Mines Branch Information Circular IC 306

SURVEY OF PHYSICAL-MINERALOGICAL CHARACTERISTICS OF UNDERGROUND MINES IN CANADA

by

R. Sage* and D.F. Coates**

SUMMARY

A survey of underground mines in Canada has been made to determine the nature and extent of orebodies, mining techniques, and physical properties of rocks. The response to the survey was good in that 85% of the mines participated. The results are stored on tape, and a computer program has been written to search for particular mine characteristics. The results show that Canadian underground mining is over a wide range of depths (to 8000 ft), generally in steeply dipping orebodies and in a wide variety of rock types and conditions. Cut-and-fill is the commonest mining method, although all techniques are used. The variability of mining conditions requires careful planning and development to establish the optimum mining methods and equipment.

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KEYWORDS: underground mines, ore properties, rock properties, mining methods.

Direction des mines
Circulaire d'information IC 306

UNE ÉTUDE SUR LES CARACTÉRISTIQUES PHYSIQUES ET MINÉRALOGIQUES DES MINES SOUTERRAINES AU CANADA

par

R. Sage* et D.F. Coates**

RÉSUMÉ

Les auteurs ont fait une étude sur les mines souterraines au Canada pour déterminer la nature et l'étendue des corps de minerai, des techniques minières et des propriétés des roches. La participation a été très bonne; 85% des mines ont pris part au sondage. Ils ont enregistré les résultats sur une bande magnétique et ils ont écrit un programme machine pour trouver les caractéristiques particulières d'une mine. D'après les résultats, les auteurs ont pu montrer que l'exploitation souterraine au Canada couvre une vaste gamme de profondeurs (jusqu'à 8000 pieds) généralement dans des corps de minerai très inclinés avec des types et conditions de roches très variés. Ils ont trouvé que la méthode d'abattage de déblais et remblais était la plus employée quoique toutes les techniques soient employées. Ils ont trouvé aussi que la variabilité des conditions minières exige une planification et un développement bien soignés afin d'établir les meilleurs méthodes et équipements pour l'exploitation minière.

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MOTS CLEFS: mines souterraines, propriétés de minerai, propriétés des roches, méthodes d'exploitation.

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INTRODUCTION

A knowledge of the physical and mineralogical properties of orebodies and the surrounding rocks is important to the development of improved mining techniques and machinery for ore excavation, handling and processing. These properties are also of immediate interest to the Mining Research Centre for its studies on excavation and support of rock. Accordingly, it was decided to initiate a survey of these properties, with two objectives: the collection of information on these physical and mineralogical properties, for immediate use by the Mining Research Centre and other Canadian mining organizations, and for the determination of the feasibility of maintaining a comprehensive, up-to-date file of physical characteristics of ore deposits in Canada.

SCOPE OF THE SURVEY

Information requested

A knowledge of the physical and mineralogical properties of orebodies and surrounding rocks is important in the design of equipment and the development of mining techniques in underground mining. The characteristics to be determined for each mine were as follows:

- the depth, thickness, and extent of orebodies,
- the dip of the orebodies,
- the characteristic distribution of ore in the host rock,
- the current mining technique, and
- the strength and deformation characteristics of the orebodies and surrounding rocks.

The characteristics other than strength and deformation are known to the geologist or mine engineer on a particular project. The determination of strength and deformation characteristics requires tests which, ideally, fall into two groups: tests to determine the characteristics of the rock mass and tests to determine the characteristics of the rock substance. However, it was recognized that the former would require very large expenditures of time and money, so the study of strength and deformation characteristics was restricted to the rock substance.

Good rock mechanics practice requires such characteristics of rock substances to be determined from a series of tests on samples from a given rock type; ideally at least ten samples would be used. Again, however, the testing of ten samples from each type of rock and ore from the estimated 160 underground mines in Canada would be very expensive. Therefore, it was decided to ask each mine for one sample from the most competent rock in the orebody and surrounding rocks and to accept that the survey would give only an indication of the required properties. For convenience, the sample rocks were designated as from either hanging wall or footwall. The lab testing procedures are described in the appendix.

Response to the survey

The survey was conducted by means of a questionnaire. As well as returning the questionnaire, mines were asked to send rock samples to the Mining Research Centre for tests on the rock substance. The questionnaire was sent to members of the Mining Association of Canada (the questionnaire, guide, and accompanying letter from the Association are shown in the appendix). Completed questionnaires were received from 137 mines operated by 70 companies; this represents a return of 85%. The response to the request for samples was not so good. Sixty consignments, representing 198 samples, were received; only 160 samples were successfully tested, due either to small size or to difficulties in coring.

Storage and retrieval of data

The questionnaire data and the results of the tests on rock samples are stored on magnetic tape. COBOL programs to update the file and retrieve data have been written for the CDC 6400 computer of Mines Branch, Department of Energy, Mines and Resources. The program will search the file for any characteristics stored on the file and list mines that satisfy specified characteristics. The appendix shows the typical output for a mine; the Mining Research Centre will accept requests, through the Mining Association of Canada, for data retrieval from the file.

RESULTS OF THE SURVEY

The mines which replied to the survey reported gross ore reserves of approximately one billion short tons (though not all mines stated their reserves). The gross daily ore production is approximately 250,000 short tons, giving an apparent life of about 15 years. Half of the mines produce some copper, 35% some silver, 20% some zinc, 20% some nickel, and 10% some lead.

The principal results of the survey are shown in the histograms of Figures 1 to 8, and Tables 1 to 3. Figure 1 shows the distribution of maximum and minimum orebody depths. The maximum depths are spread over a wide range, with only a slight concentration at 1200 - 1400 ft. The extreme depth is 8,000 ft, but note that orebody depths are not necessarily mining depths. The minimum depth values show a strong concentration at less than 100 ft or, in effect, surface outcropping. This is to be expected because many orebodies have been identified by outcrops.

Figures 2 and 3 show the distribution of orebody thickness - the distance between the hanging wall and the footwall - and orebody dip angles, respectively. The typical orebody can be seen to dip steeply (at about 70^{o}) and to be less than 50 ft thick. However, there is a considerable range in values, particularly in thickness. This range in thickness can, of course, reflect the actual variation in orebody size. However, an orebody often does not have clearly defined limits. In this case, the orebody limits are those where economic mining ceases. This can be affected by the difficulty of mining - in supporting the walls, for example - as well as by the mineral content of the orebody. Thus the range of values shown for orebody thickness is influenced by economic, as well as geological, considerations, and the range is probably larger than actual geological boundaries.

