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Appendix D

The Statistical Treatment of the Nonferrous Metal Mining Industries, with Special Reference to Copper

THE NONFERROUS metal mining industries, as defined in this study, ordinarily furnish two broad groups of products: ores and concentrates. The ores represent the part of the product that passes directly from the mine to the smelter and receives no further processing by the mining industry. The concentrates account for that part of the industry's product which was unsuitable for smelting as it came from the mine, and which had to be further treated by concentration and perhaps separation before the industry could dispose of it to the smelter.[1]

The natural unit for measuring the output of such industries is the tonnage of ores and concentrates produced. Where the grade of ores and concentrates varies widely, and also shifts from year to year, as it does in these industries, the ideal index would be based on a breakdown of output sufficiently detailed to make for homogeneous groupings. As we point out in Chapter 12, the ideal index of copper mining, for example, would be derived by aggregating such output data with suitable unit values as weights. Unfortunately, such data are not available for copper or any of the other important nonferrous metals, and hence such an index of physical output must be approximated otherwise.

Usually two broad classes of data may be used to measure the output of these metals: total tonnage of ore, and recovered or recoverable metallic content of ore. Ordinarily, therefore, we must choose one of these two series. To use tonnage of ore as a measure of physical output we should at least require assurance that the average grade of ore mined had changed but little during our period of study. But we know that among nonferrous metals this condition has not been fulfilled. In fact, the average grade of nonferrous ore mined has continually declined, and it is quite clear that the average ton of ore today is much different from the average ton of ore at the turn of the century. For example, half of the nation's copper now comes from deposits that were known in 1900 but were then considered valueless because of their low metal content.[2]

[1] Often mines (with mills) and smelters are under identical ownership so that no sale is involved; but the distinction of principle remains.

[2] A. V. Corry and O. E. Kiessling, *Grade of Ore* (National Research Project, Philadelphia, 1938), p. 84.

Evidently these changes vitiate a simple tonnage aggregate when it is used as a measure of mineral production. We are left, therefore, with recoverable metallic content of the ore as a gauge of production in these industries.[3] Series that relate to metal contained in the ores and concentrates are free from difficulties of measurement caused by changes in grade of ore; a unit of copper metal, for example, remains more or less constant over time. However, the use of such series does not free us entirely from problems of measurement.

To begin with, we cannot escape the influence of declining grade of ore by the simple expedient of using something other than ore as a measure of output. For to the extent that ore has declined in grade, so must our measure of productivity (the ratio of output to employment) be subject to varying interpretations. Thus to insist that a man produce a given recoverable content is obviously, under such circumstances, a more stringent condition than to require of him a stated ore tonnage. Clearly our test of what constitutes a rise of productivity is strict in proportion as our definition of output is circumscribed. This must be borne in mind, but it is more a matter of interpretation than a defect in measurement. Of greater relevance is the fact that recoverable content of ore itself does not yield an unambiguous index of physical output in mining. In the first place, a given amount of metal in highly concentrated form is plainly more valuable to the smelter than the same quantity in low grade form, that is, dispersed through a much larger mass of gangue (waste matter). Recoverable content makes no allowance for differences of this sort in the quality of the product. In the second place, because of advances in metallurgy a greater percentage of metal is being recovered from ore today than formerly. If the total metallurgical process were part of mining, as defined, this would not concern us. However, the processes of smelting and refining fall within the scope of manufacturing; therefore, to the extent that improvements in these techniques have altered the ratio of recovery, our indexes are biased upward as measures of physical output in mining.

It so happens that in the case of copper the available statistics allow us to test the importance of these considerations. We shall therefore examine briefly the adequacy of recoverable content as a measure of output, or at least we shall note the differences which would result from the use of other principles of measurement. To do this we must restrict ourselves to sample data, and for simplicity we shall consider the product, copper, rather than the industry, copper mining. The comparison of alternative measures of output has special relevance in the case of copper because of the decline that has occurred in the grade of

[3] We use recoverable content rather than recovered content (i.e., smelter output) for reasons set forth in Appendix B.

copper ore, and the technological revolution that has accompanied this decline. We may start with several remarks designed to clarify certain of the concepts with which we shall deal.

