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Chapter 11

Iron Mining and Beneficiating

FROM COAL MINES and oil wells—the source of the nation's fuel—we turn, in this chapter and the next, to a review of two important metal mining industries—iron and copper. The first of these, like bituminous coal mining, is geographically scattered. Most iron ore comes from the Lake Superior district (Minnesota, Michigan and Wisconsin), from Alabama, or from the northeastern district (New York, New Jersey and Pennsylvania); but iron is also mined in many other states. The ore is obtained both from underground and from open pit mines, but principally from the latter (Table 21 below). Of all ore mined, about one ton in five is beneficiated (Table 20 below),[1] and the remainder is shipped to smelters as crude ore. Even the ores that are beneficiated undergo only a very simple treatment which serves to raise the grade of ore to such a level that they can be used directly in the blast furnace. The additional treatment results, therefore, in a fairly homogeneous total product, and for this reason it is possible to utilize ore tonnage as a measure of physical output in the industry for a given year. It must be specified, however, that such a figure would relate to merchantable ore, which means that where beneficiation has been employed the data refer to the beneficiated product.

It is possible, of course, for average grade of ore to change considerably over the long run even though output for any single year is homogeneous. It happens this, too, is not the case in iron mining.[2] Any tendency for increased mining of lean ore to dilute grade has been overcome by the wider use of beneficiating. Hence, a ton of (beneficiated) ore at the end of the period was pretty much the same as a ton at the beginning, a fact which obviates a

[1] The process was described in Chapter 7.

[2] Data in N. Yaworski and others, *Iron Mining* (National Research Project, Philadelphia, 1940), Table A-4, p. 206, indicate a barely perceptible diminution in the average grade of merchantable ore from 1880 to date.

host of statistical problems that arise when such a happy situation does not obtain.[3]

Actually, the quantity data available for iron mining and beneficiating permit the derivation of an index of physical output which approaches quite closely the ideal index[4] for a metal mining industry. This is noteworthy because in the case of most nonferrous metals we have to be satisfied with data which result only in rough approximations to such an index. Any variations that do arise within total iron ore production in any year are accounted for in the fourfold classification of ores we have utilized. Even here, however, one variety of ore—hematite—is of such preponderant importance that the utilization of the breakdown results in an index which deviates but slightly from one based on a single series embracing all varieties of ore.[5]

THE RELATION BETWEEN OUTPUT AND EMPLOYMENT

The World War period provides a convenient dividing point in the history of output and employment in the iron ore industry. In 1917 both employment and output reached their peak after a general upward movement over the entire period preceding the war. After that conflict both output and employment tended downward. In both periods, as is evident from Chart 44, there were short run reversals in the direction of movement (largely cyclical in nature), but the general impression of growth in one period, and decline, or at least absence of growth, in the other, is unmistakable.

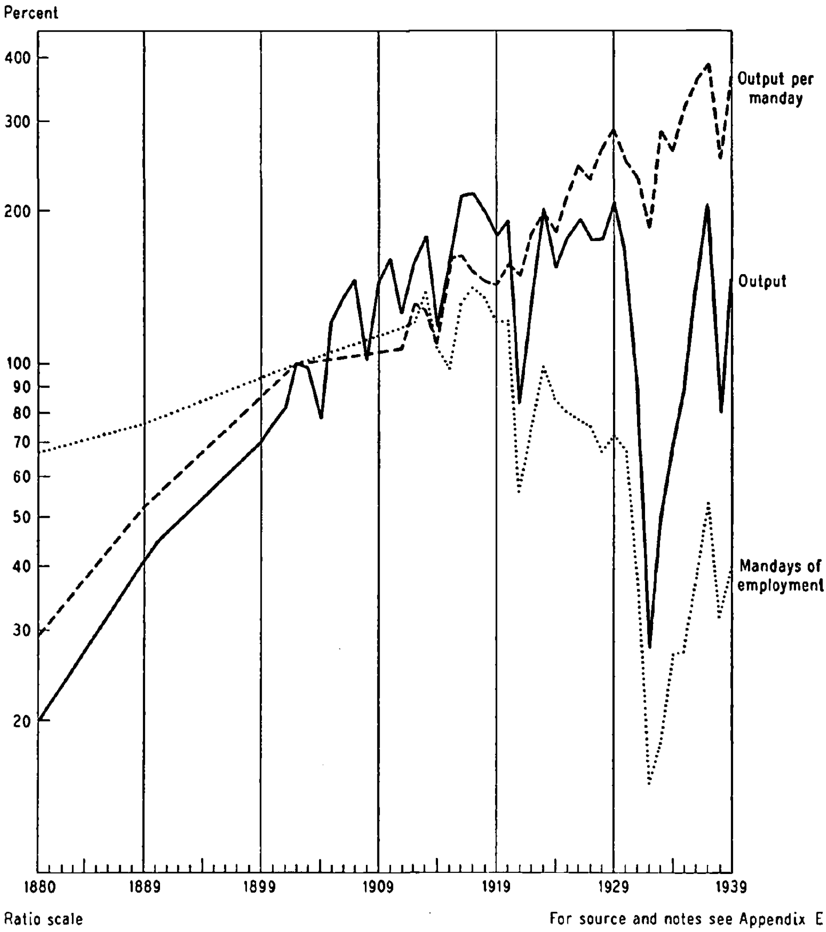
Although the entire period preceding the World War witnessed a similarity of general movement in both output and employment, there was a difference in their respective rates of growth. This is clear from the fact that from 1902 until 1917 production increased by 114 percent while mandays of employment rose only