Figure 4 shows the distribution of mining method with average orebody depth. Again, the average orebody depth is not necessarily related to actual mining levels. Generally, of course, production begins in the upper levels of an orebody, and maximum depths of mining in a typical orebody will be less than the maximum orebody depth. However, Figure 4 does show some trends in mining methods with depth. Bearing in mind that the average orebody depth is less than 4000 ft. (as shown in Figure 1), cut and fill mining occurs fairly uniformly over the different orebody depths, whereas shrinkage is used for shallower orebodies. Open stoping occurs in orebodies with an average depth between 1000 ft and 2000 ft. For the remaining methods, there are too few samples for the histograms to have statistical significance.

The distribution of mining method with average thickness of orebody shown in Figure 5, indicates that both cut-and-fill and shrinkage are associated with narrow orebodies, whereas open stopes and caving are used with all orebody thicknesses.

Tables 1 and 2 show the proportion of total underground ore production for 1971 by the different mining methods and by average depth of orebody respectively. Cut-and-fill and room-and-pillar account for over half of all production; similarly, half of all production is from orebodies with an average depth of less than 2000 ft. Table 3 shows the percentage of actual mines using the different mining methods for the principal part of their ore recovery. Cut-and-fill is the most common method, followed by shrinkage. However, shrinkage accounted for less than 10% of total 1971 ore production (Table 1). Room-and-pillar mining, though accounting for 25% of total 1971 ore production, is used by only 8% of the reporting mines; this relatively large production is mostly from the prairie potash mines.

The histograms of Figures 1 to 5 and Tables 1 to 3 present some general characteristics of orebodies and mining methods used. Figures 6 to 8 show the results of laboratory tests on the rock samples from the mines. Figure 6 shows the distribution of sample density. There is a strong grouping of densities around 180 lb/cu ft. The isolated group between 240 and 300 lb/cu ft corresponds to massive sulphide ores.

Figure 7 shows the distribution of the ultimate compressive strengths of the samples. There is a wide scatter in these strengths, with a substantial number stronger than 15,000 lb/sq in. which already signifies a strong rock. The extreme value, 60,000 lb/sq in. represents a very hard rock. The number of high-strength samples reflects the request in the questionnaire for samples from the most competent rock.

The distribution of sonic moduli of deformation (obtained from sonic velocities) is shown in Figure 6. The moduli determined on the loaded and unloaded specimens do not show a great deal of scatter. The moduli determined under load are grouped quite closely around 12,000,000 lb/sq in. The mean of the values under load is higher than the mean of the values under no load. It is generally believed that loading a rock sample closes minor discontinuities in the rock substance, giving better sound transmissibility and an apparently higher modulus.

The distribution of orebody types does not lend itself to illustration. Approximately half (65) mines described their ore deposits as vein type; 27 as tabular; 22 as pod type; and 21 as disseminated.

CONCLUSIONS

1. In Canada, underground mining is conducted in orebodies which dip between 0 and 90°, are between 0 and 7000 ft thick, and are between 0 and 8,000 ft deep.

2. Further, the rock that must be broken has a wide range of hardness (i.e. compressive strengths 200 to 61,000 psi and moduli 5 to 35 M psi).

3. The geological types of deposits include tabular, vein, pod and disseminated orebodies.

4. Compared to the underground mining industries in other countries, Canadian miners must be very flexible and alert in selecting, developing, and using methods that are minimum-cost for the particular conditions encountered.

APPENDIX

Sample test procedure

Test samples were prepared by diamond drilling an AX core from the rock samples, cutting the cores to the desired length by diamond saw, and lapping the ends square in accordance with usual test specimen preparation procedure. Where cores had been sent by the mines they were cut and lapped. The many small samples sent were drilled with a small bit in an attempt to obtain specimens, but, usually, these specimens were unsatisfactory. If a specimen could not be obtained, a small section of the rock was cut with two sides roughly parallel, for determination of the sonic modulus and density only.

The prepared specimens were weighed to determine density, and then the modulus of elasticity was determined by sonic velocity measurements+. These measurements were taken on the unloaded specimen and then on the loaded specimen. The modulus, determined thus, tends to increase with load until a limiting, steady value is reached. If this limiting value could be determined without risk of a sudden failure of the specimen (judged by the experience of the operator) which might have damaged the sonic testing apparatus, this was done.

After sonic testing, the specimens were loaded to failure to determine the ultimate crushing strength; for the rough-cut sections, density and the moduli, unloaded and loaded, were determined alone.

+ The formula used in the determination is

$$E = \frac{\text{density x (sonic velocity)}^2 \text{ x } (1+\mu)\ (1-2\mu)}{(1-\mu)}$$

where E, μ are the modulus and Poisson's ratio. μ was assumed to be 0.25.

return to: MINING RESEARCH CENTRE, 555 BOOTH ST., OTTAWA - ATTN. R. SAGE

Survey of Physical-Mineralogical Characteristics of Underground Mines in Canada

for sections marked * see guide attached

1 Mine Name

2 Name and Address of Operating Company

3 Postal Address of Mine

* 4 Geographical Location of Mine Shaft

5 Principal Ore Mined

6 Principal Metals or Minerals Produced

7 Published Ore Reserves ____ Short tons

8 Normal Ore Production ____ Short tons per day

9 Ore Processing (Mill) Capacity ____ Short tons per day

10 Mining Method — Caving [1] / Supp. Walls [2] — mark X

11 Geological Field Name of Wall Rocks

12 Dip of Orebody max [1] min [2] average [3]

13 Depth to Orebody max [1] ft. min [2] ft.

14 Thickness of Orebody, Wall to Wall max [1] ft. min [2] ft. average [3] ft.

15 Length of strike of Orebody ____ ft.

* 16 Type of Orebody - mark X tabular [1] Pod [2] Vein [3] Disseminated [4]

* 17 Rock Samples have been sent to the Mining Research Centre - mark X yes [1] no [2]

18 Name and Position of Person completing Questionnaire ____ Date ____

19 Comments

* 20 Bibliography of published papers describing the geology and mining

Survey of Underground Mines in Canada

GUIDE TO QUESTIONNAIRE

Section 4

It is intended to record the location of the mine shaft in the Universal Transverse Mercator System (U.T.M.). If the U.T.M. co-ordinates are known please give these. If not, please give the latitude and longitude of the mine shaft. If these are also not known please give the distance and bearing of the shaft from the nearest town.

