Department of the Interior
Roy O. West, Secretary

U. S. GEOLOGICAL SURVEY
George Otis Smith, Director

Professional Paper 144

THE COPPER DEPOSITS OF MICHIGAN

BY

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IN COLLABORATION WITH

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UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON
1929

ADDITIONAL COPIES

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WASHINGTON, D. C.
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$2.50 PER COPY

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PART 2. ORE DEPOSITS

HISTORY

That the existence of native copper in the Lake Superior district was known to early Indians and that copper was mined by them is shown by numerous ancient pits containing masses of native copper in various stages of removal, together with the crude stone tools used in mining, and by the implements made from copper that are found in the region. (See pl. 1)

The earliest visits to the district by white men were made about the middle of the seventeenth century. In 1672 two Jesuit priests published a map of Lake Superior, and from time to time the Jesuit missionaries and others brought accounts of copper found along its shores. The names of these early explorers—La Salle, Allouez, Mesnard, Marquette, and Du Luth—have been preserved in the geographic nomenclature of the region.

In 1771 Alexander Henry, an Englishman, began the first mining operations on the banks of Ontonagon River near the present Victoria mine, where a great boulder of copper had been found. This boulder attracted much attention and was eventually sent to Washington, where it is still on exhibition at the National Museum. This work was soon abandoned, however, for the country rock was the unproductive Jacobsville ("Eastern") sandstone, the boulder as it later appeared being a glacial erratic derived from lodes that crop out farther north.

The Lake Superior copper industry had its real beginning in 1830, the year in which Dr. Douglass Houghton, Michigan's first State geologist, made his initial visit to the region. His report, published in 1841, aroused a general interest in the district. In 1844 the Federal Government began a land survey at the instance and under the direction of Doctor Houghton, which was combined with the geologic and topographic surveys he was then making for the State of Michigan. These surveys, though interrupted by the death of Doctor Houghton late in 1845, were pushed to rapid completion and served both to increase interest in the district and to facilitate its early exploration and development. Mining permits were issued by the Federal Government, the first in 1844, but they were abolished in 1846, and all mining lands were placed on sale.

The Pittsburgh & Boston Mining Co., organized in 1844, began operations at Copper Harbor, where a few tons of black oxide of copper was mined. In the following year it opened the first successful mine, the Cliff mine, on a cross fissure vein in the north end of the district; the first dividend was paid in 1849. The Minesota mine was opened on a strike fissure toward the southwest end of the district in 1849 and paid its first dividend in 1854, followed by the neighboring National mine with a dividend in 1861. The Central mine, operating on the Central fissure, northeast of the Cliff mine, made its first shipment in 1856 and began to pay dividends in 1864. These fissure mines were noted for the enormous pieces of "mass" copper encountered in them. Several of these masses were estimated to weigh about 500 tons each.

The Pewabic and Quincy mines were the first successful mines on an amygdaloid lode. They were opened on the Pewabic amygdaloid, in the Portage Lake region, in the central part of the district, in 1856; both mines began paying dividends in 1862.

The Isle Royale lode,[1] also in the Portage Lake region, had been opened as early as 1852 by the Isle Royale Mining Co., incorporated originally to mine on Isle Royal, in Lake Superior. Although worked intermittently by a number of companies, this lode yielded no dividends until 1913.

The Atlantic lode was discovered in 1864 and explored by the South Pewabic Mining Co. Intensive development was begun by the Atlantic Mining Co. in 1872.

The famous Calumet & Hecla conglomerate was opened in 1864, and the company paid its initial dividend in 1869. Ten years later the Kearsarge and Osceola lodes were opened.

The Baltic lode was discovered in 1882 but remained unexplored until 15 years later. This was the last important lode to be opened.

Most of the fissure deposits have long since ceased to be productive. Of the lode deposits, all that have been largely productive are still producing or may be expected to produce under favorable conditions, though some of the mines on the lodes have been worked out or consolidated with others.

[1]The terms "lode" and "fissure deposit" are here applied in accordance with local usage. Strictly speaking, the "fissure deposits" are lodes, arid the so-called "lodes" are not so, being rather in the nature of bed-replacement deposits. The latter, however, will consistently be called lodes in the present report; for the word is convenient and readily understood, and its use in this sense is perhaps not positively incorrect. As much can hardly be said of other applications of the term that are current in the district, where the word is used to designate (1) lava tops or conglomerates, or parts of them, which, though susceptible of mineralization, are not actually mineralized; (2) rock substance that has been mineralized; and (3) rock substance that is susceptible of mineralization. In general the use of the word in any of these senses will be avoided in this report, as being not only illogical but likely to cause confusion where the word is used in two or more senses in the same sentence.

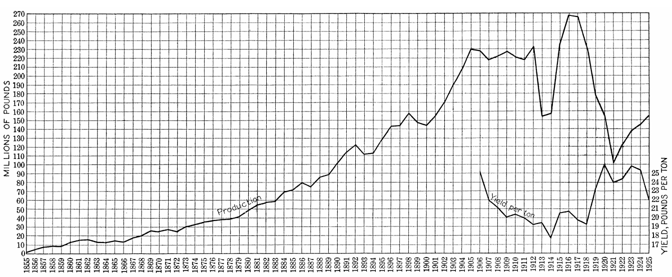

FIGURE 12.—Production of copper by Michigan mines, 1855-1925, and average yield in copper per ton of ore, 1906-1925.

PRODUCTION

The first production of copper in the Lake Superior district marked the real beginning of copper mining as a great industry in the United States. In its first six years of activity—from 1844 to 1850—the district produced more than 4,000,000 pounds, while all the rest of the country produced less than one-fourth as much. Yearly production steadily increased to a maximum of 269,700,000 pounds in 1916.

The total production from 1845 to the end of 1925 has been 7,500,000,000 pounds. Among the copper districts of the United States the Lake Superior district ranks second in total production. As a State, Michigan ranks third, having produced 21 per cent of all the copper produced in the United States to the end of 1925, while Arizona had produced 31 per cent and Montana 25 per cent.[2]

During the 18 years 1906-1923, for which definite figures are available, an average of 9,240,000 short tons of ore was mined annually, which yielded an average of 200,000,000 pounds of copper, or 21.56 pounds to the ton. The yield was 25.2 pounds to the ton for 1906, but dropped to 17.7 pounds for 1914. For 1918, 1919, 1920, and 1921 the respective yields were 19.2, 22.1, 23.7, and 24 pounds to the ton.

The following tables show the production of the district by years, by mines, and by lodes from the beginning of operations to the end of 1925. (See also figs. 12-14.)

Refined copper produced in Michigan copper district, 1845–1925

[Compiled from U. S. Geol. Survey Mineral Resources; figures for 1924 and 1925 furnished by Bureau of Mines. Smelter production]

	Pounds		Pounds
1845	26, 880	1887	75, 471, 890
1846	58, 240	1888	86, 472, 034
1847	477, 120	1889	88, 175, 675
1848	1, 032, 640	1890	101, 410, 277
1849	1, 505, 280	1891	114, 222, 709
1850	1, 281, 280	1892	123, 198, 460
1851	1, 744, 960	1893	112, 605, 078
1852	1, 744, 080	1894	114, 308, 870
1853	2, 905, 280	1895	129, 330, 749
1854	4, 074, 560	1896	143, 524, 069
1855	5, 808, 320	1897	145, 282, 059
1856	8, 211, 840	1898	158, 491, 703
1857	9, 531, 200	1899	147, 400, 338
1858	9, 157, 120	1900	145, 461, 498
1859	8, 926, 400	1901	156, 289, 481
1860	12, 069, 120	1902	170, 609, 228
1861	15, 037, 120	1903	192, 400, 577
1862	13, 585, 600	1904	208, 309, 130
1863	12, 985, 280	1905	230, 287, 992
1864	12, 490, 240	1906	229, 695, 730
1865	14, 358, 400	1907	219, 131, 503
1866	13, 749, 120	1908	222, 289, 584
1867	17, 525, 760	1909	227, 005, 923
1868	20, 935, 040	1910	221, 462, 984
1869	26, 624, 640	1911	218, 185, 236
1870	24, 622, 080	1912	231, 112, 228
1871	26, 750, 080	1913	155, 715, 286
1872	24, 552, 640	1914	158, 009, 748
1873	30, 089, 920	1915	238, 956, 411
1874	34, 332, 480	1916	269, 794, 531
1875	36, 039, 360	1917	268, 508, 098
1876	38, 270, 400	1918	231, 096, 150
1877	39, 025, 280	1919	177, 594, 135
1878	39, 690, 560	1920	153, 483, 952
1879	42, 848, 960	1921	100, 918, 001
1880	49, 736, 960	1922	122,545, 126
1881	54, 573, 120	1923	137, 691, 306
1882	56, 982, 765	1924	145, 333, 227
1883	59, 702, 404	1925	138, 029, 764
1884	69, 353, 202		
1885	72, 148, 172		7, 504, 265, 441
1886	79, 890, 798		

[2] Figures furnished by Bureau of Mines.

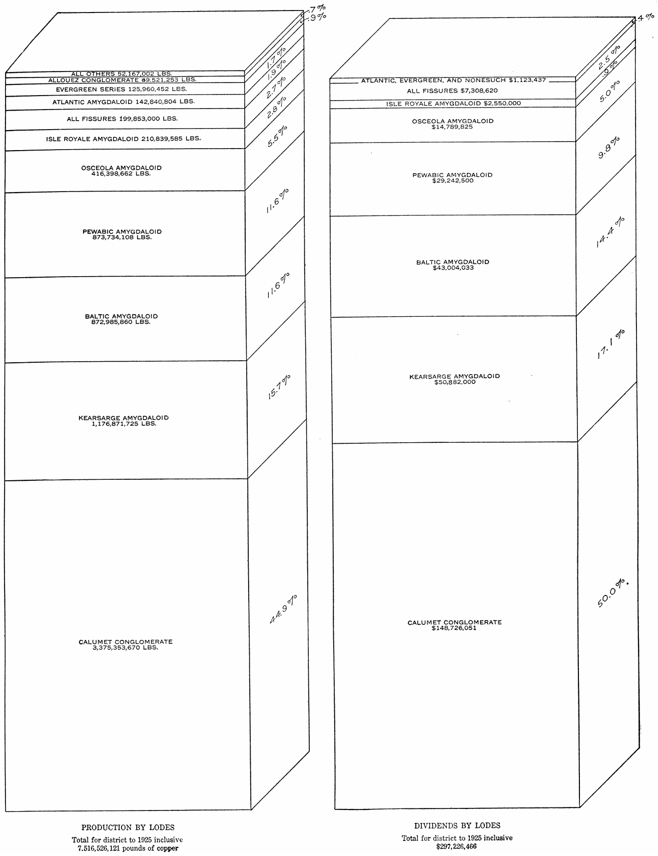

FIGURE 13.—Production and dividends of Michigan copper mines to end of 1925, by lodes.

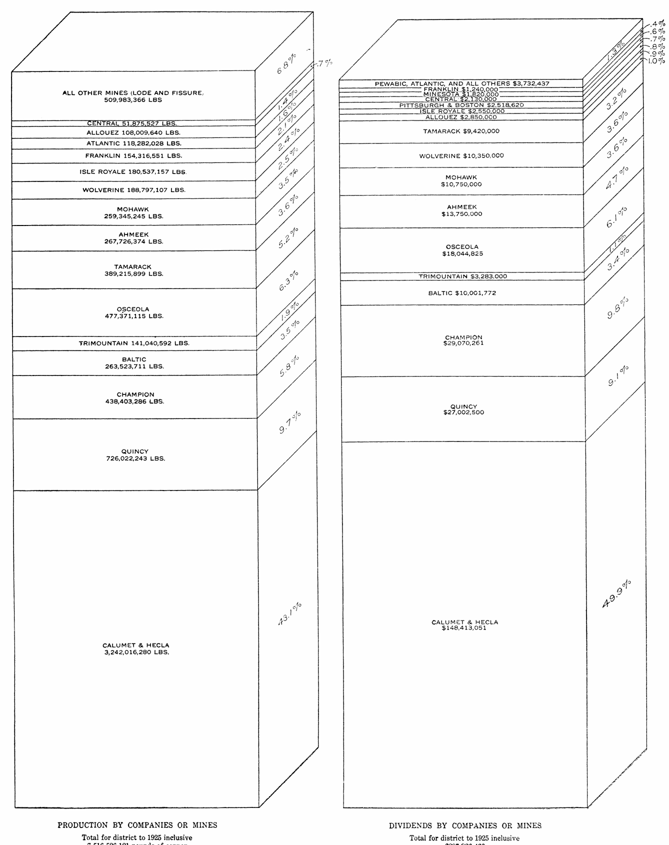

FIGURE 14.—Production and dividends of Michigan copper mines to end of 1925, by companies or mines.

Statistics of copper production in Michigan copper district, 1845–1925, by companies

Company	Lode	Period	Copper (pounds)	Rock treated (tons)	Yield per ton (pounds)	Dividends	
						Total	Per pound (cents)
Adventure		1851–1917	10, 783, 889				
Aetna	Fissures	1864–1873	140, 881				
Ahmeek	Kearsarge amygdaloid	1904–1923	249, 915, 343	10, 853, 819	23. 03	$14, 050, 000	5. 25
	Mass fissure		17, 811, 031				
Albany & Boston	Pewabic amygdaloid	1862–1864	14, 982				
	Allouez conglomerate	1865–1878	865, 057				
Algomah	Algomah amygdaloid	1914	12, 467				
Allouez	Allouez conglomerate	1869–1892	25, 786, 651				
	Kearsarge amygdaloid	1905–1923	82, 222, 989	4, 918, 843	16. 72	2, 850, 000	3. 47
Amygdaloid	Drexel fissure	1862–1878	1, 541, 180				
Arcadian	Arcadian amygdaloid	1864–1902	3, 019, 206				
Arnold	Ashbed amygdaloid	1898–1900	1, 772, 231				
Ashbed	Ashbed amygdaloid	1881–1884	[a] 78, 957				
	Fissures		[a] 20, 000				
Atlantic	Atlantic amygdaloid	1873–1910	118, 282, 028	8, 714, 452	13. 57	990, 000	. 84
Aztec		1852–1882	686, 357				
Baltic	Baltic amygdaloid	1898–1916	200, 584, 164	8, 672, 553	23. 13	7, 950, 000	3. 96
Bay State	Phoenix fissure	1865–1867	399, 115				
Belt		Prior to 1855–1886.	666, 031				
Caledonia		1855–1871	475, 747				
Calumet & Hecla	Calumet & Hecla conglomerate: Mine	1865–1925	2, 831, 092, 153	57, 229, 052	49. 47	[b] 160, 963, 755	4. 96
	Reclamation plant	1915–1925	127, 686, 924	12, 374, 823	10. 32		
	Osceola amygdaloid	1904–1925	213, 817, 584	14, 598, 914	14. 65		
	Kearsarge amygdaloid	1904–1925	67, 351, 569	2, 331, 524	28. 89		
	Mass fissure	1923–1925	2, 128, 050				
Carp Lake		1860–1865	33, 935				
Centennial [c]	Calumet & Hecla conglomerate.	1882	83, 554			360, 000	1. 01
		1897–1898	119, 190	6, 285	18. 96		
	Osceola amygdaloid	1891, 1897–1900	2, 449, 884	182, 193	13. 45		
		1892	106, 801				
	Kearsarge amygdaloid	1900–1923	33, 033, 675	2, 261, 890	14. 60		
Central	Central fissure	1855–1864	2, 901, 635	565, 393	83. 52	2, 130, 000	4. 11
		1865–1894	47, 219, 399				
		1895–1898	1, 754, 493				
Champion	Baltic amygdaloid	1902–1925	438, 403, 286	14, 156, 309	30. 97	29, 070, 260. 96	6. 75
Clark	Fissures	1872–1879	187, 915				
Cliff	Cliff fissure	1871–1887	4, 606, 690				
Concord	Arcadian amygdaloid	1866–1881	1, 595, 003				
Conglomerate	Fissures	1881–1887	806, 633				
	Allouez conglomerate	1882–1885	1, 770, 570				
Connecticut	Fissures	Prior to 1860	116, 800				
Copper Falls	Ashbed amygdaloid	1858–1893	[c] 17, 706, 352				
	Fissures	1847–1882	[c] 8, 633, 603			100, 000	1. 16
Copper Range	Baltic amygdaloid	1917–1925	64, 282, 850	1, 864, 236	34. 48	[d] 28, 576, 646	
Delaware	Fissures	1864–1880	1, 576, 885				
Derby		1853	2, 934				
Douglass	Arcadian amygdaloid	1860–1877	169, 502				
Douglass Houghton		Prior to 1857	143, 217				
Eagle River	Babbitt fissure	1853–1867	49, 678				
Evergreen Bluff		1854–1890	2, 915, 730				
Forest		1850–1855	332, 000				
Flint Steel River		Prior to 1855–1881.	869, 164				
Franklin	Pewabic amygdaloid	1857–1860	669, 981			1, 240, 000	1. 03
		1861–1870	14, 329, 231	457, 450	31. 32		
		1871–1883	24, 656, 624				
		1884–1919	[c] 80, 186, 631	[c] 3, 888, 462	20. 62		
	Allouez conglomerate	1901–1919	[c] 34, 473, 984	[c] 3, 053, 240	11. 29		
Fulton	Fulton fissure	1853	1, 255				
Garden City	Ashbed amygdaloid	1859–1866	75, 397				
Grand Portage	Isle Royale amygdaloid.	1863–1884	3, 529, 822				
Gratiot	Kearsarge amygdaloid	1910–1920	313, 848	30, 315	10. 35		
Hancock		1861–1918	17, 559, 557				
Hilton		Prior to 1855–1890.	123, 724				
Houghton Copper	Superior amygdaloid	1915–1917	540, 052	49, 729	10. 81		
Huron	Isle Royale amygdaloid.	1855–1893	25, 309, 270				
Island		1876–1878	213, 245				

[a] Assumed.
[b] Includes $12,550,704 received from other companies.
[c] Based partly on estimates.
[d] Includes $26,491,874 estimated dividends received from other companies.

Statistics of copper production in Michigan copper district, 1845–1925, by companies—Continued

Company	Lode	Period	Copper (pounds)	Rock treated (tons)	Yield per ton (pounds)	Dividends	
						Total	Per pound (cents)
Isle Royale	Isle Royale amygdaloid.	1853–1885	8, 818, 194				
		1901–1925	171, 718, 963	10, 469, 751	16. 39	$2, 550, 000	1. 48
Kearsarge	Kearsarge amygdaloid	1887	21, 237			160, 000	1. 10
		1888–1896	14, 490, 836	521, 707	15. 55		
Keweenaw Copper		1908, 1909	179, 565				
Knowlton		1862–1891	992, 757				
Lac La Belle	Fissures	Prior to 1850	3, 499				
Lake	Lake amygdaloid	1909–1917	6, 608, 824	320, 409	20. 63		
		1918	717, 403				
Lake Superior		1864–1879	14, 821				
La Salle	Kearsarge amygdaloid	1910–1920	7, 814, 730	739, 624	10. 57		
Madison	Madison, West Lode, and Perkins fissures.	1856–1881	72, 091				
Manhattan	Medora fissure	1863	10, 000				
Mass		1857–1901	6, 222, 015				
		1902–1919	44, 394, 862	2, 986, 136	14. 87		
Mesnard	"Mesnard" epidote	1863–1877	84, 095				
Michigan	Branch vein	1902–1912	[a] 9, 174, 108				
	Calico amygdaloid	1900–1913	[a] 8, 006, 420				
	Evergreen series	1916–1920	4, 065, 175				
Minesota	Minesota fissure	Prior to 1855–1885.	34, 706, 668			1, 820, 000	5. 24
Minong		1875–1883	498, 650				
Mohawk	Mohawkite	1900, 1901	[b] 230, 897				
	Kearsarge amygdaloid	1902–1925	259, 114, 348	14, 014, 050	18. 49	10, 750, 000	4. 15
New Arcadian	New Arcadian amygdaloid.	1915–1917	164, 794	10, 136	16. 26		
National	Minesota fissure	1853–1895	11, 612, 952			320, 000	2. 76
New York & Michigan.		1852	1, 800				
Nonesuch	Nonesuch	1868–1885	389, 556				
North American	North American fissure.	1849–1852	444, 640				
	Cliff fissure	1853–1859	1, 509, 163				
North Cliff	Cliff fissure	1859, 1864	5, 657				
Northwestern	Northwestern fissure	1852–1880	313, 005				
Norwich		1852–1869	993, 360				
Ogima		1857–1887	1, 138, 897				
Ohio Trap Rock		1853, 1858	41, 440				
Ojibway	Kearsarge amygdaloid	1911	49, 662	7, 448	6. 63		
Osceola	Calumet & Hecla conglomerate.	1874–1880, 1897–1903.	[a] 25, 056, 028	977, 928	25. 62	18, 044, 825	3. 78
	Kearsarge amygdaloid	1897–1920	[a] 261, 527, 694	16, 250, 345	16. 09		
	Osceola amygdaloid	1879–1920	[a] 190, 787, 393	9, 513, 943	20. 05		
Peninsula (Houghton County).	Allouez conglomerate	1883–1892	6, 624, 991				
Peninsula (Ontonagon County).		1851	4, 480				
Pennsylvania	Fissures	1849–1867	3, 034, 311				
Petherick	Ashbed amygdaloid	1862–1877	[c] 556, 424				
	Fissures	1862–1877	[c] 130, 000				
Pewabic	Pewabic amygdaloid	1855–1884	27, 823, 416			1, 000, 000	3. 60
Phoenix	Fissures	1846–1905	[a]16, 632, 536			20, 000	. 12
	Ashbed amygdaloid	1855–1862, 1865	[a] 357, 032				
		1916–17	449, 416	48, 063	9. 35		
Pittsburgh & Boston	Cliff fissure	1845–1870	33, 600, 216			2, 518, 620	7. 50
Pittsburgh & Isle Royale.		1849–1853	24, 730				
Portage		1853	6, 608				
Quincy	Pewabic amygdaloid	1856–1861	4, 505, 266				
		1862–1906	367, 124, 148	12, 897, 426	28. 46	27, 002, 500	3. 74
		1907–1910	85, 425, 417				
		1911–1925	268, 945, 488	14, 371, 072	18. 71		
Rhode Island	do	1903, 1906	31, 000				
Ridge		1853–1893	5, 443, 195			100, 000	1. 84
Rockland	Fissures	1854–1880	5, 821, 136				
Saginaw		1877, 1879	51, 264				
St. Clair	Fissures	1865–1885	1, 011, 071				
Schoolcraft	Calumet & Hecla conglomerate.	1869–1874	1, 882, 529				
Seneca	Kearsarge conglomerate.	1872–1878	17, 222				
	Kearsarge amygdaloid	1920–1925	3, 846, 163	165, 843	23. 19		
Shelden & Columbian.	Isle Royale amygdaloid.	1864–1884	1, 463, 336				

[a] Based partly on estimates.
[b] Pounds of mohawkite.
[c] Assumed.

Statistics of copper production in Michigan copper district, 1845–1925, by companies—Continued

Company	Lode	Period	Copper (pounds)	Rock treated (tons)	Yield per ton (pounds)	Dividends: Total	Dividends: Per pound (cents)
Siskowit		1849–1853	190, 736				
South Lake		1915–1918	1, 042, 211	80, 075	13. 02		
South Pewabic	Atlantic amygdaloid	1866–1870	3, 562, 967				
Star	Fissures	1855–1881	17, 938				
Superior (Houghton County).	Superior amygdaloid	1908–1920	30, 018, 271	1, 550, 474	19. 36	$649, 000	2. 16
Superior (Ontonagon County).		1858–1879	525, 880				
Tamarack	Calumet & Hecla conglomerate.	1882–1883	7, 798				
		1885–1917	[a] 379, 971, 101	13, 591, 141	28. 64	9, 420, 000	2. 48
	Osceola amygdaloid	1885–1917	[a] 9, 237, 000				
Tamarack Junior	Calumet & Hecla conglomerate.	1892–1896	9, 462, 191				
Tecumseh	Kearsarge amygdaloid	1906	59, 874				
Toltec		1853–1866	379, 153				
Trimountain	Baltic amygdaloid	1902–1923	139, 697, 289	6, 703, 079	20. 84	3, 250, 000	2. 33
Victoria		1863–1878, 1904	124, 721				
		1906–1921	19, 567, 792	1, 700, 518	11. 51		
Vulcan		1864	613				
White Pine	Nonesuch	1915–1920	18, 233, 169	887, 654	20. 54	33, 437. 50	. 18
Windsor		Prior to 1856	68, 000				
Winona		1902–1919	16, 497, 396	1, 207, 471	13. 66		
		[b] 1918, 1920	1, 186, 838				
Wolverine	Kearsarge amygdaloid	1882–1886	1, 979, 378			10, 350, 000	5. 48
		1891–1925	186, 817, 729	8, 468, 263	22. 06		
Wyandot		1916–17	39, 973	2, 927	13. 66		
			7, 516, 504, 197	251, 320, 142		335, 969, 044. 46	
Total production, omitting figures for which no corresponding tonnages are given:							
Including copper reclaimed from sands			7, 031, 648, 114	251, 320, 142	27. 98		
Not including copper reclaimed from sands			6, 903, 961, 190	251, 320, 142	27. 47		
Total dividends						335, 969, 044. 46	
Duplication (estimated dividends paid from dividends received from other companies [c]).						39, 042, 578. 00	
Estimated dividends paid from actual mining operations						297, 266, 466. 46	3. 95

[a] Based partly on estimates. [b] Tribute copper for 1918. [c] Calumet & Hecla, $12,550,704; Copper Range (estimated), $26,491,874.

Production and dividends from principal lodes, 1845–1925

Lode	Refined copper (pounds): Total	Refined copper (pounds): Per ton	Dividends: Total	Dividends: Per pound of copper (cents)
Calumet & Hecla conglomerate	3, 375, 300, 000	[a] 51. 26	[b] $148, 726, 051	4. 41
Kearsarge amygdaloid	1, 176, 900, 000	19. 14	[b] 50, 882, 000	4. 32
Pewabic amygdaloid	873, 700, 000	23. 11	29, 242, 500	3. 35
Baltic amygdaloid	873, 000, 000	26. 91	43, 004, 032	4. 93
Osceola amygdaloid	416, 400, 000	16. 75	[b] 14, 789, 825	3. 55
Isle Royale amygdaloid	210, 800, 000	[c] 16. 39	2, 550, 000	1. 21
Atlantic amygdaloid	142, 800, 000	13. 55	990, 000	. 69
Allouez conglomerate	69, 500, 000	[d] 11. 29	None.	
Evergreen and succeeding lodes	66, 500, 000	10 to 20	None.	
Superior amygdaloid	30, 500, 000	19. 04	649, 000	1. 12
Forest ("Victoria") amygdaloid	20, 000, 000	11. 55	None.	
Nonesuch lode	18, 200, 000	20. 54	33, 437	. 18
Lake amygdaloid	7, 300, 000	20. 62	None.	

[a] Includes copper recovered from tailings. [b] Estimated. [c] Average 1901–1925 only. [d] Franklin Jr. mine only.

Production and dividends in Michigan copper district, 1845–1925, by lodes and mines

Calumet & Hecla conglomerate

Mine	Company	Period	Production: Rock treated (tons)	Refined copper (pounds): Total	Refined copper (pounds): Per ton	Dividends: Total	Dividends: Per pound (cents)
Conglomerate	Centennial Copper Mining	1869–1882		1, 966, 083			
		1897–1898	6, 285	119, 190	18. 96		
Conglomerate	Tamarack Mining	1885–1917		379, 971, 101			
Conglomerate Branch.	Calumet & Hecla: Mine	1866–1925	57, 229, 052	2, 831, 092, 153	49. 47	[a] $148, 726, 051	4. 44
	Reclamation plant	1915–1925	12, 374, 823	127, 686, 924	10. 32		
Conglomerate Branch.	Osceola Mining	1873–1880	358, 450	12, 652, 028	35. 30		
Tamarack Junior	Tamarack Junior Mining	1892–1896		9, 462, 191			
	Osceola Consolidated Mining	1897–1902	619, 478	12, 404, 000	20. 02		
				3, 375, 353, 670		[a] 148, 726, 051	4. 41
Total production, omitting figures for which no corresponding tonnages are given:							
Mine production			58, 213, 265	2, 856, 267, 371	49. 07		
Including copper reclaimed from sands			58, 213, 265	2, 983, 954, 295	51. 26		

Kearsarge amygdaloid

Mine	Company	Period	Rock treated (tons)	Refined copper: Total	Per ton	Dividends: Total	Per pound (cents)
Ahmeek	Ahmeek, Allouez, Calumet & Hecla, Centennial, Kearsarge, and Osceola.	1887–1925		16, 795, 681		[a] $29, 782, 000	4. 11
			10, 801, 252	241, 492, 186	22. 36		
Allouez			4, 918, 843	82, 222, 989	16. 72		
Centennial			2, 261, 890	33, 033, 675	14. 60		
Kearsarge Branch			2, 331, 524	67, 351, 569	28. 89		
North Kearsarge				21, 237			
			10, 344, 447	160, 862, 279	15. 55		
South Kearsarge			6, 427, 605	115, 156, 251	17. 91		
Gratiot	Gratiot Mining	1910–1920	30, 315	313, 848	10. 35		
LaSalle	LaSalle Copper	1910–1920	739, 624	7, 814, 730	10. 57		
Mohawk	Mohawk Mining	1902–1925	14, 014, 050	259, 114, 348	18. 49	10, 750, 000	4. 15
Ojibway	Ojibway Mining	1911	7, 448	49, 662	6. 63		
Seneca	Seneca Copper Corporation	1920–1924	148, 530	3, 561, 922	23. 98		
	Seneca Copper Mining	1925	17, 313	284, 241	16. 42		
Wolverine	Wolverine Copper Mining	1882–1886		1, 979, 378		10, 350, 000	5. 48
		1891–1925	8, 468, 263	186, 817, 729	22. 06		
				1, 176, 871, 725		50, 882, 000	4. 30
Total production, omitting figures for which no corresponding tonnages are given.			60, 511, 104	1, 158, 075, 429	19. 14		

Pewabic amygdaloid

Mine	Company	Period	Rock treated (tons)	Refined copper: Total	Per ton	Dividends: Total	Per pound (cents)
Albany & Boston	Albany & Boston Mining	1862–1864		14, 982			
Franklin	Franklin Mining	1857–1860		669, 981		$1, 240, 000	1. 03
		1861–1870	457, 450	14, 329, 231	31. 32		
		1871–1883		24, 656, 624			
Franklin; Franklin Junior	do	1883–1919	[a] 3, 888, 462	[a] 80, 186, 631	[a] 20. 62		
Pewabic	Pewabic Mining	1855–1884		27, 823, 416		1, 000, 000	3. 60
Quincy	Quincy Mining	1856–1861		4, 505, 266			
		1862–1906	12, 897, 426	367, 124, 148	28. 46	27, 002, 500	3. 74
		1907–1910		85, 425, 417			
		1911–1925	14, 371, 072	268, 945, 488	18. 71		
Rhode Island	Rhode Island Copper	1903, 1906		31, 000			
				873, 712, 184		29, 242, 500	3. 55
Total production omitting figures for which no corresponding tonnages are given.			31, 614, 410	730, 585, 498	23. 11		

Baltic amygdaloid

Mine	Company	Period	Rock treated (tons)	Refined copper: Total	Per ton	Dividends: Total	Per pound (cents)
Baltic	Baltic Mining	1898–1916	8, 672, 553	200, 584, 164	23. 13	$7, 950, 000	3. 96
	Copper Range	1917–1925	1, 820, 612	62, 939, 547	34. 57	[a] 2, 084, 772	3. 23
Trimountain	Copper Range	1924–1925	43, 624	1, 343, 303	30. 79		
	Trimountain Mining	1902–1923	6, 703, 079	139, 697, 289	20. 84	3, 250, 000	2. 33
Champion	Champion Copper	1902–1925	14, 156, 309	438, 403, 286	30. 97	29, 070, 261	6. 75
Superior	Superior Copper	1908–1920	1, 550, 474	30, 018, 271	19. 36	649, 000	2. 16
Houghton	Houghton Copper	1915–1917	49, 729	540, 052	10. 86		
			32, 996, 380	873, 525, 912	26. 50	43, 004, 033	4. 93

[a] Estimated.

Production and dividends in Michigan copper district, 1845–1925, by lodes and mines—Continued

Osceola amygdaloid

Mine	Company	Period	Production: Rock treated (tons)	Refined copper (pounds): Total	Refined copper (pounds): Per ton	Dividends: Total	Dividends: Per pound (cents)
Osceola Branch	Calumet & Hecla	1904–1925	14, 598, 914	213, 817, 584	14. 65	[a] $14, 789, 825	3. 63
Osceola Branch	Centennial Copper Mining	1891	28, 531	531, 983	18. 64		
		1892		106, 801			
		1897–1900	153, 662	1, 917, 901	12. 48		
Osceola	Osceola Consolidated	1897–1923	9, 513, 943	190, 787, 393	20. 05		
Osceola Branch	Tamarack Mining			[a] 9, 237, 000			
				416, 398, 662		[a] 14, 789, 825	3. 55
Total production omitting figures for which no corresponding tonnages are given.			24, 295, 050	407, 054, 861	16. 75		

Isle Royale amygdaloid

Mine	Company	Period	Rock treated (tons)	Refined copper: Total	Per ton	Dividends: Total	Per pound (cents)
Grand Portage	Grand Portage Mining	1863–1884		3, 529, 822			
Huron	Huron Mining	1855–1893		25, 309, 270			
Isle Royale	Isle Royale Mining	1853–1885		8, 818, 194			
	Isle Royale Copper	1901–1925	10, 469, 751	171, 718, 963	16. 39	$2, 550, 000	1. 48
Shelden & Columbian.	Shelden & Columbian Copper.	1864–1884		1, 463, 336			
				210, 839, 585		$2, 550, 000	1. 21

Ashbed (=Atlantic) amygdaloid

Mine	Company	Period	Rock treated (tons)	Refined copper: Total	Per ton	Dividends: Total	Per pound (cents)
Arnold	Arnold Mining	1898–1900		1, 772, 231			
Ashbed	Ashbed Mining	1881–1884		[b] 78, 957			
Atlantic	Atlantic Mining	1873–1910	8, 714, 452	118, 282, 028	13. 57	$990, 000	0. 84
Copper Falls	Copper Falls Mining	1858–1893		[a] 17, 706, 352			
Garden City	Garden City Mining	1859–1866		75, 397			
Petherick	Petherick Mining	1862–1877		[b] 556, 424			
Phoenix	Phoenix Copper	1855–1862, 1865		[a] 357, 032			
	Phoenix Consolidated Copper.	1916–1917	48, 063	449, 416	9. 35		
South Pewabic	South Pewabic Mining	1866–1870		3, 562, 967			
				142, 840, 804		990, 000	. 69
Total production omitting figures for which no corresponding tonnages are given.			8, 762, 515	118, 731, 444	13. 55		

Allouez conglomerate

Mine	Company	Period	Rock treated (tons)	Refined copper: Total	Per ton	Dividends: Total	Per pound (cents)
Albany & Boston	Albany & Boston Mining	1865–1882		861, 057			
Allouez	Allouez Mining	1869–1892		25, 786, 651			
Delaware	Conglomerate Mining	1882–1885		1, 770, 570			
Franklin Junior	Franklin Mining	1901–1919	[a] 3, 053, 240	[a] 34, 473, 984	[a] 11. 29		
Peninsula	Peninsula Mining	1883–1892		6, 624, 991			
				69, 521, 253			None.

Nonesuch lode

Mine	Company	Period	Rock treated (tons)	Refined copper: Total	Per ton	Dividends: Total	Per pound (cents)
Nonesuch	Nonesuch	1868–1885		389, 556			
White Pine	White Pine Copper	1915–1920	887, 654	18, 233, 169	20. 54	33, 437. 50	0. 18
				18, 622, 725	20. 54	33, 437. 50	0. 18

[a] Estimated. [b] Assumed.

Production and dividends from fissures in Michigan copper districts, 1845–1925

Fissure	Mine	Period	Refined copper (pounds)	Dividends: Total	Dividends: Per pound (cents)
Minesota	Minesota	Prior to 1855–1885	34, 707, 000	$1, 820, 000	5. 24
	National	1853–1895	11, 613, 000	320, 000	2. 76
	Michigan, Branch	1902–1912	[a] 9, 174, 000		
	Rockland	1854–1880	5, 821, 000		
			61, 315, 000		
Central	Central	1855–1898	51, 875, 000	2, 130, 000	4. 11
Cliff	Cliff	1845–1887	38, 207, 000	2, 518, 620	6. 59
	South Cliff	1853–1859	1, 509, 000		
	North Cliff	1859, 1864	6, 000		
			39, 722, 000		
Phoenix	Phoenix	1846–1905	[a] 16, 633, 000	20, 000	. 12
	Bay State	1865–1867	399, 000		
			[a] 17, 032, 000		
Mass	Ahmeek	1909–1925	[a] 11, 567, 000	([b])	
	Copper Falls	1847–1882	[a] 8, 634, 000	100, 000	1. 16
	Delaware	1846–1887	5, 418, 000		
Drexel	Amygdaloid	1862–1878	1, 541, 000		
St. Clair	St. Clair	1865–1885	1, 011, 000		
North American	North American	1849–1852	445, 000		
Northwestern	Northwestern	1852–1880	313, 000		
Mohawkite	Mohawk	1900–1901	[c] 230, 000		
	Clark	1872–1879	188, 000		
	Aetna	1864–1873	141, 000		
Copper Falls	Petherick	1862–1877	[d] 130, 000		
Connecticut	Connecticut	Prior to 1860	117, 000		
Madison, West Lode, Perkins	Madison	1856–1881	72, 000		
Babbitt	Eagle River	1853–1867	50, 000		
Copper Falls	Ashbed	1881–1884	[d] 20, 000		
	Star	1855–1881	18, 000		
Medora	Manhattan	1863	10, 000		
	Lac LaBelle	Prior to 1850	3, 000		
Fulton	Forsyth	1853	1, 000		
			199, 853, 000	$6, 908, 620	3. 46

[a] Estimated. [b] Not separated from Kearsarge lode. [c] Pounds of mohawkite. [d] Assumed.

Dividends paid in Michigan copper district, 1845–1925

Company	Period	Dividends	Company	Period	Dividends
Ahmeek	1911–1923	$14, 050, 000	Pewabic	1862–1895	$1, 000, 000
Allouez	1915–1919	2, 850, 000	Phoenix	1877	20, 000
Atlantic	1878–1905	990, 000	Pittsburgh & Boston	1849–1879	2, 518, 620
Baltic	1905–1913	7, 950, 000	Quincy	1862–1920	27, 002, 500
Calumet & Hecla	1869–1925	[a] 160, 963, 755	Ridge	1873–1881	100, 000
Centennial	1916–1918	360, 000	Superior	1916–1922	649, 000
Central	1864–1905	2, 130, 000	Tamarack	1888–1907	9, 420, 000
Champion	1903–1925	29, 070, 260. 96	Trimountain	1903–1919	3, 250, 000
Copper Falls	1864–1871	100, 000	White Pine	1917–1918	33, 437. 50
Copper Range	1905–1925	[b] 28, 576, 646	Wolverine	1898–1920	10, 350, 000
Franklin	1863–1894	1, 240, 000			
Isle Royale	1913–1925	2, 550, 000			335, 969, 044. 46
Kearsarge	1890–1897	160, 000			
Minesota	1854–1876	1, 820, 000	Duplication (estimated dividends paid from dividends received from other companies [c])		39, 042, 578. 00
Mohawk	1906–1925	10, 750, 000			
National	1861–1872	320, 000	Estimated dividends paid from actual mining operations		297, 226, 466. 46
Osceola	1878–1923	18, 044, 825			

[a] Includes $12,550,704 received from other companies.
[b] Includes $26,491,874 estimated dividends received from other companies.
[c] Calumet & Hecla, $12,550,704; Copper Range (estimated), $26,491,874.

Dividends paid in Michigan copper district, 1845–1925, by companies and years

Ahmeek

[All from workings on Kearsarge lode]

Year	Number	Amount
1911	1	$100, 000. 00
1912	4	900, 000. 00
1913	4	1, 100, 000. 00
1914	3	300, 000. 00
1915	3	1, 150, 000. 00
1916	4	2, 500, 000. 00
1917	4	3, 200, 000. 00
1918	5	2, 000, 000. 00
1919	3	600, 000. 00
1920	3	300, 000. 00
1922	2	400, 000. 00
1923	------	500, 000. 00; [a] 1, 000, 000. 00
	------	14, 050, 000. 00

Allouez

[All from workings on Kearsarge lode]

Year	Number	Amount
1915	1	$100, 000. 00
1916	4	700, 000. 00
1917	4	1, 200, 000. 00
1918	5	750, 000. 00
1919	1	100, 000. 00
	15	2, 850, 000. 00

Atlantic

[All from workings on Atlantic (Ashbed) amygdaloid]

Year	Number	Amount
1878	------	$20, 000. 00
1880	------	40, 000. 00
1882	------	80, 000. 00
1883	------	80, 000. 00
1884	------	40, 000. 00
1885	------	20, 000. 00
1886	------	40, 000. 00
1887	------	40, 000. 00
1888	------	120, 000. 00
1889	------	80, 000. 00
1890	------	100, 000. 00
1891	------	40, 000. 00
1897	------	40, 000. 00
1898	([b])	40, 000. 00
1900	------	80, 000. 00
1901	------	80, 000. 00
1905	------	50, 000. 00
	------	990, 000. 00

Baltic

[All from workings on Baltic lode]

Year	Number	Amount
1905	------	$1, 250, 000. 00
1906	------	1, 400, 000. 00
1907	------	1, 000, 000. 00
1908	------	900, 000. 00
1909	------	1, 000, 000. 00
1910	------	1, 000, 000. 00
1911	------	500, 000. 00
1912	------	700, 000. 00
1913	------	200, 000. 00
	------	7, 950, 000. 00

[a] Liquidating. [b] 16 dividends to 1898.