[3] Compare, for instance, the difficulties encountered in measuring the output of copper (discussed in Chapter 12 below and in Appendix D) where the opposite conditions prevail.

[4] I.e., a measure which, in the absence of price changes, would be proportional to value of products.

[5] See Appendix Table A-1.

Chart 44
IRON MINING AND BENEFICIATING
Output, Employment and Productivity, 1880 - 1939
(1902 : 100)



For source and notes see Appendix E

41 percent.[6] Similarly in the post-war period the decline in employment is much more marked than that in production: output in the post-war period almost regained its wartime peak on sev-

[6] By using data in Yaworski and others, *Iron Mining,* we may extend our series back to 1880. In the period from 1880 to 1902 the same tendency manifests itself although in a more pronounced form than in the later period of more moderate growth. Thus, from 1880 to 1902 there was a fivefold increase in production while employment rose by about 50 percent (Chart 44).

eral occasions, whereas employment continued to decline. This is abundantly clear from a comparison of successive peaks in output in 1920, 1923, 1929 and 1937, each of which is associated with a level of employment relatively lower than in the preceding peak. By 1937 this progressive divergence culminated in a production index which stood but 4 percent below the 1917 level; employment, on the other hand, had declined 62 percent from its 1917 peak.

Employment, it is clear, reached a peak some time during the second decade of this century. Prior to about 1917 the trend in employment was in the same direction as the trend in output, which was of course expanding. That is to say, the growth in production was sufficiently large to offset the rise in output per manday. After the first World War circumstances had changed. Production was stagnant; hence rising output per manday was translated into a decline in the volume of employment in the industry. And the post-war decline was rather persistent. The only sustained rise in employment was that which succeeded the very low level of 1932. We may note, also, that each case of increase of employment over that of the preceding year was associated, not with any decline in productivity, but rather with a spurt in production which outstripped the rise in productivity.

We may summarize the net result of 37 years of change in output and employment in the statement that by 1939 the industry's labor input, measured in mandays, had declined to 40 percent of the 1902 level, whereas production had risen to a level 50 percent higher than that of 1902. That is, the industry used two fifths as many mandays to produce one and a half times as much iron ore. In terms of manday output, productivity in 1939 was three and a half times as great as in 1902. The rise in output per manhour was even larger: according to the best estimate we can make, the later was four and a half times the earlier level. Thus manhour productivity in iron ore mining expanded about twice as rapidly as in the metal mining group as a whole, and at about the same pace as it did in the petroleum and natural gas industry. Among industries for which we have data, only phosphate rock and gypsum—both of minor importance—bettered this record.

With the exception of the first decade of the period covered by our analysis, the increase in productivity seems to have been spread quite evenly over the years included. That is to say, from about 1911 to 1939 it is not possible to point to a single period to which the bulk of the net increase between the two years may be allocated. Even so, there are marked short time fluctuations in the direction of movement of the productivity index. Between 1911 and 1939 there are almost as many years in which productivity declined from the preceding year as there are years in which a rise from the preceding year occurred. Several of these declines were of only one year's duration, but there are two cases where the decline continued over three years. Moreover, even the declines that lasted only a year were rather severe on two occasions. Thus, the net increase between 1911 and 1939 is made up of successive short spurts in productivity of sufficient magnitude to outweigh intervening short run declines.

