NATURAL VENTILATION OF MICHIGAN COPPER MINES

BY

G. E. McELROY
# CONTENTS

<table>
<thead>
<tr>
<th>Introduction</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acknowledgments</td>
<td>2</td>
</tr>
<tr>
<td>Mines and mining conditions</td>
<td>2</td>
</tr>
<tr>
<td>Labor and production</td>
<td>3</td>
</tr>
<tr>
<td>Occurrences of ore</td>
<td>3</td>
</tr>
<tr>
<td>Mine openings</td>
<td>3</td>
</tr>
<tr>
<td>Mining methods</td>
<td>4</td>
</tr>
<tr>
<td>Ventilation conditions</td>
<td>4</td>
</tr>
<tr>
<td>Control of distribution</td>
<td>5</td>
</tr>
<tr>
<td>Auxiliary ventilation</td>
<td>6</td>
</tr>
<tr>
<td>Air conditions</td>
<td>6</td>
</tr>
<tr>
<td>Mine-air temperatures</td>
<td>6</td>
</tr>
<tr>
<td>Surface-air temperatures</td>
<td>7</td>
</tr>
<tr>
<td>Rock temperatures</td>
<td>8</td>
</tr>
<tr>
<td>Quality of air</td>
<td>8</td>
</tr>
<tr>
<td>Timber-decay fungi</td>
<td>8</td>
</tr>
<tr>
<td>Ahmeek mine</td>
<td>8</td>
</tr>
<tr>
<td>Location and description</td>
<td>8</td>
</tr>
<tr>
<td>Production and employees</td>
<td>9</td>
</tr>
<tr>
<td>Mine openings</td>
<td>9</td>
</tr>
<tr>
<td>Mining methods</td>
<td>9</td>
</tr>
<tr>
<td>Ventilation</td>
<td>11</td>
</tr>
<tr>
<td>Distribution of air currents</td>
<td>11</td>
</tr>
<tr>
<td>Auxiliary ventilation</td>
<td>12</td>
</tr>
<tr>
<td>Conditions and dimensions of airways</td>
<td>13</td>
</tr>
<tr>
<td>Natural draft pressures</td>
<td>13</td>
</tr>
<tr>
<td>Air temperatures</td>
<td>14</td>
</tr>
<tr>
<td>Rock temperatures</td>
<td>14</td>
</tr>
<tr>
<td>Quality of air</td>
<td>14</td>
</tr>
<tr>
<td>Conglomerate mine</td>
<td>15</td>
</tr>
<tr>
<td>Location and description</td>
<td>15</td>
</tr>
<tr>
<td>Production and employees</td>
<td>15</td>
</tr>
<tr>
<td>Mine openings</td>
<td>15</td>
</tr>
<tr>
<td>Mining methods</td>
<td>16</td>
</tr>
<tr>
<td>Ventilation</td>
<td>16</td>
</tr>
<tr>
<td>Distribution of air currents</td>
<td>16</td>
</tr>
<tr>
<td>Auxiliary ventilation</td>
<td>18</td>
</tr>
<tr>
<td>Conditions and dimensions of airways</td>
<td>18</td>
</tr>
<tr>
<td>Doors and bulkheads</td>
<td>20</td>
</tr>
<tr>
<td>Natural draft pressures</td>
<td>20</td>
</tr>
<tr>
<td>Air temperatures</td>
<td>21</td>
</tr>
<tr>
<td>Rock temperatures</td>
<td>21</td>
</tr>
<tr>
<td>Quality of air</td>
<td>22</td>
</tr>
<tr>
<td>Osceola mine</td>
<td>22</td>
</tr>
<tr>
<td>Location and description</td>
<td>22</td>
</tr>
<tr>
<td>Osceola mine—Continued.</td>
<td>23</td>
</tr>
<tr>
<td>Production and employees</td>
<td>23</td>
</tr>
<tr>
<td>Mine openings</td>
<td>23</td>
</tr>
<tr>
<td>Ventilation</td>
<td>23</td>
</tr>
<tr>
<td>Distribution of air currents</td>
<td>24</td>
</tr>
<tr>
<td>Ventilation of dead ends</td>
<td>25</td>
</tr>
<tr>
<td>Conditions and dimensions of airways</td>
<td>25</td>
</tr>
<tr>
<td>Doors and bulkheads</td>
<td>25</td>
</tr>
<tr>
<td>Natural draft pressures</td>
<td>26</td>
</tr>
<tr>
<td>Air temperatures</td>
<td>26</td>
</tr>
<tr>
<td>Rock temperatures</td>
<td>26</td>
</tr>
<tr>
<td>Quality of air</td>
<td>27</td>
</tr>
<tr>
<td>Isle Royale mine</td>
<td>27</td>
</tr>
<tr>
<td>Location and description</td>
<td>27</td>
</tr>
<tr>
<td>Production and employees</td>
<td>28</td>
</tr>
<tr>
<td>Mine openings</td>
<td>28</td>
</tr>
<tr>
<td>Ventilation</td>
<td>28</td>
</tr>
<tr>
<td>Distribution of air currents</td>
<td>29</td>
</tr>
<tr>
<td>Auxiliary ventilation</td>
<td>29</td>
</tr>
<tr>
<td>Conditions and dimensions of airways</td>
<td>30</td>
</tr>
<tr>
<td>Doors and bulkheads</td>
<td>30</td>
</tr>
<tr>
<td>Natural draft pressures</td>
<td>31</td>
</tr>
<tr>
<td>Air temperatures</td>
<td>31</td>
</tr>
<tr>
<td>Rock temperatures</td>
<td>32</td>
</tr>
<tr>
<td>Quality of air</td>
<td>32</td>
</tr>
<tr>
<td>Champion mine</td>
<td>32</td>
</tr>
<tr>
<td>Location and description</td>
<td>32</td>
</tr>
<tr>
<td>Production and employees</td>
<td>33</td>
</tr>
<tr>
<td>Mine openings</td>
<td>33</td>
</tr>
<tr>
<td>Ventilation</td>
<td>33</td>
</tr>
<tr>
<td>Distribution of air currents</td>
<td>35</td>
</tr>
<tr>
<td>Auxiliary ventilation</td>
<td>35</td>
</tr>
<tr>
<td>Conditions and dimensions of airways</td>
<td>36</td>
</tr>
<tr>
<td>Doors and bulkheads</td>
<td>36</td>
</tr>
<tr>
<td>Natural draft pressures</td>
<td>36</td>
</tr>
<tr>
<td>Air temperatures</td>
<td>37</td>
</tr>
<tr>
<td>Rock temperatures</td>
<td>37</td>
</tr>
<tr>
<td>Quality of air</td>
<td>37</td>
</tr>
<tr>
<td>Conclusions and recommendations</td>
<td>38</td>
</tr>
<tr>
<td>Direction of flow in operating shafts</td>
<td>39</td>
</tr>
</tbody>
</table>

# ILLUSTRATIONS

1. Plan map of Ahmeek mine, showing distribution of air currents by natural draft, July, 1928 .......................... 10
2. Isometric sketch of Conglomerate mine, showing distribution of air currents by natural draft, July, 1928 .... 16
3. Plan map of Osceola mine, showing distribution of air currents by natural draft, August, 1930 .................. 22
4. Plan map of Isle Royale mine showing distribution of air currents by natural draft, August, 1930 ........... 22
5. Longitudinal section on 70° of Champion mine, showing distribution of air currents by natural draft, August, 1930 ...... 34

III
NATURAL VENTILATION OF MICHIGAN COPPER MINES

By G. E. McElroy.

INTRODUCTION

The "copper country," as it is commonly called, of the Keweenaw Peninsula, Mich., is not only the oldest copper-mining district in the United States but has also been one of the most continuously active producing districts since the early forties of the last century. Although all of the earliest mines have been exhausted and abandoned for many years the present large producers have a long record of practically continuous production. The mines of the district enjoy exceptional natural advantages with respect to ventilation in that: (1) The ore deposits being worked permit a high degree of regularity in mine openings; (2) the character of the ground is such that open-stope methods of mining with exceptionally large extraction openings predominate; (3) although differences in surface elevation are negligible and natural drafts are limited largely to those set up by differences in underground temperatures in comparatively cool rock, the resistances to flow are commonly exceptionally low, and small natural drafts circulate large quantities of air; (4) operations are conducted at great depths and differences in surface air temperatures are minimized to such an extent during vertical flow that there is considerable constancy, both in direction and quantity of flow, of natural-draft air currents the year around; (5) the normal increase in temperature of virgin rock with increase of depth from the surface is at a moderate rate; and (6) the average surface temperatures are low. These natural conditions have resulted, in the main, in well-ventilated mines with low temperatures throughout.

However, two of the mines are the deepest in the United States, and lower workings are in warm rock in which the retreating systems of mining used require the driving of long development drifts, and the same necessity for long dead-end drifts exists in other mines where the rock temperatures are lower. These conditions have resulted in the comparatively recent introduction of auxiliary ventilation of long dead-ended development openings in a number of mines. In a few mines natural ventilation is inadequate to cope with conditions satisfactorily, but the economic and physical conditions of the mines are not such that thorough mechanization of the ventilation systems of the mines can be considered except as a last resort. Only one mine is seriously considering installing fans for mechanical primary ventilation.

As part of a more general country-wide study of metal-mining methods the Bureau of Mines is engaged in a limited study of

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1 Work on manuscript completed Jan. 8, 1931.
2 Mining engineer, U. S. Bureau of Mines.
methods of ventilating metal mines. Previous papers have discussed methods, practices, and costs for the large Arizona copper mines \(^3\) and for the silver-lead mines of the Coeur d’Alene district of Idaho \(^4\). This paper discusses the methods and practices (no separate cost data are available) for Michigan copper mines as obtained by brief personal surveys in July, 1928, and July and August, 1930, supplemented by information furnished by the mine management. The study was confined to five of the largest mines—the Conglomerate, Ahmeek, Osceola, Isle Royale, and Champion. Underground observations occupied two to six days at each mine and were confined chiefly to the active working zones. A few observations were also made in the Quincy mine, which was not on a normal operating basis at these times.

Detailed data regarding mining and ventilation conditions in the mines studied are preceded, in this report, by a section summarizing the mining conditions and another section summarizing the ventilation conditions of the district as a whole.

**ACKNOWLEDGMENTS**

The author wishes to acknowledge the unfailing courtesy and cooperation of all of the officials of the mines visited and particularly the following: James MacNaughton, president, Harry Vivian, chief engineer, Ocha Potter, superintendent of the Ahmeek-Kearsarge mines, Allen Cameron, mine captain of the Conglomerate mine, and Samuel Richards, mine captain of the Osceola mine—of the Calumet & Hecla Consolidated Copper Co.; Chas. L. Lawton, general manager, Quincy mine; A. H. Wohlrab, superintendent, Isle Royale mine; W. H. Schacht, president and general manager, and Albert Mendolsohn, general superintendent, of the Copper Range Co.; and William Jose, mine captain, Champion mine.

The author also wishes to acknowledge his obligations, for data on operating conditions and for assistance in underground observations, to the various engineers and other mine officials of the mines studied and particularly to Frank C. Gregory, formerly supervising mining engineer of the Bureau of Mines in this district, and George Rupp, formerly efficiency engineer of the Calumet & Hecla Consolidated Copper Co., for their assistance in underground observations during July, 1928.

The mine air samples taken during this study were analyzed at the Pittsburgh Experiment Station of the bureau under the direction of W. P. Yant, then supervising engineer of the health laboratory section.

**MINES AND MINING CONDITIONS**

The mines of the district occupy a narrow belt about 2 to 4 miles wide on a series of parallel beds of lava flows and conglomerate sediments whose outcrops approximately bisect the Keweenaw Peninsula that projects from the extreme northern part of upper Michigan into Lake Superior. Although the copper-bearing formations ex-

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ceed 100 miles in length the present large producers are included in a 25-mile strip extending from about 8 miles southwest to 17 miles northeast of Portage Lake and from Painesdale on the south through the twin cities of Houghton and Hancock on Portage Lake and through Calumet to Mohawk on the north.

LABOR AND PRODUCTION

The mines of the district normally employ about 5,000 miners. Climate and housing conditions are exceptionally good, and the district is essentially a "white man's" camp, employing a large proportion of native-born workers. The district yields all of the copper produced in the State of Michigan, which ranked first in the United States until 1887, second until 1910, and third since. It now accounts for almost 10 per cent of the copper production of the United States. The production for 1929 was 186,402,218 pounds. Total dividends from the district, since mining started in a small way in 1844, have exceeded $300,000,000.

OCCURRENCES OF ORE

The main ore deposits are native copper-bearing beds or lodes of two general types, conglomerates in which the copper fills interstices between pebbles and boulders, and amygdaloid lavas in which the copper fills openings made by gas bubbles and is in the form of rough pellets and irregular masses. Mass copper is also found in fissure veins paralleling the strike or cutting it approximately at a right angle, but only a small production comes from such deposits. The thickness of the beds and of the mineralized portions is quite variable, and the mineralization itself is sometimes erratic. The workable parts of the lodes are from 4 to 50 feet thick and a good average would be about 8 feet at present depths. The average grade of the ore now mined is approximately 20 pounds per ton (1.0 per cent), but sorting of waste below and above ground raises the grade of the mill material to an average of about 30 pounds per ton (1.5 per cent).