Calumet & Hecla

CALUMET MINING

Year	Number	Amount
1870	2	$200, 000. 00
1871	1	100, 000. 00
	3	300, 000. 00

HECLA MINING

Year	Number	Amount
1869	1	$100, 000. 00
1870	3	300, 000. 00
1871	3	250, 000. 00
	7	650, 000. 00

CALUMET & HECLA MINING

Year	Number	Amount
1871	------	$900, 000. 00
1872	------	2, 400, 000. 00
1873	------	2, 000, 000. 00
1874	------	1, 600, 000. 00
1875	------	1, 600, 000. 00
1876	------	1, 600, 000. 00
1877	------	1, 600, 000. 00
1878	------	1, 600, 000. 00
1879	------	1, 600, 000. 00
1880	------	2, 500, 000. 00
1881	------	2, 000, 000. 00
1882	------	2, 000, 000. 00
1883	------	2, 000, 000. 00
1884	------	800, 000. 00
1885	------	1, 700, 000. 00
1886	------	1, 500, 000. 00
1887	------	1, 000, 000. 00
1888	------	2, 000, 000. 00
1889	------	1, 500, 000. 00
1890	------	2, 000, 000. 00
1891	------	2, 000, 000. 00
1892	------	2, 000, 000. 00
1893	------	2, 000, 000. 00
1894	------	1, 500, 000. 00
1895	------	2, 000, 000. 00
1896	------	2, 500, 000. 00
1897	------	4, 000, 000. 00
1898	------	5, 000, 000. 00
1899	------	10, 000, 000. 00
1900	------	7, 000, 000. 00
1901	3	4, 500, 000. 00
1902	4	2, 500, 000. 00
1903	4	3, 500, 000. 00
1904	4	4, 000, 000. 00
1905	4	5, 000, 000. 00
1906	4	7, 000, 000. 00
1907	4	6, 500, 000. 00
1908	4	2, 000, 000. 00
1909	4	2, 700, 000. 00
1910	4	2, 900, 000. 00
1911	4	2, 400, 000. 00
1912	4	4, 200, 000. 00
1913	4	3, 200, 000. 00
1914	2	1, 000, 000. 00
1915	4	5, 000, 000. 00
1916	4	7, 500, 000. 00
1917	4	8, 500, 000. 00
1918	4	5, 500, 000. 00
1919	2	1, 000, 000. 00
1920	1	500, 000. 00
1922	2	1, 000, 000. 00
1923	3	2, 700, 000. 00
	[c] 194	155, 000, 000. 00

[c] Includes 117 to 1900.

CALUMET & HECLA CONSOLIDATED COPPER

Year	Number	Amount
1923	1	$1, 002, 751. 00
1924	1	1, 002, 751. 00
1925	3	3, 008, 253. 00
	5	5, 013, 755. 00

SUMMARY

Calumet Mining Co	$300, 000
Hecla Mining Co	650, 000
Calumet & Hecla Mining Co	155, 000, 000
Calumet & Hecla Consolidated Copper Co	5, 013, 755
Paid by Calumet & Hecla	160, 963, 755
Received from other companies	12, 550, 704
Paid from its own mining operations	148, 413, 051

Centennial

[All from workings on Kearsarge lode]

Year	Number	Amount
1916	1	$90, 000. 00
1917	1	90, 000. 00
1918	2	180, 000. 00
	4	360, 000. 00

Central

[All from fissure workings]

Year	Number	Amount
1864	1	$50, 000. 00
1865	1	50, 000. 00
1866	1	50, 000. 00
1867	1	50, 000. 00
1868	1	40, 000. 00
1869	1	70, 000. 00
1870	1	80, 000. 00
1871	1	50, 000. 00
1872	1	80, 000. 00
1873	1	160, 000. 00
1874	1	160, 000. 00
1875	1	80, 000. 00
1876	1	100, 000. 00
1877	1	140, 000. 00
1878	1	100, 000. 00
1879	1	80, 000. 00
1880	1	100, 000. 00
1881	2	120, 000. 00
1882	1	50, 000. 00
1883	1	60, 000. 00
1884	1	40, 000. 00
1885	1	30, 000. 00
1886	1	40, 000. 00
1887	1	40, 000. 00
1888	2	70, 000. 00
1889	1	40, 000. 00
1890	1	20, 000. 00
1891	1	20, 000. 00
1905	------	160, 000. 00
	------	2, 130, 000. 00

Dividends paid in Michigan copper district, 1845–1925, by companies and years—Continued

Champion

[All from workings on Baltic lode]

Year	Number	Amount
1903	------	$300, 000. 00
1904	------	200, 000. 00
1905	------	1, 000, 000. 00
1906	------	1, 200, 000. 00
1907	------	1, 000, 000. 00
1908	------	500, 000. 00
1909	------	800, 000. 00
1910	------	900, 000. 00
1911	------	500, 000. 00
1912	------	1, 100, 000. 00
1913	------	900, 000. 00
1915	------	3, 100, 000. 00
1916	------	6, 014, 540. 96
1917	------	4, 480, 000. 00
1918	------	1, 975, 720. 00
1919	------	1, 280, 000. 00
1920	------	600, 000. 00
1922	------	600, 000. 00
1923	------	700, 000. 00
1924	------	780, 000. 00
1925	------	1, 140, 000. 00
	------	29, 070, 260. 96

Copper Falls

[All from fissure workings]

Year	Number	Amount
1864	1	$60, 000. 00
1871	2	40, 000. 00
	3	100, 000. 00

Copper Range

Year	Number	Amount
1905	------	$1, 536, 086. 00
1906	------	2, 304, 810. 00
1907	------	2, 304, 810. 00
1908	------	1, 536, 740. 00
1909	------	1, 536, 930. 00
1910	------	1, 537, 340. 00
1911	------	1, 357, 104. 00
1912	------	788, 428. 50
1913	------	1, 084, 498. 00
1915	------	1, 182, 003. 00
1916	------	3, 941, 648. 00
1917	------	3, 943, 912. 50
1918	------	2, 366, 394. 00
1919	------	986, 015. 50
1920	------	591, 625. 50
1922	------	394, 422. 00
1923	------	394, 425. 00
1924	------	394, 727. 00
1925	------	394, 727. 00
	------	28, 576, 646. 00
Estimated dividends received from other companies	------	26, 491, 874. 00
Estimated dividends paid from its own mining operations	------	2, 084, 772. 00

Franklin

[All from workings on Pewabic lode]

Year	Number	Amount
1863	------	$60, 000. 00
1864	------	100, 000. 00
1865	------	60, 000. 00
1871	------	20, 000. 00
1872	------	40, 000. 00
1884	------	80, 000. 00
1885	------	40, 000. 00
1886	------	80, 000. 00
1887	------	40, 000. 00
1888	------	120, 000. 00
1889	------	80, 000. 00
1890	------	80, 000. 00
1891	------	80, 000. 00
1892	------	160, 000. 00
1893	------	120, 000. 00
1894	------	80, 000. 00
	21	1, 240, 000. 00

Isle Royale

[All from workings on Isle Royale lode]

Year	Number	Amount
1913	1	$150, 000. 00
1916	2	450, 000. 00
1917	4	900, 000. 00
1918	5	375, 000. 00
1919	2	150, 000. 00
1922	2	150, 000. 00
1923	3	225, 000. 00
1925	1	150, 000. 00
	20	2, 550, 000. 00

Kearsarge

[All from workings on Kearsarge lode]

Year	Number	Amount
1890	------	$80, 000. 00
1895	------	40, 000. 00
1897	------	40, 000. 00
	------	160, 000. 00

Minesota

[All from fissure workings]

Year	Number	Amount
1854	------	$90, 000. 00
1855	------	90, 000. 00
1856	------	200, 000. 00
1857	------	300, 000. 00
1858	------	300, 000. 00
1859	------	180, 000. 00
1860	------	120, 000. 00
1861	------	100, 000. 00
1862	------	160, 000. 00
1863	------	160, 000. 00
1864	------	60, 000. 00
1872	------	50, 000. 00
1876	------	10, 000. 00
	19	1, 820, 000. 00

Mohawk

[All from workings on Kearsarge lode]

Year	Number	Amount
1906	2	$500, 000. 00
1907	2	900, 000. 00
1908	1	250, 000. 00
1909	2	300, 000. 00
1910	2	200, 000. 00
1911	2	175, 000. 00
1912	2	350, 000. 00
1913	2	500, 000. 00
1914	1	100, 000. 00
1915	2	600, 000. 00
1916	2	1, 700, 000. 00
1917	3	2, 050, 000. 00
1918	3	1, 000, 000. 00
1919	4	500, 000. 00
1920	4	550, 000. 00
1922	3	300, 000. 00
1923	3	315, 000. 00
1925	4	460, 000. 00
	44	10, 750, 000. 00

National

[All from fissure workings]

Year	Number	Amount
1861	2	$80, 000. 00
1862	2	80, 000. 00
1864	2	80, 000. 00
1865	1	40, 000. 00
1871	1	20, 000. 00
1872	1	20, 000. 00
	9	320, 000. 00

Osceola

Year	Number	Amount
1878	1	$40, 000. 00
1879	1	60, 000. 00
1880	3	210, 000. 00
1881	3	225, 000. 00
1882	4	200, 000. 00
1883	4	150, 000. 00
1884	4	87, 500. 00
1887	1	50, 000. 00
1888	3	150, 000. 00
1889	1	50, 000. 00
1890	4	225, 000. 00
1891	3	150, 000. 00
1892	3	150, 000. 00
1893	2	100, 000. 00
1895	2	100, 000. 00
1896	2	125, 000. 00
1897	3	191, 000. 00
1898	2	277, 250. 00
1899	2	558, 450. 00
1900	2	571, 200. 00
1901	2	576, 900. 00
1904	2	192, 300. 00
1905	2	384, 600. 00
1906	2	961, 500. 00
1907	2	1, 249, 950. 00
1908	1	192, 300. 00
1909	2	769, 200. 00
1910	2	961, 500. 00
1911	2	721, 125. 00
1912	3	1, 201, 875. 00
1913	4	1, 009, 575. 00

Dividends paid in Michigan copper district, 1845–1925, by companies and years—Continued

Osceola—Continued

Year	Number	Amount
1914	3	$288, 450. 00
1915	3	769, 200. 00
1916	4	1, 538, 400. 00
1917	4	1, 923, 000. 00
1918	5	961, 500. 00
1919	3	288, 450. 00
1920	2	96, 150. 00
1922	2	192, 300. 00
1923	1	96, 150. 00
	101	18, 044, 825. 00

Pewabic

Year	Number	Amount
1862	1	$60, 000. 00
1863	2	120, 000. 00
1864	2	200, 000. 00
1871	1	20, 000. 00
1872	2	40, 000. 00
1873	1	20, 000. 00
1893 [d]	------	400, 000. 00
1895 [d]	------	140, 000. 00
	------	1, 000, 000. 00

Phoenix

Year	Number	Amount
1877	1	$20, 000. 00

Pittsburgh & Boston

[All from workings on Cliff fissure]

Year	Number	Amount
1849	1	$60, 000. 00
1850	2	84, 000. 00
1851	2	60, 000. 00
1852	2	60, 000. 00
1853	2	90, 000. 00
1854	2	108, 000. 00
1855	2	78, 000. 00
1856	2	180, 000. 00
1857	2	180, 000. 00
1858	2	160, 000. 00
1859	2	180, 000. 00
1861	2	80, 000. 00
1862	2	80, 000. 00
1863	2	180, 000. 00
1864	2	320, 000. 00
1865	2	200, 000. 00
1866	2	120, 000. 00
1867	1	60, 000. 00
1871 [d]	1	100, 000. 00
1872 [d]	1	100, 000. 00
1879 [d]	1	38, 620. 00
	37	2, 518, 620. 00

Quincy

Year	Number	Amount
1862	1	$60, 000. 00
1863	2	200, 000. 00
1864	2	280, 000. 00
1865	1	160, 000. 00
1868	1	60, 000. 00
1869	1	40, 000. 00
1870	1	120, 000. 00
1871	2	140, 000. 00
1872	2	350, 000. 00
1873	1	100, 000. 00
1874	1	160, 000. 00

[d] In liquidation.

Quincy—Continued

Year	Number	Amount
1875	2	$220, 000. 00
1876	2	160, 000. 00
1877	1	80, 000. 00
1878	1	100, 000. 00
1879	1	40, 000. 00
1880	2	220, 000. 00
1881	2	320, 000. 00
1882	2	520, 000. 00
1883	2	380, 000. 00
1884	2	280, 000. 00
1885	2	180, 000. 00
1886	2	240, 000. 00
1887	2	200, 000. 00
1888	2	360, 000. 00
1889	2	280, 000. 00
1890	2	320, 000. 00
1891	2	450, 000. 00
1892	2	350, 000. 00
1893	2	300, 000. 00
1894	2	400, 000. 00
1895	2	400, 000. 00
1896	5	1, 200, 000. 00
1897	2	800, 000. 00
1898	2	650, 000. 00
1899	2	950, 000. 00
1900	2	900, 000. 00
1901	2	900, 000. 00
1902	2	700, 000. 00
1903	2	550, 000. 00
1904	2	500, 000. 00
1905	2	600, 000. 00
1906	4	1, 250, 000. 00
1907	4	1, 485, 000. 00
1908	4	495, 000. 00
1909	4	440, 000. 00
1910	4	550, 000. 00
1911	4	440, 000. 00
1912	4	550, 000. 00
1913	3	412, 500. 00
1914	1	55, 000. 00
1915	4	880, 000. 00
1916	4	1, 760, 000. 00
1917	4	1, 980, 000. 00
1918	4	935, 000. 00
1919	4	440, 000. 00
1920	1	110, 000. 00
	130	27, 002, 500. 00

NOTE.—Copper Handbook, 1922, says: "Year 1918 marked Quincy's seventieth anniversary. During this time it paid its stockholders $26,452,500 in dividends and still had $2,803,124 cash surplus: this is equivalent to a profit of 4⅓ cents on each of 613,596,622 pounds copper produced, and sold at an average price for the entire 70 years of 16.13 cents, equal to $98,973,406."

Ridge

Year	Number	Amount
1873	1	50, 000. 00
1874	1	20, 000. 00
1875	1	20, 000. 00
1881	1	10, 000. 00
	4	100, 000. 00

Superior

Year	Number	Amount
1916	------	100, 000. 00
1917	------	100, 000. 00
1922	------	[e] 200, 000. 00
1925	------	[f] 249, 000. 00
	------	649, 000. 00

[e] First liquidating. [f] Second liquidating.

Tamarack

Year	Number	Amount
1888	3	$440, 000. 00
1889	4	640, 000. 00
1890	4	590, 000. 00
1891	4	800, 000. 00
1892	3	600, 000. 00
1893	3	600, 000. 00
1894	2	400, 000. 00
1895	2	400, 000. 00
1896	2	360, 000. 00
1897	2	360, 000. 00
1898	2	480, 000. 00
1899	2	600, 000. 00
1900	2	1, 020, 000. 00
1901	2	1, 200, 000. 00
1904	1	90, 000. 00
1905	1	120, 000. 00
1906	2	300, 000. 00
1907	2	420, 000. 00
	43	9, 420, 000. 00

Trimountain

[All from workings on Baltic lode]

Year	Number	Amount
1903	------	$300, 000. 00
1908	------	500, 000. 00
1910	------	150, 000. 00
1912	------	300, 000. 00
1913	------	200, 000. 00
1918	------	500, 000. 00
1919	------	1, 300, 000. 00
	------	3, 250, 000. 00

White Pine

Year	Number	Amount
1917	------	$29, 062. 50
1918	------	4, 375. 00
	------	33, 437. 50

Wolverine

Year	Number	Amount
1898	1	$60, 000. 00
1899	2	210, 000. 00
1900	2	240, 000. 00
1901	2	240, 000. 00
1902	2	240, 000. 00
1903	2	330, 000. 00
1904	2	450, 000. 00
1905	2	660, 000. 00
1906	2	1, 020, 000. 00
1907	2	1, 050, 000. 00
1908	2	600, 000. 00
1909	2	600, 000. 00
1910	2	600, 000. 00
1911	2	540, 000. 00
1912	2	600, 000. 00
1913	1	300, 000. 00
1914	1	120, 000. 00
1915	2	540, 000. 00
1916	2	720, 000. 00
1917	3	810, 000. 00
1918	2	240, 000. 00
1919	4	150, 000. 00
1920	1	30, 000. 00
	45	10, 350, 000. 00

Detailed statistics of production in Michigan copper district, 1815-1925, by companies

[Definite information as to no production is indicated in the tables by the word "None." Years for which no information is available are omitted]

Adventure.—In Ontonagon County. Organized in 1850 as Adventure Mining Co.; 1,000 shares, $200,000. First company to introduce tribute system about 1855; proved profitable. In 1858 purchased property of the Merchants Co. Sold in 1870 and new company organized. No work done by company since 1877, although some work was done by tributers after that date. Adventure Consolidated Copper Co. organized in October, 1898; 100,000 shares at $25. Made up of Adventure, Hilton, and Knowlton mines. Worked Knowlton, Ogima, Merchant, Evergreen, Mass, and Butler lodes. Hilton, formerly Ohio, was opened 1863. Knowlton opened 1860, worked intermittently 1865-1900 by tributers.

Year	Rock treated (tons)	Refined copper (pounds)	
		Total	Per ton
1851		12, 478	
1852		29, 120	
1853		11, 988	
1854		[a] 14, 400	
1855		63, 253	
1856		146, 363	
1857		233, 941	
1858		115, 678	
1859		198, 431	
1860		42, 749	
1861		4, 676	
1862		22, 089	
1863		138, 124	
1864		1, 755	
1865		7, 491	
1866		4, 439	
1869		1, 154	
1870		2, 931	
1871		6, 391	
1872		17, 055	
1873		5, 345	
1874		6, 165	
1875		30, 470	
1876		40, 784	
1877		64, 609	
1878		54, 115	
1879		21, 785	
1880		2, 951	
1881		7, 500	
1882		429	
1884		4, 333	
1885		8, 436	
1886		985	
1889		694	
1890		15, 485	
1891		56, 008	
1900		23, 572	
1901		[b] 29, 361	
1902	42, 904	606, 211	14. 13
1903		[c] 2, 182, 608	
1904	97, 036	1, 380, 480	14. 23
1905	130, 895	1, 606, 208	12. 27
1906	136, 094	1, 552, 628	11. 41
1907		1, 244, 874	
1908		90, 870	
1916		19, 500	
1917 [d]		652, 977	
		10, 783, 889	

[a] Estimated.
[b] Sold.
[c] During first 4 months 66,410 tons stamped yielded 975,944 pounds refined copper.
[d] Mine closed October, 1917. Silver sold in 1918, $1,283.59.

Aetna.—In Keweenaw County. Organized January, 1864; 20,000 shares, $500,000.

Year	Refined copper (pounds)	Year	Refined copper (pounds)
1864	6, 857	1868	3, 389
1865	4, 131	1873	4, 650
1866	58, 996		
1867	62, 858		140, 881

Ahmeek.—In Keweenaw County. Incorporated March 22, 1880; capital $1,250,000, shares $25 par, paid in $17. Increased June 8, 1915, to $5,000,000, par $25, fully paid. In the change four new shares were given for each old share. Absorbed by Calumet & Hecla Consolidated Copper Co. September 1, 1923, one share of Ahmeek being given for 2.68 shares of Calumet & Hecla.

KEARSARGE AMYGDALOID

Year	Rock treated (tons)	Refined copper (pounds)	
		Total	Per ton
1903		None.	
1904	16, 400	376, 687	22. 97
1905	78, 360	1, 552, 957	19. 82
1906	166, 960	3, 077, 507	18. 43
1907	320, 733	5, 510, 985	17. 18
1908	298, 178	6, 280, 241	21. 06
1909	404, 385	8, 974, 585	22. 19
1910	528, 705	11, 621, 429	21. 98
1911	596. 889	14, 972, 602	25. 08
1912	650, 600	16, 232, 244	24. 95
1913	381, 459	8, 912, 214	23. 36
1914	586, 331	13, 071, 555	22. 29
1915	937, 548	20, 334, 718	21. 69
1916	1, 151, 002	22, 920, 313	19. 91
1917	1, 267, 592	27, 288, 657	21. 53
1918	1, 195, 158	24, 681, 483	20. 65
1919	750, 750	16, 559, 046	22. 06
1920	818, 263	19, 900, 682	24. 32
1921	212, 170	5, 742, 200	27. 06
1922	439, 769	13, 482, 081	30. 65
	10, 801, 252	241, 492, 186	22. 36

MASS FISSURE

Year	Rock treated (tons)	Total	Per ton
1909	1, 660	223, 525	134. 65
1910	1, 660	223, 525	134. 65
1911	1, 660	223, 525	134. 65
1912	1, 660	223, 525	134. 65
1913	2, 290	308, 660	134. 79
1914	4, 188	563, 050	134. 44
1915	11, 326	1, 465, 774	129. 42
1916	13, 008	1, 221, 845	93. 93
1917	3, 683	631, 155	171. 37
1918	1, 383	169, 752	122. 74
1919	6, 120	664, 065	108. 51
1920	3, 929	588, 756	149. 85
1921	342	513, 000	([a])
1922	914	1, 403, 000	([a])
		8, 423, 157	

[a] No rock from fissure stamped; entire production from masses. Percentage of copper, 1921, 75; 1922, 76.75.

TOTAL

Year	Rock stamped (tons)	Refined copper (pounds)		Silver sold
		Total	Per ton	
1903		None.		
1904	16, 400	376, 687	22. 97	
1905	78, 360	1, 552, 957	19. 82	
1906	166, 960	3, 077, 507	18. 43	
1907	320, 733	5, 510, 985	17. 18	
1908	298, 178	6, 280, 241	21. 1	
1909	406, 045	9, 198, 110	22. 7	
1910	530, 365	11, 844, 954	22. 33	
1911	598, 549	15, 196, 127	25. 4	
1912	652, 260	16, 455, 769	25. 2	
1913	383, 749	9, 220, 874	24. 0	
1914	590, 519	13, 634, 605	23. 1	$4, 025. 54
1915	948, 874	21, 800, 492	23. 0	14, 026. 50
1916	1, 164, 010	24, 142, 158	20. 7	16, 503. 60
1917	1, 271, 275	27, 919, 812	22. 0	16, 171. 37
1918	1, 196, 541	24, 851, 235	20. 8	
1919	756, 870	17, 223, 111	22. 8	
1920	822, 192	20, 489, 438	24. 9	
1921	212, 170	6, 255, 200	29. 48	
1922	439, 769	14, 885, 081	33. 85	
1923 [a]		17, 811, 031		
		267, 726, 374		

[a] To Aug. 31.

Albany & Boston.—In Houghton County. Organized June, 1860; 20,000 shares, $500,000. In spring of 1862 most of the work suspended in this location. Resumed late in 1862 and continued actively in 1863. Worked Pewabic amygdaloid. About 1864 worked “Albany & Boston” (Allouez) conglomerate. Sold to Peninsula Copper Mining Co. in 1882, and to Franklin Mining Co. in 1895; mine now known as Franklin Jr.

Year	Refined copper (pounds)	Year	Refined copper (pounds)
1862	7, 982	1873	66, 200
1864	7, 000	1876	6, 018
1865	[a] 318, 160	1877	11, 998
1866	163, 906	1878	1, 746
1867	62, 493		
1868	234, 536		880, 039

[a] During year ending March, 1866, produced and sold 271,200 pounds of ingot copper.

Albion.—See Manhattan.

Algomah.—In Ontonagon County. Algomah Mining Co. organized June 4, 1910. Worked 1852-1854 by a company of the same name with negative results. No rock milled. In 1914, 12,467 pounds of refined copper from hand-picked ore.

Allouez.—In Keweenaw County. Organized September, 1859. Little work done to 1869, when work began on Allouez conglomerate. Temporary suspension, and in 1871 work resumed to 1877. Leased to Allouez Tribute Co. for three years, November, 1877-1880. Company resumed control November 10, 1880, and at once began active operations. Reorganized with capital of 800,000 shares at $25 and worked to June 1, 1885, when it was leased to Watson & Walls for term of three years, but in 1887 property attached by creditors and work stopped. Company resumed control in 1889, and a reorganization was made. Absorbed by Calumet & Hecla Consolidated Copper Co. September 1, 1923.

ALLOUEZ CONGLOMERATE

Year	Rock treated (tons)	Refined copper (pounds)	
		Total	Per ton
1869		3, 575	
1873		21, 163	
1874		1, 008, 134	
1875		1, 385, 574	
1876		[a] 1, 561, 785	
1877		1, 300, 279	
1878		1, 131, 146	
1879		1, 431, 452	
1880		1, 318, 471	
1881	63, 362	1, 204, 224	19. 0
1882	97, 232	1, 683, 557	17. 3
1883	102, 388	1, 751, 377	17. 2
1884	119, 630	1, 932, 170	16. 2
1885		[b] 2, 170, 476	
1886	116, 612	1, 725, 463	14. 8
1887		885, 010	
1888		314, 198	
1889	116, 608	1, 762, 816	15. 1
1890	97, 020	1, 407, 828	14. 5
1891	96, 164	1, 241, 423	12. 9
1892		[c] 546, 530	
1893		None.	
		25, 786, 651	

[a] During year ending July 1, 1876, 51,135 tons stamped yielded 1,433,833 pounds refined copper.
[b] 62,500 tons stamped by company produced 1,050,546 pounds ingot, or 16.8 pounds per ton; tributers produced 1,119,930 pounds ingot.
[c] Sold.

KEARSARGE AMYGDALOID

Year	Rock treated (tons)	Refined copper (pounds)	
		Total	Per ton
1905	[a] 41, 120	1, 167, 957	28. 40
1906	[b] 178, 400	3, 486, 900	19. 54
1907	214, 720	2, 934, 116	13. 66
1908	220, 905	3, 047, 051	13. 80
1909	253, 049	4, 001, 532	15. 93
1910	247, 119	4, 655, 702	18. 84
1911	288, 610	4, 780, 494	16. 56
1912	333, 618	5, 525, 455	16. 56
1913	236, 663	4, 091, 129	17. 29
1914	354, 457	6, 056, 548	17. 09
1915	534, 705	10, 043, 459	18. 78
1916	566, 960	10, 219, 290	18. 02
1917[c]	566, 674	8, 892, 915	15. 69
1918	514, 888	7, 071, 218	13. 73
1919	235, 312	3, 749, 984	15. 94
1920	131, 643	2, 499, 239	18. 98
1921–1923		None.	
	4, 918, 843	82, 222, 989	16. 72

[a] Includes 4,895 tons from stock pile.
[b] Includes 108 tons from stock pile.
[c] Silver sold, $22,589.24.

Total production, 108,009,640 pounds.

American.—See North American.

Amygdaloid.—In Keweenaw County. Organized July, 1860; 20,000 shares, $500,000. Company operations suspended in 1866 and mine worked on tribute.

Year	Refined copper (pounds)	Silver sold (ounces)
1862	97, 591	374 ($558.50).
1863	138, 124	
1864	135, 795	152.
1865	418, 964	209 ($358.35).
1866	340, 668	
1867	161, 375	
1868	122, 694	
1869	33, 010	
1870	47, 610	
1873	28, 250	
1874	15, 840	
1878	1, 259	
	1, 541, 180	

Arcadian.—In Houghton County. Organized July, 1864; 20,000 shares, $500,000. Mining operations were not commenced until after September 1, 1864. Arcadian Copper Co. incorporated under laws of Michigan, June, 1898, with capital of $2,500,000; reincorporated under laws of New Jersey, 1899. Reorganized as NeW Arcadian Copper Co. April 27, 1909. Arcadian Consolidated formed January 1, 1920, taking over all property and effects of the New Arcadian and the New Baltic Copper companies; 250,000 shares, $6,250,000. Mineral lands comprise six old mines—the Arcadian, Edwards, Douglass, Concord, Highland, and St. Mary's.

ARCADIAN LODE

Year	Refined copper (pounds)	Year	Refined copper (pounds)
1864	4, 593	1900	1, 350, 000
1865	5, 816	1901	500, 000
1879	24, 760	1902	600, 000
1890	34, 037		
1899	500, 000		3, 019, 206

NEW ARCADIAN LODE

Year	Rock treated (tons)	Refined copper (pounds)	
		Total	Per ton
1915	3, 845	79, 209	20. 62
1916	1, 391	32, 307	23. 23
1917	4, 900	53, 278	10. 87
1918–1925		None.	
	10, 136	164, 794	16. 26

Total production, 3,184,000 pounds.

Arnold.—In Keweenaw County. Arnold operated in small way in 1860. Arnold mine proper, developed on Ashbed amygdaloid, was opened in 1863. Incorporated in April, 1864; 100,000 shares at $25. Two holdings, Copper Falls mine and Arnold; Copper Falls, absorbed 1898. Operated 1863 to about 1869; closed 1869-1892; active 1892-1894; idle 1894 to February, 1897, when work was resumed. Worked mostly on Ashbed.

Year	Refined copper (pounds)
1898	152, 320
1899	763, 911
1900	856, 000
	1, 772, 231

Ashbed.—In Keweenaw County. Petherick Mining Co. organized April, 1861, by Copper Falls Mining Co. Worked 1861-1865 and suspended operations; resumed in 1872; became idle again in 1877. In 1873 Indiana mill purchased. In 1877 property closed out at sheriff's sale. In 1880 Ashbed Mining Co. organized; 40,000 shares at $25. Work resumed in 1881 and discontinued in 1882, producing a few tons of copper. Between 1898 and 1900 exploratory work carried on; idle in 1900. In June, 1905, resumed activity.

Year	Rock treated (tons)	Refined copper (pounds)	
		Total	Per ton
1861	1, 392		
1862		31, 832	
1863		133, 183	
1864		51, 228	
1865		9, 169	
1866		None.	
1868		12, 000	
1869		None.	
1870		None.	
1872		10, 570	
1873		13, 348	
1874	5, 115	172, 291	33. 68
1875	4, 449	152, 946	34. 38
1876	5, 563	85, 224	15. 32
1877		14, 633	
1881		24, 804	
1882		72, 636	
1884		1, 517	
		785, 381	

Atlantic.—In Houghton County. Atlantic Mining Co-organized December 31, 1872, by consolidation of South Pewabitf and Adams mining companies; 40,000 shares at $25. (South Pewabic organized 1865; capital exhausted and sold to Atlantic. Started work 1865; began production 1866.) Mine closed by caving in May, 1906.

Year	Rock treated (tons)	Refined copper (pounds)	
		Total	Per ton
1866		13, 475	
1867		1, 760	
1868		1, 528, 258	
1869		1, 646, 857	
1870		372, 617	
1873	51, 048	863, 366	16. 91
1874	69, 728	1, 372, 406	19. 68
1875	80, 000	1, 567, 036	19. 58
1876	96, 696	1, 835, 041	18. 99
1877	105, 780	2, 054, 304	19. 42
1878	111, 709	2, 006, 075	18. 0
1879	122, 668	2, 339, 073	19. 1
1880	169, 825	2, 423, 225	14. 3
1881	176, 555	2, 528, 009	14. 36
1882	189, 800	2, 631, 708	13. 866
1883	195, 669	2, 682, 197	13. 71
1884	209, 510	3, 163, 585	15. 1
1885	241, 010	3, 582, 256	14. 86
1886	247, 035	3, 503, 670	14. 18
1887	255, 750	3, 641, 865	14. 24
1888	298, 055	3, 974, 972	13. 34
1889	278, 680	3, 698, 837	13. 27
1890	278, 300	3, 619, 972	13. 00
1891	297, 030	3, 653, 671	12. 3
1892	300, 900	3, 703, 875	12. 31
1893	315, 670	4, 221, 933	13. 37
1894	315, 626	4, 437, 609	14. 06
1895	331, 058	4, 832, 497	14. 6
1896	371, 128	4, 894, 228	13. 19
1897	394, 296	5, 109, 663	12. 96
1898	370, 767	4, 377, 399	11. 8
1899	380, 781	4, 675, 882	12. 28
1900	410, 674	4, 930, 149	12. 0
1901	409, 124	4, 666, 889	11. 4
1902	446, 098	4, 949, 366	11. 09
1903	431, 397	5, 505, 598	12. 76
1904	390, 526	5, 321, 859	13. 63
1905	295, 220	4, 049, 731	13. 63
1906	75, 000	1, 439, 082	19. 19
1908	420	[a] 10, 000	
1909	768	[a] 11, 000	
1910	151	[a] 4, 000	
		121, 844, 995	

[a] Estimated.

Aztec.—In Ontonagon County. First known as Aztec Mining Co. Reorganized in August, 1863; 20,000 shares, $500,000. In 1871 mine bought by P. T. Rogers, by whom it was sold to Doctor Hussey and a new company organized in July, 1880; 40,000 shares, $1,000,000. All work discontinued in July, 1882. Reincorporated in 1909 as South Lake Mining Co.

Year	Refined copper (pounds)	Year	Refined copper (pounds)
1852	3, 381	1870	25, 288
1853	10, 058	1871	13, 153
1854	2, 321	1872	11, 550
1855	3, 467	1874	13, 412
1856	51, 139	1875	16, 252
1857	29, 361	1876	27, 378
1858	6, 251	1877	29, 934
1859	18, 493	1878	23, 392
1860	6, 203	1879	16, 737
1865	8, 700	1880	5, 757
1866	32, 000	1881	1, 734
1867	80, 000	1882	3, 129
1868	72, 000		
1869	175, 267		686, 357

Baltic.—In Houghton County. Exploratory work was first done on the Baltic property in 1882, when the lode was exposed by test pits. Property was purchased from St. Mary's Canal Mineral Land Co. in November, 1897, and Baltic Mining Co. organized December, 1897; 100,000 shares, $2,500,000. Absorbed by Copper Range Co. in 1917.

Year	Rock treated (tons)	Refined copper (pounds)	
		Total	Per ton
1898	2, 400	42, 766	17. 8
1899	35, 411	603, 570	17. 0
1900	88, 598	1, 735, 060	19. 58
1901	114, 703	2, 641, 432	23. 0
1902	275, 175	6, 285, 819	22. 84
1903	490, 237	10, 580, 997	21. 58
1904	535, 624	12, 177, 729	22. 74
1905	604, 709	14, 384, 684	23. 78
1906	649, 932	14, 397, 557	22. 15
1907	761, 288	16, 704, 868	21. 94
1908	764, 117	17, 724, 854	23. 19
1909	814, 260	17, 817, 836	21. 88
1910	781, 419	17, 549, 762	22. 46
1911	696, 795	15, 370, 449	22. 06
1912	652, 433	13, 373, 961	20. 50
1913	333, 289	7, 736, 124	23. 21
1914	324, 433	7, 001, 945	21. 58
1915	378, 443	12, 028, 947	31. 79
1916	369, 287	12, 425, 804	33. 65
1917	325, 342	11, 214, 861	34. 47
1918	293, 601	10, 406, 097	35. 44
1919	235, 832	7, 864, 653	33. 35
1920	175, 357	6, 613, 918	37. 71
1921	195, 816	7, 608, 847	38. 86
1922	165, 804	5, 329, 568	32. 14
1923	137, 801	4, 877, 248	35. 39
1924	150, 101	4, 769, 286	31. 77
1925	140, 958	4, 255, 069	30. 18
	10, 493, 165	263, 523, 711	25. 11

Bay State.—In Keweenaw County. Organized May, 1853(?). Purchased by Phoenix in 1868.

Year	Refined copper (pounds)
1865	75, 000
1866	210, 000
1867	114, 115
	399, 115

Belt (**Bohemian**).—In Ontonagon County. The original company was organized March 27, 1848, and about that time work was begun. Location was early known as Piscatauqua and was sold to Bohemian in 1853. Bohemian commenced mining operations late in 1850 (probably on another tract); suspended in December, 1851; resumed June, 1852. Reorganized 1862. Worked until 1866, closed to 1870; resumed for short time after 1870. Bohemian and Great Western passed into hands of Belt Mining Co. by purchase in 1882 and worked until 1885. Work resumed on small scale in spring of 1886. Company wound up its organization, and property was turned over to bondholders, who foreclosed mortgage and sold. In 1900 a new organization was formed and property acquired by Arctic Copper Mining Co. Option taken on Belt in 1901 and shafts unwatered in June of that year, but work was soon suspended. Became Lake Copper Co. in November, 1905; 100,000 shares, $2,500,000.

Year	Refined copper (pounds)	Year	Refined copper (pounds)
Prior to 1855	12, 000	1875	8, 762
1859	3, 903	1876	10, 653
1862	[a] 33, 945	1877	17, 703
1863	32, 563	1878	1, 488
1864	22, 069	1879	417
1865	63, 502	1882	5, 625
1866	69, 823	1883	16, 402
1870	8, 630	1884	130, 851
1971	19, 482	1885	27, 433
1872	65, 100	1886	7, 300
1873	100, 845		
1874	7, 535		666, 031

[a] Estimated.

Bohemian.—See Belt.

Caledonia (**Nebraska**).—In Ontonagon County. Organized March, 1863; 20,000 shares, $500,000. Property formerly known as Nebraska. Absorbed by Flint Steel Copper Co. in 1871.

Year	Refined copper (pounds)	Silver sold
1855	54, 000	
1856	5, 500	
1858	17, 000	
1860	40, 400	
1863	7, 730	
1864	23, 484	
1865		$59. 30
1866	104, 652	57. 91
1868	26, 243	
1869	105, 853	
1870	87, 508	
1871	3, 377	
	475, 747	

Calumet & Hecla.—In Houghton County. Calumet Mining Co. organized 1865. Hecla Mining Co. organized 1866. Portland Copper Co. and Scott Copper Co. were purchased and on May 1, 1871, were consolidated with the Calumet Mining Co. and the Hecla Mining Co., forming the Calumet & Hecla Mining Co. Allouez, Ahmeek, Centennial, Calumet & Hecla, and Osceola were consolidated September 1, 1923, forming the Calumet & Hecla Consolidated Copper Co. The lands of the company include the following tracts:

Ahmeek.
Allouez.
Amygdaloid.
Calumet.
Centennial.
Central.
Conglomerate.
Dana.
Delaware.
Eagle Harbor.
Eagle River.
Florida.
Frontenac.
Hecla.
Iroquois.
Lac La Belle.
Laurium.
Madison.
Manice Lands.
Manitou.
Mendota.
Montreal.
North Kearsarge.
Northwest.
Northwestern.
Opechee.
Osceola.
Pawnee.
Portland.
Scott.
St. Louis.
South Kearsarge.
Tamarack.
Tamarack Jr.

Production from all lodes

[Does not include copper reclaimed from sands]

Year [a]	Rock treated (tons)	Refined copper (pounds)		Remarks
		Total	Per ton	
1865–1872	1, 116, 601	61, 683, 174	55. 24	
1873	194, 770	18, 853, 736	96. 8	
1874	238, 709	20, 147, 040	84. 4	
1875	249, 583	21, 364, 305	85. 6	
1876	259, 971	21, 577, 593	83. 0	
1877	249, 164	22, 574, 258	90. 6	
1878	276, 123	25, 237, 642	91. 4	
1879	284, 026	26, 300, 808	92. 6	
1880	325, 074	31, 272, 119	96. 2	
1881	334, 911	31, 347, 670	93. 6	
1882	341, 905	32, 070, 689	93. 8	
1883	396, 378	34, 881, 264	88. 0	
1884	437, 768	40, 449, 763	92. 4	Mine fire.
1885	567, 129	50, 020, 778	88. 2	
1886	633, 585	51, 700, 536	81. 6	
1887	605, 239	43, 940, 351	72. 6	Mine fire in July and November.
1888	814, 213	53, 738, 058	66. 0	Mine fire Nov. 30.
1889	852, 803	51, 338, 741	60. 2	
1890	936, 465	60, 495, 639	64. 6	
1891	1, 008, 249	66, 746, 084	66. 2	
1892	1, 008, 481	71, 803, 847	71. 2	
1893	1, 114, 133	77, 320, 830	69. 4	
1894	1, 212, 335	78, 559, 308	64. 8	
1895	1, 248, 051	82, 620, 976	66. 2	Started exploratory work on Osceola.
1896	1, 271, 334	86, 704, 979	68. 2	
1897	1, 276, 866	85, 039, 276	66. 6	
1898	1, 404, 506	89, 045, 680	63. 4	
1899	1, 621, 416	89, 097, 026	54. 95	
1900	1, 454, 694	75, 865, 202	52. 15	Conglomerate mine fire May 27.
1901	1, 625, 634	84, 924, 642	52. 24	Stopped work on Osceola lode.
1902	1, 697, 010	84, 432, 491	49. 75	
1903	1, 673, 221	83, 224, 042	49. 74	
1904	1, 717, 645	86, 180, 541	50. 17	Work on Osceola resumed in July.
1905	1, 939, 588	87, 304, 689	45. 01	
1906	2, 253, 672	92, 594, 167	41. 09	
1907	2, 503, 117	86, 528, 009	34. 57	
1908	2, 699, 919	81, 178, 326	30. 07	
1909	1, 927, 800	53, 252, 402	27. 62	
1910	2, 795, 514	72, 059, 545	25. 77	
1911	2, 909, 972	74, 130, 977	25. 47	
1912	2, 806, 610	67, 856, 429	24. 18	
1913	2, 035, 625	45, 016, 921	22. 11	
1914	2, 592, 462	53, 691, 562	20. 70	
1915	3, 188, 583	71, 030, 518	22. 28	
1916	3, 166, 274	71, 349, 591	22. 53	Silver sold, $181,460.36.
1917	3, 159, 570	68, 419, 826	21. 65	Silver sold, $238,368.06.
1918	2, 876, 392	58, 722, 969	20. 42	Silver sold, $294,065.12.
1919	1, 830, 760	43, 776, 194	23. 91	Silver sold, $140,323.58.
1920	1, 560, 240	43, 489, 643	27. 87	
1921	261, 320	9, 865, 400	37. 75	
1922	620, 160	29, 130, 500	47. 08	
1923 [b]	1, 073, 014	45, 672, 600	42. 56	
1924	1, 463, 245	54, 510, 000	37. 24	
1925	2, 047, 661	64, 250, 000	31. 37	
	74, 159, 490	3, 114, 389, 356	42. 0	

[a] Fiscal years beginning Apr. 1, 1873–1908; Apr. 1 to Dec. 31, 1909; calendar years 1910–1925.
[b] Includes production of consolidated mines beginning Sept. 1.

Refined copper per ton of rock treated (pounds)

Year	Calumet & Hecla conglomerate	Osceola amygdaloid	Year	Calumet & Hecla conglomerate	Osceola amygdaloid
1865–1872	55.24	--------	1898	63.4	--------
1873	96.8	--------	1899	54.95	--------
1874	84.4	--------	1900	52.15	--------
1875	85.6	--------	1901	52.24	--------
1876	83.0	--------	1902	49.75	--------
1877	90.6	--------	1903	49.74	--------
1878	91.4	--------	1904	51.53	21.38
1879	92.6	--------	1905	48.41	19.51
1880	96.2	--------	1906	46.19	17.64
1881	93.6	--------	1907	39.76	18.52
1882	93.8	--------	1908	35.04	17.07
1883	88.0	--------	1909	32.38	16.31
1884	92.4	--------	1910	30.12	15.82
1885	88.2	--------	1911	30.38	15.89
1886	81.6	--------	1912	29.73	15.08
1887	72.6	--------	1913	27.85	14.31
1888	66.0	--------	1914	26.38	13.62
1889	60.2	--------	1915	29.74	13.32
1890	64.6	--------	1916	29.97	13.60
1891	66.2	--------	1917	28.78	12.79
1892	71.2	--------	1918	28.00	11.58
1893	69.4	--------	1919	29.61	15.12
1894	64.8	--------	1920	35.10	15.74
1895	66.2	--------	1921	37.75	--------
1896	68.2	--------	1922	47.08	--------
1897	66.6	--------			

Reclamation from old tailings (Calumet & Hecla conglomerate)

CALUMET & HECLA RECLAMATION PLANT

Year	Rock treated (tons)	Refined copper (pounds)	
		Total	Per ton
1915	181,732	1,582,802	8.71
1916	545,727	5,412,649	9.92
1917	730,543	9,075,457	12.42
1918	715,007	9,245,388	12.93
1919	915,659	9,082,952	9.92
1920	1,378,500	14,138,240	10.26
1921	367,000	5,301,736	14.45
1922	1,378,250	11,362,500	8.24
1923	1,743,100	16,901,200	9.70
1924	1,687,700	18,627,000	11.04
1925	2,125,000	20,278,000	9.54
	11,768,218	121,007,924	10.32

TAMARACK RECLAMATION PLANT

1925[a]	606,605	6,679,000	11.01

[a] 7½ months.

