety stub drifts are provided at switch throws, and lighted safety entries are located at convenient intervals in untimbered drifts. Standard haulage sets provide 2 feet of clearance between cars and timber, and all chute ladders or manways are placed with at least this much clearance also. The intersection point of main line with spur or gathering drifts is timbered solidly with timber packs.

The intervals between gathering drifts or spurs are 30 meters, 33 meters or 50 meters, depending on the width of the block served and the difference in elevation from grizzlies to haulage level.
Gathering systems using conveyors either of the belt or shaker type, together with slusher feeders instead of haulage drifts and trains, are being considered for recovering ore below the adit level. Here, the additional cost of shaft sinking and ore hoisting, plus storage bin construction for supplying the mine-to-mill adit trains, added to the higher cost of mine haulage drifts compared to a simpler layout of smaller section conveyor and scraper drifts, makes the latter system a definite possibility. With this in view, a small scale experiment is being conducted with a conveyor belt and slusher drift system as discussed under Central Sulfide, page 41.

4. Block Development

Blocks are developed in a sequence of operations proceeding upwards to take advantage of gravity removal of ground broken with a minimum of hand shoveling or tramming as development openings advance. The most important consideration controlling the layout of these extraction openings is drawpoint area. Drawpoint area may be defined as the undercut area served by an individual branch raise, and in a plan of equal branch raise intervals it is equal to the undercut area of the block divided by the number of branch raises in the block.

Experience has proven that no matter how great the drawpoint area, channelling occurs through a comparatively small area nearly vertical over a drawpoint in broken rock and along weakest structures in caving rock at a rate proportional to the speed of withdrawal. Drawpoint spacing
is, therefore, planned considering the caving characteristics of the block and the presence or absence of waste overburden. In general, closer spacing is desirable in blocks overlain by waste overburden, especially if the ore is soft and talcy. This type of ore packs easily, channels through a smaller area and has little tendency to arch; hence, branch raises will not maintain their forms or positions. In harder ore, greater drawpoint spacing is feasible, and where no overburden exists spacing is as great as is practicable for the removal of broken ore from the undercut level during development and extraction operations.

Drawpoint spacing determines the number of extraction openings necessary to develop a block, and thus the cost and time of development. It is also an important factor in the extraction control and the productive capacity of a block, as well as in the amount of work necessary to maintain extraction openings. Thus, the cost and efficiency of extraction of a block are largely determined by the proper selection of the drawpoint spacing. At Andes, four spacings are being used successfully.

(1) Weak, freely caving ore with waste overburden - Grizzlies spaced 5 x 7.8 meters, each serving 2 branch raises of 19.5 square meters drawpoint area. (See Plate 10, fig. 3).

(2) Weak, freely caving ore with waste overburden - Grizzlies spaced 7-1/2 x 9-1/3 meters, each serving 2 branch raises of 34.8 square meters drawpoint area. (See Plate 10, fig. 6).

(3) Firm slowly caving ore, with waste overburden -
Grizzlies spaced 7-1/2 x 12-1/2 meters, each serving 2 branch raises of 46.9 square meters drawpoint area. (See Plate 10, fig. 5).

(4) Firm slowly caving ore, no waste overburden - Grizzlies spaced 12.5 x 16-2/3 meters, each serving 2 branch raises of 104 square meters drawpoint area. (See Plate 11, fig. 3).

Main transfer raises - The purpose of main raises is to transfer ore from grizzlies to haulage level chutes. Chute location and design are governed by the principles of efficient car loading. Main raise length is governed by the difference in elevation between haulage and grizzlies. Main raise design is controlled by the principles of efficient gravity ore flow and pillar strength, plus the consideration of grizzly level coverage, storage capacity and wear due to ore drawing.

Interval between main raises: This is governed by the length of cars in haulage level trains, since most efficient car loading results when chutes are spaced so that a single "spotting" of a train accommodates loading from all the chutes in that area. At Andes, some blocks have alternate main raises planned to right or left of their respective chutes to accommodate a grizzly drift interval, not a multiple of car lengths.

Inclination: Not less than 50° for efficient gravity ore flow. Steeper raising is practical where local conditions require it.

Form: To provide strong pillar support between branches and below grizzlies, the design, number and location of main raise branches is important. The number of branches...
in a main raise is controlled chiefly by the difference in elevation from chute to grizzly level, the interval between haulage drifts and the grizzly coverage of a single raise system necessary to serve a grizzly drawing area consistent with successful practice. (See Plates 5 and 6).

For maximum pillar strength in a main raise system, it has been found best to have a vertical section below grizzlies, both in the main trunk and in its branch feeders. The junctions of branches with the trunk raise are kept as far as possible below grizzlies and as nearly normal to the trunk raise as possible for greater pillar strength.

At Andes, a single haulage chute has served as many as 6 grizzlies in an oxide block where the haulage to grizzly interval was 73 meters, but present practice is to limit the number of grizzlies per chute to 2 or 4 in the oxide system (27 meters grizzly to haulage), using a "V" branching layout out of plane with the trunk raise, and the junctions 12 meters below the grizzly level. In the sulfide system (19-20 meters grizzly to haulage), 2 or 3 grizzlies are served per chute, with the junctions 8 to 10 meters below the grizzly level, using an in plane "back-over" branch layout. It is noted that in weaker ground (but ground sufficiently strong to be driven without cribbing) main raises are usually well worn after 40,000 tons have passed through them. In blocks where raises are longer and junctions are farther apart, 250,000
tons have been passed through unlined raises without any failure. An unlined orepass for transferring South Oxide ore has passed 2,000,000 tons and is still in successful operation.

Size and support: When possible, raises are driven and the ore withdrawn through them without timber support, resulting in most economical development and most efficient and trouble-free ore withdrawal. Since ore drawing results in main raises wearing to a larger cross section at a rate governed by the hardness of the rock through which they are driven, it is expedient to drive the initial cross section at a minimum through which grizzly-sized ore will run with a minimum of hang-ups. This is especially true in the vertical section below the grizzlies.

At Andes, this has been found to be a 1 meter cross section. Where the ground is so weak as to require support, cribbing is placed with a 42 in. inside section.