Both the substantial long period rise and the erratic year-to-year behavior of the index are part of the same picture so far as productivity in iron mining is concerned. Both have their roots in certain basic factors operative in the industry. The most important of these factors is open cut mining—the industry's response to a unique resource condition.

RESOURCE CONDITIONS

The striking rise in productivity disclosed by our figures suggests that little if any deterioration has occurred in the physical conditions under which the ore is mined. To be sure, the highest grades of ore are being rapidly depleted.[7] But it does not necessarily follow that the accessibility or ease of mining of iron ore currently extracted is less than it was some decades ago. We should like to know whether the difficulties of gaining access to ore have increased over time, or whether the efforts of the iron miner today yield a product significantly lower in grade than that produced at the turn of the century. In copper mining, as we shall see, the answer to both of these questions is an emphatic affirmative. Increases of productivity in that industry have been achieved in the face of a deterioration in the physical conditions of mining. The production of iron ore, by contrast, is not sharply characterized by aggravation of natural difficulties.

We may consider first the accessibility of the ore itself. Since deterioration in this respect has occurred primarily in underground mining, the pronounced shift toward open cut technique

[7] Yaworski and others, *Iron Mining*, Chapter VI.

has tended, in part, to eliminate this difficulty.[8] It still prevails in many places, however, for underground mines are even now of considerable importance in the industry; indeed, in years of low production such mines may well outproduce the open cut enterprises. In the underground mining of iron—as in the underground mining of most other minerals—the miners have been forced to go to greater depths to reach the ore,[9] so that the many problems associated with deep mining have been intensified.[10]

It is when we consider the trend in grade of ore that the good fortune of iron mining becomes most apparent. Compared with other metals, and especially copper, iron resources have undergone remarkably little deterioration. Our best indicator of the trend in the grade of iron ore is the changing percentage of total ore produced that requires beneficiation. Data presented in Table 20 indicate that this fraction increased from about 10 percent in 1914 to roughly 18 percent in most recent years.[11] Although there was almost a twofold rise in ore requiring beneficiation over this period it is significant that even at the present time no more than about a fifth of the merchantable ore produced undergoes beneficiation. A comparison with the copper industry, in which 95 percent of the ore mined in 1939 had to be concentrated (equivalent to 84 percent of recoverable copper metal),[12] indicates that the relative importance of concentration in the iron mining industry is still remarkably low.

Equally significant is the fact that among the ores that need beneficiation no marked decline in grade is apparent.[13] This sug-

[8] To a certain extent open pits also are hampered by greater depth of operation, but the disadvantages imposed by greater thickness of overburden do not seem to be of the same order as those encountered in underground mines. For a description of the difficulties of the open cut mine, see Yaworski and others, *Iron Mining*, p. 30.

[9] For instance, from 1916 to 1937 the average maximum vertical depth of underground mines in the Lake Superior district increased by about 650 feet—from 854 feet in 1916 to 1,511 in 1937 (Yaworski and others, *Iron Mining*, p. 29).

[10] The auxiliary functions of drainage and ventilation are rendered more difficult; men and materials must be hoisted over greater distances; the presence of more overlying rock strata increases the difficulties of support, etc.

[11] In Yaworski and others, *Iron Mining*, there is also a 1909 figure which indicates that beneficiation was practically negligible at that time.

[12] See below, Chapter 12, Table 22.

[13] This may be deduced from data in Yaworski and others, *Iron Mining*, Table A-8, p. 227, which indicate little change over the period 1914–37 in the ratio of crude ore consumed to concentrates produced. If anything, the ratio tends to decline. The decline may, however, merely reflect increased recoveries in beneficiating. This possibility must be considered if the ratio is to be used to indicate changes in grade.