Summary

	Period	Rock treated (tons)	Refined copper (pounds)	
			Total	Per ton
Calumet & Hecla conglomerate	1865–1925	57,229,052	[a] 2,958,779,077	51.70
Kearsarge amygdaloid	1904–1925	2,331,524	67,351,569	28.89
Mass fissure	1923–1925	--------	2,128,050	--------
Osceola amygdaloid	1904–1925	14,598,914	213,817,584	14.65
		74,159,490	3,242,076,280	43.72

[a] Includes 127,686,924 pounds reclaimed from tailings.

Carp Lake.—In Ontonagon County. Organized in 1858, Mining begun in 1859 and suspended in 1862. Resumed September 25, 1897, and worked a few months. Work resumed for a short period in summer of 1898. In 1901 the property was owned by the Porcupine Copper Co.; 500,000 shares at $5.

Year	Refined copper (pounds)
1860	6,428
1862	2,800
1863	976
1864	10,546
1865	13,185
	33,935

Centennial.—In Houghton County. Schoolcraft organized in 1863. Work commenced in small way in 1866. Worked without profit 1868-1875 and abandoned. Leased about 1873. Company went into bankruptcy and Centennial organized about 1878; 40,000 shares at $25. In 1880 work was begun by new company on Osceola amygdaloid. Work suspended in fall of 1883 because of lack of funds. Resumed December, 1888. Very little work done to 1897. Reorganized as Centennial Copper Mining Co. in 1896. Absorbed by Calumet & Hecla Consolidated Copper Co. September 1, 1923.

Year	Rock treated (tons)	Refined copper (pounds)	
		Total	Per ton
1869	--------	8,290	--------
1870	--------	426,366	--------
1871	--------	743,228	--------
1872	--------	384,242	--------
1873	--------	309,785	--------
1874	--------	10,618	--------
1882	--------	83,554	--------
1891	28,531	531,983	18.64
1892	--------	106,801	--------
1894–1896	--------	None.	--------
1897	4,612	127,202	27.58
1898	56,032	871,403	15.55
1899	77,903	722,486	9.27
1900	64,982	1,012,314	15.58
1901	69,710	921,070	13.21
1902[a]	5,939	76,480	12.88
1904	[b] 69,453	641,294	9.23
1905	84,890	1,446,584	17.04
1906	166,000	2,253,015	13.58
1907	200,040	2,373,572	11.86
1908	169,693	2,196,377	12.94
1909	196,525	2,583,793	13.15
1910	102,133	1,572,566	15.40
1911	86,543	1,493,834	17.26

[a] No production after January.
[b] July 4 to Dec. 31. Includes 9,043 tons from stock pile.

Year	Rock treated (tons)	Refined copper (pounds)	
		Total	Per ton
1912	106,517	1,742,338	16.36
1913	85,443	1,612,262	18.87
1914	138,136	2,287,130	16.56
1915	150,191	2,347,500	15.63
1916	150,617	2,367,400	15.72
1917	148,332	2,002,857	13.50
1918	159,040	2,492,857	15.67
1919	87,688	1,365,148	15.57
1920[c]	41,418	561,284	13.55
1921–1923	--------	None.	--------
		37,675,633	

[c] January to July.

The figures given above for 1869-1874 and 1882 represent production from the Calumet & Hecla conglomerate; the estimated quantity derived from the conglomerate in 1897 (1,285 tons) was 35,440 pounds (27.58 pounds per ton) and in 1898 (5,000 tons) 83,750 pounds (16.75 pounds per ton), making a total from the conglomerate of 2,085,273 pounds. The production from the Osceola lode was as follows:

Year	Rock treated (tons)	Refined copper (pounds)	
		Total	Per ton
1891	28,531	531,983	18.64
1892	--------	106,801	--------
1894–1896	--------	None.	--------
1897	[a] 3,327	[a] 91,762	[a] 27.58
1898	[a] 51,032	[a] 787,653	[a] 15.43
1899	77,903	722,486	9.27
1900	[a] 21,400	[a] 316,000	[a] 14.00
	--------	2,556,685	--------

[a] Estimated.

The figures given in the first table above for 1901-1920 represent production from the Kearsarge lode; the estimated output from this lode in 1900 (43,582 tons of rock treated) was 696,314 pounds or 15.93 pounds per ton, making the total output from the Kearsarge lode (2,261,890 tons treated) 33,033,675 pounds, or 14.60 pounds per ton.

Central.—In Keweenaw County. Organized November 15, 1854. During 1855 net earnings $7,000; first mine in Michigan district to produce and sell during its first year enough copper to more than pay expenses for the year. Cost to stockholders for Central $100,000. Started stamping in March, 1865; closed July, 1898. Sold to Frontenac Copper Co. in 1905? and later absorbed by Calumet & Hecla Mining Co.

Year	Rock treated (tons) [a]	Refined copper (pounds)		Silver sold
		Total [b]	Per ton	
1855	----------	83, 836	--------	----------
1856	----------	64, 903	--------	----------
1858	----------	143, 011	--------	----------
1859	----------	241, 622	--------	----------
1860	----------	114, 197	--------	----------
1861	----------	248, 742	--------	----------
1862	----------	484, 764	--------	----------
1863	----------	619, 268	--------	----------
1864	----------	901, 292	--------	----------

[a] Includes tons stamped plus heavy copper.
[b] Smelter production 1855-1886; mine production 1887-1898.

Year	Rock treated (tons)	Refined copper (pounds)		Silver sold
		Total	Per ton	
1865	18, 107	[c] 1, 131, 998	63	----------
1866	20, 141	[d] 1, 393, 036	69	$1, 221. 06
1867	17, 526	1, 244, 441	71	891. 76
1868	15, 882	1, 800, 943	113	1, 168. 47
1869	18, 361	1, 807, 801	98	1, 142. 78
1870	18, 741	1, 327, 156	71	594. 77
1871	21, 927	1, 432, 662	65	691. 74
1872	19, 353	1, 246, 061	64	824. 88
1873	16, 537	1, 503, 117	91	724. 60
1874	16, 456	1, 740, 603	106	663. 94
1875	17, 866	1, 466, 952	82	412. 06
1876	13, 681	2, 161, 400	158	362. 52
1877	15, 187	1, 995, 609	131	166. 25
1878	15, 030	1, 891, 013	126	522. 45
1879	13, 452	1, 799, 495	134	672. 03
1880	15, 535	2, 026, 078	130	835. 12
1881	21, 259	1, 418, 465	. 67	1, 109. 62
1882	19, 158	1, 353, 597	71	1, 126. 02
1883	18, 817	1, 268, 556	67	1, 023. 17
1884	18, 789	1, 446, 747	77	485. 25
1885	18, 689	2, 157, 408	116	390. 90
1886	[e] 21, 106	2, 512, 886	[e] 120	432. 70
1887	[e] 21, 737	1, 923, 279	[e] 89	437. 77
1888	[e] 22, 286	1, 817, 023	[e] 82	309. 40
1889	[e] 21, 527	1, 270, 592	[e] 59	----------
1890	[e] 23, 536	1, 413, 391	[e] 60	----------
1891	24, 316	1, 313, 197	54	----------
1892	[e] 21, 931	1, 625, 982	[e] 74	----------
1893	[e] 22, 750	1, 180, 040	[e] 52	----------
1894	[e] 15, 710	549, 871	[e] 35	----------
1895	----------	379, 020	--------	----------
1896	----------	469, 243	--------	----------
1897	----------	614, 891	--------	----------
1898	----------	291, 339	--------	----------
	----------	51, 875, 527	--------	----------

[c] Includes 32,756 pounds of ingot lost in lake.
[d] Includes 60,000 pounds of ingot (estimated) lost in lake.
[e] Estimate.

Champion.—In Houghton County. Organized December, 1899. One-half of capital stock owned by Copper Range Co. and other half by St. Mary's Mineral Land Co. Under Copper Range Co. management.

Year	Rock treated (tons)	Refined copper (pounds)	
		Total	Per ton
1902	121, 478	4, 165, 784	34. 29
1903	389, 082	10, 564, 147	27. 15
1904	442, 061	12, 212, 954	27. 63
1905	604, 483	15, 707, 426	25. 98
1906	671, 785	16, 954, 986	25. 24
1907	708, 685	16, 489, 436	23. 26
1908	794, 703	17, 786, 763	22. 38
1909	753, 908	18, 005, 071	23. 88
1910	722, 051	19, 224, 174	26. 62
1911	734, 392	15, 639, 426	21. 30
1912	765, 306	17, 225, 508	22. 51
1913	421, 849	12, 080, 594	28. 64
1914	614, 854	15, 807, 206	25. 71
1915	923, 743	33, 407, 599	36. 17
1916	936, 656	33, 601, 136	35. 87
1917	776, 036	27, 550, 343	35. 50
1918	594, 235	21, 748, 514	36. 60
1919	503, 030	19, 886, 917	39. 05
1920	321, 664	13, 610, 324	42. 42
1921	531, 780	20, 719, 307	39. 02
1922	503, 593	19, 583, 806	38. 89
1923	449, 130	18, 412, 630	41. 03
1924	457, 160	20, 061, 630	43. 88
1925	414, 645	17, 957, 605	43. 31
	14, 156, 309	438, 403, 286	30. 97

Clark.—In Keweenaw County. Mine was opened in 1858 by the French Copper Mining Co. and passed through various hands. In 1900, after 15 years of idleness, work was resumed. Was under option to Calumet & Hecla Mining Co. in 1905 and to U. S. Smelting, Refining & Mining Co. in 1910. An unsuccessful attempt was also made to mine a manganese deposit on this property.

Year	Refined copper (pounds)	Year	Refined copper (pounds)
1872	17, 749	1878	21, 520
1874	7, 244	1879	340
1875	67, 475		
1876	38, 774		187, 915
1877	34, 813		

Cliff.—In Keweenaw County. Pittsburgh & Boston Copper Harbor Mining Co. organized in 1844. Pittsburgh & Boston Mining Co. organized March 18, 1848, and worked the Cliff fissure to its closing in June, 1870. Paid its first dividend in 1849. First dividend-paying property in district. Paid regular semiannual dividends 1850 to 1857. The property was sold to Cliff Copper Co. in 1871, and operations were resumed in April, 1872. Affairs of Pittsburgh & Boston Mining Co. wound up and corporation dissolved in 1879. Property later sold to Tamarack Mining Co. Cliff Mining Co. organized in 1910.

Year	Rock treated (tons)	Refined copper (pounds)	Silver sold
1845		19, 891	
1846		37, 609	[a] 290
1847		410, 771	[a] 390
1848	1, 940	996, 464	[a] 975
1849	2, 792	1, 282, 131	[a] 297
1850	3, 072	714, 650	[a] 2, 868
1851	3, 057	846, 474	[a] 418
1852	2, 080	829, 360	$5, 040. 48
1853		1, 071, 288	
1854		1, 315, 308	
1855		1, 874, 197	
1856	11, 742	2, 220, 934	
1857		[b] 2, 435, 380	
1858	14, 031	2, 260, 433	6, 751. 07
1859	16, 671	1, 415, 007	2, 405. 17
1860	17, 676	1, 843, 393	1, 196. 37
1861	26, 607	1, 928, 011	7, 265. 26
1862		2, 004, 960	2, 921. 69
1863		2, 100, 354	1, 771. 19
1864	14, 276	1, 351, 334	2, 127. 55
1865	18, 285	1, 494, 626	5, 270. 17
1866	20, 730	1, 642, 428	4, 033. 80
1867	16, 329	1, 121, 725	3, 327. 86
1868	13, 730	1, 227, 746	2, 338. 00
1869	11, 336	711, 361	1, 032. 43
1870		444, 381	1, 396. 46
1871		141, 238	410. 08
1872		[c] 118, 386	
1873		[c] 401, 606	
1874		[c] 1, 009, 218	
1875		[c] 1, 389, 190	
1876		[c] 751, 552	
1877		161, 319	
1878		[c] 206, 000	
1879		134, 336	
1880		78, 962	
1881		79, 382	
1882		66, 053	
1883		10, 374	
1884		28, 255	
1885		8, 332	
1886		22, 342	
1887		145	
		38, 206, 906	

[a] Ounces.
[b] Includes 71,530 pounds from accumulated slags.
[c] Estimated.

Concord.—In Houghton County. Organized May, 1864. In 1868 Concord and Pewabic consolidated. Concord set off as separate organization in 1879. Absorbed by Arcadian in 1898.

Year	Refined copper (pounds)	Year	Refined copper (pounds)
1866	9, 980	1874	22, 518
1867	52, 020	1875	440
1868	171, 185	1876	900, 146
1870	9, 815	1880	10, 464
1871	123, 626	1881	28, 849
1872	143, 792		
1873	122, 168		1, 595, 003

Conglomerate.—See Delaware; Pennsylvania.

Connecticut.—In Keweenaw County. Operated on a fissure west of Delaware. Absorbed by Amygdaloid Co. Produced prior to 1860 116,800 pounds of refined copper, including 29,000 pounds in the year ending September 1, 1856, and 37,000 pounds in the year ending September 1, 1857.

Copper Falls.—In Keweenaw County. Copper Falls Co. organized October 16, 1845. In 1848 reorganized as Copper Falls Mining Co. In 1855 a reorganization with capital stock increased to $500,000 divided into 20,000 shares. In 1861 the company set off and organized the Petherick. In 1876 a reorganization with capital stock increased to $1,000,000 divided into 20,000 shares. Stamp mill burned in 1878. Worked Ashbed and five fissures. All operations suspended in 1893.

ALL LODES

Year	Refined copper (pounds)	Year	Refined copper (pounds)
1847	44, 800	1872	520, 862
1848	22, 400	1873	1, 286, 540
1849	22, 400	1874	1, 070, 359
1850	4, 480	1875	407, 587
1851	None.	1876	17, 488
1852	12, 651	1877	11. 950
1853	91, 737	1878	11, 790
1854	144, 269	1879	None.
1855	200, 000	1880	6, 615
1856	208, 010	1881	669, 121
1857	307, 305	1882	587, 500
1858	444, 661	1883	804, 000
1859	576, 788	1884	891, 168
1860	510, 818	1885	1, 150, 538
1861	560, 011	1886	1, 378, 679
1862	458, 299	1887	736, 477
1863	319, 348	1888	1, 199, 950
1864	358, 808	1889	869, 136
1865	470, 000	1890	1, 330, 000
1866	1, 137, 169	1891	1, 427, 000
1867	1, 594, 604	1892	1, 181, 975
1868	479, 384	1893	870, 005
1869	691, 400		
1870	772, 990		26, 339, 955
1871	478, 883		

ASHBED

Year	Refined copper (pounds)	Year	Refined copper (pounds)
1858	214, 091	1875	[b] 50, 000
1859	[a] 527, 540	1880	6, 615
1860	[a] 488, 818	1881	[a] 649, 121
1861	[b] 560, 011	1882	586, 000
1862	[b] 458, 299	1883	804, 000
1863	[b] 319, 348	1884	891, 168
1864	[b] 358, 808	1885	1, 150, 538
1865	[a] 354, 000	1886	1, 378, 679
1866	[a] 376, 169	1887	736, 477
1867	[a] 238, 604	1888	1, 199, 950
1868	[a] 80, 000	1889	869, 136
1869	[b] 100, 000	1890	1, 330, 000
1870	[b] 100, 000	1891	1, 427, 000
1871	[b] 100, 000	1892	1, 181, 975
1872	[b] 100, 000	1893	870, 005
1873	[b] 100, 000		
1874	[b] 100, 000		17, 706, 352

[a] Estimated. [b] Assumed.

FISSURES

Year	Refined copper (pounds)				
	Owl Creek	Copper Falls	Hill	Old Copper Falls	Child
1847				44, 800	
1848				22, 400	
1849				[a] 11,200	[a] 11,200
1850					4, 480
1852		[a] 6, 325	[a] 6, 326		
1853		[a] 45, 868	[a] 45, 869		
1854	2, 000	[a] 71, 134	[a] 71, 135		
1855		[a] 100, 000	[a] 100, 000		
1956		[a] 104, 000	[a] 104, 010		
1857		[a] 153, 655	[a] 153, 650		
1858		[a] 210, 230	[a] 5, 620	[a] 8, 000	[a] 6, 720
1859	[a] 7, 277	[a] 25, 000	[a] 7, 277		9, 694
1860		[a] 15, 000	[a] 7, 000		
1865	[a] 116, 000				
1866	[a] 761, 000				
1867	[a] 1, 356, 000				
1868	[a] 399, 384				
1869	[b] 591, 400				
1870	[b] 672, 990				
1871	[b] 378, 883				
1872	[b] 420, 862				
1873	[b] 1, 186, 540				
1874	[b] 970, 359				
1875	[b] 357, 587				
1876	[b] 17, 488				
1877	[b] 11, 950				
1878	[b] 11, 790				
1881	[a] 20, 000				
1882	1, 500				
	7, 283, 010	731, 212	500, 887	86, 400	32, 094

[a] Estimated. [b] Assumed.

SUMMARY

Lode	Period	Refined copper (pounds)
Child fissure	1849–1859	32, 094
Copper Falls fissure	1852–1860	731, 212
Hill fissure	1852–1860	500, 887
Old Copper Falls fissure	1847–1858	86, 400
Owl Creek fissure	1854–1882	7, 283, 010
Total production from fissures		8, 633, 603
Ashbed	1858–1893	17, 706, 352
Grand total		26, 339, 955

Delaware (**see also Pennsylvania**).—In Keweenaw County. In 1847 Northwest Copper Mining Association formed. In 1849 reorganized as Northwest Mining Co. with increased capital stock. About 1850-1860, $939,000 expended, exhausting capital. Reorganized in 1861 as Pennsylvania Mining Co. In June, 1863, estate divided and Delaware Mining Co. organized. Idle 1865-1872. In 1866-67 property in hands of bondholders for two years, when bonds were purchased by E. M. Davis, of Philadelphia, who perfected a fourth organization in 1876—the Delaware Copper Mining Co. In January, 1881, Conglomerate Mining Co. took possession; articles of association dated January 5, 1880; 50,000 shares of $25 each; included Northwest, Delaware, Pennsylvania, Maryland, and Wyoming properties. In 1888 property reorganized as Lac La Belle Mining Co. but no effort made to resume operations. Oneida Copper Co. incorporated in November, 1899, and did some exploratory work. Operations were on fissures, Allouez conglomerate, and various amygdaloids. Later acquired by Calumet & Hecla Mining Co.

Year	Rock treated (tons)	Refined copper (pounds)	
		Total	Per ton
1863 [a]			
1864		58, 700	
1865		102, 492	
1872		163, 161	
1873		[b] 280, 743	
1874		81, 271	
1875		25, 220	
1876		177, 710	
1877		33, 417	
1878		280, 345	
1879		140, 012	
1880		233, 814	
1881		386, 091	
1882		[c] 734, 249	
1883	20, 295	[d] 222, 117	10. 94
1884	120, 868	[d] 1, 140, 173	9. 43
1885		[d] 41, 155	
1886		[e] 44, 505	
1887		[e] 8, 913	
		4, 154, 088	

[a] For production prior to organization of Delaware see Pennsylvania.
[b] Mineral Statistics, 1882, gives 340,743 pounds.
[c] One-half from Allouez conglomerate; one-half from fissure; 41,104 tons stamped yielded 671,681 pounds refined copper.
[d] From Allouez conglomerate.
[e] From Northwest vein; no work on conglomerate, 1886–1891.

Derby.—In Ontonagon County. 20,000 shares of $5 each. Work was begun in 1852 and continued for three years. In 1853 produced 2,934 pounds of refined copper.

Douglass.—In Houghton County. Organized January, 1863, and worked until 1868. Sunk four shafts, probably on Arcadian amygdaloid. Later acquired by Arcadian.

Year	Refined copper (pounds)	Year	Refined copper (pounds)
1860?	27, 240?	1868	50, 109
1865	6, 809	1877	3, 258
1866	16, 209		
1867	65, 877		169, 502

Douglass Houghton.—In Ontonagon County. Operations commenced on small scale in 1846, but work not vigorously pushed until 1850. Sold out in February, 1864, to Henwood Mines Corporation, which recommenced mining operations in May, 1865. To the end of 1856 the mine had produced 143,217 pounds of refined copper.

Eagle River.—In Keweenaw County. Organized February, 1853; 20,000 shares, $500,000. Did considerable work an Babbitt vein. In 1855 small stamp mill put up.

Year	Refined copper (pounds)	Year	Refined copper (pounds)
1853–54	500	1860	9, 651
1855	1, 500	1862	5, 652
1856	2, 611	1866	738
1857	2, 000	1867	8, 389
1858	6, 637		
1859	12, 000		49, 678

Evergreen Bluff.—In Ontonagon County. Organized September, 1853; 20,000 shares of $25 each. Mining suspended in fall of 1857; resumed June, 1858, until 1863. In March, 1863, new directors, continued to 1870; after 1878 little work on tribute.

Year	Refined copper (pounds)	Year	Refined copper (pounds)
1854	2, 599	1870	111, 420
1855	14, 007	1871	45, 048
1856	25, 110	1878	71, 873
1857	46, 942	1879	30, 405
1858	6, 665	1880	10, 651
1859	38, 811	1881	968
1860	63, 817	1884	955
1861	99, 187	1885	6, 736
1862	119, 257	1886	1, 006
1863	141, 446	1887	1, 077
1864	[a] 413, 765	1888	26, 888
1865	[b] 281, 142	1889	21, 580
1866	[c] 413, 100	1890	15, 304
1867	[c] 435, 700		
1868	322, 609		2, 915, 730
1869	147, 662		

[a] Jan. 1, 1864, to May 1, 1865, estimated.
[b] May 1 to Dec. 31, 1865, estimated.
[c] Estimated.

Flint Steel River.—In Ontonagon County. Organized April, 1853, but property had been worked in 1850. Suspended work in summer of 1858, and from that time until middle of July, 1863, nothing was done on the property, except some small explorations made in 1860 and 1861. Worked Caledonia also Caledonia formerly known as Nebraska; changed to Caledonia in 1863. Consolidated in 1871 as Flint Steel Copper Co. In 1873 mines shut down and leased for eight years.

Year	Refined copper (pounds)	Year	Refined copper (pounds)
Prior to 1855	8, 651	1874	48, 772
1855	4, 000	1875	33, 054
1858	2, 106	1876	30, 115
1864	29, 657	1877	26, 067
1865	216, 959	1878	38, 356
1866	[a] 110, 054	1879	43, 192
1870	30, 889	1880	28, 080
1871	92, 500	1881	4, 140
1872	45, 874		
1873	76, 698		869, 164

[a] Includes the product of 40,506 pounds of mineral from 1865.

Forest.—See Victoria.

Franklin.—In Houghton County. Organized April, 1857. Commenced work in July, 1857, on Pewabic amygdaloid. Stamp mill completed in 1861. Leased 1870-1874. Franklin Co. resumed work in July, 1874. In 1894 purchased Franklin Jr. mine. In 1908 Franklin mine sold to Quincy. In 1909 Allouez conglomerate abandoned. In September, 1915, Franklin made profits for first time in 20 years. Operations discontinued in May, 1919. An exploratory shaft begun on Kearsarge amygdaloid at Franklin Jr. in 1923 and discontinued in spring of 1926. Franklin Jr. mine once known as Albany & Boston, and next as Peninsula.

Year	Rock treated (tons)	Refined copper (pounds)		Silver sold
		Total	Per ton	
1857		6, 699		
1858		113, 211		
1859		234, 211		
1860		315, 860		
1861	42, 434	1, 566, 043	37. 0	$610. 71
1862	40, 474	1, 466, 645	36. 3	105. 00
1863	36, 610	1, 278, 684	34. 9	
1964	28, 134	1, 211, 335	43. 1	1, 065. 12
1865	40, 136	1, 559, 481	38. 9	349. 89
1866	57, 196	1, 638, 994	28. 65	
1867	51, 356	1, 402, 455	27. 3	
1868	43, 028	1, 467, 476	34. 15	
1869	67, 154	1, 559, 940	23. 2	
1870	50, 928	1, 178, 178	23. 1	

Year	Rock treated (tons)	Refined copper (pounds)		Silver sold
		Total	Per ton	
1871		673, 678		
1872		[a] 417, 598		
1873		366, 000		
1874		567, 790		
1875		1, 167, 633		
1876	100, 582	1, 926, 641	19. 1	
1877		2, 339, 817		
1878	96, 358	2, 599, 073	26. 98	
1879	112, 590	2, 829, 703	25. 13	$563. 21
1880		2, 336, 466		
1881	113, 328	2, 678, 797	23. 7	
1882	118, 370	3, 264, 120	27. 7	880. 04
1883	125, 775	3, 489, 308	27. 8	850. 40
1884	128, 878	3, 748, 652	25. 44	2, 399. 83
1885	137, 276	3, 999, 172	29. 2	1, 511. 81
1886	138, 385	4, 264, 297	30. 81	2, 001. 20
1887	137, 137	3, 915, 838	28. 55	4, 046. 59
1888	143, 347	3, 655, 751	25. 50	2, 727. 28
1889	141, 579	4, 346, 062	30. 68	3, 143. 10
1890	144, 393	5, 638, 112	39. 05	3, 700. 34
1891	135, 578	4, 319, 840	31. 13	2, 371. 34
1892	123, 236	3, 769, 605	30. 59	1, 592. 55
1893	124, 890	3, 504, 244	28. 06	819. 76
1894	138, 163	3, 556, 487	25. 81	
1895	126, 990	3, 086, 933	24. 31	
1896	122, 079	2, 746, 076	22. 49	
1897	132, 026	2, 908, 384	22. 03	
1898	116, 696	2, 623, 702	22. 48	
1899	89, 789	1, 230, 000	13. 70	
1900	268, 571	3, 663, 710	13. 64	
1901	313, 552	3, 757, 419	11. 98	700. 86
1902	315, 687	[b] 5, 259, 140	16. 59	949. 11
1903	347, 458	[c] 5, 309, 030	15. 25	566. 00
1904	389, 470	4, 771, 050	12. 3	258. 71
1905	374, 130	4, 206, 085	11. 25	
1906	372, 378	4, 571, 570	12. 28	
1907	383, 290	4, 401, 248	11. 48	
1908	342, 596	3, 703, 421	10. 82	
1909	170, 546	1, 615, 556	9. 47	
1910	113, 859	966, 353	8. 49	
1911	86, 300	820, 203	9. 50	
1912	176, 462	1, 710, 651	9. 80	
1913	123, 179	1, 021, 440	8. 30	
1914	7, 324	93, 283	12. 73	
1915	122, 018	1, 314, 969	10. 80	
1916	267, 286	3, 116, 566	11. 66	
1917	303, 625	3, 155, 574	10. 39	
1918	273, 964	2, 827, 313	10. 32	
1919	109, 565	1, 062, 879	9. 70	
1920–1925		None.		
		154, 316, 451		

[a] Includes 1,558 pounds from sands.
[b] Includes 21,680 pounds from sands.
[c] Includes 3,879 pounds from sands.

Fulton.—In Keweenaw County. Fulton Mining Co. began work in 1853, on Forsyth mine. In 1853 produced 1,255 pounds of refined copper. Total production probably larger, but no definite data available.

Garden City.—In Keweenaw County. Organized October 24, 1855; 20,000 shares, $500,000. Two shafts sunk in Ashbed in 1856, and large stamp mill built. Work ceased 1858, resumed 1859. No work done since 1866. In 1879 reorganized as Caton Mining Co. but no work done on property.

Year	Refined copper (pounds)	Year	Refined copper (pounds)
1859	4, 000	1866	11, 397
1861	14, 000		
1863	36, 000		75, 397
1864	10, 000		

Grand Portage.—In Houghton County. Portage Mining Co. organized 1852. Reorganized in May, 1860, as Grand Portage Mining Co. and some work done. Sold in 1879 and organized anew in 1880; capital $500,000. Operations suspended in 1884. In 1897 sold to Isle Royale Consolidated Mining Co.

Year	Refined copper (pounds)	Year	Refined copper (pounds)
1863	403, 321	1880	[a] 77, 860
1864	489, 104	1881	26, 264
1865	483, 592	1882 [b]	757, 080
1868	159, 282	1883	735, 598
1869	72, 314	1884	255, 860
1878	34, 124		
1879	35, 423		3, 529, 822

[a] Mineral Statistics, 1880, gives product for the year (all tribute work) as 80,326 pounds refined copper.
[b] Rock treated, 18,959 tons; yield, 39.93 pounds per ton.

Gratiot.—In Keweenaw County. Organized February, 1906. Lately operated by Seneca. In 1923 22,051 tons hoisted to stock pile.

Year	Rock treated (tons)	Refined copper (pounds)	
		Total	Per ton
1910	28, 522	265, 869	9. 32
1911	1, 347	14, 275	10. 60
1920 [a]	[b] 446	33, 704	75. 56
	30, 315	313, 848	10. 35

[a] 13,158 tons hoisted, 35 per cent of which was placed on stock pile.
[b] Mill test (taken from stock pile).

Great Western.—See Belt.

Hancock (**Sumner**).—In Houghton County. Organized in April, 1859, as Hancock Mining Co. Company continued work until capital was exhausted and then leased the mine on tribute until 1872, when it was sold; in 1873 name changed to Sumner Mining Co., but little work was done; in winter of 1879 or 1880 it was sold and Hancock Copper Mining Co. organized; 40,000 shares of $25 each. Work started July, 1880, and discontinued in summer of 1885. Hancock Consolidated Mining Co. organized June, 1906. Idle in 1922-1925. (Sumner organized November, 1867.)

Year	Rock treated (tons)	Refined copper (pounds)	
		Total	Per ton
1861[a]	2,548	98,662	38.72
1862	4,139	111,432	26.92
1863		103,822	
1864		61,044	
1865		75,000	
1866		596,717	
1867		854,000	
1868		160,000	
1869		76,000	
1870		407,731	
1871		59,710	
1872		54,366	

[a] April to December.

Year	Rock treated (tons)	Refined copper (pounds)	
		Total	Per ton
1873		89,132	
1874		61,365	
1875		28,229	
1879		7,294	
1880		3,032	
1881		571,897	
1882		540,575	
1883		484,906	
1884		562,636	
1885		203,037	
1886		150,000	
1911	[b] 41,499	754,749	18.21
1913[c]	12,612	212,089	16.82
1914		488,678	
1915		871,124	
1916	203,112	2,824,934	13.91
1917	302,725	4,005,882	13.22
1918	227,049	3,041,514	13.40
		17,559,557	

[b] Mill test.
[c] Operations suspended from July 13, 1913, to Jan. 2, 1914.

Hilton (**Ohio**).—In Ontonagon County. First mining operations on this property in 1850. Location abandoned from 1853 until May, 1863, when Hilton Mining Co. was organized. Sunk a few trial shafts. A few tributers worked since 1865.

Year	Refined copper (pounds)	Year	Refined copper (pounds)
Prior to 1855	4,000	1879	2,050
1856	705	1885	10,342
1864	11,179	1886	19,135
1865	6,411	1887	17,155
1866	5,757	1888	14,631
1870	3,345	1890	18,642
1877	3,555		
1878	6,807		123,724

Houghton.—See Huron.

Houghton Copper.—In Houghton County. Incorporated January, 1910.

Year	Rock treated (tons)	Refined copper (pounds)	
		Total	Per ton
1915	14,657	156,766	10.69
1916	19,444	204,274	10.55
1917	15,628	179,012	11.45
1919–1925		None.	
	49,729	540,052	10.81

Huron.—In Houghton County. Organized December, 1853 Huron mine opened in 1855 on Isle Royale lode. Called Agawam from 1868 to 1871, when name was changed to Houghton. In 1880 reorganized as Huron Copper Mining Co. In 1897 included in Isle Royale Consolidated Mining Co.

Year	Rock treated (tons)	Refined copper (pounds)		Silver sold
		Total	Per ton	
1855		6,000		
1856		24,000		
1857		70,000		
1858		48,000		
1859		45,387		
1860		9,000		
1861		98,000		
1862		139,305		
1863		[a] 138,206		
1864		101,745		
1865		476,011		
1866[b]				
1867		1,367,169		
1868		1,480,080		
1869		1,682,863		
1870		84,183		
1871		269,453		
1872		553,689		
1873		475,883		
1874		251,005		
1875		63,289		
1876		63,857		
1877		82,161		
1878		65,100		
1879		29,760		
1880		70,285		
1881		254,515		
1882	8,552	364,037		
1883		720,213		
1884	66,313	1,927,660	29.0	$148.67
1885	95,476	2,258,885	23.7	315.73
1886	90,130	1,992,695	22.0	160.10
1887		1,484,103		
1888		2,375,147		
1889	112,723	2,219,473	19.7	155.51
1890	101,384	1,736,777	17.2	
1891		1,257,059		
1892		461,499		
1893		562,776		
		25,309,270		

[a] From Feb. 1 to Oct. 31, 85,345 pounds of refined copper produced.
[b] Annual report dated 1880 says, "The year 1866 is omitted because an accurate statement of amount mined can not be obtained from any record in possession of present company."

Indiana.—In Ontonagon County. Indiana Copper Co. organized in 1862 and worked steadily for three years, then stopped; recommenced in July, 1863. Stamp mill sold to Petherick Co. Indiana Mining Co. organized in 1909. No rock milled.

Island.—On Isle Royal. Organized 1874 as Island Mining Co.; 40,000 shares of $25 each. Operated three years. Stamp mill built in 1875 and burned in 1876. Leased on tribute.

Year	Refined copper (pounds)
1876	48,340
1877	88,867
1878	[a] 76,038
	213,245

[a] By Island Tribute Co.

Isle Royale.—In Houghton County. Old Isle Royale mine opened in May, 1852. The work on this property was the first mining done in the Portage Lake district. Company stopped work in 1857, and the mine was leased on tribute to Mabbs Brothers. In 1862 purchased what was known as the Webster Mining Co. property. Company worked again 1863-1870, leasing the mine once more to Mabbs Brothers, who worked it for some years. Isle Royale Copper Co. incorporated 1899 and in April of that year took over Isle Royale Consolidated Mining Co., organized in 1897, and Miners' Copper Co., organized in 1898. Present Isle Royale includes old Isle Royale, Grand Portage, Huron, which comprised original Isle Royale consolidation in 1897, and also Frue and Dodge, which were taken into Miners' consolidation in 1898.

Year	Refined copper (pounds)	Year	Refined copper (pounds)
1853	18, 738	1871	181, 217
1854	[a] 97, 262	1872	250, 164
1855	186, 000	1873	240, 100
1856	[b] 323, 510	1874	180, 876
1857	356, 810	1875	96, 682
1858	[a] 386, 000	1876	28, 199
1859	416, 056	1877	31, 985
1860	336, 198	1878	31, 933
1861	[c] 896, 139	1879	26, 880
1862	[c] 826, 770	1880	77, 469
1863	[c] 588, 130	1881	47, 308
1864	582, 386	1882	35, 447
1865[d]	787, 547	1884	16, 874
1866	532, 793	1885	30, 164
1867	762, 852		
1868	295, 033		8, 818, 194
1869	150, 672		

[a] Estimated.
[b] Includes 11,125 pounds of refined copper estimated in mineral lost in lake.
[c] Smelter production.
[d] 14,000 tons stamped from Mabbs vein, yielding about 2.5 per cent.

Year	Rock treated (tons)	Refined copper (pounds)		Silver sold
		Total	Per ton	
1853–1885		8, 818, 194		
1901	185, 175	2, 171, 955	11. 7	
1902	263, 672	3, 569, 748	13. 5	[a] $8, 881. 61
1903	199, 493	3, 134, 601	15. 7	
1904	154, 830	2, 442, 905	15. 8	
1905	195, 150	2, 973, 761	15. 2	
1906	192, 210	2, 937, 098	15. 3	
1907	175, 450	2, 667, 608	15. 2	
1908	218, 940	3, 011, 664	13. 8	
1909	401, 280	5, 719, 056	14. 3	12, 073. 18
1910	520, 860	7, 567, 399	14. 5	23, 215. 99
1911	457, 440	7, 490, 120	16. 37	20, 336. 55
1912	531, 105	8, 186, 957	15. 41	38, 126. 16
1913	314, 679	4, 158, 548	13. 21	14, 878. 01
1914	474, 349	6, 601, 235	13. 91	17, 477. 98
1915	680, 270	9, 342, 106	13. 73	38, 973. 56
1916	925, 419	12, 412, 111	13. 41	53, 086. 76
1917	922, 160	13, 480, 921	14. 6	84, 962. 44
1918	974, 508	15, 442, 508	15. 9	80, 743. 43
1919	724, 667	13, 007, 647	17. 95	94, 144. 01
1920	591, 971	10, 621, 801	17. 94	75, 075. 53
1921	116, 576	2, 491, 000	21. 37	
1922	246, 641	6, 639, 970	26. 92	
1923	308, 940	8, 002, 244	25. 90	
1924	315, 507	8, 103, 000	25. 68	
1925	378, 459	9, 543, 000	25. 22	
		180, 537, 157		

[a] 18,523 ounces.

Kearsarge.—In Houghton County. Organized as Kearsarge Mining Co.; 50,000 shares of $25 each. Absorbed by Osceola Consolidated Mining Co. in December, 1897.

Year	Rock treated (tons)	Refined copper (pounds)		Silver sold
		Total	Per ton	
1887		21, 237		
1888	24, 250	829, 185	33. 95	
1889	56, 104	1, 918, 849	34. 2	$400. 77
1890	60, 619	1, 598, 525	26. 37	275. 57
1891	81, 424	1, 727, 390	21. 21	706. 73
1892	60, 986	1, 467, 758	24. 07	749. 90
1893	75, 450	1, 627, 030	21. 56	
1894	64, 287	1, 998, 710	31. 09	
1895	64, 000	1, 946, 163	30. 2	
1896	34, 587	1, 377, 226	39. 82	
		14, 512, 073		

Keweenaw Copper.—In Keweenaw County. Organized March 13, 1905. Work was started in summer of 1905 by diamond drilling on Medora and Mandan properties. Includes Aetna, Empire, Girard, Hanover, Copper Harbor, Washington, Keweenaw, Mandan, Medora, Vulcan, Resolute, Boston, and Phoenix (Penn?). Resolute was sold to Keweenaw Copper Co. late in 1905 or early in 1906. 7,500 tons of stamp rock on stock pile in 1906.

Year	Refined copper (pounds)
1908	122, 474
1909	57, 091
	179, 565

King Philip.—See Winona.

Knowlton.—In Ontonagon County. Organized August 6, 1860. Mine opened in 1862; discontinued on company account 1866-1867, then worked on tribute. Absorbed by Adventure Consolidated Copper Co. O. Ashley says (Copper mines of Lake Superior, 1873): "1,086,000 pounds ingot copper taken out from 1863 to 1869."

Year	Refined copper (pounds)	Year	Refined copper (pounds)
1862	37, 040	1877	5, 975
1863	85, 451	1878	8, 629
1864	122, 877	1884	21, 368
1865	196, 724	1885	21, 976
1868	197, 021	1886	18, 806
1869	106, 977	1887	38, 870
1872	17, 559	1890	23, 145
1873	70, 442	1891	7, 120
1874	6, 215		
1875	6, 562		992, 757

Lac La Belle.—In Keweenaw County. Prior to 1850 the Lac La Belle Co. had driven a tunnel into the hill 400 feet and found a vein 18 inches wide. No further work was done until 1866. The following statement is taken from Eng. and Min. Jour., October 18, 1890, p. 448: "Mendota Mining Co. commenced operations in 1866 on property formerly worked by the Lac La Belle Mining Co., secs. 29 and 32, T. 58, R. 29, Keweenaw County. Three hundred feet of sinking and 700 feet of drifting were done and operations were suspended. Later the lands of the company were sold for taxes. Company owned 4,320 acres surrounding Lac La Belle. In fall of 1866 this company completed a canal from Lac La Belle to Bete Gris at cost of $100,000, receiving from the Government in consideration therefor 100,000 acres of land in Schoolcraft County, Mich. About the time of the completion of this canal mining operations in the vicinity of Lac La Belle were suspended, and the canal was allowed to fill up. The production was 3,499 pounds of refined copper prior to 1850.

Lake.—In Ontonagon County. Organized in November, 1905. Property formerly Belt. First work on Knowlton lode. Shut down from July 1, 1913, to April, 1915. Work suspended January 31, 1919.

Year	Rock treated (tons)	Refined copper (pounds)	
		Total	Per ton
1909 [a]	10, 125	170, 801	21. 06
1910	14, 485	318, 050	21. 96
1912	[b] 83, 109	1, 300, 562	15. 64
1913 [c]	19, 211	287, 200	15. 39
1915 [d]	59, 848	1, 581, 071	26. 42
1916	70, 440	1, 489, 247	21. 14
1917	63, 191	1, 461, 893	23. 13
1918		717, 403	
1919–1925		None.	
		7, 326, 227	

[a] Fiscal year April, 1909, to April, 1910.
[b] 12,141 tons from stock pile.
[c] May 1 to July 1.
[d] Nine months ending Apr. 30, 1916.

Lake Superior.—In Ontonagon County. Lake Superior Copper Co. organized in 1859 by Minesota Co. to work a portion of its estate. Worked by tributers from time to time after 1874.

Year	Refined copper (pounds)	Year	Refined copper (pounds)
1864	2, 432	1877	2, 106
1865	1, 951	1879	1, 086
1866	2, 018		
1874	5, 228		14, 821

Lake Superior Copper.—In Keweenaw County. See Phoenix.

La Salle.—In Houghton County. Organized December, 1906. Includes Caldwell and other lands. Purchased Tecumseh in May, 1910. Mined on Kearsarge amygdaloid and drove crosscut from Osceola amygdaloid to Allouez conglomerate. All production is from Kearsarge amygdaloid.

Year	Rock treated (tons)	Refined copper (pounds)		Silver sold
		Total	Per ton	
1910	49, 274	633, 778	12. 86	
1911	18, 970	280, 598	14. 79	
1912		None.		
1913	2, 221	43, 906	19. 76	
1914	45, 509	540, 731	11. 88	$3, 583. 25
1915	80, 959	782, 493	9. 67	6, 034. 90
1916	144, 829	1, 380, 352	9. 53	13, 843. 80
1917	185, 014	1, 919, 775	10. 38	12, 408. 87
1918	176, 423	1, 832, 665	10. 39	
1919	32, 995	340, 719	10. 33	
1920	3, 430	59, 713	17. 41	
1921–1925		None.		
	739, 624	7, 814, 730	10. 57	

Madison (**Summit**).—In Keweenaw County. Summit organized 1852-53. Mining work continued until 1856. In August, 1859, reorganized as Madison Mining Co., 20,000 shares of $25 each. Work resumed in 1863. Some tribute up to 1876, when company began again. Property sold at sheriff's sale in 1878 but redeemed by company in September, 1879, and reorganized with 40,000 shares of $25 each. Work resumed in 1880 and continued until May, 1882. Property bought by Central about 1885.

