THE INTERRELATION BETWEEN MINE PRODUCTION AND THE AMOUNT OF LAND REQUIRED FOR MINING PURPOSES

by

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ABSTRACT

This report studies the land requirements at 33 mines.

The data are analyzed for significant correlations of production with five categories of land use. The five categories of land use are total land, mineral land, ore land, non-mineral land, and waste disposal land. Efficiency factors are developed for each of the land use categories and these efficiency factors are analyzed for correlations with production. The geologic setting, the per cent of mineral land, the per cent of ore land, the primary mineral produced, the depth of mine, and the mining method are analyzed for relationships to land use.

There are significant correlations of production with total land, total land efficiency factor, mineral land efficiency factor, ore land efficiency factor, non-mineral land area, and waste disposal area. The geologic setting, the per cent of mineral land, the per cent of ore land, and the per cent of marketable commodity are related to mining land requirements. No other relationships were found.

CHAPTER I

INTRODUCTION

America's resources have made her great. However in using the natural resources for the public welfare, millions of acres have been changed (or disturbed) from their natural condition. These disturbances have come from the production of food, timber, water, and minerals, the construction of highways and homes, and the development of our vast industries. In the total concept of land disturbance, it is interesting to note that the Department of Interior could attribute only 0.14 per cent of the total surface of this nation to occupancy by the mining industry (Abdnor, 1968, p. 54).

It is obvious that the economy needs minerals and that some land will be disturbed in winning these minerals. The mining industry must supply these minerals and in so doing keep the area of disturbance to a minimum. Thus, the mineral production per acre of land occupied is of interest. It is in this context that this study is initiated.

Statement of Problem

The hypothesis is that larger mines require more land than do smaller mines, that larger mines make more efficient use of land, and that by studying conditions at existing mines the relationships can be correlated.

The specific questions to be analyzed are:

1. What are the average land requirements?
2. What is the relationship between the total land owned and the mine production?
3. How much of the land is mineral land and what is its relation to production?
4. How much of the land is directly over the orebody and what is its relation to production?
5. How much of the land is non-mineral land and what is its relation to production?
6. How much land is required for waste disposal and what is its relation to production?
7. Is there a relationship between land owned and the geologic setting?
8. Is there a relationship between land owned and the mineral involved?
9. Is there a relationship between land owned and the depth of the mine?
10. What are the various interrelations of land uses?

Sources of Data

These data were acquired from the Department of Economic Research of The University of Arizona. Dr. G. F. Leaming (1969a, b, c) of the Department of Economic Research prepared a series of questionnaires which he mailed to 412 mining operations. Thirty-three companies responded with sufficient data to be used in this analysis (Tables 1 and 2). The questionnaires asked for many kinds of data, most of which were not used in this analysis. A detailed copy of the questions whose data were used in this analysis appear in the Appendix. Table 1 and Table 2 are summaries of the data.

Assumptions

In order to crystalize the problem and make the analysis meaningful, the following assumptions are made:

1. The daily mine production is a measure of the size of the mine.
2. The questionnaires were answered with some degree of uniformity among the various mines as to the land use included in each question.
3. The mining companies acquired their land with some degree of prudence in regard to mineralization and mining expectations.

Definition of Terms

Production: the average daily mine production during the period from January 1, 1967, to December 31, 1967.

Total Land: all mineral land plus all non-mineral land owned by the mining company at the mine

Table 1. Summary of the Individual Mine Data

Mine No.	Depth ft.	Production tpd	Total Acres	Non-mineral Acres	Mineral Acres	Ore Acres	Waste Disposal Acres
1	-	33,000	4,380	3,920	460	460	2,590
2	300	20,000	10,886	1,522	9,364	9,364	1,522
3	650	61,000	32,280	17,780	14,500	1,300	3,800
4	250	6,000	13,640	12,538	1,136	1,136	360
5	200	36,000	4,128	3,350	778	129	839
6	240	100,000	11,980	11,145	815	735	2,560
7	-	9,000	3,721	61	3,660	1,151	920
8	980	4,000	21,856	700	21,156	20,799	700
9	35	5,700	10,400	400	10,000	10,000	400
10	-	120	9,100	7,000	2,100	50	50
11	10	360	94	53	41	41	53
12	10	400	2,000	1,000	1,000	1,000	20
13	20	1,283	32,052	100	31,952	31,952	100
14	8	1,000	1,000	460	540	540	460
15	-	7,500	380	-	380	380	40
16	-	2,100	16,475	113	16,362	11,200	200
17	-	1,600	2,700	-	2,700	2,700	10
18	600	600	2,067	148	1,919	1,100	170
19	-	9,500	15,500	11,400	4,100	300	10
20	800	1,500	9,041	718	8,323	8,323	120
21	2068	40,000	52,788	42,632	10,156	10,156	1,142
22	515	13,000	2,824	2,664	160	160	839
23	-	1,000	1,284	-	1,284	-	-
24	-	1,100	1,086	266	820	100	100
25	-	700	135	45	90	90	45
26	3000	450	6,380	-	6,380	410	40
27	3000	44,000	12,288	11,888	400	400	3,445

Table 1.--Continued

28	-	2,000	1,072	313	760	700	190
29	-	375	3,630	2,300	1,330	551	20
30	887	10,320	16,438	320	16,118	16,118	320
31	-	125	3,320	-	3,320	120	10
32	200	200	440	-	440	220	10
33	200	120	6,380	-	6,380	551	10

Table 2. Individual Mine Data Showing Geologic Setting, Primary Minerals Mined, and Mining Method

Mine No.	Geologic Setting	Mining Method	Primary Minerals
1	Disseminated	Open Pit	Copper
2	Disseminated	Open Pit	Copper
3	Disseminated	Open Pit	Copper
4	Disseminated	Open Pit	Copper
5	Disseminated	Open Pit	Copper
6	Disseminated	Open Pit	Copper
7	Disseminated	Open Pit	Copper
8	Bedded	Surface	Trona
9	Bedded	Surface	Phosphate
10	Vein	Surface	Lead-Zinc
11	Bedded	Surface	Gypsum
12	Bedded	Surface	?
13	Bedded	Surface	Trona
14	Bedded	Surface	Clays
15	Disseminated	Open Pit	Gold
16	Bedded	Surface	Phosphate
17	Bedded	Surface	Limestone
18	Disseminated	Open Pit	Copper
19	Disseminated	Open Pit	Copper
20	Vein	Underground	Copper
21	Disseminated	Underground	Copper
22	Disseminated	Underground	Copper
23	Vein	Underground	Lead-Zinc
24	Vein	Underground	Lead-Zinc with Au, Ag, and Cu
25	Vein	Underground	Lead-Silver
26	Vein	Underground	Lead-Silver
27	Disseminated	Underground	Molybdenum
28	Disseminated	Underground	Molybdenum
29	Vein	Underground	Mercury
30	Bedded	Underground	Potash
31	Bedded	Underground	Uranium
32	Bedded	Underground	Uranium
33	Bedded	Underground	Uranium

site. (Questions 11 and 12 of the Land Use Questionnaire, see Appendix.)

Mineral Land: all land, at each mine, held primarily for and by virtue of its mineral content. Such mineral may or may not be of ore quality. The data are taken from question 11 of the Land Use Questionnaire (see Appendix).

Non-mineral Land: all land, at each mine, held for reasons other than its mineral content. The data are taken from question 12 of the Land Use Questionnaire (see Appendix).

Ore Land: that mineral land which is directly over the orebody (question 14 of the Land Use Questionnaire, see Appendix).

Waste Disposal Land: that land used for waste disposal including mill tailings, overburden dump, and leach dump areas (question 16 of the Land Use Questionnaire, see Appendix).

Land Efficiency Factor: a ratio determined by dividing the daily production by the acres of land. The units are tons per day per acre of land. The factor is regarded as a measure of the efficiency of land use. The larger number is regarded as being more efficient. The efficiency factor is developed for five categories of land use:

1. Efficiency factor of total land
2. Efficiency factor of mineral land
3. Efficiency factor of non-mineral land
4. Efficiency factor of ore land
5. Efficiency factor of waste disposal land

High or Low Mineral Content: some minerals are more valuable than others and consequently, they do not require as high a grade (per cent of marketable commodity) as do the less valuable minerals. In this study, the minerals which as a general rule require a grade of less than ten per cent to be of economic value are referred to as "low." Minerals which generally require a grade of more than ten per cent to be of ore quality are referred to as "high." The metallic minerals (ores of copper, lead, gold, mercury, uranium) generally fall into the "low" category while the nonmetallic industrial minerals (sand, gypsum, trona, phosphate, potash) are generally in the "high" category.

Geologic Setting: the mines are divided into groups according to three very broad geologic settings. The mines are classified as belonging to either disseminated ore deposits, bedded ore deposits, or vein ore deposits. Of the mines reporting, those classified as disseminated deposits are exploited by open pit and block caving methods. The bedded deposits are mostly nonmetallic mineral deposits exploited by stripping methods, and the vein deposits are metallic deposits being exploited by various underground methods.

Average Mine: the mean value (average) of the data for all mines reporting under the particular category under discussion.

Statement of Method

A series of questionnaires was mailed to 412 mining companies and operations throughout the United States (Leaming, 1969a, b, c). The data for this study are taken from these questionnaires. (See Appendix for detailed questions.)

The method of analysis used is to correlate the mine production with the various land and efficiency factors by means of a computor program which computes correlation coefficients (Table 3) and to display these relationships in graphs. The data are analyzed on linear and logarithmic basis. In many instances the logarithmic displays are more convenient because of the wide range of values. In one instance where it is desired to display a graphic illustration on a linear scale, a series of three

Table 3. Correlation Coefficients Between Variables

	Production	Total Land	Efficiency Total Land	Mineral Land	Efficiency Mineral Land	Non-Mineral Land	Efficiency Non-Mineral Land	Ore Land	Efficiency Ore Land	Waste Disposal Land	Efficiency Waste Disposal Land
Production	--	0.381	0.413		0.727	0.566			0.504	0.822	
Total Land		--						0.421		0.550	
Efficiency Total Land			--		0.559		0.698		0.584		0.764
Mineral Land				--				0.918			
Efficiency Mineral Land					--				0.609	0.623	
Non-Mineral Land						--				0.539	
Efficiency Non-Mineral Land							--				0.940
Ore Land								--			
Efficiency Ore Land									--		
Waste Disposal Land										--	
Efficiency Waste Disposal Land											--

graphs are used with each succeeding graph being a ten-power magnification of the previous graph.

Statistical Correlation

Production is correlated with ten different variables; namely, the five categories of land, and the corresponding five efficiency factors. The confidence level is set at 95 per cent. The data are limited to 32 observations for this analysis. A correlation coefficient of 0.351 or higher is determined to be significant (Dixon and Massey, 1957, p. 468).

Discussion of Efficiency Factor

In this study, the efficiency factor has been defined as production divided by area and presented as efficiency of production in tons per acre. It must be noted that when the efficiency factor is correlated with production there exists a danger of intercorrelation arising from the fact that production occurs in some way in both the dependent and independent variables.

It is obvious that given a constant number of acres and a steadily increasing production that both efficiency factor and production increase proportionately and have a linear relationship. This could possibly be true of an individual mine, but in this study it is assumed that each mine is brought to a practical production level and it is these practical levels that have been correlated. It must be remembered that production is normally a function of the orebody volume and the land required is a result of needs due to orebody geometry and total production.

It is evident that intercorrelation of production and efficiency factor is negligible in this study when waste disposal land is considered. There is a strong correlation of production with the area and no correlation with the efficiency factor. If the results were affected by intercorrelation, it should have shown up in this comparison.

CHAPTER 2

THE LAND REQUIREMENTS OF MINES

The data from the 33 mines used in this analysis varied over a wide range of values. Mine production varied from a minimum of 120 tpd to a maximum of 100,000 tpd (Table 1). The area owned by the mining company at each mine site varied from a minimum of 94 acres to a maximum of 52,788 acres.

The Average Land Requirement

Based on the data used, the average mine production is 12,500 tpd, the average land owned per mine site is 9,150 acres. The foregoing averages yield an efficiency factor of 1.37 tpd per acre (Tables 4 and 5).

An analysis of the average values of the mines grouped into each of the three geologic settings is of further interest.

The average mine of the disseminated ore deposit group has a production of 27,286 tpd and occupies 11,990 acres of land (efficiency factor = 2.28). The average bedded ore deposit mine has a production of 2,267 tpd and occupies 9,210 acres of land (Tables 4 and 5). The average bedded deposit mine occupies 81 per cent as much land as the average disseminated deposit mine but averages

Table 4. Production Statistics Showing Ranges, Averages, and Totals

Type Deposit	No. of Mines	Primary Mineral	Average tpd	Range of Values tpd
DISSEMINATED ORE DEPOSITS:				
Surface	9	Copper	30,610	500-100,000
	1	Gold	7,500	--
Total	10		28,300	500-100,000
Underground	2	Copper	26,500	13,000- 40,000
	2	Molybdenum	23,000	2,000- 44,000
Total	4		24,750	2,000- 44,000
TOTAL DISSEMINATED	14		27,286	500-100,000
BEDDED ORE DEPOSITS:				
Surface	8	Nonmetallics	2,055	360- 5,700
Underground	1	Nonmetallic	10,320	--
	3	Uranium	148	120- 200
Total	4		2,690	360- 10,320
Nonmetal Mines	9	Industrial minerals	2,974	360- 10,320
TOTAL BEDDED	12		2,267	120- 10,320

Table 4.--Continued

VEIN ORE DEPOSITS:				
Surface	1	Lead	120	--
Underground	6	Lead, Mercury, Copper	954	375- 1,500
TOTAL VEIN	7		749	120- 1,500
TOTALS ALL MINES	33		12,559	120-100,000

Table 5. Land Statistics Showing Averages of Land Uses

	Total Land	Mineral Land	Non-mineral Land	Ore Land	Waste Disposal Land	No. Mines
DISSEMINATED ORE DEPOSITS						
Average Underground	17,240	2,869	14,374	2,869	1,404	4
Average Surface	9,890	3,703	6,186	1,614	1,403	10
Average Disseminated Deposit	11,990	3,465	8,540	1,904	1,390	14
BEDDED ORE DEPOSITS						
Average Underground	6,645	6,564	80	4,252	80	4
Average Surface	10,221	10,468	3,532	9,779	188	8
Average Nonmetal Mines	11,146	11,096	390	10,483	203	9
Average Uranium Mines	3,380	3,380	--	--	10	3
Average Bedded Deposit	9,290	9,160	262	7,870	163	12
VEIN ORE DEPOSITS						
Average Surface	9,100	7,100	2,000	50	50	1
Average Underground	3,593	3,078	555	1,900	375[a]	6
Average Vein Deposit	4,379	3,618	761	1,587	62	7
AVERAGE ALL MINES	9,150	5,570	3,870	4,120	687	33

[a]Only 5 mines reporting in this category.

only 8.3% as much production. Obviously, the bedded ore deposit group has a much lower efficiency factor (efficiency factor = 0.243).

The average vein ore deposit mine has a production of 749 tpd and occupies 4,379 acres of land (efficiency factor = 0.167). The land requirements for vein deposits are lower (38 per cent of disseminated deposit) but the production rate is so much lower that the vein deposit group has the lowest efficiency factor of the three geologic settings (Table 5).

When only mineral land is considered, disseminated deposits compare even better. The average mineral land requirements at disseminated deposits is only 38 per cent as at the average bedded deposit. The mean mineral land requirements at vein deposits is slightly larger than for disseminated deposits (Table 5).

When the averages of non-mineral land are examined, it is found that the relative positions of each geologic setting are reversed to show bedded deposit mines using very little non-mineral land whereas the vein and disseminated deposit mines use non-mineral land in proportion to their production (Table 5).

Disseminated deposit and vein deposit mines make efficient use of ore land and use waste disposal land in direct proportion to production. Bedded deposits occupy relatively large amounts of ore land and very little waste disposal land.

The group of nonmetallic mines produces an average of 2,974 tpd and occupies an average of 11,146 acres of land. These land requirements are almost equal to disseminated deposits while the production is much smaller (8%).

The "Largest" Mines

The mine with the largest production does not occupy the most land. It is an open pit mine producing 100,000 tpd and having 11,980 acres for a very high efficiency factor of 8.4. The mine which has the most land, 52,788 acres, is an underground block caving mine, whose production is 40,000 tpd (Table 6). Both these mines are on disseminated ore deposits.