Section 16

For this questionnaire the orebody types are defined as follows.

- Tabular - layered or bedded like coal, or like the Elliot Lake Uranium orebodies.
- Pod - pear or onion shaped as in the Geco or the Horne mines.
- Vein - like gold veins.
- Disseminated - like a porphyry copper.

Section 17

Rock samples from the most competent rock from each of the orebody, the hanging wall and the footwall - three samples total - are requested. The samples should be six-inch long cores of size AX or larger, or should be cubes of side approximately six inches.

The sample should be sent to the Mining Research Centre, 555 Booth Street., Ottawa, marked for the attention of R. Sage.

Section 19

Please list any publications that have dealt with the mine in particular, or the local geology. Use additional sheets if necessary.

THE MINING ASSOCIATION OF CANADA

NINTH FLOOR 20 TORONTO STREET TORONTO 210, ONTARIO

April 29th,1971.

TO: Head Offices and Mine Offices -
Executive Directors of Provincial
Mining Associations -

SURVEY OF PHYSICAL-MINERALOGICAL CHARACTERISTICS OF UNDERGROUND MINES IN CANADA

After consultation with the MAC, the Mining Research Centre of the Mines Branch wishes to conduct a survey of rock conditions in underground mines in Canada. The compiled information will be made available to guide future research into mining techniques and equipment, by Mines Branch, by the Universities and by the manufacturers of equipment and will also be made available at an early date to all respondents to the survey who request it.

The Research Advisory Committee of this Association believes that the survey is definitely worth supporting and is hereby asking for your co-operation. A questionnaire is attached to this letter; would you kindly have it completed and returned direct to the Mines Branch. The form is quite general - should you feel the questions do not apply to your property please indicate this in the comment space.

The survey will include the physical properties of the ore and surrounding rocks. Consequently, would you send direct to the Mines Branch one sample each of the most competent rock from the orebody, from the hanging wall and from the foot wall. The samples should be six inch long cores, size 4X or larger, or cubes approximately 6" x 6" x 6".

The completed questionnaire and the rock samples should be sent to the following:

Mining Research Centre,
Mines Branch,
555 Booth Street,
Ottawa, Ont.

ATTENTION: Mr. R. Sage.

W.R. Horn
(for Research Advisory Committee)

TELEPHONE, 363-8019 & 364-2716 (AREA CODE: 416)

MINE NUMBER 1

MINE NAME AGNICO MINES LTD. - NIPISSING 401 SHAFT
BOX 140,
COBALT,
ONTARIO

OWNED BY AGNICO MINES LTD.
BOX 140
COBALT
ONTARIO

MINE LOCATION SEE O.D.M. GEOL MAP 2050

REGION NOT YET ALLOCATED

OREBODY TYPE VEIN

MINING METHOD SHRINKAGE

WALL ROCKS ARE DESCRIBED AS 1. KEEWATIN TYPE LAVAS 2. COLEMAN FORMATION - SEDIMENTS 3. NIPISSING DIABASE SILL

PUB. ORE RES. (S.TNS) NIL   DAILY ORE PROD. (S.TNS.) 300   MILL CAP. (S.TNS/DAY) 350

OREBODY PROPERTIES
STRIKE LENGTH (FT.) 300   THICKNESS (FT.) - MAX 15   MIN 1   AVERAGE 3
DEPTH (FT.) - MAX 440   MIN 236   DIP (DEGREES) - MAX 90   MIN 80   AVERAGE 85

ORES MINED SILVER

METALS OR MINERALS PRODUCED SILVER

TESTS ON SAMPLES   WERE SAMPLES SENT? NOT STATED   WERE SAMPLES RECEIVED? YES

#	DENSITY LBS/CU.FT.	U.C.S. KSI	NOLOAD MOD. MILLION PSI	LOADED MOD. MILLION PSI	DESCRIPTION OF SAMPLE OR COMMENTS
1	185.1	31.2	15.8	16.7	DIABASE
2	164.6	25.2	10.7	11.9	CONGLOMERATE
3	195.5	52.4	16.3	17.2	KEEWATIN LAVA

MINE COMMENTS ON ORIGINAL QUESTIONNAIRE
(1) RE DEPTH TO OREBODY NOT DIAGNOSTIC - MINERALISATION RELATED TO PROXIMITY OF MARGINS OF DIABASE SILL.C.
(2) RE THICKNESS OF OREBODY NOT DIAGNOSTIC UNLESS WALL ROCK TYPE CONSIDERED
(3) RE LENGTH OF STRIKE OF OREBODY - VARIES IN EVERY CASE
(4) RE LOCATION SHAFT - O.D.M. GEOL. MAP 2050 FROM N. END TIP OF COBALT LAKE - A3M 168.5 DEGREES, 6380 FT.

BIBLIOGRAPHY
KNIGHT C.W. - 1922 COBALT AND S. LORRAIN SILVER AREAS O.D.M. VOL XXXI PT. 2 PP 60 AND 153.   THOMSON R.W. 1961 PREL REPORT OF PART OF COLEMAN TOWNSHIP CON V LOTS 1-68 DIST OF TEM. O.D.M. PRELIM REPORT, 1961-4, PP 87-90   THORNILEY B.H. COBALT AND DISTRICT GUIDEBOOK OF C.I.M.M. CENT FIELD EXCURT. PP 154-156   SERGIADES A.O. 1968 SILVER COBALT CALCITE VEIN DEPOSITS OF ONTARIO, O.D.M. MIN RESOURCES CIRC NO. 10 P 174.