Grizzly level - The purpose of a grizzly level is to provide communication to grizzlies with a working space and ventilation for grizzly men to tap caved ore from the undercut level via branch raises, and to size the ore through grizzly bars to facilitate its removal by gravity through main raises and haulage chutes into cars. The grizzly set is designed to support the ground, control the flow of ore from branch raises and provide a grizzly of suitable spacing to reduce the ore to the maximum size the chute will accommodate.
The layout of a grizzly level depends on the grizzly spacing, which in turn depends on the drawpoint area decided upon as consistent with successful practice. Main communication drifts are planned to serve all of the grizzlies in a block with a minimum of drift driving. Their location is dependent upon the location of main raise sections, as it is expedient to drive them with as strong pillar support as possible in order to avoid excessive maintenance. At Andes, there are now two general layouts in use.

a. The "through-grizzly" layout. At present this is used only in sulfide blocks with grizzly intervals 5 x 7.8 meters and 7-1/2 x 12-1/2 meters. With this layout the main grizzly communication drifts are parallel to and in the plane of main raise sections, and are connected with two fringe drifts on the boundaries of the block at right angles to the main raise sections. All drifts are driven 1-1/2 x 2 meter section unsupported where possible. (See Plate 7, figs. 2 and 4).

b. The "T-off" grizzly layout. At present this is used in all oxide blocks and in sulfide blocks of 7-1/2 x 9-1/3 meters grizzly intervals. (See Plate 7, figs. 5 & 6, and Plate 8, fig. 3).

In oxide blocks, (grizzly interval 16-2/3 x 12-1/2 meters) the main grizzly communication drifts are parallel to and halfway between main raise coordinates. They are connected with stub drifts to grizzlies, and with two fringe drifts on the boundaries of the block at right angles to the main raise coordinates.

In sulfide blocks, the main communication drifts are spaced 15 meters apart at right angles to the main raise coordinates and are connected with stub drifts to grizzlies and with two fringe drifts on the boundaries of the block, parallel to main raise coordinates.

All drifts are 1-1/2 x 2 meter section unsupported.
where possible. Sulfide blocks are provided with grizzly sets for controlling ore drawing as described on page 32, (Central Sulfide). Oxide blocks are provided with all-steel grizzlies but with no controlling set, as none is necessary. These are described on page 27, (Central Oxide).

The following are some of the advantages and disadvantages of each layout:

1. Safety - The "T-off" layout is safer for plug-hole blasting on grizzlies, and there is less danger from walking over grizzlies; ventilation is about equally effective in both.

2. Development drifting - 20% to 30% more drifting is necessary in the "T-off" system with a high proportion of it beyond hand shoveling distance from main raise openings as compared with the "through-grizzly" system. Less timber support is required in the "T-off" system, as drifts have stronger pillar support.

3. Maintenance - Greater in the "through-grizzly" layout, as main communications are in the planes of main raises, and thus have weaker pillar support and are more seriously affected by wear or crushing of main or branch raises. Collapse of one grizzly set can prevent entry to several. Sets are more difficult to clock in place as compared with the "T-off" layout with one solid face.

4. The "T-off" layout allows for branch raise development as in the oxide system with the drawpoint entry located beyond the end of the grizzly to avoid flooding where no control set is used. It also allows for the raising of grizzlies to avoid flooding when branch raises have worn larger, as discussed on page 26, (Central Oxide).

5. Supervision - Simpler in the "through-grizzly" layout, as more grizzlies can be seen from one point.

The "T-off" layout as compared with the "through-grizzly" layout has advantages that outweigh its disadvantages, and present plans indicate that it may soon become standard for sulfide blocks at Andes, as it already has in the oxide mining system. This is particularly true if the use of branch raises of greater drawpoint area is
Branch Raises - The purpose of branch raises is to withdraw caved ore from the undercut level to grizzlies placed on main raise entries at the grizzly level.

The ideal branch raise design provides efficient operational characteristics with a minimum of maintenance during the withdrawal of the tonnage it is required to handle. It requires a minimum of initial driving and timbering. Efficient operational characteristics include drawing caved ore evenly from an undercut area equal to its drawpoint area, and delivering oversize pieces to a point within safe reaching distance of blasters, pluggers and grizzly men with a minimum of hang-ups and without flooding the grizzly. The ideal cannot be completely achieved in practice because of the characteristics of caving action, but well planned development results in high operational efficiency and a minimum of operation difficulties.

Branch raise design: Coned branches have been proven most satisfactory. The entry at the undercut level is as nearly equal in area to the drawpoint area as is practicable, and the throat exit to grizzlies is as wide as the ground and grizzly set will permit with a good brow-pillar to protect the grizzly set cap or to prevent flooding of the grizzly where no grizzly set is used.

The flow angle of branch raises should not be less than 50° to avoid excessive hang-ups. Steeper branches have less brow-pillar protection at the entry to grizzlies, and wear results in earlier maintenance work to prevent flooding or to repair damage done to grizzly.
grizzly flooding or to repair damage done to grizzly set caps by boulder blows.

Branches divided into separate finger drawpoints with a common exit have been found unsatisfactory because of the impossibility of control of the individual drawpoints. The use of the control sets between the grizzly level and the undercut level in the branch raise has been abandoned as unnecessary, and their elimination has resulted in a simpler safer operation with a big reduction in branch raise development and maintenance costs.

To provide sufficient pillar support for the grizzly level and yet bring oversize pieces of caved ore within safe reaching distance of the extraction crew, it has been found expedient to maintain a difference of elevation between grizzlies and undercut of not less than 6 meters nor more than 10 meters. At Andes, three types of branch raises are in successful use at present.

1. Grizzly interval 5 x 7.8 meters, elevation difference from grizzly to undercut 6.2 meters, and a grizzly set necessary for ground support and drawing control. This type consists of two branches per grizzly at center-sides. Each branch is developed by driving a raise 1 meter in diameter for 3 meters at 45° from the center of the grizzly, then vertically to the undercut, gradually widening the raise cross section to 2 meters at the undercut level. (See Plate 9, fig. 2-a).

2. Grizzly interval 7.5 x 9-1/3 meters or 7-1/2 x 12-1/2 meters, elevation difference from grizzly to undercut 7 meters, and a grizzly set necessary for ground support and drawing control. This type consists of 2 branches per grizzly at center-sides. Each branch is developed by driving a raise of 1 meter diameter for 4 meters at 45° from the center of the grizzly, then dividing the
branch into 4 fingers of 1.3 meters cross section, inclined 50° to the undercut level. If the ground is firm, all 4 fingers are driven; if not, as many of the 4 as can be safely driven. As a final operation in advance of or in conjunction with undercutting, the 4 fingers are drilled and blasted with sideswiping and long-holes to unite the 4 fingers to a single coned drawpoint 7 meters in diameter at the undercut level. (See Plate 9, figs. 3-4).

(3) Grizzly interval 12.5 x 16-2/3 meters, elevation difference grizzly to undercut 9 meters, and no grizzly set necessary for ground support and draw control. This type consists of 2 branch raises in a "V" layout at one end of the grizzly. Each branch is developed from a stub drift 1.5 meters long beyond the end of the grizzly opposite the communication entry. Starting at a point 3.5 meters from the center of the grizzly or 1 meter from the end of the grizzly, each branch is driven as a raise of 1 meter diameter for 6 meters on a 45° inclination at right angles to the axis of the grizzly and stub drift, then divided into 4 fingers of 1.3 meters diameter driven at 50° inclination to the undercut level. As in (2) the final operation consists in uniting these fingers to a single coned drawpoint of 8 meters diameter at the undercut level. (See Plate 9, fig.2-0x).