Among the bedded deposit group the largest producer is an underground potash mine producing 10,320 tpd from 16,438 acres of land. This mine lists 98% of its land as ore land and 2% as waste disposal land. The bedded deposit controlling the most land is a surface trona mine producing 4,000 tpd from 21,856 acres. This mine also lists 98% of its land as ore land and 2% as waste disposal land. Both of these bedded deposit mines have more land than the largest producing disseminated deposit mine (Table 6).

Table 6. Listing of Largest Mines (Both by Production and by Area)

Type Mine	Production (tpd)	Area (acres)	Mining Method
DISSEMINATED ORE DEPOSITS			
Largest Mine Production	100,000	11,980	Open Pit
Largest Mine Area	40,000	52,788	Block Caving
BEDDED ORE DEPOSITS			
Largest Mine Production	10,320	16,438	Underground
Largest Mine Area	4,000	21,856	Surface
VEIN ORE DEPOSITS			
Largest Mine Production	1,500	9,041	Underground
Largest Mine Area	--- Same Mine ---		

Among the vein deposits, one mine has both the largest area and largest production. It is an underground copper mine which has 9,041 acres and produces 1,500 tpd.

Land Ownership Level

Table 7 illustrates the distribution of mines at different land ownership levels. It is significant that 63.7% of the mines have less than 10,000 acres and that 87.9% have less than 20,000 acres of total land.

Table 7. Distribution of Total Land Requirements per Mine

Land Ownership Level	Per Cent of Total Mines Reporting	Cumulative Per Cent
Less than 1,000 acres	15.2	15.2
1,000-10,000 acres	48.5	63.7
10,000-20,000 acres	24.2	87.9
20,000-30,000 acres	8.0	90.9
Over 30,000 acres	9.1	100.0

The Correlation of Production to Total Land

The correlation coefficient between production and total land is 0.381 (Table 3), which is only slightly higher than the minimum (0.351) considered for significance.

However, it is a significant correlation statistically. Larger mines do have more land than small mines.

The graphic demonstration (Figure 1) shows that the correlation is not precise. It demonstrates that there is a wide range of variation in the relationship, especially among the smaller mines. The larger copper mines form a cluster in the over 10,000 tpd range. It should be noted that a large molybdenum mine falls about the center of this cluster. These mines belong to a group whose geologic setting is that of disseminated ore deposit (Table 2).

The conclusions to be reached from Figure 1 are: (1) in a general way, mines of larger production have more land than do smaller mines; and, (2) there is considerable variation, particularly among the smaller mines.

Because of the fact that there is a significant yet poor correlation between production and total land, it can be inferred that there are inner factors, some which do correlate and some which do not correlate.

The Correlation of Production with the Efficiency Factor of Total Land

Statistically, the correlation coefficient of production with efficiency of total land was marginally better than with the coefficient of total land, 0.413 to 0.381. Again, it is above the minimum level of significance, and there is a significant positive correlation between production and the efficiency factor of total land

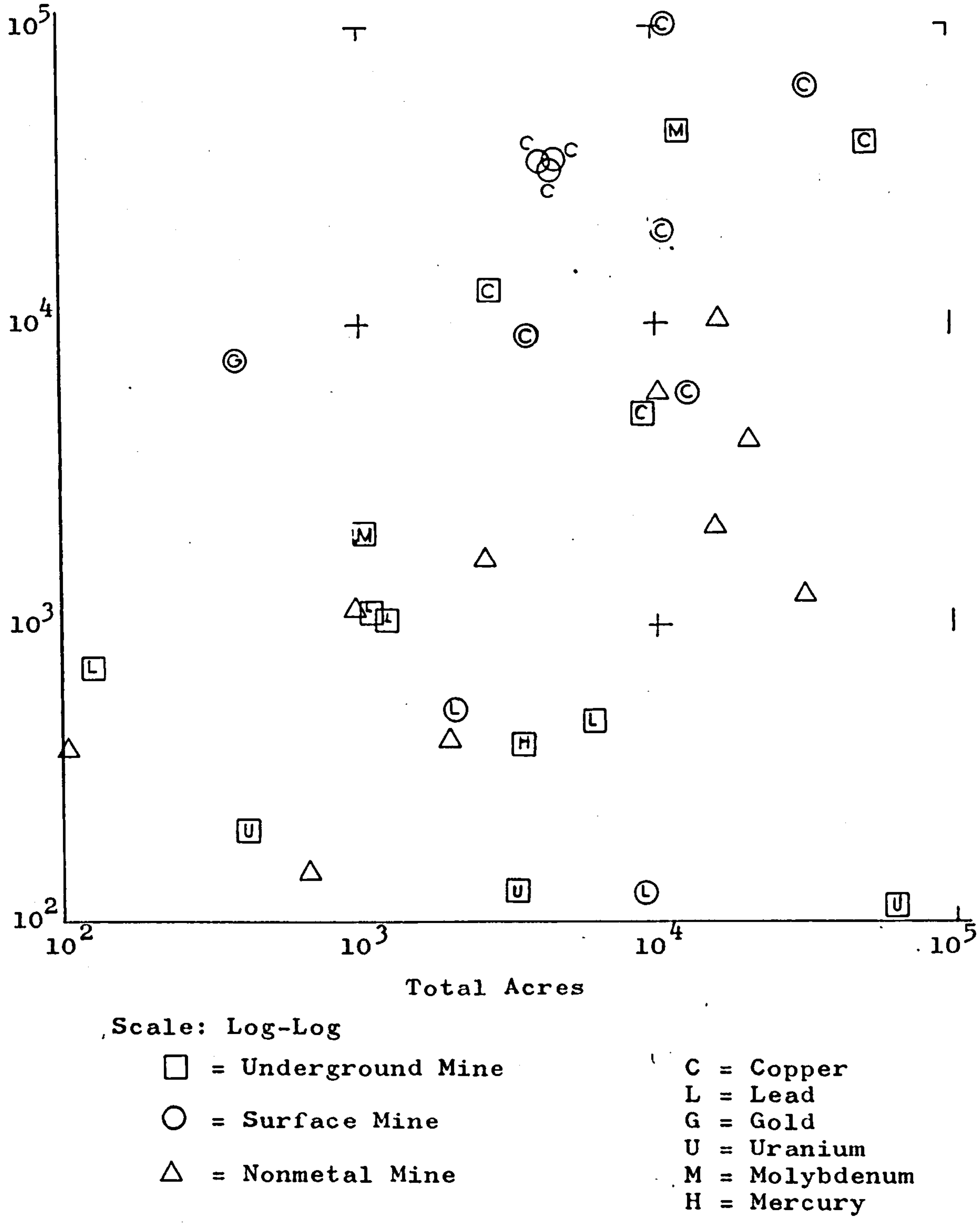


Figure 1. Production in Relation to Total Land

at the 95% confidence interval. Larger mines do make more efficient use of their land.

In the graphic illustration (Figure 2), there is a general trend of increasing efficiency with increasing production. There are three groups or clusters discernible. The large metal mines (primarily copper) appear in the upper reaches with a cluster of nonmetallic mineral mines lying in the central region and somewhat cross-current to the general trend. The smaller metal mines make a cluster in the lower and central area. The largest divergence in Figure 2 comes with the smaller mines and the nonmetallic mineral mines.

In order to investigate further the lack of correlation in Figure 2 and find other correlations, a sequence of graphs (Figures 3, 4, and 5) was prepared in which a linear scale was used instead of the log-log scale. A series of graphs was necessary because of the wide range of values and the need to magnify the scale in Figures 4 and 5. It can be seen in these figures that, starting with the smaller mines, there are two distinct trend lines. There does not seem to be any particular grouping along these trend lines as to the type of mines, the type of deposits, or other characteristics. The only real conclusion we can reach is that efficiency increases with production faster along one trend line than it does along the other. An alternate explanation in these graphs is that only one

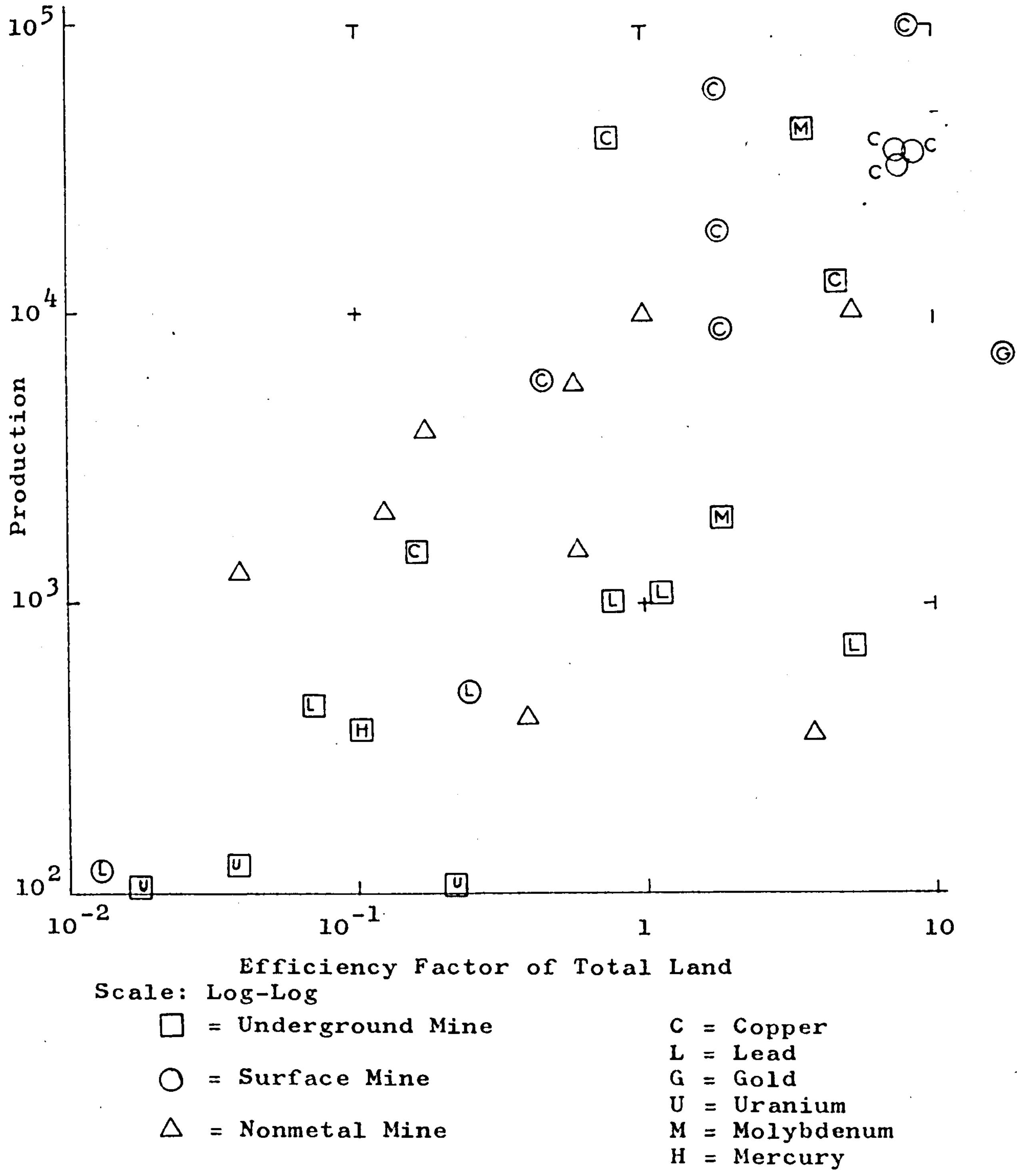


Figure 2. Production in Relation to Total Land Efficiency Factor

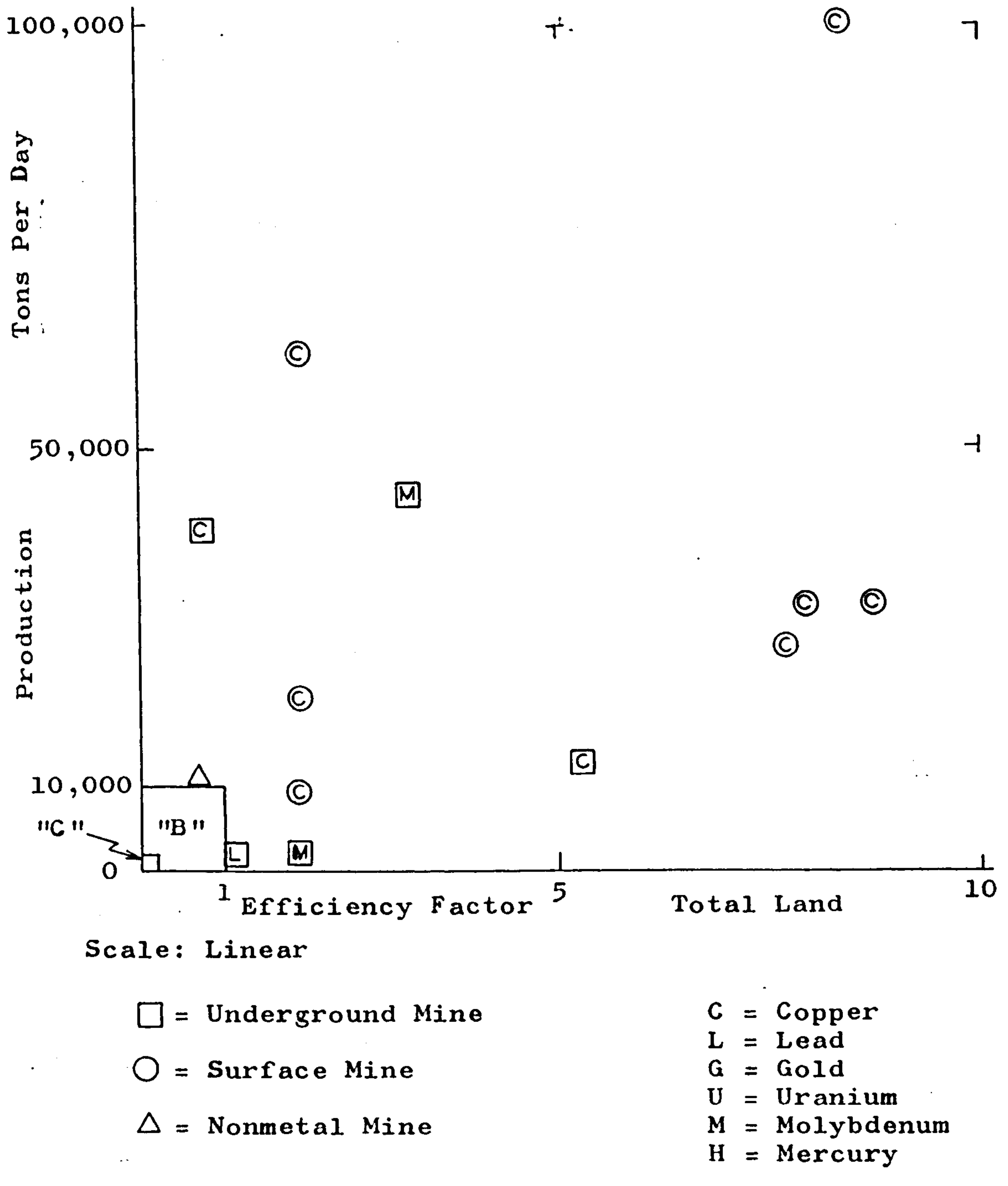
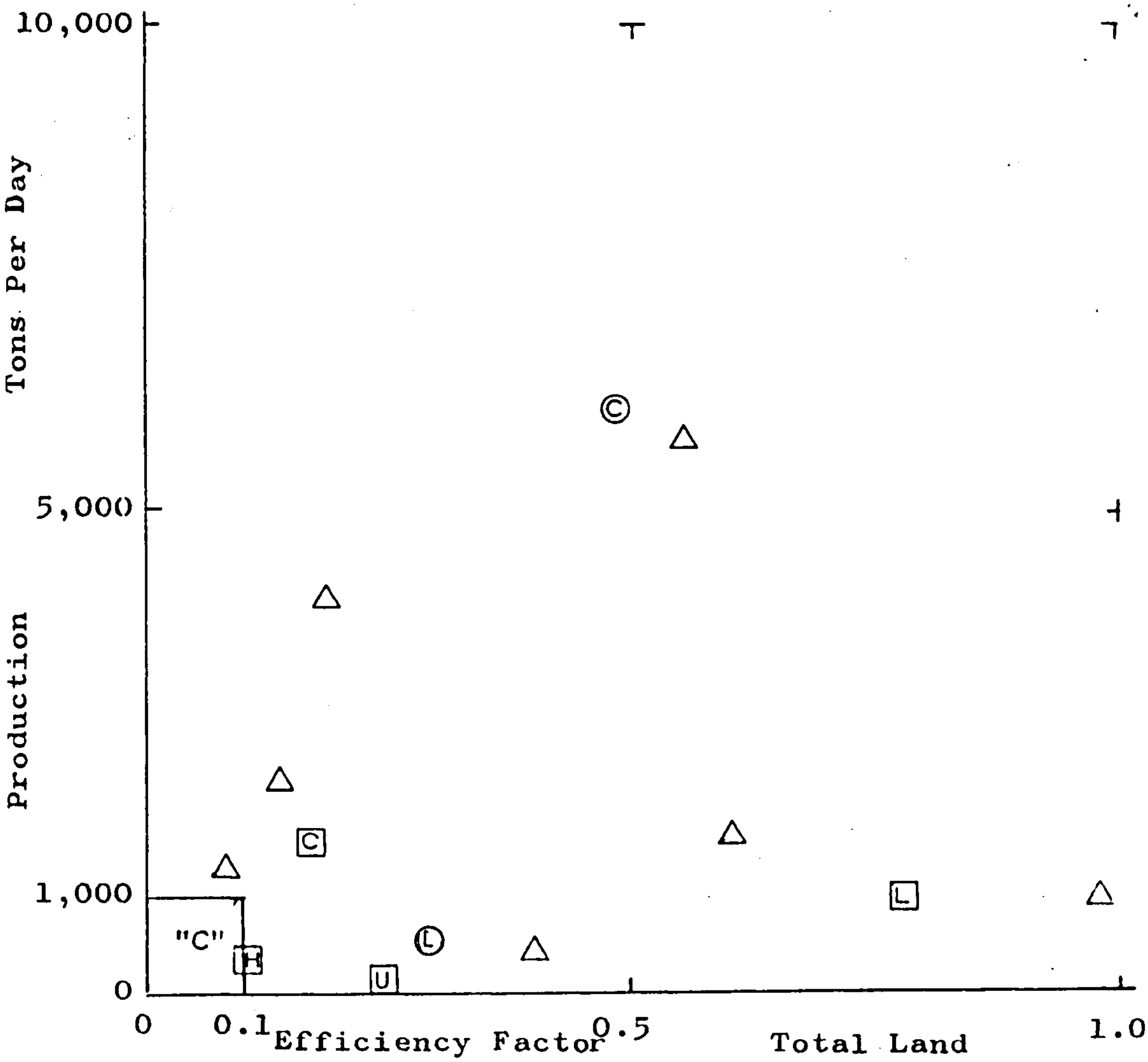