TABLE 20

BENEFICIATION OF IRON ORE SHIPPED FROM MINES IN THE UNITED STATES, 1914–40[a]

Year	*Beneficiated*[b] (*Th. long tons*)	*Total* (*Th. long tons*)	*Percentage Beneficiated of Total*
1914	4,130	39,714	10.4
1915	5,581	55,493	10.1
1916	8,105	77,871	10.4
1917	8,167	75,573	10.8
1918	7,882	72,021	10.9
1919	7,356	56,373	13.0
1920	8,515	69,281	12.3
1921	3,728	26,653	14.0
1922	6,623	50,613	13.1
1923	10,687	69,811	15.3
1924	7,093	52,083	13.6
1925	8,736	63,925	13.7
1926	8,372	69,293	12.1
1927	8,115	61,232	13.3
1928	8,621	63,433	13.6
1929	9,424	75,603	12.5
1930	8,974	55,201	16.3
1931	4,676	28,516	16.4
1932	407	5,331	7.6
1933	3,556	24,624	14.4
1934	4,146	25,793	16.1
1935	6,067	33,426	18.1
1936	9,659	51,466	18.8
1937	12,350	72,348	17.1
1938	4,836	26,431	18.3
1939	9,426	54,827	17.2
1940	12,926	75,198	17.2

[a] *Minerals Yearbook* and its predecessor *Mineral Resources.* Excludes ore containing 5 percent or more of manganese and ore sold for paint.

[b] Excludes ores that undergo no treatment beyond crushing and screening to improve their physical structure.

gests that in the past, once a mine changed from the production of direct-shipping ores to ores requiring beneficiation, grade remained rather stable and, in addition, that accretions to the group of ores requiring beneficiation were of approximately the same grade as the ores already in the group. In the case of copper, on the other hand, the decline in the grade of concentrating ores as such has been a problem solved only through increased elaboration of milling techniques. Iron has still another advantage, in that the level of grade of ore undergoing concentration (as compared with the grade of the merchantable product produced) is much higher than in copper, as is apparent from the fact that the ratio of concentration in iron is about 2 to 1, whereas in copper it is commonly 20 or 25 to 1. About 2 tons of crude iron ore will yield one ton of iron concentrates (merchantable iron ore), but it takes 20 or more tons of copper ore to produce one ton of copper concentrates.[14] Thus, by comparison with copper—which represents an extreme example of declining grade—the relative decline in the grade of iron ore is remarkably slight and the absolute level of iron ore grade is exceedingly high.

It appears that neither in accessibility nor in grade of ore have iron ore resources seriously deteriorated. Evidently, in its efforts to raise the level of productivity, technology has had a clear field.

TECHNOLOGY

The recent history of the industry's technology is dominated by the rise of open cut iron mining. Prior to 1892 the surface mining of iron ore played an insignificant role: in 1937 two thirds of all merchantable ore produced in the United States came from open cut mines. Thus, within the space of four or five decades, the character of iron mining in this country underwent a radical change. Unfortunately the statistical record of this change does not begin before the year 1909; we have assembled such data as are available in Table 21.

Both the shift toward open cut mining and the fluctuating contribution of open cut mines to the total help to explain the two characteristics of iron mining productivity that we noticed earlier in this chapter. To begin with, open cut mines are characterized by a higher output-labor ratio than underground mines. This is clearly evident from Table 21, which gives figures on tons per manhour for both types of mine. Hence any tendency for open cut mines to increase their share of the total—even without a rise in the productivity of either type of iron mining operation—would cause the productivity ratio to rise. Part of the net change over the period 1902–37 is certainly to be attributed to this factor. It is more convenient, however, to postpone our consideration of the long run net change to a later point in the discussion and to deal

[14] Data for iron are taken from the source cited in the preceding footnotes; data for copper from Appendix Table D-3.

TABLE 21

OPEN CUT AND UNDERGROUND IRON MINES, 1909–38
Percentage Contribution to Total Production and Output per Manhour[a]