MINING RESEARCH CENTRE COMMENTS
NO COMMENT

[illegible]IRE WAS COMPLETED BY [illegible].THORNILEY   QUESTIONNAIRE WAS DATED 21ST MAY, 1971

Table 1 - Ore Production by Mining Method (1971)

Method	% of total ore
Cut-and-fill	25.7
Room-and-pillar	25.4
Sub-level caving	13.3
Open stoping	13.1
Shrinkage	9.7
Long-hole open stoping	8.4
Caving	3.1
Other	1.3

Table 2 - Ore Production by Average Depth* to Orebody (1971)

Depth	% of total ore
0 - 1000 ft	21.9
1000 - 2000 ft	37.9
2000 - 3000 ft	17.7
3000 - 4000 ft	12.2
4000 - 5000 ft	10.2
greater than 5000 ft	0.1

* mean of minimum and maximum orebody depths, not necessarily related to depth of production workings.

Table 3 - Mining Methods by Number of Producing Mines

Method	% of mines
Cut-and-fill	35
Shrinkage	25
Long-hole open stoping	8
Room-and-pillar	8
Caving	4
Open stoping	14
Sub-level caving	6

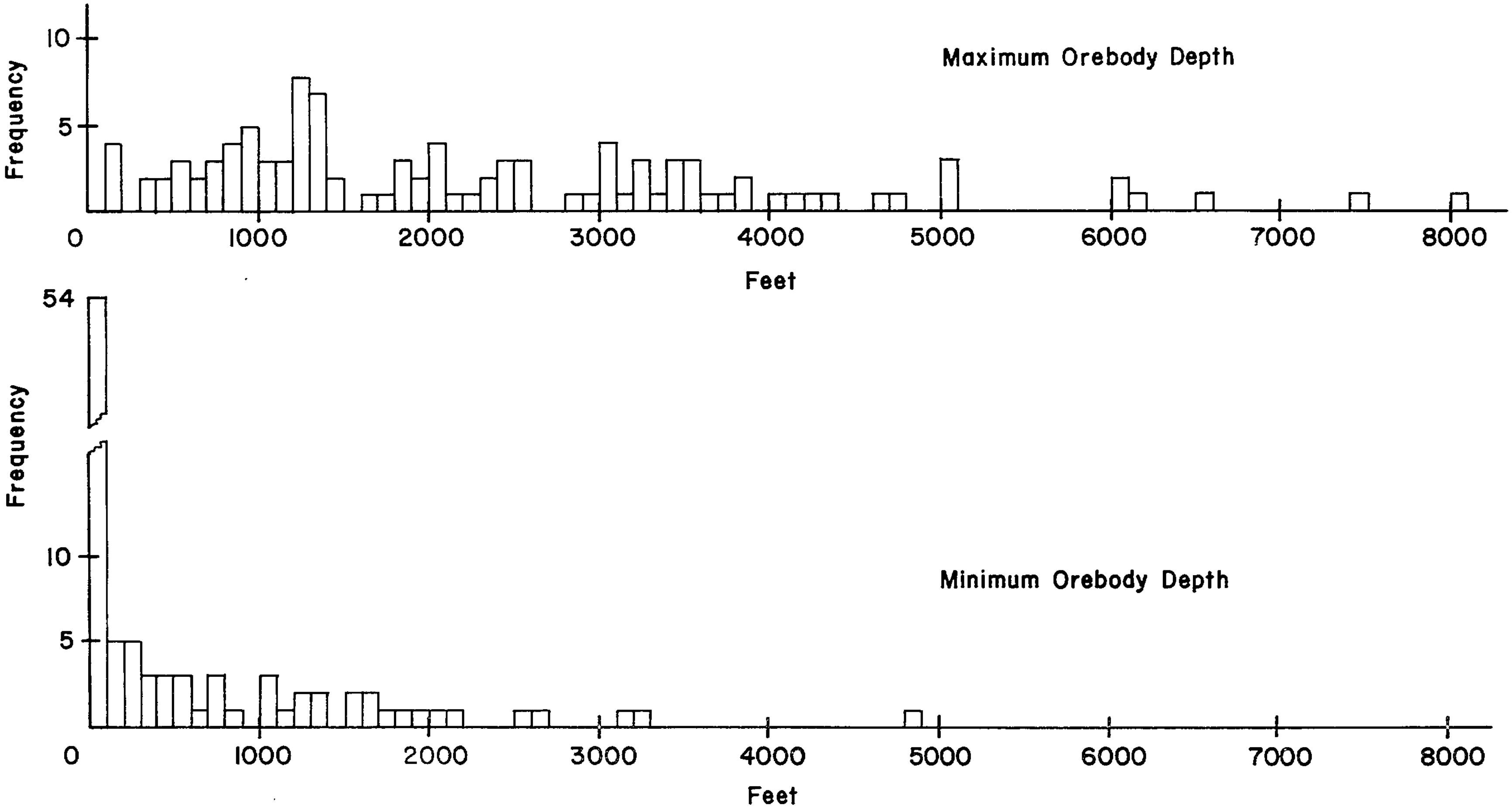

Figure 1: Distribution of Orebody Depth.