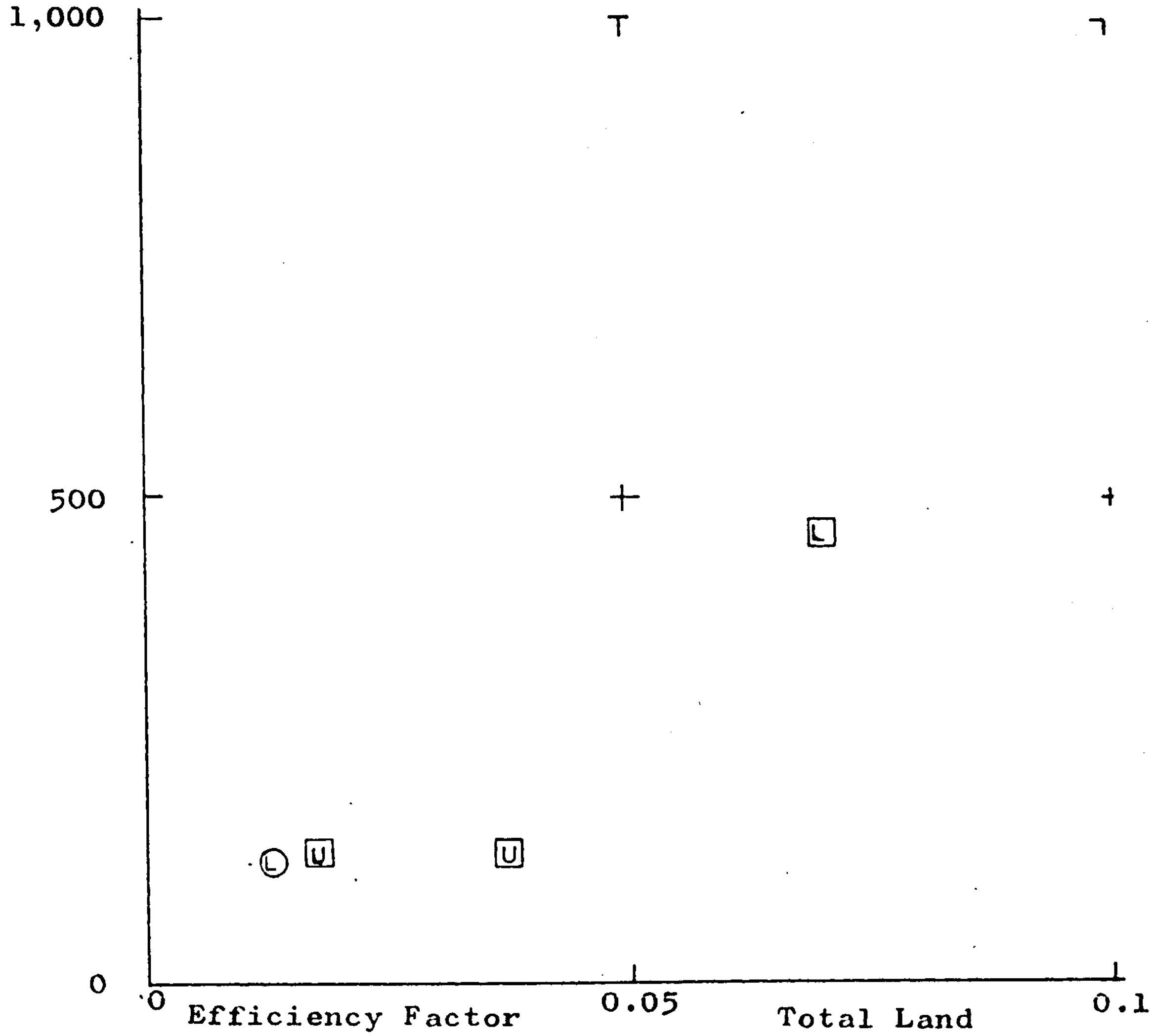
Figure 3. Production in Relation to Total Land Efficiency Factor without Distortion of Log-Log Scale



Scale: Linear and 10X Figure 3

Legend: Same as Figure 3

Figure 4. Inset "B" of Figure 3 Magnified Ten Times



Scale: Linear and 100X Magnification of Figure 3

Legend: Same as Figure 3

Figure 5. Inset "C" of Figure 3 Magnified 100 Times

trend line exists with a much wider range of divergence at lower production ranges.

The Correlation of Production with Mineral Land

The statistical correlation of production with the mineral land area yielded correlation coefficients far below the level acceptable for significance. The graphic analysis (Figure 6) demonstrates the random scattering of the points. It can be concluded that there is no correlation between production and mineral land.

The Correlation of Production with Mineral Land Efficiency Factor

The correlation coefficient between mineral land efficiency factor and production is very high, 0.727 (Table 3), indicating a close relationship. The statistical correlation is confirmed graphically in Figure 7 as a strong increase in efficiency factor is noted with increasing production. Again, note the cluster of copper mines and one molybdenum mine in the upper reaches, the cross trend of nonmetallic mines in the central region, and the confirming upward trend of the smaller mines similar to those in Figure 2. It is also interesting to note that there appear to be two trend lines similar to those discussed in reference to Figures 3, 4, and 5. These are roughly the same mines in each of the upper and lower trends as appeared in Figures 3, 4, and 5 (Table 8),

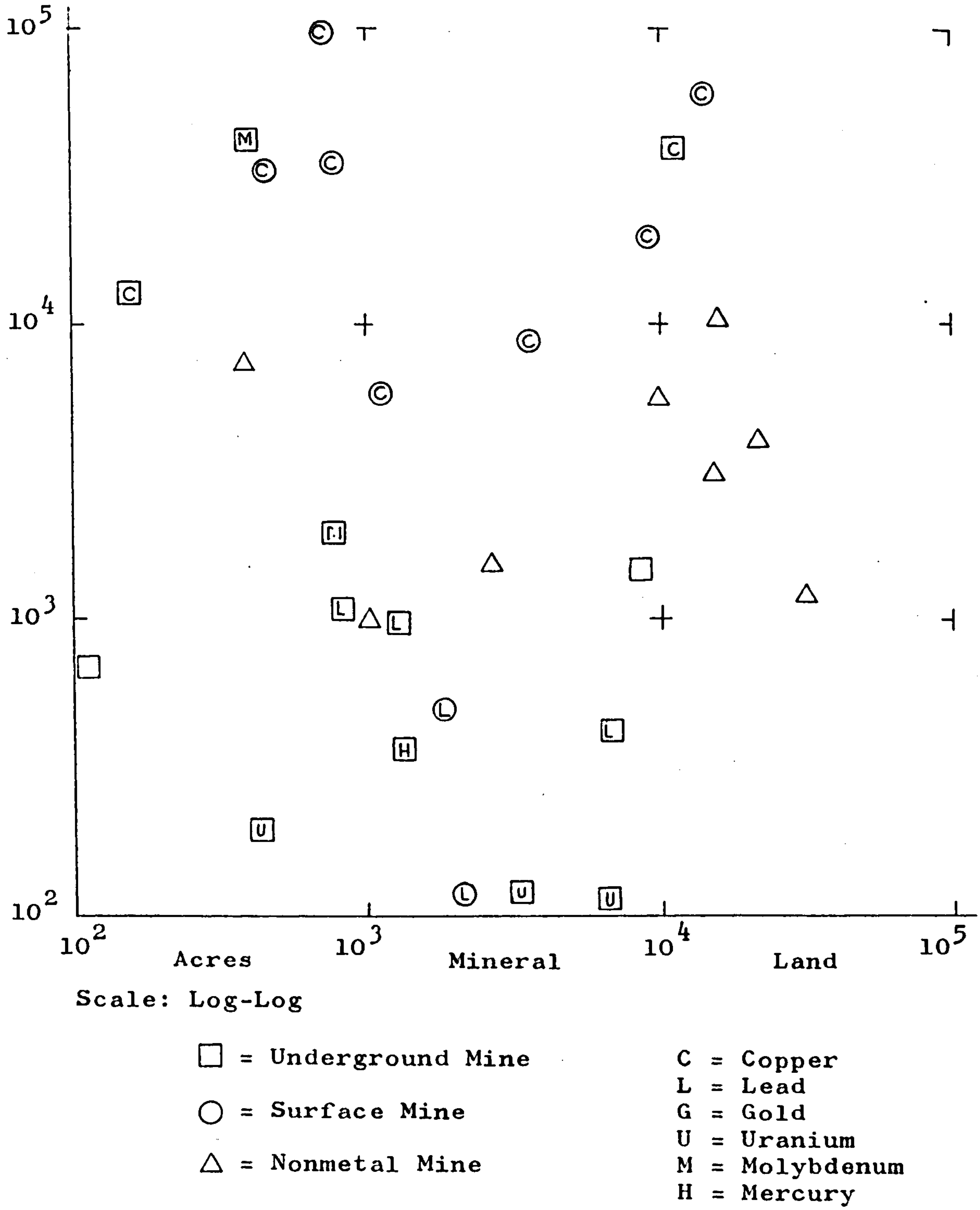


Figure 6. Production in Relation to Mineral Land

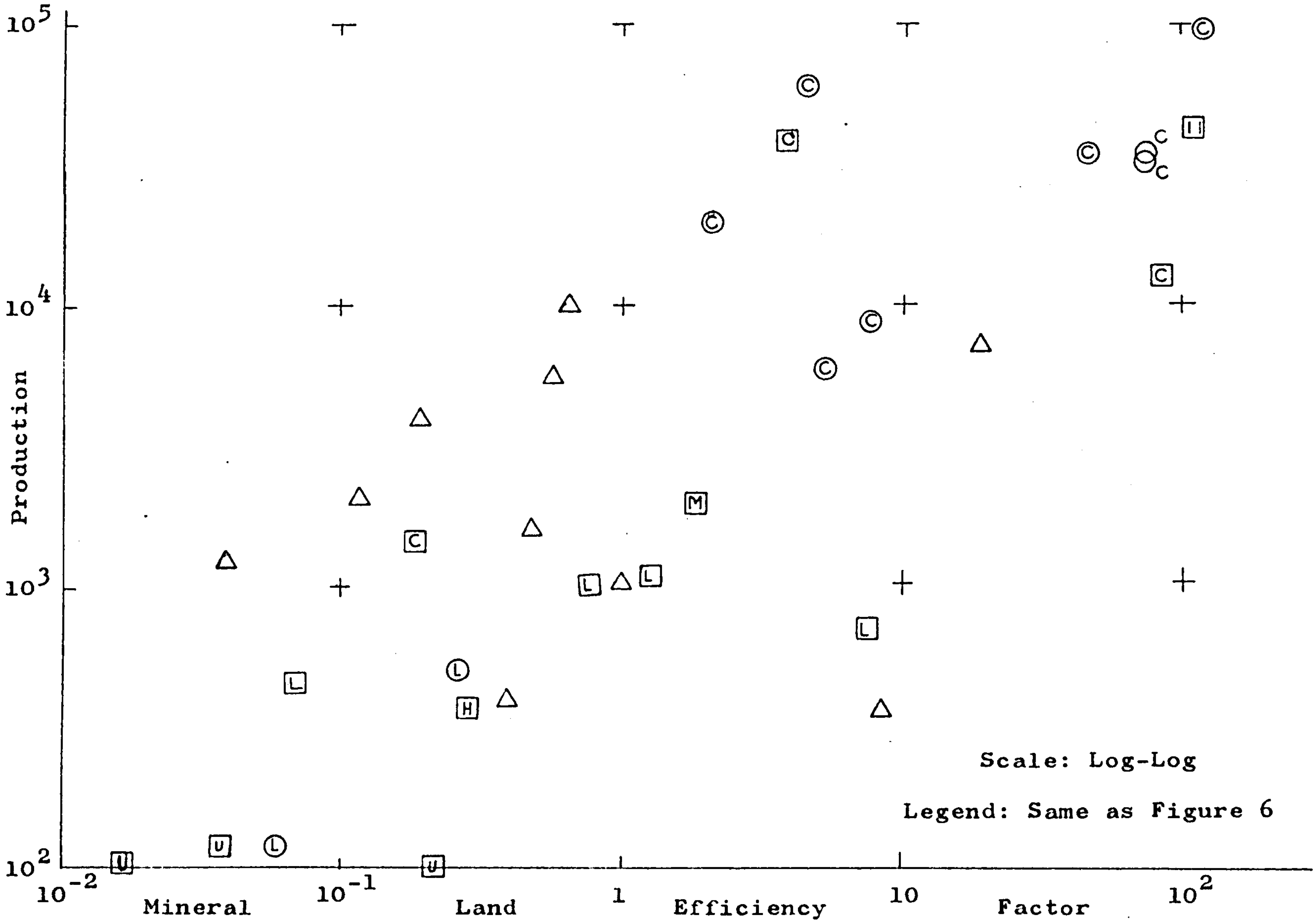


Figure 7. Production in Relation to Mineral Land Efficiency Factor

Table 8. Mines Which Belong to Trend Lines 1 and 2 in Figures 3, 4, and 5 (Number Designations Refer to Table 1)

Line 1	Line 2
2	1
3	5
4[a]	7
6[a]	12
8	14
10[a]	17
13	18
16	22
20	23
21	24
27	26[a]
30	28
31	29
33	32

[a]These mines are not in the same trend line in Figure 6.

indicating that these mines have the same relative position between efficiency factors of total land and mineral land. This correlation is confirmed statistically (Table 3) with a correlation coefficient of 0.559 between efficiency total land and efficiency mineral land.