Undercut level & undercutting procedure: The purpose of the undercut level is to provide a working level for the breaking of an interval of ore over the entire area of the block at the top of the branch raises by drilling and blasting operations. The ideal is to effect complete breakage of this interval with a minimum of drifting, sideswiping and long-holing.

The general plan of an undercut level is a system of drifts and crosscuts at a given elevation above the grizzly level, dividing the block area into pillars of convenient size which are removed during undercutting in a retreating operation by blasting Leyner long-holes or stoper mill-holes or both. The drifts and crosscuts are located over or near branch raise openings to facilitate removal of broken rock.
The pillar size is determined by the support necessary for safe working conditions, and, in general, are as large as can be conveniently removed by Leyner long-holing and/or stoper mill-holing with a minimum of side-swiping for long-hole drilling stations. Pillars should not be larger than is possible to "pull out" during undercutting to observe breaking effectiveness with a chance of reentering the broken area to redrill any remaining solid points. Complete undercutting is important for effective caving and to avoid excessive channelling, ore loss and localized crushing of underlying workings.

The amount of drifting completed on the undercut level prior to undercutting depends on the character of the ground and the time set for placing the block in ore production. It is desirable to have at least 80% of the drifting completed when starting undercutting operations in order to avoid slowing up undercutting for lack of preliminary development.

In firm ground, undercutting may proceed slowly with little danger of crushing making the working conditions unsafe; but in weak ground, rapidity of undercutting is important, as crushing of the area adjoining the newly created void due to cantilever type stresses is a common occurrence when caving action begins, and the operation becomes slow, dangerous and difficult.

At Andes, there are two undercut layouts and undercutting methods in present practice.

1. Grizzly interval 5 x 7.8 meters with each branch raise developed as an individual drawpoint.

-18-
Undercut drifts, 6.2 meters above grizzlies, are driven halfway between and parallel to grizzly drifts (7.8 meter intervals) with a cross section of 2 x 1.5 meters. Crosscuts are driven on 7.8 meter intervals normal to the drifts and located so as to break alongside the branch raise openings. (See Plate 10, fig. 3).

Undercutting is accomplished by sideswipe drilling and blasting of pillars to form stations of sufficient area to accommodate long-holing operations. Long-holing and blasting follows station widening in a cycle of operations, re-treating across the block. Following each undercut blast, the broken area is "pulled" to observe the effectiveness of breaking. The number of stations undercut with each blast is limited to an area that can be "pulled out", and if any unbroken pillar remains it is redrilled and blasted. No effort is made to increase the 2 meter height of undercut working by drilling and blasting during undercutting operations. Two to three rows of holes, spaced 2-1/2 feet apart, generally suffice to remove the pillars, and primacord is used in all long-hole blasting for the safety and convenience of instantaneous blasting. As many as 500 holes have been blasted at one time, but blasts average about 250 holes.

(2) Grizzly interval 7.5 x 9-1/3, 7-1/2 x 12-1/2, 12-1/2 x 16-2/3 meters, with initial branch raises divided into fingers to the undercut level. Undercut drifts and crosscuts, 7 to 9 meters above the grizzlies, are driven 2 x 1.5 meters section in such a manner that each finger opening (if all 4 per branch are driven) falls at the corner of an undercut level pillar. Thus, each branch raise system is circumscribed by drifts and crosscuts, and the dividing point of branch raises into fingers lies vertically below the center of pillars. (See Plate 10, figs. 5 & 6, and Plate 11, fig. 3).

Undercutting with this layout is accomplished by coning the branch raise fingers into a common drawpoint with stopers and removing the remaining solid pillar points with Leyner or jackhammer holes, drilled from the undercut level.

Two to three cuts in a shrinkage fashion are taken from the solid areas between branch raise fingers by stopers working in the branch raise on broken ore. This work is done in a cycle of operations in advance of final undercutting, so that the final stoper round is blasted together with the undercut level holes to complete pillar
removal to the height of undercut drifts. Since a minimum of medium length holes is required on the undercut level, no widening of stations is necessary. The broken area is pulled out as in the other method to observe breaking effectiveness, and any remaining solid points are redrilled and blasted, undercutting proceeding in a retreatting fashion across the block.

This second method has proven to be more economical and rapid than (1) and will undoubtedly be adopted as standard practice at Andes, providing the greater drawpoint spacing is adopted allowing for the development of subdivided branch raises as an initial development.

Some thought and experiment have been given to undercutting with stopers only, by coning branch raises to interjoin them at the undercut level with no preliminary drifting on this level. The difficulty of complete undercutting, more dangerous working conditions and the impossibility of observing the effectiveness of breakage, defeat the economy of this method.

Diamond drilling or Leyner long-holing with jointed steel has possibilities in eliminating some of the undercut level development work if, by careful planning, longer holes can efficiently break larger pillars. Crushing during undercutting operations may seriously interfere with the loading of holes, and it would be impossible to observe the effectiveness of breakage as in the present method.

Isolation: The purpose of isolation is to weaken block boundaries in order to insure caving of the entire block area both during undercutting and as caving actions proceed upward. It is necessary in all blocks of firm ore which are overlain by waste. Isolation promotes caving action, and thus increases early life of the operation. Any mining of the overlying ore in place proceeds upwards in an arch so that a dome is formed whose area roughly coincides with those of the block unless weak structures or drilling planes of weakness break up the spring lines of the arch under the character of the ore and overburden. Insufficient or ineffective isolation results in an “overhang” of ore within the block which is withdrawn and overburden waste settles downward. This is undesirable and permits a caving disaster. If ore so caved is removed economically, it entails much added time, labor and extraction work. Various levels have thus been chosen for the location of the block with respect to adjacent areas, and the proximity of workings at higher elevations is determined chiefly by past experience, taking into account the character of the ore and overburden, geological conditions, and the proximity of workings at lower elevations above, and too much isolation is a waste and may cause serious crushing of underlying workings because of too rapid shattering of the block’s solid side, resulting in the block’s settling practically “as mass.” This “chugger action” has been known to cause complete abandonment of a
overlain by waste. Isolation promotes caving action, and thus increases the producing capacity of a block in its early life with improved ore recovery.

Observation has shown that, as a block of firm ore caves following undercutting and the removal of broken ore, caving of the overlying ore in place proceeds upwards in an arch so that a dome is formed whose axes roughly coincide with those of the block unless weak structures or developed planes of weakness break up the spring lines of the arch.