Strikes and dips are somewhat variable but in general are quite uniform over considerable areas. Surface dips range from about 35° at the north end of the district to about 70° at the south end and decrease somewhat with depth. As a rule the workings are in ground that stands well and except on steep dips have required little support until considerable depths had been reached.

MINE OPENINGS

The producing mines occupy a narrow plateau about 500 to 600 feet above Lake Superior cut by a narrow valley at Portage Lake. The country in general is very flat, and there are but slight differences in surface elevation between the various connected shafts. The depth of the lowest workings ranges from about 2,500 to 6,000 feet vertically and 4,000 to 9,000 feet in the planes of the lodes. As a rule, the mines are developed by inclined shafts sunk from the surface in or near the lodes and by drifts on the lode. Distances between operating shafts range from 1,000 to 3,000 feet, the average for the more recent operations being 2,000 to 2,500 feet. Development and mining are carried on concurrently in all mines of the district. A
few vertical, or nearly vertical, shafts have been sunk to intersect the lodes where holdings do not extend to the outcrops.

MINING METHODS

Mining methods of the district have been covered in detail by the technical press and a recent bulletin of the Bureau of Mines. Retreating systems of mining predominate in the district, open-stope methods being used with few exceptions. One mine uses a shrinkage-stope method, and another uses inclined cut-and-fill methods. Except in the latter, openings through the stopes are exceptionally large, and openings to the stopes—shafts and drifts—are exceptionally large in all cases. Even caved stopes, in most of the mines, offer little resistance to the flow of air, and many of the mines have huge open stopes near the surface. On account of the water troubles that develop when openings are broken through to the glacial till overburden there are few openings to the surface, except the shafts, in recent operations.

VENTILATION CONDITIONS

Due to favorable circumstances the mines of the district have been able to work to great depths without resorting to primary mechanical ventilation. Even though working zones are now from one-half to well over a mile vertically below the surface, natural ventilation continues to provide air in good quantities and of good quality to all connected workings. As a rule, development headings have been cleared of blasting gases by blowing compressed air between shifts, but the great length of the headings required for retreating methods of mining, combined with the higher temperatures encountered in lower working zones, has led to the comparatively recent introduction of auxiliary fan units in a number of mines for the ventilation of such headings.

Shafts, drifts, and crosscuts are, as a rule, of generous dimensions, and these, in conjunction with large stope openings in active territory, offer relatively low resistance to the flow of air, which in part compensates for the long distances necessarily traveled by air currents. Most of the flow travels at low velocities; the average differences in temperature between vertical openings are very small, but, acting through air columns of 2,000 to 6,000 feet, produce sufficiently large natural drafts to provide fairly large quantities of flow the year around, and, with a few exceptions in the case of flow through openings near the surface, the directions of flow are constant.

Distribution surveys, made in the larger and deeper mines under conditions of minimum summer natural drafts, have shown quantities of air in circulation ranging from 30,000 to 145,000 cubic feet per minute. Under normal summer operating conditions these quantities are equivalent to about 125 to 300 cubic feet per minute per man underground on the largest shift. No surveys were made under winter conditions, and no data are available; but natural drafts in winter are much stronger, and quantities of flow, although restricted by closing shaft houses on the surface and by closing doors on under-

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ground passages, average somewhat larger, without doubt, and have been estimated as ranging from about 200 to 350 cubic feet per minute per man for normal operating conditions.

In general, the air currents intake through abandoned shafts and connected openings to the lower parts of the mine, cross the lower active level drifts with fair uniformity as to quantities of flow, and upcast through the active stopes to the operating shafts and connected openings through which they discharge to the surface. In the general layout the active zone of operations is the most open zone as respects air flow, and the stope openings are so large compared with the shafts that, even though the latter are relatively large as shafts go, most of the flow through active stopping zones occurs through the stopes rather than the shafts. In worked-out stopping areas openings are relatively restricted by caving, and larger proportions of the total flows occur in the shafts. Near the surface of most of the mines are large stope openings; and, where these are not bratticed off, the flow occurs through them rather than through the shafts and at such extremely low velocities that it is sometimes difficult to determine the direction of flow even where large volumes are concerned.

Larger quantities of air circulating at higher velocities are required to improve comfort and efficiency conditions in the deepest mines, and most of the mines would be benefited by a more rigid control of air currents, particularly from a fire protection point of view. In general, attempts are being made to meet these requirements without resorting to mechanical primary ventilation, and only one of the largest and deepest mines in the district is seriously considering complete mechanical primary ventilation by means of surface fans.

Mechanical ventilation was once seriously considered for the Tumutmine mine, but connections made to the adjoining Champion mine gave the desired improvement in conditions, and the idea was abandoned. Following a fire in the Tamarack mine early in 1906, large surface exhaust fans were installed on the Nos. 2 and 1 shafts to clear the mine of fire gases. They were operated, as far as can now be ascertained, about 9 and 18 months, respectively, and then, with the mine clear and the shafts back in operation, were discontinued. A surface fan was installed on a shaft at the Quincy mine about 30 years ago for the purpose of holding a main operating shaft upcast in winter, but the installation did not accomplish the object sought and was soon discarded. It is also reported that a fan was once operated for a short time on the eighteenth level of one of the Gratiot (now Seneca) shafts, working a section isolated by flooding of adjacent shafts, with the intake through the bratticed-off manway compartment of the shaft.

CONTROL OF DISTRIBUTION

Few attempts are made to control the distribution of air currents, and high degrees of recirculation are therefore common. About the only major control of air currents attempted by the operators has either of two objects: (1) To throttle otherwise high-velocity cold currents in winter; and (2) to keep certain operating shafts upcast in winter to minimize ice troubles. In three mines, lines of bulkheads have been carried down along one or both sides of certain
shafts, or in crosscuts connecting vertical shafts with the lode, to provide a certain degree of control of air currents in case of mine fires, and these provisions have a considerable effect on distribution. In general, the operators have found that the major requirement in obtaining good ventilation is to provide two connections to all operating sections, including a through raise in starting stopes. Attempts have at times been made to operate isolated sections, but ventilation conditions in such sections, except those provided with auxiliary fan-pipe units, were such that the sections were either abandoned or provided with additional connections. Natural ventilation of shafts and connected openings extending two or three levels below the lowest level connection has been accomplished with a fair degree of satisfaction, where short drifts only were involved, by carrying a tight brattice down the shaft separating the manway from the skip compartments, but the method necessitated leaving the manways uncovered at the levels and resulted in accidents that led to its abandonment.

**AUXILIARY VENTILATION**

With the generally used advancing systems of stoping, development headings were ordinarily quite short and were satisfactorily ventilated by exhausts of compressed-air-operated drills and other appliances, supplemented by blowing compressed air rather freely between shifts. Exceptionally long connections were similarly ventilated, working but one shift where conditions were unusually bad. With the introduction of auxiliary fan-pipe methods of ventilation in other mining districts, such units were used only for isolated sections or exceptionally long headings. The change to retreating systems of mining, involving long headings for development, resulted in increasingly poorer air conditions in the development headings as depth was gained and higher rock and air temperatures were encountered. Auxiliary units were gradually introduced at a number of mines for the ventilation of such headings, starting in the Calumet & Hecla mine in April, 1919, in the Quincy mine in 1920, and in the Trimountain and Baltic mines in 1921. Although these units have materially improved conditions where they have been used, they have not been adopted uniformly throughout the district. Although some small-diameter pipe was originally used with small units, under present conditions the units are of ample size to handle large quantities of air through varying lengths of tubing 12 to 16 inches in diameter. The tubing used is practically all jute or canvas, except in the Conglomerate mine where underground generator, pump, and hoist rooms are supplied with large-volume circulations through large diameter up to 30-inch galvanized-iron pipe. The life of canvas and jute tubing under the mine conditions encountered is practically indefinite, and mechanical wear and tear only determine replacement needs.

**AIR CONDITIONS**

**MINE-AIR TEMPERATURES**

The mine workings are generally damp without being wet; and the air throughout all of them, except at the greater depths, is every-

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*All temperatures noted in following pages are to be understood as degrees Fahrenheit.*
where cool and comfortable. Considering the great average depth of workings, the rock temperatures are low, and air temperatures are also low; and, in addition, relative humidities are lower than the average for metal-mine conditions. In working zones 2,500 to 3,500 feet vertically below the surface dry-bulb temperatures in stopes generally range from about 65° to 70°, with wet-bulb temperatures 1° to 3° lower; and the range for lowest development headings is about 70° to 75°, with wet-bulb depressions of 2° to 5°. In working zones 5,000 to 6,000 feet deep air temperatures in stopes range from about 75° to 80° wet bulb and 80° to 85° dry bulb; and both wet and dry bulb temperatures average about 5° higher in the lowest development headings. Average wet-bulb depressions increase with depth even where there is no apparent change in moisture conditions, and relative humidities become increasingly lower than the average for normal mine conditions of damp to wet openings as depth is gained. This phenomenon is apparently due to gradual increase in the salinity of mine waters with increasing depth and was demonstrated exceptionally well in the bottom development drifts of the Quincy mine in July, 1928, at which time no stoping was in progress in the workings above. Wet-bulb depressions of 7° to 11° and relative humidities as low as 62 per cent were noted at development faces and elsewhere in the presence of a plentiful supply of mine water that would, under normal mine conditions, result in wet-bulb depressions of not over 1°. At moderate depths sodium chloride is the major saline constituent, but at greater depths calcium chloride predominates, and samples from near the bottom of the Quincy mine are reported to have been practically saturated calcium chloride solutions. Such solutions are diluted at working places by water used in drilling, both at the face and at workings up the dip; the possible wet-bulb depressions are thereby diminished, and relative humidities are increased. However, the lowest development headings in the Quincy and Conglomerate mines under normal operating conditions showed wet-bulb depressions of 3° to 8°, averaging 5°.

Saline mine water is occasionally used for drilling water under special conditions of difficulty in obtaining pure water under pressure. Troubles due to corrosion are thereby increased, and sores that are difficult to heal often develop from superficial cuts. However, in consideration of the fact that it is possible to use salt solutions in place of pure water and thereby obtain a decrease in wet-bulb temperatures and a corresponding increase in comfort in warm working places where the inflow of nonsaline mine water is relatively slight, the suggestion has been made informally to several mining engineers of the South African Rand, and is repeated here, that the use of saline water for drilling, spraying, and other purposes underground in the deep Rand mines might serve to ameliorate the uncomfortable conditions of high humidities experienced in lowest development faces, a subject about which there has been considerable discussion in the technical press of South Africa during the last five years or so.

SURFACE-AIR TEMPERATURES

Due to the geographical location of the district surface-air temperatures are naturally low, winter seasons are severely cold, and snow-
falls are heavy. United States Weather Bureau records for the 27-year period ending in 1928 show an average mean surface dry-bulb air temperature at Calumet, Mich., of 39.5° at an elevation of 1,246 feet above sea level; and a mean relative humidity for the same period at 8 a.m. at Houghton, 668 feet above sea level, of 82 per cent, which would indicate an average mean wet-bulb temperature at Calumet of approximately 37° F. Average temperatures at the mines should correspond closely with the averages for Calumet.

ROCK TEMPERATURES

A predominating factor in obtaining low temperatures at great depths is the moderately low rate at which the rocks of the district increase in temperature with depth. The gradients have been roughly determined, by correlation of rock temperatures observed on lower levels with an average surface temperature of 39.5°, as varying from 1° per 86 to 102 feet, with a probable average close to 1° per 95 feet for the present large producers. Average rock temperatures are approximately 90° F. at a vertical depth of 5,000 feet, a temperature often encountered in a number of mining districts in this country at depths of 3,000 feet or less. The highest rock temperature determined was 99.7° for a depth close to 6,000 feet below the surface.

QUALITY OF AIR

Numerous samples of air from different parts of the operating mines show that the air is of good to fair quality throughout. The mines are not troubled by strata gases of any type, and there are no indications of the occurrence of chemical reactions that vitiate the air to any perceptible extent, except for a possible slight effect in the mines south of Portage Lake. The main vitiating element appears to be timber decay, and in two instances methane has caused explosions during unwatering operations in timbered workings. Even in long dead ends having relatively large cross-sectional areas and ventilated only by compressed air, samples of air showed oxygen deficiencies and carbon dioxide increases of less than 0.2 per cent as a rule. Values of 0.4 to 0.5 per cent for both were obtained in a few places on return air currents that had passed through extensive zones of decayed timber.

TIMBER-DECAY FUNGI

Timber-decay fungi are not particularly abundant and are confined for the most part to the upper parts of return currents and upper sections of the mines where intermittently reversed circulation is, or has been, the prevailing condition. These fungi are relatively scarce in the operating zones, except where the air supply is taken through fungi-infested old workings and then only where condensation of moisture is brought about by the junction of practically saturated air currents of different temperatures.