Year	Refined copper (pounds)	Year	Refined copper (pounds)
1856	4, 000	1878	1, 676
1857	16, 000	1881	1, 534
1865	14, 881		
1866	34, 000		72, 091

Manhattan (**Old Albion**).—In Keweenaw County. Albion commenced operations in 1848; suspended 1857-1862; resumed operations as Manhattan Mining Co. in January, 1863; 20,000 shares of $25 each. Abandoned in 1865. 5 tons of copper taken out in sinking shaft (about 1863).

Mass.—In Ontonagon County. Mass Mining Co. organized in May, 1856, worked until 1860, idle 1860-1864, when work was begun on Evergreen lode; totally suspended again in 1868. A little work on tribute. Company resumed in 1874 and continued to 1884, when property was leased to Mass Tribute Co., which worked it until 1888, when operations ceased. Mass Consolidated Mining Co. organized February, 1899; made up of Ridge, Mass, Ogima, Merrimac, and Hazard mines; capital $2,500,000. Ridge began 1850. Ogima opened 1860; closed 1868. Merrimac organized in 1863. Hazard did little work on North Range, or Minesota Belt. A few old test pits and shafts. Purchased Evergreen Bluff Mining Co. in 1911 (?).

Year	Rock treated (tons)	Refined copper (pounds)		Silver sold
		Total	Per ton	
1857		16, 228		
1858		12, 000		
1859		52, 682		
1864		9, 452		
1865		12, 936		
1866		10, 112		
1867		10, 040		
1868		18, 939		
1869		3, 213		
1870		3, 408		
1871		18, 692		
1872		1, 903		
1873		8, 265		
1874		11, 925		
1875		3, 014		
1876		81, 952		
1877		108, 238		
1878	5, 940	[a] 412, 339		
1879		456, 294		
1880	7, 779	517, 159		
1881	7, 761	467, 684		
1882	15, 472	737, 440		
1883		659, 474		
1884		481, 396		
1885		365, 000		
1886		247, 179		
1887		16, 000		
1888		70, 944		
1889		58, 349		
1890		62, 187		
1891		30, 114		
1892		17, 450		
1893		22, 737		
1894		41, 805		
1895		18, 372		
1896		53, 507		
1897		65, 250		
1899		[b] 42, 800		
1900		122, 239		
1901		873, 297		
1902	152, 562	2, 345, 805	15. 38	
1903	122, 611	2, 576, 447	21. 01	$1, 303. 89
1904	105, 614	2, 182, 931	20. 67	
1905	143, 430	2, 007, 950	14. 00	
1906	185, 789	2, 106, 739	11. 34	

[a] Includes 6,732 pounds produced by tributers prior to October, 1874.
[b] 49,700 pounds estimated from annual report.

Year	Rock treated (tons)	Refined copper (pounds)		Silver sold
		Total	Per ton	
1907	204, 599	2, 078, 677	10. 16	
1908	171, 268	1, 766, 930	10. 32	$347. 56
1909	139, 404	1, 723, 436	12. 36	681. 82
1910	90, 747	1, 321, 885	14. 59	
1911	73, 475	1, 326, 898	17. 58	
1912	132, 891	2, 045, 006	15. 39	
1913	78, 250	1, 213, 545	15. 51	
1914	209, 354	2, 955, 952	14. 07	
1915	323, 335	4, 638, 452	14. 35	
1916	287, 900	4, 752, 588	16. 51	[c] 1, 359. 37
1917	244, 671	3, 984, 616	16. 27	[d] 1, 290. 95
1918	196, 456	3, 403, 827	17. 33	
1919	123, 780	1, 963, 178	15. 86	[e] 1, 655. 40
1920–1925		None.		
		50, 616, 877		

[c] 1,813 ounces.
[d] 1,572 ounces. Sale of silver from date of organization to end of 1917, $15,280.37.
[e] 1,264 ounces.

Mesnard.—In Houghton County. Organized in May, 1859; 20,000 shares of $25 each. Tributers worked after company ceased. In 1876 taken over by Pewabic interests. Sold to Quincy in 1897.

Year	Refined copper (pounds)	Year	Refined copper (pounds)
1863	43, 127	1873	9, 269
1864	4, 000	1877	6, 589
1865	15, 600		
1868	5, 510		84, 095

Michigan.—In Ontonagon County. Organized June, 1898, and began work in September. Reorganized January, 1899. Owns properties formerly known as Minesota, Rockland, and

Superior. Rockland set off from Minesota in 1853 and closed in 1870. Little work on tribute. Minesota mine discovered 1847, opened 1848, closed 1870. Little work on tribute after 1870. Michigan discontinued work on company account at end of 1910 and mine let on tribute until May, 1913, when all work stopped and mine was idle until July, 1915. Work was again suspended October 1, 1920. Consolidated with Mohawk Mining Co. in 1923. Silver sold, $294 (in 1921).

Year	Rock treated (tons)	Refined copper (pounds)	
		Total	Per ton
1900 [a]		33, 601	
1902		166, 898	
1903		275, 078	
1904	125, 055	2, 746, 127	21. 9
1905	152, 200	2, 891, 796	19. 0
1906	140, 225	2, 875, 341	20. 5
1907	150, 407	2, 665, 404	17. 7
1908	190, 331	3, 000, 206	15. 8
1909	148, 172	1, 979, 305	13. 4
1910		36, 682	
1911		327, 773	
1912		162, 590	
1913		19, 727	
1916		[b] 80, 000	
1917	2, 091	35, 400	16. 9
1918	40, 865	1, 177, 176	28. 8
1919	62, 373	1, 697, 107	27. 21
1920	46, 289	1, 075, 492	23. 23
1921–1925		None.	
		21, 245, 703	

[a] Mill test of 1,100 tons of rock treated yielded 14,670 pounds of refined copper, or 13.33 pounds per ton.
[b] Estimated from 90,000 pounds of mass copper shipped.

PRODUCTION BY LODES

Year	Refined copper (pounds)		
	Branch vein	Calico lode	Evergreen and succeeding lodes
1900		33, 601	
1902	[a] 50, 000	[a] 116, 898	
1903	[a] 75, 000	[a] 200, 078	
1904	[a] 1, 373, 000	[a] 1, 373, 127	
1905	[a] 1, 445, 000	[a] 1, 446, 796	
1906	[a] 1, 875, 341	[a] 1, 000, 000	
1907	[a] 1, 665, 404	[a] 1, 000, 000	
1908	[a] 1, 500, 000	[a] 1, 500, 206	
1909	[a] 700, 000	[a] 1, 279, 305	
1910		36, 682	
1911	327, 773		
1912	162, 590		
1913		19, 727	
1916			[a] 80, 000
1917			35, 400
1918			1, 177, 176
1919			1, 697, 107
1920			1, 075, 492
	9, 174, 108	8, 006, 420	4, 065, 175

[a] Estimated.

Minesota.—In Ontonagon County. Incorporated in 1848, 3,000 shares; reorganized in 1855, 20,000 shares of $50 each. Mine worked by tributers after 1870. Later became part of Michigan, which was consolidated with Mohawk in 1923.

Year	Refined copper (pounds) [a]	Silver sold [b]
Prior to 1855	3, 020, 000	
1855	2, 080, 000	
1856	3, 490, 714	$986.95 (112 pounds).
1857	3, 952, 000	$654.44 (78 pounds).
1858	3, 802, 914	$606.83 (70 pounds).
1859	3, 344, 587	$644.61 (88 pounds).
1860	[c] 2, 680, 500	
1861	3, 016, 824	$1,039.92 (185 pounds).
1862	[d] 2, 520, 000	$912.71.
1863	[e] 1, 677, 500	$757.68.
1864	1, 446, 000	
1865	403, 000	
1866	391, 500	
1867	376, 500	
1868	230, 900	
1869	227, 500	
1870	401, 500	
1871	368, 000	
1872	252, 000	
1873	148, 171	
1874	186, 338	
1875	133, 419	
1876	88, 954	
1877	113, 148	
1878	175, 027	
1879	92, 762	
1880	32, 033	
1881	24, 227	
1882	10, 672	
1883	6, 226	
1884	1, 144	
1885	12, 608	
	34, 706, 668	

[a] Smelter production 1848–1868, 27,307,893 pounds.
[b] Silver sold in 1852 amounted to $261.69, and in 1854 to $186.46.
[c] Smelter production given as 3,212,426 pounds.
[d] Smelter production given as 2,135,936 pounds.
[e] Smelter production given as 1,634,885 pounds.

Minong.—On Isle Royal. Minong Mining Co. organized December 16, 1874; 40,000 shares of $25 each. Built stamp mill in 1876. Reorganized in 1879 as Minong Copper Co.; 20,000 shares of $25 each. Company stopped work in 1881 but tributers worked for two seasons. Since the fall of 1883 no work has been done.

Year	Refined copper (pounds)	Year	Refined copper (pounds)
1875	48, 344	1881	15, 397
1876	114, 537	1882	21, 380
1877	104, 892	1883	3, 582
1878	90, 596		
1879	72, 515		498, 650
1880	27, 407		

Mohawk.—In Keweenaw County. Mohawk Mining Co- organized November, 1898, and took over part of lands of Fulton Mining Co. Started stamping in December, 1902. Wolverine and Michigan consolidated with Mohawk on August 15, 1923. In 1900 produced 70,000 pounds mohawkite; in 1901, 160,897 pounds.

Year	Rock treated (tons)	Refined copper (pounds)	
		Total	Per ton
1902	8, 613	226, 824	26. 34
1903	288, 441	6, 284, 327	21. 79
1904	459, 162	8, 149, 515	17. 75
1905	586, 305	9, 387, 614	16. 01
1906	618, 543	9, 352, 252	15. 12
1907	640, 777	10, 107, 266	15. 77
1908	685, 823	10, 295, 881	15. 01
1909	819, 019	11, 248, 474	13. 73
1910	802, 537	11, 412, 066	14. 22
1911	802, 548	12, 091, 056	15. 07
1912	787, 941	11, 995, 598	15. 22
1913 [a]	366, 458	5, 778, 235	15. 76
1914	649, 649	11, 094, 859	17. 08
1915	829, 789	15, 882, 914	19. 15
1916	664, 547	13, 834, 034	20. 82
1917	605, 202	12, 313, 887	20. 35
1918	454, 293	10, 781, 041	23. 73
1919	560, 734	12, 857, 392	22. 93
1920	434, 988	10, 269, 824	23. 61
1921	688, 273	14, 054, 235	20. 42
1922	512, 393	11, 209, 396	21. 88
1923	405, 412	9, 452, 539	23. 32
1924	702, 534	15, 215, 197	21. 66
1925	640, 069	15, 819, 922	24. 72
	14, 014, 050	259, 114, 348	18. 49

[a] Stamp mill idle July 14 to Dec. 18.

National.—In Ontonagon County. Chartered April, 1848. Worked until 1871. Remained idle except for tribute work until May, 1880. Rechartered in 1878 and in 1908. Active mining ceased August, 1893; since then a little tributing has been done.

Year	Refined copper (pounds)	Silver sold	Year	Refined copper (pounds)	Silver sold
1853	57, 631	---------	1874	142, 052	---------
1854	[a] 100, 000	---------	1875	98, 878	---------
1855	49, 302	---------	1876	166, 647	---------
1856	176, 483	---------	1877	68, 737	---------
1857	316, 957	---------	1878	22, 736	---------
1858	264, 804	---------	1879	17, 506	---------
1859	488, 176	---------	1882	17, 060	---------
1860	1, 078, 609	$776. 96	1883	26, 006	---------
1861	1, 383, 760	547. 82	1884	87, 368	---------
1862	865, 752	} 2, 051. 88	1885	162, 252	---------
1863	561, 179		1886	184, 706	---------
1864	688, 516	---------	1887	25, 187	---------
1865	695, 027	1, 011. 41	1889	454, 134	---------
1866	647, 371	[b] 916. 71	1890	123, 879	---------
1867	475, 633	495. 66	1891	103, 888	---------
1868	443, 048	[c] 178. 74	1892	36, 385	---------
1869 [d]	256, 947	336. 40	1893	63, 433	---------
1870	260, 659	---------	1894	36, 390	---------
1871	411, 086	---------	1895	50, 128	---------
1872	336, 770	---------			
1873	167, 870	---------		11, 612, 952	---------

[a] Estimated. [b] 679 ounces. [c] 198 ounces. [d] 8,750 tons of rock treated

New Arcadian.—See Arcadian.

New York and Michigan.—In Keweenaw County. Opened in 1846; closed in 1847; reopened 1852-5. Four small masses weighing about 1,800 pounds were shipped in 1852.

Nonesuch.—In Ontonagon County. Organized in June, 1867. Worked at intervals for several years. In 1875 stock increased to 40,000 shares. Idle 1875-1877, and stamp mill burned soon afterward. Leased for seven years by Capt. Thomas Hooper. Over $500,000 spent.

Year	Refined copper (pounds)	Year	Refined copper (pounds)
1868	3, 502	1881	119, 061
1869	3, 261	1882	46, 450
1871	257	1884	23, 867
1874	27, 450	1885	28, 484
1875	49, 667		
1879	31, 973		389, 556
1880	55, 584		

North American,—In Keweenaw County. Organized in 1848; 6,000 shares, $300,000. Shares increased to 10,000 with same capital about 1851. Opened old North American mine in 1846 and worked until 1853. In 1852 opened South Cliff mine. In 1860 sold entire property to Pittsburgh & Boston Mining Co. It was then let on tribute for three years. In 1864 North American mine set aside by the Pittsburgh & Boston to be operated by newly organized American Mining Co. The North American fissure, during the four years it was worked, yielded 445,000 pounds of copper. Remainder of production by North American Mining Co. came from Cliff fissure.

Year	Refined copper (pounds)	Year	Refined copper (pounds)
1849	51, 296	1856	408, 252
1850	170, 688	1857	275, 958
1851	171, 360	1858	38, 919
1852	51, 296	1859	22, 852
1853	251, 597		
1854	[a] 203, 763		1, 953, 803
1855	307, 822		

[a] Estimated.

North Cliff.—In Keweenaw County. Organized September 20, 1858, by setting off 1,002.25 acres from lands of Pittsburgh & Boston Mining Co. Reorganized March 22, 1859, under special charter which had originally been granted to the "Swamscott Mining Co. of Michigan" and the name changed to North Cliff Mining Co. of Michigan. Operations suspended at end of 1860; resumed in 1863. In 1859 produced 2,435 pounds of refined copper (from openings); in 1864, 3,222 pounds; total, 5,657 pounds.

North Lake.—In Ontonagon County. Organized August, 1908. No rock milled.

Northwest.—See Pennsylvania.

Northwestern.—In Keweenaw County. Organized April, 1845, as Northwestern Mining Co. Reorganized as Northwestern Mining Co. of Detroit, March 16, 1848; capital $300,000. Stamp mill erected in 1852. Work suspended in 1857, resumed in spring of 1863, again suspended in January, 1865. Later absorbed by Central. In 1863 silver sold amounting to $108.54.

Year	Refined copper (pounds)	Year	Refined copper (pounds)
1852	8, 622	1864	6, 651
1853	44, 166	1880	961
1854	154, 900		
1855	80, 830		313, 005
1856	16, 875		

Norwich.—In Ontonagon County. Vein discovered on Norwich and Windsor properties in July, 1846. Operations at Norwich mine began May, 1850, but not worked with any considerable force until 1852. In February, 1855, American Mining Co. of Vermont organized Norwich Mining Co.; 20,000 shares of $25 each. Operations suspended in 1858 because of financial difficulties. Some work done on tribute 1858-1863. In May, 1863, Norwich reorganized and formed a consolidation with Windsor mine, and work recommenced immediately. Consolidation with Hamilton Co. was decided on, April 14, 1864, followed immediately by a division of the property, exchange of stock and the formation of two companies, the Norwich ceding the property known as the Windsor mine and receiving the north part of the Hamilton. Mine was shut down in 1865. Some work was done in 1899-1900 under the name of Essex Copper Co.

Year	Refined copper (pounds)	Year	Refined copper (pounds)
1852	6, 339	1858	39, 000
1853	34, 451	1864	9, 730
1854	[a] 293, 210	1865	53, 330
1855	216, 000	1869	5, 300
1856	220, 000		
1857	116, 000		993, 360

[a] Estimated.

Ogima.—In Ontonagon County. Property worked under tribute 1857-1860. Purchased in fall of 1860 and Ogima Mining Co. organized in December of that year; 20,000 shares of $25 each. Stopped work in 1868. Ground above adit level worked at intervals by tributers. In 1888 leased for three years to A. Meads. Later absorbed by Mass.

Year	Refined copper (pounds)	Year	Refined copper (pounds)
1857–1860 [a]	114, 650	1878	2, 800
1861	14, 166	1879	17, 937
1862	40, 957	1880	5, 885
1863	[b] 28, 700	1881	16, 776
1864	[b] 35, 000	1882	4, 207
1865	167, 436	1883	3, 000
1866	277, 310	1884	1, 106
1867	168, 480	1885	12, 291
1868	199, 360	1887	952
1869	18, 045		
1871	9, 839		1, 138, 897

[a] Summer of 1857 to Oct. 1, 1860. [b] Estimated.

Ohio.—See Hilton.

Ohio Trap Rock.—In Ontonagon County. Special charter granted 1849; 6,000 shares, $25 each. Company commenced operations in 1846 and up to September, 1853, had expended about $90,000 with but little returns of copper. Capital exhausted in 1855, and company reorganized with capital stock $300,000. No work done since 1857. In 1853 produced 2,755 pounds of refined copper; in 1858, 38,685 pounds; total, 41,440 pounds.

Ojibway.—In Keweenaw County. Organized June, 1907; 100,000 shares of $25 each. Worked Kearsarge amygdaloid. In 1911 treated 7,448 tons of rock and produced 49,662 pounds of refined copper, or 6.65 pounds per ton. Mass copper retained at mine amounted to 0.7 pound per ton stamped, bringing total product up to 7.35 pounds per ton, with tailings losses of about 3 pounds.

Osceola.—In Houghton County. Organized September 25, 1873. In 1879 consolidated with Opechee, forming Osceola Consolidated Mining Co. Reincorporated 1903. First worked on Calumet & Hecla conglomerate. In 1877 Osceola amygdaloid located. Kearsarge and South Kearsarge mines operated on Kearsarge amygdaloid, and Tamarack Jr. on Calumet & Hecla conglomerate. Reorganized 1897 including three mines—Osceola, Tamarack Jr., and Kearsarge. Tamarack Jr. set off from Tamarack about 1890. South Kearsarge mine opened by Osceola Consolidated Mining Co. in 1899. Absorbed by Calumet & Hecla Consolidated Copper Co. September 1, 1923.

ALL LODES

Year	Rock treated (tons)	Refined copper (pounds)		Silver sold
		Total	Per ton	
1874	25, 763	936, 002	36. 33	----------
1875	33, 848	1, 330, 313	39. 30	----------
1876	43, 075	1, 693, 737	39. 32	----------
1877	78, 339	2, 774, 777	35. 42	----------
1878	79, 439	[a] 2, 705, 998	34. 1	$5, 525. 61
1879	95, 055	[b] 3, 197, 387	33. 64	4, 898. 36
1880	107, 386	3, 381, 061	31. 48	1, 294. 07
1881	160, 880	4, 176, 976	26. 0	2, 694. 25
1882	172, 529	4, 179, 782	24. 2	3, 476. 91
1883	175, 320	4, 256, 409	24. 3	3, 757. 78
1884	181, 608	4, 247, 630	23. 4	2, 383. 99
1885	72, 923	1, 939, 169	26. 6	----------
1886	137, 725	3, 560, 786	25. 85	1, 308. 93
1887	145, 200	3, 583, 723	24. 68	----------
1888	183, 036	4, 134, 320	22. 59	----------
1889	175, 587	4, 534, 127	25. 82	827. 91
1890	183, 825	5, 294, 792	28. 80	1, 238. 74
1891	234, 325	6, 543, 358	27. 92	1, 249. 10
1892	247, 575	7, 098, 656	28. 67	155. 27
1893	236, 875	6, 715, 870	28. 35	----------
1894	264, 050	6, 918, 502	26. 20	----------
1895	233, 238	6, 270, 373	26. 88	----------
1896	248, 062	6, 251, 304	25. 2	----------
1897	443, 086	11, 201, 103	21. 4	----------
1898	505, 008	12, 682, 297	25. 1	----------
1899	546, 326	11, 258, 049	20. 6	----------
1900	683, 066	12, 566, 471	18. 4	----------
1901	793, 207	13, 723, 487	17. 3	----------
1902	836, 400	13, 416, 396	16. 0	----------
1903	924, 400	16, 059, 636	17. 4	----------
1904	1, 095, 520	20, 472, 429	18. 7	----------
1905	1, 007, 200	18, 938, 965	18. 8	----------
1906	1, 016, 240	18, 588, 451	18. 3	----------
1907	811, 603	14, 134, 753	17. 4	----------
1908	1, 241, 400	21, 250, 794	17. 1	----------
1909	1, 494, 845	25, 296, 657	16. 9	----------
1910	1, 217, 720	19, 346, 566	15. 9	----------
1911	1, 246, 596	18, 388, 193	14. 8	----------
1912	1, 246, 557	18, 413, 387	14. 8	----------
1913	735, 044	11, 325, 010	15. 4	----------
1914 [c]	1, 108, 447	14, 970, 737	13. 5	----------
1915	1, 361, 089	19, 731, 472	14. 5	----------
1916	1, 284, 681	19, 586, 501	15. 25	----------
1917	1, 237, 805	16, 084, 958	13. 0	----------
1918	1, 194, 967	15, 919, 647	13. 3	----------
1919	739, 364	10, 824, 331	14. 64	----------
1920	455, 982	7, 465, 773	16. 37	----------
1921–1923	----------	None.	--------	----------
	26, 742, 216	477, 371, 115	17. 85	----------

[a] Includes 79,878 pounds from sands.
[b] Includes 58,555 pounds from sands.
[c] No. 5 Osceola closed in August.

OSCEOLA MINE (CALUMET & HECLA CONGLOMERATE)

Year	Rock treated (tons)	Refined copper (pounds)	
		Total	Per ton
1873	----------	None.	--------
1874	25, 763	936, 002	36. 33
1875	33, 848	1, 330, 313	39. 30
1876	43, 075	1, 693, 737	39. 32
1877	78, 339	2, 774, 777	35. 42
1878	79, 439	[a] 2, 705, 998	34. 1
1879	58, 600	[b] 1, 971, 140	33. 6
1880	39, 386	1, 240, 061	31. 5
1882	----------	None.	--------
	358, 450	12, 652, 028	35. 30

[a] Includes 79,878 pounds from sands. [b] Includes 58,555 pounds from sands.

TAMARACK JUNIOR MINE (CALUMET & HECLA CONGLOMERATE)

[See Tamarack Jr. Mining Co. for production 1892–1896]

Year	Rock treated (tons)	Refined copper (pounds)	
		Total	Per ton
1897	64, 857	[a] 1, 655, 000	[a] 25. 5
1898	100, 764	[a] 2, 620, 000	[a] 26. 0
1899	105, 742	[a] 2, 511, 000	[a] 23. 7
1900	121, 744	[a] 2, 276, 000	[a] 18. 7
1901	121, 652	[a] 1, 879, 000	[a] 15. 4
1902	100, 959	[a] 1, 413, 000	[a] 14. 0
1903	3, 760	[a] 50, 000	[a] 13. 3
	619, 478	12, 404, 000	20. 02

[a] Estimated.

NORTH KEARSARGE MINE (KEARSARGE AMYGDALOID)

[See Kearsarge Mining Co. for production 1887–1896]

1897	[a] 68, 194	[a] 1, 305, 000	[a] 19. 1
1898	70, 534	[a] 2, 186, 000	[a] 31. 0
1899	77, 368	[a] 1, 544, 000	[a] 20. 0
1900	88, 578	[a] 1, 639, 000	[a] 18. 5
1901	104, 162	[a] 1, 800, 000	[a] 17. 3
1902	197, 601	[a] 3, 149, 000	[a] 15. 9
1903	347, 600	[a] 6, 046, 000	[a] 17. 4
1904	456, 960	[a] 8, 446, 000	[a] 18. 5
1905	381, 520	[a] 6, 993, 000	[a] 18. 3
1906	345, 200	[a] 6, 023, 000	[a] 17. 45
1907	256, 314	[a] 4, 306, 000	[a] 16. 8
1908	465, 870	[a] 8, 155, 000	[a] 17. 5
1909	605, 055	10, 212, 628	16. 85
1910	701, 315	10, 154, 790	14. 48
1911	767, 272	9, 654, 053	12. 58
1912	672, 248	8, 611, 720	12. 81
1913	300, 903	4, 369, 000	14. 52
1914	458, 609	5, 695, 737	12. 42
1915	612, 831	7, 886, 579	12. 87
1916	651, 079	9, 267, 738	14. 23
1917	691, 263	8, 667, 441	12. 54
1918	745, 722	9, 395, 968	12. 60
1919	465, 034	6, 380, 660	13. 72
1920	291, 508	4, 483, 129	15. 38
1921–1923		None.	
	9, 822, 740	146, 371, 443	14. 90

[a] Estimated.

SOUTH KEARSARGE MINE (KEARSARGE AMYGDALOID)

1900	5, 670	[a] 93, 000	[a] 16. 4
1901	59, 979	[a] 995, 000	[a] 16. 6
1902	160, 320	[a] 2, 839, 000	[a] 17. 7
1903	275, 440	[a] 4, 840, 000	[a] 17. 6
1904	348, 440	[a] 6, 737, 000	[a] 19. 3
1905	350, 560	[a] 6, 986, 000	[a] 19. 9
1906	392, 520	[a] 7, 789, 000	[a] 19. 9
1907	310, 925	[a] 5, 969, 000	[a] 19. 2
1908	392, 627	[a] 7, 273, 000	[a] 18. 5
1909	456, 380	8, 609, 666	18. 87
1910	450, 103	8, 168, 794	18. 15
1911	479, 324	8, 734, 140	18. 22
1912	458, 745	8, 322, 025	18. 15
1913	256, 233	5, 004, 000	19. 53
1914	388, 402	6, 303, 000	16. 23
1915	476, 185	7, 962, 824	16. 72
1916	408, 572	6, 968, 749	17. 06
1917	343, 254	4, 900, 781	14. 28
1918	218, 728	3, 271, 446	14. 96
1919	124, 107	2, 078, 445	16. 75
1920	71, 091	1, 311, 381	18. 45
1921–1923		None.	
	6, 427, 605	115, 156, 251	17. 91

[a] Estimated.

OSCEOLA MINE (OSCEOLA AMYGDALOID)

Year	Rock treated (tons)	Refined copper (pounds)	
		Total	Per ton
1879	36, 455	1, 226, 247	33. 6
1880	68, 000	2, 141, 000	31. 5
1881	160, 880	4, 176, 976	26. 0
1882	172, 529	4, 179, 782	24. 2
1883	175, 320	4, 256, 409	24. 3
1884	181, 608	4, 247, 630	23. 4
1885	72, 923	1, 939, 169	26. 6
1886	137, 725	3, 560, 786	25. 9
1887	145, 200	3, 583, 723	24. 68
1888	183, 036	4, 134, 320	22. 59
1889	175, 587	4, 534, 127	25. 82
1890	183, 825	5, 294, 792	28. 80
1891	234, 325	6, 543, 358	27. 92
1892	247, 575	7, 098, 656	28. 67
1893	236, 875	6, 715, 870	28. 35
1894	264, 050	6, 918, 502	26. 20
1895	233, 238	6, 270, 373	26. 9
1896	248, 062	6, 251, 304	25. 2
1897	310, 035	[a] 8, 241, 103	[a] 26. 6
1898	333, 710	[a] 7, 876, 297	[a] 23. 6
1899	363, 216	[a] 7, 203, 049	[a] 19. 8
1900	467, 074	[a] 8, 558, 471	[a] 18. 4
1901	507, 414	[a] 9, 049, 487	[a] 17. 8

[a] Estimated.

OSCEOLA MINE (OSCEOLA AMYGDALOID)—continued

Year	Rock treated (tons)	Refined copper (pounds)	
		Total	Per ton
1902	377, 520	[a] 6, 015, 396	[a] 15. 9
1903	297, 600	[a] 5, 123, 636	[a] 17. 2
1904	290, 120	[a] 5, 289, 429	[a] 18. 2
1905	275, 120	[a] 4, 959, 965	[a] 18. 0
1906	278, 520	[a] 4, 776, 451	[a] 17. 1
1907	244, 364	[a] 3, 859, 753	[a] 15. 8
1908	382, 903	[a] 5, 822, 794	[a] 15. 2
1909	433, 410	6, 474, 363	14. 94
1910	66, 302	1, 022, 982	15. 43
1911	None.		
1912	115, 564	1, 479, 642	12. 80
1913	177, 908	1, 952, 010	10. 97
1914	261, 436	2, 972, 000	11. 37
1915	272, 073	3, 882, 069	14. 27
1916	225, 030	3, 350, 014	14. 89
1917	203, 288	2, 516, 736	12. 38
1918	230, 517	3, 252, 233	14. 11
1919	150, 223	2, 365, 226	15. 74
1920	93, 383	1, 671, 263	17. 90
1921–1923		None.	
	9, 513, 943	190, 787, 393	20. 05

[a] Estimated.

SUMMARY

	Period	Rock treated (tons)	Refined copper (pounds)	
			Total	Per ton
Calumet & Hecla conglomerate	1874–1880, 1897–1903	977, 928	25, 056, 028	25. 62
Kearsarge amygdaloid	1897–1920	16, 250, 345	261, 527, 694	16. 09
Osceola amygdaloid	1879–1920	9, 513, 943	190, 787, 393	20. 05
		26, 742, 216	477, 371, 115	17. 85

Peninsula.—In Houghton County. Was Albany & Boston up to 1882, when it became Peninsula. Mine closed in 1892. Purchased by Franklin Mining Co. in 1894, after which known as Franklin Jr. mine. Output all derived from Allouez conglomerate.

Year	Refind copper (pounds)	Year	Refined copper (pounds)
1883	849, 400	1890	1, 108, 660
1884	1, 225, 981	1891 [a]	1, 599, 670
1885	None.	1892	973, 217
1886	131, 556		
1889	736, 507		6, 624, 991

[a] 99,591 tons stamped, yielding 16.06 pounds to the ton.

Peninsula.—In Ontonagon County. Organized July 30, 1850. A vein was worked to some extent in 1851. Abandoned by 1854, as there was little encouragement to go on. Produced 4,480 pounds of refined copper in 1851.

Pennsylvania (**Northwest**).—In Keweenaw County. Organized in 1861; 20,000 shares of $25 each. See Delaware.

Year	Refined copper (pounds)	Year	Refined copper (pounds)
1849	34, 322	1859	148, 144
1850	195, 020	1860	242, 097
1851	293, 199	1861	109, 920
1852	269, 174	1864	163, 960
1853	229, 077	1865	379, 369
1854	[a] 89, 208	1866	128, 090
1855	198, 080	1867	326, 660
1856	3, 348		
1857	58, 543		3, 034, 311
1858	166, 100		

[a] Estimated.

Petheriek.—See Ashbed.

Pewabic.—In Houghton County. Organized April, 1853. Tributers did some work beginning 1855. In 1868 Concord and Pewabic were consolidated. Mine leased from June, 1870, to July, 1874. Concord set off as a separate organization in 1879. Purchased by Quincy in 1891.

Year	Rock treated (tons)	Refined copper (pounds)		Silver sold
		Total	Per ton	
1855		22, 179		
1856		[a] 129, 546		
1857		236, 254		
1858		416, 603		
1859		[b] 1, 032, 087		
1860	([c])	1, 917, 426		
1861	38, 724	1, 849, 192	47. 8	$1,406.86 (1,382 ounces).
1862	37, 268	1, 571, 281	42. 2	$1,032.93 (919 ounces).
1863	37, 320	1, 691, 724	45. 3	$593.35 (428 ounces).
1864		1, 429, 857		
1865	39, 864	1, 731, 394	43. 4	$397.10 (270 ounces).
1866	51, 913	1, 346, 140	25. 9	$195.82 (116 ounces).
1867	46, 000	1, 646, 458	35. 8	
1868	42, 494	1, 043, 523	24. 6	
1869	43, 199	960, 409	22. 23	
1870		546, 616		
1871		444, 600		
1872		467, 000		
1873		572, 400		
1874		294, 607		
1875		625, 271		
1876		568, 995		
1877		693, 777		
1878		523, 826		
1879	7, 299	336, 519	46. 10	$94.33.
1880	33, 982	970, 509	28. 6	
1881	60, 427	1, 872, 878	31. 05	
1882	63, 592	1, 482, 664	23. 31	$753.97.
1883		1, 171, 847		$566.54.
1884		227, 834		
		27, 823, 416		

[a] Includes 21,879 pounds lost by shipwreck.
[b] Includes 2,138 pounds lost by shipwreck.
[c] Stamped 23,912 tons during 7 months and 22 days

Phoenix.—In Keweenaw County. Phoenix Consolidated Copper Co., organized April, 1399; 100,000 shares of $25 each. Comprised old Phoenix, Bay State, St. Clair, Garden City, and 80 acres of the old Atlas purchased in 1900. Successor of Lake Superior Copper Co., which was organized February 22, 1844; 1,200 shares of $100. Mining commenced October 22, 1844; abandoned in 1847; recommenced in 1850 and continued to February, 1853. A stamp mill was built in 1845, the first in the district, but proved a failure. In August, 1849, reorganized and Phoenix Copper Co. took over assets. Started work on Ashbed in 1855. In 1863 worked Phoenix and Robbins fissures. In 1871 Bay State property acquired. Worked on company account to 1883 and on tribute July, 1883, to 1886 Garden City worked 1859-1868. St. Clair operated 1865-1874 and 1880-1885. Work discontinued June 15, 1905. Resumed work on Ashbed October, 1913, and continued to December, 1917. Property sold to Keweenaw Copper Co. in 1923 and Phoenix Co. dissolved.

Year	Refined copper (pounds)	Silver sold
1846	8, 960	
1847	11, 200	
1852	15, 680	
1853	3, 427	
1855	6, 000	
1856	16, 000	
1857	34, 000	
1858	[a] 45, 000	
1859	56, 590	
1860	40, 062	
1861	68, 790	
1862	63, 590	
1863	144, 118	
1864	332, 775	
1865	[b] 244, 158	
1866	202, 000	
1867	196, 000	
1868	260, 000	
1869	796, 630	
1870	999, 000	
1871	1, 219, 862	$1,147.08 (878 ounces).
1872	728, 470	
1873	521, 081	$898.09 (681 ounces).
1874	1, 398, 440	$2,950.49 (2,250 ounces).
1875	1, 404, 276	$6,204.69 (4,732 ounces).
1876	1, 396, 530	$2,120.42 (1,841 ounces).
1877	1, 022, 493	$1,267.03 (1,100 ounces).
1878	301, 172	$777.12 (727 ounces).
1879	543, 426	
1880	436, 010	
1881	409, 357	
1882	537, 177	
1883	512, 291	
1884	621, 004	
1885	361, 108	
1886	101, 804	
1887	11, 000	
1900	88, 206	
1901	93, 643	
1902 [c]	100, 000	
1903	202, 823	
1904	1, 162, 201	$7,428.60 (13,375 ounces).
1905	273, 214	
1916 [d]	68, 880	
1917 [e]	380, 536	
1918	None.	
	17, 438, 984	

[a] Estimated to October 29.
[b] Includes 33,000 pounds from Ashbed.
[c] 15,200 tons on stock pile.
[d] October to December. Rock treated, 6,915 tons; yield, 9.96 pounds per ton.
[e] Rock treated, 41,148 tons; yield, 9.25 pounds per ton.

Pittsburgh & Boston.—See Cliff.

Pittsburgh & Isle Royale.—On Isle Royal.

Year	Refined copper (pounds)
1849	3, 360
1850	8, 960
1853	12, 410
	24, 730

Portage.—In Houghton County. Organized in 1852 and mining commenced in November of that year. See Grand Portage. Produced 6,608 pounds of refined copper in 1853.

Quincy.—In Houghton County. Incorporated March 30, 1848. In 1856 Pewabic lode discovered. New company formed under same name in 1878. Reincorporated in 1908. Absorbed Pewabic in 1891. In 1897 purchased Mesnard and Pontiac properties and increased their capital stock to 100,000 shares. Purchased old Franklin mine December 1, 1908.

Year	Rock treated (tons)	Refined copper (pounds)		Silver sold
		Total	Per ton	
1856		13, 462		
1857		122, 762		
1858		306, 772		
1859		357, 114		
1860		1, 140, 304		
1861		2, 564, 852		
1862	42, 633	[a] 2, 125, 000	[a] 49. 9	$517. 16
1863	50, 670	[a] 2, 420, 000	[a] 47. 8	369. 04
1864	47, 445	[a] 2, 400, 000	[a] 50. 6	
1865	48, 557	[a] 2, 200, 000	[a] 45. 3	364. 37
1866	49, 903	[a] 2, 300, 000	[a] 46. 1	280. 45
1867	37, 774	[a] 1, 800, 000	[a] 47. 7	
1868	36, 557	[a] 1, 500, 000	[a] 41. 0	605. 59
1869	59, 767	2, 460, 635	41. 2	588. 77
1870	55, 027	2, 572, 980	46. 7	717. 75
1871	59, 757	2, 338, 882	39. 0	287. 76
1872	60, 628	2, 276, 308	37. 5	535. 56
1873	64, 220	2, 800, 005	43. 6	562. 34
1874	67, 112	3, 046, 698	45. 4	990. 55
1875	71, 487	2, 892, 617	40. 5	770. 22
1876	74, 717	2, 949, 863	39. 5	930. 74
1877	73, 251	2, 720, 558	37. 2	407. 79
1878	61, 450	[a] 2, 900, 000	[a] 47. 19	
1879	59, 750	[a] 2, 800, 000	[a] 46. 86	784. 30
1880	84, 426	[a] 4, 000, 000	[a] 47. 38	1, 287. 83
1881	98, 869	5, 702, 606	57. 7	2, 280. 94
1882	101, 327	5, 682, 663	56. 08	3, 142. 83
1883	97, 100	5, 549, 087	57. 14	2, 482. 96
1884	99, 196	5, 680, 087	57. 26	3, 638. 01
1885	108, 181	5, 848, 530	54. 06	2, 941. 25
1886	109, 702	5, 923, 519	54. 0	3, 349. 39
1887	94, 250	5, 609, 762	59. 52	3, 772. 12
1888	117, 514	6, 367, 809	54. 10	4, 173. 84
1889	117, 785	6, 405, 686	54. 38	2, 195. 87
1890	165, 140	8, 064, 253	48. 83	3, 826. 98
1891	263, 678	10, 542, 519	39. 98	3, 646. 98
1892	323, 051	11, 103, 926	34. 37	2, 263. 35
1893	422, 239	14, 398, 477	34. 10	
1894	454, 783	15, 484, 014	34. 04	3, 081. 86
1895	495, 402	16, 304, 721	32. 9	3, 745. 53
1896	555, 543	16, 863, 477	30. 35	22, 080. 42
1897	542, 623	16, 924, 618	31. 19	18, 024. 95
1898	543, 592	16, 354, 061	30. 08	29, 405. 60
1899	559, 164	14, 301, 182	25. 57	24, 490. 64
1900	558, 723	14, 116, 551	25. 26	25, 474. 00
1901	886, 266	20, 540, 720	23. 17	17, 170. 85
1902	953, 019	18, 988, 491	19. 92	16, 300. 00
1903	958, 935	18, 498, 288	19. 29	21, 000. 00

[a] Estimated.

Year	Rock treated (tons)	Refined copper (pounds)		Silver sold
		Total	Per ton	
1904	1, 018, 873	18, 343, 160	18. 00	$25, 758. 89
1905	1, 135, 162	18, 827, 557	16. 59	27, 077. 20
1906	1, 012, 178	16, 194, 838	16. 0	25, 358. 00
1907		19, 796, 058		
1908		20, 600, 361		
1909		22, 511, 984		
1910		22, 517, 014		
1911	1, 382, 524	22, 252, 943	16. 10	23, 005. 28
1912	1, 309, 253	20, 634, 800	15. 76	30, 227. 51
1913	804, 645	12, 184, 128	15. 2	20, 832. 79
1914	1, 016, 666	15, 356, 380	15. 1	12, 630. 00
1915	1, 269, 000	22, 054, 813	17. 4	11, 829. 08
1916	1, 204, 026	21, 065, 612	17. 5	26, 159. 19
1917	1, 277, 873	22, 195, 577	17. 3	
1918	1, 174, 147	19, 948, 965	16. 9	54, 680. 06
1919	960, 393	19, 476, 320	20. 3	[b] 89, 163. 30
1920	809, 263	19, 216, 070	23. 8	84, 379. 33
1921	767, 100	16, 960, 265	22. 12	[c] 60, 744. 46
1922	674, 499	15, 402, 726	22. 83	[d] 73, 751. 34
1923	546, 670	13, 000, 733	23. 78	[e] 76, 701. 81
1924	588, 100	14, 838, 633	25. 24	[f] 43, 074. 65
1925	586, 913	14, 357, 523	24. 46	[g] 53, 600. 38
		726, 000, 319		

[b] 133,050 ounces. [c] 146,774 ounces. [d] 150,139 ounces. [e] 115,137 ounces. [f] 118,478 ounces. [g] 139,498 ounces.

Rhode Island.—In Houghton County. Rhode Island Mining Co. organized about 1860 and worked Allouez conglomerate. Rhode Island Copper Co. organized 1898. First exploratory work done by Rhode Island Mining Co. 1864-65, extending a trench from a point west of highway east to Allouez conglomerate, which exposed all the lodes for that distance. No. 1 shaft started on Pewabic lode in 1898.

Year	Refined copper (pounds)
1903	[a] 24, 000
1906	[b] 7, 000
	31, 000

[a] Estimated from 31,611 pounds mass and barrel for the year.
[b] Estimated from 9,892 pounds mass and barrel for the year.

Ridge.—In Ontonagon County. Organized April, 1850. Worked five years; leased 1855-1863. In October, 1863, new company organized. Some work at intervals by tributers. Title lost in 1896 by failure of owners to pay tax. Later became part of Mass Consolidated Mining Co. Silver amounting to $254.55 sold in 1876.