In firm ore overlain by overburden, insufficient or no isolation results in an "overhang" of ore within the block boundaries, eventually supported by waste dilution as ore is withdrawn and overburden waste settles downward. This results in a loss of ore, and although caving of an adjoining block breaks up this "overhang", it cannot be withdrawn without also removing waste dilution. If such ore can be removed economically, it entails much added time, maintenance and extraction work.

The amount of isolation work needed in a block is determined chiefly by past experience, taking into account the character of the ore and overburden, geologic structures, the location of the block with respect to adjoining caved areas, and the proximity of workings at higher elevation. Too little isolation has the undesirable results discussed above, and too much isolation is a waste and may cause serious crushing of underlying workings because of too rapid shearing of the block's solid sides, resulting in the block's settling practically "en masse". This "plunger action" has been known to cause complete abandonment of a
block at another mine using the block caving system.

At Andes it is thought that isolation is most effective on solid corners, and that if the corners can be made to cave, the rest of the side will cave also with sufficient resistance to shearing to avoid any "plunger action". In general, practice has shown that soft talcy ore requires no isolation, and that average mine ore should have about 30% of the solid sides covered with isolation workings, concentrating on the corners of the block. This is accomplished by driving a vertical raise 1 meter in diameter on each solid corner from the undercut level to the top of the ore or to overlying workings. At vertical intervals of approximately 16 meters, subdrifts (1.5 x 2 meters section) are driven from the vertical raise 16 meters along each side of the block. A system of raises at 45° inclination are driven along each side at the corner of the block connecting the vertical raise and subdrifts. Isolation raises are all designed and developed with the idea of weakening the boundary, as well as to provide an exit to the undercut level for the ore broken by crushing and shearing along the boundary. (See Plate 12, figs. 3 & 4).

In harder ground additional corner weakening is accomplished by running a rill stope 15 meters long and 1.5 meters wide from the undercut level to the first subdrift on each side of the block, and the back of the subdrifts are drilled for an additional 2 meters cut. The intersections of isolation inclined raises are
drilled to weaken the pillars formed by isolation work­
ings. All of these holes are blasted in advance of
undercutting.

At present some experimental work is being done
with diamond drilling on block corners to form isola­
tion panels. This method has promise as a more
economical and convenient means of developing panels of
weakness on block corners.

5. *Ore drawing & extraction control:* With the block de­
tails planned and developed, the operation follows,
for which all preliminary work was intended and upon
which the success of the whole method depends - viz.
are withdrawal. This procedure must follow a definite
plan, including the rate of draw and control of
dilution, for successful ore production with maximum
drawing efficiency.

The plan of ore drawing depends upon the char­
acter of the ore and the presence of waste overlying
the block or adjacent to it in extracted blocks.

Mr. C. M. Brinckerhoff, in a paper written for Andes
staff instruction, brings out the following important
points:

1. Supervision: A close check is maintained at
all times over the ore drawing operations. An ore
control man works in each block being drawn. He acts
as an assistant to the shift boss and stays on the
grizzly level with the extraction crew to see that
drawing orders are carried out and to note the amount
and distribution of ore withdrawal for each shift.
The shift boss and the ore control man receive identical
daily drawing orders. The daily report of the ore
control man furnishes the data for graphs which are
posted daily. The greatest value of these graphs is
in indicating branch raises which, for some reason, are not being drawn, and in showing the slope of the draw in a general way.

2. Drawing distribution: The first ore drawn from an undercut is that broken by undercut blasting. After this ore interval has been withdrawn, the undercut area is placed in limited daily production. Branch raises nearest to the waste of adjoining extracted blocks are bulkheaded off. Minimum daily withdrawal is given the drawpoints along the solid sides and reduced successively across the block to the sealed branches.

In firm, slowly caving ore, the general idea is to make the caving arch center over the new block, or at least as far away from the adjoining extracted block as possible, by leaving an artificial barrier above the sealed branches. Should ore drawing be too great near the boundary, waste may break through and run under the arch of uncaved ore, bringing dilution into the new block in its early producing life, and possibly resulting in a large loss of ore. In soft, talcy ore, the general plan of drawing distribution is the same, and there is usually no danger of the area hanging up and arching; but there is difficulty in maintaining the position of drawpoints. Branch raises wear rapidly toward the grizzly control set, and this results in irregular spacing of drawpoints. It is difficult to maintain control sets in good condition and to keep the drawpoints from packing. Fingers draw from a small area vertically above the branch raise opening, and the draw consists of a complex funnelling which is entirely different from the caving action of firmer ore.

3. Rate of withdrawal: Weak, freely caving ore can generally be withdrawn with success more rapidly than harder ore. Weak ore has a tendency to funnel over each drawpoint or over small groups of drawpoints, whereas harder ore caves to form an arch which extends from the solid boundaries to the artificial barrier which is maintained by not drawing branch raises adjacent to waste in adjoining extracted blocks.

Most successful caving of firm, slowly caving ore results when the quantity of ore withdrawn daily does not exceed 0.75 vertical feet of ore over the block area until extraction has proceeded to 50% or more of the estimated ore in the block, or until surface subsidence indicates that the block is caving to its vertical limits. Although production requirements have at times made it necessary to extend this amount, it is not recommended. Less than this amount is not detrimental to caving, but lengthens the time of extraction and may result in increased maintenance work.
Ore drawing should not be stopped for any extended period, as broken ore consolidates, supporting the overlying unvented ore, and caving action stops.

If any branch raises become empty during this early period of withdrawal, it may indicate that the block is being drawn faster than it is caving or that a pillar remains at the undercut level and is interfering with caving action. This must be investigated carefully, and ore drawing decreased or even stopped in the area until caving action again fills the area with broken ore.

When ore removal has proceeded to 50%, or surface subsidence indicates that the block has caved to its vertical limits, the daily amount of ore withdrawal is increased if there is not an excessive amount of dilution present. As the block approaches complete extraction, the rate of ore withdrawal is not controlled nor limited. Ore is drawn from the block as rapidly as needed without endangering the drawing efficiency. Branch raises sealed from the start of ore withdrawal are now put into production and drawn slowly.

The rate of ore withdrawal in blocks of soft, talcy ore is greater than for firmer, slower caving ore. As much as 1.5 vertical feet of ore per day may be withdrawn with success. Stopping the draw for any extended period has more serious results than in firmer ore, as packing is more pronounced in talcy ore, and to start removal again in the consolidated area it may be necessary to repeat undercutting.

4. Dilution control: Waste dilution usually appears when extraction has proceeded to 20% or 30% of the block ore estimate. It may appear anywhere in the block, but the surface subsidence coincident with the appearance of dilution in the branch raises is generally centrally located over the block, especially in ore of the firm, slow caving type.