AHMEEK MINE

LOCATION AND DESCRIPTION

The Ahmeek mine of the Calumet & Hecla Consolidated Copper Co. is on an extensively mineralized section of the Kearsarge amyg-
daloid about 5 miles northeast of Calumet and close to the villages of Ahmeek and Mohawk, in Keweenaw County. The properties of the Seneca Copper Mining Co. and the Mohawk Mining Co. adjoin it on the north, with the latter occupying the upper part of the lode above north end workings. The Allouez and North Kearsarge mines, now owned by the Calumet & Hecla but not operating, occupy the lode south of Ahmeek, whose operations now extend into the Allouez ground.

The lode is very regular and uniform, with a mining width averaging about 8.5 feet in present active zones and about 6 feet in recently developed Allouez ground. The dip at present depths is approximately 35°. Lowest development headings are (July, 1930) about 3,500 feet vertically below the surface and about 5,500 feet on the dip of the lode. The surface is practically flat and about 950 feet above sea level.

**PRODUCTION AND EMPLOYEES**

During June, 1928, the mine produced about 104,000 tons of ore averaging 32.6 pounds of native copper per ton with an average of 570 underground employees on two shifts and with about 70 per cent of the men on the day shift. In July, 1930, operations were at a lower rate; production had decreased about a third accompanied by a reduction in underground employees of about a fifth.

**MINE OPENINGS**

Figure 1 is a horizontal plan of the mine openings. The holdings on the lode extend to the surface only on the south end where two shafts, Nos. 1 and 2, have been sunk on the lode. On the north the Mohawk holdings occupy the upper part of the lode, and the Ahmeek ground is entered through two shafts, Nos. 3 and 4, inclined at about 80° to the point where they enter the lode, which they follow down the dip. These shafts are 50 feet apart at the surface, but each diverges at an angle of 21° from a line normal to the strike. The No. 1 shaft has been abandoned, but the other three are in active use as main operating shafts, and each has two skip ways and a manway.

**MINING METHODS**

The ore body is opened by drifts at approximately 160-foot (inclined) intervals off the slope shafts and mined overhand open stoping, retreating from boundary pillars or mid-points between shafts. Thin slab pillars on 42-foot centers divide the stopes into sections, and a thin pillar, pierced at 20-foot intervals for rough timbered chutes, is left above each drift. These pillars eventually cave to some extent, but the stopes are practically open, as regards air flow, for a long time after mining ceases. As a rule, active mining proceeds in three stope sections, while a fourth is being opened up. Little mucking to chutes is required, except a final clean-up, usually by scraper methods. No underground sorting is attempted. Seven-ton cars are loaded from the chutes, hauled by storage-battery locomotives, and dumped directly into 7-ton skips at the shafts. In development headings, carried through in groups of six—on three levels in both directions from a shaft—mule haulage is used
Figure 1.—Plan map of Ahmeek mine
for hauls less than 1,000 feet long and storage-battery locomotives for longer hauls.

VENTILATION

The primary ventilation of the mine is accomplished through the agency of natural drafts generated practically entirely by differences in underground air temperatures. The maximum difference in surface elevations of shafts is 64 feet. On account of the great length of the air columns above the wedge of Mohawk ground and the low velocities of air travel the effect of surface-air temperature changes on average temperatures of air columns is small, and the major air currents are constant in direction the year around.

DISTRIBUTION OF AIR CURRENTS

The major elements of the air-distribution system, as determined by a brief survey of the active workings in July, 1928, are shown on the plan map, Figure 1. The air supply entered through No. 2 shaft, downcast mainly through the stopes south of it (including Allouez stopes), coursed across the bottom of the mine through about eight lower active stoping levels, upcast mainly through the stopes north of No. 4 shaft, and eventually discharged from Nos. 3 and 4 shafts at the surface. Stopes, even those that are worked out, present such large openings that most of the flow occurs through them rather than through the shafts and large volumes are moved by small natural draft pressures.

The air movements above active territory and in the connected Allouez workings to the south were not investigated in detail. However, it is thought that the intake through No. 2 shaft represented practically the total intake of surface air. It was measured as 42,000 cubic feet per minute, and this quantity, plus the compressed air liberated in the mine, is practically equivalent to the total measured discharge of 53,000 cubic feet per minute from the Nos. 3 and 4 shafts. The latter measurement was closely checked by two groups of measurements in the lower part of No. 4 shaft.

The measurements along No. 2 shaft in the active zone showed a total air flow of about 65,000 cubic feet per minute, which indicates that the deep wedge of Mohawk ground between Nos. 2 and 3 shafts and the lack of adequate open connections for free flow between these shafts, were deflecting a large quantity of air—possibly 25,000 cubic feet per minute—up through caved stopes and back into the downcast circuit. The air throughout all of the main flow was so close to normal surface air in composition that analyses of air could not check this assumption of recirculation. The barrier pillar between the Ahmeek and Mohawk workings was said to be intact, and this rules out the assumption that there was an actual intake of about 25,000 cubic feet per minute of surface air taken in via Allouez shafts and a similar amount lost through openings to the Mohawk mine.

At this time, as can be seen by inspection of the map, a number of the lower levels were not connected through between shafts at blocks of poor ground that occur approximately midway between
the shafts and define the positions at which retreating stopes were started. Lack of more open connections at these zones materially restricted the total flows at that time. Two years later, at a lower stage of operations embracing three to four levels open between shafts, a considerable increase in air flows was reported by the mine officials, and it was noted that the lowest of the four through levels between Nos. 2 and 3 shafts was carrying 22,000 cubic feet per minute, whereas the only open through level in this section carried but 14,000 cubic feet per minute at the time of the original survey.

These figures are all for times when natural drafts are practically at a minimum. Midwinter flows are said to be considerably larger, but no detailed data are available. Rough estimates of probable shaft-temperature changes indicate the possibility of the flows averaging almost double these quantities in winter.

The measured discharge of 53,000 cubic feet per minute for July, 1928, was equivalent to about 130 cubic feet per minute per man employed underground. Although no exact data can be presented for other times of the year and later conditions of more through openings, there is no doubt that present (1930) summer conditions with a normal operating force would give a figure somewhere between 150 and 200 cubic feet per minute per man or better and that normal winter conditions now range between 250 and 300 cubic feet per minute per man.

**AUXILIARY VENTILATION**

Until the early spring of 1930, development headings were ventilated only by compressed air. Except in a few of the longest headings—over 1,000 feet in length—drill exhaust air sufficed during the drilling period, supplemented by a compressed-air blower set about 50 feet back of the face in the longer headings. Practically all of the headings used compressed-air blowers during the mucking period. Faces were blown out after blasting with compressed air for the 2 or 5 hour period between shifts with 15-pound pressure air, and each heading had one or two smoke zones, depending on its length, during the working shift.

Development is carried on in groups of three levels drifting both ways from a shaft coincident with sinking the shaft, so that seven development headings are carried off a single shaft. In the development of the 35, 36, and 37 levels, air conditions were such that, to avoid a decrease in working efficiency, plans were formulated for auxiliary ventilation of lower development, particularly as it was desired to carry exceptionally long drifts into the Allouez ground south off No. 2 shaft. Single large units, used with large-diameter canvas pipe extending to all development ends off a shaft, were decided upon, and the first unit was installed in March, 1930, for the ventilation of the 38-39-40 level development off No. 3 shaft. Early in July, 1930, another unit was installed for the ventilation of the same development off No. 2 shaft. No appreciable increase in efficiency or marked change in temperature conditions has accompanied the change, according to the mine officials, but air conditions in general have greatly improved in the development ends, and the consumption of compressed air has been reduced slightly. It is considered that the installations have prevented an otherwise
probable decrease in labor efficiency and are therefore justified economically.

A No. 80 Sturtevant, Turbované design 5 (backward-curved blade), double-inlet, double-width, centrifugal fan operated at 1,450 revolutions per minute by direct connection to a 25-horsepower, 440-volt, 3-phase, 25-cycle induction motor is installed on the 37-level station close to No. 3 shaft. It has top horizontal discharge into an 18 by 36 inch metal duct which connects, below the station, with two 18-inch diameter canvas tubes which are carried to the 39 and 40 level stations, respectively. Sixteen-inch branches are carried from the stations to within about 200 feet of each face, which is about as close as the canvas can be kept to the faces without mechanical injury from blasting. Blasting pieces are not used to extend the pipes closer to the faces during the shift.

The new layout at the No. 2 shaft is also on the 37 level station and similar to that at No. 4 shaft, except that the fan (transferred from another operation) is a No. 10 Sturtevant, steel pressure blower design 2 (straight radial blade) double-inlet, single-width centrifugal fan operated at 1,270 revolutions per minute by Textrope drive from a 75-horsepower, 440-volt, 480 revolutions per minute motor, and discharges through an 18-inch metal pipe to two 18-inch canvas tubes in the man way.

CONDITIONS AND DIMENSIONS OF AIRWAYS

The airways of this mine are relatively large and numerous. They are also fairly straight, regular, clean, and clear of obstructions. Worked-out stopes are comparatively open and offer little resistance to air travel. There is practically no timbering on the drifts. Slope shafts are timbered either with well-aligned timber sets or rows of stalls.

The No. 2 shaft has two 6.5 by 6.5 foot skip ways and a 4.0 by 6.5 foot man way separated by two rows of 10-inch square stalls on about 10-foot centers. The Nos. 3 and 4 shafts also have two skip ways and a man way each. The upper 1,250 feet of each shaft is on an 80° slope and has regular timber sets on 5-foot centers forming 6.5 by 7.0 foot skip ways and a 4 by 7 foot man way. On the lode these shafts have about 7 by 7 foot skip ways and a 5 by 7 foot man way, separated by two lines of 10-inch square stalls on about 10-foot centers. Man ways are covered at the surface and at all levels, so very little air flow occurs in them.

Drifts are about 8 feet high and 10 to 14 feet wide, with an average cross section of approximately 100 square feet. These are exceptionally large drifts for a metal mine and are responsible in large part for the good natural ventilation of the mine.

Although abandoned stopes gradually cave to some extent, it is evident that there is plenty of passage left for the ready flow of air through mined-out sections, more particularly through recently mined areas.

NATURAL DRAFT Pressures

For July, 1928, computations show average air densities of the shaft columns of approximately 0.077 pound per cubic foot and an
average difference to working zones of about 0.0004 pound per cubic foot. This difference was due mainly to a difference of but 3° in average temperatures of downcast and upcast air columns and created natural drafts of about 0.18 and 0.23 inch water to the top (27 level, 2,400 feet deep) and bottom (34 level, 3,000 feet deep) of the stoping zone, respectively, or an average of 0.20 inch of water for this zone.

This figure represents close to a minimum for natural draft at this mine. The probable winter maximum is difficult to estimate, but the relatively high average temperatures observed in the No. 2 downcast shaft indicate that a figure of 1.0 inch of water is possible, which is enough to more than double the summer flow.

AIR TEMPERATURES

In July, 1928, the average temperature condition in active stopes, which appeared dry throughout, was approximately 67° wet bulb and 70° dry bulb, but varied about 2° higher or lower with the exact location of the stope; and these working places were quite comfortable. The average temperature condition in development headings was about 72° wet bulb and 76° dry bulb; and these places were very slightly uncomfortable. Maximum temperatures of 73.0° wet bulb and 77.5° dry bulb were noted in the lowest development headings—off No. 3 shaft on the 37 level at a vertical depth of 3,200 feet.

The air in the damp-to-dry downcast No. 2 shaft was being cooled from the surface condition to a minimum of 58.5° at the twelfth level (approximate vertical depth of 1,150 feet) and then gradually increased to 62.5° just above the working zones, where warmer air from the Allouez side caused a rapid increase to a maximum of 69.5° at the lowest connection to the No. 3 shaft.

The temperature of the air discharged at the surface from Nos. 3 and 4 shafts was constant at 60° wet bulb and 61.5° dry bulb, representing a gradual decrease of about 10° from the bottom stope condition.

ROCK TEMPERATURES

No effort was made to determine the rock-temperature gradient. However, the temperature of the rock at the face of 38 drift north off No. 3 shaft, at 1,000 feet from the shaft and a depth of 3,410 feet, was determined under conditions favorable for accuracy as 79.3° F. Correlated with the average surface temperature at Calumet of 39.5°, this gives an approximate figure of 1° increase in virgin temperature of the rock for each 86 feet increase in depth vertically below the surface.

QUALITY OF AIR

Table 1 on the following page gives the analytical results of eight samples of mine air taken in the Ahmeek mine. They show air of exceptionally good quality throughout the stoping zone and of fair quality in the development headings.
Table 1.—Air-sample analyses:¹ Ahmeek mine, Calumet & Hecla Consolidated Copper Co.