Year	*Open Cut Mines*		*Underground Mines*	
	Percent of Total Production	Output per Manhour[b] (long tons)	Percent of Total Production	Output per Manhour[b] (long tons)
1909	46.7	[c]	53.3	[c]
1915	39.9	1.121	60.1	.389
1916	46.4	1.104	53.6	.369
1917	47.1	.912	52.9	.347
1918	51.3	.832	48.7	.321
1919	46.3	1.062	53.7	.313
1920	48.3	.966	51.7	.351
1921	47.0	.762	53.0	.364
1922	52.4	1.087	47.6	.395
1923	56.4	1.171	43.6	.408
1924	47.2	.989	52.8	.438
1925	48.4	1.393	51.6	.493
1926	51.1	1.784	48.9	.510
1927	50.0	1.591	50.0	.493
1928	53.1	1.815	46.9	.548
1929	55.7	1.837	44.3	.589
1930	49.6	1.496	50.4	.563
1931	45.0	1.212	55.0	.583
1932	34.9	.931	65.1	.503
1933	64.6	1.993	35.4	.508
1934	57.1	1.791	42.9	.598
1935	58.7	2.470	41.3	.663
1936	63.1	2.655	36.9	.701
1937	65.8	3.005	34.2	.692
1938	48.9	1.795	51.1	.642

[a] N. Yaworski and others, *Iron Mining* (National Research Project, Philadelphia, 1940), Table A-6, p. 218. Some mines using a combination of underground and open cut methods did not report separately for the two; the breakdown in these cases was estimated by the authors of the NRP report. The figures are based on data whose coverage of the industry, in terms of output, varies from 88.4 to 100.0 percent. Ore containing 5 percent or more of manganese is not included.

[b] Ratio derived from employment figures including beneficiating plants at the mine.

[c] Not available.

first with the erratic year-to-year behavior of the productivity index.

Shifts in the internal composition of total iron ore output from year to year must exert some influence on industrial productivity. As we have noted, the relative importance of open cut mines has tended to change from one year to another, so that this factor may afford a partial explanation of the jerky movement of productivity in iron mining. Indeed, if we compare the years in which iron ore productivity has declined from the preceding year's level with those in which the relative contribution of open cut mines has decreased, we find a marked similarity of movement. Since 1915 productivity has declined from the preceding year's level on 11 occasions: in 9 of these years the relative contribution of open cut mines also dropped; the other 2 were war years, when productivity might be expected to fall for other reasons.

There appears to be still another factor—closely associated with the first—which helps to influence the short-run fluctuations in productivity. It derives from the fact that in open cut mining barren rock must be removed before the underlying ore deposits are reached. However, the stripping of overburden is an operation which need not be evenly distributed over time (at least not in proportion to ore production) and usually is not so distributed. Hence we find that in some years more overburden per unit of output is removed than in others. In those years, then, the relative amounts of labor devoted to direct mining, and to the tasks of preparing certain sections of the mine for future exploitation, have been altered in favor of future operations. Relatively less labor is allocated to mining proper, and relatively more labor is used in preparations for the future: the result is a fall in output per unit of total employment (our sole measure). This may happen in two ways: either stripping of overburden is purposely carried through at the expense of the extraction of iron ore, or else production of iron ore falls to such low levels that even a "normal" amount of stripping will appear large in relation to current production. It is significant, however, that both of the ways in which this influence may operate seem to be concomitants of a low level of activity in the industry. Not only would "normal" stripping activities appear relatively large in a year of low production, but the possibility of keeping men and machinery active in the face of a low level of demand by assigning them to prepare for future operations would play a part in the mine operator's calculations.[15] It seems likely, then, that a low level of activity in

[15] Data bearing on this point are available only for the years since 1923, and for Minnesota alone. During this period Minnesota produced, on the average, close to 90 percent of total open cut production and may therefore be considered a good indicator of movement of the United States totals. The ratio of overburden stripped to ore produced in Minnesota open cut mines increased on nine occasions after 1923 and in six of these nine years the increase was associated with a decline in produc-

open cut mining would be associated with a lower output-labor ratio than would a higher level of productive activity.[16]

Chart 44 reveals a clear synchronization in the fluctuations of productivity and production. Although deviations from the general pattern have occurred, there can be little doubt that in this industry there is a definite tendency for year-to-year movements in productivity to proceed in the same direction as those in production. What happens, apparently, is that a decline in the absolute level of production usually results in a greater relative decline in the output of open cut mines than of underground mines.[17] This shift in the relative importance of the two types of producers exerts a depressing influence on productivity. And, as we have noted, there is an additional tendency for open cut productivity to decline when production is at a low level because of the relative increase in stripping operations. This may be expected to intensify the depressing effect of the first influence, and the combination of the two factors probably accounts in good part for the year-to-year fluctuations of productivity in the industry.