We have seen that copper ore must pass through several stages of production before copper metal emerges as a product. The reader will recall that most copper ores are milling ores, that is, they are too lean to be smelted before they are concentrated; the remainder consist of high grade or direct smelting ores. Thus for the smelter product to emerge, the material must pass through either two or three phases of the production cycle. At the conclusion of each of these phases the product is different from that at the conclusion of each of the other phases. Recoverable content—our measure of output—relates to the product which emerges at the end of the smelting operations. How shall we determine whether an index based on this measure of output is similar to an index which might be based on output measured at some other stage of production? More precisely, how may we determine whether output measured at this stage will differ significantly from output measured at the conclusion of those operations which we have called mining?

Having once adopted metallic content as a measure of output we may reconsider the problem just raised in another fashion. Ore, when mined, contains a certain amount of metal. This is its *actual* content as distinguished from its recoverable content. The latter is smaller by reason of losses of metal in concentrating and smelting. A certain portion of this ore is concentrated before smelting. The concentrates produced also contain a certain amount of metal—their *actual* content. This is a smaller amount of metal than was contained in the ore, but a greater amount than will appear as smelter output. We are obviously confronted here by a choice between several principles of measurement. Conceivably, physical output can be measured by either the actual content of the ore, the actual content of the concentrates (assuming all the ores to be "milling ores"), or the recoverable content of the ores or concentrates (the measure of output we have used throughout).

Ordinarily we do not have at hand the several types of information mentioned. But if we did, and were to convert the data to index form, what would the resultant indexes mean? An index based on the actual content of ore could be used to measure output in mining (narrowly defined to include only those processes in which the ore is broken and brought to the surface). An index based on the actual content of concentrates could be used to measure physical output in the mining and concentrating of "milling ores." (Such an index is actually the sum of two components: an index of mining in the narrow sense used above and a net index of milling or concentrating.[4]) This index would come closest to measuring output for the bulk of the copper mining industry, and we should therefore be particularly interested in observing the differences between this index and that based on recoverable content.

The data which we have gathered for copper enable us to construct index numbers of the type described. The remainder of this Appendix deals with the behavior of the alternative indexes derived, and relates the lessons of their behavior to the questions raised several paragraphs above.

First, we may ask, how do indexes of copper content of ore, copper content of concentrates, and of ore itself, differ from one another? As pointed out, we must content ourselves with sample data for an undetermined section of the industry. Because of variations in coverage, the indexes we obtain are without interest in themselves: but since the coverage of each index is the same in any given year, the relations between them are significant. These indexes are shown, on a 1911 base, in Table D-2 and Chart 50. We must remember that these figures are concerned only with milling ores, and that they take no account of products of the copper mining industry other than copper itself.

Over the period as a whole, tonnage of ore mined rises in relation to its copper content. The ratio of the latter to the former is of course a measure of grade of ore; a growing spread between these two curves, in a relative sense, is an indication of declining grade (for further evidence on this point, see Table 22 above). It will be noticed that the ratio diminishes somewhat in years of low output: the improvement in grade in such years is no doubt occasioned by a temporary return to more selective mining methods.

Considered as a measure of output of the copper mining industry (if we exclude ore dressing), tonnage of ore is clearly subject to an upward bias, for it takes no account of the apparent decline in the quality of the product. The actual copper content of the ore mined may afford a suitable measure of the output of mining activity proper, but it is evident that it does not do so if we define the industry to include the dressing of ore. For the product of the "copper mining and ore dressing industry" consists for the most part of concentrates,[5] and the output of concentrates, measured by copper content, moved differently from either of the other two indexes shown in the chart. From 1911 to 1918 the content of concentrates, and the content of ore from which they were derived, moved together: it would appear that during this

[4] See Solomon Fabricant, *The Output of Manufacturing Industries, 1899–1937* (National Bureau of Economic Research, 1940), for a discussion of the concept of net indexes of physical output.