The Correlation of Production to Ore Land

There is not a significant statistical correlation (Table 3) between production and area of the ore land. This lack of correlation is confirmed graphically by the random scattering of points in Figure 8. It is interesting

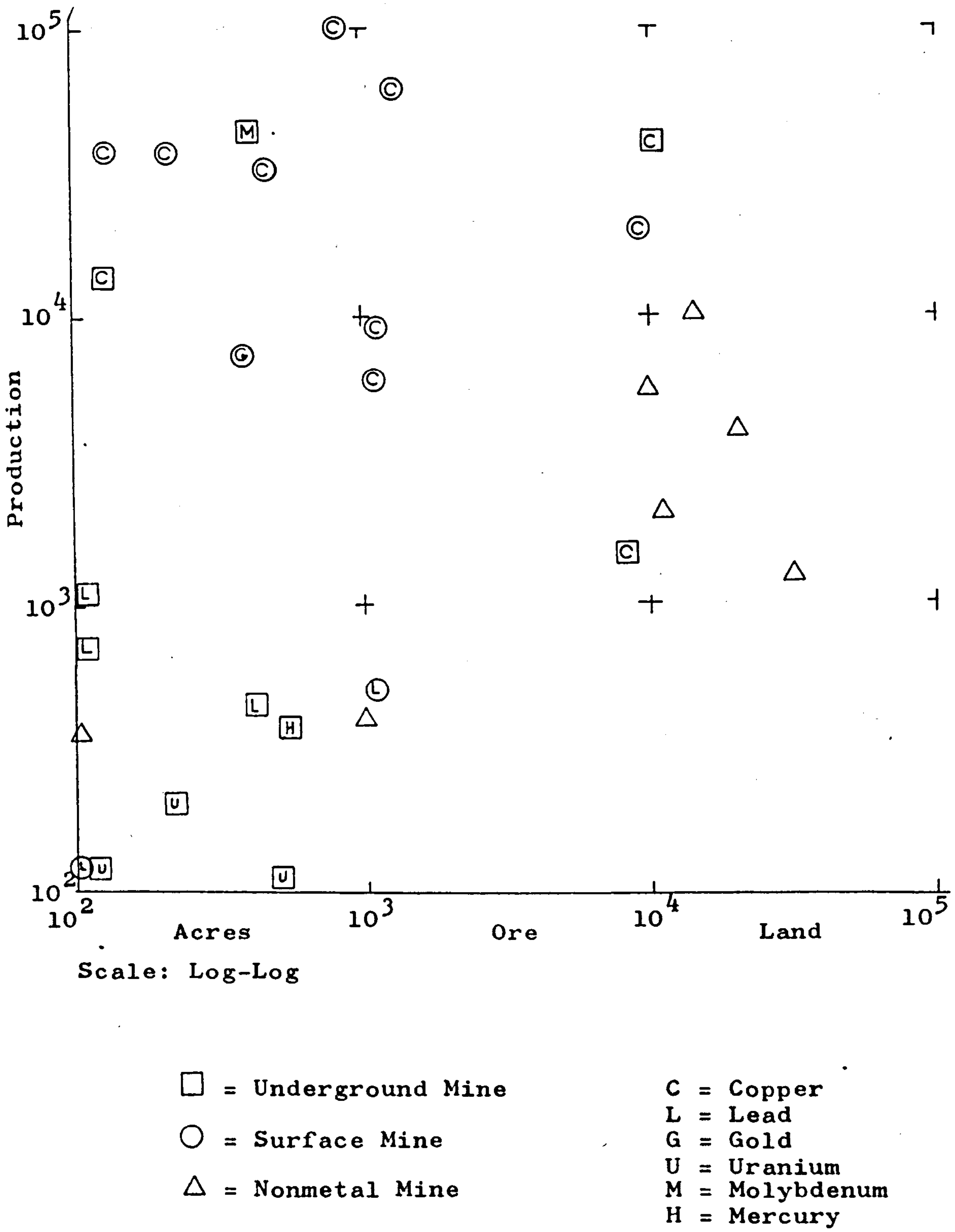
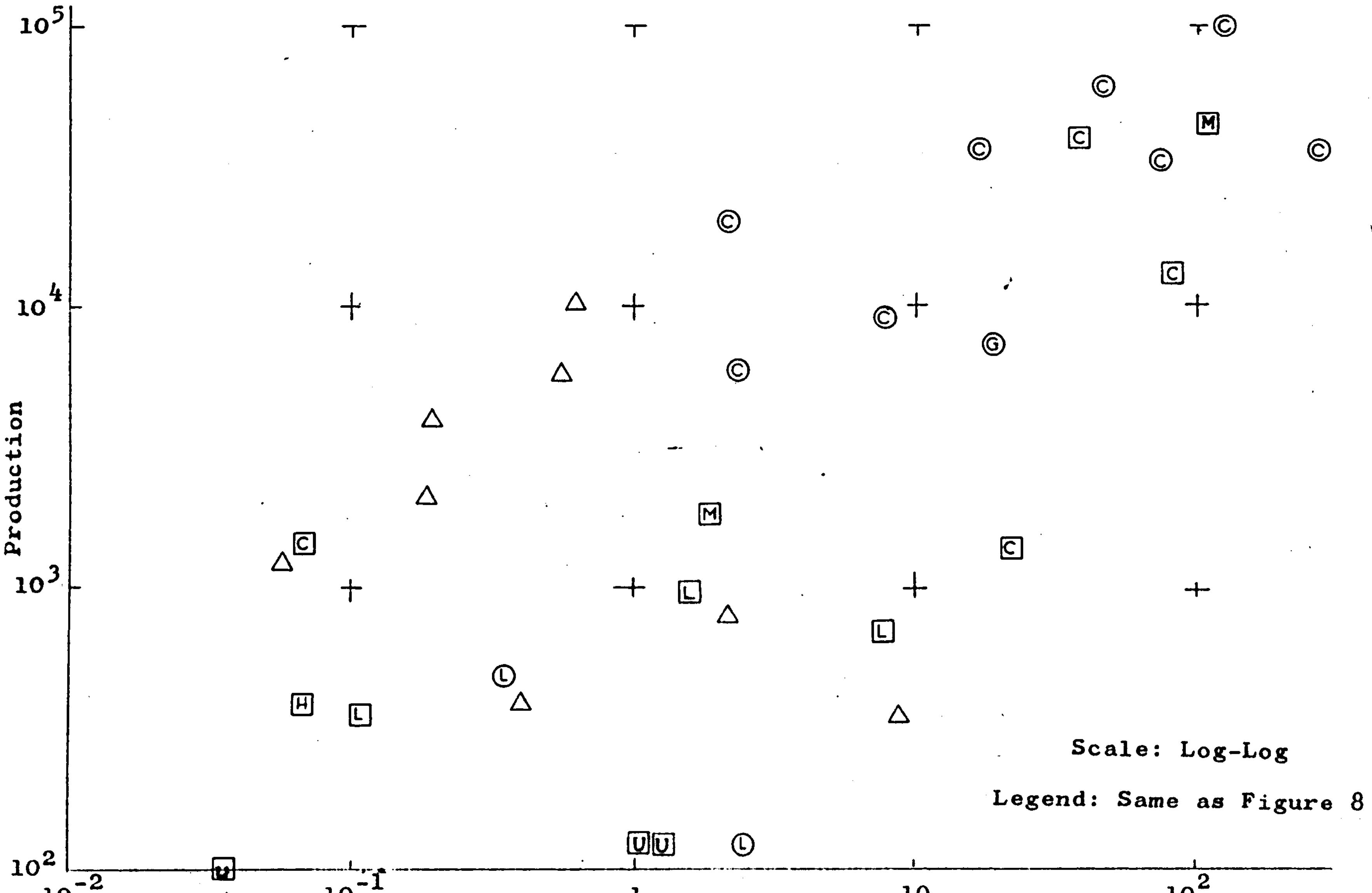


Figure 8. Production in Relation to Acres of Ore Land

to note that some of the very large mines use a relatively small amount of ore land. Note the five non-metal mines which use over 10,000 acres of ore land to support production ranging from ± 1,000 tpd to ± 10,000 tpd. It will be demonstrated later that the large metal mines, primarily disseminated ore deposits, have a low percentage of ore land to total land, and the non-metal mines have most of their land over the orebody.

The Correlation of Production to Ore Land Efficiency Factor

A correlation coefficient of 0.504 indicates a high correlation between production and ore land efficiency factor (Table 3). Figure 9 demonstrates that the efficiency of ore land increases with increasing production. It will be noted that this trend is much flatter than the graph of total land. The reason for this is that large mines have a smaller proportion of their land as ore land or mineral land than do the smaller mines. (This is demonstrated later in Figure 19.) The non-metal mines occupy approximately the same area and have the same cross trend as in previous graphs (Figures 2, 7). The large metal mines and the small metal mines occupy approximately the same area as established in the mineral land and total land efficiency categories.



Efficiency Factor Ore Land

Figure 9. Production in Relation to Efficiency Factor of Ore Land

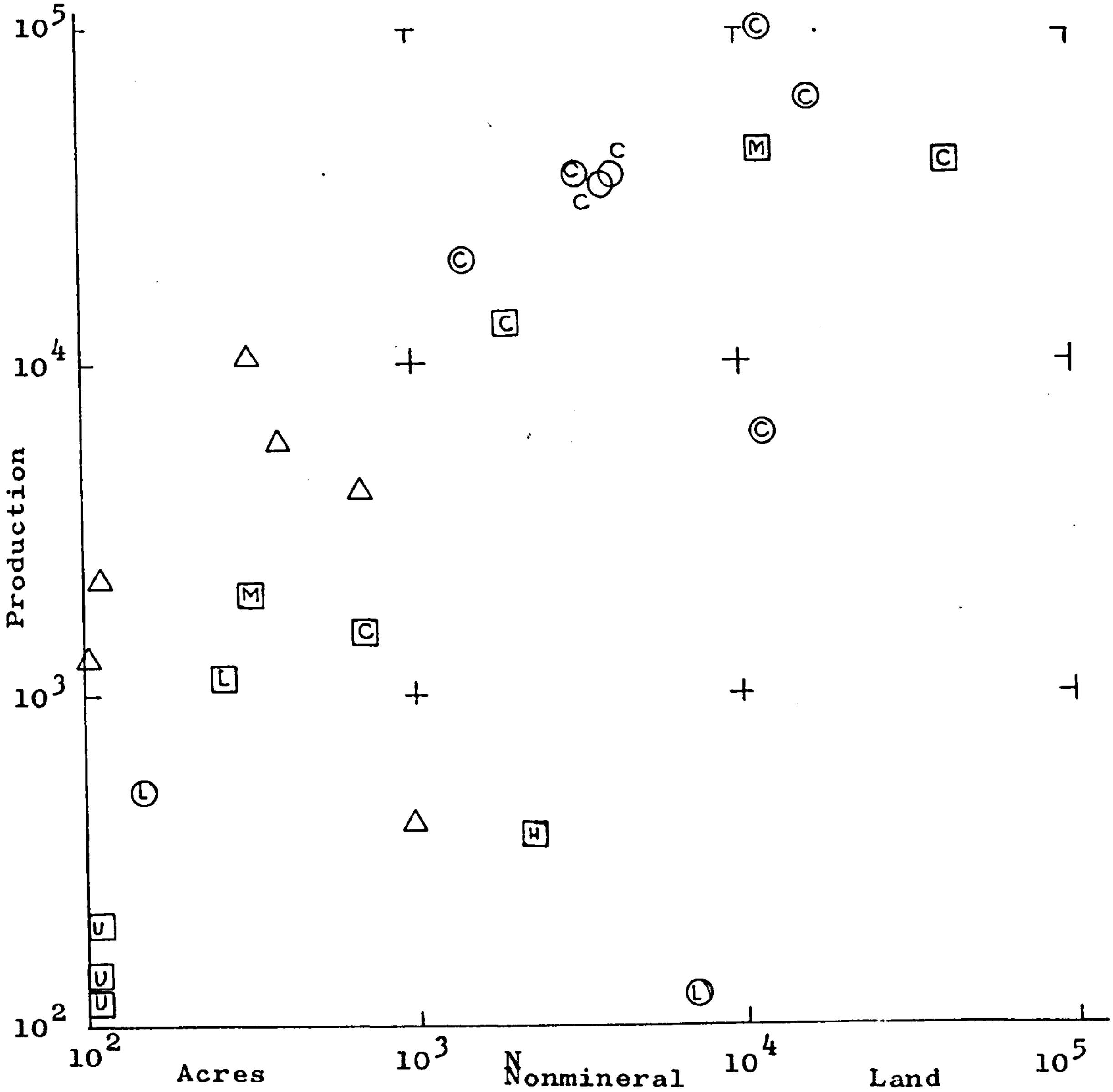
The Correlation of Production with Non-Mineral Land Area and Non-Mineral Land Efficiency Factor

The statistical correlation of non-mineral land with production is high, 0.566 (Table 3). However, the correlation with efficiency of non-mineral lands is below the level of significance. This is a reversal of the pattern noted in mineral lands and ore lands where the efficiency factor correlated and the areas did not correlate.

The graphic demonstrations (Figures 10 and 11) confirm the statistical analysis. Figure 10 shows a loose, but definite trend of area increasing proportionately to production. Note the relative position of the nonmetallic mines. They are much farther to the left than in the graphs for ore and mineral lands, where they were generally on the right of center (Figures 1, 6, and 8). This is evidence that the nonmetallic mines have a low percentage of their land as non-mineral land.

Figure 11 further confirms that nonmetallic mines have low percentage of non-mineral land by displaying all the nonmetallic mines with higher than average efficiency factors.

By studying Figure 11, it can be seen that the average value of the efficiency factor will be a line approximately parallel with the Y-axis. Statistically, the efficiency factor is a constant and, therefore, lacks



Scale: Log-Log

□ = Underground Mines

○ = Surface Mines

△ = Nonmetal Mines

C = Copper
L = Lead
G = Gold
U = Uranium
M = Molybdenum
H = Mercury

Figure 10. Production in Relation to Acres of Non-Mineral Land

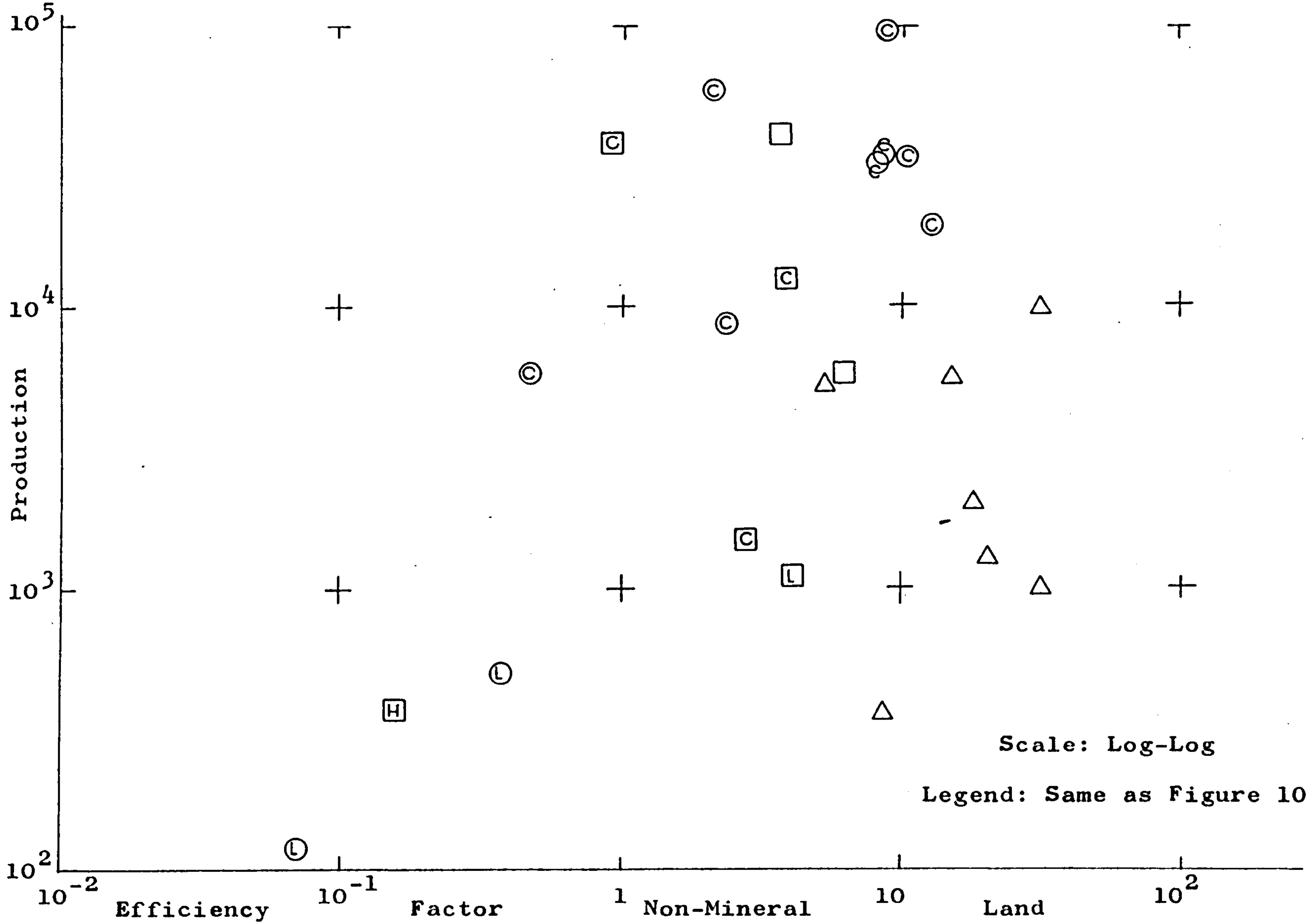


Figure 11. Production in Relation to Efficiency Factor of Non-Mineral Land

correlation with production. Without the influence of the nonmetallic mines there might be some positive correlation between production and efficiency of non-mineral land. However, the data are too limited in the lower production ranges to make a definite assertion.