When dilution appears in a branch raise, the rate of drawing is decreased in the area of the waste. If the amount of waste dilution increases or becomes greater than 30% of the material drawn, ore drawing is stopped in all branches containing waste; and raises drawing dilution encircling this area are sealed also. These drawpoints are stopped for two to three weeks to form a barrier to break up the entry channel bringing waste through the broken ore overlying this area. After this period, the branches are again opened and drawing proceeds slowly. Once waste enters other areas of the block, the same procedure is followed.

In blocks of soft, talcy ore, when waste appears in the branch raises, they are stopped for a few days and then reopened. If the ore drawn does not clear up or waste runs in again, a few sets of cribbing are placed in the mouths of the branch
raises to force drawpoints farther away from the grizzly control set.

5. General: Successful ore drawing depends on (1) conscientious hard work, (2) close observation, (3) imagination, and (4) cooperation between supervisors and extraction crews.

By observing closely the character of the ore in the branch raises, any changes in the character and the location of these changes, it is possible to construct an imaginary picture of the caving block and to make changes in the drawing control. There is no substitute for the hard, daily routine of block inspection. Ore drawing control is important, but daily tonnage production is necessary. These two points do not necessarily mean a conflict, but they do require a common understanding and, at times, a compromise.

The following is a table of the drawing rate in a typical Andes sulfide block:

<table>
<thead>
<tr>
<th>Month</th>
<th>Cumulative Percent drawn</th>
<th>Tons Withdrawn per 24 hours</th>
<th>Vertical feet of ore column drawn per 24 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>1%</td>
<td>550 tons</td>
<td>0.12 ft.</td>
</tr>
<tr>
<td>2nd</td>
<td>9%</td>
<td>2900</td>
<td>0.59</td>
</tr>
<tr>
<td>3rd</td>
<td>18%</td>
<td>3100</td>
<td>0.64</td>
</tr>
<tr>
<td>4th</td>
<td>26%</td>
<td>3150</td>
<td>0.65</td>
</tr>
<tr>
<td>5th</td>
<td>40%</td>
<td>5000</td>
<td>1.03</td>
</tr>
<tr>
<td>6th</td>
<td>55%</td>
<td>4500</td>
<td>0.92</td>
</tr>
<tr>
<td>7th</td>
<td>65%</td>
<td>4600</td>
<td>0.93</td>
</tr>
<tr>
<td>8th</td>
<td>74%</td>
<td>7100</td>
<td>1.46</td>
</tr>
<tr>
<td>9th</td>
<td>89%</td>
<td>5300</td>
<td>1.09</td>
</tr>
<tr>
<td>10th</td>
<td>102%</td>
<td>4630</td>
<td>0.95</td>
</tr>
</tbody>
</table>

Ore drawing efficiency: As a guide to the caving progress of individual blocks, performance graphs are kept on each block, showing the cumulative monthly percent of ore extracted and the percent of copper extracted using the geology department's block estimate as a base. Drawing efficiency is shown as a curve expressing the relation between the ore drawing curve and the copper drawing curve. (See Curve Chart, page).

A compiled table of all blocks since the beginning of
ore production gives the following results on 100,159,311 metric tons of ore delivered to the plant from the Andes mine:

<table>
<thead>
<tr>
<th></th>
<th>% of estimated block ore tonnage extracted</th>
<th>% of estimated copper content extracted</th>
<th>% of drawing efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central Sulfide</td>
<td>116.5%</td>
<td>104.3%</td>
<td>89.6%</td>
</tr>
<tr>
<td>South Sulfide</td>
<td>106.8%</td>
<td>90.6%</td>
<td>84.9%</td>
</tr>
<tr>
<td>Central and South Oxide</td>
<td>101.9%</td>
<td>99.2%</td>
<td>97.4%</td>
</tr>
</tbody>
</table>
### Copper Mining Co.

#### Potrerillos-Chile

**Stope Block Drawing Efficiency Chart**

### Drawing Record

<table>
<thead>
<tr>
<th>Month</th>
<th>Tons of Ore Drawn</th>
<th>Grade</th>
<th>Kilos of Cu</th>
<th>%L. Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>5,857</td>
<td>0.956</td>
<td>56,192</td>
<td>0.044</td>
</tr>
<tr>
<td>Feb</td>
<td>5,857</td>
<td>0.956</td>
<td>56,192</td>
<td>0.044</td>
</tr>
<tr>
<td>Mar</td>
<td>5,857</td>
<td>0.956</td>
<td>56,192</td>
<td>0.044</td>
</tr>
<tr>
<td>Apr</td>
<td>6,013</td>
<td>0.926</td>
<td>576,120</td>
<td>0.056</td>
</tr>
<tr>
<td>May</td>
<td>70,568</td>
<td>1.156</td>
<td>821,578</td>
<td>0.056</td>
</tr>
<tr>
<td>Jun</td>
<td>132,588</td>
<td>1.056</td>
<td>1,397,646</td>
<td>0.041</td>
</tr>
<tr>
<td>Jul</td>
<td>76,488</td>
<td>1.161</td>
<td>893,676</td>
<td>0.041</td>
</tr>
<tr>
<td>Aug</td>
<td>208,076</td>
<td>1.096</td>
<td>2,281,546</td>
<td>0.046</td>
</tr>
<tr>
<td>Sep</td>
<td>78,154</td>
<td>1.189</td>
<td>906,077</td>
<td>0.049</td>
</tr>
<tr>
<td>Oct</td>
<td>267,228</td>
<td>1.133</td>
<td>3,197,437</td>
<td>0.048</td>
</tr>
<tr>
<td>Nov</td>
<td>305,535</td>
<td>1.118</td>
<td>4,350,044</td>
<td>0.048</td>
</tr>
<tr>
<td>Dec</td>
<td>106,654</td>
<td>1.115</td>
<td>2,111,716</td>
<td>0.044</td>
</tr>
<tr>
<td>Totals</td>
<td>56,165</td>
<td>0.92</td>
<td>519.92E</td>
<td>0.04</td>
</tr>
</tbody>
</table>