[5] In 1939, 80 percent of all copper came from milling ores; the remainder came from ores smelted directly or leached.

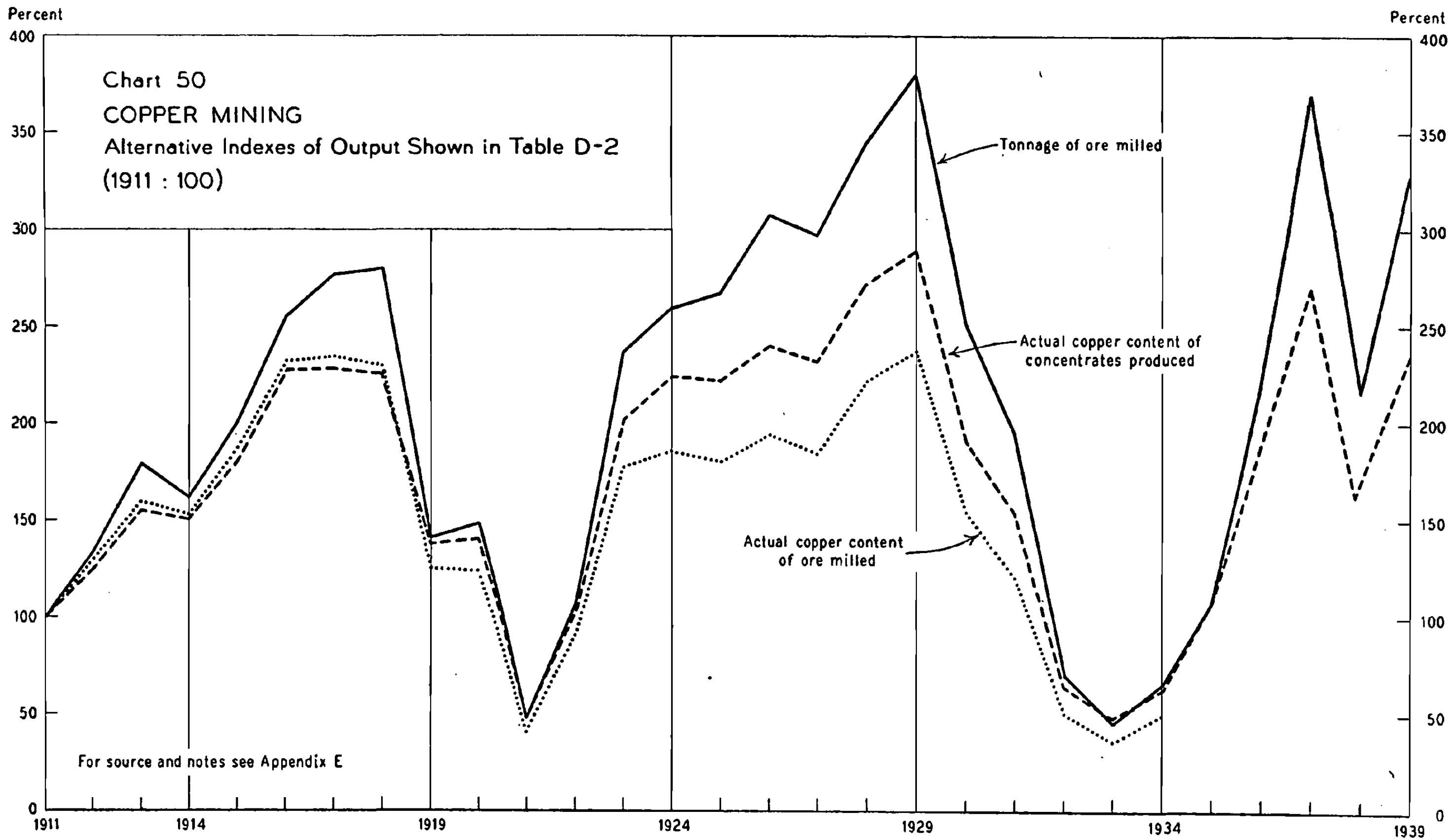
Chart 50
COPPER MINING
Alternative Indexes of Output Shown in Table D-2
(1911 : 100)
Percent
400
350
300
250
200
150
100
50
0
1911
1914
1919
1924
1929
1934
1939
Tonnage of ore milled
Actual copper content of concentrates produced
Actual copper content of ore milled
For source and notes see Appendix E