Year	Rock treated (tons)	Refined copper (pounds)	Year	Rock treated (tons)	Refined copper (pounds)
1853		22, 400	1876	2, 178	290, 018
1854		[a] 37, 600	1877	2, 017	296, 815
1855		70, 631	1878	2, 565	251, 837
1856		73, 874	1879		215, 469
1857		58, 790	1880	3, 925	223, 353
1858		78, 690	1881	2, 300	235, 606
1862		[a] 40, 000	1882	1, 448	102, 936
1863		[a] 60, 000	1883		60, 155
1864		16, 917	1884		74, 030
1865		170, 433	1885		63, 390
1866		142, 411	1886		158, 272
1867		184, 037	1887		84, 902
1868		162, 037	1888		50, 924
1869		253, 840	1889		28, 000
1870		245, 400	1890		17, 645
1871		350, 150	1891		43, 049
1872		257, 910	1892		23, 611
1873		231, 140	1893		64, 363
1874		374, 113			
1875		328, 447			5, 443, 195

[a] Estimated.

Rockland.—In Ontonagon County. Organized September 27, 1853; 20,000 shares of $25 each. Stamp mill erected in 1855-56. In 1870 company shut down. Passed into hands of National interests. Worked by tributers more or less to 1880.

Year	Refined copper (pounds)[a]	Silver sold	Year	Refined copper (pounds)[a]	Silver sold
1854	34, 554		1869	119, 000	
1855	139, 801		1870	95, 000	
1856 [b]	282, 067		1871	60, 000	
1857	568, 264	[c] $143. 08	1872	51, 000	
1858	372, 647	[d] 116. 14	1873	23, 400	
1859	515, 788	[e] 72. 84	1874	45, 260	
1860	851, 945		1875	11, 440	
1861	688, 446	[f] 90. 66	1876	57, 600	
1862	455, 582		1877	38, 700	
1863	269, 043		1878	17, 877	
1864	521, 624		1879	1, 924	
1865	232, 173		1880	33, 800	
1866	116, 077				
1867	119, 634			5, 821, 136	
1868	98, 500				

[a] 1854–1863 and 1865–1867 are smelter returns.
[b] 1,700 tons of rock treated.
[c] 18 pounds.
[d] 16 pounds.
[e] 7 pounds.
[f] 10 pounds.

Saginaw.—On Isle Royal. Worked from 1875 to 1879. In 1877 produced 1,800 pounds of refined copper; in 1879, 49,464 pounds; total, 51,264 pounds.

Schoolcraft.—See Centennial.

St. Clair.—In Keweenaw County. Organized in 1863 and operated on fissure. Stamp mill erected in 1872 but not used, as work was suspended during panic of 1873, and property went into hands of creditors until 1879, when company was reorganized. Later became part of Phoenix Consolidated Copper Co.

Year	Refined copper (pounds)	Year	Refined copper (pounds)
1865	8, 815	1880	13, 195
1866	62, 200	1881	125, 493
1867	87, 723	1882	87, 126
1868	130, 665	1883	125, 225
1869	46, 197	1884	139, 407
1872	18, 072	1885	79, 686
1873	81, 867		
1874	5, 400		1, 011, 071

Seneca.—In Keweenaw County. Seneca Mining Co., organized March, 1860; dissolved October 10, 1918, all of its stock being conveyed to the Seneca Copper Corporation, which was incorporated in 1916 in New York. Mine closed in April, 1924. Seneca Copper Mining Co. incorporated February 27, 1925, and work resumed in November of that year.

Year	Rock treated (tons)	Refined copper (pounds)	
		Total	Per ton
1872		1, 603	
1877		7, 810	
1878		7, 809	
1920	21, 395	497, 680	23. 26
1921	14, 397	466, 323	32. 39
1922	8, 617	272, 182	31. 58
1923	21, 644	529, 189	24. 45
1924	82, 477	1, 796, 548	21. 78
1925	17, 313	284, 241	16. 4
		3, 863, 385	

Shelden & Columbian.—In Houghton County. Shelden Mining Co., organized in 1853. Albion Mining Co. conducted operations on this property in 1853. Work suspended in 1857. In 1860 the property was sold and the Columbian was organized; began work in June of that year; operations suspended in January, 1861, and resumed in November, 1862. In June, 1864, changed name to Shelden & Columbian Copper Co. Idle since 1870 except for some tributing.

Year	Refined copper (pounds)	Year	Refined copper (pounds)
1864	5, 496	1880	46, 931
1865	114, 200	1881	10, 031
1866	133, 497	1882	3, 299
1867	618, 946	1884	9, 828
1868	333, 118		
1869	186, 368		1, 463, 336
1878	1, 622		

Siskowit.—On Isle Royal. Work began on this location as early as 1845. Siskowit Mining Association commenced operations in summer of 1847. Siskowit Mining Co. of Michigan organized May, 1849, and resumed the mining operations which had been suspended by the association. Mine closed in 1855.

Year	Refined copper (pounds)
1849	31, 360
1850	30, 912
1851	37, 363
1852	62, 272
1853	28, 829
	190, 736

South Lake.—In Ontonagon County. Formerly known as Aztec; reorganized in August, 1909, as South Lake Mining Co. and capital stock increased to $2,500,000. Production ceased in July, 1918.

Year	Rock treated (tons)	Refined copper (pounds)	
		Total	Per ton
1915	3, 993	61, 637	15. 40
1916–17	68, 388	754, 433	11. 03
1918	7, 694	226, 141	28. 09
1919–1925		None.	
	80, 075	1, 042, 211	13. 02

Star.—In Keweenaw County. Began work in 1851 and worked until 1857. Resumed in 1864.

Year	Refined copper (pounds)	Year	Refined copper (pounds)
1855	1, 000	1872	535
1857	4, 778	1881	758
1858	9, 107		
1865	1, 760		17, 938

Summit.—See Madison.

Sumner.—See Hancock.

Superior.—In Houghton County. Organized July 23, 1904; 100,000 shares of $25 each. Mine closed November, 1920. Property purchased by Calumet & Hecla and company dissolved in 1925.

Year	Rock treated (tons)	Refined copper (pounds)		Silver sold
		Total	Per ton	
1908	962	21, 244	22. 08	
1909	81, 641	1, 781, 315	21. 82	
1910	140, 514	3, 181, 041	22. 64	
1911	162, 599	3, 236, 233	19. 90	
1912	172, 322	3, 921, 974	22. 76	
1913	130, 826	2, 992, 765	22. 87	$20, 478. 26
1914	191, 628	3, 217, 635	16. 79	16, 247. 05
1915	212, 051	3, 866, 484	18. 23	19, 404. 78
1916	185, 315	3, 034, 656	16. 38	
1917	129, 587	2, 201, 672	16. 99	8, 141. 48
1918	106, 213	1, 676, 446	15. 78	
1919	27, 267	563, 935	20. 68	
1920	9, 549	322, 871	33. 81	
1921–1925		None.		
	1, 550, 474	30, 018, 271	19. 36	

Superior.—In Ontonagon County. Organized in October, 1855; 20,000 shares of $25 each. Sold to Michigan in December, 1899.

Year	Refined copper (pounds)	Year	Refined copper (pounds)
1858	635	1867	36, 400
1859	1, 740	1868	56, 000
1860	10, 000	1869	4, 521
1861	54, 642	1876	3, 936
1862	70, 000	1877	5, 870
1863	66, 500	1878	1, 965
1864	56, 522	1879	1, 476
1865	89, 673		
1866	66, 000		525, 880

Tamarack.—In Houghton County. Organized January, 1882. Declared first dividend in 1888. Property sold to Calumet & Hecla Mining Co. on April 1, 1917, and company dissolved.

Year [a]	Rock treated (tons)	Refined copper (pounds)	
		Total	Per ton
1882	------------	[b] 363	--------
1883	------------	[b] 7, 435	--------
1885	36, 129	1, 979, 400	54. 76
1886	90, 587	4, 636, 521	51. 18
1887	144, 412	10, 389, 867	71. 95
1888	169, 250	11, 036, 469	65. 21
1889	155, 250	8, 928, 249	57. 51
1890	282, 987	14, 076, 957	49. 74
1891	338, 700	16, 805, 360	49. 62
1892	345, 925	16, 061, 106	46. 43
1893	393, 862	15, 580, 214	39. 4
1894	410, 250	13, 472, 818	32. 8
1895	229, 174	8, 022, 213	35. 0
1896	490, 625	16, 045, 039	32. 70
1897	611, 539	20, 222, 559	33. 07
1898	670, 832	19, 662, 545	29. 31
1899	631, 090	18, 565, 602	29. 42
1900	625, 422	19, 181, 605	30. 99
1901	626, 905	18, 000, 852	28. 72
1902	658, 720	15, 961, 528	24. 2
1903	657, 920	15, 286, 093	23. 2
1904	642, 320	14, 961, 885	23. 3
1905	750, 120	15, 824, 008	21. 1
1906	389, 680	9, 832, 644	25. 2
1907	533, 600	11, 078, 604	20. 8
1908	654, 897	12, 806, 127	19. 6
1909	689, 099	13, 533, 207	19. 6
1910	525, 554	11, 063, 606	21. 1

[a] Calendar years, 1882-1883 and 1896-1916; fiscal years (July 1 to June 30), 1885-1894; July 1 to Dec. 31, 1895; Jan. 1 to June 30, 1917.
[b] From shaft sinking.

Year	Rock treated (tons)	Refined copper (pounds)	
		Total	Per ton
1911	392, 338	7, 494, 077	19. 1
1912	421, 385	7, 908, 745	18. 8
1913	227, 563	4, 168, 743	18. 3
1914	57, 410	1, 074, 808	18. 7
1915	217, 027	3, 888, 150	17. 9
1916	363, 649	6, 618, 505	18. 2
1917	156, 920	5, 039, 995	13. 25
	------------	389, 215, 899	--------

Tamarack Junior.—In Houghton County. Organized in 1888. Absorbed by Osceola Consolidated Mining Co. in 1897.

Year	Refined copper (pounds)
1892	796, 769
1893	1, 610, 259
1894	2, 372, 302
1895	2, 547, 861
1896	2, 135, 000
	9, 462, 191

Tecumseh.—In Houghton County. Tecumseh Copper Co. organized in March, 1880. Consolidated with La Salle Copper Co. the later part of 1906. Produced 59,874 pounds of refined copper in 1906.

Toltec—In Ontonagon County. Organized in 1850. Began mining in July, 1851. In 1855 consolidated with Farm Mining Co. and became Toltec Consolidated Mining Co.

Year	Refined copper (pounds)	Year	Refined copper (pounds)
1853	6, 720	1859	32, 186
1854	[a] 13, 000	1860	7, 140
1855	[a] 106, 000	1866	12, 670
1856	118, 401		
1857	83, 036		379, 153

[a] Estimated.

Trimountain.—In Houghton County Organized January, 1899. Dissolved in 1923, mine being acquired by Copper Range Co.

Year	Rock treated (tons)	Refined copper (pounds)	
		Total	Per ton
1902	207, 956	5, 730, 633	27. 55
1903	507, 377	9, 237, 051	18. 20
1904	534, 640	10, 211, 230	19. 1
1905	570, 843	10, 476, 462	18. 36
1906	506, 924	9, 507, 933	18. 76
1907	444, 358	8, 190, 711	18. 43
1908	334, 929	6, 034, 908	18. 00
1909	323, 408	5, 282, 404	16. 33
1910	317, 299	5, 694, 868	17. 95
1911	347, 885	6, 120, 417	17. 59
1912	366, 663	6, 980, 713	19. 04
1913	229, 149	4, 990, 938	21. 78
1914	277, 251	5, 048, 306	18. 21
1915	349, 684	8, 302, 896	23. 75
1916	349, 504	8, 720, 558	24. 94
1917	264, 655	6, 278, 097	23. 72
1918	201, 433	5, 343, 586	26. 52
1919	171, 995	5, 274, 387	30. 66
1920	116, 768	3, 532, 025	30. 24
1921	143, 172	4, 341, 584	30. 32
1922	130, 913	4, 116, 100	31. 44
1923	6, 273	281, 482	44. 87
1924	8, 159	278, 259	34. 10
1925	35, 465	1, 065, 044	30. 03
	6, 746, 703	141, 040, 592	20. 90

Victoria.—In Ontonagon County. Mine first opened in 1849 as Cushin. Forest Mining Co. organized 1850. Glenn set off from Forest in 1852. Reorganized April, 1858, as Victoria Mining Co. Operated regularly 1850 1855, then at intervals until present company assumed control. Victoria Copper Mining Co. organized January, 1899, and work commenced in March of that year. Includes old Victoria, Glenn, Shirley, Sylvan, Oneida, and Arctic properties. Operations suspended July, 1904; resumed early in 1906. Idle since end of April, 1921.

Year	Rock treated (tons)	Refined copper (pounds)	
		Total	Per ton
1850	------------	6, 720	--------
1851	------------	3, 360	--------
1852	------------	8, 960	--------
1853	------------	41, 354	--------
1854	------------	[a] 93, 000	
1855	------------	[a] 178, 606	--------
1863	------------	7, 490	--------
1865	------------	581	--------
1866	------------	8, 360	--------
1868	------------	9, 820	--------
1870	------------	3, 570	--------
1871	------------	3, 903	--------
1872	------------	1, 890	--------
1876	------------	752	--------
1877	------------	861	--------
1878	------------	4, 052	--------
1904	------------	[b] 83, 442	
1906	39, 185	546, 334	13. 94
1907	95, 035	1, 207, 337	12. 7
1908	109, 015	1, 290, 040	11. 8
1909	118, 605	1, 062, 218	8. 96
1910	122, 497	1, 164, 564	9. 51
1911	126, 894	1, 303, 331	10. 28
1912	131, 955	1, 224, 911	9. 28
1913	137, 163	1, 428, 693	10. 42
1914	124, 842	1, 486, 242	11. 9
1915	133, 984	1, 499, 695	11. 1
1916	146, 690	1, 661, 832	11. 33
1917	137, 286	1, 612, 640	11. 75
1918	106, 730	1, 533, 536	14. 3
1919	89, 206	1, 245, 590	14. 0
1920	61, 031	1, 060, 829	17. 38
1921	20, 400	240, 000	11. 75
1922-1925	None.	None.	--------
	------------	20, 024, 513	--------

[a] Estimated.
[b] Sold in June. Represents mass and barrel taken out in running the drifts.

Vulcan.—In Keweenaw County. Operations commenced in 1864; 613 pounds of refined copper taken from openings.

White Pine.—In Ontonagon County. Organized in 1909; 150,000 common and 50,000 preferred shares; capital $5,000,000. Operations ceased in November, 1920.

Year	Rock treated (tons)	Refined copper (pounds)		Silver sold (ounces)[a]
		Total	Per ton	
1915	114, 039	2, 824, 145	24. 76	--------
1916	188, 890	4, 207, 449	22. 27	[b]73, 866
1917	212, 889	4, 067, 529	19. 11	[c]66, 933
1918	194, 568	3, 273, 680	16. 83	46, 188
1919	84, 008	1, 979, 268	23. 56	30, 877
1920	93, 260	1, 850, 787	19. 85	[d]38, 107
1921	--------	[e]30, 311	--------	4, 710
1922–1925	None.	None.	--------	--------
	887, 654	18, 233, 169	20. 54	260, 681

[a] 95 per cent of production.
[b] $62,131.83.
[c] $28,937.46.
[d] $39,356.16.
[e] Smelter clean-up.

Windsor.—In Ontonagon County. Worked in 1854-55 as a separate and distinct interest of the American Mining Co. of Vermont. Absorbed by Norwich in 1863. Prior to 1856 produced 68,000 pounds of refined copper.

Winona.—In Houghton County. Organized in April, 1864. Few shipments. In 1870 mine was let to tributers. Reorganized as Winona Copper Co. November 3, 1898. In 1911 absorbed King Philip Copper Co. Closed in May, 1920.

Year	Rock treated (tons)	Refined copper (pounds)	
		Total	Per ton
1902	3, 772	101, 188	26. 82
1903	51, 435	1, 036, 944	20. 16
1904	34, 030	646, 025	18. 98
1906	19, 399	278, 182	14. 34
1907	102, 100	1, 285, 863	12. 59
1908–1910	--------	None.	--------
1911	97, 445	1, 275, 675	13. 09
1912	181, 148	2, 307, 237	12. 74
1913	120, 806	1, 448, 737	11. 99
1914	123, 339	1, 352, 085	10. 96
1915	102, 594	1, 722, 638	16. 79
1916	161, 829	2, 167, 255	13. 39
1917	112, 083	1, 494, 472	13. 33
1918	--------	[a]756, 826	--------
	57, 837	819, 857	14. 15
1919	39, 654	561, 238	14. 15
1920	--------	430, 012	--------
1921–1925	None.	None.	--------
	--------	17, 684, 234	--------

[a] Produced by lessees.

Wolverine.—In Houghton County. Operated from January, 1882, to November, 1884. Reorganized as Wolverine Copper Mining Co. in August, 1890. Consolidated with Mohawk Mining Co. August 16, 1923. Mine closed April, 1925.

Year[a]	Rock treated (tons)	Refined copper (pounds)	
		Total	Per ton
1882	--------	25, 623	--------
1883	--------	699, 622	--------
1884	--------	800, 000	--------
1885	--------	370, 925	--------
1886	--------	83, 208	--------
1891	31, 524	500, 074	15. 86
1892	10, 491	218, 855	20. 86
1893	76, 440	1, 611, 857	21. 08
1894	90, 195	1, 744, 070	19. 33
1895	85, 155	2, 011, 638	23. 62
1896	82, 270	2, 237, 698	27. 20
1897	130, 089	3, 470, 927	26. 68
1898	184, 799	4, 700, 373	25. 43
1899	184, 594	4, 756, 646	25. 77
1900	190, 104	4, 907, 646	25. 81
1901	187, 482	4, 984, 367	26. 59
1902	279, 011	8, 260, 386	29. 60
1903	314, 091	9, 300, 695	29. 61
1904	321, 813	9, 729, 971	30. 23
1905	341, 820	9, 681, 706	28. 32
1906	344, 062	9, 372, 982	27. 24
1907	348, 860	9, 356, 123	26. 82
1908	373, 694	9, 995, 748	26. 75
1909	390, 837	9, 757, 101	24. 96
1910	388, 476	9, 617, 168	24. 75
1911	401, 308	9, 408, 960	23. 45
1912	388, 502	8, 350, 312	21. 49
1913	182, 127	3, 435, 459	18. 86
1914	397, 614	7, 250, 866	18. 23
1915	388, 898	6, 641, 492	17. 07
1916	352, 845	5, 856, 889	16. 59
1917	303, 498	4, 608, 865	15. 19
1918	298, 089	4, 562, 617	15. 31
1919	257, 294	3, 932, 225	15. 28
1920	263, 053	3, 640, 303	13. 84
1921	290, 419	3, 924, 270	13. 51
1922	244, 310	3, 544, 879	14. 51
1923	95, 408	1, 605, 121	16. 82
1924	205, 428	3, 265, 356	15. 90
1925	43, 663	574, 084	13. 15
	--------	188, 797, 107	--------

[a] Calendar years, 1882–1886 and 1924; 1891 includes Sept. 1, 1891, to April, 1892; 1892 includes May 10 to June 30, 1893; fiscal years (July 1 to June 30), 1893–1922; July 1 to Dec. 31, 1923; January to April, 1925.

Wyandot.—In Houghton County. Organized February 23, 1899; 100,000 shares of $25 each. Idle from September, 1914, to April, 1915. Closed late in 1917 or early in 1918.

Year	Rock treated (tons)	Refined copper (pounds)	
		Total	Per ton
1916	1, 605	19, 973	[a]12. 54
1917	1, 322	[b]20, 000	[b]14. 9
1918–1925	None.	None.	--------
	2, 927	39, 973	13. 66

[a] Tailings assay 5.26 pounds.
[b] Estimated.

OPERATING PRACTICE

An adequate discussion of the prevailing mining and metallurgical practice in the district at the present time by competent authority would make a very considerable report. Here it is intended only to give the reader a general idea of the methods used.

MINING

DEVELOPMENT

The ore bodies are tabular in form, average from 5 to 30 feet or more in thickness, and dip at angles of 30° to 72°.

All the lodes have been opened from the outcrops by inclined shafts sunk in or close under the lode and spaced, in modern operations, at intervals of 2,500 feet or more along the strike. In early operations the spacing was closer. The deepest of these shafts, which is on the Calumet & Hecla conglomerate, has a length along the incline of 9,065 feet and attains a vertical depth of 5,459 feet—that is, 4,815 feet below Lake Superior, or 4,213 feet below sea level. The Michigan copper properties are bounded on all sides by vertical planes. This has undoubtedly avoided many of the legal difficulties that have plagued western mining operations, but it has in places been a handicap to the most effective development.

To open the deeper portion of the Calumet & Hecla conglomerate ore body the old Tamarack Co. sunk five vertical shafts to depths of 3,409 to 5,308 feet and connected them on several levels by crosscuts. In the meantime the Calumet & Hecla Co. put down a deep vertical shaft, the Red Jacket, to serve its deeper levels. The vertical shafts are connected by crosscuts with the drifts on the lode. To reach deep parts of the Kearsarge amygdaloid, where the outcrop was owned by others, the Allouez and Ahmeek companies sunk four shafts at an angle of 10° from the vertical, curving the shafts into or parallel to the lode where this was reached. The Seneca Co. sunk a vertical shaft to the Kearsarge lode and curved it parallel to the lode. On account of low capacity and expensive maintenance the inclined shafts are less effective for very deep mining, and the Calumet & Hecla Consolidated Copper Co. is abandoning one after another of its deep inclined shafts on the conglomerate lode and is preparing to work at greater depth by subinclines from a main haulageway on the eighty-first level, which is tributary to the Red Jacket vertical shaft.

In the early days the distance between levels, measured down the dip, was usually 60 feet (10 fathoms); now the interval is 100 to 150 or even 200 feet.

An effective method of sampling the native copper deposits has not been developed. The choice of ground to be mined is made by the mining captains on the basis of visual inspection, aided by feeling, for the small rough particles of metal may be felt where they are not easily seen. The standards for judgment are empirical, subject to such checks as are afforded by the weekly or monthly mill returns on the ore from all stopes of a given shaft or of the entire mine. In general, any rock in which copper is detected by sight or touch goes as ore, and that in which none is so detected is not intentionally mined.

STOPING

Open stope.—Where the dip is between 35° and 45°, as it is in the mines near Calumet, the open stope is commonly used. A raise is put up to the level above, after which stoping proceeds, leaving a floor pillar under the level above and a sufficient number of round pillars in the stope to support the hanging wall. The commonest practice has been to advance these slopes outward from the shaft pillar to the limit of the ground tributary to the shaft, and before abandoning the level to recover as many of the pillars as can be taken out with safety; later still the floor pillars are removed provided they are rich enough to justify this independent operation. The more recent practice, however, carries the drifts to the limit farthest from the shaft and stopes on the retreat. In this way only enough pillars are left to give temporary protection to the breast of the stope, and as the stope retreats, all possible stope pillars and the floor pillars also are mined out. In either case no timber is used except in the construction of loading chutes.

In mining the deeper parts of the Calumet & Hecla conglomerate lode stope pillars are not used. Instead, timber stulls are used in sufficient number to afford a zone of protection near the breast of the stope, but as this zone moves along with the progress of the stope the timbers are removed, and caving of the hanging wall follows.

Room and pillar.—In the deeper levels of the Quincy mine, where the dip is less than 40° and the lode narrow, a modification of the open-stope method has been adopted to meet the condition of great rock pressure. The interval between levels is 200 feet; stopes 100 feet long are supported temporarily by short stulls and later are partly or completely filled with waste rock from development operations. Between the stopes pillars 100 feet wide are left extending through from level to level, as round stope pillars have been found inadequate. On the advance, therefore, something over 50 per cent of the lode is mined, the remainder being left for support to be recovered so far as may be possible on the retreat.

Shrinkage stope.—At the Isle Royale mine the dip ranges from 50° to 56° and is thus too steep to permit work in an open stope without timber. A timber bulkhead with numerous loading chutes is erected to separate the drift from the stope. Extraction is accomplished by inclined cuts; usually poor ore left unbroken affords sufficient support. The ore is allowed to accumulate to a convenient height, and the surplus is drawn off through the chutes. Upon completion of the stope all ore is drawn off and the stope is abandoned, beginning at the limits farthest from the shaft.

Horizontal cut and fill.—At the Baltic, Champion, and Trimountain mines the dip approximates 70° and the lode is unusually wide. Two dry walls with openings for loading chutes are constructed of waste rock and covered with timber, forming a haulage way along the center of the lode on the level. As waste from mining operations accumulates behind and above these haulage ways circular dry-walled mill holes are extended upward from the loading chutes and kept even with the top of the fill. Stoping is carried on by horizontal cuts worked from the top of the fill. As each round is blasted down the broken rock is sorted by handling and visual inspection, the ore is thrown into the mill holes, and the reject is left to constitute the filling. Where the lode is rich and the amount of reject therefore inadequate to maintain the fill at a proper height additional filling material is obtained by exploratory stoping along the footwall and by blowing in wet mill tailings shot down from the surface. Floor pillars below the fill of the overlying lavel are supported by large timber cribs and are then sloped by inclined cuts from under the pillar.

The size of shaft pillars varies with the depth. In some of the old inclined shafts no shaft pillars were left in the upper levels of the early days. As the shafts were deepened pillars were left, say, 50 feet wide or sometimes less, on each side. At still greater depths the shaft pillars were made 100 feet wide on each side, and now, in certain shafts at the deepest levels, 200 feet is left for each pillar, or a total block of 400 feet, for the shaft. Where the shafts are carried in the footwall of the lode shaft pillars are not necessary, and by some it is regarded as better not to leave pillars in the lode over the shaft.

TRANSPORTATION

The ore is drawn from the stopes through chutes of varying design and construction into cars, which are commonly of several tons capacity. In the flatter stopes drag-line scrapers are used for moving the ore down the footwall. By the use of long platforms erected over the track scrapers are also used to some extent for loading cars where no chutes are provided, as in the deep levels of the Calumet & Hecla conglomerate, and for mucking in drifts. The so-called mucking machines and other forms of mechanical shovels have gained little foothold in this district.

Power has largely displaced handwork for tramming. At most mines the cars are dumped directly into the skip, but at the Quincy and Seneca mines skip pockets are used. Hoisting is, of course, in balance, except in some of the old inclines. Each shaft is equipped with a rock house containing grizzlies and crusher, so that about 4 inches is the maximum size of material delivered to the railway cars for transportation to the stamp mills.

UNDERGROUND CONDITIONS

The mines of the district are notably clean and comfortable. Natural ventilation commonly suffices, even in the deepest workings, to maintain the air clear, fresh, and cooler than the adjacent rocks. The rock temperature is low. A compilation of existing data on rock temperature by C. E. Van Orstrand, of the United States Geological Survey, gives the following gradients of increase with depth:

From 60 to 1,080 feet 1° F. to every 99.1 feet.
From 60 to 1,915 feet 1° F. to every 105.6 feet.
From 60 to 3,090 feet 1° F. to every 119.3 feet.
From 60 to 5,367 feet 1° F. to every 117.4 feet.

The rock temperature on the eighty-first level of the Red Jacket shaft In the Kearsarge lode, at a depth of approximately 4,900 feet, as determined by Mr. Van Orstrand, is 86.2° F. It seems evident that, so far as temperature is concerned, mining may be extended much deeper without any such serious inconvenience as has been encountered, for example, in the deep St. John del Rey mine, in Brazil.

Except in the upper levels, where water is plentiful, the mines are strikingly dry. So far as possible water is caught and pumped from shallow depths, but some escapes and flows down the shafts and accounts for the greater part of the water encountered at depth. Away from the shafts the workings are dusty, and water has to be piped from the surface for use in the Leyner drills; otherwise the air of the stopes would be filled with dust. Occasional drops accumulate on the roofs of drifts, but rarely is there enough water to drip. Even in newly opened ground only a little water is encountered, and that quickly drains out. The expense of pumping, then, is relatively low. In the Calumet & Hecla mine, with over 200 miles of drifts and shafts and practically continuous stopes covering between 2 and 3 square miles on the plane of the lode, the total pumping duty amounts to only 1,200 gallons a minute, notwithstanding the fact that removal of so much ore during 60 years of operation has caused much fracturing, crushing, and caving of the hanging wall and thus has made the rocks much more permeable than they were before mining began. The drift cover of the district may contain much water, and if the mine workings break through to the drift a considerable flow of water may result, as occurred in the Champion mine in 1924.

MILLING

Nearly all the ore mined from the district is sent to the stamp mills. The exceptions are the “masses”[3] encountered in the lodes and commonly in the cross fissures; these are sent direct to the smelter. In all the mills the ore is first crushed by steam stamps of large capacity. Then follow successive concentrations and crushings, involving ball mills, rod mills, and jigs and tables. Flotation follows gravity concentration in the Calumet & Hecla and Quincy mills, and ammonia leaching is the final stage in the former. By the best practice a recovery of 95 per cent is obtained. The copper content of the mill concentrates or “mineral” ranges from 50 to 75 per cent and averages about 60 per cent.

A recent development of technical and economic interest is the reworking of the great tonnage of old conglomerate mill tailings accumulated in Torch Lake near the Calumet & Hecla and Tamarack mills. The mill records of tonnage and copper content of the tailings produced yearly for over half a century gave a basis for computing the copper contained in the entire mass. Both tonnage and metal content were checked by elaborate sampling, and the figures thus obtained were in striking agreement with those derived from the mill records. The winning of copper from these tailings will require many years at the present rate of production. The tailings are elevated by suction dredge and pumped to a plant on shore, where crushing, concentration, flotation, and leaching are employed, with a very satisfactory recovery. The cost per pound of producing copper from these tailings is the lowest in the district.

[3]Several types of material produced at the mines and mills are known by local terms. "Mass" copper consists of the large bodies of copper found in the fissures and in some of the lodes, ranging in weight from 100 pounds or less to hundreds of tons. Smaller bodies of copper that were separated from the rock were formerly stored and shipped in barrels and were consequently known as "barrel" work, and this term is still used. Rock containing small bodies of copper sent to the mills for separation is known as "mill" rock. The concentrate from the mill rock is known as "mineral." "Ore" as used locally in the district refers to the sulphide and arsenide minerals, but this use of the term is not followed in the present paper.

As the copper is coarser and the rock softer in the amygdaloid than in the conglomerate lodes, the former have always yielded a larger proportion of their copper to initial treatment. Re-treatment of amygdaloid tailings is therefore not yet feasible.

SMELTING

The copper in the product delivered to the smelters is already almost wholly in the metallic state and forms from 50 to nearly 100 per cent of the product, the proportion depending on whether it is mill concentrate or mass copper of the lower grades. The smelting process is therefore simple in principle, but, as most of the product is furnace-refined, and the standard of quality for Lake copper is high, much care is exercised in the smelting operations. Copper that carries a sufficient amount of silver to make the separation and recovery of this metal profitable is refined electrolytically. Electrolytic refining has been used also in order to purify some of the copper containing small amounts of arsenic, but in recent years nearly all of the arsenical copper is furnace-refined and sold for special uses. Lake copper has long been regarded by some consumers as excelling in certain qualities and has commanded a premium over electrolytic copper.

COPPER DEPOSITS

PRINCIPAL TYPES

The copper deposits of Keweenaw Point are commonly divided into two broad groups—lode deposits and fissure deposits. The lode deposits comprise conglomerate lodes,[4] mineralized beds of felsite conglomerate interstratifled with the lavas, and amygdaloid lodes, the mineralized vesicular, brecciated, or "scoriaceous" tops of the lava flows.

The fissure deposits are veins along fractures that parallel or cross the beds. A subtype of the conglomerate lodes is represented in the Porcupine Mountain region by mineralized beds of sandstone and of shale.

All the deposits are thus of tabular form. There are no irregular bodies, large in all dimensions, like those of the well-known low-grade disseminated deposits of copper in other regions.

In the lode deposits and most of the larger fissure deposits the copper is in the metallic state, some of it slightly arsenical. A few of the larger fissure deposits carry copper-rich arsenides, and many of the smaller ones carry the copper-rich sulphide chalcocite. Copper arsenides and sulphides are rarely and sparingly present in the lodes independent of fissures.

[4]The term "lode" as thus used in the region denotes an ore zone parallel to the rock bedding and made up largely of the rock itself—a restriction of the general structural significance of the term as applied to an ore deposit of tabular form.

Although great masses of metallic copper, as much as hundreds of tons in weight, have been encountered in some of the fissures and in certain of the amygdaloid lodes, the deposits as a whole are of low grade; the highest average yield for a year ever attained by the district as a whole was about 4½ per cent; for the last 10 or 15 years the average recovery for all the mines has been about 20 pounds to the ton, or 1 per cent, and that for certain individual mines as low as 11 to 15 pounds.

DISTRIBUTION IN THE KEWEENAWAN SERIES

The economically important known deposits with a single exception are confined to the portion of the Keweenawan series that is composed predominantly of lava flows, but they have a wide stratigraphic range within that portion. The principal productive lodes from the base upward are the Baltic amygdaloid, Isle Royale amygdaloid, Kearsarge amygdaloid, Osceola amygdaloid, Calumet & Hecla conglomerate, Allouez conglomerate, Pewabic amygdaloid, and Ashbed amygdaloid.

The fissure deposits are confined to the same stratigraphic portion of the series, though in the main the valuable fissure deposits and the lode deposits occur in different areas along the strike of the formation.

The exception to the distribution indicated above is the Nonesuch lode, in the formation of that name, well up in the sedimentary portion of the series. The mineralization at this horizon occurred mainly in sandstone, and to a less extent in shale. The abnormally high position of the lode in the Keweenawan rocks is probably due to the presence of intrusive rocks in the near-by Porcupine Mountains.

CONGLOMERATE LODES

PHYSICAL CHARACTER

Much of what is said below regarding the conglomerate lodes is based on observation of the Calumet & Hecla conglomerate, which has been the most closely studied. Most of the other conglomerates, though they have been less thoroughly explored, appear to resemble it in their essential characters. The conglomerates are composed mainly of siliceous material, chiefly felsite and quartz porphyry. They contain few boulders more than a foot in diameter, and for most of the Calumet & Hecla conglomerate the largest pebbles are considerably less than a foot in diameter. The matrix consists of fine material of the same general composition as the pebbles. Where the Calumet & Hecla conglomerate thins to 5 feet or less it is not a true conglomerate but a rock of finer texture ranging from coarse grit to sandstone. The horizon of this conglomerate, recognized for many miles along the strike, is marked chiefly by red or brown basic shaly to sandy sediment with some felsitic sand. Near Calumet it opens out rather abruptly into a lens of typical felsite conglomerate, pitching to the north at an angle of about 35° and broadening and thickening down the dip. Where truncated by the erosion surface the lens has a horizontal extent of about 10,000 feet. On the seventy-fifth level a similar section measures 17,000 feet, and it apparently continues to broaden as it goes deeper; the lowest workings, at the ninety-third level, have not yet been extended to its lateral limits. Within the limits of exploration the thickness of the conglomerate ranges from 5 feet or less near the margins and 10 or 15 feet where the axis reaches the surface to 30 feet and more along the axis of the lens on the lower levels. In other words, the area of a given section of the lode increases from the surface downward to the present depth of development.

Explorations along the horizon of the Calumet & Hecla conglomerate both north and south of the lens at Calumet have failed to disclose either another thick body of felsite conglomerate or any encouraging evidence, of mineralization.

The Allouez conglomerate is very similar in character to the felsitic portion of the Calumet & Hecla conglomerate, though much more persistent and over considerable areas much thicker. It is lenticular, however, in places pinching out completely or represented only by a thin clay seam. Such clay seams have been called “slides” and interpreted as faults, parallel or nearly parallel to the bedding, which locally have cut out the conglomerate. Similar clay seams are found where the conglomerate is present, and although they undoubtedly represent slipping, there seems to be no reason for believing that they have faulted out the conglomerate. It seems more likely, unless other evidence of important faulting is found, that the so-called “slides” represent areas where the conglomerate was not deposited.

The Kearsarge conglomerate in places closely resembles the Calumet & Hecla, but at several points where it has been opened, even, though much thicker than the Calumet & Hecla, it is composed mainly of relatively fine material and ranges from a fine conglomerate to grit and sandstone. No. 8 conglomerate is in general similar to the others. Where cut in the Arcadian workings it is somewhat mineralized.

The great conglomerate formations in the upper part of the Keweenawan series are in general similar in character to the lower beds, though in places, at least, they contain a larger proportion of basic material.

IRON CONTENT

The felsite conglomerates throughout the series are of strong dark-red color. This redness is a property both of the pebbles and of the finer matrix in which they are inclosed. The red color of the felsite and porphyry pebbles, like that of the massive bodies of felsite and porphyry in the district, is due to the presence of small crystals of hematite, which microscopic study of thin and polished sections shows to be an original constituent of the rocks. The available data indicate that these siliceous rocks of the Keweenawan series are relatively rich in ferric compared with ferrous iron, as is shown by the following determinations:

Iron in Mount Houghton felsite and in a felsite pebble from the Allouez conglomerate

	Fe_2O_3	FeO
Mount Houghton felsite	2.27	0.15
Do	1.72	.18
Do	1.44	.66
Felsite pebble from Allouez conglomerate	4.88	.58

The iron oxide in the finer part of the conglomerate and in the sandy bands is of two kinds—included plates of hematite in the grains of felsite, as just described, and irregular clastic grains of iron oxide that once were titaniferous magnetite. In the sandstone lenses the grains of oxide are in large part concentrated in layers of “black sand,” giving the rock a banded appearance; some of these grains, as seen under the microscope, are made up of limonite crossed by bars of ilmenite. In the thin conglomerate beds that mark the lower part of the series these grains consist mainly of hematite with similar ilmenite bars; very few of the grains are attracted by an ordinary magnet. Some of the iron oxide grains in the Great conglomerate, however, are distinctly magnetic and under the microscope are found to consist mainly of magnetite with bars of ilmenite; the magnetite is partly oxidized, but the ilmenite is unattacked. These facts suggest that the clastic grains of iron oxide were derived from the erosion of areas of basalt and that although the amygdaloid and trap were largely destroyed and dissipated (though perhaps represented in part by the red basic mud rock underneath the felsite conglomerates) the compact iron oxide grains, because heavy and chemically stable, were preserved and were accumulated with the felsitic debris.

Hematite, the prevailing oxide in the conglomerates, is not a by-product of copper mineralization; it is present in all the beds whether mineralized or not, and mineralization instead of producing it has destroyed it. (See p. 103.) The conglomerates, indeed, though not as rich in hematite as the amygdaloids, contained before mineralization a notable amount of ferric iron but, except for a few amygdaloid pebbles, very little ferrous iron.

The average amount of iron in the conglomerates has not been closely determined. A felsite pebble from the Allouez conglomerate was found to contain 4.88 per cent of Fe_2O_3 and 0.6 per cent of FeO. The iron content of the conglomerate is probably very close to 5 per cent of Fe_2O_3 and 0.6 per cent of FeO. Certain porphyry pebbles and boulders much higher in ferric oxide are of interest because of their especial susceptibility to copper replacement; those that have been peripherally or entirely replaced by copper form, respectively, the copper "skulls" and "boulders" so often described. One of these iron-rich pebbles gave 12.68 per cent of Fe_2O_3 and 1.30 per cent of FeO.

MINERALIZATION

MINERALOGY

The minerals that have been introduced into the conglomerate since its consolidation are few and of simple character as compared with the corresponding minerals of the amygdaloids. They all belong to the same general period of mineralization as the copper. The more abundant minerals, named in the order of their deposition, are red alkali feldspar, early; epidote and pumpellyite, mainly earlier than copper; calcite and quartz, throughout; copper; chlorite, associated with the alteration accompanying copper, especially in the iron-rich pebbles.

The zeolites and the allied minerals like prehnite are strikingly absent from the conglomerate; laumontite, though present in fissures in the adjacent trap, almost never persists where these fissures continue into the conglomerate. It is evident, therefore, that the zeolites were not a characteristic and necessary product of the mineralizing solutions but that their formation was primarily dependent on the nature of the rock through which the solutions passed.

ROCK ALTERATION

The copper occurs chiefly in the finer cementing material of the medium to coarse grained conglomerate. Undoubtedly in part it filled pore spaces in the sandy matrix of the pebbles, but mainly it replaced the cement.

The pebbles, especially those of dense felsite, are generally unreplaced, though here and there bleaching may affect their borders or extend through them along planes of permeability. A few pebbles of quartz porphyry were attacked by copper, but even where advanced replacement has occurred the phenocrysts of quartz and of feldspar remain. In some pebbles the feldspar crystals contain minute copper flakes, and the feldspars may have been attacked thus before the groundmass was replaced. Where iron-rich pebbles were partly replaced by copper, the ferric oxide was in part removed and in part reduced and recombined into chlorite, which is a conspicuous alteration product of such pebbles, as described by Pumpelly and Lane. In these pebbles, chloritized and partly converted to copper, crystals of barite may be present.

The most conspicuous alteration associated with the copper was a pronounced bleaching of the conglomerate from a rich brownish red to a light pink or salmon color. This change is recognized by all those working on the lode as an accompaniment of good ore and is so intimately and faithfully associated with copper from the largest masses down to microscopic particles as to leave no doubt that an intimate causal relation exists between the two. It resulted from the removal of a part, commonly a large part, of the hematite of the conglomerate with no very pronounced change in the other minerals. In the mineralized portions of the rock the fine material and the small pebbles are generally bleached entirely, but the larger pebbles may be bleached only at their margins, the centers remaining dark. This bleaching, as exemplified in the Calumet & Hecla lode, is somewhat more conspicuous in the lower part of the mine than in the upper part but is to be seen practically everywhere.

Alteration of another type, whose effects are most conspicuous in certain lenses of sandstone, converted a large part of the rock into pale yellowish-green epidote. This change resulted from a recombination of the materials originally present, together with a considerable addition of ferric iron. Evidence of alteration of this kind is to be seen especially in the sandy margins of the Calumet & Hecla conglomerate where it is thinning down.

DISTRIBUTION OF COPPER IN THE LODE

GENERAL CONTROLS

The following discussion applies directly to the Calumet & Hecla conglomerate, but in its general features it relates to the other conglomerate lodes in so far as they are known.

The copper occurs chiefly in the sandy matrix of the medium and coarser conglomerate. It may be present as small isolated grains, but more commonly it forms a spongy mass through the matrix; and in especially rich places the matrix has been largely replaced, so that the ore consists of abundant felsite pebbles in a cement of metallic copper. Deposition of the copper in the matrix, more than in the pebbles, probably was due to physical causes rather than to differences in composition. The contacts between the sand grains of the matrix and the smooth surfaces of the pebbles are much more permeable than the pebbles themselves and notably more so than the masses of closely packed grains in the midst of the sandy matrix or in the larger sandy lenses. Higher permeability means greater facility for the passage of solutions, and all the evidence indicates that the intensity of mineralization varied in proportion to the quantity of solution that passed through a given volume of rock. The rate at which copper was deposited by replacement of rock was proportionate to the rock surface exposed to replacement, and the ratio of surface to mass is higher in the sandy matrix than in the pebbles. Those two controls, then, were favorable to deposition of copper in the sand mixed with abundant pebbles but unfavorable to deposition where sand occurred alone.