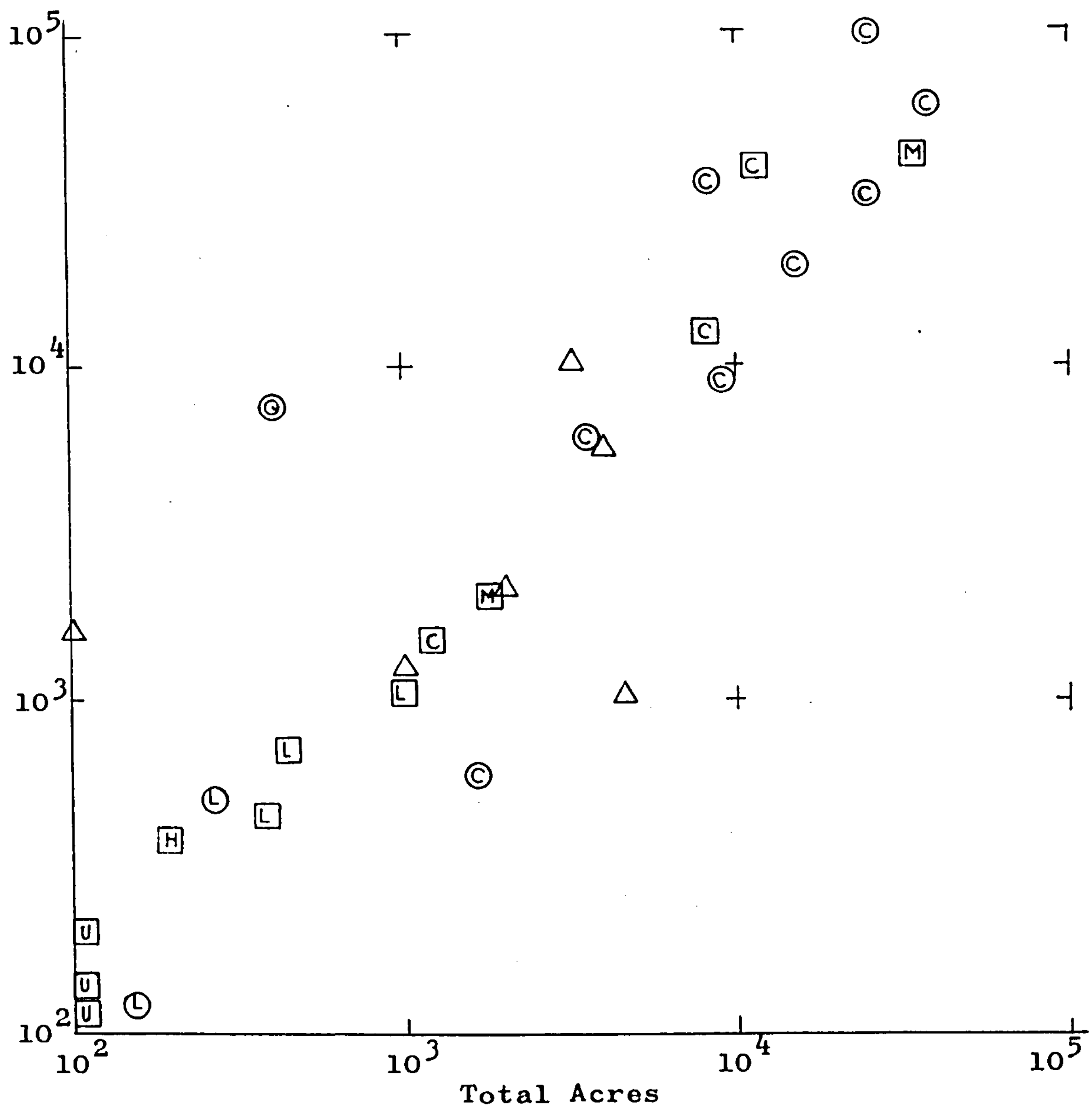
The Correlation of Production with Waste Disposal Land and Waste Disposal Land Efficiency Factor

Waste disposal land exhibits the highest correlation with production. The correlation coefficient is 0.822 and, therefore, there is a close relationship between production and the land required for waste disposal.

In Figure 12 it can be seen that most examples are close to the trend line. The use of land for waste disposal varies directly with production.

There is not a statistical correlation between production and the efficiency factor of waste disposal land. The coefficient is far below the level of significance.

Figure 13 is an example of what happens to the efficiency factor when there is a high correlation between area and production. The efficiency factors become nearly a constant and produce a line parallel to the dependent variable axis (Y-axis). Note the strong cross trend of the nonmetallic mines which has been evident in each category of land use. The small mines are more tightly clustered than they were in the non-mineral land study. This is



Scale: Log-Log

□ = Underground Mine

○ = Surface Mine

△ = Nonmetal Mine

C = Copper
L = Lead
G = Gold
U = Uranium
M = Molybdenum
H = Mercury

Figure 12. Production in Relation to Waste Disposal Land

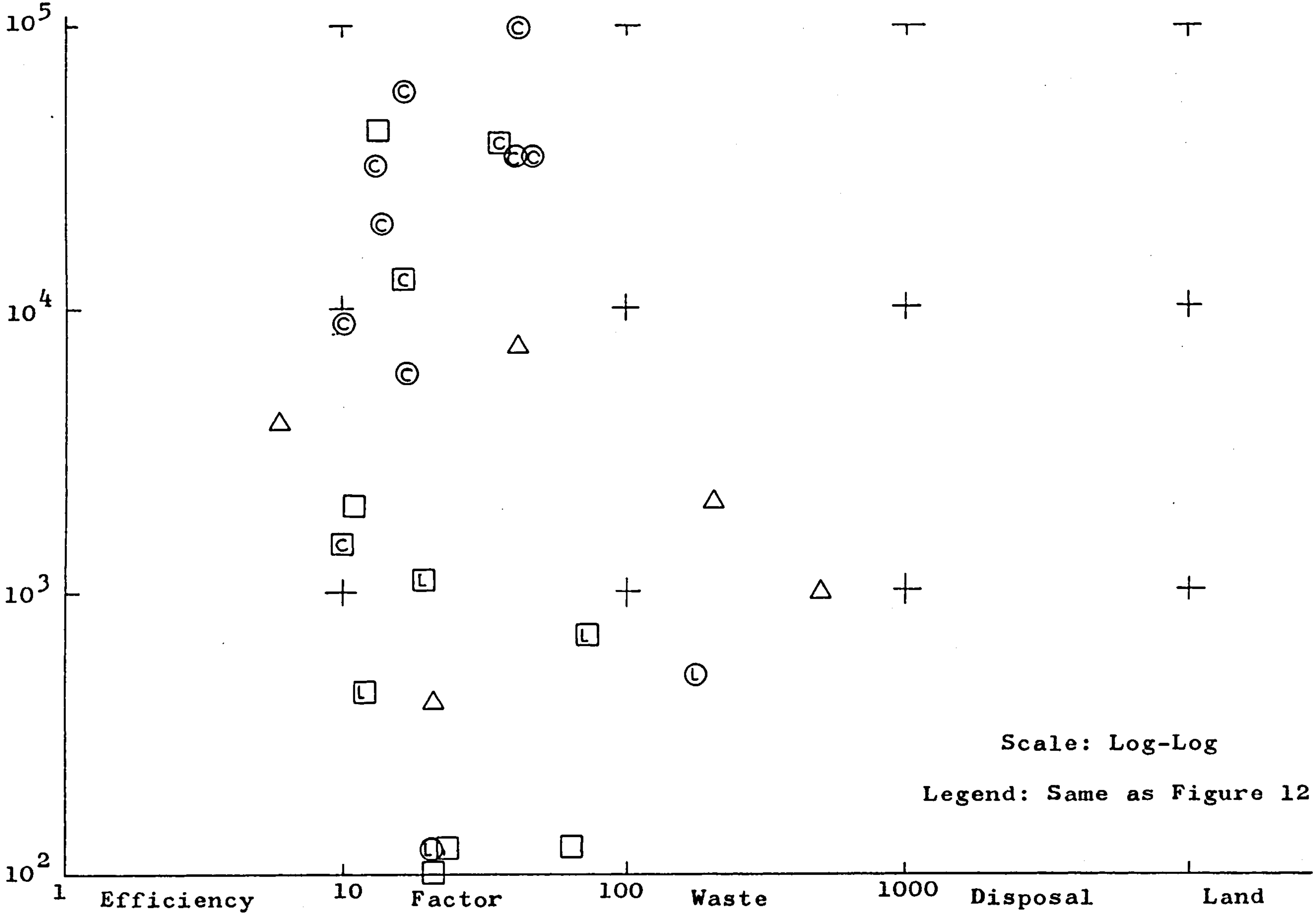


Figure 13. Production in Relation to the Efficiency Factor of Waste Disposal Land

because there is land included in the non-mineral land that is used for buffer zones and other miscellaneous purposes.

The correlation of production with the area and not with the efficiency factor of waste disposal land follows the pattern noted for non-mineral land and is opposite to the pattern noted for mineral land and ore land.

The Effect of the Geologic Setting on Land Requirements

The disseminated ore deposit group occupies a position of high production and high efficiency factor. This is displayed in Figure 14, where all but two mines outside of inset "B" are in disseminated ore deposits. The two exceptions (one bedded and one vein deposit) are very near to the fringe of inset "B." It can be concluded that large mines of over 10,000 tpd production and mines with an efficiency factor greater than one are usually disseminated ore deposits.

Inset "B" (Figure 15) is the production range 1,000 to 10,000 tpd and efficiency factor range of 0.1 to 1.0. In this range there is a uniform scattering of bedded deposit mines. This seems to be their province. Comparing Figures 14 and 15 we can see that there is only one example of a bedded deposit with production of over 1,000 tpd and no example of an efficiency factor of over one. The two examples of bedded deposit mines with efficiency factors of less than 0.1 (Figure 16) are uranium mines. Uranium bedded

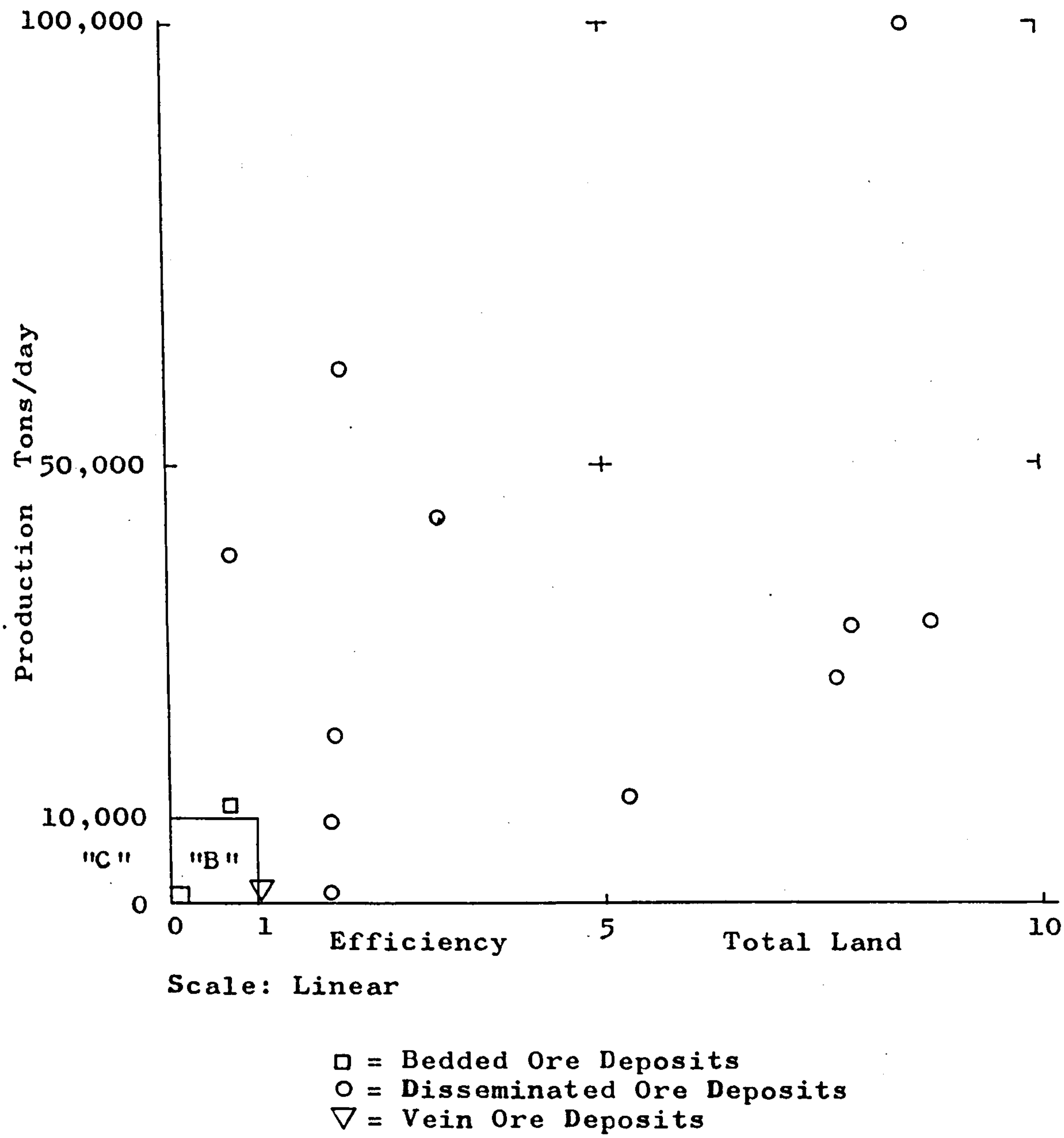


Figure 14. The Geologic Setting in Relation to Production and Total Land Efficiency Factor