period milling techniques were making small progress in overcoming the effects of the decline in the grade of ore. After 1918, however, perhaps with the general introduction of flotation and refinements in the technique, the ratio of content of concentrates to content of ore rises rather steadily: the increasing efficiency of the ore dressing process is reflected very clearly in the rising percentage of mill recovery shown in Table D-3.[6]

Next we may consider how the index of recoverable content would differ from the index of actual content of concentrates. It will be remembered that the former is the index on which we have relied in this volume, whereas (for concentrating ores) the latter is the index we should have preferred to show.[7] Unfortunately, we are not able to derive a series on recoverable content comparable with the series we have worked with in this appendix. Hence we cannot make the comparison which would directly reveal the differences in behavior of the two indexes. We are, however, able at least to cast some light on the probable behavior of the two indexes relative to each other.

In Table D-1 we have brought together scattered figures on smelter recovery for that portion of the industry covered in this appendix, and, for more recent years, for some direct smelting ores. It can be seen from these figures that smelter recovery of metal from concentrates has been remarkably constant over the period treated by our analysis. We may contrast this with the change in mill recovery indicated in the first two columns of Table D-3. Smelter recovery was very high at the beginning of our period and increased but little in succeeding years, while mill recovery jumped from about 70 percent to over 90 percent. This comparison suggests rather strongly that (so far as concentrating or milling ores are concerned) the advances in metallurgy making for a higher recovery of the metallic content of the ore have been almost

[6] Ordinarily the index based on content of concentrates lies somewhere between the extremes represented by ore on the one hand, and content of ore on the other. In 1921 and 1933, however, the two years of lowest output, the index of content of concentrates actually stood somewhat higher than the index of ore—when 1911 is used as a base. Such a result is not unexpected in years of low output in view of the high degree of selectivity in mining in such years. The narrowing in the gap between the index of ore and content in these two years—observed in the preceding paragraph—reflects the relative rise in grade. This shift in grade has combined with a ratio of recovery much higher than that in the base year to produce the results observed. Whether such a combination will cause the index of content of concentrates to exceed the index of ore must depend in good part on the choice of the base year. Obviously, the higher the grade in the base year, the less is the likelihood that even the combination of highly selective mining and relatively greater recovery will result in an index of content which stands higher than the index of ore.

[7] We may recall that this discussion deals chiefly with the concentrating ores. For ores that are not concentrated the proper index of physical output (in this context) would be based on actual content of ores. For these ores, too, we have relied on recoverable content.

wholly in milling and not in smelting: i.e., in mining, as defined here, and not in manufacturing. The gains which have been made in smelter recovery are too slight to have caused much of a difference between indexes of actual and recoverable content of concentrates. It follows that an output index for copper mining and ore dressing based upon actual copper content of concentrates and direct smelting ores would not differ significantly from the indexes (Tables A-5 and A-7) based upon data for recoverable content (Table A-1).[8]

Some further qualifications are necessary. Even in a purely technical sense the percentage of mill recovery is not a perfect measure of the efficiency of ore dressing; nor is metal content a perfect measure of the output of concentrates. We should also consider the ratio of concentration (tonnage of ore to tonnage of concentrates derived therefrom) in the one connection; and percentage copper content of concentrates in the other. Thus the higher the ratio of concentration for a given mill recovery, the more efficient is the ore dressing process; while the smaller the weight of concentrates necessary to contain a given weight of copper, the higher is the quality of the product which the mining industry passes along to the smelter.