Despite the undulations of productivity in iron mining and beneficiating, we find a decided long term increase in output per manday and per manhour. Similarly, the fluctuating importance of open cut mines in the industry has not prevented a marked long term increase in the relative share of this type of mine in the output of the entire industry. It is reasonable to conclude, moreover, that the secular rise in the relative importance of the open cut technique (aside from any change in open cut productivity) has been a factor of great importance in the net increase in output per man. For in 1937 (the year of peak productivity) out-

tion; in the remaining three years (1928, 1934 and 1937) the change in the stripping ratio was very slight. (Data from Yaworski and others, *Iron Mining*, Table A-19, p. 238.)

[16] It is true that other influences, more or less common to all industries, affect productivity during periods of low activity. Here we are concerned not with these influences but with a special factor which operates in open cut iron mining alone. For a statement of some more general cyclical influences on productivity as we are able to measure it, see Solomon Fabricant, "Productivity of Labor in Peace and War," *Occasional Paper 7* (National Bureau of Economic Research, 1942), pp. 13-14.

[17] This phenomenon is clearly observable. It is probably explained by the greater flexibility of operation of open cut mines, which can cease production in response to curtailed demand without running up against the fixed costs for drainage and other types of maintenance that burden the underground mine operator. (See *Minerals Yearbook, 1934*, p. 323.) In addition, the open cut operator may find it simpler to curtail production because of the ease with which men and machines can be shifted to the task of preparing the mine for future operations.

put per manhour in open cut mines was 4.3 times that in underground mines. If we take the period 1915–38 as a whole in order to even out such influences as changes in the stripping ratio, manhour productivity of open cut mines is still about three times as great as the average for underground mines (see Table 21).[18]

The shift to open cut mining, although in the nature of a response to a unique resource condition, represents one aspect of technological change in iron mining. Technological change has appeared also in other forms. Within the framework of the open cut technique important mechanical improvements have been achieved; these, for the most part, have centered about the development of the power shovel and the attendant increases in its strength, capacity and flexibility.[19] In addition technology has effected changes in underground iron, as in other underground metal, mines. Here mechanization of functions and improvement in tools have been a continuing influence over the entire period covered by our analysis. New methods of mining have been developed which use gravity for breaking and loading the ore, and greatly reduce the need for drilling and blasting.[20]

The striking rise in the productivity of iron mining is therefore to be attributed to the exceptionally favorable circumstances of the industry. It has been able to share to the full in the many innovations introduced into the metal mining industries during

[18] Output per manday in iron mining rose from 4.6 long tons in 1915–17 (annual average) to 10.6 tons in 1935–37, or by 6.0 tons. Using the method of Table 13 (reading long tons of iron ore for dollars, and mandays for manhours) we may associate 4.6 tons of the increase with changes in underground and open pit productivity as such, and 1.4 tons with the shift from the former to the latter method of mining. (Data are from Yaworski and others, *Iron Mining,* Table A-5, p. 216.) The relative contribution of the shift in mining method to the rise in productivity during the last 20 or 25 years appears to have been slightly greater in iron than in copper mining: see Chapter 12, footnote 16.

[19] For a much fuller discussion of these changes, see Chapter 6 above.

[20] See above, Chapters 5 and 6. So far as concerns underground production, the soft ores of the Lake Superior district were mined mainly by square-set methods until top slicing was introduced after 1885, and sublevel caving after 1890. The substitution of these methods for square-set mining was stimulated by the development of scraper mechanisms and improved ventilation after 1900. Shrinkage began to replace open stoping in mining the hard ores of New Jersey after 1912. These changes greatly reduced the amount of timbering required and led to increased use of gravity in loading the ore. Block caving has been seldom used in underground iron mines, but it is thought possible that it may eventually play a role in winning ores of lower grade than those at present mined. During 1929–37 about half the output of iron ore from underground mines was produced either by top slicing or by sublevel caving, about one third by stoping methods (especially in Alabama), and the remainder by combinations of stoping and caving. (See Yaworski and others, *Iron Mining,* Chapter V.)

the past several decades; but, unlike most other metal mining industries, it has not felt the pressure of increasing natural difficulty. In the next chapter we turn to copper mining, a form of extraction in which technological advance has been, if anything, even more rapid than in iron mining, but in which the deterioration of resource conditions has played an important role.