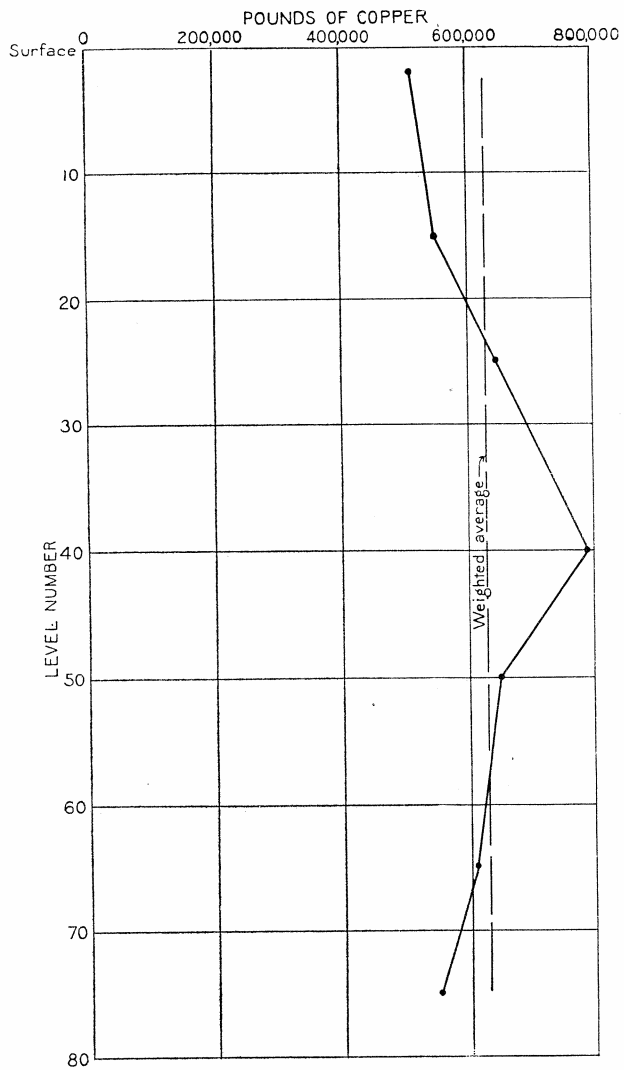

FIGURE 15.—Variation in copper content per foot of depth, Calumet & Hecla mine

Not only in detail but in a larger way the copper is distributed irregularly through the lode. The conglomerate is distinctly a banded rock, made up of layers or thin lenses that differ in texture. Certain of these bands are well charged with copper; others near by and apparently similar may contain little. This difference in intensity of mineralization from place to place is again not due to variation in composition but is an evident consequence of difference in permeability; the more permeable layers were channel ways for the solutions, and in these channelways more copper was precipitated.

In a given cross section of the lode, however, the most permeable layer may not always be the one most largely replaced. This may be the result of local causes. For example, solution that has entered a fairly permeable layer lying near the middle of the lode and bounded on each side by less permeable bands may continue along this channelway for some distance to a place where other layers are more permeable but are dammed off by less permeable bands. Farther along these more, permeable beds may be reached by the solution and may eventually become the principal channelways in a given stretch of the lode. The consequence is that the copper is found in overlapping streaks or lenses through the conglomerate bed.

The well-mineralized streak may occupy any position in the lode from footwall to hanging wall, and at places two or more good streaks may be present with lean conglomerate between. These well-mineralized layers may persist for long distances or they may be of relatively short extent.

RICHNESS IN RELATION TO DEPTH

In the deeper parts of the Calumet & Hecla mine, where the Calumet & Hecla conglomerate lens is broad and thick, the mineralized streaks and lenses constitute a smaller proportion of the conglomerate and the poor lenses a larger proportion. Higher up, where the conglomerate body is smaller and thinner, the richer streaks predominate over the poor ones. In consequence, the conglomerate as a whole is distinctly richer in the upper than in the lower part of the mine. The difference in grade, however, is due mainly to the fact that in the lower part a smaller portion of the lode has been mineralized rather than to any material difference in intensity of mineralization or abundance of copper in the part that has been mineralized. That is, if the mineralized lenses of the lower levels could be mined without inclusion of material from the unmineralized parts of the lode, the ore so obtained would compare favorably in copper content with that from higher levels, where the lode as a whole is much richer.

The richest rock in the Calumet & Hecla conglomerate, averaging about 80 pounds to the ton for yearly yield, was essentially at the present surface (see pl. 38), and there has been a fairly steady decrease in richness of the rock mined till at the present depth of operations the yield is 35 to 40 pounds. The axis of maxi-mum mineralization occupies a position about parallel with and a little above the axis of greatest thickness of the conglomerate lens. (See pl. 38.)

There is no considerable change in total quantity of copper at any given horizontal section from the top to the bottom of the mine—that is, horizontal sheets of unit thickness at the twenty-fifth, fiftieth, and seventy-fifth levels would each contain about the same quantity of copper. (See fig. 15.) But as depth is, attained and the conglomerate lens increases in size, essentially the same quantity of copper is distributed through a greater volume of rock, with resulting lower grade for the lode as a whole at the deeper levels.

In the upper levels, where the lode was relatively thin and the ore rich, the entire width of the lode was stoped, and all the copper that it contained was recovered, even though part of the thickness of the lode was too lean to pay provided it could conveniently have been left unmined. As the lode thickened and decreased in average grade lower down, streaks that were barren or too poor in copper to pay for handling were left unmined wherever they were thick enough or so related to the good ore as to make this possible. Because of the copper thus left the recovery from the lode at depth has been less than the recovery at higher levels, where all the lode was mined.

The actual decline in richness from top to bottom, viewed geologically, results apparently from the fact that as the solution rose through the conglomerate mass that contracted upward it encountered a constantly decreasing volume of conglomerate and consequently traveled through and mineralized a larger and larger proportion of it, until, near the present surface, the cross section was so reduced that nearly all the conglomerate was traversed and converted into ore. The inference is that had the Calumet & Hecla conglomerate maintained to the surface the same cross section as it has at depth, the ore near the surface would be of essentially the same grade as that at the deep levels. The inverted-funnel structure afforded by the conglomerate lens is a special case of the barrier condition, which is considered in more detail on page 115.

The Allouez is the only other conglomerate that has been explored to any great extent. It has been opened and mined at three localities—at the Franklin Jr., Allouez, and Delaware mines. The mineralization is very similar to that of the Calumet & Hecla conglomerate, but in all three places the conglomerate is rather thick, and only portions of it are mineralized. It has yielded on the whole a low-grade ore, though it contains lenses of good grade. A notable feature of the Allouez conglomerate is the unusual amount of chalcocite in it wherever it has been opened. This sulphide occurs characteristically intergrown with calcite in veinlets along joints; the calcite is dark because of its chalcocite content, and the metallic luster and streak of the sulphide are obscured by the calcite. Chalcocite occurs similarly though in lesser amount in the Kearsarge conglomerate and, indeed, in all others examined, including the Calumet & Hecla. In the latter it is apparently most abundant near the margins of the ore shoot, for it is relatively abundant on the dumps of the Centennial shafts and, to a less extent, on those of the Osceola shafts, at the north and south ends of the shoot, respectively.

SANDSTONE AND SHALE LODES

GENERAL RELATIONS

Sandstone and shale become increasingly abundant in the upper part of the Keweenawan sediments. They are plentiful in the Copper Harbor group and become dominant in the overlying Nonesuch, Freda, and Jacobsville formations.

The only formation that needs special consideration as a copper bearer is the Nonesuch. It consists prevailingly of red sandstone and shale, but in the Porcupine Mountain region it includes a considerable thickness of black, fine-textured shale that covers a considerable area. Immediately beneath this black shale the sandstone, in several localities at least, is gray instead of red. This gray sandstone and the black shale are the principal copper-bearing rocks of the Porcupine Mountain region. The old Carp Lake mine is high up on the north side of the uplift and at a lower horizon—namely, in red sandstone just below the Lake Shore trap.

Most of the exploration at the Nonesuch horizon has been done at the White Pine, Nonesuch, and White Pine Extension mines. These mines are several miles apart, south and southeast of the Porcupine Mountain uplift. The three deposits are near pronounced faults, and the ore bodies at White Pine, at least, are associated with minor cross faults and fissures.

The Porcupine Mountain uplift is probably due to a laccolithic intrusion either of the felsite that forms most of the range, which, however, is commonly regarded as a lava flow, or of coarser porphyry, of which small exposures are known. The fracturing and faulting in the surrounding rocks was, like the doming, a result of this intrusive action. Along the openings so produced the ore solutions probably ascended, and they may be regarded as having come from the same source as the igneous rock.

MINERALIZATION AND ROCK ALTERATION

In the sandstone, which is arkosic, copper occurs in the more permeable layers, especially those immediately under impermeable covers of shale. It has filled the pore spaces and partly replaced the less resistant grains and is present also along small joints arid fractures. The proportion of silver to copper is higher than in most other deposits of the district, and, in exceptional patches a few inches across, silver may quite displace copper and make up a considerable fraction of the rock.

Part of the gray sandstone of the Nonesuch formation has clearly been derived from the red by bleaching, as it repeatedly grades into the red. It is not so clear that the layer immediately under the shale was once red and has been bleached. This alteration can not be as definitely ascribed to copper mineralization as the bleaching in the conglomerates and amygdaloids lower in the series. It is believed, however, that the bleaching of the sandstone has been accomplished by sulphur-bearing solutions that deposited the copper. The sandstone that lies immediately below the shale is persistently gray wherever exposed, whether mineralized or not, though sandstones at other horizons are characteristically red except near mineralized rock, where they are bleached gray. The cause for this change of color can not be definitely assigned, but three possible causes have been recognized—namely, the action of bituminous matter from the overlying shales, of hydrocarbon entering the sandstone through the fault fissures, and of the solutions that deposited copper and chalcocite.

In the White Pine mine, where the gray rocks were most thoroughly examined, they contain a considerable amount of black asphaltic hydrocarbon, as well as of copper and of chalcocite. The hydrocarbon or the agencies that deposited it may have exerted a bleaching effect on the rocks. The distribution of both hydrocarbon and copper seems to be controlled by fissuring and by the permeability of the beds, so that in this small area wherever copper is present hydrocarbon is present also, and the influence of each on the iron oxide has not been clearly distinguished. The hydrocarbon appears to be earlier than the copper, for some of it has been partly replaced by chlorite, and some of the chlorite has been in turn replaced by copper. There is also the possibility that the black shale itself, which at the White Pine mine is bituminous, reduced the iron of the sandstone immediately underneath it and thus accounted for the bleaching in that layer. Hydrocarbon in the shale so far as known is confined to the White Pine area, where the fractures extend into the shale. It is possible that the hydrocarbon may have been distilled from the shale by the igneous intrusion, but it may have been introduced into both shale and sandstone from some outside source.

Irving[5] speaks of having observed cores of magnetite in the copper of the Nonesuch formation, and this statement has been frequently repeated. Nishio[6] examined specimens from this formation and failed to find magnetite. He did, however, find hydrocarbon with the relations that Irving had attributed to magnetite. Observations of the present writers confirm those of Nishio as to both the absence of magnetite and the presence of hydrocarbon.

[5]Irving, R. D., Copper-bearing rocks of Lake Superior: U. S. Geol. Survey Mon. 5, p. 132, 1884.

[6]Nishio, Keijiro, Native copper and silver in the Nonesuch formation, Michigan: Econ. Geology, vol. 14, pp. 124-134, 1919.

Another erroneous impression that may be gained from the literature is that the copper in the Nonesuch formation occurs mainly as chalcocite; this belief probably resulted from mistaking hydrocarbon for chalcocite. Samples of all grades of concentrates from the White Pine mill in December, 1918, as reported by Mr. George L. Heath, indicate that about 98 per cent of the copper is native and about 2 per cent occurs as sulphide. This proportion of sulphide, however, is much more than is shown in the conglomerate and amygdaloid lodes.

At the Carp Lake mine the red sandstone immediately below the Lake Shore trap has been mineralized locally from a few inches to a few feet below the base of the trap, and in these places it has been bleached to a gray color. The copper in the bleached sandstone is metallic copper, at least in large part. The bleaching of the red sandstone seems clearly related to the copper. On the dump of the tunnel is fissure material consisting of ankerite or some mixed carbonate containing plentiful chalcocite. In the Carp Lake occurrence no hydrocarbon was noted.

AMYGDALOID LODES

TYPES OF AMYGDALOID

Three types of amygdaloidal tops of flows have been recognized—banded cellular; brecciated, including some that combine both brecciated and nonbrecciated amygdaloid; and scoriaceous amygdaloid. These types differ from one another in those physical and chemical characters, especially in degree of permeability and hematite content, that determine the extent to which they are likely to be impregnated with copper. The banded cellular amygdaloid is common in the flows of the district, but it is not important as a copper producer except in the coalescing type. Scoriaceous amygdaloids have been still less productive. The brecciated amygdaloid is the dominating type as regards copper production, and it will be described first; the other types will then be contrasted with it.

BRECCIATED AMYGDALOID LODES

PHYSICAL CHARACTER

The structural and textural characteristics of the lava tops that were brecciated during solidification are described on page 29. Their chief features that concern ore deposition are variation from place to place in degree of fragmentation—they range from layers of nearly massive material 3 or 4 feet thick to thoroughly brecciated layers 6, 10, 20, and even 50 or 60 feet thick; chilled or finer-grained borders for many of the fragments, especially near the top of the flow; and a high degree of vesiculation of most of the fragments. As a rule, the thick parts of these tops are well brecciated and therefore highly permeable; the thin parts are relatively dense and impermeable; the change from one to the other type may be gradual or abrupt. Commonly the thick breccia tops bulge up into the overlying trap and down into the underlying flow; the thin lode breccia, on the contrary, is pinched between a sag of the overlying trap and an upward bulge of the underlying trap. The presence of bars or slabs of trappy rock in the midst of the breccia gives in places the effect of a double lode.

The brecciated amygdaloid type is well represented by the Osceola, Isle Royale, and Baltic lodes. The Kearsarge lode, which represents a transition to the banded cellular type (see p. 30), has been subdivided into brecciated amygdaloid, intermediate somewhat broken cellular amygdaloid, and unbroken cellular foot amygdaloid.

IRON CONTENT

The red color shown by the tops of all the flows is especially conspicuous in those of the brecciated type.

It is believed (see p. 34) that the countless tiny plates of hematite to which this red color is due were formed before the copper mineralization, having been produced while each flow was solidifying, whereas the copper was introduced after all the flows and sediments of the series had accumulated and had been tilted. In the amygdaloids, as in the conglomerates, the red color is present throughout the known extent of the lodes, continuing far beyond those relatively small parts of the lodes where copper has been deposited in important amount.

The percentage of ferric iron as hematite in these brecciated amygdaloids exceeds the total percentage of iron in deeper parts of the corresponding flows—in some places by as much as 40 per cent.

MINERALIZATION

Mineralogy.—The mineral composition of the top rock before it was acted on by the ore solutions was simple. Feldspar, hematite, and glass or its devitrified equivalent were the chief constituents. After the action by the ore solutions, however, the mineralogy was varied and complex. By far the greater number of the long list of mineral species found in this district were produced in these permeable lava tops by heated solutions. Most of these minerals are either present in small amount or are not intimately and significantly associated with the copper. Some characteristically fill vesicles, others occur chiefly in cracks and fissures, still others have replaced the rock material, and most varieties occur in all these ways.

The minerals most intimately associated with the copper are quartz, calcite, epidote, pumpellyite (a greenish fibrous or prismatic mineral which resembles zoisite and which was called zoisite in making the records of drill cores), chlorite, red feldspar, and prehnite. Datolite accompanies the copper in parts of the Pewabic, Osceola, Isle Roy ale, and Evergreen lodes. Sericite is present plentifully in the Isle Royale lode but is not intimately associated with the copper. It is locally abundant in the Baltic lode with similar relations. Ankerite is abundant in parts of the Baltic lode. The hydrous magnesium-aluminum silicate, saponite, is common in some of the rich ground, especially in the Kearsarge lode.

Analcite is rather widespread but rarely plentiful and as a rule not closely connected with the copper. Apophyllite is found sparingly with copper in the Phoenix mine on the Ashbed lode. Laumontite is the most abundant of the zeolites. It occurs mainly in fissures with little or no copper, and where it is locally abundant in amygdules the lode is generally poor; the mineral is regarded by the miners as a bad sign and apparently justly so. All told, the zeolites play a distinctly subordinate and inconsequential part in the mineralogy of the deposits. Prehnite and datolite, hydrous silicates transitional in character toward the zeolites, are far more intimately connected with the copper.

Sulphides and arsenides of copper are present in veins that cut the lodes at various angles. So also is native copper. The copper of some of the lodes is somewhat arsenical, but in a lode of low arsenic content the proportion of arsenic may rise perceptibly in the lode copper close to an arsenide vein. Native silver is present along with the copper in all the lodes, generally in amount too small to pay for separation, but in some of the lodes or parts of them, especially the Pewabic, it adds in appreciable degree to the value of the product.

Rock alteration.—Alteration of the lava tops, the filling of the vesicles to form amygdules, and the cementation of the breccias were effected at the same time and by the same solutions. The vesicles were still unfilled when mineralization began, for pebbles of amygdaloid included in the felsite conglomerates contain clastic sand grains in their peripheral vesicles, and this sand has been partly replaced by the same minerals that filled the interior vesicles. Each of the minerals in the amygdules is present between fragments and replaces rock material; conversely all the minerals that replaced the rock after the magma tic stage are found also as breccia cement and as amygdule fillings; and all the minerals of the fissures have also replaced rock, cemented breccia, and filled vesicles. Very commonly the material of the amygdule continues beyond the original vesicle boundary, having partly or completely replaced portions of the rock. The cementing of the breccia has also been accomplished largely by replacement of much of the finer material between the larger fragments, though there has been some filling of open spaces.

The most common and abundant minerals of the amygdules are calcite, quartz, epidote, pumpellyite, chlorite, and copper. Epidote and copper favor the upper parts of the lode, or those which were richest in ferric iron; chlorite and pumpellyite are more abundant in the lower parts of the lode, near the horizon where it grades into trap. The same minerals, with the addition of sericite in the Isle Royale lode, are the chief constituents of the breccia cement and of the replacement products. Thus it is evident that the three processes of vesicle filling, breccia cementation, and rock replacement were inseparable and interrelated and were associated with the deposition of copper.

In all the amygdaloid lodes, as in the conglomerate lodes, the most conspicuous alteration of the country rock accompanying the deposition of copper was a pronounced bleaching of the red color. Along with this destruction of the red color, which was due to removal of hematite, the rock suffered an even more profound alteration. This occurred around the copper in all the amygdaloid lodes, and in general the same minerals have resulted in all, though there is a marked difference in the proportion of the several alteration minerals in the different lodes and even in different parts of the same lode. Two general types of bleaching are recognized and have been called, from lodes in which each is characteristically shown, the Kearsarge type and the Isle Royale type, or, in descriptive terms, the iron-removal type and the quartz-pumpellyite type. Only here and there was copper deposited in red rock without attendant alteration and bleaching of one or the other of these types, but the deposition of copper occurred at places in the dark part of the lode near the underlying trap without bleaching, though accompanied by rock alteration.

The alteration typical of the red, brecciated upper portion of the Kearsarge and other highly oxidized lodes effected a destruction of hematite and the formation of epidote, calcite, pumpellyite, chlorite, and quartz. The rock around the copper was bleached to a light-gray color of greenish or pinkish cast and commonly somewhat softened; areas rich in copper are thus conspicuous. The copper has been formed largely by replacement of the rock, and apparently having once started to form at a given place, it continued growing till considerable lumps were accumulated. The copper has clearly replaced the altered rock in the bleached zone around it. Roughly, the diameter of a bleached zone is three to four times the diameter of the copper which it surrounds, but both the copper and the bleached zone are very irregular.

In the Isle Royale lode and in many of the lodes in the south end of the district the alteration has resulted in a characteristic grayish-green rock of hard, compact texture composed mainly of pumpellyite, epidote, calcite, and quartz. The pumpellyite is the most abundant mineral and gives the color to the rock. The copper occurs in the midst of the bleached rock into which it grew, as in the Kearsarge type. Bleached rock of this type is conspicuous in the Baltic lode and, with more quarts and less pumpellyite, in the Pewabic lode.

Alteration of a third type occurred in the dark-colored basal portion of the Kearsarge lode and more or less commonly in the other lodes. In the rock thus altered chlorite is abundant and intimately associated with the copper, which occurs mainly in amygdules, producing "shot copper," but also forms films or plates along joints. Red feldspar may be plentiful in places. There has been no conspicuous bleaching, mainly because the rock near the foot of the lode was never very red, and because chlorite, the predominant alteration product, is dark like the trap, and epidote is far less common than in the upper red parts of the lodes, where it seems to have been formed through a recombination of part of the ferric iron. The lower few inches of the overlying trap generally shows alteration of this chloritic type, and in places a very little copper is present.

CELLULAR AMYGDALOID LODES

The only lodes of the cellular type that have been extensively mined are the Pewabic amygdaloid lodes. These lodes belong to the "coalescing" variety of the cellular type; they are composed of layers in which amygdules are relatively scarce, alternating with layers in which the gas bubbles were so abundant that they coalesced so as to form irregular flat cavities. These cavities are filled with vein minerals, and the lode has the appearance of a banded vein. In places these cavities extend continuously in a cross section of the lode for as much as 10 to 15 feet, though their average extent is much less. (See pl. 58.) In the plane of the lode some of these openings must have been continuous for tens and perhaps for hundreds of feet. The Pewabic lodes are characterized by this type of top, but they contain large areas of fragmental top and some of the more ordinary type of cellular top. This "coalescing" type of flow is commonly flat-surfaced. The drifts in the Quincy mine that follow the narrow lodes are essentially straight for hundreds of feet and contrast strikingly with drifts following the tops of fragmental lodes.

It is evident that the coalescing top, with its long continuous openings, would be relatively permeable and permit the passage of large quantities of mineralizing solutions.

The coalescing Pewabic lodes are of a brownish color where least mineralized but distinctly less red than most of the fragmental lodes, including the fragmental areas of the Pewabic lodes. They are probably less completely oxidized than these other lodes, though some of the difference in the color may be due to the coarser grains of the hematite.

In the coalescing Pewabic lodes quartz and pumpellyite are the characteristic minerals, though calcite and epidote are not rare. The rock alteration is of the quartz-pumpellyite type, and the lode is consequently hard. Bleaching is not as pronounced as in most of the other lodes. An unusual amount of the copper occurs in masses, some weighing many tons, that characteristically lie parallel with the lode and are associated with strongly developed amygdular bands. Most of the copper, however, occurs in small grains scattered throughout the amygdaloid, much of it having replaced the rock. The fine copper is also commonly associated with strong amygdular bands.

In the fragmental Pewabic lodes bleaching is more pronounced and is in part of the iron-removal type. In the upper levels of the Quincy mine, probably in the fragmental lode, nodular masses of porcelanic datolite were present. No datolite was noted in the deeper levels.

SCORIACEOUS AMYGDALOID LODES

The Ashbed lode, which has been most productive in the Atlantic mine but has also yielded copper in the Phoenix mine, near Eagle River, and in the Copper Falls nine, farther north, is the principal representative of the amygdaloid lodes of scoriaceous type. Other examples of this type are numerous but so far as known contain little copper.

As none of the mines on the Ashbed lode are active there has been but meager opportunity to examine the lode. Apparently it varies much from place to place.

In the Atlantic mine its character is apparently rather typically "scoriaceous," as described on page 176. It is composed of amygdular fragments cemented with brown to red sediment and is distinctly soft. The copper was distributed rather uniformly through the rock, and its deposition was accompanied by rather feeble bleaching.

In the Phoenix mine the upper or “gray” lode appears to be similar in character but the lower or “red” lode is possibly less scoriaceous.

At Copper Falls much of the amygdaloid is apparently rather typically fragmental, though containing some sediment. It is well oxidized, and bleached rock of the iron-removal type is conspicuous in association with the copper.

DISTRIBUTION OF COPPER IN AMYGDALOID LODES

DISTRIBUTION OF SHOOTS IN THE LODES

None of the important amygdaloid lodes are mineralized over more than a small part of their known extent. The Kearsarge lode has been traced for 40 miles or more but is known to be commercially mineralized for only about 5 miles, though it contains notable amounts of copper for double that distance. The Osceola lode has been developed for but little more than 3 miles along the outcrop, although its length is known to be several times 3 miles. Similar conditions exist in the other lodes. The copper, then, is concentrated in shoots within the lodes.

With the possible exception of the Allouez conglomerate and the Ashbed amygdaloid, neither of which has been shown to be rich at any point, no lode is known to be commercially mineralized in two widely separated parts. This probably does not result from any fundamental cause but is the outcome of generalization from a small number of cases. It is frequently stated in the district that but one mineralized lode is to be found in any one section across the series. This statement, however, is by no means true, as is indicated by the overlapping of the Calumet & Hecla conglomerate and Osceola ore shoots. Moreover, in the closely spaced series of lodes, like the Pewabic amygdaloid lodes and the Evergreen and succeeding lodes, several ore shoots have been developed in the same cross section. Immediately above the main Baltic lode is an ore shoot in the Baltic West lode, and above the main Superior lode is an ore shoot in the Superior West lode. The distribution of ore bodies in each lode appears to be independent of the adjacent lodes and to be governed by local causes, which are discussed under “Causes of ore shoots” (p. 115).

DISTRIBUTION OF COPPER IN THE SHOOTS

Within the mineralized portion of a lode or what may be regarded as a major ore shoot, the copper shows considerable inequality of distribution, both in the plane of the lode and across the lode.

In drifting along the lode through a major ore shoot patches or zones of lean ground, in part too lean to be worked, are generally encountered. Some of these are areas in which the lode is thin; some occur along fractures or shatter zones. The areas of profitable ground between such lean areas may be regarded as shoots of a second order. An example is afforded by the rich South Kearsarge-Wolverine shoot, which lies within the main shoot that extends from Centennial to Gratiot on the Kearsarge lode. These better shoots differ greatly in size, but all are large as measured by the standards of the usual mining district. Their size, indeed, is generally so great that, although they have been developed to depths and lengths of several thousand feet, neither their shape nor the pattern of their distribution is satisfactorily known. There is strong indication, however, that many of the better shoots are of elongated shape and that some of them pitch rather steeply within the plane of the lode.

Variations across the plane of the lode permit closer investigation. The amygdaloid lodes are generally richest near the hanging wall and decrease in value toward the footwall. This is notably true of the Kearsarge lode. It is also true of the Osceola lode, though in the Osceola and Baltic lodes there are well-mineralized areas near the footwall.

The Pewabic amygdaloid lodes are narrow, and the variation in distribution of copper within them is not so noticeable. No definite information is available for the Ashbed lode. In the Isle Royale lode, in contrast to the others, the richest ground is pretty consistently along the footwall.

Permeability seems to have been a controlling factor in determining the place of deposition of copper in the lode. In general the top of an amygdaloid was the more permeable, and the greatest volume of solution passed through that part of the lode. In highly fragmental lodes some of the deeper parts are loose and permeable and therefore were well mineralized.

The reason for the reversal of the usual relation in the Isle Royale lode is not entirely clear. The cause that seems most likely is the presence of joints or shearing planes parallel to the lode near its base. These joints did not develop in the friable most thoroughly brecciated portion of the lode, and the presence of the mineralized zone in and near the joints along the footwall suggests that these fractures, which are continuous for long distances, made this the most permeable portion of the lode.

RICHNESS IN RELATION TO DEPTH

Several ore bodies in the district have given indication of decreasing copper content with increase in the depth to which they have been mined. The main Superior lode and the Superior West lode were found too poor in depth to justify continued operations, and the Calumet & Hecla conglomerate is known to have decreased rather steadily downward in grade of rock. The Baltic mine is of low grade in the bottom levels, though the Champion mine; on the same lode, has rich ground in its lower levels; the North Winona shafts went into poorer ground in the lowest levels, though there is indication that the southern shafts encountered the ore shoot pitching downward.

Are such changes in grade due to increase in depth, or are they due to local conditions peculiar to each case? This subject is more fully discussed under “Cause of ore shoots,” but it may be said here that where the ore bodies are best known the decrease can be accounted for by conditions peculiar to the particular deposit.

Thus the Calumet & Hecla conglomerate shoot increases in size down the dip and decreases in grade in about the same ratio. The amygdaloid in the lower levels of the Baltic is relatively thin, cellular, and unfavorable and has the same effect on copper content that similar rock does higher in the shoot, even where surrounded by rich ore. The bottom of the Superior West lode is also relatively thin and cellular. The condition of the bottom of the main Superior shoot is not known. It thus appears that in the amygdaloid deposits the decrease in tenor with depth is due to changes in rock texture that result in similar changes along the strike as well as in depth.

The Quincy mine has been opened for 8,000 feet down the dip. In this mine one lode was found most productive in the upper levels, another in the deeper levels, also one in the north end of the mine, another in the south end. On the whole there is no evidence that there is a notable decrease in the grade of rock to the present depth. In the deep levels, as in the upper levels, favorable lode rock is usually well mineralized and unfavorable rock is poorly mineralized.

In the Kearsarge lode, which has been opened continuously for 4 to 5 miles along the strike, some stretches in the top levels were poor, such as parts of the North Kearsarge and Wolverine ground, but other stretches were rich, such as the South Kearsarge part of the Wolverine, the Ahmeek, and the South Mohawk. These differences are pretty clearly due to differences in character of the amygdaloid. Similar differences occur in the lower workings on the lode and are apparently due to the same cause, and not to change in depth.

No change in the character of minerals or the type of rock alteration has been noted even in the deepest workings, such as those of the Quincy mine.

There is little doubt that for a lode of uniform size and character a depth exists at which the degree of mineralization would change—probably for the worse—because of factors correlated with increase in depth; if, for example, the lode were fed by fissures, it might be expected that a change would occur where such feeding fissures were passed. The fissure deposits, with the single exception of that on the Ahmeek Mass fissure, have decreased in richness downward to such an extent that they have been abandoned, and in this fact there is certainly a suggestion that depth is influential. There is no clear evidence, however, that the changes of grade observed in the lode mines up to the present time are primarily due to increase in depth.

FISSURE DEPOSITS

GENERAL FEATURES

Fissure deposits or veins have been of relatively slight importance in the Michigan copper district as compared with the lode deposits, though a number of mines, notably the Cliff, the Central, and the Minesota, were operated profitably on fissures, and the Ahmeek Mass fissure is being worked by the Calumet & Hecla Co. in conjunction with its amygdaloid mine. Many other fissures have been developed and have yielded considerable copper. But the combined production from fissure mines has been less than 3 per cent of the total production of the district, and the dividends from these mines have been only about 2.5 per cent of the total dividends.

The fissures in the north end of the district strike across the beds and dip steeply. They are apparently tension cracks that developed during the folding of the beds transverse to the Lake Superior syncline. The fissures in the south end of the district strike nearly parallel with the beds and dip somewhat more steeply. They may possibly be related in origin to the Keweenaw fault.

The principal fissures, in the miner’s sense, are not single breaks through the rock but rather zones of parallel or interbranching fractures. The width of the fissures or fissure zones ranges from that of a tight crack up to 10 feet or more. At many places there is some brecciation of the rock within the fissure walls, but little gouge is present.

In respect to mineral content, the fissures may be separated into three types—those in which copper is predominantly native, to which all the commercially important fissures belong; those that carry copper arsenides; and those that contain copper sulphides. There is no sharp line between the types, but commonly the copper in a single fissure occurs chiefly in one of these conditions.

The gangue minerals of the fissures are the same as those associated with the copper in the amygadaloid lodes. In some, like the Mass fissure, the mineralogy is simple, the copper being accompanied chiefly by calcite, quartz, epidote, and chlorite, with only minor quantities of other minerals. In other fissures, like the Copper Falls (Owl Creek), prehnite, datolite, analcite, and some rarer zeolites are plentifully associated with the commoner minerals. Apophyllite is present in some, and laumontite is common in many. Certain fissures carry copper that is distinctly arsenical. Some of the arsenide fissure deposits are essentially quartz-arsenide veins, though most of them contain carbonate, which is in part iron bearing. Many of the sulphide veins contain dolomite and siderite or ankerite, together with a little specularite. The minerals of the fissure veins are similar to those of the lodes, though there is perhaps more extreme variation among the fissures than among the lode deposits.

Rock alteration along the fissures is not extensive where they cut through the dense traps. Chlorite is the most abundant alteration product in these rocks, but pumpellyite, epidote, laumontite, and calcite are common, and sericite is formed plentifully along some of the sulphide and arsenide veins. Alteration of the amygdaloids where they are cut by the fissures is more difficult of recognition because of their complex mineralogy. The most noteworthy change is a darkening of the red amygdaloid lodes for distances in some places as much as 100 feet on each side of the fissures. This darkening is occasioned chiefly by the development of chlorite but in part from removal of hematite, especially that of finest grain.

DISTRIBUTION OF COPPER IN VEINS

The distribution of copper in the fissure veins is even more irregular than that in the amygdaloid lodes. In some of the fissure veins most of the copper formed large masses weighing a ton or more, finely disseminated copper occurring in but relatively small quantity. In others small masses were commonest; and in a few "stamp copper" (copper disseminated through the vein material in small grains) predominated. Several masses estimated at nearly 500 tons each have been encountered in fissure veins.

It is now impossible to study the underground relations in the more extensively developed old fissure mines, which have been closed for some years, but certain deductions may be drawn from the descriptions and reports concerning them and from examination of the fissures that cross the Kearsarge lode.

In the fissures that cross the Kearsarge lode, both those that contain native copper and those that contain arsenides, the copper was deposited in greater part at and near, mainly above, the crossing of the lode. Few if any masses worth the cost of getting them have been found more than 400 feet from the lode.

Descriptions of the old mines strongly suggest that the fissures in them likewise were more productive where they crossed a series of thick, well-oxidized amygdaloids below the Greenstone flow and at the Ashbed horizon, above the Greenstone flow. A similar relation is suggested in the Minesota fissure, at the south end of the district. This fissure and the associated Branch fissure have been found to be mineralized at and above but not below their intersections with the Minesota conglomerate. Likewise, in the fissures carrying chalcocite, which are rather abundant in the Baltic lode and less so in the Isle Royale lode, the chalcocite seems to be most abundant where the fissures are within the lode or near the points where they cut the lode.

Thus the general rule for copper occurrence in fissures of all types seems to be that it is most abundant at and near the intersections of the fissures with thick, well-oxidized amygdaloids. This concentration of copper at such intersections suggests that hematite is needed for precipitation of copper in fissures as well as in conglomerates and amygdaloids. According to descriptions of old fissure mines, the amygdaloids and conglomerates were commonly mineralized for a short distance from the fissures. In a few places this lode mineralization formed commercial ore. What happened to the Kearsarge lode near the intersecting fissures is not so clear, because of the mineralization of the entire lode for several miles along the strike by solutions that ascended along the lode apparently independently of the fissures. The net result of the mineralization of fissures and lode is that the lode is darkened near the fissures because of chloritization and the removal of hematite and its copper content is somewhat lower than away from the fissures. The reasons for the abundant precipitation of copper at the intersections of some of the fissures with the lodes and the impoverishment of lodes near intersections of other fissures are discussed in the section on genesis (p. 135).

HAS THERE BEEN ENRICHMENT OF THE DEPOSITS?

In either prospecting for or developing ore bodies it is important to know the general behavior of the type that is under consideration. It is well established that the richness of some types of deposits is greatest near the surface and decreases downward. Some types have a barren zone at the surface followed by a rich zone, which in turn gives place to ore of lower grade. Many copper deposits are of the latter type, and it has been clearly shown that the barren zone near the surface and the underlying rich zone have resulted from a leaching of metal from the former and its deposition in the latter—a process known as enrichment.

In the following paragraphs the data relative to the behavior of the Lake Superior copper deposits with increase in distance from the outcrop are set forth, and the conclusion is reached that in these deposits enrichment has been unimportant.

NO EVIDENCE THAT THE LOBES ARE POOR AT THE SURFACE AND RICHER BELOW

In either prospecting or developing sulphide deposits, it is of fundamental importance to recognize that an outcrop that is nearly barren of copper may give place at depth to a zone of rich ore, which may grade off into material of lower grade.

In the Lake Superior district there seems to be a general though far from definite feeling that the best ore is some hundreds of feet below the outcrop—that is, that there is a gradual increase of copper for some distance below the outcrop to a maximum depth, below which there is a decrease. Lane[7] has implied his acceptance of this idea by suggesting the explanation that copper is leached in the fresh-water zone and that it attains its maximum richness at about the boundary between the fresh-water and salt-water zones or at the calcium chloride zone, below which it gradually falls off. This influence of water is discussed on page 122.

If it is true that there is commonly a leached zone near the surface, prospecting of a lode should be carried on at considerable depth, despite the heavy expense entailed by so doing; if it is not true, a given sum of money may be better expended in examining a greater stretch of lode near the outcrop. The location of property boundaries of course must affect any scheme that calls for extended exploration of a lode along the strike, but even so the presence or absence of surface leaching and downward enrichment will materially affect the planning of explorations.

[7]Lane, A. C., Lake Superior Min. Inst. Proc, vol. 17, p. 134, 1912.

Kearsarge lode.—At the South Kearsarge mine good ore was present practically at the outcrop, and although the ground varied in grade in different parts of the mine, there is no record of a consistent change from the surface downward. In the Wolverine and North Kearsarge mines and at least a part of the Ahmeek mine the upper levels were relatively poor and the intermediate and lower levels decidedly richer. In the south end of the Mohawk mine there was very good ground in the upper levels, notably south of No. 5 shaft, and apparently the rock in the upper levels of this part of the mine was as good as deeper in the mine or as in the North Ahmeek mine, which is opened below it. In the north end of the Mohawk mine surface pits encountered good rock, and so far as known the upper levels of that part of the mine averaged as good as the deeper levels, though this end averages poorer than the south end. It appears, then, that a part of the productive portion of the Kearsarge lode was as rich at or very near the outcrop as at greater depth, but that the remainder of the lode was relatively poor near the surface. A study of all available facts regarding the character of rock in relation to tenor of ore has shown, however, that the areas of low-grade ore near the surface are coincident with areas of relatively thin or cellular, impermeable lode rock. Areas of rock of similar character deeper in the mines are similarly low in copper, a fact which, together with the lack of evidence that these portions ever contained more copper, has led to the belief that the lower copper content is due to the character of the rock, and that depth below the present outcrop of the lode is not causally related to it.

Osceola lode.—The outcrop of the Osceola lode was richest at the north end of the Osceola mine, where, to judge from reports, the rock was as good as any found at depth on the lode. Throughout the Calumet & Hecla workings on the Osceola lode the top levels average as rich as at any greater depth. South of No. 3 shaft, in the Osceola mine, the top levels were poor. The ground was also poor in No. 6 shaft to the twenty-fifth level and farther south to greater depth. It is thus apparent that for the Osceola lode, as well as for the Kearsarge, the upper portion was good over part of the area and poor over the remainder. There is a bar of thin lode rock, along the south boundary of the shoot, and this, rather than any leaching of the lode, is thought to be the cause for the poor ground to the south. This relation is discussed under "Conditions determining position of ore shoots" (p. 115).

Calumet & Hecla conglomerate.—The Calumet & Hecla conglomerate lode was rich at the surface between No. 3 Calumet and No. 5 Hecla, and again from a point 400 feet south of No. 10 Hecla to and beyond No. 1 Osceola. In the Osceola mine and in No. 12 shaft of the Hecla the shafts went from good ore into poor ground with depth. Nos. 6, 7, and 8 Hecla went through poor ground into rich ore. No. 2 Hecla to No. 3 Calumet went from rich ore into lower-grade ground with increase in depth. Nos. 5 and 6 Calumet went through poor ground to the thirtieth level before they entered good ore. The outcrop of the Calumet & Hecla conglomerate lode was, in short, rich in some places and poor in others. A study of the character of the lode rock has shown that the differences in copper content are correlated with differences in the original character of the rock; where the ore was poor, the felsite conglomerate was very thin or was represented by a thin bed of sandstone; where conglomerate was present at the outcrop in consider able thickness it was well mineralized. There is no indication that the poor areas were ever mineralized and subsequently leached or that the rich areas have been subsequently enriched. It is therefore logical to conclude that the variation in richness is dependent on the character of the rock rather than on position relative to the outcrop.

Pewabic amygdaloid lodes.—Some of the Pewabic amygdaloid lodes were richest near the surface, and some at greater depth. In general, it may be said that commercial ore was found in the upper levels in the central and southern parts of the Quincy property, whereas to the north, in No. 8 shaft, a long stretch of lode was passed through before commercial ore was encountered, and farther north the profitable ore is still deeper. It appears, then, that the conditions in the Pewabic lodes are similar to those in the other lodes discussed.

Atlantic lode.—The maps of the Atlantic mine indicate that in places stoping was carried close to the outcrop. The grade of the ore in these places is not known, but as the ore in the deeper parts of the lode was of low grade it is reasonable to suppose that the ore near the surface was not much poorer, else it would not have been mined.

Isle Royale lode.—Stoping was carried close to the outcrop in the Isle Royale lode, and although a larger percentage of the lode has probably been mined at the lower than at the higher levels, this fact is apparently more the result of change of mining methods than of difference in character of the lode.

Baltic lode.—At all three mines on the Baltic lode the ground appears to have been good at the outcrop and to have shown no zone of decided enrichment at lower levels.

Evergreen and succeeding lodes.—The mines on the Evergreen and succeeding lodes in the south end of the district have practically all stoped close to the surface with apparently as good ground as at any greater depth.

Nonesuch lode.—In the Nonesuch lode as developed at the White Pine mine there seems to be no evidence to connect grade of the rock with its position relative to the outcrop of the lode.

Veins.—Without following out each important vein in detail, it may be said that in a general way the veins show the same relation as the lodes. Most of the productive veins that have been developed have had good copper near the surface in places, though not necessarily or usually throughout their productive extent. For example, the Cliff fissure was apparently rich in copper at the outcrop east of the Greenstone flow, but No. 4 shaft, which was sunk through the Greenstone flow, did not encounter ore till it had passed through that bed. It is evident that the rich and poor parts of the vein are related to the character of the fissure and of the adjacent rocks rather than to position relative to the present surface. Similar relations might be cited for many of the veins through the district.

NO EVIDENCE OF LEACHING AND REMOVAL OF COPPER NEAR THE SURFACE

Statistics of production indicate that the lodes at the outcrop have been as rich as at greater depths. The question may be asked, however, if there is physical evidence of leaching of copper near the surface or precipitation at depth. The first point to determine in answering this question is, What constitutes evidence of leaching of copper? At first sight the alterations of the rock associated with the copper might be taken for such evidence. The most striking of these alterations is the bleaching of the rock around the copper. In places there has been considerable bleaching of the pumpellyitization type, with which little deposition of copper was associated, and it might be inferred that this bleaching is of the same origin as that seen in rich copper ore and has persisted after the copper was removed. This barren bleached rock, however, seems as abundant on the deeper as on the higher levels. In rock affected by bleaching of the iron-removal type, copper seems always to be present. In the conglomerate there has been some bleaching associated with epidotization and accompanied by little deposition of copper, but this again seems to be no more abundant near the surface than deep in the mine. The amount of bleached rock associated with copper seems, indeed, to be rather less in the upper than in the deeper parts of the lodes. Nowhere has bleached barren lode rock that suggested that it had once been rich in copper been seen near the surface.