Such evidence as we could collect on this topic is given in Table D-3. There are some suggestions of a rising tendency, both in the ratio of concentration and in the percentage copper content of concentrates: but in neither case is any conclusive statement possible. However, the clear absence of any *decline* in concentration ratios, coupled with the equally clear improvement in mill recovery, appears further to substantiate our judgment concerning the increased technical efficiency of milling.[9] Meanwhile, any rise that may have occurred over the period in the percentage copper content of concentrates, along with the greater relative importance of concentrates in the total output, suggests the presence of a downward bias in our index of output, based as it is upon metallic content. For copper in more available and less bulky form represents a better product, and we should like to allow for this improvement in quality in our index. Clearly, we cannot do so. The improvement in the grade of concentrates appears to have been rather moderate: however, the relative importance of high grade concentrates

[8] At least so far as the milling or concentrating ores are concerned. Probably this conclusion is not sound with regard to the direct smelting ores. The period 1929–39 covered by the data in Table D-1 is too recent to be of much value for any judgment on this point. For that segment of copper mining output an index of recoverable content may, in fact, be a measure that is biased upward.

[9] This means that the relative contribution of milling activity to the output of mining and milling combined has probably risen over the period. In other words, the *net* output of milling appears to have risen in relation to the output of mining. In addition, such advances in the efficiency of milling may have resulted in an improvement in the grade of concentrates produced.

has increased a good deal, so that there may be a substantial bias in our index on this account.

We may conclude that, so far as milling ores are concerned, output could best be measured by actual content of concentrates; and by actual content of ore, in the case of direct smelting ores. However, no important change appears to have occurred in percentage rates of recovery by smelters, at least with respect to concentrating ores. We may therefore regard recoverable content as an acceptable substitute, in a statistical sense, for actual content of metal. Put otherwise, our indexes for copper (Tables A-5 and A-7) do reflect changes in the output of mining and ore dressing, and are probably undistorted by developments in smelting and refining. The grade of direct smelting ores appears to have changed little (Table 22). The grade of concentrates may have risen (Table D-3), and certainly their relative importance has increased. This represents an improvement in the quality of the product —an improvement which we have no means of incorporating in our indexes of output. Meanwhile, to obtain a ton of copper more tons of ore must be mined than formerly; but the increase in the amount of ore required is less than that suggested by the decline in its copper content. For the deterioration which has occurred in the grade of concentrating ores has been offset in large measure, though not completely, by improvements in the ratio of mill recovery.[10]

[10] While it is true that the grade of ore mined by the copper mining industry has declined during the past forty years (Table 22), the grade of the material which constitutes the input of the smelting industry appears, if anything, to have improved in quality. (See Table D-3 for content of concentrates; Table 22 for content of direct smelting ores.) Nor have smelter recovery ratios changed appreciably over the period (Table D-1). Consequently, there seems to be no evidence (at least so far as concerns copper) that the net output of the smelting and refining industries has increased more rapidly than their gross output (see Fabricant, *op. cit.*, p. 279).