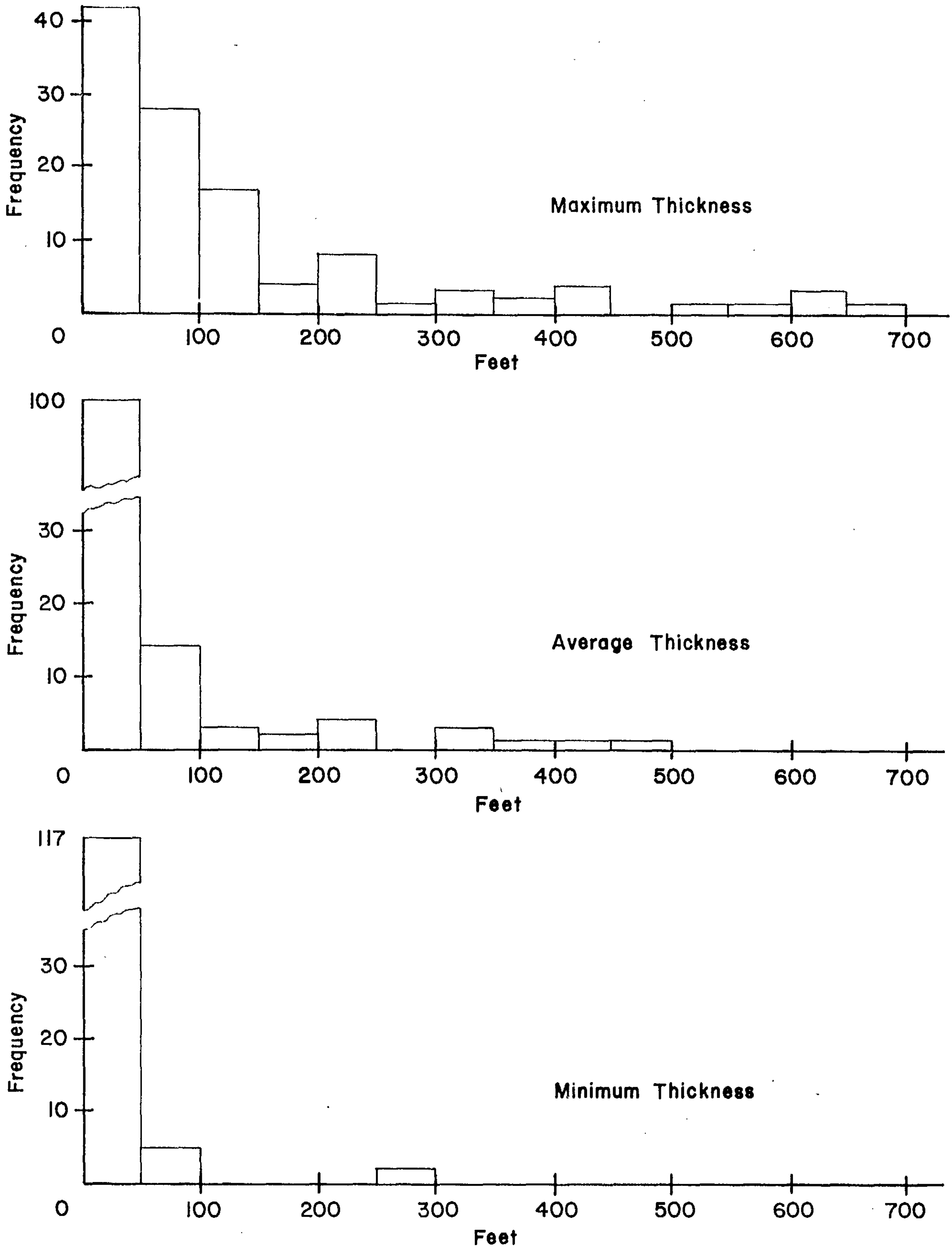

Figure 2 - Distribution of Orebody Thickness.

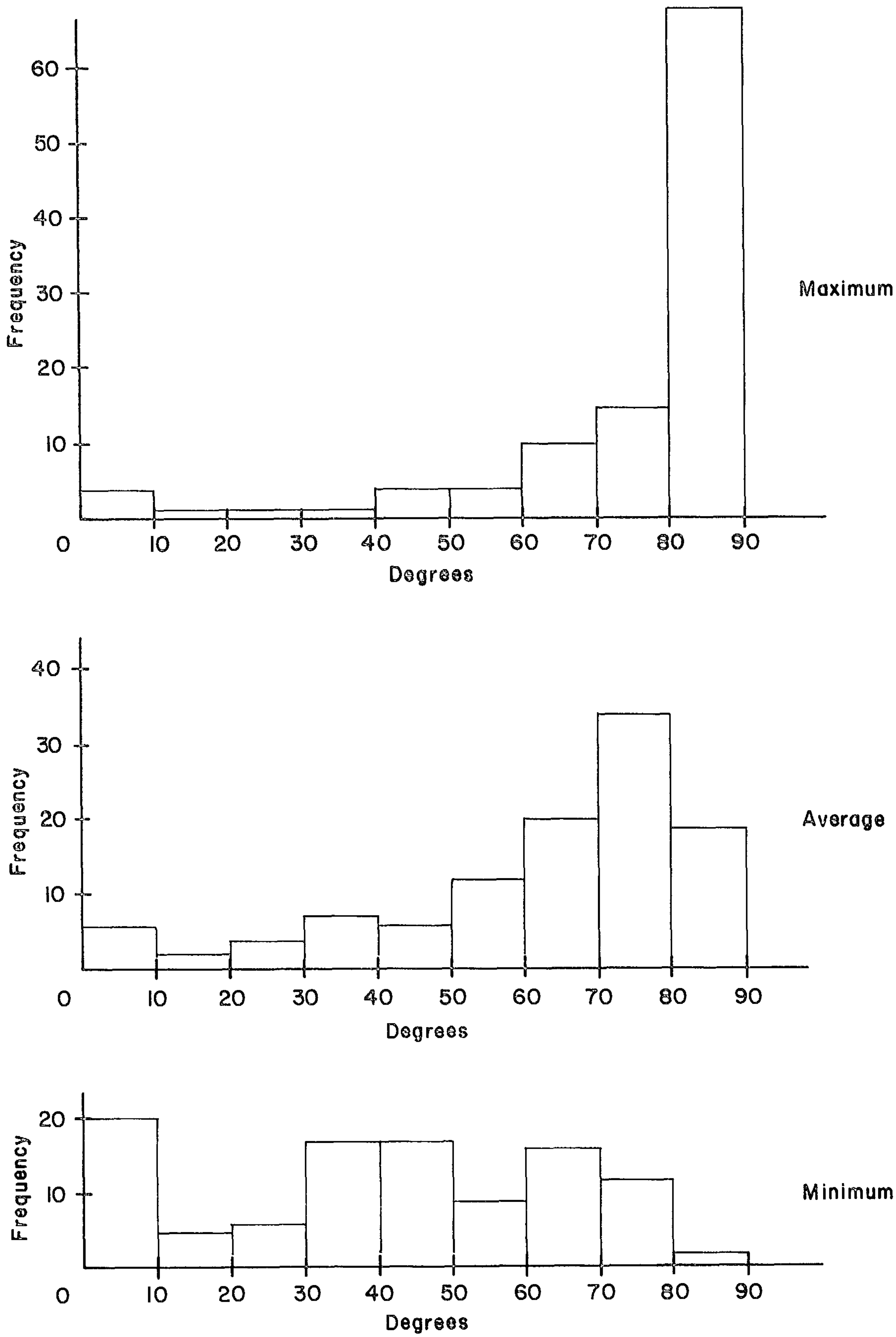

Figure 3 - Distribution of Orebody Dip Angles.