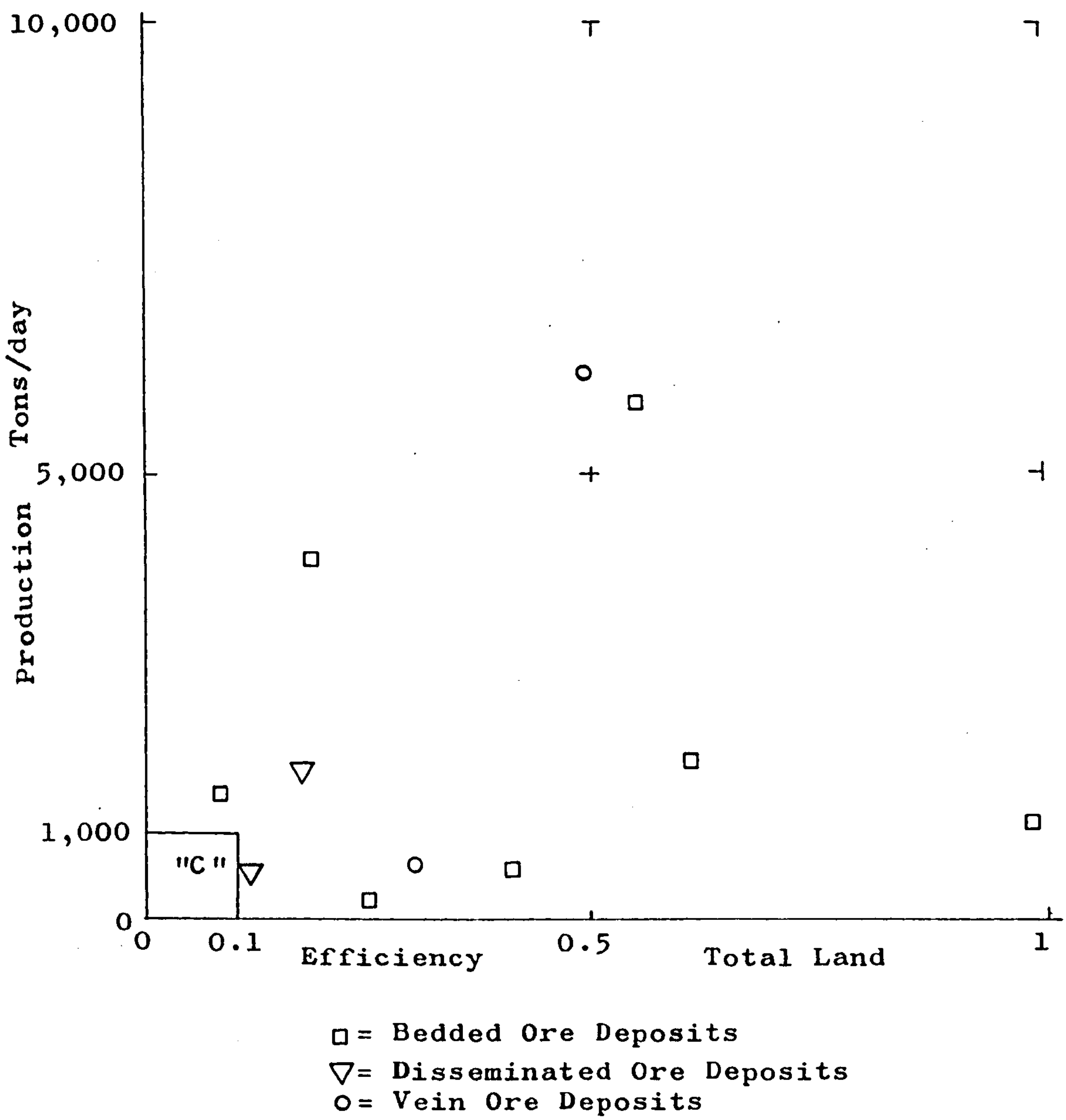


Figure 15. Inset "B" of Figure 14 Magnified Ten Times

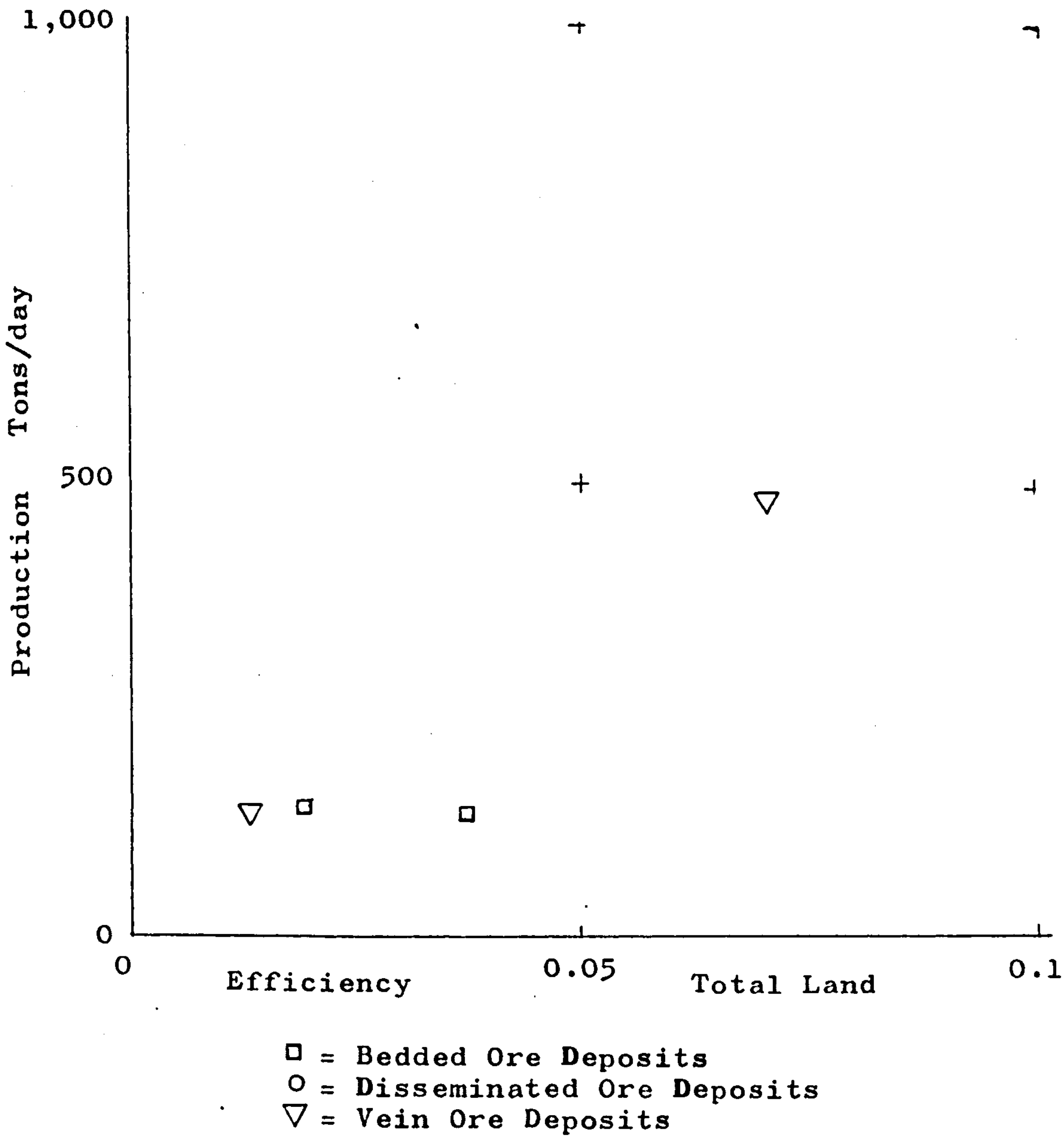


Figure 16. Inset "C" of Figure 14 Magnified 100 Times

deposits usually have only one long dimension and are long slender deposits, rather than the tabular form generally associated with bedded orebodies and their shape contributes to their low production and low efficiency factor.

Among vein deposit examples we have very limited information. They are generally mines of small production and low efficiency factors compared to the majority of mines (Figures 14, 15, and 16).

The Per Cent of Mineral Land and Ore Land to Total Land

The most striking contrast of mines of geologic settings occurs when we study the per cent of land owned which is mineral land or that which is ore land. Figure 17 depicts the different geologic settings and production in relation to per cent of total which is mineral land. It is evident that the disseminated ore deposit mines have a very low per cent of mineral land to total land, generally below 20 per cent. This trend is more pronounced with the ore land (Figure 18). The bedded ore deposit mines, with the exception of the uranium mines, generally have over 40 per cent of the land as mineral land and there are many examples near the 95 per cent level. The same is true for vein deposits (Figure 17).

Figures 17 and 18 emphasize that disseminated ore deposit mines have a low per cent of the land as mineral land or as ore land. Bedded and vein deposit mines have

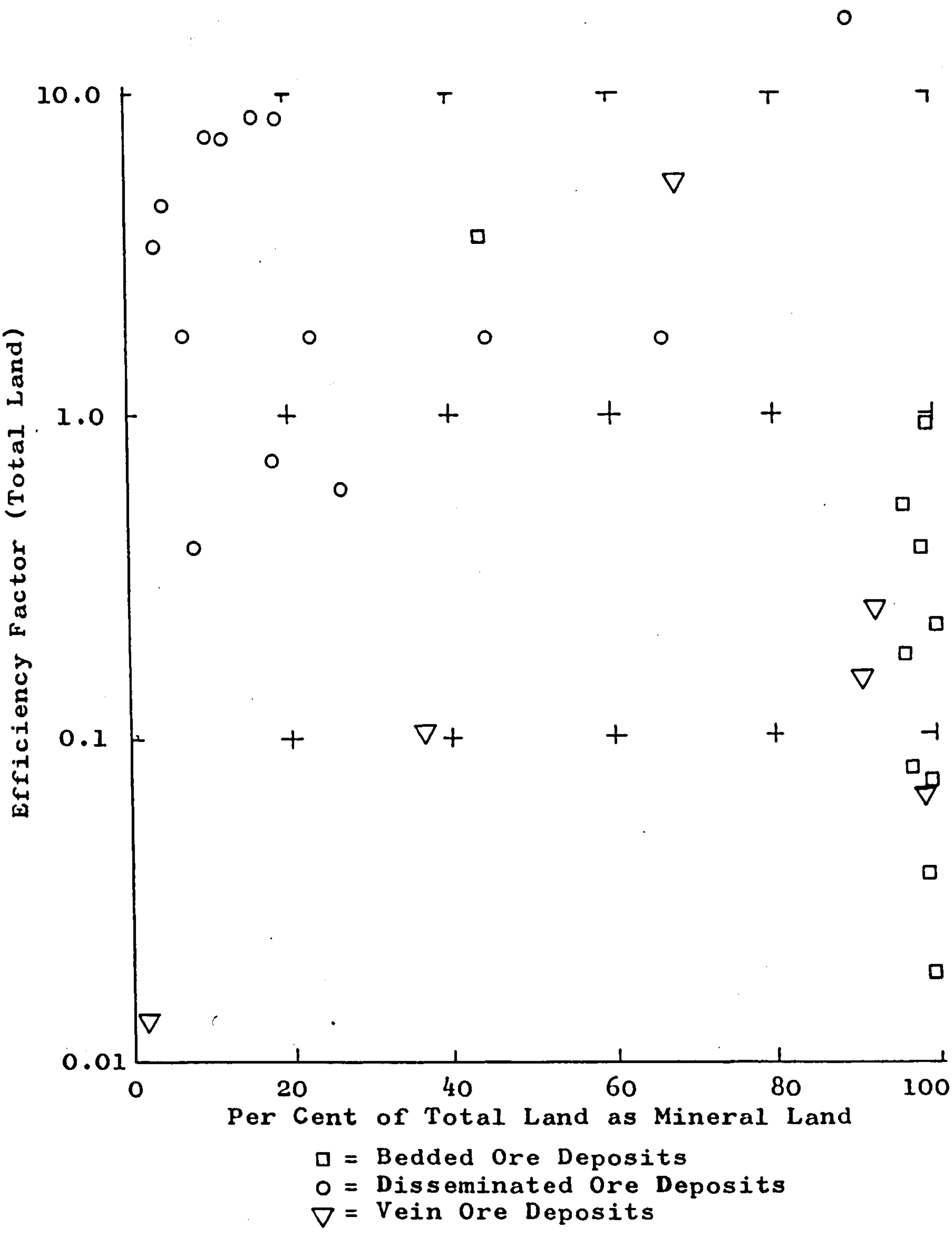
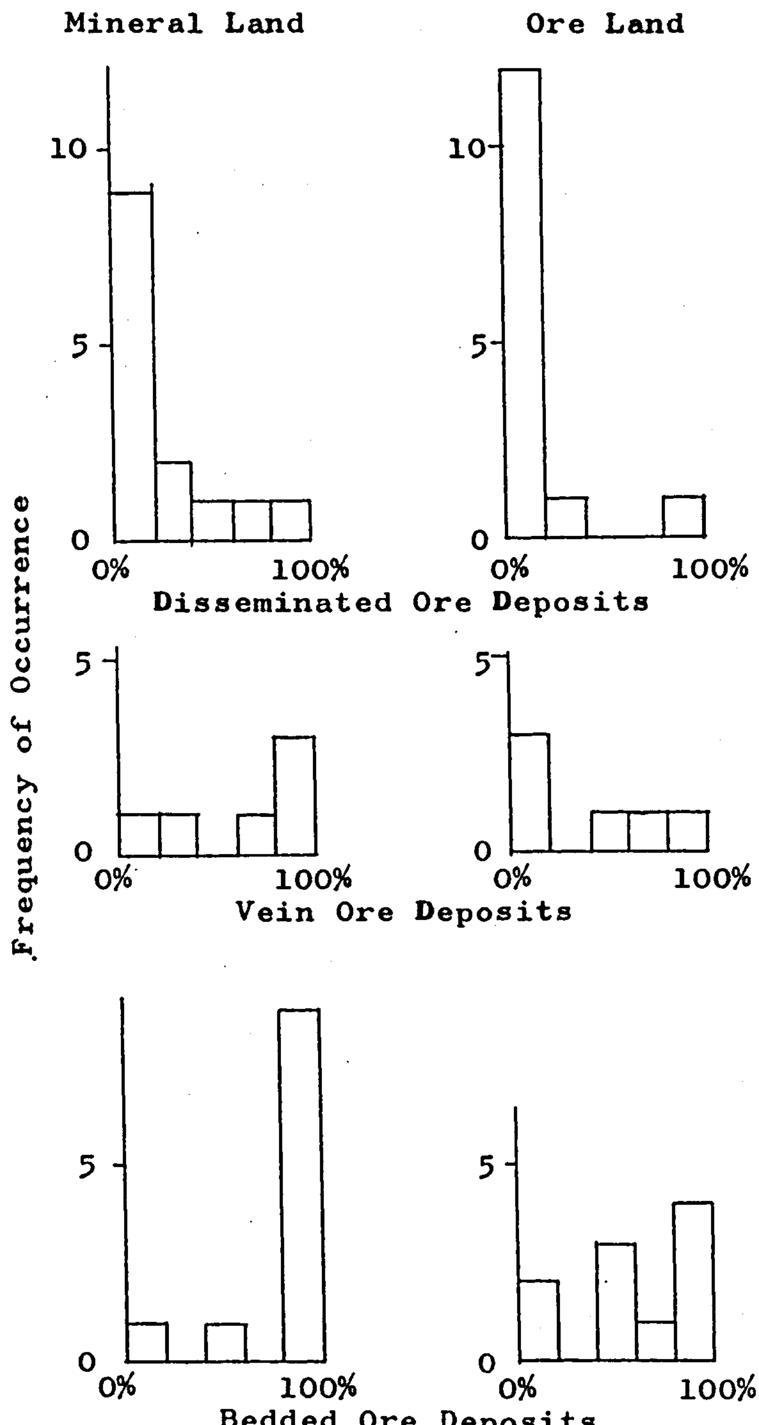


Figure 17. Total Land Efficiency Factor as a Function of Per Cent Mineral Land with Mines Divided According to Geologic Setting



Legend: Horz. 20% increments (1/5 in.)
Vert. 5 mines per inch

Figure 18. Frequency Distribution of Per Cent Mineral Land and Ore Land in Each Geologic Setting

much higher percentages of the land as mineral land and as ore land. Evidently disseminated ore deposits require and take land other than mineral land to support production, often five times the area of mineral land. Other mines have most of their land as mineral land but not all the mineral land is over the ore zone.

To understand why mines with disseminated deposits require such a high percentage of their land for support purposes, one needs only to consider the needs that generally arise with the exploitation of this type of deposit.

Disseminated deposits are usually developed by open pit or block caving methods and are characteristically of low grade with a mineralized fringe area. The first consideration with land surrounding a disseminated deposit is the delineation of the fringe or protore areas so that potential ore may be reserved from encroachment by waste dumps; second, that land must be reserved for dumping waste from stripping and tailings; and third, that land must be set aside for leaching dumps. Since disseminated deposits characteristically produce large quantities of waste and leach material, the areas reserved for those purposes are necessarily large.

In contrast, the bedded deposits often lend themselves to methods which use the mineral land itself for dumping purposes. In the case of flat dipping relatively shallow beds, the overburden may be stripped and cast behind the mining zone on land previously mined.

Vein deposits also have low waste disposal land requirements. They are generally of higher grade and produce little or no waste other than tailings; therefore, their land requirements for waste disposal are not as great as disseminated deposits. Vein mines also have the opportunity to dump tailings in old stopes or over mined-out areas thereby using mineral lands for waste disposal.

The Relation of Primary Mineral Produced to Land Requirements

Throughout this study the primary mineral produced at each mine has been displayed on the figures and graphs by letter code. No justification can be found to assert that any particular mineral dominates any specific land consideration or efficiency factor. Copper mines have a certain amount of segregation on the charts and there is a strong temptation to give an interpretation similar to the interpretation given disseminated ore deposits. However, the two disseminated molybdenum mines appear near the center of these clusters of copper mines, indicating that the clustering of copper mines is due to their belonging to the disseminated class rather than because they are copper mines.