<table>
<thead>
<tr>
<th>Location and description</th>
<th>Volume of air</th>
<th>Chemical analyses ¹</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Return air from No. 2 stope on 31 south drift off No. 3 shaft</td>
<td>12,000 C. f. m.</td>
<td>CO₂</td>
<td>0.04</td>
</tr>
<tr>
<td>Return air from No. 3 stope on 31 north connection</td>
<td>14,000</td>
<td>O₂</td>
<td>0.08</td>
</tr>
<tr>
<td>31 south drift off No. 3 shaft. Air supply for ventilation of No. 3 development headings</td>
<td>14,000</td>
<td></td>
<td>0.04</td>
</tr>
<tr>
<td>50 feet back of face of 600-foot 37 south development drift off No. 3 shaft</td>
<td>(3)</td>
<td></td>
<td>0.16</td>
</tr>
<tr>
<td>Intake air in No. 2 shaft at 27 level</td>
<td>10,000</td>
<td></td>
<td>0.03</td>
</tr>
<tr>
<td>Split of intake air via Allouez stope. 32 south drift off No. 2 shaft</td>
<td>13,000</td>
<td></td>
<td>0.03</td>
</tr>
<tr>
<td>29 north stope off No. 4 shaft</td>
<td>8,000</td>
<td></td>
<td>0.17</td>
</tr>
<tr>
<td>Face of 1,300-foot 33 north development drift off No. 4 shaft</td>
<td>(7)</td>
<td></td>
<td>0.16</td>
</tr>
</tbody>
</table>

¹ CO, 0.00 per cent. ² Drilling exhaust.

CONGLOMERATE MINE

LOCATION AND DESCRIPTION

The Conglomerate mine of the Calumet & Hecla Consolidated Copper Co. is on the Calumet conglomerate and embraces a mineralized section of this lode about 2½ miles along the strike in and adjacent to the town of Calumet, in Houghton County. In addition to the original Calumet & Hecla properties it also includes the former Tamarack and Tamarack Junior properties. The formation is very uniform and ranges from 15 to 20 feet in thickness, of which 12 to 15 feet is being mined in present active zones. The dip is approximately 35° in working areas though somewhat steeper in upper worked-out areas.

This is the second deepest mine in the United States, the neighboring Quincy mine exceeding it in vertical depth below surface by about 700 feet in August, 1930. The lowest development headings are about 5,500 feet below the surface, which is practically flat and about 1,200 feet above sea level. The inclined distance along the dip to these lowest openings is a little over 9,000 feet.

PRODUCTION AND EMPLOYEES

During June, 1928, the mine produced 69,000 tons of ore averaging about 45 pounds of native copper per ton, with an average of 1,142 underground employees on two shifts. About 60 per cent of the production was coming from scattered pillar-extraction operations in old stopes and abandoned slope shafts. About 70 per cent of the men were working day shift.

MINE OPENINGS

The mine has been opened by a large number of shafts, some of which are slope shafts in the vein, while others are vertical shafts connected to the vein by crosscuts throughout a part of their depth only. The Red Jacket, a 6-compartment vertical shaft, is the main operating shaft. It extends to the 81 level (4,800 feet vertical depth) and has crosscuts to the vein every third level from the 36 down. On the 81 level the crosscut connects to a main haulage way
rock drift which extends to the No. 12 Hecla slope shaft on the southern limit of the ore body. With the exception of the latter, used as a man and material shaft, all slope shafts have been abandoned above this level which in effect becomes the top of a new mine in process of development. The extensions of two of the slope shafts below the 81 level are separately designated as A and C slope shafts. A similar slope shaft, starting below this level in line with the No. 3 (vertical) Tamarack shaft, is connected to C slope and is also served as to haulage by the 81 level of the Red Jacket shaft. An inclined plane, designed as Red Jacket slope shaft, is developing the northern limits of the ore body at higher levels and is served by the 57 level of the Red Jacket shaft through a rock-drift haulage way.

Two vertical shafts—the 4-compartment No. 5 Tamarack and the 3-compartment No. 3 Tamarack—are open and used for pumping arrangements. All other vertical shafts are abandoned.

**MINING METHODS**

The ore body is opened by drifts at approximately 100-foot (inclined) intervals off slope shafts and mined by open overhand stopping retreating from boundaries or mid-points between haulage slopes. Operating sections 50 to 100 feet long are held open temporarily by rows of 3-stull batteries. The mined-out sections cave quite tightly shortly after stopping operations are completed. All ore is loaded into cars by scrapers operated on the drifts below the open stopes. No underground sorting is attempted. Irregular blocks of lean ore are left in place. Cars are trammed mainly by storage-battery locomotives and are dumped directly into skips on slope shafts. Ore from the lower slope shafts is transferred in large cars by electric haulage on the 81 level haulage ways to Red Jacket shaft.

**VENTILATION**

The primary ventilation of the mine is accomplished entirely through the agency of natural drafts, or pressures, generated almost entirely by differences in underground air temperatures, the maximum difference in elevations of shaft collars being but 31 feet. On account of the great length of the air columns above open connections and the moderate velocities of air travel the effect of surface-air temperature changes on the average temperature of air columns is large but not sufficient to change the direction of the major air currents, which are constant in direction the year around.

**DISTRIBUTION OF AIR CURRENTS**

The major elements in the air-distribution system, as determined by a brief survey in July, 1928, are shown by an isometric sketch of the workings in Figure 2. Measurements of the intake air currents from five downcast shafts just above the working zones gave a total air supply of about 102,000 cubic feet per minute at an average air density of 0.085 pound per cubic foot. Measurements of the total return air currents at the collars of seven upcast shafts gave a total air discharge of about 145,000 cubic feet per minute at an average air density of 0.072 pound per cubic foot. At surface-air density the underground supply becomes about 120,000 cubic feet per
Figure 2.—Isometric sketch of conglomerate mine, showing distribution of air currents by natural draft, July, 1928
minute; and this, plus possibly 15,000 cubic feet of compressed air per minute, gives a total air supply of 135,000 cubic feet per minute as a check against the measured discharge of 145,000 cubic feet per minute. The discrepancy of about 10,000 cubic feet per minute includes a small known, but unmeasured, split of intake air across upper workings, leakage between shafts and through surface caves, variations in natural draft, and errors of measurement.

The Red Jacket slope workings were receiving about 10,000 cubic feet per minute, partly from No. 2 Tamarack Junior and partly from No. 3 Tamarack. This air traveled to the No. 5–6 Calumet upcast, partly through the 57 level rock drift and partly through caved stopes. About 14,000 cubic feet per minute from No. 3 Tamarack ventilated the No. 3 Tamarack slope workings, the C slope workings, and the north stopes off of A slope. About half of this air was going to No. 5 Tamarack upcast, and the other half eventually upcast through No. 6 Hecla. Small splits, totaling 14,000 cubic feet per minute, passed from Red Jacket shaft on the 51, 57, and 78 levels to the Nos. 4 and 5–6 Calumet shafts. About 39,000 cubic feet per minute from Red Jacket shaft passed to the 81 level main haulage way; about 30,000 cubic feet per minute of this was being drawn down through two compartments of the No. 5 Tamarack by the action of an auxiliary fan to a large pump room (1,000 horsepower) at the shaft bottom on the 87 level and was returned to an upcast compartment. The remaining 9,000 cubic feet per minute was continuing south along the main haulage way and exhausting through Nos. 6 and 7 Hecla after ventilating a generator station and electric hoist station near the top of A slope.

About 27,000 cubic feet per minute was downcasing through the completely bratticed-off No. 12 Hecla slope shaft, 10,000 cubic feet per minute was escaping directly to No. 9–10 Hecla upcast, and 15,000 cubic feet per minute was ventilating the slope workings south of A shaft, exhausting through No. 7 Hecla.

From this brief summary it may be noted that less than half of the total underground supply of approximately 100,000 cubic feet per minute was ventilating the lower active stoping areas: 10,000 cubic feet per minute through the Red Jacket (north) slope workings, 14,000 cubic feet per minute through the No. 3 Tamarack and C slope workings and north stopes off A slope, and 15,000 cubic feet per minute through the south workings off A slope.

Two “dead” zones—that is, open but unventilated passageways connecting ventilated openings—were noted. One of these was the connection between the 81 haulage way and the top of C slope. The other was the main haulage way rock drift from No. 7 Hecla shaft south to its junction with 80 level drift. Such “dead” zones, since they are due to a balanced condition of natural draft forces, are intermittently ventilated to a slight extent by the disturbance of pressure conditions created by moving skips, cages, and trains. Similar conditions are often found in naturally ventilated mines and occasionally in multishift, mechanically ventilated mines.

The measured discharge of 145,000 cubic feet per minute for July, 1928, is equivalent to about 180 cubic feet per minute per man employed underground. A brief inspection of lower workings in July, 1930, indicated that total quantities of flow had fallen off slightly,
probably due to the fact that, although more thorough connections had been made on the lowest levels, the extension of pillar-robbing operations up the dip on the old slope shafts had resulted in less open conditions below these shafts and reductions in the quantities upcast through them. As this reduction in flow had been accompanied by a decrease in men employed, the supply per man had probably not changed to any considerable extent.

Under winter conditions there would normally be a considerable increase in total flow, but the normal increase is considerably minimized by operating conditions: The No. 2 Tamarack Junior shaft is blocked off completely by heavy snowfalls; the crosscut from Red Jacket shaft to the 81 haulage way rock drift is shut off by an air lock on account of the discomfort of the otherwise high-velocity cold air current; "salamander" heaters are used at the collar of the downcast Red Jacket shaft to reduce ice troubles in the shaft and to prevent freezing of the water pipes; and all of the shaft tops are considerably restricted, compared to summer conditions, by closing the doors of the shaft houses. Quantities of flow are probably very little larger in winter than in summer, but the intake air travels at higher velocities and is slightly colder at operating zones, and conditions as to comfort are said to be perceptibly better during the winter season.

**AUXILIARY VENTILATION**

Although auxiliary ventilation, in the form of fan-pipe installations, is in use for all dead ends locally heated by electrical equipment, such as main pump rooms and generator stations, development headings are ventilated only by compressed air. In the upper sections of the mine drill exhaust only is used for ventilation during the shift, but in the lower headings a number of large-volume compressed-air blowers were noted in continuous use during the working shift for improving comfort conditions by local air motion. In these headings mucking accompanies drilling with two large drills, so that twice the normal amount of drill exhaust air is available for ventilation.

The fan-pipe installations for ventilating local sources of heat handle comparatively large volumes through short runs of large-diameter iron piping. Two of these, located in the main pump rooms off the No. 5 Tamarack shaft, in each of which there are three 350-horsepower motors, are especially large for auxiliary equipment. Both fans are of the No. 6, Sturtevant multivane (forward-curved blade), single-inlet, single-width, centrifugal type, are operated at 720 revolutions per minute by direct connection to 75-horsepower induction motors, and pass about 30,000 cubic feet per minute of air through 150 feet of 30-inch galvanized-iron pipe from the rear of the pump rooms to the shaft.

**CONDITIONS AND DIMENSIONS OF AIRWAYS**

The airways of this mine are relatively large and numerous. They are also remarkably straight, regular, clean, and, with few exceptions, clear of obstructions. There is very little timbering on crosscuts and drifts. Slope shafts are timbered either with well-aligned timber sets or stalls only. A few openings through caved ground are
supported by pack walls of mixed timber and rock, which present unusually straight and smooth surfaces. Caved stopes appear to be tight, but air currents pass quite freely through recently caved sections.

The Red Jacket vertical shaft is the largest opening and is timbered throughout with 12 by 12 inch timber sets on 5-foot centers. It has six 6.5 by 7.0 foot compartments arranged in two rows of three each and a narrow pump compartment. Only the outer four compartments are in use—two skip ways and two cage ways; the two central compartments are floored over at the surface and at a number of points underground. The shaft is wet throughout, but little free water drips through it.

The No. 5 Tamarack vertical shaft is the next largest opening and is also timbered with 12 by 12 inch timber on 5-foot centers. It has four 5.2 by 7.0 foot compartments arranged in line, with a small manway and pump compartment on one end. Two compartments are used as cage ways and two as water-bailing skip ways, the pairs being separated by a tight brattice from top to bottom. This is a very wet shaft, with heavy drippers throughout. It is used as a main pump shaft and has two large pump rooms off it, both of which have three vertical triplex pumps operated by 350-horsepower motors. One is at the bottom of the shaft, about 5,200 feet deep, and is connected by a crosscut to the 87 level drift. The crosscut and part of this drift are used as a sump which is intended to be permanent and to be protected by leaving a sufficient block of ore. The other main pump room adjoins the shaft at the 2,400-foot level and operates in series with the lower one. Both pump rooms have auxiliary ventilation in the form of centrifugal fans located at the rear of the rooms, which draw air through the rooms from the bail-way compartments and then discharge it through 30-inch pipe into the manway compartment. This is an upcast shaft, but the bail-way compartments are downcast from the 81 haulage level to the bottom, from which point the man-way compartment is bratticed off to a point just above the 81 haulage level.

The No. 3 Tamarack vertical shaft has three 5.2 by 7.0 foot compartments arranged in line and timbered similarly to the No. 5. One compartment contains a ladderway, which occupies about one-half of the compartment. This is also a very wet shaft. It is about 5,100 feet deep, extends to approximately the elevation of the 85 level, and is used for hoisting ore and waste from north end development.

The No. 2 Tamarack Junior vertical shaft is almost the same type and size of shaft as the No. 3 Tamarack but is partly caved in places. It is about 3,000 feet deep and is connected through a 50-square-foot crosscut and raise to the north side of the Red Jacket slope shaft workings.