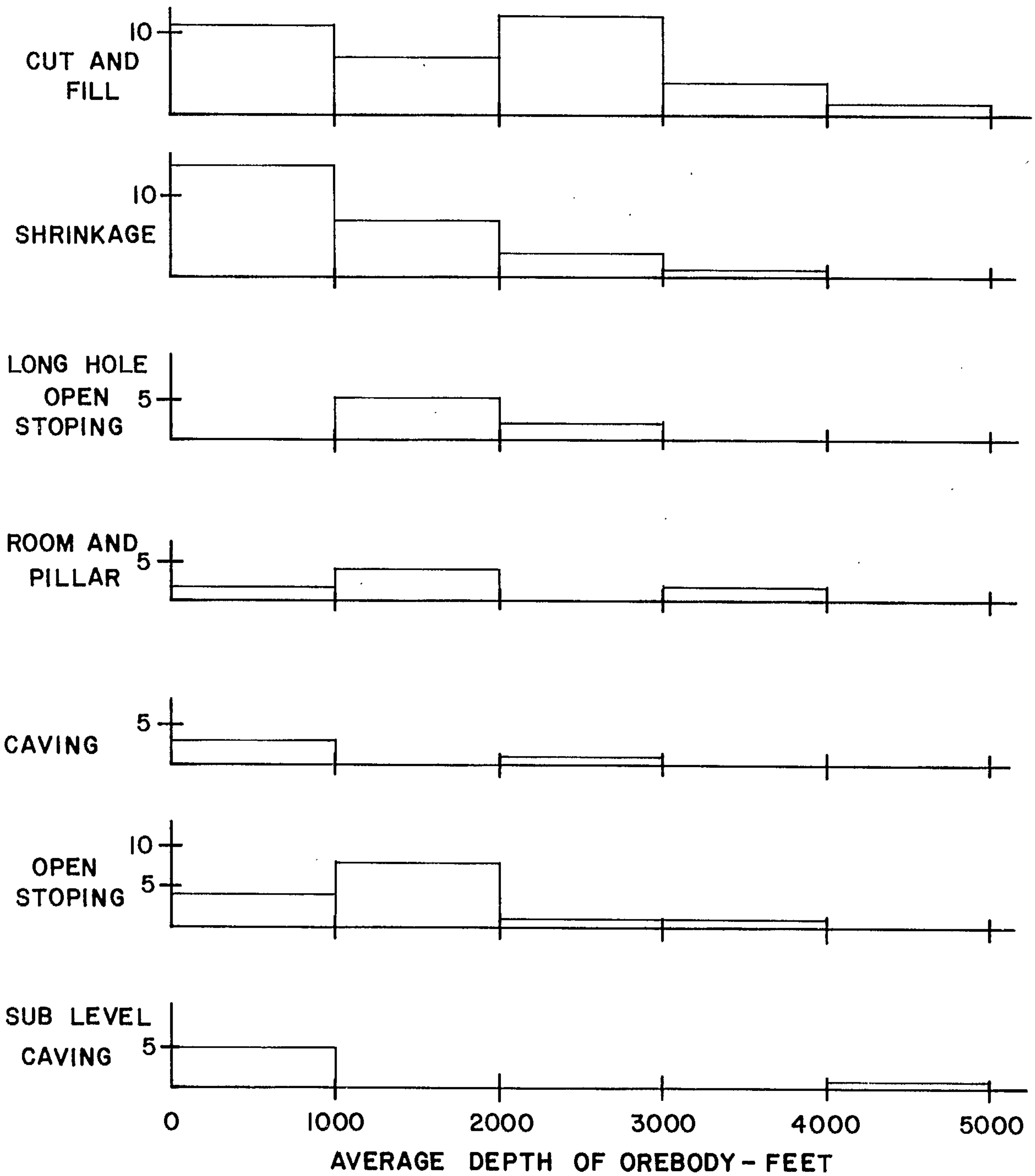

Figure 4 - Distribution of Mining Methods with Average Depth of Orebody.