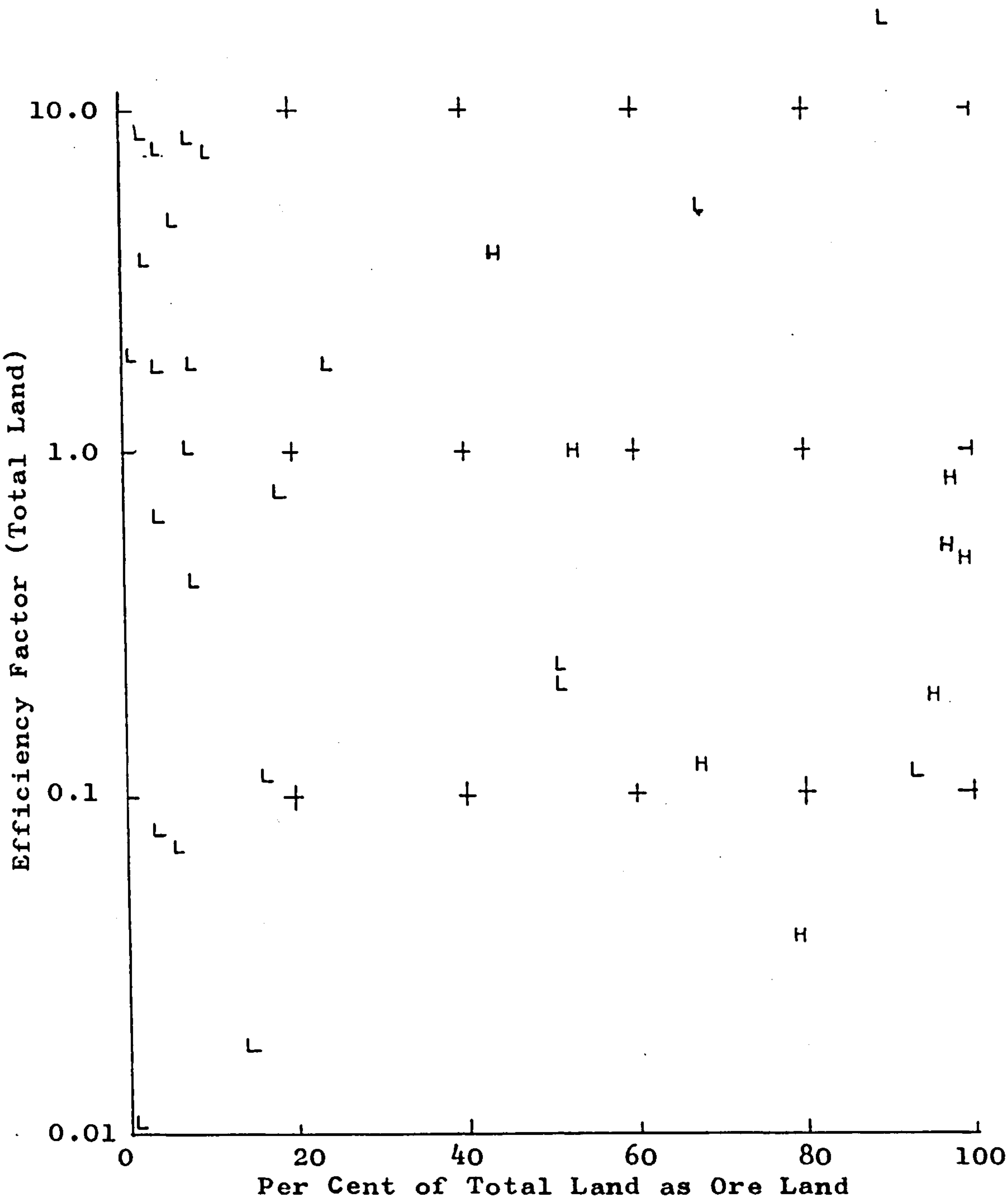
What does seem to be of significance is the per cent of recoverable mineral in the ore. In Figures 19 and

20 the mines are divided into two classes according to high or low mineral content. Metallic minerals which need only a small per cent per ton to be of ore quality are "lows," and industrial minerals (gypsum, clay, sandstone, etc.) requiring a high percentage of the bulk to be a marketable mineral in order to be of ore quality are "highs." As it happens in this study, the "highs" are all nonmetallic bedded deposits and the "lows" are metallic mineral deposits. Thus, we can look at the nonmetallic mines on all previous graphs to see the relation of the "highs" in each case. In Figure 19, there is a definite segregation of the "lows" in the low per cent of ore land and a concentration of "highs" in the high per cent of ore land. The same is true for mineral land (Figure 20). This indicates that the industrial mineral producers have most of their land as mineral land directly over the ore deposit and the "lows" require considerable land for support purposes.

As noted before, the nonmetallic mines or "highs" exhibit strong cross trends on most efficiency factor charts. The cross trend is most likely due to production being keyed to demand rather than to production ability.

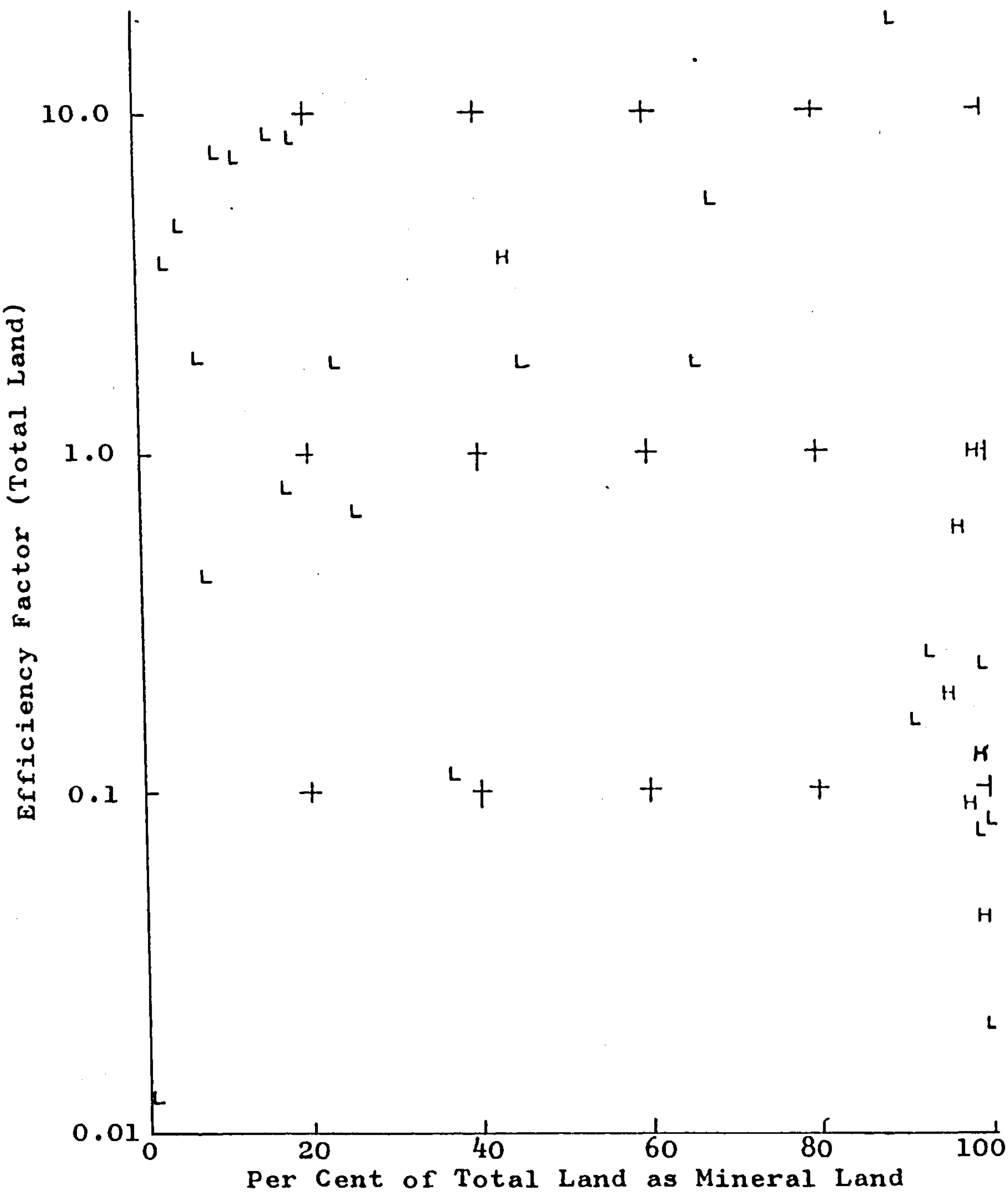
The Relation of Land Uses to Depth

Depth was analyzed in relation to production, total land, and total land efficiency factor (Figures 21, 22, and



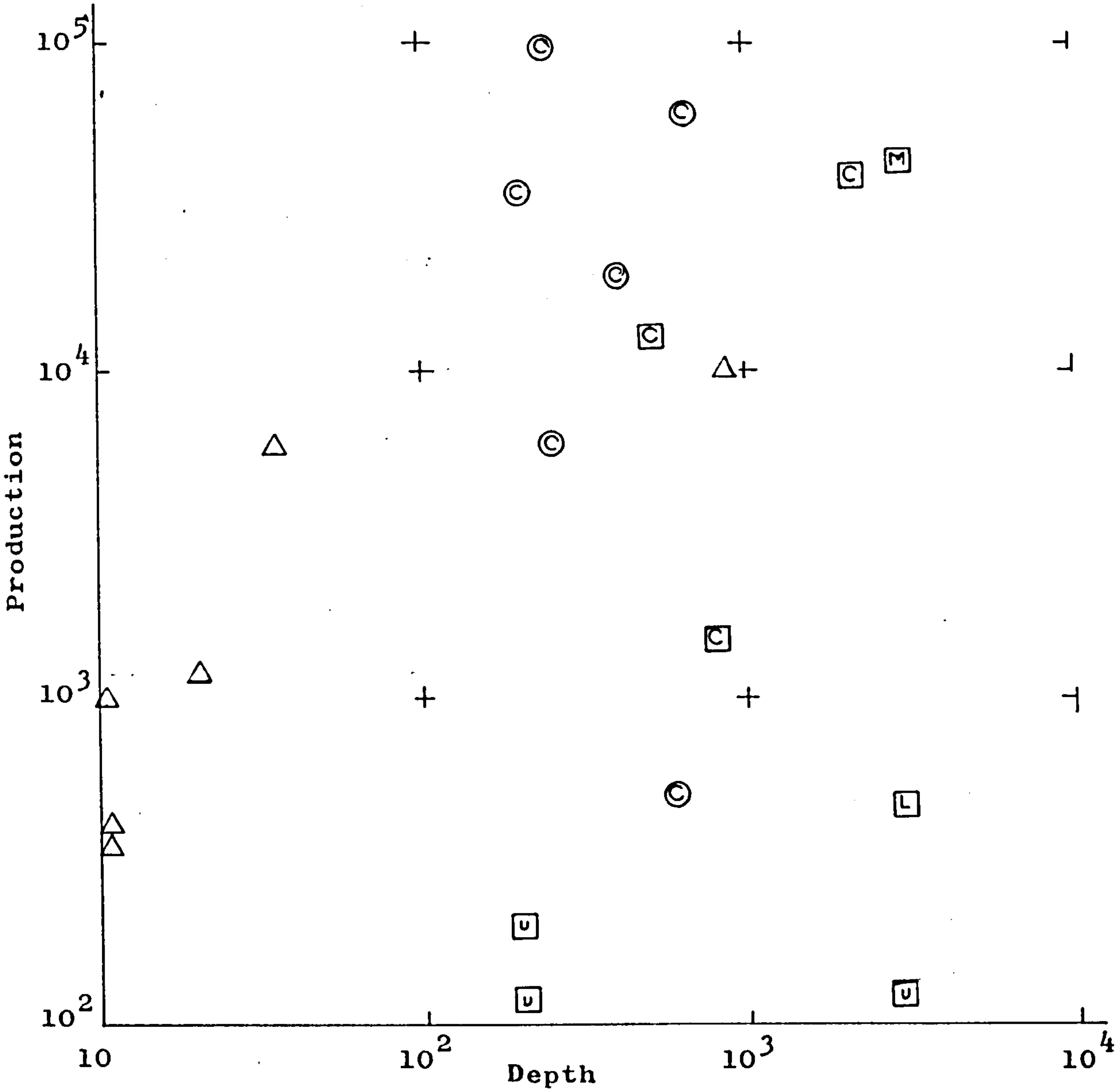
L = Low mineral content
H = High mineral content

Figure 19. Mines of High and Low Mineral Content with Efficiency Factor of Total Land as a Function of Per Cent Ore Land



L = Low mineral content
H = High mineral content

Figure 20. Mines of High and Low Mineral Content with Total Land Efficiency Factor as a Function of Per Cent Mineral Land