TABLE D-1

COPPER

Smelter Recovery

Percent of copper recovered from ores or concentrates smelted

	From Ore Mined at Individual Properties[a]				From Ore Mined in Nine Western States[b]	
Year	Ray (Arizona)	Chino (New Mexico)	Morenci (Arizona)	Miami (Arizona)	Direct Smelting Ores	Concentrates
1909	..	..	94.3	..	..	..
1910	..	..	..	..	..	..
1911	..	..	92.6	95	..	..
1912	..	95	..	95	..	..
1913	96.6	95	..	95	..	..
1914	96.5	95	96.4	95	..	..
1915	96.5	95	94.1	95	..	..
1916	96.3	95.5	95.2	95	..	..
1917	96.1	95.6	94.4	95	..	..
1918	96.2	95.4	93.4	95	..	..
1919	96.9	95.7	94.0	95	..	..
1920	96.8	95.6	..	95	..	..
1921	95.8	96.1	..	95	..	..
1922	96.0	96.3	..	95	..	..
1923	96.4	96.0	..	95	..	..
1924	96.3	96.1	..	95	..	..
1925	96.4	96.0	..	95	..	..
1926	..	..	..	97	..	..
1927	..	..	..	97	..	..
1928	..	..	..	97	..	..
1929	..	..	..	97	93.3	95.8
1930	..	..	..	97	93.7	96.1
1931	..	..	..	97	93.1	95.8
1932	..	..	..	..	95.5	95.7
1933	..	..	..	..	96.5	96.0
1934	..	..	..	..	95.8	96.6
1935	..	..	..	..	94.1	96.7
1936	..	..	..	..	94.1	95.5
1937	..	..	..	..	94.1	96.3
1938	..	..	..	..	94.2	96.6
1939	..	..	..	..	94.5	96.6

[a] Obtained from annual reports of individual companies: Ray Consolidated Copper Co. (Ray and Chino), Phelps Dodge Corp. (Morenci), Miami Copper Co. (Miami).

[b] Obtained from data collected by U. S. Bureau of Mines and published in successive annual issues of *Minerals Yearbook*. States included are Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, Washington.

TABLE D-2

COPPER

Alternative Indexes of Output[a]

1911:100

Year	*Tonnage of Ore Milled*	*Actual Copper Content of Ore Milled*	*Actual Copper Content of Concentrates Produced*
1911	100	100	100
1912	134	128	126
1913	178	160	155
1914	162	153	151
1915	199	187	181
1916	255	232	227
1917	277	234	228
1918	280	230	226
1919	140	125	138
1920	148	124	140
1921	47	41	49
1922	106	90	104
1923	237	177	202
1924	259	186	224
1925	268	181	222
1926	308	194	240
1927	297	184	232
1928	346	222	272
1929	381	237	289
1930	252	154	191
1931	195	121	153
1932	70	50	64
1933	46	36	47
1934	66	49	63
1935	107	..	107
1936	221	..	191
1937	371	..	271
1938	216	..	162
1939	328	..	235

[a] Because of year-to-year variations in coverage, the three indexes of output shown in this table must not be regarded as applicable, either to the entire copper mining industry, or to the product, copper. For comparisons between successive years, however, the three indexes have the same coverage, so that they are comparable among themselves. The data are confined to milling (as distinct from direct smelting) ores.

For 1911–29 the indexes were obtained by aggregating the results of individual properties, as follows: Ray (1911–25) and Chino (1912–25), Ray Consolidated Copper Co.; Nevada (1912–29), Ray (1926–29) and Chino (1926–29), Nevada Consolidated Copper Co.; Morenci (1911–19) and Copper Queen (1924–29), Phelps Dodge Corp.; Miami (1911–29), Miami Copper Co.; Utah (1911–29), Utah Copper Co. Data were taken from annual reports of the companies concerned. In years in which the number of properties changed the indexes were spliced. Coverage varies from 33 to 46 percent of all milling ores.

For 1929–39 the figures relate to all milling ores produced in Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Utah and Washington, as collected by U. S. Bureau of Mines and published in successive annual issues of *Minerals Yearbook*. In 1939 copper from milling ores in these states represented slightly more than 90 percent of all copper produced from milling ores, or about three quarters of total copper production from domestic ores.

The indexes for 1929–39 were spliced to those computed for 1911–29.