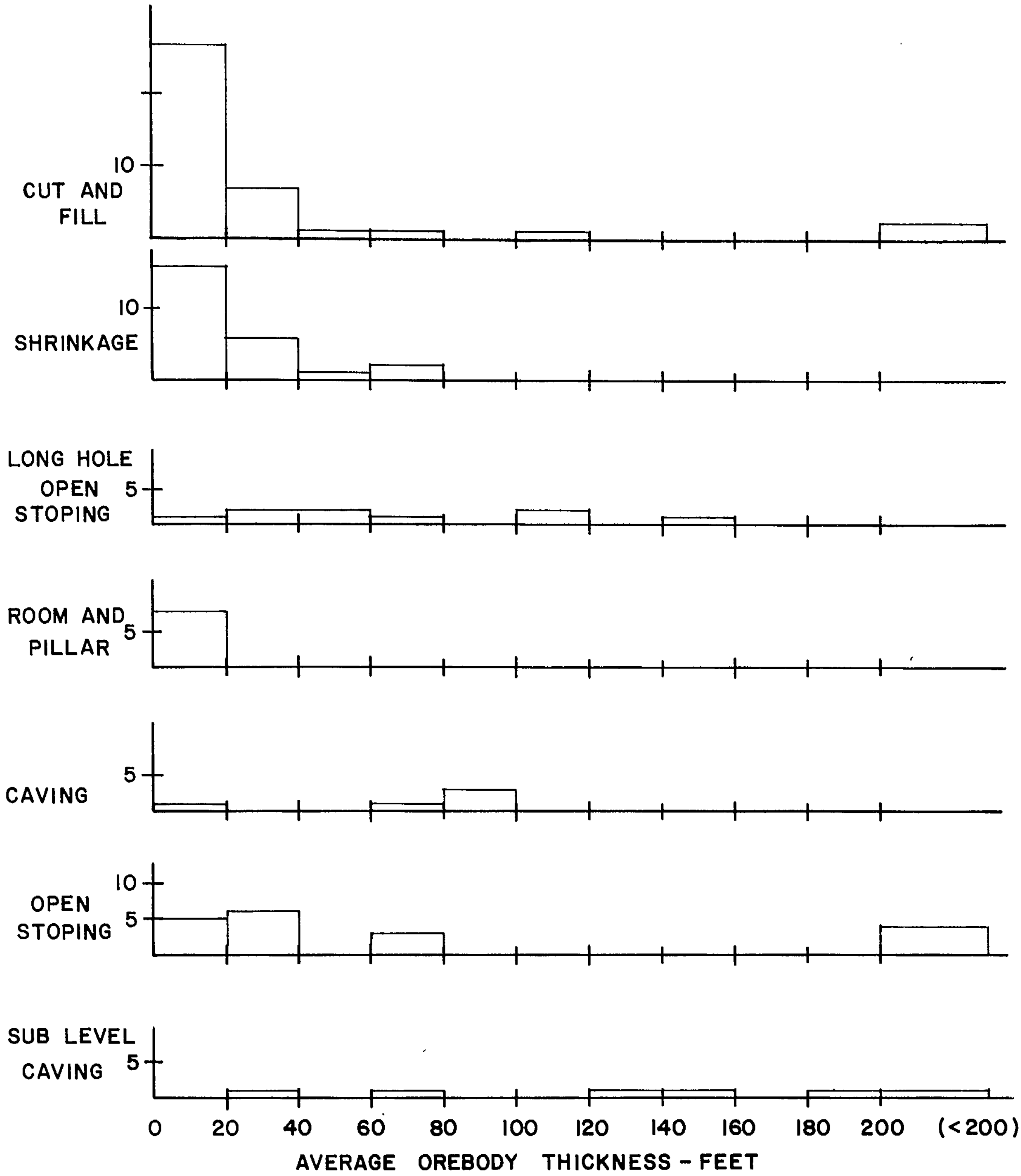

Figure 5 - Distribution of Mining Methods with Average thickness of orebody.

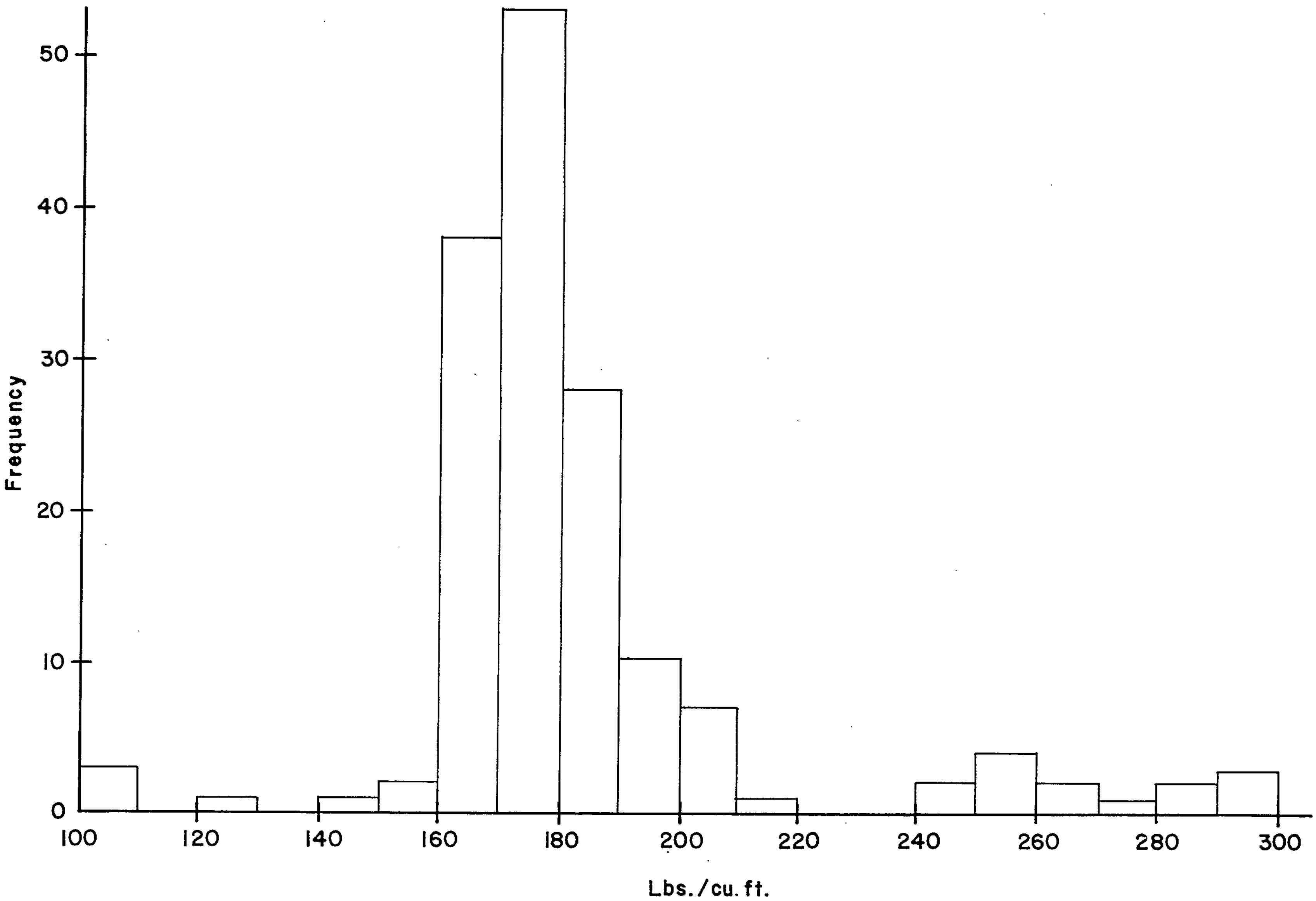

Figure 6: Distribution of Sample Density.