Scale: Log-Log

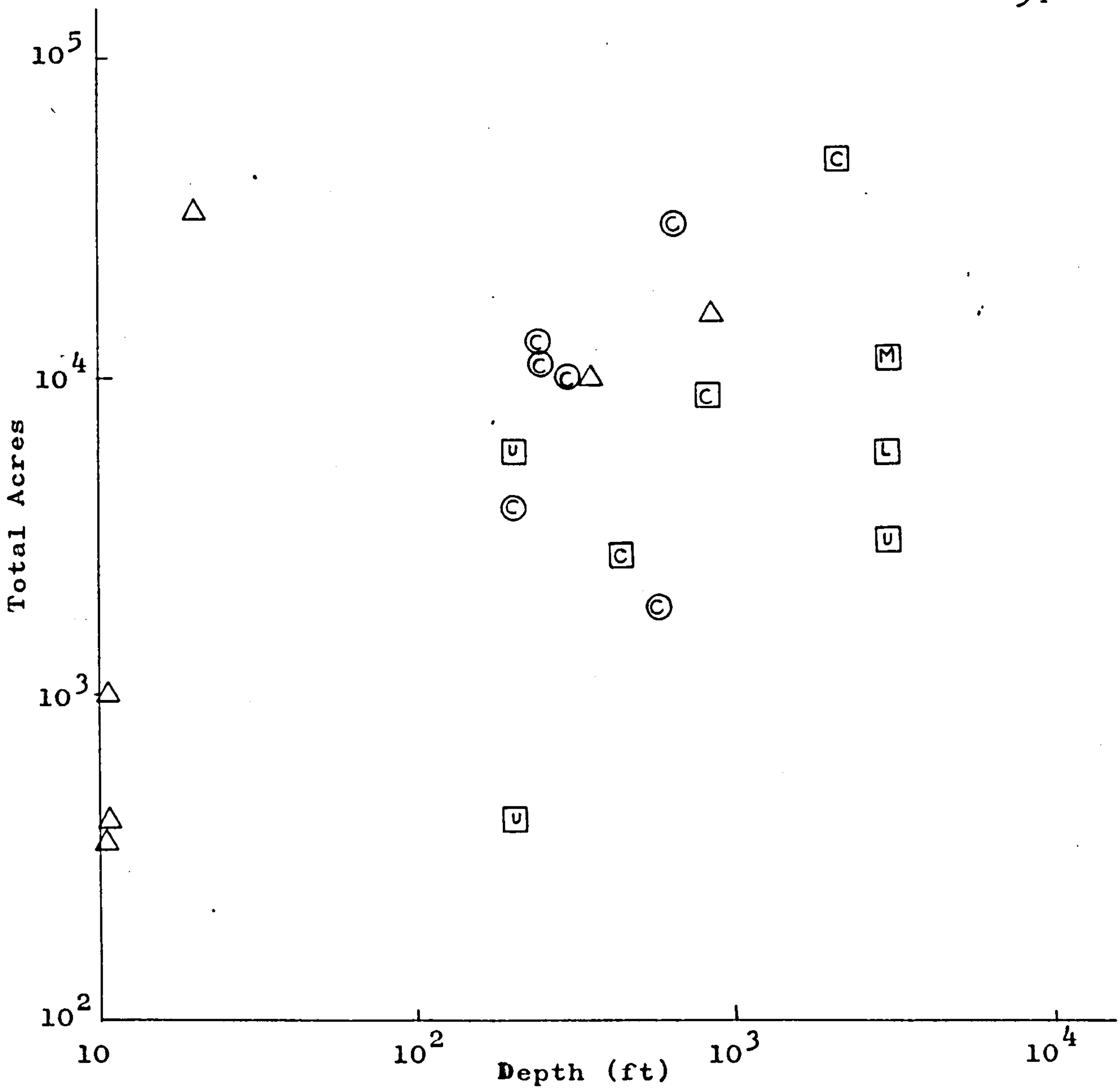
□ = Underground Mine

○ = Surface Mine

△ = Nonmetal Mine

C = Copper
L = Lead
G = Gold
U = Uranium
M = Molybdenum
H = Mercury

Figure 21. Production as a Function of Depth



Scale: Log-Log

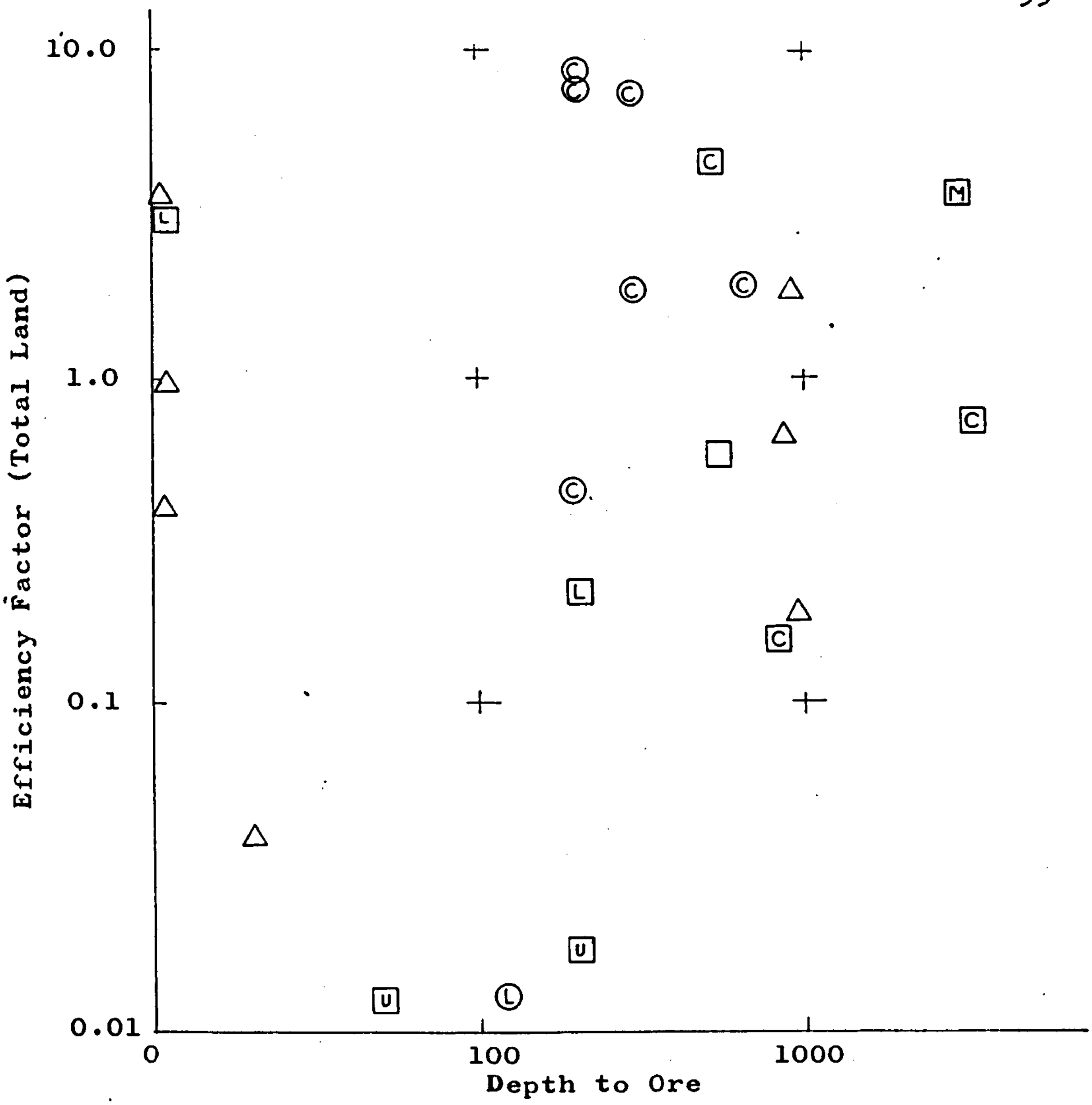
□ = Underground Mine

○ = Surface Mine

△ = Nonmetal Mine

C = Copper
L = Lead
G = Gold
U = Uranium
M = Molybdenum
H = Mercury

Figure 22. Total Acres as a Function of Depth



Scale: Log-Log

□ = Underground Mine

○ = Surface Mine

△ = Nonmetal Mine

C = Copper
L = Lead
G = Gold
U = Uranium
M = Molybdenum
H = Mercury

Figure 23. Efficiency Factor of Total Land as a Function of Depth

23). There is no recognizable trend in any of these cases. The points appear to be random. In these limited data, there is no reason to assert that any relationship between land and depth exists.

The Relation of Mining Method to Land Requirements

In this study the mining methods are divided into surface mining methods and underground mining methods. On the charts, the surface and underground mining methods are identified by different shaped symbols. It is difficult to see any significant trend or segregation in this sense. Open pit mines do tend to be large and underground mines small, but some underground block caving mines are as large as many open pit mines. Again this segregation of mines is a reflection of their being disseminated ore deposits rather than the mining method being used. Disseminated ore deposits simply make large mines.

It might seem at first that underground mines would not require as much auxiliary land because they do not have to dispose of additional waste material from stripping overburden. Apparently this is not the case. If we refer back to the charts on waste disposal land (Figures 12 and 13), we can see that nearly all examples, both surface and underground mines, are near the trend line.

To explain why the stripping of overburden does not necessarily lead to consistently higher requirements for waste disposal land, consider the hypothetical case of two disseminated ore deposits of equal size but of greatly different depths (Figure 24).

At d_1 the deposit is shallow resulting in a decision for open pit methods and allowances are made for dumping areas. At d_2 the deposit is much deeper resulting in the decision for block caving. Since the cave will finally reach the surface and theoretically break back to the angle of subsidence, a land allowance must be made at the surface for future subsidence. The angle of subsidence, estimated at 65° for this example, radiates outward from the edges of the ore to encompass more land than the theoretical pit, thus tending to compensate for the overburden dump area in the open pit example. Therefore, the land requirements in disseminated deposits of open pit and underground tend to be about the same because the depth tends to influence the decision as to mining method, and depth combined with the angle of subsidence, in one case, tends to compensate for the land used for dumping overburden in the other case.

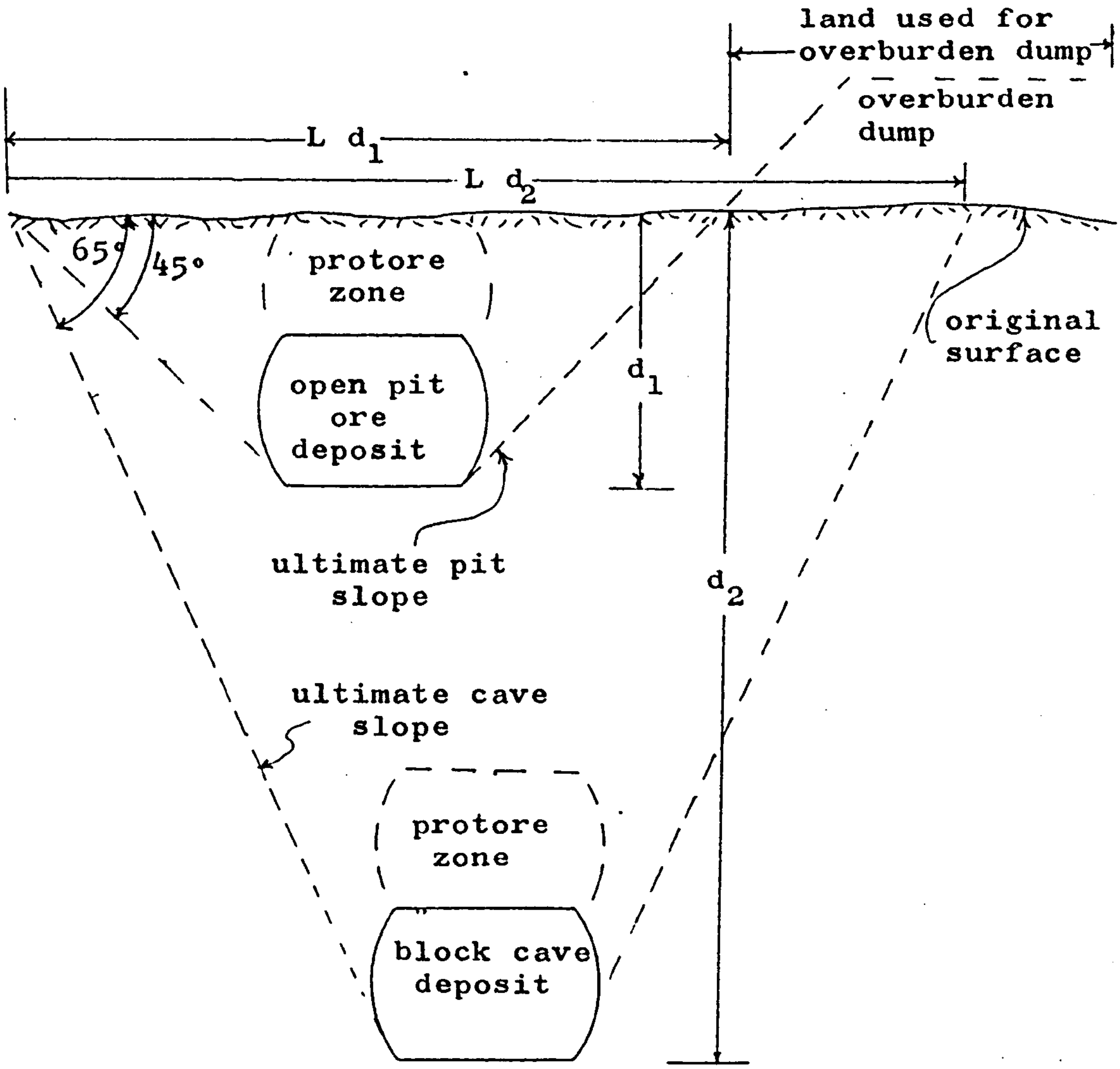


Figure 24. Theoretical Disseminated Ore Deposit

CHAPTER 3

CONCLUSION

The land requirements for the various mining operations vary over a wide range of values with a maximum of 52,788 acres and a mean value of 9,150 acres. The disseminated deposit group has an average land requirement of 11,990 acres, the bedded deposit group has an average land requirement of 9,200 acres (which is 81% of the value of disseminated deposits), and the vein deposit group has an average land requirement of 4,379 acres (which is 38% of the value of disseminated deposits).

It can be concluded that large mines, on the average, own and use more land than do small mines. There is a significant positive correlation, at the 95% confidence level, between mine production and land area. However, the correlation is not precise and there are many individual examples where it can be shown that a particular small mine has more land than some specific large mine.

There is a significant positive correlation between efficiency factor (total land) and production which indicates that large mines are more efficient users of land.

It is significant that the efficiency factor of total land correlates with production when it is remembered the larger mines use four or five times their mineral area for waste dumps and support purposes. The large mines, in spite of having a large per cent of their land for support purposes, still make the most efficient use of land.

There is not a significant correlation between production and either mineral land or ore land. However, there is a correlation between production and the efficiency factors of both mineral land and ore land. These correlations of production with the efficiency factor and not with the areas indicate that the large mines use both mineral land and ore land more efficiently and that they do not necessarily require more mineral land or ore land to be a large producer.

Non-mineral land and waste disposal have a close correlation with production. The reason for this is that most mines, especially metal mines, produce waste in proportion to ore production and the dump areas are a result of that waste production.

The geologic setting does have a relation to land requirements. Mines at disseminated deposits are characteristically large producers with large total land and waste disposal land requirements. They are the most efficient users of land. Mines at bedded deposit have high land requirements but much lower efficiency factors. Vein deposit mines are the smallest producers, have the lowest efficiency factors, and a wide range of land requirements.

Mines at disseminated deposits generally require more than 80% of their land to be non-mineral land used for waste dumps and other support purposes. Mines at bedded and vein deposits have a much higher per cent of mineral land.

There is no evident relationships between the primary mineral produced and land requirements other than those imposed by the geologic setting. Minerals which habitually occur in disseminated deposits, copper for example, may appear to have all the qualities attributed to the disseminated group. The reason for this apparent relationship is that these deposits are disseminated deposits and not because they are copper deposits. However, it must be remembered that some minerals characteristically occur in certain geologic settings. Copper and molybdenum frequently occur in disseminated deposits. Industrial minerals frequently occur as bedded ore deposits. Epithermal minerals usually occur in veins. Thus, it may be inferred that some minerals belong to a particular land requirement relationship because of their characteristic geologic occurrence.

There is no recognizable relationship between depth of mine and any of the land factors analyzed. If such a relationship exists it is too obscure to be identifiable in the limited information available.

The mining method does not significantly influence the land requirements. There is an apparent correlation arising from the fact that each geologic setting has characteristics which lend themselves to certain mining methods; for example, disseminated deposits are usually mined by open pit or block caving methods, bedded deposits are usually exploited by strip or room and pillar methods, and vein mines are exploited by a variety of underground methods. However, these correlations are due to the geologic setting and not due to the mining method.

APPENDIX

LISTING OF QUESTIONS USED TO SOLICIT DATA

The questions on the following pages are detail copies of the questions used to solicit the data from various mining companies. The questionnaires were prepared by Dr. Leaming of the Department of Economic Research of The University of Arizona. The questionnaires asked for many kinds of data, most of which were not used in this study. The questionnaires referred to are entitled: (1) Land Use Questionnaire (from which questions 11, 12, 14, and 16 were used), (2) Mining Operation Questionnaire (from which question 1 was used), and (3) Exploration and Development Questionnaire (from which questions 2 and 3 were used).

Question 11 of the Land Use Questionnaire.

At your property, what amount of mineral lands now held were acquired by:

	Acres	Size of Rental or Royalty
a. direct location on federal lands?..........................	____	____________
b. direct location on state lands?.	____	____________
c. federal leases?................	____	____________
d. state land leases?..............	____	____________
e. Indian land leases?.............	____	____________
f. private land leases?............	____	____________
g. private lease with option to buy?...........................	____	____________
h. purchase of unpatented claims?..	____	____________
i. purchase of patented claims?....	____	____________
j. land exchange?..................	____	____________
k. merger or partnership?..........	____	____________
l. other means? (please specify)...	____	____________
(Total mineral acreage).......	____	____________

Question 12 of the Land Use Questionnaire.

At your property, what amount of auxiliary or non-mineral lands now held are acquired by:

	Acres	Size of Rental or Royalty
a. direct location on federal land?..........................	____	____________

	Acres	Size of Rental or Royalty
b. direct location on state land?..	____	____
c. purchase of federal land?.......	____	____
d. purchase of state land?.........	____	____
e. purchase of private land?.......	____	____
f. federal lease?..................	____	____
g. state lease?....................	____	____
h. Indian lease land?..............	____	____
i. private land leases?............	____	____
j. private lease with option to buy?...........................	____	____
k. land exchange?..................	____	____
l. merger or partnership?..........	____	____
m. other (please describe)?........	____	____
(Total non-mineral land)......	____	____

Question 14 of the Land Use Questionnaire.

How much of the mineral land actually over the ore-body or mineable mineral is on:

	Acres
a. patented claims?...............................	____
b. unpatented claims?............................	____
c. state lease land?.............................	____
d. federal lease land?...........................	____

	Acres
e. private lease land?............................	______
f. other (please specify)?__________..............	______
(Total acreage)...................................	______

Question 16 of the Land Use Questionnaire.

How much of the land now being used for waste disposal (and dump leaching if applicable) is on:

	Acres
a. patented claims?...............................	______
b. unpatented claims?.............................	______
c. state lease land?..............................	______
d. federal lease land?............................	______
e. private lease land?............................	______
f. other (please specify)?__________..............	______

REFERENCES

Abdnor, J. S., Environmental Controls--Land Reclamation, Mining Congress Journal, December, 1968, pp. 54.

Dixon, W. J., and Massey, F. J., Jr., 1957, Introduction to Statistical Analysis, McGraw-Hill, New York, pp. 468.

Leaming, G. F., Exploration and Development Questionnaire, Department of Economic Research, The University of Arizona, 1969a.

Leaming, G. F., Land Use Questionnaire, Department of Economic Research, The University of Arizona, 1969b.

Leaming, G. F., Mining Operation Questionnaire, Department of Economic Research, The University of Arizona, 1969c.