**August**

<table>
<thead>
<tr>
<th>Month</th>
<th>Tons of Ore Drawn</th>
<th>Grade</th>
<th>Kilos of Cu</th>
<th>%L. Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>102,329</td>
<td>1.151</td>
<td>1,152,671</td>
<td>0.048</td>
</tr>
<tr>
<td>Feb</td>
<td>93,508</td>
<td>1.027</td>
<td>958,676</td>
<td>0.067</td>
</tr>
<tr>
<td>Mar</td>
<td>6,92,775</td>
<td>1.096</td>
<td>7,506,343</td>
<td>0.096</td>
</tr>
<tr>
<td>Apr</td>
<td>78,366</td>
<td>1.073</td>
<td>8,428,912</td>
<td>0.106</td>
</tr>
<tr>
<td>May</td>
<td>83,034</td>
<td>1.184</td>
<td>1,160,616</td>
<td>0.170</td>
</tr>
<tr>
<td>Jun</td>
<td>83,046</td>
<td>1.068</td>
<td>9,688,533</td>
<td>0.156</td>
</tr>
<tr>
<td>Jul</td>
<td>78,173</td>
<td>1.026</td>
<td>8,017,221</td>
<td>0.195</td>
</tr>
<tr>
<td>Aug</td>
<td>94,217</td>
<td>1.086</td>
<td>10,361,258</td>
<td>0.206</td>
</tr>
<tr>
<td>Sep</td>
<td>40,134</td>
<td>1.037</td>
<td>416,108</td>
<td>0.206</td>
</tr>
<tr>
<td>Totals</td>
<td>1,002,207</td>
<td>1.079</td>
<td>10,807,363</td>
<td>0.206</td>
</tr>
<tr>
<td>Oct</td>
<td>1,005,120</td>
<td>1.074</td>
<td>10,835,608</td>
<td>0.206</td>
</tr>
<tr>
<td>Nov</td>
<td>15,044</td>
<td>0.925</td>
<td>141,329</td>
<td>0.156</td>
</tr>
<tr>
<td>Dec</td>
<td>6,439</td>
<td>0.651</td>
<td>40,675</td>
<td>0.119</td>
</tr>
<tr>
<td>Totals</td>
<td>1,026,588</td>
<td>1.073</td>
<td>11,016,010</td>
<td>0.206</td>
</tr>
</tbody>
</table>

**September**

<table>
<thead>
<tr>
<th>Month</th>
<th>Tons of Ore Drawn</th>
<th>Grade</th>
<th>Kilos of Cu</th>
<th>%L. Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>102,688</td>
<td>1.073</td>
<td>11,016,010</td>
<td>0.206</td>
</tr>
<tr>
<td>Feb</td>
<td>27,677</td>
<td>0.600</td>
<td>16,452</td>
<td>0.076</td>
</tr>
<tr>
<td>Mar</td>
<td>1,026,322</td>
<td>1.072</td>
<td>11,032,452</td>
<td>0.076</td>
</tr>
</tbody>
</table>

---

**Calculated Metric Tons of Ore**: 874,871

**Grade of Ore**: 1.214%

**Kilos of Copper**: 10,620,157

---

**Coordinate**: North = 596.09-689.84

**East**: 715.00-275.00
6. Timbering: In general, the cost of timbering depends on the quantity and kind of timber used, framing costs and the labor costs of placing the original sets and repair timber.

Since the kind and amount of timber used in a block caving system is governed by the character of the ground through which extraction openings are driven, or the purpose for which it is intended and the permanency required of the opening. Timbering is used for ground support and to facilitate ore drawing operations. In general, haulage drifts, grizzly level drifts, undercut drifts and all raises are driven without timbering where the ground will stand unsupported, except for timber necessary for ore drawing operations, such as chute sets and grizzly control sets. Timber sets for ground support are constructed as lightly and spaced as far apart as safety permits, except in the more permanent openings, such as main line transfer haulage drifts, ore pass dumping stations and supply or manway raises. Ore passes, permanent openings subject to much wear, are lined with steel and concrete tied to solid ground.

At Andes, timber framing is limited to haulage sets, chute sets, cribbing and maintenance diagonals. All other sets are constructed of square out timber held in place by "scabs" and blocking. Framed grizzly control sets with battered posts have been tried and found no more satisfactory than the present set.
Maintenance timber, in general, is of bigger or section but square out as before, and every effort is made to utilize salvage timber stripped from extracted areas for this work. Stripping is a continuous job, since block caving is an advancing operation destroying the overlying workings. Thus, there is a continuous supply of usable timber made available by stripping crews.

Where possible, the driving of branch raises is done in advance of placing grizzly control sets, and high grizzly sets are placed to fit the block.
2. Lighter back and side lagging. Split poles, or 2 in. x 10 in. plank back lagging; and willow poles, or 1 in. x 6 in. plank side lagging have been used with success, the idea being that the lagging should bend and eventually break to relieve the pressure on the stronger supporting timber.

3. No standardization of spacing timber sets on haulage or grizzly levels. Sets are placed as the ground requires, except for the placing of chute or grizzly sets.

4. Where possible, the driving of branch raises is done in advance of placing grizzly control sets, and high grizzly sets are placed to fit the ground where the opening is large. A fill of old timber is placed between grizzly set posts and branch raise shoulders to support the set and to act as a "muck buffer". This decreases maintenance caused by boulder blows and blasting. Stop rails are also placed in the fill supported by angle iron U's with at least 6" of timber between rail and post.

5. Caps are placed on supports of old steel in drill holes where back support is necessary, but sides are firm.

6. The development of the "T-off" grizzly system which provides stronger grizzly level pillar support, and thus requires less timber support.

7. The development of blocks with a greater draw-point spacing, which decreases the number of extraction openings and increases pillar support, thus requiring less timbering.

8. The development of the oxide grizzly level and branch raise system, which has eliminated the use of grizzly control sets in these blocks.

7. Maintenance of blocks: The repair of extraction openings in producing blocks is a continuous operation made necessary by the crushing of supporting pillars, wear because of the movement of broken ore, and blasting of oversize pieces and hang-ups.

Mr. C. M. Brinckerhoff's paper on caving for the instruction of the Andes mine staff brings out the following important points:
1. When crushing develops on the working levels of a block, it is necessary to make repairs as rapidly as possible and to maintain grizzly control sets in a condition to continue ore withdrawal. In the early stages of block withdrawal, this is very important. If the block cannot be drawn over the entire area after undercutting, there is little opportunity for it to break up. Rapid block repairs are more important up to 50% of the block ore withdrawal than in the later period.

2. Increasing the drawing rate does not make the weight "ease off". It shortens the time which the area will have to be maintained for production. The rate of withdrawal should not be increased because of weight in the early stages of ore drawing, as it might adversely affect final extraction. After the block is 50% withdrawn, an increase in drawing rate does no harm and speeds up the final extraction of the block.

3. After supporting pillars are thoroughly crushed from weight, the remaining life of the grizzly level consists of alternating periods of repair and drawing. Except for localized areas or zones of structural weakness, weight generally increases away from the solid boundaries of a block. The resistance to shearing of solid sides, weakened by isolation workings, decreases the vertical force overlying this area. However, the caving stresses breaking up the orebody over the remainder of the block, added to the weight of broken ore, increases the crushing force toward the boundaries adjoining extracted blocks. A block with four solid sides has less tendency to crush the underlying workings than one which adjoins an old block on one side. Crushing is more pronounced as the number of solid sides decreases and the sides adjoining old blocks increase. Occasionally, in the early producing life of a block, tremendous weight develops which crushes out much of the grizzly level. A crush of this type is usually of short duration, but the damage to pillars has been done. The area continues to crush at a slower rate for the rest of its extraction life. Block areas have been known to crush and be repaired five times or until the original pillar to the undercut level was completely removed.