TABLE D-3

COPPER

Mill Recovery and Ratio of Concentration

Year	Mill Recovery[a] (percent)		Ratio of Concentration[d]				Actual Copper Content of Concentrates (percent)			
	Corporate Sample[b]	Nine Western States[c]	Morenci[e] (Arizona)	Utah[e] (Utah)	Miami[e] (Arizona)	Nine Western States[c]	Morenci[e] (Arizona)	Utah[e] (Utah)	Miami[e] (Arizona)	Nine Western States[c]
1909	..	..	6.6	..	..	..	15.8	..	..	..
1910	..	..	6.8	26.6	..	..	15.4	27.3	..	..
1911	70	..	7.6	24.4	22.2	..	15.9	25.6	40.4	..
1912	68	..	7.1	22.9	22.3	..	16.7	20.8	37.0	..
1913	67	..	7.7	21.7	23.3	..	15.8	17.3	38.1	..
1914	68	..	7.6	19.3	24.6	..	15.7	18.2	39.3	..
1915	67	..	6.8	20.8	25.7	..	13.5	19.2	41.9	..
1916	67	..	7.1	20.9	27.8	..	12.1	18.7	42.5	..
1917	67	..	6.8	20.4	30.6	..	11.2	16.6	43.0	..
1918	68	..	7.8	20.1	27.8	..	11.3	16.1	40.1	..
1919	76	..	6.8	20.1	25.9	..	12.8	19.9	43.5	..
1920	78	..	..	17.5	27.0	..	..	16.4	43.9	..
1921	82	..	..	21.9	25.6	..	..	21.3	38.4	..
1922	79	..	..	23.3	26.8	..	..	23.5	43.6	..
1923	79	..	..	20.5	29.5	..	..	18.6	42.0	..
1924	84	..	..	19.6	30.4	..	..	18.1	39.5	..

1925	85	..	..	19.6	29.9	..	..	17.5	27.9	..
1926	86	..	..	19.4	37.2	..	..	17.1	28.0	..
1927	87	..	..	28.8	51.6	..	..	25.1	34.3	..
1928	85	..	..	37.1	65.7	..	..	31.5	38.4	..
1929	84	87.5	..	37.6	60.0	20.2	..	32.1	36.2	23.7
1930	86	89.0	..	37.2	60.4	19.7	..	32.2	34.1	23.1
1931	89	90.5	..	37.2	69.6	21.2	..	32.6	40.9	25.8
1932	..	92.0	..	35.7	..	19.6	..	32.4	..	27.5
1933	..	93.9	..	35.4	..	17.8	..	33.8	..	28.3
1934	..	93.7	..	..	..	19.0	..	..	..	28.4
1935	..	..	..	..	..	17.1	..	..	..	26.3
1936	..	..	..	..	..	21.9	..	..	..	29.1
1937	..	..	..	..	..	25.3	..	..	..	28.4
1938	..	..	..	..	..	22.5	..	..	..	25.8
1939	..	..	..	..	..	24.7	..	..	..	27.3

[a] Ratio of actual copper content of concentrates to actual copper content of ore concentrated.

[b] Ratio obtained by aggregating results at individual properties as follows: Ray (1911–25) and Chino (1912–25), Ray Consolidated Copper Co.; Nevada (1912–29), Ray (1926–29) and Chino (1926–29), Nevada Consolidated Copper Co.; Morenci (1911–19) and Copper Queen (1924–29), Phelps Dodge Corp.; Miami (1911–31), Miami Copper Co.; Utah (1911–31), Utah Copper Co. Data were taken from annual reports of the companies concerned. Dispersion of the ratio among individual properties was so slight as to make splicing unnecessary. Properties concerned produce from 33 to 46 percent of all milling ores.

[c] States included are Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Utah and Washington. Figures based on data collected by U. S. Bureau of Mines and published in successive annual issues of *Minerals Yearbook*. In 1939 copper from milling ores in these states represented slightly more than 90 percent of all copper produced from milling ores, or about three quarters of total copper production from domestic ores.

[d] Ratio of tonnage of milling ores to tonnage of concentrates derived therefrom.

[e] Obtained from annual reports of individual companies: Phelps Dodge Corp. (Morenci), Utah Copper Co. (Utah), Miami Copper Co. (Miami).