The underground slope shafts and the Hecla series of surface slope shafts have a skip way about 7 by 7 feet and a 3 by 7 foot manway. Surface slope shafts of the Calumet series are a little smaller, about 6 by 6 feet with a 3 by 6 foot manway. Platforms or "plats" restrict the clear area of the skip way and practically block off the manways in all the slope shafts, so that in general the manways carry very little air.
Drifts and crosscuts, although somewhat variable, average about 7 by 7 feet or approximately 50 square feet in cross-sectional area. The crosscuts off the Red Jacket shaft and the 81 level rock-drift main haulage way are somewhat larger and average 70 to 80 square feet in cross section.

Due to the method of mining, which aims at 100 per cent extraction and the caving of stopes retreating from boundaries and mid-points between slope shafts, the fact that air travels quite freely through caved ground is an important factor in the ventilation of the mine.

DOORS AND BULKHEADS

Relatively few bulkheads and doors are used for control of air currents and for protection in case of an underground fire. All openings off the No. 12 Hecla intake shaft are bulkheaded or doored off, as are all but one or two of the crosscuts off each vertical shaft. Most of these bulkheads are made of concrete and, where installed on inactive connections, the doors are made of iron plate and hung horizontally from the top of the frame. On active connections the doors are single or double vertically hung types set in heavy timber, or rock-filled timber, bulkheads. Wooden doors are made of two plies of 1-inch board, with one ply vertical and the other horizontal. An air lock, formed of two fully automatic doors operated from the rails, is installed on the crosscut from the Red Jacket shaft to the 81 rock haulage way but is used only in winter.

NATURAL DRAFT PRESSURES

For July, 1928, computations show average air densities of the shaft columns of approximately 0.080 pound per cubic foot, and average differences to working zones of 0.0007 to 0.0015 pound per cubic foot. These differences result in natural drafts of the approximate magnitudes listed in Table 2.

Table 2.—Approximately natural draft pressures; Conglomerate mine, Calumet & Hecla Consolidated Copper Co., July, 1928

<table>
<thead>
<tr>
<th>Downcast shaft</th>
<th>Ucast shaft</th>
<th>Natural draft pressures, inches of water</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>4,000 feet (Red Jacket slope)</td>
</tr>
<tr>
<td>3 Tamarack</td>
<td>5-6 Calumet</td>
<td>1.1</td>
</tr>
<tr>
<td>2 Tamarack</td>
<td>6-7 Calumet</td>
<td>1.0</td>
</tr>
<tr>
<td>12 Hecla</td>
<td>9 Hecla</td>
<td>0.6</td>
</tr>
<tr>
<td>Do.</td>
<td>7 Hecla</td>
<td>0.6</td>
</tr>
<tr>
<td>Red Jacket</td>
<td>5 Hecla</td>
<td>1.3</td>
</tr>
<tr>
<td>3 Tamarack</td>
<td>6 Hecla</td>
<td>1.4</td>
</tr>
<tr>
<td>Do.</td>
<td>5 Tamarack</td>
<td>1.4</td>
</tr>
</tbody>
</table>

These figures represent close to a minimum for natural draft at this mine. Winter maximums, it is estimated, would be approximately 2 inches for 5,500 feet. With mechanical ventilation, the summer minimum is estimated at about 1.5 inches and the winter maxi-
mum at about 2.5 inches, or an average natural draft of approximately 2 inches of water that would act in series with surface fan pressures to overcome the resistance to flow of the mine airways.

AIR TEMPERATURES

In the Red Jacket slope workings—about 3,500 feet below the surface—air temperatures in stopes ranged from 61° to 69° wet bulb and from 65° to 72° dry bulb.

In the stopes off the three lower slopes the air temperatures ranged from 75° to 80° wet bulb and 80° to 85° dry bulb, and the working places were somewhat uncomfortable. In the development headings off these slopes air temperatures ranged about 5° higher than in the stopes—that is, 80° to 85° wet bulb and 85° to 90° dry bulb—and the men were working stripped to the waist.

Due to the preponderance of pillar extraction operations, over half the workings in the mine are adjacent to upcast slope shafts where the wet and dry bulb temperatures range from about 65° to 75°, and air conditions are quite comfortable. The air discharged at the surface from the return shafts ranged from about 65° to 70° dry bulb with wet-bulb depressions, or differences from dry bulb of about 1°.

The air in downcast shafts was being rapidly cooled from the surface temperature until a minimum was reached at a vertical depth of about 1,000 feet; it then increased gradually and uniformly in temperature with depth. At the 81 level in the very wet vertical shafts it was about 68° saturated, whereas at the bottom of the dry-to-damp No. 12 Hecla slope shaft, at about the same elevation but after almost twice as long a travel, it was only 64° wet bulb and 72.5° dry bulb, which corresponds to 63 per cent relative humidity. This is remarkably cool dry air to be encountered 4,750 feet underground; and, more remarkable still, much of it retains a wet-bulb depression of about 8° through another 3,000 feet of longitudinal travel. This dry-bulb temperature is estimated to be at least 14° below virgin rock temperature for this depth. The dryness of the air, it is thought, is due in part to the dry condition of the shaft and probably to a greater extent to a high natural calcium chloride content of the mine water in the lower part of the lode, which reduces the rate of evaporation of the water.

ROCK TEMPERATURES

No special effort was made to determine temperatures of virgin rock, as it was known that company-obtained data dating back to 1895 were available. Two good values were obtained, however, during the course of the July, 1928, survey from the air temperatures in two long uniform-temperature dead ends extending into virgin ground at extreme ends of the ore body. These indicated rock temperatures of 77° at a depth of 3,770 feet on the 64 level at the north end and 92° at a depth of 5,370 feet on the south end. This is at the rate of 1° rise per 107 feet increase in depth between these points and checks closely with the average of company data for eight development drifts and crosscuts from the 500 to the 5,000 foot levels. Projection of this rock-temperature gradient to the surface gives 42°, which is close to the average surface temperature of 39.5 (at Calumet) and indicates a practically uniform gradient from the
surface down. Company data for low-velocity air shafts show rock temperatures at the bottom of holes 10 feet deep ranging from 6° below to 19° above the original rock temperatures determined by this gradient.

Two additional rock-temperature determinations were made in July, 1930, in drill holes at the face of advancing drifts. One gave 90° at the face of 89 north, in 1,100 feet off A slope at a depth of 5,170 feet, a value that falls practically on the gradient previously determined. The other gave 95.5° at the face of 93 south, in 700 feet off C slope at a depth of 5,490 feet, a value about 2° higher than that determined by previous data and one that, correlated with an average surface temperature of 39.5°, indicates that the gradient may possibly be as high as 1° per 98 feet, a figure that is corroborated by correlation of the other three rock temperatures with the average surface temperature rather than with each other and one that is more in line with determinations similarly made for other mines in the district.

QUALITY OF AIR

Table 3 on the following page gives the analytical results of eight samples of mine air taken in the Conglomerate mine. With the exception of the last, they show air of good quality throughout the mine. The sample taken at the collar of the damp, timbered, upcast No. 9 Hecla shaft, in which the air had traveled at low velocity for about 7,000 feet, is not abnormal for such a condition but indicates timber decay in this shaft. The conditions in the other upcast slope shafts are quite similar, except that the velocities are higher. It is probable that, if these slope shafts became low-velocity downcasts through changes in the ventilating system, the resulting air supply would be a little high as to CO₂ content, but well within permissible limits.

| Location and description | Volume of air | Chemical analyses ¹
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C. f. m.</td>
<td>Per cent</td>
</tr>
<tr>
<td>Return air from Red Jacket slope section on 57 level</td>
<td>7,000</td>
<td>0.15</td>
</tr>
<tr>
<td>Face of 88 south slope off Red Jacket slope</td>
<td>2,500</td>
<td>0.11</td>
</tr>
<tr>
<td>Face of 64 north (abandoned) drift off Red Jacket slope</td>
<td>None</td>
<td>0.22</td>
</tr>
<tr>
<td>Face of 92 south drift 100 feet off C slope</td>
<td>(?)</td>
<td>0.10</td>
</tr>
<tr>
<td>Face of 91 south drift 700 feet off C slope</td>
<td>(?)</td>
<td>0.12</td>
</tr>
<tr>
<td>Return air from stopes, on 98 drift 2,000 feet north of No. 6 Hecla shaft</td>
<td>7,000</td>
<td>0.09</td>
</tr>
<tr>
<td>No. 5 Tamarack upcast shaft at 29 (71 Red Jacket) level</td>
<td>37,000</td>
<td>0.05</td>
</tr>
<tr>
<td>50 feet below collar of No. 9 Hecla upcast shaft</td>
<td>10,000</td>
<td>0.46</td>
</tr>
</tbody>
</table>

¹ CO₂, 0.00 per cent.
² Drilling exhaust.

OSCEOLA MINE

LOCATION AND DESCRIPTION

The Osceola mine of the Calumet & Hecla Consolidated Copper Co. is in the town of Calumet and occupies part of a mineralized section of the Osceola amygadaloid lode, which is practically parallel
Figure 3.—Plan map of Ouareau mine, showing distribution of air currents by natural draft, August, 1930

Figure 4.—Plan map of Isle Royale mine, showing distribution of air currents by natural draft, August, 1930
to the Calumet conglomerate lode and about 800 feet east of it. On
the south it joins the abandoned workings of the old Osceola Con-
solidated Mining Co. The formation is moderately uniform; but
the ore is low in average grade, and a considerable degree of selec-
tion must be used in mining, with the result that large irregular
sections are not mined under present conditions. The ore occurs
mostly close to the hanging wall of the lode, where an average width
of about 6 feet is mined. Local ore shoots that dip into the footwall
account for a large part of the production and increase the average
width mined to about 8.5 feet. The dip averages about 38° at the
surface but decreases to about 36.5° at present depths.

This is one of the shallower mines of the district. The lowest
development headings (33 level) are about 2,400 feet below the sur-
fage, which is almost flat, and about 1,200 feet above sea level. The
inclined distance along the dip to the lowest openings is about 4,000
feet.

PRODUCTION AND EMPLOYEES

During June, 1930, the mine produced 66,600 tons of ore, averaging
18.3 pounds of native copper per ton, with an average of 425 under-
ground employees on two shifts, of whom about 225 were on the day
shift. At this time both production and number of men employed
were below normal, approximately one-third and one-fifth, respec-
tively.

MINE OPENINGS

As shown in Figure 3, a horizontal plan of the workings, the mine
has been opened by five shafts, Nos. 13 to 18, respectively, sunk on
the lode 1,600 to 2,800 feet apart, the interval increasing from north
to south. Nos. 13, 17, and 18 shafts have been abandoned as active
operating shafts but are used for development and ventilation. All
shafts are about 9 by 22 feet over all in section and are divided into
three compartments by two lines of stulls, the manway being in the
center with a skip way on either side. The ore body is opened by
drifts at approximately 120-foot inclined intervals off the slope shafts
and mined by overhand open stoping retreating from boundary pil-
lars or mid-points between shafts. Irregular sections and pillars
too poor to mine occur at frequent intervals and provide sufficient
support so that no regular system of pillars is required. A thin
temporary pillar, pierced at close intervals for rough-timbered
chutes, is formed above the drift; and occasional temporary pillars
of ore are used to protect openings, particularly where the regular
progress of the stope is delayed by footwall stoping, but practically
all pillars are mined immediately following stoping. Worked-out
stopes gradually cave, but large openings remain for the free flow
of air. Little mucking to chutes is required, except for occasional
footwall ore near the level. Large cars are loaded at the chutes and
hauled by storage-battery locomotives to the shafts, where they are
dumped directly into the skips. No underground sorting is attempted.

VENTILATION

The primary ventilation of the mine is accomplished through the
agency of natural drafts generated almost entirely within the mine
by differences in air temperatures. Maximum differences in eleva-
tions of surface openings are less than 50 feet. Lines of brattices are carried down one side of each of the three operating shafts, and these limit the crossflow in upper workings to a large extent. The effect of surface-air temperature changes on shaft-air temperatures is small; and the major air currents are constant in direction although, due to the layout of the workings, there are reversals, or attempts at reversals, of minor currents.

DISTRIBUTION OF AIR CURRENTS

The major elements of the air-distribution system, as determined by a brief survey in August, 1930, when natural drafts were at a minimum for the year, are shown on the plan map, Figure 3. Lines of brattices along the north side of three of the shafts and a barrier pillar, pierced only by the shafts, between the 10 and 11 levels, divide the mine into separate blocks and practically control the distribution. Both ends are downcast, and the central section is upcast. The total exhaust averaged about 60,000 cubic feet per minute at this time, of which about 6,000 cubic feet per minute was compressed air liberated underground. The north end, including Nos. 17 and 18 shafts, is shallow and had but one open connection to the return zone, which restricted the supply on this end to about 12,000 cubic feet per minute. The balance of the intake was through the south end: About 20,000 cubic feet per minute in No. 14 shaft and across the stopes above the barrier pillar to No. 13; 12,000 cubic feet per minute in No. 13 and downcast; and an estimated 10,000 cubic feet per minute in through caved sections of the south barrier pillar from adjoining workings and downcast through No. 13 shaft. Nos. 16 and 15 shafts were through upcasts, the former carrying about two-thirds of the total. Large amounts of recirculation were noted in the open zones at each end of the mine, but under the conditions obtaining no appreciable vitiation of the air results from such recirculation.