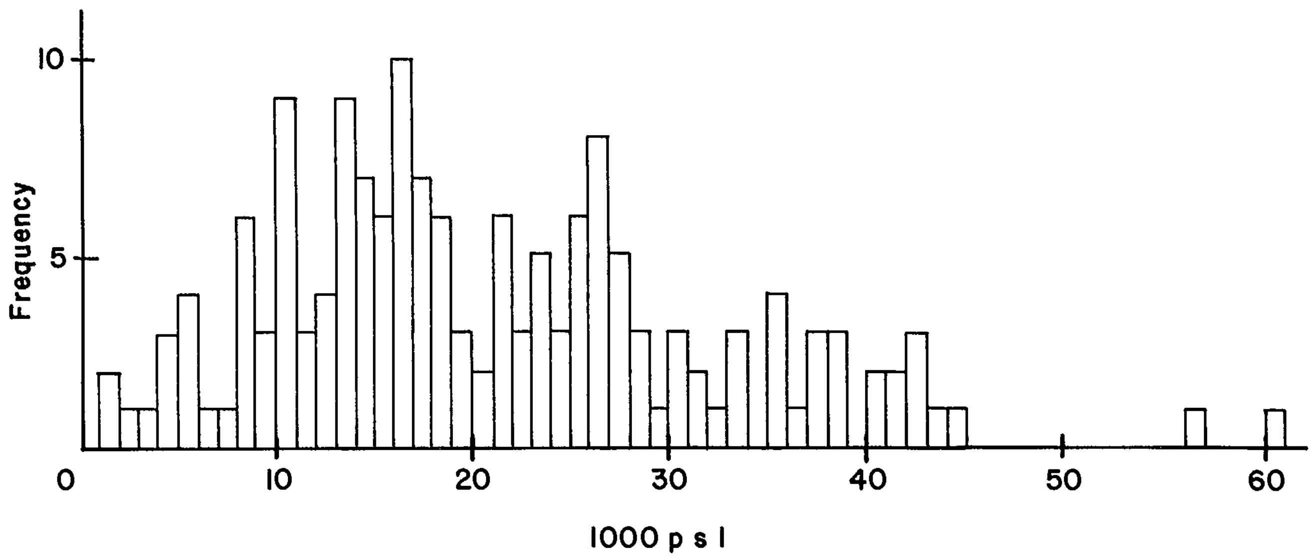

Figure 7 - Distribution of Uniaxial Compressive Strength.

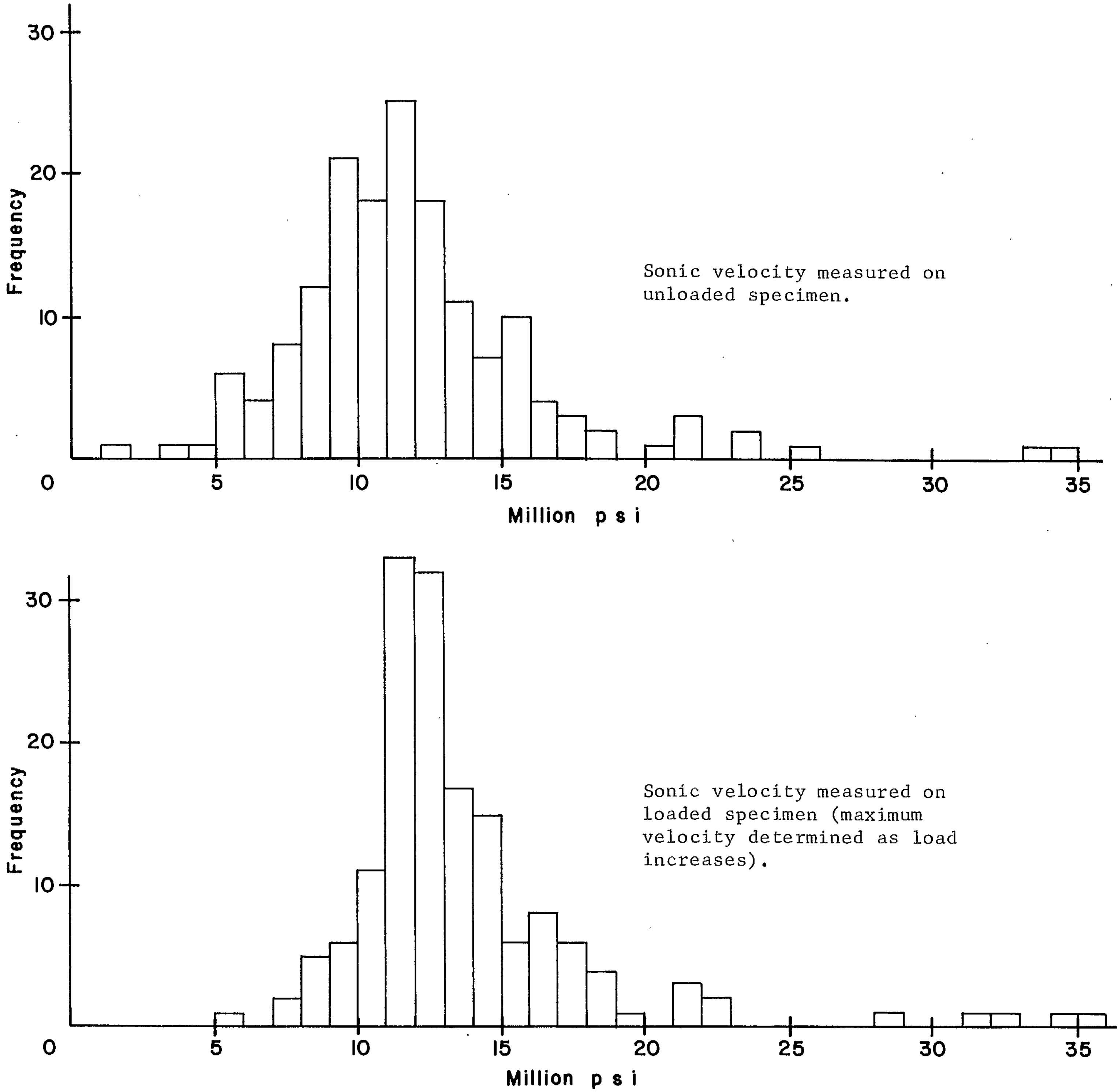

Figure 8 - Distribution of Modulus of Elasticity Determined from Measurements of Sonic Velocity.