Another evidence of leaching might be the passage from rich ore at depth to lean rock near the surface without change in the character of the lode-forming rock. In the mines studied no example of such a change has been found. On the other hand, in the conglomerate lodes there is a rather steady increase in grade of rock from the deeper levels to the surface. In the amygdaloid lodes change in grade in the mines studied has been much more closely associated with change in character of lode than with increase in distance from the outcrop.

It is to be expected that the ordinary surface waters will dissolve some metallic copper, but the metal has not been so dissolved in sufficient amount to leave evidence that has been recognized. The deep salt waters are also known to contain copper, which will be deposited on iron, as has occurred in the waters from deep drill holes in the Baltic mine. (See “Chemistry of ore deposition,” p. 121.) In a few places, as at Copper Harbor and the Algomah mine, oxidized copper minerals have been formed, but these are near the surface and afford no evidence of movement of the copper.

NO EVIDENCE OF ENRICHMENT AT THE SALT-WATER HORIZON

In the mines studied no evidence has been recognized of enrichment at the horizon of the change from fresh to salt water or to calcium chloride water. Lane points out that leaching has probably occurred m some shatter zones and cites particularly the one in section 16, Atlantic. The main evidence of leaching, however, seems to be the lack of copper. If such negative evidence is accepted as valid, the Allouez shatter zone also must be regarded as leached near the surface; yet this zone has been opened well below the top of the salt water without encountering evidence of enrichment. The shatter zones are pretty clearly poor in copper, but, all evidence considered, it seems more likely that copper was not deposited abundantly than that it was deposited and later removed.

SUMMARY AND CONCLUSIONS

The foregoing details regarding leaching and enrichment may be summarized as follows:

Virtually every lode has been as rich at some place near the surface as in any of its deeper portions.

Where the lode is lean near the surface no evidence is afforded by the way in which the rock has been altered to indicate that this portion of the lode was ever rich in copper.

In every lode examined, where lean ore near the surface gives place to rich ore at depth, it has been found that the change coincides with a change in the original character of the lode rock that seems adequate to account for the change in copper content.

No evidence of enrichment at the zone of change from fresh to salt water or to calcium chloride water has been found in any of the mines.

PERSISTENCE WITH DEPTH

All ore deposits must sooner or later show a decrease in metal content with increase in depth; there is however, a great difference in the depth at which such decrease becomes important in different types of deposits, and it is desirable to have some basis for judging what may be expected for a given type, with due allowance for the fact that each deposit has its own peculiarities.

For example, in the well-known type of disseminated copper deposit which owes its better portions to downward enrichment, it is reasonably certain that the enriched zone will be but a few hundred feet thick. It is also pretty well established that in the Tertiary type of gold-silver deposits the bulk of the precious metal is likely to be found within 1,000 to 2,000 feet of the surface and that many deposits fail before a depth of 1,000 feet is reached. On the other hand, in certain gold-quartz deposits, as those of the Mother Lode of California, the metal content of the veins persists at least to 3,000 feet and probably to considerably greater depth. In planning the development of mines to work deposits so extensive as those of the Lake Superior copper district, some basis of judgment as to what is to be expected at depth is of prime importance.

In appraising the effect of depth, it is necessary to consider geologic units and not property units. Thus a study of the mineralization of the Calumet & Hecla conglomerate based on the results attained in depth in the property of the Osceola Mining Co. would lead to conclusions quite different from those reached by considering the ore shoot as a unit.

Developments have been carried to so great a depth in certain deposits that there is a very considerable body of fact on which to base judgment as to what is likely to be found in deposits that have not been so deeply developed, as well as to what may be expected at still greater depth. Development has been carried to a vertical depth of about a mile in the Calumet & Hecla conglomerate and the Pewabic amygdaloid and to more than half that depth in other amygdaloids. To this depth there has been recognized no significant change in the type of minerals in the lode. In the conglomerate lode there seems to be less bleaching or removal of the iron in the higher levels; locally at least this lack of bleaching is rather pronounced. The same seems to be true for the Osceola lode. That it holds for the other lodes is less certain. Lane[8] states that sodium minerals, like analcite and natrolite, are confined to the upper levels. This statement is not supported by the present investigation of the amygdaloid lodes, for analcite has been found on the deeper levels of the Osceola mine. In the Calumet & Hecla conglomerate lode zeolites are characteristically absent.

The literature contains numerous statements that silver is more abundant on the upper levels. These statements have not been verified. So far as regards the recovery of silver from the electrolytic treatment of copper, there seems to be no basis for the belief that the ratio of silver to copper decreases with depth. Shoots relatively rich in silver, for the conglomerate lode, are present in the lower levels at the south end of the Calumet & Hecla conglomerate body. It seems pretty certain that vugs rich in silver, which display the metal conspicuously, were more abundant at the higher levels, but it is not certain that silver was actually more abundant at these levels than lower.

[8]Michigan Geol. Survey Pub. 6, p. 871, 1911.

It has also been stated that sulphides are less abundant in depth, but this also has not been verified. In the Isle Royale mine it does not seem to be true, and sulphides appear to be as abundant in the lower levels of the Baltic lode as at higher levels.

Some of the lodes lying near the base of the Keweenawan series were relatively high in arsenic, and it has been suggested that this may be so because the solution that mineralized these lodes had flowed for a relatively short distance in them and therefore had been less completely oxidized than the solution that mineralized the higher lodes. If this is true, it would be expected that there would be, in general, an increase in the arsenic content of a given lode with increase in depth. Such an increase, however, has not been definitely observed to the present depth of mining.

Mineralogically, therefore, there is no conspicuous change recognized to the present depth. The available evidence indicates that the native copper of the Lake Superior region was deposited through a wide vertical range. As the content of some of the great lodes has failed to show any systematic decrease with depth after having been followed down for thousands of feet, copper ore may be expected to persist to great depth—even greater than is now known. It is not to be expected, however, that all deposits of the type will attain the same depth, and the suggestion that some have been commercially bottomed is at least warranted by the rather general failure of the fissure deposits with increased depth. It is also possible that some lodes that show strong alteration with little copper may represent the roots of deposits that were richer in their higher parts, which have been eroded.

CONDITIONS DETERMINING POSITION OF ORE SHOOTS

In general there are two main factors that have influenced the formation of the ore shoots—(*a*) permeability, which influenced the flow of solutions, and (*b*) the character of the rocks, which may have had a chemical influence in precipitating minerals. In addition structural relations may have had an important effect. The great ore shoots are related to structural features and peculiarities of the individual lodes. Chief among these are, on the one hand, the occurrence of impermeable or barrier conditions in an otherwise open-textured lode, and, on the other hand, the local opening up of a prevailingly tight, impermeable lode. The former type is exemplified by the Osceola lode; the latter by the Calumet & Hecla conglomerate and the Kearsarge lode.

PERMEABILITY OF ROCK

The lode deposits are formed only in the more permeable beds, such as the conglomerates, fragmental amygdaloids, and coalescing amygdaloids, and are consistently lacking in the more abundant but less permeable cellular amygdaloids. The continuous breaks in which the fissure deposits occur also permit the ready flow of solution. Permeable rock, then, is essential to the formation of such ore deposits as these copper lodes. Roughly, the rocks of the district may be grouped in the following order of permeability: Fissured rock, fragmental amygdaloid, felsite conglomerate, coalescing amygdaloid, sandstone, "scoriaceous amygdaloid," ordinary cellular amygdaloid, trappy fragmental amygdaloid more or less lava-cemented, trap, shale, fault gouge.

BARRIERS OF RELATIVELY IMPERMEABLE ROCK

The more permeable rocks are a positive factor in the formation of ore bodies, but the less permeable rocks may be an important negative factor in directing the movement of ore solutions. This is well shown in some of the ore shoots of the district.

The Calumet & Hecla conglomerate shoot is a relatively small lens of felsite conglomerate which thins in each direction along the strike. The sandy and shaly beds underlying the felsite conglomerate continue along the strike in both directions. The conglomerate body is thinnest and shortest near the outcrop and thickens and lengthens with increased depth, thus giving the effect of an inverted funnel. Solutions rising along the lode are converged by the less permeable rocks at the margins of the felsite conglomerate and by the relatively impermeable hanging-wall and footwall rocks into a steadily contracting channel of permeable rock, so that more solution passes through each unit volume of conglomerate in the upper part than in the lower part. (See fig. 16.) The richness of the ore at any depth is about in inverse ratio to the thickness and extent of the lode at that depth, a fact which indicates that copper was deposited in proportion to the amount of solution passing through the rock.

The funneling effect illustrated in the Calumet & Hecla conglomerate perhaps gives the most favorable conditions for the convergence of solutions and the formation of ore shoots; the Calumet & Hecla shoot, at any rate, is the richest yet opened. A concentrating effect may, however, result if a barrier of relatively impermeable rock interrupts a permeable lode. Such damming may result either from a change in character of the lode itself, as from fragmental to cellular, or from the offsetting of the lode by a fault.

In all the amygdaloid lodes there are repeated examples of cellular impermeable lava in the fragmental permeable lava, and consistently the cellular lode is poor, apparently because it has not permitted the ready passage of solutions but has diverted them to the more open rock. The south boundary of the Osceola shoot is formed by a southward-pitching inclined bar of cellular amygdaloid in the prevailingly fragmental amygdaloid. (See pl. 39.) The Osceola shoot is richest close under this impermeable bar, and it gradually decreases in richness northward and away from the bar. Above the bar the amygdaloid is fragmental and favorable in character but contains little copper. This relation suggests that solutions rising along the lode were diverted by and concentrated under the bar and that the most copper was deposited where the flow was greatest—that is, close under the bar.

The examples cited above illustrate two general conditions favorable to concentration of solutions and the formation of ore bodies—(*a*), a lode that is generally impermeable but has areas of permeable rock (see fig. 16); (*b*), a lode that is prevailingly permeable but has bars or areas of impermeable material so placed as to cause a diversion and concentration of solutions rising along the lode.

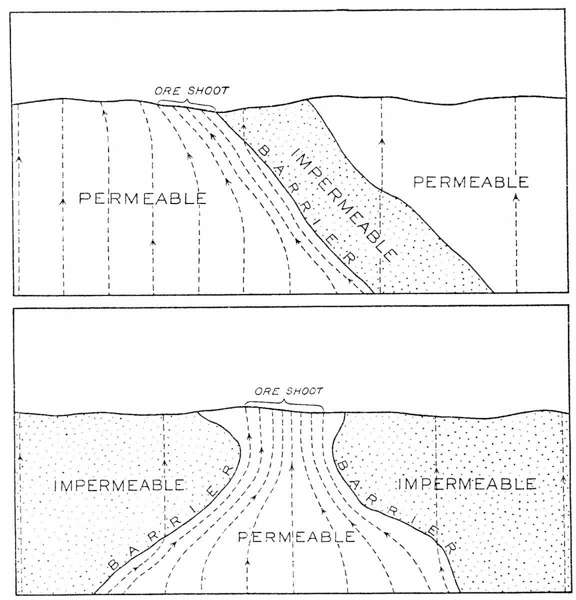

FIGURE 16.—Influence of varying permeability of rock on flow of solutions and formation of ore shoots

In the first class are the Calumet & Hecla conglomerate and the Kearsarge lode. The rocks at the Calumet & Hecla conglomerate horizon have been examined for many miles along the strike, but only at Calumet has a well-developed felsite conglomerate been found. The Kearsarge lode for the 4 to 5 miles in which it is commercially mineralized is in the main a well-developed fragmental lode, but for miles to the north and south, so far as known, it is prevailingly cellular. This class perhaps includes other lodes about which less is known.

In the second class are the Osceola lode and the Allouez conglomerate. The Osceola lode is prevailingly fragmental and permeable for miles and is somewhat mineralized at many places, but it is known to contain a commercial ore shoot only at Osceola, where it is interrupted by an inclined bar of cellular amygdaloid. The Allouez conglomerate is a thick, well-developed conglomerate over long stretches but locally is represented by a clay “seam” or “slide.” This conglomerate has been found to be so well mineralized as to encourage extensive development at the Franklin Jr., Allouez, and Delaware mines. The Arcadian lode should probably be assigned to this class and perhaps the Winona, of whose character less is known. The Ashbed is a lode that is permeable over long stretches and mineralized at several places, as at the Atlantic, Phoenix, Arnold, and Copper Falls mines. The details of the character of rock at these places are not well known. Some of the southern lodes may also be in this class, but too little was seen of them to warrant a classification. The rock at the general horizon of the Baltic lode northeast and southwest of the developed area is fragmental lava, but the correlation is somewhat uncertain. The principal developed area of the Baltic lode in the Copper Range mines is bounded in both directions by strong zones of fissuring and shattering.

FAULT BARRIER

A fault offsetting a lode and so situated that the intersection with the lode makes an angle with the dip of the lode would constitute a barrier similar to an inclined bar within the lode itself. No example of an ore shoot under such a fault barrier has been clearly established; but the Hancock fault forms such an intersection with the lodes it crosses, and practically all the ore from the lodes of the Hancock mine and the Pewabic amygdaloid lodes in the vicinity of the fault has come from the north or lower side of the fault.

The productive portion of the Baltic lode is bounded by faulted zones with heavy gouges, but their attitude, so far as known, does not seem particularly favorable to the converging of solutions.

The fissures in the north end of the district have been most productive for a short distance under the Greenstone flow, which has been regarded by Smyth, Lane, and others as a barrier to rising solutions, but there has been slipping or faulting between the Greenstone flow and the Allouez conglomerate, which has produced fault gouge or “slide,” and this gouge is probably the true barrier so far as one exists. There can be no doubt that the fissures are relatively rich under the Greenstone flow or “slide,” but the cause may be a combination of barrier and chemical effect, as is shown on page 118. In some of the fissures the copper is said to spread out under the “slide.”

At the White Pine mine the Nonesuch shale is thought to have acted as a barrier. Solutions rising along fissures have spread out when they reached the shale, forming an ore shoot in the sandstone under the shale. Lane, who favors the hypothesis of downward-moving solutions, regards the White Pine fault as a barrier, with the ore shoot above it.

FOLDS

The broad pitching anticlines, like the Allouez, Baltic, Winona, and Mass anticlines, might have a converging influence on rising solutions and thus produce ore shoots. If solutions were rising along a lode they would have a tendency to concentrate toward the crests of such anticlines. Several important ore shoots, including the Kearsarge, Baltic, Winona, and Mass, are situated on such anticlines, though their richest portions are not consistently near the crests, and in detail the distribution of rich and poor ground is far more dependent on character of rock than on structural position. The Isle Royale shoot, indeed, has its richest portion near the trough of a syncline, and here too the character of the lode rock seems to have a more effective control than position on the syncline. The effect of the anticlines is therefore somewhat uncertain.

STRIKE FISSURES

Both Hubbard and Lane have suggested a relation-ship between mineralization and fissures parallel to the lodes, and they have cited the Baltic lode particularly as an example. Most of the numerous strike fissures in the Baltic lode are slightly steeper than the dip of the lode and cross it at a low angle, so that it seems unlikely that they were produced by simple slipping between beds of trap, as suggested by Hubbard. They may, rather, have been formed by the forces that produced the Keweenaw fault. Regardless of how the fissures were formed, however, the kinds and relation of the minerals in the fissures and in the lode indicate that the mineralization in the lode and that in the fissures had a common origin. A somewhat similar relation between strike veins and lode mineralization exists in the Isle Royale mine.

The Branch fissure, in the Minesota mine, crossed the Calico lode at a low angle. The Calico lode was mined profitably above the intersection but was found poor below. In the Pewabic, Osceola, Calumet & Hecla conglomerate, and Kearsarge lodes, however, strike fissures are not conspicuous, and there is no evidence to suggest that the mineralization of these lodes is dependent on strike fissures. It seems, on the whole, that strike fissures may well be a cause for ore shoots in lodes, but they do not appear to be present in all the lodes nor to be a necessary condition of mineralization.

CROSS FISSURES

Fissures crossing the strike of the lodes have also been regarded for a long time as a possible cause of ore shoots, and such fissures and their relation to intrusive felsite bodies have been emphasized particularly by T. S. Woods.[9] Steeply dipping fissures striking generally across the lodes are numerous on all the anticlines, and practically all the lodes in the district are crossed by such fissures. They are abundant in the Kearsarge lode north of the North Kearsarge mine, in the Isle Royale mine, in the mines on the Baltic lode, and in the Evergreen and succeeding lodes on the Mass anticline; they are present but not abundant in the Quincy mine, the Osceola lode, and the Calumet & Hecla conglomerate.

[9]Woods, T. S., The porphyry intrusives of the Michigan copper district: Eng. and Min. Jour., vol. 107, pp. 299-302, 1919.

Cross fissures are especially abundant in the north end of the district on the Keweenaw anticline. The available descriptions of the fissure deposits in this end of the district indicate that in many places the lodes were mineralized near the fissures and that some were mined for a short distance from the intersections but were soon abandoned because of marked falling off in richness. This relation suggests that the lode rock was mineralized by solutions leaking from the fissures, and so does the fact that in the Kearsarge lode the ore near the arsenic fissures is distinctly arsenical. Here, however, the lode is consistently poorer near the fissures than away from them, and the general relations do not indicate that these fissures served as feeders for the main mineralization. One prominent fissure crosses the Calumet & Hecla conglomerate, but the mineralization does not seem to have been related to it; in general, the lode is perhaps poorer near the fissure. There is also a prominent fissure crossing the Pewabic lodes, and the lodes were distinctly poorer near it in the upper levels and apparently also, though to a less marked degree, in the lower levels. A prominent fissure is also present in the Atlantic mine, but its relation to mineralization is not known. On the whole there seems to be no close relation between the mineralization and the cross fissure.

It is, then, fairly clear that there was some mineralization of lodes where crossed by well-mineralized fissures; and it is shown on page 110 that the lodes also affected mineralization in the fissure. It does not seem likely, however, that the main mineralization of the larger lode deposits extended outward from cross fissures.

In suggesting a relation to felsite intrusives, Woods has called attention to the felsite bodies, including that of Mount Bohemia, under the Keweenaw anticline; that under the Kearsarge mines, below the Allouez anticline; that east of Calumet; and that at the Indiana mine. He believes that the cross fissures reached the intrusive bodies and that the ore solutions passed outward from these bodies along the fissures.

The presence of felsite under some of the anticlines and the suggestion that intrusive bodies may underlie other anticlines, where not exposed, is discussed under "Structure" (p. 50). On page 124 it is shown to be possible that the ore solutions originated from the same source as the small intrusive bodies and that some of the sulphide veins may bear a close relation to certain exposed intrusive bodies such as the one at Mount Bohemia. With due consideration of all these suggestive relations, the evidence does not seem sufficient to prove that the main lodes were mineralized by solutions conducted into them, by way of cross fissures, from the small exposed intrusive bodies, or from unexposed bodies of the same type. The most serious objection seems to be the lack of mineralization in many favorable lodes crossed by the fissures. If the solutions passed along such fissures and from them into the permeable lodes, it would be expected that every lode that was physically and chemically favor able would be mineralized, at least to some extent, where crossed by a mineralized fissure. For instance, two fragmental well-oxidized amygdaloids have been opened in many places between the mineralized portions of the Calumet & Hecla conglomerate and the Osceola amygdaloid, but nowhere have they been found to contain much copper. This fact is difficult to reconcile with the hypothesis of mineralization by cross fissures, but it may be explained if the solutions found entrance deeper in the lode.

It seems clear that the lodes have influenced the mineralization in cross fissures and that there has been some mineralization of the lodes outward from cross fissures, but it also seems unlikely that the chief mineralization of the great lodes has been effected through the cross fissures. The helpfulness for prospecting in recognizing a relation of ore shoots to cross fissures, to anticlines, or to felsite bodies is apparent, but this fact makes it all the more necessary to beware of exaggerating the closeness of such relations.

INFLUENCE OF THICK FLOWS

Lane has pointed out that some of the ore shoots may lie below unusually thick flows. This relation has long been recognized for the fissure deposits beneath the Greenstone flow, but, as already suggested, its real cause may be the "slide" at the Allouez conglomerate. An examination of the geologic map does not seem to give strong support to this idea for other known deposits.

The Kearsarge lode is a long distance below the Greenstone flow, which, moreover, is not very thick over the southern part of the productive area of the Kearsarge lode, and the "Big" trap above No. 8 conglomerate is a heavy flow below this lode. There are no particularly thick beds above the Calumet & Hecla and Osceola lodes at Calumet. The beds above the Pewabic amygdaloid lodes at Quincy are rather thin. The flow above the Isle Royale lode is thick but not exceptionally so; the thickest and most massive flow in the section at the Isle Royale mine is the Mabb ophite, which lies below the Isle Royale lode but above the Baltic lode. Farther south, at the Copper Range mines on the Baltic lode, the thickness of the Mabb ophite has decreased to ordinary size and the thickest bed lies near No. 8 conglomerate, at a considerable distance above the Baltic. Altogether, therefore, there seems to be no clear indication of a relation between known ore deposits and thick overlying beds.

CHEMICAL COMPOSITION

The ferric iron of the rocks is believed to be a controlling factor in the precipitation of metallic copper. Ferric iron is abundant in all the amygdaloids and conglomerates that have a physical character favorable to ore deposition and was therefore present in all the beds through which large volumes of solution passed, and because of this wide distribution it may not have greatly influenced the localization of the ore shoots in the lodes.

Ferric iron may, however, have had a much more active part in forming the ore shoots in the fissure deposits. Developments show that in the arsenide fissures and in the Mass fissure, crossing the Kearsarge lode, most of the copper and arsenide was precipitated near the lode, chiefly above it. Descriptions of the fissure deposits in the north end of the district indicate that a similar relation between copper and a group of well-oxidized fragmental amygdaloids was recognized by those who explored the fissures. In the south end of the district the fissures worked by the Minesota and adjoining mines carried their copper at and above their intersection with the Minesota conglomerate, a typical felsite conglomerate. A similar relation is shown in some of the fissures crossing the Baltic lode. Ore shoots in fissures, then, appear to occur most commonly at the intersection of the fissure with a thick, well-oxidized bed.

The foregoing statements regarding the conditions favorable to the formation of ore shoots imply, of course, that mineralizing solutions rose along the lodes and fissures. That even under the most favorable conditions solutions in sufficient volume to form ore bodies traversed all the favorable lodes and all the fissures is not probable.

How the solutions may have gained access to the lodes and fissures is discussed on page 125. It may be stated here that the answer to this question would be very helpful in the search for ore bodies, but at present the problem is obscure, little recognized evidence being available on which to base conclusions. It seems certain, however, that many favorable lodes— in fact, most favorable lodes over long stretches—were not traversed by ore-bearing solutions in large volume and therefore do not have ore shoots.

GENESIS OF THE DEPOSITS

SIMILAR ORIGIN OF ALL TYPES

The outstanding trait that is common to all the copper deposits of Michigan—to fissure deposits as well as to lode deposits in widely differing rocks—is the fact that the copper is mainly present as native metal. In copper deposits the world over the occurrence of native copper, except as an alteration product of other minerals, is unusual and has evidently resulted from conditions that are not widespread. Native copper is abundant, however, in the deposits of all types in this district—a fact which points to common conditions or at least a close similarity in conditions of deposition for all the deposits.

FEATURES COMMON TO ALL TYPES

A common result in the deposits of different types might come either from a similar solution regardless of the kind of rock in which it acted or from some feature common to all the rocks that produced the result. The idea of the copper being carried in solution as native metal and precipitated as such is regarded as unlikely. (See p. 129.) If the features common to all the types can be separated from the numerous features that are not common to all, the causes of copper precipitation and the nature of the mineralizing solutions are more likely to appear. Such a comparison may be first made between the conglomerate and amygdaloid lodes and extended to the others.

All the rocks that have been mineralized to form lodes were originally relatively permeable. The lode deposits are in the conglomerates, in fragmental and coalescing amygdaloids, and in sandstone, which, however carries ore only near fissures. They are consistently lacking in the relatively impermeable shales, traps, and cellular amygdaloids. The fissures were of course permeable regardless of the type of rock through which they passed.

In original mineral composition the conglomerates are much simpler than the amygdaloids, yet as the copper in the lodes of both types is native, all the conditions essential to the deposition of native copper must have been present in both.

The outstanding feature that seems to have been common to the two types of rock before the copper mineralization was the presence of abundant ferric oxide in the form of hematite. The sandstone lodes also are red and hematite bearing, and the fissures seem to be productive only near the points where they cross red conglomerate or amygdaloid.

The minerals of the ore-depositing period that are common to the conglomerate and the amygdaloid lodes are comparatively few. A red potash-soda feldspar was formed early in lodes of both types. This feldspar is not conspicuous in all the amygdaloids, but in some of those in which it is lacking a potash mica, sericite, is present, though in the Isle Royale lode, where the sericite is particularly abundant, it seems to have been formed, in part at least, late in the mineralizing period. Epidote and pumpellyite are present in both conglomerates and amygdaloids. Chlorite is abundant in the amygdaloid lodes and much less plentiful in the conglomerates. Calcite and quartz are abundant in both. These comprise the minerals that are at all common in the two types of lodes. The whole series of zeolites and allied minerals, which range from rare to abundant in the amygdaloids and the fissure deposits, are practically absent from the conglomerates. There can be little doubt that they have resulted mainly from a recombination of elements in the amygdaloid lodes, which, in contrast with the conglomerates, were chemically unstable in contact with the ore-forming solutions. The boron of datolite, the fluorine of apophyllite, the potash of feldspar and sericite, and perhaps other elements besides the copper doubtless came from the solutions and not from the rock. Most of the minerals introduced into the amygdaloids and the fissures, whether filling vesicles or fractures or replacing the rocks, can not be regarded as essential to the formation of the native copper, but as something is known of their conditions of occurrence elsewhere and, from experimental work, something of their range of stability, these minerals indicate the physical conditions under which the native copper was formed.

The striking alteration that is common to the lodes in conglomerate, in sandstone, and in amygdaloid is the bleaching of the red rock in the immediate vicinity of copper and as a rule nowhere else. This bleaching has resulted in different minerals in different lodes, but the chemical change in all lodes is in the same direction—namely, toward a removal or recombination of the ferric iron. In the fissure deposits a similar tendency is shown by the alteration of part of the hematite and the formation of chlorite in the red lodes near the fissure intersections.

The essential features shown by all the types of deposits are therefore permeability and presence of ferric iron originally and removal or recombination of the iron close to the introduced copper.

SINGLE PERIOD OF MINERALIZATION

The mineralization has been assigned by various writers to different times according to their conception of the origin of the ores.

Pumpelly, believing that the copper was leached from the sandstones overlying the trap series, supposed that the ore was deposited later than the traps and the overlying sandstone. The general abandonment of the idea of derivation of the copper from the upper sandstones removes that basis for the dating of the ores.

Van Hise and Leith[10] regarded the main mineralization as confined to middle Keweenawan time and therefore as of essentially the same age as the mineralized rocks. They state, however, that mineralized boulders derived from underlying beds are present in some barren conglomerates and thus indicate an earlier period of mineralization, before the conglomerates were laid down. They do not mention where or by whom this observation was made. In the work on which the present report is based no pebbles or boulders that had been mineralized before being incorporated in a conglomerate were seen. Mineralized amygdaloid boulders in conglomerate were found, but there was good reason to believe that the mlneralization occurred long after the conglomerate was deposited. The hypothesis of a preconglomerate period of mineralization needs verification before it is entitled to credit.

[10]U.S. Geol. Survey Mon. 52, p. 581, 1911.

Lane believes that the ores were deposited while the basalts were still hot and therefore, presumably, fairly soon after their formation, but his conceptions of imbibition of surface waters and of the dependence of copper deposition on the present position of water zones appear to imply mineralization after tilting had been accomplished. He regards the arsenide and sulphide veins as possibly of later and independent origin.

The conclusion reached in this work is that the major mineralization was effected during a single period of somewhat complex activities that followed the completion of all the essential deformation that the rocks reveal. This deformation, it is thought, began during the outpouring of the Keweenawan lavas and the deposition of the associated sediments and was completed shortly after their accumulation was finished; the mineralization probably followed immediately afterward, perhaps overlapping the last structural adjustments. The evidence upon which this conclusion is based is summarized below.

The Keweenaw fault bends with the cross folds, such as the Keweenaw anticline, the Allouez anticline, and the Isle Royale syncline, and its changes in direction are too great to be reasonably explained in any other way than to assume that the fault itself was folded. It is therefore probably older than at least the last of this folding. The cross fissures from Allouez northward are tension cracks radial to the cross folds and produced at the same time. The countless minor fractures that cut the rocks are also most plausibly ascribed to the stresses that produced the faulting and cross folding, because these minor breaks are more conspicuous and numerous near the places of major deformation and are disposed conformably to them.

Copper mineralization did not occur in the Keweenaw fault itself, so far as known, but it affected the highly fractured zone adjacent to the fault and therefore was undoubtedly later than the fault and this attendant shattering. The mineralization in the cross fissures was of course later than the fissures. The mineralization of the lodes was similar in character to that of the fissures, and the presence of arsenides and sulphides in the lodes adjacent to fissures containing these minerals is a further indication of their close relation.

The same mineral association in all these types and the interrelation of the types indicate mineralization of all types from a single source and during a single period. The sulphide veins contain intergrown metallic copper or merge into native copper veins. The same is true of the arsenide veins, with the modification that the copper is arsenical, as are some of the copper fissures themselves, and the arsenide veins carry some chalcocite. The sulphide and arsenide fissures are thus apparently of the same source and of the same age as the deposits of metallic copper.

The domical uplift of the Porcupine Mountains is not closely connected with the other structures of Keweenaw Point and is probably due to intrusion. Faults of varying magnitude are associated with the uplift. The age relation of the dome to the other structural features of Keweenaw Point is not known, though the latest rocks of the region are involved in all of them. The precipitation of native copper and subordinate chalcocite along and near the faults of the Porcupine Mountain region may therefore have occurred in a different period from that of the main mineralization farther northeast, though there is no evidence that it did. Similarly the sulphide fissures that extend out from the intrusive mass of Mount Bohemia may belong to an independent period, but it seems more reasonable and in accord with the known facts to assume that all the mineralization was accomplished in a single period.

Such a period doubtless was of considerable length. Some of the minerals were formed earlier and some later in the period, and the same minerals were deposited at different times in different places. Some veins apparently were slightly earlier than the mineralization of the lodes they cut, and some were later. There was, however, no cessation of mineralization from the beginning to the end.

As all the rocks of Keweenawan age known on Keweenaw Point were affected by the structural deformation already described, it is evident that the mineralization was later than the Keweenawan rocks of the district. It is believed, however, from evidence given on page 124, to have been accomplished within the limits of Keweenawan time.

HYPOTHESES OF ORIGIN

It is clear that the copper is later than the rocks in which it is found and was therefore introduced into them. The important elements of genesis of such epigenetic deposits are the source of the copper, the method of transportation, and the cause of precipitation. Two contrasting views of the origin of the Michigan deposits are presented in the literature and may be designated as that of descending origin and that of ascending origin.

DEPOSITION BY DESCENDING SOLUTIONS

SOURCE OF COPPER

Pumpelly, who first formulated the hypothesis of descending origin, supposed the copper to have been derived from the sandstones that originally overlay the traps. The failure to find copper in the sandstone beds where they are still present has led to the abandonment of the idea that they were a source of the copper.

Lane, whose views are presented in detail in his report on the Keweenawan series, suggests different sources, all directly connected with the basic lava flows. He suggests that the copper was dissolved in the waters of desert lakes or playas that collected on the surface of the lavas. The copper in the waters was either derived from the weathering of the lavas or was contained in volcanic emanations given off by the lavas and collected in the surface waters. Lane further suggests that the copper may have been derived from the solution of the copper that is disseminated in the freshest traps.

MODE OF TRANSPORTATION

Pumpelly supposed the copper to have been leached from the sandstones by surface waters and to have been carried into the underlying rocks by gravity. At the time of Pumpelly's study the deposits had been developed only to shallow depth, and the assumption of such a movement of the solutions seemed to offer no difficulties. Since then the deposits have been developed to a vertical depth of more than a mile or a distance down the dip of the lodes of more than 9,000 feet. The presence of strong mineralization far below present sea level can hardly be attributed to the action of ordinary gravity circulation under present conditions. Moreover, the deeper levels of all the mines are essentially dry. Pockets of water encountered on these levels quickly drain off and remain dry. Some deep drill holes, however, maintain a small flow of water for considerable periods at least, and in the Baltic and other mines the water is under some pressure. The region is one of moderate precipitation, and the upper levels of the mines contain abundant water. The failure of the surface water to sink through the lodes to the deep openings indicates that the ordinary gravity circulation to great depth is very slight. This conclusion, of course, corresponds with the general experience in other districts.

The position of the ore shoots beneath relatively impermeable barriers, such as that of the Osceola lode, the White Pine deposits, and the fissure deposit below the Allouez "slide," is also hard to reconcile with gravity circulation but suggests solutions rising from depth under pressure.

The fact should be kept in mind that concentration of the ores of iron in the neighboring iron country, where the deposits have been opened to considerable depths, is attributed to circulation of surface waters, but where the iron is concentrated near impermeable rocks it is above rather than below them.

The difficulties of attributing the movement of the mineralizing solutions to ordinary gravity circulation have been recognized by Lane, who has suggested the hypothesis of "imbibition." This hypothesis apparently supposes that the flows remained hot and the vesicles were filled with hot gases or liquids till the rocks were tilted to their present positions and were, in places at least, covered by desert lakes or playas containing copper in solution. As the rocks cooled the gases and liquids in the openings contracted and thus made room for the solutions that covered the outcrops to pass down the lodes. This hypothesis has the advantage over that of ordinary gravity circulation in that it accounts for the space necessary for the solution to enter at great depth. It only allows, however, for sufficient solution to fill the cavities and necessitates more highly concentrated solutions than are known as surface solutions in order to produce the deep ore shoots. Moreover, it encounters most of the difficulties of ordinary gravity circulation as to position of ore shoots under barriers and slight circulation at depth. Lane points out that the tendency to form a vacuum as the gases contract would produce a "sucking" or "imbibition" effect. This, however, could help but little in overcoming the friction of deep circulation, as at best it could amount to only one atmosphere, or the pressure of a 33-foot column of water.

Lane has also applied the idea of concentration by diffusion to the Michigan deposits. This idea apparently assumes that the rocks are saturated with essentially stagnant water or solution. This solution would dissolve some of the copper that is disseminated through the flows, and the copper so dissolved would tend to become uniformly diffused through the solution. It is supposed that certain of the rocks had a precipitating effect on the copper in solution. Where the copper was being precipitated, the solutions would contain less than elsewhere, but the diffusion force would cause more to come in to equalize the concentration. This in turn would be precipitated. By this process the copper disseminated through the traps would be concentrated in certain parts of the series.

This idea of concentration does not encounter the difficulties involved in that of deep gravity circulation. That the present-day deep waters contain copper is indicated by analyses. Water from a deep drill hole in the Baltic mine precipitates copper on scrap tin, and Mr. W. H. Schacht, general manager of the Copper Range Co., states that the same water dissolved the copper from fuse caps that chanced to fall into it.

The hypothesis of diffusion certainly has attractions in explaining the filling of amygdular cavities with copper and other minerals. It is difficult, however, to reconcile this hypothesis with some of the broader features of copper occurrence. If the hypothesis is valid, it is not easy to understand why a generally fragmental well-oxidized lode like the Osceola is not uniformly mineralized throughout its extent. Under this hypothesis there would seem to be nothing except the character of the lode rock that would tend to cause ore shoots, and there seems to be nothing in the process that would cause the precipitation to occur under impermeable barriers. In fact, it would be natural to expect that precipitation would occur throughout all amygdaloids and conglomerates, though varying in amount according to the character of the rock. The diffusion hypothesis fails to explain why the Calumet & Hecla conglomerate is rich while, so far as known, most of the other conglomerates are lean or barren. The same difference in richness is shown by amygdaloids that appear equally well adapted for mineralization. It is difficult to explain the concentration in sandstone adjacent to fissures under the Nonesuch shale at a considerable distance from lava flows.

It seems, then, that although the hypothesis of diffusion avoids some of the difficulties presented by that of gravity circulation or that of "imbibition" it encounters others that make it equally hard to accept.

CAUSE OF PRECIPITATION

Pumpelly considered that the copper was taken into solution in the oxidized form as sulphate or carbonate, as would be expected and is known to occur in the action of surface water. He further supposed that these solutions in passing into the trap beds encountered abundant ferrous minerals and that the copper solutions were reduced and the ferrous iron oxidized to ferric iron, resulting in native copper and the ferric minerals hematite, epidote, and chlorite. The abundance of hematite and other ferric minerals in the lodes evidently suggested this explanation.

The modifications of Pumpelly's idea likewise assume that the copper is in the oxidized state, though Lane considers it to have been carried as chloride in the waters of desert lakes that were sucked into the lodes; he supposes the copper to have been reduced and the iron oxidized essentially as outlined by Pumpelly.

CHLORIDE WATER CONCEPTION

At Lane's suggestion, G. Fernekes undertook what amounted to a laboratory demonstration of Pumpelly's method of copper precipitation. He found[11] that under certain conditions ferrous chloride acting on cupric chloride will precipitate metallic copper and ferric oxide, one of the conditions being the presence of an alkaline mineral to neutralize the hydrochloric acid formed in the reaction. Prehnite and datolite were found to work satisfactorily as neutralizers, whereas with labradorite and laumontite no native copper was produced. Fernekes expressed these reactions by the following equations:

$$2FeCl_2 + 2CuCl_3 = 2CuCl + 2FeCl_3$$
$$2FeCl_2 + 2CuCl = 2Cu + 2FeCl_3$$
$$FeCl_3 + 2H_2O = Fe\,(OH)_2Cl + 2HCl.$$

These experiments, together with some made by H. N. Stokes[12] slightly earlier, which showed that the ferrous iron minerals, siderite and hornblende, will precipitate metallic copper from cupric sulphate solutions, caused Lane to adopt the hypothesis that the precipitation of the metallic copper was brought about by the reducing action of ferrous iron. He concluded that the common association of copper with prehnite and datolite and its rarer association with feldspar and laumontite are explained by Fernekes's findings, and he emphasizes the connection between the chloride waters of the mines, particularly those containing calcium chloride, which, as he points out, carry small quantities of copper, and the solutions from which the copper was precipitated. Lane rearranged and expanded Fernekes's equations into a single one, which he gives as follows:

$$2FeCl_2 + 2CuCl + 3CaSiO_2 = 2Cu + Fe_2O_3 + 3SiO_2 + 3CaCl_2.$$

[11] Econ. Geology, vol. 2, pp. 580-584, 1907.

[12] Econ. Geology, vol. 1, pp. 648-649, 1906.

MINE WATERS

Further discussion of Lane's ideas necessitates some specific consideration of the concentrated brines present in all the mines except near the surface. As Lane has discussed the matter fully,[13] a brief summary will suffice.

The character of the water shows progressive changes from the surface downward. Lane makes the following classes:

(*a*) At and near the surface, soft and fresh, with sodium in quantities more than sufficient to combine with the chlorine present.

(*b*) At some distance (generally 500 to 2,000 feet before it attracts attention unless especially sought) the chlorine is higher and the water is charged with common salt.

(*c*) At great depth a strong solution of calcium chloride containing some copper.

The following analyses illustrate the composition of each of the three classes:

Analyses of mine waters

[Grams per liter]

	Surface	Intermediate		Deep	
	1	2	3	4	5
Cl	7. 0	0. 357	3. 172	176. 027	175. 4
Br				2. 200	1. 5
Ca	6. 9	. 067	. 993	86. 478	87. 2
Na	4. 6	. 154	. 914	15. 188	13. 8
K				. 411	. 9
SO_4	Tr.			. 110	None.
SiO_2	4. 0			. 020	
Fe_2O_3 and Al_2O_3	1. 3			. 010	Fe.001
Mn				. 004	
Cu				. 016	. 0001
Ni				. 006	
Sr				Tr.	. 3
Ba				Tr.	
Li				Tr.	
Mg	2. 3			. 020	. 2
PO_4					None.
B				Tr.	
CO_2	6. 6			None.	
Loss	1. 1				
Total salinity	43. 8	. 700	5. 079	280. 489	279. 3

1. Allouez mine pond. Lane, A. C., Lake Superior Min. Inst. Proc., vol. 13, p. 94, 1908. Dearborne Chemical Works, analyst.
2. Mohawk mine, No. 1 shaft, tenth level, dripping. Idem, p. 121.
3. Mohawk mine, No. 1 shaft, twelfth level, dripping. Idem, p. 121.
4. Quincy mine, dripping on fifty-fifth level north of No. 2 shaft. Idem, p. 110.
5. Kearsarge lode, Red Jacket crosscut, eighty-first level, depth 4,900 feet. Collected August, 1921, from drip. R. C. Wells, U. S. Geol. Survey, analyst.

[13] Lane, A. C, Michigan Geol. Survey Pub. 6, vol. 2, pp. 774-846, 1911.

The explanation proposed by Lane for the different types of waters is that the deep water was connate—that is, inclosed in the rocks when they were buried; that the water near the surface is water that was "sucked" into the beds and dissolved carbonates as it passed through the rock; and that the intermediate water resulted from reaction between the other two, the essential reaction being between Na_2CO_3 of the upper water and $CaCl_2$ of the lower to produce NaCl and $CaCO_3$. He believes that when the concentration of sodium chloride became sufficient in the middle water zone, sodium zeolites, like analcite, were precipitated. Lane explains the strongest brines as probably the residue left after most of the water had been absorbed in hydration of the rock.

Van Hise and Leith[14] regard similar solutions encountered at depth in the iron region, as resulting from a condition of "deep stagnancy" in which the waters became progressively richer in the most soluble salts, and they do not believe that these solutions are related to any particular type of rock or to iron deposition in the region. In considering the solutions in the copper district, however, they suggest[15] that these waters may represent the "residuum or brine" of the ore-depositing solutions, but why they are so regarded in the copper district and not in the iron district is not stated.

The following points may be regarded as facts or well-founded deductions:

1. The shallow waters are of surface origin and have derived their character from materials taken up from the air, the soil, and the rocks.

2. As greater depth is attained the waters become progressively less in amount.

3. The relative proportion of calcium chloride to sodium chloride increases with the downward decrease in the amount of water and increase in concentration.

4. It is probable that in the copper country a very considerable amount of erosion has taken place, so that the rocks now in the zone of fresh water were at one time much farther from the surface and possibly were in a zone that bore the same relation to the surface then existing that the present deep "dry" zone bears to the surface of to-day.

5. From the foregoing conclusions it is probably true that there has been a progressive downward migration of the upper zones.

[14] U. S. Geol. Survey Mon. 52, p. 544, 1911.

[15] Idem, p. 588.