The No. 13 shaft and the adjacent stope openings have always been downcast and the No. 16 shaft always upcast; and as now connected the No. 18 shaft is always downcast, although sometimes blocked with ice. The direction of flow in Nos. 14, 15, and 17 shafts occasionally changes or is prevented from changing by manipulating doors and supplying heat under the collar of the shaft. Little attention is paid to the shafts other than No. 15, which is kept continuously upcast through the methods mentioned, though not without considerable difficulty at times.

Although there is a tendency for the total quantities of flow to increase in midwinter, the currents are throttled in various ways so that the increases are small, and no appreciable differences are said to be noticeable in the lower levels as between winter and summer conditions.

The total exhaust of 60,000 cubic feet per minute is equivalent to approximately 265 cubic feet per minute per man underground for July, 1930, conditions. Under conditions of normal production and winter operation this figure probably would not change much from that given; for normal production and summer operation the figure would probably be close to 200 cubic feet per minute per man.
VENTILATION OF DEAD ENDS

All dead ends, including development headings as long as 1,500 feet, are ventilated by compressed air, using drill exhaust only during the shift and compressed-air blowers between shifts. Drilling and mucking proceed at the same time, with one drill to a face. Blasting is confined to the end of shift periods, and faces are blown out with compressed air about 30 minutes at the end of the shift and for about 45 minutes at the beginning of a shift. Between shifts the compressors are shut down. In exceptionally long development headings the blower at the face is supplemented, after blasting, with blowers installed at 400 to 500 foot intervals along the drift. These are open-ended ¾-inch pipes leading off the main pipe and are carried to a height of about 5 feet with the discharge pointed away from the face.

Development is carried on in groups of two levels drifting both ways coincident with sinking the shaft, so that there are ordinarily five development headings off the bottom of each shaft.

CONDITIONS AND DIMENSIONS OF AIRWAYS

The airways are exceptionally large, regular, and clear of obstructions. The skip compartments of the shafts average about 8 by 8 feet in cross section and the manways about 4 by 7 feet. Drifts average about 8 by 15 feet, except in long connections through poor rock, where they may be reduced to about 8 by 8 feet. Raies are put up to the level above in starting stopes in most cases and are also used for development in excess of 1,500 feet. Worked-out and abandoned stopes cave gradually; but there are always large openings through caved sections, particularly along the ribs of pillars and unmined sections.

Free flow through stoped-out sections is prevented in large part by the lines of shaft bulkheads and by the barrier pillar between 10 and 11 levels. The bulkheads force the air currents to travel across the lower open levels. The barrier pillar and the surface pillar confine the air currents to relatively small shaft sections, and these two sets of restricted openings comprise the major resistances to flow, as the resistances to flow through the stope sections are practically nil.

DOORS AND BULKHEADS

Bulkheads and doors are confined to the three sets installed on the north side of each of three shafts and were erected according to a well-conceived plan of fire protection initiated soon after the mine was opened. As soon as a connection is made to the drift off the north side of any of these shafts a concrete frame having a 5.5 by 5.5 foot opening is installed in the north end of the shaft pillar, and an iron door is hung horizontally from the top of the frame. The door is held in the open position against the roof by means of buttons supported on hanging rods, one on each side close to the end of the door. When the opening becomes inactive the door is closed and latched shut from the shaft side. When the active workings have progressed so far below a group of levels that occasions for intermittent use of the doors have ceased, a group of doors is removed from the frames and the openings in the frames are filled with con-
crete to make solid bulkheads. Doors are left in place, however, on No. 11 level and on the uppermost one or two levels to permit attempts at controlling the directions of flow at the surface to minimize ice troubles.

In a very few places, where it is desired to close off an active level by doors, the horizontally-hung iron door is replaced temporarily by a light single or double vertically-hung door.

Shaft collars are also provided with iron doors for emergency use, and two or more stations in each shaft have been provided with concrete collars to facilitate the rapid installation of bulkheads in an emergency.

**NATURAL DRAFT PRESSURES**

For August, 1930, conditions of minimum natural draft, computations show average air densities of the shaft columns of approximately 0.077 pound per cubic foot and an average difference between Nos. 13 and 16 shafts to working zones of about 0.001 pound per cubic foot. This was due mainly to a difference in average temperatures of downcast and upcast columns of but 6° and created a natural draft of approximately 0.44 inch of water to the bottom of the stoping zone, the 31 level, which is about 2,300 feet below the average surface elevation.

This figure, of course, represents close to a minimum natural draft pressure. The probable winter maximum is difficult to estimate but is probably much larger than the summer value, even though low-velocity travel through stopes near the surface exists on both the downcast and upcast sides. Ice is said to form as low as the 15 level in the downcast No. 13 shaft, and the No. 18 shaft becomes almost clogged with ice each winter.

**AIR TEMPERATURES**

All of the workings are cool and comfortable. Dry-bulb temperatures in the active zones, both stopes and development, range from about 57° at the No. 13 shaft (intake) to about 63° at the No. 16 shaft (return) and are remarkably uniform, no doubt because they are close to the virgin-rock temperatures. These temperatures are accompanied by wet-bulb depressions of 2° to 3°.

The mine is dry to damp throughout, and the pumps handle an average of but 63 gallons per minute. Saline waters were first noted on the 28 level.

With surface temperatures of 65° to 75° at noon, temperatures in the downcast No. 13 shaft and connected stopes, through which air flowed at extremely low velocities, decreased from the variable surface condition to a practically constant temperature of 46° at the No. 8 and a few lower levels and then gradually increased to a maximum of about 57° at the bottom. In the upcast Nos. 15 and 16 shafts the temperatures decreased uniformly from 60° to 63° at the bottom to about 53° saturated at the surface.

**ROCK TEMPERATURES**

Four rock-temperature observations were made in drill holes at advancing development faces penetrating virgin ground with the following results: 52° at the north face of 15 level drift, in 2,600
feet off No. 17 shaft at a depth of 1,150 feet; 63° at the face of 31 north drift, in 1,400 feet off No. 16 shaft at a depth of 2,260 feet; 67.6° at the face of 33 north drift, in 750 feet off No. 15 shaft at a depth of 2,410 feet; and 67.6° at the face of 33 south drift, in 800 feet off No. 15 shaft at the same depth. Correlated with the average surface temperature of 39.5°, the first two check closely with the data for the adjacent Conglomerate mine and give gradients of 1° per 92 and 96 feet; but the last two, which may be too high because taken too hurriedly, check the Ahmeek data closely and give a gradient of 1° per 86 feet.

QUALITY OF AIR

Table 4 on the following page gives the analytical results of four samples of mine air taken in the Osceola mine. They show air of good quality throughout the workings, the samples representing places having maximum conditions of vitiation only.

Ammonia dynamite was formerly used for blasting development faces and occasioned considerable complaint from the miners. A few years ago a change was made to gelatin powder for these places, and the complaints immediately ceased. Ammonia powder is still used in the stopes, but these are uniformly well ventilated.

Table 4.—Air-sample analyses; Osceola mine, Calumet & Hecla Consolidated Copper Co.¹

<table>
<thead>
<tr>
<th>Location and description</th>
<th>Chemical analyses, per cent ²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CO₂</td>
</tr>
<tr>
<td>No. 31 north stope off No. 15 shaft, in dead end at shaft pillar 90 feet above level</td>
<td>0.05</td>
</tr>
<tr>
<td>In haxe 1,000 feet from face of 15 north drift off No. 17 shaft and 1,000 feet from air current</td>
<td>.04</td>
</tr>
<tr>
<td>200 feet from face of 32 north drift off No. 13 shaft and 600 feet from air current</td>
<td>.15</td>
</tr>
<tr>
<td>At face of 31 north drift in 1,300 feet from No. 16 shaft</td>
<td>.22</td>
</tr>
</tbody>
</table>

¹ Volume of air, cubic feet per minute, drill exhaust only.
² CO₂, 0.00 per cent; CH₄, 0.00 per cent.

ISLE ROYALE MINE

LOCATION AND DESCRIPTION

The Isle Royale mine of the Isle Royale Copper Co., controlled and operated by the Calumet & Hecla Consolidated Copper Co., is on a mineralized section of the Isle Royale amygdaloid lode extending south from the town of Houghton. It includes the old Huron, Grand Portage, and Miners properties, with over 3 miles of workings along the strike. Present operations are confined to a 2-mile length, with most of the workings in an intensively developed zone about 1 mile long. Strike, dip, and ore occurrence in the lode are very irregular compared with the rest of the district, and drifts along the lode are relatively very irregular in direction. The dip ranges from an average of about 56° at the surface to an average of about 53° in the lowest workings. Most of the ore occurs along the footwall and ranges from 4 to 40 feet in width, the computed average mining width in 1929 being 8.8 feet.
Lowest development headings—36 level drifts off No. 4 shaft—are about 3,650 feet below the surface, which is quite flat and about 1,000 feet above sea level. The inclined distance along the dip to the lowest openings is about 4,600 feet.

**PRODUCTION AND EMPLOYEES**

During July, 1930, the mine produced about 43,000 tons of ore averaging about 20 pounds of native copper per ton, with an average of 363 underground employees on two shifts, of whom about 210 were on the day shift. Production figures are for ore sent to the mill after waste-sorting on surface, which discards about 25 per cent of the rock hoisted. At this time both production and number of men were below normal, approximately in the same proportion as the rest of the district.

**MINE OPENINGS**

Figure 4 (p. 22) is a horizontal plan of the active mine openings. In addition to the shallow shafts of old operations the present mine has been opened by six shafts sunk on the lode at intervals of approximately 2,000 feet and numbered consecutively from north to south, but with a blank at the No. 3 shaft position which the old workings indicated was a lean zone. The end shafts, Nos. 1 and 7, have been entirely abandoned, and No. 6 is continued by raises for ventilation only. Nos. 4 and 5 shafts are the present main operating shafts, while No. 2 is a minor operating shaft. North of No. 1 shaft there are connections to old workings having more or less obstructed openings to the surface on the hill between the mine and Houghton. All shafts are open-timbered shafts divided into three compartments—two skip ways and a manway.

The lode is opened by drifts at 100-foot vertical distances, which gives a stoping interval of about 135 feet, and is mined by shrinkage stoping retreating from midpoints between shafts. Irregular pillars of poor rock are left for support and are supplemented by thin floor pillars where the rock is of average or low grade. Chutes are placed on 18-foot centers in heavy stull and lagging brattices. When the ore is drawn the stopes gradually cave, but there are always large openings alongside of pillars, particularly the shaft pillars. Large cars are loaded at the chutes and hauled by storage-battery locomotives for long hauls, or by mules for short hauls, to the shaft, where they are dumped directly into skips. No sorting is attempted underground, but a considerable degree of selection is exercised in locating the pillars of poor rock left for support.

**VENTILATION**

The primary ventilation of the mine is accomplished entirely through the agency of natural drafts, generated for the most part by the differences in average densities of the air columns within the mine. There is, however, a range of about 50 feet in the difference in elevation of the shaft collars, and there are old north end workings extending to the surface at points as much as 200 to 300 feet below the average surface elevation of the operating shafts. Lines of brattices and doors are carried down both sides of all shafts, and
these limit crossflow in upper workings to a large extent. The shafts are constant as to direction of air flow the year around. In order to keep the No. 4 shaft upcast near the surface in winter and thus minimize ice troubles, it is necessary to deflect warm currents into this section of the shaft and occasionally to add heat under the collar by means of steam pipes.

**DISTRIBUTION OF AIR CURRENTS**

The major elements of the distribution system, as determined by a brief survey in August, 1930, when natural drafts were at a minimum for the year, are shown on the plan map of the mine, Figure 4. Lines of brattices along both sides of all shafts and a barrier pillar, pierced only by the shafts, between the 16 and 17 levels divide the mine into separate blocks and virtually control the distribution. North of the No. 4 shaft there are numerous openings to the surface, but south of this shaft the surface pillar is intact and pierced only by the shafts. The whole north end, up to and including the No. 4 shaft, was downcast and Nos. 5 and 6 shafts were upcast. No. 7 shaft was closed off and neutral. No. 4 shaft, although designated as a downcast, was upcast at the collar with the intake to the shaft entering as small leakages through bulkheads and totaling 16,000 cubic feet per minute. Both Nos. 1 and 2 shafts were practically neutral at the surface, and all the intake air was through the numerous other surface openings.

The total quantity exhausting from the mine at Nos. 4, 5, and 6 shafts averaged about 90,000 cubic feet per minute, of which about 70,000 cubic feet per minute was traveling through active workings. The latter quantity is equivalent to about 330 cubic feet per minute per man underground on the day shift.

On account of the double lines of brattices along the shafts there is very little recirculation of air currents. No attempt is made to facilitate air flow, and, except for one connection driven between the lower sections of Nos. 2 and 4 shafts, there are no direct paths for the intake air currents, which find their way to active workings through a maze of old workings.