4. Experience has shown that by carrying large broken ore reserves, maintenance costs are increased. Best results are obtained by carrying sufficient broken reserves to assure the continuity of production but without an excess. Practice has shown that a supply of three months' production of broken reserves is ample, providing development work is advanced so that new blocks are available for undercutting when needed.

5. Timber repairing is hard and dangerous work and requires the most competent timbermen. To reopen crushed areas in heavy ground, the back has to be raised to make
room for new sets. When feasible, the ground is allowed to pack before advancing which results in safer, faster repair work. Light side and back lagging will break before the stronger supporting timber. This results in relieving the set.

Among other methods which have been successfully used for the support of heavy ground are the following:

a. Steel 8 in. x 8 in. "H-beam" caps and sills.
b. Sharpened 3-1/2 in. angle iron spiling.
c. Concrete collars below grizzly sills.
d. Flexible 2 in. round willow poles for lagging.
e. Small section (4-1/2 ft. x 3 ft.) grizzly communication drifts.
f. Addition of stulls, diagonals and extra bracing in heavy areas.

6. Where repair work is made necessary by wear, boulder blows or blasting, the following have been found effective:

a. When wear of branch raises in the sulfide grizzly control set system results in damage by boulder blows, the set is replaced by a higher, longer set blocked to solid ground out of the area of running ore.
b. When wear of branch raises in the oxide system results in the running ore flooding the grizzly, the branch raises are blocked off, and the grizzly raised sufficiently to again furnish brow protection and control, but with sufficient head room for the grizzly man to work. Where the brow is too weak to withstand the wear of ore running, a concrete arch is constructed at the branch raise entry end of the grizzly to furnish brow protection and control. Where the ground is too weak to withstand the wear of running ore below the grizzly sills, concrete piers, tied to solid ground by old steel in drill holes, are placed to support the sills.
THE FOLLOWING TABLE PROVIDES A COMPARATIVE ANALYSIS OF THE IMPORTANT ELEMENTS IN DEVELOPING SIMILAR BLOCK AREAS HAVING DIFFERENT DRAWPOINT SPACINGS

<table>
<thead>
<tr>
<th></th>
<th>1936 Sulfide Block</th>
<th>Recent Sulfide Blocks</th>
<th>Recent Oxide Block</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grizzly Interval (meters)</td>
<td>5 x 7.8</td>
<td>5 x 7.8</td>
<td>7.5 x 9.75</td>
</tr>
<tr>
<td>Drawpoint Area (Sq.meters)</td>
<td>19.5</td>
<td>19.5</td>
<td>34.8</td>
</tr>
<tr>
<td>Block Dimension</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length x Width (meters)</td>
<td>62.5 x 60</td>
<td>65.5 x 60</td>
<td>62.5 x 60</td>
</tr>
<tr>
<td>Undercut Area (Sq. meters)</td>
<td>3750</td>
<td>3937</td>
<td>3750</td>
</tr>
</tbody>
</table>

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>LDD</td>
<td>125</td>
<td>125</td>
<td>125</td>
</tr>
<tr>
<td>MRD</td>
<td>1024</td>
<td>1094</td>
<td>1094</td>
</tr>
<tr>
<td>GDD</td>
<td>605</td>
<td>605</td>
<td>605</td>
</tr>
<tr>
<td>BRD</td>
<td>1305</td>
<td>1306</td>
<td>1306</td>
</tr>
<tr>
<td>UCD</td>
<td>1162</td>
<td>1024</td>
<td>1024</td>
</tr>
<tr>
<td>IRD (3 panels)</td>
<td>1224</td>
<td>640</td>
<td>640</td>
</tr>
<tr>
<td>IDD (3 panels)</td>
<td>150</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>TOTAL</td>
<td>5596</td>
<td>4932</td>
<td>5055</td>
</tr>
</tbody>
</table>

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Pony Sets</td>
<td>16</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Number of Grizzlies</td>
<td>96</td>
<td>96</td>
<td>96</td>
</tr>
<tr>
<td>Elevation LD-GD (meters)</td>
<td>19</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>Elevation GD-UD (meters)</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Undercutting - Sq.meters/shift</td>
<td>4</td>
<td>4.2</td>
<td>4.1</td>
</tr>
<tr>
<td>No. of finger divisions in branch raise</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>LDD</td>
<td>280</td>
<td>151</td>
<td>151</td>
</tr>
<tr>
<td>(Cribbing)</td>
<td>317</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>MRD</td>
<td>22</td>
<td>13</td>
<td>15</td>
</tr>
<tr>
<td>(Chutes)</td>
<td></td>
<td>141</td>
<td>50</td>
</tr>
<tr>
<td>GDD</td>
<td>294</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>BRD</td>
<td>56</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Pony Sets (Bd.Ft. per unit)</td>
<td>1418</td>
<td>899</td>
<td>899</td>
</tr>
<tr>
<td>Grizzly Sets (Bd.Ft. per unit)</td>
<td>1006</td>
<td>503</td>
<td>503</td>
</tr>
<tr>
<td>Control Set (Bd.Ft. per unit)</td>
<td>2608</td>
<td>(Not included in blocks after 1933)</td>
<td></td>
</tr>
</tbody>
</table>

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Approximate ratio of cost per sq.mt. of area to develop recent sulfide blocks</td>
<td>100</td>
<td>92</td>
<td>84</td>
</tr>
</tbody>
</table>

Timber - Board Feet Per Meter Of Driving

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>LDD</td>
<td>151</td>
<td>151</td>
</tr>
<tr>
<td>(Cribbing)</td>
<td>317</td>
<td>None</td>
</tr>
<tr>
<td>MRD</td>
<td>22</td>
<td>13</td>
</tr>
<tr>
<td>(Chutes)</td>
<td></td>
<td>141</td>
</tr>
<tr>
<td>GDD</td>
<td>294</td>
<td>None</td>
</tr>
<tr>
<td>BRD</td>
<td>56</td>
<td>None</td>
</tr>
<tr>
<td>Pony Sets (Bd.Ft. per unit)</td>
<td>1418</td>
<td>899</td>
</tr>
<tr>
<td>Grizzly Sets (Bd.Ft. per unit)</td>
<td>1006</td>
<td>503</td>
</tr>
<tr>
<td>Control Set (Bd.Ft. per unit)</td>
<td>2608</td>
<td>(Not included in blocks after 1933)</td>
</tr>
</tbody>
</table>

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Approximate ratio of cost per sq.mt. of area to develop recent sulfide blocks</td>
<td>100</td>
</tr>
</tbody>
</table>
The following is a summary of some significant facts and figures taken from operational reports of the Andes mine for 1946:

**Labor**

Pay system - Incentive; development & repair by contract, extraction & service by bonus

<table>
<thead>
<tr>
<th>Shifts working</th>
<th>Development</th>
<th>Extraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Board feet of timber used per ton</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of men underground per shift</td>
<td>Day</td>
<td>Afternoon</td>
</tr>
<tr>
<td></td>
<td>Night</td>
<td></td>
</tr>
<tr>
<td>Number of men underground per day</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of surface men charged to mining</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total number of men charged to mining</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of men directly on development</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of men directly on extraction &amp; repair</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Production**

| Ore mined per day (U.S. short tons) | 31,500     |
| Haulage distance chute to orepass (meters) | 300 to 1,000 |
| Tons mined per man shift (men chargeable to mining) | 32.8     |
| Tons mined per man shift (men underground) | 39.0     |
| Tons mined per man shift (Men on extraction & repair) | 72.2     |
| Number of blocks producing            | 13         |
| Number of blocks developing           | 8          |

**Safety**

| Cubic feet of air supplied per man-minute | 500 |
| Accident severity rate (per 10,000 shifts): | |
| Fatal                                     | 0.049 |
| Serious (15 + days lost time)             | 0.269 |
| Slight (1 to 14 days lost time)            | 1.517 |
| Slight (No lost time)                      | 25.098 |
| Accident frequency rate (per 10,000 shifts) | 26.93 |
Blasting method - Driving and raising - Running fuse and No. 8 detonators.
Plug-holes and bombs - Electric No. 6 caps, no delay.
Undercut blasting - Instantaneous method using Primacord.

Supplies & Consumption

Type of explosive used .................. 34% gelatine

Board feet of timber used per ton of ore mined ........... Sulfide 0.2136
                                                                 Oxide 0.0230

Pounds of dynamite used per ton of ore mined ........... Sulfide 0.1221
                                                                 Oxide 0.1343

Electric power used, Kilowatt hours per ton of ore mined 1.6
Acknowledgment:

I wish to thank Mr. C. M. Brinckerhoff, General Manager of the Andes Copper Mining Company, for reading the manuscript and for extensive information taken from his unpublished paper on caving written for the instruction of the Andes mining staff. Grateful acknowledgment is also due the mining staff for their cooperation in providing information and illustrations for the preparation of this paper; particularly to R. L. Tobie, Mine Superintendent; H. E. Robbins, Assistant Mine Superintendent; J. A. Bain, Chief Mine Engineer; C. A. Wendel and W. T. Swensen, Geologists; and I Sanchez, Draftsman.

References:


W. S. March, Jr: Ore Deposits at Potrerillos, Chile. Copper Resources of the World; International Geological Congress, 1933.


C. M. Brinckerhoff: Underground Transportation at the Andes Copper Mining Company, Potrerillos, Chile. A.I.M.E. Transactions, Volume 163, 1945.
1925 - Tributary Transfer Raise System, Cribbed throughout.
Horizontal Interval Chute to Chute 12.50 Meters

1934 - Branching Main Raise System, Cribbed throughout

1938 - Branching Main Raise System, generally unlined.

1940 - Branching Main Raise System, generally unlined

1943 - Branching Main Raise System, generally unlined

1946 - Branching Main Raise System, generally unlined
1925 - Tributary Raise System directly to Ore Passes with No Haulage transfer (East-West Section)

1939 - Long Main Raise with "V" Branches to Grizzlies, T-off Grizzly Layout (East-West Section on Coordinate 1000)

1944 - Main Raise System with "V" Branches to Grizzlies, T-off Grizzly Layout Located between Raise Systems (East-West Section on Coordinate 1500)

1959 - Long Main Raise with "V" Branches to Grizzlies, T-off Grizzly Layout (East-West Section on Coordinate 1000)

OXIDE MAIN RAISE SYSTEMS
GRIZZLY LEVEL LAYOUTS - SULPHIDE SYSTEM

1930 "Through System" 10 m. x 12.5 m.

1934 "Through System" 5 m. x 7.8 m.

1943 "Through System" 10 m. x 15.6 m.

1944 "Through System" 7.5 m. x 12.5 m.

1945 "T-Off System" 7.5 m. x 12.5 m.

1946 "T-Off System" 7.5 m. x 9.37 m.
**GRIZZLY LEVEL LAYOUTS - OXIDE SYSTEM**

1936 - "Through System" - 11 m. x 16.5 m.

1940 - "T-Off System" 11 m. x 16.6 m. - Communications in plane of Main Raises.

1944 - "T-Off System" 12.5 m. x 16.6 m. - Communications between planes of Main Raises.  

*PLATE 8*
1925 - No crosscuts, finger drawpoints from Control Sets.

1926 - Finger drawpoints from Control Sets.

1934 - Layout for grizzly interval 5 m. * 7.8 m.

1943 - Layout for grizzly interval 10 m. * 15.6 m. - Fingers joined to form coned drawpoints.

1944 - Layout for grizzly interval 7.5 m. * 12.5 m. - Fingers joined to form coned drawpoint.

1946 - Layout for grizzly interval 7.5 m. * 9.37 m. - Fingers joined to form coned drawpoint.
1936 - No crosscuts, 3 fingered drawpoints, not coned.

1940 - 3 fingered drawpoints, not coned.

1944 - 4 fingered Branches, coned to single drawpoints when undercutting.

PLATE II
**ISOLATION LAYOUTS.**

1. **1925 - Full Panel-10 m. x 10 m. at 45° on all solid boundaries.**

2. **1932 - Full Panel-10 m. x 10 m. at 45° on all solid boundaries.**

3. **1938 - Corner Isolation System on all solid corners.**

4. **1946 - Corner Isolation System on all solid corners.**
HAULAGE DRIFT TIMBERING

1. Standard Haulage Drift Set (10" X 10")
   (Solid 8"x8" or Plank and block 8x8 also used)

2. Haulage Set Used in Heavy Ground (10"x10")

PLATE 13
STANDARD HAULAGE CHUTE LAYOUT

Gate Dwg A-17

Drift Set Dwg E-1

Ladder
EARLY TIMBERING - SULPHIDE SYSTEM

Control Set - 4 Fingers

Grizzly Segment-Set  Grizzly Square-Set

Control Gate in Main Raise

PLATE 15
Grizzly Control Set-Present Sulphide System

Spacer Block

Angle Iron U for Stop-rail
Special Grizzly Set - Placed to fit ground.
1930 - Grizzly Control Set.

Cuts in One Flange of H Beam.

1940 - All Steel Grizzly-Branch Raise brow serves as control.
HAULAGE EQUIPMENT

10 Ton Locomotive

120 Cu. Ft. Granby Dump Car

Rocker Dump Car
3 Cu. Yd. Cap.