The evidence seems indecisive as to whether these strong chloride waters are "connate" waters still further concentrated, as Lane supposes; "deep stagnant" portions of the general ground water; or the residual parts of ascending magmatic waters. Strong brines are found at depth in many parts of the world. Concentration has been explained as due to hydration, as Lane suggests, and to evaporation by expanding gases in oil and gas regions.[16] Their particular composition has been explained by reduced solubility of certain salts in presence of a common ion,[17] which might cause sodium chloride to precipitate while calcium chloride remains in solution. As a matter of fact, stalactites of sodium chloride have been observed in the Quincy mine and have been reported to occur in other places where the waters are mainly calcic. There is, moreover, good reason to believe that in the deep levels, where the rocks are essentially dry, both calcium and sodium chlorides are present as solids. After a specimen of such rock has been wetted it will on drying accumulate a considerable crust of salts that have been dissolved and brought to the surface of the specimen. Specimens from deep levels, essentially dry when collected, become wet and even drip during damp or rainy weather, owing to their absorption of water from the air.

Of more concern in the present study than the origin and relations of the waters of the district is their possible connection with copper deposition. Lane's ideas in this regard have already been outlined. In the investigation here recorded no evidence indicating a close genetic connection between the salt waters and the deposition of copper has been recognized.

In general, the salt waters are as abundant and as concentrated in unmineralized as in mineralized portions of the lodes. There is practically no evidence that the mineralizing solutions were acid; a little calcite has been dissolved, but this result could have been accomplished as well by alkaline as by acid solutions, and the whole character of the mineralogy indicates that the solutions were not acid. No evidence of sodium zeolite deposition or copper deposition in zones that correspond to the present water zones has been found. Zeolites, except laumontite, which in places is abundant, are scantily present in both shallow and deep zones of the amygdaloid lodes but absent from the conglomerate lodes, and copper deposition shows no recognizable dependence on depth. The presence of traces of copper in the strong brines is not surprising when it is realized that these liquors have digested the copper-bearing rocks for untold years. Wells found that an artificial copper-free brine of otherwise the same composition as the deep waters (sample 5, p. 122), when put in contact with metallic copper, quickly dissolved copper in an amount comparable to that contained in the mine waters.

[16]Mills, R. V. A., and Wells, R. C., U. S. Geol. Survey Bull. 693, pp. 84-86, 1919.

[17]Idem, p. 73.

Pumpelly supposed that the oxidized copper solutions entered rocks rich in ferrous iron and were reduced, at the same time oxidizing the iron. But it is now established, as discussed in the oxidation of lava tops and ferric iron content of conglomerates, that the mineralized amygdaloids and the conglomerates were especially rich in ferric iron and low in ferrous iron before they were acted on by the mineralizing solutions. Furthermore, the ferric iron of the lodes in the vicinity of copper has been removed or chemically reduced to ferrous iron. This removal or change of iron is pretty clearly connected with the deposition of the copper. These facts not only cast grave doubt on any idea of origin that supposes the copper to have resulted from the reduction of oxidized copper solutions, as solutions of surface origin probably would be, and were assumed to be, but they strongly suggest that the direct opposite was true—namely, that the copper solutions were reducing in character.

The minerals, moreover, that accompany the copper and were formed at the same time are of a class that are believed to originate at moderately high temperature and certainly are not such as are formed by cool surface solutions. Altogether both the chemical changes and the character of the minerals seem opposed to the idea of formation from surface solutions.

There appears, however, no such chemical objection to the idea of concentration by diffusion. A part at least of the copper in the traps is in the form of sulphide, and it might be taken into solution and transported as such. When it entered the highly oxidized amygdaloids and conglomerates it might react with the ferric oxide, reducing that to ferrous oxide and in turn having its sulphur oxidized and the copper precipitated as metal, essentially in the manner set forth in the following section for ascending solutions. However, it is difficult to explain why so many amygdaloids, all rich in ferric iron and favorable physically and chemically to the process of diffusion, are barren.

From the foregoing discussion it appears that there are serious physical and chemical objections to the idea that the deposits were formed by descending surface waters. The hypothesis of concentration by diffusion avoids some of these difficulties but encounters others equally serious in regard to the distribution of the copper.

DEPOSITION BY ASCENDING SOLUTIONS

To show that the copper was deposited by ascending solutions would by no means fully account for the deposits. The hypothesis now to be discussed goes further and assumes that the copper-bearing solutions were expelled forcibly, at high temperature, from a magma chamber in which they originated. The probability of this assumption must depend largely upon the degree to which the chemical character of the solutions, as judged by the work they have done, resembles that of ore-forming solutions that have been active in other regions where there is virtual proof of their genetic relationship to igneous magmas.

A magmatic origin for the Michigan copper deposits was first proposed by H. L. Smyth in 1896. F. E. Wright, Van Hise, Leith, and Steidtman, R. E. Hore, T. S. Woods, and J. E. Spurr have since implied or asserted a similar origin.

The Coro Coro deposits, in Bolivia, which show many points of resemblance to the Michigan deposits, were ascribed to deep-seated causes as early as 1846 by C. A. de la Ribette and definitely to a magmatic origin in 1906 by G. Steinmann, and still later by Singewald and Miller and Singewald and Berry. For somewhat similar deposits in New Jersey J. Volney Lewis in 1907 proposed a magmatic source.

SOURCE OF THE COPPER

There is no direct connection between the main ore deposits of the district and the exposed intrusive rocks. However, certain associations of small copper deposits with the known intrusive rocks indicate what is thought to be true of the large ore bodies.

Copper sulphide veinlets cut the intrusive mass of Mount Bohemia[18] and adjacent rocks and apparently terminate outward from the intrusive body; copper sulphides are concentrated also in the miarolitic cavities of the aplitic phase of the intrusive gabbro. Wright appears to regard the intrusive mass as derived from the magmatic reservoir that furnished the somewhat older basalts and felsites and to consider the copper sulphides inclosed in it as related in source to the native copper and the copper sulphides and arsenides of the larger deposits of the region. Sulphide veins are likewise associated with the intrusive gabbro near the Michigan-Wisconsin boundary and the quartz porphyry bodies north of Lake Gogebic.

Native copper, with some sulphide, occurs near the Porcupine Mountains, where intrusive rocks that are probably of late Keweenawan age are thought to account for the uplift and faulting.

Arsenical copper with some sulphide occurs at the Indiana mine in felsite, which Lane[19] regards as intrusive. Chalcocite is present also in probably intrusive felsite east of Allouez.

The Duluth gabbro, thought by most who have studied it to be of late Keweenawan age, may well be a part of the same intrusive mass with Mount Bohemia, the Porcupine Mountains, and the bodies of intrusive felsite and quartz porphyry known at many places throughout the district; this mass would thus underlie the whole lava series. Small copper sulphide deposits,[20] with or without nickel, are found in the gabbro or just outside its contact.

[18]Wright, F. E., Michigan Geol. Survey Rept. for 1908, pp. 392-394, 1909.

19Private report to the company.

[20]Nebel, M. L., Econ. Geology, vol. 14, p. 399, 1919.

Pegmatitic knots or lenses occur in some of the traps of the district, especially those of greater thickness, and some of these contain copper sulphides and native copper. These pegmatitic lenses are present only well within the thicker flows. They seem to have resulted from a differentiation during the process of crystallization similar to that which produces the pegmatitic portion of intrusive bodies, though they are of small extent, and the differentiation has not progressed far. They do, however, show a differentiation toward increasing copper content that in a great intrusive body might well result in abundant copper-bearing solutions.

In nearly all these examples of close association of copper with intrusive bodies copper sulphides are present, and in most of them, except where the inclosing rock is red, sulphide predominates over native copper. Where the veins are within the intrusive rocks, only sulphides are usually present, though copper occurs in felsite at the Indiana mine.

DIRECTION OF MOVEMENT OF THE SOLUTIONS

The concentration of copper on the under sides of relatively impermeable barriers is perhaps the most direct indication that the solutions came from below after the rocks had assumed their present attitude, but it is not the most convincing evidence of ascending flow.

If, as most students of the problem now agree, the ores were deposited from hot solutions, they must have been hot either because they flowed through hot rocks or because they came from a heated source; the first assumption would imply precipitation within so short a period that the lavas had not cooled; the second, indicative also of rapid action, would probably require a magmatic source for both the solution and the heat. From what has been said in connection with gravity circulation (p. 121) it is clear that the permeability of the rocks was low when the driving force on the solutions was only gravity, or gravity plus one atmosphere. Greater fluidity and greater driving force would help to overcome low permeability, and both these advantages would exist if the solutions came from a magmatic source.

Marked decrease in viscosity of solutions attends rising temperature and undoubtedly continues as solutions pass from the liquid to the gaseous state. The solutions coming from a magma reservoir may be assumed to be under pressure sufficient to lift columns of molten rock thousands of feet to the surface. The more mobile constituents, the ore-forming solutions, should start out from the magma chamber, therefore, with pressure at least equal to that on a column of molten rock from the same source and should be able to maintain that pressure to higher levels in the crust because of their lesser weight and viscosity and their lower solidifying point. Recent work at the Carnegie Geophysical Laboratory[21] suggests that great pressure may be developed just at the time the volatile constituents are liberated and made available for migration. Altogether, the evidences of enormous forces associated with igneous activity, such as volcanic explosions, elevation of vast quantities of magma, and penetration of emanations into dense rocks, as in contact metamorphism, show that solutions from magmatic sources have a much greater ability to move through difficultly permeable rocks than waters impelled only by their own head. Ascending solutions are never in want of an outlet, provided their pressure is great enough. The farther descending solutions penetrate the tighter they find the rocks; but rising solutions, which are least viscous and under greatest pressure at depth, where the difficulty of ascent is greatest, are continually reaching more permeable material above as their ability to flow becomes diminished through loss of temperature and pressure, and at the surface there is always a free outlet.

[21]Morey, G. W., The development of pressure in magmas as a result of crystallization: Washington Acad. Sci. Jour., vol. 12, p. 219, 1922.

With great volumes of solution passing any given point on the upward journey there would tend to arise a uniformity of temperature for long distances along the channelway. Hot water starting through a long cold pipe would warm the near end of the pipe and emerge cold at the far end, whereas much hot water flowing continuously through the pipe would in due time warm it from end to end to about the same temperature. Where the rate of heat conduction is so low as it is in rocks, this tendency could doubtless afford essentially uniform temperatures throughout as great a vertical range as that represented by the mine workings and thus give the observed constancy to the character of mineral deposition throughout that range.

MEANS OF ACCESS OF THE SOLUTIONS

If the solutions ascended from some deep-seated source they must have had means of reaching the horizons where they are known to have precipitated copper. Two possible means of access may be considered—- intersection of the productive beds by the underlying intrusive mass from which the ore solutions came; or ascent along fractures that cut these beds. More specifically, these hypotheses are that the solutions reached their horizons of precipitation from crosscutting contacts of the Duluth gabbro; or that they were brought to these horizons by the deep extension of the Keweenaw fault. A third means would be utilization of whatever avenues presented themselves in the regions lying near the magmatic source and the gradual and progressive collection of the solutions into the more permeable channel ways at the higher levels.

ASCENT FROM CONTACTS OF THE DULUTH GABBRO

There is reason to suppose that the Duluth laccolith extends beneath this region at or near the contact of the Keweenawan and the underlying rocks. Grout and Hotchkiss have suggested, further, that the Lake Superior basin has resulted from slumping of the essentially horizontal crustal strata into an under lying magmatic basin, and that during this slumping the magma pushed into higher parts of the crust. Whether this or some other idea as to the cause of the basin is correct, it is to be expected that a mass of magma of the size of the Duluth or Lake Superior laccolith would send offshoots into the overlying rocks and show an irregular upper surface. That there are such offshoots may be inferred from the presence of intrusive rocks suggestive of Duluth gabbro parentage well above the base of the Keweenawan. That the main gabbro would actually inject its more mobile constituents into adjacent openings is indicated by the analogous occurrence of copper minerals in fractures near these minor intrusive masses.

If the main intrusive body, in working its way upward, intersected a permeable amygdaloid or conglomerate bed, the mobile constituents given off by the magma would pass upward along such a channelway, and where they encountered favorable physical and chemical conditions they would deposit certain of their constituents. This inference supposes that the beds now mineralized extend for long distances down the dip—a supposition that seems probable from the known extent along the outcrop of most of the productive beds and also from the less positive correlation of certain beds or groups of beds on Keweenaw Point and Isle Royal. It is perhaps also worthy of note that the productive parts of the Kearsarge, Baltic, and Osceola lodes coincide with the thickest portions of the flows as shown along the outcrop.

It is not likely, however, that all beds that extend to great depth will be equally favorable as solution channels. It is known that an amygdaloid or a conglomerate may change within a short distance along the strike from a relatively permeable to a relatively impermeable bed. To be favorable it must not only have been permeable at its intersection with the source of solutions but must have continued as a permeable channel to the level of the present surface at least, and doubtless to the original surface, in order to have an outlet that would permit the passage of a large volume of solution. It is obvious that not every bed that is favorable where cut by the present erosion surface or mine workings would be equally favorable for an indefinite distance down the dip any more than along the strike. Some beds, therefore, might be well mineralized while others that are of apparently equal promise where now exposed received only enough mineralization of the feebler kind to fill vesicles or cause cementation.

Beyond the analogy with the deposits adjacent to the subordinate intrusive bodies like that of Mount Bohemia and the intrusive mass which probably underlies the Porcupine uplift and with ore deposits on the margins of intrusive bodies in many other parts of the world, there is little direct evidence in support of this particular pathway of transfer for the magmatic solutions to the places where they acted. Perhaps the most suggestive fact relative to direct ascent along the permeable lodes from their intersection with the Duluth gabbro is the presence of the chief copper-bearing beds in the lower part of the Keweenawan series. But even this may be due to the influence of the Keweenaw fault.

ASCENT FROM THE KEWEENAW FAULT

The Keweenaw fault has long been considered by Lane and others a possible channel for eruptive rocks. Attention has been called by Lane to the several bodies of intrusive rock close to the fault, with the implication that the intrusive material may have risen along it. This implication suggests the fault as a possible channelway for the ore solutions.

That the copper mineralization followed the main fault movement seems to be indicated by the mineralization of the breaks in the highly shattered area near the fault. So far as known, however, no evidence of mineralization has been found on the fault itself; this would indicate that it was not particularly permeable as compared with fractures less filled by gouge or with open-textured amygdaloid or conglomerate beds.

The great horizontal extent of the fault and the magnitude of its throw indicate that it persists downward for a great distance—far enough, it is easy to believe, to tap the magmatic reservoir in which the mineralizing solutions originated. Although evidently less permeable than open fractures and porous beds, its greater accessibility and continuity may have made it the chief channelway by which the solutions passed upward in a direction transverse to the rock structure. The Keweenaw fault is a reverse fault, dipping with or slightly flatter than the beds, and there are smaller nearly parallel faults above it which probably branch from it. If the main fault and its branches truncate the higher beds down the dip, because the beds dip more steeply than the fault, solutions rising along the fault would tend to enter any porous bed and continue along it as affording a shorter and probably an easier channelway to the surface than the upper part of the fault fissure.

Essentially the same conditions would control the beds selected and mineralized in this ascent of the solutions in the beds from the Keweenaw fault as would control the beds entered directly from intersection with the Duluth gabbro.

It may be supposed that the fractures occupied by the fissure deposits reached down to the fault and thus furnished easy channelways for the upward movement of solutions. Where fissure deposits are abundant, as along the crest of the Keweenaw anticline in the north end of the district, no largely productive lode deposits have been developed, but in the central area, where fissures are less numerous, the copper occurs mainly in the lodes. This difference suggests that where plentiful Assuring furnished easy channels of escape for the solutions they did not traverse the lodes in sufficient quantity to form large deposits. Many of the smaller fissures, however, were fed locally from the lodes they cut, and the same thing may be true of some of the larger ones.

The presence of the copper in the Nonesuch lode at White Pine in close association with faults and fractures branching from a pronounced reverse fault which itself is not known to be mineralized, is suggestive of similar relations between the main copper deposits of Keweenaw Point and the Keweenaw fault.

If the Keneenaw fault down the dip cuts into higher beds than those which lie against it at the surface, there probably is some horizon in the folded beds to which it becomes tangent and below which it cuts back again to older beds. (See fig. 10.) If this is so, any of the favorable beds near the bottom of the series might receive solutions direct from the fault and become mineralized, but beds above the horizon of tangency would not be cut and so would receive only such solutions as were able to leak out from the major channelways and therefore would be only feebly mineralized. Several beds of the lower part of the series as high as the Ashbed lode carry considerable quantities of copper, but above that horizon there is nothing of known value save in the Porcupine region, where local conditions account for the exception.

Sulphides are more abundant in fractures that cut amygdaloid lodes near the fault than in those that cut lodes higher in the series. This difference would be explained if, as suggested under "Causes of precipitation" (p. 130), the solutions were originally sulphide solutions and were oxidized by long contact with the hematite of the lodes. At horizons near the fault the solutions may have followed the lodes for shorter distances and thus have been less completely oxidized, with more abundant sulphides as a result. But the Allouez conglomerate and some other conglomerates well above the fault carry widespread chalcocite, so that no great significance can be attached to this occurrence of sulphide.

The lodes farthest from the fault, the Ashbed, Pewabic, Calumet & Hecla conglomerate, and Osceola, carry high-grade copper, exceedingly low in arsenic. The Kearsarge and Isle Royale lodes, nearer to the fault, and especially the Baltic, which is closest to it, contain more arsenic. This may likewise be an indication that the solutions became more highly oxidized as they travel farther from the Keweenaw fault. The Lake lode, which lies relatively low in the series and near the fault, contains nonarsenical copper, and this occurrence, although it may be an exception to the general rule through some special conditions not known, may indicate that the generalization is unfounded. It must be recognized, moreover, that there is much more fissuring of the rocks near the base of the series and that arsenical copper in fissures may, in part at least, account for the higher arsenical content of the lower lodes.

There is reason to believe that some of the lodes are fed by fissures that enter or cross them within the present range of observation. This seems especially evident in the Calico lode of the Michigan mine, which was largely mined above the intersection of the Branch fissure but is poor below the intersection. The similarity of the minerals in some of the strike fissures that cross the Baltic lode to the minerals in the lode and the local merging of fissure mineralization into lode mineralization are highly suggestive that the lodes were at least in part fed by the fissures.

GRADUAL ACCUMULATION IN PERMEABLE CHANNELWAYS

If solutions are forced against a body of rock varying in permeability from place to place, they will enter such openings as are first presented but will seek the avenues easiest to follow and eventually will flow in greatest volume through the most permeable portions of the rock. This principle may have governed the upward movement of the mineralizing solutions in Michigan. Aside from its plausibility and the certainty that it works on an important scale in movements of the shallow ground water, there is only one reason for thinking that it may apply here. It possibly explains more readily than the other suggestions the fact that the mineralizing solutions appear to have reached essentially all parts of the rocks of the lava series.

CAUSES AND CONDITIONS OF PRECIPITATION

Three contrasting views may be considered as to the nature of the copper-bearing solutions from which the ores were deposited—(1) that the copper was transported in an oxidized condition as sulphate, chloride, carbonate, or silicate and was deposited by chemical reduction of such compounds; (2) that the copper was transported actually or potentially in the metallic state and so deposited; (3) that the copper was transported actually or potentially as sulphide and arsenide and was deposited mainly as native metal as a result of the removal of the sulphur or arsenic by oxidation. These views may be called respectively the reduction hypothesis, the saturation hypothesis, and the oxidation hypothesis.

PRECIPITATION BY REDUCING ACTION OF FERROUS IRON

To Smyth[22] belongs the credit of recognizing that the mineralogy of the deposits and certain structural features, such as the occurrence of copper in the fissure deposits on the under side of the Greenstone flow, are not in accord with the view that the solutions came from above, as Pumpelly had proposed, but indicated instead that they came from a deep-seated source, of which boron and fluorine are especially suggestive. Smyth concluded that each of the amygdaloid lodes had been weathered while exposed at the surface and so had acquired the ferromagnesian alteration products which Pumpelly had ascribed to the breakdown of the pyroxene and olivine of the basalts. The calcium and sodium minerals, however, which Pumpelly thought were similarly derived from the feldspar, Smyth said had been introduced, along with the copper that is found associated with them, from below, after the rocks had been tilted to their present attitude. Smyth accepted Pumpelly's explanation of the cause of precipitation as the one best in accord with known facts—namely, reduction of oxidized copper compounds by the ferrous iron minerals of the lodes. It is to be regretted that these ideas were recorded only in the most summarized form and therefore failed to receive the recognition that they deserved.

[22]Smyth, H. L., Science, new ser.. vol 3, pp. 251-252, 1896.

Smyth's account of the mineralogy, structure, and age of the deposits still seems correct. Since that account was published, however, it has been shown that chlorite, epidote, pumpellyite, and allied minerals are hydrothermal minerals rather than products of weathering, and, as set forth on page 38, weathering is thought to have been of minor importance in producing red lava tops. The mineralization and rock alteration, therefore, represent a single period and a single cause rather than two widely separated periods and different causes. Again, Pumpelly's idea, accepted by Smyth, of copper precipitation by reduction is contradicted by the fact that copper is not closely accompanied by hematite but is intimately associated with bleached rock. It also fails to account for the copper in the conglomerates, particularly in the rich Calumet & Hecla conglomerate. It is subject, in short, to exactly the same objections as the hypothesis that the solutions were descending. It postulates, moreover, the presence in ascending solutions of oxidized copper compounds, whereas ascending solutions, the world over, are now known to deposit copper in combination with sulphur or some similar element of antioxidizing character.

In describing the native copper and chalcocite deposits of New Jersey, Lewis[23] noted the tendency toward concentration under barriers of low permeability, the bleaching of the red rocks around the copper, which had also been noted by Weed,[24] and the close association of the copper with igneous masses. Lewis concluded that the copper had been deposited from ascending hot solutions, probably derived from the underlying source of the basic rocks of the region. For the formation of native copper, Lewis cited experiments by Stokes[25] and suggested that cupric sulphate contained in the ascending solutions had been reduced to cuprous sulphate by the action of minerals and solutions containing ferrous iron, and that native copper had been deposited from the cuprous sulphate where the solutions had become sufficiently cooled. The bleaching he explained as resulting from leaching of the hematite by acid sulphate solutions.

[23]Lewis, J. V., Econ. Geology, vol. 2, pp. 242-257, 1907.

[24]Weed, W. H., New Jersey Geol. Survey Ann. Rept. for 1902 ,p. 135, 1903.

In a later paper, read at the meeting of the Society of Economic Geologists in December, 1922, Lewis further emphasized the structural relations outlined above and the relation of the copper deposits to intrusive bodies. In this paper he recognized the probability that the solutions as they came from the magmatic source were reducing rather than oxidizing.

In general, Lewis's idea of the New Jersey occurrences will apply equally well to those of Michigan.

Watson[26] regards the native copper deposits of the South Atantic States as derived from sulphides disseminated in the basic lavas. The copper was collected by circulating hot solutions and precipitated as metallic copper in areas rich in ferric iron by the oxidation of the solutions. Watson recognizes the possibility that the solutions may have been derived from deep-seated intrusive magmas.

Wright's reference to the presence of sulphides near intrusives and in the lower beds of the series and of native copper with little sulphide higher up[27] indicates relations similar to those in New Jersey. He asserted that any theory of origin would have to explain these relations. Beyond implying that the copper near the intrusives is magmatic and that therefore all of it throughout the district may be magmatic, Wright did not go.

Van Hise[28] cited the Michigan copper ores as examples of deposits formed by meteoric waters that had first descended, then moved laterally, dissolving copper as they went, and finally ascended and precipitated the copper as now seen. He adopted the Pumpelly idea of precipitation by ferrous iron.

Van Hise, Leith, and Steidtmann[29] concluded that the ores were formed by hot solutions and that the type of rock alteration is unlike that accomplished by meteoric waters. As to the source of the water, they said: "On the whole the evidence is taken to point to a probable original concentration of copper by hot solutions, largely of juvenile contribution but more or less mixed, necessarily, with meteoric waters, and a later working over of the deposits by waters dominantly of meteoric source." As to whether the juvenile (that is, magmatic) waters were derived from the intrusive rocks or from the lava flows they were uncertain, but they somewhat favored the origin from the flows. The heat they thought was partly supplied by the hot magmatic waters and partly by the still hot flows. The copper they considered in part to have come as chloride from the same magmatic source as the hot juvenile solutions, along with boron, fluorine, CO_2, and perhaps other magmatic emanations, but in part to have been derived from leaching of the basic wall rocks by the mingled hot solutions. The precipitation of the copper, they concluded, was accomplished through reduction of the copper solutions by ferrous iron minerals and by ferrous solutions derived from them, in essentially the way Pumpelly had proposed. Finally, they concluded that the brines of the deep levels are probably the residues of the ancient ore-forming solutions, possibly mixed with meteoric water.

[25]Stokes, H. N., Econ. Geology, vol. 1, p. 645, 1906.

[26]Watson, T. L., Native copper deposits of South Atlantic States compared with those of Michigan: Econ. Geology, vol. 18, pp. 732-751, 1923.

[27]Wright, F. E., Michigan Geol. Survey Rept. for 1908, pp. 392-394, 1909.

[28]Van Hise, C. R., Am. Inst. Min. Eng. Trans., vol. 30, pp. 189-98, 1900.

[29]U. S. Geol. Survey Mon. 52, pp. 580-591, 1911.

The parts of these views of Van Hise, Leith, and Steidtmann that have to do with meteoric waters are discussed on page 120. The parts that deal with magmatic waters follow Smyth in large measure but go further in recognizing that the type of rock alteration contrasts entirely with that produced by weathering or by meteoric waters. If the magmatic waters came from the lava flows, there were presumably several periods of mineralization, as successive flows were in the proper condition to yield emanations. The presence of mineralized boulders of amygdaloid in what was considered unmineralized conglomerate was thought to mean mineralization before conglomerate deposition and apparently strengthened the belief that the lavas rather than the intrusives were the source of the mineralizing solutions.

Hore[30] appended to an excellent summary of previous literature on the district his own ideas as to the origin of the deposits. He concluded that the copper and the Keweenawan igneous rocks had a common source; that the copper is essentially a primary deposit from ascending solutions which followed the extrusion of lava so closely that the rocks were still hot, although they had already been fractured; that tilting and faulting followed copper deposition; that the copper replaced the rocks and was precipitated from chloride solutions by the reducing action of ferrous iron. These conclusions were well presented and accompanied by shrewd and pertinent observations on other features of the copper deposits. The conceptions introduced are discussed above.

Woods[31] emphasized the possibility that the felsite and quartz porphyry intrusive masses may have been the sources of the copper, which he thought may have been first deposited by ascending magmatic solutions and then enriched by downward-moving waters in just the same way that the porphyry deposits of the West have been originally formed and later enriched.

[30]Hore, R. E., Michigan Geol. Survey Pub. 19, pp. 157-161, 1915.

[31]Woods, T. S., Eng. and Min. Jour., vol. 107, p. 300, 1919.

PRECIPITATION IN CONSEQUENCE OF SATURATION

It may be supposed that metallic copper was deposited, because that was what the solutions carried, and that it was precipitated by cooling of the solution or by some other cause, in the same way that calcium carbonate solutions precipitate calcite. Perhaps Spurr had some such idea in mind when, in his short article[32] arguing for the magmatic origin of these deposits, he asked if the intercrystallization of copper with chalcocite does not indicate a deficiency of sulphur in the solutions.

The chief objection to this idea of precipitation by saturation is that in all but a few of the thousands of copper deposits that have been studied throughout the world it is apparent that the copper has been transported either as a sulphur, arsenic, or allied compound, as in most primary deposits, or as an oxidized compound, as in the secondary deposits. The native copper in many secondary deposits has clearly resulted from the oxidation of sulphides in place. On the other hand, the conception has certain attractions. Native gold may possibly be carried as such in solution and perhaps native silver also. In general, precipitation that takes place without evident attack of the solutions on the wall rocks may be thought to result from the fact that the solutions had reached the saturation point through decrease of temperature or other physical causes rather than from some chemical reaction that rendered the substances they carried less soluble.

In the Michigan deposits there is characteristically a pronounced chemical change in the inclosing, rock, but locally copper is present in rock that shows little change, as in parts of the upper levels of the Calumet & Hecla conglomerate, locally in the Kearsarge and Pewabic lodes, and in fissures. Doubtless the chemical reactions that caused the precipitation of native copper did not all take place just where the copper was precipitated. It is entirely probable that the reactions began as soon as the temperature and other physical conditions permitted, and they may have gone on for some time before any copper was precipitated. Once copper started to form, it would act as nuclei for further precipitation from solution that had been undergoing chemical reaction some distance away. In considering the immense masses of copper, hundreds of tons in weight, it is not reasonable to suppose that the entire chemical reaction was confined to the rock replaced by the copper or to that immediately surrounding it, and the supposition would be no more reasonable for the smaller masses.

PRECIPITATION BY OXIDATION

Most of the copper deposits of the world consist of sulphides[33] or have been derived directly from sulphides by superficial oxidation. The relatively small class of primary deposits of native copper, of which the Michigan deposits afford the chief example, constitutes the only exception to the rule.

[32]Spurr, J. E., The copper ores of Lake Superior: Eng. and Min. Jour., vol. 110, pp. 355-357, 1920.

[33]For brevity in expression the sulphide group is here used to include also the related compounds with arsenic, antimony, etc.

Although the transportation of copper in solutions that deposit it as sulphide or allied minerals is not yet well understood, the fact that it is so transported and deposited in by far the greater number of deposits must be accepted. It is advisable, therefore, to inquire whether the Michigan and similar deposits represent not an entirely different and independent scheme of copper transportation and deposition but rather a modification of the ordinary method through the influence of special conditions. What kind of special modifying conditions would serve to precipitate native copper from solutions that normally would deposit copper sulphide? The metallurgist, who transforms copper sulphide into metallic copper, would answer that if the copper sulphide solutions could be oxidized under the right conditions and to the proper degree, metallic copper would be formed.

Twenty years ago, G. Steinmann[34] advanced the idea that the native copper and chalcocite deposits of Coro Coro, Bolivia, originated from ascending magmatic solutions that would normally have deposited only copper sulphides, but because, the solutions entered hematite-bearing rocks, part of the sulphur was oxidized by the oxygen of the hematite and therefore part of the copper was precipitated as native metal in the midst of bleached areas of the rock, and the rest of the copper united with the remaining sulphur to form chalcocite.

How does this idea of precipitation by oxidation apply to the Michigan deposits? Several conditions must be met to make it seem applicable.

1. There should be definite evidence that sulphides had been present in the ore-forming solutions.

2. If oxidation was the cause of the conversion of copper sulphide into native copper, the rocks in which the metallic copper was deposited must have been oxidizing in their nature.

3. At the places where copper was deposited the oxidizing power of the rock should have been lessened if not destroyed.

4. Oxidized compounds of sulphur might be expected.

The extent to which these requirements are met by the Michigan deposits is discussed below.

[34]Festschrift Harry Rosenbusch, p. 360, 1906.

PRESENCE OF SULPHIDES

Sulphides and arsenides of copper in the Michigan district are subordinate in quantity but are of widespread occurrence. Copper sulphides occur in pegmatitic knots or lenses in certain of the thicker traps, and there is a close connection between sulphides and intrusive masses. Copper sulphide has been found in several of the lodes, especially in the Baltic and Isle Royale, and in countless fissures, large and small, in and near the lodes. Copper arsenides have been observed sparingly in the Isle Royale lode and are plentiful in several large cross fissures. Copper sulphide and metallic copper (see pl. 68) or copper arsenides and metallic copper are in many places intimately intergrown. There is thus proof that practically throughout the district at least a part of the copper was transported in the manner common to most primary copper deposits elsewhere, and that the deposition of sulphide and arsenide of copper went on at the same time as the deposition of metallic copper.

If the sulphide and arsenide compounds of copper represent the minor residues of sulphur and arsenic that escaped oxidation, it might be expected that the copper sulphides and arsenides formed would be those lowest in sulphur and arsenic and highest in copper, and such is the case. The prevailing copper sulphide is chalcocite, with a molecular ratio of copper to sulphur of 2:1, the highest among all known copper-sulphur minerals. Bornite, with a ratio of 5:4, is far less common; chalcopyrite, with a ratio of 1:2, less common still; and pyrite, the commonest sulphide in nature and the one that suggests an abundance of sulphur, is in the Michigan deposits practically absent.

The arsenides show a similar tendency. In other regions the common unoxidized copper-arsenic minerals are enargite and tennantite, with proportions of copper, arsenic, and sulphur of 3:1:4 and 8:2:7, respectively. In Michigan these minerals are absent and instead the arsenic is combined in the uncommon minerals domeykite, algodonite, and whitneyite, all high in copper, low in arsenic, and devoid of sulphur, with copper arsenic ratios of 3:1, 6:1, and 9:1, respectively.[35] Moreover, certain of the lodes, notably the Baltic and Isle Royale and in less degree the Kearsarge, carry “arsenical copper”—that is, metal containing small amounts of arsenic but enough to modify the mechanical and electrical properties of the copper.

Although sulphur doubtless exceeds arsenic in total amount in the district, there are no such massive and extensive occurrences of chalcocite as the so-called “mohawkite” arsenide veins of the Ahmeek and Mohawk mines, and arsenic is more abundant in proportion to sulphur than in other copper districts. The idea suggests itself that sulphur was oxidized with relatively greater ease than arsenic, and this idea accords with the behavior of these elements in copper smelting.

Finally, the oxidation hypothesis would suggest that the solutions that had traveled in the most intimate contact with the oxidizing agent would precipitate the least sulphide and arsenide, and vice versa. This suggestion likewise is borne out by the facts, as discussed below.

[35]The exact composition of these arsenides has not been worked out, because of the intimate intergrowths that prevent isolation of any single variety. The ratios given are those recorded in the textbooks.

PRESENCE OF AN OXIDIZING AGENT

The conglomerate layers and the lava tops contained a noteworthy proportion of ferric iron, chiefly as hematite. This hematite was present in the rocks from the time of their formation and therefore long antedated the deposition of copper, which came only after the entire series had been accumulated and the tilting and faulting had been accomplished.

Ferric compounds can part with one-third of their oxygen in the presence of a reducing agent. Hematite, therefore, may be regarded as a potential oxidizing agent toward a solution of reducing nature. The question then arises. Did hematite actually oxidize ore solutions bearing copper sulphide and thus cause the precipitation of metallic copper?

That rocks of normal composition contain copper sulphide ores, whereas red rocks rich in ferric oxide are likely to contain native copper, is shown by the following figures:

Ferric and ferrous iron content of inclosing rock of some copper deposits

	Fe as Fe_2O_3	Fe as FeO	Total Fe
Sulphide:			
Butte, Mont., monzonite	1.47	2.01	3.48
Bingham, Utah, monzonite	2.27	1.97	4.24
Ely, Nev., monzonite	2.38	2.69	5.07
Bisbee, Ariz., limestone (Fe_2O_3 + FeO)	.12–.24		.36
Native copper:			
Kearsarge lode, Michigan	11.38	.33	11.71
Osceola lode, Michigan	7.15	1.23	8.38
Isle Royale lode, Michigan	3.66	5.30	8.96
Sandstone, Calumet & Hecla conglomerate, Michigan	3.3	.04	3.34
Iron-rich boulder, Calumet & Hecla conglomerate, Michigan	8.88	1.01	9.89
Allouez conglomerate, felsite pebble, Michigan	3.42	.47	3.89
Puca sandstone, Coro Coro, Bolivia (about)	6.3		6.3
Sandstone, New Jersey:			
Purple ore bed	6.21		6.21
Shale	9.61	1.54	11.15

Not only is the ferric iron higher in the rocks that inclose native copper but it is present as the oxide, whereas most of the iron in the rocks that contain sulphides is combined as silicate and thus probably is less available for reaction.

Native copper is common in the upper levels of deposits that have undergone sulphide enrichment. The conditions of occurrence and method of formation of this native copper are well understood; it is plainly an oxidation product of ehalcocite. The oxidation is probably accomplished by atmospheric oxygen, but many believe[36] that it is accomplished also by ferric sulphate, well known as an oxidizing agent. In the production of native copper by the action of ferric sulphate on chalcocite, the iron compound would be in solution and the copper compound solid, whereas the Michigan native copper is inferred to have been formed by reaction between copper sulphide in solution and ferric iron in the solid state. Inasmuch as the first reaction certainly takes place, it would seem that the second might do so under the proper conditions; and it has actually been produced experimentally.[36a] The results of experiments relating to this problem and conclusions drawn from them are presented by R. C. Wells on pages 137-141.

[36]Lindgren, Waldemar, Mineral deposits, pp. 789-792, 1913.

Another indication that hematite acted as an oxidizing agent to precipitate metallic copper is seen in the field relations. The field evidence may be considered under two heads—the relation of native copper and copper sulphide to the proximity of hematite-bearing rocks, and the effect upon hematite where metallic copper has been precipitated. The first of these topics is considered here; the second in the succeeding section on bleaching.

Where the ore solutions evidently traveled in most intimate contact with the oxidizing agent, the largest proportion of metallic copper and the smallest proportion of sulphide or arsenide are found; and conversely where the solutions appear to have moved mainly through rock of nonoxidizing character, the proportion of sulphide or arsenide to metallic copper is highest.

The first requirement for ore formation on a commercial scale was the presence of extensive through-going channels of relatively high permeability through which the ore solutions could pass. These permeable channels were of three sorts—the conglomerate layers; the vesicular lava tops, especially the brecciated tops; and large fractures relatively free from gouge, such as the cross fractures due to the tension on the anticlines, as the Allouez and Keweenaw anticlines, and strike fissures near the base of the series, as near the Baltic lode. Innumerable smaller fractures present throughout the district but especially abundant in the regions of major disturbances also acted as minor channels for the ore-forming solution. The channels afforded by the conglomerate layers and the lava tops were relatively rich in hematite. If hematite exerted an oxidizing effect on the solutions that came into contact with it, then those that moved for the longest distances through the small openings of these hematite-bearing lodes had the greatest opportunity to become oxidized.

The channels of the third type—the major cross fissures—cut mainly through the dark, unoxidized traps; only small parts of their walls consist of the hematite-bearing conglomerates or amygdaloids. Moreover, these fissures probably afforded readier and more direct passageways for the solutions than the more interrupted, more circuitous and probably smaller openings of the lodes. The solutions in the fissures were therefore not in such close contact with the adjacent rock as the solutions in the conglomerates and the lava tops, and consequently it might be expected that the solutions moving through the conglomerate and amygdaloid lodes would be more thoroughly oxidized than the solutions passing along the fissures. This in general is true; very little sulphide occurs in the amygdaloid lodes independent of fissures.

[36a]If it is assumed that the copper was carried in solution as some compound—sulphide, for example—a condition in which it must have been carried in nature, then the action of ferric oxide was to prevent its deposition as sulphide through selective oxidation of the sulphur. The copper under these conditions could still deposit as native metal, whereas the more common process in the formation of ores is the change of native metal to sulphide.

In the conglomerate lode practically no sulphide occurs in the cement in the way common for the metallic copper. The Allouez conglomerate in particular and some of the other conglomerates in less degree contain widespread chalcocite in notable though noncommercial amount. But this chalcocite is not chiefly within the conglomerate rock itself, like the metallic copper, but is intergrown with calcite (see pl. 68) in fractures that cut the conglomerate at close intervals in all directions. The abundance of sulphide veins in the conglomerates may be due to the greater brittleness of the conglomerate, which made small-scale fracturing more easy, the lower hematite content of the conglomerate, and the greater chemical stability of the rock, which rendered its hematite less available.

Very little sulphide is present in the main ore shoot of the Calumet & Hecla conglomerate, but sulphide is relatively abundant along the margins of the main ore shoot at Centennial and Osceola.

In the sandstone lodes of the Nonesuch formation and in the overlying shale a little chalcocite is present. Here the ore solutions probably did not move for long distances in the red sandstones but gained access to the beds from the White Pine fault and the related minor fractures, and so opportunity was not afforded for complete oxidation of the solutions by the hematite of the red rocks. The ratio of chalcocite to metallic copper, in the shales, which appears to be higher than in the sandstones, would be due to lack of hematite in the black shales. The amount of copper occurring as sulphide is relatively small: Samples in the White Pine mine indicated that only 2 per cent of the total copper is combined as sulphide, and by far the largest part of this is present in fissures and minor faults, where the opportunity for oxidation by the rocks was low.

Some of the amygdaloid lodes contain "arsenical copper," but in this the ratio of arsenic to copper is exceedingly low—a small fraction of 1 per cent. Definite copper-arsenide minerals are practically unknown as constituents of any of the lodes except in the immediate vicinity of some of the arsenide fissures.

Many fissures contain pure metallic copper, but many also carry arsenical copper, and the fissures are the chief source of the sulphides and almost the sole source of the arsenides of the district.

Moreover, the cross fissures of the Cliff-Central type have been found to carry notable quantities of copper only near their intersections with hematite-rich amygdaloid or conglomerate lodes. For the old fissure veins of Keweenaw County, one such horizon occurs under the Greenstone flow and another in the vicinity of the Ashbed amygdaloid. The relation of copper in the cross fissures to the intersection of a hematite-rich lode is well shown by the Mass fissure and the Kearsarge lode in the Ahmeek mine: The copper in the fissure is very distinctly concentrated in the neighborhood of its intersection with the lode, especially on the hanging-wall side of the lode; at many levels the Kearsarge lode is cut across by a solid wall of copper in the fissure. This suggests that the solutions that moved along the fissure would not have deposited copper in abundance in any form at this point had it not been for the effect of the amygdaloid.

The many small seams of copper that extend from the Kearsarge lode into the trap of the footwall or hanging wall as a rule contain copper for only short distances away from the main lode. It appears evident that they were fed by the solutions that flowed along the lode and that the reactions that caused the precipitation of copper occurred in the lode rather than in the fissures.

One further relation suggests the influence of long contact with red rock on the condition in which the copper was deposited. The copper of the lodes highest in the series, the Ashbed, Pewabic, Calumet & Hecla conglomerate, and Osceola, is notably pure. In the Kearsarge, Isle Royale, and Baltic lodes, which are low in the series, the copper becomes increasingly arsenical. The two lowest lodes, the Isle Royale and particularly the Baltic, contain more sulphide-bearing fissures than any other lode.

If the solutions gained access to the beds that are now the lodes from the Keweenaw fault as the main feeding channel, it would follow that the lodes highest in the series are at the present surface farther from their intersection with the Keweenaw fault than the lodes that lie deeper in the series and crop out closer to the fault. On the assumption that the fault continues downward at a dip 5° flatter than that of the beds, it is found that the distance down the lode from the present surface to the intersection with the Keweenaw fault is about six times as great for the Ashbed, five times for the Pewabic, four times for the Calumet & Hecla conglomerate, and between four and three times for the Osceola, Kearsarge, and Isle Royale as it is for the Baltic. This would mean that the solutions traveled six times as far from the connection with the fault in the oxidizing environment of the red lode of the Ashbed (and corresponding distances in the other lodes) as they did in the Baltic.