In winter some of the openings are throttled, and shaft houses are also closed, so that the natural tendency for the total flows to increase in quantity is checked, and underground conditions remain about the same the year around. All attention, as respects ventilation, is concentrated on preventing trouble with ice in the shafts during the winter, as the formation of ice in the slope shafts is attended with considerable danger.

**AUXILIARY VENTILATION**

Auxiliary ventilation, in the form of four fan-tubing units, is used for exceptionally long development headings. All other development headings are ventilated by drill exhaust from two drills during the drilling period and usually by a compressed-air blower during the mucking period. Faces are blown out with compressed air between shifts, with low pressure on the lines. Where the drifts are long and not supplied with auxiliary ventilation compressed-air
blowers set at 300 to 400 foot intervals, with the end pointed away from the face and the discharge restricted to a \( \frac{3}{4} \)-inch nipple or two saw cuts in a pipe plug, are used during the blowing period to facilitate the removal of blasting fumes.

Development drifts are driven in pairs off either one or both sides of a shaft. Under these conditions long drifts are driven one shift only and one auxiliary unit is used to ventilate two headings on alternating shifts.

The first fan for auxiliary service was installed in January, 1924, and one has been added about each two years since. Two are No. 4A Siroccos, another is a No. 5 Highspeed Sirocco, and the fourth is a Coppus TM4 Vano fan. All are used with 12 and 16 inch jute canvas, with the discharge about 200 feet from the working face.

CONDITIONS AND DIMENSIONS OF AIRWAYS

Skip compartments of the shafts average 6.5 by 7.5 to 8 feet and manways about 4 or 4.5 by 7 feet in the clear. Drifts through unstoped sections average about 7 by 7 feet but are about 9 by 18 feet through good rock and about 8 by 12 feet through shaft pillars. Raise stopes are put up to the level above in starting stopes where the mineralization is at all uniform and similar raises connect the ends of long development drifts. Advancing stope faces are carried on an incline from level to level and provide wide passages for air flow. Except as it is prevented by the shaft bulkheads and barrier pillars, there is free flow of air through stoped-out sections, even though they are caved. Between Nos. 2 and 4 shafts are large sections of unmined poor rock, which restricts the free flow of intake air to a large extent, but practically all of the resistance to flow is in the upcast shafts above the barrier pillar.

The lines of brattices down both sides of the shafts were installed for emergency use in case of fire and are installed on all but two or three bottom levels off each shaft, which would thus be the only points requiring much attention in case of a fire. They serve the purpose of forcing the air currents to paths across the bottom of the mine and through active workings.

DOORS AND BULKHEADS

Few doors are used for controlling the air currents, except for the doors placed on all levels in the shaft pillars and eventually converted into brattices by removing the door and filling up the opening. Doors have been damaged by cars so much in the past that the present design is very light and cheap. All doors are set in a concrete frame. The door itself is made of one ply of creosoted 1-inch boards braced by similar 1-inch material and is not tight in itself nor installed with sill blocks to insure tightness. As soon as a level becomes inactive the door is made relatively tight by the liberal application of mud.

Doors are hung by strap hinges that extend the full width and are single doors hung vertically. Originally, all doors were provided with latches arranged for operation from the shaft side. Lately the latches have been dispensed with, but a slot in the door closes over a large staple set in the frame and provides a means of holding
the door closed. No counterweights are provided, and all doors are hung to open toward the shaft regardless of the direction of flow. The doors are set in a jamb, contrary to usual mining practice, but have given no trouble because they are set in solid ground not subject to movement.

 Shafts are provided with concrete collars but are not equipped with doors, except that light wooden doors are installed at the surface of the nonoperating No. 6 shaft.

**NATURAL DRAFT PRESSURES**

For August, 1930, conditions of minimum natural draft, computations show average air densities of the shaft columns of approximately 0.079 pound per cubic foot and an estimated average difference between the accessible downcast and upcast columns in Nos. 2 and 5 shafts of about 0.0012 pound per cubic foot. Neglecting the surface column over the north end, which affects the active zones more particularly in winter only, the natural draft created by the computed density difference would be approximately 0.8 inch of water to the lowest connection on 33 level.

During the winter the natural drafts are much higher, but the heavy draft from the north end resulting from the 200 to 300 foot surface component is largely shut off, and the intake air moves so slowly through the old workings that it is doubtful if the effect of lower surface temperatures is carried to any great depth. The excess draft produced in winter is counteracted by a general increase in resistance to flow, so that the actual quantities flowing may be reduced on the average through the winter season, particularly as the intake openings become clogged with snow to a large extent.

**AIR TEMPERATURES**

All of the workings are cool and comfortable. Dry-bulb temperatures in the active stopes range from about 65° to 70°, with a gradual average increase from north to south and with wet-bulb depressions of 1° to 3°. In development ends at lower levels the dry-bulb temperatures average about 5° higher—70° to 75°—and wet-bulb depressions range from 2° to 5°. The slight average increase in wet-bulb depressions in lower levels appeared to be due more to an increasing degree of salinity in the mine waters than to increasing dryness of workings, as the workings appeared to average wetter. Much lower average wet-bulb depressions were noted when two drills were operating at a face than when the drills had been stopped for a few minutes or when mucking only was in progress, a condition noted generally throughout the district.

With surface temperatures close to 70° at noon, the lowest temperature noted in the downcast shafts was 50° at the 8 level in No. 2 and 53° from levels 2 to 6 in No. 4, and in both cases involved air that entered at low velocity at other surface openings, since No. 2 was neutral at the surface and No. 4 was slightly upcast. Below these points there were gradual increases to 56° at the 29 level in No. 2 and to 60° at the 24 level in No. 4. One large intake of 17,000 cubic feet per minute from the north end via the 29 level connection to the No. 4 shaft was reaching the latter at an average temperature condition of 64° wet bulb and 68° dry bulb.
The air discharged from the Nos. 5 and 6 shafts had temperatures of 55.5° and 55.0° saturated, respectively, representing gradual decreases from shaft-bottom conditions of 68° to 70° with 2° to 3° wet-bulb depressions.

ROCK TEMPERATURES

Three rock-temperature observations were made in drill holes at comparatively short advancing development faces, with the following results: 72.1° at the face of 29 south drift, in 750 feet off No. 6 shaft at a depth of 2,915 feet; 75.2° at the face of 32 south drift, in 600 feet off No. 5 shaft at a depth of 3,245 feet; and 76.0° at the face of 35 north drift, in 350 feet off No. 4 shaft at a depth of 3,550 feet. Correlated with an average surface temperature of 39.5°, the three gradients are 89, 91, and 97 feet per degree, respectively. The first of this group, in 29 south drift off No. 6 shaft, offered the best conditions for reliable results.

QUALITY OF AIR

Table 6 on the following page gives the analytical results of four samples of mine air taken in the Isle Royale mine. They indicate that the air is of exceptionally good quality throughout the general circulations and of fair quality throughout the development ends. Degrees of air vitiation are very slightly higher than the average for the district, where similar conditions as to extent of timbering exist and probably correspond to a slightly higher percentage of sulphides in the ore.

<table>
<thead>
<tr>
<th>Location and description</th>
<th>Volume of air</th>
<th>Chemical analyses ¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead-ended stope, 23 south off No. 5 shaft against shaft pillar.</td>
<td>None.</td>
<td>CO₂</td>
</tr>
<tr>
<td>Face of idle untimbered 33 north drift, 1,400 feet in off No. 4 shaft.</td>
<td>None.</td>
<td>O₂</td>
</tr>
<tr>
<td>Face off 800 feet H.W. crosscut off 33 north drift 160 feet from No. 4 shaft.</td>
<td>Compressed air blower only.</td>
<td>N₂</td>
</tr>
<tr>
<td>Intake air on 29 north drift connection from No. 2 to No. 4 shaft.</td>
<td>17,000.</td>
<td>CO₂</td>
</tr>
<tr>
<td></td>
<td></td>
<td>O₂</td>
</tr>
<tr>
<td></td>
<td></td>
<td>N₂</td>
</tr>
</tbody>
</table>

¹ CO₂, 0.00 per cent; CH₄, 0.00 per cent.

CHAMPION MINE

LOCATION AND DESCRIPTION

The Champion mine of the Champion Copper Co., operated by the Copper Range Co., which has a one-half interest in the property, is on a long mineralized section of the Baltic amygdaloid lode in and south of the town of Painesdale, Houghton County. The Trimountain mine of the Copper Range Co., shut down about June, 1930, adjoins on the north and is connected underground. North of the Trimountain and on the same lode is the Baltic mine of the same company, which was limited to small-scale pillar-robbing operations in the summer of 1930.
Present operations occupy a little over a mile on the strike of the lode. Both strike and dip are very regular. The dip averages close to 70°, being a little steeper at the surface and a little flatter at depth. The ore occurrence in the lode is quite irregular, and both selective mining and sorting underground are practiced. The average width mined is about 17 feet.

Lowest development headings—37 level off No. 1 shaft—are about 3,700 feet vertically, and 4,000 feet on the dip, below surface, which is quite hilly in this part of the district, but averages about 1,200 feet above sea level.

PRODUCTION AND EMPLOYEES

During August, 1930, the mine was producing at the rate of about 40,000 tons a month of ore averaging about 44 pounds of native copper per ton, with an average of 650 underground employees on three shifts, of whom about 240 were on the day shift. About 50 per cent of the rock mined was being discarded by waste-sorting underground. At this time production and number of men were but slightly below normal.

MINE OPENINGS

Figure 5 is a longitudinal section of the workings on the average dip of the lode, 70°. The mine is opened by four shafts, Nos. 1 to 4, inclusive, from north to south at approximate intervals of 1,000 feet, with workings extending south of No. 4 shaft, 2,000 to 2,500 feet to a major fault zone. No. 2 shaft has been abandoned, and No. 1 shaft is used only for operating a small isolated section off this shaft. Nos. 3 and 4 are the main ore hoisting and supply shafts.

The lode is opened by drifts driven off the shafts at 100-foot intervals on 70°. All operations are by inclined cut-and-fill methods of mining retreating from boundaries. In August, 1930, about 90 per cent of the production was coming from stopes operated by the Baltic method, as developed in the neighboring Baltic mine, and about 10 per cent from a new system of sublevel retreating cut and fill, making 100 per cent extraction followed by caving. There is practically no flow of air through filled or caved ground, and all flow is confined to openings made in mining.

VENTILATION

The primary ventilation of the mine is accomplished entirely through the agency of natural drafts generated by density differences in the mine-air columns, as there is less than 50 feet difference in surface elevations of the shafts. Practically no attempt is made to control air flow, except that numerous raises are employed in the mining systems, and these are left filled or open as required for ventilation of the active stopes. A few bulkheads have also been installed north of No. 4 shaft in the shaft pillar. Large sections of the old stopes are either filled tightly or caved tightly, but many of the old levels and stope mill holes are sufficiently open to allow considerable air flow. Attention as to ventilation is mainly centered in keeping the No. 4 shaft upcast in winter to avoid excessive ice trouble.
Figure 5.—Longitudinal section on 70° of Champion mine, showing distribution of air currents by natural draft, August, 1930
DISTRIBUTION OF AIR CURRENTS

The major elements of the distribution system, as determined by a brief survey in August, 1930, when natural drafts were at a minimum for the year, are shown in Figure 5, a longitudinal section of the workings on the average dip of the lode. Above the active zones the old workings are fairly tight as respects air flow, and crossflow is limited. Most of the air was intaking through the No. 3 shaft; and all of it, including about 6,000 cubic feet per minute of compressed air liberated underground, was exhausting through the No. 4 shaft. Other shafts and surface openings were minor intakes. The total exhaust averaged about 30,000 cubic feet per minute, equivalent to about 125 cubic feet per minute per man underground on the day shift. Almost twice this amount was found circulating underground due to large degrees of recirculation, particularly from the upcast No. 4 shaft to the downcast No. 3 shaft and from the upcast Trimountain workings to the No. 1 downcast shaft.

Openings through the stoping zones are relatively small as compared with similar openings provided by the open-stope and shrinkage-stope systems of mining used elsewhere in the district, and much lower proportions of the total flows circulate through the stopes. Near the bottom of No. 4 shaft, only 7,500 cubic feet per minute of the 28,000 available passed through the lower sublevel stoping zone by natural distribution, the balance going directly up the shaft. In the upper zone of stopes mined by the Baltic method, there was but 10,000 cubic feet per minute upcasting through the stopes at 21 level as compared with 27,000 cubic feet per minute upcasting in the shaft.

The fact that minimum areas are available for air flow is recognized and a special effort, found nowhere else in the district, is made to avoid restricting the openings present, particularly the tops of open fill raises which come up in the centers of the drifts and are provided with special pipe-grill covers that restrict the openings to a minimum extent.

AUXILIARY VENTILATION

Auxiliary ventilation, in the form of fan-tubing units, is used for all long development headings. In August, 1930, there were eight units on hand and six in use. Although some 12-inch tubing is in use the present standard is 16-inch jute tubing. Tubing lines are straight and kept in practically perfect condition. Development headings rarely extend over 1,000 feet from a raise connection, for it is considered better practice to put up a raise connection to the level above about the 1,000-foot point if the development required extends much farther than this distance from a shaft.

The use of auxiliary ventilation was started in the Champion mine in 1923 (in 1921 in the adjoining Trimountain and Baltic mines); but the units were not used efficiently or kept in condition until the desire to operate three shifts required improvement, which was brought about by placing the installation and maintenance of these units in sole charge of an experienced timber boss. With present conditions of installations it is possible to start work in a face 20 minutes after blasting.

The units on hand include 1 No. 10 Buffalo Forge blower, 3 No. 6 Duplex Baby Conoidal fans, 3 No. 2½ Troy Siroccos, and 1 No. 250
SM Coppus fan, all operated by direct connection to alternating-current or direct-current motors, the latter being used in places where there is no alternating-current cable installed for other mine equipment. The most recent direct-current-operated units are provided with automatic restarting equipment.

Short development headings and raises are ventilated only by drill exhaust and all development faces are blown out with high-pressure compressed air after blasting which is used in conjunction with air-pressure-operated water blasts. Raises are worked but one shift.

CONDITIONS AND DIMENSIONS OF AIRWAYS

Shafts are open-timbered 3-compartment shafts with two 6.3 by 7 foot skip ways and a 5 by 7 foot manway. The latter, however, is not available for air flow, as it is separated by a solid brattice from the skip compartments and has three solid platforms per level interval. Rock-walled drifts in the upper levels mined by the Baltic method are 7 by 7 feet in section, whereas in the new development the rock drifts average 8 by 13 feet. Rock-walled mill holes in upper workings are about 5 feet in diameter and fill raises about 4 by 5 feet. Raises in the new development are 2-compartment stuff raises with a 4 by 4 chute and a 4 by 3 foot manway. As planned, the sublevel method now coming into production will provide three such raises per level, although there were an average of but two per level in August, 1930, in addition to the raises driven during development for ventilation. The manways of these raises make up most of the resistance to air flow and cause most of the flow to stay in the shafts.

DOORS AND BULKHEADS

Doors are installed at the collars of the shafts for emergency use in case of fire and are used occasionally in winter to control the direction of flow in a shaft. During the winter of 1929–30 the No. 4 shaft turned downcast one exceptionally cold day and was almost immediately reversed by closing the doors on the shaft. In an attempt to reverse the No. 1 shaft flow the No. 2 shaft was bulk-headed over tight during the winter of 1929–30 without effecting the desired result. The bulkhead was left in place and was still in place when the survey was made in August, 1930.

At one time light wooden bulkheads were installed in the openings in the shaft pillar along the upper part of the No. 4 shaft, but most of these had been dislodged when observed. On account of moving ground along the shafts concrete bulkheads can not be used, and the intention is to use cribs of solid timbers 3 to 4 feet thick with the surface mudded or plastered over.

NATURAL DRAFT PRESSURES

For August, 1930, conditions of minimum natural draft, computations show average air densities of the shaft columns of approximately 0.076 pound per cubic foot, and an estimated average difference between the accessible downcast and upcast columns of about 0.0010 pound per cubic foot. The corresponding average natural draft was computed as approximately 0.6 inch of water
to the 32 level between the No. 3 shaft downcast and the upcast through the stopes south of No. 4 shaft.

Since most of the downcast flow is through the shafts at moderate velocities the winter natural drafts should be much larger, but resistance is added by closing up shaft houses, and the effect on total flows is not known. Ice is reported to extend as low as the 10 level of No. 3 shaft in winter, and it is possible that surface components of the winter drafts, exerted through the Trimountain connections to No. 1 shaft, may be opposed to the drafts generated wholly underground.

AIR TEMPERATURES

All of the workings are cool and comfortable. Dry-bulb temperatures in the active stopes range from about 55° to 67° with wet-bulb depressions ranging from 0.5° at the top of the pillar zone to 1.5° at the bottom of the lowest stoping zone. Temperatures in the development ends below stoping zones range from 65° to 70°, and wet-bulb depressions are practically uniform at 2°. The slight increase in average wet-bulb depression accompanying depth may or may not be due to increasing salinity of mine waters, as the effects noted could be ascribed to other causes, such as direction of travel and relative dryness of walls.

With surface temperatures averaging close to 70° at noon the lowest temperature noted in the downcast shafts was 50°. At 32 level the downcast air was 56° wet bulb and 58° dry bulb at the No. 3 shaft and 60° wet bulb and 63° dry bulb at the same level of the upcast No. 4 shaft. The temperature of the saturated air discharged from the latter was 53.5°.

ROCK TEMPERATURES

Two rock-temperature observations were made in drill holes at development faces penetrating virgin ground, with the following results: 58° at the face of 18 drift south of No. 4 shaft, which extended 1,400 feet into virgin ground beyond the stopes and was 1,840 feet below the collar of No. 4 shaft; and 69.8° at the face of 30 drift south off No. 4 shaft in 800 feet beyond the last air connection and 2,985 feet below the collar of No. 4 shaft. These two observations by themselves indicate a gradient of 1° per 97 feet and correlation of both with an average surface temperature of 39.5° (at Calumet) gives an average gradient of 99 feet per degree.

QUALITY OF AIR

Table 6 on the following page gives the analytical results of four samples of mine air taken in the Champion mine. Although they show a fair quality of air throughout the mine they also show more air vitiation than the other mines of the district, apparently a result primarily of air recirulating through areas having much timber but no doubt due in part to a slightly higher sulphide content of the lode. The sample from 37 level at the bottom of No. 1 shaft was taken while the auxiliary ventilation was temporarily shut down and represents compressed air rather than mine air; it is probable that a sample from the No. 1 stopes would have shown more vitiation than any in the table, as the surface-air supply to this circuit appeared to be extremely small:
TABLE 6.—Air-sample analyses; Champion mine, Champion Copper Co.

<table>
<thead>
<tr>
<th>Location and description</th>
<th>Volume of air</th>
<th>Chemical analyses 1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C. f. m.</td>
<td>Per cent</td>
</tr>
<tr>
<td></td>
<td>Drilled exhaust and 300 feet from 1,800 cubic feet per minute pipe discharge</td>
<td>6.49</td>
</tr>
<tr>
<td>West face off 18 drift south off No. 4 shaft; 1,400-foot fan-pipe ventilated, development face.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Face of 37 drift north off No. 1 shaft</td>
<td>Drilled exhaust only</td>
<td>.10</td>
</tr>
<tr>
<td>21 drift north off No. 4 shaft at 42 mill; return air at top of active zone.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Face of 30 drift south off No. 4 shaft; 850-foot, fan-pipe ventilated, development face.</td>
<td>Drilled exhaust and 100 feet from 800 cubic feet per minute pipe discharge</td>
<td>.30</td>
</tr>
</tbody>
</table>

1 CO, 0.00 per cent; CH₄, 0.00 per cent.

CONCLUSIONS AND RECOMMENDATIONS

Detailed data have been presented for five of the largest and most active mines of the district and cover the present operating mines with but few exceptions. The mines of the district enjoy marked natural advantages with respect to ventilation, and there are but relatively few working places in the district that are not cool, comfortable, and well ventilated, even though operating zones are 2,000 to 6,000 feet vertically below the surface and 4,000 to 9,000 feet on the dip of the lodes.

In the two deepest mines of the district the lower stopes and development faces are in rock zones having virgin temperatures of 90° to 100°, yet the natural dryness of the workings and the presence of saline mine waters result in such low wet-bulb temperatures that the resulting conditions of comfort at working places correspond more to a "warm" mine than a "hot" mine.

Conditions that could be remedied, at an expense within the limits set by the advantages to be derived, are not as numerous or as apparent in this district as they are in the average metal-mining district, and many of the improvements suggested to the operators concerned fire protection rather than ventilation proper. From a fire-protection point of view it is desirable to be able to stop or slow down the ventilating currents as quickly as possible, and only one mine was found to be fully so prepared. Two others, however, were extensively equipped for this purpose, but the others visited had practically no equipment along this line, except doors at shaft collars that would require putting the whole mine out of commission were they put to use. Practically the only control of air currents regularly attempted by the operators is the attempt to keep certain shafts upcast in winter to prevent operating troubles caused by the formation of ice in the shaft and water pipes. Most of the shaft doors were installed for this purpose, except at mines that have had serious mine fires.

The extent of the old workings above active zones, both laterally and on the dip, is so great and embraces ordinarily such variable
conditions that natural drafts can be considerably augmented only at an almost prohibitive expense. However, many opportunities are presented in mines of the district where provisions for control of air currents at time of mine fires can be coupled with provisions for increasing the natural drafts by eliminating recirculations and by other changes in the air-flow conditions.

Maximum ventilation by natural drafts depends to a large extent on the presence of large or numerous connections for low-resistance flow conditions normally present throughout the mines of the district. In certain parts of certain mines, however, ventilation was found to be throttled by lack of sufficient areas for free flow, and recommendations were made for better flow conditions through larger or more numerous connections.

Recommendations for primary mechanical ventilation were made only for the Conglomerate mine, although there were several other mines in the district for which similar recommendations might have been made under more favorable economic conditions. A complete mechanical system for the Conglomerate mine, involving large fans at the surface on the Nos. 3 and 5 Tamarack vertical shafts, has been planned, and only the recent depression in the copper market has delayed its installation.

All of the mines, with but few exceptions, are interested in auxiliary ventilation and have a number of such installations that are giving very satisfactory service. In particular cases, recommendations were made regarding details of equipment and practice, but in the majority of instances practice was found to be as efficient as the conditions demanded, and only general recommendations for future practice could be made.

DIRECTION OF FLOW IN OPERATING SHAFTS

Practically all of the operating shafts in the district are upcast shafts, and on account of the long cold winters it is the universal desire of the operators to have them so. A few operating shafts are naturally downcast, but in general the operating shafts are upcasts, and whenever one turns downcast no effort is spared in the attempt to change it back to an upcast. Operating troubles caused by ice in the shafts and by freezing of water pipes are given as the reason for this preference but the uncomfortably cold conditions in a downcast shaft and shaft house in winter probably have a predominating effect.

As a matter of maximum safety for the men when a mine fire occurs, it is practically a universal custom to make main man-carrying shafts downcast in mechanically ventilated metal mines, because in an emergency the men will naturally go to the usual means of ingress and exit. It is true that most of the mechanically ventilated mines have vertical shafts and manway exits that are not easily or quickly climbed from the lower levels to surface, in which respect the inclined shafts with commodious ladderways, that are available for emergency exits in most of the mines of this district, have a considerable advantage. Main downcast-operating shafts are found in mining districts where conditions as to winter temperatures and wet formations are comparable; and it seems possible that many, if not most, of the main operating shafts of the district could operate as
downcasts without more expense than the consequent increase in general safety conditions would justify.

Special conditions exist at some of the mines whereby a shaft could be made downcast throughout, except for a short distance below the collar, but upcast (with a small slit of intake air) at the collar and with temperatures above freezing throughout. At other shafts, it is possible that the heat in tightly bratticed-off manway compartments would be sufficient to turn this compartment upcast near the surface, even in a downcast shaft, or the downcast current in the manway compartment could be held to such a low velocity that only a small amount of extraneous heat would be required to prevent water pipes from freezing.

Freezing of cages and skips to the rails at or below the surface of inclined shafts would be a very real added element of danger but one that it seems could be effectively guarded against.

As to the possibility of turning shafts downcast that are, and have been for years, natural upcasts, it must be admitted that this is sometimes a difficult procedure and, under certain conditions, impossible. In general, the operating shafts became upcast because a little more heat was being released in them, mainly from compressed-air and water pipes and from ore in transit from lower and warmer levels, than in the naturally downcast shafts. Once started, the direction of flow tends to be perpetuated by the transfer of heat from the intake airways to the return airways and, in deep shafts having low-velocity flow, is usually maintained constant, even during summer periods of high intake-air temperatures. Average temperature differences between the downcast and upcast air columns are normally quite small in the mines of this district, and could be considerably modified under controlled distribution conditions. Velocity of flow is an important factor in controlling temperature changes in flowing air and sometimes offsets the effects of heating in shafts from extraneous sources. It is possible, under certain combinations of conditions, to create higher average temperature conditions in one shaft than in adjoining shafts and thus make it an upcast, even though it was formerly a downcast; but the procedure is usually very expensive, as it normally requires a large number of brattices and doors. Some upcast shafts turn downcast in winter; and it is possible that, in certain instances, advantage could be taken of this initial condition to make it permanent. At other shafts it may be possible to reverse the air flow temporarily by means of fans operating through temporary bulkheads and to depend on the temperature differences thus created to perpetuate themselves, after the fan and bulkhead have been removed, to a sufficient extent to prevent reversal of flow.

In general, attempts to reverse deep shafts are difficult of successful accomplishment and a considerable knowledge of temperature changes and natural draft effects is desirable to prevent costly mistrials, for which reason it is not expected that the operators will make many efforts in this direction under present conditions when they are practically fighting for the opportunity to merely continue operating.